# A HYDROGEOCHEMICAL ANALYSIS OF GEOTHERMAL RESOURCES IN THE STATE OF HAWAIʻI

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**Abstract**

Geothermal heat has played a role in Hawaiian history from times preceding European arrival, as evident by the various place names that speak of volcanic activity, hot waters, and sulfuric smells. In the 1970s, geothermal exploration began in the State of Hawaiʻi with the Hawaiʻi Geothermal Resource Assessment Program which identified twenty possible sites for potential geothermal heat. The development of a geothermal power plant, currently named Puna Geothermal Venture, has provided energy for Hawaiʻi Island residents since 1993.

In 2015, Hawaiʻi Governor David Ige signed HB623, targeting 100% renewable energy for the State of Hawaiʻi by 2045. Along with rising oil and electricity costs, Hawaiʻi residents are turning to renewable energy sources, such as solar, to reduce their carbon footprint and lower costs. In the same year, the University of Hawaiʻi at Mānoa received funding from the U.S. Department of Energy to conduct a Play Fairway Analysis of the state of geothermal potential for the islands. Phase I included the aggregation of all existing geologic, geophysical and geochemical data available. A probability model incorporating heat, fluid, and permeability was then created to assess the probability of viable geothermal development. Phase II is the focus of this paper, with new data collection as the goal for this funding period.

The Play Fairway Project collected new geochemical groundwater data from 60 wells and 1 spring across the State of Hawaiʻi. Geochemical geothermal indicators used previously in Hawaiʻi, and around the world, were investigated for the newly acquired data in Phase II. These indicators include groundwater temperature, chloride:magnesium ratios, sulfate:chloride ratios, and silica concentrations. All chemical analyses were collected by participants of the Play Fairway team and analyzed at various labs at the University of Hawaiʻi at Mānoa.

Of the ten target areas identified for Phase II, two of the sites provide encouraging groundwater geochemical results for potential geothermal resources. These sites include the Southwest Rift Zone of Haleakalā, Maui and the Pālāwai Basin, Lānaʻi. Multiple geothermal indicators have been observed in these areas, and therefore provide encouragement to further explore for subsurface heat. Further investigation is recommended in these target areas, through geological, geophysical and geochemical exploration.

The development of geothermal resources in either of these locations could provide residents and communities with dramatically lowered energy costs. This would provide more jobs for local residents, create electricity costs at less than half the current price, and allow for a cleaner future in line with the targeted renewable energy goal of 100% renewable by 2045.

# 1. Introduction

## 1.1 Hawaiian mythology

In Hawaiian mythology, tales of Pele, goddess of fire, speak of the evolution of volcanism across the Hawaiian Island chain. Until the 1840's, the Hawaiian language was exclusively an oral language. When missionaries arrived, they helped to create the written Hawaiian language, with the sole purpose of translating the bible for all to read. Before this time, however, all of the Hawaiian history was passed down through generations of Native Hawaiians, or *kanaka*, through oral history. Within the oral history are many accounts that can aid scientists by giving an account of volcanic activity with specific time frames, that can then be used to correlate to age dates and other scientific observations.

In 1823, Reverend William Ellis and other missionaries were the first westerners to visit the summit of Kīlauea (Ellis, 1825). The Native Hawaiian guide accompanying them spoke of the history of the volcano, including lava flows destroying parts of the island and explosive eruptions accompanied by earthquakes. The guide also spoke of the explosive eruption that killed Keōua's army as they were on their way to battle Kamehameha for control of the island. Swanson (2008) compared the oral history timeline with geologic information, and was able to correlate specific Hawaiian mythologies with geologic occurrences.

*Kanaka* were observant. Specific names were given to winds and rains based on the locations where they existed, and sometimes for how they interacted with the surrounding environment. In many of the place names around Hawaiʻi, the names speak of volcanic activity including sulfuric smells and steam vents. These features may no longer be active, however the name provides a glimpse into the past.

## 1.2 Ocean Island Hotspot

The Hawaiian Islands originate from hotspot, or mantle plume, volcanism. As the Pacific Plate moves, a chain of volcanic islands forms above the mantle plume, producing an island track trending in the Northwest direction consistent with plate movement. The oldest of the main Hawaiian Islands is Kauaʻi at around six million years old, and the youngest is Hawaiʻi Island, with Mauna Loa and Kīlauea still in the active shield building stages of growth. Results of recent research suggest that, as a deep plume of material rises toward the top of the mantle, decompressional melting produces magma that accumulates at the base of the crust and then moves through the crust resulting in the eruptions that form Hawaiʻi's volcanoes.

Volcanoes in the Hawaiian Islands typically experience four stages of life: pre-shield, shield-building, post-shield and rejuvenation volcanism. During this life cycle, active or residual heat from intrusive magma below calderas, rift zones, and vents may provide the heat needed for a geothermal resource to exist. Previous research has provided evidence that residual heat from late stage volcanism may contribute geothermal heat. For example, the island of Kauaʻi went through its shield stage of volcanism approximately five million years ago, but had the largest volume of rejuvenation phase lavas, and currently has warm water in wells that penetrate only to the shallow, groundwater aquifer (Thomas et al., 1979; Thomas, 1985a).

Hawaiian rocks can be grouped into three main types: tholeiitic, alkalic and nephelenic (MacDonald et al., 1983). The average chemical composition of these rocks is in Table 1. This chemistry informs the expected water-rock exchange interactions under the condition of geothermal heating. The average composition of water can also inform this exchange, and is found in Table 2.

**Table 1**. Average compositions of Hawaiian rocks in weight percent (wt. %), (adapted from MacDonald et al., 1983).

| | **Alkali Basalt** | **Hawaiite** | **Trachyte** | **Oceanite** | **Tholeiitic Basalt** |
|---|---|---|---|---|---|
| **$SiO_2$** | 46.5 | 48.6 | 61.7 | 46.4 | 49.4 |
| **$TiO_2$** | 3.0 | 3.2 | 0.5 | 2.0 | 2.5 |
| **$Al_2O_3$** | 14.6 | 16.5 | 18.0 | 8.5 | 13.9 |
| **$Fe_2O_3$** | 3.3 | 4.2 | 3.3 | 2.5 | 3.0 |
| **FeO** | 9.1 | 7.4 | 1.5 | 9.8 | 8.5 |
| **MnO** | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| **MgO** | 8.2 | 4.7 | 0.4 | 20.8 | 8.4 |
| **CaO** | 10.3 | 7.8 | 1.2 | 7.4 | 10.3 |
| **$Na_2O$** | 2.9 | 4.4 | 7.4 | 1.6 | 2.1 |
| **$K_2O$** | 0.8 | 1.6 | 4.2 | 0.3 | 0.4 |
| **$P_2O_5$** | 0.4 | 0.7 | 0.2 | 0.2 | 0.3 |

**Table 2**. Average compositions of water in Hawaii in milligrams per liter (mg/L) (Waller, 2015).

| | **Sea water** | **Fresh groundwater** | **Geothermal production fluids** | **Rain water** |
|---|---|---|---|---|
| **$SiO_2$** | 4 | 45 | 561 | 0 |
| **Na** | 10,760 | 27 | 4,420 | 4.5 |
| **K** | 399 | 3 | 910 | 0.4 |
| **Ca** | 412 | 10 | 177 | 0.8 |
| **$SO_4$** | 2,712 | 13 | 15.4 | 1.8 |
| **Mg** | 1,292 | 31 | 0.2 | 1.1 |
| **Cl** | 19,353 | 34 | 7,920 | 7.9 |

1.3 Hawai‘i’s Energy Goals

In 2015 Hawai‘i Governor David Ige signed House Bill 623 as part of the Hawai‘i Clean Energy Initiative, targeting 100% renewable energy for Hawai‘i by 2045. Residents in the State of Hawai‘i paid about $0.30/kWh in 2015, more than double the national average (DBEDT, 2017). According to the Hawai‘i State Energy Office, only 2.3% of Hawai‘i’s electricity was produced by geothermal resources in 2015, whereas about 70% was produced by petroleum and only 0.5% from solar (DBEDT, 2017). In that same year, the Hawai‘i State Energy Office recorded the overall renewable energy contribution for the State to be about 25%, and the Island of Hawai‘i at about 50%, with a large contribution being from geothermal (Figure 1).

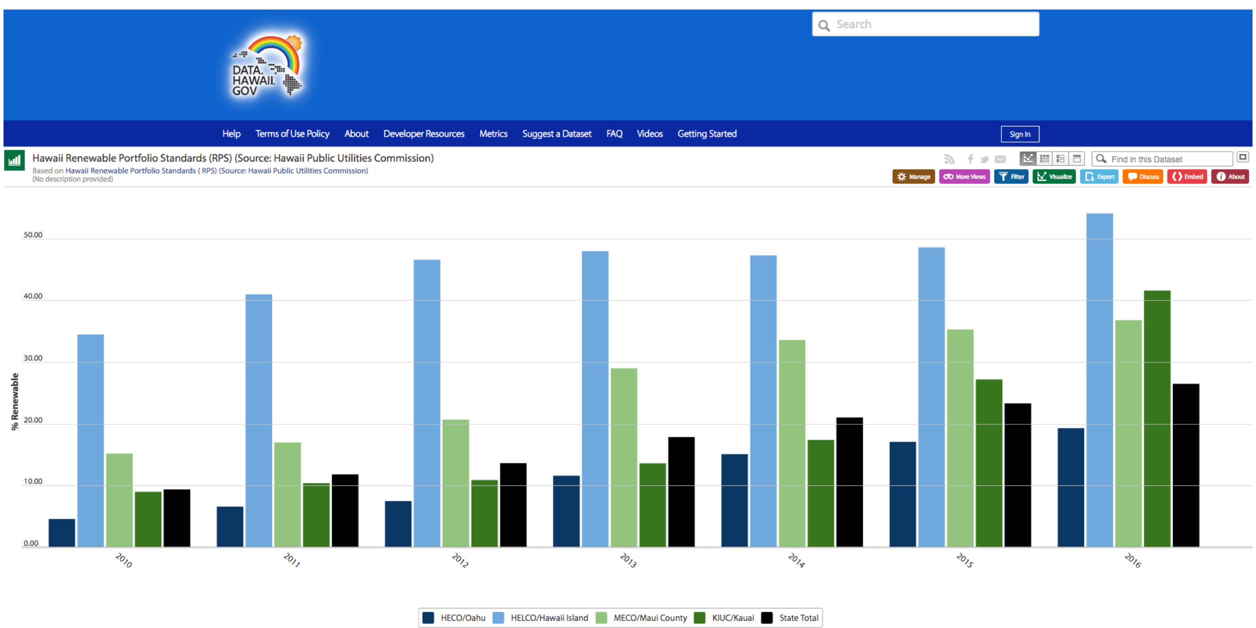


**Figure 1**. The amount of renewable energy (% Renewable) utilized by individual county public utilities, and overall state percentage, for years 2010-2016 (Hawai‘i State Energy Office).

In order to reach the 100% renewable energy goal, Hawai‘i will need to consider options for base load, renewable energy sources. Base load energy is a resource that can reliably meet the minimum demand for power consumption over an extended period of time. Currently, the discussion in Hawai‘i is focused on renewable energy sources such as solar and wind power, however these are not baseload renewable energy sources as they can fluctuate with the weather and seasons. Therefore, the results of the Play Fairway Project at the University of Hawai‘i at Mānoa can inform future renewable energy plans for the State of Hawai‘i.

## 2. Background

### 2.1 Previous Geothermal Work in Hawai‘i

The Hawai‘i Geothermal Project began in 1972 at the University of Hawai‘i at Mānoa, funded by the National Science Foundation. This project focused on the identification of magmatic heat, as well as the engineering aspects of extracting usable energy from a geothermal resource (Thomas, 1990). Drilling of the HGP-A well began in December 1975, and the well was completed to a depth of 1966 m. After performing multiple preliminary tests on the well, a 3 MWe wellhead generator was installed and began to generate power in 1981, with commercial sale of electrical power beginning in March 1982 (Thomas, 1990). The HGP-A well demonstrated that temperatures present in the Kīlauea East Rift Zone were comparable to geothermal systems around the world. For a comprehensive list of geothermal wells drilled in Hawai‘i, see Appendix 7.1.

The Hawai‘i Geothermal Resources Assessment Program was initiated in 1978 under the Western States Cooperative Direct Heat Resources Assessment Program (Thomas, 1985b). That assessment identified twenty sites throughout the State of Hawai‘i that had the potential for geothermal development through the compilation of existing geological, geochemical and geophysical data (Figure 2), however only fifteen of these sites were explored. Probabilities of geothermal resources existing in the fifteen sites ranged from 100% for areas of recent volcanism to less than 5% for unconfirmed reports of warm water wells or old groundwater chemistry data (Thomas, 1985b).

Puna Geothermal Venture (PGV) is a geothermal power plant on the Island of Hawai‘i operated by Ormat Technologies, Inc. Conceptually formed in 1980, Puna Geothermal Venture has passed through multiple owners, such as Thermal Power Company and Diamond Shamrock

(Richard, 1990). In 1988, Ormat Energy Systems, Inc. purchased 100% of interests related to PGV. In 1993, the plant began commercial operations. The facility currently occupies about 25 acres of land within a 500-acre area, producing 38 MW.

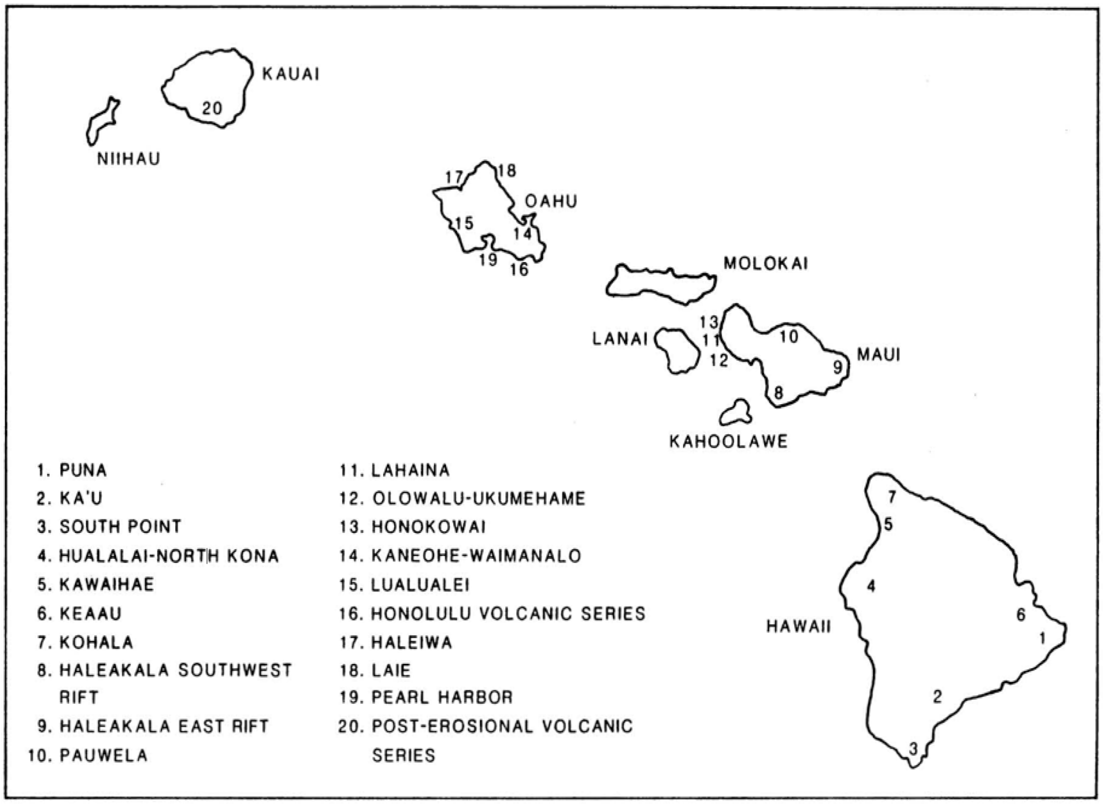


**Figure 2**. The preliminary twenty sites of potential geothermal development identified by the Hawaiʻi Geothermal Resource Assessment Program (Thomas, 1985).

In 2013 an Army-funded project in the Humuʻula Saddle region, between the Hawaiʻi Island volcanoes Mauna Kea and Mauna Loa, discovered elevated groundwater temperature (Thomas et al., 2014). At a depth of about 1.7 kilometers below ground surface, groundwater temperatures was ~140°C, and the temperature gradient from 1 to 1.7 km was 165°C/km. These findings of subsurface heat in an area outside of any known rift zone or caldera demonstrate that our understanding of geothermal resources in the State of Hawaiʻi is incomplete.

Three decades after the 1985 geothermal assessment, the Play Fairway Analysis project at the University of Hawaiʻi at Mānoa was funded by the United States Department of Energy

(Lautze et al., 2017a). Play Fairway Analysis (PFA) refers to a method of integrating individually weighted datasets that indicate the potential for subsurface resources (a Play) in a specific geographic region (a Fairway; Lautze et al., 2017b). A statewide map of the probability of a subsurface was created, addressing three critical parameters and four development viability factors for geothermal development.

During Phase I, the Hawai‘i team compiled all available geologic, groundwater geochemical, and geophysical data relevant to prospective geothermal resources and developed a systematic statistical approach to integrate these data into resource probability. Although the method developed was applied to an assessment of the probability for a geothermal resource in Hawai‘i, it was designed to be easily adaptable to other types of resources and geographic locations (Ito et al., 2017). The resource probability model takes into account three major parameters deemed necessary for geothermal development by the Department of Energy: subsurface heat, the presence of fluids that can transport that heat to the surface and sufficient permeability to allow efficient extraction of the heat (Figure 3). These three parameters are characterized by the compilation of geological, geophysical and geochemical (here noted as “groundwater”) data. The numbers in parentheses correspond to the ranking of each type of data set on a relative scale from 1 to 10, in which scientists who are experts in their respective fields, gave input on the rankings through a process of ‘expert elicitation’ (Lautze et al., 2017a).

After analyzing the resource probability, a development viability assessment was conducted. There were four factors considered: i) ease of access to the existing grid; ii) vulnerability to natural hazards; iii) current and prospective land use; and iv) the surrounding community perception and acceptance of geothermal power production (Lautze et al., 2017b). These factors constrain target areas for new data acquisition even further. Limited access to areas of high probability due to land use such as protected conservation areas or national park lands, as well as community perception of geothermal development, narrowed the potential target areas. It is not surprising that areas of highest probability occur in areas where magma is known to have been present: rift zones and calderas.

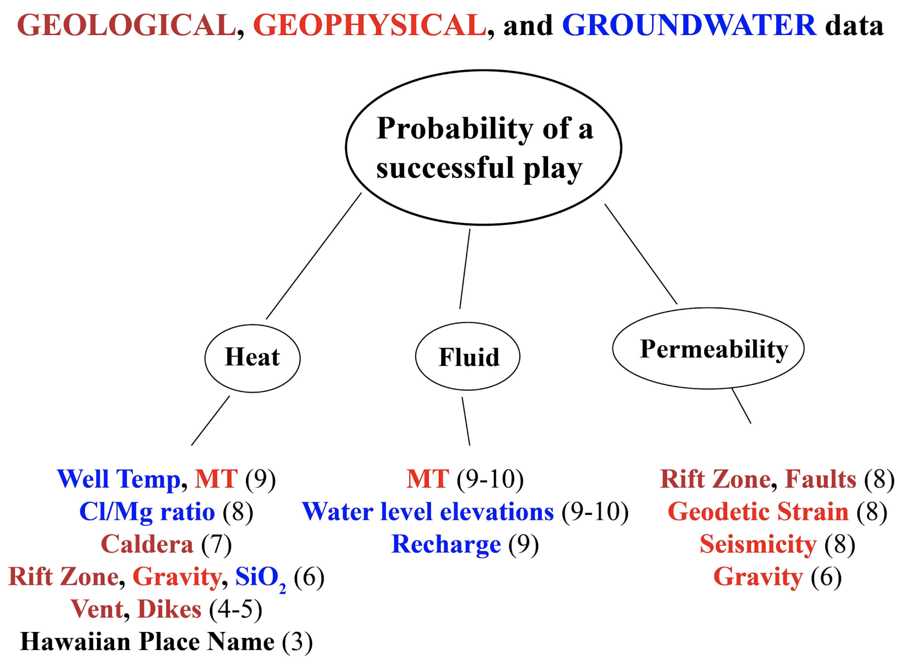


**Figure 3**. Resource probability model designed by the University of Hawaiʻi at Mānoa Play Fairway Project team. The resource probability model takes into account three main parameters: heat, fluid, and permeability, by incorporating geological, geophysical and geochemical data.

The resource probability model combined with the development viability assessment was used to determine study sites for new data acquisition in Phase II, which resulted in the identification of 10 target areas for further study (Figure 4). These include three targets on Hawaiʻi Island - A) North Hawaiʻi Island, B) Saddle Region and C) South Hawaiʻi Island; three targets on Maui - D) Hana, E) Southwest Rift Zone and F) Northwest Rift Zone; one target on Lānaʻi - G) Lānaʻi; two targets on Oʻahu - H) Koʻolau Mountains and I) Waiʻanae Mountains; and one target on Kauaʻi - J) Southeast Kauaʻi.

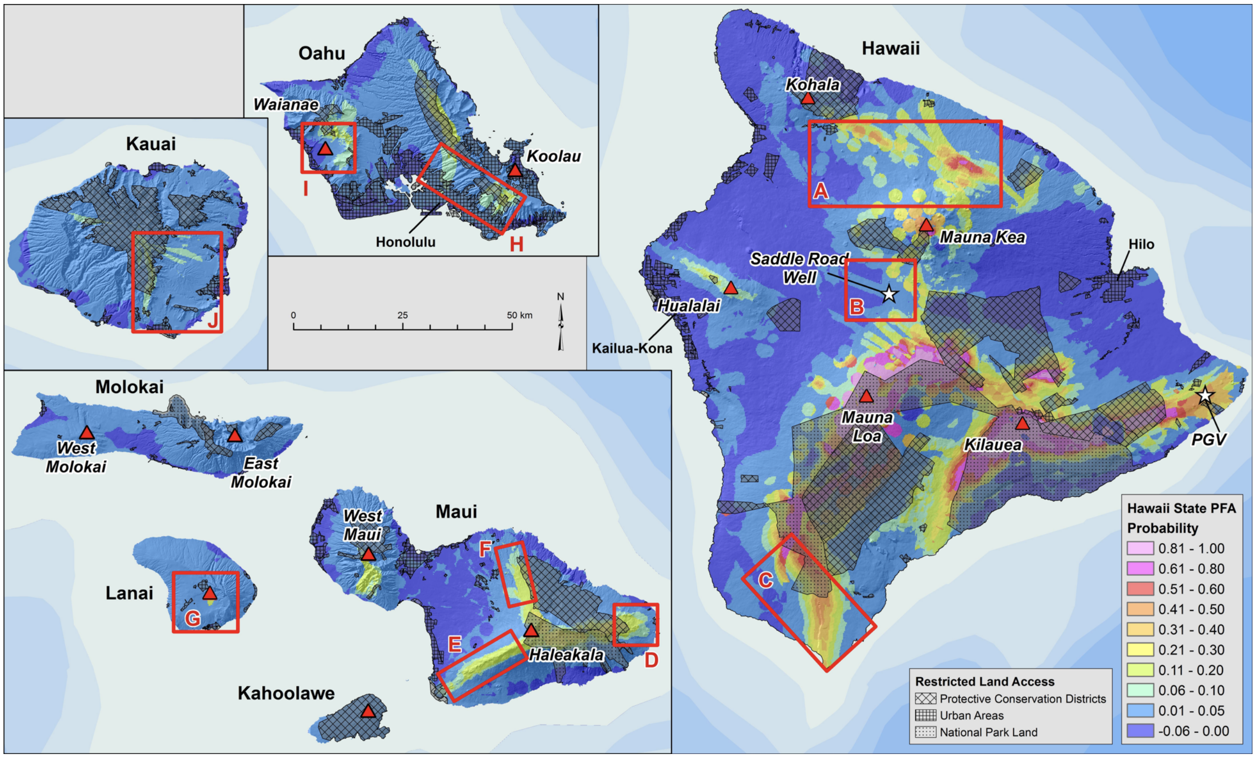


**Figure 4**. Probability map produced by the resource probability model. Ten target locations were chosen across five of the major Hawaiian Islands: A) North Hawai‘i Island, B) Saddle Region, C) South Hawai‘i Island, D) Hana, Maui, E) Southwest Rift Zone, F) Northwest Rift Zone, G) Lāna‘i, H) Ko‘olau Mountain, I) Wai‘anae Mountain, J) Southeast Kaua‘i (Lautze et al., 2017b).

## 2.2 Hawai‘i Play Fairway Project, Phase II

Based on the probability model, every island in the Hawaiian island chain had some evidence of geothermal potential, similar to the map produced from the last geothermal assessment in 1985. One of the methods applied to verify the resource potential was to conduct a more current and detailed analysis of groundwater chemistry in the identified prospect areas. For this work, we reviewed the Department of Land and Natural Resources Commission on Water Resources Management database to find groundwater wells in the red box target locations, with a goal of 100 well samples total. Overall, we were able to collect samples from 60 groundwater wells and 1 freshwater spring across the State of Hawai‘i, providing fair coverage of the target locations (Figure 5).

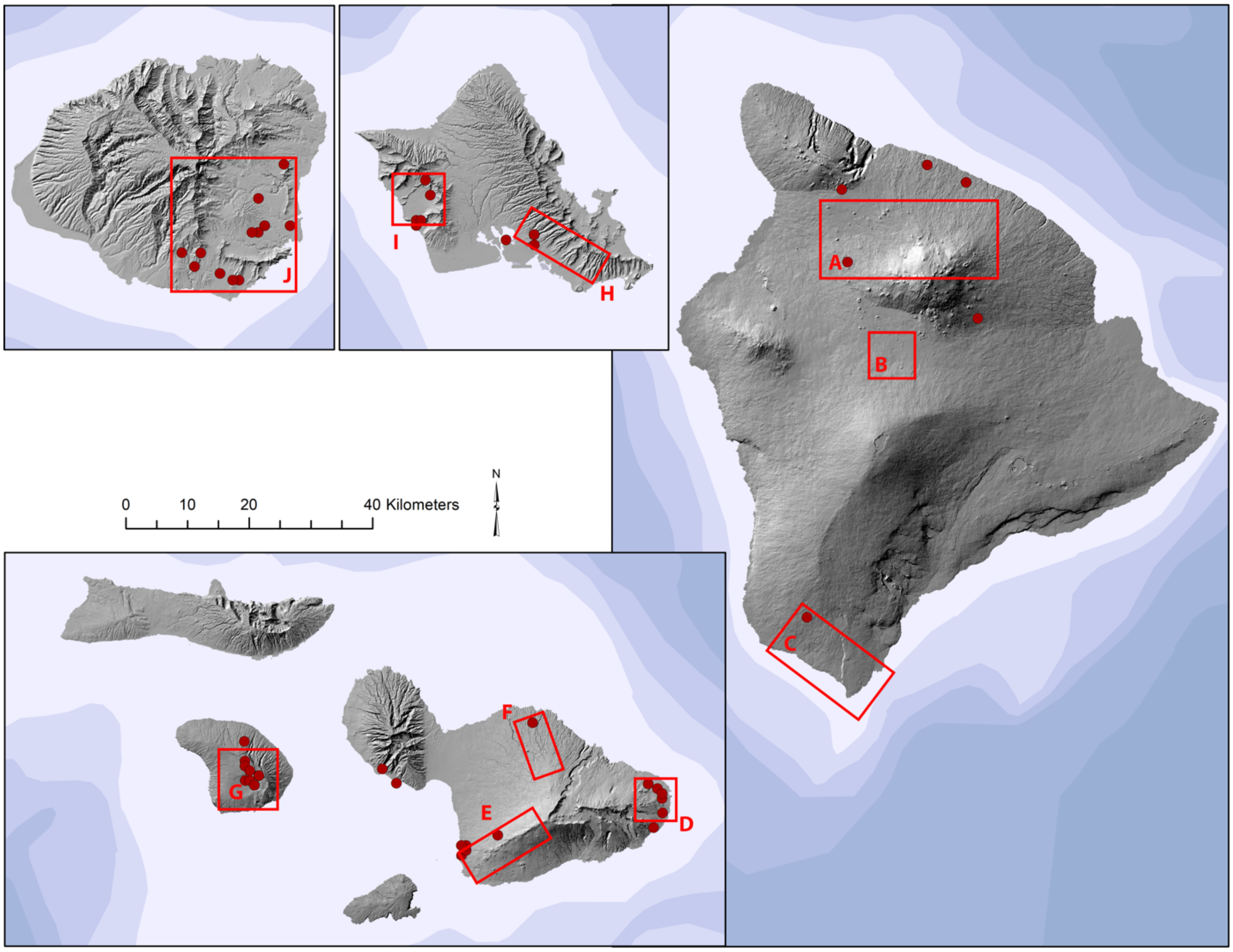

**Figure 5**. Ten target sites identified by the probability map shown in red boxes, with the 61 sample sites where new data was collected for Phase II.

## 2.3 Geothermal Indicators

Chemical species in geothermal fluids can be divided into two groups: tracers or geoindicators. Tracers are chemically inert and non-reactive, leaving them unchanged as they are transported by water through the hydrologic system (i.e., chloride). Geoindicators are chemically reactive, and respond to a changing thermal environment (i.e., magnesium). A chemical exchange occurs between water and rocks, and is accelerated under unique conditions such as geothermal heating.

As groundwater passes through a geothermal reservoir, some of the dissolved chemical constituents will react with minerals present in the rock matrix, and come to a new equilibrium value consistent with the temperature of the thermal reservoir. An abundance of ions due to dissolution, or a depletion of ions due to secondary mineral formation, can be key indicators for geothermal heat present in the subsurface. Analyzing groundwater geochemistry is a relatively simple, inexpensive first step in a geothermal assessment as a pre-drilling technique to extract information unobtainable by geologic or geophysical methods.

Known geothermal indicators used to explore areas for geothermal resources include temperature, chloride vs. magnesium ratios, sulfate vs. chloride ratios, and silica abundance. A single chemical indicator cannot be used alone, as there are many factors to consider (land use, contamination, etc.) when analyzing water chemistry for geothermal exploration. Therefore, we use multiple indicators in conjunction to gain higher confidence in the resource (Giggenbach, 1991).

### 2.3.1 Temperature

Temperature of groundwater is used as an indicator of subsurface heat around the world. Because thermal fluids are buoyant, groundwater circulating through a geothermal reservoir often finds a permeable zone through which the fluids can rise to the surface; where the groundwater table is near the ground surface, hot springs, geysers, and fumaroles can form at the discharge point. Where water tables are deeper, such as Hawaii, thermal fluids are deposited in the shallow groundwater and can be identified by anomalously warm groundwater. Deep geothermal wells in Hawaiʻi have experienced temperatures in excess of 300 °C, with bottom hole temperatures exceeding 350 °C (Thomas 1990).

Temperature measurements are made in wells, after water has been purged from the groundwater well for about fifteen minutes. This ensures that we are sampling water from depth, as opposed to the surface where groundwater temperatures can be influenced by surface air temperatures. Groundwater temperatures can gain heat from four possible sources: (i) volcanic activity; (ii) frictional flow; (iii) return irrigation water and relatively limited recharge from rain in irrigated areas; (iv) terrestrial heat flow (Mink, 1964). In Hawaiʻi, high level groundwater ranges from 18° to 21°C, basal groundwater from 20° to 24°C, and sedimentary groundwater from 22° to 26°C. Anomalous temperatures exceeding 27°C do not necessarily indicate significant geothermal sources, as variations of 2° to 3°C are common (Cox and Thomas, 1979).

2.3.2 Chloride:Magnesium Ratios

In Hawaiʻi, chloride in groundwater is almost entirely marine in origin (Cox and Thomas, 1979). Sea salts in precipitation and salt water intrusion provide chloride to groundwater aquifers, with other sources of chloride considered to be negligible. Chloride is not affected by chemical reactions with other ions or anionic exchanges, and the chloride content of seawater is unaffected by temperatures of up to 350°C (cite Schofield, 1956; Mink, 1961; Swain, 1973; Bischoff and Seyfried, 1978).

Magnesium is a chemical constituent in Hawaiian rocks with relatively high abundance. Magnesium abundance can be altered by the formation of various secondary minerals at varying equilibrium temperatures. The formation of chlorite [$Mg_3(Si_4O_{10})(OH)_2Mg_3(OH)_6$] occurs under extremely high temperature, smectite clays under intermediate temperature, and illite [$(AlMgFe)_4(SiAl)_8O_{20}(OH)_4$] at lower temperatures. The formation of these minerals removes magnesium from the groundwater (Cox and Thomas, 1979). Precipitation of magnesium oxysulfates and hydroxylated magnesium silicates is also possible when high temperature reactions occur between basalt and seawater (Bischoff and Seyfried, 1978; Mackenzie et al., 1967). Low temperature exchange of magnesium between intruding seawater and the basal aquifer are complicated, and are described in detail in previous research (Cox and Thomas, 1979). The depletion of magnesium is reflected after the geothermally heated waters have cooled through conductive heat loss or mixing with cooler waters, and therefore allows us to continue to use chloride:magnesium ratios as a geothermal indicator of conditions in the deeper subsurface (Cox and Thomas, 1979).

The chloride to magnesium ratio in groundwater was used as a geothermal indicator in previous research (Cox & Thomas, 1979). The chloride to magnesium ratio in rainfall is approximately 7, 2 to 3 in fresh groundwater as water picks up magnesium from the rock, and 2 to 6 in saltwater stored in island aquifers as saltwater intrusion creates a cation exchange between the intruding seawater and calcareous marine sediments (Cox & Thomas, 1979). The high temperature magnesium reactions of clay formation remove magnesium from the groundwater thus increasing the chloride:magnesium ratio. A ratio greater than 15 is considered anomalous. For a comparison of ratios of other water sources, see Table 3.

### 2.3.3 Sulfate:Chloride Ratios

As mentioned above, chloride found in groundwater is almost entirely marine in origin. Sulfate is also highly abundant as a salt in seawater, as shown in Table 2. Sulfate is depleted in waters due to the formation of gypsum at increasing temperatures, with precipitation beginning around 150°C (Libes, 2009). Gypsum has a retrograde solubility, meaning solubility decreases as water temperature increases. Seawater and brackish water can circulate sea salts such as sulfate into a geothermal system via saltwater intrusion, and the decreasing solubility of gypsum causes nearly complete depletion of sulfate (Libes, 2009).

At higher temperatures, around 340℃ to 465℃, iron minerals may chemically reduce the sulfate ion to hydrogen sulfide, further removing the sulfate through the following reaction:

$$Mg_{1.5}Fe_{0.5}Si_2O_6 + 0.083H^+ + 0.0416SO_4^{2-} + 0.5H_2O \rightarrow Mg_{1.5}Si_2O_5OH + 0.167Fe_3O_4 + 0.0416H_2S$$

(Libes, 2009). The sulfate:chloride ratio of seawater is 0.14, and the sulfate:chloride ratio of geothermal production fluids is around 0.002. Using groundwater chemistry data from a USGS Scientific Report which focused on the Puna Geothermal Venture power plant (Evans et al., 2015), sulfate:chloride ratios between 0.002 and 0.03 are found for the sites where $H_2S$ was measured. Therefore, we use values less than 0.05 as a geothermal indicator threshold. For a comparison of ratios of other water sources, see Table 3.

2.3.4 Silica

Silica is the most abundant chemical species in Hawaiian rocks, and is a dissolved constituent of groundwater that originates in basalt. It has been used around the world as an indicator of subsurface heat (Mahon, 1966; Fournier and Rowe, 1966; Ellis, 1970; Fournier and Truesdell, 1970; McMurtry et al. 1977). In Hawaii, previous research has shown that rainwater has a silica concentration of 1 to 3 ppm as it interacts with the ground surface, 15 to 45 ppm as it moves through the groundwater aquifer, and 30 to 60 ppm as it resides in high level aquifers (Davis, 1969). Recirculation by irrigation and reinjection of industrial waters can cause values up to 50 to 85 ppm, which must be considered when using silica as an indicator of heat.

Silica is continuously dissolved from the rock matrix as it is saturated by the groundwater aquifer. Windward sides of the islands remove silica more rapidly as the rainfall recharge weathers rocks more rapidly than the leeward sides (Cox and Thomas, 1979). Agricultural phosphates also increase dissolution of silica (Fox et al., 1967). Silica abundance in groundwater can be affected by many factors, making it essential to use care in the interpretation of silica concentrations insofar as their ability to indicate geothermal potential in Hawai‘i. For the purposes of this paper, we use a concentration of 85 ppm as a starting value for indication of subsurface heat. For a comparison of silica concentrations of water sources, see Table 3.

**Table 3**. Geothermal indicator ratios for average water compositions from Table 2 (adapted from Waller, 2015).

| | **Sea water (mg/L)** | **Fresh groundwater (mg/L)** | **Geothermal production fluids (mg/L)** | **Rainwater (mg/L)** |
|---|---|---|---|---|
| **Mg** | 1,292 | 31 | 0.189 | 1.1 |
| **Cl** | 19,353 | 34 | 7,920 | 7.9 |
| **$SO_4$** | 2,712 | 13 | 15.4 | 1.8 |
| **Cl:Mg** | 14.98 | 1.097 | 41,904.76 | 7.18 |
| **$SO_4$:Cl** | 0.14 | 0.38 | 0.0019 | 0.23 |
| **$SiO_2$** | 4 | 45 | 561 | 0 |

## 3. Methods and Results

### 3.1 Methods

#### 3.1.1 Field Parameters

Groundwater samples were collected from 61 wells and freshwater springs across the State of Hawai‘i in the target areas for Phase II. Water quality parameters, including temperature, pH, specific conductivity and dissolved oxygen, were collected in the field using a YSI Multi-Parameter Sonde. Samples were collected from pumping wells when available, and sampled before the chlorination point at drinking supply wells. Groundwater samples were filtered through an Enviro-Tech High Capacity 0.45 μm filter. Samples were stored in a refrigerator until sample analyses were conducted at various laboratories on the University of Hawai‘i at Mānoa campus.

#### 3.1.2 Sample Analyses

All samples were chemically analyzed on the University of Hawai‘i at Mānoa campus. The four sets of analytes sampled include stable isotopes (oxygen, hydrogen, carbon), major ions, trace metals and fluorescence microscopy. An extensive suite of analytes were sampled in order to obtain as much information about Hawai‘i’s groundwater aquifers as possible. Not all analytes were used to identify potential geothermal resources.

Oxygen and hydrogen isotopes were analyzed at the Biogeochemical Stable Isotope Facility at the University of Hawai‘i at Mānoa. A Picarro L1102-i WS-CRDS is used to analyze water samples for hydrogen and oxygen isotopes, following similar methods as Godoy et al. (Godoy et al., 2012). Major ions were analyzed by the Water Resources Research Center Chemistry Laboratory. A dual Dionex ICS-1100 Ion Chromatograph was used to analyze water samples, following the US EPA Method 300.1 for determining inorganic ions in drinking water by ion chromatography (Hautman and Munch, 1997).

Trace metals were analyzed by the Inductively Coupled Plasma Facility. Following US EPA Method 200.7 for determining metals and trace elements, the lab uses a Varian Vista MPX inductively coupled plasma optical emission spectrometer (Martin et al., 1994). These chemical analyses were not used as geothermal indicators; however trace metals are valuable informants of other chemical environments in the groundwater aquifers. For example, mercury or arsenic can be used as indicators of groundwater contamination and inform groundwater flow paths, which was a goal of the Play Fairway project.

Fluorescence microscopy was analyzed by the C-MORE Fluorescence Laboratory. Fluorescence microscopy is a tool used to identify microbes, as they ca indicate the presence of some chemicals in groundwater. The fluorescence data was not intended for use as a geothermal indicator.

## 3.2 Results

For a full list of groundwater field data collected during Play Fairway Phase II, see Appendix 7.2. For a full list of groundwater geochemistry data collected, see Appendices 7.3 through 7.7. For a full list of the compiled legacy groundwater data aggregated during Play Fairway Phase I, see Waller (2015) Appendix IV – Master Database. The results discussed further in this paper are reflective of data collected during Play Fairway Phase II, and utilize data from Play Fairway Phase I to fill in data gaps.

### 3.2.1 Temperature

Temperature measurements are shown in Figure 6. The temperature values here are the measurements at ground surface, after water has been pumped up. No corrections have been applied to account for surface air temperatures. Temperatures range from below 21℃ to almost 30℃, with large variations within each island and within target areas.

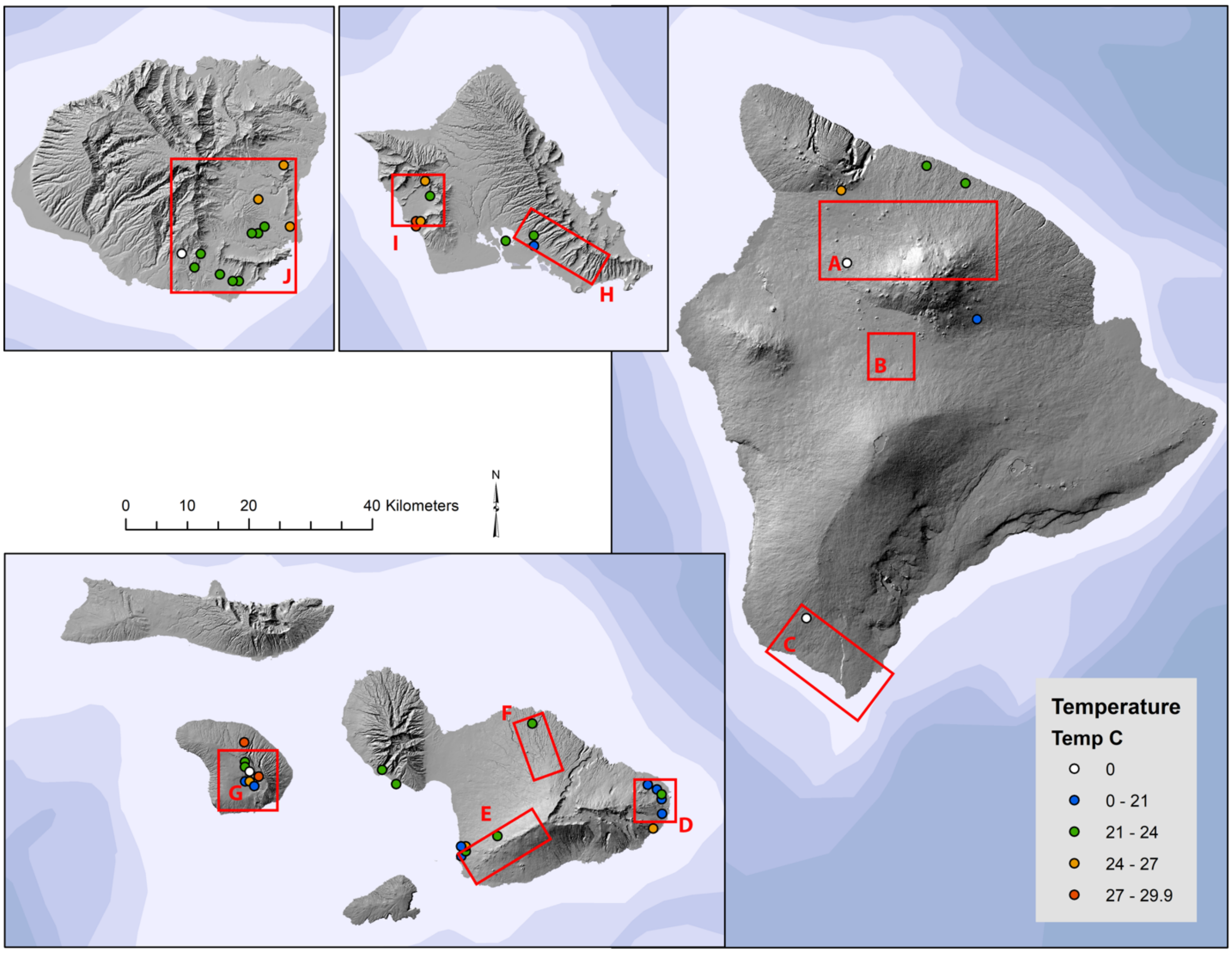


**Figure 6**. Temperature distribution of groundwater sampled during Play Fairway Analysis Phase II.

### 3.2.2 Chloride:Magnesium Ratios

Chloride:magnesium ratios are shown spatially in Figure 7. A chloride vs. magnesium plot is shown in Figure 8, with ratio lines plotted to show distribution of Play Fairway samples and islands separated by colors. Geothermal wells that have been previously sampled have been included for reference. Chloride:magnesium ratio values range from less than five to greater than fifteen, and are widely distributed across all islands and within target areas. Play Fairway II samples that plot above an anomalous ratio value of 15 are found on the islands of Lānaʻi and Maui.

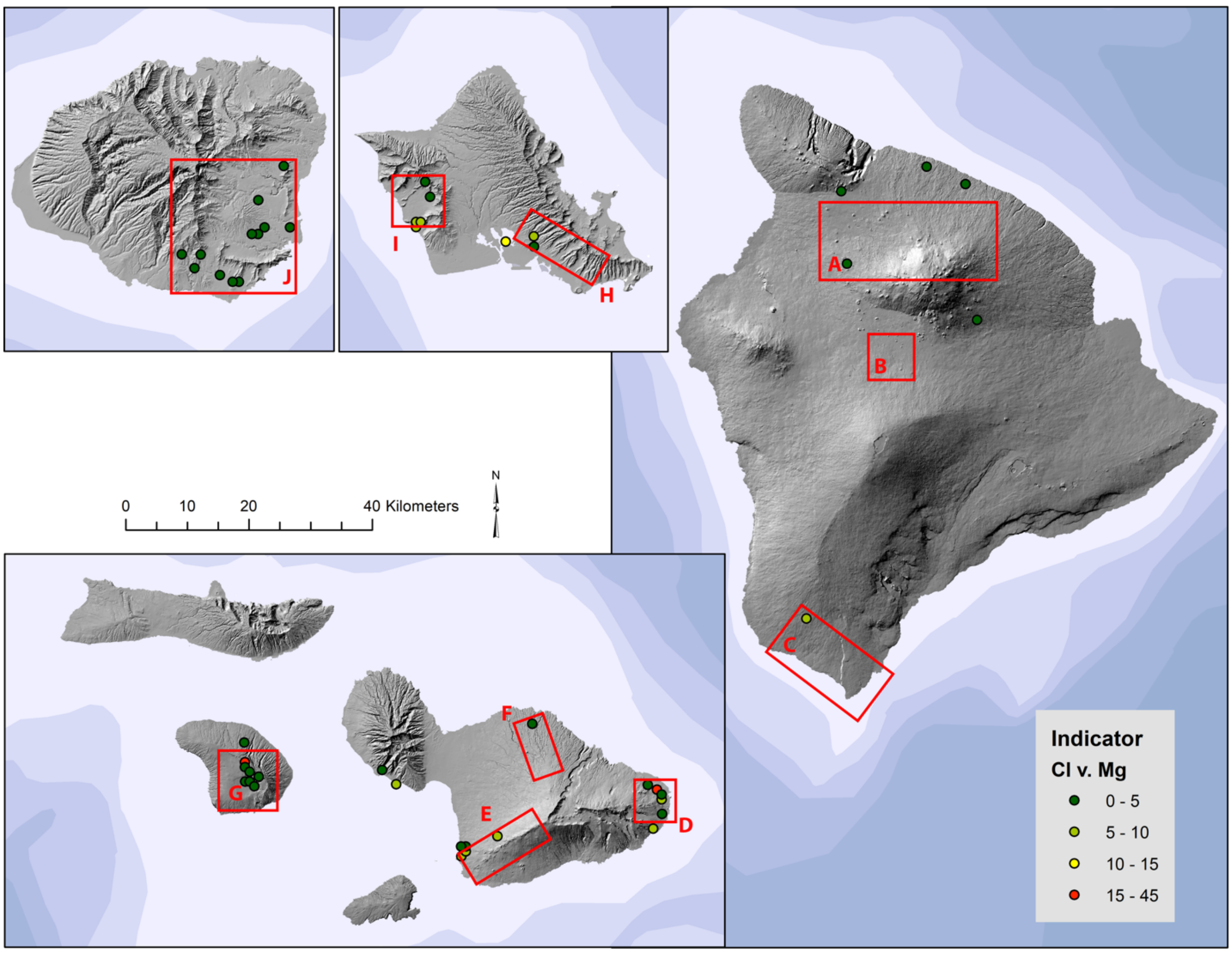


**Figure 7**. Chloride:magnesium ratio distribution of groundwater sampled during Play Fairway Analysis Phase II.

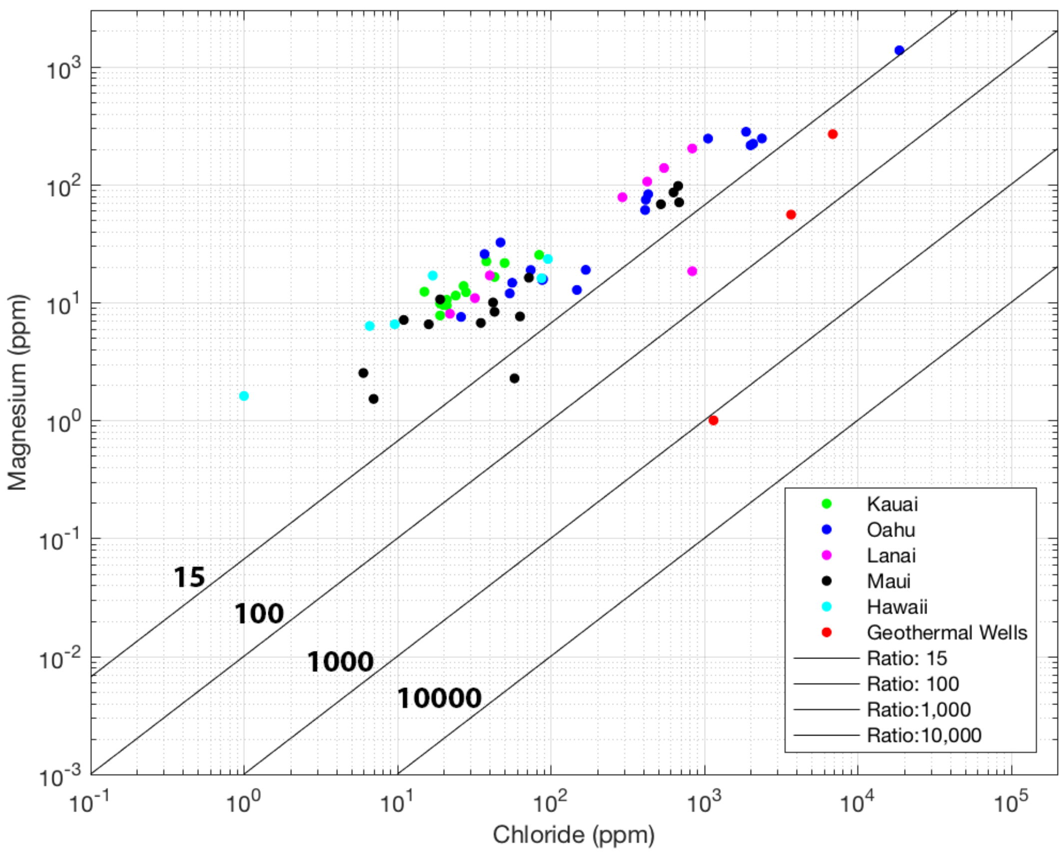


**FIGURE 8**. Chloride:magnesium ratios, plotted by island with geothermal wells and ratio lines for reference.

### 3.3.3 Sulfate:Chloride Ratios

The distribution of sulfate:chloride is shown in Figure 9. Values less than 0.1, representing the sulfate:chloride seawater ratio of 0.14, are plotted in red. Values between 0.1 and 0.4 are plotted in orange, and values greater than 0.4 are plotted in various shades of green. Anomalous values occur on the islands of O‘ahu, Maui and Lāna‘i.

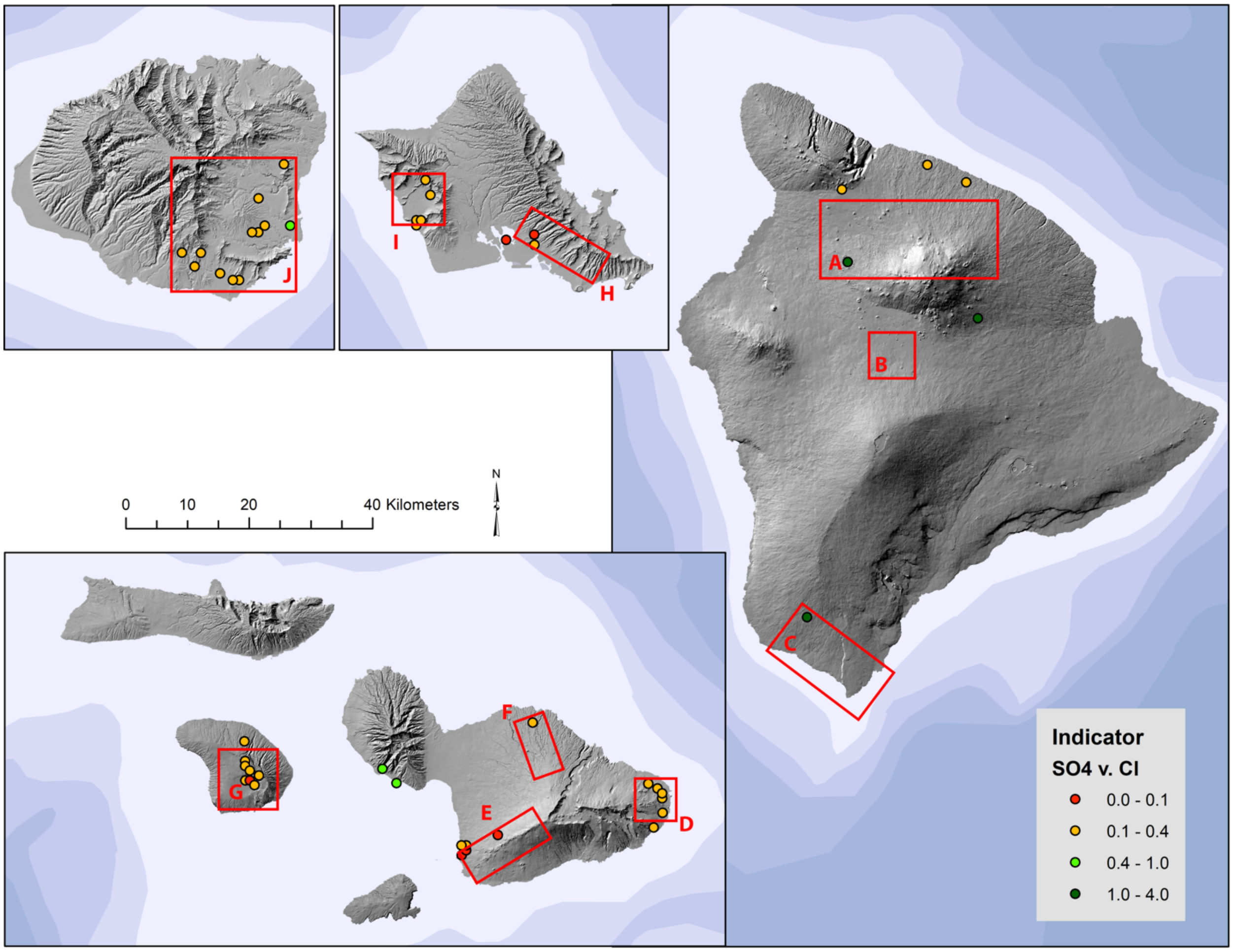


**Figure 9**. Sulfate:chloride ratio distribution of groundwater sampled during Play Fairway Analysis Phase II.

### 3.4.4 Silica

When analyzing the silica data collected during Play Fairway Phase II, we compared it to land cover maps as a first step to determine if contamination from irrigation was possible. Silica distribution is shown in Figure 10. Silica concentrations for groundwater samples collected in Phase II are in shown in Figure 11, using the same color scheme for island designation as Figure 8, and similarly with known geothermal wells and reference lines added. High silica concentrations that indicate possible geothermal heat were observed in groundwater samples from Oʻahu, Lānaʻi and Maui. Many of the groundwater samples that fell within the range of 60 to 85 ppm are located on agriculturally designated lands, possibly indicating silica input to groundwater aquifers via irrigation recharge.

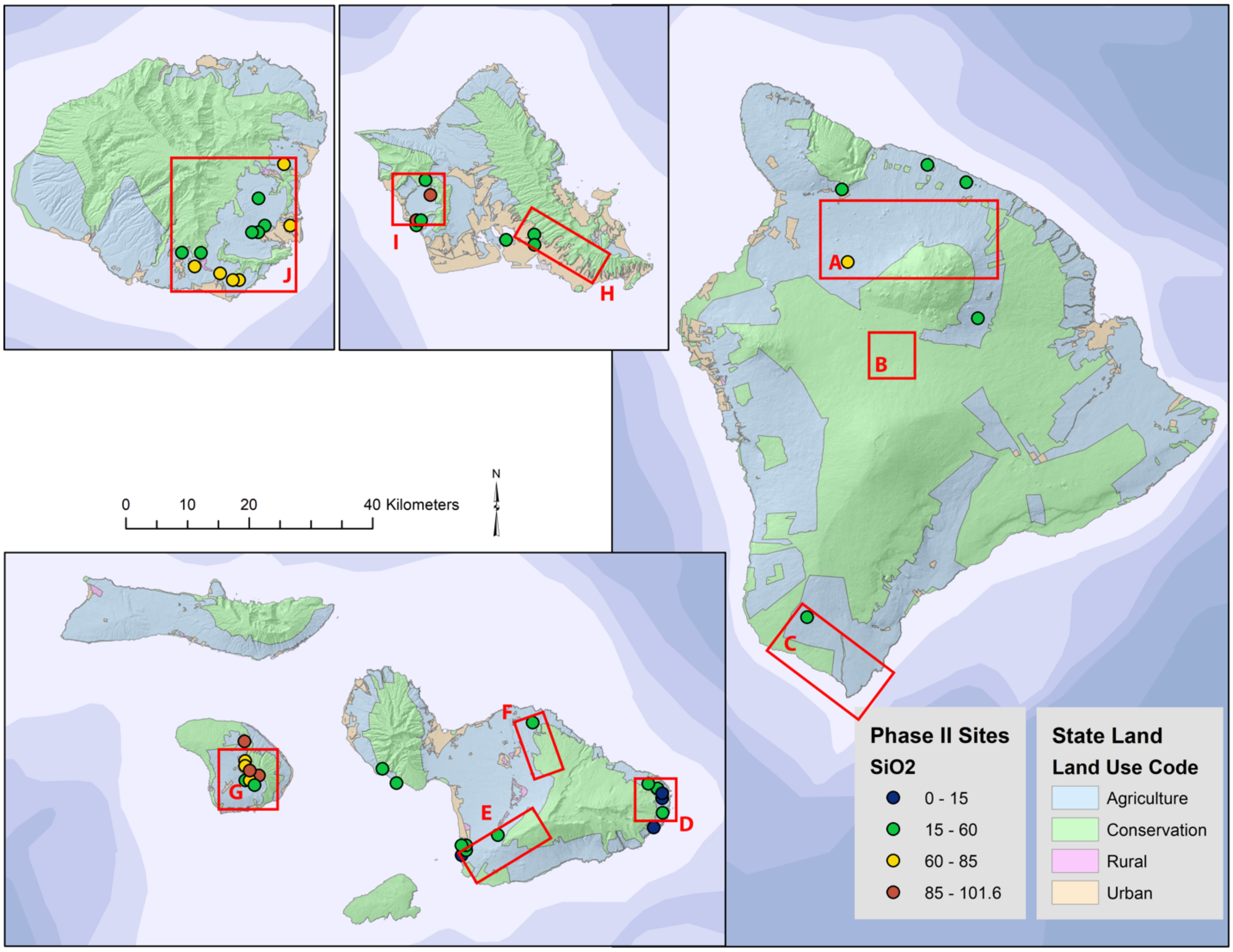


**Figure 10**. Silica distribution of groundwater sampled during Play Fairway Analysis Phase II.

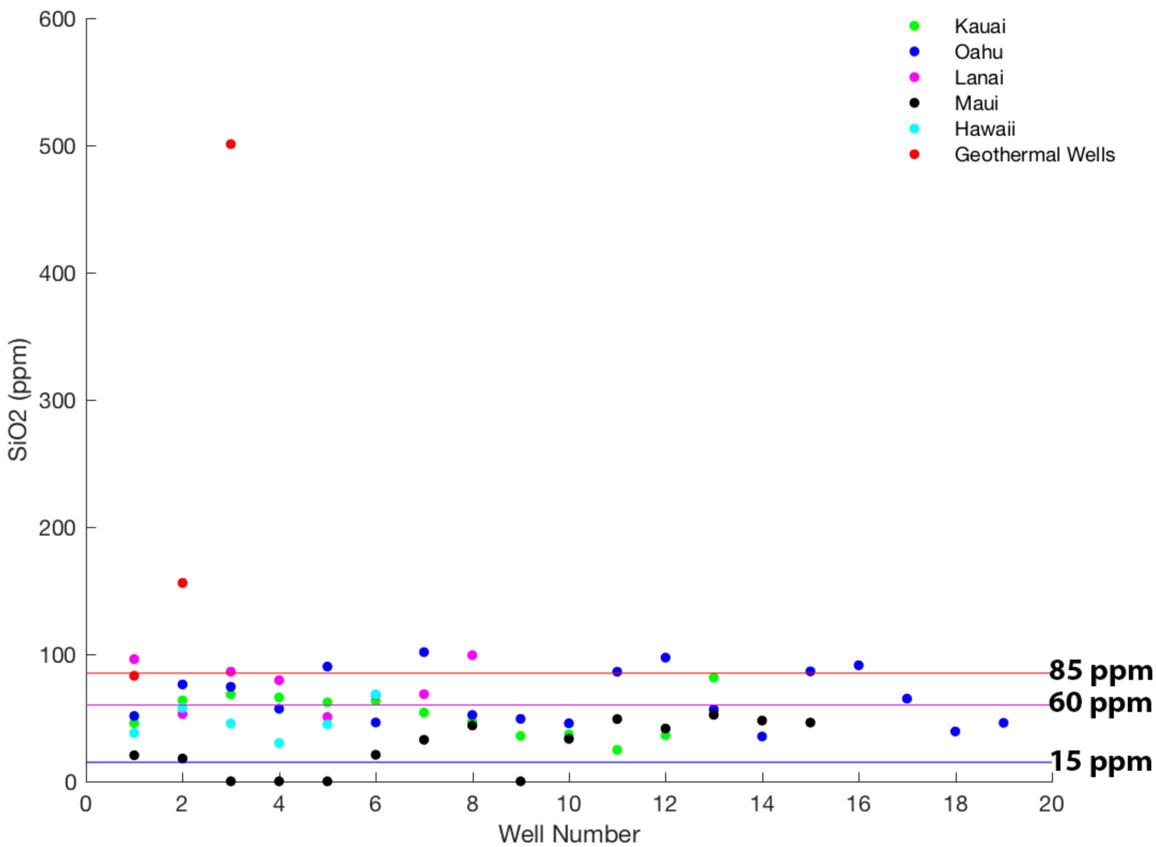


**FIGURE 11**. Silica concentration of samples collected during Play Fairway Analysis Phase II, with geothermal wells plotted for reference. The color scheme for each island is the same as Figure 8. Reference lines are plotted to show the various silica concentrations of 15 ppm, 60 ppm and 85 ppm to represent groundwater aquifers, high-level aquifers, and possible geothermal wells, respectively.

## 4. Discussion and Conclusions

A - North Hawaiʻi Island

North Hawaiʻi Island has water temperatures that range from 21.8ºC to 24.5ºC, as shown in Figure 6 and Appendix 7.2. These values do not represent an anomalous temperature in the subsurface.

Chloride:magnesium ratios range from 1.0 to 4.1, as shown in Figures 7 and 8, and Appendix 7.7. Chloride values in these wells are low because these are drinking water wells that provide water to the communities in the area. These low chloride:magnesium ratios are representative of recharge as it percolates through the rock matrix and accumulates more magnesium as it moves to the groundwater aquifer.

Sulfate:chloride ratios range from 0.17 to 2.99, as shown in Figure 9 and Appendix 7.7. The lower value of 0.17 is close to the seawater sulfate:chloride ratio of 0.14. Other ratio values around 0.3 are similar to the groundwater sulfate:chloride ratio.

Silica concentrations range from 37.98 ppm to 68.44 ppm, as shown in Figures 10 and 11, and Appendix 7.7. The higher silica value is located near Parker Ranch, which is a heavily used Ranch dating back to the 1800s. The high silica concentration could be attributed to the anthropogenic inputs in this area.

Based on the data collected in this project, further work in the area is not recommended. Groundwater geothermal indicators are not encouraging of geothermal potential in this region.

B - Saddle Region

The Saddle Region target area did not have sampled wells, however the Mauna Kea Spring is between the North Hawaiʻi Island and Saddle Region targets, therefore we classify it within Saddle Region. The temperature of the spring was 15.8ºC, as shown in Figure 6 and Appendix 7.2. Due to the high elevation and exposure to surface temperatures, the colder temperature of the spring is not indicative of subsurface heat.

A low chloride:magnesium ratio of 0.6 was observed for the spring, as shown in Figures 7 and 8 and Appendix 7.7. This may be due to the fact that it is freshly recharged groundwater that has not had a long residence time in the rock matrix to pick up magnesium. Chloride exists in trace amounts in rain due to evaporated sea salts, and therefore this could provide the low chloride:magnesium ratio for the freshwater spring on Mauna Kea.

The observed sulfate:chloride ratio is 4.0, as shown in Figure 9 and Appendix 7.7. The sulfate:chloride ratio is fairly high for the Mauna Kea spring. Sulfate and chloride possibly both exist as evaporated sea salts in the precipitation and recharge, and that could potentially account for the high sulfate concentration.

The silica concentration of the Mauna Kea spring is around 30 ppm, as shown in Figures 10 and 11 and Appendix 7.7. This is higher than expected, as rain having recently fallen on the ground surface has a silica concentration of about 1 to 3 ppm. Therefore, this spring water may have originated further up the mountain, and gained silica during flow. There is no reason to suspect an anthropogenic contribution of silica to the freshwater spring.

The spring water on Mauna Kea does not indicate a subsurface resource. However, the groundwater from the spring may be part of a shallow perched system and therefore not be representative of deep subsurface conditions in the vicinity. Further work in the target area, specifically in the Humuʻula Saddle region where previous high temperature waters have been found, is recommended for a more in depth hydrogeochemical investigation.

C - South Hawaiʻi Island

We were unable to collect groundwater temperatures at the time of sample collection in South Hawaiʻi Island, therefore the groundwater temperature value reads zero. However, previous groundwater sampling at this location provides us with a temperature of 27ºC (Waller, 2015), which is anomalously high.

The chloride:magnesium ratio for this well is 5.4, as observed in Figures 7 and 8, and Appendix 7.7. This value falls between the average rainfall and groundwater chloride:magnesium ratios, 7.2 and 1.1 respectively. Chloride is found in rainfall as a constituent of sea salts, where magnesium is commonly found in basalt rock and therefore reduces the ratio once it has spent enough time in the subsurface to accumulate magnesium. The chloride:magnesium value for the South Hawaiʻi Island sample may be representative of groundwater that has recently recharged and has spent enough time in the subsurface to accumulate magnesium, however not long enough to be representative of average groundwater chemistry.

The sulfate:chloride ratio is 2.6, as observed in Figure 9 and Appendix 7.7. Sulfate and chloride can both be found in rainfall as constituents of sea salts. It is unlikely that these contributions are from saltwater intrusion, as the chloride:magnesium ratio would be higher than observed. Therefore, it is more likely that the high sulfate:chloride ratio seen here is from either rainfall or anthropogenic contributions.

Silica concentration for the South Hawaiʻi Island well is 44.74 ppm, as observed in Figures 10 and 11 and Appendix 7.7. This abundance is comparable to a groundwater aquifer under normal conditions. The value is too low to be representative of geothermal systems, and also too low to have anthropogenic contributions from agricultural lands.

Based on the amount of data provided in this study, further work in this area is not recommended, as there is no strong geothermal indication in the groundwater geochemistry.

D - Hana, Maui

Groundwater samples collected in this target area are located in Hana, Maui, which is a community located near the base of the East Rift Zone of Haleakalā. Hana, Maui has a wide range of temperature values, ranging from 19.4°C to 25.7°C, as shown in Figure 6 and Appendix 7.2. The colder wells are located in northern Hana, whereas the warmer well was located in southern Hana near the base of the rift zone.

Chloride:magnesium ratios range from 2.4 to 25.6, as shown in Figures 7 and 8 and Appendix 7.7. Sulfate:chloride ratios range from 0.16 to 0.83, as shown in Figure 9 and Appendix 7.7. The high chloride:magnesium ratio sample is located north of the rift zone and supplies drinking water to the communities in Hana, Maui. This well also has a sulfate:chloride ratio of 0.19, which is close to the sulfate:chloride ratio of seawater. It might be possible for seawater intrusion to happen in this area, as it is only a mile and a half from the shoreline.

Another well, located just north of the base of the rift zone, has a high chloride:magnesium ratio of 8.3 and sulfate:chloride ratio of 0.16. This well is located about a mile from the shoreline. The elevated chloride:magnesium ratio and sulfate:chloride ratio, without the temperature anomaly, may suggest that saltwater is infiltrating into the groundwater aquifer in this area.

Silica concentrations range from 17.87 ppm to 20.88 ppm, as shown in Figures 10 and 11, and Appendix 7.7. Three wells in this area did not have silica analyses performed, and therefore have a value of 0. These silica concentrations are comparable to average groundwater aquifers in Hawai‘i.

Further work in this area is not recommended, as the geothermal signature is not strong in this area. However, it is recommended that further investigation be done on the groundwater to identify if saltwater intrusion is possible, as this has potential impacts to the communities in this remote community of Maui.

E - Southwest Rift Zone, Maui

The Southwest Rift Zone on Maui has varying groundwater temperatures, ranging from 19.5°C to 26.4°C, shown in Figure 6 and Appendix 7.2. There are two wells in the Makena area that have anomalous groundwater temperatures of 23.1ºC and 26.4ºC, with the wells located only about a mile from each other.

Chloride:magnesium ratios range from 2.5 to 9.7, as shown in Figures 7 and 8, and Appendix 7.7. Chloride:magnesium values are higher for wells that are located closer to the rift zone, as seen in Figure 7. All wells except for one are within two miles of the shoreline, so it is possible that the high chloride:magnesium ratios are due to saltwater intrusion in these wells.

Sulfate:chloride ratios range from 0.138 to 0.213, as shown in Figure 9 and Appendix 7.7. A similar pattern is shown in the sulfate:chloride ratios, with the more anomalous values located closer to the rift zone. As mentioned, all except for one of these wells are located near the shoreline, therefore the sulfate:chloride ratio may be more attributed to saltwater intrusion than geothermal heating.

Silica concentrations range from around 33 ppm to 49 ppm, as shown in Figures 10 and 11, and Appendix 7.7. One sample from this target area did not have silica analyses performed, and therefore shows a value of 0. The silica concentrations in these groundwater samples are comparable to average groundwater aquifers in Hawaiʻi, and do not express any anomalous geothermal heating contributions.

Further work is recommended in this target area. Based on the data collected in the region, there may be geothermal potential, and more data collection is encouraged. Also, collecting data on the southern side of the Southwest Rift Zone is recommended, to see if similar patterns exist in this location.

F - Northwest Rift Zone, Maui

One groundwater sample was collected in the Northwest Rift Zone on Maui, with a temperature value of 21.7ºC as shown in Figure 6 and Appendix 7.2. The chloride:magnesium ratio is 1.5, as shown in Figures 7 and 8, and Appendix 7.7. The sulfate:chloride ratio is 0.3, as shown in Figure 9 and Appendix 7.7. The silica concentration is 52.24 ppm, as shown in Figures 10 and 11, and Appendix 7.7.

With a low chloride:magnesium ratio and sulfate:chloride ratio representative of average groundwater, this location does not have an indication of subsurface heat. Silica concentrations are higher than other groundwater samples collected on Maui, however this could be due to the sugarcane plantations that are located in the Northwest Rift Zone of Haleakalā, Maui, rather than geothermal influence.

Based on the data collected, further work in this area is not recommended as there is no encouraging, strong geothermal indication via hydrogeochemical investigation.

G - Lānaʻi

Target area G is located around and within the Pālāwai Basin, the collapsed caldera of Lānaʻi. Groundwater temperatures range from 18.9ºC to 29.8ºC, as shown in Figure 6 and Appendix 7.2. Groundwater temperatures were not measured in one well, which was sampled at a later date, and therefore a temperature value is not provided. Two anomalously warm wells are located within the caldera, another is located north of the caldera.

Chloride:magnesium ratios range from 2.4 to 4.1, with an anomalously high well with a value of 45.5, shown in Figures 7 and 8 and Appendix 7.7. The anomalously high chloride:magnesium value is located within the caldera region. The remaining chloride:magnesium ratios are low, possibly due to high magnesium values.

Sulfate:chloride ratios range from 0.128 to 0.20, as shown in Figure 9 and Appendix 7.7. The low value of sulfate:chloride is located within the Pālāwai Basin, and is one of the high temperature wells. This well has a high magnesium concentration, possibly lowering the chloride:magnesium value. Other values of sulfate:chloride are low and comparable to the seawater ratio.

Silica concentrations range from 50.6 ppm to 99.16 ppm, as shown in Figures 10 and 11, and Appendix 7.7. The range of silica for Lāna‘i is high, with values exceeding the expected concentrations for recycled or irrigation waters. This provides encouragement for a geothermal resource near the caldera region of Lānā‘i.

Further work is recommended in this area. The chloride:magnesium ratios may be lower than expected for a geothermal resource, and this may be due to the fact that the magnesium content is very high in this region. The Pālāwai Basin has previously been studied and has a high abundance of olivine, a mineral commonly found in Hawaiian basalts and are rich in magnesium. The unusually high abundance of magnesium may allow for the chloride:magnesium values to be lower, and therefore would suggest no geothermal potential exists in this region. However, when combined with other geothermal indicators, it seems possible that a geothermal resource exists in the Pālāwai Basin, and therefore further research is recommended.

H - Ko‘olau Mountains

The Ko‘olau Mountain samples were collected mostly near the Red Hill Storage Facility, one at a golf course, and one ocean end-member sample was collected from Ford Island. The temperature values range from 20.9ºC to 27.37ºC, as shown in Figure 6 and Appendix 7.2. The anomalously high temperature value is from within the Red Hill Storage Facility.

Chloride:magnesium ranges from 1.4 to 13.6, as shown in Figures 7 and 8 and Appendix 7.7. The high chloride:magnesium ratio is from the ocean end member sample. The next highest ratio value is 11.6, which is also from the Red Hill Storage Facility.

Sulfate:chloride ratios range from 0.011 to 0.94, as shown in Figure 9 and Table 7.7. The anomalously low value is located within the Red Hill Storage Facility and also has a slightly high temperature of 23.5ºC. The sulfate:chloride ratio of the ocean end member is 0.138, which verifies that the average ratio of seawater is 0.14.

Silica concentrations range from 35.25 ppm to 91.26 ppm, as shown in Figures 10 and 11, and Appendix 7.7. The high silica value is the same well with anomalously low sulfate:chloride ratio and slightly warm temperature. Many of the Red Hill Storage Facility wells have a high silica value.

Further investigation into geothermal resources is not recommended in this area. The geothermal indicators in the region are not encouraging. An investigation of the groundwater chemistry in the Red Hill Storage Facility is underway, and may provide further insight into the anomalous temperatures and chemistry values seen in this project. Further work may be suggested after the findings are investigated.

I - Wai‘anae Mountains

Wai‘anae Mountain samples have elevated groundwater temperatures throughout the target region. The values range from 24.0ºC to 29.9ºC, as shown in Figure 6 and Table 7.2. The higher temperature values are from monitoring wells located at a solid waste management facility, and the lower ones are from deep wells near the base of the western side of Wai‘anae Mountain range.

Chloride:magnesium ratios range from 3.5 ppm to 9.4 ppm, as shown in Figures 7 and 8, and Appendix 7.7. Chloride:magnesium ratios are elevated near the coast, while the inland samples have low chloride:magnesium ratios. Saltwater intrusion may contribute to the high chloride:magnesium ratio. Sulfate:chloride ratios range from 0.167 to 0.371, as shown in Figure 9 and Table 7.7.

Silica concentrations range from 46.29 ppm to 101.6 ppm, as shown in Figures 10 and 11, and Appendix 7.7. One of the deep wells has a silica concentration of 97.28 ppm, and two of the solid waste management facility wells have silica values of 90.21 ppm and 101.6 ppm.

The high temperatures, chloride:magnesium ratios, and silica concentrations at the solid waste management facility could be attributed to the waste management and not encouraging of geothermal activity. Therefore, further work in the area is not recommended.

J - Southeast Kaua‘i

Southeast Kaua‘i has groundwater temperatures ranging from 23.2ºC to 25.4ºC, as shown in Figure 6 and Table 7.2. The warmer temperature wells are located in the northeastern part of the target area, with the colder wells near the southern part. One of the groundwater wells did not have a temperature value collected and therefore has a value of 0.

Chloride:magnesium ratios range from 1.2 to 3.3, as shown in Figures 7 and 8, and Appendix 7.7. Chloride:magnesium ratios are low throughout the entire study area. Sulfate:chloride ratios range from 0.153 to 0.690, as shown in Figure 9 and Appendix 7.7. The sulfate:chloride ratios are reflective of average rain and groundwater. The anomalously high value of sulfate:chloride is located within a mile of the shoreline, and could be representative of saltwater intrusions as sulfate and chloride both are abundant as sea salts in seawater.

Silica concentrations range from 24.76 ppm to 81.47 ppm, as shown in Figures 10 and 11, and Appendix 7.7. High silica concentrations in this area could be due to the plantations on Kauaʻi, and not indicative of geothermal resources.

Based on the data collected in this project, future work is not recommended in this area, as there are lacking amounts of encouraging indicators.

## Conclusions

The University of Hawaiʻi at Mānoa Play Fairway Analysis Project, Phase II collected new groundwater chemistry data from 61 sites across the State of Hawaiʻi, in an effort to investigate geothermal resources for the first time in three decades. With Hawaiʻi's energy goals of 100% renewable energy by the year 2045, geothermal resources have the potential to provide baseload energy to residents in Hawaiʻi, lowering energy costs and providing a cleaner future.

Of the ten target areas, this work identified two as priority targets for further investigtion: the Southwest Rift Zone of Haleakalā, Maui and the Pālāwai Basin, Lānaʻi. Groundwater collected in both sites contain encouraging evidence for subsurface heat. The next steps in geothermal exploration could include surface geophysics and/or drilling of a test well.

## 5. Future Work

### 5.1 Play Fairway Analysis, Phase III

The Hawaiʻi Play Fairway Analysis project is currently in its third phase, which has a goal of obtaining scientific data from a test well. The Hawaiʻi Play Fairway team is working with Pūlama Lānaʻi, a management group for Lānaʻi Island. Pūlama Lānaʻi has a mission to build a sustainable future for the island by preserving the culture, building economic opportunity, stewarding lands and investing in local communities. Currently, Lānaʻi is using hydroelectric and solar as renewable energy resources, with solar providing enough energy to sustain 25% of Lānaʻi homes. Hydroelectric power is used when available.

### 5.2 Kyushu University Collaboration

Geothermal power is an energy resource in Hawaii and Japan. As of 2015, Japan had 520 MW and Hawaii had 38 MW of geothermally generated electricity. Geophysical and geological exploration techniques have been applied in search of viable geothermal resources. The biggest hurdle in geothermal development in Japan is that most areas with active volcanoes are located on national park lands. Similar issues occur in Hawaii, with current volcanism located within Hawaii Volcanoes National Park.

Additional areas of geothermal interest, such as onsen (hot springs), are popular tourist destinations in Japan. Local communities are resistant to development of power production facilities in these thermal areas in order to maintain the pristine conditions of these regions. Similar situations occur in Hawaii, with local organizations protesting geothermal development in order to preserve and perpetuate Native Hawaiian traditional rights, customs and practices. Utilization of the Play Fairway statistical method can provide insight into viable locations of geothermal development in Japan. The statistical approach is easily adaptable to other geothermal regions around the world, taking in to account heat, fluid and permeability data.

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# 7. Appendix

## 7.1 Geothermal Wells Drilled in Hawai‘i

| Well | Year Drilled | Total Depth (feet) | BHT (°F) | Operator | Comments | Status* |
|---|---|---|---|---|---|---|
| TH-1 | 1961 | 178 | 130 | Thermal Power | | |
| TH-2 | 1961 | 556 | 187 | Thermal Power | Abandoned at 350 feet due to loose formation. | |
| TH-3 | 1961 | 690 | 203 | Thermal Power | | |
| TH-4 | 1961 | 290 | 109 | Thermal Power | Hole plugged at 98 feet. | |
| NSF Kilauea (Keller) | 1973 | 4,140 | 279 | Colorado School of Mines / GEDCO | Research well drilled within Hawaii Volcanoes National Park. | Observation |
| HGP-A | 1976 | 6,456 | 680 | State of Hawaii | Field discovery well; produced about 100,000 lbs/hr of steam and brine; supported 2.8-MW plant from 1981-1989; plugged and abandoned. | P&A |
| FNB No. 1 (Steamco 1) | 1978 | 6,200 | | STEAMCO & GEDCO | Drilled by Puuwaawaa Steam Co. (STEAMCO) & Geothermal Exploration and Development Co. (GEDCO); converted to water well in 1980. | Water well |
| FNB No. 2 (Steamco 2) | 1979 | 6,800 | | STEAMCO & GEDCO | Drilled by Puuwaawaa Steam Co. (STEAMCO) & Geothermal Exploration and Development Co. (GEDCO); converted to water well No. 4850-01 MW-1 Pin 1980. | Water well |
| Ashida 1 | 1980 | 8,300 | 550 | Barnwell-WRI | Exploratory well - dry; no LCZ encountered; plugged and abandoned; T of 619F noted in Patterson et al. (1994) | P&A |
| KS-1 (Kapoho-State 1) | 1981 | 7,290 | 650 | Thermal Power | Short test; tested at 3.2 MW; damaged; plugged and abandoned. | P&A |
| Lanipuna 1 (& Lanipuna 1 Redrill [ST]) | 1981 | 8,389 | 685+ | Barnwell-WRI | Low permeability, possible trace of fluids; abandoned. Redrill in 1983; kicked-off at 3570 ft - drilled to 6,271 feet; 429°F maximum recorded at 5300 ft.; no fluids - probably outside reservoir; abandoned. | P&A |
| KS-2 (Kapoho-State 2) | 1982 | 8,005 | 670+ | Thermal Power | Short test; tested at 2 MW; damaged; plugged and abandoned. | P&A |
| Lanipuna 6 | 1984 | 4,956 | 335 | Barnwell-WRI | Major LCZ below 4,285 feet; coolest hole in field - probably outside reservoir; suspended. | |
| KS-1A (Kapoho-State 1A) | 1985 | 6,505 | 670 | Thermal Power | 17-day flow test; tested at 3 MW; damaged; worked over to deepen and converted to injection service in 1992. | Original Injector |
| TRUE 1 (also known as KA1-1, TMP-1, KMERZ A-1 and KMERZ-1) | 1989-1994 | 8,741 (A-1 ST) (and other various) | 635 | True/Mid-Pacific Geothermal | Initial reports of high-pressure steam entries in original vertical hole, plus sidetrack and 3 redrills; TDs include 8,651 ft, 8,741 ft, 7,824 ft, 7,658 ft, and 7,850 ft; steam flows not sustained in flow tests; deepest hole in rift zone; plugged and abandoned. | P&A |
| SOH 4 | 1990 | 6,562 | 576 | State of Hawaii | Maximum reading thermometer = 583°F; no adequate permeability shown by injection in completion interval of 1,991-6,562 feet; may have entered reservoir; plugged and abandoned. | P&A |
| KAPOHO PUNA MW1 (MW-1) | 1990 | 720 | 111 | PGV | Monitoring / water supply wells | |
| PUNA GEO MW2 (MW-2) | 1991 | 640 | 153 | PGV | Monitoring / water supply wells | |
| KS-3 | 1990-91 | 7,406 | 664+ | PGV | Short test; tested at 3.2 MW; converted to injection service in 1992. | Original Injector |
| KAPOHO PUNA MW3 (MW-3) | 1991 | 720 | 111 | PGV | Monitoring / water supply wells | |
| KS-7 | 1991 | 1,678 | 500+ | PGV | Hot pressured fluids vented after injection test at 1,678 feet; plugged and abandoned. | P&A |
| SOH 1 | 1991 | 5,526 | 408 | State of Hawaii | Maximum reading thermometer = 403°F; adequate permeability not shown by injection in interval of 4,103-6,802. Some injectate loss at +/-4,600 feet, where 341°F was recorded; probably outside reservoir; plugged and abandoned. | Shut-in. Scheduled for abandonment |
| SOH 2 | 1991 | 6,802 | 661 | State of Hawaii | Inconclusive; may have entered reservoir; funding limits imposed stopping at 5,526 in rising BHT; plugged and abandoned. | Shut-in. Scheduled for abandonment |
| KS-8 | 1991-1992 | 3,488 | 630+ | PGV | Blowout at 3,488 feet in June 1991 vented fluids for 31 hours; completed to production at high-pressure bottom zone; repaired and producing for Puna plant at 10 MW briefly in Oct-Nov 1992; possible casing damage; plugged and abandoned. | P&A |
| KS-4 | 1992 | 6,795 | 620 | PGV | Injection test capacity >860 gpm at zero WHP and 1,100 gpm at 150 psig WHP; completed in November 1992 for injection service; converted to producer in 2006-7; plugged and abandoned in 2009-10. | P&A |
| KS-9 | 1992-1993 | 4,564 | 647 | PGV | Cleaned out and repaired casing damage; flow tested and placed online in April 1993. | Original Producer |
| KS-10 (& KS-10-RD) | 1993 | 5,083 | - | PGV | Original hole abandoned at 200 feet due to stuck bit; slide rig and redrill; put online for production in 1993; attempted to clean out scale in early 2000s - unsuccessful. Plugged back to ~4,700 ft and redrilled in 2005 after production declined starting in 2001; cement squeezed into parted casing at 1,578 feet and casing patch installed; well drilled to major LCZ below 5,154 feet; well put online in 2005 - producing 7.5 MW. | Original Producer (1993-2005); Re-drill is Active Producer |
| KS-11 (& KS-11 RD) | 2000 | 5,061 | - | PGV | Shut-in April 2002 due to casing failure and breakthrough; redrilled in 2003, kicked-off at 4,422 feet and drilled to 7,951 feet; fish left in hole; injection capacity 2,000 gpm at zero WHP; converted to injector after repairs; workover in 2006-7. | Orig. producer (2000-2003); Re-drill is Active Injector |
| KS-5 | 2003 | 6,299 | 315 (steam T°) | PGV | Completed in January 2003 after KS-11 declined in production from plugging in the wellbore. Surface casing was 22-inch set in 26-inch hole. | Acitve Producer |
| KS-13 | 2005 | 8,297 | - | PGV | Converted to injector in 2006; LCZ began at 109 feet from surface - encountered several LCZ between 4921 and 7218 feet; melt of dacitic composition was encountered at 8,163 feet; injtection test capacity 1,700 gpm at 30 psig WHP. | Active Injector |
| KS-6 | 2005 | 6,532 | - | PGV | LCZ began at 98 feet from surface - used foam cement for casing strings. Surface casing was 22-inch set in 26-inch hole. LCZ began again at 6,510 feet; well put online in Oct 2005 - producing 8.3 MW. | Acitve Producer |
| KS-14 | 2010 | - | - | PGV | Surface casing 22-inch set in 26-inch hole, drilled with foam cement. 11 3/4-inch casing set at 4,878; TD not published. | Active Producer |
| KS-15 | 2012 | - | - | PGV | 22-inch casing to 1,040 feet; 11 3/4-inch casing to 4,705 feet (26-inch hole depth of 4,709 feet); TD not published. | Producer |

Source: modified from GeothermEx, Inc., 1994; Patterson *et al*., 1994b. Selected references: Rickard *et al*., 2011a.

* Status based on most recent publicly available data (see References in Appendix A).

Notations: TD - total depth; P&A - plugged and abandoned; ST - sidetrack; LCZ - lost circulation zone; BHT - bottom-hole temperature as measured by wireline tools; WHP - wellhead pressure

## 7.2 Play Fairway Analysis Phase II groundwater data - Field parameters

| Well ID | Well Name | Island | Sample Date | Sample Time | pH | Temp (C) | Sp. Cond. (uS/cm) | DO (mg/L) | DO (%) | ORP (mV) |
|---|---|---|---|---|---|---|---|---|---|---|
| -9999 | OWDFMW1 | Oahu | 7/19/16 | 11:37 AM | 8.02 | 25.8 | 4042 | 3.97 | N/A | 117 |
| -9999 | RHMW07 | Oahu | 7/19/16 | 12:05 PM | 7.26 | 22.9 | 1869 | 2.62 | 35.2 | 152.1 |
| -9999 | RHMW06 | Oahu | 7/19/16 | 2:14 PM | 6.93 | 22.6 | 1568 | 6.26 | N/A | 192.6 |
| -9999 | RHMW04 | Oahu | 7/19/16 | 3:50 PM | 6.5 | 22.8 | 437.4 | 8.64 | N/A | 201.2 |
| 6-4600-003 | Wakiu B | Maui | 8/8/16 | 9:07 AM | 7.49 | 19.4 | 309.5 | 11.26 | 116.1 | 46.7 |
| 6-4300-002 | Hamoa 1 | Maui | 8/8/16 | 9:49 AM | 7.76 | 20.6 | 74.5 | 11.12 | 126.2 | 64 |
| 6-4100-002 | Wallach | Maui | 8/8/16 | 12:05 PM | 7.42 | 25.7 | 222.5 | 7.42 | 94.7 | 40 |
| 6-4559-001 | Wananalua | Maui | 8/8/16 | 1:45 PM | 7.9 | 21 | 300.3 | 11.6 | 134.4 | 6.2 |
| 6-4600-001 | Wakiu | Maui | 8/8/16 | 2:14 PM | 6.81 | 21.5 | 402.2 | 13.67 | 161.2 | -4.4 |
| 6-4701-001 | Kaeleku | Maui | 8/8/16 | 2:49 PM | 7.41 | 20.1 | 95.4 | 222 | 19.02 | -20.4 |
| 6-3926-003 | Wailea 8 | Maui | 8/9/16 | 8:01 AM | 7.8 | 19.5 | 1963 | 11.36 | 132.5 | -27.9 |
| 6-3826-001 | Seibu 2 | Maui | 8/9/16 | 1:55 PM | 7.36 | 21.4 | 2072 | 13.62 | 165.8 | 79.8 |
| 6-3926-005 | Seibu 6 | Maui | 8/9/16 | 2:20 PM | 7.91 | 20.5 | 1864 | 11.66 | 134 | 25.7 |
| 6-3926-002 | Makena 1 | Maui | 8/9/16 | 2:32 PM | 7.87 | 23.1 | 1627 | 14.25 | 185.8 | 17.2 |
| 6-3926-011 | Makena Surf | Maui | 8/9/16 | 3:22 PM | 7.5 | 26.4 | 264 | 12.83 | 168.2 | 680.6 |
| 6-5417-004 | JN & RS Well 1 | Maui | 8/10/16 | 8:32 AM | 7.91 | 20.5 | 154.7 | 11.99 | 136.7 | 131.1 |
| 6-5317-001 | Kaupakulua | Maui | 8/10/16 | 12:48 PM | 7.88 | 21.7 | 156.6 | 13.43 | 148.1 | 131.6 |
| 5-4854-002 | Lanai Well 14 | Lanai | 9/12/16 | 9:38 AM | 7.23 | 29.8 | 1817 | 4.98 | 69.1 | 52.1 |
| 5-4952-002 | Lanai Well 4 | Lanai | 9/12/16 | 10:31 AM | 7.89 | 18.9 | 166 | 189.5 | 7.58 | 88.5 |
| 5-4853-002 | Lanai Well 1 | Lanai | 9/12/16 | 11:05 AM | 7.66 | 28.1 | 910 | 4.94 | 66 | 118.3 |
| 5-4753-001 | Lanai Well 15 | Lanai | 9/12/16 | 11:26 AM | 7.14 | 25.8 | 1342 | 5.18 | 66.1 | 135.3 |
| 5-5054-002 | Lanai Well 6 | Lanai | 9/12/16 | 11:52 AM | 7.9 | 19.8 | 218.3 | 6.06 | 71.4 | N/A |
| 5-4954-002 | Lanai Well 8 | Lanai | 9/12/16 | 12:16 PM | 8 | 22.9 | 294.1 | 5.61 | 69.5 | 227.4 |
| 5-4954-003 | Lanai Well 3a | Lanai | 9/12/16 | 12:33 PM | 7.91 | 22.7 | 264.1 | 5.58 | 67.9 | 196.2 |
| 5-4854-001 | Lanai Well 9 | Lanai | 11/18/16 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 2-0124-03 | Hanamaulu 4 | Kauai | 10/7/16 | 9:14 AM | 7.57 | 24.9 | 194 | N/A | N/A | N/A |
| 2-0421-02 | Wailua Homesteads B | Kauai | 10/7/16 | 8:00 AM | 7.32 | 24.8 | 356 | N/A | N/A | N/A |
| 2-5425-15 | Koloa F | Kauai | 10/7/16 | 1:32 PM | 7.73 | 23.9 | 317 | N/A | N/A | N/A |
| 2-5426-05 | Koloa D | Kauai | 10/7/16 | 1:49 PM | 7.55 | 23.9 | 411 | N/A | N/A | N/A |
| 2-5427-03 | Koloa E | Kauai | 10/7/16 | 1:07 PM | 7.88 | 23.5 | 229 | N/A | N/A | N/A |
| 2-5530-03 | Lawai 1 | Kauai | 10/7/16 | 12:06 PM | 7.78 | 23.2 | 240 | N/A | N/A | N/A |
| 2-5629-01 | Piwai 2 | Kauai | 10/7/16 | 11:45 AM | 7.75 | 23.2 | 205 | N/A | N/A | N/A |
| 2-5631-01 | Kalaheo Deep Well 1 | Kauai | 10/7/16 | 12:45 PM | 8.02 | N/A | 196 | N/A | N/A | N/A |
| 2-5823-01 | Garlinghouse Tunnel | Kauai | 10/7/16 | 10:31 AM | 7.01 | 23.4 | 175 | N/A | N/A | N/A |
| 2-5923-07 | Kilohana I | Kauai | 10/7/16 | 10:14 AM | 7.51 | 23.6 | 187 | N/A | N/A | N/A |
| 2-5824-05 | Puhi 3 | Kauai | 10/7/16 | 10:57 AM | 6.66 | 23.6 | 154 | N/A | N/A | N/A |
| 2-5824-06 | Puhi 4 | Kauai | 10/7/16 | 11:16 AM | 7.11 | 23.2 | 170 | N/A | N/A | N/A |

| Well ID | Well Name | Island | Sample Date | Sample Time | pH | Temp (C) | Sp. Cond. (uS/cm) | DO (mg/L) | DO (%) | ORP (mV) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2-5921-01 | Kalepa Ridge | Kauai | 10/7/16 | 8:43 AM | 7.3 | 25.4 | 446 | N/A | N/A | N/A |
| 6-4937-001 | Olowalu Shaft | Maui | 10/19/16 | 10:30 AM | 7.53 | 23 | 424 | N/A | N/A | 207 |
| 6-4936-001 | Olowalu Well | Maui | 10/19/16 | 11:20 AM | 7.48 | 22.5 | 227 | N/A | N/A | 700 |
| 8-6223-001 | Paauilo Deepwell | Hawaii | 12/7/16 | 9:30 AM | 8.24 | 21.8 | N/A | N/A | N/A | N/A |
| 8-6240-002 | Waimea Deepwell | Hawaii | 12/7/16 | 11:10 AM | 7.03 | 24.5 | N/A | N/A | N/A | N/A |
| 8-6528-001 | Haina Well | Hawaii | 12/7/16 | 10:35 AM | 6.96 | 22.4 | N/A | N/A | N/A | N/A |
| -9999 | PVT MW1 | Oahu | 1/3/17 | 11:20 AM | 6.96 | 28.4 | 70.2 | N/A | N/A | N/A |
| -9999 | PVT MW2 | Oahu | 1/3/17 | 12:15 PM | 6.81 | 27.9 | 22.8 | N/A | N/A | N/A |
| -9999 | PVT MW3 | Oahu | 1/3/17 | 1:15 PM | 6.69 | 29.9 | 79.8 | N/A | N/A | N/A |
| -9999 | PVT MW4 | Oahu | 1/3/17 | 2:15 PM | 6.17 | 26.8 | 69.7 | N/A | N/A | N/A |
| -9999 | RHWM2254-01 | Oahu | 1/9/17 | 3:30 PM | 7.54 | 21.84 | 450 | 8.59 | N/A | 170.9 |
| -9999 | RHMW08 | Oahu | 1/11/17 | N/A | 8.2 | 24.01 | 1001 | 4.7 | N/A | 167.6 |
| -9999 | RHMW03 | Oahu | 1/12/17 | N/A | 6.77 | 27.37 | 802 | 2.99 | 37.2 | 197.9 |
| 3-2607-001 | Lualualei Deepwell | Oahu | 1/19/17 | 9:00 AM | 7.18 | 24 | 425.6 | 9.79 | 111.9 | 26.4 |
| 3-2808-002 | Lualualei Well | Oahu | 1/19/17 | 10:06 AM | 7.79 | 24.1 | 223.2 | 13.54 | 151 | 105.1 |
| 3-2157-005 | Ford Island Saltwater Well | Oahu | 1/26/17 | 10:20 AM | 7.01 | 21.7 | 48065 | 5.05 | 51.2 | 100.3 |
| -9999 | RHMW05 | Oahu | 2/7/17 | 10:07 AM | 7.91 | 23.8 | 844 | 8.2 | N/A | 133.6 |
| -9999 | RHMW02 | Oahu | 2/7/17 | 1:45 PM | 6.54 | 23.54 | 519 | 0.1 | N/A | -36.8 |
| 3-2253-003 @ 276 ft | Halawa Deep Monitor | Oahu | 3/6/17 | 9:45 AM | 6.71 | 22.6 | 484.9 | 5.11 | 59.2 | 56.1 |
| 3-2253-003 @ 851 ft | Halawa Deep Monitor | Oahu | 3/6/17 | 10:15 AM | 7.15 | 22.7 | 5500 | 7.24 | 87.1 | 41.2 |
| 3-2154-001 | Honolulu Intl Country Club | Oahu | 3/13/17 | 9:50 AM | 7.97 | 20.9 | 353.8 | 9.85 | 113.2 | 70.4 |
| -9999 | Spring on Mauna Kea | Hawaii | 3/20/17 | 3:38 AM | 7.86 | 15.8 | 86.7 | 8.73 | 114 | 66 |
| 8-0545-001 | Hawaiian Ocean View Estates Well | Hawaii | 7/12/17 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| 8-5239-001 | Waikii 1 | Hawaii | 7/12/17 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

## 7.3 Play Fairway Analysis Phase II groundwater data – Geochemistry: Major Ions

Chemistry values reported in mg/L

| Well ID | Well Name | $HCO_3$ | Cl | $SO_4$ | Na | K | Mg | Ca |
|---|---|---|---|---|---|---|---|---|
| -9999 | OWDFMW1 | 202.52 | 1059 | 321.05 | 368.5 | 7.25 | 244.86 | 106.13 |
| -9999 | RHMW07 | 118.34 | 431 | 72.55 | 162.3 | 3.02 | 82.62 | 61.17 |
| -9999 | RHMW06 | 122 | 416 | 94.63 | 198.88 | 2.36 | 74.17 | 45.22 |
| -9999 | RHMW04 | 68.32 | 74 | 10.86 | 33.78 | 2.26 | 18.8 | 18.56 |
| 6-4600-003 | Wakiu B | 32.94 | 58 | 10.2 | 50.91 | 3.16 | 2.27 | 1.7 |
| 6-4300-002 | Hamoa 1 | 21.96 | 7 | 1.6 | 9.22 | 2.19 | 1.52 | 3.32 |
| 6-4100-002 | Wallach | 53.68 | 35 | 6 | 25 | 1.5 | 6.7 | 12 |
| 6-4559-001 | Wananalua | 48.8 | 63 | 10.1 | 51 | 3.5 | 7.6 | 5.7 |
| 6-4600-001 | Wakiu | 100.04 | 72 | 12.5 | 59 | 3.7 | 16.2 | 10.8 |
| 6-4701-001 | Kaeleku | 36.6 | 6 | 2.3 | 11.79 | 1.95 | 2.52 | 4.73 |
| 6-3926-003 | Wailea 8 | 120.78 | 686 | 102.9 | 373.13 | 21.14 | 70.51 | 39.98 |
| 6-3826-001 | Seibu 2 | 287.92 | 676 | 95.1 | 365.63 | 28.37 | 97.19 | 54.14 |
| 6-3926-005 | Seibu 6 | 136.64 | 631 | 91.7 | 324 | 22 | 85.6 | 45.4 |
| 6-3926-002 | Makena 1 | 135.42 | 522 | 72 | 255.35 | 17.92 | 67.97 | 40.79 |
| 6-3926-011 | Makena Surf | 65.88 | 42 | 7.2 | 26.92 | 2.26 | 9.98 | 15.89 |
| 6-5417-004 | JN & RS Well 1 | 52.46 | 16 | 3.4 | 14 | 2.08 | 6.52 | 10.25 |
| 6-5317-001 | Kaupakulua | 57.34 | 11 | 3.3 | 12.81 | 3 | 7.1 | 11.08 |
| 5-4854-002 | Lanai Well 14 | 146.4 | 836 | 151.2 | 126.88 | 12.71 | 201.84 | 179.55 |
| 5-4952-002 | Lanai Well 4 | 52.46 | 22 | 4.2 | 15.77 | 2.12 | 8.01 | 9.77 |
| 5-4853-002 | Lanai Well 1 | 134.2 | 293 | 54.6 | 57.57 | 6.83 | 77.85 | 73.13 |
| 5-4753-001 | Lanai Well 15 | 136.64 | 547 | 69.9 | 64.55 | 7.15 | 137.83 | 116.25 |
| 5-5054-002 | Lanai Well 6 | 81.74 | 32 | 6.4 | 22.9 | 2.67 | 10.87 | 12.8 |
| 5-4954-002 | Lanai Well 8 | 86.62 | 836 | 151.2 | 23.16 | 2.85 | 18.38 | 20.74 |
| 5-4954-003 | Lanai Well 3a | 82.96 | 40 | 7.2 | 21.93 | 1.93 | 16.91 | 15.63 |
| 5-4854-001 | Lanai Well 9 | 82.96 | 425 | 76 | 60.84 | 5.96 | 105.8 | 104.49 |
| 2-0124-03 | Hanamaulu 4 | 75.64 | 15 | 3.3 | 14.29 | 1.34 | 12.32 | 8.72 |
| 2-0421-02 | Wailua Homesteads B | 108.58 | 38 | 5.8 | 21.74 | 1.19 | 22.27 | 17.78 |
| 2-5425-15 | Koloa F | 90.28 | 43 | 9.4 | 34.16 | 1.38 | 16.44 | 10.96 |
| 2-5426-05 | Koloa D | 75.64 | 84 | 15 | 36.23 | 1.56 | 25.27 | 17.32 |
| 2-5427-03 | Koloa E | 69.54 | 28 | 5.9 | 21.2 | 1.27 | 12.2 | 10.96 |
| 2-5530-03 | Lawai 1 | 76.86 | 27 | 7.2 | 21.58 | 1.17 | 13.77 | 10.49 |
| 2-5929-01 | Piwai 2 | 69.54 | 24 | 4.7 | 18.35 | 1.3 | 11.42 | 9.88 |
| 2-5631-01 | Kalaheo Deep Well 1 | 61 | 21 | 3.6 | 14.96 | 0.85 | 10.51 | 9.75 |
| 2-5823-01 | Garlinghouse Tunnel | 56.12 | 20 | 6 | 16.66 | 1.08 | 9.48 | 7.55 |
| 2-5923-07 | Kilohana I | 57.34 | 19 | 4.4 | 15.68 | 1.3 | 9.78 | 7.77 |
| 2-5824-05 | Puhi 3 | 36.6 | 19 | 8 | 16.27 | 1.11 | 7.75 | 5.02 |

| Well ID | Well Name | $HCO_3$ | Cl | $SO_4$ | Na | K | Mg | Ca |
|---|---|---|---|---|---|---|---|---|
| 2-5824-06 | Puhi 4 | 53.68 | 21 | 5.3 | 15.16 | 0.8 | 9.42 | 7.63 |
| 2-5921-01 | Kalepa Ridge | 107.36 | 50 | 34.5 | 40.33 | 1.35 | 21.58 | 20.54 |
| 6-4937-001 | Olowalu Shaft | 120.78 | 43 | 22.1 | 59.74 | 2 | 8.32 | 12.03 |
| 6-4936-001 | Olowalu Well | 91.5 | 19 | 15.6 | 19.66 | 1.3 | 10.61 | 17.07 |
| 8-6223-001 | Paauilo Deepwell | 47.58 | 9.6 | 3.7 | 9.13 | 2.43 | 6.52 | 11.82 |
| 8-6240-002 | Waimea Deepwell | 65.88 | 6.6 | 2.1 | 10.76 | 2.71 | 6.31 | 7.28 |
| 8-6528-001 | Haina Well | 109.8 | 95.8 | 16.2 | 35.72 | 3.67 | 23.32 | 30.02 |
| -9999 | PVT MW1 | 250.1 | 2083 | 348.1 | 1111.87 | 32.88 | 221.38 | 180.09 |
| -9999 | PVT MW2 | 309.88 | 412 | 152.7 | 266.29 | 11.65 | 60.63 | 142.34 |
| -9999 | PVT MW3 | 357.46 | 2377 | 510.7 | 1311.78 | 41.24 | 245.38 | 240.75 |
| -9999 | PVT MW4 | 336.72 | 2005 | 413.9 | 1119.14 | 25.28 | 214.76 | 210.11 |
| -9999 | RHWM2254-01 | 65.88 | 89 | 15.2 | 41.82 | 2.52 | 15.72 | 16.66 |
| -9999 | RHMW08 | 68.32 | 169 | 79 | 108.62 | 5.55 | 18.87 | 32.36 |
| -9999 | RHMW03 | 307.44 | 47 | 44.2 | 98.16 | 3.25 | 32.23 | 24.5 |
| 3-2607-001 | Lualualei Deepwell | 106.14 | 56 | 10.9 | 50.1 | 3.21 | 14.66 | 16.76 |
| 3-2808-002 | Lualualei Well | 58.56 | 26 | 4.9 | 21.24 | 2.98 | 7.53 | 11.23 |
| 3-2157-005 | Ford Island Saltwater Well | 92.72 | 18708 | 2578 | 9572 | 155 | 1371 | 824 |
| -9999 | RHMW05 | 109.8 | 148 | 46.2 | 138.78 | 4.86 | 12.75 | 7.77 |
| -9999 | RHMW02 | 229.36 | 37 | 0.4 | 52.96 | 2.34 | 25.68 | 13.36 |
| 3-2253-003 @ 276 ft | Halawa Deep Monitor | 54.9 | 88 | 27.6 | 50.72 | 0.35 | 15.48 | 11.84 |
| 3-2253-003 @ 851 ft | Halawa Deep Monitor | 37.82 | 1874 | 247.2 | 473.82 | 15.93 | 279.37 | 320.87 |
| 3-2154-001 | Honolulu Intl Country Club | 61 | 54 | 11.6 | 33.38 | 2.04 | 11.91 | 13.39 |
| -9999 | Spring on Mauna Kea | 24.4 | 1 | 4 | 5.18 | 1.55 | 1.61 | 4.5 |
| 8-0545-001 | Hawaiian Ocean View Estates Well | 91.5 | 87 | 227 | 130.64 | 8.43 | 16.04 | 37.71 |
| 8-5239-001 | Waikii 1 | 152.5 | 17 | 50.7 | 53.24 | 7.69 | 16.88 | 11.52 |

7.4 Play Fairway Analysis Phase II groundwater data – Geochemistry: Trace Metals

Chemistry values reported in mg/L

| Well ID | Well Name | Fl | Br | Li | As | Fe | Pb | Si | Zn |
|---|---|---|---|---|---|---|---|---|---|
| -9999 | OWDFMW1 | 0.05 | 3.01 | 0 | 0 | 0 | 0 | 24.01 | 0 |
| -9999 | RHMW07 | 0.06 | 1.36 | 0 | 0 | 0 | 0 | 35.61 | 0 |
| -9999 | RHMW06 | 0.06 | 1.32 | 0 | 0 | 0 | 0 | 34.75 | 0 |
| -9999 | RHMW04 | 0.06 | 0.26 | 0 | 0 | 0 | 0 | 26.68 | 0.04 |
| 6-4600-003 | Wakiu B | 0.12 | 0.19 | 0 | 0 | 0 | 0 | 9.57 | 0 |
| 6-4300-002 | Hamoa 1 | 0.04 | 0 | 0 | 0 | 0 | 0 | 8.35 | 0.01 |
| 6-4100-002 | Wallach | 0.04 | 0.13 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6-4559-001 | Wananalua | 0.06 | 0.22 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6-4600-001 | Wakiu | 0.07 | 0.28 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6-4701-001 | Kaeleku | 0.16 | 0 | 0 | 0 | 0 | 0 | 9.76 | 0 |
| 6-3926-003 | Wailea 8 | 0.14 | 2.31 | 0 | 0 | 0.18 | 0 | 15.27 | 0.14 |
| 6-3826-001 | Seibu 2 | 0.11 | 2.33 | 0 | 0 | 0 | 0 | 20.51 | 0.01 |
| 6-3926-005 | Seibu 6 | 0.13 | 2.15 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6-3926-002 | Makena 1 | 0.11 | 1.78 | 0 | 0 | 0.06 | 0 | 15.61 | 0.02 |
| 6-3926-011 | Makena Surf | 0.07 | 0 | 0 | 0 | 0 | 0 | 22.87 | 0.01 |
| 6-5417-004 | JN & RS Well 1 | 0.07 | 0 | 0 | 0 | 0.07 | 0 | 19.4 | 0.13 |
| 6-5317-001 | Kaupakulua | 0.07 | 0.08 | 0 | 0 | 0 | 0 | 24.42 | 0.01 |
| 5-4854-002 | Lanai Well 14 | 0.13 | 3.06 | 0 | 0 | 0.16 | 0 | 44.89 | 0.06 |
| 5-4952-002 | Lanai Well 4 | 0.04 | 0.06 | 0 | 0 | 0 | 0 | 24.73 | 0 |
| 5-4853-002 | Lanai Well 1 | 0 | 1.04 | 0 | 0 | 0 | 0 | 40.32 | 0 |
| 5-4753-001 | Lanai Well 15 | 0.08 | 2.06 | 0 | 0 | 0 | 0 | 37.16 | 0.01 |
| 5-5054-002 | Lanai Well 6 | 0.04 | 0.04 | 0 | 0 | 0 | 0 | 23.65 | 0.01 |
| 5-4954-002 | Lanai Well 8 | 0.13 | 3.06 | 0 | 0 | 0 | 0 | 31.74 | 0 |
| 5-4954-003 | Lanai Well 3a | 0 | 0.14 | 0 | 0 | 0 | 0 | 32.02 | 0.01 |
| 5-4854-001 | Lanai Well 9 | 0.06 | 1.35 | 0 | 0 | 0.78 | 0 | 46.36 | 0.02 |
| 2-0124-03 | Hanamaulu 4 | 0.07 | 0.04 | 0 | 0 | 0 | 0 | 21.42 | 0.01 |
| 2-0421-02 | Wailua Homesteads B | 0.03 | 0.15 | 0 | 0 | 0 | 0 | 29.73 | 0 |
| 2-5425-15 | Koloa F | 0.07 | 0.18 | 0 | 0 | 0 | 0 | 31.93 | 0 |
| 2-5426-05 | Koloa D | 0.05 | 0.3 | 0 | 0 | 0 | 0 | 30.84 | 0 |
| 2-5427-03 | Koloa E | 0.04 | 0.08 | 0 | 0 | 0 | 0 | 29.03 | 0 |
| 2-5530-03 | Lawai 1 | 0.05 | 0.09 | 0 | 0 | 0 | 0 | 29.53 | 0.02 |
| 2-5929-01 | Piwai 2 | 0.03 | 0.09 | 0 | 0 | 0 | 0 | 25.26 | 0 |
| 2-5631-01 | Kalaheo Deep Well 1 | 0.04 | 0.05 | 0 | 0 | 0 | 0 | 21.92 | 0.01 |
| 2-5823-01 | Garlinghouse Tunnel | 0.08 | 0.11 | 0 | 0 | 0 | 0 | 16.69 | 0 |
| 2-5923-07 | Kilohana I | 0.08 | 0.09 | 0 | 0 | 0 | 0 | 17.24 | 0.02 |
| 2-5824-05 | Puhi 3 | 0.06 | 0.1 | 0 | 0 | 0 | 0 | 11.58 | 0 |
| 2-5824-06 | Puhi 4 | 0.07 | 0.09 | 0 | 0 | 0 | 0 | 16.93 | 0 |

| Well ID | Well Name | Fl | Br | Li | As | Fe | Pb | Si | Zn |
|---|---|---|---|---|---|---|---|---|---|
| 2-5921-01 | Kalepa Ridge | 0.07 | 0.26 | 0 | 0 | 0 | 0 | 38.08 | 0 |
| 6-4937-001 | Olowalu Shaft | 0.23 | 0.14 | 0 | 0 | 0 | 0 | 22.34 | 0 |
| 6-4936-001 | Olowalu Well | 0.07 | 0 | 0 | 0 | 0 | 0 | 21.59 | 0 |
| 8-6223-001 | Paauilo Deepwell | 0.05 | 0.05 | 0 | 0 | 0 | 0 | 17.75 | 0 |
| 8-6240-002 | Waimea Deepwell | 0.11 | 0 | 0 | 0 | 0 | 0 | 27.02 | 0 |
| 8-6528-001 | Haina Well | 0.04 | 0.35 | 0 | 0 | 0 | 0 | 21.24 | 0 |
| -9999 | PVT MW1 | 0.17 | 7.01 | 0.01 | 0 | 0 | 0 | 42.17 | 0 |
| -9999 | PVT MW2 | 0.18 | 1.66 | 0 | 0 | 0 | 0 | 21.64 | 0 |
| -9999 | PVT MW3 | 0.24 | 7.92 | 0.01 | 0 | 0 | 0 | 47.49 | 0 |
| -9999 | PVT MW4 | 0.15 | 6.86 | 0 | 0 | 0 | 0 | 24.39 | 0 |
| -9999 | RHWM2254-01 | 0.07 | 0.32 | 0 | 0 | 0 | 0 | 22.95 | 0 |
| -9999 | RHMW08 | 0.23 | 0.58 | 0 | 0 | 0 | 0 | 21.31 | 0 |
| -9999 | RHMW03 | 0.18 | 0.2 | 0 | 0 | 0 | 0 | 40.27 | 0 |
| 3-2607-001 | Lualualei Deepwell | 0.24 | 0.23 | 0 | 0 | 0 | 0 | 45.48 | 0 |
| 3-2808-002 | Lualualei Well | 0.06 | 0.1 | 0 | 0 | 0 | 0 | 26.41 | 0 |
| 3-2157-005 | Ford Island Saltwater Well | 0 | 64 | 0.065 | 0 | 0 | 0 | 16.48 | 0 |
| -9999 | RHMW05 | 0.33 | 0.51 | 0 | 0 | 0 | 0 | 40.42 | 0 |
| -9999 | RHMW02 | 0.64 | 0.14 | 0 | 0 | 2.73 | 0 | 42.66 | 0 |
| 3-2253-003 @ 276 ft | Halawa Deep Monitor | 0.06 | 0.23 | 0 | 0 | 2.77 | 0 | 30.4 | 0 |
| 3-2253-003 @ 851 ft | Halawa Deep Monitor | 0.01 | 6.36 | 0 | 0 | 1.07 | 0 | 18.34 | 0 |
| 3-2154-001 | Honolulu Intl Country Club | 0.04 | 0.21 | 0 | 0 | 0 | 0 | 21.5 | 0 |
| -9999 | Spring on Mauna Kea | 0.08 | 0 | 0 | 0 | 0 | 0 | 14.09 | 0.025 |
| 8-0545-001 | Hawaiian Ocean View Estates Well | 0.41 | 0.29 | 0.01 | 0 | 0 | 0 | 20.92 | 0.18 |
| 8-5239-001 | Waikii 1 | 0.31 | 0.1 | 0 | 0 | 0 | 0 | 31.99 | 0 |

7.5 Play Fairway Analysis Phase II groundwater data – Geochemistry: Nutrients

Chemistry values reported in mg/L

| Well ID | Well Name | $NO_2$ | $NO_3$ as N | $PO_4$ | $NH_4$ |
|---|---|---|---|---|---|
| -9999 | OWDFMW1 | 0 | 1.6 | 0.27 | 0 |
| -9999 | RHMW07 | 0 | 0.94 | 0.31 | 0 |
| -9999 | RHMW06 | 0 | 0.61 | 0.35 | 0 |
| -9999 | RHMW04 | 0 | 0.61 | 0.23 | 0 |
| 6-4600-003 | Wakiu B | 0 | 0 | 0.2 | 0 |
| 6-4300-002 | Hamoa 1 | 0 | 0 | 0 | 0.11 |
| 6-4100-002 | Wallach | 0 | 0 | 0 | 0 |
| 6-4559-001 | Wananalua | 0 | 0 | 0 | 0 |
| 6-4600-001 | Wakiu | 0 | 0 | 0 | 0 |
| 6-4701-001 | Kaeleku | 0 | 0 | 0 | 0.15 |
| 6-3926-003 | Wailea 8 | 0 | 2.41 | 0 | 0 |
| 6-3826-001 | Seibu 2 | 0 | 0.87 | 0 | 0 |
| 6-3926-005 | Seibu 6 | 0 | 2.06 | 0 | 0 |
| 6-3926-002 | Makena 1 | 0 | 1.4 | 0 | 0 |
| 6-3926-011 | Makena Surf | 0 | 0.44 | 0.25 | 0.08 |
| 6-5417-004 | JN & RS Well 1 | 0 | 0 | 0 | 0 |
| 6-5317-001 | Kaupakulua | 0 | 0.68 | 0.13 | 0.1 |
| 5-4854-002 | Lanai Well 14 | 0 | 3.46 | 0 | 0 |
| 5-4952-002 | Lanai Well 4 | 0 | 0.48 | 0.12 | 0 |
| 5-4853-002 | Lanai Well 1 | 0 | 3.9 | 0 | 0 |
| 5-4753-001 | Lanai Well 15 | 0 | 7.59 | 0.18 | 0 |
| 5-5054-002 | Lanai Well 6 | 0 | 0.55 | 0.15 | 0 |
| 5-4954-002 | Lanai Well 8 | 0 | 3.46 | 0 | 0 |
| 5-4954-003 | Lanai Well 3a | 0 | 0.64 | 0 | 0 |
| 5-4854-001 | Lanai Well 9 | 0 | 4.24 | 0 | 0 |
| 2-0124-03 | Hanamaulu 4 | 0 | 0.4 | 0.38 | 0 |
| 2-0421-02 | Wailua Homesteads B | 0 | 0.92 | 0.09 | 0 |
| 2-5425-15 | Koloa F | 0 | 0 | 0 | 0 |
| 2-5426-05 | Koloa D | 0 | 0.57 | 0.23 | 0 |
| 2-5427-03 | Koloa E | 0 | 0.47 | 0.27 | 0 |
| 2-5530-03 | Lawai 1 | 0 | 0.89 | 0.3 | 0 |
| 2-5929-01 | Piwai 2 | 0 | 0.62 | 0.1 | 0 |
| 2-5631-01 | Kalaheo Deep Well 1 | 0 | 0.26 | 0 | 0 |
| 2-5823-01 | Garlinghouse Tunnel | 0 | 0.86 | 0.18 | 0 |
| 2-5923-07 | Kilohana I | 0 | 0.49 | 0.17 | 0 |
| 2-5824-05 | Puhi 3 | 0 | 0.79 | 0.19 | 0 |
| 2-5824-06 | Puhi 4 | 0 | 0 | 0 | 0 |

| Well ID | Well Name | $NO_2$ | $NO_3$ as N | $PO_4$ | $NH_4$ |
|---|---|---|---|---|---|
| 2-5921-01 | Kalepa Ridge | 0 | 2.11 | 0.44 | 0 |
| 6-4937-001 | Olowalu Shaft | 0 | 0.11 | 0.13 | 0 |
| 6-4936-001 | Olowalu Well | 0 | 0.15 | 0 | 0 |
| 8-6223-001 | Paauilo Deepwell | 0 | 1.54 | 0 | 0 |
| 8-6240-002 | Waimea Deepwell | 0 | 0.2 | 0.22 | 0 |
| 8-6528-001 | Haina Well | 0 | 0.92 | 0 | 0 |
| -9999 | PVT MW1 | 0 | 12.82 | 0 | 0 |
| -9999 | PVT MW2 | 0 | 6.58 | 0 | 0 |
| -9999 | PVT MW3 | 0 | 27.44 | 0 | 0 |
| -9999 | PVT MW4 | 0 | 20.23 | 0.1 | 0 |
| -9999 | RHWM2254-01 | 0 | 0.02 | 0 | 0 |
| -9999 | RHMW08 | 0 | 0.46 | 0.6 | 0 |
| -9999 | RHMW03 | 0 | 1.76 | 0.35 | 0 |
| 3-2607-001 | Lualualei Deepwell | 0 | 1.72 | 0.41 | 0 |
| 3-2808-002 | Lualualei Well | 0 | 0.91 | 0.16 | 0 |
| 3-2157-005 | Ford Island Saltwater Well | 0 | 0 | 0 | 0 |
| -9999 | RHMW05 | 0 | 1.04 | 1.66 | 0 |
| -9999 | RHMW02 | 0 | 0 | 0 | 0.05 |
| 3-2253-003 @ 276 ft | Halawa Deep Monitor | 0 | 0.2 | 0 | 0 |
| 3-2253-003 @ 851 ft | Halawa Deep Monitor | 0 | 0.19 | 0 | 0 |
| 3-2154-001 | Honolulu Intl Country Club | 0 | 0.65 | 0 | 0 |
| -9999 | Spring on Mauna Kea | 0 | 0 | 0 | 0 |
| 8-0545-001 | Hawaiian Ocean View Estates Well | 0 | 0.29 | 0 | 0 |
| 8-5239-001 | Waikii 1 | 0 | 0.63 | 0 | 0 |

7.6 Play Fairway Analysis Phase II groundwater data – Geochemistry: Isotopes

Isotope values reported in ‰

| Well ID | Well Name | $^{18}O$ | D | $^{13}C$ |
|---|---|---|---|---|
| -9999 | OWDFMW1 | -3.4 | -20.14 | NA |
| -9999 | RHMW07 | -2.96 | -13.22 | NA |
| -9999 | RHMW06 | -3.01 | -12.85 | NA |
| -9999 | RHMW04 | -3.03 | -11.61 | NA |
| 6-4600-003 | Wakiu B | -3.44 | -12.64 | NA |
| 6-4300-002 | Hamoa 1 | -2.92 | -9.63 | NA |
| 6-4100-002 | Wallach | -2.87 | -10.07 | NA |
| 6-4559-001 | Wananalua | -3.04 | -10.36 | NA |
| 6-4600-001 | Wakiu | -3.39 | -12.7 | NA |
| 6-4701-001 | Kaeleku | -3.25 | -10.45 | NA |
| 6-3926-003 | Wailea 8 | -5.24 | -30.1 | NA |
| 6-3826-001 | Seibu 2 | -4.95 | -26.05 | NA |
| 6-3926-005 | Seibu 6 | -5.09 | -28.25 | NA |
| 6-3926-002 | Makena 1 | -5.4 | -29.95 | NA |
| 6-3926-011 | Makena Surf | -3.46 | -13.49 | NA |
| 6-5417-004 | JN & RS Well 1 | -2.91 | -11.13 | NA |
| 6-5317-001 | Kaupakulua | -3.39 | -11.8 | NA |
| 5-4854-002 | Lanai Well 14 | -3.95 | -22.36 | -17.9 |
| 5-4952-002 | Lanai Well 4 | -4.1 | -19.97 | -12.8 |
| 5-4853-002 | Lanai Well 1 | -4.38 | -23.8 | -14.2 |
| 5-4753-001 | Lanai Well 15 | -4.21 | -24.21 | -10.9 |
| 5-5054-002 | Lanai Well 6 | -4.19 | -20.89 | -15.9 |
| 5-4954-002 | Lanai Well 8 | -4.23 | -21.87 | -16 |
| 5-4954-003 | Lanai Well 3a | NA | NA | -16.1 |
| 5-4854-001 | Lanai Well 9 | NA | NA | NA |
| 2-0124-03 | Hanamaulu 4 | -3 | -11.2 | -18.6 |
| 2-0421-02 | Wailua Homesteads B | -3.7 | -17.1 | -20.6 |
| 2-5425-15 | Koloa F | -3 | -11.7 | NA |
| 2-5426-05 | Koloa D | -2.6 | -11.5 | NA |
| 2-5427-03 | Koloa E | -3.1 | -12.3 | -18 |
| 2-5530-03 | Lawai 1 | -2.9 | -10.2 | -18.2 |
| 2-5929-01 | Piwai 2 | -3 | -11 | -20.4 |
| 2-5631-01 | Kalaheo Deep Well 1 | -1.9 | -9.1 | NA |
| 2-5823-01 | Garlinghouse Tunnel | -3.3 | -11 | -17.5 |
| 2-5923-07 | Kilohana I | -3.1 | -12.5 | -20.4 |
| 2-5824-05 | Puhi 3 | -2.9 | -10.8 | -16.5 |
| 2-5824-06 | Puhi 4 | -1.9 | -8.2 | -18.1 |

| Well ID | Well Name | $^{18}O$ | D | $^{13}C$ |
|---|---|---|---|---|
| 2-5921-01 | Kalepa Ridge | -3.2 | -13.9 | -15.7 |
| 6-4937-001 | Olowalu Shaft | -3.2 | -10.8 | -12 |
| 6-4936-001 | Olowalu Well | -3.1 | -9.1 | -14 |
| 8-6223-001 | Paauilo Deepwell | -4 | -15.6 | -19.6 |
| 8-6240-002 | Waimea Deepwell | -3.7 | -11.5 | -18.5 |
| 8-6528-001 | Haina Well | -3.6 | -12.4 | -14.5 |
| -9999 | PVT MW1 | -4.2 | -23.9 | -12.6 |
| -9999 | PVT MW2 | -4.3 | -21.9 | -13.1 |
| -9999 | PVT MW3 | -4 | -21.3 | -13.9 |
| -9999 | PVT MW4 | -3.6 | -18.1 | -14.4 |
| -9999 | RHWM2254-01 | -3.2 | -10.3 | -18.1 |
| -9999 | RHMW08 | -3.6 | -16.7 | -19.3 |
| -9999 | RHMW03 | -3.7 | -17.9 | -18.7 |
| 3-2607-001 | Lualualei Deepwell | -4.7 | -24.1 | NA |
| 3-2808-002 | Lualualei Well | -4.5 | -19.7 | NA |
| 3-2157-005 | Ford Island Saltwater Well | NA | NA | NA |
| -9999 | RHMW05 | -3.3 | -13 | -11.7 |
| -9999 | RHMW02 | -3.2 | -11.8 | -4.8 |
| 3-2253-003 @ 276 ft | Halawa Deep Monitor | -2.9 | -11.8 | NA |
| 3-2253-003 @ 851 ft | Halawa Deep Monitor | NA | NA | NA |
| 3-2154-001 | Honolulu Intl Country Club | -3.2 | -10.4 | NA |
| -9999 | Spring on Mauna Kea | -5.3 | -27.7 | NA |
| 8-0545-001 | Hawaiian Ocean View Estates Well | -7.6 | -49.9 | NA |
| 8-5239-001 | Waikii 1 | -10.2 | -70.8 | NA |

7.7 Play Fairway Analysis Phase II groundwater data – Geochemistry: Geothermal Indicators & Ratios

Chemistry values reported in mg/L

| Well ID | Well Name | Cl | $SO_4$ | Mg | $SiO_2$ | Cl:Mg | $SO_4$:Cl |
|---|---|---|---|---|---|---|---|
| -9999 | OWDFMW1 | 1059 | 321.05 | 244.86 | 51.37 | 4.32 | 0.30 |
| -9999 | RHMW07 | 431 | 72.55 | 82.62 | 76.17 | 5.22 | 0.17 |
| -9999 | RHMW06 | 416 | 94.63 | 74.17 | 74.34 | 5.61 | 0.23 |
| -9999 | RHMW04 | 74 | 10.86 | 18.8 | 57.07 | 3.94 | 0.15 |
| 6-4600-003 | Wakiu B | 58 | 10.2 | 2.27 | 20.47 | 25.55 | 0.18 |
| 6-4300-002 | Hamoa 1 | 7 | 1.6 | 1.52 | 17.87 | 4.61 | 0.23 |
| 6-4100-002 | Wallach | 35 | 6 | 6.7 | 0 | 5.22 | 0.17 |
| 6-4559-001 | Wananalua | 63 | 10.1 | 7.6 | 0 | 8.29 | 0.16 |
| 6-4600-001 | Wakiu | 72 | 12.5 | 16.2 | 0 | 4.44 | 0.17 |
| 6-4701-001 | Kaeleku | 6 | 2.3 | 2.52 | 20.88 | 2.38 | 0.38 |
| 6-3926-003 | Wailea 8 | 686 | 102.9 | 70.51 | 32.67 | 9.73 | 0.15 |
| 6-3826-001 | Seibu 2 | 676 | 95.1 | 97.19 | 43.88 | 6.96 | 0.14 |
| 6-3926-005 | Seibu 6 | 631 | 91.7 | 85.6 | 0 | 7.37 | 0.15 |
| 6-3926-002 | Makena 1 | 522 | 72 | 67.97 | 33.39 | 7.68 | 0.14 |
| 6-3926-011 | Makena Surf | 42 | 7.2 | 9.98 | 48.92 | 4.21 | 0.17 |
| 6-5417-004 | JN & RS Well 1 | 16 | 3.4 | 6.52 | 41.51 | 2.45 | 0.21 |
| 6-5317-001 | Kaupakulua | 11 | 3.3 | 7.1 | 52.24 | 1.55 | 0.30 |
| 5-4854-002 | Lanai Well 14 | 836 | 151.2 | 201.84 | 96.04 | 4.14 | 0.18 |
| 5-4952-002 | Lanai Well 4 | 22 | 4.2 | 8.01 | 52.89 | 2.75 | 0.19 |
| 5-4853-002 | Lanai Well 1 | 293 | 54.6 | 77.85 | 86.24 | 3.76 | 0.19 |
| 5-4753-001 | Lanai Well 15 | 547 | 69.9 | 137.83 | 79.5 | 3.97 | 0.13 |
| 5-5054-002 | Lanai Well 6 | 32 | 6.4 | 10.87 | 50.6 | 2.94 | 0.20 |
| 5-4954-002 | Lanai Well 8 | 836 | 151.2 | 18.38 | 67.89 | 45.48 | 0.18 |
| 5-4954-003 | Lanai Well 3a | 40 | 7.2 | 16.91 | 68.51 | 2.37 | 0.18 |
| 5-4854-001 | Lanai Well 9 | 425 | 76 | 105.8 | 99.16 | 4.02 | 0.18 |
| 2-0124-03 | Hanamaulu 4 | 15 | 3.3 | 12.32 | 45.82 | 1.22 | 0.22 |
| 2-0421-02 | Wailua Homesteads B | 38 | 5.8 | 22.27 | 63.61 | 1.71 | 0.15 |
| 2-5425-15 | Koloa F | 43 | 9.4 | 16.44 | 68.3 | 2.62 | 0.22 |
| 2-5426-05 | Koloa D | 84 | 15 | 25.27 | 65.97 | 3.32 | 0.18 |
| 2-5427-03 | Koloa E | 28 | 5.9 | 12.2 | 62.09 | 2.30 | 0.21 |
| 2-5530-03 | Lawai 1 | 27 | 7.2 | 13.77 | 63.17 | 1.96 | 0.27 |
| 2-5929-01 | Piwai 2 | 24 | 4.7 | 11.42 | 54.04 | 2.10 | 0.20 |
| 2-5631-01 | Kalaheo Deep Well 1 | 21 | 3.6 | 10.51 | 46.89 | 2.00 | 0.17 |
| 2-5823-01 | Garlinghouse Tunnel | 20 | 6 | 9.48 | 35.7 | 2.11 | 0.30 |

| Well ID | Well Name | Cl | $SO_4$ | Mg | $SiO_2$ | Cl:Mg | $SO_4$:Cl |
|---|---|---|---|---|---|---|---|
| 2-5923-07 | Kilohana I | 19 | 4.4 | 9.78 | 36.89 | 1.94 | 0.23 |
| 2-5824-05 | Puhi 3 | 19 | 8 | 7.75 | 24.76 | 2.45 | 0.42 |
| 2-5824-06 | Puhi 4 | 21 | 5.3 | 9.42 | 36.22 | 2.23 | 0.25 |
| 2-5921-01 | Kalepa Ridge | 50 | 34.5 | 21.58 | 81.47 | 2.32 | 0.69 |
| 6-4937-001 | Olowalu Shaft | 43 | 22.1 | 8.32 | 47.78 | 5.17 | 0.51 |
| 6-4936-001 | Olowalu Well | 19 | 15.6 | 10.61 | 46.18 | 1.79 | 0.82 |
| 8-6223-001 | Paauilo Deepwell | 9.6 | 3.7 | 6.52 | 37.98 | 1.47 | 0.39 |
| 8-6240-002 | Waimea Deepwell | 6.6 | 2.1 | 6.31 | 57.79 | 1.05 | 0.32 |
| 8-6528-001 | Haina Well | 95.8 | 16.2 | 23.32 | 45.44 | 4.11 | 0.17 |
| -9999 | PVT MW1 | 2083 | 348.1 | 221.38 | 90.21 | 9.41 | 0.17 |
| -9999 | PVT MW2 | 412 | 152.7 | 60.63 | 46.29 | 6.80 | 0.37 |
| -9999 | PVT MW3 | 2377 | 510.7 | 245.38 | 101.6 | 9.69 | 0.21 |
| -9999 | PVT MW4 | 2005 | 413.9 | 214.76 | 52.18 | 9.34 | 0.21 |
| -9999 | RHWM2254-01 | 89 | 15.2 | 15.72 | 49.1 | 5.66 | 0.17 |
| -9999 | RHMW08 | 169 | 79 | 18.87 | 45.6 | 8.96 | 0.47 |
| -9999 | RHMW03 | 47 | 44.2 | 32.23 | 86.16 | 1.46 | 0.94 |
| 3-2607-001 | Lualualei Deepwell | 56 | 10.9 | 14.66 | 97.28 | 3.82 | 0.19 |
| 3-2808-002 | Lualualei Well | 26 | 4.9 | 7.53 | 56.5 | 3.45 | 0.19 |
| 3-2157-005 | Ford Island Saltwater Well | 18708 | 2578 | 1371 | 35.25 | 13.65 | 0.14 |
| -9999 | RHMW05 | 148 | 46.2 | 12.75 | 86.47 | 11.61 | 0.31 |
| -9999 | RHMW02 | 37 | 0.4 | 25.68 | 91.26 | 1.44 | 0.01 |
| 3-2253-003 @ 276 ft | Halawa Deep Monitor | 88 | 27.6 | 15.48 | 65.03 | 5.68 | 0.31 |
| 3-2253-003 @ 851 ft | Halawa Deep Monitor | 1874 | 247.2 | 279.37 | 39.23 | 6.71 | 0.13 |
| 3-2154-001 | Honolulu Intl Country Club | 54 | 11.6 | 11.91 | 45.98 | 4.53 | 0.21 |
| -9999 | Spring on Mauna Kea | 1 | 4 | 1.61 | 30.14 | 0.62 | 4.00 |
| 8-0545-001 | Hawaiian Ocean View Estates Well | 87 | 227 | 16.04 | 44.74 | 5.42 | 2.61 |
| 8-5239-001 | Waikii 1 | 17 | 50.7 | 16.88 | 68.44 | 1.01 | 2.98 |