# Assessing significant geothermal features in the Bay of Plenty region – the application and testing of Method 4

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## DISCLAIMER



## BIBLIOGRAPHIC REFERENCE

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# EXECUTIVE SUMMARY

Four methodologies and assessment procedures for classifying the significance of surface thermal features were proposed to the Bay of Plenty Regional Council (BOPRC) (Scott and Bromley 2017). Method 4 of Scott and Bromley (2017) was chosen by BOPRC for further evaluation. This report summarises high-level testing of Method 4 and its applicability to ranking geothermal surface features in the Bay of Plenty.

Method 4 results in a numerical ranking of surface features from 1 to 5 where 1 is a lower ranking and 5 is a high ranking (i.e., likely to be significant). A team of assessors was used to test this method. Defining significance from the ranking is not addressed.

Method 4 has been successfully applied to the 12 surface geothermal feature types defined in the BOPRC Regional Policy Statement (RPS) (2014). This has enabled the 12 feature types to be ranked in a high-level approach. The results from the three assessors showed more variation than expected which we attribute to the assessors having difficulty applying the criteria consistently due to the spectrum of interpretations that can be derived from the criteria in Set 7 and the continuum that exist in surface feature types.

The geysers and overflowing springs with primary fluids rank higher than other feature types, having weighted scores over 4 out of 5. The mud geyser, fumarole, ejecting mud pot and non flowing springs with primary fluid all scored in the 3–4 range. Mixed spring, mud pool, intermittent or active hydrothermal crater, steaming ground, mixed pool (mixed chemistry) and heated ground all score between 2–3.

The BOPRC Geothermal Surface Feature database (as at 23 March, 2018) shows that mixed pools and non flowing primary springs account for 47% of the catalogued features. Four feature types (heated ground, steaming ground, mud pools, and mixed springs) account for 43% of the catalogued features. The remaining 5 feature types (geyser, flowing primary springs, mud geyser and ejecting mud pot) account for the remaining 10%.

Sixteen individual geothermal features were selected and assessed by three assessors. The independent weighted scores for each feature show less variation between the assessors than what was apparent for the feature types. We feel this is due to the assessors being able to apply the criteria more readily on an individual feature basis. The two highest scoring features are geysers (matching the ranking of feature type). The next 5 features considered were a mix of the feature types and there is no strong correlation to the feature type ranking. Interestingly the 2 flowing primary springs are ranked 8$^{th}$ and 9$^{th}$, while as feature types they ranked 2$^{nd}$.

The lower ranked individual features also only have a loose relationship with feature type ranking. It is apparent that size and aesthetic values contribute to the lower scores for these.

Although difficulty was experienced applying the BOPRC RPS criteria this pilot study has shown that consistent results can be obtained when examining individual features. Method 4 could be a suitable method for ranking geothermal surface features.

# 1.0 INTRODUCTION

Geothermal surface features can be categorised according to feature type (e.g., primary spring, geyser, mud pool). Using agreed criteria these various types of geothermal surface features or catalogues of features can be assessed for significance. This can produce a statutory list ranking significant geothermal features (SGFs).

The results of this process can assist resource managers and developers oversee potential adverse effects on geothermal surface features. The method used categorises the geothermal features and associated attributes according to their values (i.e., the things that make them significant) and the threats to those values. This then helps inform decisions around various levels of protection or utilisation. This process is required as part of the Resource Management Act (1991) and the consenting process administered by local, regional and national government agencies.

Scott and Bromley (2017) examined and reported on options to rank the significance of geothermal surface features for Bay of Plenty Regional Council (BOPRC). Four methods were proposed with no one method recommended. BOPRC have assessed the methods and have requested GNS Science to further develop and test Method 4 in the Scott and Bromley (2017) report. This was to be done by:

1. Ranking the 12 geothermal surface feature types identified by BOPRC using Method 4 from Scott and Bromley (2017).
2. Report the number of features from the BOPRC geothermal surface feature database (GNS Science 2018) that fit into each feature type.
3. Test up to 15 geothermal surface features with Method 4.

This report covers the application of Method 4 to the three tasks listed above and evaluates the results.

## 1.1 Summary of Method 4

The concept of Method 4 is to amalgamate aspects of each method presented and discussed by Scott and Bromley (2017). This is achieved by identifying features, ranking them in accordance with feature type, then by individual feature characteristics (relative to the Taupo Volcanic Zone (TVZ)) to determine significance. Aspects of Methods 2 or 3 from Scott and Bromley (2017) are also utilised.

A flow chart illustrating the proposed amalgamated method is provided as Figure 1.1. The process is subdivided into three phases. The first phase involves producing a catalogue of known surface geothermal features using field mapping techniques as out lined by Scott (2012). As features will change over time (both naturally and due to anthropogenic effects) and new features can appear, be newly discovered, or stop, it is important that the catalogue is updated regularly and the version used as reference is assessment is noted.

The second phase involves a ranking process first at the ‘feature type’ level, then at the individual feature level (with some criteria relative to geothermal surface features in the TVZ). Potential methods for this process are described in detail by Scott and Bromley (2017). At both the higher level and detailed individual feature level a number of criteria are assessed and scored. Ranking criteria include scientific and aesthetic values, which are discussed in detail below. A final combined and weighted score is then given. A final distribution of relative rankings is constructed.

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.

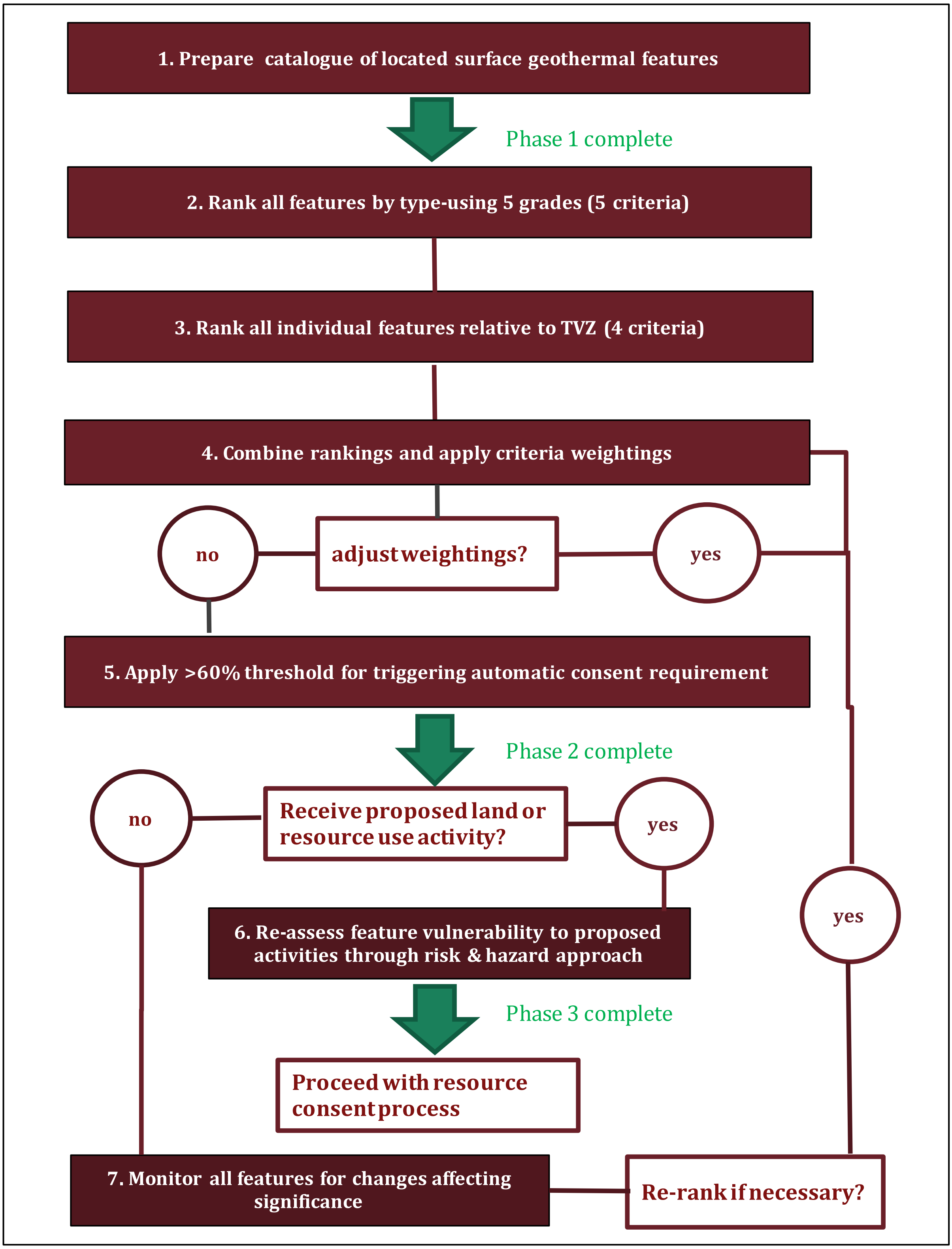


Figure 1.1: SGF Assessment: Method 4: Process Flow-chart. Note that for items 2 and 3 in the flowchart we have used criteria to evaluate the Natural and Aesthetic factors. Note, also, that the triggering threshold under item 5 is just an example and could vary at the discretion of consenting authorities and is not considered here.

## 2.0 GEOTHERMAL SURFACE FEATURE CLASSIFICATION

For the development of the BOPRC Regional Policy Statement (RPS) (2014) a classification for surface geothermal features and habitats was established (Figure 2.1) following the techniques outlined by Scott (2012). The classification was kept very high level and did not include sub divisions of feature types. Based on the field data available this could be achieved if needed. Associated with this mechanism of classifying surface geothermal features three broad categories of habitats were also defined in the RPS related to the geothermal environment. These are:

1. The atmosphere above and around the surface geothermal features.
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.

From this work a primary listing of 12 geothermal surface feature types has been derived and defined by BOPRC (2014) (Table 2.1). The subsurface relationships with the surface features are shown schematically in Figure 2.2.

| **Discharge energy** | | | | |
|---|---|---|---|---|
| High ↑ | 1. Geysers | 4. Intermittent or active hydrothermal eruption craters | 7. Mud geysers | 10. Fumaroles |
| ↕ | 2. Flowing springs | 5. Mixed springs | 8. Ejecting mud pots | 11. Steaming ground |
| Low ↓ | 3. Non flowing pools | 6. Mixed pools | 9. Mud pools | 12. Heated ground |
| | *Primary geothermal fluid* | *Mixed/diluted geothermal fluid* | *Mixed/diluted steam heated fluid* | *Steam Fed* |
| Geothermally-influenced aquatic habitat | | | | |
| Geothermal habitat on heated/acid dry ground | | | | |
| Habitat dependent on geothermally-altered atmosphere overlays all types (warm air, frost-free) | | | | |

Figure 2.1: A schematic representation of surface geothermal features (BOPRC 2014, after Scott 2012). Note the inclusion also of three broad categories of habitat (atmosphere, aquatic and heated ground).

Table 2.1: List of primary geothermal surface feature types as defined in BOPRC (2014).

| **Geothermal Surface Feature Types** |
|---|
| Geyser |
| Flowing spring (primary fluid) |
| Non flowing spring (primary fluid) |
| Intermittent or active hydrothermal crater |
| Mixed spring (mixed chemistry) |
| Mixed pool (mixed chemistry) |
| Mud geyser |
| Ejecting mud pot |
| Mud pool |
| Fumarole |
| Steaming ground |
| Heated ground |
| Other (not considered in this report) |

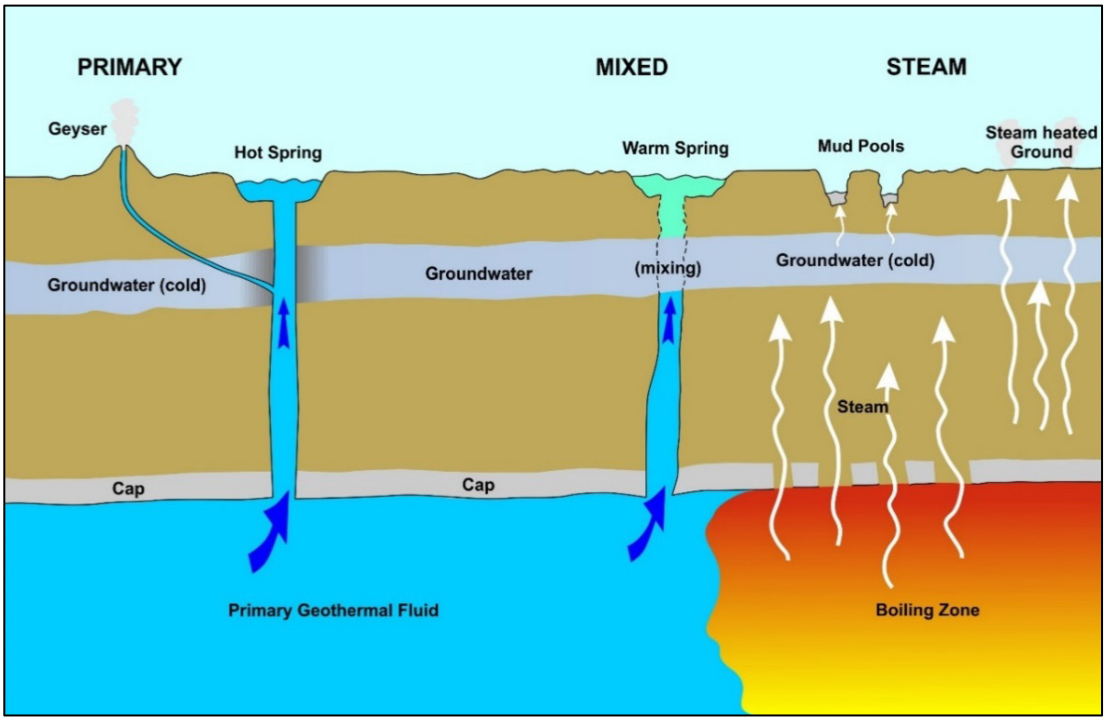


Figure 2.2: Schematic relationship between the various types of geothermal surface features and process's that support them.

## 2.1 Classification Parameters (Set 7)

The BOPRC policy statement (BOPRC 2014) outlines how significance is defined and is known as Set 7 (Appendix 1). The Set 7 parameters define 9 criteria (organised into science and aesthetic values) to be used to assess significance. These are discussed below. Note that Set 7 (BOPRC 2014) also defines a set of associative values, but these are not assessed because they are beyond the scope of this report.

The natural science values 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 natural and induced 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 associates with a surface feature, via how memorable or natural the feature appears. Natural transient characteristics of some surface geothermal features are also considered under aesthetics.

### 2.1.1 Natural Science Values

#### 2.1.1.1 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*."

An assessor is looking at how well a feature represents feature types within the whole of the TVZ. Is this an exemplifying example of the identified feature types? If you had to bring a visitor to see surface geothermal features, would this be the one type 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 refers to a single feature type and a group of features. It is assumed that the group is of features of the same type, however this is uncommon. Often a group of features in close proximity will include a variety of feature types (For example, Kuirau Park, Rotorua includes a variety of feature types, including primary springs, mixed pools and mud pools). Also of consideration is the physical process that controls the feature type. These can be complex interactions and create some uncertainty in an assessment.

"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.

#### 2.1.1.2 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.

This is a difficult criterion to address at the type level, as geothermal surface features are often clustered, forming a continuum of types with associated and diverse individuals. The usual assessment approach focuses on individual features, whereas this criterion has a bias for the 'collective' value of associated feature type. There is no guidance to spatial cover or scale. An assessor will be looking at a feature type and assessing that feature without respect to neighbouring features.

We have interpreted this to be related to the immediate 'viewshed' an assessor would see at or near the feature been evaluated, not a wider perspective out of view but nearby to the feature.

#### 2.1.1.3 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. 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). Some feature types require very special cases to exist, for example geysers or mud pots.

Past activities have a bearing on the number present today, and the number present in the past may also be a consideration. Some are rare due to natural physical constraints while others are surviving examples.

#### 2.1.1.4 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 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 naturally 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 when scoring this value some form of weighting should be considered.

#### 2.1.1.5 Clause 7.5 Resilience

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

The phenomenon of natural variability and the inherent resilience of a feature type is influenced by the context of the physical environment (lake and river water levels, rainfall, climate change, etc.). Features that can survive climatic variability are likely to score higher than those that may not. 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.

Many geothermal systems today have experienced some form of exploitation or adaptation. Any assessment must consider if the geothermal system is currently being utilised or has been affected by human works. Significance ranking may need to take consideration of the phenomenon of variability in a different way than in a natural situation.

#### 2.1.1.6 Clause 7.6 Vulnerability

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

Overall judgement on detailed understanding of the type of exploitation, the mitigations and the current knowledge of the system under judgement is critical in this assessment.

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. In some cases, these pressure changes may have no discernible effect (within natural variations), but in other cases, they could have greater influence. These induced changes could cause an *increase* in surface fluid 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.

A *vulnerability* assessment, at the feature type level, needs to consider whether the expected adverse effect is caused by a decline in liquid pressure and/or a decline in steam pressure. 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).

### 2.1.2 Aesthetic Values

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

#### 2.1.2.1 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*."

This measure works well for a type assessment, as personal differences are minimised. The assessors view considers a majority opinion regarding the impressive and memorable nature of typical examples. However, that can be restrictive as visual appeal is a subjective opinion. Typically, it is hard to measure and this is usually defined by user research methods and analytics of user experiences.

#### 2.1.2.2 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 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 measure is about significance we have applied added weight to the scoring for this attribute.

This is a "site-specific" criterion rather than a "type" criterion. Although the criteria of this clause appear binary; intact or not, a scaled approach is more appropriate; Completely natural, very/moderately/slightly/not natural.

Key factors that are considered when assessing naturalness include:

- 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.

#### 2.1.2.3 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.*"

This criterion is an attempt to capture the aesthetically appealing nature of the time-varying characteristics of some feature types. This criterion is essentially a measure of the capacity of the feature to elicit pleasure for an observer, to evoke a sense of appreciation, hence how dynamic the feature type is.

## 3.0 RANKING ASSESSMENT

For this assessment of the relative significance of geothermal surface features the criteria defined in the RPS ((BOPRC 2014) Appendix 1) are used.

### 3.1 Numerical Ranking

For this pilot study we have applied a numerically-based ranking scheme to test Method 4. 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 ranking criteria allows for ranking of geothermal feature types into five categories for the Natural Science Factors (Table 3.1), being “exceptional”, “high quality”, “typical”, “common” and “inferior”. While the Aesthetic Values are categorised or ranked as “exceptional”, “notable”, “typical”, “low notability” and “insignificant” (Table 3.2).

However, some ranking criteria in the BOPRC RPS (2014) are determined by feature characteristics relative to the full range and number of geothermal features found in the TVZ. Other criteria are related to ‘external factors’ and their impact on the feature type (*rarity, resilience, vulnerability and naturalness*). For these ranking criteria, aspects of the descriptors benefit from further clarification. To assist, we have introduced further descriptors for these attributes in Table 3.1. These are intended to guide an assessor and to help align with the scale of the numerical ranking system. That is, something that is robust gets a high score, like being an exceptional example, while something that is vulnerable also gets a high score. This allows the numerical ranking to work across these various descriptors and definitions.

Table 3.1: Guidance qualifiers for the Natural Science Values.

| Level | Feature Descriptor | Representativeness, Diversity, Distinctiveness | Resilience | Vulnerability and Rarity |
|---|---|---|---|---|
| 1 | Inferior | Common feature, poor example with few attributes of significance | Not very resilient to natural change | Very abundant feature, not normally affected or vulnerable (robust) |
| 2 | Common | An imperfect feature type, showing some attributes of significance | Weakly resilient to natural change | Abundant feature, weakly affected with some vulnerability |
| 3 | Typical | Typical feature type, with significance | Resilient to natural change | Common feature with normal resilience |
| 4 | High Quality | A distinctive and quality feature type with significance | Highly resilient to natural change | Rare feature, with some susceptibility and vulnerability |
| 5 | Exceptional | Exceptional TVZ example showing supremacy of type significance | Strongly resilient to natural change | Very rare, with high susceptibility and vulnerability |

Table 3.2: Guidance qualifiers for the Aesthetic Values.

| Level | Descriptor | Memorability and Transient | Naturalness |
|---|---|---|---|
| 1 | Insignificant | Few attributes of feature significance | Totally impacted and compromised, not natural |
| 2 | Low notability | Poor geothermal feature, displays some aesthetic feature attributes | Slightly natural, very high level of impact |
| 3 | Typical | Typical geothermal feature, possesses most aesthetic feature attributes. | Moderately natural with high level of impact and compromising |
| 4 | Notable | Notable feature type, possesses many aesthetic feature attributes | Very natural, some impact and compromising |
| 5 | Exceptional | Exceptional example, reflects all attributes of TVZ feature type significance for aesthetic values | Totally intact and uncompromised, completely natural |

Before an overall ranking is calculated from a numerical sum of the individual criteria ranking, it is necessary to construct a listing of relative weightings for each criterion. Feature types are then weighted accordingly, by using a different multiplication factor in the weighting matrix.

There are six parameters under consideration for the natural science values. 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 of Set 7 are presented and discussed in Section 2.1.

For the ranking of the 12 SGF types in Table 2.1 and the selected individual features tested in Table 3.7 we have used the following weightings:

- 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.

There are three parameters under consideration for the Aesthetic Values and ideally, they would also all have equal weighting. We have given slightly higher weighting to naturalness (50%) as this criterion is arguably a more important contributor 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 visitor's experience or response. All other parameters are weighted at 25%. The definitions and criteria are presented in Section 2.1.

For the ranking of the 12 SGF types in Table 2.1 and the selected individual features tested in Table 3.7 we have used 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.

The weighted Natural Science Factors sub-total represents 66.6 % of the total maximum score, while the weighted Aesthetic Values sub-total represents the remaining 33.3% (rounded).

## 3.2 Results

### 3.2.1 Ranking the 12 Geothermal Surface Feature Types Using Method 4 from Scott and Bromley (2017)

To rank the 12 geothermal feature types defined by BOPRC (2014) we have given a numerical number as discussed above (Section 3.1). The numbers range from 1 to 5. Three individual assessors independently undertook this assessment. The result of applying the numerical ranks for Assessor 1 are summarised in Table 3.3 as an example.

Then we have applied the weighting as discussed above to the results for Assessor 1 in Table 3.3 to obtain the final of weighted numerical rankings for that assessor (Table 3.4) as an example of the process utilised.

To examine the variability and test the robustness of Method 4 this process was under taken by three assessors independently, who are very familiar with surface geothermal features. From this process we have obtained relative rankings using the weighted scores (Table 3.5). The rankings obtained by numerical scoring is shown above only for completeness (Table 3.3)

We recommend only the weighted scores are adopted to rank the significance of geothermal surface features.

As can be seen from Table 3.5 there is some variability in the scores, with a range in the values assigned. This is attributed to the difficultly in using the criteria in Section 3.1 across the wide variability of the feature attributes. The feature types sorted using the mean values are presented below. Looking at the distribution of the mean scores, two feature types scored above 4 (geysers and flowing springs) and one below 2 (heated ground). The other 9 types are shared in the ranges 2–3 (5 types) and 3–4 (4 types). This is shown in Figure 3.1.

Surface geothermal features in order of mean weighted scores they are:

1. Geyser (4.5).
2. Flowing spring (primary fluid) (4.0).
3. Mud geyser (3.7).
4. Fumarole (3.6).
5. Ejecting mud pot (3.3).
6. Non flowing spring (primary fluid) (3.1).
7. Mixed spring (mixed chemistry) (2.6).
8. Mud Pool (2.6).
9. Intermittent or active hydrothermal crater (2.5).
10. Steaming ground (2.4).
11. Mixed pool (mixed chemistry) (2.2).
12. Heated ground (1.8).

Table 3.3: The rankings derived by applying numerical scores to the 12 feature types defined in BOPRC (2014) using the criteria definitions as defined in BOPRC (2014). The below is from Assessor 1.

| Geothermal Surface Feature Types | Feature Evaluation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Natural Science Factors | | | | | | | Aesthetic Values | | | | |
| | Representativeness | Diversity and Pattern | Rarity | Distinctiveness | Resilience | Vulnerability | **Sub-total** | Memorability | Naturalness | Transient Value | **Sub-total** | **TOTAL** |
| Geyser | 4 | 4 | 5 | 5 | 4 | 5 | **27** | 5 | 5 | 5 | **15** | **42** |
| Flowing spring (primary fluid) | 4 | 4 | 4 | 4 | 4 | 5 | **25** | 5 | 5 | 4 | **14** | **39** |
| Non flowing spring (primary fluid) | 3 | 3 | 4 | 2 | 3 | 3 | **18** | 4 | 4 | 3 | **11** | **29** |
| Intermittent or active hydrothermal crater | 3 | 2 | 3 | 3 | 3 | 2 | **16** | 3 | 3 | 3 | **9** | **25** |
| Mixed spring (mixed chemistry) | 3 | 3 | 3 | 3 | 3 | 2 | **17** | 3 | 3 | 3 | **9** | **26** |
| Mixed pool (mixed chemistry) | 2 | 2 | 2 | 2 | 2 | 2 | **12** | 3 | 2 | 2 | **7** | **19** |
| Mud geyser | 4 | 3 | 4 | 4 | 3 | 3 | **21** | 4 | 4 | 4 | **12** | **33** |
| Ejecting mud pot | 3 | 3 | 3 | 3 | 3 | 3 | **18** | 4 | 4 | 4 | **12** | **30** |
| Mud pool | 2 | 2 | 2 | 2 | 2 | 2 | **12** | 3 | 3 | 3 | **9** | **21** |
| Fumarole | 4 | 4 | 4 | 4 | 4 | 3 | **23** | 4 | 4 | 3 | **11** | **34** |
| Steaming ground | 3 | 3 | 3 | 3 | 4 | 2 | **18** | 2 | 2 | 2 | **6** | **24** |
| Heated ground | 2 | 2 | 2 | 2 | 3 | 2 | **13** | 2 | 2 | 2 | **6** | **19** |
| Other (not considered in this report) | | | | | | | | | | | | |

Table 3.4: The rankings derived by weighting the numerical scores obtained in Table 3.3 to the 12 feature types defined in BOPRC (2014). The below is from Assessor 1.

| **Geothermal Surface Feature Types** | **Feature Evaluation** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Natural Science Factors** | | | | | | | **Aesthetic Values** | | | | |
| | **Representativeness** | **Diversity and Pattern** | **Rarity** | **Distinctiveness** | **Resilience** | **Vulnerability** | **Sub-total** | **Memorability** | **Naturalness** | **Transient Value** | **Sub-total** | **TOTAL** |
| Geyser | 4 | 4 | 5 | 5 | 4 | 5 | **4.6** | 5 | 5 | 5 | **5** | **4.7** |
| Flowing spring (primary fluid) | 4 | 4 | 4 | 4 | 4 | 5 | **4.2** | 5 | 5 | 4 | **4.75** | **4.4** |
| Non flowing spring (primary fluid) | 3 | 3 | 4 | 2 | 3 | 3 | **3.1** | 4 | 4 | 3 | **3.75** | **3.3** |
| Intermittent or active hydrothermal crater | 3 | 2 | 3 | 3 | 3 | 2 | **2.7** | 3 | 3 | 3 | **3** | **2.8** |
| Mixed spring (mixed chemistry) | 3 | 3 | 3 | 3 | 3 | 2 | **2.8** | 3 | 3 | 3 | **3** | **2.9** |
| Mixed pool (mixed chemistry) | 2 | 2 | 2 | 2 | 2 | 2 | **2.0** | 3 | 2 | 3 | **2.5** | **2.2** |
| Mud geyser | 4 | 3 | 4 | 4 | 3 | 3 | **3.5** | 4 | 4 | 4 | **4** | **3.7** |
| Ejecting mud pot | 3 | 3 | 3 | 3 | 3 | 3 | **3.0** | 4 | 4 | 4 | **4** | **3.3** |
| Mud pool | 2 | 2 | 2 | 2 | 2 | 2 | **2.0** | 3 | 3 | 3 | **3** | **2.3** |
| Fumarole | 4 | 4 | 4 | 4 | 4 | 3 | **3.8** | 4 | 4 | 3 | **3.75** | **3.8** |
| Steaming ground | 3 | 3 | 3 | 3 | 4 | 2 | **3.0** | 2 | 2 | 2 | **2** | **2.6** |
| Heated ground | 2 | 2 | 2 | 2 | 3 | 2 | **2.2** | 2 | 2 | 2 | **2** | **2.1** |
| Other (not considered in this report) | | | | | | | | | | | | |

Table 3.5: List of the weighted scores for the three assessors and related statistics.

| Geothermal Surface Feature Types | Assessor 1 | Assessor 2 | Assessor 3 | Mean | S Dev | Max | Min | Diff. |
|---|---|---|---|---|---|---|---|---|
| Geyser | 4.7 | 4.8 | 4.0 | 4.5 | 0.34 | 4.8 | 4.0 | 0.8 |
| Flowing spring (primary fluid) | 4.4 | 3.8 | 3.9 | 4.0 | 0.24 | 4.4 | 3.8 | 0.6 |
| Non flowing spring (primary fluid) | 3.3 | 3.0 | 3.0 | 3.1 | 0.14 | 3.3 | 3.0 | 0.3 |
| Intermittent or active hydrothermal crater | 2.8 | 2.0 | 2.8 | 2.5 | 0.38 | 2.8 | 2.0 | 0.8 |
| Mixed spring (mixed chemistry) | 2.9 | 2.2 | 2.8 | 2.6 | 0.32 | 2.9 | 2.2 | 0.7 |
| Mixed pool (mixed chemistry) | 2.2 | 1.9 | 2.5 | 2.2 | 0.22 | 2.5 | 1.9 | 0.5 |
| Mud geyser | 3.7 | 3.9 | 3.5 | 3.7 | 0.13 | 3.9 | 3.5 | 0.3 |
| Ejecting mud pot | 3.3 | 3.7 | 3.0 | 3.3 | 0.29 | 3.7 | 3.0 | 0.7 |
| Mud pool | 2.3 | 2.6 | 2.7 | 2.6 | 0.16 | 2.7 | 2.3 | 0.4 |
| Fumarole | 3.8 | 3.8 | 3.3 | 3.6 | 0.22 | 3.8 | 3.3 | 0.5 |
| Steaming ground | 2.6 | 2.0 | 2.6 | 2.4 | 0.29 | 2.6 | 2.0 | 0.6 |
| Heated ground | 2.1 | 1.2 | 2.2 | 1.8 | 0.45 | 2.2 | 1.2 | 1.0 |
| Other (not considered in this report) | | | | | | | | |

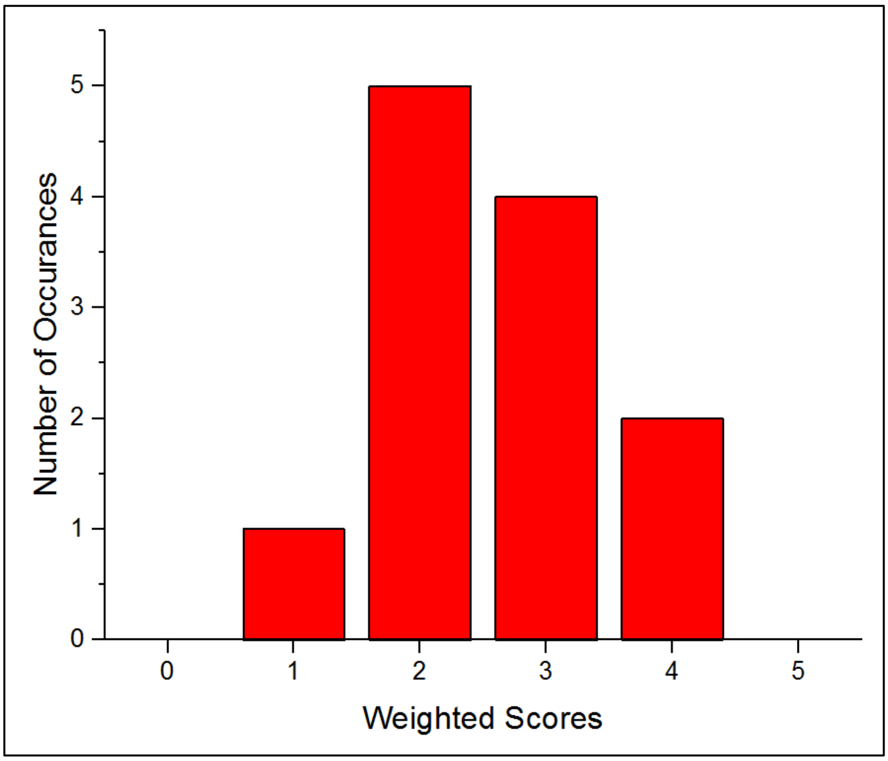


Figure 3.1: Bar graph showing the distribution of the mean weighted feature type scores.

### 3.2.2 Report the Number of Features from the BOPRC Geothermal Surface Feature Database that Fit into Each Feature Type

The BOPRC Geothermal Surface Feature database (GNS Science 2018) as at 23 March 2018 held 1847 entries for geothermal surface features. The database was searched by feature types that match the BOPRC (2014) classifications and definitions (Table 2.1) and returned 1770 features.

We have sorted the features to find the number of features in each of the 12 feature types using the 1770 features identified in the Geothermal Surface Feature database. The results of this are presented in Table 3.6 and Figure 3.2. Note the category Intermittent or active hydrothermal crater is not currently in the database as a feature type.

Table 3.6: Number of geothermal surface features and percentages as held in the Geothermal Surface Feature database as at 23 March 2018.

| Geothermal Surface Feature Types | Number of Features | Percentage |
|---|---|---|
| Geyser | 16 | 0.9 |
| Flowing spring (primary fluid) | 370 | 20.9 |
| Non flowing spring (primary fluid) | 50 | 2.8 |
| *Intermittent or active hydrothermal crater* | | |
| Mixed spring (mixed chemistry) | 247 | 14.0 |
| Mixed pool (mixed chemistry) | 456 | 25.8 |
| Mud geyser | 19 | 1.1 |
| Ejecting mud pot | 46 | 2.6 |
| Mud pool | 194 | 11.0 |
| Fumarole | 54 | 3.1 |
| Steaming ground | 158 | 8.9 |
| Heated ground | 160 | 9.0 |

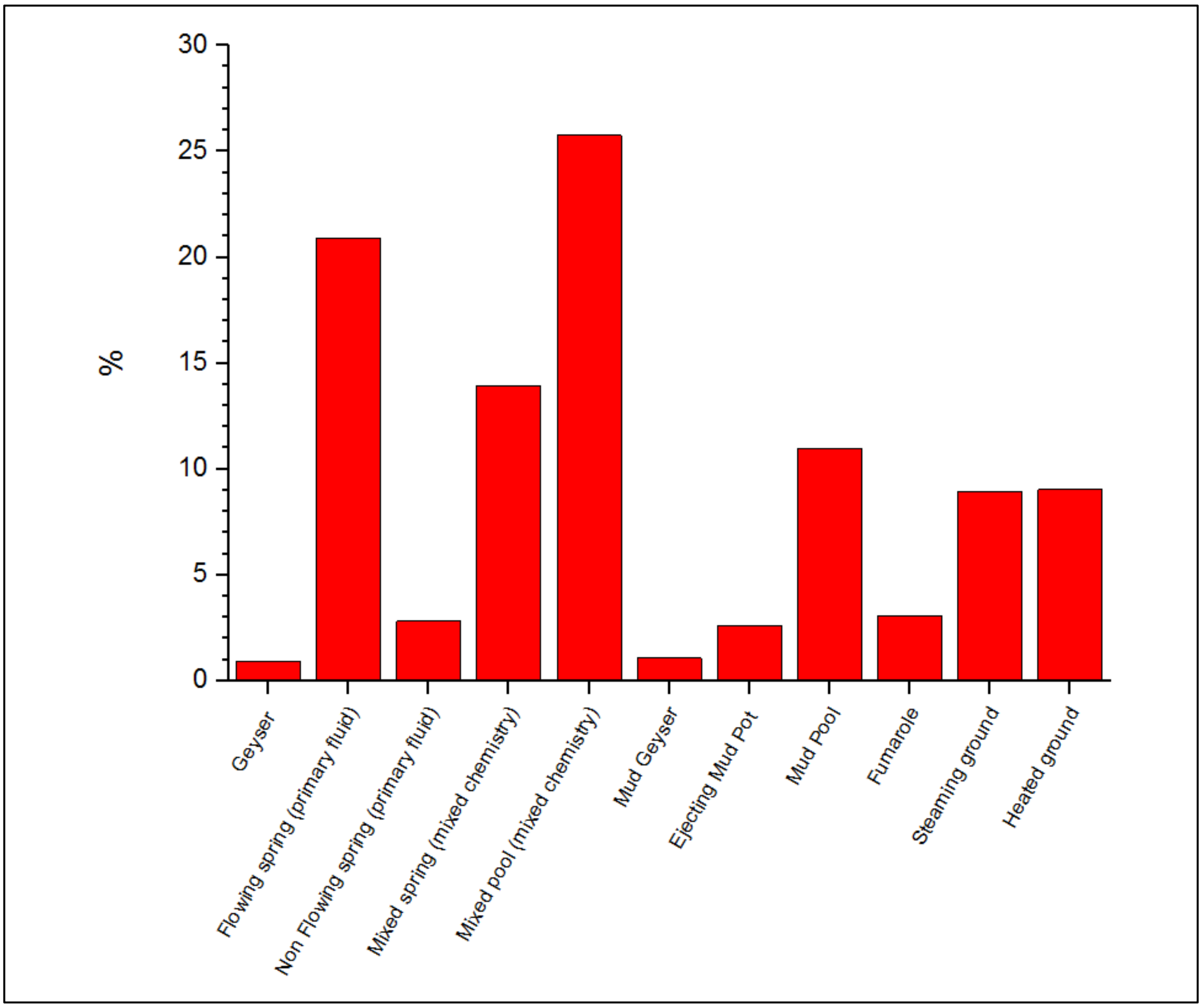


Figure 3.2: Column plot showing the percentage of geothermal features for each feature type in the Geothermal Surface Features database.

### 3.2.3 Test Geothermal Surface Features with the Feature-type Ranking

To further test and evaluate Method 4 we have selected 16 geothermal surface features. Four assessors who are very familiar with TVZ surface features applied the same numerical and weightings as discussed in Section 3.1 in this part of the pilot study.

The results of the four individual weighted assessments and related statistics are shown in Table 3.7.

As can be seen from Table 3.7 there are some variability in the scores, with less range in the values assigned than was seen above for the feature types (Table 3.3). This is attributed to the assessors having less difficultly in using the criteria in Section 3.1. Here the criteria are easier to apply as the assessor can apply 'relativity' when examining one feature against another.

Table 3.7: List of the weighted scores for the four assessors and related statistics.

| Feature | A #1 | A #2 | A #3 | A #4 | Mean | S Dev | Max | Min | Diff. |
|---|---|---|---|---|---|---|---|---|---|
| Geyser: Pohutu | 4.6 | 4.5 | 5.0 | 4.6 | 4.7 | 0.2 | 5.0 | 4.5 | 0.5 |
| Geyser: Crater Bay Lake Rotomahana | 4.6 | 4.5 | 4.5 | 4.6 | 4.5 | 0.0 | 4.6 | 4.5 | 0.1 |
| Flowing spring: Parekohoru | 3.6 | 3.4 | 4.4 | 3.6 | 3.8 | 0.4 | 4.4 | 3.4 | 1.0 |
| Flowing spring: Soda Spring | 3.4 | 3.0 | 3.7 | 3.4 | 3.4 | 0.3 | 3.7 | 3.0 | 0.7 |
| Non flowing spring: Korotiotio | 3.6 | 3.5 | 4.5 | 3.6 | 3.9 | 0.5 | 4.5 | 3.5 | 1.0 |
| Non flowing spring: Rachel Pool | 3.0 | 2.5 | 4.5 | 3.0 | 3.3 | 0.9 | 4.5 | 2.5 | 2.0 |
| Mixed spring: Lake Roto-a-tamaheke | 3.6 | 4.0 | 3.9 | 3.6 | 3.8 | 0.2 | 4.0 | 3.6 | 0.4 |
| Mixed spring: Frying Pan Lake | 4.2 | 4.6 | 4.1 | 4.2 | 4.3 | 0.2 | 4.6 | 4.1 | 0.5 |
| Mixed pool: RRF2051 (Arikikapakapa) | 2.4 | 2.6 | | 2.4 | 2.0 | 0.3 | 3.1 | 2.4 | 0.6 |
| Mud geyser: Te Kopia Road | 3.9 | 4.3 | 4.0 | 3.9 | 4.1 | 0.2 | 4.3 | 3.9 | 0.4 |
| Ejecting mud pot: Waiotapu Loop Road | 3.2 | 3.2 | 3.2 | 3.2 | 3.3 | 0.2 | 3.5 | 3.2 | 0.4 |
| Mud Pool: RRF2112 (Arikikapakapa) | 2.1 | 2.5 | 2.1 | 2.1 | 2.3 | 0.2 | 2.5 | 2.1 | 0.4 |
| Fumarole: Fumarole 0, Whakaari | 4.2 | 4.2 | 4.3 | 4.2 | 4.2 | 0.1 | 4.3 | 4.2 | 0.2 |
| Steaming ground: KAF3001 (Kawerau, sports centre) | 2.2 | 2.6 | 2.2 | 2.2 | 2.4 | 0.2 | 2.6 | 2.2 | 0.4 |
| Heated ground: Sulphur Flats – Rotorua | 3.1 | 3.3 | 3.1 | 3.1 | 3.2 | 0.2 | 3.4 | 3.1 | 0.4 |
| Heated ground: Outlet of Frying Pan Lake, Waimangu | 1.7 | 2.2 | 1.7 | 1.7 | 2.0 | 0.4 | 2.6 | 1.7 | 0.9 |

# 4.0 DISCUSSION

Method 4 has been applied to the 12 feature types defined in the BOPRC RPS (2014) using 3 assessors. This has enabled the 12 feature types to be ranked. The results did show more variability than expected between the assessors. We attribute this to the assessors having difficulty applying the criteria consistently due to the spectrum of interpretations that can be derived from the criteria in Set 7 and the continuum that exist in surface feature types.

Feature types *geyser* and *overflowing springs with primary fluids* are ranked higher having weighted scores over 4. Feature types *Mud Geyser, Fumarole, Ejecting Mud Pot and Non flowing spring (primary fluid)* all scored in the 3–4 range.

Five feature types (mixed spring, mud pool, intermittent or active hydrothermal crater, steaming ground, mixed pool (mixed chemistry) and heated ground are clustered in the 2–3 weighted score range). The upper 4 have similar scores ranging from 2.4 to 2.6 and are also separate from the feature types in the 3–4 range (minimum score was 3.1).

Heated ground is ranked as the least significant feature type.

Feature types mixed pools and non flowing primary springs account for more than 45% of the catalogued features from the BOPRC geothermal surface feature. Four feature types (heated ground, steaming ground, mud pools, and mixed springs) account for 43% of the features. The remaining 5 feature types (geyser, flowing primary springs, mud geyser and ejecting mud pot) account for remaining 10%.

Sixteen individual geothermal surface features were selected and assessed by four independent assessors (Table 3.7). The independent weighted scores show less variation than the variation measured when ranking the feature types. We feel this is due to the assessors being able to think more about the relative values between the individual features and apply the criteria more easily. The two highest scoring features are geysers (matching the feature ranking). The next 5 features are a mix of the feature types and there is no strong correlation to the feature type ranking.

The lower ranked individual features also only have a soft relationship with feature type ranking. It is apparent that size and aesthetic values contribute to the lower scores for these.

Although difficulty was experienced using the BOPRC RPS criteria by the assessors used in this pilot study, the ranking results indicate that consistent results can be obtained by assessors familiar with the types of geothermal surface features seen in the Bay of Plenty region and the TVZ. This was particularly so for the individual features.

## 5.0 REFERENCES

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# APPENDICES

# APPENDIX 1: 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*<br>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*<br>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*<br>7.3 The extent to which the feature is unique or rare in the context of the Taupō Volcanic Zone. |
| *Distinctiveness*<br>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*<br>7.5 The extent to which the feature is resilient to natural changes. |
| *Vulnerability*<br>7.6 The extent to which the feature is vulnerable to fluid extraction. |
| ***Aesthetic values*** |
| *Memorability*<br>7.7 The extent to which the geothermal feature(s) is striking or visually spectacular due to its recognisable and memorable qualities. |
| *Naturalness*<br>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*<br>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. |

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