MAPPING THERMAL FEATURES OF THE ROTORUA GEOTHERMAL FIELD USING AERIAL THERMAL INFRARED PHOTOGRAPHY: 1988 VS 2014

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ABSTRACT

Aerial thermal infrared (TIR) surveys of geothermal areas have been used for identifying and monitoring surface geothermal features for over 24 years in New Zealand. The technique has been successful in mapping the locations and extent of thermal anomalies and obtaining estimates of relative surface temperatures in geothermal areas thus making it a useful monitoring tool.

Over 1500 surface geothermal features are mapped in the Rotorua Geothermal Field (RGF), New Zealand. Surface geothermal features include geysers, springs, hot pools, mud pools and thermal ground.

TIR data collected in 2014 over the RGF is presented, demonstrating the significant technological advances in collecting TIR data that have been made since the first TIR survey over Rotorua in 1988. Advantages of the current data collection and processing techniques include; the ability to collect large areas of data economically, Geographical Information System (GIS) compatibility of the final TIR data, and the use of GIS processing techniques to assist with the analysis and interpretation of the data.

1. INTRODUCTION

Aerial thermal infrared (TIR) surveys of geothermal areas have been used for identifying and monitoring surface geothermal features for over 24 years in New Zealand (e.g. Mongillo, 1994; Mongillo and Bromley, 1990; Mongillo and Bromley, 1992). The technique is based on the principle that objects having temperatures above 0° K emit thermal infrared radiation with energy dependent on temperature. The radiation can be detected by specialist instruments. Aerial TIR data is collected by attaching a TIR camera and recording instrumentation to an aircraft and flying over areas of interest.

Quantitative aerial TIR data can be difficult to analyse due to factors affecting the measured TIR signal such as humidity, distance between the sensor and the source, emissivity, aircraft stability and method of measuring TIR. However, the technique has been successful in mapping the location and extent of thermal anomalies and obtaining estimates of relative surface temperatures in geothermal areas thus making it a useful monitoring tool.

Repeat TIR surveys enable time-series monitoring of TIR anomalies. This can be particularly useful in helping identify changes in surface thermal features caused by both natural and anthropogenic (e.g. development of the geothermal resource) causes. However, differences in how the data is collected and processed from each survey can influence how much can be interpreted for an individual survey, and between surveys over time. Factors that can influence interpretation between surveys include pixel size, resolution of the TIR detector, the data recording method, the survey method, areas that were surveyed, data processing and image registration.

This paper presents an example of TIR data collected from the 1988 and 2014 surveys over the Rotorua Geothermal Field (RGF). It demonstrates some of the advances in geothermal-field scale aerial TIR data collection and processing techniques and it's applicability to monitoring geothermal surface features at a geothermal-field scale.

2. SETTING

The Rotorua Geothermal Field (RGF) is located at Rotorua city, in the central part of the North Island, New Zealand (Figure 1). The RGF is an active geothermal field covering an area of approximately 12 km^2 (Wood, 1992) with over 1500 mapped surface geothermal features. Geothermal features in the RGF include geysers, springs, hot pools, mud pools and thermal ground. The shallow geothermal resource is used passively with tourists visiting the features, and actively for spas, swimming, cooking, and, domestic and commercial heating. A management plan for the RGF is currently in place under the authority of the Bay of Plenty Regional Council (BOPRC).

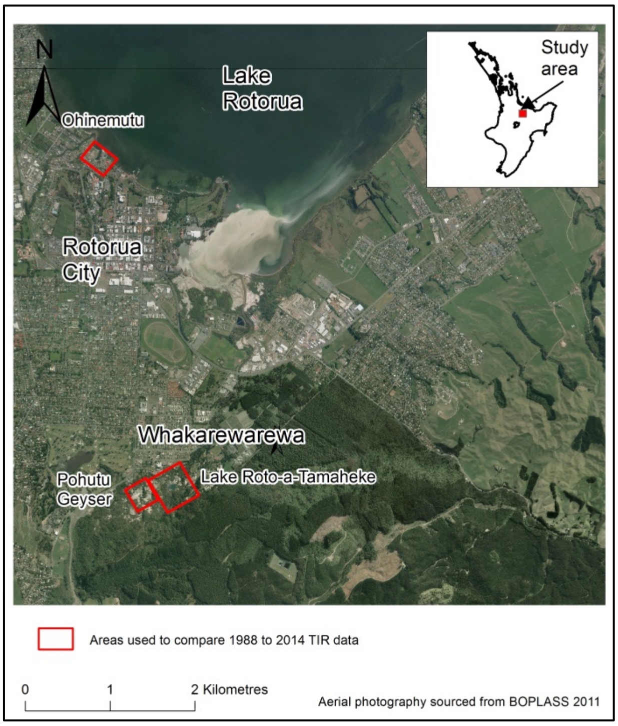

Figure 1: Location of the Rotorua study area.

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The RGF is located at the southern margin of the Rotorua caldera with the shallow hydrology (<300 m) controlled by the Mamaku Ignimbrite, a series of Rhyolitic domes and sedimentary sequences (Wood, 1992). Faults are also thought to provide permeable pathways for geothermal fluid flow (at least at depth). These geological units provide a geothermal resource that is accessible through aquifers at relatively shallow depths (<200 m) in the Rotorua city area. Surface geothermal features have formed where geothermal fluids are present at the surface. Surface geothermal features in the RGF are found in four main areas; Whakarewarewa, Ngapuna, Government Gardens and Kuirau Park/Ohinemutu.

Anomalous surface feature behavior in the 1970s to 1980s (which included loss of some geysers and hot springs) was attributed to increased development of the RGF during this time (Allis and Lumb, 1992). Public concerns about the potential effect on major geothermal features (such as Pohutu Geyser in Whakarewarewa) led to a government enforced management regime for the RGF in 1987 and 1988. This included a bore closure programme for bores within 1.5 km of Pohutu Geyser and reducing the net take of geothermal fluid from nearly 30,000 tons per day to 3,800 tons per day. Although this had a positive effect on some geothermal surface features (Allis and Lumb, 1992), some features are still to recover to pre-1980 conditions (Scott et al., 2005).

3. METHOD

Mongillo (1988) describe in detail the data acquisition, processing and the limitations for the Rotorua 1988 TIR survey of Rotorua. In summary, data were collected using an Inframetrics 525 TIR camera that uses a liquid nitrogen cooled, mercury-cadmium-telluride detector sensitive in the 8-12 µm wavelength band. TIR data were recorded to a VHS videotape resulting in a TIR video. The system was mounted to a helicopter and flown on 6 February between 8:05 pm and 8:45 pm at a height of about 500 m above ground. This results in a pixel size of approximately 1 m. The imagery is recorded as 6 bit grey scale, with the temperatures dependent on the temperature range of the camera. The survey area did not cover the entire RGF, with the survey focus on the Ohinemutu, Ngapuna and Whakarewarewa areas. Although a banding issue with the data is recognized, the data was used successfully to map thermal features in the survey areas.

The 1988 TIR data was digitized into an AVI file from which “screen grabs” were obtained in the form of JPEG files. These files were manually mosaicked to obtain TIR images of areas of the RGF. Mosaicking errors (location and joining) are apparent due to changes in flight elevation and camera angles at the time the images were taken.

Reeves et al. (in prep) describe in detail the data acquisition and processing and the limitations for the 2014 TIR survey of Rotorua. In summary, data were collected using a Flir A615 camera (with a 25 mm lens) that uses an uncooled microbolometer focal plane array detector measuring TIR in the 7.5-13 µm wavelength band. The camera was mounted to a fixed wing aircraft. TIR images are collected as the aircraft follows flight lines. These images are mosaicked and geo-registered resulting in a single band 16 bit TIR map covering the Rotorua survey area. Temperature measurements made of water features during the survey are used to calibrate the TIR data and derive an inferred temperature map. The survey was flown on 6 March between 9:15 pm and 00:20 am at about 900 m above ground. Although the TIR map published by Reeves et al. (in prep) has a 2 m pixel size, an unpublished 0.7 m pixel size map is used in this paper.

TIR data from the 1988 and 2014 surveys over the Ohinemutu and Whakarewarewa (Pohutu Geyser and Lake Roto-a-Tamaheke) areas are compared visually to identify areas of change. It is assumed that strongly elevated TIR signatures are caused by geothermal activity in both surveys.

Several important limitations to the interpretations should be considered where identifying changes in TIR between these surveys:

- Absolute changes in temperature between surveys cannot be determined because of the difference in data collection methods.
- Only changes in shape and location can be identified.
- No allowance has been made for objects that screen the TIR signal from the camera e.g. a change in vegetation between surveys may enable a previously covered TIR anomaly to now be detectable via an aerial survey and appear as a ‘new’ anomaly and vice versa.
- Changes in infrastructure may influence how some TIR anomalies appear e.g. building a road over heated ground between surveys may suggest a change in the features appearance.
- Consistency between TIR images can not necessarily be interpreted as “no change”. Although the technique can identify areas where changes in surface thermal activity may have occurred, a change in feature type cannot be determined without visual evidence as well e.g. a hot spring that has dried up but is now thermal ground may have similar TIR signatures, and may not be identified as an area where change has occurred.
- Steam is a significant absorber of infrared radiation. Some data (in both surveys) may have been affected by steam absorption in areas of natural geothermal activity.

4. RESULTS AND DISCUSSION

4.1 Ohinemutu

Surface geothermal features in the Ohinemutu area (Figure 1) generally consist of chloride springs, steam heated features and warm ground. Figure 2 shows the TIR images for 1988 and 2014 for part of the Ohinemutu area. Strong elevated thermal anomalies can be seen in both images (white in the 1988 image and yellows/red in the 2014 image). Key thermal features identified in both surveys include: thermal streams; thermal water entering the small bay with a thermal plume into Lake Rotorua; numerous “hot spots”; and infrastructure (e.g. roads, buildings).

There are strong similarities in the locations and extents of the thermal anomalies between 1988 and 2014 in the area compared (Figure 2). This suggests that there is little change in the surface thermal features in this area which is consistent with temperature monitoring data from springs RRF1215 (Little Waikite) and RRF1227 (Porahi) (Figure 2) that show a small measured temperature difference (<5°C) between 1989 and 2014 (unpublished data, BOPRC). We assume that the water temperature of these features, and other monitored features, was the same in 1989 as it was during the 1988 TIR survey.

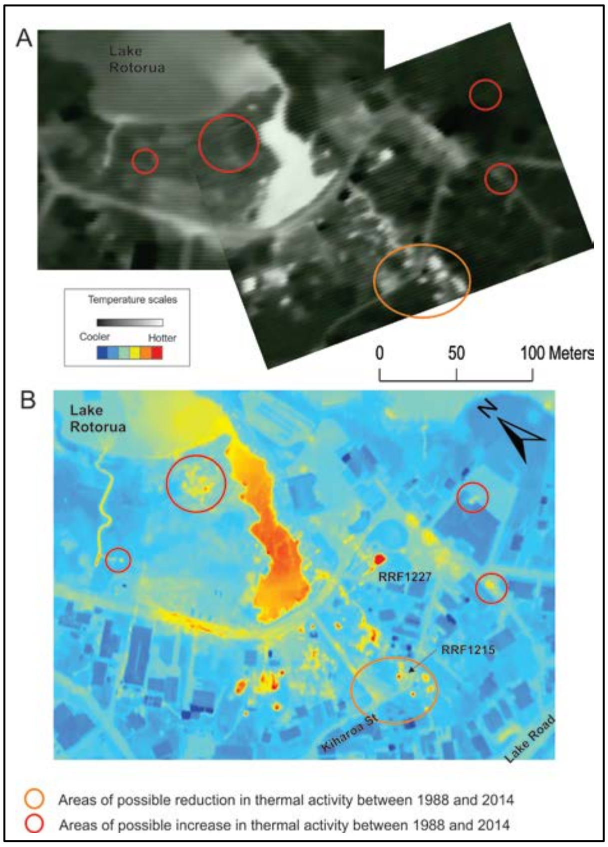

Figure 2: TIR images of the Ohinemutu study area. A is the 1988 TIR data; B is the 2014 TIR data. Approximate location of the images can be seen in Figure 1. Scales and image orientation between surveys are approximate.

Although there are strong similarities in the TIR patterns between the surveys, five areas of minor differences in surface thermal activity between 1988 and 2014 are identified. Four areas of possible increases occur in the northern part of the image (Figure 2) with the largest increase near the lake shore. One area of possible decrease is located between Kiharoa Street and Lake Road (Figure 2) where a series of springs occur. An apparent reduction of TIR anomalies in this area could be related to man-made influences where spring modification has occurred for bathing pools, thus possibly reducing the area of the thermal water that can be detected. Changes in infrastructure (e.g. new buildings, roads) may also mask some areas of thermal change.

4.2 Whakarewarewa

Surface geothermal features in the Whakarewarewa area (Figure 1) generally consist of chloride springs, steam heated and mixed water features (springs, hot pools and mud pools), warm ground and sinter deposits. Lake Roto-a-Tamaheke is the largest thermal water feature at Whakarewarewa. Figure 3 shows the TIR images for 1988 and 2014 for areas around Lake Roto-a-Tamaheke and Pohutu Geyser in Whakarewarewa.

Lake Roto-a-Tamaheke (the 'lake') TIR data (Figures 3A, 3B and 3C) clearly show a large number of thermal anomalies around the lake. Figure 3B is an image taken in 1988 using a higher temperature range in an attempt to identify hotter areas and avoid saturation as seen in Figure 3A. The lake area consists of many small springs and hot pools, with the lake as the central feature in the images. The lake has two surface discharge points: in the west; and through a lakelet at the northern end of the lake (Figure 3, D1 and D2). The northern discharge area gains thermal inputs (presumable through other spring discharges) as it flows through other lakelets to the Puarenga Stream.

Overall, locations and shapes of TIR anomalies are similar between the 1988 and 2014 surveys; however several changes to the thermal regime in this area are identified; 1) Change in shape of the lake; particularly along the northern and western edges (although this may be caused by the different lake levels at the time of the surveys) 2) A cooler area in the eastern part of the lake apparent in the 2014 data (1 in Figure 3C) 3) Possible reduction in thermal features to the northwest of the lake (green circles, Figures 3A and 3C).

Higher temperature inputs into the lake can be identified from Figures 3B and 3C. Overall, the locations of the high-temperature inputs into the lake are similar in the 1988 and 2014 surveys. These include; a large source on the western side of the lake, numerous small sources along the southern edge of the lake, and sources on the northern edges of the lake (Crimson circles, Figures 3B and 3C). An area of high temperature inputs on the northern edge of the lake seen in 1988 is not apparent in the 2014 data (green circle, Figure 3B) indicating an area where changes have occurred. Monitoring data collected close to the northern outlet (D1, Figure 3C) show that the water temperatures of the lake between 1989 and 2014 are similar (within 6°C), and that the water level of the lake was approximately 0.5 m lower in 2014 than in 1989 (unpublished data, BOPRC).

Numerous thermal anomalies are detected around Pohutu Geyser in both the 1988 and 2014 TIR surveys. The area is dominated by an approximately 60 m wide, northwest-southeast trending series of thermal anomalies that includes geysers, hot ground, springs and hot pools. The thermal signature of Pohutu Geyser and its associated water discharge can be seen in Figures 3D and 3E. The overall pattern of thermal anomalies is similar between the 1988 and 2014 surveys, although it is difficult to distinguish some patterns in the 1988 data due to the high density of thermal anomalies. Three areas of apparent decreases and one area of apparent increase in surface thermal anomalies since 1988 are shown in Figures 3D and 3E. The areas are small and the cause of the changes may be natural. The changes in shapes of some features may depend on the water level in that feature at the time of the survey. This may affect the surface area of water that was detected at the time of each survey. Monitoring data from Feature RRF0079 (Figure 3E) shows little change in temperature (<5°C) between 1989 and 2014. This feature is located within one of the apparent areas of decreased activity (Figure 3E) suggesting that any decrease in this area is probably localized.

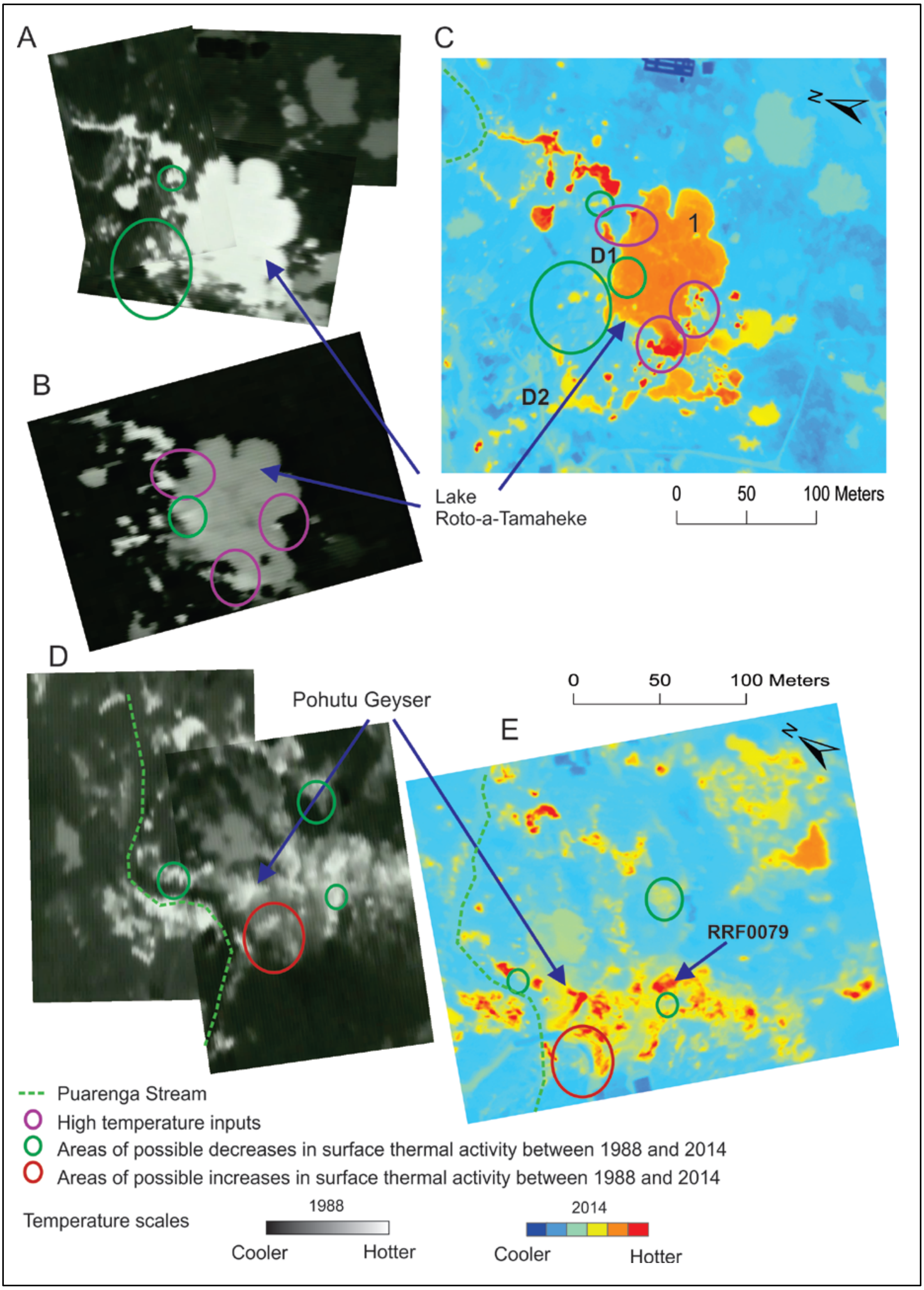

Figure 3: TIR images of the Lake Roto-a-Tamaheke (A, B and C) and Pohutu Geyser (D and E) areas. Approximate location of the images can be seen in Figure 1. A – 1988 TIR at the low range. B – 1988 TIR at the high range. C – 2014 TIR. D – 1988 TIR at Pohutu Geyser in the low range. E – 2014 TIR at Pohutu Geyser. D1 and D2 are the surface water outlets from Lake Roto-a-Tamaheke. Scales and image orientation between surveys are approximate.

4.3 Technique comparison

Key advances in geothermal field-scale aerial TIR data and processing techniques have been made in the last 20 years. Key differences between the TIR data collected in 1988 and 2014 include:

- Improvements in camera technology enabling uncooled TIR cameras, with increased number of pixels and fast shutter speeds to enable high resolution data to be collected faster, over a single temperature scale with data recorded directly to a computer system.
- Suitable mountings to fixed wing aircraft that enable fast data collection over large areas on a stable platform utilizing survey-specific navigation systems to improve survey design.
- Improved mosaicking capability utilizing the data collected to produce geothermal field-scale images that can be geo-referenced and used in a GIS system enabling the use of GIS tools to help analyse and interpret the data.

Figure 4 shows an example of how GIS tools can be used to help analyse TIR data in a geothermal setting. Geostatistical methods have been applied to the 2014 TIR dataset to derive outlines (or polygons) of thermal features using an automatic classification scheme (Alcaraz, in prep). The classification scheme groups the data interpreted to have geothermal influences into three categories; Least likely, Likely and Most likely to be caused by geothermal signatures. The resulting classification can be used to help define the extent of surface thermal features. This can be particularly useful for investigating the extents of warm ground which can be very difficult to map from field surveys. Resulting thermal outlines should be field checked to ensure that the TIR anomalies defined are in fact due to geothermal causes when using this method.

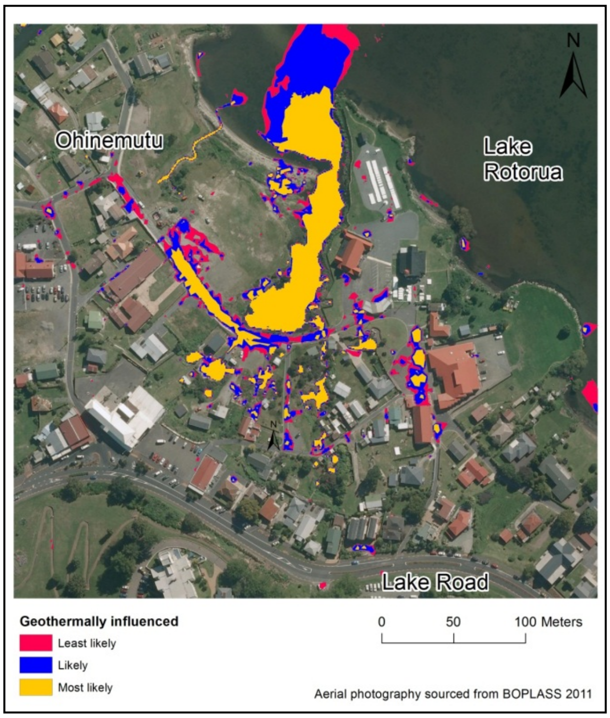

Figure 4: TIR classification based off the 2014 TIR data for Ohinemutu.

Figure 4 shows numerous areas interpreted to be caused by geothermal influences. This includes plumes of warm water flowing into Lake Rotorua from streams and the lakelet. The extent of thermal water flowing across the lake surface from springs along the Lake Rotorua shoreline can also be seen.

Potential applications of this technique to TIR datasets could include thermal feature identification, hazard identification and management, resource allocation management, and monitoring.

5. CONCLUSION

TIR data from 1988 and 2014 are compared at Ohinemutu and at two places in Whakarewarewa, Rotorua, New Zealand. The data show that, overall, there are strong similarities in the locations and spatial extents of thermal anomalies between the 1988 and 2014 data with small differences identified in each of the areas compared. The cause of the differences cannot be ascertained from this data alone, but could be due to a number of factors that could include natural variations, changes in extractive use of the geothermal field, the bore closure program and surface development (e.g. building new roads). Further work is required to investigate more areas around Rotorua city in order to obtain a better assessment of changes that have occurred over the Rotorua Geothermal Field over time.

Advances in technology have improved aerial TIR data collection rates and quality for geothermal field-scale studies that now enable GIS tools to be used for improved data analysis and interpretation.

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