An Iwi-inspired System Management Plan for Tikitere geothermal system

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Keywords: *Tikitere geothermal system, iwi, geothermal system management plan, regulatory framework, sustainable system utilisation.*

ABSTRACT

Work toward a Tikitere Geothermal System Management Plan (GSMP) is a forward-looking initiative by Ngāti Rangiteaorere, working with Bay of Plenty Regional Council, with the intention any future use of the geothermal system is sustainable, addresses iwi, hapū and landowner aspirations, kaitiakitanga and the needs of future generations.

Tikitere occurs in a rural setting, north-east of Lake Rotorua, with surface thermal activity dominated by steaming ground, fumaroles and warm to vigorously boiling, steam-heated muddy pools. Geoscience investigations show the Tikitere geothermal system extends over ~10 km^2.

Here, we set the stage for a collaborative approach to establishment of a GSMP, that is informed by traditional knowledge, scientific research and the aspirations of local communities. At its core is our goal to seek a balance of customary practices and environmental stewardship, ensuring the Tikitere geothermal system is managed holistically. Special attention is paid to integrating mātauranga Māori, upholding kaitiakitanga and recognising the interconnectedness of land, water and people. Our proposed framework aims to provide clarity and adaptability for all stakeholders, supporting enduring benefits and responsible guardianship.

'Hells Gate Geothermal Reserve and Spa' is an internationally recognised tourist attraction. Its surface manifestations have been used for centuries by Māori for bathing, heating, mineral extraction and domestic use. The Tikitere geothermal system is not developed for electric power, industrial heat-utilisation or large-scale direct use, but is classified in the Bay of Plenty Regional Council Policy Statement (RPS) as 'Group 3', for conditional development.

Geothermal system management plans can take different forms. In this instance there is an opportunity to proactively develop a whole system approach, which can help guide future resource consenting and management decisions. While the final form of the GSMP is not yet determined, we aim it will accommodate system wide objectives, management of relationships, sound decision-making processes, effective monitoring and reporting frameworks.

Other issues for the Tikitere geothermal system are strategies to monitor system health and integrate Mātauranga Māori to mitigate / avoid effects from any future fluid extraction or injection (including at hydrologically connected developments nearby), consistent with guiding principles and vision of Ngāti Rangiteaorere.

1. INTRODUCTION

Tikitere is located to the north-east of Lake Rotorua, at the western end of Lake Rotoiti. The Tikitere geothermal system occurs within the northern sector of the Taupō Volcanic Zone, in a region of active volcanism and seismicity that extends from Tongariro National Park to Whakaari (White Island), and includes Hell's Gate, Ruahine, Maraeroa, Parengarenga and Manupirua Hot Springs.

The Tikitere geothermal system has been studied at many scales, including by New Zealand Government initiated regional geoscience, which complements iwi records and academic and private research. Understanding of the system has evolved and learning continues to be shared. For centuries, the Tikitere thermal area has been used for medicinal and domestic uses and bathing. The Hells Gate area is a major tourist attraction, with numerous surface manifestations, mineral extraction and bathing. Geothermal water supplies the hot pools at Lakes Ranch Resort, Hopeta te Hou te Horo Whānau Baths and Pomare Baths.

The importance of ongoing and future management of the Tikitere geothermal system, being adaptive to iwi priorities and aspirations, existing activities and potential developments by future users of the resource, is complementary to the Bay of Plenty Regional Council (BOPRC) Policy Statement (RPS) and Growth Strategy.

2. A BRIEF HISTORY OF NGATI RANGITEAORERE

Ngāti Rangiteāorere trace descent from Puhāorangi he Atua i te rangi. Te Ārawa and Tainui are the only tribes that have heavenly descent from Puhāorangi, known as Te Hekenga a Rangi, and whakapapa by: Atuamatua - Houmaitawhiti - Tamatekapua - Kahumatamōmoe - Tawakemoetāhanga - Uenukumairarotonga - Rangitihi - Rangiwhakaekeau - Rangiteāorere, with Ngāti Rangiteāorere being one of eight iwi of the Ārawa confederation of tribes.

Rangiteāorere's father (Rangiwhakaekeau) lived at Te Teko with his wife Uenukurauiri (sister to Ngāi Tūhoe eponymous chief Tūhoe Pōtiki). Before Rangiteāorere was born, Rangiwhakaekeau was called by his father (Rangitihi) to Rangiwhakakapua Pā (at Mourea). Rangiwhakaekeau grew up with his mother's people and became a renowned warrior.

In time, Rangiteaorere set out to find his father at Mourea. Rangiteaorere entered Rangiwhakakapua pā, who alerted his father. When Rangiwhakaekeau neared his whare puni, Rangiteāorere began singing an oriori taught by his mother:

> E tama e…. i
> Nāku koe i kimi, nāku koe i rangahau….
> Ki te pō uriuri ki te pō tangotango
> Hohoro te kii mai Uenukurauiri
> Ki te puta he wahine tapāia ki te au e rere nei…

ISSN 2703-4275

Ki te puta he tane tapāia ki te āo e tu nei
I tokona e tō tupuna e Tanewhirinaki ki runga rā
Kōia te rangi pūātea e tū nei e…. i.

When Rangiwhakaekeau heard the oriori, he knew it was his son, and they shared salutations. Rangiwhakakapua Pā became tapu and Rangiteāorere undertook purification rites befitting his rank. Rangiteāorere noted his father and others would leave each morning with weapons to an unknown place. On questioning, he learned of plans to retrieve Te Motutapu a Tinirau, now known as Mokōia Island, from the Kawaārero hapu of the Tuarotorua tribe. Rangiteāorere said he and his warriors would take the island fortress.

Rangiwhakaekeau agreed Rangiteāorere would lead an attack on Mokōia Island, that used canoes tied to submerged ropes, secured by stakes. When Kawaārero hapu came out from the island Rangiteāorere and his warriors pulled on the ropes and rushed towards the enemy, who were defeated.

Rangiteāorere moved to Paetutu Pā (at Tikitere) and then to Pukepoto (Waikuta) at Ngongotaha after taking the life of Uenukukōpako's son (Tūmahaurangi) due to a perceived insult, and to avoid possible reprisals. However, no serious matter eventuated, and Rangiteāorere returned to Paetutu Pā.

Ngāti Rangiteāorere settled on the eastern shore of Lake Rotorua, with traditional boundaries from Rangitoto (at the eastern end of Whakapoungakau Ranges) to Cookson Road near Matawera, to Lake Rotorua. From there, to Mokoia Island, to Tamawhakaaikai where Rangiteaorere's mokopuna Tuteniu had a pā to the Ohau Channel at Mourea, and Rangitoto, which include Mātaikotare Marae on the shores of Lake Rotorua, the Waiohewa River, the thermal area at Hell's Gate and Rotokawau. Ngāti Rangiteāorere also own land at Tumu Kaituna between Papamoa and Maketū.

In 1882 the Native Land Court awarded the 10,350-acre Whakapoungakau-Pukepoto block, running from Ohau Channel to Waingaehe Stream at Hannah's Bay, and inland to Tikitere and the Whakapoungakau Range, to Ngāti Rangiteāorere and Ngāti Uenukukōpako. In 1886 they went back to the Court for a sub-division, awarding seven blocks in the northern portion to Ngāti Rangiteāorere and nine in the south to Ngāti Uenukukōpako. Tikitere is situated within the northern Whakapoungakau Maori Land Blocks awarded to Ngati Rangiteaorere by the Native Land Court.

"Aue! Kua tere nei taku hei tiki"

Anei te korero na tetahi kaumatua no Ngati Rangiteaorere. Ahakoa, ko te riu o Tikitere ka whakatau ki tenei whenua, a, ko Tikitere he ingoa o tetahi ngawha i te riu o Tikitere, I aro mai na tetahi tamahine o tetahi Rangatira o Ngāti Rangiteāorere. Ko Huritini tana ingoa. Ka whakaipo ia ki tetahi tane maruwehi, engari ka hiahia taua tane maruwehi i tana teina ke, ā , ka raru te whakāāro a Huritini, ā, ka mate whakamōmori ia, ka tarapeke i tetahi ngawha, ko Huritini te ingoa o taua ngawha. Ka kitea e tana whaea i tana korowai i te taha o te ngawha, ka whakahāmama ia:

"Aue! Kua tere nei taku hei tiki ".

Ngāti Rangiteaorere hold a statutory acknowledgement over the geothermal resource, meaning that as part of their Treaty settlement the Crown formally recognises their unique relationship with the taonga.

3. TIKITERE GEOTHERMAL AREA

Ngāti Rangiteaorere's Tikitere geothermal system is located ~10 km north-east of Rotorua City, and ~40 km west of Kawerau township. Surface geothermal manifestations at Tikitere comprise hot springs, pools, warm seeps, areas of steaming ground and low pH alteration. Past geophysical surveys suggest the Tikitere geothermal system extends beneath Lake Rotoiti. Whilst the extent of a hydrological connection between Tikitere and neighboring Taheke geothermal system is unclear, a connection at some depth is likely. Tikitere has renowned manifestations at "Hells Gate", Maraeroa, Ruahine, Manupirua Springs and other areas.

The Tikitere geothermal system has been designated by BOP Regional Council as a resource allocated to 'conditional development'. No power generation projects have been commissioned, although the area is a focus for geothermal tourism, bathing and therapeutic applications. Geoscience investigations at Tikitere were included in New Zealand Government surveys from the 1950's to assess the geothermal power potential of the central North Island.

Land in the vicinity of Tikitere is mainly used for farming but includes housing and geothermal tourism. Recreational and cultural uses include thermal bathing and geothermal tourism at Hells Gate thermal park, but it is not used for industrial, or large-scale direct-use geothermal applications.

3.1 Tikitere Geothermal System Characterisation

Geology and Field Stratigraphy

The geology, structure and nature of surface manifestations at Tikitere have been described by Espanola (1974) and others and help inform the subsurface stratigraphy and controls on system hydrology. Tikitere occurs in a region of rhyolitic volcanism, near the NE-margin of the Rotorua Caldera, which formed ~225 ka ago, from which large-scale caldera-forming events erupted voluminous ignimbrite, volcanic lava and domes; and Okataina Volcanic Centre. Lacustrine sediments are interbedded with the volcanic deposits.

Surface geothermal activity is located on the tectonically subsiding Tikitere Graben. Geothermal activity is likely controlled by NE-trending faults associated with the Rotorua Caldera, which include possible ring structures on the margin of the caldera. Rotoiti Breccia and Pokopoko Breccia are unconsolidated rhyolitic-pumice breccia that partly or wholly obscure inferred fault structures. Deposition of the Rotoiti Breccia is thought to have dammed outflow from Lake Rotorua. Pokopoko Brecca is inferred to host a shallow groundwater aquifer. Lake Rotoiti is a perched lake, sitting above the Pokopoko aquifer, with the inference most springs around the lake are supplied from steam-heated groundwater.

Mamaku Ignimbrite is inferred to have originated from the Rotorua Caldera and underlies Rotoiti Breccia. The Mamaku Ignimbrite is a variably welded, pumice-lapilli tuff / flow deposit. Rhyolite lavas are believed to underlie much of the field, based on the occurrence of rhyolite clasts in hydrothermal eruption deposits surrounding mapped vents in the Tikitere area. The hydrothermal eruptions are thought to have occurred ~7,000 to 40,000 years before present.

Geochemistry – Reservoir Characteristics

Water, gas and isotopic chemistry of surface thermal manifestations and shallow bore discharges at Tikitere have been collated by Glover (1974), Sheppard and Lyon (1979)

ISSN 2703-4275

and others. Field studies suggest the features are predominantly steam- and gas-heated pools / springs. Waters discharging from low-lying springs have a high Cl content, which point to a contribution of deep-sourced fluid, albeit diluted by shallow HCO_3-SO_4 / acid-condensate water.

Fluid geothermometry (esp. T_{NaKCa}) point to reservoir waters equilibrating at 180 to 230 ºC. Bores to ~100 m depth in the area tap a 140 ºC bicarbonate-rich water / condensate, with 10-20% contribution from a deep-sourced chloride-rich water. One of the bores reached 384 m depth and encountered a bottom hole temperature of 169 ºC.

Bores to the NE were drilled to 50 to 130 m and encounter low chloride / high sulphate-bicarbonate waters up to 130 ºC, that delineate the northern low resistivity anomaly / system boundary, that dilute the hot thermal upflow.

A hydrological model proposed by Sheppard and Lyon (1979) assumed a parent of ~1800 ppm Cl and 5 mole% gas (predominantly CO_2), with discharge into Lake Rotoiti being an outflow of a deep-sourced chloride aquifer. The H_2/Ar - CO_2/Ar geothermometer indicated gas equilibrium occurring in a shallow vapour zone beneath Tikitere, with a deep source of >290 ºC, and shallow steam zone of >200 ºC.

Figure 1. Steam-heated acid-sulphate pools, Tikitere (https://www.boprc.govt.nz)

Geophysical Structure of Tikitere Geothermal System

MacDonald (1974) used resistivity traversing at AB/2 spacing of 600 m (c.f. nominal depth of resolution of ~300 m) to infer a low resistivity anomaly of ~10 km^2 (Figure 2). However, if seeps and springs in Lake Rotoiti are hydrologically linked the combined resource area could ~18 km^2. Shallow bores at Hells Gate, Ruahine and Maraeroa Springs, confirm the presence of a laterally extensive thermal aquifer.

The central part of the low resistivity anomaly at Tikitere, (where resistivity values are <10 Ωm) is ~4 km^2. The low resistivity anomaly is elongated in a NE-direction, coincident with inferred NE-oriented faults transecting the area, which have a major role in focusing thermal fluids towards the ground surface. Apparent resistivities decrease from ~40 Ωm near the ground surface to values of ~3 Ωm at a few hundred metres depth, consistent with a conductive cap of intense hydrothermal alteration, above the hydrothermal reservoir.

Modelling of gravity survey data indicates the greywacke basement at Tikitere probably occurs at ~1.5 km depth, which may constrain the depth of future deep drilling in the area. The natural heat flow from Tikitere surface thermal features point to an estimate of 120 MW(t), which doesn't include thermal seepage into Lake Rotoiti.

Conceptual Model

A conceptual model describes the physical and chemical character of a geothermal system, accommodating controls and physical processes (e.g. geological structure, controls on fluid flow (permeability) and heat transfer). In summary, the conceptual model for Tikitere can be characterised by :

- lithologies consisting of a sequence of volcanic breccia, lake sediments and ignimbrite, cumulatively to ~1500 m depth, which likely overlies fractured greywacke, in a NE-trending fault-controlled graben.
- surface geothermal activity at Hells Gate and Ruahine driven by shallow vapour zones, with 5-11 wt% gas contents (CO_2, H_2S, CH_4, H_2 and NH_3). Chloride water feed springs near Lake Rotoiti and Hells Gate bores, where it is diluted by steam condensate and groundwater.
- gas geothermometry points to a deep source of >290 ºC, and shallow steam zone of >200 ºC. Perched aquifers of mixed groundwater, steam / gas and chloride water occur at shallow depth.
- a low resistivity anomaly of ~10 km^2, with a possible extension beneath Lake Rotoiti (+8 km^2). The high enthalpy resource is ~5 km^2, coincident with Hells Gate, Maraeroa, Ruahine and Manupirua Springs.
- natural heat output at Tikitere is 120 MWt, with possible ~150 MWt outflow through Lake Rotoiti.
- a two-phase (boiling) reservoir is inferred, with vapour-dominated zones, occasional downflows and crossflows of cooler acid condensate and CO_2-rich groundwater, overlying a probable deep-seated chloride reservoir.

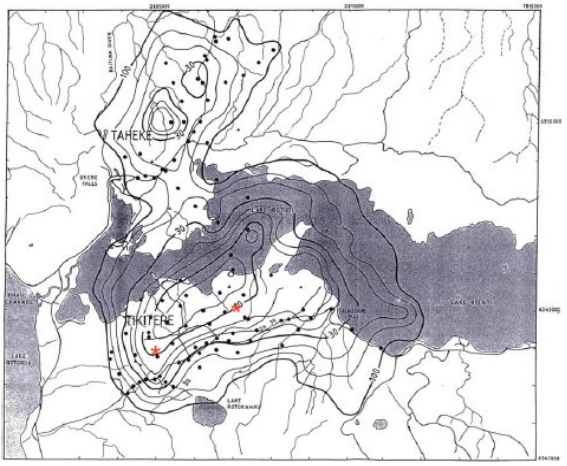

Figure 2. Resistivity contours from Schlumberger traverse measurements (AB/2 spacing of ~600 m) and MT soundings (red star) near Ruahine (TKT001) and Hells Gate (TKT002).

Geothermal Vegetation

The Tikitere thermal area is ecologically distinct, and includes farmland, plantation and geothermally influenced vegetation of national significance. The geothermal vegetation occurs predominantly in the vicinity of the Hells Gate thermal park, but also elsewhere, where warm soils and acidic / steaming ground support prostrate kanuka, dwarf mistletoe, ferns and other thermally dependent plants.

Significance of Geothermal Surface Features

Most geothermal surface features at Tikitere are believed to be in a natural state, but they have changed over geological

ISSN 2703-4275

timescale. Some may be at risk of degradation if development was to occur without mitigation of possible impacts. Many of the thermal features are culturally significant and have a special place in the history of Ngāti Rangiteaorere and others. Work is ongoing to meld geothermal type, natural rarity / threat of extinction, as well as ecological habitat and cultural importance with BOPRC's initiative to identify manifestations that should be regarded as "Significant Geothermal Features" (SGFs).

Geological Hazards

Seismicity : Earthquakes are common in the Bay of Plenty region. Seismic events can occur in swarms and some may be large enough to be felt. Distinguishing natural from induced seismicity is difficult, and any future utilisation will need to accommodate strategies that mitigate induced seismicity.

Hydrothermal eruptions : Hydrothermal eruptions have occurred at most geothermal fields of the central North Island, naturally, or induced by geothermal fluid withdrawal. The likelihood of hydrothermal eruptions at Tikitere is low but will need to be assessed if expanded utilisation is proposed.

Subsidence : Non-geothermal subsidence related to regional tectonic deformation through the TVZ is 1-10 mm/year, although the subsidence rate at Tikitere is unclear. Local subsidence can be induced by pressure drawdown and thermal contraction, and may require baseline / ongoing monitoring.

4. A TIKTERE GEOTHERMAL SMP

System management plans are a requirement of the Bay of Plenty Regional Policy Statement (RPS) for certain systems. This is primarily for systems that are classified as Development, or that have a certain level of use. In the Bay of Plenty Region, geothermal system management plans (GSMPs) have been developed for Rotorua and Kawerau, and one is under development for Tauranga.

The goal of a system management plan is integrated management, an approach that considers the geothermal system as a whole. This is not dissimilar to the Te Ao Māori approach to viewing the environment as interconnected, and people's wellbeing as intimately linked to environmental wellbeing. A GSMP is not a regulatory document, but it does lay out expectations and operational guidance.

Some GSMPs are developed post consent and may be required as a condition of consent for any significant development. A GSMP developed pre-consenting, and approved by Council, may be considered under section 104 of the Resource Management Act through the resource consent application process. While there is currently no requirement for Tikitere GSMP, due to its relatively low level of use, this is likely to change. As such, a proactive, coordinated approach to developing the GSMP is preferred.

The intention is for the Tikitere geothermal system to be managed in a collaborative, integrated and sustainable manner, with wide consultation and community engagement, and accordance with regulatory requirements.

The GSMP will guide how the Tikitere geothermal system should be managed to meet the needs of tangata whenua, current and future generations, in a respectful and sustainable manner. It can be expected to include guidelines from Ngati Rangiteaorere, informed by BOPRC system management experience and protocols, and will integrate concerns of existing users and interested parties.

The Tikitere Geothermal SMP will provide an integrated approach to sustainable management of the Tikitere geothermal system, including an understanding of potential adverse effects from use of the geothermal resource. It may provide recommendations for processing and administration of resource consent applications (including new consents) and reflect guiding principles of Ngāti Rangiteaorere.

4.1 Scope of the System Management Plan

The scope and content of the Tikitere Geothermal SMP will be guided by aspirations and concerns of Ngāti Rangiteaorere, and Policy 7B of Bay of Plenty's current Regional Policy Statement (RPS) and Regional Resource Management Plan (RRMP), and it can be expected to include:

- the geological setting and system characteristics
- recognition of the relationship of Ngāti Rangiteaorere with the geothermal taonga, and the cultural context and values, including customary practices and values
- provision for an adaptive system management approach (e.g. reservoir response and subsidence predictions)
- guidance how relationships will be managed, including cooperation between BOPRC and Ngāti Rangiteaorere, and with ahu whenua trusts and other parties
- provisions for peer review panels if/when necessary to provide independent oversight in management of the system, including cultural oversight
- processes for resolving issues, such as between neighbouring systems, or different users
- identification of significant surface features (SGFs).
- monitoring strategies, including baseline monitoring of surface features
- process to remedy or mitigate adverse effects on SGFs (e.g., adaptive management, buffer distances between production and/or injection wells of nearby operators)
- a process for reporting on "system health".

The Tikitere Geothermal SMP will propose sustainable and long-term management, accommodating Ngāti Rangiteaorere aspirations. The regional setting will be considered when and where it might impact management of the reservoir, due to natural processes (e.g. discharge to nearby lakes and surface waterways, effects of geothermal take and discharges to land, air or water) or possible induced effects (e.g. subsidence or adverse impacts on surface features).

4.2 Development of the GSMP

The Tikitere Geothermal SMP will benefit from a coordinated system management strategy, involving :

Kaitiaki / Tangata whenua

Ngāti Rangiteaorere are tangata whenua of the Tikitere Geothermal Field and hold a Statutory Acknowledgement over the system. Hapū/iwi expect to have an overarching decision-making influence on system management, and future consents to draw from / discharge into the field.

Bay of Plenty Regional Council

BOPRC currently has functions under Section 30 of the RMA in relation to the management of geothermal resources. Sections 5, 14 and 15 of the RMA are relevant in relation to the assessment and determination of resource consent applications for the take (heat and energy), use and discharge

ISSN 2703-4275

of geothermal fluid. Management is under the RPS and the Regional Natural Resources Plan (RNRP) lay out the policy provisions, including resource consent requirements.

Other Kaitiaki or tangata whenua interests

- Ahu whenua trusts overlying the geothermal system
- Hau kainga with an ongoing day to day relationship with the geothermal system

Other Stakeholders / Interested parties

There are numerous other parties who may have an interest in the vitality and sustainable management of the Tikitere geothermal system, including:

- general public
- existing (and possible future) consent holders
- commercial operators in the Tikitere area
- Other landowners in the vicinity of Tikitere
- relevant Government Agencies (e.g. DOC etc).

4.3 A Draft Tikitere Geothermal SMP

Ngati Rangiteaorere has been aspirational and taken a leadership role in the ongoing development of the GSMP. Some of the impetus was a result of the Waitangi Tribunal Claim Wai 2358, Māori Rights and Interests in Geothermal. As part of these proceedings, Ngati Rangiteaorere presented the Tribunal with a draft GSMP, with the aim to inform the proceedings and ensure the overall context of system management was properly considered.

We envisage the Tikitere Geothermal SMP proposed by Ngāti Rangiteaorere, now in draft form, is an excellent starting point for wider discussion and a collaborative approach to refining the GSMP. Drawing in wider views and aspirations is essential to ensure whole system integrated and sustainable management, and for the GSMP to carry weight in a policy and consenting process.

BOPRC and Ngati Rangiteaorere are currently developing an approach to engage with others on the further development of the GSMP.

5. AIMS OF THE GEOTHERMAL SMP

When finalised, the GSMP will be used:

(a) to provide interested and potentially affected parties with an understanding of how the Tikitere geothermal system should be managed

(b) provide transparency how the Ngāti Rangiteaorere expect the Tikitere geothermal system to be managed

(c) as a non-statutory document that should be considered in relation to the assessment and determination of resource consent applications

(d) to provide operational guidance in the administration of any existing or future resource consents by BOPRC

(e) to identify processes to manage and mitigate risk to significant surface features

(f) to indicate key relationships and parties to engage with in management of the system

(g) in the development of operational management plans

(h) to inform development or reviews of policy and planning documents prepared under legislation related to the Tikitere geothermal system.

5.1 Overall System Purpose

The RPS currently classifies Tikitere as a conditional development system. This means use and development is anticipated, provided significant adverse effects on identified SGFs can be avoided, remedied and mitigated.

While it provides guidance, time will show how it captures the nuanced view of what is hoped for the system, especially by tangata whenua. The GSMP presents an opportunity to more carefully describe what sustainable management means in the Tikitere context, present a more Te Ao Maori view, and move away from traditional ‘planning speak’.

5.2 Adaptive System Management

Adaptive management is at the centre of most GSMPs. Ngāti Rangiteaorere is working with BOPRC to develop a Tikitere SMP that will draw on iwi experience, as well as technical survey results, and establish a management approach that promotes flexibility as new insight is acquired, including:

- for a numerical model of the system, which accommodates future development scenarios and predicts the response of the system (and surface features) to utilisation
- proposed monitoring of key thermal features and reservoir characteristics (e.g. any well data) – with monitoring results integrated with numerical model predictions
- strategies for avoidance, remediation and mitigation of observed and modelled effects
- approach to update conceptual / numerical models, responding to new field data, inconsistencies with model outputs etc, and facility to monitor and appropriately report on observed effects to the environment.
- use of Mātauranga Māori to inform adaptive management

An adaptive management strategy is integral to sustainable / long-term management of a geothermal system. It reflects an informed and reasoned response to otherwise unpredicted adverse effects. The strategy requires baseline information and ongoing monitoring, with thresholds to trigger remedial action before any effects become severe or irreversible. Defining a material adverse effect is not straight-forward but has been described by BOPRC in other GSMP’s.

5.3 Conceptual, Reservoir and Subsidence Models

Modelling is integral to sustainably managing a geothermal system and mitigating effects from consented activities, and therefore of great interest to Ngāti Rangiteaorere. Models are used to predict local and field-wide effects, and comprise :

Conceptual models, reflecting the collective scientific understanding of the geothermal system – e.g., to infer the heat source for the reservoir, location of recharge zones, fluid flow paths, as well as resource boundary, temperature and physical processes such as boiling and groundwater ingress.

A numerical reservoir model, integrating insights from the conceptual model and a quantitative estimate of fluid mass and energy in the system. Model verification is carried out by comparing theoretical predictions of surface heat flow, temperature and pressure distribution in the reservoir, discharge enthalpy, fluid gas and salinity content, etc. Models are used to relate reservoir predictions and performance.

A ***subsidence model*** is used to predict the effect of take and discharge of geothermal fluid on land deformation.

There are currently no reservoir or subsidence models for Tikitere, although it is likely that this would be a requirement of any future consenting process.

We expect the Tikitere GSMP will signal:

- a requirement for a single reservoir and subsidence model
- expectations around ownership
- process for review and updating models
- arrangements for access to models, to inform management decisions.

5.4 Production and Disposal (injection) Strategies

Currently, the Tikitere geothermal system is not used for power generation or industrial-scale direct use. However, there may be activities in the future that might require an increase in fluid abstraction and disposal.

The SMP can signal early key principles to guide production and reinjection, such as the type of discharges anticipated (e.g. deep reinjection or targeted shallow reinjection), and also spatial distribution of production and injection activities.

To ensure the Tikitere geothermal system is sustainably managed, we are working towards a development strategy that will :

- use model predictions to inform take of high temperature fluid and discharge, while minimising risk of excessive pressure drawdown or cooling
- support flexibility and sustainable fluid take, avoiding material adverse effects on the geothermal system
- provide reservoir model predictions for disposal of geothermal fluid back to the system
- avoid, remedy and/or mitigate of subsidence, impacts on geothermal features, groundwater aquifers and surface waterways, and risk of hydrothermal eruptions
- promote monitoring and reporting on the discharge strategy, and implementation of adaptive management responses to resource utilisation.

A production and reinjection strategy requires modelling insight, which takes account of spatial distance between discharge and take points, well interference etc, and strategies to manage material adverse effects.

5.5 Management of Surface Adverse Effects

Managing the fragile and significant surface features at Tikitere will be front of mind in the development of the SMP, and likely an important consideration of any resource consent application process. A further step in the management of surface effects is identifying SGFs, and criteria in the RPS lay out a methodology to do this. Features may be important from a cultural, hydro-geological or ecological perspective, and different criteria apply.

The taking, use and discharge of geothermal fluid may give rise to a range of surface effects. An aspect of a resource consent compares measured and predicted effects and proposes responsibility for mitigation (e.g. when an effect arises that is not attributable to a single tapper, but the result of cumulative effects of various tappers).

Adverse effects on SGFs in a Conditional Development System must be avoided, remedied or mitigated. Determining the likely cause of the effect, and whether it is attributable to one or multiple consent holders is challenging, and a robust monitoring approach will be important.

Monitoring may be a requirement of a resource consent, and carried out by consent holders, by BOPRC as part of its State of the Environment Monitoring programme as part of the community, or by iwi or hapu.

The SMP cannot dictate monitoring conditions of consent, as these will largely be guided by the regional plan and the consent process.

An important role of the SMP is to present a system wider plan for monitoring that can guide:

- key monitoring priorities
- best practice methodologies appropriate for Tikitere
- where responsibility (and costs) of monitoring might lie

We envisage this will be prepared in consultation with Ngāti Rangiteaorere, BOPRC, existing consent holders, landowners, and DOC, and will consider:

- cultural and environmental concerns of tangata whenua, including Mātauranga Māori monitoring and the role of tangata whenua in carrying out this monitoring
- routine / periodic observations of surface features (e.g. in Hells Gate thermal area), and on other ahu whenua blocks, including monitoring of water levels, flow rate, temperature, photographic record and chemistry of discharging features, potentially as part of BOPRC monitoring programme
- monitoring of vegetative patterns (including a ground temperature survey)
- informed reporting on geothermal system health, including natural change to surface manifestations.

5.6 Peer Review Panel

We anticipate a Peer Review Panel (PRP) can be engaged to provide technical advice on the management of the Tikitere geothermal system.

The PRP would be comprised of independent experts in geothermal system management and/or environmental effects. An important consideration will be the form and function of the PRP, and processes for decision making. The PRP could potentially include a member with expertise in Te Ao Maori, or cultural impacts, or advice on cultural matters, relating to kaitiakitanga, mātauranga Māori or tikanga Māori could be provided through some other model. A consideration will be the role of the iwi in this process.

The role of the PRP is to review information supplied by consent holders, i.e., annual reports and operational plans, monitoring reports, changes to reservoir conditions and effects of resource utilisation, with recommendations for avoiding, remedying or mitigating adverse effects on the reservoir, but is itself not a decision-making body.

5.7 Relationships

A goal of a GSMP is that communication and engagement expectations are clearly outlined. For example, what are the processes for engagement, and how does system wide reporting play a role?

For Tikitere, one option is that Ngāti Rangiteaorere, BOPRC and consent holders would endeavour to inform interested and affected parties and the wider community about the state of the geothermal system (via annual community type reports to BOPRC / excluding any parts considered confidential or commercially sensitive and community meetings) and address impacts identified to be having an adverse effect on the resource and surface manifestations.

The Tikitere Geothermal SMP will be updated (i.e., ideally every five years) to ensure it reflects the current state of knowledge and management of the geothermal system.

Figure 3. Barren ground, steaming ground and steam-heated features at Tikitere (https://www.boprc.govt.nz)

6. CONCLUSIONS

There is currently no geothermal system management plan for the Tikitere Geothermal Field. Ngāti Rangiteaorere, with support of BOPRC, are advocates of a proactive forward-thinking approach to developing a GSMP. They consider a collaborative process is the best way to ensure an effective whole system approach, that takes account of the needs of tangata whenua, consent holders and the wider community.

Geothermal surface features at Tikitere (i.e., hot springs, seeps and mud pools; Figures 1 and 3) are greatly valued – and many are unique in character. Avoiding adverse environmental or ecological impacts from poorly considered take or discharge of high temperature fluid is a central pillar to Ngāti Rangiteaorere's concern for Tikitere, and a driver for establishing a Tikitere Geothermal SMP. Looking ahead, sustainability, vitality and ecological diversity of the geothermal system will be best achieved through adaptive management, melding co-operation between iwi, regulators and consent holders, and by addressing / understanding geothermal system dynamics.

Noting the current Tikitere geothermal SMP is still "work in progress", there remain numerous issues that will need to be considered in the future to meld the aspirations and concerns of iwi, BOPRC and interested parties.

At the broadest level this may include :

- the overall objectives for the system
- management of relationships and decision-making process
- guidance for future consenting and consent conditions
- monitoring frameworks
- reporting processes
- managing competing interests in terms of resource use, and coordination of take and discharge, which may impact sustainable use of the system.

Work is ongoing to develop the Tikitere Geothermal SMP that accommodates system health and longevity, and the aspirations of existing and future users of the resource.

ACKNOWLEDGEMENTS

We appreciate support by Ngāti Rangiteaorere, and collaboration with BOPRC and others to advance this initiative. We look forward to wide engagement to advance the Tikitere geothermal system management plan, for the benefit of present and future generations, and system health.

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