State of the Environment Reporting using the DPSIR Model in the Waikato Region

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ABSTRACT

Waikato Regional Council (WRC) is responsible for sustainable management of the Regional Geothermal Resource, which encompasses approximately 70% of the nation's total. It comprises 15 high-temperature systems and about 30 low-temperature system. There are 9 geothermal power stations in the region, generating 800 MWe (Figures 1, 3). Under the Resource Management Act 1991 (RMA), WRC is required to monitor, keep records, and report on the state of the environment, including that of geothermal resources. In 2022 - 2023, WRC produced a set of State of the Environment reports, including one that examined the state and trends in nature, extent, and condition of the Regional Geothermal Resource (Luketina 2023), assessed against the internationally accepted DPSIR framework (Drivers, Pressures, State, Impact and Response model).

Degradation of geothermal surface resources through large-scale destruction of surface features and depletion of the geothermal resource by excessive extraction of the subsurface energy and fluid has effectively ceased since the RMA was enacted in 1991. Under the RMA the Waikato Regional Policy Statement (2016) and Waikato Regional Plan (2012) were developed, giving policies and rules to ensure sustainable management of natural and physical resources including geothermal resources.

However, ongoing small-scale destruction of geothermal features through inappropriate land use activities continues as a result of land use intensification. Ensuring that all uses of geothermal resources are sustainable is now more important than ever as we face increased pressure to use geothermal resources, for electricity generation and direct heat uses, and as intensification of land use and subdivision encroach upon rare and vulnerable geothermal ecosystems.

The adverse effects on geothermal resources of anthropogenic activity have been assessed for the four major cause-and-effect dynamics acting on the Regional Geothermal Resource:

1) Effects of geothermal energy development on surface features and their dependent ecosystems;

2) Effects of geothermal energy development on amount of energy and fluid available for future generations;

3) Effects of geothermal development on other uses of surrounding land and water; and

4) Effects of land uses on geothermal surface features and their dependent ecosystems.

Lack of funding for geothermal monitoring and research severely impairs the council's ability to identify and respond to threats.

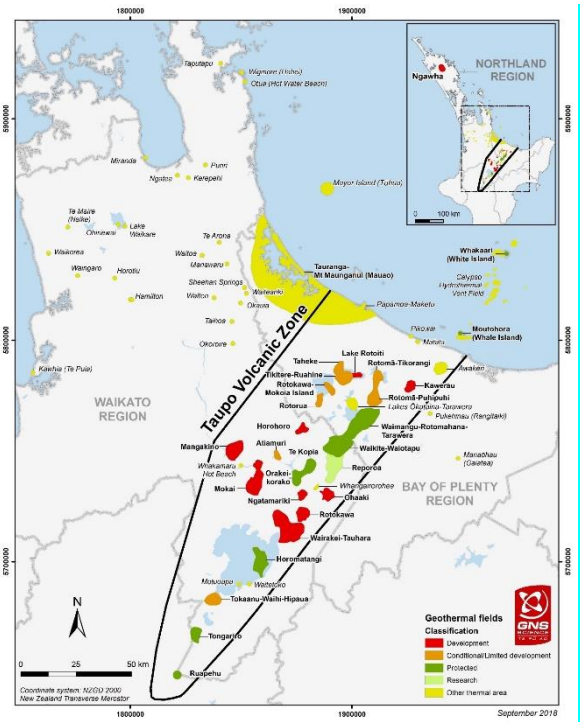

Figure 1: Taupō Volcanic Zone showing regional boundaries and geothermal systems. Image courtesy of GNS and NZ Geothermal Association.

1. ENVIRONMENTAL MANAGEMENT OF GEOTHERMAL RESOURCES

1.1 Adverse effects on geothermal features

In some cases, large-scale extraction of energy and fluid has led to the demise of geysers, and to large scale increases in heat flow. For example, at Orakei Korako, approximately 75% of the geysers were inundated by the creation of Lake Ohakuri for hydroelectricity (Lloyd 1972) and at Wairakei the geysers in Geyser Valley were rendered extinct by large-scale geothermal fluid extraction for the Wairakei Power Station, which also caused a large increase in the heat outflow and extent of hot ground at Craters of the Moon. Many significant geothermal ecosystems have been consequently extensively modified or destroyed, although reinjection can reduce the damage and sometimes partially reverse it (Milloy et al., 2014). There is no documented evidence to suggest all damage is reversible; instead, new flow regimes occur, and introduced species invade the modified habitats. Geothermal fluid extraction can also increase the rate of steam discharge, increasing the activity and extent of steam-fed features such as hot ground and fumaroles. Where new surface outflows have occurred, existing land use practices such as farming and recreational use may prevent or suppress the establishment of geothermal ecosystems. As a result, natural geothermal ecosystems are extremely rare.

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Many highly valued characteristics of geothermal systems, their surface features and dependent ecosystems, are either under threat or already adversely affected by inappropriate use of the surrounding land. Example include (Wildlands Consultants Ltd 2023):

- at Reporoa, land drained for farming has caused some sinter-depositing springs to cease discharging (Spring-Rice, 1966).
- Forestry operations in geothermal areas can lead to geothermal features being damaged by trees falling into them and harvesting machinery destroying delicate sinter terraces.
- Allowing livestock or vehicles access to geothermal features, or using geothermal features as rubbish dumps, can lead to a range of adverse effects including the crushing of fragile sinters and harm to rare native plants, animals and micro-organisms.
- Spray drift and surface run-off can damage vegetation buffer zones and contaminate geothermal surface water, harming or destroying the native thermophilic ecosystems.
- Land uses associated with the operation of a geothermal power station, such as roading and tracking and the placement of bores, pylons, buildings, dumps, and other infrastructure, can destroy or adversely affect geothermal features if they are placed on or near them.
- Geothermal tourism can lead to littering and vandalism. Building access roads, or paths for the tourists to walk on, can cause contamination of pools and sinter by paving materials such as gravel, or inundation from storm water. Native vegetation and thermophilic organisms can be destroyed or colonized by adventive exotic species. In some cases, features may be drained or flows altered in order to preserve the paths that lead to or near them.
- Subdivision and land development can restrict or prevent access to, and use of, the geothermal resource.

1.2 Development of sustainability awareness

Over decades, several factors have influenced WRC's understanding of geothermal resources and their management. We have learnt more about the uniqueness and fragility of geothermal features and ecosystems. At the same time, society has become more aware of the value of biodiversity, and places greater value on rare ecosystems and their dependent organisms. The economic, employment and educational values of geothermal tourism is becoming more important to the people of the region. The adverse effects of some uses of geothermal resources are better understood, and society now requires that such effects not be a burden on the society, but a cost to those who cause the effects. Sustainability of natural and physical resources is more important now and the issues surrounding sustainability are better understood.

2 GROWTH OF GEOTHERMAL ELECTRICITY GENERATION IN THE WAIKATO REGION

The Wairakei geothermal power station was the second large-scale geothermal power station in the world, and the first to harness the power of wet steam. It was commissioned over several years from 1958 to 1963 (Bolton, 1998). The Ohaaki power station followed soon after, in 1989 (Hunt, 1989). Both of these stations were developed under the era of 'Think Big' central government policies. The National Development Act and the oil shocks of the 1980s (Easton, 2001), had very little environmental consideration involved in their development and operations. The Wairakei power station was discharging all its used geothermal fluid, with high concentrations of arsenic, into the Waikato River. Additionally, the pressure drawdown in the reservoir induced many changes in the natural flow of surface geothermal features resulting in the extinction of many geysers and sinter-depositing springs in the area. Subsidence west of the power station is more than 14 metres (Koros *et al.*, 2016).

At Ohaaki, the Ohaaki ngawha, a large steaming geothermal pool with an extensive sinter terrace dried up (Glover *et al*., 1996), as did geothermal springs beside the Waikato River including a geyser (Lloyd, 1957). The nearby urupā became heated ground, with steam rising through the graves. Compared to the large subsidence seen at Wairakei, which was mostly in a forested area with little infrastructure and therefore little subsidence-induced damage, a modest 2 m of extraction-induced subsidence led to the inundation of large areas of land next to the Waikato River (Kortright, 2015).

It was not until the mid-2000s, following the 10-year grace period allowed to existing operations, that these two power stations were re-consented under the RMA and the environmental mitigation policies and rules of the Waikato Regional Policy Statement (2016) and Waikato Regional Plan (2102), leading to significant improvements in environmental practices, particularly increasing reinjection and therefore reducing the discharge of geothermal fluid to the Waikato River.

The Poihipi Rd power station, which came online in 1996 and was then known as the McLachlan power station, was the first geothermal power station consented under the RMA and the Waikato Regional Council's policy instruments, and the first following a legislation change sought by Mr McLachlan that allowed private ownership of electricity sources for public supply (Bradford, 1997).

Since a relatively flat period in the 2000s when there was little increased demand for electricity, the last decade or so has seen a doubling in installed capacity as New Zealand's population grows and fossil fuel electricity sources are phased out (see Figure 3) (NZGA, 2023). A settled and enabling Waikato Regional geothermal policy, which provides developers with certainty about what can and cannot be done, and where, has also helped the uptake.

3 STATE OF THE ENVIRONMENT REPORTING UNDER THE DPSIR FRAMEWORK

In 2019, the Parliamentary Commissioner for the Environment produced a report on the state of the environment SOE monitoring in New Zealand, evaluated against the requirements of the Environmental Reporting Act 2015 (Parliamentary Commissioner for the Environment, 2019). One of the recommendations was the adoption of the internationally accepted (Kosamu *et al.*, 2022) 'Drivers, Pressures, State, Impact, Response' (DPSIR) framework for evaluating the state of the environment (See Figure 4).

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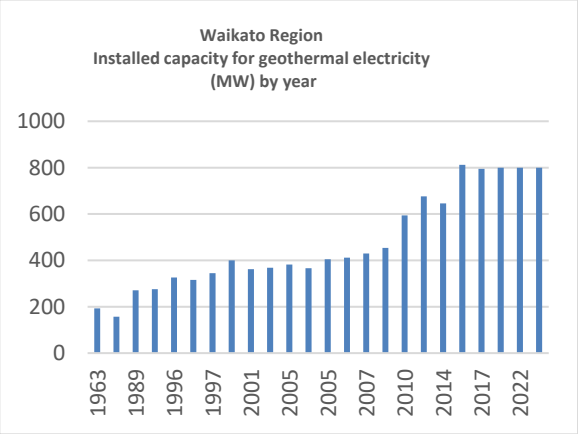

Figure 3: Growth of geothermal electricity production in the Waikato Region (NZGA, 2023)

In 2021, the WRC's Science section adopted the DPSIR model for an updated SOE report, and it is under that model that this paper, derived from the WRC Technical Report (Luketina 2022) evaluates the state of the Regional Geothermal Resource.

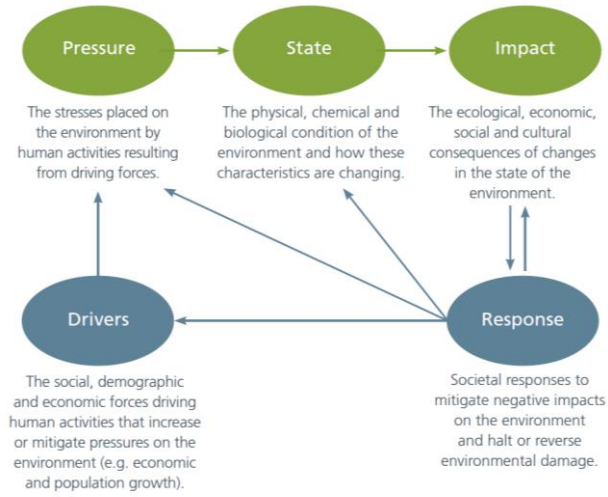

Figure 4: The DPSIR reporting framework (from Parliamentary Commissioner for the Environment, 2019)

4 INFORMATION MANAGEMENT

Sustainable management of a resource requires understanding of the characteristics of that resource. Management of the resource is improved by greater availability of relevant information. The complex and dynamic nature of a geothermal resource is such that there is always an uncertainty in knowledge. Surface features, where they exist, provide only a very small indication of the extent of the subsurface resource and its hydrodynamic characteristics. Geophysical and geochemical techniques, as well as an understanding of the local geology, must be applied to enable understanding of the resource. However, the level of knowledge varies from system to system, depending on the size, depth and other characteristics of the system, the extent to which it has been investigated, and the availability of the results of investigation.

Previously, much of this data and information has not been readily accessible to the public either because of the limitations of the information systems or because of the format in which the information has been presented (Huser, 1991). In addition, much data and information about the Regional Geothermal Resource that has been collected by the government using public funds, such as information about deep wells drilled in central government programmes, is now retained in confidence by the government as a commercial asset, as is much new data collected (Burnell et al., 2016). The unavailability of this data and information to regional and local authorities, to the public (including independent researchers) and to resource users creates uncertainty in decision-making, limiting the opportunities for use of the Regional Geothermal Resource. It also can lead to higher costs for ratepayers and resource users through duplication of effort in collecting the same information.

5 UNDERSTANDING GEOTHERMAL RESOURCE USE AND EFFECTS DYNAMICS

The RMA requires that regional councils manage natural and physical resources sustainably. Objectives, policies, rules, and methods to ensure this are set out in the Waikato Regional Policy Statement and Waikato Regional Plan. Through these policy documents and resource consent conditions that devolve from them, users of the Regional Geothermal Resource are both enabled and constrained by resource consent conditions and other mechanisms in what they can and cannot do in respect of that use. Their environmental compliance with those conditions is overseen by regulatory staff. In addition, science staff monitor the state of the regional geothermal environment in areas where there are no large consent holders. The effects of resource use are complex and often difficult to determine in the short term. Each type of geothermal feature, for example, is potentially subject to a range of effects, both anthropomorphic and natural. Uses of the geothermal resource generally can lead to both negative and positive effects on other natural resources and communities (Keam *et al.*, 2005).

5.1 Performance of geothermal resource users against Environmental Results Anticipated

For geothermal resources, Section 15.4.6 of the Waikato Regional Policy Statement (Waikato Regional Council 2016) has thirteen Environmental Results Anticipated (ERAs) from the application of its policy instruments. These are reproduced below:

"15.4.6 Geothermal

a) Tāngata whenua have a greater role in the management of the Regional Geothermal Resource.
b) There is greater public awareness of the characteristics of geothermal resources, including Significant Geothermal Features.
c) Adverse effects on Significant Geothermal Features are managed consistently with the relevant Geothermal System Classification.
d) Some geothermal energy available for use by present and future generations.
e) Land use, development and use of non-geothermal water are compatible with the purpose for which geothermal systems are classified.
f) Adverse effects on Significant Geothermal Features from the development and uses of non-geothermal water and the new development and uses of land are avoided, with the exception of

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existing effects from the operation of the Waikato River system for hydroelectric generation.

g) Large-scale use of geothermal energy and water are enabled in Development Geothermal Systems.
h) Adverse effects on other natural and physical resources, including overlying structures, from take, use and discharge of geothermal energy and water are avoided, remedied, or mitigated.
i) The risk of hydrothermal eruptions is reduced.
j) Economic benefits derived from access to some of the energy and other geothermal characteristics, including non-extractive uses, and to Significant Geothermal Features.
k) Understanding of the Regional Geothermal Resource and the characteristics of Research Systems through controlled research of these systems is increased.
l) In situ uses of geothermal energy are increased.
m) There is increased protection for the full range of geothermal features.
n) Research Geothermal Systems are reclassified as Development, Limited Development or Protected Geothermal Systems.
o) There is increased use of energy- and water-efficient technologies and more efficient use of the Regional Geothermal Resource."

In addition, Section 7.7 of the Waikato Regional Plan (Waikato Regional Council 2012) lists nine ERAs from the application of its policy instruments, as reproduced below:

"7.7 Environmental Results Anticipated

1. The sustainable management of the Regional Geothermal Resource
2. People and communities being able to provide for their social, economic, and cultural wellbeing through the appropriate use, development and protection of the Regional Geothermal Resource.
3. Geothermal surface features and resource management matters of significance to tangata whenua identified, recognised and provided for.
4. Efficient use of the Regional Geothermal Resource including the use of alternative technologies such as down-hole heat exchangers.
5. Significant adverse effects on Significant Geothermal Features in Development Geothermal Systems arising from the take, use, and discharge of geothermal energy and water remedied or mitigated in any Geothermal System.
6. No significant adverse effects on Significant Geothermal Features in Limited Development, Research, Protected, and Small Geothermal Systems as a result of human activity.
7. No significant adverse effects on Significant Geothermal Features as a result of land use and the use of non-geothermal water.
8. No reduction in the life-supporting capacity and biodiversity or overall sustainability of Research and Protected Geothermal Systems as a result of human activity.
9. Adverse effects on other natural and physical resources including overlying structures (the built environment) avoided, remedied, or mitigated."

While there has been no formal quantitative assessment of the success of these ERAs, it is fair to say that the existing geothermal policy has effectively almost halted most of the major adverse effects of development of geothermal resources and of land and water affecting geothermal resources.

5.2 Geothermal resources in the DPSIR framework

The adverse effects on geothermal resources of anthropogenic activity has been assessed in a DPSIR framework, as below, for the four major cause-and-effect dynamics acting on the Regional Geothermal Resource. These major dynamics had previously been determined during the development of WRC's geothermal policy, informed by science, refined through wide consultation with all interested and affected parties as required by the RMA, and scrutinised and decided through WRC and Environment Court hearings.

1) Effects of geothermal energy development on surface features and their dependent ecosystems;

2) Effects of geothermal energy development on amount of energy and fluid available for future generations;

3) Effects of geothermal development on other uses of surrounding land and water; and

4) Effects of land uses on geothermal surface features and their dependent ecosystems

The results are set out in Tables 1 to 4 below.

Table 1: Effects of geothermal energy development on surface geothermal features and their dependent ecosystems

Item	**Description**	Examples
Drivers	The social, demographic and economic forces driving human activities that increase or mitigate pressures on the environment (e.g. economic and population growth).	Economic and political forces driving demand for geothermally-sourced electricity and process heat.
Pressure	The stresses placed on the environment by human activities resulting from driving forces	Large-scale fluid and energy extraction from geothermal reservoirs

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Item	Description	Examples
State	The biophysical condition of the environment including its physical, chemical and biological characteristics, and how these characteristics are changing.	Ecological • Fluid output of geothermal springs is depleted or rendered extinct • Heat output of hot ground increased and expanded • Thermophilic and extremophilic ecosystems stressed • Weed incursion in geothermal areas Land use • More hydrothermal eruptions • Greater slope instability in geothermally active areas
Impact	The ecological, economic, social and cultural consequences of changes in the state of the environment.	Ecological • Species extinction or range reduction for some geothermal ecosystems • Harbouring of invasive tropical exotic species • Increase in terrestrial geothermal habitat. Cultural • Mahinga kai in geothermal water depleted • Mauri of geothermal surface features depleted • Number and experiential quality of tourism activities reduced • Number and experiential quality of customary uses reduced Land Use • More frequent landslides in geothermal areas causing damage to property and infrastructure including state highways, deaths, evacuations
Response	Societal responses to mitigate negative impacts on the environment and halt or reverse environmental damage.	Policy • More effective application and enforcement of regional policy instruments regarding sustainable management of geothermal resources • Stronger central and local government policy instruments developed to ensure sustainable management of geothermal resources • Greater engagement between local government, tangata whenua, resource users, and researchers to sustainably manage Geothermal Resource. Science, Monitoring and education • More funding from central government and other sources for environmental research and mitigation. • More environmental monitoring of the effects of geothermal resource use • More planting, stock exclusion, weed control, animal and plant pest management and site rehabilitation of geothermal features • Education targeted at geothermal resource users and the public regarding the rarity, vulnerability, and ecological importance of geothermal ecosystems.

Table 2: Effects of geothermal energy development on the amount of energy and fluid available for future generations

Item	Description	Examples
Drivers	The social, demographic and economic forces driving human activities that increase or mitigate pressures on the environment (e.g. economic and population growth).	Economic and political forces driving demand for geothermally-sourced electricity and process heat.
Pressure	The stresses placed on the environment by human activities resulting from driving forces	Large-scale energy extraction from finite geothermal reservoirs.
State	The physical, chemical and biological condition of the environment and how these characteristics are changing.	Energy available in the accessible upper part of the geothermal reservoir is depleted at a rate faster than recharge. (Accessibility requires the zone to be within the drillable depth and the zone to be permeable.)
Impact	The ecological, economic, social and cultural consequences of changes in the state of the environment.	More expensive energy Further reliance of fossil fuels Future generations do not have access to the same sustainable energy resource

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Response	Societal responses to mitigate negative impacts on the environment and halt or reverse environmental damage.	Deeper drilling, which has the potential to provide some buffering of surface features from the effects of extraction. Development of methods for extracting heat from less permeable reservoir. Development of technology to exploit hotter more extreme zones. Stronger central and local policy instruments developed regarding sustainable use Existing environmental policies applied more rigorously Greater engagement between local government, tangata whenua, resource users, and researchers to sustainably manage the Regional Geothermal Resource. More use of fossil fuels Greater investment in existing renewable energy sources New sustainable technologies developed.

Table 3: Effects of geothermal development on other uses of surrounding land and water

Item	**Description**	Examples
Drivers	The social, demographic and economic forces driving human activities that increase or mitigate pressures on the environment (e.g. economic and population growth).	Economic forces driving demand for geothermally-sourced electricity and process heat.
Pressure	The stresses placed on the environment by human activities resulting from driving forces e.g. Effects of water pollution Effects of habitat modification Effects of land cover change Erosion is a change in the state of the land and a pressure on freshwater and coastal habitats Ocean acidification is a major impact of climate change, but it is also a change in the state of the ocean and a pressure on marine biodiversity.	Large-scale energy and fluid extraction from geothermal reservoirs Associated infrastructure affecting other land users.
State	The physical, chemical and biological condition of the environment and how these characteristics are changing.	Subsidence or inflation of land causing damage to buildings and infrastructure, inundation of land and infrastructure adjacent to waterways Heat output of geothermal ground increased Increased frequency of hydrothermal eruptions Greater slope instability on hot slopes Increased risks of tomo developments through changes in subsurface water flows Weed incursion on the margins of geothermal features Noise and vibration from drilling, well tests, station activities including fans and atmospheric discharges. Visual landscape alteration by infrastructure, steam discharge etc. Potential contamination of freshwater aquifers by injection of extracted geothermal fluid Depletion of freshwater aquifers by pressure drawdown into geothermal aquifer Potential contamination of surface water by discharge of used geothermal fluid.
Impact	The ecological, economic, social and cultural consequences of changes in the state of the environment.	Costs associated with moving and repairing affected infrastructure such as roads and reticulated services. More frequent landslides in geothermal areas Mahinga kai in affected areas lost or depleted Mauri of affected areas lost or depleted More expensive sources of fresh water required
Response	Societal responses to mitigate negative impacts on the	Stronger central and local policy instruments developed regarding environmental effects of geothermal developments Existing environmental policies applied more rigorously

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Item	Description	Examples
	environment and halt or reverse environmental damage.	Greater engagement between local government, tangata whenua, resource users, and researchers to sustainably manage the Regional Geothermal Resource. New sustainable technologies developed More monitoring of effects of geothermal development More planting, fencing, landscaping More central government and other funding for environmental research and mitigation.

Table 4: Effects of land uses on surface features and their dependent ecosystems

Item	Description	Examples
Drivers	The social, demographic and economic forces driving human activities that increase or mitigate pressures on the environment (e.g. economic and population growth).	Economic forces driving urban development, changes in primary production of land and demand for geothermally-sourced electricity and process heat.
Pressure	The stresses placed on the environment by human activities resulting from driving forces	Urban encroachment (subdivision, vandalism) Land-use changes (deforestation, dairy intensification) Incompatible land-use activities (weed spraying, vegetation pruning and clearance, soil disturbance)
State	The physical, chemical and biological condition of the environment and how these characteristics are changing.	Thermophilic and extremophilic ecosystems subject to further stressors and potential destruction stressed Weed incursion in geothermal areas Geothermal features degraded, damaged or destroyed
Impact	The ecological, economic, social and cultural consequences of changes in the state of the environment.	Species extinction or range reduction for some geothermal ecosystems Harbouring of invasive tropical exotic species Mahinga kai in geothermal water depleted Mauri of geothermal surface features reduced Number and experiential quality of tourism activities reduced Number and experiential quality of customary uses (bathing, cooking) reduced
Response	Societal responses to mitigate negative impacts on the environment and halt or reverse environmental damage.	Stronger central and local policy instruments developed regarding environmental effects of geothermal developments Existing environmental policies applied more rigorously Greater engagement between local government, tangata whenua, resource users, and researchers to sustainably manage the Regional Geothermal Resource. New sustainable technologies developed More monitoring of effects of geothermal development More planting, fencing, landscaping More central government and other funding for environmental research and mitigation. More planting, stock exclusion, weed control, animal and plant pest management and site rehabilitation of geothermal features Education targeted at geothermal resource users and the public regarding the rarity, vulnerability, and ecological importance of geothermal ecosystems.

6. CONCLUSION

The Waikato Regional Geothermal Resource provides many benefits to the regional community, the nation, and to investors in the companies that derive profits from use of the resource, such as electricity providers, primary producers, and tourism companies. The WRC resource management framework ensures that use of these resources is done in a sustainable and environmentally conscious manner.

Prior to the enactment of the RMA there was destruction and depletion of significant parts of the Regional Geothermal Resource. The resource is now largely protected, at least in law, by the RMA and regional policy instruments restricting or prohibiting adverse effects on surface geothermal features and ensuring that extractive uses are sustainable. Nevertheless, increasing demands for this low-carbon energy source, and development pressures on the land surrounding geothermal surface features, lead to some adverse effects.

Surface geothermal features, and their dependent ecosystems are rare and vulnerable, and can be accidently or unintentionally exposed to adverse effects from human interaction.

We continue to learn more about the intricate nature of the Regional Geothermal Resource, the changing pressures that are placed on it, and the effects of those pressures. As socio-economic drivers such as the desire for electricity and intensifying land uses place pressure on the resource, the effects of those pressures need to be studied so that we can respond appropriately to ensure sustainable management and limit adverse effects. Lack of funding for monitoring and

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research severely impairs our ability to identify and respond to the threats.

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