Effects of reinjecting diluted mineral pool water into the Rotorua Geothermal System

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EXECUTIVE SUMMARY

This report presents the results of a geochemical modelling study into the potential effects of reinjection of dilute geothermal brine (i.e. dilution by bathing waters) into the shallow groundwater of the Rotorua Geothermal System (RGS). It also summarises the potential environmental effects from reinjection or discharge to surface waters; from both the release of pathogenic microorganisms, and the potential for biochemical changes to the environment by microbes.

The results of this study show that reinjection will have a small effect on the water composition of the shallow geothermal aquifer fluid proportional to the reinjection rate. At reinjection rates of 50 and 100 t day^{-1} (both at fluid temperatures of 120°C and 150°C) changes to the aquifer chemistry are minimal. Changes in the concentration of conservative elements will be insignificant as these are modelled to be within the ± 2% uncertainty of the aquifer brine composition. The effect on the aquifer chemistry is less notable when undiluted brine is reinjected.

A measurable change in pH (from pH = 7.7 up to 8.1) is found only at 800 t day^{-1} up to 800 m from the well. There will be a substantial decrease in the SiO_2 concentration (at 150°C from 275 mg kg^{-1} to 125 mg kg^{-1}) at reinjection rates of 300 and 800 t day^{-1} which could impact surrounding wells and surface geothermal features. The decreases in SiO_2 concentration are dependent both on mixing and temperature due to re-equilibration with silica minerals.

Less mineral precipitates are expected when injecting diluted brine compared to undiluted brine at 120˚C. For example, at a reinjection rate of 800 t day^{-1} almost four times more calcite will be precipitated with undiluted brine compered to diluted brine. The amount of calcite precipitates expected at 150˚C is large, particularly at 800 t day^{-1}, and this could pose an issue for long-term injectability.

It is also worth to note that extraction of the geothermal brine and subsequent boiling results in loss of water vapour. The lost of water results in an increase of concentration of most dissolved components (e.g. Cl, SiO_2) in the bathing fluid. Therefore, dilution of the geothermal brine with the town water, equivalent of the steam loss, brings the concentrations of components closer to a natural state before boiling occurred.

Reinjection of water from mineral pools, or discharge to surface waters, poses a risk of release of human pathogens. Pathogens may infiltrate groundwater or surface water and present a hazard through inhalation, skin contact, or ingestion of contaminated food. Microorganisms identified in nearby surface features indicate that there may also be environmental risks from the natural geothermal microbial populations. These range from increased biofilm formation leading to reduced permeability, to the production of toxic and corrosive H_2S. The gradient of risk depends on the types of microorganism, volumes and dilutions of water reinjected, and the receiving environment.

The following recommendations are made:

1. A geothermal tracer test can be conducted to determine connectivity between the production well, reinjection wells, and surface features.
2. Repeat the modelling using a larger range of fluid chemistries that represent other parts of the RGS.
3. The results do not consider long-term effects on the aquifer temperature (i.e. cooling). A separate modelling study should be undertaken if long term changes to the aquifer and connected surface feature temperatures are required.
4. Water from mineral pools should be monitored for the presence of pathogens, and appropriately treated before reinjection or discharge to surface water.

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1.0 PART 1: GEOCHEMISTRY

1.1 Introduction

The Rotorua Geothermal System (RGS) is a globally unique geothermal system that has been extensively utilised over last 50 years. The RGS, like other geothermal systems in the Rotorua-Taupō area, is a product of large-scale volcanism and rifting. It is coincident within a modern city in which brine extraction is occurring and numerous surface manifestations are found including geysers, hot springs, mud pools and pots, and warm ground (Scott et al*.* 2016).

Only the shallow Rotorua geothermal aquifer has been used for extraction, therefore, the RGS brine composition is known only from shallow commercial wells and natural springs. No deep wells (+ 500 m) have been drilled in the RGS thus the precise composition of the deep fluid is not well known (Scott et al*.* 2021). The shallow fluid chemistry is inhomogeneous and varies throughout the RGS (Scott et al*.* 2016). According to the different in fluid chemistries, the RGS can be divided into three separate zones: Kuirau Park in the north-west; Ngāpuna in north-east; and Whakarewarewa in the south (Figure 1.1).

Bay of Plenty Regional Council (BOPRC) has commissioned GNS Science (GNS) to investigate potential chemical, biological and physical effects of reinjection of diluted geothermal brine into the shallow part (100–300 m depth) of the Rotorua Geothermal System (RGS). Geothermal brine is used extensively in the RGS as a source of fluid for bathing in motels, hotels, public pools, and private pools. It is common practice for geothermal brine to be diluted with town water in order to cool it down for bathing purposes. The diluted fluid is then reinjected into the RGS.

The goal of the present study is to investigate the geochemical and biological effects reinjecting diluted brine on the RGS. The outcome of this work will broaden the knowledge on potential effects of reinjection and will help inform decisions on sustainable management.

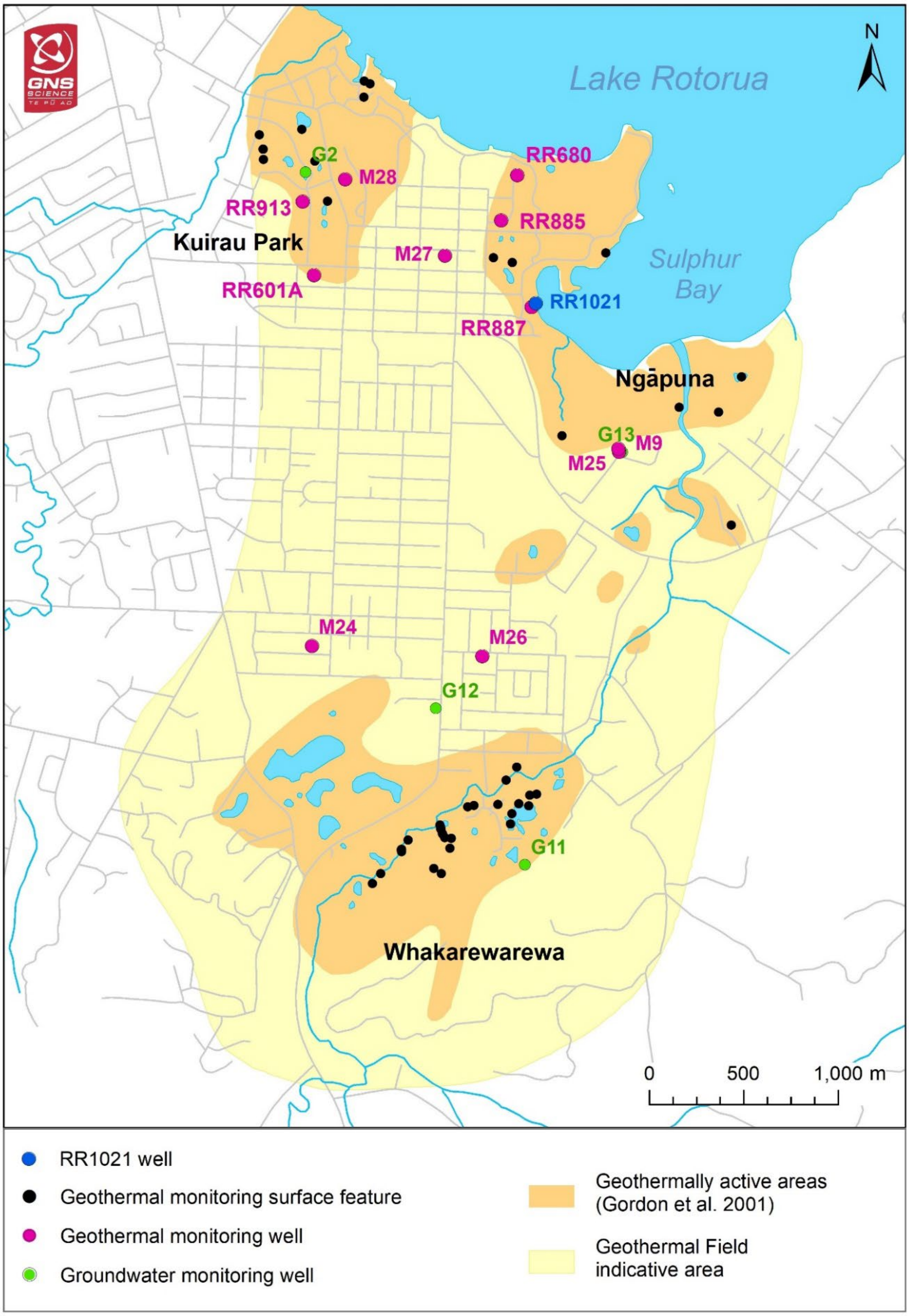

Figure 1.1 Locations of currently monitored sites in the RGS by BOPRC.

1.2 The Model

1.2.1 Methodology

In order to investigate the physical and chemical effects of reinjection of diluted geothermal brine on the aquifer fluid and surface features, we use multicomponent reaction modelling. The software tool REACT (Geochemist's Workbench® 2021) was employed to simulate multicomponent reactions (i.e. fluid mixing). The presented model is idealised but is considered representative of the reinjection process in the RGS.

The model is divided into three steps. Each step represents part of the brine flow-path (Figure 1.2). The first step is the extraction of the brine, at aquifer temperature and pressure, from the production well and boiled at atmospheric pressure where it loses most of its non-condensable gases (mainly CO_2 and H_2S). The boiled fluid is further aerated to remove any remaining toxic H_2S. In the next step, the degassed fluid is mixed with town water. For purpose of this study a ratio of brine to town water of 1:1 (the highest ratio) has been used. This mixture comprises the bathing pool fluid (40°C). The residence time of the pool fluid is set to four hours. The final step is the reinjection of the diluted brine back into the aquifer via a reinjection well where it mixes with the original geothermal brine. This three-step model has some limitations which are discussed below.

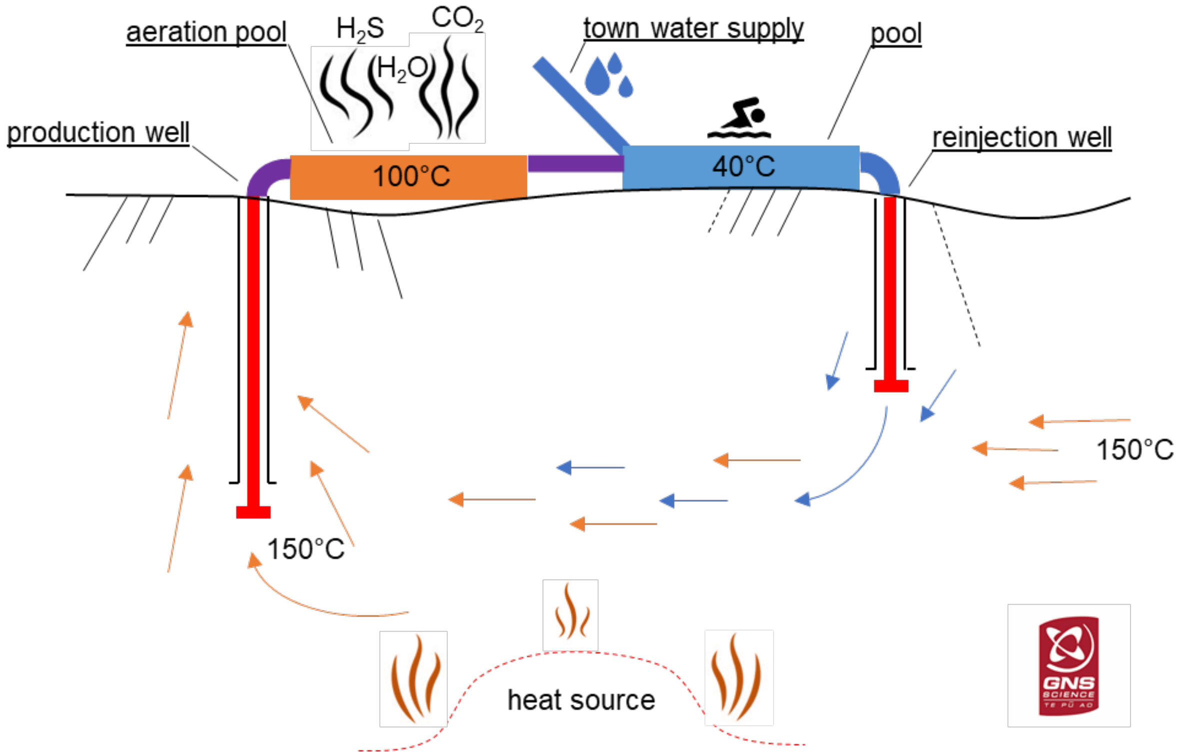

Figure 1.2 A simplified diagram showing the flow path of the geothermal brine as it is extracted and degassed, mixed with town supply and used for bathing, followed by reinjection back into the aquifer.

1.2.2 Temperature

Production wells of the RGS are characterised by a range of temperatures, with a minimum of ~30°C and up to a maximum of ~160°C. The average production temperature is 110°C (Figure 1.3). For the purpose of this study, two representative temperatures of aquifer fluid have been selected: 120°C and 150°C. Lower temperatures (< 100°C) have been omitted from this study, as at these low temperatures silicate mineral reactions are generally too slow to induce any significant changes in chemistry of fluid.

A reinjection temperature of 40°C is assumed. The temperature of mixed reinjection fluid and the aquifer fluid is calculated using the heat and mass balance equation:

$$\left(\frac{\omega_i}{\omega_i+\omega_{res}} \times H_i\right) + \left(\frac{\omega_{res}}{\omega_i+\omega_{res}} \times H_{res}\right) = H_{i+res} \qquad (1)$$

where ω_i is a mass flow of reinjection fluid, ω_{res} of aquifer fluid, H_i is an enthalpy of reinjection fluid and H_{res} of the aquifer fluid.

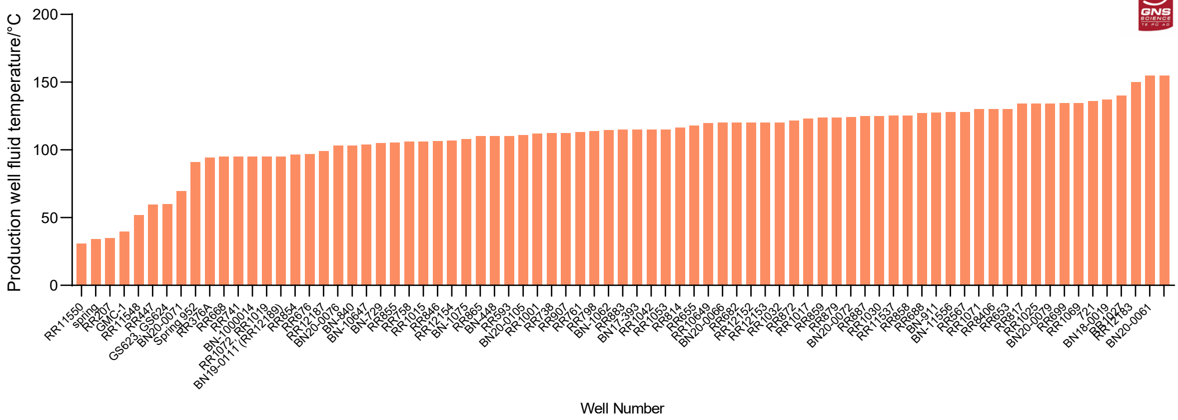

Figure 1.3 Production fluid temperature in Rotorua (data supplied by BOPRC).

1.2.3 Reinjection Rate

Consented maximum mass discharge values have been used to model the reinjection rates as there are no measurements of actual fluid reinjection rates available. The consented values are up to 800 tonne day^{-1} and as low as 50 tonne day^{-1} (Figure 1.4). Note that, the actual reinjection rates might be lower than the consented values. The following discharge rates have been considered in the model: 50, 100, 300 and 800 tonne day^{-1}.

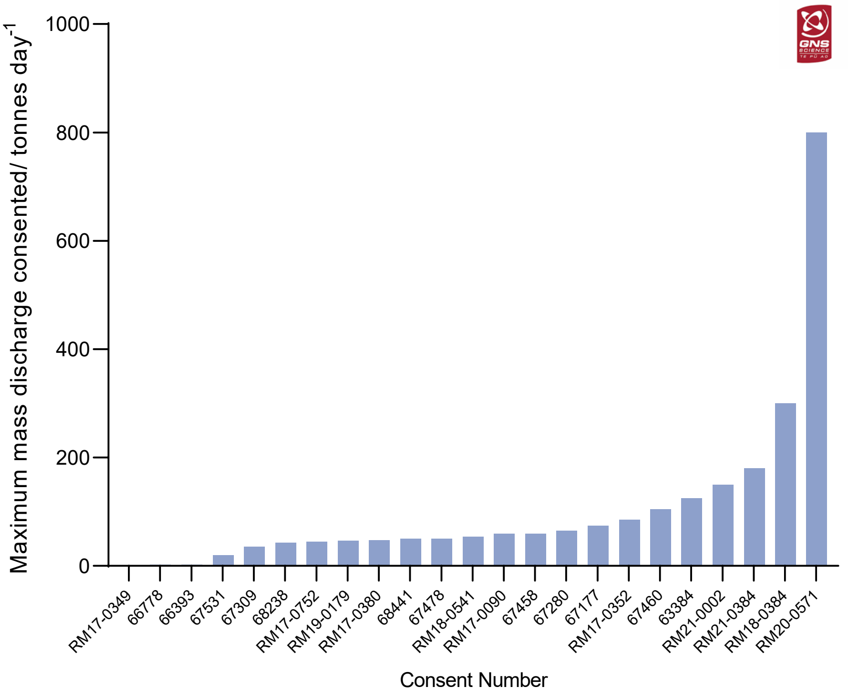

Figure 1.4 Maximum discharge rates by well consented in Rotorua (data supplied by BOPRC).

1.2.4 Distance from the Reinjection Point

Water chemistry in the aquifer will depend on the amount of mixing that occurs between the reinjected fluids and the aquifer water. We expect that more mixing will occur as the reinjected fluids move away from the reinjection point.

However, it is not trivial to predict the spatial mixing of the two fluids. The dynamics of mixing is dependent on the flow rates of the fluids and the permeability of the aquifer including width, spacing, and orientation of fractures. For this reason, some assumptions are necessary.

Previous numerical modelling has shown that the majority of the RGS fluid flows from the south to the north at a flow rate of 10 kg sec^{-1} (Burnell 2020). Therefore, if the reinjection rate of the pool fluid is 10 kg sec^{-1} then the mixing ratio is the assumed maximum value of 1:1. Whereas, if injection rate was equal 50 tonnes day^{-1} (~0.6 kg sec^{-1}) the mixing ratio has is 1:17 (Table 1.1).

Table 1.1 Conversion of injection flow rates used in this study. It has been assumed that the aquifer flow rate is 10 kg sec^{-1} (~800 ton day^{-1}).

Injection Rate		**Ratio**
tonne day^{-1}	**kg sec^{-1}**	**Injection fluid: Aquifer Fluid**
800	9.26	1:1
300	3.47	1:3
100	1.16	1:9
50	0.58	1:17

The direction of flow of the aquifer fluid and the reinjected brine is dependent on the local geology. However, for this study it has been assumed that the aquifer and reinjected fluid mixture travel in one direction.

To estimate mixing rates with distance from the reinjection point, we use a previously developed model of tracer dispersion in the RGS that was employed by Burnell (2020) (Figure 1.5). We assume that the injected fluid can be considered to behave similar to a tracer and will follow this dilution model.

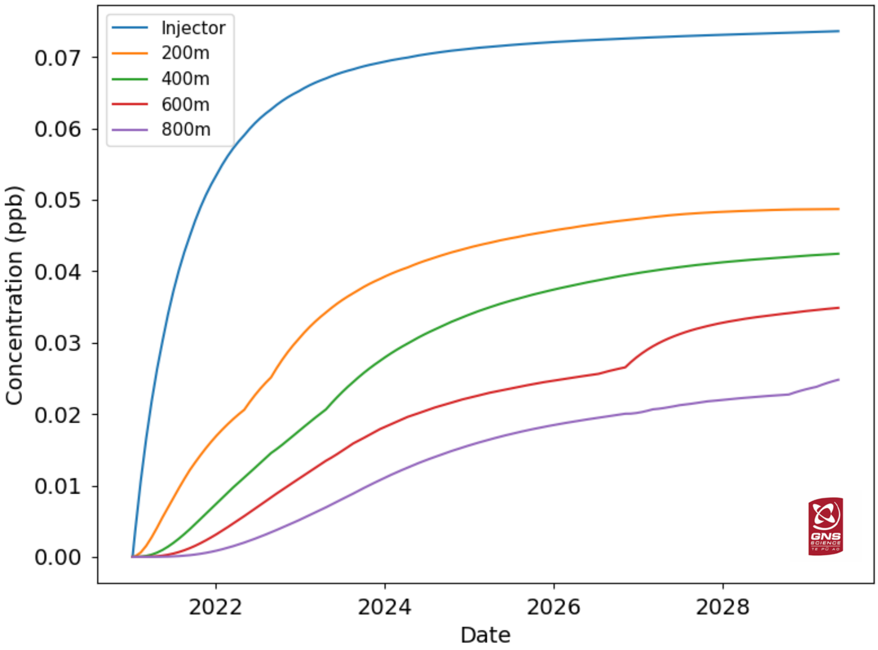

Figure 1.5 Model of dispersion of a tracer injected into the RGS (Burnell 2020).

1.2.5 Fluid Compositions

1.2.5.1 Town Supply

In this study town supply water was used to dilute the geothermal fluid in the ratio 1:1 (town water : geothermal fluid). The town supply composition is characterised by low cation and anion concentrations and a near neutral pH (Table 1.2). The complete analysis of the town supply is listed in Appendix 1.

Table 1.2 Town water composition used in this work. Further details in Appendix 1.

Analyte		Town Water
pH		7.3
Chloride	mg L^{-1}	5.4
Sulphate	mg L^{-1}	2.8
Calcium	mg L^{-1}	2.3
Boron	mg L^{-1}	0.01
Sodium	mg L^{-1}	10.01

1.2.5.2 Geothermal Brine

The RGS is tapped by series of shallow production and reinjection wells. The majority of wells are located in the north part of Rotorua City (Figure 1.1). The individual fluid compositions of these bores are variable and depends on local geology and the depth of the well. The purpose of this study was to examine a hypothetical scenario of reinjection which can be applied to the whole RGS. Hence, for the purposes of this study, the chemistry of a production well RR1021 has been employed (Table 1.3). Well RR1021 is located in Government Gardens. The well has a long history of regular sampling and shows a stable composition. It has been assumed that the fluid from this well is near equilibrium with respect to production and natural recharge (Mroczek et al*.* 2011).

Table 1.3 RR1021 well chemistry composition from 6 February 2019 (complete details in Appendix 2) and composition obtained from WATCH after boiling to 100°C (Appendix 3).

Analyte		**Measured**	**WATCH**
pH		8.3	8.5
Chloride	mg L^{-1}	379	414
Sulphate	mg L^{-1}	46	50
Calcium	mg L^{-1}	8.7	9.5
Boron	mg L^{-1}	5.5	6.0
Sodium	mg L^{-1}	482	527
SiO_2	mg L^{-1}	285	312

1.2.5.3 Mineral Pool Fluid

The mineral pool fluid is derived from flushed geothermal brine. In the chemical model the geothermal brine utilised is assumed to have the composition of well RR1021. In order to obtain the input boiled brine chemistry, it is necessary to adjust the composition for boiling to 100˚C.

The recent chemical analysis for selected components in well RR1021 is available (Table 1.3 and Appendix 2). This sample was collected at the wellhead pressure of ~3 bar using a separator. The mineral pool is filled with brine that has boiled to 100˚C. In order to obtain its composition, the software programme WATCH was used to simulate the boiling of the fluid from 3 bar and 145˚C to 1 bar and 100˚C (Appendix 3). The results for selected components are shown in Table 1.3.

After boiling to 100°C, the brine passes to the aeration pool, an example of which is pictured in Figure 1.6. In this pool the concentrations of H_2S and CO_2 are reduced, and temperature decreases due to aeration. Examples of the chemical composition of the aeration pool water is shown are Appendix 4. Assuming the highest efficiency of aeration, the lowest value for H_2S from that analysis (11.5 mg L^{-1}) has been used in the modelling. The concentrations of the remaining analytes from the analysis in Appendix 4 was not used due to lack of information on its exact sampling location. Instead, the concentrations of these analytes generated in WATCH were used.

Figure 1.6 Example of an aeration pool (aeration tank) in Rotorua.

1.2.5.4 The Aquifer Fluid

As shown in Figure 1.3, the temperatures of the shallow aquifer (reservoir) in the RGS are variable. These are mostly dependent on the depth of the well and its location. For deeper wells (~130 m) temperatures reach 150°C (Scott et al. 2021). In this study, two reservoir temperatures (120°C and 150°C) have been considered.

The chemical composition of the aquifer fluid also changes across the RGS. Due to this variability, it is challenging to select one representative brine composition for the whole RGS. The composition of the RR1021 fluid has been employed, because of availability of quality of data and relatively long history of sampling. It is also assumed that the reservoir fluid (at 120°C and 150°C) is at chemical equilibrium with reservoir rock mineralogy and not supersaturated with respect to common rock-forming minerals. Using the above assumptions, the compositions of the reservoir fluid at both temperatures have been calculated using REACT. These are shown in Table 1.4 and listed in detail in Appendix 5.

Table 1.4 Aquifer composition recalculated in GWB® using RR1021 well chemistry (details in Appendix 5).

Analyte		**120°C**	**150°C**
pH		7.7	7.7
Chloride	mg L^{-1}	371	371
Sulphate	mg L^{-1}	45	45
Calcium	mg L^{-1}	1.6	0.7
Boron	mg L^{-1}	5.4	5.4
Sodium	mg L^{-1}	472	472
SiO_2	mg L^{-1}	184	272

1.3 Descriptions of Model Scenarios

For each scenario run with the model (Figure 1.7), the following steps were taken:

1. Calculate the initial composition of the boiled geothermal brine (Fluid A) using WATCH.
2. a) Mix boiled geothermal brine with town supply (Fluid B) in 1:1 ratio using *GWB*® to give pool water composition (Fluid C); b) reference scenario with no dilution (i.e. no town water is mixed with geothermal brine) using town supply.
3. Mix pool water (Fluid C) back into reservoir fluid (Fluid D) at required ratios (Table 1.1) which results in Fluid E.
4. Re-dilution of Fluid E further away from the injection point with Fluid D.

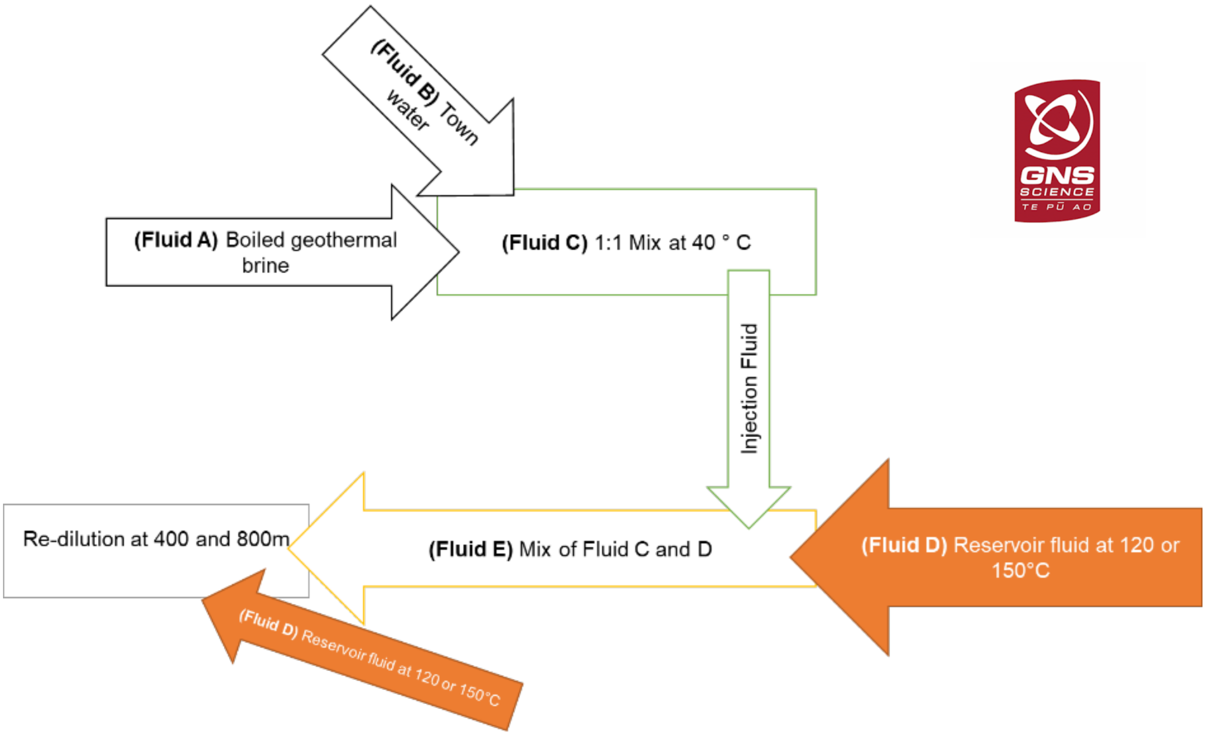

Figure 1.7 The conceptual flow chart of the model.

Additional assumptions include:

1. There is no mineral precipitation in the mineral pool fluid (Fluid C).
2. The reservoir fluid (Fluid D) is in chemical and thermal equilibrium with the aquifer at 120°C or 150°C.
3. Only the minerals anhydrite ($CaSO_4$), amorphous silica (SiO_2), calcite ($CaCO_3$), cristobalite (SiO_2), pyrite (FeS_2) and Ca-Saponite clay ($Ca_{0.165}Mg_3Al_{0.33}Si_{3.67}O_{10}(OH)_2$) are considered as possible precipitates in the reservoir.

1.4 Model Results

1.4.1 Reinjection into a 120°C Aquifer

1.4.1.1 Conservative Elements

Geothermal brines contain many different dissolved components. Some of these are often considered as conservative (e.g. Cl). Conservative elements do not take part in mineral reactions and their concentrations remain unchanged except during processes such as boiling and mixing. For example, the proportions of mixing of diluted mineral pool fluid (low Cl concentration) with reservoir fluid (high Cl concentration) can be determined based on the mixed fluid's Cl concentration.

Figure 1.8 shows the Cl and B concentration changes during reinjection of diluted fluid and, for comparison, undiluted geothermal brine (Figure 1.8b,d) versus the distance from reinjection point. At distance 0 m, the fluid is a mixture of reinjection fluid and aquifer fluid presented as Fluid E on the Figure 1.7. The dotted line shows the original reservoir concentration ± 2% uncertainty (dashed lines). It is assumed that all calculated concentrations falling within ± 2% of the original concentration are the same within uncertainty.

The results show that injection of diluted brine at rate 50 and 100 t day^{-1} results in little change to the reservoir fluid composition. At injection rates of 300 t day^{-1} and 800 t day^{-1}, when diluted fluid is reinjected, the composition change of the reservoir is considerable for both Cl and B. At 300 t day^{-1} and 800 m from the reinjection point, the mixed composition lies slightly below the original brine. At 800 t day^{-1} the mixed composition is noticeable below the original and it will take another several hundred of meters for the brine to reach the original composition. For the injection of undiluted geothermal brine at all rates there are no significant changes in reservoir composition > 800 m from the reinjection point.

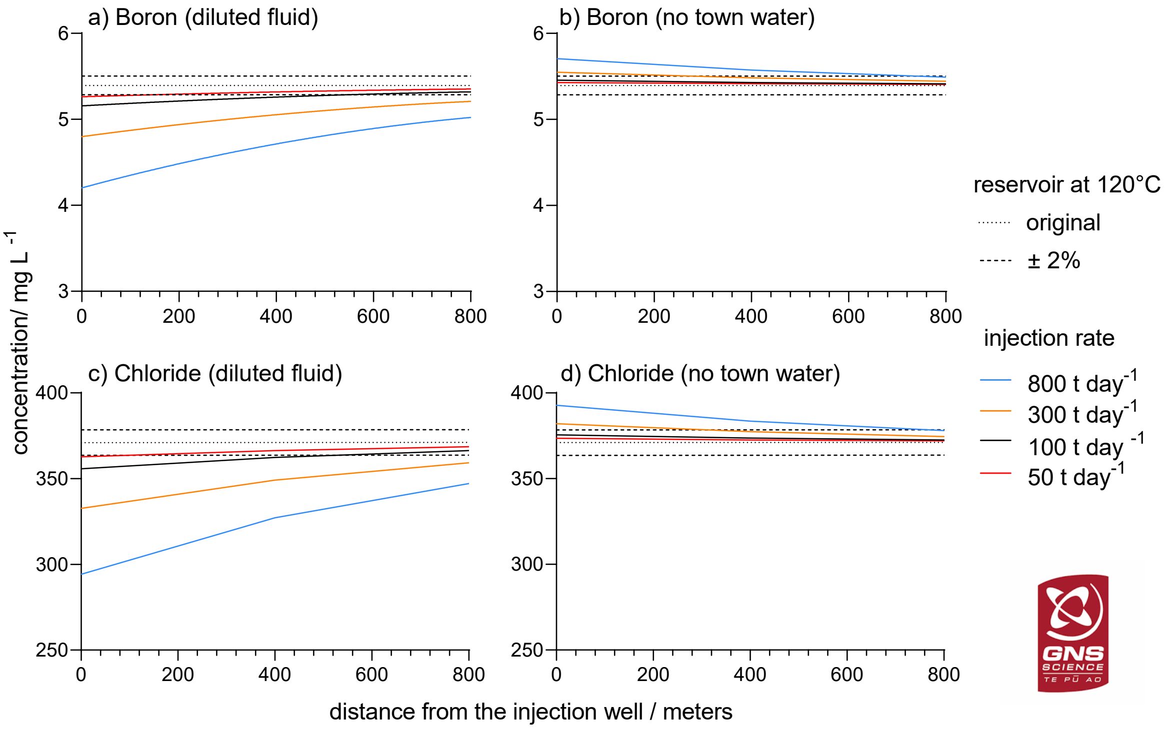

Figure 1.8 Concentration (mg kg^{-1}) of B (a,b) and Cl (c,d) versus distance (m) from a reinjection well at a reservoir temperature of 120°C at four reinjection rates (t day^{-1}). The left diagrams show the results for diluted brine and the right diagrams are for undiluted brine. Dotted lines are the original reservoir composition. Dashed lines are ± 2% of this concentration.

1.4.1.2 Non-conservative Elements

The concentrations of non-conservative species are altered due to changes in temperature, pH, fluid mixing and fluid-rock interaction. Such changes can induce mineral precipitation and/or mineral dissolution. For example, dissolved SiO_2 concentration can increase or decrease depending on the temperature of the fluid as it equilibrates with silica minerals. Dissolved cations such as Na, K, or Ca or gases (e.g. H_2S, CO_2) can also be non-conservative. In order to determine the behaviour of non-conservative species it is necessary to model changes in temperature, pH, and fluid composition due to mixing or fluid-rock interaction.

In the present model, it has been assumed that the aquifer fluid, when cooled down by reinjection of diluted brine, is not reheated by the reservoir rock and only gains temperature by mixing with further hotter reservoir fluid. Figure 1.9 shows the modelled temperature, pH, and SiO_2 concentration changes with the distance from the reinjection point at the four injection rates. It is possible that reheating of the aquifer by the reservoir rock would minimise the SiO_2 concentration changes and enhance calcite precipitation.

The results show that a measurable pH increase (+ 0.25 log units) will occur only at 800 t day^{-1} and only adjacent to the rejection well (Figure 1.9a,b). In the remaining cases, the pH shift is approximately +0.1 log units. This is likely to be close to the estimated errors given the challenges of calculating highly accurate pH values under these conditions.

In contrast, the temperature of the mixed fluid will decrease significantly, especially at reinjection rate of 300 and 800 t day^{-1} (Figure 1.9c). Also affected are the concentrations of dissolved species. For example, mixing the diluted brine with the reservoir fluid causes a decrease in SiO_2 concentration (Figure 1.9d). The change in temperature also causes SiO_2 to re-equilibrate with the silicate phases which also results in an additional decrease. The temperature of the reservoir may change over a long distance and thus affect the surrounding features.

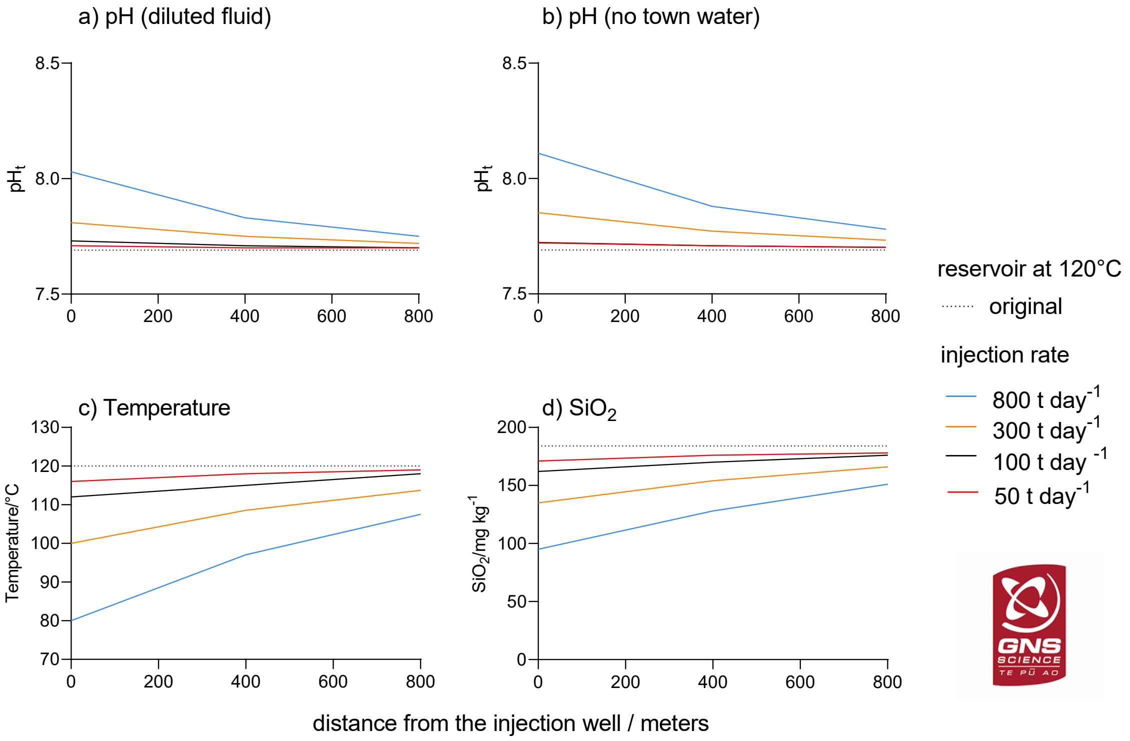

Figure 1.9 pH at temperature (pH$_t$) (a,b), temperature (c), and silica concentration (d) versus distance (m) from the reinjection well at a aquifer temperature of 120°C at four reinjection rates. For comparison, reinjection of undiluted geothermal is shown in (b).

Ca concentration is also dependent on changes in temperature and fluid composition. This is due to its concentration being controlled by Ca-bearing minerals. In the present model these are calcite, anhydrite, and Ca-saponite. The results show that during diluted fluid reinjection, Ca concentration should increase (Figure 1.10a), however, this does not consider the saturation state of Ca-bearing minerals.

Figure 1.11a and b show the saturation state of the minerals considered in this study and Figure 1.11c and d show the calculated amount of these minerals in grams per tonne of fluid reinjected.

The results show that the diluted brine, when mixed with the aquifer fluid, becomes slightly oversaturated with respect to calcite and cristobalite, and oversaturated with respect to Ca-saponite and pyrite (Figure 1.11a). A similar result is found when undiluted brine is reinjected, however the saturation indices for these minerals are higher (Figure 1.11b).

Oversaturation with respect to some minerals indicates that these minerals will precipitate. Because of the low temperature (120°C), the precipitation rates will be slow. Nevertheless, the small changes in concentration mean that the amount of precipitated minerals is minor. The estimated maximum amount of precipitated mineral is for calcite is 0.24 g t^{-1} brine at a reinjection rate of 100 t day^{-1} (Figure 1.11c). For the undiluted brine, a much larger amount of calcite is precipitated because of the brine's higher Ca concentration. Maximum calcite precipitation of 8.5 g t^{-1} brine occurs at a reinjection rate of 800 t day^{-1} while 0.8 g t^{-1} brine is precipitated at a reinjection rate of 50 t day^{-1} (Figure 1.11d).

The reinjected fluid (either diluted or not diluted) has a lower concentration of HCO_3 and H_2S when compared to the aquifer fluid. This results in a decrease in concentrations of these species which is most notable at high injection rates (Figure 1.10c,d). The lowering in concentration of these species indicates that there might be an impact on acid-sulphide features which depends on H_2S presence in the aquifer.

Because pyrite is highly insoluble at the pH values encountered, the small amounts of Fe and H_2S in the mixed fluid would result in pyrite precipitation (Figure 1.11c). The presence of Al, Ca and SiO_2 in the mixed fluid also indicates that Ca-saponite clay precipitation is also expected (Figure 1.11c). However, the amounts of these two minerals is minor, both with the diluted and undiluted brine.

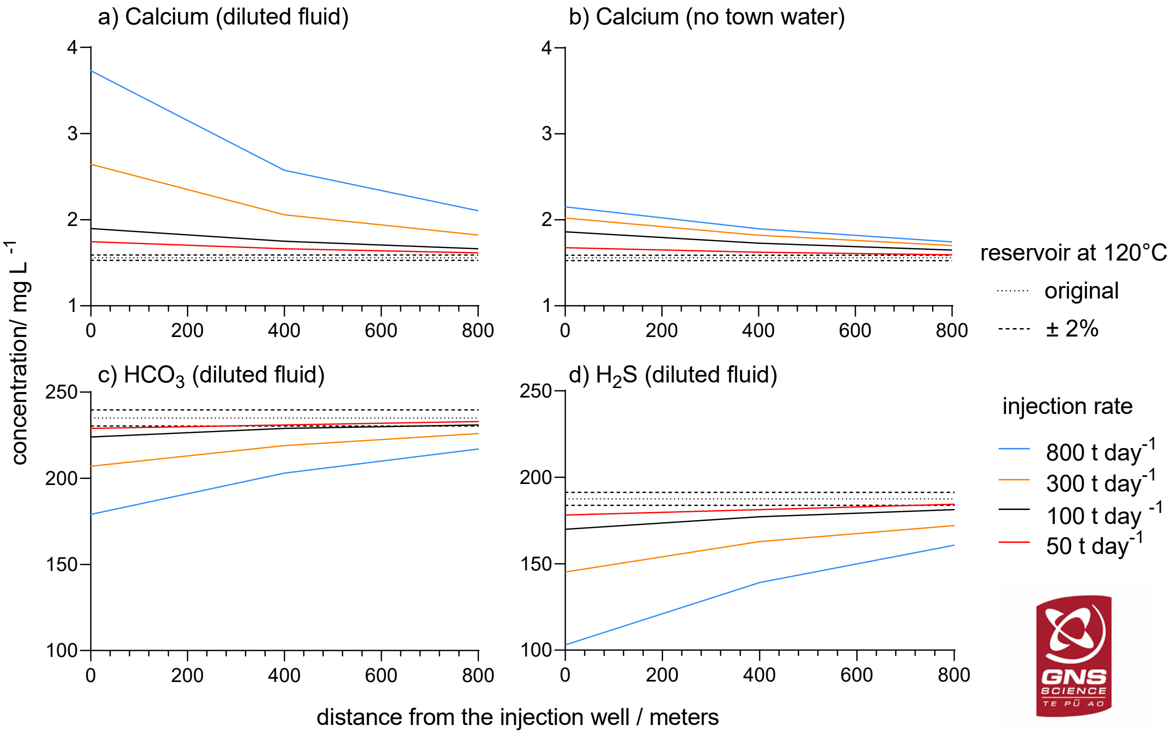

Figure 1.10 Ca (a,b), HCO_3 (c), and H_2S (d) concentration versus distance (m) from the reinjection well at an aquifer temperature of 120°C at four reinjection rates. For comparison, the effect on Ca of the reinjection of undiluted geothermal is shown in (b).

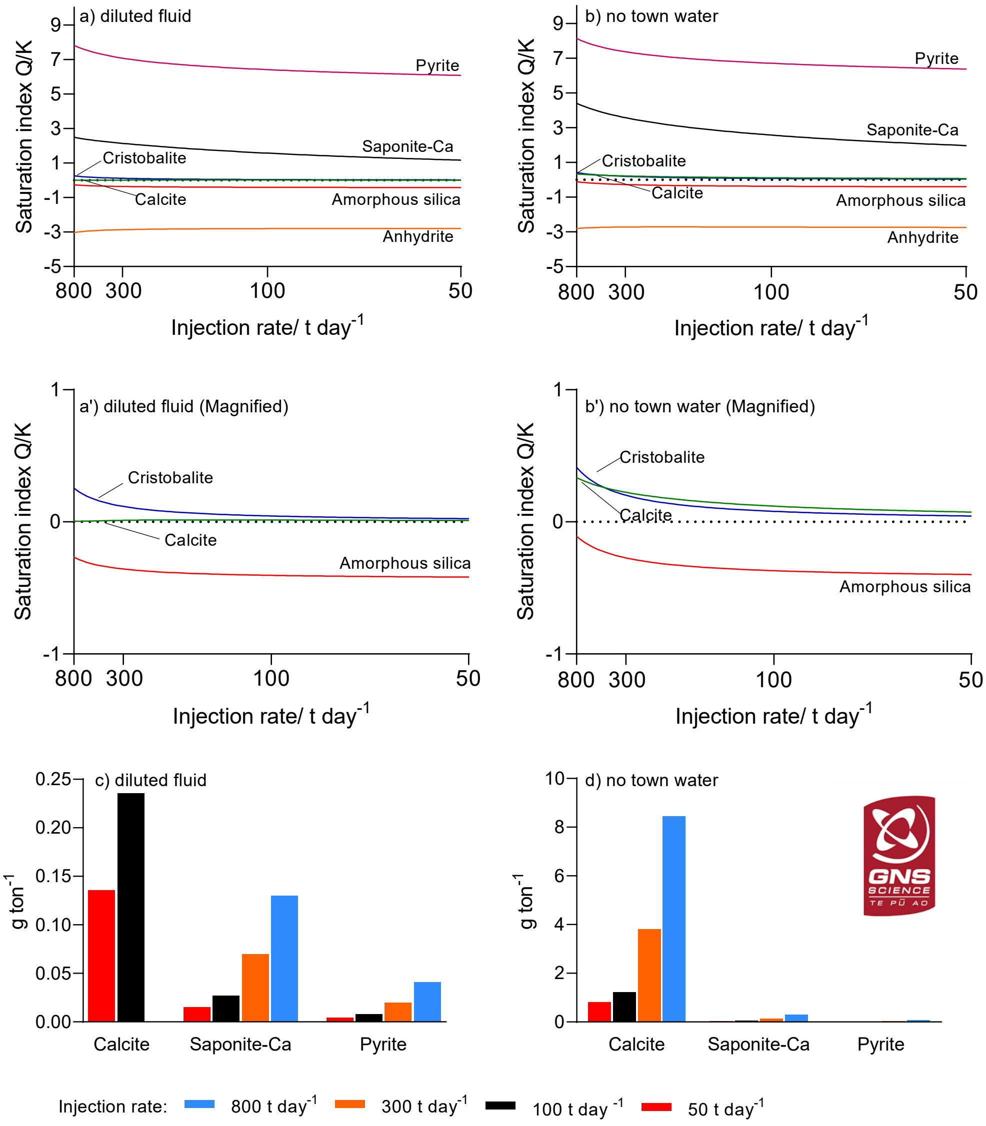

Figure 1.11 a,b) Mineral saturation index versus reinjection rate calculated using GWB. The fluid is saturated with respect to a mineral when its saturation index is greater than zero (dashed line) and undersaturated when less than zero. c,d) Calculated mass of precipitated minerals in grams per tonne of brine.

1.4.2 Reinjection into a 150°C Aquifer

1.4.2.1 Conservative Elements

Figure 1.12 shows the Cl and B concentrations during reinjection of diluted and undiluted brine (no town water) versus distance from the reinjection well. The dotted line shows the original aquifer concentrations. The dashed lines are ± 2% of the aquifer concentration, considered the uncertainty.

Because the concentration of conservative species is not dependent on temperature, the concentration profiles of these species are the same as those modelled at 120°C. As before, only at high reinjection rates (300 tonne day^{-1} and above) are large changes observed (for example decrease in concentration of Cl^- by 77 mg L^{-1}).

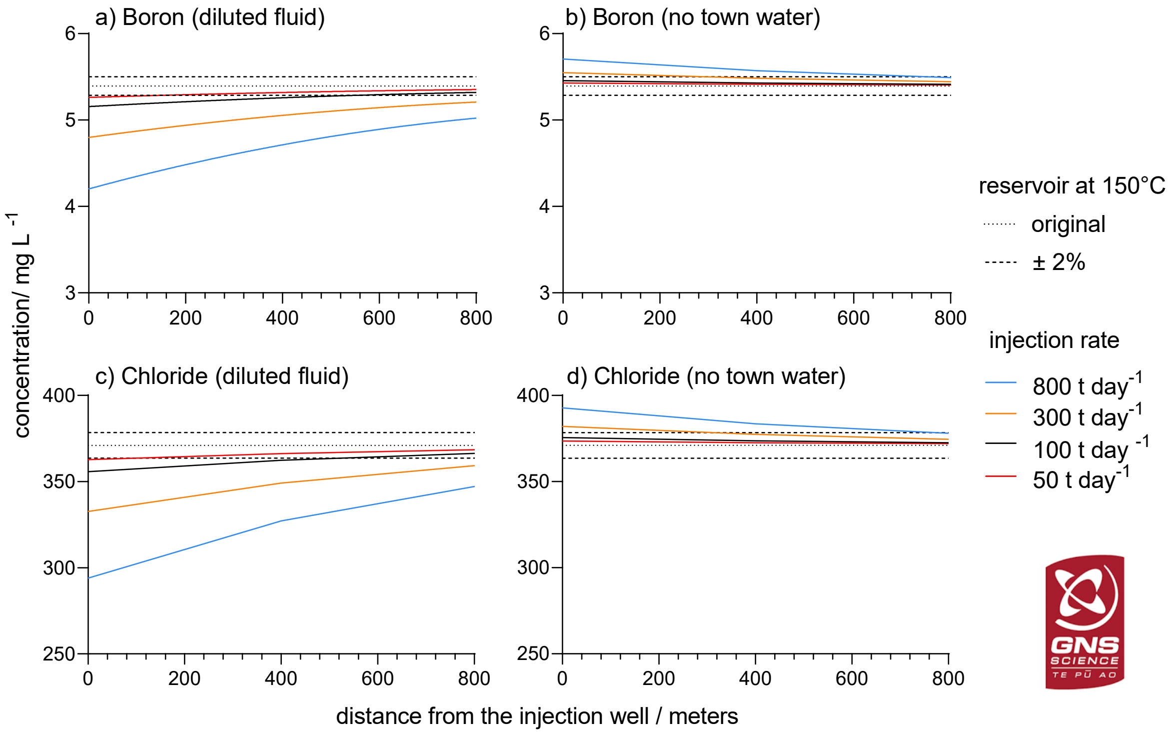

Figure 1.12 Concentration (mg kg^{-1}) of B (a) and Cl (c) versus distance (m) from the reinjection well at aquifer temperature (150°C) for all reinjection rates. For comparison, the effect on B (b) and Cl (d) is shown for undiluted brine.

1.4.2.2 Non-conservative Elements

The concentration of non-conservative elements will be affected by changes in temperature and pH, and by mineral precipitation or dissolution. As at 120°C, at 150°C calculated pH change will be measurable only at 800 t day^{-1} and only near the rejection well (Figure 1.13a,b).

Figure 1.13c shows the temperature profile versus distance from the reinjection well. Substantial decreases in temperature are observed especially at 300 and 800 t day^{-1} reinjection rate (for example drop to temperature below 100°C at 800 t day^{-1}). Decreases in SiO_2 concentration also result from reinjection (Figure 1.13d).

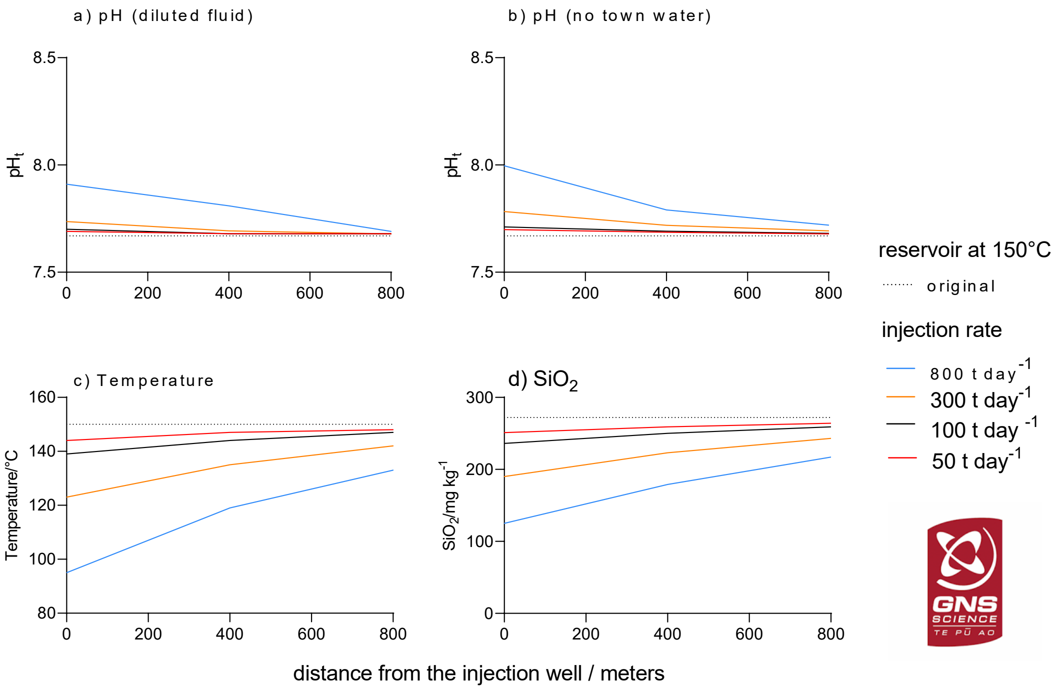

Figure 1.13 pH_t (a), temperature (c), and silica concentration (d) versus distance (meter) from the reinjection well at the aquifer temperature of 150°C. For comparison, the effect on pH_t (b) is shown for undiluted brine.

Figure 1.14 shows the effect of reinjection of diluted brine on Ca, HCO_3 and H_2S concentrations, as well as that for Ca with undiluted brine. The Ca concentration is lower at 150˚C as calcite solubility is lower at the higher temperature. HCO_3 and H_2S appear unaffected as the amount of calcite and pyrite precipitated is small and does not greatly affect their concentrations.

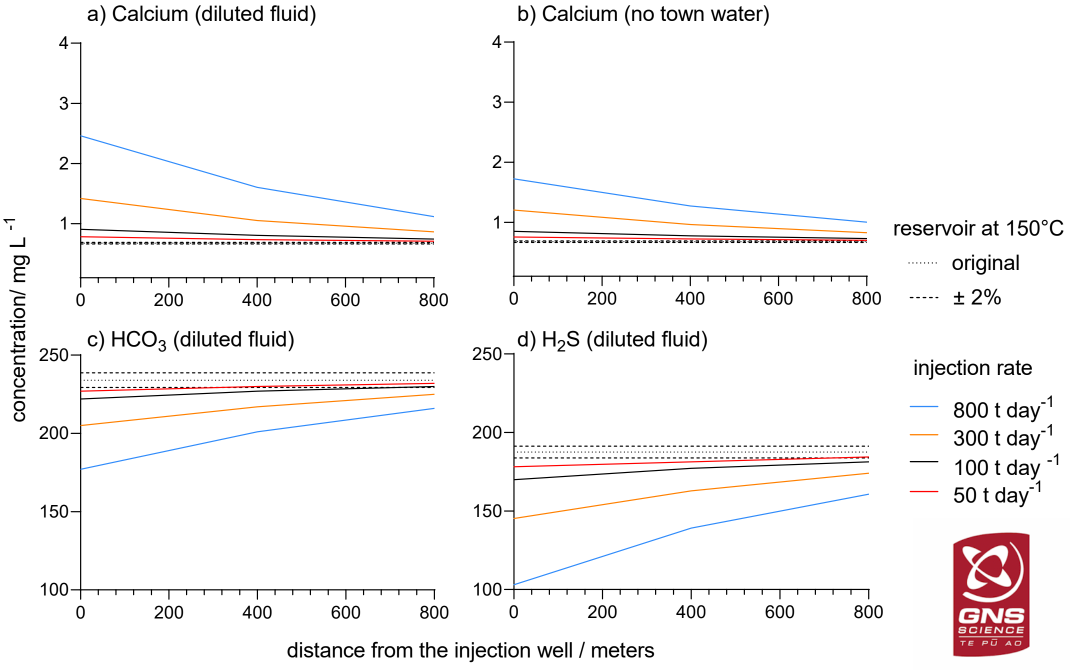

Figure 1.14 Ca (a) and HCO_3 (c) changes versus distance (meter) from a reinjection well at aquifer temperature (150°C). For comparison, the effect on Ca (b) is shown for undiluted brine.

Figure 1.15a shows that when diluted brine mixes with the re aquifer fluid the mixture is slightly oversaturated with respect to calcite and significantly oversaturated with respect to Ca-saponite. When undiluted brine is reinjected, calcite saturation is marginally higher (Figure 1.15b). The calculated amounts of precipitated minerals are shown in Figure 1.15c and d. With diluted brine, the only noteworthy precipitate is calcite ranging from 0.5 g t^{-1} brine at reinjection rates of 50 t day^{-1} to 2 g t^{-1} brine at reinjection rates of 800 t day^{-1}. With undiluted geothermal brine the amount of calcite is considerably higher with about 1 g t^{-1} brine at reinjection rates of 50 t day^{-1} to 8 g t^{-1} brine at reinjection rates of 800 t day^{-1}. This is 2–4 times greater than undiluted brine. This shows that with diluted brine at the high temperature there is considerably more calcite precipitated, 25 g to 1600 g per tonne of brine reinjected. The latter is a substantial amount of calcite; however, it is not clear exactly where this would precipitate within the aquifer and will depend of the permeability and fracture network around the well. These precipitates may reduce permeability around the well over time.

The amounts of Ca-saponite and pyrite are lower as these minerals have a higher solubility at higher temperature (Figure 1.15d).

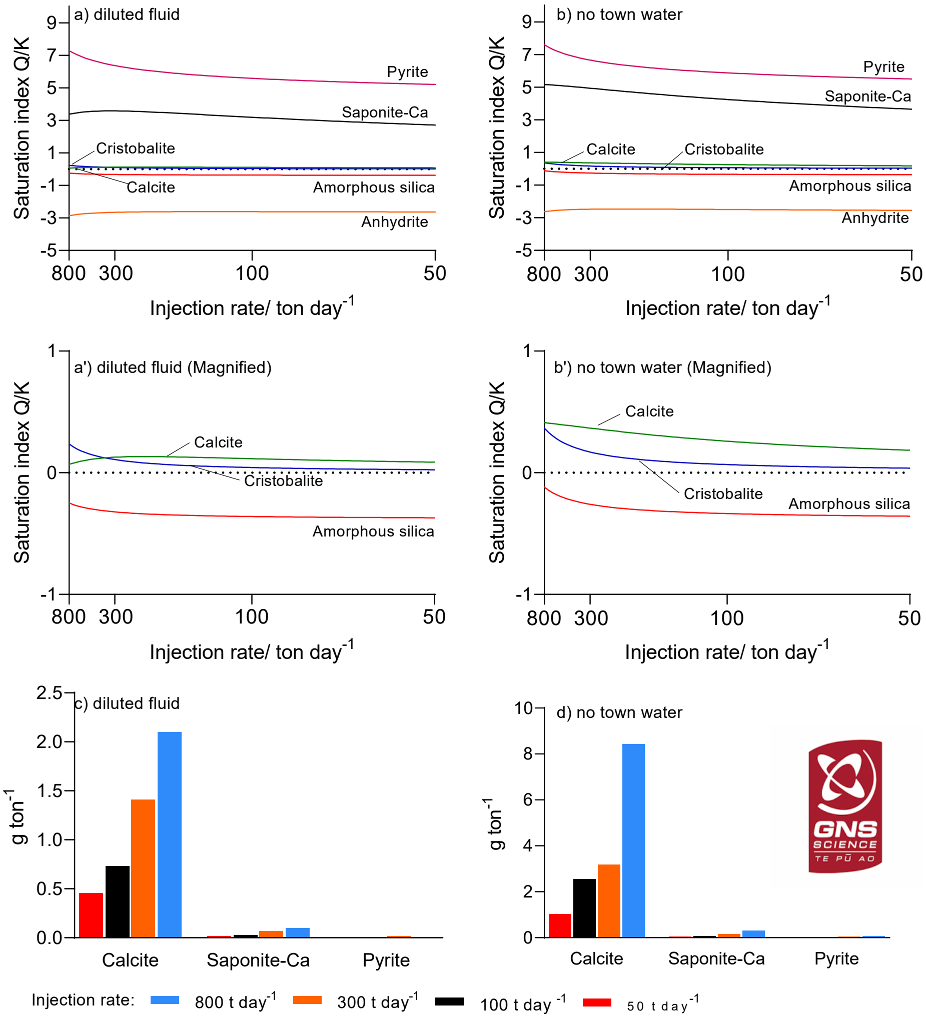

Figure 1.15 a,b) Mineral saturation index versus reinjection rate calculated using GWB. The fluid is saturated with respect to a mineral when its saturation index is greater than zero (dashed line) and undersaturated when less than zero. c,d) Calculated mass of precipitated minerals in grams per tonne of brine.

1.5 Limitations of the Study

The present geochemical model is representative of only one combination of chemistries, however, it does give a measure of the effect of reinjection. There following limitations should be considered when interpreting the model results: The geothermal brine chemistry can vary within the RGS and this will affect the amount of minerals expected to precipitate. Note, that it is not possible to predict where exactly the precipitate will occur. If the respective brine chemistries are different, the model would have to be modified.

1. It has been assumed that the reservoir fluid flows at 10 kg sec^{-1} towards the north This is a reasonable assumption, however, there are parts of the RGS where the flow rate differs. A different flow rate will result in a different proportion of mixing and will also affect the results.
2. The geochemical model assumes that the proportion of reservoir fluid during flow and mixing will increase with distance from the well. However, the degree of mixing is dependent on local geology and permeability.
3. Modelling the long-term temperature change in the reservoir was not part of this study. The present geochemical model assumes that sufficient heat is provided by the flowing reservoir fluid to maintain a temperature equilibrium.

The results from this modelling approach provide a reasonable understanding into the likely effects on the reservoir due to reinjection of brine. Note, however, to increase confidence in the predictions, or to target a specific brine combination, additional chemical data and further modelling are required.

1.6 Conclusions

The results of this study show that:

1. Reinjection of the diluted fluid will have an effect on the composition of the reservoir fluid with the impact being proportional to the reinjection rate.
2. At reinjection rates of 50 and 100 t day^{-1} (both at 120°C and 150°C) changes to the reservoir chemistry are minimal.
3. Changes in the concentration of conservative elements (Cl, B) will be insignificant as these are within the ± 2% uncertainty of the reservoir brine composition.
4. For conservative elements, the effect of reinjection on the geochemistry is even less notable when undiluted brine is reinjected.
5. In most cases the pH change of the reservoir fluid is minor (~0.1 log units) and is independent of reinjection rate, fluid type or reservoir temperature.
6. The only measurable change in pH will be at 800 t day^{-1} up to 800 m from the well.
7. There will be a major decrease in SiO_2 concentration at 300 and 800 t day^{-1} which could impact surrounding wells and surface features.
8. The decreases in SiO_2 concentration are dependent both on mixing and temperature due to re-equilibration with silica minerals (at 150°C from 275 mg kg^{-1} to 125 mg kg^{-1}).
9. At both 120°C and 150°C, when injecting diluted brine, less mineral precipitates are expected than when injecting the same amount of undiluted brine (for example, at 800 t day^{-1} almost four times less of calcite will be precipitated).

10. The amount of calcite precipitation expected at 150°C is substantial, particularly at 800 t day^{-1} of undiluted brine (6736 g per day) and could pose an issue for long-term injectability.

The geochemical model suggests that at a mixing ratio of 1:1 brine to town supply, and at slow to moderate injection rates ($\leq$ 100 t day^{-1}), there will be minimal effect on the reservoir. However, when the reinjection rate is greater ($\geq$ 300 t day^{-1}) there could be noticeable changes in reservoir fluid composition. These would be expected to be more notable near the reinjection well. It is also worth to note that extraction of the geothermal brine and subsequent boiling results in loss of water vapour. The lost of water results in an increase of concentration of most dissolved components (e.g. Cl, SiO_2) in the bathing fluid. Therefore, dilution of the geothermal brine with the town water brings the concentrations of components closer to a natural state before boiling occurred. The amount of added town water must be equal to water lost as steam.

2.0 PART 2: MICROBIOLOGY

2.1 Introduction

This Section outlines the potential environmental impacts of reinjecting bathing pool water or discharging bathing pool water to surface water, based on the microbiology of the pool water. There are two possible groups of adverse effects; the release of pathogenic microorganisms into the reinjection site and surrounding environment, and the potential for chemical changes induced by microorganisms. Social and cultural concerns are out of scope for this report. While drinking water sources are generally safeguarded through the use of source protection zones and filtration, it is important to note that pathogens may be harmful not only in drinking water but also in water used for irrigation, recreation or when interacting with surface water connected to mahinga kai. The aim of this report is to allow the development of a risk matrix for the treatment or disposal of post-bathing water, depending on the microorganisms present and the site chosen for reinjection or discharge.

2.2 Pathogens in Bathing Water

Most of the risk of infection associated with geothermal mineral pools is due to faecal contamination of the water, either from residual faecal material from bathers' bodies, from contaminated source water, or from birds and rodents. These enteric pathogens may be bacterial, viral or protozoan in origin (Table 2.1) (World Health Organisation 2006). Enteric viruses are a particular risk, as they are excreted in high numbers (up to 10^{-11} viral particles per gram of faeces) and many have a low infectious dose (10–100 particles) (Horn et al. 2016). Viruses cannot reproduce in water without host cells but can be very stable in the environment.

Bathers may also contaminate waters and the surfaces of objects by shedding non-faecal pathogenic organisms, particularly bacteria, viruses and fungi, which may lead to skin and other infections. In addition, some free-living bacteria and amoebae can grow in natural mineral waters as well as wet surfaces in heating and air-conditioning systems (World Health Organisation 2006).

Most bathing pool developments are required to monitor at least *E. coli* and *Enterococcus*, often known as faecal indicator bacteria or FIB (EPA 2012). The control of bacteria and viruses in mineral pools is usually achieved through filtration, disinfection with chlorine or other anti-microbial agents, or temporary pH adjustments. However, some pathogens such as *Pseudomonas aeruginosa*, *Cryptosporidium* and *Giardia* are resistant to disinfectants (World Health Organisation 2006), and an accidental faecal release with high pathogen contamination of the water may not be controlled by normal disinfectant levels. In these cases, heat treatment may be applied in order to decontaminate water.

Table 2.1 Potential microbial hazards in mineral bathing pools[1] spp., multiple species.

Pathogen	Illness	Health Significance	Transmission Pathway[2]	Likelihood of Infection[3]
Bacteria				
*Campylobacter spp.** [4]	Gastroenteritis, fever	High	Ingestion	Moderate
*Enterococci** [5]	Bloody diarrhoea, abdominal cramp, respiratory illness	High	Ingestion	Low
*Escherichia coli * (pathogenic strains)*	Bloody diarrhoea, abdominal cramp	Moderate	Ingestion	High
Legionella spp.	Pneumonia, gastroenteritis	High	Inhalation	Low
Leptospira spp.	Fever, headache, vomiting, jaundice	Moderate	Ingestion, contact	Low
Mycobacterium spp.	Respiratory disease, pneumonia, skin diseases	Moderate	Inhalation, contact	Low
Pseudomonas spp.	Ear infections, skin diseases	Low	Contact	High
*Salmonella spp.**	Gastroenteritis	High	Ingestion	Low
*Shigella spp.**	Bloody diarrhoea, abdominal cramp	Moderate	Ingestion	Moderate
Staphylococcus spp.	Ear infections, skin rashes, wound infections	Low	Contact	Moderate
Viruses				
Adenoviruses*	Gastroenteritis, respiratory disease, conjunctivitis	High	Ingestion, inhalation	High
Enteroviruses*	Gastroenteritis, respiratory infections	Moderate	Ingestion	High
Hepatitis A*	Liver disease	High	Ingestion	Moderate
Molluscipoxvirus	Skin diseases, warts	Low	Contact	Moderate
Noroviruses (Norwalk viruses)*	Diarrhoea, vomiting	High	Ingestion	High
Papillomavirus	Plantar warts	Low	Contact	High
Rotavirus	Gastroenteritis	High	Ingestion	High
Protozoa				
Acanthamoeba spp.	Universally fatal granulomatous encephalitis, corneal inflammation	High	Ingestion	Low
Cryptosporidium spp.*	Diarrhoea, abdominal pain, fever	High	Ingestion	High
Entamoeba histolytica	Amoebic dysentery	High	Ingestion	High
Giardia spp.*	Diarrhoea, abdominal cramp	High	Ingestion	High
Naegleria fowleri	Almost invariably fatal amoebic meningoencephalitis	High	Contact	Low
Fungi				
Epidermophyton spp.	Athlete's foot	Low	Contact	Moderate
Trichophyton spp.	Athlete's foot	Low	Contact	Moderate

1 Data taken from (World Health Organisation 2006; NHMRC 2008; Tiwari et al. 2021).

2 The amount of water ingested by swimmers and bathers will depend upon a range of factors, including age, experience, skill and type of activity. Inhalation exposure will be largely associated with aerosols, within a hot tub (for example), or where there is significant splashing. Contact may involve water coming into contact with skin, mucus membranes or cuts in the skin, or physical contact with wet surfaces, edges of pools, shared towels etc.

3 Likelihood of infection depends on the number of organisms needed for an infectious dose, as well as length and type of transmission and the age and health status of individuals.

4 * May be faecally-derived.

5 Enterococci is defined as “members of the genus Enterococcus that show growth at least between 10°C and 45°C, at pH 9.6 and at 6.5% NaCl; are able to reduce 0.1% methylene blue; and show resistance to 60°C for 30 minutes” (World Health Organisation 2009). However, as the most common faecally-derived organisms also fulfil these criteria, the terms “enterococci”, “intestinal enterococci”, “the Enterococcus group” or “faecal streptococci”, are in practice interchangeable.

2.2.1 Heat Treatment, D Values and Sterilisation Methods

D values are used to indicate the heat resistance of contaminants, which is the time needed at a specific temperature in order to kill 90% of the organisms. *D* values for viruses indicate a reduction of at least 3 log units for complete inactivation (Bozkurt et al. 2015), associated with an acceptable risk reduction for human contact. Table 2.2 shows *D* values for common contaminants, including faecally-derived pathogens, in mineral pools. Bacteria, protozoa, and fungi often produce resting stages such as spores and cysts, which are more resistant to heat and other stresses than active cells. D values for these resting stages have been included in Table 2.2 where known.

The exposure of microorganisms for a short time to temperatures above their maximum growth temperature is known as heat shock. If the heat shock is not lethal, it can lead to tolerance of more severe stress (Richter et al. 2010). After repeated heat shocks, strains of *Legionella pneumophila* were heat resistant to 70°C with up to 85% of cells viable after 60 minutes at this temperature (Allegra et al. 2011). Many bacteria, including faecal coliforms, show not only recovery but increased growth after heat shock (Davenport et al. 1976). The abundance of *Vermamoeba vermiformis*, a known *Legionella* host, also increased after heat shock (Ji et al. 2018). Resistance to heat shock is highest during the stationary phase of growth (White 1953), which would be expected for pathogens sitting in thermal pools for prolonged periods.

Recovery after heat shock depends on a range of environmental factors, including temperature, nutrient availability, alkalinity and the presence of trace elements such as Al, Mo and Sb (García-Gil et al. 2018). Resistance to heat shock is difficult to predict and is organism-dependent.

Table 2.2 Heat resistance values of common contaminants.

Bacterium/Bacterial Groups	**Temperature (°C)**	***D* range or maximum (minutes)**	**Reference**
Campylobacter jejuni/coli	55	0.2–3.2	(Sörqvist 2003)
	60	0–0.5	
	65	0–0.9	
	72	0–0	
Enterococcus faecalis	55	3.7–146.9	(Sörqvist 2003)
	60	1.1–43.2	
	65	0.3–12.9	
	72	0.1–2.4	
Enterococcus faecium	55	17.4–232.8	(Sörqvist 2003)
	60	5.3–69.4	
	65	1.6–20.9	
	72	0.3–4	
Escherichia coli	55	0.9–22.3	(Sörqvist 2003)
	60	0.1–3.2	
	65	0–0.5	
	72	0–0	
Legionella pneumophila	58	18	(Dennis et al. 1984)
Legionella spp.	80	2.1	(Stout et al. 1986)
Mycobacterium paratuberculosis	72	0.25	(Juffs and Deeth 2007)
Pseudomonas aeruginosa (cells)	60	> 30	(Ricker et al. 2018)
	80	5–30	
Pseudomonas aeruginosa (biofilms)	60	> 30	
	80	> 30	
Salmonella spp.	55	1.1–12.9	(Sörqvist 2003)
	60	0.1–1.4	
	65	0–0.2	
	72	0–0	
Shigella sonnei	65	0.2	(Spinks et al. 2006)
Staphylococcus aureus	50	104–128	(Kennedy et al. 2005)
	55	13–21	
	60	4.8–6.6	
Streptococcus faecalis	60	2.5– > 30	(White 1953)
Adenovirus 5	70	21	(Maheshwari et al. 2004)
Enteroviruses	60	30	(Mocé-Llivina et al. 2003)
Hepatitis A virus	50	56.2–385	(Bozkurt et al. 2015)
	60	2.7–74.6	
	70	1.1–3.8	
	85	1.0	
	100	0.3	

Bacterium/Bacterial Groups	Temperature (°C)	*D* range or maximum (minutes)	Reference
Human norovirus (Norwalk) GI.1	60	> 30	(Horn et al. 2016)
Human norovirus GII	56	100	(Bozkurt et al. 2015)
	63	25	
	72	3.3	
	85	1.1	
	100	0.3	
Acanthamoeba sp.	71	18.3	(Gabriel and Panaligan 2020)
	76	9.3	
	81	7.4	
	86	4.5	
	91	1.8	
Cryptosporidium parvum	60	5	(Fayer 1994)
	72	1	
Giardia	56	15	(Sauch et al. 1991)
	70	15	(Ongerth et al. 1989)
Naegleria spp. (cells and cysts)	51	25–120	(Chang 1978)
	55	7.5–75	
	63	0.5–9	
	65	< 0.5–3	
Trichophyton mentagrophytes	80	4	(Essien et al. 2009)
Trichophyton rubrum	80	3.2	
Epidermophyton floccosum	80	4.4	(Essien et al. 2009)

Reinjection of post-bathing water poses a potential hazard to the environment if pathogens are not eliminated. Depending on the temperature of the receiving geothermal reservoir, the ratio of water reinjected and the estimated residence time, pathogens could be inactivated by heat. However, this would need exposure to a suitably high temperature for a long enough period to kill the majority of pathogens. For example, more than two minutes at 90°C is required if *Acanthamoebae* are present, or heating to 100°C if Noroviruses or Hepatitis A virus are present. The risk from pathogens will be lower if water is reinjected into zones where temperatures and flow paths have been previously measured or modelled at higher temperatures (> 100°C). Concentrations of microorganisms will be naturally attenuated through processes including dispersal and dilution, soil filtration and adsorption, and die-off, although microbes may also multiply if conditions are conducive to growth.

The pH of the receiving environment is unlikely to assist in the control of pathogens. While the optimum pH of most pathogens is generally from neutral to mildly alkaline (in line with their hosts), many are resistant to at least short periods of more extreme pH. Food borne or enteric pathogens are acid resistant in order to cope with exposure to gastric acid (pH 1.5 to 5) in the human digestive system. These include the bacteria *M. paratuberculosis*, *E. coli*, *S. aureus* and *Streptococcus* and *Salmonella* species (Audia et al. 2001; Cotter and Hill 2003). Resistance to low pH increases with concentration of cells, starvation, and being in a stationary phase or in a biofilm (Cotter and Hill 2003). In addition, many viruses are also resistant to low pH (Lee et al. 2015).

For alkaline conditions, the outlook is more promising. High pH (pH > 10.5) has been shown to kill some bacterial pathogens, including *S. aureus*, *E.coli* and *Salmonella typhimurium* (Mendonca et al. 1994), as well as the amoeba *N. fowleri* (Sykora et al. 1983). However, compounds which increase pH to this level are often corrosive and may have unintended effects on the environment. For example, if water from the geothermal reservoir mixes with groundwater, the effect of an increase in pH on the naturally present microbes which provide essential ecosystem services such as denitrification (conversion of nitrate to dinitrogen gas) is not known.

Other methods of sterilisation could include treatment with UV or disinfectants, although some viruses are resistant to UV (Bozkurt et al. 2015), and *Acanthamoebae* are resistant to chlorine (Gabriel and Panaligan 2020). *P. aeruginosa*, *Cryptosporidium* and *Giardia* are resistant to several disinfectants (World Health Organisation 2006), and again, the downstream effects of these compounds are not known.

Filtration has been shown to be highly effective in an Australian hot spring bathing facility where post-bathing water is filtered before being reinjected, removing *E. coli* and *Pseudomonas* which were the only pathogens identified (Aburto-Medina et al. 2020).

2.3 Rotorua Geothermal Water in Mineral Pools

Geothermal takes for thermal pools often have outflow temperatures conducive to pathogenic microbial growth. In the Rotorua area, several consented geothermal takes were identified which currently discharge post-bathing water potentially contaminated with pathogens into surface water or reinject it into the geothermal system (Table 2.3). The microbial risk from these discharges will depend on the number of bathers, volume of water used each day and the ratio of geothermal water to town water. Consented takes which currently discharge into sewers where water will be transported to a Waste Water Treatment Plant are not considered here. There will also be customary takes not requiring a consent which are not recorded here.

In addition, other sites which reinject post-bathing water into geothermal systems may pose a risk if the mean residence times of microorganisms at temperatures below their *D*-value allow continued growth or survival until infiltration into groundwater or surface water. The distance microbial pathogens may travel could be modelled if geological and hydrological data is available for the reinjection area.

There has been some research done on the transport of viruses through groundwater in e.g. alluvial sand and gravel (Pang et al. 2021). There are also national guidelines on separation distances for wells from potential contamination (Moore et al. 2010) and methods for determining capture zones based on either set distances or time-of-travel (Moreau et al. 2014), which may assist with risk assessment and mitigation.

Table 2.3 Consented Rotorua geothermal takes used for mineral pools with high potential for microbial contamination (outflow temperature < 60°C (data supplied by BOPRC).

Consent	Location	Well Number	Mineral Pool Discharge Temperature (°C)	Maximum Consented Discharge (m^3/day)	Geothermal Water in Outflow (%)	Current Discharge Site
RM17-0752	The Boulevard Motel	RR872	37–42	45	25	Soak hole
66393	1 Kuirau St	RR447/ BN20-0094	37–42	2	50	Soakage trench
67531	Spa Lodge	BN20-0103	37–42	20	50	Soakage trench
67177	Aura Accommodation	RR10649	42–47	25	50	Stormwater
RM18-0384	Polynesian Spa	RR887, RR1067, RR12184, BN19-0156	37–42	300	100	Lake Rotorua
RM20-0571	QE Health and Wellness Spa	RR858, RR1012, RR12751	40	800	75	Reinjection/ WWTP
68238	Cosy Cottage Thermal Holiday Park	RR1000014	37–42	43.2	100	Stream

2.4 Chemical Changes Induced by Microorganisms

Geothermal water is not sterile, harbouring natural microbial communities which includes a diversity of non-harmful microorganisms as well as potential pathogens. Many mineral waters used for bathing are not filtered or otherwise treated in order to protect the natural physical and chemical properties of the water and their therapeutic effects (Valeriani et al. 2018). If this is the case with the proposed source for re-injection, the natural microbes present and their potential effects need to be considered.

During reinjection of geothermal water, microbial metabolism may result in bio-clogging, reducing the hydraulic conductivity by several orders of magnitude (Feng et al. 2021). This has halted operations in several geothermal plants around the world (Filippidou et al. 2016; Croese 2018b; Dinkel et al. 2018). Bio-clogging may be caused by an accumulation of cells into a biofilm, held together by extracellular polysaccharides (EPS); or by precipitation of carbonates or iron hydroxides by bacteria (Vetter et al. 2010; Feng et al. 2021). These processes are mediated by a range of bacteria and are affected by temperature, pH, nutrient availability, and redox status as well as the type of bedrock surrounding the reservoir.

Although the specific microbial communities of the takes in this project are not known, the microbial diversity of a large number of geothermal springs in the Kuirau Park has been previously investigated (One Thousand Springs 2013), and these surface feature populations may be used as a proxy for bathing pools. The major taxa (none pathogenic to humans) found in 25 sites close to the monitoring sites RRF913 and RRF0601 are shown in Table 2.4. These sites covered a range of temperature (22–97°C) and pH (1.38–8.72).

Table 2.4 Major microbiological taxa identified at Kuirau Park sites.

Bacterial/Archaeal Species or Group	Known Metabolism	Specific Issues
Acidithiobacillus	Sulphur, sulphide, ferrous iron	Produces H_2SO4, corrodes concrete
Alkalibacter	Fermentation	Produces H_2, CO_2
Aquifex	Sulphur, thiosulphate	Produces H_2S
Thiobacter	Sulphur, thiosulphate, sulphide	Produces H_2S
Caldisericum	Sulphur, sulphite, tetrathionate	-
Cryptomonadaceae	Photolithotrophy	-
Desulfurella	Sulphur, thiosulphate	Produces H_2S, CO_2
Fervidicoccus	Peptides	-
Hydrogenobacter	H2-O2-CO2	-
Hydrogenobaculum	H2-O2-CO2	-
Hydrogenophilus	H2-CO2, organic acids	-
Hydrotalea	Heterotrophy	Forms biofilms
Ignavibacterium	Fermentation	Forms biofilms
Methylomonas	Methane oxidation	-
Micrococcineae	Probably saprotrophic (detritus)	-
Ohtaekwangia	Heterotrophic	Forms biofilms
Peptoniphilus	Peptone	-
Persephonella	Sulphur, thiosulphate, H2	Produces H_2S
Salinisphaera	Thiosulphate, CO_2, organic acids	Produces H_2S
Sediminibacterium	Heterotrophic	Forms biofilms
Sideroxydans	Ferrous iron	-
Sphingobacteriales	Heterotrophic	Produces H_2S, forms biofilms
Sulfurihydrogenibium	Sulphur, thiosulphate, CO_2	Produces H_2S
Sulfurimonas	Sulphur, thiosulphate, sulphide, sulphite, H_2	Produces H_2S, sulphate
Thermodesulfobacterium	Sulphate, H_2	Produces H_2S
Thermogymnomonas	Heterotrophic	-
Thermoplasmata	Sulphur	-
Thermus	Heterotrophic	Forms biofilms
Thiobacillus	Sulphur, tetrathionate, sulphide	Produces H_2S
Thiobacter	Sulphur, thiosulphate, sulphide	Produces H_2S, sulphate
Thiomonas	Thiosulphate, tetrathionate	Produces H_2S
Thiovirga	Sulphur, sulphide, thiosulphate	Produces H_2S
Venevivibrio	Sulphur, thiosulphate, H_2	Produces H_2S

Many of the microorganisms identified from surface features located close to known takes for mineral pools are capable of producing biofilms, trapping suspended particles and reducing the porosity and permeability of the reinjection area (Feng et al. 2021). Most of these microbes are heterotrophic, obtaining carbon and energy from a wide variety of sources likely to be found in bathing water, including sugars, organic acids and amino acids and peptides. These come from shed skin and hair cells as well as residual material from bathers' bodies, and plant or insect materials which fall into open pools. However, no bio-clogging has been reported at the RR sites following field-scale re-injection, so this may be a minor issue under the current environmental conditions.

A large number of sulphur oxidising and sulphate reducing bacteria and archaea were also identified from the geothermal springs. Sulphur oxidisers can use either elemental sulphur (S^0) or sulphide (HS^- or H_2S) to produce sulphate, and usually fix CO_2 to obtain carbon. *Acidithiobacillus*, which dominated five of twenty five sites with up to 78% of all DNA sequences, is of particular note as it produces H_2SO_4 and is known to corrode even concrete (Li et al. 2017). Sulphur oxidisers are often filamentous and may also form biofilms, in addition to the heterotrophs noted in the table.

Sulphate-reducing organisms convert sulphate, and sometimes thiosulphate, into the toxic and corrosive gas H_2S, using either dissolved carbon compounds or CO_2 for their carbon source. These bacteria are known to cause issues in geothermal systems. In 2018, a geothermal plant in the Netherlands experienced bio-clogging and used sodium bisulphite as an oxygen scavenger to prevent corrosion, but this increased growth of sulphate-reducers and led to dangerously high levels of H_2S being released (Croese 2018a). Sulphate reducing bacteria can also induce calcium carbonate precipitation, both by increasing alkalinity and through acting as nucleation sites (Lin et al. 2018). The increase in alkalinity will also increase pH buffering of the system, supporting growth of more microorganisms (García-Gil et al. 2018).

Microorganisms involved in the formation of iron hydroxides (e.g. *Gallionella*, *Shewanella*, *Geothrix*) (Dinkel et al. 2018) were not detected in the 25 springs used in this report.

2.5 Conclusions

Reinjection of post-bathing water poses a risk of pathogen release to the environment, therefore monitoring and appropriate treatment (e.g. filtration) is recommended before this water is returned to the geothermal reservoir or discharged to surface water. Pathogens may infiltrate groundwater or surface water used for purposes other than drinking water and present a hazard through inhalation of aerosols, skin contact, or ingestion of contaminated food. There is a gradient of risk depending on the volume of water, the types of microorganisms present and the temperature, pH and permeability of the receiving environment.

Filtration will remove the natural microbial population as well as pathogens from the water and reduce the risk of adverse effects from their metabolic processes. Other methods of decontamination, such as chlorination or chemical disinfection, may be employed but care must be taken that resistant pathogens (e.g. *P. aeruginosa*, *Cryptosporidium, Giardia*) and abnormally high levels of other pathogens are controlled.

The microbial populations in nearby geothermal surface features can be used as a proxy for the microorganisms likely to be introduced into bathing pools. Many of the microorganisms identified from surface features located close to known takes for mineral pools are capable of producing biofilms which may reduce the porosity and permeability of the reinjection area. Sulphur – oxidising and – reducing microbes were identified in nearby surface features, and these may produce corrosive and toxic substances such as H_2SO_4 and H_2S. Growth of some of these microbes may be stimulated by energy sources found in post-bathing water such as sugars, organic acids, amino acids and peptides.

3.0 RECOMMENDATIONS

The following are recommended:

1. The geochemical model presented in this work represents a single combination of brine chemistries, however, the natural diversity in reservoir composition and the variation in local permeability and fracture network geometry needs to be considered. We propose to conduct a tracer test to investigate the connectivity between the production well, re-injection wells, and the surface features.
2. Repeat the modelling using a larger range of fluid chemistries that represent other parts of the RGS.
3. The results do not consider long-term effects on the reservoir temperature (and hence mineral dissolution and precipitation). A separate modelling study should be undertaken if long term changes to the reservoir and connected surface features temperature are required.
4. Water from mineral pools should be monitored for the presence of pathogens. It is recommended that this monitoring covers a wide range of potentially pathogenic microorganisms and is more extensive than enterococci or faecal indicator bacteria.
5. Water from mineral pools should be appropriately treated before reinjection or discharge to surface water. Filtration is recommended as this will remove the natural microbial population as well as pathogens from the water and reduce the risk of adverse effects. Other methods of decontamination, such as chlorination or chemical disinfection, may be employed but care must be taken that resistant pathogens are controlled, as well as abnormally high levels of other pathogens (e.g. after an accidental faecal release).

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APPENDICES

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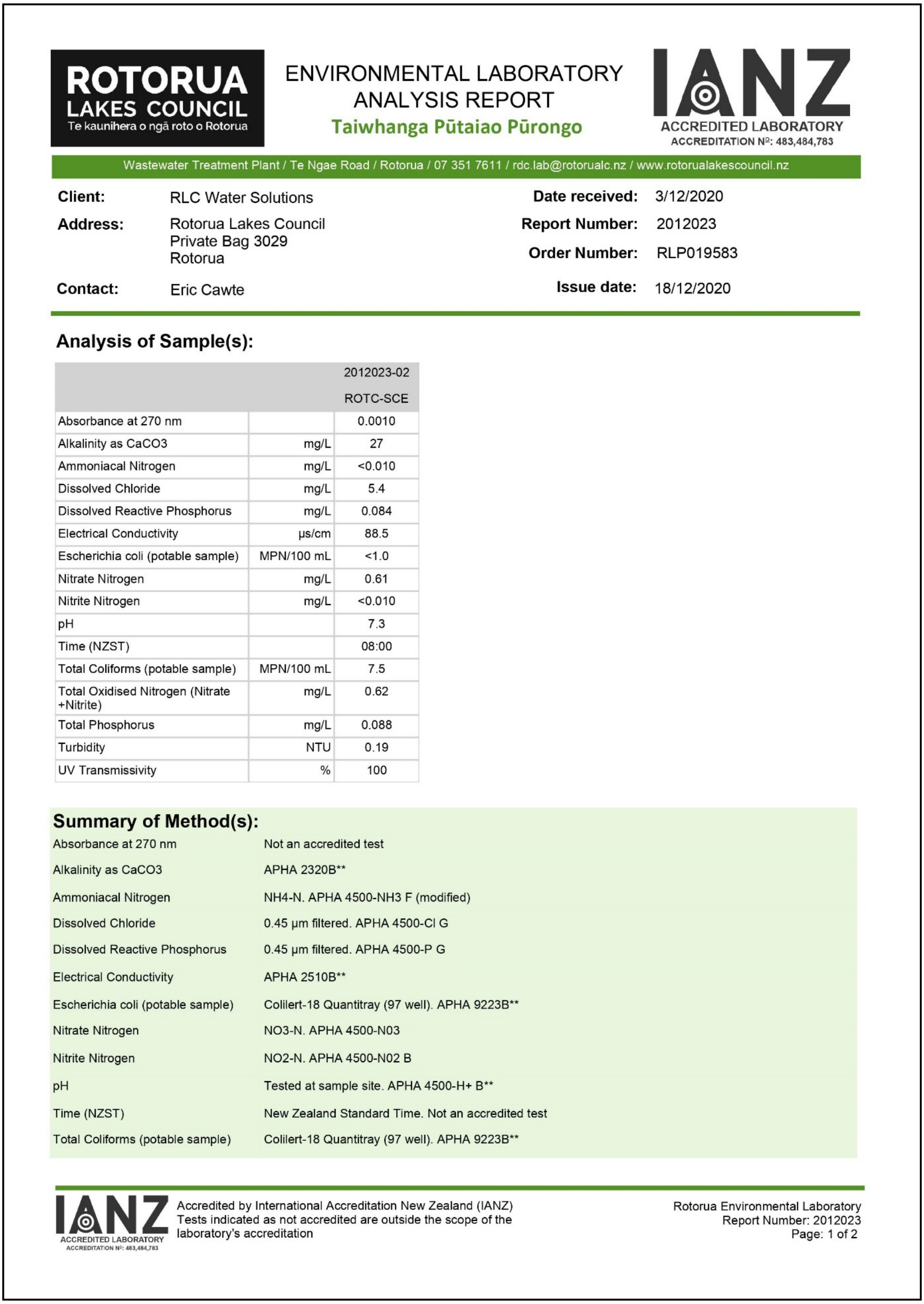
APPENDIX 1 TOWN WATER COMPOSITION



ROTORUA
LAKES COUNCIL
Te kaunihera o ngā roto o Rotorua

ENVIRONMENTAL LABORATORY
ANALYSIS REPORT
Taiwhanga Pūtaiao Pūrongo

IANZ
ACCREDITED LABORATORY
ACCREDITATION Nº: 483,484,783

Wastewater Treatment Plant / Te Ngae Road / Rotorua / 07 351 7611 / rdc.lab@rotorualc.nz / www.rotorualakescouncil.nz

Client:	RLC Water Solutions	**Date received:**	3/12/2020
Address:	Rotorua Lakes Council Private Bag 3029 Rotorua	**Report Number:**	2012023
		Order Number:	RLP019583
Contact:	Eric Cawte	**Issue date:**	18/12/2020

Analysis of Sample(s):

		2012023-02 ROTC-SCE
Absorbance at 270 nm		0.0010
Alkalinity as CaCO3	mg/L	27
Ammoniacal Nitrogen	mg/L	<0.010
Dissolved Chloride	mg/L	5.4
Dissolved Reactive Phosphorus	mg/L	0.084
Electrical Conductivity	µs/cm	88.5
Escherichia coli (potable sample)	MPN/100 mL	<1.0
Nitrate Nitrogen	mg/L	0.61
Nitrite Nitrogen	mg/L	<0.010
pH		7.3
Time (NZST)		08:00
Total Coliforms (potable sample)	MPN/100 mL	7.5
Total Oxidised Nitrogen (Nitrate +Nitrite)	mg/L	0.62
Total Phosphorus	mg/L	0.088
Turbidity	NTU	0.19
UV Transmissivity	%	100

Summary of Method(s):

Absorbance at 270 nm	Not an accredited test
Alkalinity as CaCO3	APHA 2320B**
Ammoniacal Nitrogen	NH4-N. APHA 4500-NH3 F (modified)
Dissolved Chloride	0.45 µm filtered. APHA 4500-Cl G
Dissolved Reactive Phosphorus	0.45 µm filtered. APHA 4500-P G
Electrical Conductivity	APHA 2510B**
Escherichia coli (potable sample)	Colilert-18 Quantitray (97 well). APHA 9223B**
Nitrate Nitrogen	NO3-N. APHA 4500-N03
Nitrite Nitrogen	NO2-N. APHA 4500-N02 B
pH	Tested at sample site. APHA 4500-H+ B**
Time (NZST)	New Zealand Standard Time. Not an accredited test
Total Coliforms (potable sample)	Colilert-18 Quantitray (97 well). APHA 9223B**

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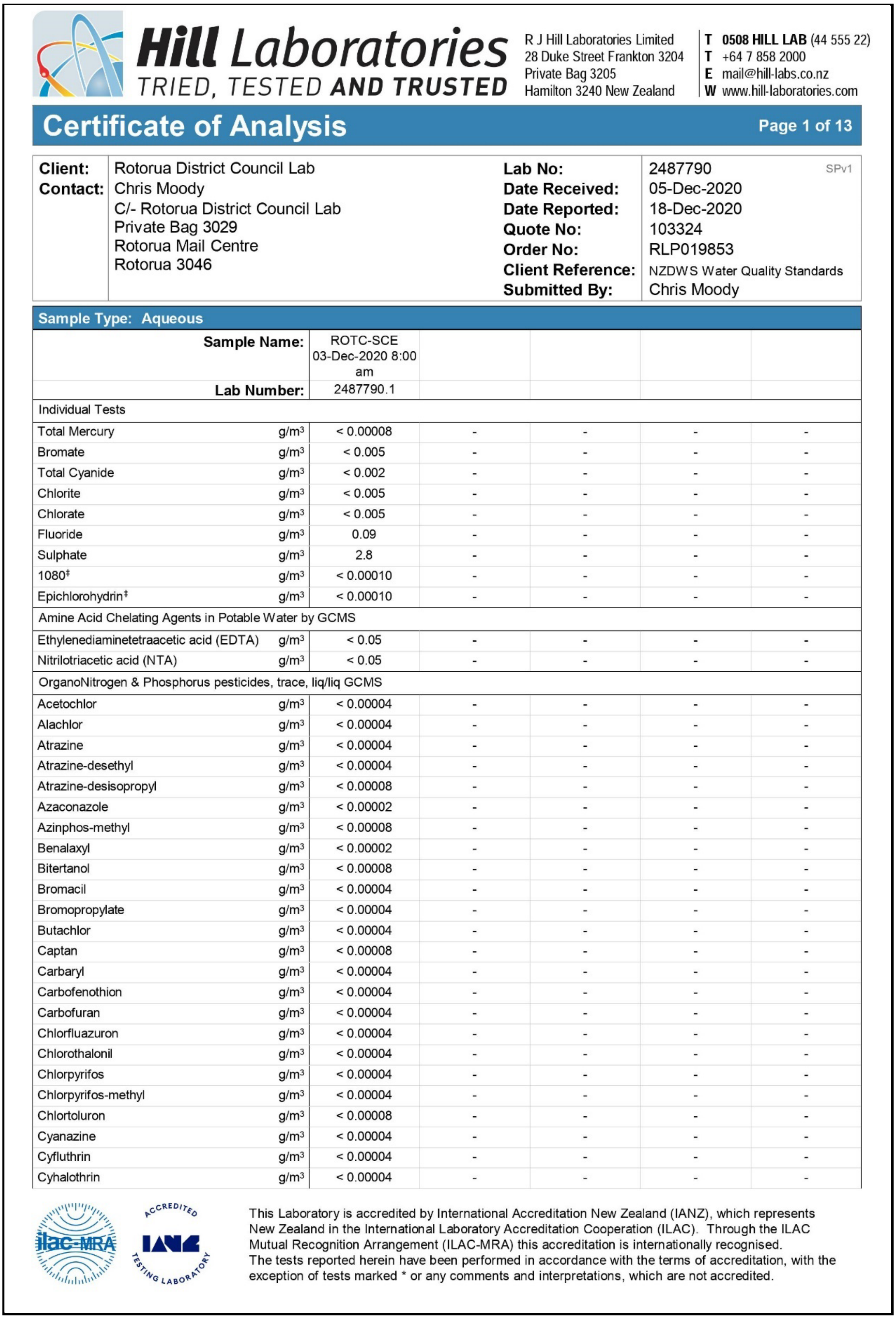
ACCREDITATION Nº: 483,484,783

Accredited by International Accreditation New Zealand (IANZ)
Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Rotorua Environmental Laboratory
Report Number: 2012023
Page: 1 of 2

Figure A1.1 Rotorua Environmental Laboratory Analysis Report



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Certificate of Analysis

Page 1 of 13

Client: Rotorua District Council Lab
Contact: Chris Moody
C/- Rotorua District Council Lab
Private Bag 3029
Rotorua Mail Centre
Rotorua 3046

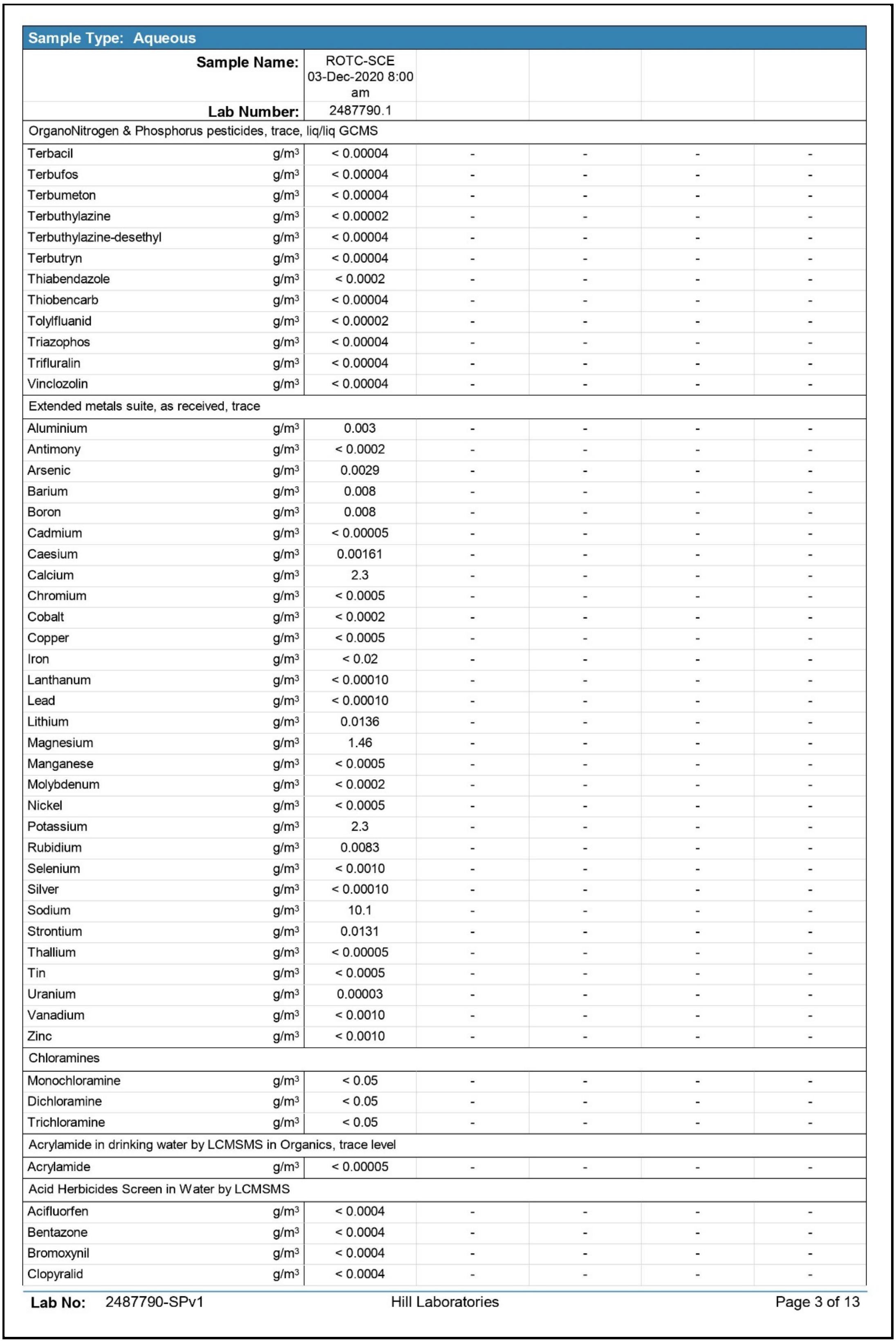
Lab No: 2487790 SPv1
Date Received: 05-Dec-2020
Date Reported: 18-Dec-2020
Quote No: 103324
Order No: RLP019853
Client Reference: NZDWS Water Quality Standards
Submitted By: Chris Moody

Sample Type: Aqueous

Sample Name:		ROTC-SCE 03-Dec-2020 8:00 am				
Lab Number:		2487790.1				
Individual Tests						
Total Mercury	g/m³	< 0.00008	-	-	-	-
Bromate	g/m³	< 0.005	-	-	-	-
Total Cyanide	g/m³	< 0.002	-	-	-	-
Chlorite	g/m³	< 0.005	-	-	-	-
Chlorate	g/m³	< 0.005	-	-	-	-
Fluoride	g/m³	0.09	-	-	-	-
Sulphate	g/m³	2.8	-	-	-	-
1080‡	g/m³	< 0.00010	-	-	-	-
Epichlorohydrin‡	g/m³	< 0.00010	-	-	-	-
Amine Acid Chelating Agents in Potable Water by GCMS						
Ethylenediaminetetraacetic acid (EDTA)	g/m³	< 0.05	-	-	-	-
Nitrilotriacetic acid (NTA)	g/m³	< 0.05	-	-	-	-
OrganoNitrogen & Phosphorus pesticides, trace, liq/liq GCMS						
Acetochlor	g/m³	< 0.00004	-	-	-	-
Alachlor	g/m³	< 0.00004	-	-	-	-
Atrazine	g/m³	< 0.00004	-	-	-	-
Atrazine-desethyl	g/m³	< 0.00004	-	-	-	-
Atrazine-desisopropyl	g/m³	< 0.00008	-	-	-	-
Azaconazole	g/m³	< 0.00002	-	-	-	-
Azinphos-methyl	g/m³	< 0.00008	-	-	-	-
Benalaxyl	g/m³	< 0.00002	-	-	-	-
Bitertanol	g/m³	< 0.00008	-	-	-	-
Bromacil	g/m³	< 0.00004	-	-	-	-
Bromopropylate	g/m³	< 0.00004	-	-	-	-
Butachlor	g/m³	< 0.00004	-	-	-	-
Captan	g/m³	< 0.00008	-	-	-	-
Carbaryl	g/m³	< 0.00004	-	-	-	-
Carbofenothion	g/m³	< 0.00004	-	-	-	-
Carbofuran	g/m³	< 0.00004	-	-	-	-
Chlorfluazuron	g/m³	< 0.00004	-	-	-	-
Chlorothalonil	g/m³	< 0.00004	-	-	-	-
Chlorpyrifos	g/m³	< 0.00004	-	-	-	-
Chlorpyrifos-methyl	g/m³	< 0.00004	-	-	-	-
Chlortoluron	g/m³	< 0.00008	-	-	-	-
Cyanazine	g/m³	< 0.00004	-	-	-	-
Cyfluthrin	g/m³	< 0.00004	-	-	-	-
Cyhalothrin	g/m³	< 0.00004	-	-	-	-

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.
The tests reported herein have been performed in accordance with the terms of accreditation, with the exception of tests marked * or any comments and interpretations, which are not accredited.

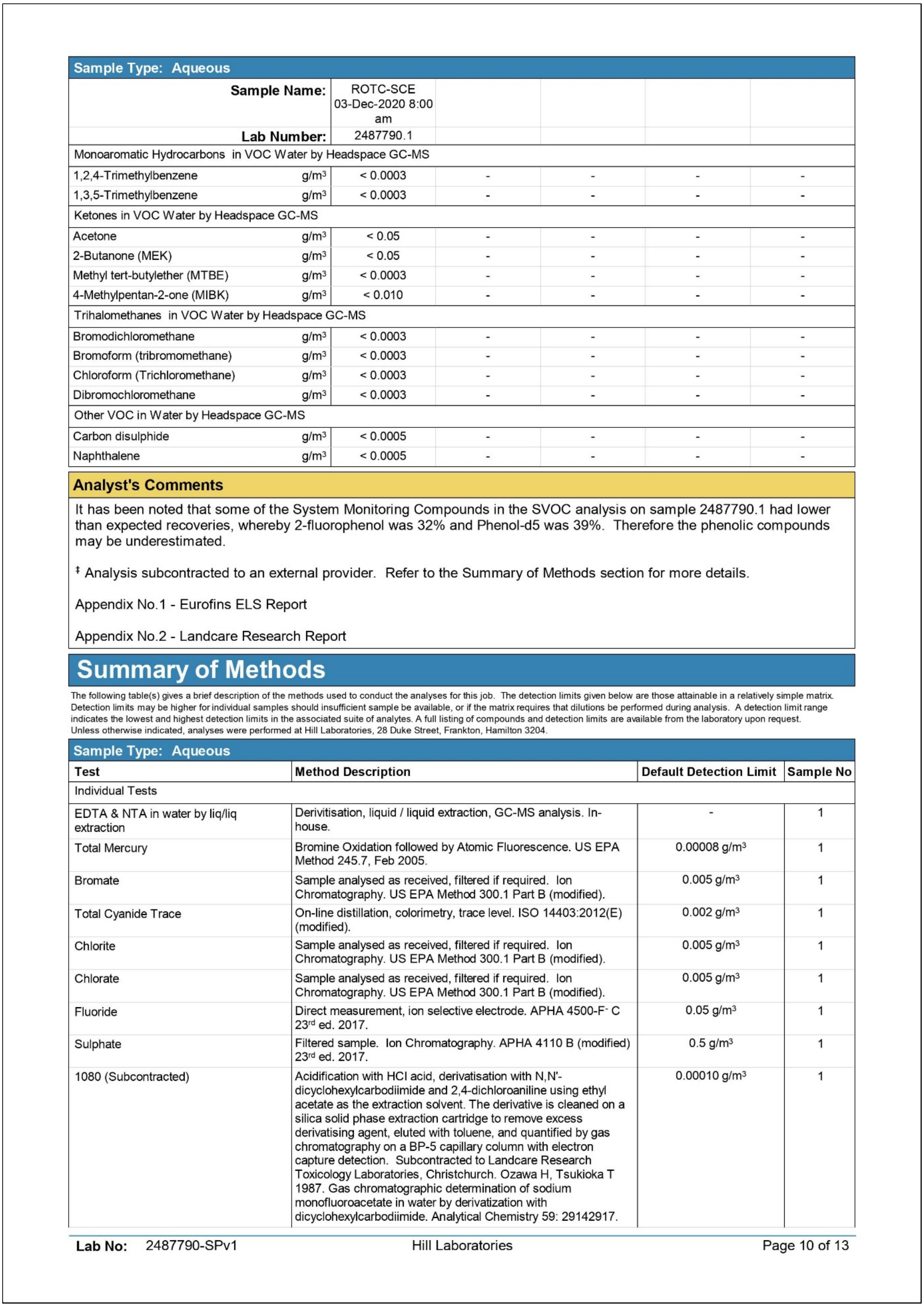
Figure A1.2 Hill Laboratories Certificate of Analysis – 18 December 2020 (1 of 6).



Sample Type: Aqueous

Sample Name:		ROTC-SCE 03-Dec-2020 8:00 am				
Lab Number:		2487790.1				
OrganoNitrogen & Phosphorus pesticides, trace, liq/liq GCMS						
Terbacil	g/m^3	< 0.00004	-	-	-	-
Terbufos	g/m^3	< 0.00004	-	-	-	-
Terbumeton	g/m^3	< 0.00004	-	-	-	-
Terbuthylazine	g/m^3	< 0.00002	-	-	-	-
Terbuthylazine-desethyl	g/m^3	< 0.00004	-	-	-	-
Terbutryn	g/m^3	< 0.00004	-	-	-	-
Thiabendazole	g/m^3	< 0.0002	-	-	-	-
Thiobencarb	g/m^3	< 0.00004	-	-	-	-
Tolylfluanid	g/m^3	< 0.00002	-	-	-	-
Triazophos	g/m^3	< 0.00004	-	-	-	-
Trifluralin	g/m^3	< 0.00004	-	-	-	-
Vinclozolin	g/m^3	< 0.00004	-	-	-	-
Extended metals suite, as received, trace						
Aluminium	g/m^3	0.003	-	-	-	-
Antimony	g/m^3	< 0.0002	-	-	-	-
Arsenic	g/m^3	0.0029	-	-	-	-
Barium	g/m^3	0.008	-	-	-	-
Boron	g/m^3	0.008	-	-	-	-
Cadmium	g/m^3	< 0.00005	-	-	-	-
Caesium	g/m^3	0.00161	-	-	-	-
Calcium	g/m^3	2.3	-	-	-	-
Chromium	g/m^3	< 0.0005	-	-	-	-
Cobalt	g/m^3	< 0.0002	-	-	-	-
Copper	g/m^3	< 0.0005	-	-	-	-
Iron	g/m^3	< 0.02	-	-	-	-
Lanthanum	g/m^3	< 0.00010	-	-	-	-
Lead	g/m^3	< 0.00010	-	-	-	-
Lithium	g/m^3	0.0136	-	-	-	-
Magnesium	g/m^3	1.46	-	-	-	-
Manganese	g/m^3	< 0.0005	-	-	-	-
Molybdenum	g/m^3	< 0.0002	-	-	-	-
Nickel	g/m^3	< 0.0005	-	-	-	-
Potassium	g/m^3	2.3	-	-	-	-
Rubidium	g/m^3	0.0083	-	-	-	-
Selenium	g/m^3	< 0.0010	-	-	-	-
Silver	g/m^3	< 0.00010	-	-	-	-
Sodium	g/m^3	10.1	-	-	-	-
Strontium	g/m^3	0.0131	-	-	-	-
Thallium	g/m^3	< 0.00005	-	-	-	-
Tin	g/m^3	< 0.0005	-	-	-	-
Uranium	g/m^3	0.00003	-	-	-	-
Vanadium	g/m^3	< 0.0010	-	-	-	-
Zinc	g/m^3	< 0.0010	-	-	-	-
Chloramines						
Monochloramine	g/m^3	< 0.05	-	-	-	-
Dichloramine	g/m^3	< 0.05	-	-	-	-
Trichloramine	g/m^3	< 0.05	-	-	-	-
Acrylamide in drinking water by LCMSMS in Organics, trace level						
Acrylamide	g/m^3	< 0.00005	-	-	-	-
Acid Herbicides Screen in Water by LCMSMS						
Acifluorfen	g/m^3	< 0.0004	-	-	-	-
Bentazone	g/m^3	< 0.0004	-	-	-	-
Bromoxynil	g/m^3	< 0.0004	-	-	-	-
Clopyralid	g/m^3	< 0.0004	-	-	-	-

Lab No: 2487790-SPv1 Hill Laboratories Page 3 of 13



Sample Type: Aqueous

Sample Name:		ROTC-SCE 03-Dec-2020 8:00 am				
Lab Number:		2487790.1				
Monoaromatic Hydrocarbons in VOC Water by Headspace GC-MS						
1,2,4-Trimethylbenzene	g/m^3	< 0.0003	-	-	-	-
1,3,5-Trimethylbenzene	g/m^3	< 0.0003	-	-	-	-
Ketones in VOC Water by Headspace GC-MS						
Acetone	g/m^3	< 0.05	-	-	-	-
2-Butanone (MEK)	g/m^3	< 0.05	-	-	-	-
Methyl tert-butylether (MTBE)	g/m^3	< 0.0003	-	-	-	-
4-Methylpentan-2-one (MIBK)	g/m^3	< 0.010	-	-	-	-
Trihalomethanes in VOC Water by Headspace GC-MS						
Bromodichloromethane	g/m^3	< 0.0003	-	-	-	-
Bromoform (tribromomethane)	g/m^3	< 0.0003	-	-	-	-
Chloroform (Trichloromethane)	g/m^3	< 0.0003	-	-	-	-
Dibromochloromethane	g/m^3	< 0.0003	-	-	-	-
Other VOC in Water by Headspace GC-MS						
Carbon disulphide	g/m^3	< 0.0005	-	-	-	-
Naphthalene	g/m^3	< 0.0005	-	-	-	-

Analyst's Comments

It has been noted that some of the System Monitoring Compounds in the SVOC analysis on sample 2487790.1 had lower than expected recoveries, whereby 2-fluorophenol was 32% and Phenol-d5 was 39%. Therefore the phenolic compounds may be underestimated.

‡ Analysis subcontracted to an external provider. Refer to the Summary of Methods section for more details.

Appendix No.1 - Eurofins ELS Report

Appendix No.2 - Landcare Research Report

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Individual Tests			
EDTA & NTA in water by liq/liq extraction	Derivitisation, liquid / liquid extraction, GC-MS analysis. In-house.	-	1
Total Mercury	Bromine Oxidation followed by Atomic Fluorescence. US EPA Method 245.7, Feb 2005.	0.00008 g/m^3	1
Bromate	Sample analysed as received, filtered if required. Ion Chromatography. US EPA Method 300.1 Part B (modified).	0.005 g/m^3	1
Total Cyanide Trace	On-line distillation, colorimetry, trace level. ISO 14403:2012(E) (modified).	0.002 g/m^3	1
Chlorite	Sample analysed as received, filtered if required. Ion Chromatography. US EPA Method 300.1 Part B (modified).	0.005 g/m^3	1
Chlorate	Sample analysed as received, filtered if required. Ion Chromatography. US EPA Method 300.1 Part B (modified).	0.005 g/m^3	1
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F^- C 23rd ed. 2017.	0.05 g/m^3	1
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	1
1080 (Subcontracted)	Acidification with HCl acid, derivatisation with N,N'-dicyclohexylcarbodiimide and 2,4-dichloroaniline using ethyl acetate as the extraction solvent. The derivative is cleaned on a silica solid phase extraction cartridge to remove excess derivatising agent, eluted with toluene, and quantified by gas chromatography on a BP-5 capillary column with electron capture detection. Subcontracted to Landcare Research Toxicology Laboratories, Christchurch. Ozawa H, Tsukioka T 1987. Gas chromatographic determination of sodium monofluoroacetate in water by derivatization with dicyclohexylcarbodiimide. Analytical Chemistry 59: 29142917.	0.00010 g/m^3	1

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Epichlorohydrin (Subcontracted)	Method based on USEPA 8260. Sub-contracted to Eurofins ELS Limited, Lower Hutt.	0.00010 g/m^3	1
Sum of HAA DWSNZ MAV ratios	Calculated as the sum of the individual haloacetic acids specified in DWSNZ (monochloroacetic acid, dichloroacetic acid and trichloroacetic acid) to their respective Maximum Allowable Values (MAVs). Drinking-water Standards for New Zealand 2005 (Revised 2008), Section 8.2.1.1.	0.001	1
Sum of Haloacetonitriles MAV ratios (NZ DW Stds)	Calculated as the sum of the individual haloacetonitriles specified in DWSNZ (dibromoacetonitrile & dichloroacetonitrile) to their respective Maximum Allowable Values (MAVs). Drinking-water Standards for New Zealand 2005 (Revised 2018).	-	1
Amine Acid Chelating Agents in Potable Water by GCMS	Derivitisation, liquid / liquid extraction, GC-MS analysis. In-house.	0.05 g/m^3	1
Extended metals suite, as received, trace	Analysed as received (after acid preservation, if required), ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.00002 - 0.05 g/m^3	1
Acrylamide in drinking water by LCMSMS in Organics, trace level	LC-MS/MS analysis. In-house.	0.00005 g/m^3	1
Acid Herbicides Screen in Water by LCMSMS	LC-MS/MS analysis. In-house.	0.0003 - 0.0006 g/m^3	1
Halogenated Acetic Acids in Water by GC-MS	Solvent extraction, derivitisation, GC-MS analysis. In-house based on US EPA 552.	-	1
Halogenated Volatile Disinfection By-Products in Water by GCMS	Solvent extraction, GC-MS analysis. In-house based on US EPA 551.	-	1
Org LCMS, trace level	LC-MS/MS analysis. In-house.	0.0004 - 0.006 g/m^3	1
Microcystins in Water by LCMSMS	SPE extraction, LC-MS/MS analysis. In-house.	0.00002 - 0.00003 g/m^3	1
Multiresidue Pesticides Trace in Water by Liq/liq GCMS	Liquid / liquid extraction, GC-ECD and GC-MS analysis. In-house based on US EPA 8081 and US EPA 8270.	-	1
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.000005 g/m^3	1
Semivolatile Organic Compounds Trace in Water by GC-MS	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	-	1
Volatile Organic Compounds Trace in Water by Headspace GC-MS	Headspace GC-MS analysis. In-house based on US EPA 8260 and 5021.	0.0003 - 0.05 g/m^3	1
Chloramines			
Monochloramine	Colorimetric. APHA 4500-Cl G 23rd ed. 2017.	0.05 g/m^3	1
Dichloramine	Colorimetric. APHA 4500-Cl G 23rd ed. 2017.	0.05 g/m^3	1
Trichloramine	Colorimetric. APHA 4500-Cl G 23rd ed. 2017.	0.05 g/m^3	1
Multiresidue Extra Pesticides Trace in Water samples by Liq/liq			
Bendiocarb	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Benodanil	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m^3	1
Bifenthrin	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00002 g/m^3	1
Bromophos-ethyl	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Bupirimate	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Buprofezin	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Captafol	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.0002 g/m^3	1
Carboxin	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Chlorfenvinphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Chlorpropham	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m^3	1
Chlozolinate	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Coumaphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m^3	1
Cyproconazole	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Cyprodinil	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Demeton-S-methyl	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m³	1
Dichlobenil	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Dichlofenthion	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Dicofol	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.0002 g/m³	1
Dicrotophos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Dinocap	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.0003 g/m³	1
Disulfoton	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
EPN	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Esfenvalerate	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Ethion	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Etrimfos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Famphur	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Fenamiphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Fenarimol	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Fenitrothion	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Fenpropathrin	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Fensulfothion	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Fenthion	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Fenvalerate	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Folpet	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m³	1
Hexythiazox	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.0002 g/m³	1
Imazalil	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.0002 g/m³	1
Indoxacarb	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Iodofenphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Isazophos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Isofenphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00002 g/m³	1
Leptophos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Methacrifos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Methidathion	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Methiocarb	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Mevinphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m³	1
Nitrofen	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m³	1
Nitrothal-isopropyl	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m³	1
Oxychlordane	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00002 g/m³	1

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Penconazole	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Phorate	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m^3	1
Phosmet	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Phosphamidon	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Propetamphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00006 g/m^3	1
Propham	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Prothiofos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Pyrazophos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Pyrifenox	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Pyrimethanil	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Quintozene	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m^3	1
Sulfotep	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Tebufenpyrad	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00002 g/m^3	1
Tetrachlorvinphos	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1
Thiometon	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00008 g/m^3	1
Triadimefon	Liquid / liquid extraction, GC-MS analysis. In-house based on US EPA 8270.	0.00004 g/m^3	1

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 06-Dec-2020 and 18-Dec-2020. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

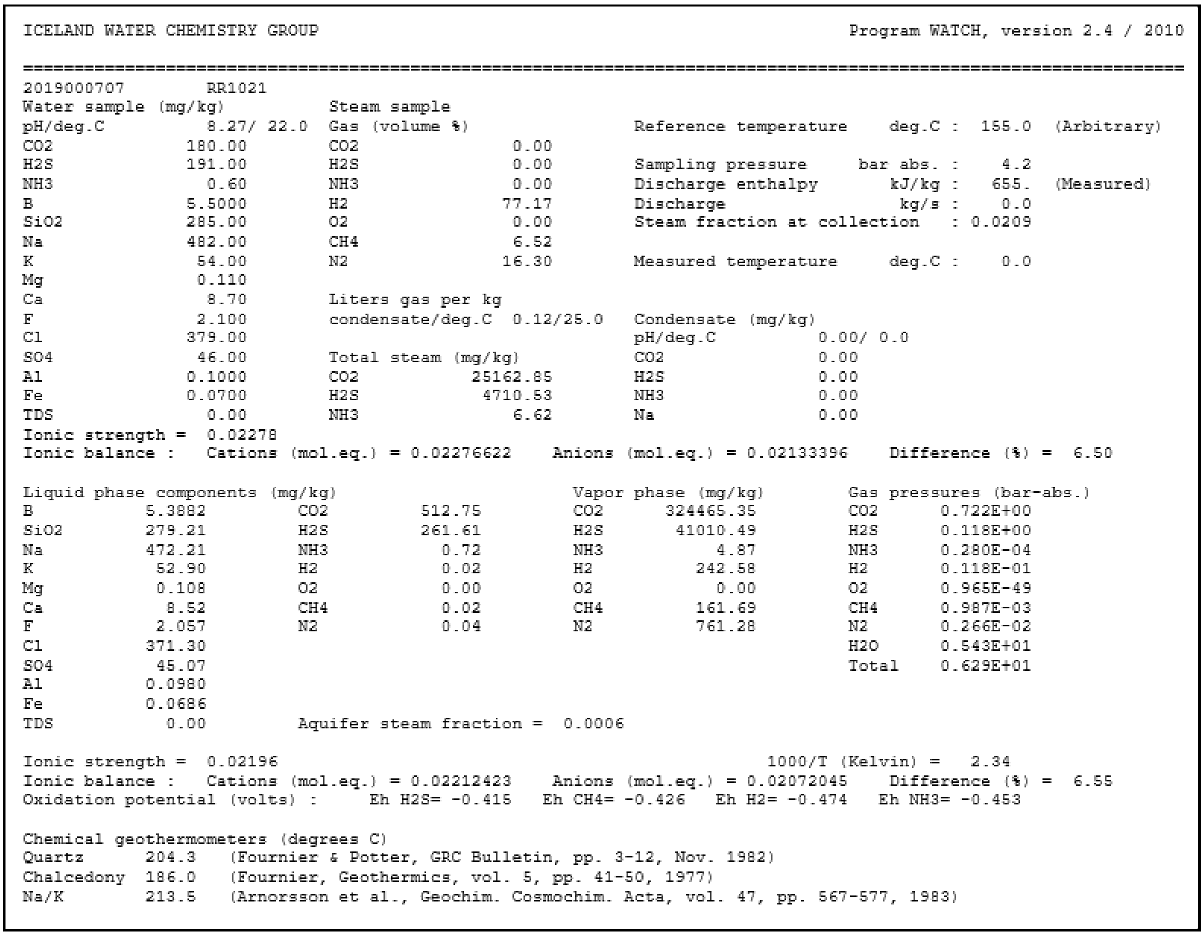
Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 2 COMPOSITION OF WELL RR1021

Webre Separated Steam	**Sample No:**	**2536-Poly-Spa-1021**
	Sampling Date:	**6 February 2019**
	Site ID:	**RR1021**
	Field ID:	**Polynesian Spa Bore**
Carbon Dioxide	umol/mol discharge	10139
Hydrogen sulphide	umol/mol discharge	2458
Argon	umol/mol discharge	0.26
Helium	umol/mol discharge	0.004
Hydrogen	umol/mol discharge	70.5
Methane	umol/mol discharge	6.3
Nitrogen	umol/mol discharge	14.6
Oxygen	umol/mol discharge	0.255
Carbon Monoxide	umol/mol discharge	0.199
Ammonia	umol/mol discharge	6.85
Steam		987305
Deuterium	‰	-43.8
Oxygen 18	‰	-7.76
Sampling Point Pressure	bg	3.02–3.3
Separation Pressure	bg	3.0–3.28

Webre Separated Water	**GNS Sample No.**	**2019000707**
	Collection Date:	**6 February 2019**
	Site ID:	**RR1021**
	Field ID:	**Polynesian Spa Well**
	Sample Type:	**Separated Water**
Bicarbonate (Total)	mg/l	250
pH	-	8.27
HCO_3 Analysis temperature	ºC	22
HCO_3 Analysis Date	-	8/02/2019
Aluminium	mg/l	0.1
Ammonia	mg/l	0.6
Arsenic	mg/l	0.03
Boron	mg/l	5.5
Bromide	mg/l	1.8
Calcium	mg/l	8.7
Chloride	mg/l	379
Diss. Reactive Phosphorus	mg/l	0.03
Fluoride	mg/l	2.1
Iron	mg/l	0.07
Lithium	mg/l	4.2
Magnesium	mg/l	0.11
Nitrate as N	mg/l	< 0.01
Potassium	mg/l	54
Silica (as SiO_2)	mg/l	285
Sodium	mg/l	482
Sulphate	mg/l	46
Sulphide (total as H_2S)	mg/l	191
H_2S Date Developed	-	7/02/2019
H_2S Date Analysed	-	12/02/2019
Deuterium	per mil	-33.8
Oxygen 18	per mil	-4.68
Sampling Point Pressure	bg	3.02–3.30
Separation Pressure	bg	3.00–3.28

APPENDIX 3 WATCH OUTPUT FILE FOR WELL RR1021



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ICELAND WATER CHEMISTRY GROUP                                                    Program WATCH, version 2.4 / 2010

==================================================================================================================
2019000707        RR1021
Water sample (mg/kg)          Steam sample
pH/deg.C          8.27/ 22.0  Gas (volume %)                Reference temperature    deg.C :  155.0  (Arbitrary)
CO2             180.00        CO2               0.00
H2S             191.00        H2S               0.00        Sampling pressure     bar abs. :    4.2
NH3               0.60        NH3               0.00        Discharge enthalpy       kJ/kg :   655.  (Measured)
B               5.5000        H2               77.17        Discharge                 kg/s :    0.0
SiO2            285.00        O2                0.00        Steam fraction at collection   : 0.0209
Na              482.00        CH4               6.52
K                54.00        N2               16.30        Measured temperature     deg.C :    0.0
Mg               0.110
Ca                8.70        Liters gas per kg
F                2.100        condensate/deg.C  0.12/25.0   Condensate (mg/kg)
Cl              379.00                                      pH/deg.C          0.00/ 0.0
SO4              46.00        Total steam (mg/kg)           CO2               0.00
Al              0.1000        CO2           25162.85        H2S               0.00
Fe              0.0700        H2S            4710.53        NH3               0.00
TDS               0.00        NH3               6.62        Na                0.00
Ionic strength =  0.02278
Ionic balance :   Cations (mol.eq.) = 0.02276622    Anions (mol.eq.) = 0.02133396    Difference (%) =  6.50

Liquid phase components (mg/kg)                       Vapor phase (mg/kg)        Gas pressures (bar-abs.)
B           5.3882         CO2         512.75         CO2      324465.35         CO2      0.722E+00
SiO2        279.21         H2S         261.61         H2S       41010.49         H2S      0.118E+00
Na          472.21         NH3           0.72         NH3           4.87         NH3      0.280E-04
K            52.90         H2            0.02         H2          242.58         H2       0.118E-01
Mg           0.108         O2            0.00         O2            0.00         O2       0.965E-49
Ca            8.52         CH4           0.02         CH4         161.69         CH4      0.987E-03
F            2.057         N2            0.04         N2          761.28         N2       0.266E-02
Cl          371.30                                                               H2O      0.543E+01
SO4          45.07                                                               Total    0.629E+01
Al          0.0980
Fe          0.0686
TDS           0.00         Aquifer steam fraction =  0.0006

Ionic strength =  0.02196                                                1000/T (Kelvin) =   2.34
Ionic balance :   Cations (mol.eq.) = 0.02212423    Anions (mol.eq.) = 0.02072045    Difference (%) =  6.55
Oxidation potential (volts) :     Eh H2S= -0.415   Eh CH4= -0.426   Eh H2= -0.474   Eh NH3= -0.453

Chemical geothermometers (degrees C)
Quartz      204.3   (Fournier & Potter, GRC Bulletin, pp. 3-12, Nov. 1982)
Chalcedony  186.0   (Fournier, Geothermics, vol. 5, pp. 41-50, 1977)
Na/K        213.5   (Arnorsson et al., Geochim. Cosmochim. Acta, vol. 47, pp. 567-577, 1983)
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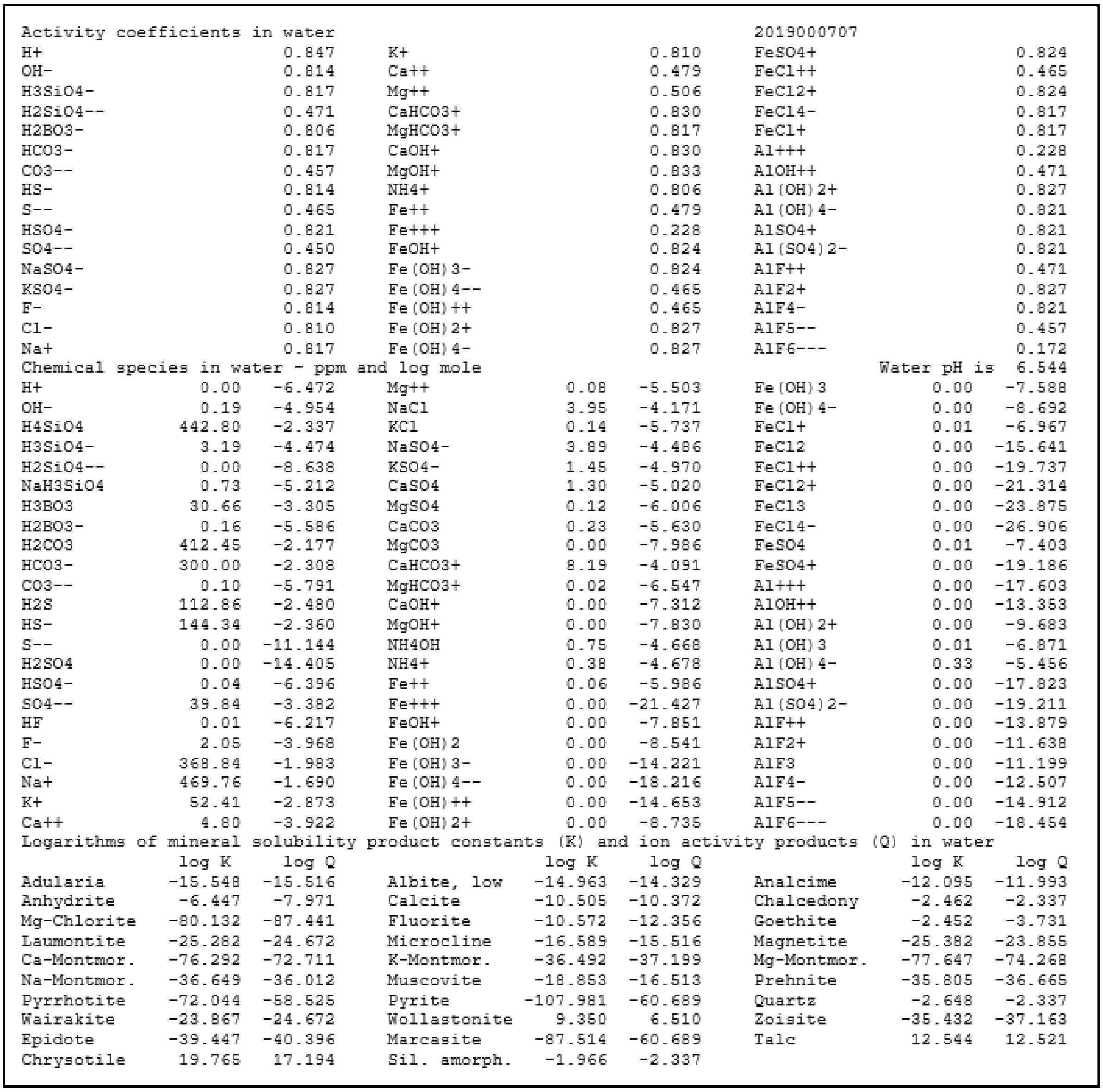

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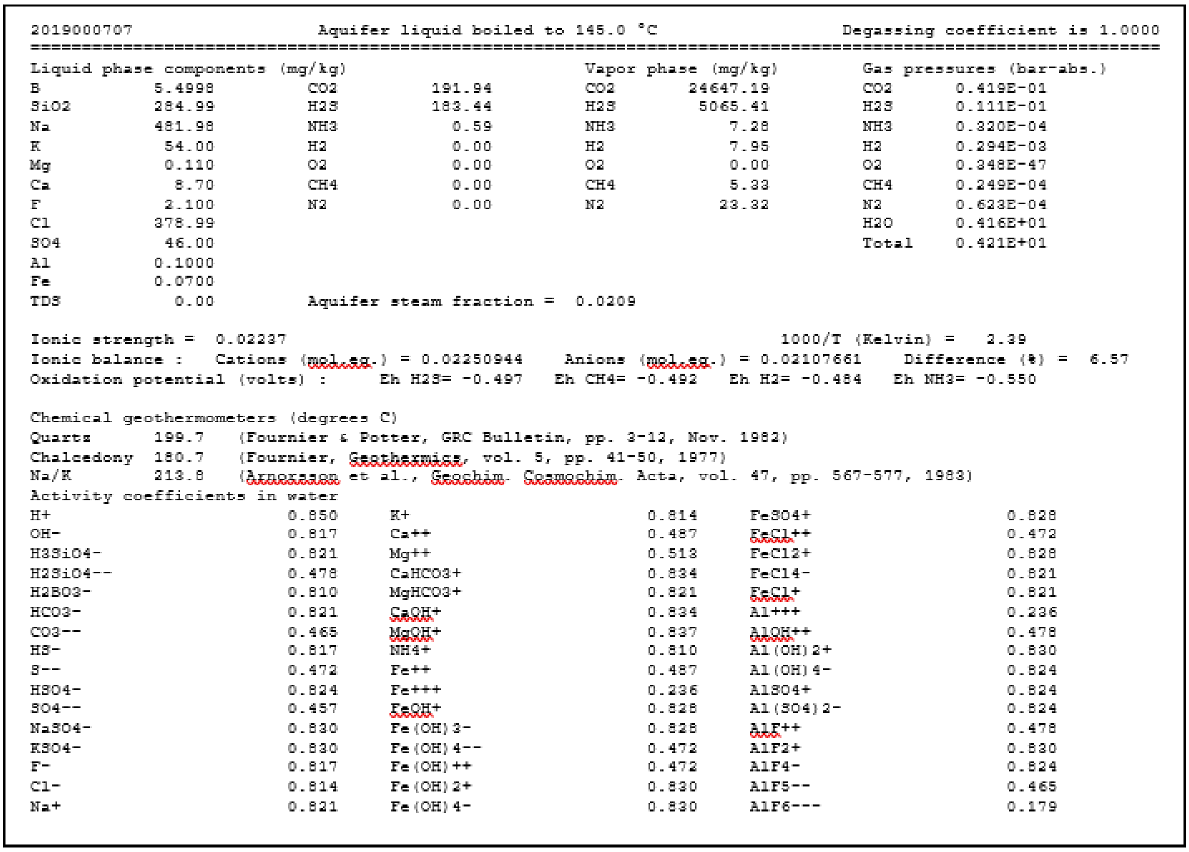
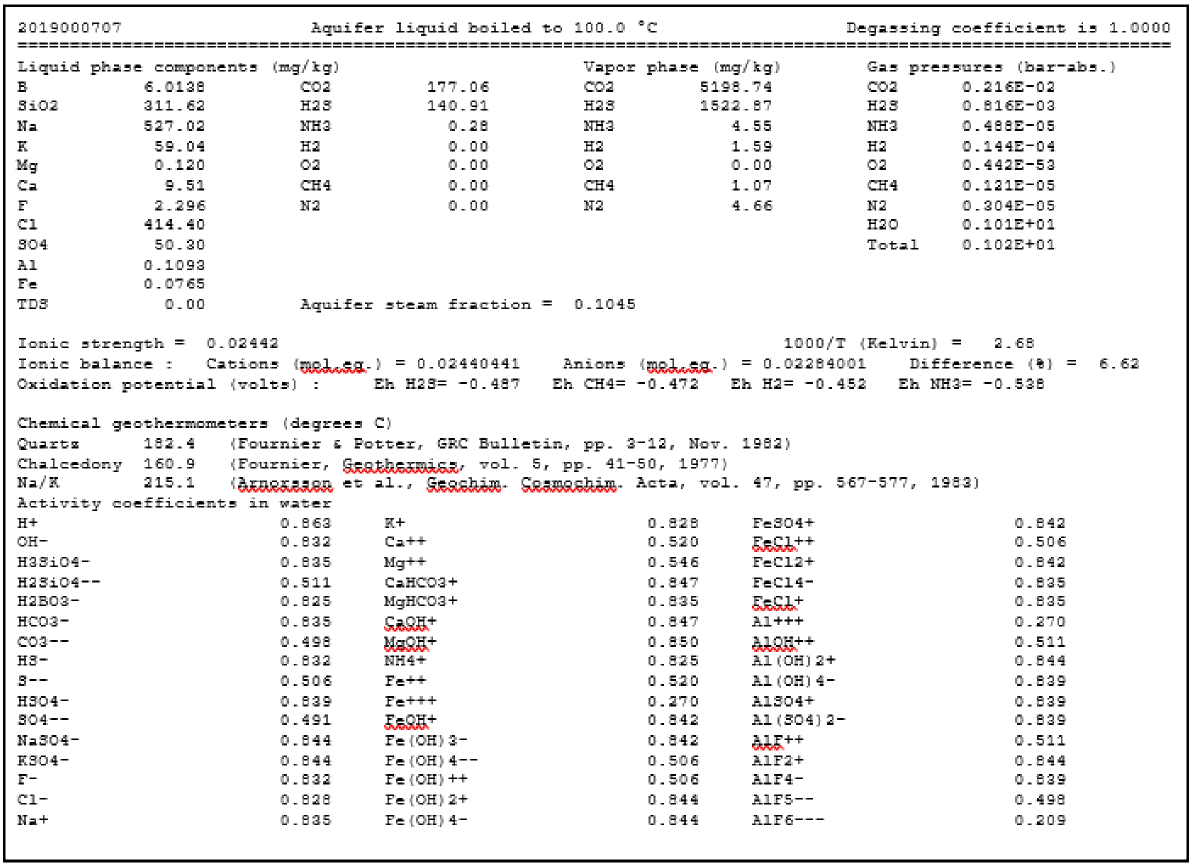
Activity coefficients in water                                        2019000707
H+                       0.847     K+                       0.810     FeSO4+                   0.824
OH-                      0.814     Ca++                     0.479     FeCl++                   0.465
H3SiO4-                  0.817     Mg++                     0.506     FeCl2+                   0.824
H2SiO4--                 0.471     CaHCO3+                  0.830     FeCl4-                   0.817
H2BO3-                   0.806     MgHCO3+                  0.817     FeCl+                    0.817
HCO3-                    0.817     CaOH+                    0.830     Al+++                    0.228
CO3--                    0.457     MgOH+                    0.833     AlOH++                   0.471
HS-                      0.814     NH4+                     0.806     Al(OH)2+                 0.827
S--                      0.465     Fe++                     0.479     Al(OH)4-                 0.821
HSO4-                    0.821     Fe+++                    0.228     AlSO4+                   0.821
SO4--                    0.450     FeOH+                    0.824     Al(SO4)2-                0.821
NaSO4-                   0.827     Fe(OH)3-                 0.824     AlF++                    0.471
KSO4-                    0.827     Fe(OH)4--                0.465     AlF2+                    0.827
F-                       0.814     Fe(OH)++                 0.465     AlF4-                    0.821
Cl-                      0.810     Fe(OH)2+                 0.827     AlF5--                   0.457
Na+                      0.817     Fe(OH)4-                 0.827     AlF6---                  0.172
Chemical species in water - ppm and log mole                                      Water pH is  6.544
H+               0.00   -6.472     Mg++             0.08   -5.503     Fe(OH)3          0.00   -7.588
OH-              0.19   -4.954     NaCl             3.95   -4.171     Fe(OH)4-         0.00   -8.692
H4SiO4         442.80   -2.337     KCl              0.14   -5.737     FeCl+            0.01   -6.967
H3SiO4-          3.19   -4.474     NaSO4-           3.89   -4.486     FeCl2            0.00  -15.641
H2SiO4--         0.00   -8.638     KSO4-            1.45   -4.970     FeCl++           0.00  -19.737
NaH3SiO4         0.73   -5.212     CaSO4            1.30   -5.020     FeCl2+           0.00  -21.314
H3BO3           30.66   -3.305     MgSO4            0.12   -6.006     FeCl3            0.00  -23.875
H2BO3-           0.16   -5.586     CaCO3            0.23   -5.630     FeCl4-           0.00  -26.906
H2CO3          412.45   -2.177     MgCO3            0.00   -7.986     FeSO4            0.01   -7.403
HCO3-          300.00   -2.308     CaHCO3+          8.19   -4.091     FeSO4+           0.00  -19.186
CO3--            0.10   -5.791     MgHCO3+          0.02   -6.547     Al+++            0.00  -17.603
H2S            112.86   -2.480     CaOH+            0.00   -7.312     AlOH++           0.00  -13.353
HS-            144.34   -2.360     MgOH+            0.00   -7.830     Al(OH)2+         0.00   -9.683
S--              0.00  -11.144     NH4OH            0.75   -4.668     Al(OH)3          0.01   -6.871
H2SO4            0.00  -14.405     NH4+             0.38   -4.678     Al(OH)4-         0.33   -5.456
HSO4-            0.04   -6.396     Fe++             0.06   -5.986     AlSO4+           0.00  -17.823
SO4--           39.84   -3.382     Fe+++            0.00  -21.427     Al(SO4)2-        0.00  -19.211
HF               0.01   -6.217     FeOH+            0.00   -7.851     AlF++            0.00  -13.879
F-               2.05   -3.968     Fe(OH)2          0.00   -8.541     AlF2+            0.00  -11.638
Cl-            368.84   -1.983     Fe(OH)3-         0.00  -14.221     AlF3             0.00  -11.199
Na+            469.76   -1.690     Fe(OH)4--        0.00  -18.216     AlF4-            0.00  -12.507
K+              52.41   -2.873     Fe(OH)++         0.00  -14.653     AlF5--           0.00  -14.912
Ca++             4.80   -3.922     Fe(OH)2+         0.00   -8.735     AlF6---          0.00  -18.454
Logarithms of mineral solubility product constants (K) and ion activity products (Q) in water
               log K     log Q                    log K     log Q                    log K     log Q
Adularia      -15.548  -15.516     Albite, low   -14.963  -14.329     Analcime      -12.095  -11.993
Anhydrite      -6.447   -7.971     Calcite       -10.505  -10.372     Chalcedony     -2.462   -2.337
Mg-Chlorite   -80.132  -87.441     Fluorite      -10.572  -12.356     Goethite       -2.452   -3.731
Laumontite    -25.282  -24.672     Microcline    -16.589  -15.516     Magnetite     -25.382  -23.855
Ca-Montmor.   -76.292  -72.711     K-Montmor.    -36.492  -37.199     Mg-Montmor.   -77.647  -74.268
Na-Montmor.   -36.649  -36.012     Muscovite     -18.853  -16.513     Prehnite      -35.805  -36.665
Pyrrhotite    -72.044  -58.525     Pyrite       -107.981  -60.689     Quartz         -2.648   -2.337
Wairakite     -23.867  -24.672     Wollastonite    9.350    6.510     Zoisite       -35.432  -37.163
Epidote       -39.447  -40.396     Marcasite     -87.514  -60.689     Talc           12.544   12.521
Chrysotile     19.765   17.194     Sil. amorph.   -1.966   -2.337
```



```
2019000707              Aquifer liquid boiled to 145.0 °C              Degassing coefficient is 1.0000
==================================================================================================
Liquid phase components  (mg/kg)                   Vapor phase  (mg/kg)        Gas pressures  (bar-abs.)
B          5.4998       CO2         191.94         CO2        24647.19         CO2       0.419E-01
SiO2       284.99       H2S         183.44         H2S         5065.41         H2S       0.111E-01
Na         481.98       NH3           0.59         NH3            7.28         NH3       0.320E-04
K           54.00       H2            0.00         H2             7.95         H2        0.294E-03
Mg          0.110       O2            0.00         O2             0.00         O2        0.348E-47
Ca           8.70       CH4           0.00         CH4            5.33         CH4       0.249E-04
F           2.100       N2            0.00         N2            23.32         N2        0.623E-04
Cl         378.99                                                              H2O       0.416E+01
SO4         46.00                                                              Total     0.421E+01
Al         0.1000
Fe         0.0700
TDS          0.00       Aquifer steam fraction =  0.0209

Ionic strength =  0.02237                                      1000/T (Kelvin) =   2.39
Ionic balance :   Cations (mol.eq.) = 0.02250944    Anions (mol.eq.) = 0.02107661    Difference (%) =  6.57
Oxidation potential (volts) :     Eh H2S= -0.497   Eh CH4= -0.492   Eh H2= -0.484   Eh NH3= -0.550

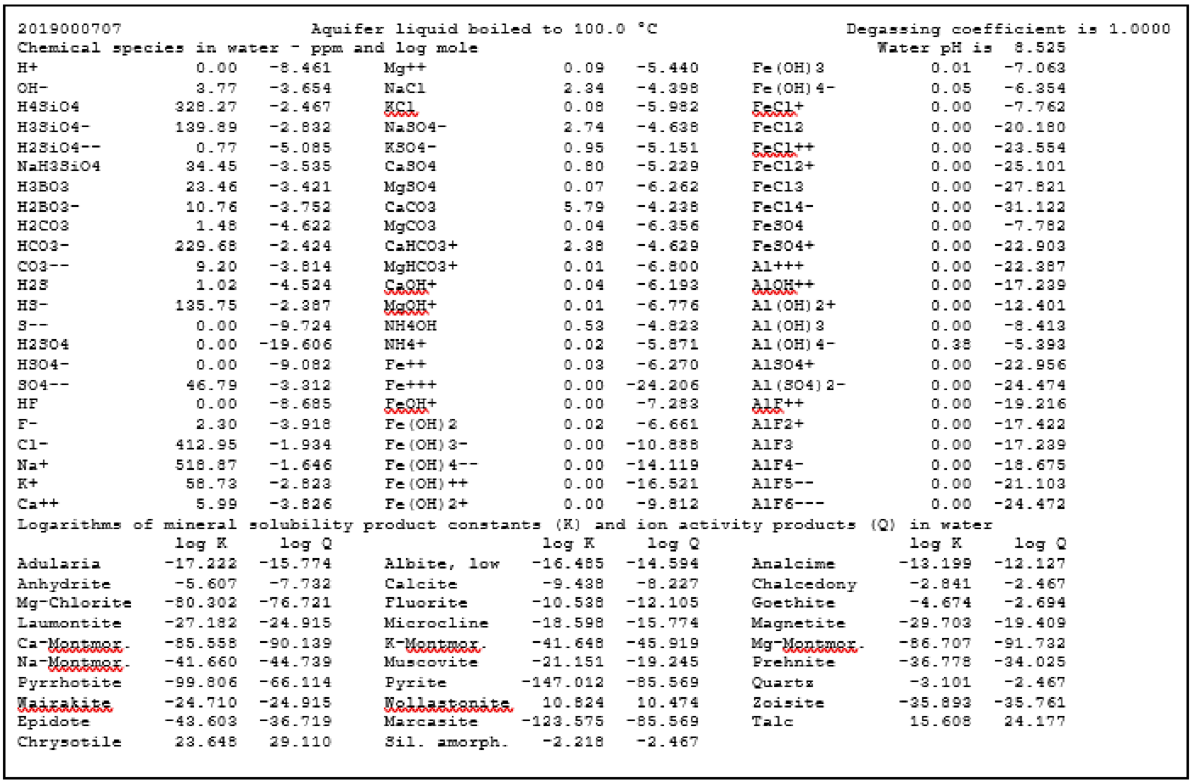
Chemical geothermometers (degrees C)
Quartz       199.7   (Fournier & Potter, GRC Bulletin, pp. 3-12, Nov. 1982)
Chalcedony   180.7   (Fournier, Geothermics, vol. 5, pp. 41-50, 1977)
Na/K         213.8   (Arnorsson et al., Geochim. Cosmochim. Acta, vol. 47, pp. 567-577, 1983)
Activity coefficients in water
H+                       0.850     K+                        0.814     FeSO4+                    0.828
OH-                      0.817     Ca++                      0.487     FeCl++                    0.472
H3SiO4-                  0.821     Mg++                      0.513     FeCl2+                    0.828
H2SiO4--                 0.478     CaHCO3+                   0.834     FeCl4-                    0.821
H2BO3-                   0.810     MgHCO3+                   0.821     FeCl+                     0.821
HCO3-                    0.821     CaOH+                     0.834     Al+++                     0.236
CO3--                    0.465     MgOH+                     0.837     AlOH++                    0.478
HS-                      0.817     NH4+                      0.810     Al(OH)2+                  0.830
S--                      0.472     Fe++                      0.487     Al(OH)4-                  0.824
HSO4-                    0.824     Fe+++                     0.236     AlSO4+                    0.824
SO4--                    0.457     FeOH+                     0.828     Al(SO4)2-                 0.824
NaSO4-                   0.830     Fe(OH)3-                  0.828     AlF++                     0.478
KSO4-                    0.830     Fe(OH)4--                 0.472     AlF2+                     0.830
F-                       0.817     Fe(OH)++                  0.472     AlF4-                     0.824
Cl-                      0.814     Fe(OH)2+                  0.830     AlF5--                    0.465
Na+                      0.821     Fe(OH)4-                  0.830     AlF6---                   0.179
```



```
2019000707              Aquifer liquid boiled to 100.0 °C              Degassing coefficient is 1.0000
==================================================================================================
Liquid phase components  (mg/kg)                   Vapor phase  (mg/kg)        Gas pressures  (bar-abs.)
B          6.0138       CO2         177.06         CO2         5198.74         CO2       0.216E-02
SiO2       311.62       H2S         140.91         H2S         1522.87         H2S       0.816E-03
Na         527.02       NH3           0.28         NH3            4.55         NH3       0.488E-05
K           59.04       H2            0.00         H2             1.59         H2        0.144E-04
Mg          0.120       O2            0.00         O2             0.00         O2        0.442E-53
Ca           9.51       CH4           0.00         CH4            1.07         CH4       0.121E-05
F           2.296       N2            0.00         N2             4.66         N2        0.304E-05
Cl         414.40                                                              H2O       0.101E+01
SO4         50.30                                                              Total     0.102E+01
Al         0.1093
Fe         0.0765
TDS          0.00       Aquifer steam fraction =  0.1045

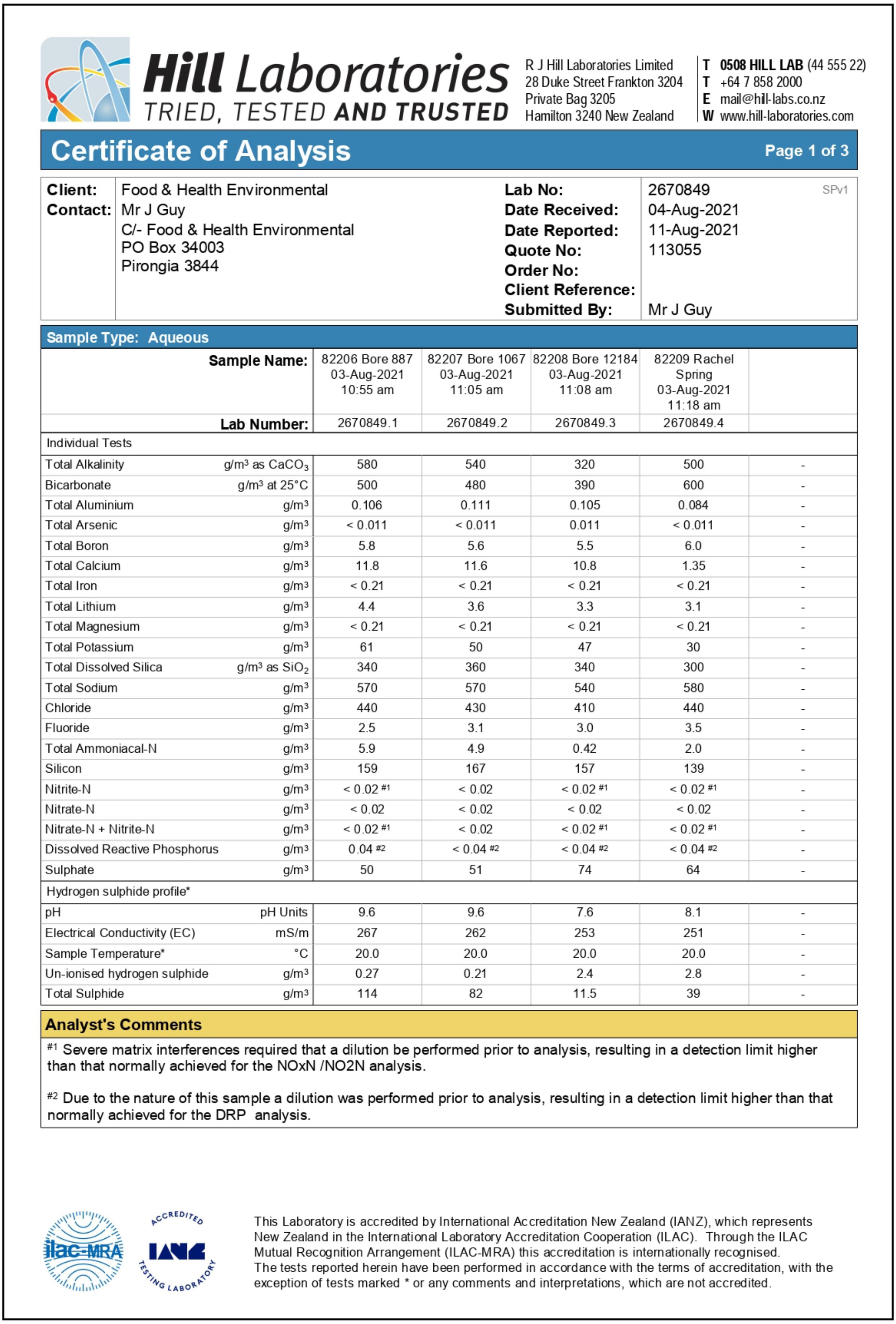
Ionic strength =  0.02442                                      1000/T (Kelvin) =   2.68
Ionic balance :   Cations (mol.eq.) = 0.02440441    Anions (mol.eq.) = 0.02284001    Difference (%) =  6.62
Oxidation potential (volts) :     Eh H2S= -0.487   Eh CH4= -0.472   Eh H2= -0.452   Eh NH3= -0.538

Chemical geothermometers (degrees C)
Quartz       182.4   (Fournier & Potter, GRC Bulletin, pp. 3-12, Nov. 1982)
Chalcedony   160.9   (Fournier, Geothermics, vol. 5, pp. 41-50, 1977)
Na/K         215.1   (Arnorsson et al., Geochim. Cosmochim. Acta, vol. 47, pp. 567-577, 1983)
Activity coefficients in water
H+                       0.863     K+                        0.828     FeSO4+                    0.842
OH-                      0.832     Ca++                      0.520     FeCl++                    0.506
H3SiO4-                  0.835     Mg++                      0.546     FeCl2+                    0.842
H2SiO4--                 0.511     CaHCO3+                   0.847     FeCl4-                    0.835
H2BO3-                   0.825     MgHCO3+                   0.835     FeCl+                     0.835
HCO3-                    0.835     CaOH+                     0.847     Al+++                     0.270
CO3--                    0.498     MgOH+                     0.850     AlOH++                    0.511
HS-                      0.832     NH4+                      0.825     Al(OH)2+                  0.844
S--                      0.506     Fe++                      0.520     Al(OH)4-                  0.839
HSO4-                    0.839     Fe+++                     0.270     AlSO4+                    0.839
SO4--                    0.491     FeOH+                     0.842     Al(SO4)2-                 0.839
NaSO4-                   0.844     Fe(OH)3-                  0.842     AlF++                     0.511
KSO4-                    0.844     Fe(OH)4--                 0.506     AlF2+                     0.844
F-                       0.832     Fe(OH)++                  0.506     AlF4-                     0.839
Cl-                      0.828     Fe(OH)2+                  0.844     AlF5--                    0.498
Na+                      0.835     Fe(OH)4-                  0.844     AlF6---                   0.209
```



```
2019000707                  Aquifer liquid boiled to 100.0 °C                 Degassing coefficient is 1.0000
Chemical species in water - ppm and log mole                                     Water pH is  8.525
H+              0.00   -8.461      Mg++            0.09   -5.440      Fe(OH)3         0.01   -7.063
OH-             3.77   -3.654      NaCl            2.34   -4.398      Fe(OH)4-        0.05   -6.354
H4SiO4        328.27   -2.467      KCl             0.08   -5.982      FeCl+           0.00   -7.762
H3SiO4-       139.89   -2.832      NaSO4-          2.74   -4.638      FeCl2           0.00  -20.180
H2SiO4--        0.77   -5.085      KSO4-           0.95   -5.151      FeCl++          0.00  -23.554
NaH3SiO4       34.45   -3.535      CaSO4           0.80   -5.229      FeCl2+          0.00  -25.101
H3BO3          23.46   -3.421      MgSO4           0.07   -6.262      FeCl3           0.00  -27.821
H2BO3-         10.76   -3.752      CaCO3           5.79   -4.238      FeCl4-          0.00  -31.122
H2CO3           1.48   -4.622      MgCO3           0.04   -6.356      FeSO4           0.00   -7.782
HCO3-         229.68   -2.424      CaHCO3+         2.38   -4.629      FeSO4+          0.00  -22.903
CO3--           9.20   -3.814      MgHCO3+         0.01   -6.800      Al+++           0.00  -22.387
H2S             1.02   -4.524      CaOH+           0.04   -6.193      AlOH++          0.00  -17.239
HS-           135.75   -2.387      MgOH+           0.01   -6.776      Al(OH)2+        0.00  -12.401
S--             0.00   -9.724      NH4OH           0.53   -4.823      Al(OH)3         0.00   -8.413
H2SO4           0.00  -19.606      NH4+            0.02   -5.871      Al(OH)4-        0.38   -5.393
HSO4-           0.00   -9.082      Fe++            0.03   -6.270      AlSO4+          0.00  -22.956
SO4--          46.79   -3.312      Fe+++           0.00  -24.206      Al(SO4)2-       0.00  -24.474
HF              0.00   -8.685      FeOH+           0.00   -7.283      AlF++           0.00  -19.216
F-              2.30   -3.918      Fe(OH)2         0.02   -6.661      AlF2+           0.00  -17.422
Cl-           412.95   -1.934      Fe(OH)3-        0.00  -10.888      AlF3            0.00  -17.239
Na+           518.87   -1.646      Fe(OH)4--       0.00  -14.119      AlF4-           0.00  -18.675
K+             58.73   -2.823      Fe(OH)++        0.00  -16.521      AlF5--          0.00  -21.103
Ca++            5.99   -3.826      Fe(OH)2+        0.00   -9.812      AlF6---         0.00  -24.472
Logarithms of mineral solubility product constants (K) and ion activity products (Q) in water
                log K    log Q                     log K    log Q                     log K    log Q
Adularia      -17.222  -15.774     Albite, low   -16.485  -14.594     Analcime      -13.199  -12.127
Anhydrite      -5.607   -7.732     Calcite        -9.438   -8.227     Chalcedony     -2.841   -2.467
Mg-Chlorite   -80.302  -76.721     Fluorite      -10.538  -12.105     Goethite       -4.674   -2.694
Laumontite    -27.182  -24.915     Microcline    -18.598  -15.774     Magnetite     -29.703  -19.409
Ca-Montmor.   -85.558  -90.139     K-Montmor.    -41.648  -45.919     Mg-Montmor.   -86.707  -91.732
Na-Montmor.   -41.660  -44.739     Muscovite     -21.151  -19.245     Prehnite      -36.778  -34.025
Pyrrhotite    -99.806  -66.114     Pyrite       -147.012  -85.569     Quartz         -3.101   -2.467
Wairakite     -24.710  -24.915     Wollastonite   10.824   10.474     Zoisite       -35.893  -35.761
Epidote       -43.603  -36.719     Marcasite    -123.575  -85.569     Talc           15.608   24.177
Chrysotile     23.648   29.110     Sil. amorph.   -2.218   -2.467
```

APPENDIX 4 ANALYSES OF AERATION POOL WATER



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Certificate of Analysis

Page 1 of 3

SPv1

Client:	Food & Health Environmental	**Lab No:**	2670849
Contact:	Mr J Guy C/- Food & Health Environmental PO Box 34003 Pirongia 3844	**Date Received:**	04-Aug-2021
		Date Reported:	11-Aug-2021
		Quote No:	113055
		Order No:	
		Client Reference:	
		Submitted By:	Mr J Guy

Sample Type: Aqueous

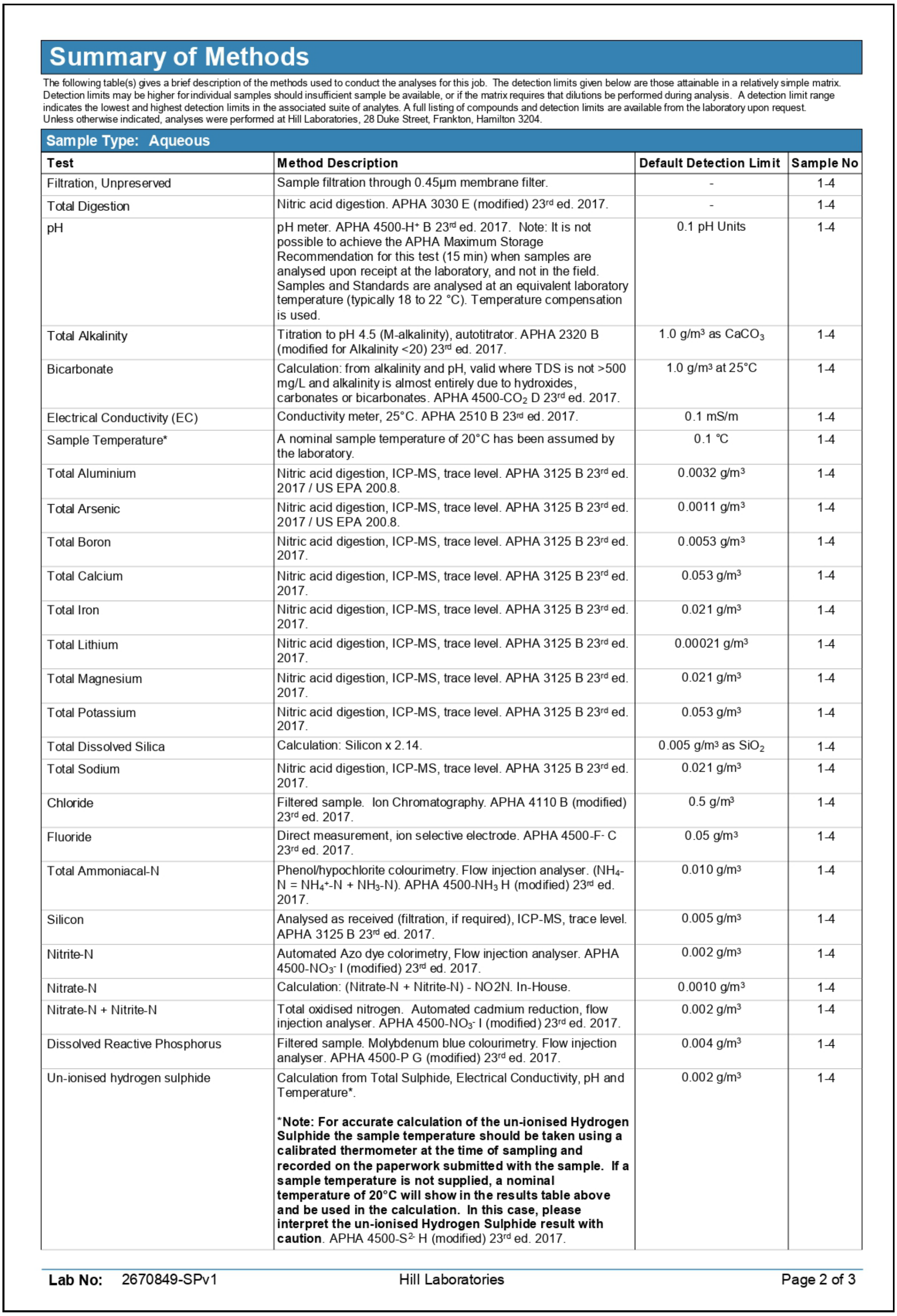
Sample Name:		82206 Bore 887 03-Aug-2021 10:55 am	82207 Bore 1067 03-Aug-2021 11:05 am	82208 Bore 12184 03-Aug-2021 11:08 am	82209 Rachel Spring 03-Aug-2021 11:18 am	
Lab Number:		2670849.1	2670849.2	2670849.3	2670849.4	
Individual Tests						
Total Alkalinity	g/m^3 as $CaCO_3$	580	540	320	500	-
Bicarbonate	g/m^3 at 25°C	500	480	390	600	-
Total Aluminium	g/m^3	0.106	0.111	0.105	0.084	-
Total Arsenic	g/m^3	< 0.011	< 0.011	0.011	< 0.011	-
Total Boron	g/m^3	5.8	5.6	5.5	6.0	-
Total Calcium	g/m^3	11.8	11.6	10.8	1.35	-
Total Iron	g/m^3	< 0.21	< 0.21	< 0.21	< 0.21	-
Total Lithium	g/m^3	4.4	3.6	3.3	3.1	-
Total Magnesium	g/m^3	< 0.21	< 0.21	< 0.21	< 0.21	-
Total Potassium	g/m^3	61	50	47	30	-
Total Dissolved Silica	g/m^3 as SiO_2	340	360	340	300	-
Total Sodium	g/m^3	570	570	540	580	-
Chloride	g/m^3	440	430	410	440	-
Fluoride	g/m^3	2.5	3.1	3.0	3.5	-
Total Ammoniacal-N	g/m^3	5.9	4.9	0.42	2.0	-
Silicon	g/m^3	159	167	157	139	-
Nitrite-N	g/m^3	< 0.02 [#1]	< 0.02	< 0.02 [#1]	< 0.02 [#1]	-
Nitrate-N	g/m^3	< 0.02	< 0.02	< 0.02	< 0.02	-
Nitrate-N + Nitrite-N	g/m^3	< 0.02 [#1]	< 0.02	< 0.02 [#1]	< 0.02 [#1]	-
Dissolved Reactive Phosphorus	g/m^3	0.04 [#2]	< 0.04 [#2]	< 0.04 [#2]	< 0.04 [#2]	-
Sulphate	g/m^3	50	51	74	64	-
Hydrogen sulphide profile*						
pH	pH Units	9.6	9.6	7.6	8.1	-
Electrical Conductivity (EC)	mS/m	267	262	253	251	-
Sample Temperature*	°C	20.0	20.0	20.0	20.0	-
Un-ionised hydrogen sulphide	g/m^3	0.27	0.21	2.4	2.8	-
Total Sulphide	g/m^3	114	82	11.5	39	-

Analyst's Comments

[#1] Severe matrix interferences required that a dilution be performed prior to analysis, resulting in a detection limit higher than that normally achieved for the NOxN /NO2N analysis.

[#2] Due to the nature of this sample a dilution was performed prior to analysis, resulting in a detection limit higher than that normally achieved for the DRP analysis.

Figure A4.1 Hill Laboratories Certificate of Analysis – 11 August 2021(1 of 3).



Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Laboratories, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter.	-	1-4
Total Digestion	Nitric acid digestion. APHA 3030 E (modified) 23rd ed. 2017.	-	1-4
pH	pH meter. APHA 4500-H^+ B 23rd ed. 2017. Note: It is not possible to achieve the APHA Maximum Storage Recommendation for this test (15 min) when samples are analysed upon receipt at the laboratory, and not in the field. Samples and Standards are analysed at an equivalent laboratory temperature (typically 18 to 22 °C). Temperature compensation is used.	0.1 pH Units	1-4
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (modified for Alkalinity <20) 23rd ed. 2017.	1.0 g/m^3 as $CaCO_3$	1-4
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 23rd ed. 2017.	1.0 g/m^3 at 25°C	1-4
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 23rd ed. 2017.	0.1 mS/m	1-4
Sample Temperature*	A nominal sample temperature of 20°C has been assumed by the laboratory.	0.1 °C	1-4
Total Aluminium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017 / US EPA 200.8.	0.0032 g/m^3	1-4
Total Arsenic	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017 / US EPA 200.8.	0.0011 g/m^3	1-4
Total Boron	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.0053 g/m^3	1-4
Total Calcium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.053 g/m^3	1-4
Total Iron	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.021 g/m^3	1-4
Total Lithium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.00021 g/m^3	1-4
Total Magnesium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.021 g/m^3	1-4
Total Potassium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.053 g/m^3	1-4
Total Dissolved Silica	Calculation: Silicon x 2.14.	0.005 g/m^3 as SiO_2	1-4
Total Sodium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.021 g/m^3	1-4
Chloride	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	1-4
Fluoride	Direct measurement, ion selective electrode. APHA 4500-F^- C 23rd ed. 2017.	0.05 g/m^3	1-4
Total Ammoniacal-N	Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) 23rd ed. 2017.	0.010 g/m^3	1-4
Silicon	Analysed as received (filtration, if required), ICP-MS, trace level. APHA 3125 B 23rd ed. 2017.	0.005 g/m^3	1-4
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-4
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N. In-House.	0.0010 g/m^3	1-4
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) 23rd ed. 2017.	0.002 g/m^3	1-4
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) 23rd ed. 2017.	0.004 g/m^3	1-4
Un-ionised hydrogen sulphide	Calculation from Total Sulphide, Electrical Conductivity, pH and Temperature*. ***Note: For accurate calculation of the un-ionised Hydrogen Sulphide the sample temperature should be taken using a calibrated thermometer at the time of sampling and recorded on the paperwork submitted with the sample. If a sample temperature is not supplied, a nominal temperature of 20°C will show in the results table above and be used in the calculation. In this case, please interpret the un-ionised Hydrogen Sulphide result with caution**. APHA 4500-S^{2-} H (modified) 23rd ed. 2017.	0.002 g/m^3	1-4

Lab No: 2670849-SPv1 Hill Laboratories Page 2 of 3

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Total Sulphide Screen	In-line distillation, segmented flow colorimetry. APHA 4500-S^{2-} E (modified) 23rd ed. 2017.	0.05 g/m^3	1-4
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B (modified) 23rd ed. 2017.	0.5 g/m^3	1-4

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

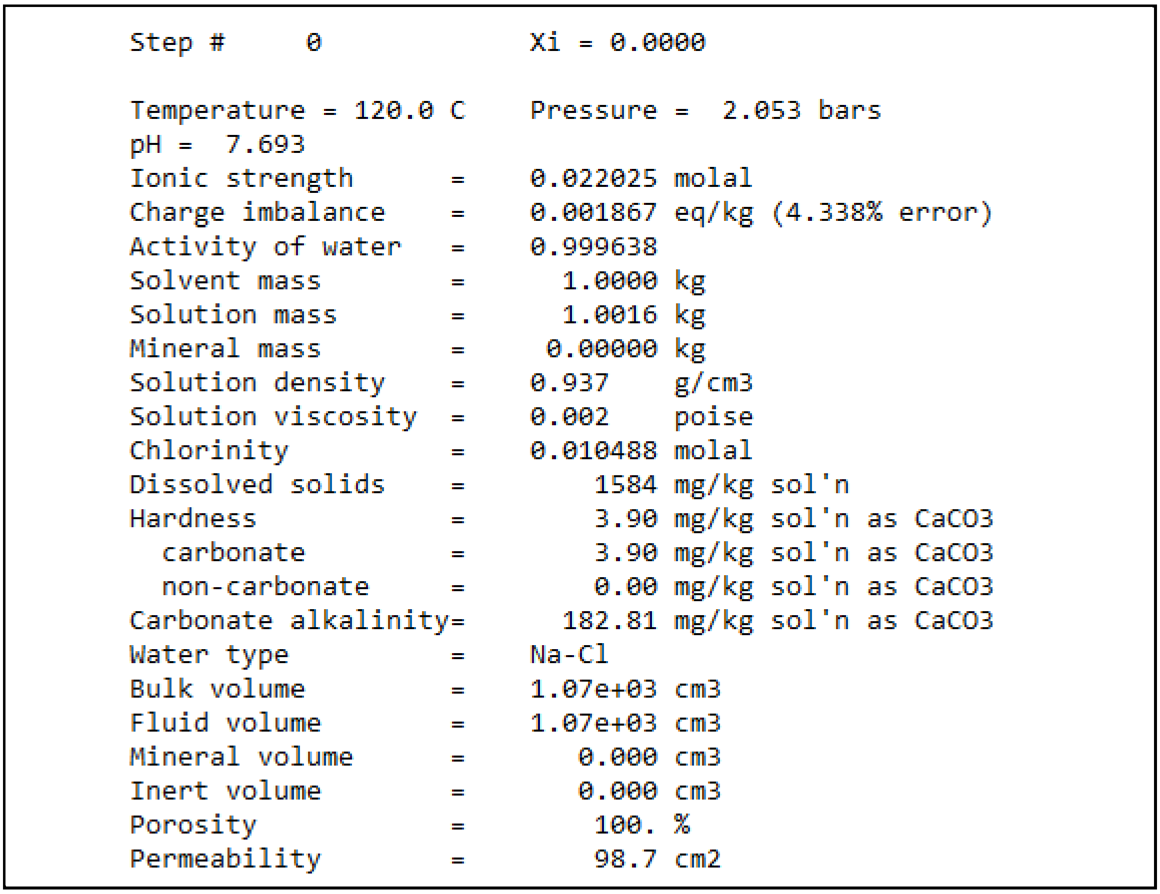
Testing was completed between 05-Aug-2021 and 11-Aug-2021. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

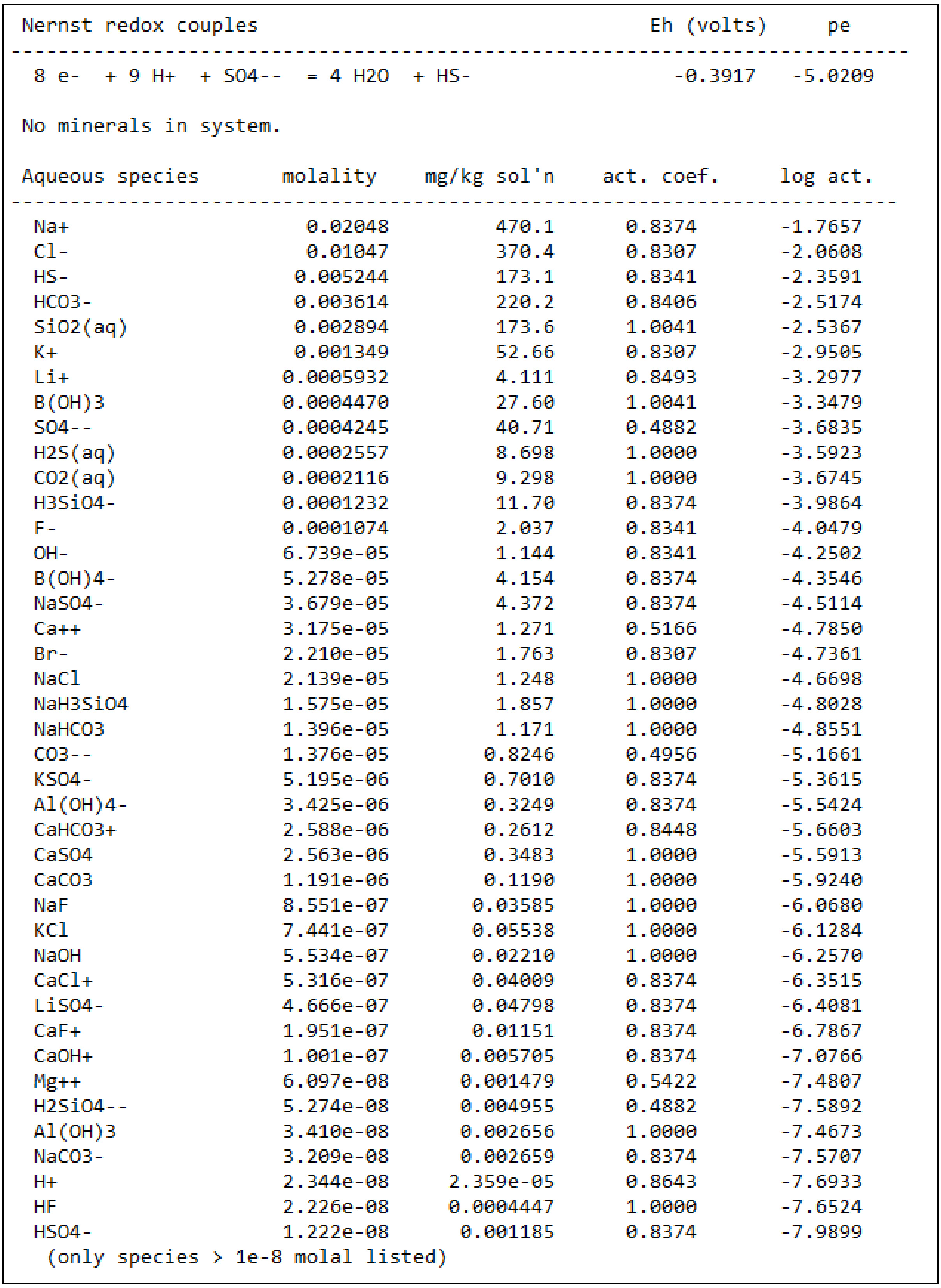
Ara Heron BSc (Tech)
Client Services Manager - Environmental

APPENDIX 5 GWB OUTPUT FILE – RECALCULATED IN GWB SOFTWARE COMPOSITION OF THE RESERVOIR AT 120°C AND 150°C



```
Step #     0            Xi = 0.0000

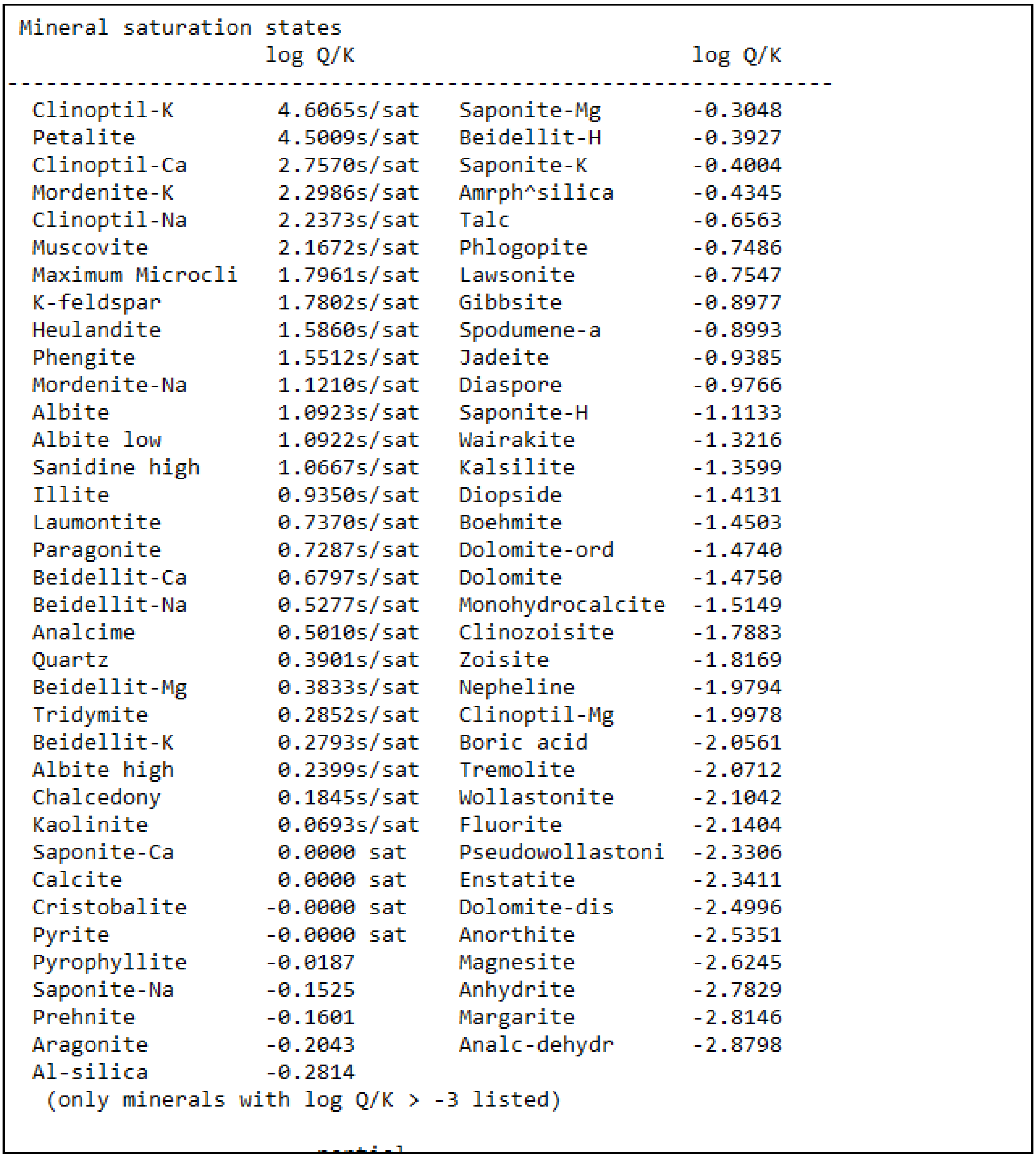
Temperature = 120.0 C    Pressure =  2.053 bars
pH =  7.693
Ionic strength       =    0.022025 molal
Charge imbalance     =    0.001867 eq/kg (4.338% error)
Activity of water    =    0.999638
Solvent mass         =      1.0000 kg
Solution mass        =      1.0016 kg
Mineral mass         =     0.00000 kg
Solution density     =    0.937    g/cm3
Solution viscosity   =    0.002    poise
Chlorinity           =    0.010488 molal
Dissolved solids     =        1584 mg/kg sol'n
Hardness             =        3.90 mg/kg sol'n as CaCO3
  carbonate          =        3.90 mg/kg sol'n as CaCO3
  non-carbonate      =        0.00 mg/kg sol'n as CaCO3
Carbonate alkalinity=       182.81 mg/kg sol'n as CaCO3
Water type           =    Na-Cl
Bulk volume          =    1.07e+03 cm3
Fluid volume         =    1.07e+03 cm3
Mineral volume       =       0.000 cm3
Inert volume         =       0.000 cm3
Porosity             =        100. %
Permeability         =        98.7 cm2
```



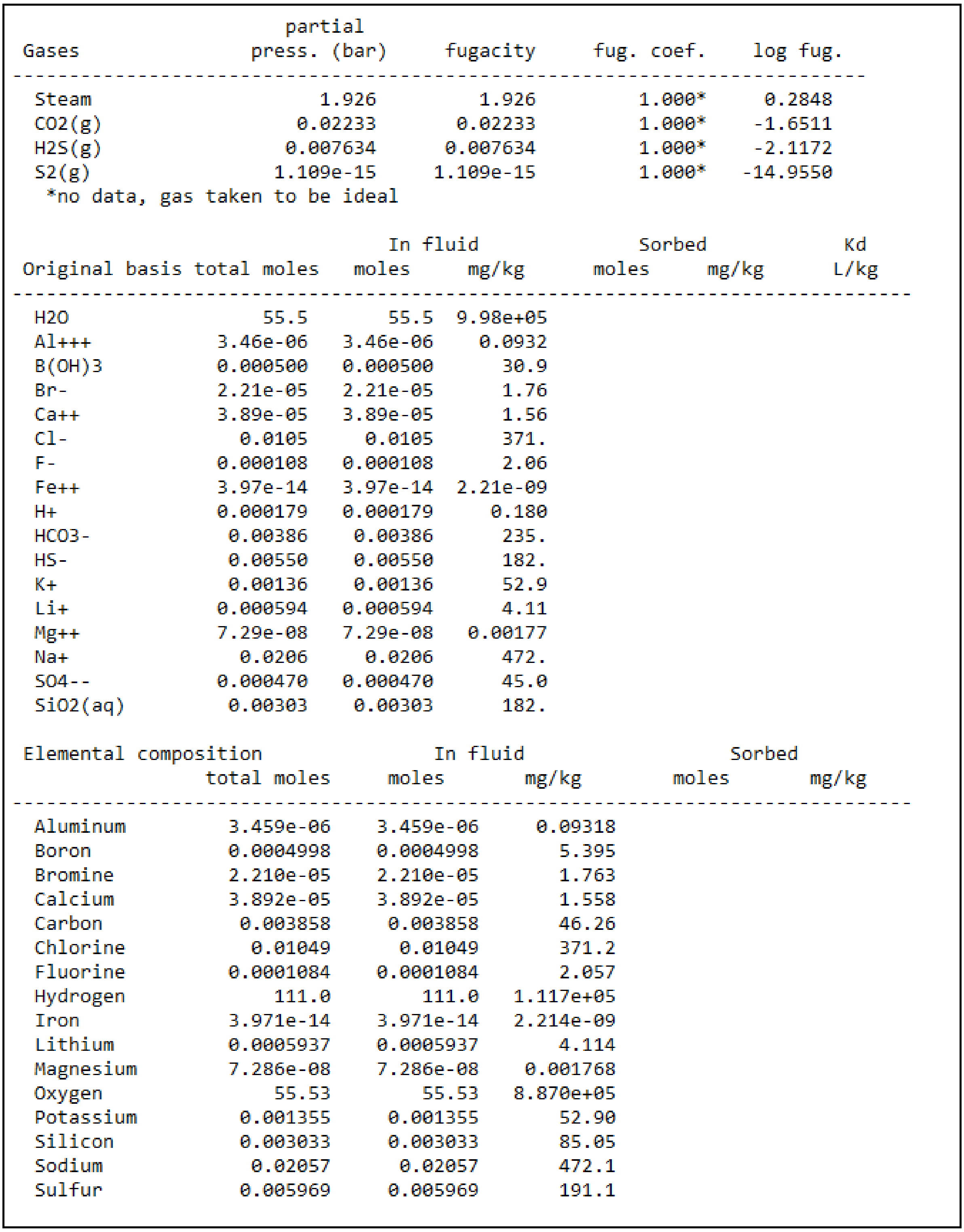
```
Nernst redox couples                                    Eh (volts)     pe
---------------------------------------------------------------------------
 8 e-  + 9 H+  + SO4--  = 4 H2O  + HS-                    -0.3917   -5.0209

No minerals in system.

Aqueous species         molality    mg/kg sol'n    act. coef.     log act.
--------------------------------------------------------------------------
 Na+                      0.02048         470.1      0.8374       -1.7657
 Cl-                      0.01047         370.4      0.8307       -2.0608
 HS-                     0.005244         173.1      0.8341       -2.3591
 HCO3-                   0.003614         220.2      0.8406       -2.5174
 SiO2(aq)                0.002894         173.6      1.0041       -2.5367
 K+                      0.001349         52.66      0.8307       -2.9505
 Li+                    0.0005932         4.111      0.8493       -3.2977
 B(OH)3                 0.0004470         27.60      1.0041       -3.3479
 SO4--                  0.0004245         40.71      0.4882       -3.6835
 H2S(aq)                0.0002557         8.698      1.0000       -3.5923
 CO2(aq)                0.0002116         9.298      1.0000       -3.6745
 H3SiO4-                0.0001232         11.70      0.8374       -3.9864
 F-                     0.0001074         2.037      0.8341       -4.0479
 OH-                    6.739e-05         1.144      0.8341       -4.2502
 B(OH)4-                5.278e-05         4.154      0.8374       -4.3546
 NaSO4-                 3.679e-05         4.372      0.8374       -4.5114
 Ca++                   3.175e-05         1.271      0.5166       -4.7850
 Br-                    2.210e-05         1.763      0.8307       -4.7361
 NaCl                   2.139e-05         1.248      1.0000       -4.6698
 NaH3SiO4               1.575e-05         1.857      1.0000       -4.8028
 NaHCO3                 1.396e-05         1.171      1.0000       -4.8551
 CO3--                  1.376e-05        0.8246      0.4956       -5.1661
 KSO4-                  5.195e-06        0.7010      0.8374       -5.3615
 Al(OH)4-               3.425e-06        0.3249      0.8374       -5.5424
 CaHCO3+                2.588e-06        0.2612      0.8448       -5.6603
 CaSO4                  2.563e-06        0.3483      1.0000       -5.5913
 CaCO3                  1.191e-06        0.1190      1.0000       -5.9240
 NaF                    8.551e-07       0.03585      1.0000       -6.0680
 KCl                    7.441e-07       0.05538      1.0000       -6.1284
 NaOH                   5.534e-07       0.02210      1.0000       -6.2570
 CaCl+                  5.316e-07       0.04009      0.8374       -6.3515
 LiSO4-                 4.666e-07       0.04798      0.8374       -6.4081
 CaF+                   1.951e-07       0.01151      0.8374       -6.7867
 CaOH+                  1.001e-07      0.005705      0.8374       -7.0766
 Mg++                   6.097e-08      0.001479      0.5422       -7.4807
 H2SiO4--               5.274e-08      0.004955      0.4882       -7.5892
 Al(OH)3                3.410e-08      0.002656      1.0000       -7.4673
 NaCO3-                 3.209e-08      0.002659      0.8374       -7.5707
 H+                     2.344e-08     2.359e-05      0.8643       -7.6933
 HF                     2.226e-08     0.0004447      1.0000       -7.6524
 HSO4-                  1.222e-08      0.001185      0.8374       -7.9899
  (only species > 1e-8 molal listed)
```



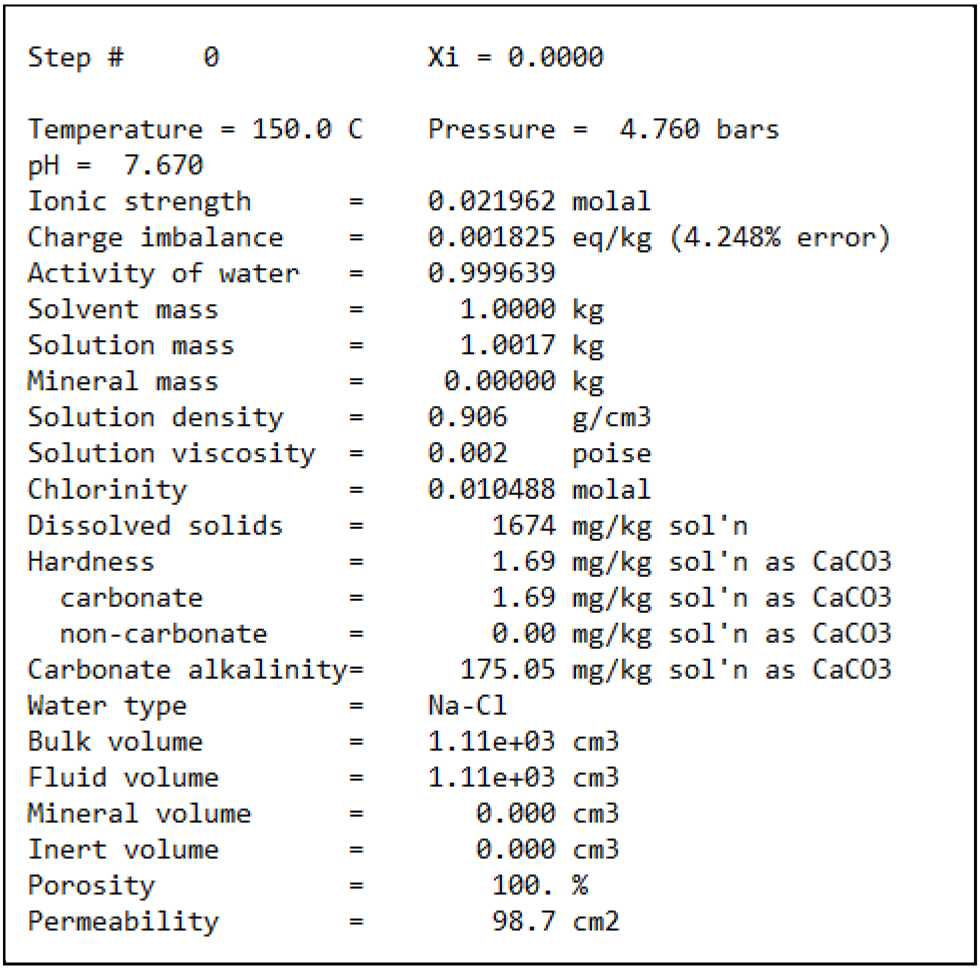
```
 Mineral saturation states
                    log Q/K                          log Q/K
----------------------------------------------------------------
  Clinoptil-K        4.6065s/sat   Saponite-Mg       -0.3048
  Petalite           4.5009s/sat   Beidellit-H       -0.3927
  Clinoptil-Ca       2.7570s/sat   Saponite-K        -0.4004
  Mordenite-K        2.2986s/sat   Amrph^silica      -0.4345
  Clinoptil-Na       2.2373s/sat   Talc              -0.6563
  Muscovite          2.1672s/sat   Phlogopite        -0.7486
  Maximum Microcli   1.7961s/sat   Lawsonite         -0.7547
  K-feldspar         1.7802s/sat   Gibbsite          -0.8977
  Heulandite         1.5860s/sat   Spodumene-a       -0.8993
  Phengite           1.5512s/sat   Jadeite           -0.9385
  Mordenite-Na       1.1210s/sat   Diaspore          -0.9766
  Albite             1.0923s/sat   Saponite-H        -1.1133
  Albite low         1.0922s/sat   Wairakite         -1.3216
  Sanidine high      1.0667s/sat   Kalsilite         -1.3599
  Illite             0.9350s/sat   Diopside          -1.4131
  Laumontite         0.7370s/sat   Boehmite          -1.4503
  Paragonite         0.7287s/sat   Dolomite-ord      -1.4740
  Beidellit-Ca       0.6797s/sat   Dolomite          -1.4750
  Beidellit-Na       0.5277s/sat   Monohydrocalcite  -1.5149
  Analcime           0.5010s/sat   Clinozoisite      -1.7883
  Quartz             0.3901s/sat   Zoisite           -1.8169
  Beidellit-Mg       0.3833s/sat   Nepheline         -1.9794
  Tridymite          0.2852s/sat   Clinoptil-Mg      -1.9978
  Beidellit-K        0.2793s/sat   Boric acid        -2.0561
  Albite high        0.2399s/sat   Tremolite         -2.0712
  Chalcedony         0.1845s/sat   Wollastonite      -2.1042
  Kaolinite          0.0693s/sat   Fluorite          -2.1404
  Saponite-Ca        0.0000 sat    Pseudowollastoni  -2.3306
  Calcite            0.0000 sat    Enstatite         -2.3411
  Cristobalite      -0.0000 sat    Dolomite-dis      -2.4996
  Pyrite            -0.0000 sat    Anorthite         -2.5351
  Pyrophyllite      -0.0187        Magnesite         -2.6245
  Saponite-Na       -0.1525        Anhydrite         -2.7829
  Prehnite          -0.1601        Margarite         -2.8146
  Aragonite         -0.2043        Analc-dehydr      -2.8798
  Al-silica         -0.2814
   (only minerals with log Q/K > -3 listed)
```



```
                       partial
 Gases               press. (bar)     fugacity     fug. coef.    log fug.
---------------------------------------------------------------------------
  Steam                     1.926        1.926        1.000*      0.2848
  CO2(g)                  0.02233      0.02233        1.000*     -1.6511
  H2S(g)                 0.007634     0.007634        1.000*     -2.1172
  S2(g)                 1.109e-15    1.109e-15        1.000*    -14.9550
   *no data, gas taken to be ideal

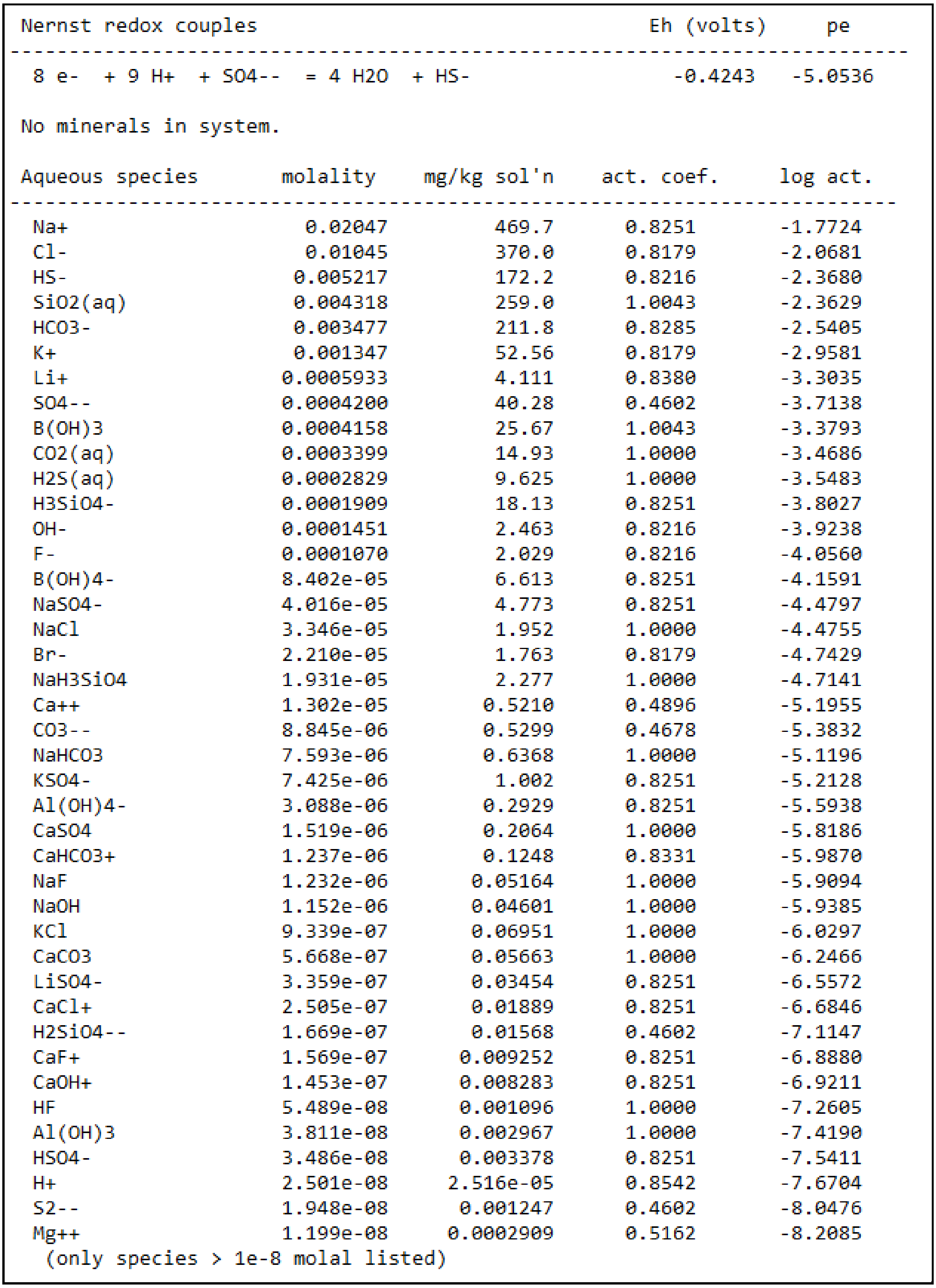
                                     In fluid              Sorbed             Kd
 Original basis total moles    moles       mg/kg       moles       mg/kg      L/kg
-------------------------------------------------------------------------------
  H2O                 55.5        55.5  9.98e+05
  Al+++           3.46e-06    3.46e-06    0.0932
  B(OH)3          0.000500    0.000500      30.9
  Br-             2.21e-05    2.21e-05      1.76
  Ca++            3.89e-05    3.89e-05      1.56
  Cl-               0.0105      0.0105      371.
  F-              0.000108    0.000108      2.06
  Fe++            3.97e-14    3.97e-14  2.21e-09
  H+              0.000179    0.000179     0.180
  HCO3-            0.00386     0.00386      235.
  HS-              0.00550     0.00550      182.
  K+               0.00136     0.00136      52.9
  Li+             0.000594    0.000594      4.11
  Mg++            7.29e-08    7.29e-08   0.00177
  Na+               0.0206      0.0206      472.
  SO4--           0.000470    0.000470      45.0
  SiO2(aq)         0.00303     0.00303      182.

 Elemental composition             In fluid                 Sorbed
                total moles      moles        mg/kg        moles        mg/kg
-------------------------------------------------------------------------------
  Aluminum         3.459e-06    3.459e-06     0.09318
  Boron            0.0004998    0.0004998       5.395
  Bromine          2.210e-05    2.210e-05       1.763
  Calcium          3.892e-05    3.892e-05       1.558
  Carbon            0.003858     0.003858       46.26
  Chlorine           0.01049      0.01049       371.2
  Fluorine         0.0001084    0.0001084       2.057
  Hydrogen             111.0        111.0   1.117e+05
  Iron             3.971e-14    3.971e-14   2.214e-09
  Lithium          0.0005937    0.0005937       4.114
  Magnesium        7.286e-08    7.286e-08    0.001768
  Oxygen               55.53        55.53   8.870e+05
  Potassium         0.001355     0.001355       52.90
  Silicon           0.003033     0.003033       85.05
  Sodium             0.02057      0.02057       472.1
  Sulfur            0.005969     0.005969       191.1
```



```
Step #     0             Xi = 0.0000

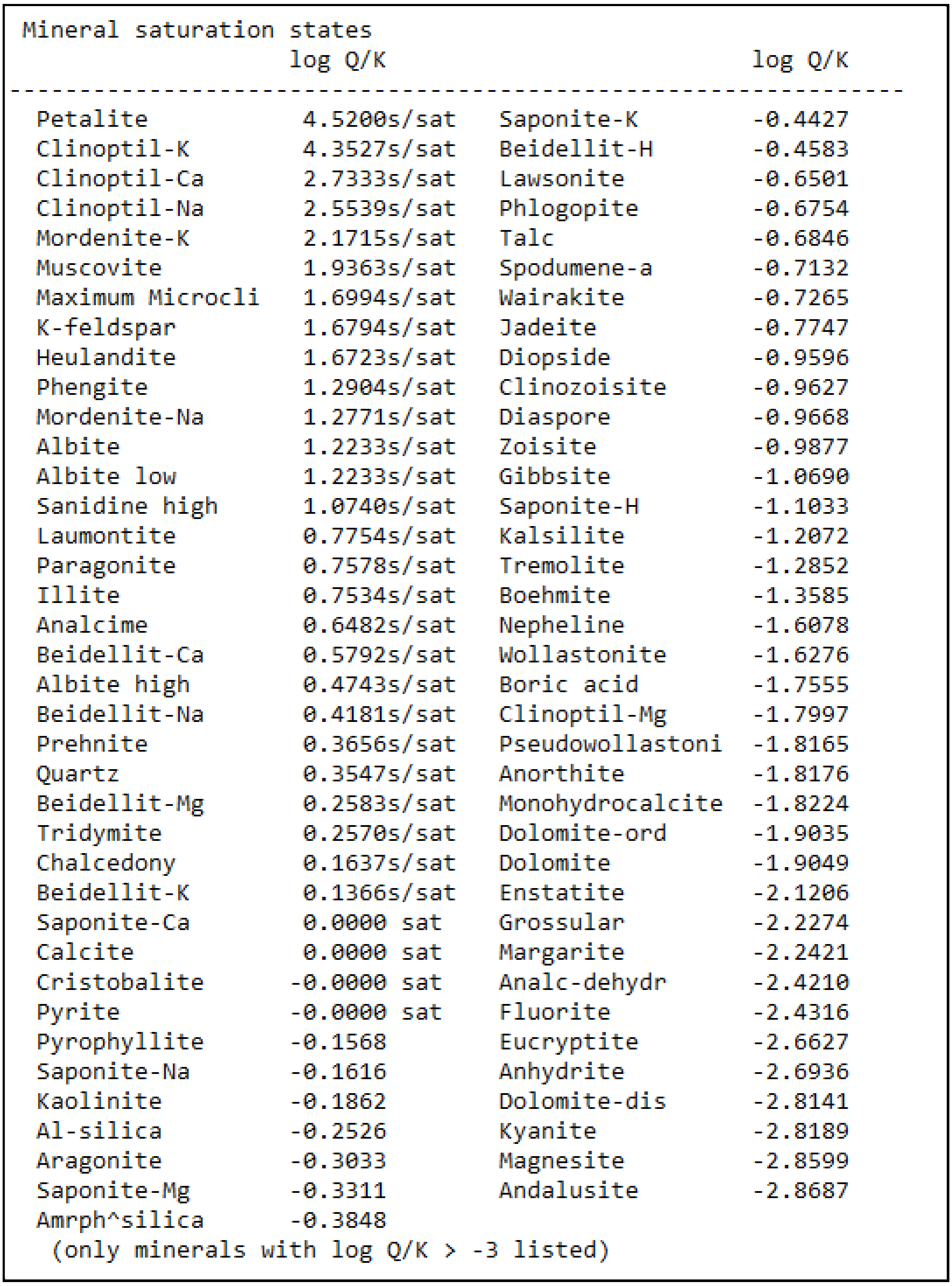
Temperature = 150.0 C    Pressure =  4.760 bars
pH =  7.670
Ionic strength      =    0.021962 molal
Charge imbalance    =    0.001825 eq/kg (4.248% error)
Activity of water   =    0.999639
Solvent mass        =      1.0000 kg
Solution mass       =      1.0017 kg
Mineral mass        =     0.00000 kg
Solution density    =    0.906    g/cm3
Solution viscosity  =    0.002    poise
Chlorinity          =    0.010488 molal
Dissolved solids    =        1674 mg/kg sol'n
Hardness            =        1.69 mg/kg sol'n as CaCO3
  carbonate         =        1.69 mg/kg sol'n as CaCO3
  non-carbonate     =        0.00 mg/kg sol'n as CaCO3
Carbonate alkalinity=      175.05 mg/kg sol'n as CaCO3
Water type          =    Na-Cl
Bulk volume         =    1.11e+03 cm3
Fluid volume        =    1.11e+03 cm3
Mineral volume      =       0.000 cm3
Inert volume        =       0.000 cm3
Porosity            =        100. %
Permeability        =        98.7 cm2
```



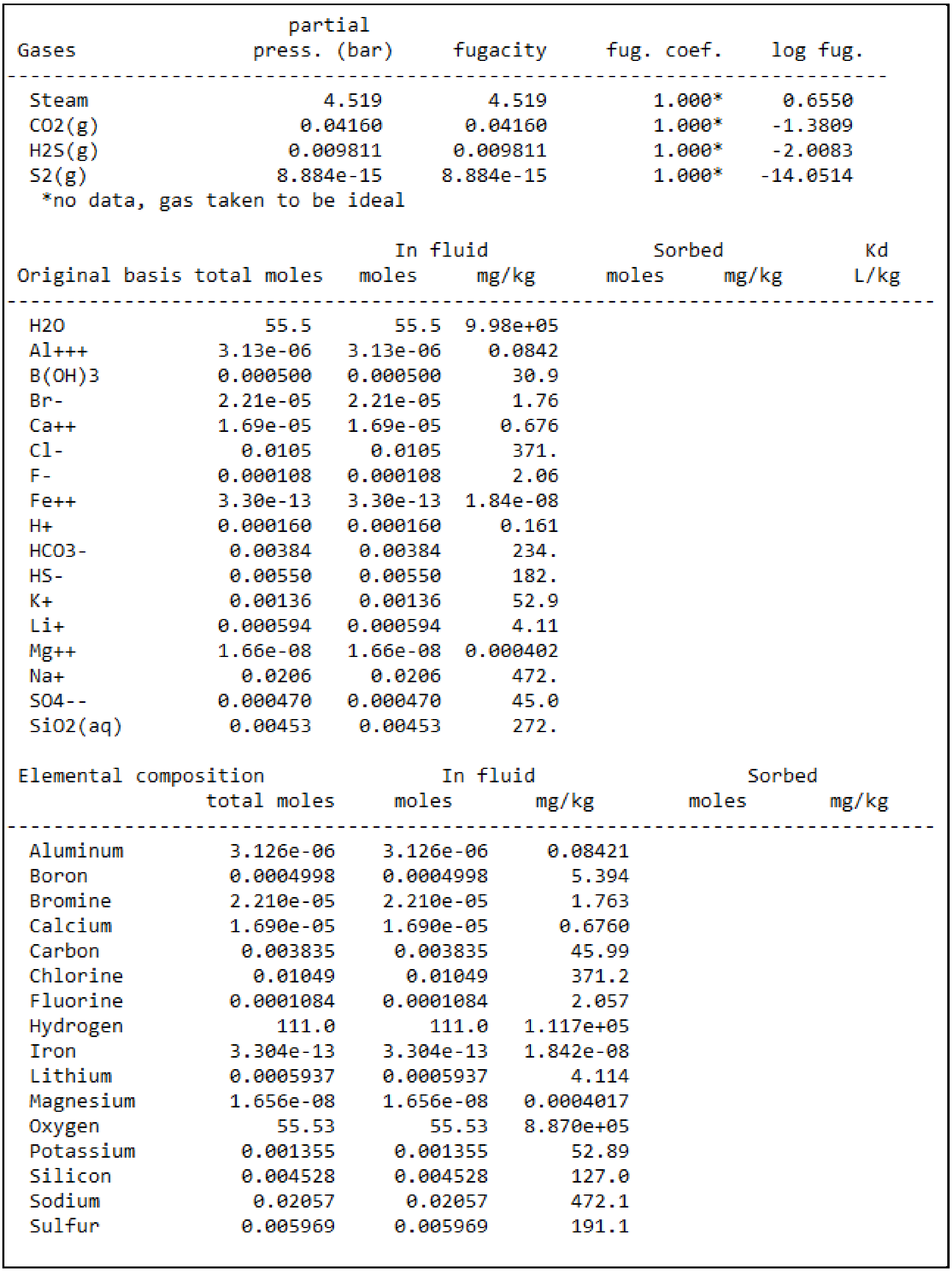
```
Nernst redox couples                                  Eh (volts)     pe
----------------------------------------------------------------------------
 8 e-  + 9 H+  + SO4--  = 4 H2O  + HS-                  -0.4243    -5.0536

No minerals in system.

Aqueous species       molality    mg/kg sol'n    act. coef.     log act.
---------------------------------------------------------------------------
 Na+                    0.02047        469.7       0.8251       -1.7724
 Cl-                    0.01045        370.0       0.8179       -2.0681
 HS-                   0.005217        172.2       0.8216       -2.3680
 SiO2(aq)              0.004318        259.0       1.0043       -2.3629
 HCO3-                 0.003477        211.8       0.8285       -2.5405
 K+                    0.001347        52.56       0.8179       -2.9581
 Li+                  0.0005933        4.111       0.8380       -3.3035
 SO4--                0.0004200        40.28       0.4602       -3.7138
 B(OH)3               0.0004158        25.67       1.0043       -3.3793
 CO2(aq)              0.0003399        14.93       1.0000       -3.4686
 H2S(aq)              0.0002829        9.625       1.0000       -3.5483
 H3SiO4-              0.0001909        18.13       0.8251       -3.8027
 OH-                  0.0001451        2.463       0.8216       -3.9238
 F-                   0.0001070        2.029       0.8216       -4.0560
 B(OH)4-              8.402e-05        6.613       0.8251       -4.1591
 NaSO4-               4.016e-05        4.773       0.8251       -4.4797
 NaCl                 3.346e-05        1.952       1.0000       -4.4755
 Br-                  2.210e-05        1.763       0.8179       -4.7429
 NaH3SiO4             1.931e-05        2.277       1.0000       -4.7141
 Ca++                 1.302e-05       0.5210       0.4896       -5.1955
 CO3--                8.845e-06       0.5299       0.4678       -5.3832
 NaHCO3               7.593e-06       0.6368       1.0000       -5.1196
 KSO4-                7.425e-06        1.002       0.8251       -5.2128
 Al(OH)4-             3.088e-06       0.2929       0.8251       -5.5938
 CaSO4                1.519e-06       0.2064       1.0000       -5.8186
 CaHCO3+              1.237e-06       0.1248       0.8331       -5.9870
 NaF                  1.232e-06      0.05164       1.0000       -5.9094
 NaOH                 1.152e-06      0.04601       1.0000       -5.9385
 KCl                  9.339e-07      0.06951       1.0000       -6.0297
 CaCO3                5.668e-07      0.05663       1.0000       -6.2466
 LiSO4-               3.359e-07      0.03454       0.8251       -6.5572
 CaCl+                2.505e-07      0.01889       0.8251       -6.6846
 H2SiO4--             1.669e-07      0.01568       0.4602       -7.1147
 CaF+                 1.569e-07     0.009252       0.8251       -6.8880
 CaOH+                1.453e-07     0.008283       0.8251       -6.9211
 HF                   5.489e-08     0.001096       1.0000       -7.2605
 Al(OH)3              3.811e-08     0.002967       1.0000       -7.4190
 HSO4-                3.486e-08     0.003378       0.8251       -7.5411
 H+                   2.501e-08    2.516e-05       0.8542       -7.6704
 S2--                 1.948e-08     0.001247       0.4602       -8.0476
 Mg++                 1.199e-08    0.0002909       0.5162       -8.2085
  (only species > 1e-8 molal listed)
```



```
Mineral saturation states
                   log Q/K                           log Q/K
-----------------------------------------------------------------
  Petalite           4.5200s/sat   Saponite-K         -0.4427
  Clinoptil-K        4.3527s/sat   Beidellit-H        -0.4583
  Clinoptil-Ca       2.7333s/sat   Lawsonite          -0.6501
  Clinoptil-Na       2.5539s/sat   Phlogopite         -0.6754
  Mordenite-K        2.1715s/sat   Talc               -0.6846
  Muscovite          1.9363s/sat   Spodumene-a        -0.7132
  Maximum Microcli   1.6994s/sat   Wairakite          -0.7265
  K-feldspar         1.6794s/sat   Jadeite            -0.7747
  Heulandite         1.6723s/sat   Diopside           -0.9596
  Phengite           1.2904s/sat   Clinozoisite       -0.9627
  Mordenite-Na       1.2771s/sat   Diaspore           -0.9668
  Albite             1.2233s/sat   Zoisite            -0.9877
  Albite low         1.2233s/sat   Gibbsite           -1.0690
  Sanidine high      1.0740s/sat   Saponite-H         -1.1033
  Laumontite         0.7754s/sat   Kalsilite          -1.2072
  Paragonite         0.7578s/sat   Tremolite          -1.2852
  Illite             0.7534s/sat   Boehmite           -1.3585
  Analcime           0.6482s/sat   Nepheline          -1.6078
  Beidellit-Ca       0.5792s/sat   Wollastonite       -1.6276
  Albite high        0.4743s/sat   Boric acid         -1.7555
  Beidellit-Na       0.4181s/sat   Clinoptil-Mg       -1.7997
  Prehnite           0.3656s/sat   Pseudowollastoni   -1.8165
  Quartz             0.3547s/sat   Anorthite          -1.8176
  Beidellit-Mg       0.2583s/sat   Monohydrocalcite   -1.8224
  Tridymite          0.2570s/sat   Dolomite-ord       -1.9035
  Chalcedony         0.1637s/sat   Dolomite           -1.9049
  Beidellit-K        0.1366s/sat   Enstatite          -2.1206
  Saponite-Ca        0.0000 sat    Grossular          -2.2274
  Calcite            0.0000 sat    Margarite          -2.2421
  Cristobalite      -0.0000 sat    Analc-dehydr       -2.4210
  Pyrite            -0.0000 sat    Fluorite           -2.4316
  Pyrophyllite      -0.1568        Eucryptite         -2.6627
  Saponite-Na       -0.1616        Anhydrite          -2.6936
  Kaolinite         -0.1862        Dolomite-dis       -2.8141
  Al-silica         -0.2526        Kyanite            -2.8189
  Aragonite         -0.3033        Magnesite          -2.8599
  Saponite-Mg       -0.3311        Andalusite         -2.8687
  Amrph^silica      -0.3848
   (only minerals with log Q/K > -3 listed)
```



```
                     partial
Gases              press. (bar)     fugacity     fug. coef.    log fug.
---------------------------------------------------------------------------
 Steam                   4.519        4.519         1.000*      0.6550
 CO2(g)                0.04160      0.04160         1.000*     -1.3809
 H2S(g)               0.009811     0.009811         1.000*     -2.0083
 S2(g)               8.884e-15    8.884e-15         1.000*    -14.0514
  *no data, gas taken to be ideal

                                 In fluid           Sorbed            Kd
Original basis total moles    moles      mg/kg     moles      mg/kg     L/kg
-------------------------------------------------------------------------------
 H2O                  55.5        55.5  9.98e+05
 Al+++            3.13e-06    3.13e-06    0.0842
 B(OH)3           0.000500    0.000500      30.9
 Br-              2.21e-05    2.21e-05      1.76
 Ca++             1.69e-05    1.69e-05     0.676
 Cl-                0.0105      0.0105      371.
 F-               0.000108    0.000108      2.06
 Fe++             3.30e-13    3.30e-13  1.84e-08
 H+               0.000160    0.000160     0.161
 HCO3-             0.00384     0.00384      234.
 HS-               0.00550     0.00550      182.
 K+                0.00136     0.00136      52.9
 Li+              0.000594    0.000594      4.11
 Mg++             1.66e-08    1.66e-08  0.000402
 Na+                0.0206      0.0206      472.
 SO4--            0.000470    0.000470      45.0
 SiO2(aq)          0.00453     0.00453      272.

Elemental composition                In fluid                 Sorbed
                total moles      moles         mg/kg        moles        mg/kg
-------------------------------------------------------------------------------
 Aluminum          3.126e-06    3.126e-06      0.08421
 Boron             0.0004998    0.0004998        5.394
 Bromine           2.210e-05    2.210e-05        1.763
 Calcium           1.690e-05    1.690e-05       0.6760
 Carbon             0.003835     0.003835        45.99
 Chlorine            0.01049      0.01049        371.2
 Fluorine          0.0001084    0.0001084        2.057
 Hydrogen              111.0        111.0    1.117e+05
 Iron              3.304e-13    3.304e-13    1.842e-08
 Lithium           0.0005937    0.0005937        4.114
 Magnesium         1.656e-08    1.656e-08    0.0004017
 Oxygen                55.53        55.53    8.870e+05
 Potassium          0.001355     0.001355        52.89
 Silicon            0.004528     0.004528        127.0
 Sodium              0.02057      0.02057        472.1
 Sulfur             0.005969     0.005969        191.1
```

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