REPORT

Tonkin+Taylor

Geothermal hazard risk review for residential dwellings and their occupants in Rotorua City

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1 Introduction

Tonkin & Taylor Limited (T+T) was engaged by Rotorua Lakes Council (RLC) to undertake a geotechnical assessment of the geothermal hazards and risks to residential buildings and their occupants, which is intended to support a plan change to the Rotorua District Plan (District Plan) to allow for intensification of residential development within Rotorua City. As part of this assessment T+T would provide advice regarding possible methods to manage the identified risks.

1.1 Purpose of review

The purpose of the review as set out in the Request for Proposal (RFP) provided by RLC is to:

- Summarise the geothermal hazards within Rotorua City that may affect residential buildings and their occupants.
- Summarise the risks to residential buildings and their occupants in the context of expected changes in residential building typologies and density.
- Provide summary maps.
- Summarise the existing methods to manage the risk as contained in the District Plan, bylaws and administration of the Building Act.
- Advise on potential gaps in the District Plan and possible changes.

This work is being done to support a plan change to allow for intensification of residential development within Rotorua City and in particular, whether:

- geothermal hazards should be considered a 'qualifying matter' in accordance with the 'Enabling Housing' amendment to the Resource Management Act 1991 (RMA),
- existing impervious standards are appropriate, and
- the District Plan provisions are appropriate for managing the hazard.

1.2 Summary of plan change

A summary of the plan change has been provided in the Barker & Associates memorandum to T+T dated 24 March 2022[1], which is outlined below.

RLC is drafting a plan change (Rotorua Housing Plan Change or "PC9") to the District Plan in response to the National Policy Statement for Urban Development (NPS-UD) and the Resource Management (Enabling Housing Supply and Other Matters) Amendment Act 2021 (Amendment Act). Both the NPS-UD and Amendment Act have the purpose of enabling development within urban environments.

The District Plan divides the city into various residential (zones 1 to 5), commercial, industrial, and rural zones, each with different development requirements/rules.

The NPS-UD guides RLC to enable greater urban form via increasing building heights and densities in areas serviced by existing and planned active and public transport routes. The Amendment Act requires RLC to adopt Medium Density Residential Standards (MDRS) for relevant residential zones which, in Rotorua, have been identified as Residential Zones 1 and 2. A comparison of the existing provisions and changes for Residential Zones 1 and 2 is provided in Table 1.1.

[1] Barker & Associates Limited (24 March 2022) Overview of Rotorua Housing Plan Change (PC9). Memorandum issued to Tonkin + Taylor

Table 1.1: Comparison of key MDRS against the existing performance standards in the Residential 1 and 2 zones[2]

Standard	Existing Residential 1	Existing Residential 2	MDRS - new Residential 1	New Residential 2
Permitted density (no resource consent required)	One household unit per 350 m^2	One household unit per 350 m^2 unless a comprehensive residential development plan has been approved	Three household units per site	Three household units per site
Max. height	7.5 m	7.5 m	11 m	18 m
Daylight envelope	3 m + 45˚	3 m + 45˚	4 m + 60˚	8 m + 60˚
Min. yard setback	Front: 5 m Side and rear: 2.5 m	Front yard: 3 m Side and rear: 2.5 m	Front: 1.5 m Side and rear: 1 m	Front: 1.5 m Side and rear: 1 m
Max. site coverage	40% site area	No maximum	50% net site area	50% net site area
Max. impermeable surfaces (at discretion of Council)	80% site area	No maximum	70%	80%

1.3 Review methodology

Rotorua City is globally unique as it has been built over an active geothermal system creating particular hazards which require methods to control the actual or potential effects of the use, development or protection of land to avoid or mitigate natural hazards (section 31(1)(b)(i) of the RMA). This includes residential buildings and their occupants. To evaluate the geothermal hazards, T+T has undertaken a process comprising four key steps within several different settings and with a team of collaborating consultants and client representatives. The key stages follow Risk Management guidelines outlined in ISO 3100 and are:

- Step 1: Risk Identification – Summary of the geothermal hazards in Rotorua City.
- Step 2: Risk Analysis – Summary of the geothermal risks associated with residential buildings and their occupants in Rotorua City.
- Step 3: Risk Evaluation – Review of the existing methods to manage geothermal risk and Project team discussion of known geothermal hazards, associated risks, and existing risk treatments.
- Step 4: Risk Treatment – Advise on potential gaps and suggestions for the management of geothermal hazards within the District Plan.

The outcomes of these steps are provided in the following sections of this report. The work has followed a collaborative approach with experts from RLC and GNS Science including:

- Interviews with experts and affected parties to identify risks and gaps.
- A workshop (held on 31 May 2022) to discuss the findings of the work and establish commonality with respect to treatment of the geothermal hazards for residential development.

[2] Barker & Associates Limited (24 March 2022) Overview of Rotorua Housing Plan Change (PC9). Memorandum issued to Tonkin + Taylor

- Production of a risk register identifying current geothermal risks/hazards, their treatment, future mitigation measures and gaps.
- Review of this document and the associated risk register.

2 Geothermal hazard and risk identification

2.1 Context

The Rotorua Geothermal System underlies a large portion of downtown Rotorua. The geothermal system extends from Whakarewarewa in the south to beneath Lake Rotorua in the north. It presents a number of hazards that are required to be addressed when considering residential development within the urban city centre. Sections 2.2 to 2.4 outline the data sources, the geothermal hazards identified and how the information was treated/assessed.

2.2 Literature review

As part of this assessment T+T reviewed available scientific papers, journal articles and website information that relate to the occurrence of geothermal hazards (both around the world and within other areas of New Zealand), with a particular focus on studies that focus on Rotorua City. We have also reviewed local and regional council geospatial information pertaining to geothermal features within Rotorua. The collation of the geothermal hazards identified within this literature review are summarised within the Risk Register (Appendix A). The locations of the geothermal hazards identified as part of this study are provided on plans included in Appendix B. The key hazards relating specifically to the PC9 are outlined in Section 2.3.

2.3 Geothermal hazards and risks - description

The following sections provide a summary of the geothermal hazards identified within the Rotorua Residential Zones 1 and 2. The definitions of each hazard have been drafted following advice provided by GNS Science[3] and following a workshop held at RLC on 31 May 2022.

2.3.1 Geothermal surface features

2.3.1.1 Hot water / mud / steam

Fumaroles, hot springs, mud pools and pots can be close to or at boiling temperatures. The high temperatures exist in the feature and in any associated outflow channel. Some features (for example mud pools) may also have a stratified temperature structure where the surface of the feature may be cooler than deeper parts.

2.3.1.2 Explosive hydrothermal jetting, splashing, and bubbling from surface features

Surface features that, as part of their normal style, display cyclicity that can culminate in minor explosive activity. Small spouting springs and geysers jet and splash water out of the immediate vent area. This can also occur for hot pools that experience irregular vigorous boiling. Jetting and splashing also occurs from mud pools and mud pots at times and can eject mud to small distances outside the feature.

This scale and style of activity is not considered hydrothermal eruption, and the impacted area is usually within 3-5 m of the feature.

[3] Brad Scott (2 June 2022 @ 1:38pm) Email from Brad Scott to David Milner.: RE: Spatial Data

2.3.1.3 Hydrothermal eruptions

There are two key eruption types at geothermal systems, hydrothermal and phreatic, both being steam driven. The most typical eruption type is hydrothermal where the energy is obtained from the geothermal system.

Hydrothermal eruptions typically fall into three sizes: small, with ejecta out to 10 m; moderate, with ejecta 10-100 m; and large, with ejecta >100 m from feature.

Phreatic eruptions, although steam driven have a direct magmatic heat or fluid involvement. Phreatic eruptions are not considered further here as the Rotorua Geothermal System does not have a direct magmatic source, and there has been no magmatic activity within Rotorua Caldera in the last 100,000 years[4].

2.3.2 Geothermal gas

Geothermal fluids contain dissolved gases that are released into the atmosphere. Water (H_2O) vapour is the most common geothermal gas constituent, however, there are several other gas species that, in sufficient quantities, can pose a hazard to people. After steam, carbon dioxide (CO_2) is the most common constituent of volcanic gas, though hydrogen sulphide (H_2S) and radon (Rn) are also toxic gases that are often emitted at geothermal areas. Methane (CH_4) is also recorded in Rotorua.

Gas is not solely emitted from a point source, such as a spring or fumarole, but is also diffusely emitted through soil within a geothermal system. As such, gas is a constant and always present hazard in geothermal areas.

2.3.3 Warm-hot ground

In addition to heat being transmitted from depth through steam, gas and water, the ground itself can also transmit and radiate heat by conduction. This is variable and can range from areas where temperatures are only slightly above ambient to boiling conditions at shallow depths. The weak and unstable ground hazards can be present in these areas.

2.3.4 Weak / unstable ground

2.3.4.1 Acidic and/or corrosive ground

In geothermal areas the local ground and soils can be susceptible to hydrothermal alteration. Circulation of chemically aggressive fluid and gas condensates result in dissolution and alteration of host-rock and soil material. All material in contact with these condensates is susceptible to hydrothermal alteration. Alteration weakens the soil and/or rock and can decrease its ability to support loads (i.e. people or structures).

2.3.4.2 Ground collapse

Collapse of ground occurs frequently in geothermal areas. Subsurface material can be eroded through chemical and/or physical processes (e.g. dissolution of material by acidic steam and condensates; downward percolating groundwater), causing the overlying surface to lose stability and collapse into a void. Sinter sheets, hardened bare ground surfaces, and concrete paths/driveways often conceal developing collapse holes, which may be filled with steam or hot water.

[4] B. Scott review comments received 15 June 2022

2.3.5 Geothermal bores

Geothermal bores are located across the city within the geothermal system and were drilled to exploit the geothermal resource. The key hazard in this category that affects residential buildings and their occupants pertains to bore deterioration. These are extraction and disposal bores, and also those used for heat exchangers and technical equipment. Deterioration of bores can lead to warm-hot ground, elevated emission of geothermal gases and surface features.

Similar deterioration also occurs with infrastructure such as those related to visitor access and safety such as trails, fences and viewing platforms.

2.4 Geothermal hazard and risk information

The Rotorua Geothermal System is shown along with the other geothermal systems of the Rotorua District on District Plan Map 212. These mark the location of the geothermal systems in the district as defined by resistivity surveys[5] . As part of the risk identification process, T+T has created GIS maps that compile the existing geothermal hazards and features identified above and their intersection with the proposed PC9 development zones (Residential Zones 1 and 2). Refer to Figures 1 and 2 within Appendix B. The intention of this exercise was to assess if the existing Rotorua Geothermal System extent is an appropriate area to use as a hazard overlay.

Figure 1 depicts areas where elevated ground temperatures and gas concentrations were identified within 1 m of the ground surface by the work of Finlayson (1992)[6].

There are large overlaps in the distributions of these two categories and for simplicity they have been combined here. Utilising the contour plans provided in Finlayson (1992) we have used the following limits as defining elevated temperature and gas (all within 1 m of the ground surface):

- Warm-hot ground – in situ temperature ≥20°C
- Hydrogen Sulphide – 1 mole percent
- Carbon dioxide – 10 mole percent
- Methane – 0.25 mole percent

With respect to the elevated ground temperatures and gas concentrations map it is acknowledged that Finlayson (1992) is one data set and that others could have been chosen (e.g., Horwell et al. (2005)[7], Werner and Cardellini (2006)[8], and Hollingworth (2016)[9]. However, Finlayson's work has been utilised as it appeared to have a more even distribution across Rotorua City than some other studies and temperature and gas measurements were taken from 1 m below ground level. Hollingworth (2016) and Werner and Cardellini (2006) both present more recent data from a greater number of points, however temperature readings were made within 100 mm of the ground surface (which is considered shallow and more likely to be affected by atmospheric conditions) and most collection points were centred around the active surface areas Arikikapakapa, Kuirau Park, Sulphur Point and Whakarewarewa. Hollingworth also comments that gas flux distributions across the city are similar to previous studies, and reports errors in gas flux contours in her work that are attributed

[5] Gordon, D.A, O'Shaugnessy, B.W., Grant-Taylor, D.G, Cody, A.D. Rotorua Geothermal Field Management Monitoring, Environment B.O.P. Report 2001/22
[6] Finlayson, J.B. (1992) A soil gas survey over Rotorua geothermal field, Rotorua, New Zealand. Geothermics 21, p181-195
[7] Horwell, C.J., Patterson, J.E., Gamble, J.A. and A.G. Allen (2005) Monitoring and mapping of hydrogen sulphide emissions across an active geothermal field: Rotorua, New Zealand. Journal of Volcanology and Geothermal Research, 139, p259 -269
[8] Werner, C., and C. Cardellini (2006) Comparison of carbon dioxide emissions with fluid upflow, chemistry and geologic structures at Rotorua geothermal system, New Zealand. Geothermics 35, p221-238.
[9] Hollingworth (2016) A Soil Gas Survey Quantifying Emissions of Carbon Dioxide and Hydrogen Sulphide in the Rotorua Geothermal Field and Discussing the Results in Relation to Underlying Geology and Hazardous Output. Master's Thesis, University of Birmingham

to the contouring software package. Horwell et al. (2005) studied mainly atmospheric rather than in-ground H_2S.

Figure 2 represents the mapped surface features and geothermal vegetation (associated with surface features) that have been provided by Bay of Plenty Regional Council (BOPRC). Most are located within the area identified as subject to elevated temperature or gas flux (Figure 1), but many are not. We have included a 5 m buffer in our recommendations to align with the existing provisions within the District Plan and the Rotorua Geothermal Bylaw 2016 (refer to section 4 below). For visual purposes, the points used to show surface features on Figure 2 are larger than the 5 m buffer. The actual locations of each feature will need to be obtained from the relevant RLC or BOPRC dataset and the relevant setback applied. The mapped features do not include sites of large hydrothermal eruptions as they are generally sporadic 'one off' events.

An inventory of geothermal bore locations (both extraction and disposal) is currently being compiled by RLC and BOPRC and the complete dataset was not available at the time of writing this report. Geothermal bores are located across the city and are not necessarily within areas of elevated shallow ground temperature.

Areas of weak and unstable ground have not been located as part of this work but are expected to be mostly coincident with surface features, areas of elevated temperature and gas, and within proximity of geothermal bores.

3 Geothermal hazard and risk analysis

3.1 Geothermal hazards and risks for residential buildings and their occupants

The geothermal hazards that exist within Rotorua City present a number of risks to residential buildings and their occupants. These are summarised below within Table 3.1 together with methods for mitigation.

Table 3.1: Summary of geothermal hazards within Rotorua City

Risk type	Risks to residential buildings and their occupants	Possible mitigation methods
Geothermal surface features	Geothermal surface features can pose a danger to people due to high water temperatures and the potential for ejections of steam, water, debris and gas. Interference with geothermal surface features can potentially increase the hazard risk via re-emerging fumaroles, gas emission and hydrothermal eruption.[10]	Buildings need to be sufficiently set back from geothermal surface features to minimise disturbance of the feature and the potential for damage to building foundations. In some instances, safety fences may need to be installed around surface features. Control regarding interference with geothermal surface features.

[10] Bay of Plenty Rotorua Geothermal Plan section 13.4.2

Risk type	Risks to residential buildings and their occupants	Possible mitigation methods
Geothermal gas	Geothermal gas provides one of the greatest hazards in the context of residential land development. Gas can infiltrate through tight joints in building frames, service lines and foundations and will fill up the allowable space. Gas also has the potential to accumulate within small outdoor spaces such as small building setbacks. Geothermal gas is difficult to detect without specialist sensors and can cause death or serious respiratory failure within minutes.	Areas with potential for geothermal gas accumulation should be suitably vented. Specific building design is needed to prevent the ingress of gas and ensure adequate ventilation. Gas protection measures should also consider the potential for exacerbating the gas hazard to neighbouring properties.
Warm-hot ground	Heated ground has the potential to cause damage to building foundations and can lead to uncomfortably warm living spaces.	Construction of impervious surfaces can reduce rainwater percolation which can reduce the cooling effect rainwater provides to heated ground and can create a barrier reducing heat radiation to the air. Specific engineering design of buildings is required in areas of warm-hot ground.
Acid and corrosive ground	Acid and corrosive ground can affect building foundations.	Specific engineering design of buildings is required in areas of acid and corrosive ground.
Potential for ground collapse	Ground collapse has the potential to affect building foundations and can cause disruption to services.	Ground collapse generally occurs near surface features or bores. Buildings need to have sufficient setbacks from these areas.
Bores	Bores have the potential to vent geothermal gas and undermine building foundations. Unmaintained bores have the potential to become hazardous.	Buildings and bores should be sufficiently spaced to enable bore access for maintenance purposes and to reduce the potential for damage to building foundations. Sufficient space must also be allowed to maintain access to bores (e.g. along accessways from roads, etc).

3.2 Development scenarios

Residential intensification in accordance with the MDRS may increase the risk from geothermal hazards due to:

- A general increase to impervious surfaces from buildings and building access areas (driveways and paths) due to intensification across the zone, however it should be noted that current District Plan standards enable a greater extent of impermeable surfaces per site than those currently being considered by RLC as part of PC9.
- The side and rear setback areas between the building and the boundary will decrease from 2.5 m to 1 m. Smaller setbacks may be vulnerable to the accumulation of geothermal gas.
- Greater potential for interference with geothermal surface features including from site establishment (earthworks), construction works, creation of impervious surfaces and general increased population density.

4 Geothermal hazard and risk evaluation

The following section contains a summary of the existing methods to manage geothermal risk to buildings and their occupants contained within the District Plan, the Rotorua Geothermal Bylaw 2016 and the Building Act 2004 requirements and evaluates these methods against the risk analysis in section 3 of this report. It includes consideration of how other councils manage geothermal hazards and risks.

4.1 Rotorua District Plan

The rules to manage geothermal hazards are contained within the District Plan, Hazards and Risks chapter (geothermal) and the Subdivision chapter (subdivision of sites and buildings susceptible to natural hazards). A number of geothermal terms are also defined.

contains a summary of the relevant definitions and rules.

Table 4.1: Rotorua District Plan geothermal hazard definitions and rules

Term	Definition
Geothermal activity	*Geothermal and hydrothermal processes or discharges, actively altering or depositing rocks, minerals soils and waters (including steam) at or near to the ground surface. It includes geothermal gas, hot ground and acid ground.*
Geothermal feature	*Any natural landform, heated or chemically altered waters, rocks and soils created by a geothermal system. Features may be cold and inactive, extinct or dormant, or actively altering or depositing rocks, minerals soils and waters at or near to the ground surface. Features are created by hot water or steam and/or gases given off from an underlying geothermal system or tectonic fault zone.*
Geothermal surface feature	*Geothermal surface features include active and dormant structures formed by surface manifestation of geothermal processes or discharges and includes any resulting earth forms, any geothermally activated geysers, fumaroles, sinter cones, tomos, mud pools, hot and cold water pools, springs, steam vents, pressure domes or fissures. A geothermal surface feature excludes geothermal gas, hot ground and acid ground, where it occurs in isolation from the surface feature.*
Geothermal system	*A 'geothermal system' is an individual body of geothermal energy and water, not believed to be hydrologically connected to any other body. Such a system includes material containing heat or energy surrounding any geothermal water, and all plants, animals and other characteristics and geothermal features dependent on the body of geothermal energy and water.*
Significant geothermal features	*Geothermal features assessed as being significant in accordance with the method, descriptions and criteria of the Bay of Plenty Regional Policy Statement; or within the Waikato Region: Significant Geothermal Features that are assessed in accordance with section 9B of the Waikato Regional Policy Statement, except that within Development or Limited Development geothermal systems, Significant Geothermal Features shall be those identified and mapped in the Waikato Regional Plan in accordance with method 9.2.2 of the Regional Policy Statement.*

Rule	Rule Summary
Natural Features and Landscapes	
NFL-R19 Development and earthworks adjacent to a Significant Geothermal Feature	Buildings to be set back 5 m from the edge of any Significant Geothermal Feature unless resource consent has been granted by a Regional Council. Any earthworks to be at least 5 m from the edge of any Significant Geothermal Feature. Earthworks shall not divert water into or out of a Significant Geothermal Feature. Assessment criteria for non-compliance includes the adverse impacts on any geothermal vegetation viability and its ecosystem present onsite and the extent to which adverse effects on any Significant Geothermal Feature can be avoided, remedied or mitigated, as determined by a suitably qualified and experienced expert, in accordance with the regional geothermal classification system.
NFL-R20 Development and earthworks that will affect a Significant Geothermal Feature	Development and earthworks that will affect a Significant Geothermal Feature is a discretionary activity. Assessment criteria is as for Rule NFL-R19.
Natural Hazards	
NH-R6 Buildings erected within 5 m of the edge of a geothermal surface feature or bore.	A building within 5 m of the edge of a geothermal surface feature or bore that is not associated with electricity generation requires resource consent as a restricted discretionary activity. In residential zones discretion is restricted to the management of adverse effects from natural hazards or the worsening of any hazard on the planning maps.
NH-R7 Site coverage in the geothermal systems overlay	Buildings and hard surface coverage of more than 90% of the site are permitted provided an assessment by a suitably qualified and experienced person is provided at the building consent stage showing a low level of risk from geothermal gas, hot ground and acid ground.
SUB-R42 The subdivision of sites or buildings on land affected by a geothermal feature, geothermal activity or bore	Subdivision on affected land requires resource consent as a discretionary activity. The performance standards in SUB-S8(3) require that: i. Areas of the site with visible geothermal features or disused bores shall be excluded from the location of buildings and structures. ii. An assessment is required covering the effects of the geothermal activity on the subdivision and any subsequent use of land or buildings. The effects on the geothermal surface features also need to be assessed. iii. Proposed mitigation measures shall be documented including consideration of the subsequent location and use of either habitable or non-habitable buildings on the site.

4.2 Rotorua Geothermal Bylaw 2016

The Rotorua Geothermal Bylaw 2016 (the bylaw) is centred on the geothermal gas hazard and the management of bores. It has the following objectives:

- The safety of the general public from the effects of hydrogen sulphide gas so far as is practically possible.
- The safe operation and proper maintenance of the headworks and associated pipework and plant of shallow geothermal production and reinjection bores.

Of relevance to the intensification of residential development within Rotorua City, Table 4.2 summarises the key requirements.

Table 4.2: Relevant clauses in Rotorua Geothermal Bylaw 2016

Bylaw clause	Requirement
Pools	
4.1	Adequate fencing of any natural geothermal pool, spring, geyser or other feature of geothermal activity, or any artificially created pool which may be dangerous or injurious to health.
Bores	
5.1 - 5.10	Bores to be regularly inspected and kept in sound working order.
5.12	Site access to any well shall be maintained in such a condition as to allow access to the well by a drilling rig at all times.
5.18	No person shall erect a structure or building within 5 m of either an existing well, or a closed well except with the express written approval of the council, and subject to any conditions it may impose.
Dangerous geothermal features	
6.1	Where there is any land or premises containing a natural or artificially created geothermal feature or activity which is likely to be dangerous or injurious to health, a written notice may be issued requiring the owner or occupier of the land or premises shall take steps including adequate fencing of the land or closing of the premises so as to protect any person from the danger/threat.
6.2	Any land or premises subject to a written notice under clause 6.1 shall remain fenced off or closed until the danger/threat has been made safe.
Buildings	
7.3	The developer, owner or occupier of every building shall take all reasonably practical steps to incorporate acceptable barriers to the ingress or egress of hydrogen sulphide, into or from, new or upgraded building developments.

4.3 Building Act 2004

The Building Act 2004 provides an overarching set of rules for building practitioners, developers and regulatory bodies and must be adhered to along with any planning regulations and bylaws. As defined in the Building Act 2004, its purpose is as follows:

(a) to provide for the regulation of building work, the establishment of a licensing regime for building practitioners, and the setting of performance standards for buildings to ensure that—
   (i) people who use buildings can do so safely and without endangering their health; and
   (ii) buildings have attributes that contribute appropriately to the health, physical independence, and well-being of the people who use them; and
   (iii) people who use a building can escape from the building if it is on fire; and
   (iv) buildings are designed, constructed, and able to be used in ways that promote sustainable development:

(b) to promote the accountability of owners, designers, builders, and building consent authorities who have responsibilities for ensuring that building work complies with the building code.

Several clauses within the Building Act 2004, refer to restrictions relevant to building works within areas where geothermal hazards may be present. Summaries of these clauses are outlined in the following sub-sections. All new builds must comply with these clauses irrespective of their location.

4.3.1 New Zealand Building Code Clause F1 (Hazardous agents on site)

The objective of Clause F1 is to provide restrictions that safeguard for people from injury or illness caused by hazardous agents or contaminants on a site. Clause F1 sets out assessment and performance requirements that account for the intended use of the building, the nature, potency and toxicity of hazards (including geothermal) and contaminants, and any protection afforded by the building envelope and building systems. It describes reasonable standards for the identification of hazards and the relevance of investigations when considering a development proposal within an area that is known to contain a hazardous substance or substances.

Flow charts describing the investigation, and hazard and risk assessment processes for a site (including geothermal) are provided in F1/VM1. This should be consulted when designing the appropriate investigations to identify the presence and extent of geothermal hazards within a development site.

4.3.2 New Zealand Building Code Clause B1

The objective of Clause B1 is to safeguard people from injury and to protect amenities and other property from physical damage that would be caused by structural failure. While this does not specifically refer to geothermal hazards, all foundation and structural designs must be compliant with the various clauses outlined within Clause B1 to ensure that the appropriate building materials and foundations are selected to mitigate any potential impacts relevant to a particular site.

4.3.3 New Zealand Building Code Clause B2

Under Clause B2, building materials, components and construction methods are required to be sufficiently durable. They must ensure that the building, without reconstruction or major renovation, continues to satisfy the other functional requirements of the Building Code throughout its life. Clause B2 specifies minimum durability periods building elements must meet with only normal maintenance, being not less than 50, 15 or 5 years (depending on their function).

B2 Durability must always be considered when demonstrating compliance with each of the clauses of the Building Code. In other words, it ensures that a building will continue to satisfy the

performance of the Building Code throughout its specified intended life (normally 50 years for structural components of a residential building). Construction materials must be selected that are appropriate for the conditions encountered at the development site in order that they meet the durability and design life requirements set out in Clause B2.

4.3.4 NZS 3604:2011

NZS 3604:2011 provides information to ensure timber framed buildings of up to three-storeys comply with the NZ Building Code[11]. Of relevance to this work, it discusses local environmental effects (microclimates) that can cause corrosion of structural fasteners and fixings. This includes geothermal hot spots which are defined as being within 50 m of a bore, mud pool, steam vent or other source. NZS 3604:2011-type buildings within 50 m of these locations require specific engineering design.

4.4 Other councils

4.4.1 Bay of Plenty Regional Council

4.4.1.1 Bay of Plenty Regional Policy Statement

The District Plan must give effect to the Bay of Plenty Regional Policy Statement (BoPRPS) in accordance with section 75(3)(c) of the RMA. The BoPRPS contains the following objective for natural hazards:

Objective 31 *Avoidance or mitigation of natural hazards by managing risk for people's safety and the protection of property and lifeline utilities.*

There are a number of associated policies for natural hazard risk management and outcomes. Of particular relevance is the following policy:

Policy NH 4B: *Managing natural hazard risk on land subject to urban development.*

Policy NH 4B requires a Low[12] natural hazard risk to be achieved on development sites after completion of the development by controlling the form, density and design of any urban activity within the existing urban area that involves the construction of new and/or additional buildings or reconstruction of or addition to existing buildings (including associated subdivision).

4.4.1.2 Bay of Plenty Regional Plan

The District Plan must not be inconsistent with a regional plan in accordance with section 75(4)(b)) of the RMA. The relevant regional plan is the Rotorua Geothermal Regional Plan. The regional plan seeks to control interference with geothermal surface features[13] as this may increase the hazard risk from re-emerging fumaroles, gas emission and hydrothermal eruption. Any interference with a geothermal surface feature requires resource consent as a discretionary activity.

There are also a number of provisions controlling geothermal bores, although none are of particular relevance to urban development.

[11] Schedule 1 of the Building Regulations 1992
[12] Policy NH 2B: Low natural hazard risk being the level of risk generally acceptable.
[13] Objective 13.5.1; Policies 13.5.2(c), 13.5.2(d); Rule 13.5.3(b)(i)

4.4.2 Waikato Regional Council

The jurisdictional area of the Waikato Region contains geothermal areas therefore this council has been selected to review their relevant regional plan provisions. The relevant Waikato Regional Plan provisions are contained in the Geothermal Module which contains a number of provisions relevant to a 20 m buffer. Of particular relevance is Rule 7.6.6.3 which states (with a few exceptions) that vegetation clearance and soil disturbance within 20 m of a Significant Geothermal Feature require resource consent as a discretionary activity. Significant Geothermal Features are listed and mapped[14]. However, it is important to note that these provisions are designed to protect geothermal features from adverse effects[15] rather than to mitigate against hazards from these features.

4.4.3 Taupō District Council

The jurisdictional area of Taupō District contains geothermal areas therefore this council has been selected to review their relevant district plan provisions. The Taupō District Plan contains maps of geothermal system areas and areas of hot ground where specific provisions apply.

Hot Ground Hazard Area

In accordance with Rule 4e.12, within the Hot Ground Hazard Area, soil temperature at a depth of 1 m below the ground surface needs to be measured to determine whether it exceeds the ambient temperature[16] and by how much, which will then determine the activity status for new structures. The activity status is also determined by compliance with the site coverage standard. The most relevant rules are described in Table 4.3.

Table 4.3: Hot Ground Hazard Area rules

Soil Temperature at 1 m below ground surface	Other notable requirements	Activity status
Does not exceed 10° C above ambient temperature	None	Permitted
Between 10° C and 40° C above the ambient temperature	Does not exceed 75% of total coverage of the allotment (which is determined by soil temperature)	Controlled
Between 40° C and 60° C above the ambient temperature	Meets the total coverage rule	Restricted Discretionary
Exceeds 60°C above the ambient temperature	None	Discretionary

Assessment criteria includes design and construction of the building to avoid or mitigate adverse geothermal effects, the extent of building and site coverage, the extent and risk of gas emissions, health and safety risks and increased risk from geothermal effects.

[14] Tables 7-5 and 7-6 and mapped in section 7.10.
[15] Rule 7.6.6.3 Assessment criteria
[16] Ambient temperature is defined as the temperature taken on the same day, using the same method, in a similar piece of ground to that of the Hot Ground (having regard to soil, sun, and weather conditions) in an area known to be unaffected by geothermal heating. Soil Temperature shall be measured at 10m intervals on a grid basis over the allotment. The highest temperature within the allotment shall determine which rule applies.

Geothermal System Areas

In accordance with Rule 4e.15 any residential activities (apart from one dwelling house per lot) which are located in the mapped geothermal system areas, or any subdivision of land, requires resource consent as a discretionary activity. However, this rule appears to be aimed at protecting the use of the geothermal resource and to consider reverse sensitivity effects associated with the use and development of the geothermal resource.

4.5 Effectiveness of current risk management method

Table 4.4 outlines the existing mitigation measures for each type of geothermal hazard and provides a comment regarding their effectiveness.

Table 4.4: Effectiveness of current risk management measures

Hazard type	Existing mitigation measures		Comment
Geothermal surface features	District Plan	5 m setback for buildings from geothermal surface features or resource consent. Restriction on earthworks within 5 m of a Significant Geothermal Feature. Subdivision is a discretionary activity.	The 5 m setback for buildings is considered adequate however there is no setback requirement for other site areas people frequently use such as paths and service areas. There are limited protections for geothermal features, for instance there are no requirements relating to impervious surfaces in geothermal surface feature locations and earthworks rules only protect Significant Geothermal Features rather than all geothermal surface features. Geothermal feature and geothermal activity are not defined within the bylaw. These provisions are considered to be reasonably effective but could be strengthened particularly with respect to the control of interference with geothermal surface features.
	Bylaw	Adequate fencing or closing of premises where dangerous geothermal features and activity are identified.	
	Building Act	NZ Building Code Clause F1 investigation, and hazard and risk assessment processes. Specific engineering design of some buildings if within 50 m of a bore, mud pool, steam vent or other source.	
Geothermal gas	District Plan	Sites with more than 90% coverage require an assessment at building consent stage. Subdivision is a discretionary activity.	The management of the geothermal gas hazard will only be triggered by the District Plan if sites have more than 90% coverage. The hazard may still be present with reduced levels of site coverage. The installation of new hard surface areas such as driveways may not require a building consent and it is therefore unclear when the assessment would be provided in this situation. Geothermal gas within buildings will be addressed through Building Act provisions, however these provisions do not address site layouts which could create gas accumulation areas (such as within small building setbacks adjacent to low permeability masonry boundary walls). These provisions are not considered to be sufficiently effective at managing the geothermal gas hazard.
	Bylaw	Incorporation of barriers to the ingress or egress of hydrogen sulphide within buildings.	
	Building Act	NZ Building Code Clause F1 investigation, and hazard and risk assessment processes. Specific engineering design of some buildings if within 50 m of a bore, mud pool, steam vent or other source.	

Hazard type	Existing mitigation measures		Comment
Warm-hot ground	District Plan	Sites with more than 90% coverage require an assessment at building consent stage. Subdivision is a discretionary activity.	The management of the geothermal warm-hot ground hazard will only be triggered by the District Plan if sites have more than 90% coverage. The hazard may still be present with reduced levels of site coverage. The installation of new hard surface areas such as driveways will not necessarily require a building consent and it is therefore unclear when the assessment would be provided in this situation. Geothermal feature and geothermal activity are not defined within the bylaw. Warm-hot ground hazards to buildings and their occupants are likely to be addressed through Clause F1 of the Building Code. These provisions are considered to be reasonably effective at managing the geothermal warm-hot ground hazard, however site coverage on sites subject to this hazard may need to be reduced so as not to exacerbate the hazard.
	Bylaw	Adequate fencing or closing of premises where dangerous geothermal features and activity are identified.	
	Building Act	NZ Building Code Clause F1 investigation, and hazard and risk assessment processes. Specific engineering design of some buildings if within 50 m of a bore, mud pool, steam vent or other source.	
Acid and corrosive ground	District Plan	Sites with more than 90% coverage require an assessment at building consent stage. Subdivision is a discretionary activity.	The management of the geothermal acid and corrosive ground hazard will only be triggered by the District Plan if sites have more than 90% coverage. The installation of new hard surface areas such as driveways will not necessarily require a building consent and it is therefore unclear when the assessment would be provided in this situation. Geothermal feature and geothermal activity are not defined within the bylaw. Acid and corrosive ground hazards to buildings are likely to be addressed through clauses B2 and F1 of the Building Code. These provisions are considered to be reasonably effective at managing geothermal acid and corrosive ground hazards for buildings, however, they are less effective at managing risks to impervious surfaces such as driveways and paths.
	Bylaw	Adequate fencing or closing of premises where dangerous geothermal features and activity are identified.	
	Building Act	NZ Building Code Clause F1 investigation, and hazard and risk assessment processes. NZ Building Code Clause B2 durability of materials must be such that required design life is met for site conditions. Specific engineering design of some buildings if within 50 m of a bore, mud pool, steam vent or other source.	

Hazard type	Existing mitigation measures		Comment
Potential for ground collapse	Bylaw	Adequate fencing or closing of premises where dangerous geothermal features and activity are identified.	The potential for ground collapse is often associated with a surface feature. The Building Act requires specific engineering design for buildings close to these areas. Other areas of potential ground collapse cannot generally be foreseen. These provisions are considered to be as effective as is practical.
	Building Act	Specific engineering design if within 50 m of a bore, mud pool, steam vent or other source.	
Bores	District Plan	5 m setback for buildings from bores or resource consent.	The purpose of the 5 m setback is for bore access rather than hazard mitigation, however it does provide a level of geothermal hazard protection for buildings and their occupants. The bylaw is unclear as to whether it concerns the access itself as well as the condition of the access. In the absence of any district plan provisions requiring bore access, only the bylaw clauses can be relied on as an 'other matter' to ensure site layouts and building setbacks do not restrict access (and only where matters of control or discretion allow it). The district plan on its own will potentially enable development that is contrary to the bylaw requirement which could create uncertainty for applicants. The setback requirements are considered to be effective however the access provisions could be aligned.
	Bylaw	5 m setback unless permission from council obtained. Bores to be regularly inspected and kept in sound working order. Access to the bore/well is to be maintained in such a condition as to allow access by a drilling rig at all times.	
	Building Act	Specific engineering design if within 50 m of a bore, mud pool, steam vent or other source.	

5 Geothermal hazard and risk treatment

This section outlines the potential gaps within the current District Plan with regards to the management of geothermal hazards within Rotorua City and suggestions for changes to existing plan provisions. We are of the view that geothermal hazards (where mapped) could be a qualifying matter for residential intensification in the forthcoming plan change, however it may be possible to utilise permitted activity standards for some development.

5.1 Rotorua Geothermal System extent

The risk identification process described in section 2.4 of this report shows that the current District Plan Rotorua Geothermal System as shown on Planning Map 212 is appropriate to use as a hazard overlay. It encompasses the majority of the areas noted on Figure 1 (combined gas and temperature hazard) and Figure 2 (Surface Geothermal Features), however there are two exceptions to this:

- a small area towards the southwest of Kuirau Park; and
- areas to the east of Whakarewarewa.

The Kuirau Park area is not within the current District Plan Rotorua Geothermal System, however it is included in Figure 1 and is within an area proposed for residential intensification. The Whakarewarewa area is currently zoned Rural 1 and Business and Innovation Zone 1 and is not included within either the Figure 1 map or the District Plan map, however this is a known geothermally active area.

The current District Plan Rotorua Geothermal System plan should be extended to encompass these areas. To further refine the extent of the mapped area, RLC may wish to consider developing a programme of monitoring within the Rotorua Geothermal System which may reduce the area.

5.2 Geothermal gas, warm-hot ground and acid/corrosive ground hazards

In accordance with current District Plan provisions, assessments for geothermal gas, warm-hot ground and acid/corrosive ground are only triggered when more than 90% site coverage is proposed, with reports being considered at building consent stage. We recommend deletion of this trigger and replacement with a requirement for a site-specific assessment of geothermal hazards prepared by a suitably qualified person as part of a resource consent application for any proposal within the Rotorua Geothermal System overlay which exceeds the maximum permitted impervious area.

Relevant matters for assessment include the following:

- The extent to which the site is affected by geothermal gas, warm-hot ground and/or acid and corrosive ground geothermal hazards. Note that for warm-hot ground, measurements against the ambient ground temperature should be undertaken.
- Whether the proposed site coverage, including buildings and impervious surfaces, will exacerbate the geothermal hazard risk.
- Whether the site layout, including building height and building and fencing materials will create areas where geothermal gas could accumulate.

- The extent to which building specific design can mitigate the potential geothermal hazard/s. Note this could be detailed at the building consent stage but could be covered at a high level at the resource consent stage to ensure this can be managed at building consent stage. Any resource consent conditions should be specific rather just deferring to the building consent stage.
- Whether the geothermal hazard can be mitigated to a sufficient level to enable the proposed development.

Reports should also be required at building consent stage for all development within the Rotorua Geothermal System overlay as potential gas accumulation areas (such as within small building setbacks) may result on some sites as a result of the proposed development, which will require suitable venting. Appropriate standards for the placement and design of venting structures could be included within the District Plan.

5.3 Geothermal surface features

Many of the geothermal surface features are located within the identified areas of elevated temperature and gas emission (Figure 1), however they can also occur in other locations (Appendix B, Figure 2). Buildings within 5 m of a geothermal surface feature should continue to require resource consent and applications should be accompanied by a site-specific assessment of geothermal hazards prepared by a suitably qualified person. Consideration could also be given to restricting other areas that people may frequently use such as paths and service areas within this 5 m setback.

We note there are no District Plan provisions that protect geothermal surface features themselves from interference such as through construction works, or the creation of impervious surfaces such as driveways. Rules for earthworks only protect 'Significant Geothermal Features' rather than all geothermal surface features. There should be limitations on these types of works near or within a geothermal surface feature such as requiring a 5 m setback as per the requirement for buildings.

An additional rule requiring resource consent for any interference with a geothermal surface feature could be considered and would align with the provisions of the regional plan, however RLC should be mindful that it would create double ups in assessment and resource consent conditions, which may frustrate applicants and consent holders.

5.4 Geothermal bores

Geothermal bores are located throughout Rotorua City and are not confined to the identified areas of elevated temperature and gas emission (Figure 1). Residential site layouts need to allow for access to bores and it is recommended that the 5 m building setback be retained. While this specifically relates to maintenance rigs for borehole extraction/injection, it also provides a reasonable setback from a potential geothermal hazard. We also recommend that an additional rule be introduced that requires a 5 m wide access corridor to bores which is free from permanent buildings (i.e. removable buildings and structures such as garden sheds and fences would not be captured) to enable maintenance to be undertaken. This would align with clause 5.12 of the bylaw as detailed in Table 4.4. Adequate maintenance of bores is required to ensure they do not become hazardous.

Buildings within 5 m of a geothermal bore should continue to require resource consent and applications should be accompanied by a site-specific assessment of geothermal hazards prepared by a suitably qualified person.

5.5 Definitions

A number of terms would benefit from being defined within the District Plan including 'geothermal gas', 'warm-hot ground' and 'acid and corrosive ground'.

5.6 Assessment of geothermal hazard investigation requirements

A simple flow chart has been provided in Appendix C which provides an option for investigation requirements with regards the assessment of geothermal hazards. Due to possible time constraints and the potential for a lack of appropriate expertise and favourable atmospheric conditions for the monitoring of geothermal gases, two options are presented.

- Option A: Undertake site specific measurements of temperature and geothermal gas in boreholes. Measurements should take into account the effects of temporal fluctuations, and changes and trends in atmospheric pressure (i.e. three or four gas measurements should be taken over a minimum of one month). If adequate gas measurements cannot be taken then the practitioner may determine the temperature in relation to the ambient ground temperature, assume high gas readings and design lot layout and building details accordingly.
- Option B: No specific measurement of temperature or in-ground geothermal gases. This option would require the suitably qualified person to assume high temperatures and high gas levels in their assessment and design lot layout and building details accordingly.

Table 5.1: Geothermal hazard indicator threshold values

Investigation Criteria	Threshold	Comment
Ground Temperature	>10°C above ambient ground temperature	Adopting the Taupo District Council (TDC) minimum temperature threshold would be a reasonable approach. This will require a method for determining ambient ground temperature.
Hydrogen Sulphide	0.5 ppm	Based on the NZ Workplace Exposure Standard Time Weighted Average (WES-TWA) limit, multiplied by a safety factor of 0.1 to allow for potential accumulation over time. It is recommended that further studies of background and in-ground concentration in the geothermal overlay area are undertaken to verify these thresholds
Carbon dioxide	500 ppm	

It is recommended that a practice note is developed by the Council that provides an acceptable method of undertaking a geothermal investigation. Report requirements should also be included within the District Plan for any developments that require reports as part of a resource consent application. As a general overview, depending on the option selected, site specific investigations should include but not be limited to the following:

- A walkover by an experienced geotechnical engineer / engineering geologist, who is familiar with the geothermal setting of the site at the design stage and during foundation preparation.
- Hand or machine auger boreholes to at least 2.0 metres below ground level (m bgl). A minimum of four per site or 1 per 200 m^2, whichever is greater.
- Presence or absence of geothermal alteration evidence should be noted in the logs of the augers

- A minimum of one temperature and three gas monitoring visits undertaken within the auger boreholes over a period of one month.
- Recording of atmospheric pressure conditions and trends during the time of testing. Falling atmospheric conditions should be targeted to determine a worst case-scenario for geothermal gases
- Gas readings should be taken using a gas analyser capable of measuring the threshold concentrations. Gas flow should also be recorded.
- Temperature readings taken at depths of 0.2 m, 1 m and 2 m bgl and at least three days after last rainfall event.
- Determination of ambient ground gas temperature should be established from a site known to not be affected by hot ground. Temperature should be established by tests undertaken at least three days after last rainfall event. RLC could consider installing a permanent inground thermometer in an area known to be unaffected by the geothermal field to help establish the ambient ground temperature within the city.

5.7 Uncertainties/limitations and ongoing monitoring

This report has been drafted based on data published for the Rotorua Geothermal System. In particular, the elevated gas and temperature map (geothermal hazard overlay) was based on Finlayson (1992). We note Finlayson (1992) is one dataset and there are a number of others (see Section 2.4). Subsequent studies (see Section 2.4) have yielded similar results with respect to gas and temperature distribution, however, geothermal conditions change with time.

RLC may find benefit in undertaking regular geothermal assessments and mandating the upload of investigation data to the existing New Zealand Geotechnical Database. It is important that the results of uploaded data are reviewed periodically to update the existing data sets that were used to support this review (including the overlays depicted in Figures 1 and 2 - Appendix B). RLC may wish to consider developing a programme of monitoring within the Rotorua Geothermal System with the aim of refining the area requiring geothermal assessment once the hazard is better understood.

Surface feature location points shown on Figure 2 have been sized for readability. They do not represent 5 m setback distances. The point/area locations of these features should be taken from the relevant dataset and the 5 m offset applied. Surface features have recently been mapped by BOPRC and GNS. We understand that the mapping is as complete as possible for a dynamic dataset. There will likely be features that haven't been identified and these may be uncovered by developments. If encountered during development, they will need to be treated the same way as all other surface features.

This report has focussed on the Rotorua Geothermal System, and residential buildings and their occupants. We note that there are a number of geothermal systems within the Rotorua District. We also note that the Rotorua Geothermal System affects areas that are zoned for land-uses other than 'residential' within the District Plan. The general findings in this report are applicable to other geothermal systems within the district and to other land-use zones within the District Plan.

6 Applicability

This report has been prepared for the exclusive use of our client Rotorua Lakes Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

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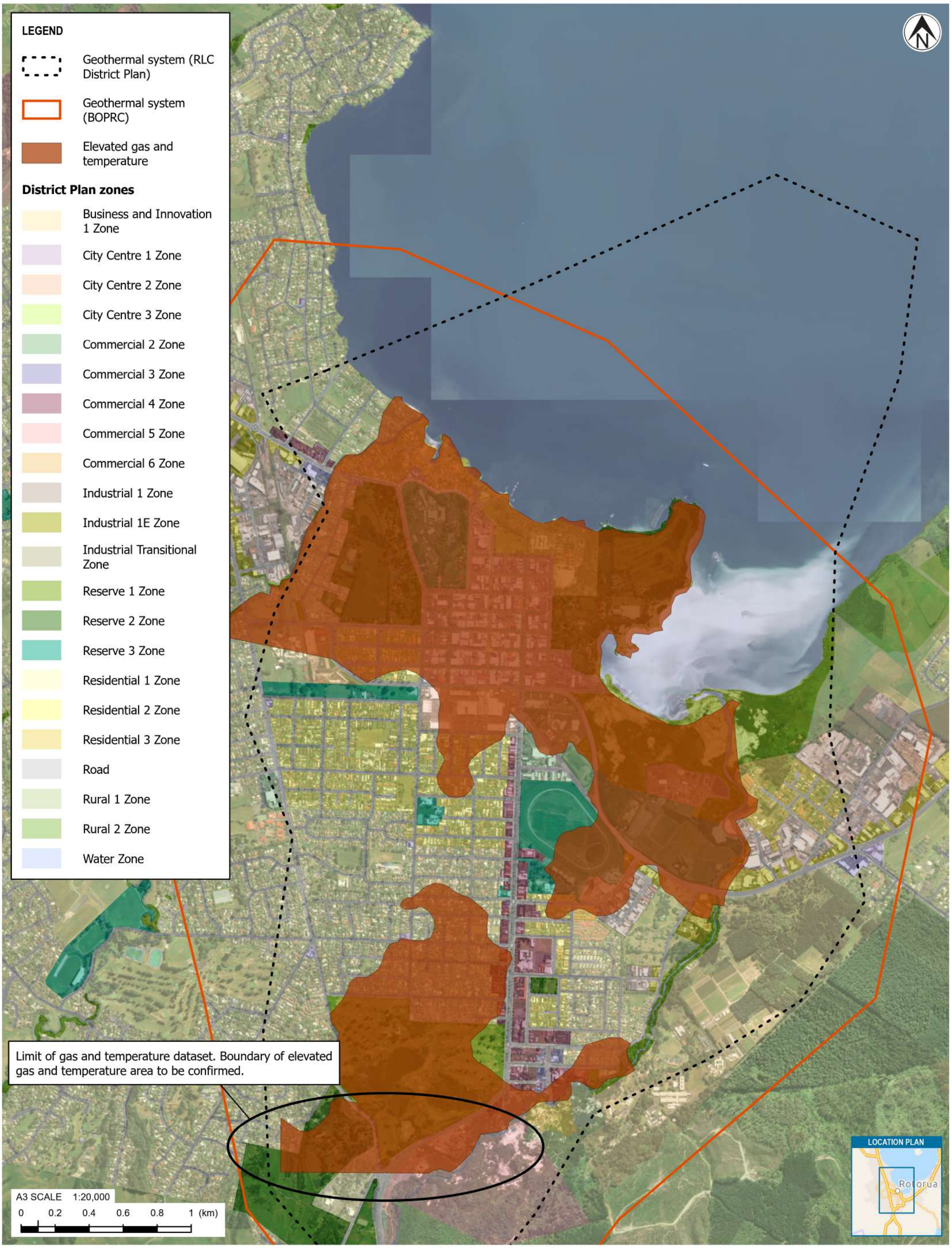
Appendix A Risk Register

Hazard		Risk Identification			Risk Analysis - Untreated Risk				
		Associated Processes	Visual Obv / Evidence	Area of interest	Potential impact on Human Life	Potential impact on Structures	Probability	Consequence	Risk
Surface Features	Hot Water / Mud / Steam	Fumaroles, hot springs, mud pools and pots can be close to or at boiling temperatures Mud Pools may have a stratified temperature structure (surface of the feature may be cooler than deeper parts)	Often have surface expressions that are visible	up to 5 but potential 10m from a geothermal surface feature	Minor injuries Disruption	Potential for damage to building foundations from associated subsidence	Possible	Significant	Moderate
	Explosive Hydrothermal Jetting	Brief geysering activity located within geothermal surface feature or bore Hot water and debris surrounding the feature	Can be known (in areas with frequent eruptiions) Can be unknown in conspicuous areas where changes in the nearby surface features (Mead St, 2019): Geyser eruption (no deaths)	up to 5 but potential 10m from a geothermal surface feature	Minor injuries Disruption	Potential for damage to building foundations from associated subsidence	Possible	Significant	Moderate
	Hydrothermal Eruptions	Superheated water trapped below the earth becomes steam Disruption of confining rock May occur in isolation related to large level changes of the lakes Triggered by local major earthquakes	Can be known (in areas with frequent eruptiions) Can be unknown in conspicuous areas where changes in the nearby surface features (Mead St, 2019): Geyser eruption (no deaths)	100-200m from a geothermal surface feature	Severe inuries to massive loss of life	Damage to building foundations	Unlikely	Critical	Moderate
Geothermal Gas		Building over geothermal areas with impermeable materials such as asphalt or concrete foundations Gas builds/seeps and is hard to pre-emptively identify. Meaning that high concentations could be present (even within the building itself) Gas could easily seep within foundation cracks/construction joins or service pipes	Imposible to visually percieve 11 deaths in rotorua since 1946 Hospital rates 1.5 - 2.7x national rate for breathing related illness Difficult to judge long term exposure rates / impacts(Priests Pool, 2011): one death due to gas/drowning (Motel death , 2003): Ellen Umlauf-Rueprecht	3 Sources of toxic gas: Cat A - venting from controlled system Cat B - venting from rogue bores Cat C - Natural venting: Most notably in vicinity of Arikikapakapa/Whakarewarewa, Sulphur Bay-Ngapuna and and Ohinemutu/Kuirau Park.	Permanent harm or death in severe cases Continued exposure can potentially cause chornic health conditions, this is still unconfirmed however Short life expancy of electronic goods Asphyxiation Headaches	Certain materials, when exposed to sulphur-containing gases are suspectible to corrosion leading to poor material durability and performance. Copper, Iron, lead Silver and zince are all affected. H2S can cuase blackening in paint and timber as well as sever deterioration of timber. services, wiring, fire hazards	Almost Certain	Major	Extreme
Warm - Hot Ground		elevated temperatures within the top 1 to 2m Upwelling of gas from deep magmatic processes Pressured gas is absorbed by upwelling heated water Water is exposed to surface via upwelling/geysers etc.	Difficult to predict as these can happen anywhere within the areas of surface geothermal features where natural heat flow is higher within the Rotorua (Priests Pool, 2011): one death due to gas/drowning	The entire Rotorua Geothermal System, depth to and temperature of hot water ground varies across the city.	uncomfortable living areas	Potential damage to deep foundations Unusable living spaces	Almost Certain	Significant	High
Weak & Unstable Ground	Acidic and/or Corrosive Ground	Circulation of chemically aggressive fluid and gas alteration of host-rock and soil materials	Discoloration of ground water Unusual smell Altered temperature	Near surface geothermal features beneath building foudnations	Minor injuries	Damage to structures Damage to services (i.e waterways)	Almost Certain	Significant	High
	Ground Collapse	Related to poor control of runoff and water disposal, larger volumes of water get flushed into susceptible soils and fines flushed out. System change/or recovery over long periods of time (1-20years) which cause landform changes beneath structures	Often concealed by hardened bare ground surfaces and concrete paths / driveways	In/around natural or reclaimed ground within areas of surface geothermal features In/around geothermal bore	Potential fall injuries when collapse occurs	Damage to foundations and/or structures	Unlikely	Minor	Low
Bores - including Infrastructrure failure & Deterioration		uncontrolled release of fluids	Subsidence around extraction bores Degradation of access/safety trails or equiptment	Around any infrastructure: Bores production and disposal, Pipes, heat exchanger	Minor injuries through to serious injury, disrupt	Subsidence of buildings Damage to roads Damage to services	Likely	Significant	High

Hazard		Risk Evaluation - Current Controls							Risk Treatment - Future State				
		Distirct Plan	Bylaws	Building Code	Mitigation methods	Probability	Consequence	Risk	Potential Mitigation Methods	Potential gaps	Probability	Consequence	Risk
Surface Features	Hot Water / Mud / Steam	NH-R6 - Buildings within 5m of a feature or Bore SUB-R42	5m Setback from geothermal feature Restricting access to dangerous geothermal features through fencing or closing	B2/AS1/VM1 NZS3604:2011 - 4.2.4c	Setback of 5m from Geothermal features	Unlikely	Minor	Low	Mapping of bores Mapping of surface features	location of geothermal bores location of surface geothermal features DP rules/Bylaws do not consider earthworks	Unlikely	Significant	Moderate
	Explosive Hydrothermal Jetting	NH-R6 - Buildings within 5m of a feature or Bore SUB-R42	5m Setback from geothermal feature Restricting access to dangerous geothermal features through fencing or closing	NZS3604:2011 - 4.2.4c F1/VM1 - hazardous agents or contaminants	Setback of 5m from Geothermal features	Unlikely	Minor	Low	Mapping of bores Mapping of surface features	location of geothermal bores location of surface geothermal features DP rules/Bylaws do not consider earthworks	Unlikely	Significant	Moderate
	Hydrothermal Eruptions	NH-R6 - Buildings within 5m of a feature or Bore SUB-R42	5m Setback from geothermal feature Restricting access to dangerous geothermal features through fencing or closing	NZS3604:2011 - 4.2.4c F1/VM1 - hazardous agents or contaminants	5m exclusion zone	Unlikely	Critical	Moderate	Mapping of bores Mapping of surface features	There are no requirements relating to impervious surfaces or earthworks in geothermal surface feature locations. Geothermal feature and geothermal activity are not defined within the bylaw. Phreatic eruptions not considered	Unlikely	Critical	Moderate
Geothermal Gas		NH-R6 - Buildings within 5m of a feature or Bore	5.1 - bore and headworks inspections 5.3 - No building within 5m of bore 7.3 - preventing ingress of gas	NZS3604:2011 - 4.2.4c F1/VM1 - hazardous agents or contaminants	Setback of 5m from Geothermal features Other bylaws - are these enforced? 90% maximum impervious surface Thermathene orange membrane (low/med. Risk sites) Butyl sealed membrane Passive ventilation	Possible	Major	High	Mandate specific investigations (ground gas monitoring) Increasing permiable ground surface	Management of gas only triggered at 90% site coverage. Hazard may still be present at lower levels of coverage. Location of geothermal bores location of surface geothermal features DP rules/Bylaws do not consider earthworks	Unlikely	Major	Moderate
Warm - Hot Ground		NH-R6 - Buildings within 5m of a feature or Bore SUB-R42	5m Setback from geothermal feature Restricting access to dangerous geothermal features through fencing or closing	NZS3604:2011 - 4.2.4c F1/VM1 - hazardous agents or contaminants	Avoid use of slabs Consider hot ground in location of services	Possible	Significant	Moderate	Mandate specific investigations (temperature readings) Adopt Taupo Guidance	Management of warm-hot ground only triggered at 90% site coverage. Hazard may still be present at lower levels of coverage.	Unlikely	Minor	Low
Weak & Unstable Ground	Acidic and/or Corrosive Ground	NH-R6 - Buildings within 5m of a feature or Bore	5m Setback from geothermal feature	NZS3604:2011 - 4.2.4c F1/VM1 - hazardous agents or contaminants B2 - Durability	Design for aggressive ground Use of resistent materials	Possible	Significant	Moderate	Additional chemical monitoring of ground water	No trigger for certain investigations, however, likely to be captured by Building Code clauses B2 and F1. to be undertaken	Possible	Minor	Moderate
	Ground Collapse	NH-R6 - Buildings within 5m of a feature or Bore	5m Setback from geothermal feature	NZS3604:2011 - 4.2.4c B1/AS1-4/VM1-4	Set-backs of 5m from surface features (Bylaws) Management of run-off, soakholes and water disposal systems (including geothermal water Hazard mapping of nearby surface featues	Unlikely	Minor	Low	Additional setbacks Mandated specific invetsigations to locate geothermal features Management of run off, and water disposal systems such as soakholes etc	Some areas of potential ground existing provisions are considered to be as effective as is practical. collapse cannot generally be foreseen.	Unlikely	Significant	Moderate
Bores - including Infrastructrure failure & Deterioration		NH-R6 - Buildings within 5m of a feature or Bore SUB-R42	5m Setback from geothermal feature Restricting access to dangerous geothermal features through fencing or closing	NZS3604:2011	n/a	Unlikely	Significant	Moderate	Foudnation and material selection at design phase	DP rules/Bylaws do not consider degradation of walkways or maintenance equipment			

Appendix B Figures

- **Figure 1 – Areas of elevated heat and gas concentrations within 1 m of the ground surface**
- **Figure 2 – Surface geothermal features**



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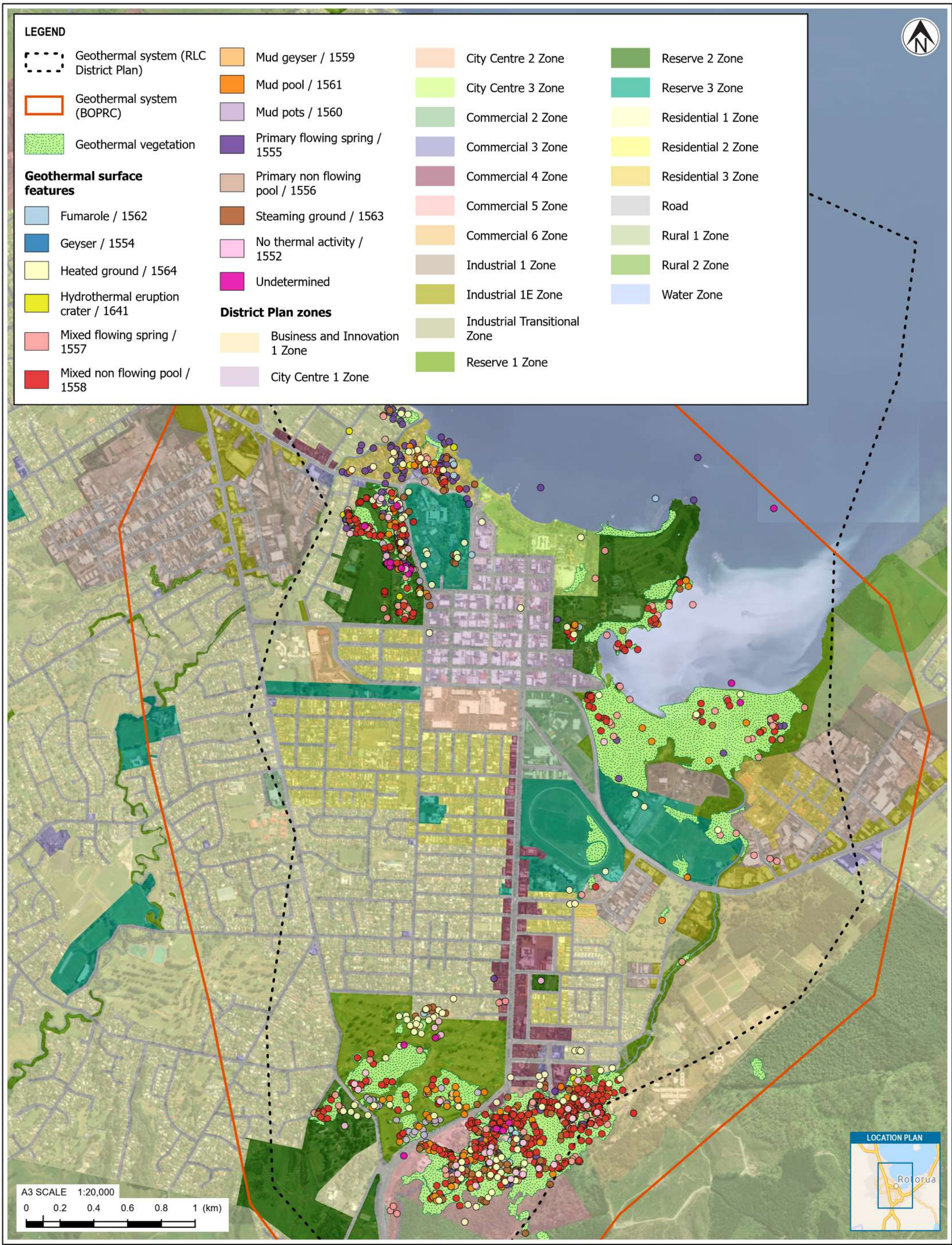
NOTES:
Basemap: LINZ Data Service
District plan zones: Rotorua Lakes Council.
Downhole temperature, CO_2, CH_4, H_2S: Finalyson (2000)

REV	DESCRIPTION	GIS	CHK	DATE
1	First issue	MOLI	JORB	17/06/22
2	Second issue	MOLI	JORB	22/06/22

PROJECT No.	1019695	
DESIGNED	MOLI	JUN.22
DRAWN	MOLI	JUN.22
CHECKED	DMMM	JUN.22
APPROVED		DATE

CLIENT **ROTORUA LAKES COUNCIL**
PROJECT **GEOTHERMAL ADVICE**
TITLE ELEVATED GAS AND TEMPERATURE COMBINED MAP
SCALE (A3) 1:20,000 FIG No. FIGURE 1 REV 2



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T:\Tauranga\Projects\1019695\WorkingMaterial\GIS\MapDocuments\RLC_GeothermalFeatures\RLC_GeothermalFeatures.aprx Layout: FIG002_SurfaceFeatures 2022-Jun-16 3:13 pm Drawn by MOLI

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Exceptional thinking together

NOTES:
Basemap: LINZ Data Service
District plan zones, geothermal surface features, and geothermal vegetation: Rotorua Lakes Council.

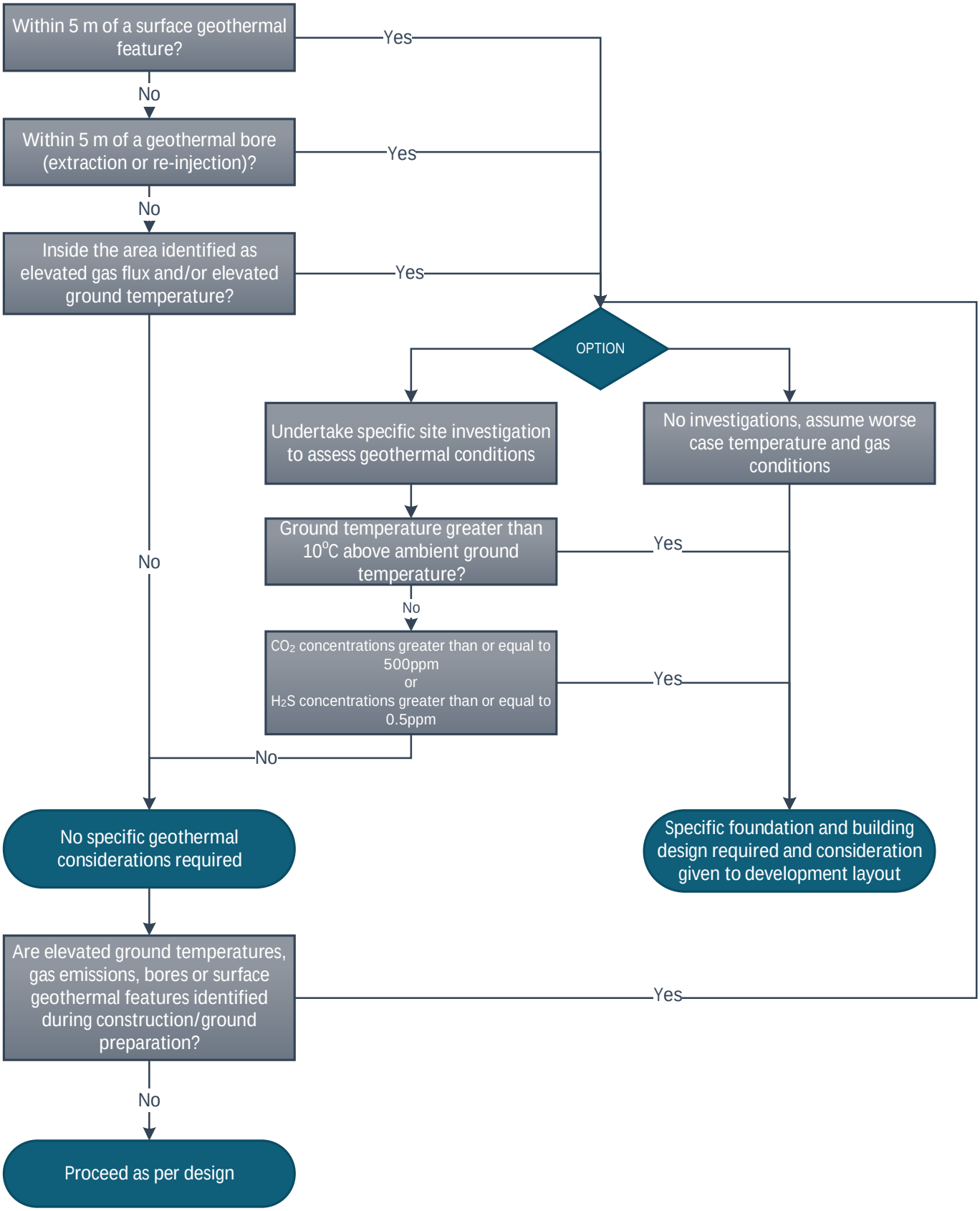
REV	DESCRIPTION	GIS	CHK	DATE
0	Draft for discussion	MOLI	JORB	07/06/22
1	First issue	MOLI	JORB	17/06/22

PROJECT No.	1019695	
DESIGNED	MOLI	JUN.22
DRAWN	MOLI	JUN.22
CHECKED	DMMM	JUN.22
APPROVED		DATE

CLIENT **ROTORUA LAKES COUNCIL**
PROJECT **GEOTHERMAL ADVICE**
TITLE SURFACE FEATURES
SCALE (A3) 1:20,000 FIG No. FIGURE 2 REV 1

Appendix C Geothermal Assessment Flow Chart

Geothermal risk assessment process for residential intensification proposals



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