PRODUCTIVE AND ALLOCATIVE EFFICIENCY - ROTORUA GEOTHERMAL SYSTEM

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ABSTRACT

The Rotorua Geothermal System is managed under the Rotorua Geothermal Regional Plan (1999), to protect its rare and vulnerable surface features. The current plan has strong imperatives to support efficiency in the use and allocation of the geothermal resource. The effectiveness of these policies, and their implementation, has been assessed as part of a review of the regional plan. This work identified the typical efficiency issues in the geothermal production and distribution systems in Rotorua, and at the user end. To improve efficiency in allocation, the Bay of Plenty Regional Council is developing a robust process and an allocation App to calculate the heat and mass (geothermal fluid) load for benchmarking efficient use and allocation of the resource. There are limited suitable methods or technologies for accurate and continuous measurement of the geothermal fluid take in Rotorua due to its unique settings (i.e. geothermal fluid properties, mixed use and shared schemes, and environmental and regulatory constraints). Those challenges were overcome with the development of a movable flow loop, and trials showed that over 50% of the users may be using less than 30% of their allocated geothermal fluid. Increasing certainty around the actual heat and mass production from the system will reduce the risk of over-allocation while making better use of the estimated sustainable resource available. Wasteful practices are expected to be minimised mostly through allocation for efficient use coupled with tighter take monitoring. Most importantly, improved allocation and use will contribute to the sustainable management of the resource and protection of its unique surface features.

1. INTRODUCTION

1.1 Rotorua Geothermal System policy framework

The Rotorua Geothermal System is in the Bay of Plenty region of New Zealand Aotearoa. The system is in the Taupō Volcanic Zone and lies under part of Rotorua City (Fig. 1). It has been used for decades for direct heat use for space and water heating, and for mineral bathing, and has been used sustainably by Māori (the indigenous people of New Zealand) for hundreds of years. The resource is a taonga (treasure) with value still embedded in daily life, especially in communities such as Whakarewarewa, Ōhinemutu, Kuirau and Ngāpuna (Ngā wai ariki o Rotorua: He kohikohinga report).

The effects of uncontrolled use of the geothermal resource in the 1960s-1980s, and the subsequent recovery of many of its surface features through improved management, is well documented in the literature (Scott *et. al.*, 2016 and references therein). Requirements for improved efficiency in the use of the resource were central to this recovery, in particular the reinjection of geothermal water into the aquifer, rather than its disposal to shallow soakage, land or surface water.

The system is now managed by the Bay of Plenty Regional Council (BOPRC) under the Resource Management Act 1991 (RMA). The Bay of Plenty Regional Policy Statement (RPS) sets the overall framework for sustainable and integrated management of the resource. Under the RPS the geothermal system must be managed to protect its unique surface features as a priority over extractive uses. The RPS contains a range of policies to direct how this should happen, including policies on the efficient use of the resource.

The Rotorua Geothermal Regional Plan (RGRP) contains more specific policies and rules to guide the use of the resource and for assessment of resource consent applications for the taking and use of geothermal water and/or heat. The plan has strong imperatives to support efficiency in the use and allocation of the geothermal resource. Rules require reinjection of geothermal water for all production-reinjection takes, with few exceptions, and ~90% of the geothermal water extracted is now reinjected. The plan also contains a suite of policies that direct efficient use, including matters such limitations to the use of doublet systems in proximity to the Pohutu Geyser [i.e. only downhole heat exchangers (DHXs) are permitted within 1.5km radius of the Pohutu Geyser, and there is to be no increase in taking heat from this area]. Policies also direct allocation of geothermal water and heat commensurate with the anticipated end use. They also point to monitoring of the actual use, and application of efficiency measures as conditions of consent such as insulation of piping and reinjection at temperatures that minimise losses to the system.

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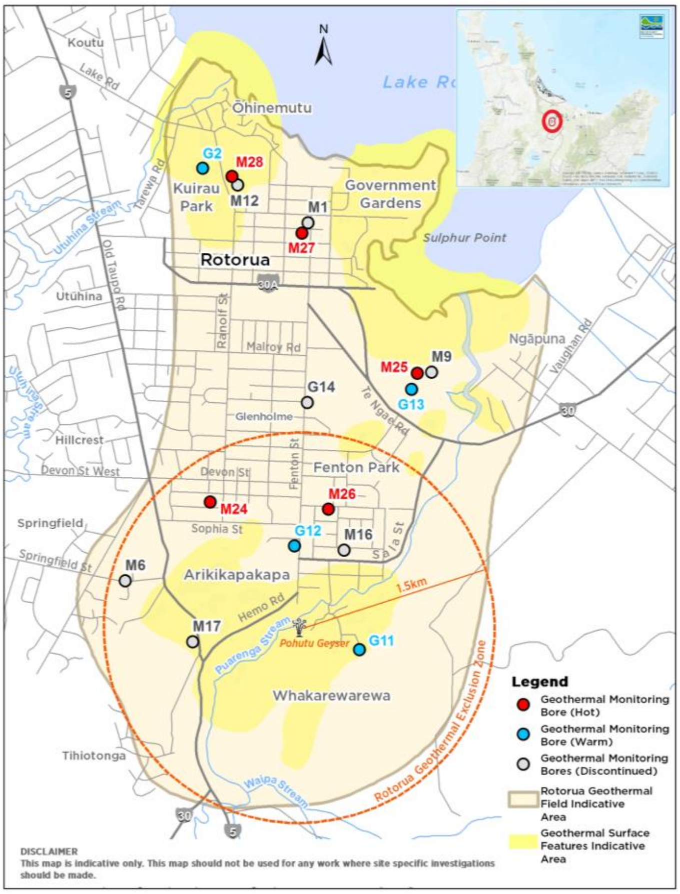

Figure 1: Rotorua Geothermal System - location and extent. 1.5 km exclusion zone (orange circle).

1.1.1 Rotorua Geothermal Regional Plan review

The effectiveness of these policies has been assessed as part of a formal RMA review of the regional plan currently underway. Despite the strong policy direction in the plan, efficiency has been identified as a key issue in community engagement for the plan review. People recognised that the Rotorua Geothermal System is vulnerable to overuse or inappropriate use, and expressed concern over waste of the resource. Some of those concerns were a perceived 'waste' (e.g. the perception that reinjection at high temperatures is a 'waste of energy'), and in other cases people cited the lack of insulation of homes and pipework and little use of heated town water pool covers. The practical limitations or reluctance of users to adjust their takes to better meet their end use was also cited (eg. leaving windows open when running geothermal heating systems). There was also a strong desire to allocate geothermal resources for the best use for the most people. There was a sense that improved efficiency could mean greater opportunities for others, better protection of the surface features and improved sustainable management of the reservoir long-term. In short, efficiency was seen to be a critical part of future management.

Another key issue raised through the plan review process has been the uncertainty of the data informing the management of the geothermal system, including data used for reservoir modelling and in resource consents. Improved data was seen as a way to create greater certainty for allocation decisions and therefore greater efficiency in use. The BOPRC has focused on building its knowledge around those issues lately.

Broadly speaking, the existing suite of policies already provides considerable direction and opportunity for improved efficiency and consent monitoring. Although the policies can be improved, it is in their implementation, particularly through the consent process, that opportunities have been missed and that most gains can be made. Several areas to improve internal Council processes have been identified, including an assessment of the efficiency of different geothermal production systems, the way in which use of the resource is monitored to minimise uncertainties around the actual heat and mass production from the system, and developing tools to ensure that allocation through the resource consent process matches the load for efficient use of the resource. We broadly refer to these below as productive efficiency.

1.2 Productive and allocative efficiency in Rotorua

Productive efficiency in the Rotorua System has recently been assessed for BOPRC by Peng & Moore (2021). The report reviews energy efficiency from two perspectives: energy distribution equipment and end use efficiency. It addresses the issues and provides recommendations on suitable system upgrades and modifications to increase efficiency for the various production methods and technologies, in the distribution system and at the user end. The recommendations of this report align with the Technical Report by the Geothermal Task Force from 1983 - 1985 (see references). This includes insulating hot pipes, reducing geothermal energy extraction by using control devices and sizing heat exchangers correctly. It has therefore been 40 years since the first initiatives to reduce the waste in the residential and commercial use of geothermal heat. It is not due to the lack of 'energy efficient equipment' or a lack of 'method' that the issue of wasteful use remains. There is a lack of drive for system efficiency improvement. The reasons behind this are multifactorial. The users and some industry providers may not have the knowledge nor the opportunity to improve efficiency, possibly due to lack of information or resistance to meet increased costs. Also, poor monitoring of actual use means that many consent holders are not aware of how much energy they are actually using. There may also be limited awareness of the importance of the efficient and sustainable use of the allocated resource, and there is a perception of unlimited 'free' heat in Rotorua.

A cross Council approach (policy, science, consents and compliance) has been used to address these constraints. Four priority areas were identified to effectively achieve higher allocative and productive efficiency in Rotorua: (i) Modify consent processes to allocate the correct amount of energy (ie. heat load to match end use); (ii) More effectively monitor the takes (iii) consider the relative effects of different production systems, and (iv) Development of educational material to support users with simple system maintenance and upgrade issues. Specific projects linked to those areas, include:

- Development of a methodology to estimate the heat and mass load based on efficiency standards for space and water heating, mineral pools and energy conservation (supported by Dobbie Engineers – refer to Peng & Moore, 2021 for standards). The key deliverables to date are a flow diagram outlining the methodology and some trial runs based on a developed spreadsheet. The end product is intended to be an App for use by consent officers to support the assessment of the resource consent applications for resource allocation. It is expected that this improvement in the consenting process will reduce potential over-allocation and encourage the users to adopt energy efficiency principles (Peng & Moore, 2021) (Section 2.2).

- Implementation of continuous metering of larger takes within the Rotorua Geothermal System (Section 2.3) through consent processes and in consultation with consent holders. This will inform our understanding of the effects of resource use and the Council's allocation decisions.

- Assessment of the relative effects of different production systems (doublets, downhole heat exchangers and enhanced downhole heat exchangers) (Section 2.1).

- Development of educational material. Further material will be developed as needed.

These are discussed in more detail in Sections 2 and 3.

2. PRODUCTIVE EFFICIENCY

2.1 Productive efficiency in Rotorua

2.1.1 Production system - issues and recommendations

Geothermal energy is extracted from the Rotorua Geothermal System through two main production methods: production-reinjection systems and conventional downhole heat exchangers (DHX). Typical thermal energy outputs from doublet systems in Rotorua are in the order of magnitude of hundreds of kW_{th} to over 1-1.5 MW_{th}. Downhole heat exchanger typical output is < 50-100 kW_{th}. A key issue to minimise wastage is to match the production system output to the users' heat and mass load, particularly for users with self-discharging wells and low heat demand yearly or seasonally.

Self-discharging production wells (doublet systems) often have outputs much higher than the user's demand, particularly during the summer months. Those wells are difficult to regulate due to the minimum sustainable flow required to prevent a discharge collapse, resulting in wastages. Excessive energy is lost, for example, as the steam vents off the reinjection well venting mast due to reinjection temperatures above 90 °C (Peng & Moore, 2021). Therefore, doublet systems are technically not suited for small takes (i.e. less than 100 kW_{th}). Downhole heat exchangers, on the other hand, can more easily be adjusted to match the heat load. However, for most commercial uses, the DHX output per well is much lower than the heat demand, and may not suit the larger takes. Additionally, takes that include geothermal fluid direct use (e.g. mineral pool) cannot be serviced by DHX only.

Peng and Moore (2021) identified that the methods below could be used to reduce the production well output (mass flow rate) to match the user heat / mass load while avoiding the minimum sustainable flow issue above mentioned. They also identified that heat exchangers should be sized to ensure that the geothermal fluid leaves the heat exchanger at a temperature lower than 90 °C (e.g. select plate heat exchangers that provide close temperature approaches).

- Sleeve the production well diameter to reduce minimum flows.

- A submersible pump in production wells that self-discharge would give the system a better ability to control the well, especially for users with heat demand lower than the well's thermal output.

- Close the well during low heat load periods (e.g. summer season), and utilise an alternative heat source as needed.

The development of additional policies and rules to incentivise or require the uptake of one production system over another within different parts of the Rotorua Geothermal System, as is currently the case for the 1.5 km Mass Abstraction Exclusion Zone where only DHX is permitted, is also supported from a reservoir effects perspective. Clearwater & Franz (2021) showed that different production systems [DHXs, DHXs with enhancements to promote heat and mass convection (promoter tube or perforated casing) and doublet systems] with the same thermal output and operating within the same reservoir conditions affect the reservoir differently. They also demonstrated that, even though the magnitude of effects in the reservoir (thermal and pressure decline) might be similar for DHXs and doublets, doublet systems have the potential to affect the reservoir pressure and temperature over a wider area due to the spacing required between production and reinjection wells (Fig. 2). Finally, the use of DHXs avoids risks that are unique to doublet systems, such as the reinjection well not effectively providing pressure support to the production area, causing additional pressure decline. The use of DHX also generally reduces the number of geothermal wells needed for smaller takes, reducing costs and risks.

Clearwater & Franz (2021) also showed that enhanced DHXs have the potential to create a much larger effect in the reservoir compared to conventional DHXs due to their capacity to generate higher thermal output (hundreds of kW_{th} compared to < $50kW_{th}$ for DHXs), and due to the creation of a localised convection cell which enhances the pressure drop locally. Therefore, while enhanced DHX technology has the potential to be adopted by users with heat loads > $50kW_{th}$ to up to a few hundreds of kW_{th}, avoiding doublet systems potential wastages above the ground, precaution is required around the potential effects of enhanced DHXs in the reservoir, especially localised effects in proximity to surface features sensitive to pressure and temperature drop. In 2021, a purposely built DHX well drilled to 150 m, utilising a promoter pipe and a 200mm diameter casing, has been shown to produce up to 150 kW_{th} from resource temperatures between 130 and 140ºC, an up to 8-fold output increase compared to a conventional DHX. This shows the potential of this more benign technology to be further adopted for users with heat load of the magnitude of hundreds of kW_{th}. It is also a fine example of increased productive efficiency through technology improvements and a better understanding of the resource.

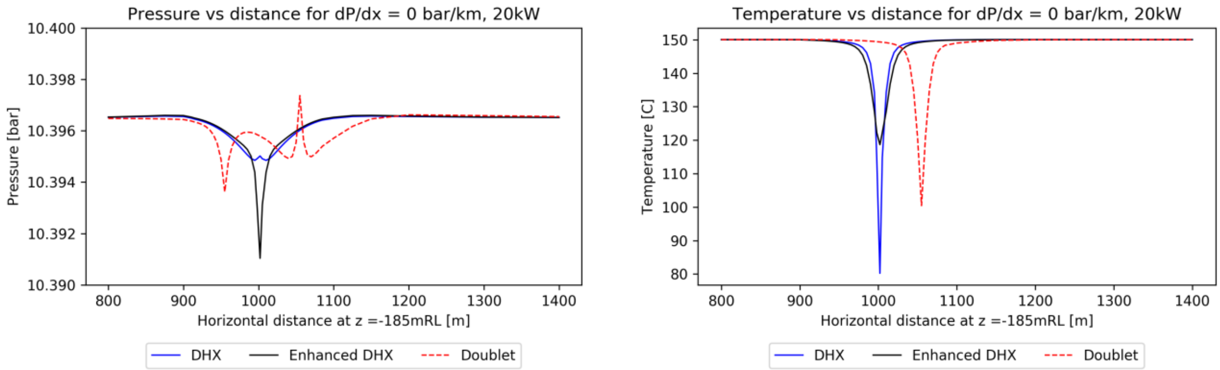

Figure 2 - Pressure and temperature effects of different production systems with $20kW_{th}$ generation in a 150 °C reservoir with no horizontal pressure gradient. For the doublet system, the production well and reinjection well are located at 952.5 m and 1052.5 m horizontal distance (x axis), respectively.

<u>2.1.2 Distribution system</u>

For the distribution system, Peng & Moore (2021) identified the issues below as key areas of concern that can lead to waste.

- Equipment rating: All above ground piping at pressures greater than 0.5 bar and above 60 ºC are required to comply with WorkSafe NZ regulations for pressure equipment. 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 always met these standards which also results in wastage in the distribution system.

- Heat loss from distribution piping from the wellhead to the heating system.

The authors also suggest that the NZS 2402P:1987 - Code of practice for geothermal heating equipment in Rotorua (parts 2, 6 and 7) provides a good benchmark for thermal performance assessment of geothermal heating systems, even though it requires updating, as it was last published in 1999. The NZS 2402P is a performance-oriented document of which some sections are cited by the Geothermal Energy Regulations 1961 for safety considerations in the system. The simple adoption of the NZS 2402P:1987 for the geothermal water piping, and possibly for the secondary water piping, would minimise waste associated with those issues.

<u>2.1.3 User end</u>

Thermal energy from the Rotorua Geothermal System is mainly used for space, domestic hot water and pool heating. Peng & Moore 2021 identified the following key areas of concern at the user end and proposed the following solutions:

- Heat loss in space heating due to poor building insulation. <u>Options</u>: End users to implement building insulation to the minimum requirements of relevant standards (refer to Peng & Moore, 2021 and references therein).

- Poor climate control – i.e. Windows open whilst heating due to poor room controls. Options: Install time clocks and controls on space heating which switch off the space heating when not required or when the house is unoccupied.

- Heat loss from domestic hot water due to lack of temperature control, poor insulation, and overuse. Options: 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.

- Heat loss from heated pools. Options: Cover heated pools when not in use with a quality pool cover.

Educational material with background information on how fluid and heat takes affect the geothermal resource and methods to save energy and fluid was developed, targeting particularly the medium to small consent holders (https://www.boprc.govt.nz/environment/geothermal/rotorua) for domestic and light commercial use, as below:

- FAQ with background information on the importance of geothermal resource savings to support the health of the system.

- Factsheet with simple measures on ways to save geothermal water and heat for the different production systems and uses. This material addressed mostly behavioural issues (wasteful practices) and simple measures around maintenance of the geothermal production and distribution systems.

While educational material helps to create awareness among the users of the importance of optimising the use of the geothermal resource for the health of the geothermal system, improving Council processes to give effect to the policies on efficiency and allocation is where most gains can be made (Section 1.1).

3. ALLOCATIVE EFFICIENCY

Currently, all resource consents applications, both for new takes and renewal, are assessed at a high-level for efficiency measures. This assessment is based on information provided by the user and is assessed against the New Zealand standard NZS 2402P:1987 and Peng & Moore (2021). A more comprehensive efficiency assessment can be required for specific cases, like large takes or takes within the 1.5 km Mass Abstraction Exclusion Zone (RGRP).

The resource consent applicant also specifies the amount of heat or mass required for the end use. A heat load estimate is also carried out by the consent officer based on reference heat load for different activities (residential and commercial) of Burnell (2007) and Peng & Moore (2021). A decision is then made on whether the resource requested is reasonable for efficient end use or should be amended. The user may also be required to provide a more comprehensive heat / mass load estimate for specific cases to inform allocation.

The BOPRC key strategy to improve the resource consent allocation processes is the development of an App with the capacity to estimate the heat and mass load for most uses (space and water heating and mineral pools). As of July 2021, Dobbie Engineers provided the engineering fundamentals and have run some preliminary trials for a range of uses. Table 1 lists the results of the trials based on four existing consents. These consents include a mixture of end use including motels and domestic users, group of hotels and / or motels, domestic shared scheme and light commercial shared scheme. It is important to note that the level of occupancy for the units when the flow loop data was obtained is unknown. Further work will be done to better understand the differences particularly between the flow loop data and the allocation app results, and to run more App trials and assess against the flow loop data.

Table 1: Allocation App trial preliminary results - peak load.

Current Consent	Description of the end use	Peak demand estimated by the Allocation App Trial	Estimated flow rate based on the available Flow loop data	Current Consented take Peak flow rate of geothermal fluid
A	Mix motel and domestic use	1.27 kg/s	1.05 ± 0.22 kg/s	1.15 kg/s
B	Shared hotels / motels use	1.10 kg/s	N/A	0.52 kg/s
C	Domestic shared scheme	0.80 kg/s	0.55 ± 0.12	1.45 kg/s
D	Light shared commercial	1.51 kg/s	0.33 ± 0.04	0.83 kg/s

3.1 Monitoring of geothermal resource use

Most consent holders in the Rotorua Geothermal System are required to take five separate spot-measurements on different days between the months of April and August (colder months), twice in the lifetime of the consent (every five years in practice), as part of their consent conditions. A few larger consent holders have consent conditions that require continuous metering of their take. However, for the majority of the users the take data is only an instantaneous flow rate around the winter months, every five years. Currently, the main method used for consent monitoring in production-reinjection systems is bucket and stop-watch. For downhole heat exchangers, the heat take is determined based on the preset pump flow rate (which is constant for most systems in Rotorua) or measured with a temporarily installed in-line flow meter and the temperature readings are carried out by 'hot tapping' the hot and cold legs (pipes) above ground. Those tests are usually done by a local contractor and the data are submitted by the consent holder to BORPC for compliance purposes.

The bucket and stop-watch data are particularly of low quality due to the lack of a standard methodology to be adopted by the contractor carrying out the tests and the large uncertainties inherent to the methodology. While the data provides a snapshot of the takes and has been useful for reconsenting processes, it is of limited use for resource management purposes due to data quality and quantity issues. Improved data is required to understand trends and patterns in resource use, the effects of on the geothermal system, and possibly improving reservoir model calibration. It will also support council processes for increased efficiency in the allocation of the resource.

To address the issue of low data quality and quantity, the BOPRC developed and trialed a movable meter (flow loop) that can now continuously measure the mass flow rate at the reinjection line, with reasonable accuracy (Barber *et. al.,* 2017). Preliminary results showed that out of the 11 takes measured with the flow loop, 6 are taking less than 30% of what is allocated (Table 2). While further work is required to verify whether this likely over-allocation is observed across most of the other sites, if confirmed, the outcomes will have major implications for resource management.

Table 2: Flow testing results: consented Vs measured take.

User number	Consented rate (l/s)	Measured Rate (average) (l/s)	Consented volume (m^3 per day)	Average measured volume (m^3 per day)	Percentage difference
1	1.2	0.32	100	27	-73%
2	1.5	0.4	130	30	-77%
3	4.3	0.9	374	74	-80%
4	1.6	1.5	139	124	-11%
5	1.1	0.3	96	24	-75%
6	2.0	1.14	175	96	-45%
7	1.2	0.8	104	66	-37%
8	0.8	0.2	72	17	-76%
9	2.0	2.8	172.5	233	+35%
10	0.7	0.12	58	10	-83%
11	0.6	0.3	50	24	-52%
Average percentage difference between consented and actual (excluding take #9)					**-40%**

Improved metering of takes is key to increase efficiency in allocation. This actual use data is also crucial to several other science and policy workstreams, as below. Therefore, the value of consent monitoring data goes beyond the scope of productive and allocative efficiency.

- Identify short- and long-term trends in use.
- Understand reservoir and surface feature response to changes in use.
- Understand type and patterns of use, such as daily and seasonal trends, and the end use of energy.
- Development of future policy direction for the various current and plans covering the Rotorua Geothermal System (RPS, RGRP, Rotorua Geothermal System Management Plan)

While the approach is yet to be confirmed, the BOPRC is working towards requiring accurate and continuous metered data for resource consents that represent 50-75% of the total mass and heat take across the system. This level of monitoring ensures sufficient data quality and quantity and good geographical spread across the Rotorua Geothermal System. This level of monitoring can be achieved by continuously metering medium and large commercial and mixed uses, and large shared schemes. Additionally, increasing the frequency of spot-measurements for small takes would help to capture variations in the user's heat demand over the years. This increase in data quantity and frequency should help to better understand the cumulative effects of small takes in the Rotorua Geothermal System.

However, Rotorua presents some constraints to monitoring geothermal uses due to the following factors:

- Each heating system in Rotorua is unique, from single domestic use to mixed schemes.
- Well infrastructure eg. pipe diameter varies between systems, so there is no 'one size fits all'.
- The nature of geothermal fluids (high gas content, steam and water phases) and types of flow in the pipeline (two-phase flow, slug flow) limits the choice of measuring techniques.
- The built-up city environment creates access, space and noise limit issues.
- Cost of equipment rated and/or suited for geothermal conditions.
- Materials in geothermal environments require frequent maintenance and have overall limited durability due to scaling or corrosion issues.
- Some wellheads may require upgrading.

As outlined above, the BOPRC has researched and developed viable options for measuring actual use, and currently can continuously measure the flow rate at the reinjection line with a movable meter (flow loop). Other methods have also been researched and discussed with industry providers (Chiquet & Moore, 2014; Withington & Anderson, 2015). The methods currently considered suitable for applying in the Rotorua system are listed in Table 3.

It is also important to note that a key compliance driver for automated continuous recording and reporting is the improved confidence that can be given to the data within the enforcement process. This includes compliance on the limits in the consents, but also whether the monitoring infrastructure and installation, data recording and data submission requirements are met.

Table 3: Techniques / technology Vs. different levels of consents take monitoring.

Consents take monitoring	**Technique / technology**
Permanent infrastructure, continuous data	Permanent flow loop (doublet systems) or heat meter (doublet systems or DHX)
Temporary infrastructure, continuous data	Movable flow loop (doublet systems)
Spot-measurement	Bucket / stop-watch (doublet systems) or DHX readings (DHX)

4. CONCLUSIONS

The current planning framework for the Rotorua Geothermal System already has strong imperatives to incentivise and implement measures to increase productive and allocative efficiency across the system. However, the implementation of these measures through consent and compliance processes has not always been effective and can be improved.

Efficient use has emerged as a key issue in community engagement for the Rotorua Geothermal Regional Plan review. The BOPRC is developing several projects to assess how the policy framework, and its implementation, can be strengthened. We have examined this from the perspective of productive and allocative efficiency, and identified measures to achieve a higher level of efficiency in both areas. This will help to guide future directions for the plan change and improved consents and compliance processes.

The current BOPRC projects to support increased allocative and productive efficiencies are the (i) the development of a methodology and tools (App) to accurately allocate the geothermal resource, and (ii) progression towards improved metering of takes as a consent condition. Currently, the project for the allocation tool (App) is under prototyping / trial stage. Trials showed that the allocation App can successfully quantify the heat and mass load for most uses, which should minimise over-allocation and incentivise energy efficiency practices if / once implemented.

Wasteful practices are common on the Rotorua Geothermal System at the user end, as well as due to poor design and maintenance of the geothermal production system. Educational material has been and will continue to be developed to raise awareness and encourage voluntary initiatives, but will also need to be backed up with some greater scrutiny through consenting.

Quality and quantity data on heat and mass production from the Rotorua Geothermal System will provide more certainty to the Bay of Plenty Regional Council, particularly around resource consenting processes. Better data will help to reduce the risk of over-allocation and minimise wasteful practices, making better use of the available resource. Most importantly, efficient allocation and use will contribute to the sustainable management of the resource and the health of its unique surface features.

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