Development of Methodology to Assess Significant Geothermal Features

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EXECUTIVE SUMMARY

Methodologies and assessment procedures for assessing the significance of surface thermal features are proposed and discussed in this report for the Bay of Plenty Regional Council. The methodologies interpret the significance criteria in the Regional Policy Statement, and provide guidance for their application. The methods include numerical scoring or ranking systems, which provide clarity about the attributes or values that contribute to the significance of a feature. They can also be used to provide a broad indication of relative significance between surface thermal features.

Aspects of vulnerability to proposed resource or land use activities are initially addressed through a risk and hazard assessment approach (Method 1). This method may be of use as a trigger for resource assessment and planning consideration once a vulnerability is recognised. However it does not work to establish significance of features. A ranking criteria with weighting is developed to measure Natural and Aesthetic values using criteria provided in the Bay of Plenty Regional Policy Statement as Method 2. It can be applied at both the feature type level and individual feature level. In Method 3, feature ranking is also proposed using criteria provided for in the Bay of Plenty Regional Policy Statement by subdividing the assessment into criteria that rely on feature ‘type’ (hence are generic, and don’t require a catalogue of features), and those criteria that rely on individual feature characteristics relative to all those within the Taupo Volcanic Zone (hence do require a catalogue). Method 4 is an amalgamation of the previous methods with a time-line that incorporates three phases. This separates an initial assessment procedure (Phases 1 and 2), from one that would be case specific, address vulnerability more robustly, and occurs upon initiation of proposals for resource or land use activities (Phase 3).

Only three of the four methods presented (Methods 2, 3 and 4) are suitable for establishing the degrees of significance or ranking required. Each have different benefits and costs associated with implementation. All identify a database is require of surface geothermal features (active and relict), regardless of their significance. While each could serve a useful purpose for the assessment and classification of surface geothermal features, no one method appears as a preferred method.

1.0 INTRODUCTION

Geothermal surface features can be categorised according to feature type (e.g., primary spring, geyser, mud pool). At the highest level, they can also be classified by separating them into two main groups: active features that could be subject to both subsurface fluid and land-use practices; and remnant geological features that could be subject to best-practice management of land-use.

Geothermal surface features of these various types can be assessed according to agreed criteria that test for significance. The result can be, for example, a statutory list of significant geothermal features (SGFs). The results of this process can assist resource managers and developers manage potential adverse effects on geothermal surface features by categorising the geothermal features and systems according to their values (i.e., the things that make them significant) and threats to those values. This then helps inform decisions around various levels of protection or utilisation. This process is generally required as part of the Resource Management Act (RMA) (RMA, 1991) and the consenting process administered by local, regional and national government agencies.

This report utilises definitions and criteria defined by the Bay of Plenty Regional Council (BOPRC) through the BOPRC Regional Policy Statement (RPS) (BOPRC, 2014). Namely:

- Definitions of the nine criteria to assess the significance of geothermal surface features (RPS p274, BOPRC, 2014), and is reproduced as Appendix 1 in this report.
- Definitions of terms as per the RPS (BOPRC, 2014), with parts reproduced in Appendix 2 in this report.
- Definitions of the geothermal feature type descriptors as per Table 16 (p214-217) of Annex A of the RPS (BOPRC, 2014).

Although criteria have already been developed in the RPS to identify significant geothermal surface features and define their attributes, there is currently no consistent, robust method to interpret and apply these criteria. Nothing to clearly establish why one feature or set of features is more or less significant. Nor have sites where significant features exist and meet the criteria been identified, making implementation of policies for their protection difficult.

GNS Science was commissioned by the BOPRC to review and develop an approach, focusing on the Geothermal Natural Science Values and Aesthetic Values criteria (i.e., excludes the Associative Values). The output is a method(s) that can be consistently applied by suitably qualified experts, for example as part of an application for resource consent or to develop comprehensive schedules of significant geothermal features.

This report reviews past work on defining the significance of New Zealand geothermal systems and surface features (Houghton et al. 1980; Houghton et al. 1989), the application of attributes of geothermal features to derive significance (Keam et al. 2005) and Bromley (2011a, b). Cody (2007) in a review of geodiversity of geothermal fields has applied some of these principles.

Four approaches (labelled 'Methods') are examined and discussed in this report to give guidance to BOPRC of robust methodologies that could be adopted. The nine RPS criteria for geothermal surface features underpin these methods. Six criteria analyse the significance from a 'Natural Science Perspective' (representativeness, diversity and pattern, rarity, distinctiveness, resilience and vulnerability; Appendix 1). The other three criteria involve the 'Aesthetic Values' (memorability, naturalness and transient values; Appendix 1).

One approach (Method 1) considers the methodologies used for the evaluation of risk and hazards in Emergency Management (Ministry of Civil Defence and Emergency Management (MCDEM), 2015). This approach looks at a method that could be particularly relevant to the 'vulnerability' criteria for significance ranking. Also based on the Civil Defence and Emergency Management (CDEM) approach a methodology is developed to examine the natural science and aesthetic values (Method 2). The third approach looks at defining the significance of surface feature by type, building on classification/criteria ranking for feature types developed by Bromley (2011a, b), Keam et al. (2005) and Cody (2007). A fourth approach (Method 4) is an amalgamation of methods. In the end, it is anticipated that the study will demonstrate that an assessment of significance of active geothermal features can be accomplished by using a numerical (or similar gradational) grading scheme, with some weighting.

1.1 WHY HAVE A METHODOLOGY

As stated in the BOPRC Policy statement (2014, Section 2.4) geothermal resource allocation decisions must take into account the potential for multiple users of a resource, and take account of the potential effects on the system's 'Significant Geothermal Features (SGFs)'. Therefore, SGFs are now a part of the management tool used to assess geothermal system utilization or protection and are important for both resource managers and users. They become important when enabling the following;

1. The categorisation of geothermal systems into geothermal management groups.
2. Setting the level of effects management on a system e.g., protection, development or something in-between.
3. Implementation of effects management including monitoring and enforcement if necessary.
4. The inclusion of rules in a Regional Water and Land Plan (RWLP) relating to:
    - reservoir maintenance/temperature and pressure;
    - natural flows of geothermal water to surface;
    - surface activities that affect SGF e.g., earthworks/damming.
5. The inclusion in relevant district plans, GIS data sets and maps to give effect to rules relating to setbacks for buildings/structures or activities like building, earthworks and vegetation clearance.
6. Hazard identification.
7. Development of outreach information and education.

Hence methods are needed to identify geothermal features (Scott 2012) in a transparent, repeatable and consistent manner that then allows a fool-proof test of the significance of the features. This in turn allows policies to be developed for their management.

1.2 ISSUES WITH DEFINING A DEGREE OF SIGNIFICANCE

The RPS policies refer to the protection of SGFs, and as such policy implementation relies on the identification of sites that are, or are not considered to be significant. For example, a "threshold" of significance could be used as a 'fixed marker' to enable planning decisions to progress (e.g., as a trigger for a rule in a regional or district plan and a requirement for a resource consent).

Application of the terms "significant" or "not significant" can be narrow with respect to categorising all the different types of geothermal features or their values. These terms have no gradational scale. Therefore, they are not very useful as a means of assessing the potential severity of an adverse surface environmental effect. Also, some form of *degree* of significance is implied by the wording of policy documents. For this reason, in this report, we believe that a gradational degree of significance is actually a more appropriate and scientifically rigorous approach to managing features, and hence the use of gradational ranking schemes.

1.3 Grouping of Ranking Criteria: Types, Time Variables and Taupo Volcanic Zone Setting

The ranking criteria described in the BOPRC Policy Statement (Appendix 1) can be grouped according to:

a) Factors generic to the feature type.

b) Factors that are generic to feature type, but also time variable, and therefore more prone to risk of interference.

c) Factors that are generic to feature type, but valued aesthetically.

d) Factors specific to the feature's relative importance in the geothermal and or volcanic setting of the Taupo Volcanic Zone (TVZ).

Another aspect that may need consideration is the benefit of grouping these criteria together. Hence the task of ranking many thousands of individual surface geothermal features across the region can be broken down and simplified into an initial exercise of generic type ranking, and then applying the 4 remaining TVZ related criteria. This latter category includes the four criteria that require an individual feature assessment on relative significance with respect to the TVZ feature set, including *Representativeness (7.1)*, *Diversity and Pattern (7.2), Distinctiveness (7.4), and Naturalness (7.8).*

Other criteria that maybe grouped are 'time based' such as *Resilience* (7.5) to natural change and *Vulnerability* (7.6) to interference (e.g., fluid extraction or disturbance). These criteria are generic to the feature type. The same may also apply to *Aesthetics* where visual appeal ranking can be done on feature type rather than relative to the TVZ. Examples are: *Memorability (7.7),* and *Transient (short-term) Values* (7.9). Although it stands alone, *Rarity* (7.3) is a criterion that should be considered from the generic feature-type point-of-view; as some feature types are simply more common than others.

1.4 Study Objectives

The objective of this study is to develop methodologies that will provide a scientifically robust method of assessing significance using the criteria listed in set 7 of the RPS. This is necessary in order to deal with the full range of geothermal feature types and characteristics, and the full range of relative importance within the TVZ region. This will result in a transparent, repeatable and consistent method to test for the significance of surface geothermal features.

Ideally, the best assessment scheme will be focussed on preferred environmental, economic and social outcomes, without being excessively prescriptive. These high-level objectives will be addressed from both global and local perspectives. The outcome will be to devise a scheme to enable and optimise sustainable energy utilisation from renewable geothermal resources, for the benefit of all, whilst avoiding, minimizing or remedying any local adverse effects, and also facilitating the appreciation, preservation and enjoyment of outstanding surface geothermal features.

2.0 HISTORICAL BACKGROUND TO ASSESSMENT METHODOLOGIES

In 1978 the Nature Conservation Council approached the Geological Society of New Zealand (GSNZ) expressing their concerns about the detrimental effects of geothermal development on hydrothermal features due to the intrinsic scientific values and other interests. The GSNZ formed a subcommittee and charged it to report with recommendations on scientific or other grounds, features that should be preserved. Houghton et al. (1980) reported the subcommittee findings to the GSNZ.

The report as presented in Houghton et al. (1980) was composed of three major parts and a set of recommendations. The first part covered hydrothermal systems: the distribution and types, fluid chemistry, discharge features, hydrothermal deposits, microbiological and botanical aspects and natural influences. The second part examined hydrothermal system use; previous and existing use, effects of artificial influences of exploitation and land use impacts. In the third part a conservation classification scheme was proposed. They devised a three-category classification based on these principles (Table 2.1): at least one area of each hydrothermal system type should be preserved intact and free from all deliberate artificial interference and areas which contain at least one example of each surface discharge phenomena. They highlighted the loss of geyser fields and unique and distinctive characteristics as key markers. Also of concern was the importance of interconnectivity between neighbouring systems.

The RPS adopts aspects of this systems approach as it identifies geothermal systems for protection and systems for development.

Table 2.1: GSNZ classification system of hydrothermal systems.

Category A:	Areas containing New Zealand's unique and outstanding hydrothermal features that must be completely preserved if a representative selection of features is to be retained.
Category B:	Areas with a selection of outstanding thermal feature. Recommended for protection from exploitation until geothermal energy demands exceed energy available from areas in Category C.
Category C:	Areas already irreversibly spoiled by exploitation and/or those with no recognisable unique geological or geophysical features. Of lowest priority for preservation.

Houghton et al.1980 identified 88 hydrothermal systems in New Zealand and drew strongly on New Zealand Geological Survey report 38D (1974). These included systems in the Taupo Volcanic Zone, Tauranga Basin-Hauraki lowlands, Auckland-Northland, Taranaki-Wanganui, North Island axial ranges and the South Island.

Four areas were given Category A status; (Whakarewarewa, Waimangu, Ketetahi and White Island), while a further seven were classed as Category B; (Waiotapu, Orakeikorako, Tikitere, Waikite, Te Kopia, Paukohurea, Tokaanu/Waihi/Hipaua). All the rest were classed as Category C. Note the naming conventions for hydrothermal systems have evolved since 1980.

The report to the GSNZ also expanded on the term 'other interest' listing seven categories. They did not develop any definitions, just a listing which is presented in Table 2.2 for completeness. They did note a bias to 'scientific values', largely geological and geophysical.

Table 2.2: GSNZ listing of items which create 'other interest' for hydrothermal systems.

A	Scenic, recreation, tourism
B	Scientific (Botanical, Geophysical, Geological, Chemical)
C	Historical, cultural (especially Maori)
D	Energy (Electric Power Production, Commercial non-electrical)
E	Therapeutic, medical
F	Mineral
G	Unusual and unique characteristics

The next significant advancement in this area was the publication by the GSNZ of an 'Inventory of New Zealand Geothermal Fields and Features' (Houghton et al. 1989). The inventory lists one hundred and forty-six geothermal fields and features, divided into three categories of geothermal fields and introduces an assessment of vulnerability based on a classification of four categories. This report is an advance on the Nature Conservation Council report (Houghton et al. 1980) as more definitions are developed in relation to surface features.

The report introduces a geothermal feature and defines a geothermal system and geothermal field. Many types of geothermal feature are described and are broadly subdivided into discharging vents and geothermal deposits. Discharging features include hot springs, geysers, fumaroles, steaming ground, perched ponds, mud pools and mud volcanoes. While geothermal deposits include sinter, precipitates of sulphur and other minerals, alteration of rock at the surface and below, collapse crater and hydrothermal eruption breccias. The report also discusses the types of geothermal systems in New Zealand and distinguishes three kinds; large intense systems in the TVZ, smaller diffuse and rare intense systems and isolated springs associated with other young volcanic regions (e.g., Northland, Hauraki Plains) and isolated warm springs associated with tectonic features particularly faulting in the axial ranges. The value and role of geothermal features is discussed along with the various threats to features. A classification system and assessment of vulnerability are also presented in the report. These are reproduced as Tables 2.3 and 2.4.

Table 2.3: Classification of importance of geothermal systems and features after Houghton et al. (1989).

A	International significance
B	National scientific, scenic or educational importance
C	Regional scientific, scenic or educational value

Table 2.4: Assessment of vulnerability of geothermal systems and features after Houghton et al. (1989).

1	A feature or field currently at risk due to exploitation of the geothermal resource or other influences such as ongoing volcanism.
2	A feature or field actively discharging geothermal fluid and hence highly vulnerable to disturbance but not currently under any known threat.
3	A feature or field not discharging fluid and hence less susceptible to disturbance.
4	A feature that maybe enhanced by human activity.

Although the three-tier system is retained, the criteria for judgement are changed from those used by Houghton et al*.* (1980). This results in 5 Category A systems been listed (International importance), 8 Category B (National importance) and 80 category C (Regional importance). Twelve geothermal features are classed as category A (International importance), while 26 features are classed as Category B (National importance) and 15 as Category C with Regional importance. In total, 53 geothermal features are categorised by this scheme. Aspects of this can feed into appraising significance, but most of the approach is aimed at systems, not features.

Application of this frame work to the ninety-four geothermal fields or isolated springs listed saw 12 geothermal fields or isolated springs scored a vulnerability of 1 on a scale of 1 to 4 (Table 2.4). All the remainder scored a vulnerability of 2. Of the 53 geothermal features listed 24 are scored a vulnerability of 1, the remaining 29 are scored 2. Hence all geothermal fields or features listed are considered vulnerable or highly vulnerable to destruction or modification.

Around the same time the Waikato Catchment Board and its successor organisation, Waikato Regional Council commissioned a series of reports that emphasised biological (dominantly botanical) aspects of geothermal fields in the Waikato Region (Given 1989, and 1995). This work initially evaluated the relative significance of thirteen geothermal fields (in the Waikato Region) by scores for various qualities. For each geothermal field two sums were explicitly presented: (1) for biological qualities and (2) for overall qualities. Later work (Given 1996) integrated the results of the earlier ones and included assessments for all geothermal sites known in the Waikato Region. Although a number of qualities such as scientific interest and educational value were included in the assessments, there was no specific consideration given to the relative importance of geothermal features. Hence this work can be considered complementary to that of Houghton et al*.* (1980, 1989 and Given 1996).

The next study of the definition and listing of geothermal features came in a Conference presentation in 2005 (Keam et al. 2005) where aspects of policy being developed by the Waikato Regional Council were presented. An extensive listing of the attributes and definitions of geothermal surface features is developed. Geothermal habitats and recent sinters or other features lost to recent development are also introduced. An assessment of the ‘degree of protection’ a geothermal feature needs is then developed based on aspects of rarity and vulnerability to changes. The changes are both natural and artificially induced.

A broad definition of geothermal features is presented, being a site of discharge (fluid or gas phase) or a land formation from a geothermal process, not necessarily still active. An extensive list of geothermal feature attributes is developed, in places building on those identified in Table 2.2 but is not directly acknowledged. The primary attributes are listed in Table 2.5 below.

Table 2.5: Attributes of geothermal features as defined by Keam et al. (2005).

1	Surface discharge
2	Fluid products
3	Time-dependant behaviour
4	Steady state behaviour
5	Mineral depositions
6	Depositional geomorphological features
7	Non-depositional geomorphological features
8	Altered ground
9	Associated distinctive ecosystems
10	Abstract attributes (cultural, historical, economic, aesthetic, recreational, educational, scientific and intrinsic).

Keam et al. (2005) have identified geothermal features types based on the processes that create or sustain them and the extent. The categories they have used are:

- Steam-dominated features.
- Remnant steam-dominated features.
- Geothermal water-dominated features.
- Remnant water-dominated features.
- Biological-type geothermal features.

They also define ‘significant geothermal habitats’.

They also argue that ‘recently lost’ or inactive geothermal features are included in the total count of features so that the percentage of geothermal feature types that have already been lost are available for consideration when it comes to applying the results of any analysis for protection and preservation. We concur with this approach and suggest that the baseline of pre development features within the Taupo Volcanic Zone is a key principle for applying the RPS criteria, especially those relating to representativeness, and also rarity.

They then develop measures based on rarity, resilience and viability, and the vulnerability to natural variations and change. This leads to a ‘endangerment index’ for each feature type that can be used to set the level of protection or applied as a significance criteria as rarity is a qualitative term they argue for and present the development of a related number scale. They establish a numerical expression for commonness and then one for rarity, based on a logarithmic term for the number of features. Where commonness, c, is defined as:

$c = k \ln n$ (k is the convenient constant), then go on to define rarity as;

$r + c = l$ (where l is a constant, e.g., l=50 and k=4)

These could be used for counts of a feature type or if there are extensive areas of the same feature total areas could be used. Problems were identified in areas of extensive and intensive feature types. This was applied to a subset of features in the Waikato Region, but never formally published or applied to a full data set. A relative ranking of regional rarity is established and presented in Keam et al. (2005). Sixteen feature types are ranked.

Keam et al. (2005) then evaluates the concept of 'resilience and viability' based on methods used on biological systems (e.g., Tisdall and Molloy, 1994). This can be further considered as the changes that occur naturally and those that could be induced by human actions. They rightly conclude that the probability of a parameter changing that may affect a feature cannot be established, hence it is not possible to calculate the vulnerabilities of individual features.

They do establish a qualitative list of the sixteen feature types ranking them according to their assessment of their relative average vulnerabilities to natural influences (Keam et al. 2005). They then apply the same criteria to disturbances caused by human agencies. They use a five value scale for each feature type and further used fluid extraction and surface interference as measures (Keam et al. 2005). This is proposed as a method to define 'SGFs', however the work was never completed to establish catalogues of features etc. nor to test the methodology. Aspects of this do flow through into the interpretation of the RPS definitions and criteria and influence the weightings or rating systems proposed.

Cody (2007) under took a project to establish the '*geodiversity*' of geothermal fields in the TVZ for the Department of Conservation (DOC). Three extensive spreadsheets were developed:

1. Geothermal Field Inventory.
2. Individual Geothermal Feature Inventory.
3. Geothermal Field Rankings.

The Geothermal Field Inventory is an extensive list of geographic attributes (area, elevation etc.) geophysical parameters (heat flow, stored heat, reservoir temperatures etc.); geothermal feature characteristics (number of feature types, flow, chemistry, sinter forms, ages of landforms etc.) and an evaluation of pre-historic characteristics, exploitation history and human impacts.

The Individual Geothermal Feature Inventory is an extensive listing of features with attributes for feature type, size name/number, hydrological, chemical and physical character. The features are also given values for status, quality, representativeness and the presence of sinter and comments.

The final table presented is a ranking of the geothermal fields. This is based on 72 geothermal feature types, 3 classes of sinter deposit, hydrothermal eruption craters, collapse craters and the altitude range. This gives scores that range from 6.65 (Mangakino) to 443.7 (Waiotapu). Also included is a measure of 'naturalness/human modification' based on feature scores multiplied by an intactness score, giving scores that range from 2.0 (Mangakino) to 340.3 (Waiotapu). Higher scores are an indication of the significance.

There are ten descriptors or qualification terms presented in Cody's report. Some have brief descriptions, while others may outline a score or ranking scale of some sort. The ten descriptors are: type and size, main features and groups of features, status and quality, representation, hydrological and gaseous character, bulk chemistry, physical character, sinter deposition, land form types and significance. Also presented is a ranking scheme for individual geothermal features in the TVZ. This is based on a scale that ranges from 0-10, however it is not clear where this is used in the evaluations mentioned above. A ranking for landscape and land use is also presented and used in the Geothermal Field Rankings.

Bromley (2011b) proposed and developed a surface thermal feature ranking scheme, for application to New Zealand geothermal systems. The scheme was numerically based, and would lead to an overall score that could be used by planners as one factor to consider when categorising geothermal systems for development or protection status. This numerical scheme in modified form is discussed in more detail under Method 2 of this report.

In 2012 as part of the process to prepare the RPS, BOPRC commissioned a guideline for mapping and monitoring geothermal features (Scott 2012). Surface geothermal features in New Zealand are hydrothermal in nature, being water or steam dominated; with most groupings having gradational boundaries. The classification developed for the BOPRC (RPS was adopted for this guide (Figure 2.1). The surface features range from those that are in high energy states, erupting (fluid or steam), through over-flowing to non over-flowing pools (lower energy). This frame work is also shown schematically in Figure 2.2 as a simplified cross section of a geothermal environment. The intent of this work was to establish a uniform data collection and classification process so that catalogues of surface geothermal features could be established and be comparable.

The classification was kept very high level and did not go into detail to create sub divisions of feature types. Based on the field data captured this can be achieved if needed. Associated with this mechanism of classifying surface geothermal features three broad categories of habitats are also defined in conjunction with the surface geothermal features. These are:

1. The atmosphere above and around them.
2. The aquatic environments of pools, lakes, marshes and streams, into which they flow or seep.
3. Areas affected by heated or hydrothermally altered ground.

Surface geothermal feature types and habitats			
Geyser		**Mud Geysers**	**Fumarole**
Primary Flowing Springs	**Mixed Flowing Springs**	**Mud pots**	**Steaming Ground**
Primary Non flowing pools	**Mixed Non flowing pools**	**Mud Pool**	**Heated Ground**
Primary geothermal fluid ←-------→	*Mixed/diluted geothermal fluid*	*Mixed diluted fluid and/or steam heated* ←--------→	*Steam Fed*

Figure 2.1: A schematic representation of surface geothermal features (after Scott 2012). Note the inclusion also of three broad categories of habitat (atmosphere, aquatic and heated ground).

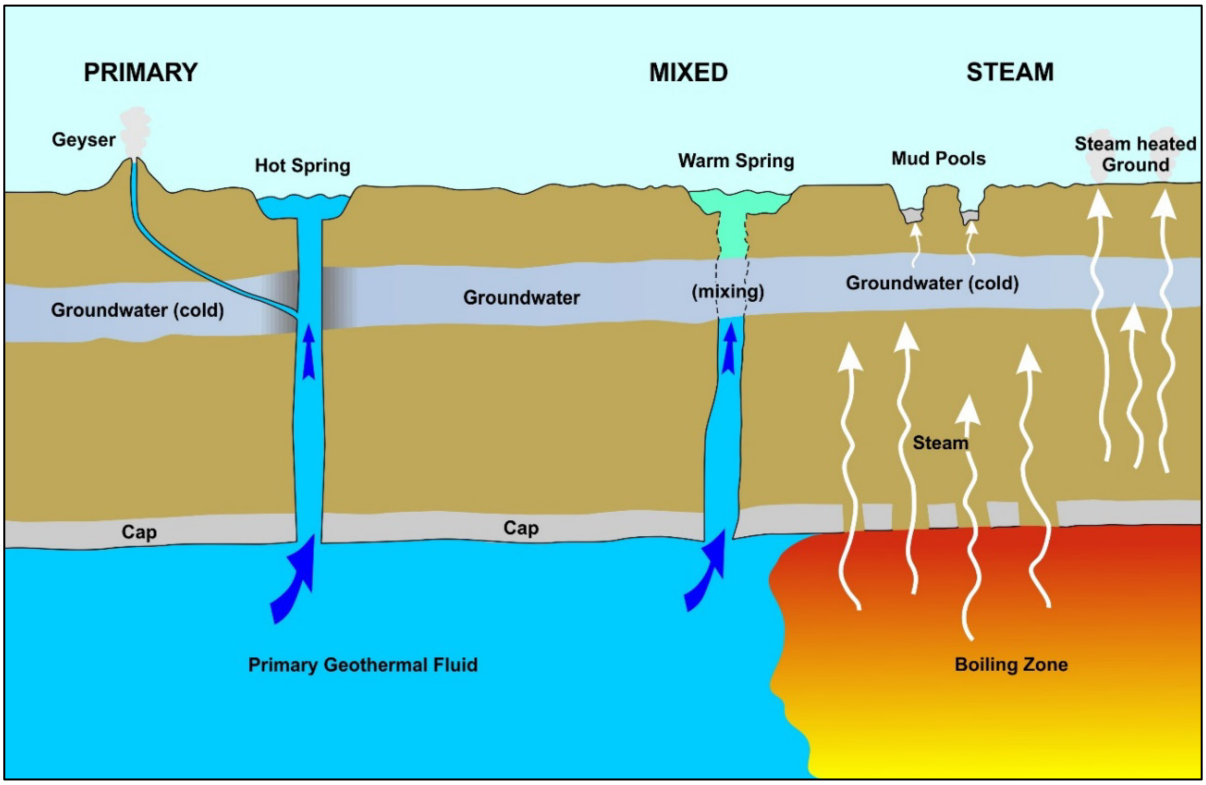

Figure 2.2: Schematic showing the relationship between the various types of geothermal surface features and process's that support them.

Significant work has also been done in the area of 'ecological significance' of geothermal areas (e.g., Given, 1995,1996). However, many aspects of that work are not directly applicable as the philosophy used is different. Also, while outside the scope of this brief, significance assessments using criteria in the RPS for landscape and biodiversity have been applied extensively in the Region. The ecological assessments look at ecological districts as an integrated system, whereas SGFs are treated as individual features rather than a full environment of multiple surface features. Never-the-less, there may be aspects of the ecological ranking and or testing tools, which have been used for some time, that could be applicable to geothermal surface feature assessments. This has not been explored further in this report. However, some principles from this work that we can apply include:

- Using a spatial framework for assessments. Whether this is landform unit, ecological district or in the case of geothermal sites the Taupō volcanic zone.
- Identifying a framework to determine representativeness and rarity. In ecological assessments this includes a historical benchmark and land environments, in geothermal assessments it could be the extent of features prior to development (where this can be reasonably assessed).
- The use of a simple rating system against each criteria.
- The use of weightings.
- The reliance on suitably qualified and expert judgement in applying criteria.
- The possible use of broad ranking systems (e.g., local significance to international).

3.0 BACKGROUND TO ASSESSMENT METHODOLOGIES

3.1 UNDERSTANDING AND MANAGING SGFS

For a RPS and companion Regional Plan to guide effectively to the management of the geothermal resource it is essential to understand the context of surface geothermal features within the TVZ and elsewhere in New Zealand. Why these features exist, what could happen to them, what presents the greatest or least vulnerability to them and what management plans and processes are already operating to manage the issues.

The TVZ is a geologically young, zone of volcano-tectonic activity primarily located in the Waikato and Bay of Plenty Regions in New Zealand (Wilson and Rowland, 2016), with other activity in the Auckland and Northland areas. Numerous, isolated low-temperature hot springs occur throughout New Zealand (New Zealand Geological Survey, 1974). The central portion of the TVZ is dominated by 'caldera' volcanism (Houghton et al. 1995, Wilson et al. 2009), characterised by rare but very large eruptions driven by large shallow magma systems. It is these large residual magma systems that provide much of the heat to drive the TVZ geothermal systems (Bibby et al. 1995, 1998, 2008, Bertrand et al. 2012). Hence there is a close relationship between the volcanism, tectonic faulting and the presence of geothermal systems. Geothermal fluids are also present in some older areas of volcanism (e.g., Hauraki, Kaimai-Coromandel) and as hot springs along some of the larger tectonic structures through the axial ranges. Their surface expressions are not uniformly distributed nor necessarily related to the subsurface size or extent of underlying geothermal reservoirs.

Across New Zealand, the environments that support and sustain geothermal surface features are somewhat limited. They are also integrated systems, needing a heat source, circulating water, favourable geology and fracturing. A number of natural surface geothermal features in the TVZ suffered substantial modification as the result of historical human activities. For example, hydro-electric development at Ohakuri drowned geysers and hot springs at Orakeikorako (Lloyd, 1972) and early liquid pressure decline at Wairakei and Ohaaki led to loss of geysers and springs (Glover and Hunt 1996, Hunt and Glover 1996, Glover et al. 2000). The nearby Spa Thermal area in Taupo was affected by artificial changes to the bed of the Waikato River. Similar events adversely affecting thermal activity have occurred at Kawerau. Conversely, however, areas of steaming ground and fumaroles (e.g., Craters of the Moon, Upper Waiora Valley, Broadlands Road Reserve, and Ohaaki West Bank) have increased in extent and heat output as underlying steams zones expanded due boiling. Also, changes in temperature and discharge rate of pools and springs (both increases and decreases over a 10 year period) have occurred at both Mokai and Rotokawa geothermal fields, in response to the shallow reinjection strategy.

The consequences of these activities are that the total number, and area, of geothermal features are less than a few decades ago. This complicates the process of evaluating for degrees of rarity and representativeness as significance criteria. Knowledge of the historical changes is important to take into account.

We would recommend that the historic state is considered as part of any evaluation of significance. In this regard, assessors should use any recorded and reliable historical documentation of surface feature activity. The age and quality of this is variable, hence no one date can be recommended. As a guide we would look to around the early 1900s.

3.2 POTENTIAL METHODOLOGIES FOR SIGNIFICANCE ASSESSMENT

Three potential methods or approaches are advanced in this report:

1. Adopting lessons and methods from the management of risk and hazards. Two are examined.
2. Adapting the Bromley and Keam ranking systems to Set 7 criteria.
3. Amalgamating the methods by first ranking feature type, then individual features relative to all features in the TVZ, then reassessing vulnerability criteria once a proposed activity is identified.

3.3 DISCUSSION OF SET 7 PARAMETERS

Before the 4 possible approaches or methods can be developed we need to discuss how the criteria developed in Set 7 (Appendix 1) apply. Clauses 7.1 through 7.9 are used and influence how significance is defined. In this work, the significance criteria are divided into two categories; firstly, natural science factors and secondly aesthetic values.

The natural science factors cover how representative or distinctive a feature may be, along with its diversity or rareness. Also included are the resilience or vulnerability of the feature to change. These are related to how a feature is recorded and catalogued (Scott 2012) and the physical processes that control the level of activity.

The aesthetic values are related to the perception and/or appreciation of the values or principles the community would associate with a surface feature, via how memorable or natural the feature appears. It also considers the natural transient characteristics of some surface geothermal features.

3.3.1 Natural Science Values

3.3.1.1 Clause 7.1 Representativeness

The RPS (BOPRC, 2014) defines this criterion as: "*The extent to which the natural feature is a good example of a geothermal feature type or group of features in close association, and/or the processes that formed it/them, in the Taupō Volcanic Zone*."

Cody (2007) also used *representativeness* relative to the TVZ as one of the assessment criteria for a 'geo-diversity' significance ranking exercise.

"Good example" is clearly a term that requires site-specific assessment. There can be some overlap between this criterion and that of *distinctiveness* (see below) which addresses relative size in terms of flow rate and temperature.

In this test, an assessor is looking at how well an individual feature represents its 'feature type' within the whole of the TVZ. Is this exemplifying of the feature type. If you had to bring a visitor to see an example of the type, would this one be the one you would visit. The complicating factor in this clause is '*a good example of a geothermal feature type or group of features in close association',* as it talks about a single feature type and a group. It is assumed the group is of the same type, however this is rare in nature. Often a group of features in close proximity will include a variety of feature types (e.g., Kuirau Park, Rotorua). Also of consideration is the physical process that controls the feature type. These can be complex interactions and create some uncertainty in an assessment.

Also of concern is the number of features have been lost due to exploitation or other development activities. The assessment would also include how a feature represents those lost. Accordingly, if a feature is representative of a feature type that is now rare it may gain a higher scoring, being thought of as noteable or even exceptional.

3.3.1.2 Clause 7.2 Diversity and Pattern

The RPS (BOPRC, 2014) defines this criterion as: **"***The extent to which a group of associated features contain a wide variety of geothermal features, reflecting the diversity of geothermal feature types in the Taupō Volcanic Zone or present a distinctive and unusual juxtaposition of features (e.g., along a physical, chemical or hydrological gradient)*."

This criterion was included to provide for higher ranking of groups or clusters of thermal features that are more diverse in both type and intensity, thereby providing a visually and scientifically interesting collection of features at one location. The 'unusual juxtaposition' term captures locations, where for example, features in close proximity show a large variation in physical, chemical or hydrological characteristics, because of natural influences, such as elevation change, groundwater mixing, fault control or rainfall recharge.

Examples of this maybe the likes of Waimangu, where the features are related to structures formed by a volcanic eruption, or Orakeikorako where regional faults control the location of many features. Kuirau Park, Rotorua is a case where features discharging primary fluids, mixed fluids and steam heated features are found in very close proximity. At Tikitere there is a dominance of only steam heated features lacking diversity but are a distinctive collection of similar features.

This is a difficult criterion to address, as geothermal surface features are often clustered, forming a continuum of associated and diverse individuals. The usual assessment approach focuses on individual features, whereas this criterion has a bias for the 'collective' value of associated features to be assessed, ignoring aspects of feature type. There is no guidance to spatial cover, number of features or scale. An assessor will be looking at a feature and making an assessment of that feature with respect to is neighbouring features.

3.3.1.3 Clause 7.3 Rarity

The RPS (BOPRC, 2014) defines this criterion as: **"***The extent to which the feature is unique or rare in the context of the Taupō Volcanic Zone".*

Rarity is a relative parameter which is assessed at the feature type level with respect to the entire geological region of the TVZ. It should be noted that a rarity assessment on the basis of some feature types is difficult to achieve objectively using simple number counts of the individual thermal features. Classification of features requires artificial feature boundaries to be introduced hence numbers depend on the grouping criterion that is applied when undertaking any feature classification.

Therefore, for many feature types, relative rarity is best assessed while considering the physical parameters required in a thermal area for the feature to exist (rate of steam flow, ground water levels, permeability, heat flow) rather than feature counts. Some feature types require very special cases to exist, for example geysers or mud pots. These have been susceptible to past activities hence the number present to day and the number present in the past need to be considered. Some are rare due to natural physical constraints while others are surviving examples.

In these cases, therefore, a reliance on the assessor's knowledge, experience and overall judgement is required.

3.3.1.4 Clause 7.4 Distinctiveness

The RPS (BOPRC, 2014) defines this criterion as: "*The extent to which a feature in a geothermal area is one of the largest remaining examples of its type in the Taupō Volcanic Zone, while exhibiting high thermal output*."

This definition allows for a quantitative estimate of the relative size and discharge flow rate of the feature to be taken into account. A larger flow and hotter temperature leads to a higher ranking. Hence features such as seeps or warm springs will, by default, be classed as less distinctive. There is also mention 'remaining examples' so knowledge of past features is also important.

This classification introduces feature size, with a bias towards larger and hotter examples, and also a bias towards those feature types (e.g., large geysers) that have few examples, either because they are natural rare or because few have been left intact. Essentially it only deals with heat and size and the largest and hottest of a particular type. So a large hot spring scores higher than a small hot spring and a large geyser scores higher than a small one. Hence the weighting of this factor should be down played

As ranking is usually undertaken of existing features, there may be some difficulty in applying a score if similar former features are not fully known. Hence, the assessor's knowledge, experience and overall judgement is critical in this assessment.

3.3.1.5 Clause 7.5 Resilience

The RPS (BOPRC, 2014) defines this criterion as: "*The extent to which the feature is resilient to natural changes".*

Natural *resilience* refers to the stability of a thermal feature type under varying atmospheric and seasonal weather conditions, such as rainfall, atmospheric pressure and ambient temperature changes. Keam et al. (2005) note that resilience is a measure of the feature's ability to withstand storms and other factors such as climate change, while viability is a measure of its ability to continue for ever, given the likely future range of climate conditions.

As a significance criterion, resilience has been argued as an important parameter for discriminating geothermal feature types with diverse physical characteristics (e.g., Bromley, 2004-2011). Some features are highly variable, ephemeral or transitory in their natural state (such as weak steam vents or mud-pools), while others are typically more stable because of their deep origin (such as alkaline-chloride springs) with high heat and fluid flows. Mixed and steam-heated groundwater springs have discharges that are typically susceptible to variations in long-term rainfall. Consequently, for these transient feature types the range of expected natural behaviour is much wider.

The phenomenon of natural variability and the inherent resilience of each feature type also needs assessment in the context of the physical environment (lake and river water levels, rainfall, climate change, etc.). Features that are able survive climatic variability are likely to score higher than those that may not.

Many geothermal systems today have experienced some form of exploitation or adaptation. Any assessment has to take into account whether or not the geothermal system is currently being utilised or has been affected by human works, for example the creation of Lake Ohakuri at Orakikorako. Significance ranking may need to take consideration of the phenomenon of variability in a different way than in a natural situation.

3.3.1.6 Clause 7.6 Vulnerability

The RPS (BOPRC, 2014) defines this criterion as: "*The extent to which the feature is vulnerable to fluid extraction".*

Extraction and injection of fluid associated with a geothermal system will inevitably cause some local pressure changes in the reservoir, even if all the extracted fluid is re-injected (as is typical of binary power plant installations). Those pressure changes will, in turn, generate additional inflows or outflows of fluid from surrounding recharge aquifers (whether adjacent, above or below the production or injection reservoir). In some cases, these pressure changes may have no discernible effect (within natural variations) on surface thermal features, but, in other cases, they could have some influence on the quantity of heat, fluid, steam and gas rising to the surface. These induced changes could cause an *increase* in surface discharge (from production-induced boiling of an underlying liquid zone, or a local pressure rise associated with injection). Alternatively, they could cause a *decrease* in surface fluid discharge (from production-induced pressure decline in a shallow steam zone or from saturation of shallow steam by liquid injection). Such effects (increases and decreases) have been observed in thermal areas in developed geothermal systems in the TVZ. Overall, the magnitude of the possible induced effects (increases and/or decreases) should be considered in the context of the background natural variability of the discharges.

Geysers and features discharging primary fluids are the most vulnerable to fluid extraction or pressure drop.

Keam et al. (2005) also addressed *vulnerability* to induced changes as a ranking criterion, with examples from the Waikato Region, but only considered the potential impacts of fluid extraction (liquid pressure decline) and the effects of ground surface interference.

However, a *vulnerability* assessment, as a criterion for feature type ranking, should also take into account whether the expected adverse effect is caused by a decline in liquid pressure and/or a decline in steam pressure. Therefore, in this proposed assessment method, the two potential adverse effects are separated into sub-criteria. The converse effects from rising pressures could be treated in a similar way, if necessary. A balanced assessment of benefits versus adverse effects may need to be undertaken for specific cases (Bromley, 2005a). The assessment also takes into account the knowledge that induced changes for many feature types are not necessarily permanent. Where appropriate, induced changes can often be reversed by adjustments to injection and production strategy. Examples of this have occurred at several geothermal systems in the TVZ, including Rotorua (Scott et al. 2016), Mokai and Rotokawa (Bromley, 2005a).

Other aspects of vulnerability include the sensitivity of feature types to nearby ground disturbance (land-use change) and changes in adjacent groundwater. Discharge characteristics may be affected by induced groundwater level changes. In general, the type of mixed spring that contains a large component of groundwater is more vulnerable to induced changes caused by nearby activities (e.g., pumping) that reduce the groundwater level. Features that rely on a supply of boiling groundwater or interactions between shallow and deep aquifers of different temperature (e.g., geysers), are also more vulnerable to nearby hydrological interference (e.g., pumping or shallow injection).

The assessment of vulnerability is therefore based on the assessor's knowledge and experience of the physical and geophysical model of the geothermal system and the expected impacts of certain types of exploitation and proposed mitigations. Overall judgement will include a detailed understanding of the type of exploitation, the mitigations and the current knowledge of the system under judgement and is critical in this assessment.

3.3.2 Aesthetic Values

Aesthetic values of valued thermal features may be adversely affected by insensitive land use or by changes to the natural setting, as well as changes to discharge characteristics.

3.3.2.1 Clause 7.7 Memorability

The RPS (BOPRC, 2014) defines this criterion as: "*The extent to which the geothermal feature(s) is striking or visually spectacular due to its recognisable and memorable qualities*."

Visual appeal is a subjective opinion, and by definition relates to the 'quality or state of being easy to remember or worth remembering'. Typically, it is hard to measure and this is usually defined by user research methods and analytics of user experiences. Visitor numbers can be a guide, along with publicity and general familiarity with feature names and types, such as 'geyser' and 'fumarole', however this can be biased by the feature being in a popular and well publicised area.

One approach could be by limiting this criterion to a 'type' assessment, then personal differences can be minimised. The assessors view takes into account a majority opinion regarding the impressive and memorable nature of typical examples of each type. However, that can be restrictive.

Parameters like size, noise, energy state, colour and odour, access, coupled with visitor experience (fine weather, excitable guide, etc.) all contribute to memorability. Therefore, larger, more energetic, well publicised and easily accessed features will score higher by default. Hence this is not a strong measure of significance.

Surface features that are common, easily seen through to typical of a type will not score very high, in the range 1-3 whereas quality examples would score a 4 or 5.

3.3.2.2 Clause 7.8 Naturalness

The RPS (BOPRC, 2014) defines this criterion as: "*The extent to which the geothermal feature(s) appears largely uncompromised and is an intact natural system, free from human modification, intervention or manipulation*."

This is a "site-specific" criterion rather than a "type" criterion. But there are degrees of modification (relative to all examples within the TVZ) that can be included in an assessment. Only a geothermal system with a range of features in a wilderness could score high in this criteria. Even a well-defined access trail could be considered a human modification, intervention or manipulation. Naturalness is typically defined as been formed by nature (as opposed to artificial), and is often measured by the lack of cultivation, planting, amount of human modification or having undergone little or no processing. The criteria of this clause appears binary; intact or not, however a scaled approach is more appropriate; Completely natural, very/moderately/slightly/not natural.

Other methods have also been suggested to evaluate naturalness. The assessment may have to consider the response of a visitor; which is a combination of the physical stimuli from the feature and the subjective interpretation by the human observer (Overvliet et al. 2008). In another study, Theobald (2010) developed a composite score of naturalness based on the proportion of area that can be considered "natural" as opposed to "human dominated". This can be applied to aerial photography where say 30 m^2 areas are scored (0 for natural, 1 for disturbed) and an integrated score derived over the surveyed area. A resultant score of say 0.6 would mean only 30% is still natural. These do not work well as measures for this assessment.

Key factors that would be considered when assessing naturalness would be

- The features association with its surroundings, connected natural features and geothermal vegetation.
- Whether the hydrology/chemistry is largely in a natural state (i.e., natural flows and levels or is it affected by inflows from a road etc.).
- Whether the form of the feature, including the size, depth, edge, sinter etc. has been modified or damaged (e.g., through earthworks, channelling).
- Structures on, over or under the feature that disturb, damage or change a feature and detract from its naturalness (e.g., culverts, bridges, walls).
- Any vandalization of the area.

Features within the locations like National Parks, native forest and scenic reserves are likely to rate higher as they will be of a higher quality and be more distinctive examples. Whereas features at Kuirau Park for example have been modified with culverts, drains, fences etc. Another example is Rachel Spring, Rotorua: surrounded by a concrete wall. A good example of a hot pool with primary geothermal fluid present, but siting in a very unnatural environment. Features at Waiotapu and Waimangu however are largely unchanged. In contrast, a geyser like Lady Knox is induced to erupt, although it is located in a scenic reserve where the environment is relatively preserved and natural.

This is an important measure and a sliding scale can work from impacted and poor locations to good examples, lightly impacted by the local environmental development to exceptional features in remote and undisturbed locations. As this exercise is about significance we would support adding weight to any scoring for this attribute.

3.3.2.3 Clause 7.9 Transient Values

The RPS (BOPRC, 2014) defines this criterion as: "*The extent to which transitory natural changes in the appearance of the geothermal feature contribute to its natural science values or aesthetic appeal.*"

Geothermal surface features are often dynamic; varying in water level, flowing, bubbling or even exploding as a geyser or mud pot. This criterion is an attempt to capture the aesthetically appealing nature of the time-varying characteristics of some feature types. Outstanding examples would be geysers, spouting springs and mud volcanoes. This criterion is essentially a measure of the capacity of the feature to elicit pleasure for an observer, to evoke a sense of appreciation.

To measure this, aspects of visual appeal, ability to stimulate and hold the viewer's attention (so they note the transitory variation), and aesthetic appeal are judged. In many ways it's a ratio of the overall pleasure over how easily it provides that. If an observer is attracted and notices the changes quickly, the ratio will tend to 1. If the changes are complex and not noted, it will be lower. How effective is the feature at giving a visual and enjoyable experience?

4.0 ADOPTING LESSONS AND METHODS FROM THE MANAGEMENT OF RISKS AND HAZARDS

4.1 METHOD 1: FEATURE EXPOSURE

Considerable work has been done on the determination of risk associated with hazards and the process of managing risk in Emergency Management (MCDEM, 2015). In this section some of the principles and tools used in risk management have been assessed and explored with respect to the definition and assessment of significance for geothermal features. The goal is to see if these principles could be applied to the process of robustly defining and undertaking SGF assessments. This work has drawn on CDEM Group Planning guide (MCDEM, 2015), Saunders and Beban (2011, 2012), Saunders et al. (2015), Saunders and Kilvington (2016), BOP Regional Plan and RPS for Natural Hazards and the Tonkin and Taylor review of the risk based approach to Natural Hazards (Tonkin and Taylor, 2016) and AS/NZS ISO 31000:2009 (Risk management-Principles and guidelines).

In this section, the principle of ranking surface geothermal features for significance by exposure or risk to loss and change is examined.

4.1.1 Establishing the Risk Context to SGFs

Emergency Management have used matrix based analysis techniques like SMUG (Seriousness, Manageability, Urgency and Growth) to carry out an analysis of the relative threats and or exposure of differing hazards. This has led to the development of a Directors Guideline on the process (MCDEM, 2015) and a support template (Excel based for the calculations). Here we examine adopting and following some aspects of the principles used in Emergency Management as a possible guideline for evaluating the significance of surface geothermal features in terms of risk to them.

4.1.2 Feature Exposure

Identification and risk descriptions would be used in the analysis of the exposure the geothermal feature(s) have to any proposed activity. This analysis involves considering the likelihood and consequences of the exposure to each type of geothermal feature to the proposed activity (energy exploitation, groundwater extraction, land use change etc.). Use Table 4.1 below to measure the likelihood of a feature been impacted, enhanced or changed.

Here we look at the likelihood and consequence of fluid withdrawal, pressure changes etc. due to the introduction or change in management of the geothermal system. This could equally be applied to land use changes.

Table 4.1: Measure of likelihood.

Level	Descriptor	Detail
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur at some time
D	Unlikely	Could occur at some time
E	Rare	May occur only in exceptional circumstances

Use Table 4.2 below to measure the consequences of change to the geothermal surface features (liquid dominated or steam-dominated).

Table 4.2: Measure of consequences.

Level	Descriptor	Detail
1	Insignificant	No change is likely to feature
2	Minor	Minor changes of water level or steam flow
3	Moderate	Moderate loss of flow and/or lowering of water level, change in steam flow
4	Major	Extensive loss of flow and/or lowering of water level or steam flow.
5	Catastrophic	Feature will fail and may not be recoverable or change significantly to another type

Once the likelihood and consequences of the exposure of a surface feature to the proposed activity have been determined, use Table 4.3 below to assign each geothermal feature with a '*risk rating'*.

This process then provides an assessment of the exposure of a feature type (or individual feature) to the proposed activity. Once the likelihood and consequences of an impact have been determined a '*susceptibility to loss or change rating*' can be derived (Table 4.3). This now gives an indication of the relative susceptibility of the feature(s) to the proposed activity across 5 steps (low through extreme). The list can be sorted so the most or least susceptible features can be identified or the numbers of features impacted can be calculated etc. This assumes that all geothermal surface features that could be affected by the proposed activity have been identified.

This can be applied at the feature type or individual feature level.

Table 4.3: Susceptibility to loss or change ratings.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
A	High	High	Very High	Extreme	Extreme
B	Moderate	High	High	Very High	Extreme
C	Moderate	Moderate	Moderate	High	Very High
D	Low	Moderate	Moderate	High	Very High
E	Low	Low	Moderate	Moderate	High

Examination of this method has highlighted that it doesn't work to establish a significance ranking system. However, aspects of the technique may become useable as a triggering tool to assess proposals. Once each feature type or individual feature has been rated for susceptibility of loss, this can be used to see if the next stage of the assessment needs to be under taken. This method could be used as a triggering test to see if a significant feature or features are at risk from a proposed activity.

The Regional Council may need to consider which geothermal features need to be evaluated; for example, whether to only consider features with risk ratings of high, very high, or extreme or evaluate all geothermal features in a catalogue, etc.

4.2 METHOD 2: FEATURE EVALUATION

4.2.1 Detailed Evaluation of Natural Science and Aesthetic Values

Regional councils can analyse or rank each of their identified geothermal features or feature types using the terms defined in the RPS for Natural Science Factors (BOPRC, 2014) (Appendix 1) these being representativeness, diversity and pattern, rarity, distinctiveness, resilience and vulnerability.

In this section a rating (number from 1-5) is assigned for each of the six categories used to define the Natural Science Factors via the use of a descriptor. A series of descriptors are used ranging from inferior, through common-typical to high quality and exceptional. These are linked to the discussion of the RPS factors in section 3. A suitably qualified assessor would be guided by the RPS definitions in applying a rating. These are outlined in Table 4.4 using measures that take into consideration the definitions developed and discussed above (Section 3.3).

Table 4.4: Natural Science Factors.

Level	Descriptor	Detail Description
1	Inferior	Common feature, poor example with few attributes of type
2	Common	An imperfect example, showing some attributes of type
3	Typical	Good example, typical of type
4	High Quality	A distinctive and quality example of type
5	Exceptional	Exceptional TVZ example showing supremacy of type

A rating uses five levels and a numerical value is assigned. In summary, a feature that is very common with few attributes, maybe small or is a poor example would be rated low or classed as inferior. Features showing imperfection, with some type attributes through to those that are good typical examples would be classed as common and typical. While those with distinctive qualities would be elevated to high quality. A few examples with unique TVZ wide attributes would gain exceptional status.

Based on the numerical values assigned (Table 4.6) a sub-total is obtained. The minimum possible value is 2 (inferior), and the maximum possible value is 10 (exceptional).

The Natural Science Factors sub-total represents half the total maximum possible value of 20.

There are six parameters under consideration; ideally, they would all have equal weighting. We have given slightly higher weighting to rarity and vulnerability (20%) as these criteria are arguably more important contributors to overall significance than the other criteria. All other parameters are weighted at 15%. The definitions and criteria are discussed in detail in Section 3.3.

The sample SGF ratings in Table 4.6 use the following weightings for Natural Science factors:

- Representativeness – worth 15% of the features total score.
- Diversity and pattern – worth 15% of the feature’s total score.

- Rarity – worth 20% of the feature's total score.
- Distinctiveness – worth 15 % of the feature's total score.
- Resilience – worth 15 % of the feature's total score.
- Vulnerability – worth 20 % of the feature's total score.

Users of this proposed ranking system can further analyse the attributes related to each of their identified geothermal features or feature types using the terms defined in the RPS (BOPRC, 2014) for Aesthetic Values (Memorability, Naturalness and Transient values).

A series of five descriptors are used ranging from insignificant, through low notability-common to notable and exceptional. A suitably qualified assessor would be guided by the RPS definitions in applying a rating. These are outlined in Table 4.5 using measures that take into consideration the definitions developed above (Section 3.3).

A feature that has few attributes would be rated low and classed as insignificant. Features showing only some type attributes through to those that possess many would be classed as low notability to typical. While those with distinctive attributes would be elevated to notable. A few examples containing unique attributes in terms of the TVZ would gain exceptional status.

A rating (number from 1-5) is assigned for each of the three categories used to define the Aesthetic values. These are defined in Table 4.5 using measures and definitions outlined above (Section 3.3).

Table 4.5: Aesthetic Values.

Level	Descriptor	Detail Description
1	Insignificant	Few attributes of feature type
2	Low notability	Poor example of this feature type, displays some feature attributes
3	Typical	Typical example of this feature, possesses most attributes.
4	Notable	Possesses many attributes of the feature type
5	Exceptional	Exceptional example, reflects all attributes of TVZ feature type

Based on the numerical values assigned (Table 4.6) a sub-total is obtained. The minimum possible value is 2 (insignificant), and the maximum possible value is 10 (exceptional).

The Asthetic Factors sub-total represents half the total maximum possible value of 20.

There are three parameters under consideration; ideally, they would all have equal weighting. We have given slightly higher weighting to naturalness (50%) as this criterion is arguably more important contributors to overall significance than the other criteria. Naturalness relates more to the physical state of the features, while the other factors are more related to a visitors response. All other parameters are weighted at 25%. The definitions and criteria are discussed in detail in Section 3.3.

The Aesthetic Values sub-total represents half the total maximum possible value of 20. The SGF template uses the following weightings for Aesthetic Values:

- Memorability – worth 25% of the Aesthetic Values subtotal.
- Naturalness – worth 50% of the Aesthetic Values subtotal.
- Transient values – worth 25% of the Aesthetic Values subtotal.

4.2.2 Assignment of Significance

This process gives a score out of 20 for the geothermal feature or feature type Table 4.6. Note the weightings suggested above have been used in this worked example. To assign significance the scores need to be sorted and then boundaries inserted to delineate the degrees of significance.

Scores in the top 20% could be given the highest ranking, while the central 60 % the moderate and the bottom 20% the lower ranking. Other barriers could also be set to give other classifications or grades of significance if desired. In the above three degrees of significance would be assigned; Highly, Moderately and Low.

Table 4.6: Sample of the rankings derived by applying Method 2.

Significant Geothermal Features	**Feature Evaluation**												
	Natural Science Factors							**Aesthetic Values**				**Total**
	Representativeness	**Diversity and Pattern**	**Rarity**	**Distinctiveness**	**Resilience**	**Vulnerability**	***Sub-total***	**Memorability**	**Naturalness**	**Transient Value**	***Sub-total***	
Geothermal System A												
Geyser #1	5	5	5	5	5	5	10	5	5	5	10	20.0
Flowing spring #1	1	1	1	1	1	1	2	1	1	1	2	4.0
Intermittent Spring #1	1	2	2	1		1	2.4	2	3	3	5.5	7.9
Hot Pool #1	1	2	2	3		3	3.8	4	4	5	8.5	12.3
Mixed flowing #1	5	5	4	2		2	6	1	4	3	6	12.0
Mixed non flowing #1							0				0	0.0
Mud Geyser #1							0				0	0.0
Mud Pot #1							0				0	0.0
Mud Pool #1							0				0	0.0
Other							0				0	0.0

4.2.3 Discussion

The process outlined above has used three steps to quantify the attributes of geothermal surface features. In the first step the features are identified by type or individually (catalogued), then analysed by this method apply a rating value, and evaluated by sorting. Aspects of these are discussed below.

Identification is about finding, recognising and describing the attributes and physical parameters that define the geothermal feature(s). It can involve current research, historical data and community knowledge, theoretical analysis, informed and expert opinions, findings from previous / historical events, and stakeholder needs and concerns. Data and opinion may vary in quality and fitness for purpose. It is therefore important that data is analysed and presented in ways that the underlying assumptions or qualifiers are robust. Credibility of this data is essential in order for the judgements and decisions that follow to be justified. Source information can include feature mapping, monitoring, quantitative modelling, and expert opinion. Information may be held outside of Regional Councils (e.g., CRI's industry and IWI) so collation of all available information on attributes and physical parameters across agencies is essential.

Analysis is about developing an understanding of the feature or type, the cause of its attributes, what influences they have, and how it may change over time. It is at this stage where the components of likelihood and consequence of external influences are examined, and different scenarios can be utilised. Interdependencies of exposure and risks, and how these may become cumulative and cascading, can also be considered.

The components of analysis may include or consider elements of any proposed activity (exploitation, land-use, etc.), extent, magnitude, frequency, duration, intensity and the characteristics of the features at risk and the natural environment. The exposure: where are features (elevation, etc.), how many are there, what is the potential for loss? The vulnerability to the feature(s) will depend on the scale of the proposed activity (e.g., shallow drilling verses deep drilling) as well as the hydrological interconnections between aquifers.

Evaluation is the crucial aspect in that the significance is established and feeds into what risks (exposures) need to be further managed, and the priorities for doing so. The evaluation provides the opportunity for Regional Councils to strategically consider which risks are already managed or partially managed, and where the responsibility lies. Therefore, providing a justification to classify geothermal systems in planning and regulatory documents. The evaluation can indicate how these risks are regarded by communities in the context of the goals and aspirations that have developed in a Plan and within other core planning processes.

The terms acceptability, tolerability and ALARP (As Low As Reasonably Practicable) are often applied in Emergency Management and Planning, recognising that many risks cannot be entirely avoided, or managed to minimal levels, without foregoing many benefits or imposing undue costs. The ranking and assessment procedure outlined above is based on lessons and procedures from the Emergency Management and Planning sector to evaluate the risk or exposure to natural and technological hazards. As these are well developed and understood, they can give guidance to an improved understanding of how these risks are managed by Plans and regarded by affected or interested parties.

5.0 ASPECTS OF BROMLEY AND KEAM RANKING SCHEMES ADAPTED TO SET 7 CRITERIA – METHOD 3

5.1 FEATURE TYPES

The first step towards developing a robust ranking method is to construct a catalogue of surface geothermal features, that will include feature types and other attributes (Scott 2012, BOPRC 2014). These will be useful for the purpose of assessing degrees of significance, particularly where generic characteristics of various types lead to different degrees of *rarity*, *resilience* and *vulnerability* to either reservoir fluid extraction or adjacent land use changes.

For the purposes of developing this method a list of feature types is given in Tables 5.1a and 5.1b, which is subdivided into: a) 'active thermal features', and b) 'remnant landforms'. In the RPS, a more complete description of geothermal feature types and examples, also landforms and habitats, is provided in Appendix A, Annex A, Table 16, (BOPRC, 2014, p.214). This is also in variance with feature type classifications developed by Scott (2012) for mapping and classifying surface features.

The subdivision in Tables 5.1a and 5.1b will assist with differentiating between management responses required to deal with possible vulnerability to: 'reservoir pressure and temperature changes' or 'land-use changes', respectively. The application of management policies that focus on resource issues related to reservoir fluid management can then be treated separately from those that deal with land-use control and physical feature protection. A similar approach could be used to categorize and rank a range of natural biological habitats that are often associated with the different types of thermal features. However, such ecosystem evaluation and ranking was not requested as part of the scope of this report.

5.2 ACTIVE THERMAL FEATURE TYPES

In Table 5.1a, the features are grouped according to type and subtype, followed by examples and a simple description. This tree structure lends itself to further subdivision, if desired, to accommodate other subsidiary feature types or features of mixed origin. Some subdivision ranking within feature types is also possible. The key point is that by identifying the source or origins of the various mixtures of fluids, gases or minerals that are discharged at the surface, then vulnerability to future changes in reservoir conditions or natural climate changes can be identified more readily. Also the rarity of the feature type can be used in the ranking process.

5.3 LANDFORM FEATURE TYPES

Relict or remnant geothermal landform features are grouped, listed and described in Table 5.1b. As examples of the landform category, features like 'sinter deposits' and 'hydrothermal eruption craters' are geological features, remnants of past geothermal activity. Because they are not currently associated with actively discharging thermal vents, they are not normally considered for significance ranking in terms of geothermal fluid management. Such features may, however, be considered for significance with respect to land use activities and through application of 'terrestrial features criteria' for significance ranking. If, in the future, the relict features become re-activated or restored, they would then be re-categorised as actively discharging thermal features and different significance criteria and management rules may then apply. Some flexibility in categorising such features is therefore needed.

Table 5.1a: Active geothermal feature types.

Type	Subtype	Examples	Description
Water-dominated	Hot Springs	Sinter depositing	Highly mineralised, vigorously deposits sinter
		Alkaline chloride	Mineralised
		Spouting	Vigorously boiling and overflowing
		Acid chloride	Mixed shallow acid and deep chloride
		Acid sulphate	Shallow origin (oxidised H_2S and steam)
		Bicarbonate	Steam-heated ground-water
		Mixed origin	Various origins, diluted by groundwater
	Geysers	Cyclic/intermittent	Relatively large discharge, >1 m height
		Crypto-geyser	Intermittent/cyclic subterranean spouter
		Soda-geyser	Driven by CO_2 discharge rather than boiling
Steam-dominated	Fumaroles	Super-heated	Large flowrate, >100 °C, noisy emission
		Sulphur depositing	Relatively high H_2S steam vent
		Boiling temperature	Atmospheric-pressure steam vent
		Minor fumaroles	Small, irregular, transient, steam vents
		Diffuse steam	Weak, diffuse emissions, not always visible
	Mud pools	Mud-volcano/geyser	Spouting mud splatter, builds cone
		Erupting or geysering	Intermittent, steam-fed, large, violent
		Non-discharging pool	Mud pools <100 °C, steam-heated, often turbid

Table 5.1b: Relict (remnant) landform features.

Landform Type	Subtype	Examples	Description
Water-deposited	Extinct geyser cones	Recent (<100 yrs)	Historically active but now dormant features
	Extinct hot spring sinters	Recent (<100 yrs)	Historically active but now dormant features
	Old sinters	Epithermal sinter	Old sinters from >100 yr old discharges
Steam-generated	Collapse pits	Thermal tomos	Old depressions in cooled steam zones
	Hydrothermal alteration	Recent clays	Historically active but now dormant features
	Old hydrothermal alteration	Epithermal clays	Pre-Historic thermal clay deposits
Boiling eruption	Hydrothermal eruption craters	Recently inactive	Dormant hydrothermal eruption vent
	Extinct eruption craters	>100 yrs inactive	Extinct hydrothermal eruption vent

5.4 SIGNIFICANCE ASSESSMENT CRITERIA

To assist with ranking thermal features, various tests for significance can be applied. For example, where surface thermal features are relatively common, or have relatively low aesthetic and scientific value, or have been significantly modified by human activity, most people would assign them a relatively low ranking. In contrast where the features are relatively rare, look impressive, and are accessible or well known, most people would give them a higher value. Where the features are of a type that are prone to significant natural variation with time, including vent changes and rainfall effects, they might be perceived to have a lower ranking value from the point of view of sustainability. But these same features could also have a higher ranking from the point of view of transient value (an aesthetic criterion). For the purpose of assessing relative significance, criteria have already been defined in the RPS ((BOPRC, 2014) Appendix 1).

5.5 NUMERICAL RANKING METHOD

Such criteria could be applied through application of a numerically-based ranking scheme. The choice of ranking numbers (1 to 5) is somewhat arbitrary and a similar outcome could be achieved by applying other grading schemes (e.g., shades of grey, or letters). In this approach, a set of criteria allows for ranking of thermal features into five categories (e.g., “outstanding”, “high”, “medium”, “moderate” or “low”). Some criteria are determined by feature characteristics relative to the full range and number of geothermal features found in the TVZ. Other criteria are related to the feature type (*rarity, resilience* and *vulnerability*) and various *aesthetic* aspects. Further criteria related to site-specific factors (termed *associative values)* could readily be added to complete the assessment.

Before an overall ranking is calculated from a numerical sum of the individual criteria ranking (or average), it may be necessary to construct a matrix (or table) of relative weightings for each criterion. Hence, if, for example, in the opinion of an independent expert assessor, the criteria of *rarity* and *vulnerability* were twice as important as the criteria of *memorability,* then they would be weighted accordingly, by using a different multiplication factor in the weighting matrix.

The numerical ranking scheme was developed from a set of queries for ranking geothermal features. They establish the degree to which:

a) The individual (named and located) features are: *representative*, *diverse*, *distinctive* and *natural* (unmodified), in the regional context (that is, relative to all geothermal features in the Waikato and BOP Regions of the TVZ).

b) The feature types (as categorised in Tables 5.1a and 5.1b) are: *rare, naturally resilient, vulnerable,* and *memorable* or *transient* from a visual perspective.

Aspects of the feature type ranking scheme ((b) above) also take into account the regional perspective. For example, the feature type ‘cyclic/intermittent geyser’ is assessed to be of outstanding rarity because there are few such examples of that particular type within the TVZ.

As noted above, the ranking scheme could easily be extended to include c) *associative values*, that is, the degree to which named and located individual features or groups of features are considered by the community to be valuable from a local or site-specific point-of-view. Queries might include the degree to which specific features are recognized and valued by the community for: *historical, recreational, educational, scientific, traditional or cultural values*.

5.6 METHOD FOR GEOTHERMAL FEATURE SIGNIFICANCE RANKING

Following on from the high-level discussion on criteria for significance ranking, this section provides a method intended to achieve the desired objective by using a numerical scheme. An example for the ranking of actively-discharging thermal feature types is presented in Table 5.2.

Figure 5.1 illustrates, by way of histogram plots, rankings of the 18 geothermal feature types, according to the six generic (or ‘type’) criteria. The final plot is a combined (average ranking) histogram. This demonstrates that the ranking values are evenly distributed. For a large enough sample of randomly selected thermal features, the average ranking value should therefore be at the midpoint, that is, a value of 3 using this 1 to 5 ranking scheme. Note no weightings are used at this stage.

Table 5.3 provides some specific examples by ranking 5 very different geothermal features in the BOP Region, using four site-specific criteria. Table 5.4 combines the site-specific criteria for these examples with their type rankings given in Table 5.2, in order to produce an average overall ranking.

Table 5.5 applies the same ranking process to eight types of relict or remnant landform features. Just two ‘terrestrial feature type’ criteria remain relevant when no fluid is discharged, *rarity* and *memorability*. The average of these two criteria provides a measure of the overall ranking for these geothermal landform feature types relative to all such features found within the TVZ. A histogram of the average ranking values assigned to these landform types is plotted in Figure 5.2. Again, this demonstrates that the ranking values for different types are evenly distributed.

Finally, a set of five examples of landform features from the BOP Region are listed in Table 5.6. The feature type is identified, and the features are ranked according to the four site-specific criteria, combined with the two type-based criteria, to calculate an average rank value.

Table 5.2: Ranking criteria, using numeric parameters, for active geothermal feature types: 5 = outstanding, 4 = high, 3 = medium, 2 = moderate, 1 = low.

Ranking of Types	Rarity and Vulnerability Factors by Feature Type				Aesthetic Values by Type		Combined Average
Feature Type	**Rarity**	**Naturally Resilient**	**Vulnerable to Liquid Pressure Decline**	**Vulnerable to Steam Pressure Decline**	**Memorability (visual)**	**Transient Values (changeable)**	
Hot Springs							
Sinter depositing	4	5	5	1	4	2	3.5
Alkaline chloride	2	5	4	1	3	2	2.8
Spouting	4	3	3	1	4	4	3.2
Acid chloride	3	3	3	2	2	2	2.5
Acid sulphate	3	2	1	3	2	1	2.0
Bicarbonate	2	2	1	4	2	1	2.0
Mixed origin	1	2	2	3	1	1	1.7
Geysers							
Cyclic/intermittent	5	1	5	1	5	5	3.7
Crypto-geyser	4	2	4	1	3	4	3.0
Soda-geyser	5	2	2	1	3	5	3.0
Fumaroles							
Super-heated	5	4	1	5	4	2	3.5
Sulphur depositing	5	4	1	5	5	2	3.7
Boiling temperature	3	3	1	3	3	3	2.7
Minor fumaroles	2	3	1	2	2	3	2.2
Diffuse steam	1	2	1	2	1	3	1.7
Mud pools							
Mud-volcano	4	1	1	4	4	5	3.2
Erupting or geysering	3	1	1	4	3	4	2.7
Non-discharging	1	2	1	2	2	3	1.8

Figure 5.1: Histogram plots of rankings (Bins 1 to 5) of 18 geothermal feature types per criteria, and as an average (combined). This shows that the outcome of the rankings by type in Table 5.2 (without site-specific considerations) produces, once averaged, a reasonably even distribution.

Table 5.3: Example of proposed ranking method applied to specific geothermal features in the BOPRC region, relative to TVZ.

Feature Ranking	BOPRC		Site-specific Natural Science Factors (relative to TVZ)				
Feature Name	**Feature ID**	**Feature Type**	**Representativeness**	**Diversity and Pattern**	**Distinctiveness**	**Naturalness-unmodified**	**Average**
White Island fumarole		Fumarole-superheat and sulphur	5	3	4	5	4.25
Pohutu, Whakarewarewa		Large geyser	4	3	5	3	3.75
Hells Gate mudpool, Tikitere		Boiling mud-pool	4	2	3	3	3
Parimahana, Kawerau		Diffuse steam	2	3	2	4	2.75
Awakeri hot spring		Mixed hot spring	3	1	2	1	1.75

Table 5.4: Example of proposed ranking method applied to specific geothermal features in the BOPRC region. Site specific criteria from Table 5.3 (upper) and generic type factors (lower) from Table 5.2 are assessed separately and the result averaged to produce a combined ranking.

Feature Ranking		Site-specific Natural Science Factors (relative TVZ)				Type Factor	
Feature Name	**Feature Type**	**Representativeness**	**Diversity and Pattern**	**Distinctiveness**	**Naturalness-unmodified**	**Rarity**	
White Island fumarole	Fumarole-superheat and sulphur	5	3	4	5	5	
Pohutu, Whakarewarewa	Large geyser	4	3	5	3	5	
Hells Gate mudpool, Tikitere	Boiling mud-pool	4	2	3	3	3	
Parimahana, Kawerau	Diffuse steam	2	3	2	4	1	
Awakeri hot spring	Mixed hot spring	3	1	2	1	1	
		Type factors (from generic type ranking table)					
		Naturally Resilient	**Vulnerable to Liquid Pressure Decline**	**Vulnerable to Steam Pressure Decline**	**Memorability (visual)**	**Transient Values Changeable**	**Average**
White Island fumarole	Fumarole-superheat and sulphur	4	1	5	4	2	3.8
Pohutu, Whakarewarewa	Large geyser	1	5	1	5	5	3.7
Hells Gate mudpool, Tikitere	Boiling mud-pool	1	1	4	3	4	2.8
Parimahana, Kawerau	Diffuse steam	2	1	2	1	3	2.1
Awakeri hot spring	Mixed hot spring	2	2	3	1	1	1.7

Table 5.5: Ranking criteria, using numeric parameters, for in-active, remnant or relict geothermal feature types: 5 = outstanding, 4 = high, 3 = medium, 2 = moderate, 1 = low. These rankings are relevant for relative assessments of potential land-use impacts on remnant geothermal landforms, and have been assessed in terms of all landform feature types found across the TVZ.

Remnant Feature Ranking			**Type**	**Aesthetic**	
Origin	**Subtype**	**Examples**	**Rarity**	**Memorability (visual)**	**Average**
Water-deposited	Extinct geyser cones	<100 yr old cones	5	5	5
	Extinct hot spring sinters	<100 yr old sheets	3	4	3.5
	Very old sinters	Epithermal deposits	3	2	2.5
Steam-generated	Collapse pits	Thermal tomos	3	3	3
	Hydrothermal alteration	Recent clay deposits	2	1	1.5
	Old hydrothermal alteration	Epithermal clays	1	1	1
Boiling eruption	Hydrothermal eruption craters	Recent	4	4	4
	Old hydrothermal eruption craters	>100 yrs old	2	3	2.5

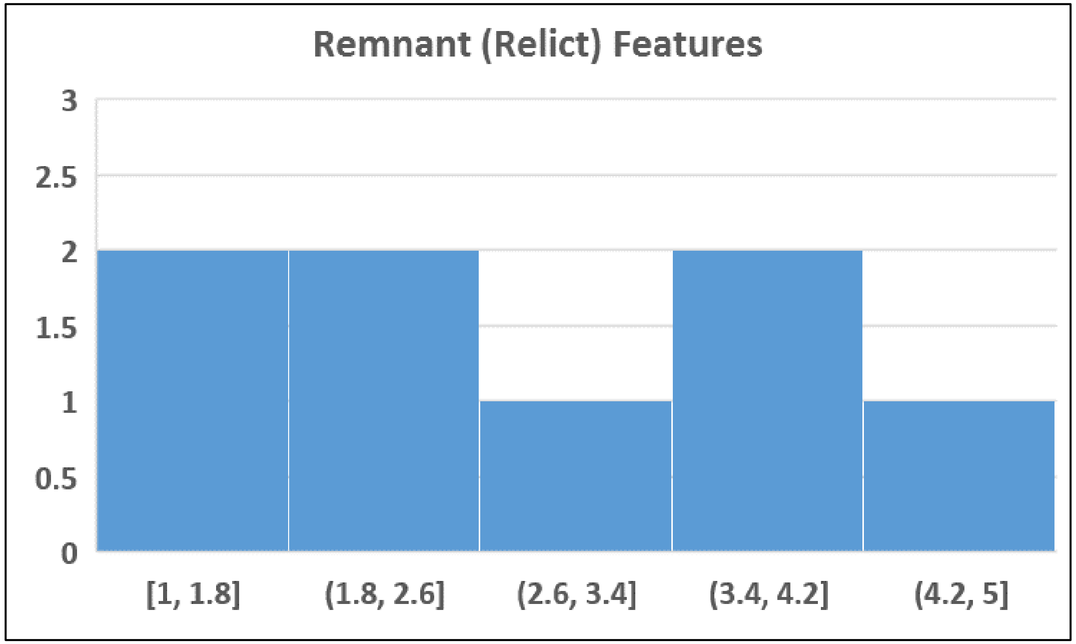

Figure 5.2: Histogram plot of average rankings (Bins 1 to 5) from Table 5.5 of eight relict (remnant or in-active) geothermal feature types to illustrate a reasonably uniform distribution. The Y-axis is the count of feature types and the X-axis label shows the bin range for the average ranking values from Table 5.5 (see section 5.7.1).

Table 5.6: Example of proposed ranking method applied to specific relict features in the BOPRC region, relative to the TVZ. Site specific criteria and generic (type) factors (shaded) from Table 5.5 are assessed separately and the result averaged to produce a combined ranking.

Feature Ranking			Site-specific Natural Science Factors (TVZ)				Type Ranking (Table 5.5)		
Feature Name	**ID**	**Feature Type**	**Representativeness**	**Diversity and Pattern**	**Distinctiveness**	**Naturalness, Un-modified**	**Rarity**	**Memorability (visual)**	**Average**
Waikite Geyser, Rotorua		Extinct geyser	5	2	4	3	5	4	3.8
Pink and White Terraces, L.Rotomahana		Very old sinters	4	3	5	4	3	2	3.5
L.Pupuwharau Crater, Kawerau		Old hydrothermal eruption crater	3	2	2	4	2	3	2.7
L. Umupokapoka, Kawerau		Extinct hot spring sinters	3	2	3	1	3	4	2.7
Tikitere micro-silica/sulphur quarry		Old hydrothermal alteration	2	2	2	1	1	1	1.5

5.7 DISCUSSION

5.7.1 Objective Assessment

The benefits of establishing a ranking scheme that results in a reasonably even distribution of features across the ranking scale (1 to 5) is that it then allows for an objective and statistically valid basis for statements such as “this feature ranks at above-average significance” if, for example, it has an average ranking value above 3. Planning decisions around land-use and resource-use can then be guided by the degree-of-significance of features, where sites of most significance (based on their attributes and the potential effects of activities on these attributes) may have a higher level of protection afforded under a regional or district plan.

The exercise of gradational ranking will provide the Regional Council and landowners or developers with a tool for making decisions or recommendations on such matters as the allowable proximity of earthworks, prospects for commercial spa development, visual enhancement initiatives, groundwater extraction or injection applications, proximity of deep well pads, deep geothermal resource utilisation applications, etc. It may mean, for example, that features ranked in the bottom quartile would have minimal constraints regarding proximity of earthworks or fluid extraction/injection proposals, while those in the upper quartile would have more-rigorous development constraints applied, especially to the immediately adjacent lands, in order to achieve protection from human interference for the highly-ranked natural geothermal features.

To support this approach, a BOPRC database of all identified surface geothermal features (active and relict), regardless of their significance, is required. This list is not static and will change over time as knowledge increases, or sites are modified or lost. Those sites that are identified as meeting the criteria for significance in the RPS may then be further identified (and possibly mapped) in planning documents. This list is likely to be utilised for the term of the planning document, and have implications for landowners. A consideration of this approach is that newly-discovered or re-activated features may not be reported and accurately described, due to concerns about sites being identified for protection.

5.7.2 Limitations

The principal limitation to this ranking exercise is that it would require considerable work by qualified and experienced assessors (who have personal knowledge of a majority of TVZ geothermal features) to rank each of the many thousands of individually-identified geothermal features, using the four site-specific criteria (see Table 5.3), before an overall combined ranking (with generic type criteria, see Table 5.4) could be calculated.

Another limitation could be the smooth integration of this numerical scheme with other ranking methods developed for habitats (e.g., vegetation) and associative values (e.g., cultural significance). However, if the same objective principle is applied to these latter assessment methods, that is, aiming for a uniform distribution of rankings about a mean, when considered across the TVZ, then it should be possible to integrate all three assessment methodologies.

5.7.3 Weighting Matrix

As noted above, it may be necessary to introduce (preferably with transparency) a weighting factor for different criteria before calculating a final ranking value. The relative importance of different criteria is worthy of further discussion. Opinions will doubtless vary over what these relative importance factors should be. As a starting suggestion, the authors agree that rarity and vulnerability criteria should have double the weighting of the other criteria in the application of this method.

5.8 RECOMMENDATIONS

Ongoing work into testing this proposed methodology using a larger subset of randomly selected but identified geothermal features is recommended in order to find out if the scheme is practicable, and to check the variances between different qualified but independent assessors.

6.0 AMALGAMATED RANKING METHOD – METHOD 4

The concept of Method 4 is to amalgamate the previously discussed methods by identifying features, ranking them in accordance with feature type, then by individual feature characteristics (relative to the TVZ) to determine significance (Methods 2 or 3), and finally (after a resource or land use proposed activity has been identified), by applying a likelihood/consequence assessment (method 1) to the proposed activity with respect to potential effects on the relevant surface features. Significance testing of vulnerability can then be undertaken at the surface feature level, based on the proposed activity. These proposed activities might involve geothermal fluid extraction, fluid reinjection, ground water use, change in land use for infrastructure projects, building permits near thermal ground, tourist access pathways, and so on.

Applying a test of susceptibility will identify the surface feature type that would be most likely, through to least likely, impacted by the proposed activity. This, in turn, can be used to extract from the catalogue a list of the 'individual' surface features that could be impacted based on the feature type attribute. The shortened list of surface features can then be tested and sorted for significance using the ranking criteria for individual features relative to TVZ (see Method 2 or 3). Those above a pre-determined threshold would remain under consideration. The advantage of this method is that the tests are applied to far fewer individual features. Therefore, it may be quicker and more efficient operationally.

A flow chart illustrating the proposed amalgamated method is provided as Figure 6.1. It is subdivided into three phases. The first phase involves preparation of a catalogue of features (Scott 2012). Because features will change (both naturally and due to human interference effects) and because new features can appear or be newly discovered, it is important that this catalogue is actively maintained and updated regularly. Appropriate monitoring tools and techniques can help achieve this objective in a cost-efficient manner.

The second phase initially involves a ranking process at the 'type' level then at the individual feature level (relative to TVZ). Potential methods for this process are described in detail in Sections 4.2 and 5 (Methods 2 and 3). The type level ranking can be completed before the catalogue is complete, but the individual feature ranking process (which uses a reduced set of criteria) requires completion of the thermal feature database first. A final distribution of relative rankings is constructed. Phase 2 is complete once a threshold (for example, the top 20% or quartile) has been established for the relative rankings of individual features in order to trigger formal consideration of potential adverse effects from proposed land use or resource use activities that would require resource consents.

Phase 3 starts when a proposed land or resource use activity is identified, and the feature vulnerability criteria can be more robustly assessed through a risk and hazard approach. This phase concludes once the resource consent process has concluded for each application. However, ongoing monitoring of surface feature activity levels will still be required (as noted above).

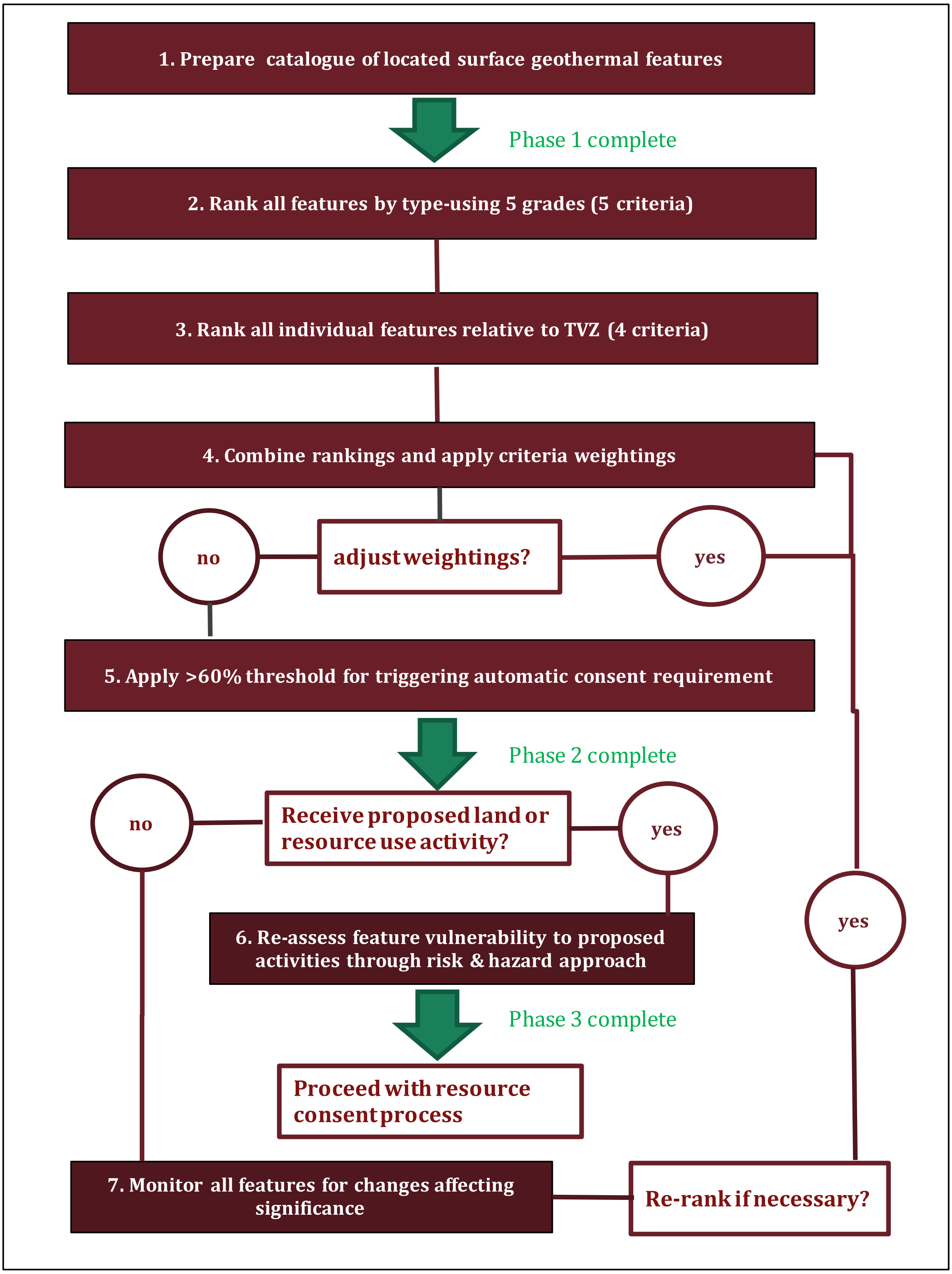

Figure 6.1 SGF Assessment: Method 4: Process Flow-chart.

7.0 DISCUSSION

The following have been identified and should be considered further before taking aspects of the potential significance ranking methodologies to an implementation stage:

- Full (or very near complete) catalogues are the ideal means to assess surface features (Phase 1 of the flow-chart, Figure 6.1). While existing databases are quite comprehensive, they are not necessarily complete and will evolve with time. Any assessment is therefore an assessment against the best knowledge available at the time it is carried out.
- Catalogues should only be developed by knowledgeable and suitably trained personal, and are labour intensive.
- Applying a significance test to a ‘full catalogue’ will also be time consuming and should only be done by trained and experienced geothermal assessors (drawn from a relatively small pool of experienced and qualified personal). Consideration could also be given to training suitably qualified staff in organisations like the regional councils to undertake these assessments. However, the process can presumably be stream-lined by first applying the ranking according to feature type, as described in Methods 2 and 3.
- A wide range of historical source material is available, which needs to be compiled and judged for quality, relevance and credibility.
- Assessments will need to consider aspects of natural change with time (feature evolution), and potential changes in extent, magnitude, frequency or duration of any proposed activities that may impact features.
- Are the criteria weightings correct and, if not, how should they be agreed on?
- Social or institutional acceptance of the consequence of relative ranking may be important. (Is it okay to temporarily lose some relatively insignificant thermal features?)
- Would infringement of rules on highly ranked significant features be treated more strongly than on lesser ranked features (given that aspects such as the type and degree or magnitude of effect are also considered)?
- How would this scheme stand up against those used for habitats or other classifications?
- Would this scheme be compatible with inclusion of the associative values?
- Despite well-defined assessment task scoping, there may still be a variance between assessors.

The following are recommended also for consideration;

- The assessment process needs to incorporate informed and expert opinion, past findings, and historical events.
- The historic state is considered as part of any evaluation of significance, and in this regard assessors should use any recorded and reliable historical documentation of surface feature activity.
- There will be a need to understand the physical processes potentially linking activities and thermal features.
- There will be a need to identify the likely risk/impact/consequence (exposure) of proposed activities on surface thermal features.

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APPENDICES

APPENDIX 1: APPENDIX F, SET 7 OF THE BOPRC POLICY STATEMENT (BOPRC, 2014) – NOTE THAT THIS DOES NOT INCLUDE THE ASSOCIATIVE VALUES

For Geothermal geological features:
Natural science factors
Representativeness 7.1 The extent to which the natural feature is a good example of a geothermal feature type or group of features in close association, and/or the processes that formed it/them, in the Taupō Volcanic Zone.
Diversity and pattern 7.2 The extent to which a group of associated features contain a wide variety of geothermal features, reflecting the diversity of geothermal feature types in the Taupō Volcanic Zone or present a distinctive and unusual juxtaposition of features (e.g., along a physical, chemical or hydrological gradient).
Rarity 7.3 The extent to which the feature is unique or rare in the context of the Taupō Volcanic Zone.
Distinctiveness 7.4 The extent to which a feature in a geothermal area is one of the largest remaining examples of its type in the Taupō Volcanic Zone, while exhibiting high thermal output.
Resilience 7.5 The extent to which the feature is resilient to natural changes.
Vulnerability 7.6 The extent to which the feature is vulnerable to fluid extraction.
Aesthetic values
Memorability 7.7 The extent to which the geothermal feature(s) is striking or visually spectacular due to its recognisable and memorable qualities.
Naturalness 7.8 The extent to which the geothermal feature(s) appears largely uncompromised and is an intact natural system, free from human modification, intervention or manipulation.
Transient values 7.9 The extent to which transitory natural changes in the appearance of the geothermal feature contribute to its natural science values or aesthetic appeal.

APPENDIX 2: LIST OF TERMS AND DEFINITIONS FROM RPS

Definitions

Clarification of terms as used by BOPRC (2014)

Geothermal hazard means hydrothermal eruptions, dormant surface features, natural gases, subsidence and tomos from geothermal systems.

Geothermal system: A system defined by scientific investigation comprising geothermal energy stored as geothermal water or steam and the rocks confining them and associated water, steam and gas emissions and the geothermal surface features resulting from these emissions and is believed to have no hydrological connection to another system.

Natural character: The qualities of the environment that give New Zealand recognisable character. These qualities may be ecological, physical, spiritual, cultural or aesthetic in nature. They include modified and managed environs. Natural character exists on a spectrum of values from low to outstanding with areas of high, very high and outstanding natural character being mapped and shown in Appendix I.

Natural hazard zone means that zone within a hazard susceptibility area defined by the relevant regional, city or district plan, on the basis of existing or proposed land use, as the appropriate geographic scale to assess hazard risk. For the avoidance of doubt, a natural hazard zone may be an entire hazard susceptibility area or such smaller zone as is appropriate taking account of the nature and scale of actual and potential land uses that are exposed to the natural hazard.

Point source discharge: A discharge from a specific and identifiable outlet, onto or into land, air, a water body or the sea.

Reinjection: The return of geothermal water into the geothermal aquifer from which the water was sourced.

Reverse sensitivity: The potential for the operation of an existing lawfully established activity to be compromised, constrained or curtailed by the more recent establishment of other activities which are sensitive to the adverse environmental effects being generated by the pre-existing activity.

Risk means the likelihood and consequences of a hazard.

Sensitive activities: Activities which suffer should they experience adverse effects typically associated with some lawful activities. For example, smells from a sewage treatment facility or noise from a port facility. Activities considered to be sensitive include but are not necessarily limited to any residential activity, any childhood education centre and any other accommodation facility.

Significant geothermal features (SGFs): Geothermal features include active and relic geothermal features and habitats including vegetation and fauna. “Significant Geothermal Features” are those that have been identified as geothermal features through the use of the feature descriptors of Appendix A – Definitions Annex A, and, then identified as significant through the application of the criteria of Appendix F Set 7 - Geothermal features, in accordance with Method 22 of the RPS (BOPRC, 2014).

State of the environment monitoring: Baseline monitoring of the health of the environment.

Susceptibility means potential of an area to generate and/or be affected by a natural hazard.

Sustainable use: For geothermal resource use purposes, "sustainable use" requires a case by case consideration of the resource for its extractable energy use values.

In the context of a proposal for extractive use, determining sustainable use will consider:

- the level and certainty of scientific information on the particular system;
- the size of the geothermal energy resource;
- the rate at which the energy within the geothermal system is proposed to be extracted, and the timeframe over which any proposed rate of take of geothermal energy is predicted to be able to be sustained, informed by modelling for a period of at least 50 years (the depletion rate is a matter for decision makers to determine when an application is being considered);
- the predicted quantity of energy available for extractive use at the end of 50 years;
- the predicted length of time that the geothermal system will take to recover once extractive use ceases;
- the overall management of the geothermal resource, including the depth and locations of the proposed take and return of geothermal fluid, and the impacts of such management on the longevity of the resource; and
- once extractive use has commenced, how closely observed changes to the geothermal resource affecting its productive capacity and longevity match the modelled or predicted effects, by review of the data and other information collected. This information could include: pressure, temperature, chemistry, surface water flow or level and vegetation monitoring indicating the state of the geothermal resource, including identified changes to geothermal features.

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