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Geothermal Energy Productive Efficiency Review

ROTORUA GEOTHERMAL REGIONAL PLAN

BAY OF PLENTY REGIONAL COUNCIL

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CONTENTS

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APPENDICES

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Should anyone wish to discuss the content of this report with Dobbie Engineers Ltd, they are welcome to contact their Rotorua office.

1. EXECUTIVE SUMMARY

1.1 Introduction

The geothermal energy in Rotorua is primarily direct use for space and water heating in residential, municipal and commercial properties, pool heating, as well as mineral pool bathing. The Rotorua Geothermal Regional Plan (RGRP) identifies efficiency as a key issue for the regional plan review and that 'Some users are wasting geothermal resource by taking more than they need or failing to insulate or control heat flows.'

Efficient use of the Rotorua geothermal resource is key to protecting existing natural features, making energy available sustainably, and ensuring the maximum benefit is achieved with the resource available. The Bay of Plenty Regional Council is interested in investigating the geothermal energy use from technical perspectives to inform the development of the Rotorua Sustainable Management Plant (SMP) and Regional Plan Change and resource consents.

This report discusses the opportunities to increase energy efficiency, controlling energy extraction and provides recommendations on reflecting efficiency requirements in the resource consent conditions and compliance monitoring.

1.2 Energy Efficiency

This report separates and reviews energy efficiency in three areas: Energy extraction methods, Energy distribution equipment and End user efficiency.

Three main methods of energy extraction (doublet, down hole heat exchanger and surface feature heat extraction) are compared and evaluated from an energy efficiency perspective. The doublet system is identified as a reliable high output energy source however it has been identified these systems are difficult to regulate which results in waste heat, have a high safety risk due to the temperatures and pressures they operate at and pose difficulty to monitor their actual energy take and volume flow. There is also little knowledge available relating to the impact of reinjection temperatures and identification of the ideal reinjection locations.

Down hole heat exchangers typically provide significantly less energy output than a doublet system however they pose a significantly lower risk to the reservoir, are easily regulated to match heat demand with use and can be monitored using standard industry energy monitoring technology. Their major disadvantage is their lower heat output and the uncertainty of their output prior to drilling and testing which has significant capital investment and financial risk.

Taking heat from natural features has limited opportunities and generally for lower energy takes. They do however provide an energy source that is already lost to the reservoir. Often their use has significant health and safety risks and the reliability of the energy supply is very dependent on environmental conditions and reservoir fluid levels.

This report recommends the further work is done on identifying:

- The effects of lower reinjection temperatures
- The ideal reinjection philosophy with respect to depth and position within the field
- Alternative monitoring systems for doublet systems
- Methods for matching the output of doublet systems to energy requirements.
- Best practice for the location and design of down hole heat exchangers.
- Updating the existing Rotorua Geothermal Energy use standard NZS 2402P

Efficiency within energy distribution systems is discussed. This includes the insulation of distribution systems, heat exchangers and control systems. At present this technology is well understood however further education and regulation is required to ensure users implement at least the minimum requirements of NZS 2402P.

Efficiency within the end use is important to reducing geothermal takes. Without a cost incentive to reduce energy use alternative measures are required. New homes are required to be built to higher insulation levels however existing housing stock is often poorly insulated and uses excess energy. This report discusses options for the BOPRC to adopt alternative energy standards for homes and through regulation and education to reduce energy use in heat, hotwater and pool systems through simple measures such as insulation, low flow shower heads, water conservation and pool covers. Most of these items are discussed in NZS 2402P and further inspection and regulation may be required to compliance with these standards.

1.3 **Geothermal Take and Heat Demand Prediction**

When allocating geothermal resources, the BOPRC have previously adopted heat load criteria to estimated geothermal flows and maximum volumes of energy or fluid take. This report provides an updated estimate based on the energy efficiency requirements discussed in previous sections and suggests that both peak and average uses be adopted to reflect the true usage patterns. It is recommended that these calculations are developed for a range of uses and over a range of environmental conditions. This will both encourage energy efficiency through preventing over allocation and encouragement to adopt energy efficiency principles.

1.4 **Technologies and Alternatives for Potential Efficiency Improvement**

Cascade heat use provides an opportunity to extract more energy per tonnes of extracted fluid increasing the efficiency of the system. As discussed earlier this needs to be carefully weighed up against the risk of lowering reinjection temperatures and the potential negative effects of this.

As some geothermal systems have limited turn down capacity it may be efficient to turn these systems off and use alternative energy systems during periods of low load. Selection of these alternative systems will need to consider their cost effectiveness given the likely short operating periods and at reduced load.

Antiscalant has been identified as a method of reducing calcium carbonate deposition in production wells, piping and heat exchangers. More widespread use of this technology will increase efficiency by increasing system pressures and temperatures, increasing heat transfer in the heat exchangers and improving reliability of control systems. It also has the advantage of reducing overall operating costs and extending production bore life expectancy.

District heating schemes and their costs are discussed. Larger systems (1000 homes) are significantly more cost effective than smaller systems (100 homes) however costs remain significant at more than $35,000 to $45,000 per home. Review of distribution systems shows that it is feasible to distribute the energy over distances of 2 to 3 kilometers provided the systems are large enough (i.e. 1000+ typical homes).

Alternative technologies are discussed. Ground source heat pumps do not have a clear use in areas where ground temperatures are significantly elevated as is the case in Rotorua. Lake Rotorua and shallow ground water would however provide suitable energy sources for this technology. Absorption chillers have been demonstrated in Rotorua in the past and can provide economic and reliable production of chilled water for air conditioning purposes. This provides a low carbon and long life alternative to traditional heat pump air conditioning. These would however introduce a technology not well understood or serviced in Rotorua.

Small scale binary plants could provide an alternative electricity supply however at the temperatures available current technology would provide efficiencies as low as 7-9% resulting in the generation of large quantities of low grade heat (40 to 50ºC) which would go to waste unless it can be matched to a suitable low grade energy use (horticulture, aquaculture, bathing or large scale under floor heating. Cost recovery from the electricity generated only has significant value if it can offset existing use as the value on the wholesale energy markets is limited.

1.5 **Consent Process and the Rotorua Geothermal Regional Plan**

The BOPRC is reviewing the resource consent application process to encourage efficient use of the resource. The following items are discussed to help improve the process, tighten consents and provide practical monitoring tools.

The consent compliance becomes more reliable when the consent requirements are given in suitable units. This report recommends that mass flow rate be adopted for all takes of fluid. With instantaneous measurements being kg/s and longer time periods being tonnes/day. Where energy is being measured this should be expressed in kWh or GJ where appropriate.

To accurately measure heat taken from doublet systems the production well and reinjection well enthalpies need to be measured and compared. Historically temperatures have been recorded and these do not necessarily reflect the energy taken especially when the production fluid is two phase.

At present consents only apply conditions to the maximum daily take and in some cases this is measured in tonnes/day and other instances in kg/s. This does not provide the consent holder with an incentive to match demand throughout the day and at different season with their actual energy requirements. This report suggests adopting a policy to encourage compliance with peak use, daily peak use and annual peak use. This can be through actual recorded measurement or increased compliance checking to ensure systems are designed, installed and operated in accordance with guidance documents for energy savings (i.e. NZS 2402P). Three levels of monitoring have been proposed based on the size of the take and access to suitable monitoring equipment.

Barriers to efficient use have been discussed and recommendations made to increase the knowledge of local trades people and users to help them make use of the current resources. Adoption of a qualified professionals (IQP) list to monitor new installations and audit compliance of existing installations are options.

1.6 **Recommendations**

A number of recommendations have been highlighted and summarised in Section 7 of this report.

2. INTRODUCTION

The geothermal energy in Rotorua is primarily direct use for space and water heating in residential, municipal and commercial properties pool heating, as well as mineral pool bathing. The Rotorua Geothermal Regional Plan (RGRP) identifies efficiency as a key issue for the regional plan review and that 'Some users are wasting geothermal resource by taking more than they need or failing to insulate or control heat flows.'

Efficient use of the Rotorua geothermal resource is key to protecting existing natural features, making energy available sustainably, and ensuring the maximum benefit is achieved with the resource available. The Bay of Plenty Regional Council is interested in investigating the geothermal energy use from technical perspectives to inform the development of the Rotorua Sustainable Management Plant (SMP) and Regional Plan Change and resource consents.

This report discusses the opportunities to increase energy efficiency, controlling energy extraction and provides recommendations on reflecting efficiency requirements in the resource consent conditions and compliance monitoring.

3. ENERGY EFFICIENCY

Energy efficiency in the geothermal system has been divided into three areas for discussion: energy extraction, energy distribution, and energy end use. This section discusses energy and efficiency in these three areas and refers to NZS 2402P which is the current benchmark for energy efficiency in Rotorua.

3.1 Energy Extraction Methods

Geothermal energy needs to be extracted from the geothermal field before it is distributed to users. Heat exchangers are used to allow the heat from the geothermal fluid to pass to a second fluid, i.e. a closed towns water system. The closed towns water system is often referred to as the secondary fluid in a geothermal direct heating system. The secondary fluid absorbs heat from the geothermal resource through a heat exchanger and releases the heat to the end use terminals, i.e. space heating or domestic hot water heating applications.

There are three main methods of extracting geothermal energy:

1) Extracting from doublet (production & reinjection bores) system
2) Extracting from a downhole heat exchanger (DHHE)
3) Extracting from surface features (less common)

Each of these system uses one or more heat exchanger(s). Heat exchangers are most efficient when proper design and selection is made. This section discusses three energy extraction systems and its advantages and disadvantages, along with areas for future work.

3.1.1 Doublet system - extracting and reinjecting geothermal fluid

Figure 1 is a schematic of a doublet system. A primary heat exchanger is fed directly by the geothermal fluid and the geothermal energy is transferred to a secondary fluid (town water). The heat is then distributed to the end user by a closed loop secondary water system where the heat emitters (radiators) transfer it to the final use.

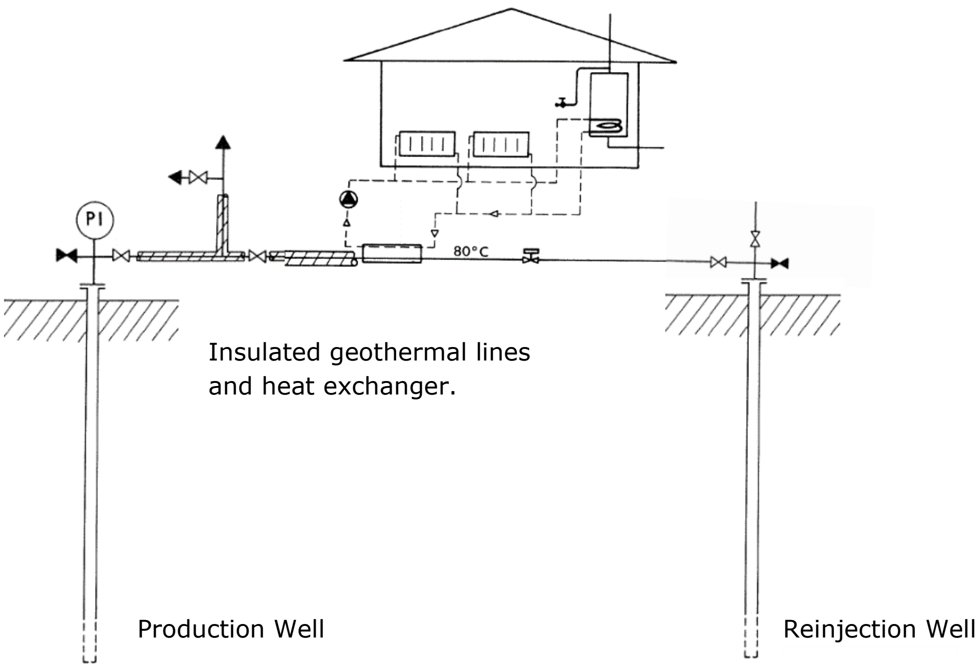

Figure 1 Doublet system

The geothermal fluid is extracted from a production well (on the left) and discharged into a reinjection well (on the right). For the existing users, the two wells are at least 10-20m apart. In Rotorua, the geothermal fluid is generally taken at 110-150°C from 100-150 m below the ground surface and ideally returned to the reservoir at the same depth by the reinjection well at or about 80°C. (Clause 204 of NZS

2402P requires the minimum reinjection temperature to be 80°C.)

The geothermal energy that can be extracted from the doublet system is equal to the mass flow rate of the fluid multiplied by the enthalpy difference between the extraction and reinjection fluid. The maximum heat output from a typical 100 mm diameter doublet system is up to 1.2 MW in Rotorua. This potential thermal energy is also referred to as the 'available heat'.

The **advantages** of a doublet system include:

- The opportunities to take over 1.2 MW which could heat up to 150 homes, or a large hotel of over 300 rooms, or an outdoor Olympic-size swimming pool (50m x 20m)
- There is zero net withdrawal of fluid, assuming the reinjection is successfully completed.

The doublet systems can withdraw a large amount of energy from a relatively small area. At present, the individual local effects on the aquifer are thought to be minimal when the fluid is successfully reinjected, however this high level of local heat extraction could cause adverse effects on natural features in local proximity, and cumulatively. More modelling work is required to evaluate these potential effects.

At present the effects of reinjections are not fully understood. NZS 2402P discussed reinjection temperatures, however the effect of lower acceptable reinjection temperature is unknown. Similarly, little work has been done on the ideal reinjection depth and position in the field relative to production zones. More modelling work is required to evaluate the effects of reinjection temperature and the reinjection position (both depth and location in the field).

There are likely to be some existing wells, where the heat output from the minimum sustainable flow exceeds the user's minimum energy demand in summer. It is a source of energy waste if these wells are kept running in the low demand seasons.

The **disadvantages** of a doublet system may include:

- Potential risk due to accidental geothermal fluid discharge.
- Difficulty in matching the well output with the required heat demand, resulting in waste.
- Some technical challenges in maintenance and monitoring
- Not suited for small takes technically nor economically (i.e. less than 100 kW)

As fluid is taken to the surface there is potential for accidental discharge of the high temperature and pressure geothermal fluid (140°C - 150°C at 3-4 Barg). This may create environmental and safety hazards. All above ground piping at pressures greater than 0.5 bar and above 60ºC are required to comply with the requirements of the Worksafe pressure equipment regulations. These require all pressure equipment to be designed, installed and operated in accordance with a recognised pressure piping/equipment standard. Historically geothermal services in Rotorua have not been fully compliant with these rules and further education and enforcement is recommended to minimise the risks associated with loss of containment of these fluids.

A well-insulated doublet system can operate efficiently at the end user's peak demand, however, it may not be equally efficient at a reduced flow. Many production wells have a minimum sustainable flow limited by the well diameter, aquifer temperature, pressure and the reservoir rock permeability, if the geothermal flow exceeds that required for the end use then reinjection temperatures will rise. Given that reinjection wells in Rotorua typically reinject by gravity at atmospheric pressure, if the reinjection temperature exceed 95°C, the reinjection fluid will flash, and steam will leave the system via venting at the reinjection well. This creates a significant loss of energy and inefficiency. Clause 201 and 207 of NZS 2402P discusses efficient geothermal systems and the following methods to limit the mass output from geothermal production wells to reduce the extracted heat and well flow to match the end use:

- Sleeve the production well diameter to reduce minimum flows.
- Use airlift or a pumped system for better control of the turn down at lower flows.
- Close the well during low load periods and have an alternative heat source for low energy periods.

Further work is required to identify the correlations between the minimum sustainable flow and the well parameters experimentally.

As the reinjection fluid contains non condensable gases (and sometimes steam) it is difficult to install off the shelf fluid flow monitoring systems and this makes management of the resource use difficult. This has been discussed in previous reports issued by Dobbie but still requires further investigation to identify where and how better monitoring can be implemented.

3.1.2 Down Hole Heat Exchanger (DHHE) – a 'non-extractive' method

The down hole heat exchanger system does not bring geothermal fluid to the surface. A closed towns water system is circulated through a 'U' tube or concentric tube arrangement immersed in the well as shown by the schematic in **Figure 2**. The well allows heat from the surrounding ground and geothermal reservoir to pass to the circulated town water without the two fluids come into direct contact. Energy is transfers from the geothermal fluid flowing through or adjacent to the geothermal well. The available heat depends on the natural heat and fluid flow through the geothermal well and the permeable rock layer. Very little heat is transferred by direct conduction from the rock formation Typically, the secondary water in the DHHE is circulated at 80°C or lower.

The **advantages** of a DHHE system are:

- Easier to regulate the energy flow
- Easier to monitor fluid flow and energy take
- Not extracting fluid from the aquifer
- Eliminating the disposal of the geothermal fluid
- It can potentially be retrofitted into an existing production well

A feature of the DHHE is that it is possible for the total heat extracted to be reduced to match demand by regulating the secondary water flow and the DHHE has much better turn down ratio when compared to the doublet systems.

It is also possible to use off-the-shelf energy meters to monitor and record energy use similar to any other utility. Use of this technology would improve regulatory compliance. DHHE do not remove fluid from the aquifer and the issues associated with reinjection temperatures, depth and position are negated.

The **disadvantages** of a DHHE system are:

- Uncertainty of heat output until full construction and testing is completed.
- Less energy (10% -20%) available compared to doublet system
- Has low economic viability (i.e. 20kW DHHE system)
- Potentially removing heat from 2-phase geothermal fluid (i.e liquid and steam mixed state)

The primary negative issue is the relatively low output and unpredictable performance of existing DHHE units. The heat output of a DHHE cannot be estimated until the well is fully constructed and tested. The maximum heat output of existing DHHEs in Rotorua is typically between 20 - 100kW. It is believed that the maximum heat output is primarily limited by the relatively small 100 mm casings used. Existing DHHE wells were initially drilled as production wells for geothermal fluid, then retrofitted for DHHE. In 2021 a purpose built DHHE well drilled to 150m utilizing a promoter pipe and a 200mm diameter casing has been shown to produce up to 150kW from resource temperatures between 130 and 140°C

A well that is specifically designed for a DHHE should consider the general factors in a heat exchanger design. Increasing the well diameter has the potential to increase the contact surface of the geothermal fluid and the circulated water. This may create a significant increase in output hence improve the economic viability of these systems.

By far the most important feature is to have good fluid flow in the reservoir local to the bore. Further reservoir modeling could help to identify the optimum conditions, and suitable locations for DHHE. Experimental data from drilling more well testing will also be valuable.

There have been some concerns regarding the local cooling effect of DHHE especially quenching steam. Localised cooling occurs if the energy extracted from the DHHE is significantly greater than the rate of heat recharging from the surroundings.

The shallow reservoir at Rotorua is generally considered to be a saturated liquid reservoir. and that steam is not present as the pressure for depth exceeds the saturation pressures. Because of this it is less likely that a DHHE will be installed in a boiling zone where energy extract may result in a significant loss of volume and the associated pressure.

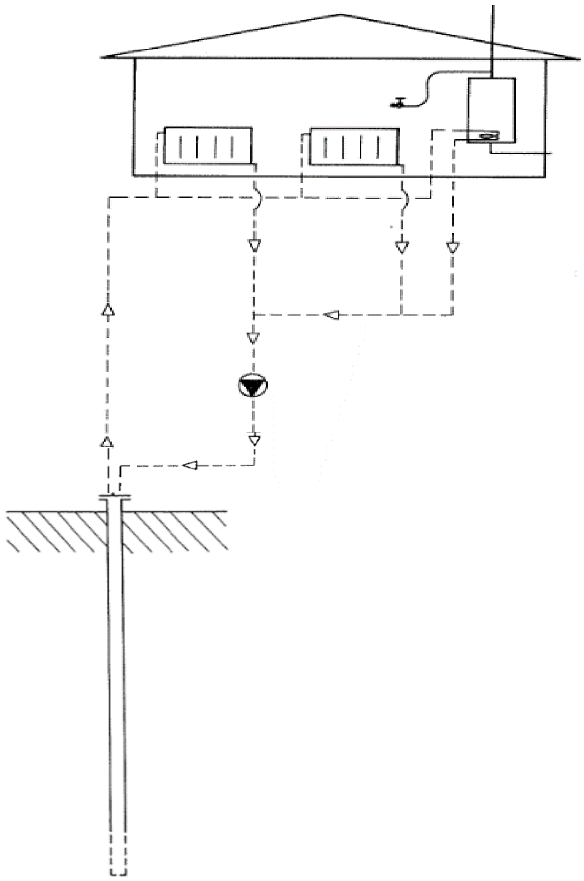

Figure 2 Down Hole Heat Exchanger (DHHE)

3.1.3 Surface Features

Using surface features is an alternative opportunity to extract heat from geothermal sources. Typically, the fluid from surface features and its thermal energy is already lost from the aquifer. There may be localized negative effects on adjacent surface features while only limited additional impact on the geothermal reservoir.

Current examples of this use are the Holiday Inn Hotel, the Polynesian Spa, and areas in Ohinemutu. The Holiday Inn Hotel takes up to 360 tonnes per day from the adjacent spring (Spring # 952) and extracts up to 500kW before returning the fluid to the Puarenga Stream. The Polynesian Spa pumps up to 200 tonnes/day from the Rachel spring (Whangapipiro Spring) for bathing. In Ohinemutu, surface features (ngāwhā) are used for bathing and cooking. The opportunities for similar development are limited due to the number of springs available, their location and values. The following advantages, disadvantages and risks exist.

The **advantages** of extracting heat from surface features are:

- No well drilling is required, lower initial capital cost
- To utilise the heat which is otherwise a lost to the ambient
- To minimize the localised effects of the energy take on the geothermal system

Extracting heat from a surface feature is a way to harvest energy which has already left the geothermal aquifer.

The **disadvantages** of extracting heat from surface features are:

- Opportunities to do this are limited to small areas of Rotorua.
- It can visually effect the surface features
- May require the building retaining structures in the feature.
- Is susceptible to changes in weather, aquifer pressure and level.
- Health and Safety issues due to working in proximity to boiling liquids and evolving geothermal gases
- Relatively low temperature and in most cases a energy flow

It is often difficult to extract the fluid from surface features without building retaining structures and the potential environmental consequences in altering natural features. These features are very susceptible to changes in weather, aquifer pressure and level. Being the highest discharge point in the reservoir, even small changes in the aquifer pressure or level can have a significant effect on mass flows. This increases the financial risk to any development. Health and Safety issues exist when accessing the area adjacent to surface features. Boiling water, gases and unstable ground are potential hazards.

Often the energy flow may be insufficient to meet user demand if the fluid from the surface features is used as the only heating source.

3.1.4 Comparison of Risks

These three extraction methods pose risks to the aquifer, public and end user at different levels. **Table 1** compares the risk of the three methods based on the level of uncertainties.

Table 1 Doublet System, DHHE, and surface feature Risks Compared

Potential Risks	**Doublet System**	**DHHE System**	**Surface features**
Insufficient heat output to match peak demand	Low	Medium	High*
Cannot match output to reduced heating demand resulting in wastage	High	Low	Low*
Energy output subject to change in environmental conditions	Low	Low	High*
Not returning geothermal fluid to source and achieving reinjection goals	Medium	Low	N/A
Potential to reinject large quantities of cool water or cool the reservoir through excessive heat extraction or inappropriate reinjection	High	Low	Low*
Contaminating or damage to surrounding surface or aquifers, destruction of values (eg. Casing failure, structures, pipes)	Medium	Low	High*
Exposure to health and safety hazards	Medium	Low	High*

*Some level of risks exists regardless of whether the surface features are utilised for energy extraction.

All of the above systems have the potential to deliver the required heat to a residential user. A doublet system has the highest energy output and most predictable. Extracting from the surface features has lowest energy output and most susceptible to weather variations, extracting heat from the lower enthalpy fluid from surface feature can be an economical way for meeting small demand, i.e. a few kilo-Watts used for cooking.

Table 1 suggests that every new well drilled for DHHE has a lower environmental risk of energy waste compared to a pair of wells for a doublet system. Converting an existing product well into a DHHE can potentially reduce the risk of the system however the DHHE reduces the available heat to 10% of the original doublet system’s potential take and ultimately may not satisfy the needs to the user.

A heat extracting system’s level of risks and uncertainty increases with its amount of heat output. Further work may be required to compare the environmental impact of a DHHE and a Doublet system when extracting the same amount of energy.

3.1.5 Location of Extraction

The Rotorua geothermal system covers ~12 km^2, indicated in ***Figure 3***. Currently, there is a 1.5 km exclusion zone around the Puhutu Geyser, where there is a moratorium on fluid extraction and limited DHHE use.

The Rotorua Geothermal System has been studied by many research groups. The studies were interested in the system in its natural state, historical use, and environmental impacts. The studies have addressed several issues, including:

- Conceptual models of the system
- Numerical models for the field
- The characteristics of the identified-up flow zones: Kuirau Park, Ngapuna and Whakarewarewa.
- The hydrology and the location of the faults and its controls on fluid flow
- Indicative environmental response to future resource use (water and heat)

Burnell's model evaluated increased use of DHHE and doublet systems in a few scenarios by measuring the mass out flow at the surface features as system response (Burnell, 2007). Burnell's work acknowledges that installing new extraction systems in some parts of the system may be more favourable than other parts. Further study is yet to done to assess the localised impact by individual wells. Following objectives can be considered for future modelling:

- Identify the locations for extraction and reinjection which has less impact on the reservoir and surface features.
- Predict areas to locate new DHHEs for better heat outputs based on the modelled aquifer temperature, permeability, and fluid flow characteristics.

Further research should be undertaken to refine the model for the following reasons:

- There is limited understanding of the deeper areas below the known reservoir.
- The limited accuracy of information available results in alarge grid size and potentially a lack of precision.
- Incomplete or out of date information on the actual energy take.

Figure 3 Rotorua geothermal system

3.1.6 Future Work in Extraction Methods

The standard NZS 2402P was written in the late 1980s. Regarding the requirements on an extractive system, a few items of the standard might need to be revised.

- The recommended reinjection temperature for a doublet system is between 80°C and 90°C. It is unclear if 80°C is the critical minimum temperature for reinjection.
- The optimum reinjection temperature requires further research (i.e., computational modelling of the system).
- The relative location and depth of the production well and the reinjection well requires further research. NZS 2402P does not suggest an optimum distance and relative depth between the extraction and reinjection wells.

It is acknowledged that there are on-going research efforts and computational work is still required to study the environmental impact of different extraction methods.

- Further study in whether the thermal energy of the reinjected fluid is returned to the resource and sustained in the reservoir and what optimum reinjection conditions are
- Further research to study the difference of the cooling effect by DHHE and the doublet systems. It is not yet proven if a DHHE and a doublet system with the same heat output have significantly different in its cooling effect to the local surroundings.

- Further work is required to quantify the DHHE's effect on a Steam Zone in the aquifer, where the geothermal fluid is above its boiling temperature and exists in two-phase. When a DHHE takes heat from these areas would they reduce the system pressure significantly.
- Confirm the effect of the 1.5km exclusion zone and if the size could be increased or decreased.

3.2 Energy Distribution Equipment

Once the energy is brought to the surface it is important that the percentage transferred directly to end use is optimized.

Areas of inefficiency include:

a. Energy flow does not match the demand
b. Steam leaving the system via venting at the reinjection well
c. Heat loss from distribution piping from the well head to the end user heating system

The respective solution to the above issues would be:

a. Implement control systems to regulate energy take and the geothermal system to be modulative.
b. Selecting suitable heat exchangers in doublet systems to ensure that the geothermal outlet temperatures are 80-90°C or as recommended by future studies.
c. Installing thermal insulation on all distribution piping.

NZS2402P defines the thermal performance requirements and provides a good benchmark. If BOPRC is to implement the standard, it needs to be further reviewed and updating.

3.2.1 Control Systems

The heat output of a doublet system can be regulated by a control system, although the geothermal production has a turndown limit. Geothermal fluid control devices are usually installed downstream of the primary heat exchanger. The control devices restrict the geothermal fluid flow through the primary heat exchangers to meet a satisfactory reinjection temperature, i.e. between 80°C and 90°C.

The temperature of the returning secondary circulating water increases when the heating demand is reduced. To match the energy take with demand, and to provide over temperature protection for secondary water circulation system the geothermal heating system should:

- Have an automatic control valve or a remote sensing thermostatic valve
- Sense the temperature of the returning secondary circulating water.
- Regulate the heat transfer in the primary heat exchanger of a doublet system. Modulating the geothermal fluid flow to maintain the secondary fluid at the desirable temperature.
- Regulate the heat taken out from the geothermal source in DHHE. Modulating the secondary fluid flow to maintain the fluid at a desirable temperature, hence the temperature takes matches the demand.

At present systems and technology exist to do this and have been demonstrated in Rotorua.

3.2.2 Heat Exchangers

Plate heat exchangers or large shell and tube units are the common heat exchangers used in geothermal direct heating systems. Units of current technology are generally considered efficient and achieve close temperature approaches with minimum energy loss. Proper heat exchanger design and selection is important, and the considerations include:

- Design and select the heat exchangers according to fluid conditions.
- Shell and tube heat exchangers can tolerate higher levels of fouling.
- Plate heat exchangers are compact and provide close temperature approaches.
- Pipe in pipe heat exchangers have poorer efficiency and wider temperature approaches compared to purpose designed shell and tune or plate heat exchangers.

The primary feature in the heat exchanger is that they shall be sized to ensure that the geothermal fluid leaves the heat exchanger at a temperature lower than 90°C. This would stop energy loss as flashing steam at the reinjection system. A lower reinjecting temperature increases the available heat to the system and the system can extract the same amount of heat with reduced fluid take. As discussed earlier, further work is required to quantify the environmental effect of lower temperature reinjection.

3.2.3 Distribution System Insulation

Distribution system heat loss is minimised by installing insulation in accordance to existing industrial standards. NZS 2402P states the following mandatory requirement on the geothermal water piping.

- Minimum thermal resistance: 0.8 m^2 °C/W
- Insulation material: 25mm to 38mm preformed fibreglass

And suggests the following for secondary water piping:

- Minimum thermal resistance: 0.6 m^2 °C/W.
- Insulation material: 19mm to 25mm preformed fibreglass

The standard states the mandatory minimal insulation requirement for the geothermal fluid piping, while it is unclear if this is also mandatory for the secondary water piping. This should be addressed in any future revision. Further enforcement of these requirements will result in reduced geothermal takes.

3.3 End user efficiency

Thermal energy from the Rotorua geothermal field is mainly used for space, domestic hot water and pools heating. The following areas of inefficiency include:

a. Heat loss in space heating due to poor building insulation
b. Poor climate control – i.e. Windows open whilst heating due to poor room controls
c. Heat loss from domestic hot water due to lack of temperature control, poor insulation, and overuse.
d. Heat loss from heated pools

The above issues could be addressed through providing information or guidance or adding to the consent criteria as mandatory requirements. The respective solution to the above issues would be:

a. End users to implement building insulation to the minimum requirements of relevant standards; Install time clocks and controls on space heating which switch off the space heating when not required or when the house unoccupied.
b. Install temperature controls with accurate feedback control on domestic hot water systems, insulate the piping and equipment in domestic hot water systems and regulate the water flows (shower etc.) to reduce waste.
c. Cover heated pools when not in use.

3.3.1 Efficiency of Space Heating

Improving the building's thermal performance is a priority to improving the system efficiency of geothermal heated space. The BOPRC may require geothermal energy users to meet minimum building insulation standards in their homes or commercial buildings.

New homes and most homes built after 1997 will comply with the New Zealand Building Code (NZBC) clause H1 Energy efficiency. This sets the minimum standards that can be demonstrated by several methods. Scheduled minimum thermal resistance (R-value) is the simplest to recognise the building's insulation levels. The insulation R-value requirements (NZS 4218) for new homes in Rotorua (Zone 2) are:

1. Roof insulations, R = 2.9 °Cm^2/W
2. Underfloor, R = 1.3 °Cm^2/W
3. Wall insulations, R = 1.9 °Cm^2/W
4. Windows, R = 0.26 °Cm^2/W
5. Skylights, R = 0.26 °Cm^2/W

and the total window area must be ≤ 30% of the total exterior wall area. These requirements limit the maximum amount of heat loss and provides the basis for the peak space heating demand calculation.

The standard for new homes is not pertinent for some existing housing stock. A method for ensuring these are of an acceptable standard is required. One option is to consider the newly legislated regulations, the Residential Tenancies (Healthy Homes Standards) Regulations 2019, for rental housing. Instead of five components being required for insulation, only two are compulsory in this regulation. The roof/ceilings are required to have a R = 2.9°Cm^2/W and the underfloor to R = 1.3°Cm^2/W. The roof and the floor losses are significantly larger compared with the other components and can be more easily dealt with hence this insulation improves would be effective in reducing heat loss.

The Healthy Homes Standard provides a system that decreases energy use and is readily applied to existing older housing stock. The requirements proposed for rental housing have been tested and have been adopted to allow retrofit to existing homes, while BOPRC regional plan cannot expect all homes to adopt current NZBC standards.

It would appear practical to require houses to at least be upgraded to meet those proposed for rental properties prior to issuing consents. Two options for BOPRC to manage this are:

- Require owners to show they have met insulation standards (by providing a certificate).
- Restrict energy use to levels required for these standards.

3.3.2 Efficiency of domestic hot water system

The Building Code clause H1 Energy efficiency calls up standard NZS 4305 and provides acceptable solutions to minimise hot water system heat lost from heating equipment and piping.

A common electric hot water cylinder stores hot water at 65°C and the vessel and associated distributing pipes should be insulated to satisfy the minimal requirements in the NZS 4305 standard.

Pipe insulation is cost effective, it costs **$20** to insulate one meter of 25NB pipe to the above standard, once installed this would save up to 69 kWh per year, equivalent to $**22** electricity at $0.33 per kWh. (Saving break down detailed in **Appendix A**).

Hot water energy use is proportional to the volume of water used. The use of low volume shower heads, washing clothes in cold water and generally reducing waste all has a significant effect on the energy use and geothermal take required. Further education of users, inspection of installation systems of limiting geothermal takes could all encourage energy conservation and significantly reduce energy takes.

3.3.3 Pool Heating & Cover

Heat loss from pools is primarily controlled by the pool temperature and the total surface area of water. Swimming pools should be heated to meet the minimum required temperature for the intended use, i.e.26ºC -27ºC for competition swimming pools, 30ºC- 33ºC for leisure pools, 37 ºC- 40 ºC for Spa pools and geothermal pools according to NZS 4441. The standard also suggests that insulating pool blankets should be deployed when the pool is unused.

Heat loss is proportional to the temperature difference between the water surface and the ambient air immediately above the pool. Pools heated to a temperature exceed the recommend range would result in high heat demands.

Heated pools (with town water) should typically be covered when not in use. Spa pools with purpose designed covers may achieve better levels of energy conservation compared to swimming pools of irregular shapes. Heat loss is controlled by evaporation, pool temperatures and level of shelter from winds. The energy losses from uncovered and covered pools are compared in ***Table 2***.

Table 2 Typical Peak Heat Losses from pools

	Swimming Pool	**Leisure Pool**	**Spa Pool**	Notes
Temperature	26 °C	32 °C	38 °C	1. Less effective - large cover
Heat Loss (Open)	600 W/m^2	900 W/m^2	1200 W/m^2	

Heat Loss (Covered)	150 W/m² (Note 1)	150 W/m² (Note 1)	100W/m² (Note 2)	2. High quality - small cover 3. 1000 m² competition pool 4. 80 m² large leisure pool 5. 4 m² Spa Pool
Never covered	600 kW (Note 3)	72 kW (Note 4)	4.8 kW (Note 5)	
50% time covered	375 kW (Note 3)	42 kW (Note 4)	2.6 kW (Note 5)	

4. GEOTHERMAL TAKE AND HEATING DEMAND PREDICTION

When allocating geothermal fluid takes the BOPRC often use some bench marked energy use levels to calculate the required geothermal take. This section proposes an alternative heating estimate for the basis of efficient end use. This estimate is significantly lower than an energy demand assumption made in previous research: a residential house would consume 20kW for space heating and hot water for 24 hours per day over 8 months per year and 2kW for 24 hours per day over 4 month per year (Burnell, 2007).

4.1 Estimate Energy Use

4.1.1 Peak Space Heating Demand

At peak demand, in winter, the external temperature in Rotorua is assumed to be 0°C and the required internal temperature is 20°C. An average house size of 140m² house (8m x 17.5m, and 2.4 m ceiling height) with a wall to window ratio of 3:1 and a ventilation rate of one air change per hour has been adopted for this example.

Under these assumptions, if the residential house meets the NZBC minimum insulation requirement, it may require **8 kW** for space heating. This increases to**12 kW** if the Healthy Home Standard is met. This value may be increased to **22 kW** if the same house is uninsulated.

4.1.2 Peak Domestic Hot Water Demand and Pool heating demand

Hot water daily use is 50-100 litres/day per person, dependent on lifestyle. The peak demand estimate can be compared to the amount of energy consumed by a common electric hot water cylinder. Assuming:

- 180 Litres of water storage
- Average cylinder temperature of 65°C
- One 3kW element in one hot water cylinder

The peak demand of medium size household is **3 kW** for domestic hot water heating. For a geothermal system it is practical to assume that the space heating system load may drop short term to meet any load exceeding this level. It is also estimated that peak domestic hot water heating demand for a hotel room is **1.5-2 kW** based on stored capacity and the diversified load available.
The heating demand of a covered pool is normally estimated at **100-150 W/m²**, as listed in ***Table 2***.

4.1.3 Total Demand

Table 3 summarises the seasonal space heating and hot domestic hot water heating demand of two typical types of building based on the criteria set above.

Table 3 Heat Demand (Winter: 8 months a year, Summer: 4 months a year)

Building Type	Season	Space Heating	Hot Water	Total	Notes
Residential	Winter	8 kW	3 kW	11 kW	A house with 140m² heated space
	Summer	0.8kW		3.8 kW	
Commercial (Hotel/Motel)	Winter	57 kW	30 kW	87 kW	A motel/hotel with 1000m² heated space (20 rooms @30m²)
	Summer	5.7 kW		35.7 kW	

A geothermal take will be oversized if it is based on the user's peak heat demand for 24 hours a day. Ideally the total take should be based on the predicted daily use based on the variable use and environmental conditions throughout the day. This variation is more significant for larger users.

An excel spreadsheet should be developed to standardise the method of heat demand estimation for various property sizes and for seasonal variation.

5. TECHNOLOGIES & ALTERNATIVES FOR POTENTIAL EFFICIENCY IMPROVEMENT

The above sections discussed the heat extraction methods of existing geothermal systems, controls for minimizing energy loss in distribution and matching the energy take to the heating demand of end users. This section discusses the opportunities of improving energy efficiency through alternative methods.

5.1 Conventional Geothermal Systems

Implementing cascaded use or adapting complementing heating methods in the doublet or DHHE system could improve the overall efficiency of common systems with existing technology.

5.1.1 Cascade Use

As discussed in section 3.2, geothermal energy is distributed by circulated town water. If the heating equipment are arranged in parallel, the end applications are supplied with water at the same temperature. If the heating equipment are arranged in series, the hot water supplied is cooled through each application.

The heating equipment should be arranged in series and cascaded to make maximum use of heat available. To deliver the expected output, each application has a different requirement on the quantity of heat and temperature of the supply. The list below shows the temperature requirement of heating equipment's in a descending order:

1. Space heating Radiator (80°C)
2. Floor convectors/convection heater (60°C)
3. Hot domestic water heating (60°C)
4. Space heating, forced convection (50°C)
5. Spa pools heating (40°C)
6. Underfloor heating (35°C)
7. Leisure/swimming pools heating (30°C)

Radiators have the highest temperature requirement and swimming pools the lowest. The secondary water should be supplied to the radiators first and the pools last. Cascading the appliances in the correct order allows maximum temperature-drop in the circulating water. Given a fixed rate of circulated town water, a greater temperature difference between the secondary water's supply and return increases the amount of heat transferred and improves the system efficiency.

On the other side of the heat exchanger, a greater amount of heat is transferred from the geothermal fluid and the quantity of the take reduced. An increased use of cascaded use may result in a lower average reinjection temperature and there may be an increase in the risk of environmental impact. As identified in section 3.1.5, further work is required to quantify this effect.

5.1.2 Complementary Heating Equipment

A disadvantage of doublet systems is the potential inefficiency in lower heating demand scenarios when wells cannot be turned down sufficiently and system standing losses become significant. Geothermal heated systems can be switched to complementary heating methods when the heating load is reduced seasonally.

The following alternatives could be considered during low demand seasons:

- Electric heaters
- Solar heating for swimming pools and domestic hot water
- Heat pump water heating (COP of between 2.0- 3.0)

The equipment's total life cost should be considered in the selection of a complementary heating equipment. Some are unlikely to be economic if only used for short periods. Electric resistive eating has a low capital cost but higher cost for short periods of use. This may however be the most cost-effective option if it is only required for short periods of low demand.

5.1.3 Antiscalant for Well Maintenance

Calcium Carbonate ($CaCo_3$) deposition has been a common fouling problem for the production systems in

Rotorua. $CaCo_3$ scaling on the casing wall of production well or fouling in the heat exchangers results in decreased fluid flow, more pressure loss and restrict the amount of energy extracted. The scaling can be effectively suppressed by adding antiscalant to the production well below the boiling point. Adding antiscalant has the following benefits:

- Increases well life, less fouling on the well casing and reduces maintenance costs.
- Improves heat exchanger performance due to less fouling in the equipment.
- Controls are more reliable due to less fouling in the equipment.
- Increase temperature into heat exchanger with less pressure drop.

5.2 District Heating Scheme (DHS)

In a district heating scheme, multiple users are connected to the same geothermal production system(s). DHS makes the geothermal resource available to more end users and increase the utilisation of the energy in the Rotorua Geothermal systems. Compared to systems operated by individual users a DHS has the following **Advantages:**

- Improved reliability as plant is central and can be professionally managed.
- Control plant limited to 2 to 3 bores (or may be more, including DHHE) that can be managed to track energy requirements.
- Larger and fewer geothermal systems required to be managed by the Regional Council
- Improved health and safety as lower temperature (80°C) fluid is pumped to houses.
- If funding is available, it provides an opportunity to distribute to lower socio-economic communicate that may not be able to access heat.

There is existing small-scale district heating in Rotorua which is economically viable. East Harbour Energy's report estimated that the savings of switching from gas/electricity to geothermal is $750 per annum per room for resorts and $1000 per annum for one residential property (Boyles et al. 2013). Boyles et al. considered four different scenarios and proposed high-level estimate for the system cost.

The proposed DHS system in Scenario One costs **$1,787,000** for 9 motels and 1 hotel. This proposed cost appears to be quite low, and the estimated net annual return is **$195,000**, which indicated an 8- or 9-years payback period. Dobbie proposes that at least an additional **40-50%** of the cost is required to cover the design (planning and engineering), construction, and management cost for the proposed system. At the same annual return rate, the payback period is increased to 13 years (Refer to **Appendix B** for details).

Previous study has identified barriers for further geothermal development and using district heating scheme. East Harbour Energy grouped the barriers into individual, systematic and technical, these categories, including:

- Individual barriers due to cost
- Unwillingness to share their own supply.
- Risk in health and safety perspectives.
- Relatively low population density, heat demand & risk of low uptake.
- Relatively mild climate means short heating and cooling seasons.
- Issue around ownership and management.

In additional to the findings of Boyles et al, the following **disadvantages** are also identified,

- Difficulty and cost of installing distribution system in the public space, obtaining easements, across roads etc.
- Historically investment in geothermal heating systems has not significantly increase property values and investment cost may not be reflected in resale values.
- To be privately owned would require a reasonable return on capital and is likely to increase energy costs towards other energy sources. (i.e. there is unlikely to be a significant cost saving for users to act as a driver for this technology)

The work of Boyles et al. considered using doublet system in the DHS only, while both the DHHE system and the doublet system can be considered for DHS. There is a significant different in the scale of potential use in group heating or district heating scheme due to the difference in heat output per borehole, summarised in ***Table 4***.

Table 4 DHHE and Doublet System Use in group heating

Comparison of Use	**DHHE System**	**Doublet System**
Typical Heat output per bore (kW)	100 kW	1,200 kW
Scale of use in district heating scheme	Suited to small scale	Suited to large scale
Motels & hotels group heating capacity	25+ rooms	300+ rooms
Residential group heating capacity	12+ homes	150+ homes

East Harbour Energy's proposed DHS scenarios are all based on Fenton Street models, which are identified with higher heat density due to the clusters of the motel and hotels. The commercial units (Hotels and motels) have annual energy budgets of $50-250,000, which makes the central group heating scheme more economically viable.

This report is intended to propose the costs of larger scale system to transfer the energy and distributed to a region that is further away from the areas above the Rotorua Geothermal System.

The cost associated with the following four items must be considered in district heating.

1) Central Plant (Represented in blue, **Figure 4**, dashed circles indicate additional wells)
2) Transfer Piping (In orange)
3) Distribution Piping (In green)
4) Domestic heating systems (In grey)

Figure 4 Four items in District Heating Scheme

Central plant usually includes production wells, geothermal piping, heat exchangers, circulation water pumps, meters, miscellaneous valves & fittings, a plant building, and etc. The plant can be professionally managed. Assume there is a group of 100 houses (800kW) are interested in a group heating scheme, the central plant costs might be **$240,000**; and if it is a group of 1000 house (8 MW), Then these costs are likely to grow to $500,000 .

The transfer piping transfers the energy by hot water reticulation. Larger size pipes are required for a higher heat demand. The material and installation cost of distribution piping (to transfer 500-800kW energy) is estimated at **$500,000/km** and up to **$950,000/km** to transferring 5-8 MW energy. The design and management cost for both is estimated at **$160,000/km**.

There is also energy efficiency in larger systems. The heat loss through the transfer pipe is estimated in **Table 5** as a percentage of the total amount of energy transferred. The heat loss becomes much less significant for larger systems. The distribution piping refers to the smaller branches that delivers the circulated water to each household. The cost per house is approximately **$10k** to **$15k.**

The domestic heating system refers a close low temperature hot water circulation system. It requires specific equipment for space, water and maybe pool heating. Typically, the existing homes do not have these, and new heating systems need to be retrofitted. Costs per household depending on the size and complexity will range from **$10k** to **$20k**. These systems require the installation of radiators, underfloor heating, or ducted hot air systems. Independent storage based hot water systems will be required.

Table 5 100 homes v.s. 1000 homes Reticulation costs and heat loss Compared

Components	Larger distribution systems	
Number of users	100 homes	1000 homes
Estimated Heat Demand (kW)	500-800 kW*	5-8 MW*
Estimated energy loss/ km	33.5 kW	83.7 kW
Energy loss %/ km	**4 - 7%**	**1.0 - 1.7%**
Transfer Piping Material & Installation Cost/ km	$474,000	$934,000
Transfer Piping Design and construction management/ km	$160,000	$160,000
Total Transfer piping cost/ km	**$634,000**	**$1,094,000**
Shared cost per home/ km	$6,340	$1,094

*Note: The overall heat demand is lower than the sum of the individual peak demand suggested in section 4, due to user diversity.

The table indicates that the shared cost for distribution piping is $1,094 per km and the energy loss is only 1- 1.7%. This cost estimate assumes that the distribution piping is laid within the road reserve in public roads. The cost per home and energy loss will increase proportionally to the additional the distance travelled. Some pipes must be laid in private property could lead to later problems with building limitations and restricted access for repair.

In addition to the central plant costs there are costs associated with distribution to the individual homes and within the individual home. The distribution piping refers to the smaller branches that delivers the circulated water to each household. The cost per house would be approximately **$10k** to **$15k.**

The domestic heating system refers to the closed low temperature hot water circulation system within the home. It requires specific equipment for space, water and maybe pool heating. Typically, the existing homes do not have these, and new heating systems need to be retrofitted. Costs per household depending on the size and complexity will range from **$10k** to **$20k**. These systems require the installation of radiators, underfloor heating, or ducted hot air systems. Independent storage based hot water systems will be required.

5.3 Alternative Application of Geothermal Resources

Ground source heat pumps, absorption cooling plant and small-scale binary cycle electricity generation are alternative applications that could utilise geothermal resources. This section briefly discusses these alternatives and the potential for applications in the Rotorua geothermal system.

5.3.1 Ground Source Heat Pumps (Heating and cooling)

A ground source heat pump (GSHP) utilises a reverse cycle heat pump to recover heat from a lower temperature heat source like an air source heat pump. A GSHP typically runs with a COP of 2.5- 3.5.

GSHP is designed to use a heat source, i.e. soil or water, in the 10-20°C range. It is primarily economic in areas where low ambient air temperatures make the conventional air heated system inefficient or if large bodies of water are available as a heat source.

Ground source heat pumps using buried coils are typically used for small domestic uses while water systems (River, lakes, large underground reservoirs) at 12-15°C can supply large systems of 100-1000kW. Potentially, lake Rotorua could be a suitable heat source.
The following three requirements need to be considered for successful GSHP operation:

- **Ground temperature requirement**: The soil or water used has a constant and moderate temperatures (10-20°C).
- **Space requirement**: A relatively large space is required for a horizontal system; Alternatively, a vertical GSHP bore may need to be 50-150m.
- **Closed loop or Open loop system:** An open system GSHP use ground water as a heat sink by passing the extracted ground water to a heat hump and returning to lake or pond; a closed system circulates a secondary fluid through closed coils. These systems are illustrated by a GNS report written for BOPRC to consider the feasibility of geothermal home heating (Bendall 2012).

GSHP are not designed to operate when heat sources exceed 40°C or 50°C. In Rotorua's 'warm ground' areas, alternative heating recovery systems as discussed elsewhere in this report become more economic compared to GSHP.

5.3.2 Absorption Plant Technology - Cooling

Absorption technology can realistically generate 0.5 to 1 MW of cooling (at 6°C) from 1 MW of heat at 110-140°C. This has been demonstrated at the Millennium Hotel in Rotorua for 20 years (1980- 2000) and at the Norske Skog Kawerau Paper Mill that operates a 1.7MW chiller.

The **advantages** of introducing this in Rotorua:

- Can provide a low carbon renewable energy source for cooling and they provide large robust plant, resistant to Rotorua's corrosive environment. It is more reliable and has longer lifer than mechanical heat pumps.
- Suited to a continuous base load application. i.e., a base load cooling or an industrial process requiring chilled water (Dairy, meat processing, short term (few days) food storage)

The **disadvantages** of introducing this in Rotorua:

- Relatively short cooling season in Rotorua for air conditioning resulting in low a opportunity of use.
- Little used technology and few credible maintenance and service teams.
- Relatively high capital cost but offset by operational costs

5.3.3 Small Scale Binary Cycle Electricity Generation

Small scale binary cycle electricity generation schemes could provide an alternative energy options for Rotorua's geothermal field.

The schematics in **Figure 4** demonstrates a small-scale generation facility with two generators. The generator, Power+4400B+ is supplied by ElectraTherm. The generator works under the principal of an organic Rankine cycle. The thermal energy from geothermal fluid converts an organic fluid (low boiling point) into vapor. The fluid vaporises and expands through a turbine, that the thermal energy is converted into mechanical energy then into electricity.

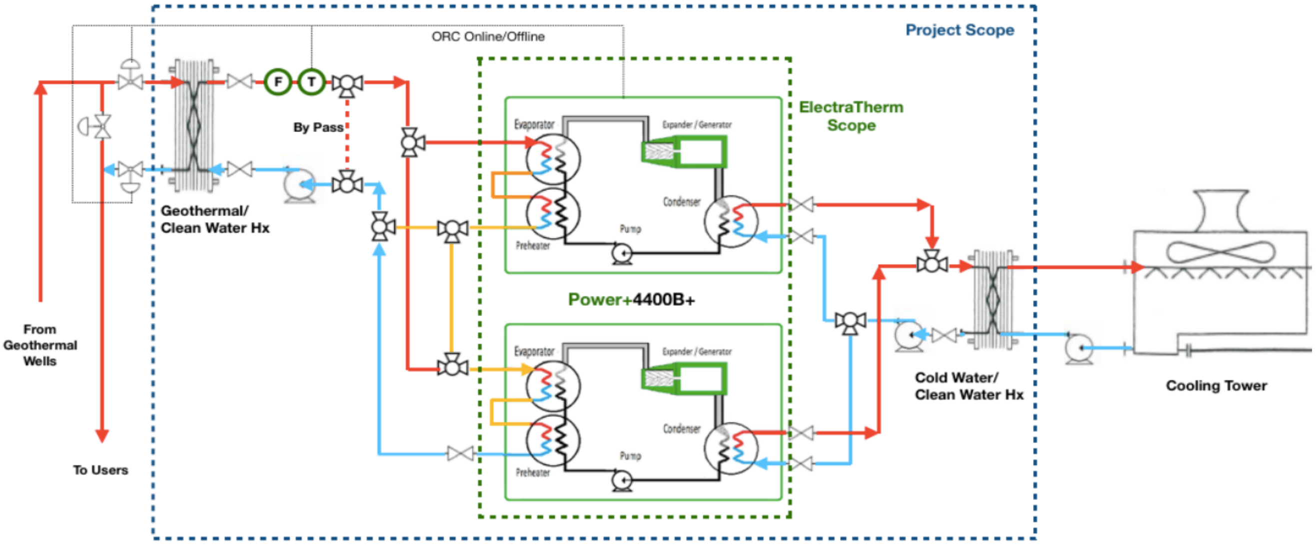

Figure 4 ElectraTherm Power+4400B+

It is an opportunity to produce electricity from a low carbon renewable energy source and forms independent power supply to meet individual businesses or local communities' own needs.

Features

- Relatively low efficiency 7-9%. 1.6 MW of geothermal fluid (130°C-140°C) is used by the system illustrated in **Figure 4,** to generate 60-75 kw of electricity output (each generator), and 900 kW of low-grade heated water at 40-50°C, and the rest of the heat is irreversibly lost to the environment.
- High capital cost $4,000/ kWe, and the return is approximately $0.24/ kWhr if this is used to offset existing purchased capacity.
- Most likely to be considered if:
    - Large level of medium grade heat is available 130-140°C with no alternative use.
    - Can be coupled with a system to use the large quantity of low-grade heat produced (40°C-50°C) This might be leisure or swimming pools, horticulture (glass house), aquaculture (fish farming) or space heating that utilise low grade heat (underfloor or air heating)
    - The generated capacity should be used in-house to offset energy cost. If sold on the whole sale electricity market, the return is reduced significantly.

Risks of introducing such applications in Rotorua:

- Unknown technology at this scale. There are no other similar plants in NZ which means there is limited-service experience. Ownership (due to scale) is likely to be private or local body where no previous operational or maintenance skills exist.
- Unlikely to install a full standby capacity so a supply agreement with a national supplier is still required. May be a suitable solution for industrial applications but less practical for domestic users or commercial uses, i.e. hotels and resorts.
- Challenges in managing the ownership of the equipment and distribution of the generated electricity.

6. CONSENT PROCESS AND ROTORUA GEOTHERMAL REGIONAL PLAN

6.1 Resource Consent

In the current consent process, applicants propose the activity and a quantity of fluid or energy required as the demand. The required information is listed in the application form, *Form 6A Geothermal take, use and discharge.*

- Part 2 of the form, Section 4 *Geothermal Energy Use* requires the applicant to provide consent conditions:
    - Temperature at the point of production and at the point of reinjection
    - Volumetric flow rate of the take and discharge of geothermal fluid
    - Description of how the flow rate is calculated.
- Section 6 *Discharge*
    - Volumetric flow rate of reinjection
- Section 8 *Mitigation Measures* requires the applicant to describe efficient use of energy:
    - The measures to protect against wastage of resource.

A number of these points should be reconsidered to add strength and clarity to the application and review process. The following section discuss the opportunities to reflect efficiency requirements in the resource consent conditions and compliance monitoring.

6.1.1 Unit for 'Rate of Use'

The units used in resource allocation can lead to confusion. In the existing application form, the suggested geothermal take and discharge is measured in Litres per second or m^3 per day. The geothermal fluid may leave the production well as a two-phase mixture of steam and liquid. In this case the volume will decrease significantly as the fluid is cooled making the volumetric measurement unsuitable. The mass of the extracted fluid, i.e. kg/s or tonnes/day, does not vary with the temperature. Mass flow rate should be used as the measured unit to show equilibrium through the process.

6.1.2 Temperature and Available Energy

The available energy in the doublet system is the product of the mass flow rate and the enthalpy difference of the extracted and the reinjected fluid. A consent applicant should identify the enthalpy of the fluid entering and leaving the system in their application. This may be taken from historical information, the output from adjacent wells operating at similar pressures or from a calorimeter test of the bore. The consent form requires the applicant to provide the temperature at the point of production and at the point of reinjection. The available energy cannot be calculated with temperature along, especially when two phase fluid is being used.

6.1.3 Consented Rate of Energy Take

Consented conditions for energy take from a down hole heat exchanger is typically requested in 'Kilowatt (kW)'. This is an instantaneous rate of energy transfer which is usually referred to as 'power'. This indicates the peak energy use and is an energy flow at a particular time instance. It can only represent one moment in the daily use.

An alternative measure of energy take is the quantity of energy consumed per day, a 'daily rate'. This should be measured in Joules (J) or for larger quantities the 'giga-joule (GJ)'. A Joule is a measure for a quantity of energy rather than the kW which is a rate of energy use. An alternative unit is the kilowatt-hour (kWh) which is a common energy unit used for utility bills, i.e. electricity. Kilowatt-hour (kWh) is a unit suitable to describe total consumption over a period of time, i.e. days, months, years. One 1kWh is equivalent to 1kW taken for 1 hr, which is 1000J/s x 3600s = 3.6 MJ or 0.0036 GJ.

It would be more useful if both peak instantaneous and daily total energy are nominated with suitable units. This would allow meaningful comparison with gas or electricity metering systems. It would Also provide an incentive for users to match their use through the day to their demand and reduce their daily take. This is further discussed in section 6.1.4.

6.1.4 Geothermal Energy Use

The following could be considered when revising the 'Geothermal Energy Use' section of the consent form. Rate of use fluctuates through the day and varies seasonally. The following measures could be used. Each measurement has its own characteristics, advantages and disadvantages.

- **Peak Rate** of the production system. This is the maximum take or energy use for one instance in time.. This is easier to estimate, and easier to measure as long as the measurement is taken at a time that is representative of maximum use (maybe early morning on the coldest winter day)
- **Daily Use** to match the maximum average daily consumption of the end user. This can be estimated, and may require continuous monitoring for short peak periods, i.e. days or weeks to prove compliance. Again the measurements must be taken at times that represent maximum daily use (i.e. the coldest day of the year or the one with the highest domestic hot water demand)
- **Annual Use** to match the average annual consumption of the end user. This is more difficult to estimate and measure compared to daily use. To simplify the measurement but maintain some seasonal variation this could be simplified into 4 seasonal or even summer/winter categories. This would ensure the take matches the peak daily seasonal requirements rather than just peak daily or peak instantaneous measurements of the above two options.

Breaking down the energy use into these categories will provide some flexibility to the end user but also allows BOPRC to better control the rate of use and total take of energy. To stimulate the incorporation of efficient low impact technologies by the user requires the BOPRC to adopt a mechanism that ensures that the consent for energy and/or mass take closely matches their heat load requirements, so there is little room for energy waste.

Combining multiple of the above methods could better control a geothermal systems energy take. Three options are proposed as listed in ***Table 6***, each nominates one or multiple of the above measurements.

- **Option1:** nominate the peak rate only. This option is at risk of abuse, will not reflect daily or seasonal demand and needs rules or other controls (inspector and operator of controls) to ensure that energy use matchs energy requirements. This would require significantly more inspection and enforcement of the use of energy saving strategies as described in NZS2402P. This may be more suitable for Small Doublet Systems (1-10 homes)**,** where it requires a spot-check of the geothermal flow and inspection to ensure energy saving features are in place. Monitoring of the reinjection temperature would also indicate the health of the system. This option is relevant where continuous geothermal flow measure is less practical.
- **Option 2** nominate both the peak rate and peak daily use. Assumptions can be less rigorous compared to option 1, requires continues monitoring, but will not control seasonal demand. Seasonal control relies on other measures (Controls and inspection). This option is more suitable for Medium Size Doublet Systems (11-20 homes or 1-2 motels), where continuous sampling the geothermal flow is less reliable.
- **Option 3** nominate all three measures. This is more difficult to measure but provides tight control or the take. It is suitable for DHHE Systems or Large Doublet Systems (multiple motels, one or more hotels, or District Heating Schemes), where a simple heat meter can provide continuous measurement. On DHHE, large secondary systems and Group Heating Schemes the use of energy metering in the secondary system would be practical provided the normal energy efficiency features of insulation and geothermal flow control are adopted.

Table 6 Proposed three options of nominating measurement in quantifying geothermal resource

Nominate \ Options	**Option 1** Small System	**Option 2** Medium System	**Option 3** Large System
Peak Rate (kW and kg/s)	✓	✓	✓
Daily Use (kWh/day, GJ/day, and Tonnes/ day)	-	✓	✓
Annual Use (kWh/year, GJ/year, and Tonnes/ year)	-	-	✓

6.1.5 Compliance Monitoring

Successful compliance monitoring relies on clearly stated consent conditions which can be measured and monitored and compared to the consent requirement. At present consent holders are required to monitor the geothermal flow and temperature 5 times between April and August on two occasions over the period of the consent (10 years). The measured values are sent to BOPRC and then logged on to the compliance database. This measurement at a discrete time of the day is unlikely to be representative of the peak usage as the consumers energy consumption varies based on the hour of the day and weather on that day. This measurement system is open to abuse with measurements taken at non seasonal days and at periods of reduced demand.

A previous issue and options report proposed to classify the fluid extracting geothermal users into 3 tiers for monitoring based on the amount of their consent allocation. A different class was proposed for DHHE users. (Dobbie 2014).

- Class 1, the biggest users, who are to provide continuous monitoring of their daily take.
- Class 2, the medium users, intermittently monitoring of daily take for 1-2 weeks every 5 years.
- Class 3, the small users, sample the geothermal fluid flow twice over 10-year consent period.
- Class 4, the DHHE users, continuous measurement with heat meter for 1 day every 5 years

Class 1 and 2 represents the 33% of geothermal users who take 80% of the allocated total geothermal fluid. This compares to section 6.1.3 with Class 1 and DHHE users using option 3 in 6.1.3. Class 2 and class 3 would suit options 2 and 1, respectively.

Ideally, extrapolating the approach used for freshwater takes to consents for geothermal takes Class 1 and DHHE would require measuring the energy use and/or mass take from the geothermal system more regularly and providing regular reporting.

- The consent holder would be required to submit geothermal fluid take data (matching the consent Condition measurements) monthly, quarterly, and annually.
- BOPRC could carry out site inspections periodically to check if the activity being undertaken is within the scope of the consent and in accordance with the requirement of the consent conditions (i.e. complies with the efficiency requirements of NZS2402P.
- Desktop audits would be performed to review the information provided by the consent holders.

Adopting these measures will significantly improve the success of the compliance monitoring.

6.1.6 Other Barriers

The consent process and the regional plan should address the following barriers to efficient use:

- A lack of manuals or information packages provided to the consent holders for the efficient installation and maintenance of the geothermal resources.
- A lack of skilled experts and technology specific installers and inspectors. The BOPRC could adopt a IQP register (similar to that adopted by local district councils) of suitable contractors to perform work and inspect systems.
- A lacking guideline or recommendation on how much geothermal resource is required in their activities. Simplified methods to calculate daily and annual energy use are required.
- A lack of drivers for the geothermal users to adopt energy saving techniques, i.e. adding a value to the energy and charge for its use.

6.2 Future Works in the Consent Process

1. Standardise the units used for 'rate of use', and record the geothermal fluid by 'mass flow rate' instead of 'volumetric flow rate'
2. Require the applicant to identify the heat load and to match this to the end use.
3. Nominate peak, daily maximum, and seasonal limits for large users (largest 25-30%). Request continuous monitoring for these large users while medium to small systems have less rigorous monitoring requirements.
4. Obtain more regular reporting and review of compliance in a similar manner as the water takes.
5. Assist applicants to achieve more efficient system by providing guidelines and recommendations.

7. RECOMMENDATIONS FOR FUTURE WORK

This report compares the relative efficiencies of Doublet and DHHE systems and surface features. Each has its merits and applications for use. To optimise the use of these systems, it is recommended that reservoir modelling is used to:

- Identify ideal reinjection temperatures and investigate if low temperature (<80°C) reinjection could have a negative impact.
- Identify where reinjection should occur to maximise its benefit, i.e. identify suitable depth and field positions.
- Identify areas in the reservoir where DHHE operation would be optimised.
- Evaluate the comparative effect of a doublet system extracting 250kW of energy and a DHHE extracting a similar heat flow in the same location.
- Identify the optimum relative depths and distances between production and reinjection wells.

It has been identified that DHHEs pose the lowest risk to the reservoir however their output is generally limited. Further work is required to optimise their performance. A purpose built DHHE in Fenton Street has demonstrated the importance of well diameter and heat transfer surface area however more work is required to identify the best locations within the field to achieve the high levels of output to make these units economically viable compared to Doublet systems.

NZS 2402P has been identified as a good tool to benchmark system efficiency.t. NZS2402P should be updated to:

- Reflect current best practice.
- To be formally adopted by New Zealand Standards or to be published in some other form (i.e. a Geothermal Users' Guideline)
- Review reinjection practices

At present the 1.5 km exclusion zone has proven to be a useful tool to maintain reservoir pressures at Whakarewarewa. Some work has been done to evaluate the impact of increase production within this exclusion zone. The size or shape of this area, however, is not based on any reservoir features or parameters. Further work should be performed to confirm the optimum area of the exclusion zone.

This report discusses setting minimum energy efficiencies within the end users' plant (i.e. buildings, hot water, and pool systems). BOPRC needs to consider if these guidelines should be included in consent criteria to ensure efficient end use of the energy.

The existing consent documentations should be revised. The following recommendations are made:

- The level of monitoring should be based on the size of take and could consider a three-tier approach which larger users providing more detailed information.
- Units of measure should be standardised to reflect the mass flow, rate of energy use and total energy use.
- Applicant should state the actual energy take required and substantiate that with measurements of take and discharge enthalpy.
- An excel spreadsheet should be developed to standardise the method of heat demand estimation for various property sizes.
- Reporting by users should be more regular and compliance should be monitored and enforced.
- Provide applicants with advice, guidelines, and recommendations to optimise efficiency.

8. REFERENCES

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NZS 4218:2009 Thermal Insulation—Housing and Small Buildings

NZS 4305:1996 Energy efficiency - domestic type hot water systems

NZS 4441: 2008 Swimming Pool Design Standard

APPENDIX A – Cost to Insulation

The cost estimate for pipe insulation is summarised in ***Table A1*** and ***Table A2*** , it costs **$20** to insulate one meter of 25DN pipe. Assumes that the secondary circulating water is at 80°C, and the ambient is at 20°C at a particular instance. The one metre insulation reduces the loss by 7.8W, which is 0.187 kWh per day -> 68kWh per year. The energy saving for insulating one meter of 25 DN is 68kWh, and the average cost of domestic electricity price in Rotorua is $0.33 per kWh. It saves **$22** if the heating is obtained from electric heating.

The annual insulation power saving and annual cost saving are estimated in a similar manner for the geothermal piping. In ***Table A2,*** it costs **$22** to insulate one meter of 25DN geothermal water piping and the reduced energy loss saves **$28** per year (Assumed that the geothermal water is at 120°C and the ambient at 20°C).

Table A1 Cost of insulating one metre Secondary water piping & annual saving

Unit Cost (per meter)	19mm thick Insulation	25mm thick Insulation	Annual power saving due to insulation	Equivalent annual cost saving due to insulation
25 DN	$20	-	69 kWh	$22
50 DN	-	$46	138 kWh	$44
100 DN	-	$56	276 kWh	$88

Table A2 Cost of insulating one metre geothermal water piping & annual saving

Unit Cost (per meter)	25mm thick Insulation	38mm thick Insulation	Annual power saving due to insulation	Equivalent annual cost saving due to insulation
25 DN	$22	-	86 kWh	$28
50 DN	-	$52	172 kWh	$56
100 DN	-	$71	344 kWh	$113

Note: The above tables reference QV Cost Builder, Table 1, copper pipes and Table 2, galvanised steel pipe with aluminium foil covered fibreglass. The price is material cost only, labour cost excluded.

APPENDIX B – DHS cost Estimate

Table B compares the DHS cost Estimate Scenario 1 of East Harbour Energy Limited and Dobbie's Estimate on Labour cost

Table B District Heating System Installation cost estimation

Items	**East Harbour Energy's cost**	**Dobbie's cost estimate**
Planning, engineering & management	$0	$250,000
Consent and approval	$20,000	$20,000
Trenches (453m)	$23,500	$100,000
Directional drill/sleeve (222m)	$21,000	$42,000
Geothermal fluid piping	$19,000	$40,000
Secondary Fluid distribution pipe(675m)	$129,000	$200,000
Central plant (pumps, plant building)	$50,000	$100,000
Miscellaneous valves, meters, and fittings	$10,000	$10,000
Traffic control, permits, locate services	$5,700	$20,000
Doublet System (2 or 3 new bores)	$160,000	$240,000
Contingency	$104,800	$255,500
Heating systems for motels (9 units)	$931,500	$931,500
Heating system Hotel (1 unit)	$312,000	$312,000
Total	**$1,786,500**	**$2,521,000**

APPENDIX C - Quantified Peak, Daily, & Annual Use

Example statements for the quantified allocation based on its **peak use:**

Non-reinjection, net outflow:

*This consent authorises a maximum abstraction rate of **XX kg/s** from Bore XXXX.*

Small Doublet system (100 kw or lower):

*This consent authorises a maximum abstraction rate of **XX kg/s** from Bore XXXX and all the abstracted fluid will be injected back to the aquifer via reinjection bore XXXX.*

*The estimated peak heat outflow is **XX kW**, based on XXX°C heat exchanger inflow temperature and 80°C reinjection temperature.*

Example statements based on its **peak use and daily use:**

Large Doublet system (more than 100 kw)

*This consent authorises a maximum abstraction rate of XX kg/s from Bore XXXX and all the abstracted fluid will be injected back to the aquifer via reinjection bore XXXX. The estimated peak heat outflow is **XX kW**, based on XXX°C heat exchanger inflow temperature and 80°C reinjection temperature (the minimum).*

*And the total energy abstraction should neither exceed **XX kWh/day** nor XX Tonnes/ day.*

Example statements based on its **peak use, daily use, and annual use:**

DHHE System

*This consent authorises a peak heat outflow of **XX kW**. And the total energy abstraction should neither exceed **XX kWh/day** nor **XXX kWh/ year**.*