Vegetation in the Wairākei-Tauhara Geothermal System: History and Future Options

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ABSTRACT

The Wairākei-Tauhara Geothermal System (WTGS), contains c.164 hectares of discontinuous geothermal vegetation and habitat that has a complex history of natural and anthropogenic change. A key feature is the extensive areas of geothermal kānuka-dominant vegetation on geothermally-heated ground. The WTGS supports populations of nine plant species classified as being either Threatened or At Risk. Changes to the patterns and dynamics of geothermal vegetation in the WTGS are linked to the effects of energy extraction. Energy extraction commenced in 1958 on the WTGS at Wairākei Power Station and since then has been subject to multiple modifications and expansions. The extraction has resulted in changes and losses to some steamy habitats (mostly alongside geothermal streams, springs, and geysers), reducing habitat for species that require steamy habitats. Between the 1950s and 1980s, there was a marked increase in geothermally-heated ground habitats, substantially increasing the extent of geothermal kānuka. Since the late 1980s geothermally-heated ground habitats have been slowly declining in size, although the extent of geothermal kānuka-dominant vegetation remains considerably larger than before energy extraction began. Monitoring and assessment of WTGS geothermal habitats has been undertaken regularly since the early 2000s. Here we present findings of these assessments, including our identification of some recent changes at specific sites. We also present options for the future management of geothermal vegetation in the WTGS under two scenarios: continued use (though modified energy extraction), compared to the likely effects of no further energy extraction. We determined that continued extraction, at least in the short term can provide opportunities to invest in the protection of geothermal habitats and species. For steamy habitats this can sometimes be achieved through artificial creation of lost habitats. Careful restoration management of the highest quality remaining geothermal habitats in the WTGS is also recommended.

1. INTRODUCTION

1.1 Wairākei-Tauhara Geothermal System

The Wairākei-Tauhara Geothermal System (WTGS) is located within and adjacent to Taupō township in Te Ika-a-Māui/the North Island of Aotearoa New Zealand (Figure 1). It is one of many geothermal systems present within the Taupō Volcanic Zone (TVZ). It is located entirely within Taupō District and the Waikato Region. The WTGS comprises two geothermal fields that are linked at the subsurface. The Wairākei Geothermal Field (GF) is located to the northwest of the Tauhara GF, and for this study areas of geothermal vegetation have been associated with each field separated physically by the Waikato River.

Waikato Regional Council (WRC) has classified all geothermal systems according to their development potential in the Waikato Regional Plan. The WTGS is classified as a 'Development Geothermal System'. This allows for large-scale use of the geothermal resources as long as activities are undertaken in a sustainable and environmentally-responsible manner.

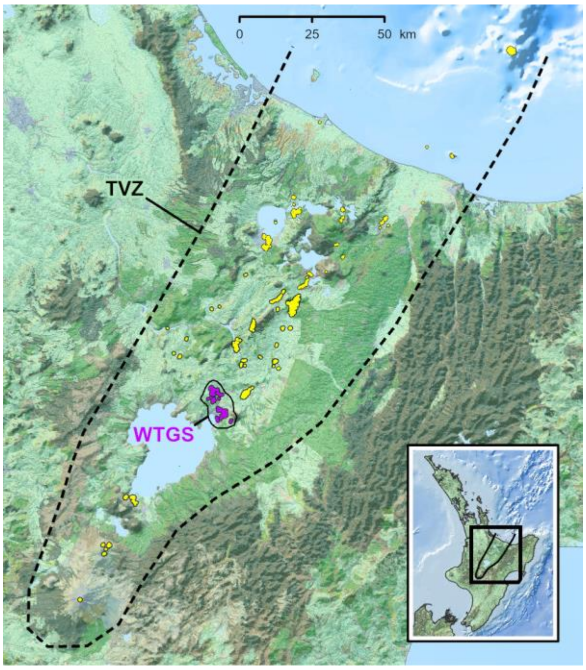

Figure 1: Location of geothermal vegetation in the WTGS (in purple) and other geothermal sites (in yellow) within the approximate boundary of the TVZ. WTGS = Wairākei-Tauhara Geothermal System. TVZ = Taupō Volcanic Zone.

1.2 GeoFuture

Contact Energy **(Contact)** holds resource consents issued by WRC for the take and discharge of geothermal fluid from the WTGS. Most of the resource consents for the continued use of the Wairākei GF were due to expire on 30 June 2026. Contact lodged applications (collectively referred to as GeoFuture) with WRC for replacement resource consents and discharges, and for a range of other related activities. Contact's aim with GeoFuture is to modernise their methods of power generation from the Wairākei GF, and to improve resource-use efficiency and its environmental footprint by reducing discharges of geothermal water, enhancing the environment and finding different ways to make the best use of the Wairākei geothermal reservoir to generate provide a reliable, low carbon, long-lived source of energy. Through the application process, Contact obtained iwi, hapū, WRC and other stakeholders' feedback and advice and incorporated this into their applications. In January 2023, independent commissioners granted new consents that allow

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for the continued use of geothermal power stations in the Wairākei GF for the next 35 years.

Resource consent applications like GeoFuture require a rigorous ecological assessment component. This assessment needed to consider the effects of the proposed take and discharge of geothermal fluid (and any other related activities) on geothermal vegetation in the wider WTGS, specifically those in the Tauhara GF due to linkages at the subsurface between the two fields. Here we describe our methodology and key findings from the 2023 consent applications' assessment of ecological effects. We also present options to guide Contact and WRC on the ongoing management of the WTGS's geothermal vegetation.

2. METHODS

Geothermal sites within the WTGS were visited between 2020 and 2022. At each site vegetation and habitats were mapped at a scale of 1:1,000. Site assessments addressed the following components: the extent and description of vegetation and habitats, flora and fauna (including threatened species), current condition of vegetation and habitats, ecological threats, and ecological management requirements. The field work used the latest aerial imagery available at the time (2017), but the site mapping has since been updated using the most recently-available imagery (2021 Waikato Regional Aerial Photography Service (WRAPS, 2021), which became available in late 2022.

An ecological assessment (Wildland Consultant 2021a) was prepared for the resource consent application. This specifically addressed the likely effects of two scenarios on geothermal vegetation and fauna habitats within the WTGS. The two scenarios:

- 'Existing Environment' (assuming shutdown of Contact's operations and the associated cascade users on the Wairākei GF when existing consents expire).
- 'Application Scenario' (assuming Contact's and associated cascade users' operations on the Wairākei GF continue as proposed under GeoFuture).

Our ecological assessment of the likely effects of both of these scenarios were based on the assessment of likely shallow hydrothermal effects described by Bromley and Reeves (2021) with a particular focus on the likely effects on hot springs, streams, and heated ground. An understanding of historical geophysical and vegetation changes in the WTGS was central to our assessment of effects. We assessed the likely effects on terrestrial vegetation and habitats, and resident flora and fauna. It should be noted that despite predictions being based on the best available data, some uncertainty remains given the nature and complexity of the System. We defined three geothermal habitat types and determined the likely effects on each of them. These were:

- Geothermally-heated ground.
- Steamy habitats.
- Geothermal wetlands.

3. OVERVIEW OF GEOTHERMAL SITES

Geothermal sites in WTGS were mapped and described. The WTGS contains the second largest area of geothermal vegetation in Te Ika-a-Māui/the North Island of Aotearoa New Zealand. Sites within the WTGS range in size from c.0.1 hectare to c.57 hectares (Table 1). Many of the sites contain small non-contiguous areas of geothermal vegetation (Figure 2). The ecological assessment report prepared for the resource consent application (Wildland Consultants 2021a) identified c.156 hectares of geothermal vegetation c.164 hectares was identified subsequently (Wildland Consultants 2023a). The increase in extent is not true change, but is due to the avalibility of much improved aerial imagery and, in a few cases, new information.

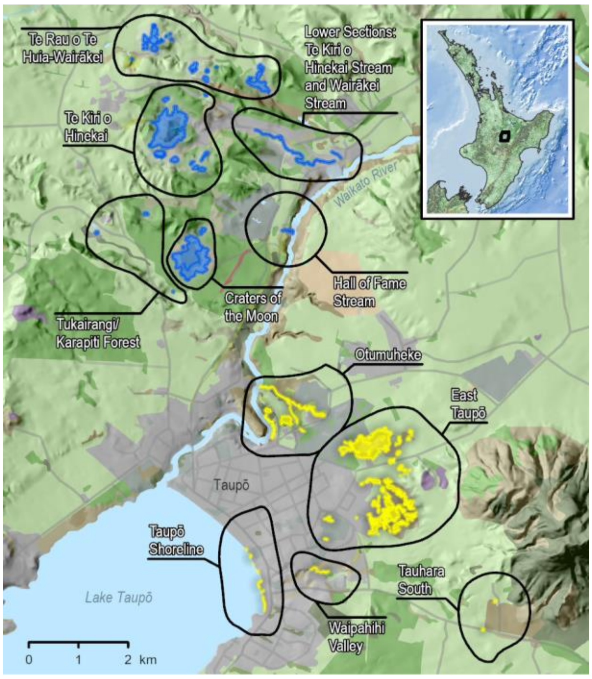

Figure 2: Location of geothermal sites in the Wairakei-Tauhara Geothermal System. Sites in blue are in the Wairākei Geothermal Field. Sites in yellow are in the Tauhara Geothermal Field.

Site	Geothermal Site Area	Geothermal Kānuka-Dominant Vegetation
Tauhara GF		
East Taupō	56.8	46.7
Otumuheke	8.5	4.4
Tauhara South	0.1	<0.1
Taupō Shoreline	0.3	0.0
Waipahihi Valley	0.4	0.2
Total (Tauhara GF)	**66.1**	**51.3**
Wairākei GF		
Craters of the Moon	36.4	31.8
Hall of Fame Stream	0.2	0.0
Lower Sections: Te Kiri o Hinekai Stream and Wairākei Stream	2.6	0.0
Te Kiri o Hinekai	42.8	36.5
Te Rau o Te Huia-Wairākei	15.2	10.9
Tukairangi/Karapiti Forest	0.6	0.3
Total (Wairākei GF)	**97.9**	**79.5**
Total (WTGS)	**164.0**	**130.8**

Table 1: Extent (hectares) of geothermal sites (Wildland Consultants 2023a) and geothermal kānuka-dominant vegetation in the WTGS. GF = Geothermal Field.

4. GEOTHERMAL PLANTS AND HABITATS

A list of vascular plant species (i.e. plants except mosses, liverworts and algae) was prepared for both the Wairākei and Tauhara GFs based on field surveys undertaken between 2004 and 2022. At Wairākei GF, 110 indigenous and 128 exotic species were recorded. At Tauhara GF, 91 indigenous and 143 exotic species were recorded. This illustrates the very high proportions of exotic species (including many known and potential pest species) in the WTGS. Pest plants were present at sites throughout the System. A greater diversity of exotic species was noted to be present nearer to urban areas and these are likely to be naturalising from gardens and from dumping of garden waste.

Nine nationally Threatened or At Risk plant species were observed in the WTGS during the 2022-23 surveys, as per the most recent assessment of the conservation status of the plants of Aotearoa New Zealand (de Lange et al. 2018). While important populations for the conservation of many of these species occur in the WTGS, none of the nine are endemic to this geothermal system and all nine species are also known to occur at other locations in the Waikato Region. The species are listed below with their threat status and plant type:

Threatened-Nationally Endangered	
Christella aff. dentata ("thermal")	Fern
Dicranopteris linearis	Fern
Geothermal kānuka (Kunzea tenuicaulis)	Shrub or tree
Threatened-Nationally Vulnerable	
Annual fern (Anogramma leptophylla)	Fern
Kānuka (Kunzea robusta)	Shrub or tree
At Risk-Declining	
Cyclosorus interruptus	Fern
Mānuka (Leptospermum scoparium)	Shrub or tree
At Risk-Naturally Uncommon	
Hypolepis dicksonioides	Fern
Nephrolepis flexuosa	Fern

Key features of geothermal habitat types in the WTGS are:

- Geothermally-heated ground. This comprises a range of vegetation types including bare ground, moss- and lichen-dominant vegetation, scrub, shrub, and forest. Geothermal kānuka-dominant vegetation is the most extensive vegetation type. Other areas are dominated by mingimingi (Leucopogon fasciculatus), mānuka, and bracken (Pteridium esculentum). Key species include monoao (Dracophyllum subulatum), Dicranopteris linearis, Nephrolepis flexuosa, Psilotum nudum, Cheilanthes sieberi subsp. sieberi, and Lycopodiella cernua.
- Steamy habitats. These occur along geothermal streamsides, and on the margins of hot springs, mud pools, fumaroles, and geysers. Vegetation can be quite varied depending on the surrounding geothermal activity, landforms, and the amount of steam. It includes fernland, shrubland, scrub, and forest. Key species are Christella aff. dentata ("thermal"), Nephrolepis flexuosa, Hypolepis dicksonioides, Cyclosorus interruptus, geothermal kānuka, Dianella nigra, Hiya distans, and Lycopodiella cernua. An interesting find in steamy habitats in November 2022 was annual fern (Anogramma leptophylla), the first record of this species in the central Te Ika-a-Māui/North Island.
- Geothermal wetlands. There is only a relatively small area of geothermal wetland in the WTGS (c.2 hectares). Dominant species include mānuka, raupō (Typha orientalis) and mixtures of sedges and rushes. The WTGS supports the southern-most known populations of Cyclosorus interruptus.

A feature of the WTGS is the relatively large area of geothermal kānuka-dominant scrub and shrubland (c.80% of the mapped vegetation; c.131 hectares of c.164 hectares of geothermal vegetation; Table 1). This represents c.35% of geothermal kānuka-dominant vegetation in the entire Waikato Region.

5. GEOPHYSICAL CHANGES

An understanding of geophysical changes through time is important to be able to understand historic changes to geothermal vegetation in the WTGS. Historical geophysical changes within the WTGS, have been summarised from Bromley et al. (2021):

- Present-day surface geothermal expressions in the WTGS consist of steam vents, weakly steaming ground, steam-heated pools, hydrothermal eruption craters, steam-heated springs, weakly-mineralised springs, and lake and river edge hot water seeps.
- Pre-1950, when the WTGS was considered to be in a natural state, deep chloride fluids reached the surface in the Upper Wairākei Valley (part of Te Rau o Te Huia-Wairākei) and on the Waikato River margins near Otumuheke. Elsewhere within the System, reservoir fluids mixed with heated groundwaters before being discharged at the surface. It should be noted that many features, especially steam vents, are dynamic and change naturally. Although the locations of geothermal features within the WTGS have not changed during recorded history, changes to the nature and levels of activity occurred both before and after extraction of geothermal energy commenced (Bromley and Reeves 2021).
- Wairākei A (commissioned in 1958) & B (commissioned in 1963) Power Stations were the second geothermal power stations built in the world and have been operating for over 60 years.
- Bromley and Reeves (2021) describe how the extraction of deep geothermal fluid at Wairākei since 1958 has had many effects on surface geothermal features. The initial reservoir pressure drawdown in the Wairākei GF had the effect of significantly diminishing surface liquid discharges from deeper reservoirs that contain high-chloride fluid, whilst increasing discharges from steam-heated features. This also raised the temperature of some shallow ground water aquifers. Furthermore, in the late 1990s and early 2000s, groundwater levels in the Waiora Valley and Alum Lakes area declined. Areas of steaming ground expanded at many sites in the WTGS during this phase of elevated temperatures (heat pulse), which was followed by a phase of reducing thermal activity.
- Following this initial phase of enhanced steam heating, resulting from liquid pressure decline and boiling, there has been a subsequent cooling phase, originating in the shallow steam zones. This process has taken place over several decades. Overall, the methods used to manage the WTGS for energy production have caused declines in the pressure of the geothermal reservoir. This resulted

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in chloride springs - such as those at Te Rau o Te Huia-Wairākei (in the upper Wairākei Thermal Valley) - to cease flowing, new steam vents to appear, several hydrothermal eruptions, and increases in temperature due to subsurface boiling at Craters of the Moon and Otumuheke. Gradual subsidence of more than one metre has accumulated across a large proportion of the area within the System (Bromley et al. 2018), and in a few locations, particularly adjacent to Upper Wairākei Valley (part of Te Rau o Te Huia-Wairākei), larger subsidence of up to 15.6 metres had accumulated by 2017 (Bromley et al. 2018). In 1998, large-scale reinjection of separated geothermal water from the Wairākei A & B Power Stations was initiated and volumes reinjected progressively increased over the following 20 years. This led to a slight recovery of pressure within the System. However further declines in pressure have been recorded in the Wairākei GF following the increase in geothermal fluid extraction at Te Mihi area from the 1980s increasing in the 2000s and increasing again in 2014 with the commissioning of the Te Mihi Power Station (Sepulveda et al. 2017).

- Although power production within the Tauhara GF did not commence until 2010 (Te Huka Binary Plant), some of the earlier pressure changes originating from extraction in the Wairākei GF were transmitted across a wide area of the Tauhara GF on the eastern side of the Waikato River.
- Declines in groundwater levels have been recorded throughout the Wairākei GF since 1955, particularly at Te Kiri o Hinekai. This has reduced water levels in lakes and hot pools, and the flow rate of some springs. A local hydrothermal eruption occurred at Alum Lakes in 2001, following an anomalous period of groundwater level declines (Bromley et al. 2018).
- Long-term declines in groundwater levels were also recorded in the northern part of the Tauhara GF from 1995 to 2006. This led to the demise of Kathleen Springs (part of Otumuheke) in 1997 and AC Springs in 2000. Conversely, increased flow rates were recorded at Otumuheke Spring (upper part of Otumuheke Stream) between 1987 and 2000, followed by a decline in flow rates. Historical temperatures in the spring which feeds the stream, were naturally lower than they were when last recorded, ostensibly due to geothermal extraction (40°C in 1964; 83°C in 2009). The spring source has since retreated c.350 metres down the valley between 2014 and 2023. The Spa Sights area, located alongside the Waikato River in Spa Thermal Park at Otumuheke historically contained geysers and springs, but these are no longer active (Bromley and Reeves 2021).
- The shallow hydrological environment in the southern part of the Tauhara GF over the past few decades has not noticeably been impacted by the Tauhara Development and the spring at Waipahihi is not expected to be affected by future Wairākei operations.
- Despite ongoing declines in groundwater levels in the Wairākei GF, the groundwater levels have remained relatively stable in the Tauhara GF since about 2009 (Bromley et al. 2018).
- Surface heat discharges in both GFs of the WTGS increased from a pre-development estimate to a peak (heat-pulse in response to development and pressure drawdowns), followed by a gradual decrease, with current measurements similar to pre-development values (Bromley et al. 2021).

6. VEGETATION - HISTORIC CHANGE AND RECEIVING ENVIRONMENT

6.1 Wairākei Geothermal Field

Geothermally-heated ground habitats. Since the 1950s there has been an increased area of steaming ground (Bromley and Reeves 2021), resulting in a larger area of vegetation dominated by geothermal kānuka. However, in recent decades, the geothermal character of this habitat has declined following the initial heat pulse. The area of geothermal vegetation at most of the larger areas of geothermally-heated ground habitats in the Wairākei GF (e.g. Te Rau o Te Huia-Wairākei, Te Kiri o Hinekai, and Craters of the Moon) expanded in the first few decades following the start of deep geothermal extraction at Wairākei in the 1950s. The heat pulse resulted in the increased expanse of geothermal kānuka that is still present at these sites today along with other species typical of geothermally-heated ground habitats. As discussed above, the extent and intensity of surface heat flows at most of these sites has declined in recent decades. Evidence of this has been gathered by the use of transect-based vegetation monitoring at Upper Wairākei Valley, Te Kiri o Hinekai, and Craters of the Moon, with some transects showing clear evidence of a decline in geothermal character based on vegetation composition and height with increased height of vegetation and decreasing surface soil temperatures (Wildland Consultants 2022a). At many sites the cooler ground has allowed the invasion of pest plants such as blackberry (Rubus fruticosus agg.) and wilding conifers.

Steamy habitats. Past collections of plant specimens indicate that the Upper Wairākei Valley part of Te Rau o Te Huia-Wairākei supported populations of most of the tropical ferns and fern allies associated with geothermal areas in Aotearoa New Zealand (Given 1989). The Upper Wairākei Valley no longer contains discharging hot springs, geysers or pools. Pools and springs have also shown declines in geothermal activity at Te Kiri o Hinekai (e.g. Alum Lakes) and flow of geothermal water has been lost from the upper part of Te Kiri o Hinekai Stream (Bromley and Reeves 2021). Many of the species associated with steamy habitats at this site are now either completely absent or much reduced in abundance and cover.

New geothermal steamy habitat has been created by the artificial release of separated geothermal water (SGW) in the lower sections of Te Kiri o Hinekai Stream and Wairākei Stream as a result of Contact's activities. Te Kiri o Hinekai Stream receives SGW from a discharge from steamfield for cultural purposes, separately from the Netcor Wairākei Terraces Tourism Facility. The lower Wairākei Stream currently receives SGW from the Western Borefield holding pond (Lake Farquhar), and separately, further downstream, from the Energy Dissipation System of the Wairākei Binary Plant. The lower sections of these streams contain steamy margin habitats due to the presence of geothermal water from these inputs providing habitat for geothermal plant species (Christella aff. dentata ("thermal") and Hypolepis dicksonioides) that have been lost from the Upper Wairākei Valley and possibly other sites in the WTGS.

6.2 Tauhara Geothermal Field

While geothermal vegetation has always been present at the East Taupō and Otumuheke sites, the extent of geothermal kānuka, and other vegetation associated with steam-heated ground, increased markedly to a peak in the 1970s (Bromley and Reeves 2021) followed by a slow decline in cover. The

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current amount of geothermal vegetation at these sites still exceeds its natural extent prior to the late 1950s, although many hot ground anomalies have cooled since the 1970s.

The Otumuheke site contains geothermal springs and streams, geothermally-heated ground, and geothermal wetland. The lower section of geothermal streams at Otumuheke provide habitat for the ferns Christella aff. dentata ("thermal"), Hypolepis dicksonioides, and Nephrolepis flexuosa. There is no evidence that there have been major changes to the distribution of these species in the lower sections of the valley since the 1950s other than human-induced issues such as vegetation clearance and the spread of pest plants. In the early period following commencement of extraction there is likely to have been an increase in geothermal wetland in the upper part of Otumuheke Valley. This wetland was still reasonably extensive in the upper part of the valley until around 2014. The location of the upper spring in the Otumuheke Valley has since retreated down the valley, which has resulted in considerable loss of geothermal wetland habitat and sinter in the upper part of the valley. This has led to a marked reduction in the population of the fern Cyclosorus interruptus at this site, from an estimated population that may have been as high as 1-2,000 plants in 2014 to less than 100 in June 2023. Once springs have stopped flowing (e.g. Kathleen Spring and Spa Sights), they no longer provide habitat suitable for species of streamside steamy habitats such as Cyclosorus interruptus and Christella aff. dentata ("thermal") and these species are killed by frosts, or outcompeted by other species. The Kathleen Stream, which flows into the Otumuheke Stream, is now fed by the discharge of thermal bore water from the AC baths. Development of responses at Otumuheke requires good information derived from the monitoring of steamy habitats and associated rare plant populations.

6.3 Other changes to geothermal sites due to human activity

In addition to changes in the composition, condition, and extent of geothermal vegetation resulting from extraction of the geothermal resource for electricity generation, geothermal vegetation and habitats have also been significantly affected by a range of other issues:

- Loss of vegetation for new roads.
- Industrial, urban development, and recreational use.
- Loss of vegetation due to fire.
- Grazing of stock at various sites, which has reduced the extent and condition of geothermal vegetation.
- Exotic plantation forest which shades geothermal vegetation is present on the margins of many sites particularly at Wairākei.
- Competition from pest plant species and impacts (browsing, trampling) of pest animals.

7. ASSESSMENT OF POTENTIAL EFFECTS

As discussed previously, the likely effects on terrestrial values in the WTGS is based on two scenarios: Existing Environment and Application.

Bromley and Reeves (2021) assessed five key aspects of the shallow and surface environment that could be affected by these scenarios: subsidence; hot springs; thermal ground; shallow aquifers; and hydrothermal eruptions. Two of these aspects are of particular relevance to terrestrial ecology: effects on hot springs and hot streams (i.e. steamy habitats); and changes to heated ground. Although subsidence and hydrothermal eruptions can also affect surface geothermal features and vegetation, both of these effects are generally more localised and not easily predicted or assessed in relation to terrestrial ecology. Hydrothermal eruptions may result in the loss of geothermal vegetation, but can also create new areas of habitat suitable for the expansion of geothermal vegetation.

7.1 Geothermally-heated ground habitats

7.1.1 Both Scenarios

Under both the Existing and Application scenarios the extent of geothermally-heated ground in the Wairākei GF, including habitats that comprise vegetation dominated by geothermal kānuka, will continue to be present but will decline in extent and condition. This will also result in reductions in the presence of associated Threatened and At Risk plant species (such as the ferns Dicranopteris linearis and Nephrolepis flexuosa). The extent of geothermal kānuka is also likely to decline in the Tauhara GF under both scenarios, although sites in the northern and central parts of this field would be more affected by the Tauhara II (another electricity generation plant separately consented on the eastern side of the Waikato River) production and reinjection than by changes to production and re-injection on the Wairākei GF. The southern part of Tauhara GF has been relatively unaffected by energy extraction from the Wairākei GF to date, and the terrestrial ecology of sites within this part of the field is therefore unlikely to be affected by either the Existing Environment or the Application Scenario for the Wairākei Geothermal Power Scheme.

7.1.2 Existing scenario

After about a decade following shutdown of the Wairākei Geothermal Power Scheme, the extent of heated and steaming ground within the WTGS is likely to diminish significantly. Eventually, heated ground would return, but it would likely take more than 200 years to return to pre-development (pre-1950s) conditions. This will result in reduction of habitat suitable for geothermal kānuka.

7.1.3 Application Scenario

The decline of geothermally-heated ground habitats in Wairākei GF and parts of Tauhara Geothermal Field will be at a slower rate than the Existing Environment Scenario. When compared with the Existing Environment Scenario, effects of the Application Scenario on geothermally-heated ground across the Wairākei GF are likely to be modestly positive, in that more boiling water associated with sustained liquid pressure drawdown should allow more steam to rise to surface geothermal sites, thus retaining habitat for geothermal vegetation.

7.2 Steamy ground habitats and geothermal wetlands

7.2.1 Both Scenarios

Because the current flow of SGW directly into the lower Wairākei Stream will cease in both scenarios, the part of this stream above the Te Kiri o Hinekai Stream confluence will no longer provide habitat suitable for geothermal plant species, including Christella aff. dentata ("thermal"), at least in the short term.

7.2.2 Existing Environment Scenario

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Following the assumed shutdown of the Wairākei Geothermal Power Scheme in 2026, Bromley and Reeves (2021) predict that reservoir pressure would fall for a few years, then steadily rise at a similar rate to the initial decline in pressure that was observed in the 1960s. After 20 to 30 years this would likely lead to surface discharges of warm geothermal water at Upper Wairākei Valley (Geyser Valley). Over a similar timeframe, geothermal activity at the existing steam-heated geothermal areas (Te Rau o Te Huia-Wairākei, and Craters of the Moon) would probably reduce. Over the next 100 to 200 years, discharges at Upper Wairākei Valley (Geyser Valley) would continue to heat up and eventually the historic (pre-development) surface features may recommence. Over several centuries, natural steam vents are also likely to re-establish at Craters of the Moon, Te Kiri o Hinekai, and Te Rau o Te Huia-Wairākei. Springs may eventually re-establish in Waiora Valley (part of Te Kiri o Hinekai) and discharge into Te Kiri o Hinekai Stream.

The artificial flows of SGW made by Contact into the lower section of Te Kiri o Hinekai Stream will no longer occur, resulting in the loss of suitable habitat for geothermal plant species, including Christella aff. dentata ("thermal") and Hypolepis dicksonioides.

If production and re-injection ceases at Wairākei, it is unlikely that there would be effects on streams and hot springs within the Tauhara GF attributed to production (or lack of it). Effects on streams and hot springs would more likely occur as a result of other consented activities on the Tauhara GF on the eastern side of the Waikato River.

7.2.3 Application Scenario

It is unlikely that the natural extent or activity of geysers, geothermal springs, and geothermal streamsides at Te Rau o Te Huia-Wairākei will increase within the 35 years of the resource consent duration.

If operation of the Wairākei Geothermal Power Scheme continues, further decreases in the pressure of the reservoir are predicted to occur. Heated springs and pools at Te Rau o Te Huia-Wairākei, Te Kiri o Hinekai, Tukairangi/Karapiti Forest (e.g. Waipuwerawera mud pools), Hall of Fame Stream, and the Waikato River margins (e.g. parts of Otumuheke) are likely to remain stable, as per existing conditions, in the medium term (<10 years), but are likely to cool over the longer term (>10 years). Unlike the Existing Environment Scenario, the springs and geysers at Upper Wairākei Valley (Geyser Valley) are unlikely to re-establish.

At Otumuheke (despite the retreat of springs in the upper valley), it is expected that a thermal microclimate will be retained in the lower part of the valley that provides habitat for the fern Christella aff. dentata ("thermal") and other geothermal species typical of geothermal streamsides. It should however be noted that the springs have retreated c.350 metres down the valley between 2014 and 2023. Although unlikely, historic springs may reappear along the Waikato River margins (e.g. Spa Sights part of Otumuheke). Effects on springs in the south of the Tauhara GF are unlikely.

The artificial discharge of SGW into the Te Kiri o Hinekai Stream would continue under this Scenario, so steamy habitat for plant species such as C. aff. dentata ("thermal") and Hypolepis dicksonioides will be maintained at this site. This has been assessed as providing a positive ecological effect because the steamy habitats and geothermal fern populations will be maintained.

8. OVERALL ASSESSMENT OF EFFECTS

A range of adverse effects will affect geothermal vegetation throughout the WTGS under both the Existing Environment and Application Scenarios. Effects will range from losses due to gradual cooling of ground and replacement with less thermal-tolerant vegetation through to major loss of complete areas of geothermal streamside and steamy habitats, and associated Threatened and At Risk species.

Overall, the ecological assessment found that for the Application Scenario, the rate of loss of habitats for geothermal plant species associated with geothermally-heated ground will occur at a slower rate than under the Existing Environment Scenario, maintaining these habitats for longer. Steamy streamsides will be artificially maintained in some locations in the Application Scenario, resulting in less loss of At Risk and Threatened fern species. This means that the Application Scenario will result in less adverse effects on ecological features and values of geothermal sites than the Existing Environment Scenario.

Future changes to the surface geothermal feature environment have been assessed using the last 60 years of responses to the Wairākei and Tauhara developments, and results from mathematical simulation tools (reservoir model scenarios). However, despite predictions being based on the best available data, some uncertainty remains regarding these predictions given the nature and complexity of the System.

9. MEASURES TO AVOID, REMEDY, MITIGATE, OFFSET OR COMPENSATE

Wildland Consultants (2021a) suggested that a comprehensive mitigation and monitoring package should be prepared to achieve no-net-loss of terrestrial geothermal ecological values within the WTGS. A preliminary plan (Wildland Consultants 2021b) identified the following options:

- Options to rehabilitate, restore, and reinstate heated ground and steamy geothermal habitats within the WTGS. This would include artificially creating habitats through the release of hot SGW or hot water, ensuring that existing steamy habitats are maintained in a good ecological condition, through appropriate ecological monitoring and management, and/or to maintain and enhance such habitats elsewhere in the TVZ;
- Actions to ensure that populations of key geothermal plant species are retained within the WTGS including protection from pest plants and pest animals, fencing to exclude stock, and restoration planting of appropriate species on the margins of geothermal sites;
- Using the lower Te Kiri o Hinekai Stream as a site to establish and maintain At Risk and Threatened plant species that have been declining elsewhere in the WTGS, subject to retention of the artificial heat source;
- Identify opportunities for offsets and compensation, as needed;
- Continue and expand the existing ecological monitoring of geothermal vegetation and habitats (including surface geothermal water features) to ensure that mitigation actions are monitored appropriately and managed adaptively to ensure that sustainable populations of key geothermal species in the System are maintained;

- Prepare restoration management plans for as many sites as possible and implement the management actions. Plans have already been prepared for Otumuheke Valley (Wildland Consultants 2022b) and the lower section of Te Kiri o Hinekai Stream (Wildland Consultants 2023b).
- Where it is not possible to avoid the loss of habitats within the WTGS, implement options to enhance and mitigate the losses by undertaking restoration works at other sites in the TVZ. This may include pest plant control, rehabilitation of geothermal wetlands, and fencing of geothermal sites, among other site-specific actions.

Contact has adopted nearly all of these recommendations under the 2023 GeoFuture consents, and has established significant annual funding to resource geothermal vegetation and biodiversity protection and restoration on the WTGS itself ($150,000 p.a); to sites across the TVZ ($150,000 p.a); and additional targeted funding for projects at Te Kiri o Hinekai; Te Rau o Te Huia, and the Wairākei Geyser Valley.

10. ADAPTIVE MANAGEMENT

As part of the GeoFuture Application, Contact provided a report (Drayton 2022) on a proposed approach to adaptive management in relation to effects on surface geothermal features. This report sets out Contact's proposed adaptive management regime (entrenched in consent conditions) to provide mitigation in the event of unexpected and unanticipated significant adverse effect (i.e. outside the range of normal variations predicted as part of GeoFuture) to geothermal sites as a result of Contact's operations on the Wairākei GF.

The adaptive management regime is premised on:

- Baseline database information which, is required to enable an identification of whether significant changes are occurring within geothermal sites.
- Monitoring and reporting which is required to enable an assessment of whether changes are occurring within geothermal sites and if so, to what degree.
- Triggers for adaptive management. The adaptive management regime provides a number of 'triggers' for identifying and responding to unexpected and significant changes at geothermal sites within the WTGS. These are not exhaustive because flexibility is required but they provide a robust indication of the types of effects where, upon identification through the monitoring programme, action will be taken.

The mitigation actions will need to vary according to the effect to be addressed and are therefore not exhaustive. Flexibility is required. However, the mitigation actions provide a robust indication of the types of actions that Contact will take where effects have triggered adaptive management, including:

- Opportunities to improve the condition of geothermal kānuka scrub and shrubland and other geothermally-heated ground habitats through additional pest plant control or planting in the WTGS.
- Opportunities to improve the indigenous character of geothermal kānuka scrub and shrubland at other geothermal sites in the TVZ.
- Opportunities to create new steamy habitat suitable for the survival of At Risk and Threatened plant species, such as the use of SGW at suitable sites.
- Maintain 'back-up' populations of Cyclosorus interruptus, Nephrolepis flexuosa, and Hypolepis dicksonioides in glasshouse or plant nursey or artificial features, which are part of the same genetic populations as those found in the WTGS.
- Transplanting from these back-up populations if feasible and if suitable habitat exists and plants do not arrive to these sites naturally.
- If none of the above activities remain a viable option, then undertake actions aimed at improving the viability of Threatened and At Risk plant populations elsewhere at geothermal sites within the Waikato and/or Bay of Plenty.

The objective of the adaptive management regime is to keep induced changes within natural variations, taking into account long-term trends. However, in some circumstances, where unexpected and significant decline is identified through monitoring and is deemed to be unavoidable, alternative sources of energy or geothermal water may be a better solution to enhance geothermal sites and associated steamy habitats elsewhere that support vegetation. The merits of each situation and management options need to be considered on a case-by-case basis.

11. CONCLUSION

Continued extraction, at least in the short term, provides an opportunity to invest in the protection of geothermal habitats and species within the WTGS. While there may be some declines in the total extent of geothermal vegetation, impacts of the Application Scenario will overall be less than with the Existing Environment Scenario. Implementation of mitigation, monitoring, and management of habitats will result in the remaining vegetation being in a better ecological condition than if no action was to be undertaken. While there will be a loss of geothermal kānuka scrub and shrubland habitats under both the Existing Environment and Application Scenarios, there are opportunities to maintain key areas of this habitat, and control threats such as pest plants, grazing by farm animals, and by undertaking pest animal control. Active management of key pest plants, where required, will maintain and potentially enhance the key indigenous species present in the WTGS. Losses of steamy habitat can be addressed by enhancing habitats in other artificially-created steamy habitat environments such as the lower Te Kiri o Hinekai Stream.

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