INVESTIGATION OF THE GEOTHERMAL SIGNATURE OF THE MOTUOAPA MARINA, LAKE TAUPO, NEW ZEALAND

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ABSTRACT

The northern Motuoapa hot springs and their potential link to the nearby marina hot springs and the Lake Taupo Volcano have not been studied before. Analyses of the near neutral 56.0 ºC water samples from the Motuoapa hot springs collected in 1967 and 2014 imply dilution of mature deep, hot alkali chloride-rich water with cooler peripheral bicarbonate-rich fluid over a period of 50 years. This is supported by a different Cl/B ratio obtained for samples collected in 1967 (Cl/B =44) and 2014 (Cl/B =26) indicating two distinct fluid sources, and by ^{18}O value of -5.16‰, but it can also reflect the recharge by cooler waters due to a different water level at the time of sampling. The concentrations of reactive metal components and non-metal components imply relatively significant mineralization of the hot springs; however, the F^{-} and SO_4^{2-} contents decreased, whereas the NH_3 content has slightly increased over the last ca 50 years.

1. INTRODUCTION

The small settlement of Motuoapa on the south-eastern shore of Lake Taupo (Figure 1) (Bibby et al, 1991) is located within the structurally controlled Taupo Volcanic Zone (TVZ; Figure 2) (Downs et al., 2014). Hot springs along 500 m of the lakeshore, from within the Motuoapa marina in the south to the lakeshore in the northeast (Figure 1) have high temperatures and mineralisation contents (Mahon & Klyen, 1968; Lovett *et al*. 2014). Because Motuoapa is located in the TVZ, it is reasonable to assume that these hot springs are related to other geothermal features in the zone in terms of structural and lihtoligical controls and a heat source. However, until now, the hot springs of the Motuoapa area have never been investigated in detail.

We discuss water temperatures in the swampy Motuoapa bay northeast of the marina collected during a field trip on 7th September 2015, the water samples from the Motuoapa hot springs collected in 1967 and 2014, and marina water temperatures recorded in 2014. All chemical and isotope data on the conservative and reactive elements for the Motuoapa hot spring water samples were compared and contrasted to identify any changes in the water temperatures and compositions and to establish a trend between the first collection and the last collection dates. The results were also correlated with the characteristics of the soil in the Motuoapa marina to identify and predict any effect of existing geothermal features on proposed earthwork in the Motuoapa marina and vice versa.

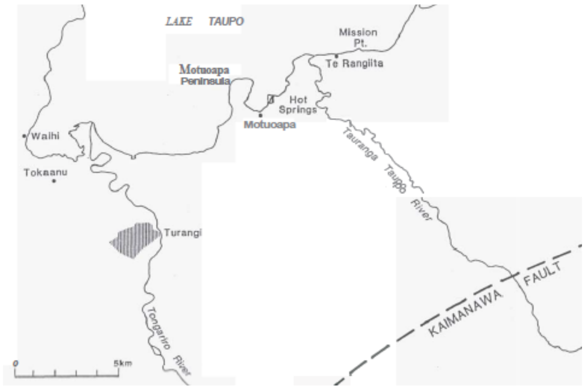

Figure 1. A location map showing Motuoapa and the nearby hot springs, Lake Taupo (Bibby and Risk, 1991)

1.1 Geological setting and hot springs of the Motuoapa area

Because of the spatial correlation between the hot springs northeast of the Motuoapa settlement and the Haparangi rhyolite, which forms the Motuoapa peninsula, several surveys were undertaken to assess the area's geothermal potential (Bibby et al, 1991). The main hot springs are located at the northeastern end of Motuoapa bay and are accessible during a dry season: they discharge minor water flows at 20–51 ºC and gas (Figure 3), and have Cl/B ratio of 8.6. Figure 3 shows that distribution of the contours indicates a temperature increase in an offshore direction. The Motuoapa springs are near the top of the map in the area where temperatures do not exceed 30 ºC. The temperature measurements were recorded by Fisher (1957) using a thermocouple probe (unpublished report. DSIR, Wairakei). The ambient temperature was 11.5 ºC and the highest temperature recorded next to the springs was 47.5 ºC. Total natural conductive heat flow was 215 kW. Based on the existing data, thermal output of these springs has been interpreted to be relatively weak.

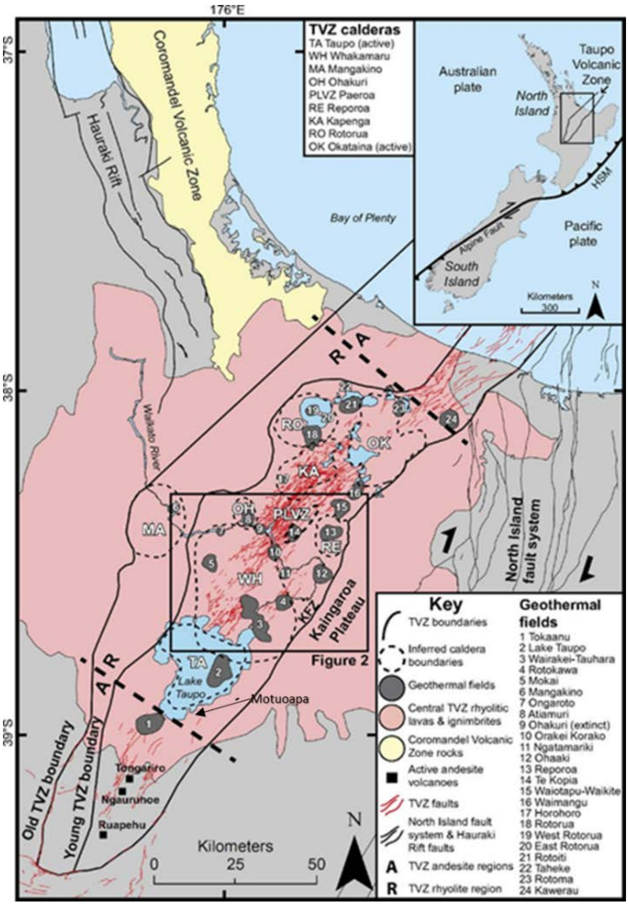

Figure 2. Geological map showing distribution of geothermal fields in the TVZ (Waikato Regional Council GIS, from GNS Qmap). The study area is shown inside the small peninsula on the southeast shore of Lake Taupo

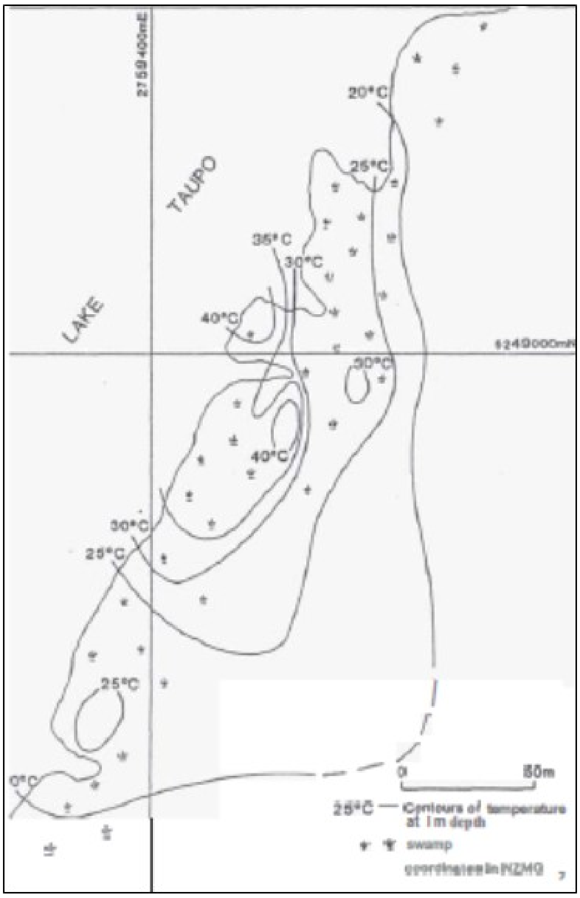

Figure 3. Map of temperature contours at 1 m depth (Bibby et al. 1991, after Fisher, 1957)

2. PREVIOUS MOTUOAPA STUDIES

In the Motuoapa area, coastal plains and lake margins with beach deposits are composed of sand, gravel, silt and mud (Roberts & Williams, 1936; Mahon and Klyen, 1968; Bibby et al., 1991). Soil samples from the Motuoapa marina basin, island and entrance channel include a mixture of loose silt, pumice sand and gravels in varying proportions**.** Resistivity survey measurements (Bibby et al., 1991) revealed a characteristic resistivity low anomaly (10-200 Ωm; Figure 4) (Bibby et al., 1991; Caldwell & Bibby, 1992) in this area consistent with the broad magnetic low. This reflects a relatively small and hydrothermally demagnetised Haparangi rhyolite dome located offshore (Roberts & Williams 1966). A large part of the Motuoapa geothermal system may lie under Lake Taupo, characterised by an even lower resistivity anomaly. An aerial thermal feature mapping-resistivity survey (TIR; Figure 5) and a ground resistivity survey (Figure 6) conducted by GNS in 2014 revealed a thermal anomaly in the Motuoapa area, in particular at the entrance to the Motuoapa marina (Lovett *et al*., 2014).

In 2005, a Motuoapa hot spring was measured at 54 °C by Ashley Cody (unpublished WRC report). A temperature probe survey conducted for a resource consent application of the Motuoapa marina (Figure 7) in 2014 gave lake bed temperatures in the marina (Crawford, 2015) of up to 26 °C. This area extends from the marina, towards the northeast swampy beach (indicated by the green line) where 54°C was recorded.

The Motuoapa hot spring area (Figure 7) was visited and described by Harry Keys and Ashley Cody in 2005 (pers. comm. Cody to Katherine Luketina, WRC, 2005). Silica cemented pumice gravels were identified along the lakeshore and around the spring for 10 m length along the shore line. However, no sinter or geothermal mineral depositions were observed. The water temperature was less than 54 °C, it was odourless and at pH=7.0. Flows were estimated between 0.1 L/s and 0.5 L/s as they appeared diffuse over more than 1 m diameter on the surface. Conductivity was *ca.* 3000 μS/cm. Elevated levels of arsenic and mercury were recorded in the water, aquatic plants and organic silts (Lovett *et al.* 2014).

2.1 Published work by Opus International Consultants

Waikato Regional Plan (Waikato Regional Council, 2007) classifies the Motuoapa area as a *Small Geothermal System*

Temperature tests in the Motuoapa marina basin and its channel entrance by Opus International Consultants Ltd on 14th May 2015 (unpublished report, Crawford, 2015) to assess the risk of an instigated hydrothermal eruption during a proposed marina upgrade. The testing of the basin and channel entrance of the Motuoapa marina was planned to be carried out on 13th May 2015.

Figure 4. Apparent resistivity contour map of L. Taupo with Motuoapa circled in red (from Bibby *et al.*, 1991).

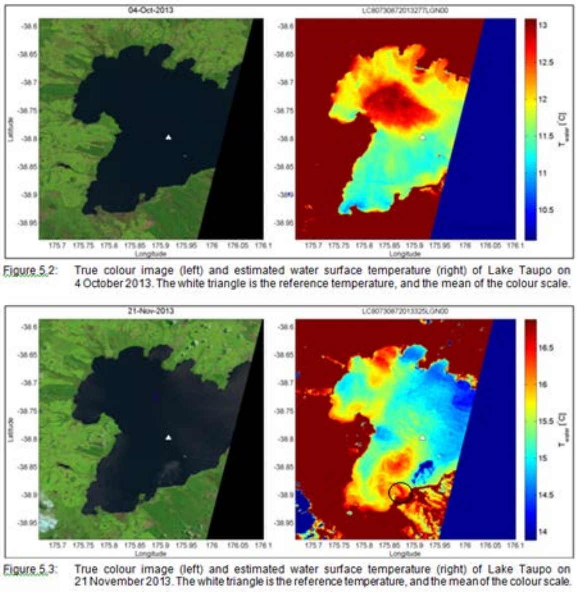

Figure 5. An aerial TIR and resistivity survey indicates a thermal anomaly at the entrance to the Motuoapa marina area shown in the circle on bottom right image (Lovett et al., 2014)

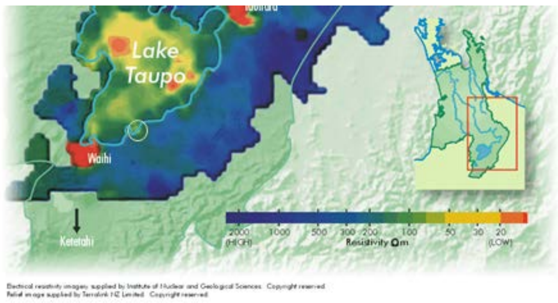

Figure 6. A resistivity map generated by GNS identifies a small thermal anomaly in the Motuoapa area shown in the grey circle (from unpublished WRC image)

Figure 7. A satellite image (Waikato Regional Council ©) shows the Motuoapa geothermal area including the marina, with the main springs to be found in the sandy lakeshore in the northeast of the photo.

The ambient air temperature was recorded at 16.5 ºC and of water surface at 13.5 ºC. The temperature profiles of the lake bed were derived from temperature measurements using a temperature probe inserted 30-40 cm into the surface sediments. The temperature range for the marina basin was from 16 ºC to 19 ºC; the highest recorded temperature of 26 ºC was recorded at the extreme north eastern corner of the marina. The conclusion was that the maximum temperature of 26 ºC suggests no siginficant geothermal feature identifiable in the Motuoapa marina and that there is no potential danger to instigate a hydrothermal eruption during the excavation work.

To determine the bearing capacity of soil in the Motuoapa marina, Opus International Consultants Ltd conducted a geotechnical assessment of soils using a cone penetration test (CPT) method on 19th June 2015 (Figure 8).

Figure 8. A cone penetrometer test (CPT) rig used to undertaking the geochemical assessment of soils in the Motuoapa marina and the locations where CPT was conducted 30th June 2015 (Crawford, 2014)

The CPT unit successfully completed several discrete temperature depth profiles. It contains soil stratigraphy profiles, cone resistance (penetration resistance of soil), sleeve friction (soil cohesive strength), temperature depth profiles, and dynamic pore pressure data for seven drill holes. The stratigraphy is mostly sand, with some sandy layers containing other material such as silt, clay and gravel. Pore pressures are low. Here, the temperature profiles are presented for eight locations given (Crawford, 2015) given in Figure 8:

- Location 1, 1849198E, 5686985N: surface soil temperature was 13.9 °C and at -21.3 m depth was 42.0 °C. The greatest temperature increase of 20.2 °C was from -1.5 m to -7.4 m depth. Below -7.4 m and down to -21.3 m the temperature variation is up to 10 °C. This location is the hottest part of the Motuoapa marina characterised by a significant temperature increase in the sand within first 7.5 m.
- Location 2, 1849214E, 5686953N: surface temperature was 25.0 °C and 17.0 °C at -2.0 m depth. The temperature remained relatively constant down to -17.5 m where temperature was 22.5 °C.
- Location 3, 1849159E, 5686845N: surface temperature was 16.5 °C and the maximum of 21.7 °C was recorded at -11.0 m and -12.0 m. At the end of the hole at -21.2 m it was 17.0 °C.
- Location 4, 1849061E, 5688225N: surface temperature was 18.8 °C and it increased to a maximum of 19.5 °C at -9.0 m. At the end of the hole at -20.2 m it was 17.0 °C. No significant temperature variation characterizes this part of the Motuoapa marina.
- Location 5, 1849219E, 5688920N: surface temperature was 17.5 °C with a maximum of 19.5 °C at -16.5m. At the end of the hole at -18.3 m it was 19 °C.
- Location 6, 1849219E, 5688920N: surface temperature was 17.5 °C and it increased to a maximum of 19.5 °C at -16.5m. At the maximum depth of -18.3 m it was 19 °C.
- Location 7, 1849095E, 5688969N: surface temperature was 17.0 °C and it increased to a maximum of 35.0 °C at -8 m and -12 m. At the maximum depth of -22.5 m it decreased down to 30.0 °C. The greatest temperature increase in this part of the Motuoapa marina is from -2.0 m depth down to -8.0 m depth.
- Location 8, 1849011E, 5688961N: (off the picture in Figure 8), but near Location 5) surface temperature was 26.9 °C and it decreased down to 25.5 °C at -0.2 m depth.

The hottest part of the Motuoapa marina is at 1849198E and 5686985N characterised by a significant temperature increase in the sand within first 7.5 m. However, the temperature reached the maximum of 42 °C at 21.3 m depth. This section of the soil profile has low but consistent pore pressure. The location at 1849095E, 5688969N is characterised with 35.0 °C between 8 and 12 m depth, but with a temperature drop down to 30.0 °C at 22.5 m depth. A cone penetrometer testing (CPT) was used to record temperature of soil in the lake bed; however, the results imply no obvious geothermal vents or resources that could be conclusively linked to a geothermal geyser activity. As part of resource consent application for the upgrade of the Motuoapa marina (Figure 9) potential adverse effects during earthworks and constructions were identified. They are of ecological nature and include reduction of habitat for mainly aquatic fauna and flora and on nesting birds, decrease in water temperature and quality and the second is erosion and sediment control plan during earthworks.

2.2 WRC and GNS geological and geochemical work

The hot spring at the locality 1849394E and 5687343N was investigated on 10th September 2014 (Figure 10; GNS staff). The spring, of diameter less than 10 cm, occurs in an area of lake-shore bed exposed at low water level, and was described as colourless, clear with no turbidity, ebullition or odour. Two areas of water outflow characterised by low flow rate were identified in the hottest spot. Ubiquitous green algae were observed in areas where water was at ca 30.0 °C, whereas black algae were observed in areas where water was ca 50.0 °C. Water samples were taken from the hottest spot and from the outflow zones. At 10 cm depth 60.8 °C temperature was recorded. To the south of the sampling area, bubbles from the lake bed were observed as the water level was low. Water temperature recorded was in a range between 18.6 °C and 20.3 °C.

Water samples were taken from the hot spring on 10th September 2014 by K. Britten from Natural Hazards-Volcanology GNS and analysed for conservative and reactive chemical and isotopic compositions. The data were compared with those obtained from the analyses of the water samples collected in July 1967 (Mahon and Klyen, 1968). The data are tabulated below for comparison (Table 1). The water samples collected in 2014 and 1967 have near neutral pH values. The water temperature measured in 2014 is consistent with the previous measurements recorded by Keys and Cody in 2005 and the temperature and base-line chemistry data (Mahon & Klyen, 1968). The water sample collected in 2014 plots in the peripheral waters region in the ternary Cl^-–SO_4^{2-}–HCO_3^- plot (Figure 11), whereas the water sample collected in 1967 plots in the mature waters region. The water sample collected in 2014 plots in the equilibrated zone in the ternary $K^+/100$–$Na^+/1000$–$\sqrt{Mg^{2+}}$ plot (Figure 12) and indicates a temperature of up to 75 °C. The analysis of the water sample collected in 1967 reported the sum of Ca^{2+} and Mg^{2+}. In this case it was not possible to plot the $\sqrt{Mg^{2+}}$ value onto the ternary plot.

Near neutral pH values and high chloride concentration reflect a deep alkali chloride-rich geothermal fluid source. The negative values for ^{18}O (-5.16 ‰) and ^{2}D (-38.7 ‰) imply depletion of ^{18}O and ^{2}D heavy isotopes from the hot spring water samples. This reflects preferential removal via isotopic fractionation as a consequence of physical state change from liquid to vapour and back to liquid during water-rock interaction. However, ^{18}O is largely controlled by recharge of bicarbonate-rich peripheral waters. The concentration of reactive metal and non-metal components imply relatively significant mineralization of the hot springs; however, between 1967 and 2014, the fluoride content decreased, whereas the ammonia content has increased. Cl/B ratio for the Motuoapa hot spring waters sample collected in 2014 is 26, whereas that collected in 1967 is 44. The different Cl/B ratio values suggest a different fluid source. Hence, the sample collected in 1967 could reflect a deep mature alkali chloride-rich geothermal fluid, whereas the sample collected in 2014 reflects dilution of deep alkali chloride-rich waters with cooler peripheral bicarbonate-rich fluids. Either the water samples were collected at different locations in 1967 compared to 2014 or over 47 years there has been a significant increase in bicarbonate concentration and interaction of deep waters with cooler peripheral waters as reflected in the composition of the waters of the hot springs collected in 2014. This could also be a result of different lake levels at the time of sampling. The data also indicate that the concentration of SO_4^{2-} and Cl^- decreased during the same period.

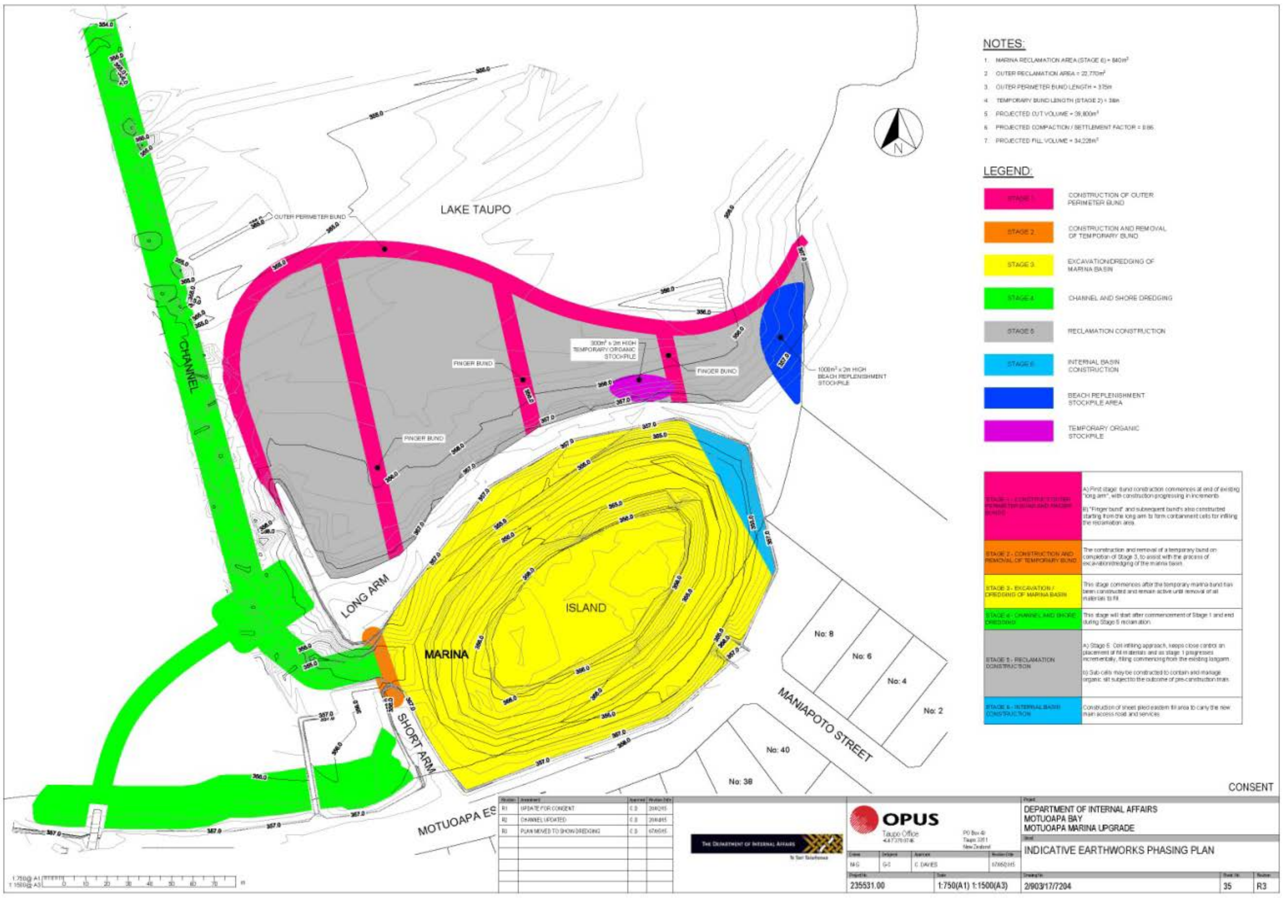

Figure 9. Motuoapa marina upgrade and earthworks plan (from Crawford, 2015)

Figure 8. Location of the hottest Motuoapa spring and the surrounding steaming ground at 184934 E and 5687343 N. The photo shows the location in the (GNS Motuoapa Field Sheet).

Table 1. Chemical and isotopic data for water samples from the Motuoapa hot spring in 2014 and 1967.

Site ID	Motuoapa Hot Spring	Motuoapa	
Collection date/collection staff	10/09/2014 K. Britten (Natural Hazards-Volcanology GNS)	May July 1967 (W.A.J. Mahon and L.E. Klyen, 1968)	
			Units
Collection Temperature	56.2		°C
Conductivity	3355		µS/cm
pH	7.65	7.4	
Total Inorg. C as HCO_3	1597	1242	mg/L
Lithium	4.4	3.9	mg/L
Sodium	739	615	mg/L
Potassium	42	37	mg/L
Calcium	33	40.7 Ca + Mg	mg/L
Magnesium	7.7		mg/L

Chloride	468	381	mg/L
Sulphate	0.29	20	mg/L
Boron	17.7	8.6	mg/L
Silica (as SiO_2)	187	162	mg/L
Sulphide (total as H_2S)	0.01		mg/L
Aluminium	0.06		mg/L
Arsenic	<0.01		mg/L
Bromide	1.5		mg/L
Fluoride	0.28	0.5	mg/L
Iron	0.68		mg/L
Nitrate as N	0.02		mg/L
Ammonia	2.6	0.2	mg/L
^{18}O	-5.16		‰
^{2}D	-38.7		‰

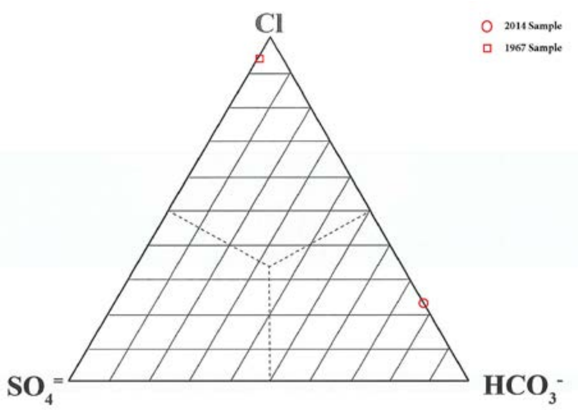

Figure 9. Ternary Cl–SO_4^{2-} –HCO_3^- plot. The sample collected in 2014 (red circle) plots in the peripheral waters region and sample collected in 1967 (red square) plots in mature waters region.

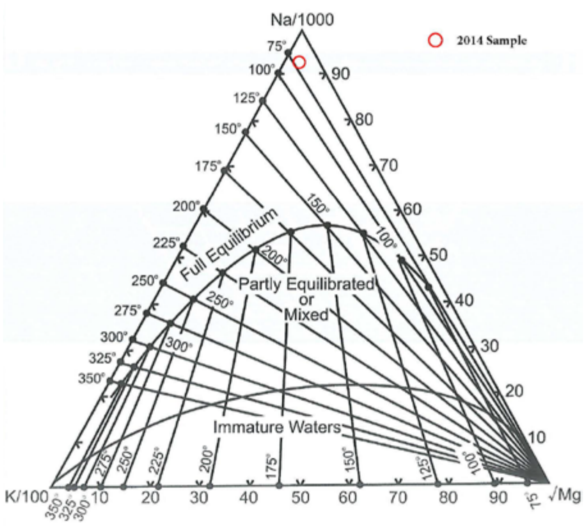

Figure 10. Ternary $K^+/100$–$Na^+/1000$ –$\sqrt{Mg^{2+}}$ plot. The sample collected in 2014 (red circle) plots in the fully equilibrated zone indicating a temperature up to 75 °C.

The Motuoapa area is classified as a *Small Geothermal System* by Waikato Regional Plan. The identified hot springs are characterised by:

a) 468 mg/L (2014) and 381 mg/L (1967) chloride
b) 0.29 mg/L (2014) and 20mg/L (1967) sulphate
c) hot springs have temperature of up to 56.2 °C.

The calculation of the temperature based on the quartz geothermometer maximum steam loss yielded 165 °C for 187 ppm SiO_2 (2014) and 157 °C for 162 ppm SiO_2 (1967), whereas quartz geothermometer no steam loss yielded 176 °C for 187 ppm SiO_2 (2014) and 166 °C for 162 ppm SiO_2 (1967). High silica content is consistent with alkali chloride-rich hot deep geothermal fluid source. However, the calculated temperatures indicate dilution as the quartz geothermometer is reliable in the temperature range between 210 °C and 250 °C. Also, high Ca content is consistent with the influx of cooler bicarbonate-rich peripheral recharge water. No such temperatures were recorded in the Motuoapa marina (including the lake bed and its banks). The Motuoapa springs most likely represent an outflow from a source located westwards under Lake Taupo. Therefore, it is essential to investigate the water in the entrance channels to the Motuoapa marina for temperature and base-line chemistry in order to gain a better insight into its link to the Lake Taupo Volcano region characterised by low resistivity anomaly.

3. METHODOLOGY

3.1 Temperature measurements in Motuoapa marina

The swampy area at locality1849340E 5687269N, which is surrounded by thick vegetation, was visited on 7th September 2015. The lake level was high due to seasonal fluctuations and the springs were under ca. 30 cm water. Temperature measurements of the ambient air, surface water and water on the bottom of the lake near the shore line were taken by a hand-held thermocouple temperature probe. The aim was to target areas on the lakebed that were releasing bubbles. The temperature data are given in Table 2.

Table 2. Water temperature in the swampy Motuoapa bay measured using a thermocouple

Location 1849340E 5687269N	Thermocouple inserted probe temperature (°C)
Air	11.0
Water	11.5
Area _1	9.9
Area _2	11.5
Area _3	11.4
Area _4	11.6
Area _5	11.6
Area _6	11.6

There is no variation in the temperature measurements and they do not differ significantly from the ambient temperature. For that reason no temperature measurements of the sub-surface were taken and no pH water measurement were taken. No steaming grounds, fumaroles, dissolution craters or mud lakes were observed in the vicinity of the area and there is no evidence for thermally stressed vegetation growing on the edges of the lakeshore. This indicates that acid sulfate- rich fluid is not active in this area. Also there was no evidence for silica sinter deposits and alkali chloride-rich waters.

4. CONCLUSIONS

The analyses of the near neutral water samples from the Motuoapa hot springs (56.0 ºC; estimated location at 1849380 E 5687350N northeast of the Motuoapa marina) collected in 1967 implies a mature, deep alkali chloride-rich geothermal fluid, whereas the sample collected in 2014 reflects dilution of this fluid with a cooler peripheral bicarbonate-rich fluid or a different level of water in the lake at the time of sampling. This is supported by ^{18}O value of -5.16‰, which reflects the recharge, and by Cl/B ratio that suggests two discrete fluids. The concentration of reactive metal components (Ca^{2+}, K^{+}, Na^{+}, Mg^{2+}, Al^{3+}, As^{3+} and Fe) and non-metal components (Br^{-}, F^{-}, NO_3^{-} and NH_3) imply relatively significant mineralization of the hot springs. The data also indicate a decrease in SO_4^{2-} and Cl^{-} concentration but an increase in NH_3 during the same period.

The swampy warm ground (1849340E 5687269N) in the vicinity of the hot springs was visited on the 7th September 2015. No temperature higher than 12 ºC was recorded. It is strongly recommended to record the water temperature during the summer when lake levels are low, to provide a better access. Sampling at the time of very low lake level could avoid the potential dilution effect by peripheral bicarbonate-rich waters. The water temperature measurements and soil assessment in the Motuoapa marina have not identified any geothermal activity that would present an obstacle to the proposed upgrade work. However, given the dynamic nature of geothermal surface features it is strongly recommended to monitor the temperature and base-line chemistry of water in the marina on regular bases. The modelling of the chemistry data for the hot springs and warm grounds does not provide conclusive evidence for its geothermal potential. It is speculated that the Motuoapa hot springs represent an outflow from a source located under Lake Taupo, as supported by the resistivity and TIR surveys. It is also recommended to investigate and assess the water and soil in the entrance channel to the Motuoapa marina. This will assist in identifying and prioritising thermal sites with respect to their geothermal potential and associated geothermal hazards.

ACKNOWLEDGEMENT

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