Ranking geothermal surface features in the Bay of Plenty Region

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CONTENTS

FIGURES

TABLES

APPENDICES

ATTACHMENTS

Excel spreadsheet of BOP geothermal surface feature rankings

EXECUTIVE SUMMARY

A method of scoring geothermal surface features for scientific significance in the Bay of Plenty (BOP) region from a desktop perspective has been developed, honouring the method presented in Scott and Bromley (2018). The method utilises a dataset of 3999 active geothermal surface features in the Taupo Volcanic Zone (TVZ), with 1873 of these in the BOP region.

Of the 1873 geothermal surface features documented in the BOP region, 847 have a score adjustment (from the default feature-type scores proposed in Scott and Bromley (2018)) based on their most recent feature length (that is, its maximum horizontal dimension), feature size (area), temperature or flow data. The feature with the greatest score using this methodology is Pohutu Geyser (RRF0075) located in the Rotorua Geothermal Field.

The method presented in this report provides indicative scores for geothermal surface features in the BOP region based on a desktop study only, without conducting specific site visits to complement ranking. It assumes that the feature has not changed significantly since its physical character was last recorded in the database. This method should not replace a full assessment in areas or cases where cultural, scientific or development sensitivities exist.

1.0 INTRODUCTION

Different types of geothermal surface features occur over New Zealand geothermal fields. These include feature types such as geysers, primary flowing springs, mud pots and heated ground (Scott 2012). The surface expressions of geothermal fields have intrinsic value that may include tourism, cultural values and ecosystem support (e.g., thermotolerant vegetation). Increasing demands on optimising resource utilisation and land use can impact geothermal surface features in areas where developments or land use change is occurring.

Geothermal surface features 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 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 potential 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 associated consenting process administered by local, regional and national government agencies.

Bay of Plenty Regional Council (BOPRC) need to identify Significant Geothermal Features (SGF) as a requirement under the Regional Policy Statement (RPS) (BOPRC 2014). The RPS provides a framework to manage geothermal systems in the Bay of Plenty region. Until recently (Scott and Bromley, 2018), no consistent and transparent method of identifying SGF’s has been available.

Scott and Bromley (2018) presented and evaluated a method to score surface geothermal features according to the Natural Science Values and Aesthetic Values defined in the RPS. Obtaining a score for each geothermal surface feature relative to another is a step in identifying significance. Small-scale testing by Scott and Bromley (2018) of this method has proven to be successful for ranking geothermal surface features.

BOPRC would like to extend the method of Scott and Bromley (2018) to all recorded geothermal surface features in the Bay of Plenty region to obtain a ranking that could be used to help identify SGF’s.

This report proposes a method to rank geothermal surface features in the Bay of Plenty region using a desktop approach. The approach utilises the BOPRC geothermal surface features database and a compilation of other geothermal surface features in the Taupo Volcanic Zone (TVZ), and use the method described in Scott and Bromley (2018) as a starting point. The method proposed in this report is expected to provide a “high-level” ranking for each geothermal feature because all factors required for an assessment are not available in a desktop study. Limitations of the method are discussed.

2.0 METHOD

A statistical approach to modify the surface geothermal feature score is trialed. The statistical approach is based primarily on the feature type, and the physical parameters of the feature such as temperature, size and/or flow rate. These parameters were used because:

- The approach provides a crude assessment of how geothermal features compare to other geothermal features, both in the BOP region and within the TVZ for these parameters. This is a key requirement of the RPS.
- Measured parameters are available for many geothermal features, enabling use of statistics as a valid and consistent methodology.

The method is described in detail below.

2.1 Data processing

Data used in this ranking consisted of:

1) Data from the BOPRC Geothermal Surface Feature Dataset (stored in the GNS Geothermal-Groundwater (GGW) Database) downloaded 10 August 2018 (GNS, 2018a).
2) Unpublished and published geothermal surface feature data compiled by GNS Science for research purposes (GNS, 2018b).

Both data sources use the same data field conventions, so could be readily compiled into a single spreadsheet for testing. Data fields that were compiled for each feature included:

- **GGWID** – a unique GGW database identifier for each geothermal surface feature in the GGW database. This is present for all features from the BOPRC dataset (1 above), but is missing for all other data (2 above) as this data has not been entered into the database at the time this report was completed.
- **Geothermal Field** – the geothermal field that the feature occurs.
- **Regional authority** – the region that the feature occurs in.
- **Common Name** – the name of the feature.
- **Other names** – other names the feature has been known.
- **Longitude, Latitude** – WGS984 longitude and latitude of the feature.
- **Error estimate of the location** – an error on the location (m) and will usually depend how the location was obtained e.g.; a GPS location may have a more accurate location than a location read off a map.
- **Feature length** – the length of a feature in metres (maximum horizontal dimension). This is only usually entered once (at the time the feature was first created in the database) and so does not provide a time-series change. Where entered, it provides an indication of the size (or, the longest side) of the feature. It should be noted that in some cases, the length may be used to represent the length of a group of features if a group of smaller features is being treated as one in the database.
- **Date** – date of the observation/measurement (includes feature type and feature properties such as temperature).

- **Reliability of the date** - an indicator of how reliable the date is. In many cases, the exact date of the observation/measurement is unknown and this must be considered when assessing date-dependent data.
- **Feature type** - the type of geothermal surface feature (e.g., geyser, primary spring etc) consistent with the RPS.
- **Detailed description** – a description of the geothermal surface feature.
- **Feature size** – the estimated area of the feature (m^2). This database field is estimated by observers on a specific date and can be tracked over time where the data is collected.
- **Water/steam temperature** – the temperature (°C) of the feature measured on a specific date. This could be water, steam or the ground temperature depending on the feature type.
- **Flow** – the water flow ($l\ s^{-1}$) of the feature measured/estimated in the field on a specific date.

In this study, we have presumed that all data are correct (i.e., no checking of the final dataset for duplicates or errors was done) and that assignment of the BOPRC feature type (e.g., geyser, primary flowing spring) to each feature was correct.

The combined dataset was checked with six corrections or amendments:

1. 28 records were deleted that did not have a BOPRC feature type.
2. The dataset was reduced to include only large geothermal fields in the Taupo Volcanic Zone (TVZ). The dataset was restricted to the TVZ to conform with the RPS geothermal surface feature comparison requirements. This resulted in rejection of 431 records associated with “Small Systems” (e.g., Coromandel or northern Waikato hot springs) and the “Ngawha” Geothermal Field. This filter will have removed features from the dataset associated with low-enthalpy, non-TVZ, geothermal fields, and so are not included in the ranking process.
3. Non-numeric data was converted to numeric data so that statistics and assessments could be made. This includes:
   - Flows of” <1” were converted to 0.5.
   - The midpoint of a range was selected where a range was given e.g., 54 was used where a temperature range of 50 – 58 was given.
4. Minor errors in some of the observation dates were corrected (i.e., errors assumed to have occurred at the time the data was uploaded into the database).
5. Additional “Feature length” data were extracted from some of the feature descriptions (where this data was stated) and entered into the dataset (or updated accordingly).
6. Feature lengths of “0” were deleted.

The dataset was reduced to include only the **most recent** field information at features where several past measurement visits had been made i.e., one record per feature. This ensures that the statistics and rankings are as accurate as possible with respect to the current situation. This may result in minor loss of data that is used if measurements of temperature, size, or flow were not made on the most recent observation.

2.2 TVZ and BOP Regional Statistics

This study uses the statistical properties median and median absolute deviation (MAD) and percentiles (5^{th}, 25^{th}, 75^{th} and 95^{th}) of the selected geothermal parameters (i.e., temperature, size, length and flow) to define "typical" values, their variability. The median, MAD and percentiles are selected because of the ability of these statistics to handle outliers better than other statistical methods. This avoids "skewing" the statistics with outliers which are known to exist within this dataset. We exclude outliers in the statistical calculations where outliers are defined as >4 MAD from the median unless stated.

The median, MAD and percentiles for the feature size, feature length, water/steam temperature and flow for each feature type are calculated using a modified excel spreadsheet developed by Daughney (2010). We used spreadsheet version "2010 NGMP Calculator Vers NS-8_2.xlsm" that has been modified to enable >200 data points to be processed at once because of the large datasets that need to be processed for this study. Note, because we were only interested in calculating the statistics for each feature type, all data were temporarily allocated the same site name and date for each feature type so that the statistics would be representative for each feature type.

Feature size (area), feature length, water/steam/ground temperature, and flow are selected because of their potential to influence the rankings (e.g., big, hot, large flowing features should intuitively rank higher) and because their data is numerical which enables mathematical manipulations to be done. Statistics are calculated for each feature type to ensure that the unique distributions that occur within a feature type are respected e.g., the size of heated ground is generally much larger that the size of a geyser, therefore the statistics for these categories need to be kept separate. This also enables changes in ranking to be done by feature type. Feature length is used as a proxy for feature size where no size data exists for a record. The term "size" used in this report may therefore refer to either length or area.

The statistics are calculated for each feature type using:

1) The entire dataset i.e., all TVZ features.
2) Only features in the BOP region.

2.3 Score adjustment

The score for each feature is calculated by adjusting the default feature-type score (Scott and Bromley 2018) (Table 2.1) based on the flow, temperature and size of a feature compared to the statistical distribution for each feature type, for each parameter. The default feature-type scores, which are a weighted mean of criteria-based ranking values between 1 (poor) and 5 (excellent), provide the initial starting point for the ranking and represent "average" features. This also ensures that a score is provided in cases where no other information exists.

The Representativeness, Rarity, Distinctiveness, Resilience and Memorability categories (categories in yellow, Table 2.1) are the categories most affected by the selected parameters and therefore are the categories that have scores modified from those presented in Scott and Bromley (2018). Resilience and Memorability are compared to the BOP dataset, while Representativeness, Rarity and Distinctiveness are compared to the TVZ dataset, as set out in the wording of the ranking criteria of the policy document (BOPRC, 2014). The scores of the other categories are not changed in this process.

The scores for the above categories are adjusted by the following procedure:

a) Calculate the adjustment for each category based on which “bracket” the data resides (Figure 2.1):

- -1 where the data is less than the 5th percentile for the relevant parameter.
- -0.5 where the data lies between the 5th and 25th percentiles for the relevant parameter.
- 0 where there is no data, or, the data lies within the 25th and 75th percentiles for the relevant parameter.
- +0.5 where the data lies between the 75th and 95th percentiles for the relevant parameter.
- +1 where the data is greater than the 95th percentile for the relevant parameter.

Selection of the amount to adjust (i.e., -1, -0.5, +0.5 and +1 units) has been based on enabling the **default total score** to vary approximately ±0.5 units which is considered by the author to be reasonable for a desktop study.

b) Average the adjustment over the parameters used, e.g., if data exists for temperature and size, the sum of the adjustments for these two parameters will be divided by 2.

c) Calculate the **total score** using the adjustment and honouring the weightings for each category as described in Scott and Bromley (2018). This results in the equation:

$$\textbf{Total Score} = \textbf{Default} + (0.333A_{TVZ} + 0.18315A_{BOP})$$

Where:

- Default = total score based on feature type (Table 2.1).
- A_{TVZ} = adjustment based on the TVZ categories (Representativeness, Rarity, Distinctiveness).
- A_{BOP} = adjustment based on the BOP categories (Resilience and Memorability).

This equation assumes that the adjustments are applied to each category without any further weightings.

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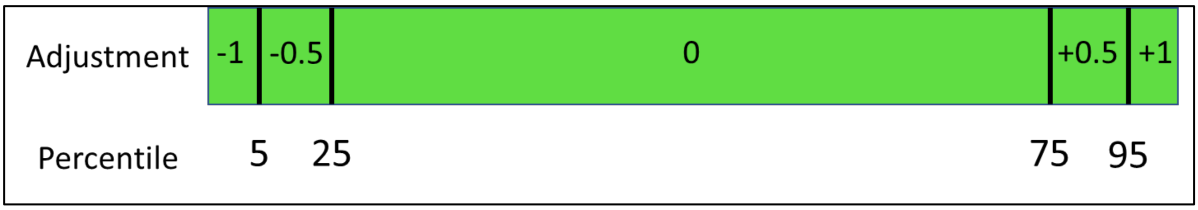

Figure 2.1 Graphical representation of the adjustment to each category based on the percentile the parameter value has.

2.4 Method exceptions

The method described above is applied in most cases, however, the method assumes that there is sufficient data of suitable quality to make the required statistical calculations. This is not the case for some features, and exceptions to the method are required to ensure adjustments can be made and that an overall score can still be calculated for a feature. The exceptions are not expected to make significant differences to the overall rankings because all features start with the default feature-type score. This issue will be resolved over time as more data is obtained of geothermal surface features in the TVZ.

Exceptions to the statistical calculations used in this study are:

- TVZ “Heated ground”, “Steaming ground” and “Geyser” temperatures use the entire dataset (i.e., statistics calculations do not exclude outliers). A value of 1 was added to the 75th percentile of the “steaming ground” temperature because this was the same value (near-boiling point temperature) as the 25th percentile.
- TVZ “Primary pool” length uses the entire dataset (i.e., statistics calculations do not exclude outliers).
- TVZ and BOP flow data is only used for the “Primary flowing spring” and the “Mixed flowing spring” feature types, because these are the only features where flow is valid (e.g., a mixed pool feature type has zero flow because it is a pool and not a spring, therefore flow is not considered in the calculations).
- TVZ and BOP “Hydrothermal eruption crater” temperature data is not used because this is not relevant for a dormant (non-discharging) landscape feature type.
- The scores for the “Cannot be located" or "No thermal activity" feature types are set to zero. These features have still been included in the scoring spreadsheet so that readers can see that geothermal activity has been recorded at a location.
- BOP “Mud geyser” and “Geyser” temperature data are not used, because they are all close to boiling so are not useful as significance discriminators, or, there is a lack of data.
- BOP “Fumarole”, “Geyser” and “Mud geyser” size data are not used because of a lack of data.
- BOP “Geyser” length data are not used because of a lack of data.

Table 2.1 Default scores for each feature type from Scott and Bromley (2018). The "Region to be compared" shows which region needs to be considered when assessing each category (as defined in the RPS). Categories in yellow show the categories considered to be influenced by the feature size, temperature, flow and length.

	Natural Science Factors							Aesthetic Values				Total
Geothermal Feature Type	**Representativeness**	**Diversity and Pattern**	**Rarity**	**Distinctiveness**	**Resilience**	**Vulnerability**	***Sub-total***	**Memorability**	**Naturalness**	**Transient Value**	***Sub-total***	
Region to be Compared	**TVZ**	**TVZ**	**TVZ**	**TVZ**	**BOP**	**BOP**		**BOP**	**BOP**	**BOP**		
Ejecting Mud Pot	3.3	3.7	3.3	3.3	2.7	2.7	3.15	3.7	3.7	3.7	3.7	3.3
Flowing spring-primary	4	4	4	3.4	4.3	4.3	4.015	4	4	4	4	4.0
Fumarole	4.3	4	3.7	4	3.7	2.7	3.68	3.7	4	2.7	3.6	3.6
Geyser	4.7	4	5	5	3.3	4	4.35	5	4.7	5	4.85	4.5
Heated ground	1.7	2	1.7	1.7	3	1.7	1.94	1.7	1.7	1.5	1.65	1.8
Hydrothermal Crater	2.3	1.7	3	2.3	3.7	2	2.5	2.3	2.3	3	2.475	2.5
Mixed pool	2.3	2.3	2	2	2.3	2	2.135	2.3	2.3	2	2.225	2.2
Mixed spring	2.7	3	2	2.7	2.7	2.3	2.525	2.7	3	2.7	2.85	2.6
Mud Geyser	4	3.3	4.7	4.3	2.7	2.7	3.625	4.3	3.7	3.7	3.85	3.7
Mud Pool	2.7	2.7	2.3	2.3	2.7	2	2.42	2.7	3	2.7	2.85	2.6
Non-flowing Spring-primary	3	3.3	3.3	2.3	3.7	2.7	3.045	3.3	3.3	2.7	3.15	3.1
Steaming ground	2.7	3.3	2.3	2.3	3	2	2.555	2	2.3	2	2.15	2.4

3.0 RESULTS AND DISCUSSION

Tables 3.1 and 3.2 summarise the statistics associated with geothermal surface features in the TVZ and BOP regions respectively. In total, 3999 active geothermal features in the TVZ (with 1873 of these located in the BOP region) are used in this assessment.

The 5th, 25th, 75th and 95th percentiles in Tables 3.1 and 3.2 are used to calculate the appropriate bracket, and therefore the adjustment to the total score. Tables 3.1 and 3.2 provide good benchmarks for basic geothermal surface feature data and can be used to monitor regional scale changes over time as this process is repeated.

The ranking of feature type based on the number of features in each feature type category is similar between the TVZ and BOP regions. Both regions have mixed pools, primary springs, mixed springs and mud pools as the most common feature types. Similarly, geyser and mud geyser types were the least common features in both regions (Tables 3.1 and 3.2).

Appendix 1 (Excel file attached) summarises the results of the score adjustments for the features in the BOP region with quality codes: 847 features received an adjustment to the default score, with 285 features reducing their total score by up to 0.51 units and 562 features increasing their total score by up to 0.51 units. The highest scoring feature is RRF0075 (GGW Feature ID 993) which is Pohutu Geyser in the Rotorua Geothermal Field. Intuitively, this feature may be predicted to score highly so this result is consistent with expectation.

The 109 highest scoring features have scores greater than 4.16 and consist of geysers, mud geysers and primary flowing springs, and occur across eight geothermal fields at Rotorua, Waimangu-Rotomahana-Mt Tarawera, Rotoma-Tikorangi-Mangakotukutuku, Lake Rotokawa-Mokoia, Centre basin – Rotoiti, Lakes Okataina-Tarawera, Tikitere, and Kawerau; (Figures 3.1 and 3.2). All 16 of the geysers identified in the BOP region are amongst the top 109 scoring features. Some caution should be used when interpreting high-scoring features because some features may have had large positive adjustments caused by “grouping” features together in the database making higher values for the geothermal parameters e.g., Feature LOF3000 is a primary spring that has a length of 50 m, however, this length describes a series of smaller discharges and is not actually a single spring with a diameter of 50 m. This situation is thought to occur only in a small number of cases.

The 129 least scoring features (excluding features with no thermal activity or could not be located) have scores less than 1.81 and consist of heated ground and 2 mixed pools spread across 10 geothermal fields (Rotorua, Rotoma-Tikorangi-Mangakotukutuku, Lake Rotokawa-Mokoia, Whale Island, Kawerau, White Island (Whakaari), Waimangu-Rotomahana-MtTarawera, Waiotapu, Taheke, and Tikitere) (Figures 3.1 and 3.2). The large proportion of heated ground features in this group probably reflects the low default feature-type score allocated to the heated ground feature type, and that additional data used for the score adjustment is scarce.

The quality control score (Appendix 1) shows that the scoring adjustment is based on limited data and that obtaining more water temperature, size and flow data for geothermal surface features will improve the reliability of the score adjustments. Of the 1873 geothermal surface features that are active, and that can be located in the BOP region, data available to calculate the adjustments (% values in blue text below) shows how this compares to the entire TVZ dataset (% values in red text below):

- All three parameters, size, temperature and flow data, were available for 191 features (BOP 10%, TVZ 17%).

- One parameter of size, temperature or flow data was available for 925 features (BOP 49%, TVZ 34%). This was dominated by size data.
- Two parameters of size, temperature or flow data were available for 42 features (BOP 2%, TVZ 20%).
- No parameter data were available for 715 features (BOP 37%, TVZ 28%).

An analysis of the observation dates is important because it provides an indicator if the data is recent or reflects much earlier conditions. "Older" data may not reflect subsequent changes that have occurred due to natural and/or anthropogenic causes and may therefore provide incorrect scoring.

The observation dates of the features in the BOP region are relatively young, with only 78 features (i.e., 4%) having been observed/measured before 1 January 2000 (i.e., most data have been observed within the last 18 years). This compares favourably to the entire TVZ region where 2083 features (i.e., 52%) were observed/measured before 2000. This suggests:

- Although relatively recent data is available for the BOP region, required data for this analysis may be incomplete.
- Data in the TVZ region (excluding BOP) is dated, and may not be fully representative of the current state of all geothermal surface features. In some developed geothermal fields, for example, regular monitoring undertaken as part of resource consent requirements reveal temporal changes in geothermal surface features of both natural and anthropogenic origin.

Overall, scores have been assigned to the known features in the BOP region, however, several limitations are identified below:

- The total score will vary from a default 'type' ranking value only where additional data (size, temperature, flow) exists. This will limit the effectiveness of the technique where data does not exist for a feature.
- The datasets used to adjust the total score are generally lacking for the "Geysers" feature type, therefore the scores for geysers do not greatly change. This is not considered to be an issue here, because geysers have a high-ranking score based on their feature type alone, but differentiation would improve with more flow, height and eruption frequency data in the dataset.
- The assessment only includes active geothermal features that were recorded as active on the last field observation. Historic activity is not considered.
- The scores for the geothermal surface features are date dependent i.e., as more data are obtained, the statistics will change causing possible changes in the boundaries used to select the value of the adjustment. "Old" data may also not accurately represent the current status of geothermal surface features.
- The scores will only be approximate given that no site visit has been made and that there are other categories not addressed in this work that are required in calculating a score for significance (e.g., diversity and pattern). An improved dataset for assessment of relative size would also be useful, for example, feature areas determined from airborne thermal infrared surveys, and vertical discharge heights of geysers.

Table 3.1 Summary statistics for the geothermal surface features in the TVZ region. Note that some values have been rounded.

TVZ statistics													
Feature type	Total number of features for each feature type	Parameter	Total number of results for each parameter	Number of results used to calculate the statistics for each parameter	Min	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile	Max	Median Absolute Deviation (MAD)	Comment
Fumaroles	214	Length of feature (m)	84	50	0.1	0.17	0.41	0.65	1	2.55	3	0.35	
		Feature size (m^2)	29	22	0.02	0.03	0.07	0.2	0.28	0.50	0.7	0.13	
		Water/steam temperature (°C)	41	27	71	77.87	94	98.8	100	101	106.5	2.2	
Geysers	64	Length of feature (m)	23	17	0.3	0.42	0.6	1.5	2.1	4.1	4.5	0.9	
		Feature size (m^2)	38	35	0.05	0.1	0.4	1.4	2.75	4.3	5	1.1	
		Water/steam temperature (°C)	45	45	35	58	90	98	99.8	100	101	2	Includes all data (i.e., outliers included)
Heated ground	256	Length of feature (m)	233	136	0.5	1.38	8	15	50	100	130	12	
		Feature size (m^2)	76	54	0.12	4.65	176	687.5	2475	5652.6	9592	680.95	
		Temperature (°C)	75	75	24.7	37.7	52	52	59	73	73	0	Includes all data (i.e., outliers included)
Eruption craters	115	Length of feature (m)	72	60	1	3.9	9.5	30	82.5	150	225	25	
		Feature size (m^2)	68	49	1	7.44	25	314	1590	3000	5000	295	
Mud geysers	30	Length of feature (m)	24	20	0.1	0.12	1.05	2	3	5.05	6	1	
		Feature size (m^2)	6	5	2.7	2.79	3.14	5.72	15.9	25.58	28	3.02	
		Water/steam temperature (°C)	3	3	82	82.3	83.5	85	88.15	90.67	91.3	3	
Mud pots	65	Length of feature (m)	56	45	0.3	0.32	2	3	6	10	11	2	
		Feature size (m^2)	47	36	0.0007	0.11	1	4.7	8.08	25.5	27	3.7	
		Water/steam temperature (°C)	45	45	24.6	29.76	49.9	76.5	90.3	98.44	100.9	19.9	

TVZ statistics													
Feature type	Total number of features for each feature type	Parameter	Total number of results for each parameter	Number of results used to calculate the statistics for each parameter	Min	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile	Max	Median Absolute Deviation (MAD)	Comment
Mixed springs	658	Length of feature (m)	382	230	0.03	0.15	0.5	1.3	3	7	8.5	1	
		Feature size (m^2)	165	118	0.0007	0.0037	0.053	0.33	1.79	4.58	6	0.32	
		Water/steam temperature (°C)	362	362	8	29.41	50	65	83.65	97.69	101.7	17	
		Flow (l/s)	241	177	0.003	0.03	0.17	0.5	0.75	2	2	0.3	
Mixed pools	828	Length of feature (m)	736	439	0.05	0.3	1	2.3	5	10	12	1.6	
		Feature size (m^2)	333	238	0.004	0.07	0.6	1.8	8.9	24.15	33	1.66	
		Water/steam temperature (°C)	337	337	10	24	40.2	62.3	85	97.54	100.5	22.3	
Mud pools	447	Length of feature (m)	277	172	0.15	0.355	1	2.5	5	9.45	10	1.5	
		Feature size (m^2)	127	99	0.02	0.2	0.73	4.5	12	25.3	30	4.2	
		Water/steam temperature (°C)	128	107	58	62.38	80	93.8	98	98.78	100.4	4.2	
Primary springs	763	Length of feature (m)	404	223	0.05	0.15	0.7	1.5	2.65	6	7	1	
		Feature size (m^2)	160	121	0.0007	0.02	0.16	0.7	1.5	3.2	4.8	0.55	
		Water/steam temperature (°C)	304	297	35.5	45.8	67	85	95.2	99	104	11.5	
		Flow (l/s)	268	223	0.00053	0.03	0.1	0.25	0.5	1	1	0.15	
Primary pools	257	Length of feature (m)	116	97	0.15	0.3	1	4	10	13.6	80	3.4	Includes all data (i.e., outliers included)
		Feature size (m^2)	168	119	0.03	0.09	0.39	1	3	7.1	10	0.84	
		Water/steam temperature (°C)	185	185	5.1	21.68	55	75	95	98.5	101.5	20	

Feature type	Total number of features for each feature type	Parameter	Total number of results for each parameter	Number of results used to calculate the statistics for each parameter	Min	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile	Max	Median Absolute Deviation (MAD)	Comment
TVZ statistics													
Steaming ground	302	Length of feature (m)	276	199	0.1	1	6	15	30	60	80	10	
		Feature size (m^2)	120	100	0.03	0.5	60	200	662.5	1138.25	1561	194	
		Temperature (°C)	76	76	28.7	43.78	80	80	81	98.15	100	0	Includes all data (i.e., outliers included). 75th percentile changed from 80 to 81
Cannot be located	27												
No thermal activity	501												
Total number of features in the TVZ	4527												
Total number of active features in the TVZ that can be located	3999												

Table 3.2 Summary statistics for the geothermal surface features in the BOP region. Note that some values have been rounded.

BOP Region statistics											
Feature type	**Total number of features for each feature type**	**Parameter**	**Total number of results for each parameter**	**Number of results used to calculate the statistics for each parameter**	**Min**	**5th Percentile**	**25th Percentile**	**Median**	**75th Percentile**	**95th Percentile**	**Max**	**Median Absolute Deviation (MAD)**
Steaming ground	164	Feature size (m^2)	12	8	0.03	0.30	0.95	4	6.28	10.61	12.5	3.05
		Temperature (°C)	14	14	41.6	45.11	69.05	88.15	98	100	100	11.85
		Length of feature (m)	162	100	0.1	1	4.5	8	15	25.25	30	5
Primary non-flowing pool	47	Feature size (m^2)	22	20	0.07	0.09	1.27	4	8.13	18.1	20	3.52
		Water/steam temperature (°C)	21	18	55.3	61.68	76.33	86.95	95.45	98.02	98.1	10.45
		Length of feature (m)	43	22	0.3	0.72	1.53	2.5	4.38	7	8	1.5
Primary flowing spring	373	Length of feature (m)	335	167	0.05	0.30	0.70	1.50	3.65	7.00	8.00	1.00
		Feature size (m^2)	25	21	0.06	0.5	2	10	20	30	40	9
		Water/steam temperature (°C)	26	25	46.9	50.28	62.8	86.6	94.2	99.84	100	8.6
		Flow (l/s)	20	11	0.00053	0.003	0.02	0.1	0.2	0.25	0.3	0.09
Mud pots	46	Length of feature (m)	46	37	0.5	1	3	4	8	11.8	15	2
		Feature size (m^2)	37	27	0.3	0.58	3.05	6	18	27	40	4
		Water/steam temperature (°C)	35	35	24.6	28.45	44.3	62.4	82.35	91.95	100.9	20.4
Mud pool	196	Length of feature (m)	195	123	0.15	0.4	1.5	3	6.75	20	300	2
		Feature size (m^2)	28	20	0.2	0.25	6.53	12	16.7	31.5	60	5.55
		Water/steam temperature (°C)	30	30	24.9	27.05	38.03	64.25	83.33	96.65	100.4	25.5
Mud geyser	19	Length of feature (m)	19	16	0.1	0.12	0.58	2	2.63	5.25	6	1

BOP Region statistics												
Feature type	Total number of features for each feature type	Parameter	Total number of results for each parameter	Number of results used to calculate the statistics for each parameter	Min	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile	Max	Median Absolute Deviation (MAD)
BOP Region only												
Feature type	Total number of features for each feature type	Parameter	Total number of results for each parameter	Number of results used to calculate the statistics for each parameter	Min	5th Percentile	25th Percentile	Median	75th Percentile	95th Percentile	Max	Median Absolute Deviation (MAD)
Mixed pool	460	Length of feature (m)	455	216	0.05	0.65	2	3.5	7	15	16	2.25
		Feature size (m^2)	58	41	0.4	1	2	15	30	100	120	13
		Water/steam temperature (°C)	58	51	22.9	24.3	27.85	33.3	48	64.65	77.2	6.9
Mixed spring	269	Length of feature (m)	237	136	0.03	0.3	1	3	7	15	20	2.05
		Feature size (m^2)	17	11	0.5	2.75	6	10	37.5	60	75	5
		Water/steam temperature (°C)	30	30	24.3	26.85	38.85	59	80	97.17	101.7	21
		Flow (l/s)	21	6	0.01	0.13	0.5	0.5	0.88	1	1	0.25
Eruption craters	35	Length of feature (m)	11	7	1	1.3	2	5	9	20.5	25	3
		Feature size (m^2)	11	8	1	2.05	4	25	61	100	100	22
Heated ground	168	Length of feature (m)	163	84	0.5	1	4.75	10	15	30	35	5
		Feature size (m^2)	18	13	0.12	0.65	5	9	100	300	300	8

BOP Region statistics												
Feature type	**Total number of features for each feature type**	**Parameter**	**Total number of results for each parameter**	**Number of results used to calculate the statistics for each parameter**	**Min**	**5^{th} Percentile**	**25^{th} Percentile**	**Median**	**75^{th} Percentile**	**95^{th} Percentile**	**Max**	**Median Absolute Deviation (MAD)**
		Temperature (°C)	15	15	24.7	26.8	35.5	48.8	55.1	62.91	63.4	7.1
Geyser	16											
Fumarole	80	Length of feature (m)	56	30	0.3	0.35	0.73	1.25	3	6	8	0.75
		Water/steam temperature (°C)	11	10	25	28.15	34.25	100.5	101	127.95	150	25
Cannot be located	27											
No thermal activity	50											
Total number of features in the BOP region	1950											
Total number of active features in the BOP region that can be located	1873											

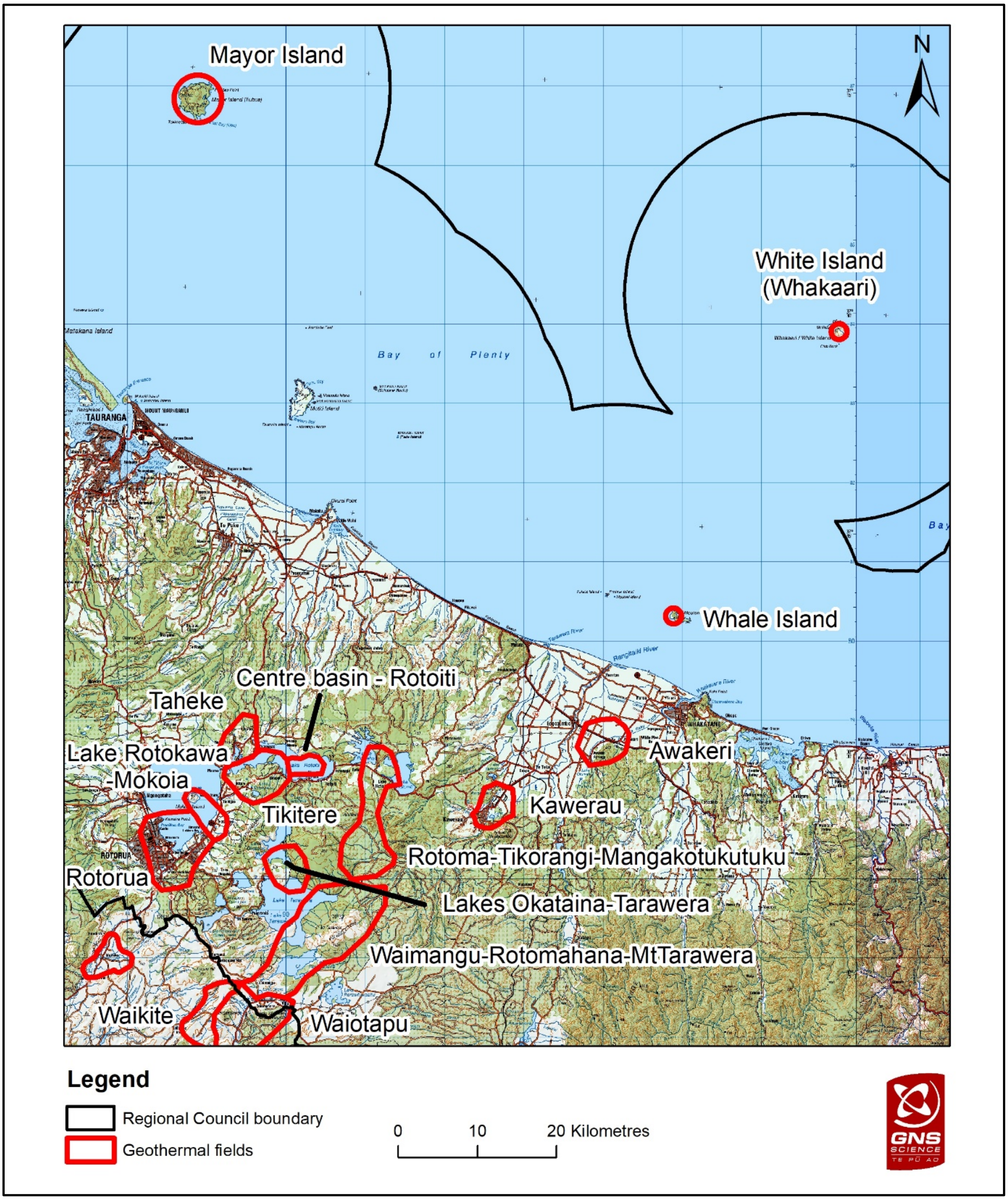

Figure 3.1 Geothermal Fields in the Bay of Plenty region.

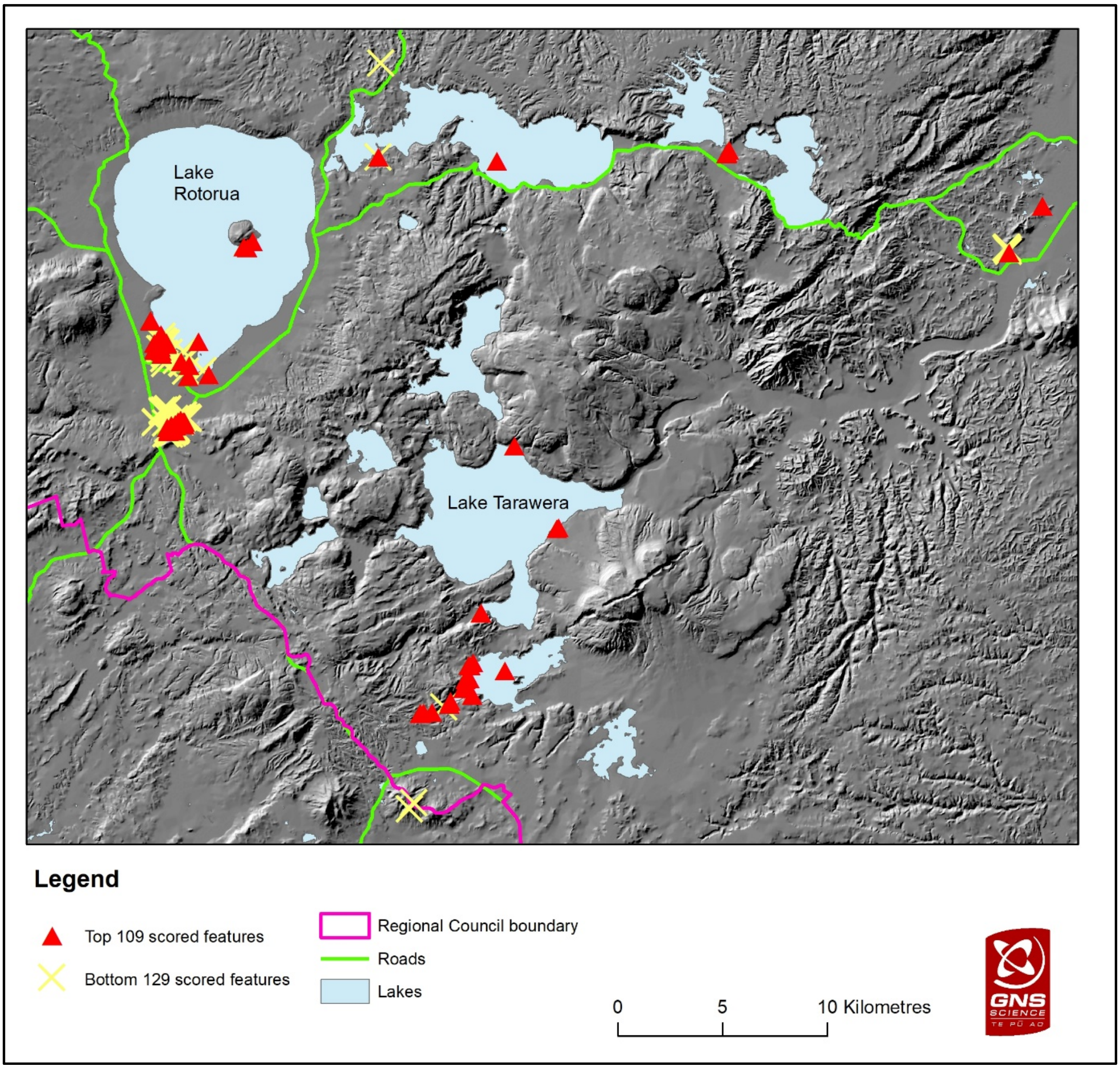

Figure 3.2 Locations of geothermal features with least and greatest scores in this study.

4.0 SUMMARY

A method of scoring geothermal surface features in the BOP region from a desktop perspective has been developed, honouring the method for assessing feature significance presented in Scott and Bromley (2018). The method utilises a dataset of 3999 active geothermal surface features in the TVZ, with 1873 of these in the BOP region.

Of the 1873 geothermal surface features in the BOP region, 847 have a score adjustment based on the most recently acquired feature length, feature size, temperature or flow data. The highest scored feature using this methodology is Pohutu Geyser (RRF0075) which is located in the Rotorua Geothermal Field.

The method presented in this report provides indicative scores for geothermal surface features based on a desktop study that addresses some of the categories required to assess relative significance of a geothermal surface feature. This method should not replace a full assessment required in areas or cases where cultural, scientific or development sensitivities exist.

Recommended work to improve these results include:

- Geothermal feature resurveys in both the BOP and other TVZ geothermal fields. The surveys would need to be standardised according to Scott (2012) and would need to include more data on geysers (including, eruption height, eruption frequency and eruption length).
- The heated ground feature type is likely under counted because of difficulties identifying heated ground. Improved data for this feature type could be obtained from aerial thermal infrared surveys to identify heated ground.
- Analysis of thermal infrared surveys would also Improve relative descriptions of ‘size’ in the feature description database by replacing “length” values with “area” values.

5.0 REFERENCES

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APPENDICES

APPENDIX 1: GEOTHERMAL SURFACE FEATURE SCORES

The scores for the geothermal surface features for the BOP region are on the attached file. The geothermal features are sorted from the highest scoring features to the lowest scoring features.

The quality control (QC) codes in the QC column are:

1. No size, temperature or flow data exist.
2. Either size or length (size) data exist.
3. Temperature data exist.
4. Flow data exist.
5. Size and temperature data exist.
6. Size and flow data exist.
7. Temperature and flow data exist.
8. Size, temperature and flow data exist.

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