Desktop assessment to define significant geothermal features in the Bay of Plenty region

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EXECUTIVE SUMMARY

The Bay of Plenty Regional Council (BOPRC) Regional Policy Statement (RPS) (BOPRC 2014) provides a framework to manage geothermal systems in the Bay of Plenty (BOP) region. BOPRC need to identify significant geothermal features (SGFs) as a requirement under the RPS. Until recently, no consistent and transparent method of identifying SGFs has been used by BOPRC. Identifying SGFs in the BOP region is required to inform management resource decisions and enable higher levels of environmental protection to these features.

This report develops and uses a desktop methodology to test definitions of SGFs in the BOP region based on assigning scores to geothermal surface features (GSFs) from previous work. Two methods of defining geothermal significance are presented:

1. SGFs are defined based on scores from a GSF database. Two tiers are proposed: Tier 1 features are classified as significant, and Tier 2 where a further assessment is needed to test the level of significance.
2. Significant geothermal landscapes are defined based on the density and length of the GSFs over larger areas. As for SGFs, two tiers are proposed.

These definitions provide a first-pass on defining SGFs and significant geothermal landscapes for resource management purposes in the BOP region from a desktop perspective. This technique should be used in conjunction with the more comprehensive approach as described by Scott and Bromley (2018).

1.0 INTRODUCTION

Different types of geothermal surface features (GSFs) are recognised and defined within New Zealand geothermal fields (Figure 1.1). These feature types include geysers, primary flowing springs, mixed pools, mud pots and heated ground (Scott 2012). The surface expressions of geothermal fields have intrinsic value to tourism, local culture and ecosystem support (e.g., thermotolerant vegetation). Increasing demands on optimising resource utilisation and land use can impact GSFs in areas where developments or land use change is occurring.

The Resource Management Act (RMA) (1991) is the main piece of legislation that sets out how we should manage our environment. The act provides policies and procedures that environmental managers must follow. The act provides a basis for which Regional Councils can develop policies to manage natural resources of each region. This includes policies for managing geothermal resources.

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 (BOP) region. Until recently, no consistent and transparent method of identifying SGFs has been used by BOPRC. Identifying SGFs in the BOP region is required to inform resource management decisions and enable higher levels of environmental protection to these features.

Reeves (2019) ranked 2165 GSFs in the BOP region based on the methodology proposed by Scott and Bromley (2018). The rankings calculated by Reeves (2019) were made from a desktop analysis of GSFs and used feature type (e.g., geyser, primary flowing spring, mud pot) (Figure 1.1), water flow, temperature and size/length as proxies to address the assessment categories defined in the RPS. Although this resulted in a relative ranking for each GSF, it did not attempt to define were the boundaries for significance could fall. Also, that report did not address how groups of GSFs (that make up part of a landscape) can be considered significant as a collective where they might not have met the threshold of an SGF in isolation.

The definition of a ‘landscape’ does not exist in the RMA (1991), and as such, has been tested under environmental case law where landscapes are important in assessing a resource consent. The New Zealand Institute of Landscape Architects describes a landscape as reflecting ‘the cumulative effects of natural and cultural processes’ (Quality Planning 2017). An assessment of a landscape in an RMA process needs to consider biophysical elements, patterns and processes; sensory or perceptual qualities; and associative meanings and values (that include cultural and social).

It is beyond the scope of this report to address all the landscape considerations in the geothermal fields of the BOP region (Figure 1.2). Instead, we propose a simple methodology that will identify “significant” geothermal landscapes based on geothermal features alone, i.e., address one of the geological components of a landscape assessment that can be used in combination with other datasets to ultimately define a significant landscape.

Camburn (2020) identified three objectives related to the definition and use of significance as related to SGFs and geothermal landscapes in the BOP region. These were:

1. Identifying a suitable tiered structure that could be used to enable a staged rule approach based off the ranking scores calculated in Reeves (2019).
2. Assess the BOPRC geothermal fields for absences of SGFs (as obtained above) and determine the significance of GSFs in these geothermal fields.
3. Develop a technique that could be used to identify significant geothermal landscapes. The aim is to define potential boundaries around groups of GSFs that by themselves may not be individually significant but acknowledges that they may be significant as a collective group.

This report develops and uses a methodology to test definitions of SGFs in the BOP region based on Camburn (2020) and conversations with Freya Camburn and Penny Doorman from BOPRC, and, Brad Scott from GNS Science.

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 1.1 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).

Figure 1.2 Geothermal fields in the BOP region assessed in this report (Note that geothermal fields such as Tauranga and Maketu are not included in this assessment).

2.0 METHOD

2.1 Method Overview

Data from Reeves (2019) is used as the underlying dataset for this assessment. Derivation of the ranking scores and limitations of these data are discussed in Reeves (2018 and 2019) and are summarised in Appendix 1. Reeves (2019) calculates a score for each GSF between 0 and 5, with higher scores representing GSFs that are considered more scientifically significant. In general, primary features (such as geysers and primary flowing springs) will rank higher than secondary features (such as heated ground and mud pots) because of the geological processes required to create these types of geothermal features. A tiered approach is used to define both SGFs and Geothermal Landscapes. In this approach, the GSFs/Geothermal Landscapes are split into three tiers based on the statistical properties of the GSFs\Geothermal Landscape scores. GSFs\Geothermal Landscapes in Tier 1 have the highest scores and would be classified as "Significant" without further assessment. GSFs\ Geothermal Landscapes in Tier 2 would require a significance assessment as part of each application that may have an impact on these GSFs/Geothermal Landscapes. This assessment would be consistent with BOPRC (2014) and, Scott and Bromley (2018). GSFs\Geothermal Landscapes in Tier 3 would require no significance assessment. A method of defining the Tier 1 and Tier 2 boundaries is described below.

The tiered approach allows for potential discrepancies and/or missing data in the database to be considered (e.g., feature data not complete resulting in under scoring/over scoring) and ensures key GSFs will not be missed. This also enables:

- Additional feature types to be considered because we expect primary features to dominate the rankings.
- The highest-ranked GSFs at geothermal fields that may not have an SGF as defined in the criteria described above to be highlighted.

Two modifications to the data were performed prior to any analysis to enable a robust assessment:

1. Only active features were used in the analyses (i.e., removed 76 GSFs that were classified as "No thermal activity" or "Feature could not be found").
2. Data from inside the BOP Region only was used (i.e., nine features from the Waiotapu Geothermal Field are removed).

Published names and boundaries of geothermal fields in New Zealand has varied over time and has usually depended on the author, organisation and method used to define geothermal field boundaries. This report uses geothermal names as entered into the database so that this report honours the data provided. Table 2.1 relates the geothermal field names used in this report to those in the RPS to ensure the results of this study can be easily mapped into a regional management context.

Table 2.1 Names of geothermal fields used in this report related to names used in the RPS.

Geothermal Field (This report)	RPS Geothermal Field
Awakeri	Awakeri
Centre basin - Rotoiti	Lake Rotoiti
Kawerau	Kawerau
Lake Rotokawa-Mokoia	Rotokawa-Mokoia Island
Lakes Okataina-Tarawera	Not in the RPS
Mayor Island	Mayor Island (Tuhua)
Rotoma-Tikorangi-Mangakotukutuku	Rotoma-Tikorangi, Rotoma-Puhi Puhi
Rotorua	Rotorua
Taheke	Taheke
Tikitere	Tikitere-Ruahine
Waimangu-Rotomahana-MtTarawera	Waimangu-Rotomāhana Tarawera
Whale Island	Moutohora Island (Whale Island)
White Island (Whakaari)	Whakaari (White Island)

2.2 Geothermal Surface Feature Significance

Two thresholds for defining a Tier 1 SGF based on the rankings are tested:

1. An assessment of the ranking distribution informed by statistical properties of the dataset.
2. Top 20% of scores. This approach uses the score (3.74) of the 431 highest ranked GSF as a cut off to define an SGF. Twenty percent was selected as a relative conservative percentage of GSFs.

The Tier 2 threshold is defined as the median of the ranked scores. This will result in approximately half the documented GSFs requiring potentially some form of assessment. These definitions will provide an indicator to the BOP regions most scientifically significant GSFs based on the desktop study.

2.3 Geothermal Landscape Significance

The fundamental assumptions adopted by this study in assessing the relative significance of geothermal landscapes are that, firstly, they contain GSFs and, secondly, large areas (of at least 25 ha) of GSFs are assumed to be more significant than smaller areas of GSFs. A mathematical technique using the same GSF database to estimate GSF length density per unit area (500 m by 500 m grid) is used to identify areas of high-geothermal-feature-length density. Boundaries for two Tiers (as for the SGF Tiers) are calculated by adopting the following procedure:

1. The length of the GSF is used as a proxy for GSF size. Of the 2156 GSF records, 1256 have a length record and only 393 have a size record. Length was selected because of the higher number of records that have this data available.
2. For records without length data, records were assigned the median length of the appropriate feature type, based on the Taupo Volcanic Zone (TVZ) dataset (as summarised by Reeves 2019). The TVZ median length was used because it provided a larger dataset to work with (and therefore will be more representative of the population) compared to the BOP dataset alone.

3. A weighted density of feature lengths is calculated for each 500 m x 500 m grid area over the BOP region. This process assumes that a significant geothermal landscape will be larger than 500 m x 500 m. A 500 m x 500 m grid was calculated automatically by the “Point Density” function in the ArcGIS software. The boundaries of the gridding are determined by the extents of the GSF data. The weighted density calculation uses the length at each GSF as its weighting (i.e., the score calculated for each area is the sum of the lengths of all of the GSFs in that area). This ensures that large GSFs have more weight than smaller GSFs in the calculation (a characteristic that is perceived from viewing many geothermal landscapes). These calculations are performed using ArcGIS software.
4. The boundaries of Tier 1 and Tier 2 were set based on an assessment of the frequency histogram of the length density data (see results section). The tier levels are set at higher thresholds (i.e., higher ranking scores) than for the SGF definitions because landscapes cover much larger areas, and thus will include large numbers of GSFs, thus making the SGF ranking redundant. Note that all grid cells with zeros (i.e., a grid area that did not contain a GSF) were removed for the analyses.

3.0 RESULTS

3.1 Definition of SGFs Through Rankings

Scores for the 2156 GSFs in the BOP region range from 1.28 to 4.67 (Appendix 2 (provided as a file attachment in the PDF)) with the key statistical parameters summarised in Table 3.1. A frequency histogram dividing the scores into 20 bins (bin width of 0.18) shows a bimodal distribution (Figure 3.1) with high GSF counts between scores 2.1–2.64 and 3.81–4.08. Based on these data sets, two thresholds for defining a Tier 1 SGF are examined:

1. Top 20% – i.e., rank score >3.74.
2. Third quartile – i.e., rank score ≥3.34. This score is very close to the frequency low that divides the two lobes of the bimodal distribution seen in Figure 3.1 and therefore supports this selection of this as a Tier boundary.

The median score of 2.6 was used as the cut off for the second Tier in both cases because this encompasses at least 50% of the features. This is considered to be a conservative Tier boundary.

Table 3.2 summarises the number of GSFs, the types of GSFs and the geothermal fields in which they occur, for the SGF definitions and the Tier 2 GSFs. Table 3.3 and Table 3.4 summarise the percentage of GSFs that occur in each Tier and the total number of features that occur in each Tier and in each geothermal field respectively.

The results show that only four feature types are represented across ten geothermal fields in Tier 1 defined as the top 20% of features (Table 3.3 and Table 3.4). The types of features that are represented are geysers, mud geysers, fumaroles and primary flowing springs. This result is expected given the higher default scores for these features (Scott and Bromley 2018) and the methods used to calculate the final ranking score for each feature (Reeves 2019). The types of features included in this Tier are generally hot and/or large. Primary springs included in this Tier are typically those depositing sinters.

Six feature types over eleven geothermal fields are represented in Tier 1, when defined (as in option 2 above) as those with scores in the top quartile (25%) (Table 3.3 and Table 3.4). Mud pots and primary flowing pools are the two feature types that are additional to the option 1 definition of Tier 1.

It is recommended that the “Top 20%” option (Option 1) be selected for defining Tier 1 SGFs over the 3rd quartile method. This recommendation is based on the authors opinion after reading the descriptions of the additional features from the database and comparing this to characteristics that might be expected from an SGF. The feature descriptions in the database generally provide qualitative detail that cannot be obtained from the numerical characteristics used in the score calculation.

However, in both cases, the Tier 1 definitions do not include some GSFs that intuitively should be included. These features are captured in the Tier 2 definition and, and, in some cases the landscape definition (discussed below), hence argue that such features will need to be assessed individually.

The Tier 2 definition (scores ≥ 2.6) has at least 13 examples of all feature types except heated ground (not included) and includes at least one GSF from each geothermal field (Table 3.3 and Table 3.4). This tier represents features that should be assessed individually for significance based on the method of Scott and Bromley (2018). This Tier boundary is set conservatively so as to ensure GSFs that could be significant are not missed. An example is Inferno Crater (WMF3026) in the Waimangu-Rotomahana-Mt Tarawera Geothermal Field. The GSF score is 2.6, hence is within Tier 2, but not Tier 1 based on this desktop assessment. However, some important characteristics of this feature (large mixed flowing spring, with cyclic water level variations of over 10 m over a 30-day period, and high tourist values) were not aspects that were automatically considered in the feature type-based database assessment. This feature would probably be defined as an SGF under a Scott and Bromley (2018) individual feature assessment, although it does not meet the Tier 1 criteria under this desktop assessment.

Including in the Tier 2 subset at least one GSF from each geothermal field also enables an assessor to consider the value of the highest-scoring features and assess their relative significance for that particular geothermal field. For example, it may be considered that a mixed spring is considered significant in a particular geothermal field because it is the only GSF for that geothermal field. This situation may also result in higher associative values for a GSF.

Scores for heated ground do not meet the criteria for either Tier 1 or Tier 2, and therefore will not be defined (or assessed) as an SGF under this ranking scheme. This is because heated ground is the lowest ranked type of GSF (Scott and Bromley 2018) and therefore will not rank as high as primary features. Although heated ground cannot be assessed as an SGF, it does play an important part in defining a significant geothermal landscape (see below) because of the large areas that heated ground can occupy. It is also important to note that heated ground features are considered indirectly when assessing geothermal vegetation as this commonly requires heated/steaming ground to support the thermotolerant vegetation.

Table 3.1 Key statistical parameters of the ranking score data.

N Total	Mean	Standard deviation	Minimum	1st Quartile (Q1)	Median	3rd Quartile (Q3)	Maximum
2156	2.80036	0.75652	1.28385	2.2	2.6	3.34579	4.6665

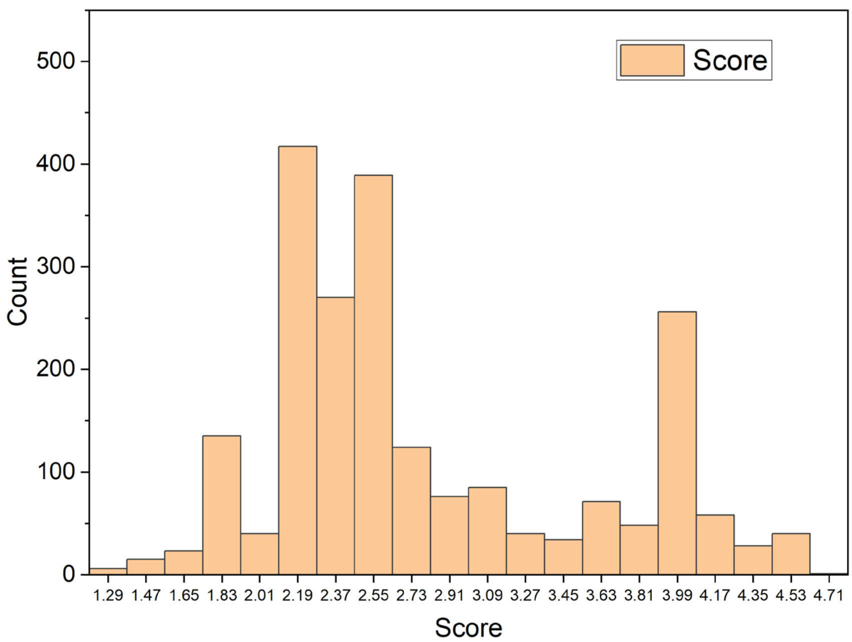

Figure 3.1 Histogram of the ranking score data.

Table 3.2 Summary of the number of GSFs at each geothermal field sorted by feature type.

		Top 20% (score >3.74)					Top quartile (≥3.34)						All GSFs ≥ median (≥2.6)										
Geothermal Field	**Total number of GSFs in the field**	**Primary flowing spring**	**Fumarole**	**Geyser**	**Mud geyser**	**Mud pots**	**Primary flowing spring**	**Fumarole**	**Geyser**	**Mud geyser**	**Mud pots**	**Primary non-flowing pool**	**Primary flowing spring**	**Fumarole**	**Geyser**	**Mud geyser**	**Mud pots**	**Primary non-flowing pool**	**Mixed flowing spring**	**Mixed non-flowing pool**	**Steaming ground**	**Mud pools**	**Hydrothermal eruption craters**
Awakeri	1																		1				
Centre basin - Rotoiti	1	1					1						1										
Kawerau	146	20	2				21	14				3	21	15			1	9	14	1	3		
Lake Rotokawa-Mokoia	15	12					12						12						1				
Lakes Okataina-Tarawera	2	2					2						2										
Mayor Island	2																		2				
Rotoma-Tikorangi-Mangakotukutuku	23	8	2				8	3					8	3					8		1		
Rotorua	1505	256	5	9	5	4	261	31	9	18	27	4	261	33	9	19	46	44	163	45	4	159	
Taheke	50		2					3						3					17		1		
Tikitere	197	3	2				3	3					3	3			1		60	5	2	2	5
Waimangu-Rotomahana-Mt Tarawera	160	80	3	7			83	8	7				83	8	7			2	18	2	5		
Whale Island	19							4						8					5		2		
White Island (Whakaari)	35		8					16						16					11	1	1	1	
Totals	2156	382	24	16	5	4	391	82	16	18	27	7	391	89	16	19	48	55	300	54	19	162	5

Table 3.3 Summary of the percentage of GSFs in the upper tiers by feature type.

Feature type	Total number of features in the database	Upper 20% of features (% of total number of features)	Upper quartile (% of total number of features)	All features at or above the median (% of total number of features)
Fumarole	89	27	92	100
Geyser	16	100	100	100
Heated ground	187	0	0	0
Hydrothermal eruption crater	39	0	0	13
Mixed flowing spring	357	0	0	84
Mixed non-flowing pool	554	0	0	10
Mud geyser	19	26	95	100
Mud pool	199	0	0	81
Mud pots	48	8	55	87
Primary flowing spring	391	98	100	100
Primary non-flowing pool	55	0	13	100
Steaming ground	202	0	0	9

Table 3.4 Summary of the number of GSFs in the upper tiers sorted by geothermal field.

Geothermal Field	Total number of geothermal surface features in each geothermal field	Number of features in the top 20% total	Number of features in the upper quartile totals	Total number of features at, or above the median
Awakeri	1	0	0	1
Centre basin - Rotoiti	1	1	1	1
Kawerau	146	22	38	64
Lake Rotokawa-Mokoia	15	12	12	13
Lakes Okataina-Tarawera	2	2	2	2
Mayor Island	2	0	0	2
Rotoma-Tikorangi-Mangakotukutuku	23	10	11	20
Rotorua	1505	279	350	783
Taheke	50	2	3	21
Tikitere	197	5	6	81
Waimangu-Rotomahana-Mt Tarawera	160	90	98	125
Whale Island	19	0	4	15
White Island (Whakaari)	35	8	16	30

3.2 Results of Defining Significant Geothermal Landscapes

The BOP region has one hundred and fifty areas (with an area size of 500 m x 500 m) calculated using this methodology that have non-zero weighted length density data. Lengths for each area range from 4 to 6600 with the key statistical parameters summarised in Table 3.5. A frequency histogram dividing the scores into 15 bins (bin width of 500) shows a skewed frequency distribution (Figure 3.2) with most areas having a score of less than 500. Areas with large scores are indicative of areas with many GSFs, or, GSFs with large lengths (or surface areas).

Based on this frequency distribution, the recommended limits for defining significant geothermal landscapes are set at >3000 for Tier 1, and >1500 for Tier 2 (geothermal areas that may need further assessment) resulting in 5 and 11 cells in Tiers 1 and 2 respectively. These limits provide a balance between ranking geothermal landscapes, as distinct from SGFs, and not including landscapes that would otherwise include most geothermal features. The resulting distribution of landscapes is intuitively correct based on the authors knowledge.

Table 3.6 and Figure 3.3 summarise geothermal fields that have Tier 1 and/or Tier 2 areas that meet this definition. The Rotorua Geothermal Field has the most areas (both Tier 1 and Tier 2) that could define significant geothermal landscapes. These are generally clustered around the Whakarewarewa and the Ohinemutu/Kuirau areas. The areas in Rotorua generally contain many individual geothermal features that are also ranked separately. Tikitere has one Tier 1 and two Tier 2 areas that meet the definition. The Tier 1 area represents a large extinct hydrothermal eruption crater that might be important from a pure landscape perspective. Eight of the BOP geothermal fields are not represented in either the Tier 1 or Tier 2 classifications.

Of note, the White Island Geothermal Field is not identified in either tier using this method and will warrant further consideration as possibly having an outstanding landscape classification based on associative values. However, this assessment will also need to consider the volcanic nature of the Island as well as its geothermal nature.

Sensitivity to reducing the Tier 2 boundary from 1500 to 1000, shows an increase from 11 Tier 2 areas to 24 areas. The Rotorua, Waimangu-Rotomahana-Mt Tarawera, Tikitere and Rotoma-Tikorangi-Mangakotukutuku Geothermal Fields see increases of three, two, two and one area respectively. Although this level reduces the risk of missing significant geothermal landscapes, the results suggest that almost every GSF in the Rotorua Geothermal Field could be classified as lying within a significant geothermal landscape which would lead to a superfluous exercise of ranking individual features.

Table 3.5 Key statistical parameters of the ranking score data.

N Total	Mean	Standard deviation	Minimum	1st Quartile (Q1)	Median	3rd Quartile (Q3)	Maximum
150	549.	979.	4	28	190	600	6600.

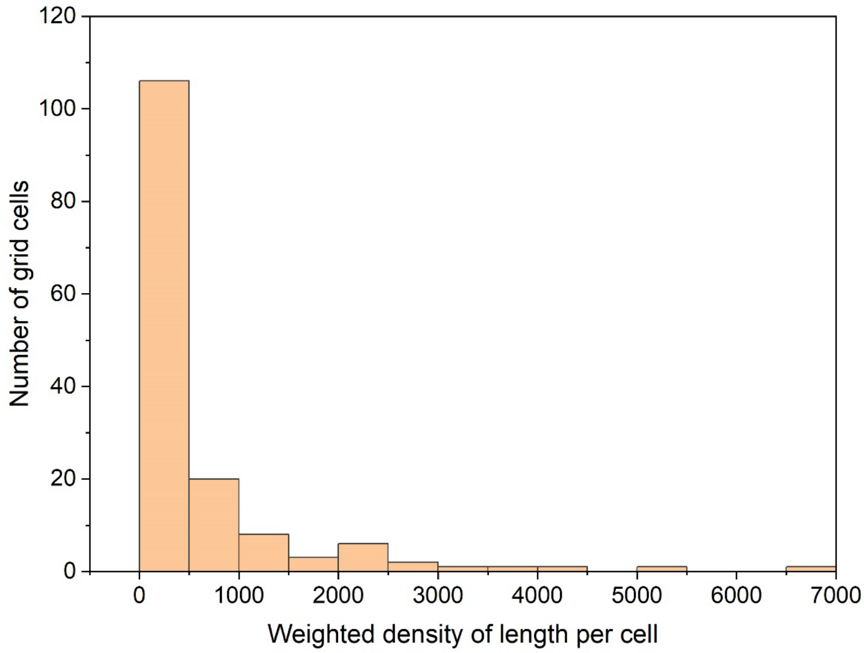

Figure 3.2 Frequency histogram of the landscape weighted density of feature length (note that all zero cells were removed).

Table 3.6 Number of grid cells in each geothermal field defining the Tier 1 and Tier 2 geothermal landscapes.

Landscape areas by Geothermal Field	Tier 1 (Score >3000)	Tier 2 (Score >1500)
Awakeri		
Centre basin - Rotoiti		
Kawerau		1
Lake Rotokawa-Mokoia		
Lakes Okataina-Tarawera		
Mayor Island		
Rotoma-Tikorangi-Mangakotukutuku		
Rotorua	4	6
Taheke		1
Tikitere	1	2
Waimangu-Rotomahana-Mt Tarawera		1
Whale Island		
White Island (Whakaari)		

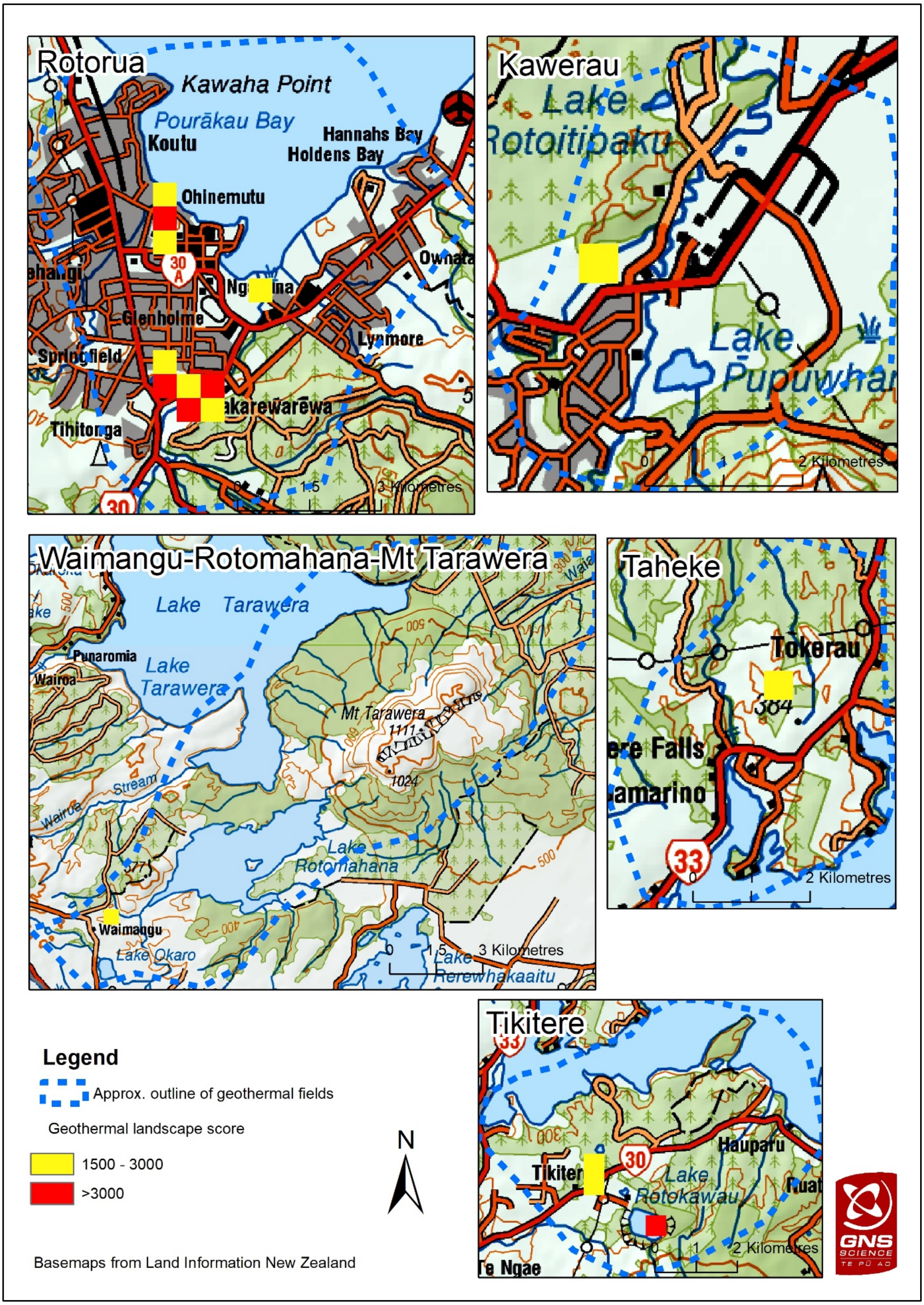

Figure 3.3 Map of the locations of the Tier 1 and Tier 2 geothermal landscapes.

4.0 KEY LIMITATIONS

During the process to develop these methods a key limitation and several anomalies are identified. The key limitation of the methods presented in this desktop study is that the calculation of scores relies on accurate GSF data in the database. This would include up-to-date information, correct feature type classification, and ideally, size data would be used instead of length. Improved data in these areas would improve both the SGF classifications and the Geothermal Landscape classifications. It should also be noted that the statistical approach used for both calculating the GSF scores and defining the Tiers will change over time given that the geothermal database receives updates as new information is added.

Two apparent anomalies in the dataset are identified:

- A high number of Tier 1 and Tier 2 GSFs are identified at Kawerau. This is likely because pre-development data is used to populate the database and that the changes in GSFs at Kawerau since development have not been considered. Kawerau is probably the only geothermal field in the BOP region where potentially large differences between the database record and the current state of the SGF occurs.
- There may be some GSFs identified as Tier 1 (i.e., meet the criteria for an SGF) that may not meet this criterion under a Scott and Bromley (2018) assessment because several smaller features have been “clumped” as one GSF. Examples of such features include WMF3153 and LOF3000 in the Waimangu-Rotomahana-Mt Tarawera and Lakes Okataina-Tarawera Geothermal systems respectively. Both features are identified as primary springs with long areas, but where the feature description suggests there are numerous seeps along an area (in which case they should be represented by a series of smaller, individual features). In these cases, a site visit is suggested to resurvey the GSF consistent with the guidelines of Scott (2012) and /or a full SGF assessment.

This is a desktop study only and uses proxies as indicators. The methodology of Scott and Bromley (2018) should be used for Tier 2 assessments and other features that may have been missed by this process.

5.0 SUMMARY

A two-Tier method for defining SGFs and Significant Geothermal Landscapes is developed based off GSF ranking scores calculated by Reeves (2018 and 2019). Sensitivity of the Tier 1 definition is tested for both SGFs and Significant Geothermal Landscapes.

Two methods are tested to define an SGF (Tier 1) based on setting a cut-off based on a score calculated for individual GSFs. A cut-off score for Tier 2 features is also derived and includes over 50% of the GSFs in the database for the BOP region. It is recommended that Tier 1 features are automatically assigned significant status, while Tier 2 GSFs should undergo an individual assessment for significance as described by Scott and Bromley (2018). The multi-tiered approach provides a conservative method of assessing GSFs for significance and provides confidence that key GSFs that did not automatically make Tier 1 level, still have an ability to be assessed.

A method for defining a significant geothermal landscape is also presented. A mathematical technique using the same GSF database to estimate GSF length density per unit area (500 m by 500 m grid) is used to identify areas of high-geothermal-feature-length density. This is based on the assumption that length is a proxy for feature size. As above, Tier 1 and Tier 2 levels are defined. The landscape areas focus more on high-GSF densities over large areas and/or large GSFs. This can provide one criterion for assessing the significance of geothermal landscapes.

Combining the two methods to identify geothermally significant features and areas, it is recommended that:

1. An SGF be initially defined as a GSF with a score >3.74 based on the database and scores calculated in Reeves (2019).
2. A GSF with a score between 2.6 and 3.74 be should be individually assessed in line with Scott and Bromley (2018) for significance where this is required in a resource management context (e.g., for a consent application).
3. A Significant Geothermal Landscape be defined as an area (≥500 m by 500 m) with a length density >3000 based on the database and scores calculated in Reeves (2019).
4. A landscape with a length density score between 1500 and 3000 should be assessed for significance where this is required in a resource management context (e.g., for a consent application).

Based on the recommended Tier definitions above and the 2156 GSFs in BOP region contained in the database:

- Four hundred and thirty-one GSFs meet the Tier 1 definition for an SGF and would default to an SGF classification.
- Seven hundred and twenty-seven GSFs lie between the Tier 1 and Tier 2 definition for an SGF. These GSFs would need to have a significance assessment as part of any consent application.
- Five areas meet the Tier 1 definition for a Significant Geothermal Landscape and would default to a Significant Geothermal Landscape classification.
- Eleven areas lie between the Tier 1 and Tier 2 definition for a Significant Geothermal Landscape. These landscapes would need to have a significance assessment as part of any consent application.

These definitions provide a first-pass on defining SGFs and Significant Geothermal Landscapes for resource management purposes in the BOP region from a desktop perspective. This technique should be used in conjunction with the more comprehensive approach as described by Scott and Bromley (2018).

6.0 ACKNOWLEDGEMENTS

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APPENDICES

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APPENDIX 1 SUMMARY OF FINDINGS AND LIMITATIONS FROM REEVES (2018 AND 2019)

A method of scoring geothermal surface features (GSFs) for scientific significance in the Bay of Plenty (BOP) region from a desktop perspective was developed, honouring the method presented in Scott and Bromley (2018). The method utilises a dataset of 4291 active GSFs in the Taupo Volcanic Zone, with 2165 of these in the BOP region.

A statistical approach is used to calculate a score for each GSF with the parameters; feature type, temperature, size and/or flow rate used in the scoring process.

Of the 2165 GSFs documented in the BOP region, 997 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 method presented in these reports provides indicative scores for GSFs 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.

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

- The study uses the type of geothermal feature, temperature, size/length of the feature and flow as proxies to estimate a score for the Natural Science Values and Aesthetic Values defined in the Regional Policy Statement (RPS) only. It is recognised that the parameters used in calculating the score mostly effect the Representativeness, Rarity, Distinctiveness, Resilience and Memorability categories of the Natural Science Values and Aesthetic Values categories of the RPS, and that other categories would be considered in a full assessment.
- It is assumed that the interpreted feature types are correct. Feature type had to be interpreted when constructing the GSF database based on the description of the feature.
- 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 GSFs 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 GSFs.
- 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.

APPENDIX 2 SUMMARY OF DATA USED TO DEFINE SIGNIFICANT GEOTHERMAL FEATURES IN THE BOP REGION

Appendix 2 is provided as a file attachment in the PDF.

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