California Energy Commission

CONSULTANT REPORT

Expansion of the Groundwater Monitoring Program for the Casa Diablo IV Geothermal Development Project

Prepared for: **California Energy Commission**
Prepared by: **Ormat Nevada Inc.**

August 2024| CEC-300-2024-020

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PREFACE

The California Energy Commission's Geothermal Grant and Loan Program is funded by the Geothermal Resources Development Account and provides funding to local jurisdictions and private entities for a variety of geothermal projects.

Expansion of the Groundwater Monitoring Program for the Casa Diablo IV Geothermal Development Project is the final report for the Geothermal Grant and Loan Program Agreement Number GEO-14-004, conducted by Ormat Nevada, Inc. The information from this project contributes to the Geothermal Grant and Loan Program overall goals to:

- Promote the use and development of California's vast geothermal energy resources.
- Mitigate any adverse impacts caused by geothermal development.
- Help local jurisdictions offset the costs of providing public services necessitated by geothermal development.

For more information about the Geothermal Grant and Loan Program, please visit the Energy Commission's website on the Geothermal Grant and Loan Program Webpage (https://www.energy.ca.gov/programs-and-topics/programs/geothermal-grant-and-loan-program).

ABSTRACT

The Casa Diablo geothermal power plants have been in operation since the mid-1980s, and expansion of the geothermal power plants into the Basalt Canyon area began in 2006. These power plants are on National Forest System lands managed by the Inyo National Forest near Mammoth Lakes in Mono County, California. An expansion of the monitoring program is necessary for additional power to be produced from the Basalt Canyon area.

The Casa Diablo IV (CD IV) Geothermal Development project in the Long Valley Known Geothermal Resource Area (KGRA) was approved by the U.S. Bureau of Land Management (BLM) and United States Forest Service in their respective records of decision on August 12, 2013. The BLM required a groundwater monitoring plan to be in place before power plant operation. As part of this required groundwater plan, the project discussed in this report planned and drilled two new monitoring wells within the geothermal well field in the Basalt Canyon area. After drilling and collecting baseline data for these monitoring wells, two existing, idle geothermal wells were flow tested for 28 days to monitor connectivity between the warm water aquifer and the hot geothermal reservoir. This project was executed in coordination with the Long Valley Hydrologic Advisory Committee.

This project sought to expand the existing monitoring program to gather additional evidence concerning any hydrologic connection between the groundwater well production zone and the deeper geothermal reservoir beneath the western part of Long Valley KGRA. Assessment of the new monitoring wells and the data collected during the 28-day test concluded that no hydraulic connection with the geothermal reservoir exist, and the new monitoring wells would adequately serve as shallow monitoring points during development of the fourth phase of the expansion project.

Keywords: Geothermal, monitor, water level, pressure, geochemistry, Casa Diablo geothermal development project, Mammoth Geothermal Complex

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EXECUTIVE SUMMARY

Introduction

The purpose of geothermal development is the process of harnessing heat from the Earth's subsurface to generate power and provide heating and cooling. Geothermal development in Long Valley Caldera has been guided by extensive geological, geophysical, and hydrologic studies, including from monitoring conducted by the Long Valley Hydrologic Advisory Committee, an advisory committee to the Mono County Board of Supervisors and to regulatory agencies that oversee the environmental aspects of both geothermal development and development of non-thermal ground water in the Long Valley Caldera; research by the United States Geological Survey (USGS) volcanic hazards; and information gathered from other geothermal exploration and evaluation of direct-use potential or using direct geothermal energy resources without an intervening medium.

The Casa Diablo geothermal power plants have been in operation since the mid-1980s, and expansion of that production into the Basalt Canyon area began in 2006. Existing monitoring has established that the Long Valley hydrologic system, a movement and storage of surface and groundwater through various processes including evaporation, transpiration, precipitation, and runoff, is affected by variations in precipitation, recharge, hydrothermal input, nonthermal groundwater withdrawals, earthquakes, magmatic activity, and crustal deformation, the changes of earth's surface caused by tectonic activity. Before additional geothermal power can be produced from the Basalt Canyon area, an expansion of the monitoring program is necessary. This program is needed to determine if a hydrologic connection exists between the thermal reservoir in Basalt Canyon, the shallow aquifers proximal to the reservoir, and non-thermal groundwater used by the Mammoth Community Water District for the Casa Diablo IV Geothermal Development.

Purpose

The purpose of this project was to expand the existing monitoring program of the western part of Long Valley Caldera. The monitoring wells and test data gained through this project aimed to contribute to the overall monitoring program as established by the U.S. Bureau of Land Management (BLM), Bishop Office.

Objectives

The project team performed three main activities to expand the monitoring program:

1) Plan and drill two shallow monitoring wells
2) Collect baseline data from the two new shallow monitoring wells
3) Perform a long-term flow test on two existing idle geothermal wells.

The locations and well designs for the new monitoring wells were determined through the Long Valley Hydrologic Advisory Committee, which involved the following agencies: Bureau of Land Management (BLM); the United States Forest Service; the USGS; Ormat Nevada, Inc. (Ormat); the Mammoth Community Water District (MCWD); and the Great Basin Unified Air Pollution Control District. These monitoring wells were sited at a shallow depth near the geothermal production wells in Basalt Canyon, yet at not far from the Mammoth Community Water District monitoring wells, in order to intercept any changing conditions related to the geothermal reservoir. Ormat completed all necessary permitting, and the USGS drilled the two wells in the fall of 2015. Baseline data collection of both monitoring wells started immediately, and USGS continued to collect data. Baseline data included downhole temperature surveys, geochemical samples, and depth-to-water level from ground surface in each monitoring well.

Ormat conducted the long-term flow test between the two idle geothermal wells in the fall of 2017. During the test, Geothermal Well 14-25 was pumped for 28 days, while the produced geothermal brine was injected into Geothermal Well 12-25. During the test, the USGS continued to collect data from the two monitoring wells (depth-to-water level, in addition to pre- and posttest geochemical sampling). Using the data collected before, during, and after the long-term test, Ormat assessed whether the shallow monitoring wells and the geothermal reservoir were hydraulically connected, to determine if there is any immediate connectivity between the shallow groundwater used by the Mammoth Community Water District and the geothermal reservoir to be utilized for the Casa Diablo IV Geothermal Development, which is not part of this agreement.

Conclusions

This project successfully expanded the monitoring program prior to development of the Casa Diablo IV project. Data collected as part of the monitoring program will be used to establish a baseline before production of the Casa Diablo IV project. The baseline will establish natural variations and fluctuations not associated with expanded geothermal production. This project also determined there is neither a hydraulic connection between the geothermal reservoir and the shallow system, nor between the geothermal system and the groundwater aquifer used by MCWD.

Benefits to California

The information collected from this project will support the assessment for continued drilling and ultimate construction and operation of the Casa Diablo IV geothermal power plant. As geothermal production expands, these two wells will monitor for potential changes in the shallow regime of the Basalt Canyon geothermal well field. This project added benefits to Mono County through property taxes, sales taxes, construction, and full-time employment. Casa Diablo IV supported the state in its Renewables Portfolio Standard goals and reducing greenhouse gases as required under Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006) by adding new renewable generation to the grid. Because the Casa Diablo IV project is on federal land, the royalties are paid to the BLM, and a portion will come back to the state to support the Geothermal Grant and Loan Program and Mono County.

CHAPTER 1: History of the Casa Diablo IV Geothermal Development Project

History and Record of Decision by the Bureau of Land Management

The Casa Diablo IV Geothermal Development (CD-IV) Project was formally proposed to the Bureau of Land Management (BLM) by Mammoth Pacific, L.P. (MPLP) in 2010. MPLP was subsequently acquired by Ormat Nevada, Inc. (Ormat), and they requested authorization to construct, operate, maintain, and decommission the proposed project on BLM-administered federal geothermal leases located on National Forest System lands managed by the Inyo National Forest near Mammoth Lakes in Mono County, California.

The BLM approved the CD-IV Project on August 12, 2013. In the record of decision for the project, the BLM acknowledged concern expressed by the Mammoth Community Water District (MCWD) that "uncertainty remained regarding the potential impact of the CD-IV Project on their domestic water supply." The BLM also recognized the "importance of ongoing data collection and monitoring related to the municipal water supply for the Mammoth Lakes community."[1]

The existing geothermal wells in Basalt Canyon are about two miles north-northeast of the Town of Mammoth Lakes production wells. Figure 1 shows existing active and nonactive wells for the Town of Mammoth Lakes and Ormat. For regional context, refer to Figure 2 for a map of the Long Valley Caldera.

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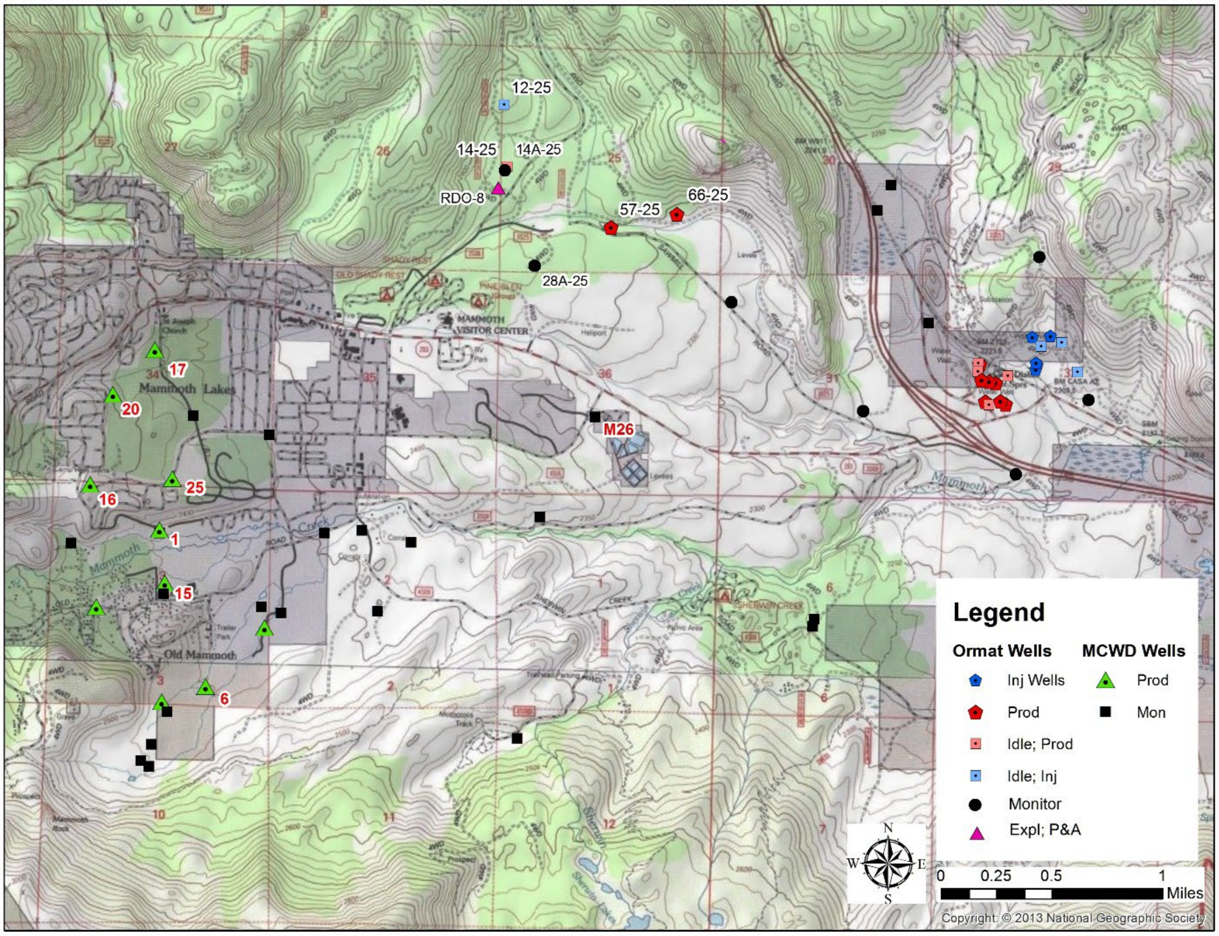
1 Bureau of Land Management, Bishop Field Office. February 10, 2022. "Casa Diablo IV Geothermal Development Affecting Recreation Activities," https://www.blm.gov/press-release/casa-diablo-iv-geothermal-development-affecting-recreation-activities CD-IV_ROD_APPX3_MOA.pdf (blm.gov)

Figure 1: Location Map of the Geothermal Field

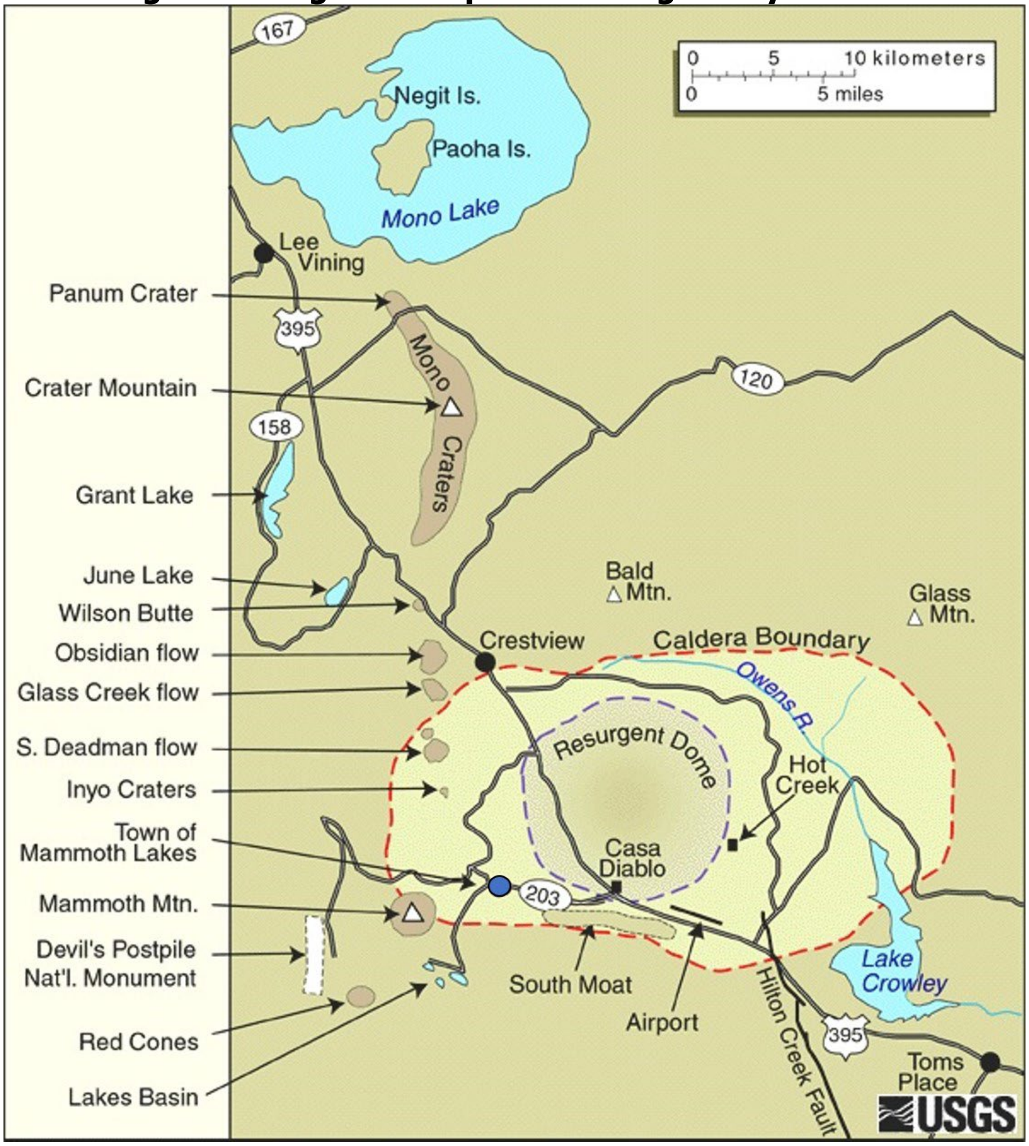


Map showing the location of Ormat's active and nonactive geothermal wells in relation to the production and non-active wells used by MCWD. For simplicity, only wells referred to in this report are labeled.

Key: "Inj" = injection, "Prod" = production, "Mon" = monitor

Source: Ormat Nevada, Inc.

Figure 2: Regional Map of the Long Valley Caldera



Regional Map of the Long Valley Caldera. The Town of Mammoth Lakes is shown as the blue circle.

Source: Modified from the United States Geological Survey (USGS).

Requirement for Monitoring Program

As a condition of approval for the CD-IV Project, (43 CFR 3200.4[f] and 43 CFR 3270.12[d]), the BLM required the "development and implementation of a cooperative shallow ground water monitoring plan focused on detecting any direct or indirect effects on the municipal water supply that may occur from geothermal production and injection in coordination with the Long Valley Hydrologic Advisory Committee." The BLM also required that the MCWD be "invited to participate in the development and implementation" of the shallow groundwater monitoring plan.[2]. The Groundwater Monitoring and Response Plan (GMRP) was developed and implemented to meet this condition of approval for the CD-IV Project. The primary intent

2 *43 CFR Part 3200 -- Geothermal Resource Leasing*. (n.d.). https://www.ecfr.gov/current/title-43/subtitle-B/chapter-II/subchapter-C/part-3200.

of the BLM-required shallow groundwater monitoring plan was to address concerns expressed by the MCWD regarding potential impacts on the domestic water supply for the Town of Mammoth Lakes from CD IV project operations. These concerns included, but are not limited to:

- the potential of reduction in the amount of shallow cold groundwater available to the MCWD from the Mammoth Groundwater Basin,
- the potential reduction in the amount of surface water available to the MCWD from Mammoth creek,
- and the potential degradation of water quality within the shallow cold groundwater aquifer in the mammoth Groundwater Basin and/or the surface water resource from Mammoth Creek.

The GMRP sought to establish a monitoring program to detect any direct and indirect effects on the municipal water supply for the Town of Mammoth Lakes that may occur from geothermal production and injection associated with the CD IV project. The objectives of the GMRP are to

1) identify and implement shallow groundwater aquifer, surface water resource, and deep geothermal reservoir monitoring strategies and protocols necessary to achieve this purpose, and
2) establish a framework for determining and implementing appropriate response actions if, and when, needed to avoid, minimize, and/or mitigate potential adverse effects to the Town of Mammoth Lakes municipal water supply based on review and analysis of the monitoring data collected.

CHAPTER 2: Completion of Two Shallow Monitoring Wells

Summary and Drilling History of Monitoring Well 14A-25

Summary

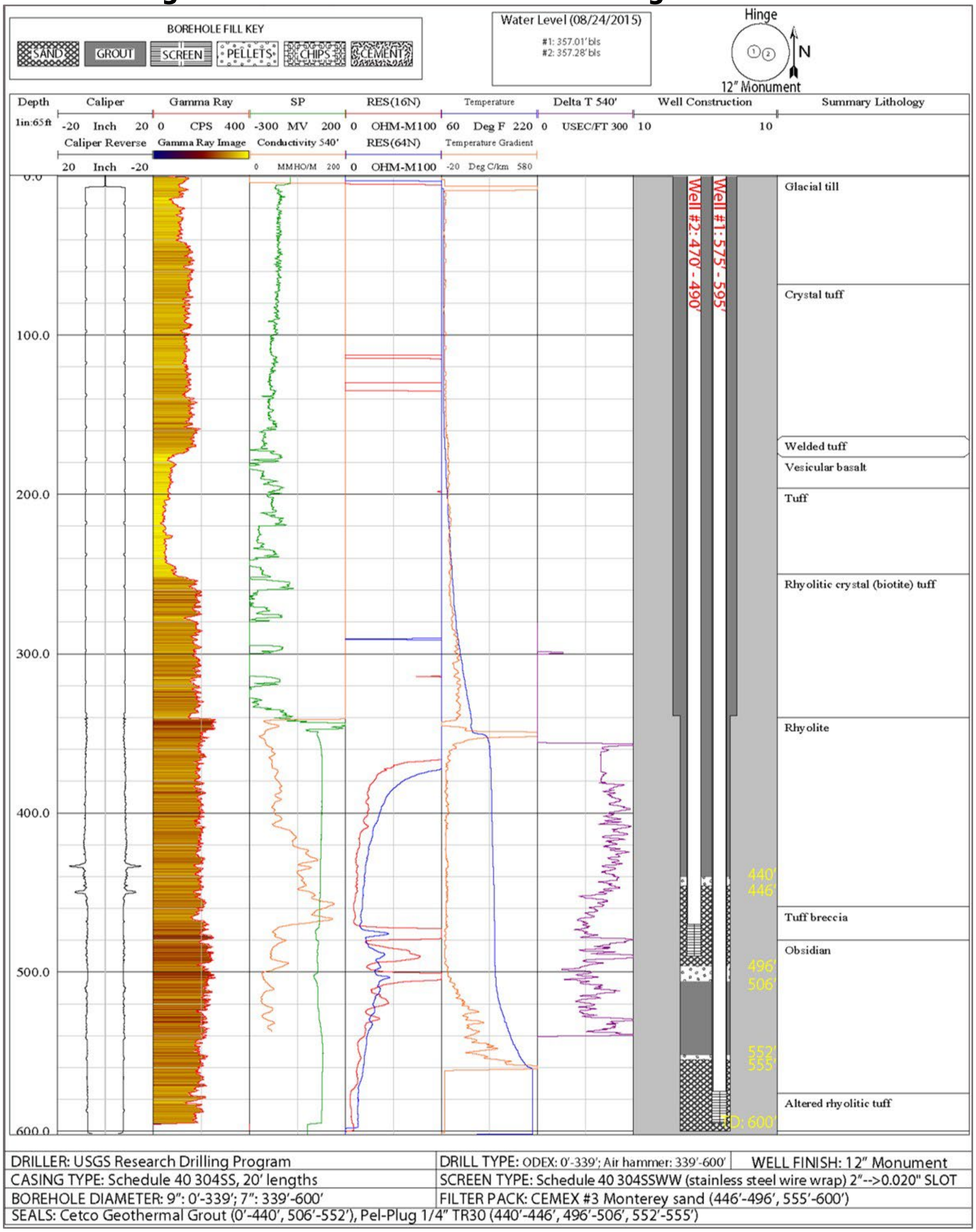
Monitoring Well 14A-25 (Well 14A-25) was drilled and completed in August 2015 by the United States Geological Society (USGS) adjacent to the idle Geothermal Well 14-25 (Well 14-25). Well 14A-25 was drilled to a total depth of 600 feet (ft) and was dually completed with two tubing strings both 2-3/8 inches (in) in diameter. The first completion (known as ML02-1) had tubing completed to a depth of 595ft and the second (known as ML02-2) had tubing completed to a depth of 490 ft. The two completions were isolated from each other by a bentonite seal.

Drilling Well 14A-25 was to allow for shallow monitoring above the geothermal reservoir in the Basalt Canyon area. Based on data collected from the monitoring well this goal was achieved and Well 14A-25 could act as a monitoring point within the Basalt Canyon geothermal field. Data gathered from drilling and monitoring of Well 14A-25 included lithology, temperature, depth-to-water level, geophysics, and geochemistry.

Drilling History

Well 14A-25 was spudded, or begun, August 1, 2015, and was completed August 9, 2015. The total depth was reached after five days of drilling. During drilling, the cuttings were logged onsite by a USGS hydrologist. Prior to completing the well, a suite of geophysical logs was collected downhole. To complete Well 14A-25, the two tubing strings were run downhole over a two-day period. The deeper tubing, ML02-1, was completed first and followed by the shallow tubing, ML02-2, on the second day. The two tubing strings (ML02-1 and ML02-2) were each completed in a filter pack composed of CEMEX #3 Monterey sand and are isolated from each other by CETCO® Geothermal Grout and Pel-Plug 1/4-in TR30 coating, a bentonite pellet. See the final schematic in Figure 3. Well 14A-25 is approximately 100 ft southwest of Well 14-25 (Figure 4). See Table 1 for location data as reported by the USGS.

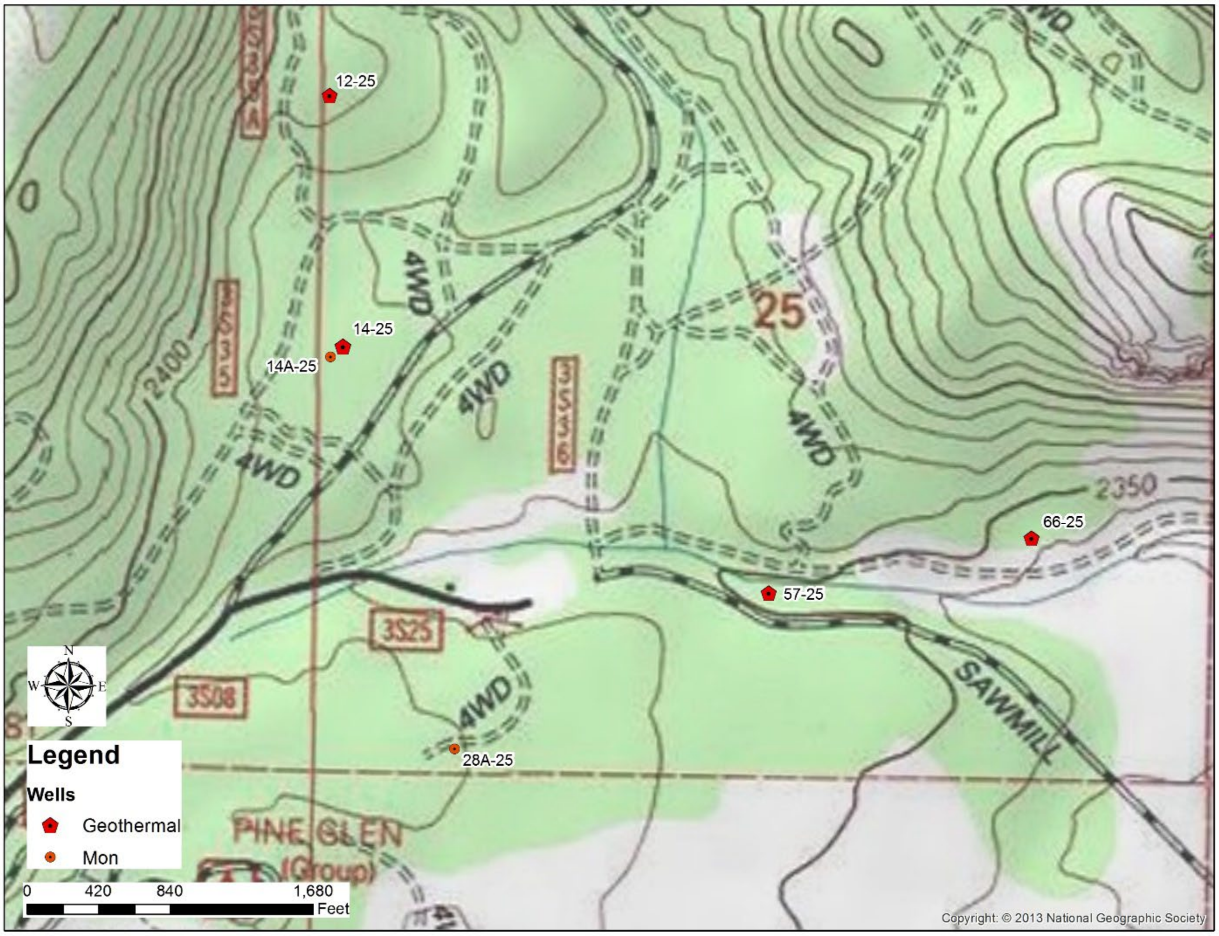
Figure 3: Final Schematic of Monitoring Well 14A-25



Final schematic of Well 14A-25. Downhole geophysical logs and stratigraphic column are also shown.

Source: Ormat Nevada, Inc.

Figure 4: Location Map of New Monitoring Wells



Location of the new monitoring wells in relation to surrounding geothermal wells.

Source: Ormat, Nevada, Inc.

Table 1: Location Data for Well 14A-25

Latitude	Longitude	Elevation
37°39'27.5"	118°57'17.5"	7,799

Coordinate system: North American Datum (NAD) 83.

Elevation is in feet above NAVD88

Source: USGS

Data Collected and Discussion of Results

Lithologies reported for Well 14A-25 were consistent with other downhole lithologies reported in the area. An upper section of glacial till is underlain by a series of tuffs interlaid with basalt and obsidian. The series of tuffs range from crystal tuff to tuff breccia and altered tuff. See Table 2 for the lithologic descriptions. Downhole geophysical logs were collected prior to completion of the well, which included gamma ray, self-potential, conductivity, and resistivity (Figure 3). From these logs, two zones for monitoring were selected by the USGS; these zones were completed as ML02-1 and MLO2-2. The water table was measured at 357.28 ft from ground surface August 24, 2014, after the well had been completed. See Appendix A for the completion report submitted by the USGS.

After reaching a depth of 600 ft, a downhole temperature survey was collected prior to completion and a follow-up temperature survey was collected in February 2016. The maximum temperature recorded in August 2015 was 212 degrees Fahrenheit (°F) (100 degrees Celsius [°C]) and the maximum recorded in February 2016 was 224°F (106.7°C). Both temperature profiles had linear thermal conductive profiles and the wellbore was shown to heat up between the first and second survey (Figure 5). The conductive profile indicated heated, low permeable rock. Heated rock was often found above hot convective geothermal reservoirs.

The thermal conductive profiles correlated with the profile of the nearby Well 14-25 at these depths as well as with Exploration Geothermal Well RDO-8 (Well RDO-8) (Figure 5). Well RDO-8 was drilled in 1986 by the USGS to explore the extents of geothermal reservoir in the Basalt Canyon area. Wells 14A-25, 14-25, and RDO-8 all have thermal gradients greater than 20°F (-6.7**°**C) per 100 ft in the upper 600 ft (Table 3).

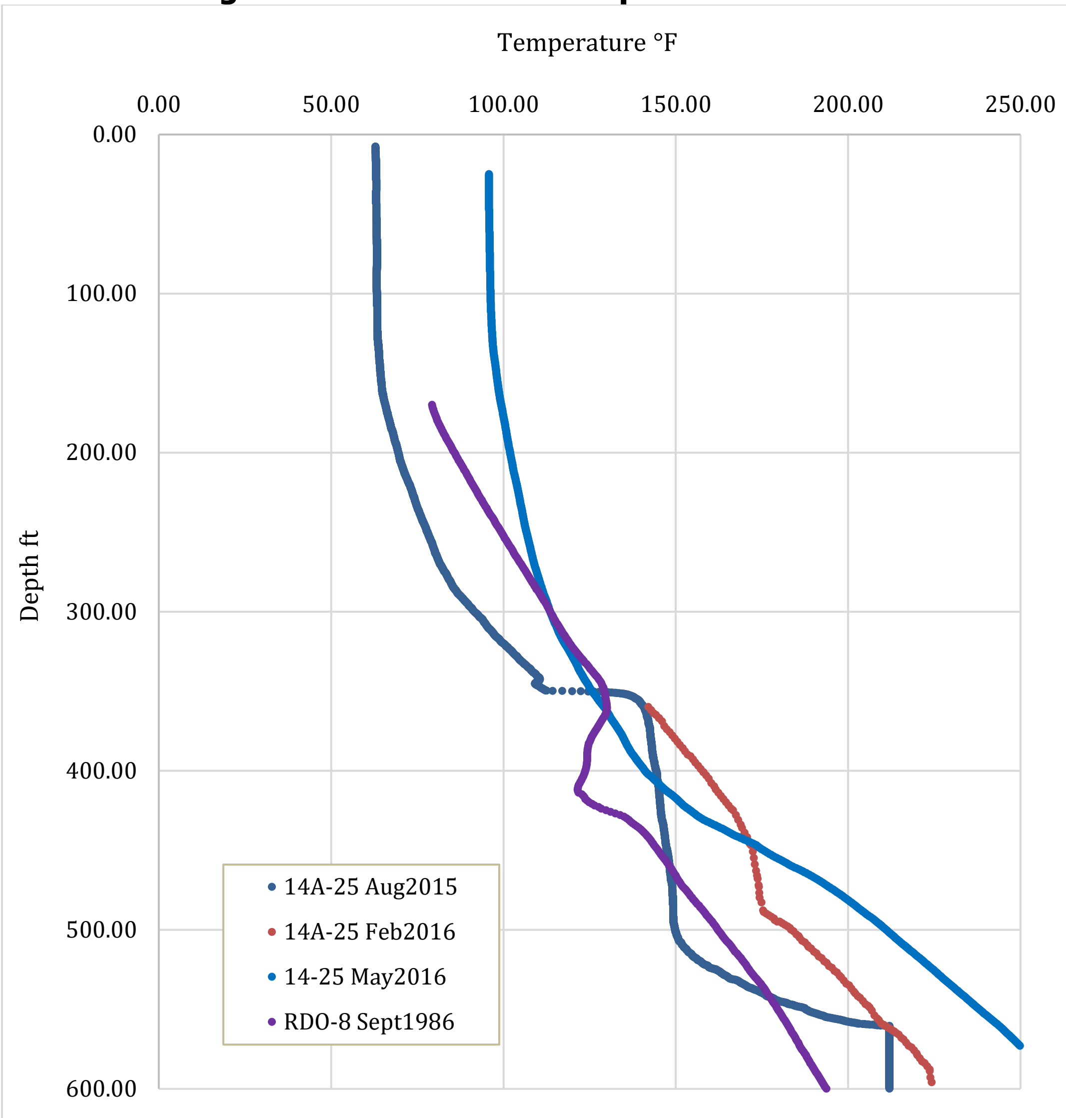
Ongoing data collection of Well 14A-25 was completed by the USGS as part of the groundwater monitoring program required by the BLM. Collected datasets included depth-to-water level from ground surface and fluid geochemistry. No water level data was recorded or reported by the USGS for ML02-2 from August 2016 until December 2017. The lapse in data collection was due to tubing that was dropped downhole, which blocked the wellbore and prevented the monitoring equipment from being reinstalled. A review of water level data prior to, during, and after the Well 14A-25 long-term flow test plus a completed geochemical analysis is discussed later in this report.

Table 2: Well 14A-25 Reported Lithologies

Depth from Surface (Initial)	Depth from Surface (Final)	Description Describe material, grain size, color, etc.
0	68	Interbedded silty sand and gravel [glacial till]
68	84	Silty Sand (f-vc) minor gravel (gran-peb, <1cm, sub-round to rounded) [crystal tuff]
84	90	Silty Sand (f-vc) minor gravel (gran-peb, <1cm, sub-round to rounded) [crystal tuff]
90	103	Silty Sand (f-vc) minor gravel (gran-peb, <1cm, sub-round to rounded crystal tuff, friable) [crystal tuff]
103	110	Sand(f-vc) and gravel(gran), minor pebbles (<2cm), sub-rounded, soft, iron staining [crystal tuff]
110	166	Sand(f-vc) and gravel (gran-peb, <2cm), sub-rnd, iron staining last few ft. [crystal tuff]
166	174	Sand(f-vc) minor granules, very hard [welded tuff]
174	181	Sand(m-vc) & gravel (gran), abundant dark reddish-brown grans [vesicular basalt]
181	196	Sandy (c-vc) gravel (gran-peb, <3cm, angular), very hard [vesicular basalt]
196	205	Sandy clay [tuff]
205	250	Clay, minor sand (f-c), very fine-grained [tuff]
250	340	Sand(m-vc) and gravel(gran-peb), hard, abundant qtz, local iron, chlorite, and biotite [Rhyolitic crystal biotite tuff]
340	350	Silty Sand (f-c) & gravel (gran-peb) trace pink gran, limonite stng [Contact, formation change to Early Rhyolite]
350	408	Abundant quartz, hard, lithic rich, greenish lithic fragments, coarsening downward [Early Rhyolite]
408	459	White-cream, abundant lt green lithic fragments, variable grain composition, conchoidal fracture [Early Rhyolite]
459	475	Highly altered zone, evidence of hydrothermal alteration [tuff breccia]
475	480	Dark Grey Glass & yellowish red granules, recemented clasts, altered clays and unaltered glass [tuff breccia]
480	576	Dark Gray Glass, silica rich, local felsic grains, local chlorite, angular, grain size decreasing down [Obsidian]
576	600	Abundant clay and water alteration, quartz, lithic rich, driller notes fractures [Altered rhyolitic tuff]

Source: Ormat Nevada, Inc.

Figure 5: Well 14A-25 Temperature Profiles



Temperature profiles for Wells 14A-25, 14-25, and RDO-8.

Source: Ormat Nevada, Inc.

Table 3: Well 14A-25 Thermal Gradients

Well	Gradient to 600 ft Depth (°F [°C] per 100ft)
14A-25	25.1 (-3.8)
14-25	21.984 (-5.6)
RDO-8	26.6 (-3)

Gradients for Wells 14A-25, 14-25, and RDO-8.

Source: Ormat Nevada, Inc.

Findings

Well 14A-25 was completed above the geothermal reservoir in an altered rhyolitic tuff. The maximum temperature of 224°F (106.7°C) along with the thermal conductive temperature gradient indicated that the monitoring well was in a heated, impermeable rhyolitic tuff. Initial data and follow up surveys concluded that the purpose of drilling Well 14A-25 was achieved, which is that the monitoring well could act as a shallow monitoring point within the Basalt Canyon geothermal well field.

Summary and Drilling History of Monitoring Well 28A-25

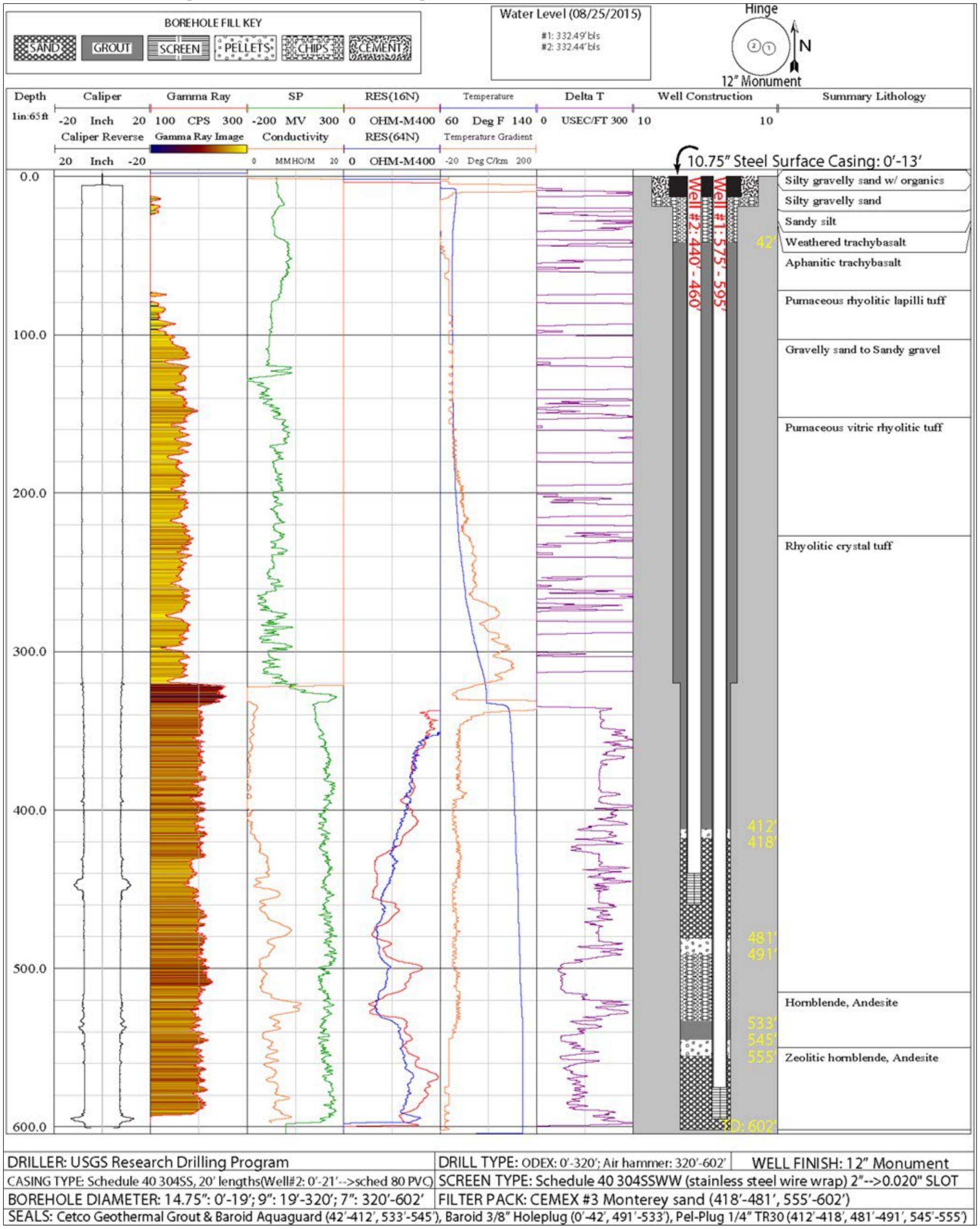
Summary

Monitoring Well 28A-25 (Well 28A-25) was drilled and completed in August 2015 by the USGS, not adjacent to any geothermal well. The well was drilled to a total depth of 602 ft and was dually completed with two tubing strings both 2-3/8 inches in diameter. The first completion (known as ML01-1) had tubing completed to a depth of 595 ft and the second (known as ML01-2) had tubing completed to a depth of 490 ft. The two completions were isolated from each other by a bentonite seal. The purpose of drilling Well 28A-25 was to allow for shallow monitoring above the geothermal reservoir in the southern portion of the Basalt Canyon area. Based on data collected from the monitoring well, this goal was achieved and Well 28A-25 could act as a monitoring point in the southern portion of the geothermal field. Data gathered from drilling Well 28A-25 included lithology, temperature, depth-to-water level, geophysics, and geochemistry.

Drilling History

The well was spudded August 13, 2015, and was completed August 22, 2015. The total depth was reached after five days of drilling. During drilling, the cuttings were logged onsite by a USGS hydrologist. Prior to completing the well, a suite of geophysical logs was collected downhole. To complete Well 28A-25, the two tubing strings were run downhole over a two-day period. The deeper tubing, ML01-1, was completed first and followed by the shallow tubing, ML01-2, on the second day. The two tubing strings (ML01-1 and ML01-2) were each completed in a filter pack composed of CEMEX 33 Monterey sand and are isolated from each other by a CETCO Geothermal Grout and Pel-Plug ¼-in TR30 coating. See the final schematic in Figure 6. Well 28A-25 is approximately 2,477 ft southeast of Well 14-25 (Figure 7). See Table 4 for location data as reported by the USGS.

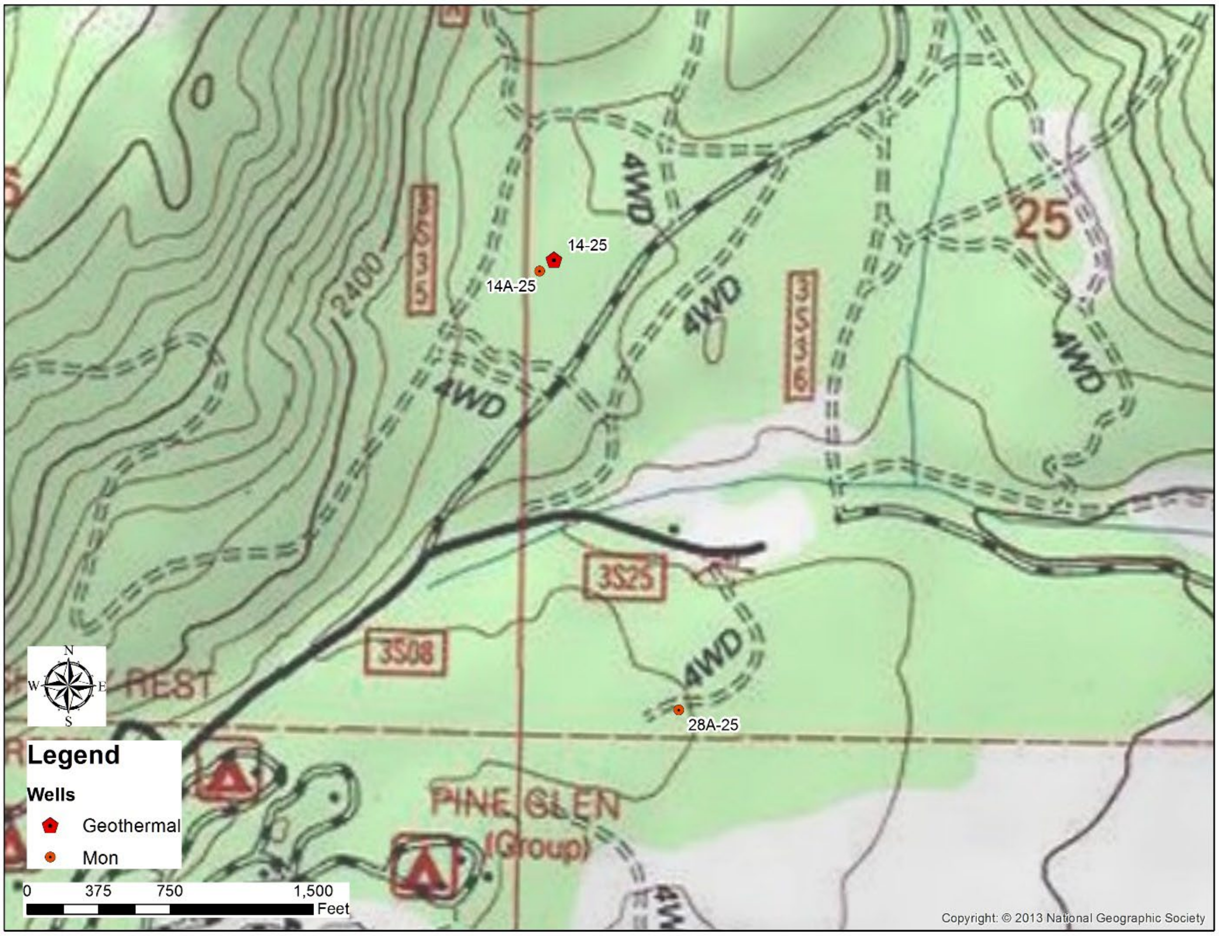
Figure 6: Monitoring Well 28A-25 Final Schematic



Final schematic of Well 28A-25. Downhole geophysical logs and stratigraphic column are also shown.

Source: USGS

Figure 7: Map of New Monitoring Wells and Geothermal Well 14-25



Location map of the new monitoring wells in relation to Well 14-25.

Source: Ormat Nevada, Inc.

Table 4: Location Data for Monitoring Well 28A-25

Latitude	Longitude	Elevation
37°39'04.7"	118°57'07.4"	7,783

Coordinate system: NAD 83. Elevation is in feet above NAVD88.

Source: USGS

Data Collected and Discussion of Results

Lithologies reported for Well 28A-25 were consistent with other downhole lithologies reported in the area. An upper section of silty gravels was underlain by a series of tuffs interlaid with basalt and andesite. The series of tuffs ranged from crystal tuff to lapilli tuff and the basalts are aphanitic to weathered trachybasalt. See Table 5 for the lithologic descriptions. Downhole geophysical logs were collected prior to completing the well, which included gamma ray, self-potential, conductivity, and resistivity (Figure 6). From these logs, two zones for monitoring were selected by the USGS. These two selected zones were completed as ML01-1 and ML01-2. The water table was measured at 332.44 ft from ground surface August 25, 2014, after the well had been completed. See Appendix B for the completion reported submitted by the USGS. After reaching a depth of 600 ft, a downhole temperature survey was collected prior to completion, and a follow-up temperature survey was collected in February 2016. The maximum temperature recorded in August of 2015 was 128.5°F (53.6 °C), and the maximum recorded in February 2016 was 127.6°F (53.1°C). Both temperature profiles had conductive profiles in the bottom 270 ft of the well. The wellbore did not heat up between surveys. In comparison to Well 14-25, Well 28A-25 had a lower recorded temperature at a depth of 600 ft (Figure 8). Even though the bottom hole temperature was lower than that of Well 14-25, the temperature gradient of Well 28A-25 was above background at 9.3°F (-12.6°C) per 100 ft. The observed elevated gradient and lower bottom hole temperature is expected based on where Well 28A-25 is located in the geothermal field. The monitoring well is located away from the geothermal wells within the southern portion of the Basalt Canyon geothermal area (Figure 9).

Ongoing data collection of Well 28A-25 was completed by the USGS as part of the groundwater monitoring program required by the BLM. Collected datasets included depth-to-water level from ground surface and fluid geochemistry. A review of water level data prior to, during, and after the Well 14-25 long-term flow test plus a completed geochemical analysis is discussed later in this report.

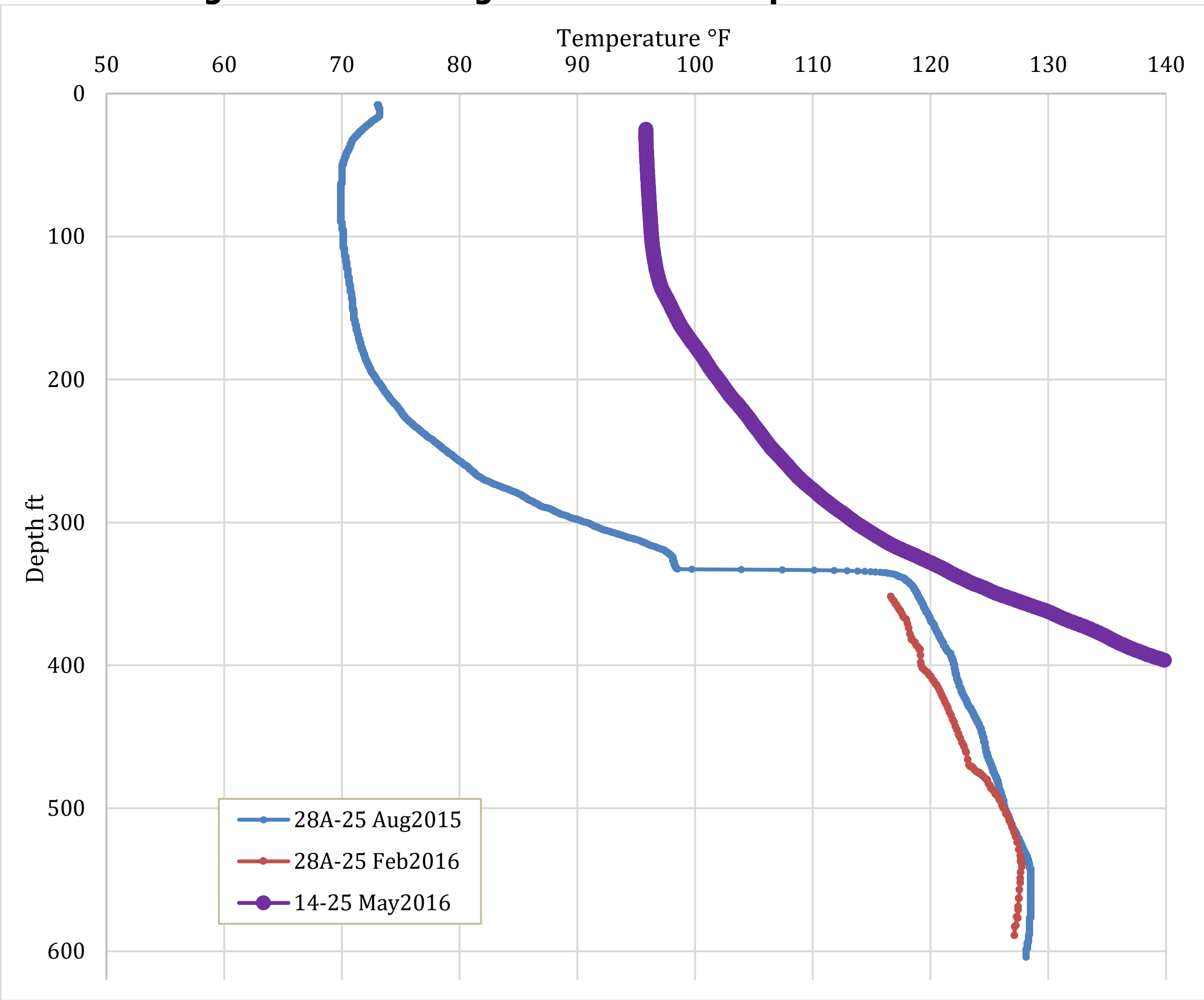
Table 5: Well 28A-25 Reported Lithologies

Depth from Surface in ft. (Initial)	Depth from Surface in ft. (Final)	Description **Describe material, grain size, color, etc.**
0	5	Silty gravelly (gran.-md.cob) sand(vf-vc) w/ abundant organic matter
5	21	Silty gravelly (gran.-md.cob) sand(vf-vc)
21	28	Sandy(vf-m) silt
28	31	Weathered Trachy basalt
31		Aphanitic trachy basalt w/minor calcite veining and hematite staining,
	72	Trace amygduoles/vesicules and olivine (1-2 mm, anhedral)
72	75	Pumaceous vitric rhyolitic lapilli tuff (backed contact w/overlying unit)
75	103	Pumaceous rhyolitic lapilli tuff w/basalt? Accidentals (gradational contact w/overlying unit?)
103	152	Slightly gravelly (g-v.lg. peb.) sand (vf-vc) to sandy gravel (volcaniclastic)
152	227	Pumaceous vitric rhyolitic tuff, moderately welded; Dark lense 170'- 173'
227	273	Rhyolitic x-tal (biotite 1-2mm anhedral, abundant quartz 1-4mm) tuff w/ 1-6mm pumice clasts
273		Rhyolitic x-tal (biotite 1-2mm anhedral abundant quartz 1-4mm) tuff w/ 1-6 mm pumice clasts
	291	limonite and hematite staining and dissolution pits (w/potential sulfides)
291	340	Rhyolitic x-tal (biotite 1-2mm anhedral, abundant quartz 1-4mm) tuff w/1-6m pumice clasts, trace limonite at 315'
340		Rhyolitic x-tal (biotite 1-2mm anhedral, abundant quartz 1-4mm) tuff w/
	515	1-6 pumice clasts, trace limonite and hematite
515		Hbl, Andesite w/ minor hematite, limonite, chlorite, and dissolution pits
	550	(discharge water change colors to rusty brown at 532'); (Canyon Lodge Andesite)
550	592	Zeolitic Hbl, Andesite w/abundant hematite, limonite, chlorite, and dissolution pits; (Canyon Lodge Andesite)
592		Zeolitic Hbl, Andesite w/abundant hematite, limonite, chlorite, and dissolution pits
	602	distinctly fractured; (Canyon Lodge Andesite)

Descriptions of lithologies reported from Well 28A-25.

Source: USGS

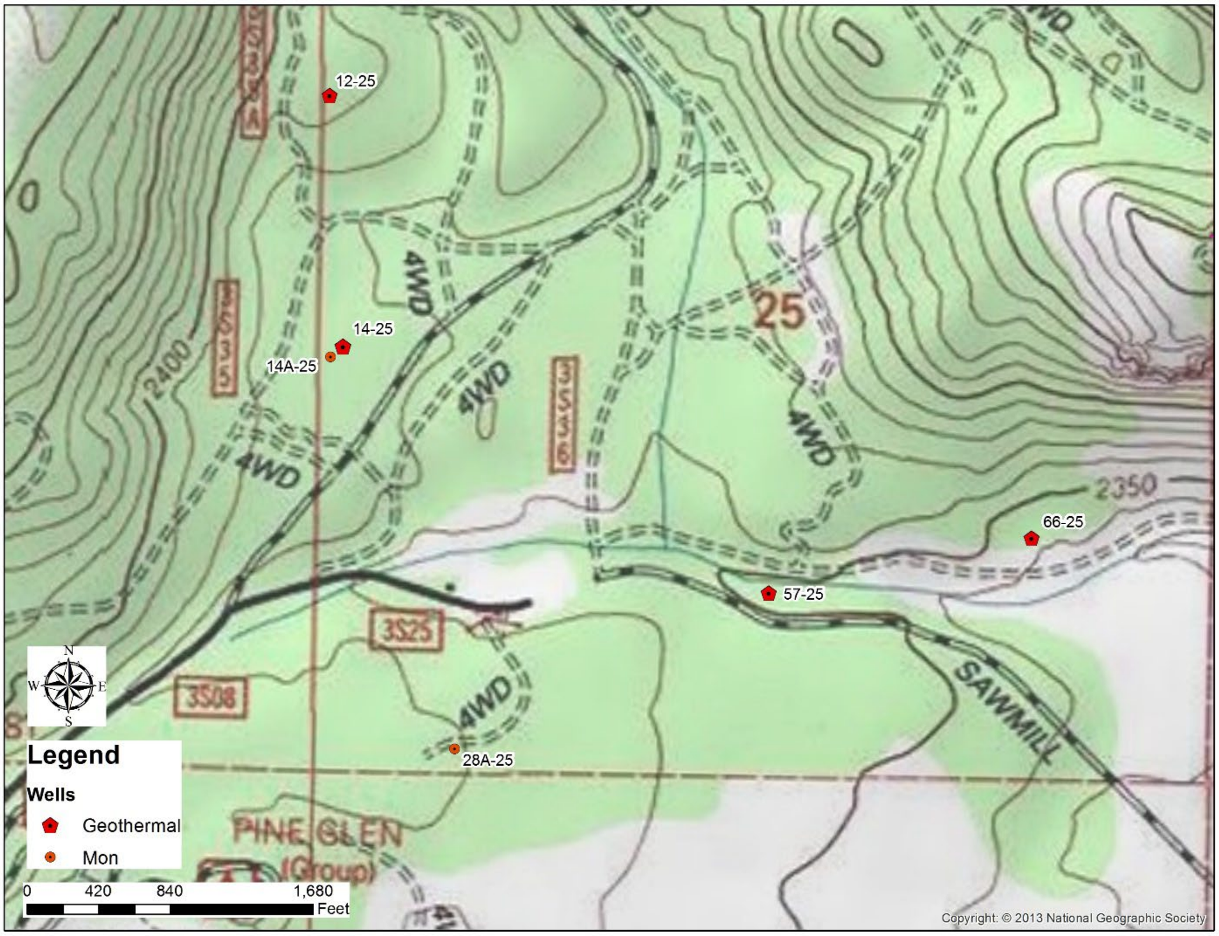
Figure 8: Monitoring Well 28A-25 Temperature Profiles



Temperature profiles for Wells 28A-25 and 14-25.

Source: Ormat Nevada, Inc.

Figure 9: Location Map of Well 28A-25



Location map of Well 28A-25 in relation to Well 14A-25 and the surrounding geothermal wells.

Source: Ormat Nevada, Inc.

Findings

Well 28A-25 was completed in a heated zone in the southern portion of the Basalt Canyon geothermal well field. The overall temperature was cooler than that of Well 14-25 but was still elevated (temperature gradient of 9.33°F [-12.6°C] per 100 ft). Initial data and follow up surveys concluded that the purpose of drilling Well 28A-25 was achieved, which is that the monitoring well could act as a shallow monitoring point above the geothermal reservoir.

CHAPTER 3:
Baseline Data Analysis

Types of Data Collected

Water Level

In both Wells 14A-25 and 28A-25, the water level from the surface was reported by the USGS in the National Water Information Systems (NWIS) or at https://nwis.waterdata.usgs.gov/nwis.[3] To navigate to the well data, use the map or search function to navigate to Mammoth Lakes, CA and select the "Groundwater Sites" box will display the wells and allow access to the data. The process for calculating the depth-to-water level from the raw pressure data was not provided. The data were continuously transmitted from each well via radio signal. Quality control of the monitoring equipment was performed each quarter by USGS personnel.

Geochemical

Each quarter the USGS collects a geochemical sample from Wells 14A-25 and 28A-25. To collect a fluid sample, the pressure monitoring equipment was removed from the well, and a portable pump was used to pump three wellbore volumes from the wellbore prior to a fluid sample being collected. The fluid sample was then sent to the USGS laboratory in Denver, Colorado. Quarterly fluid sampling was performed after the two monitoring wells were completed.

Analysis of Data

Water Level Baseline Temporal Trends

Continuous measurement of the water levels in Wells 14A-25 and 28A-25 established a baseline for detecting changes in the shallow regime as a result of production of the geothermal reservoir. Water levels were recorded for nearly two years with intermittent periods of no data collection. The periods of no data collection were assumed to be due to equipment malfunction or failure. Both Wells 14A-25 and 28A-25 showed changes in water level due to natural perturbations, such as drought conditions and recharge during drought recovery.[4] They also showed responses to barometric (atmospheric) pressure changes. Barometric fluctuations represent an overall stress applied directly at the surface and to the monitoring wells when they are open to the atmosphere.[5] Without full barometric data, Ormat was not able to determine whether the shallow monitoring wells were in unconfined or confined systems. If they are confined systems, the barometric responses would be

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3 U.S. Geological Survey. n.d. USGS Water Data for the Nation. Accessed November 2017. https://waterdata.usgs.gov/nwis/.

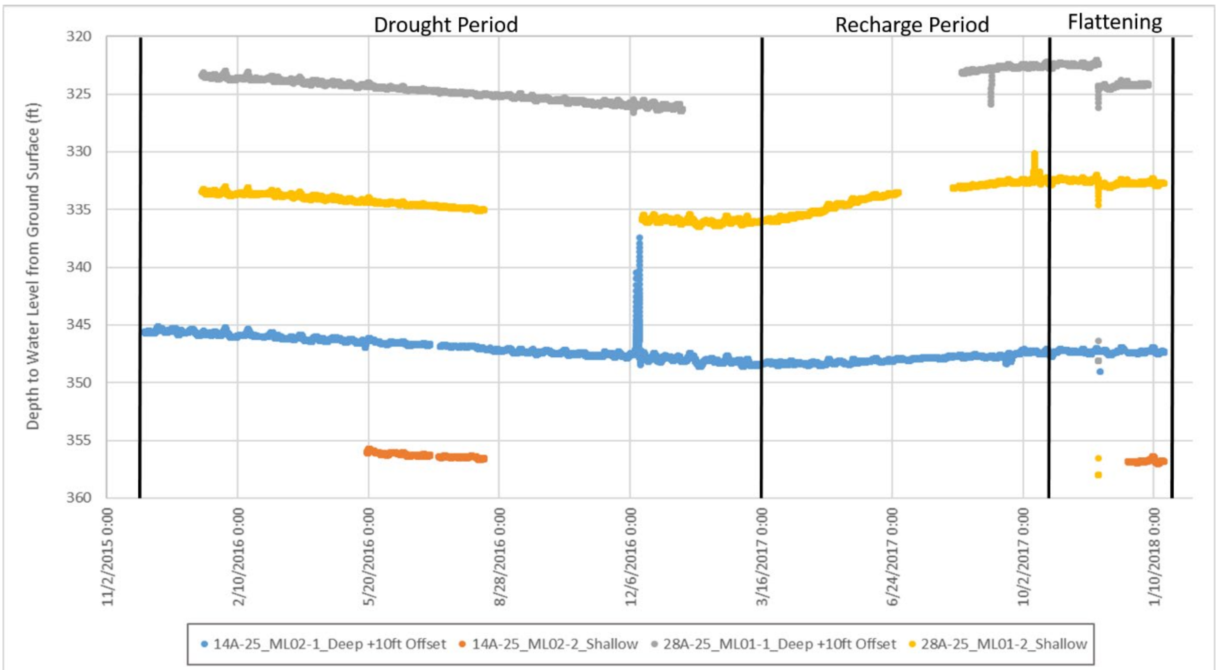
4 Howle, J. 2016. "Unpublished Provisional U.S. Geological Survey Data up to January 2016." Long Valley Hydrologic Advisory Committee. Mammoth Lakes, CA: U.S. Geological Survey, February.

5 Spane, Jr., F.A. 1999. Effects of Barometric Fluctuations on Well Water-Level Measurements and Aquifer Test Data. Richland: Pacific Northwest National Laboratory.

instantaneous and otherwise delayed if unconfined (Spane, Jr., 1999). The USGS presented preliminary data indicating the shallow wells were in a confined system (Howle, Unpublished provisional U.S. Geological Survey Data up to January 2016, 2016), but those data were not available to Ormat at the time. The barometric responses were cyclical in nature but do not obscure the general overall trend in water levels (rising or decreasing).

Both monitoring wells showed an overall decrease in water level starting in December 2015 (first available data point) until approximately mid-March 2017, during which time the Long Valley Caldera endured a drought. From mid-March to approximately mid-November 2017, a natural recharge or rise in water level was observed during a period of recovery following a long winter and substantial amount of precipitation.[6] The trends from mid-November 2015 to January 2018 appear to flatten or level out. Figure 10 and Figure 11 show the natural trends in water levels from December 2015 up to January 2018.

Figure 5: Water Level Temporal Plot for Wells 14A-25 and 28A-25 With a 10 Ft Offset



Plots showing temporal trends of Wells 14A-25 and 28A-25. The two deep completions of Wells 14A-25 and 28A-25 are shown with a 10 ft offset to distinguish them from the shallow completions.

Source: Ormat Nevada, Inc.

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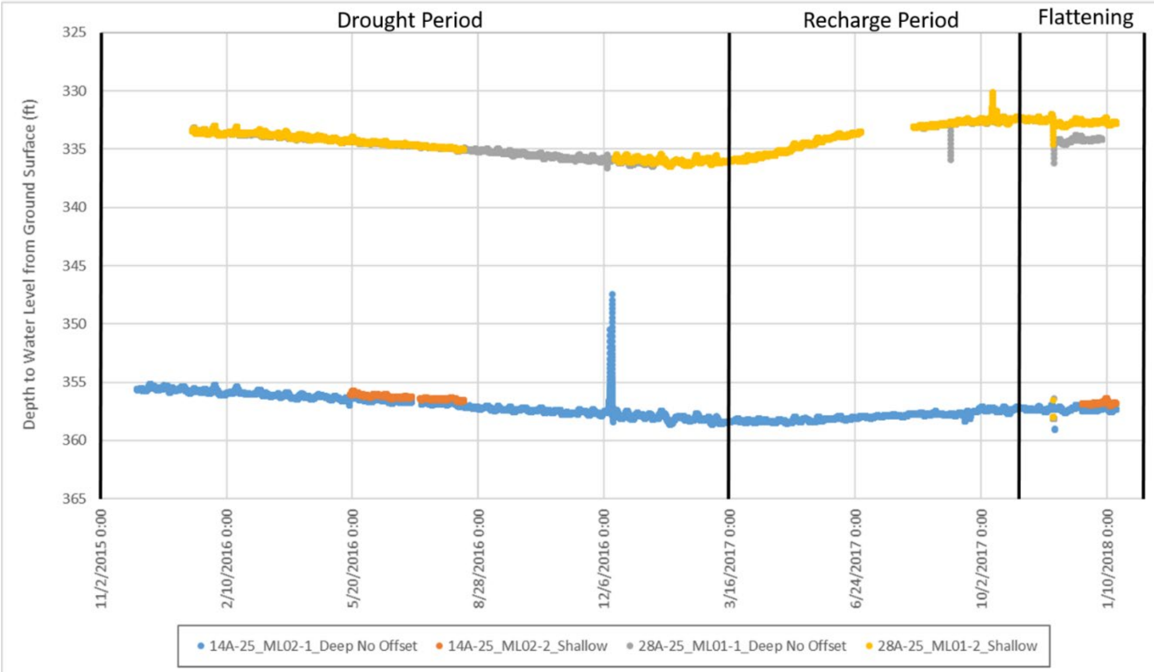
6 Howle, J. 2017. "Unpublished Provisional U.S. Geological Survey Data up to July 2017." Long Valley Hydrologic Advisory Committee. Mammoth Lakes, CA, July.

Figure 6: Water Level Temporal Plot for Wells 14A-25 and 28A-25 Without the 10 Feet Offset



Plots showing temporal trends of Wells 14A-25 and 28A-25. No data are offset in this plot in comparison to Figure 10.

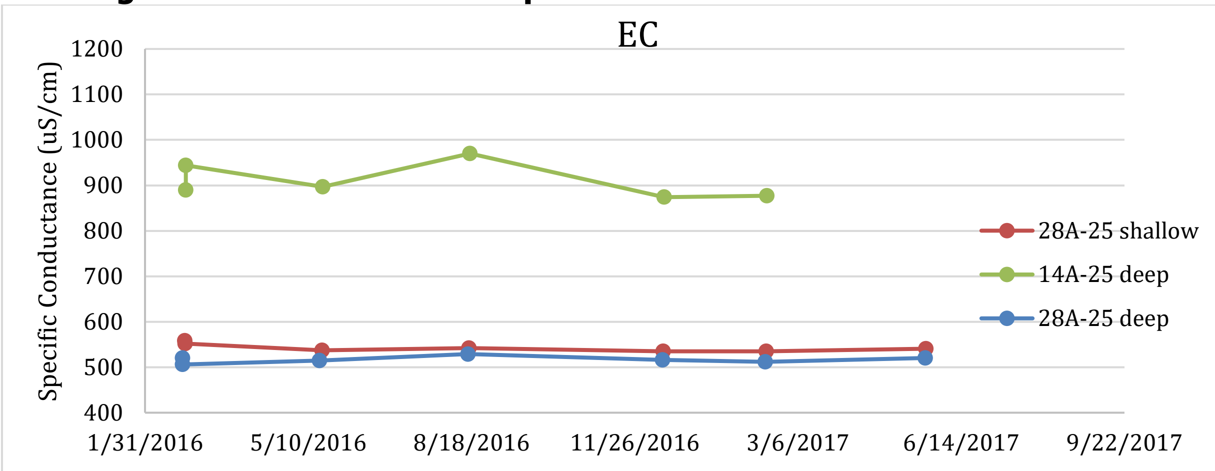
Source: Ormat

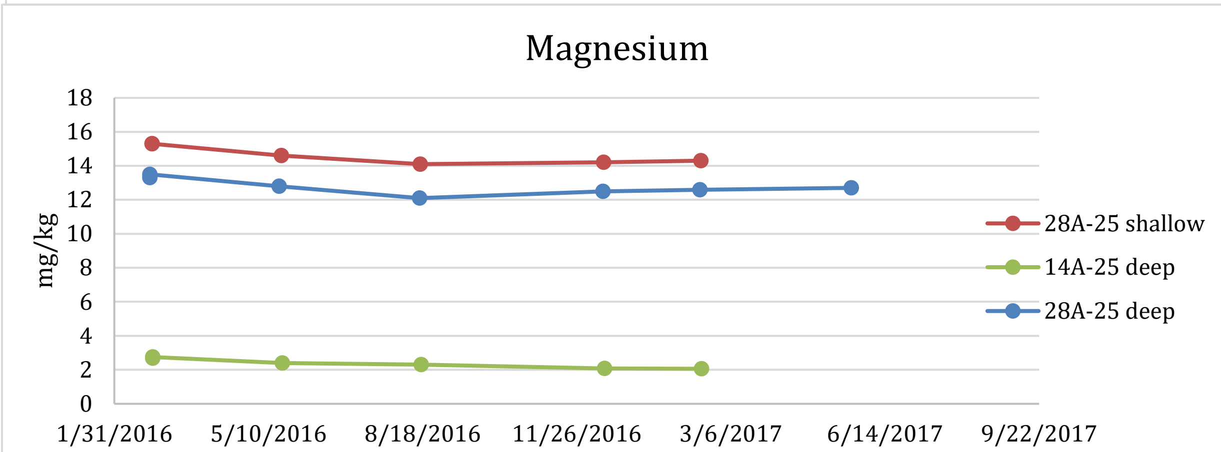
Geochemical Baseline Temporal Trends

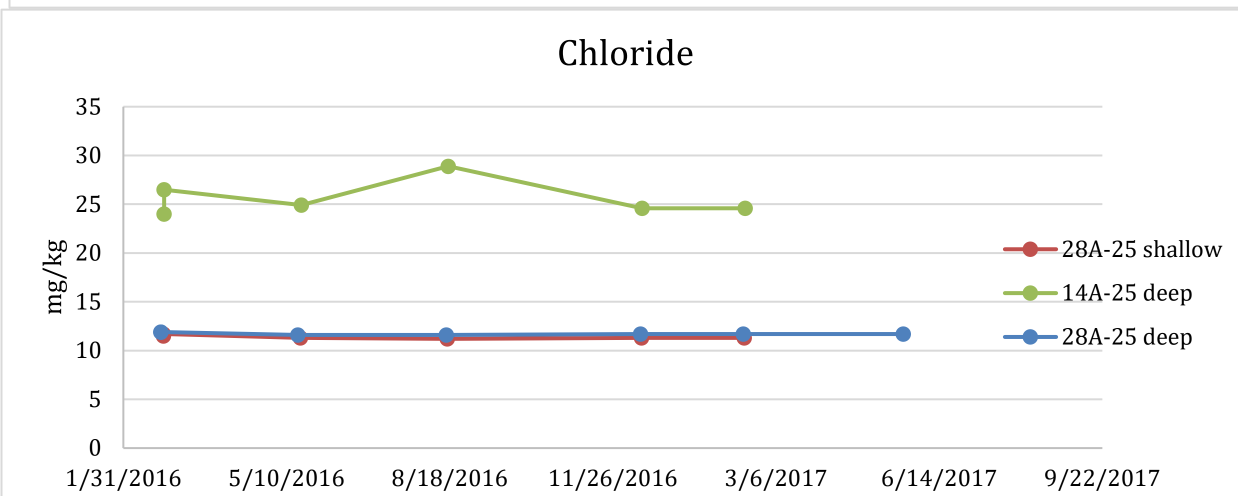
Continuous sampling of Wells 14A-25 and 28A-25 established a more robust baseline for detecting future mixing or perturbations between the Basalt Canyon well field and surrounding dilute water sources. Fifteen months of data are available for Monitoring Well 14A-25 and 18 months of data for Well 28A-25 well. Fluids from these monitoring wells appeared to be establishing a steady–state trend for all major constituents with minor fluctuations, likely due to seasonal variations and influences from snowmelt or recharge. Plots for major reactive (sulfate [SO_4^{2-}], magnesium [Mg]) and conservative (chloride [Cl], electrical conductivity [EC]) species demonstrate this in Figure 12.

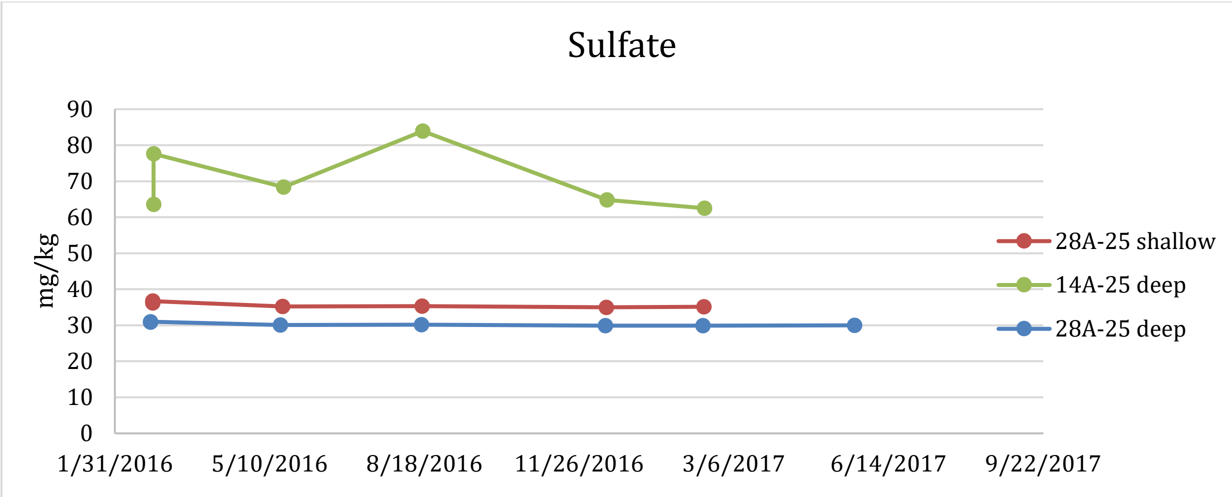
Establishing the range of variation for each of these constituents prior to development is important for delineating true perturbations due to drawdown or leakage, and that within normal seasonal conditions. Additional work is necessary to compare these baseline data to meteoric conditions, rates of precipitation, snowpack, and fluid ages to fully understand sources of recharge and expected future variations, and these monitoring well chemistries will be a vital tool for monitoring the influence of geothermal development.

Figure 7: Geochemical Temporal Plot of Wells 14A-25 and 28A-25









Temporal plot of electrical conductivity, sulfate, silica and magnesium for Wells 14A-25 and 28A-25.

Source: Ormat Nevada, Inc.

CHAPTER 4: Test of Idle Geothermal Wells to Determine Connectivity of the Shallow Groundwater System and the Geothermal Reservoir

Test and Timeline of Test Events

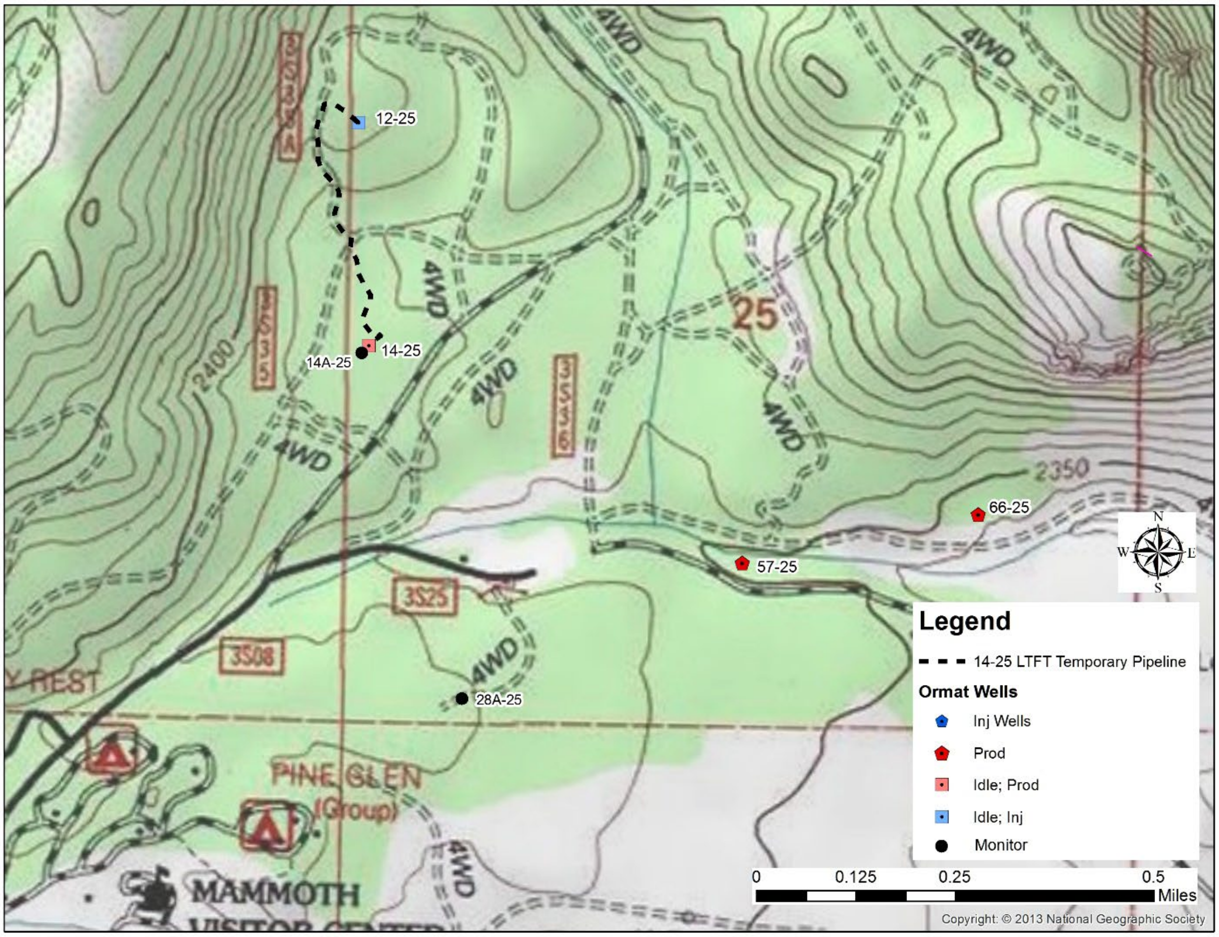
Test Overview

The long-term flow test (LTFT) for Well 14-25 began August 26, 2017, at noon when the downhole production pump in the well was started. Injection into Geothermal Well 12-25 was initiated after approximately one hour of filling tanks and temporary pipeline. On August 27, 2017, at approximately 2:39 pm, the 2-Naphthalene sulfate (2-NSA) tracer was injected into Well 12-25. The test continued without interruption until a mechanical error caused temporary shutdown at 4:00 am September 19, 2017. The mechanical error was due to the failure of the primary and backup transfer pumps on the wellpad for Well 14-25. The test was brought back on line five hours later at 9:00 am. At 1:00 pm September 22, 2017, the Well 14-25 production pump was turned off, and at 2:00 pm, the last of the fluid was injected into Well 12-25, completing the long-term test. See Figure 13 for a layout of the well configuration. Figure 14 shows a timeline of events.

To achieve production of Well 14-25, a downhole pump was installed, and two generators were brought on site to power the pump motor for the duration of the test. At the wellhead, both the annulus pressure and wellhead pressures were monitored. The Well 14-25 bubbler pressure was also monitored via a gauge installed on the tubing that ran downhole to a depth of 1200 ft. The brine produced from Well 14-25 was discharged through a steel pipeline to an atmospheric flash vessel. Along the discharge pipeline, both manual gauges and one digital meter were installed to measure discharge temperature, flow rate, and pressure. A 1-inch valve was also installed along the discharge pipeline for collecting fluid samples.

From the flash vessel, the flashed brine was separated into four 21,000-gallon BakerCorp tanks. A transfer pump downstream of the four BakerCorp tanks transferred brine through a temporary braided steel pipeline up to the Well 12-25 injection pad. On the Well 12-25 injection pad, four additional 21,000-gallon BakerCorp tanks were placed downstream of the temporary pipeline. Downstream of the tanks, an injection pump was used to pump the brine from the tanks through a steel pipeline into Well 12-25. Along the injection pipeline, both manual gauges and one digital meter were installed to monitor injection pressure, flow rate, and temperature. The pressure of Well 12-25 well was recorded from a gauge installed at the wellhead. When possible, redundant equipment was installed to minimize the chances of shutdown from equipment malfunction. Redundant equipment included backup transfer pump, backup temporary braided steel pipeline, and backup injection pump. A generalized layout of the testing equipment is shown in Figure 15. See Appendix C for photos of the testing equipment.

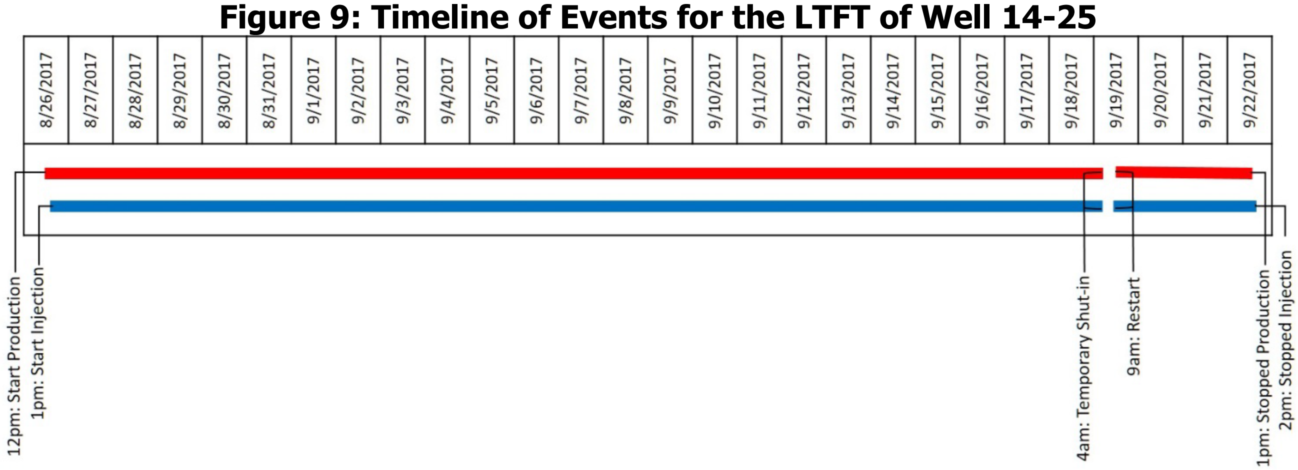
Figure 8: Location Map of the LTFT for Well 14-25



Location map of the LTFT for Well 14-25. Nearby geothermal wells and monitoring wells are also shown.

Source: Ormat

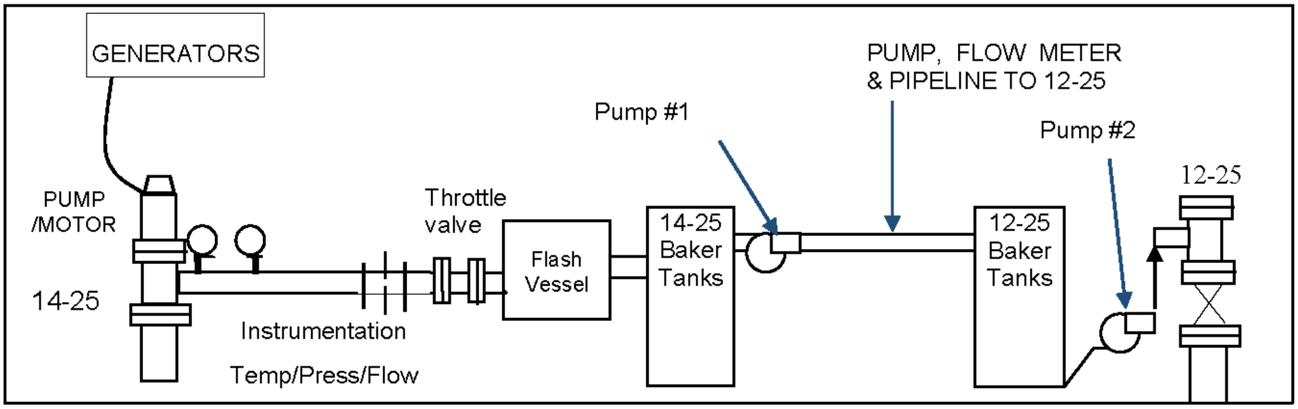
Figure 9: Timeline of Events for the LTFT of Well 14-25



Timeline of events from startup to completion of the LTFT.

Source: Ormat

Figure 10: Layout of the Testing Facility



Generalized layout of the testing facility.

Source: Ormat

Test Data

Flow Rate, Bubbler, Discharge Pressure, Temperature

During the 28-day test, the average discharge pressure (pressure at the surface) was 222 pounds per square inch gauge (psig) and controlled to achieve flow rate and prevent gas breakout. The average production rate was 1,227 gallons per minute (gpm), the average bubbler pressure (downhole pressure at the pump suction) was 278 psig, and the average temperature was 333°F (167.2°C). During the 28-day test, the average injection rate was approximately 976 gpm, the average temperature of the injectate was 174°F (78.9°C), and the average wellhead pressure was 0 psig.

See Appendix D for the complete set of data recorded during the LTFT for Well 14-25.

Tracer Analysis

A 7.5 weight percent mixture of 2-NSA tracer powder and brine was injected into geothermal Well 12-25 using a high-capacity pump. Tracer injection began at 14:39 on August 27, 2017, and lasted 10 minutes while injecting brine at full capacity into Well 12-25 (approximately 950 gpm). The research team estimated a final downhole concentration (C_o) of 0.2 weight percent or 2,000,000 parts per billion (ppb) (Table 6) This concentration is sufficient to be detected in regional wells.

Numerous wells had fluid samples collected for tracer analysis before, during, and after the 28-day test: Wells 14-25, 14A-25, 28A-25, and several MCWD wells (one monitoring well and the rest were production wells). The analysis of tracer returns in these wells allowed for a direct measure of fluid connection with Well 12-25. The wells were sampled at various intervals according to the likelihood of tracer returns and whether or not they were regularly pumped/produced. Fluid samples were sent to the Energy and Geoscience Institute at University of Utah for analysis. See Appendix E for the tracer return dataset.

Table 6: Tracer Injection Summary During the LTFT for Well 14-25

Injection Wellhead Pressure, psi	0
Injection Flow Rate, gpm	950
Injectate Temp, °F (°C)	179 (81.7)
Tracer	2-NSA
Powder Amount	75kg
Injectate Volume mixed	1000L
Initial Concentration	7.5 weight percent
Concentration injected in 10 minutes	0.2 weight percent
Actual injection Date/Time	August 27, 2017, 14:39

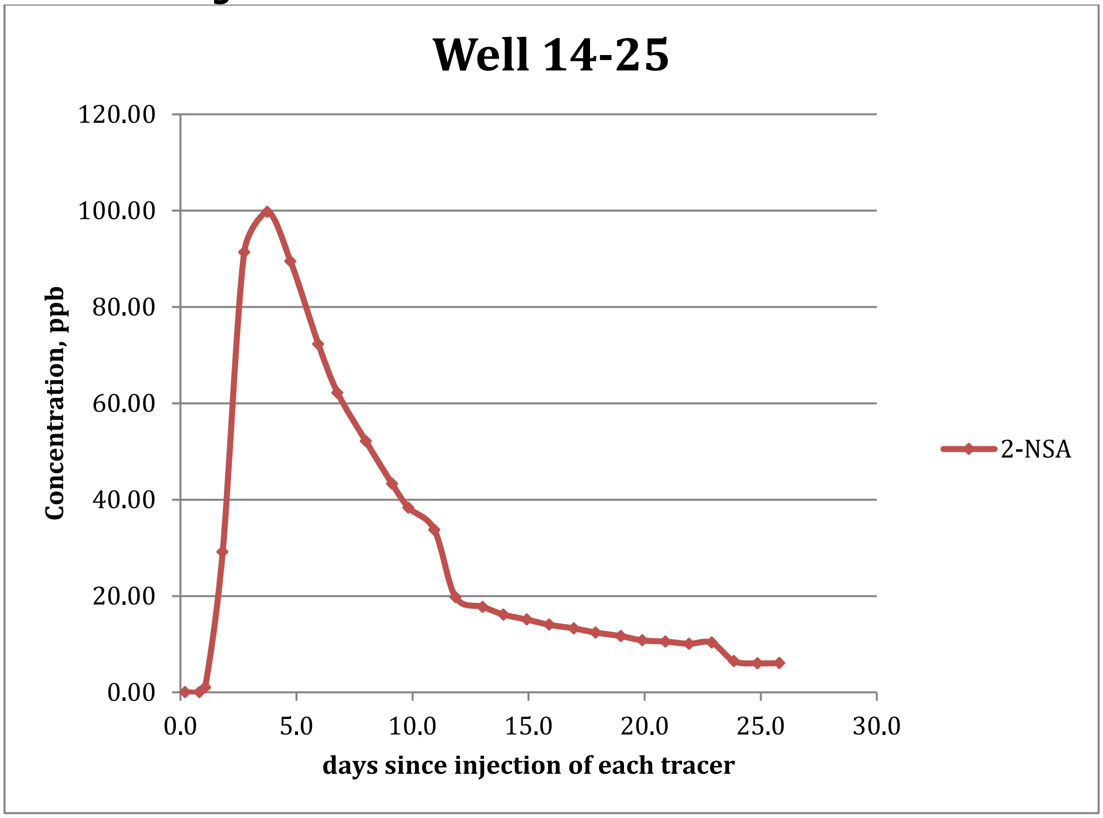
Source: Ormat

Geothermal Well 14-25

Samplings for tracer returns in Well 14-25 were performed on a daily basis for the duration of the test. Samples were collected through a 1-inch sample port that was located along the Well 14-25 discharge pipeline upstream of the atmospheric flash vessel. The fluids were cooled through a conductive cooling coil from a temperature of approximately 335°F (168.3°C) to a temperature of approximately 68°F (20°C); evaporation was determined to be negligible through this sampling process.

Initial tracer returns were identified in Well 14-25 after one day (1.02 ppb on 8/28/2017) and peaked in less than four days (99.77 ppb on 8/31/2017). Tracer concentrations declined after the peak to 6.05 ppb on the last day of the flow test on 9/22/2017). See Figure 16 for the tracer return curve.

Figure 16: Tracer Return Curve for Well 14-25



Tracer return curve observed in Well 14-25.

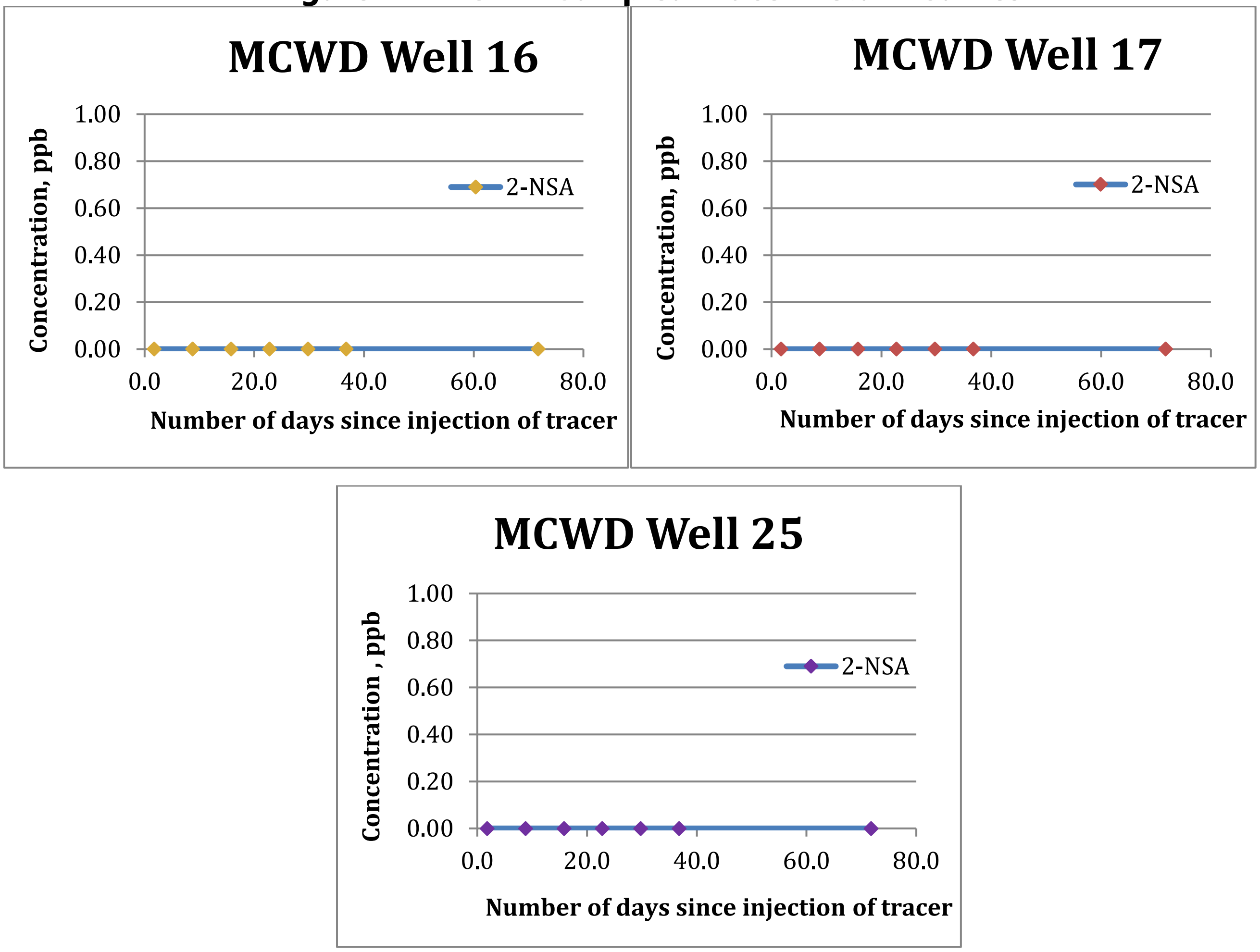
Source: Ormat

MCWD Wells

At the time of the LTFT, the MCWD production wells were not being used continuously and were primarily produced only to collect a tracer sample. A full history of the production during the LTFT was not provided to Ormat. Three of the wells (16, 17, and 25) were sampled by MCWD throughout the duration of the test on a weekly basis. MCWD continued sampling these three wells on a monthly basis following the completion of the test. See Figure 17 for the tracer return curves. The USGS also collected tracer samples from a number of MCWD production wells both before and after the LTFT: P-1, -6, -15, -16, -17, -20, and -25 (samples P-16, P-17, and P-25 were repeat samples of MCWD 16, 17, and 25). (See Figure 18.) This sampling was performed as part of their quarterly sampling in accordance with the GMRP. No tracer was detected in any of production wells. See the Discussion subsection for analysis.

Monitoring well M26 was sampled by the USGS before and after the LTFT as part of their regular quarterly sampling routine. Well M26 was not equipped with a permanent pump and therefore could not be pumped/sampled during the 28-day test. Again, no tracer was detected (Figure 19).

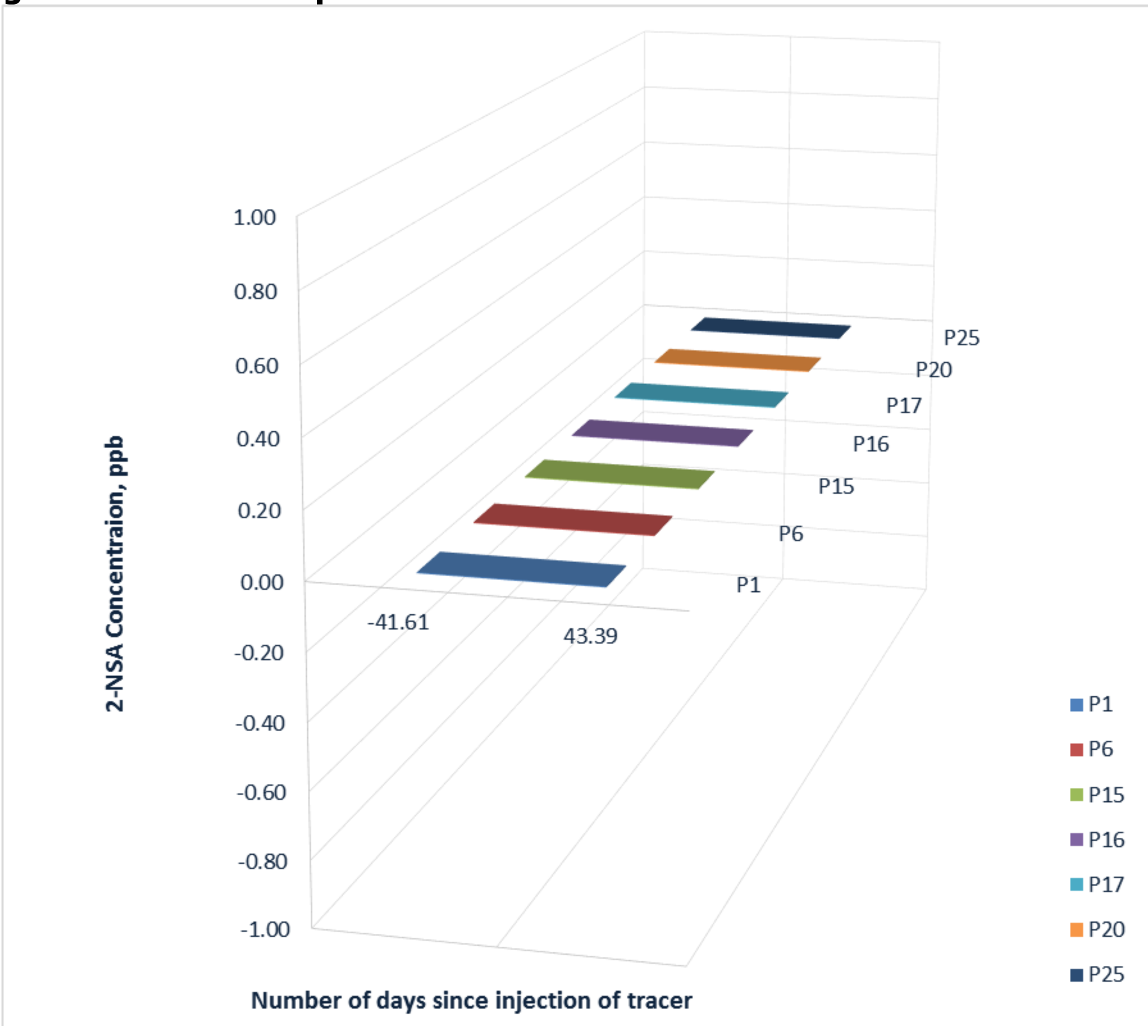
Figure 17: MCWD-Sampled Tracer Return Curves



Tracer return curves from three MCWD production wells (16, 17, and 25). The three wells were sampled by the MCWD.

Source: Ormat

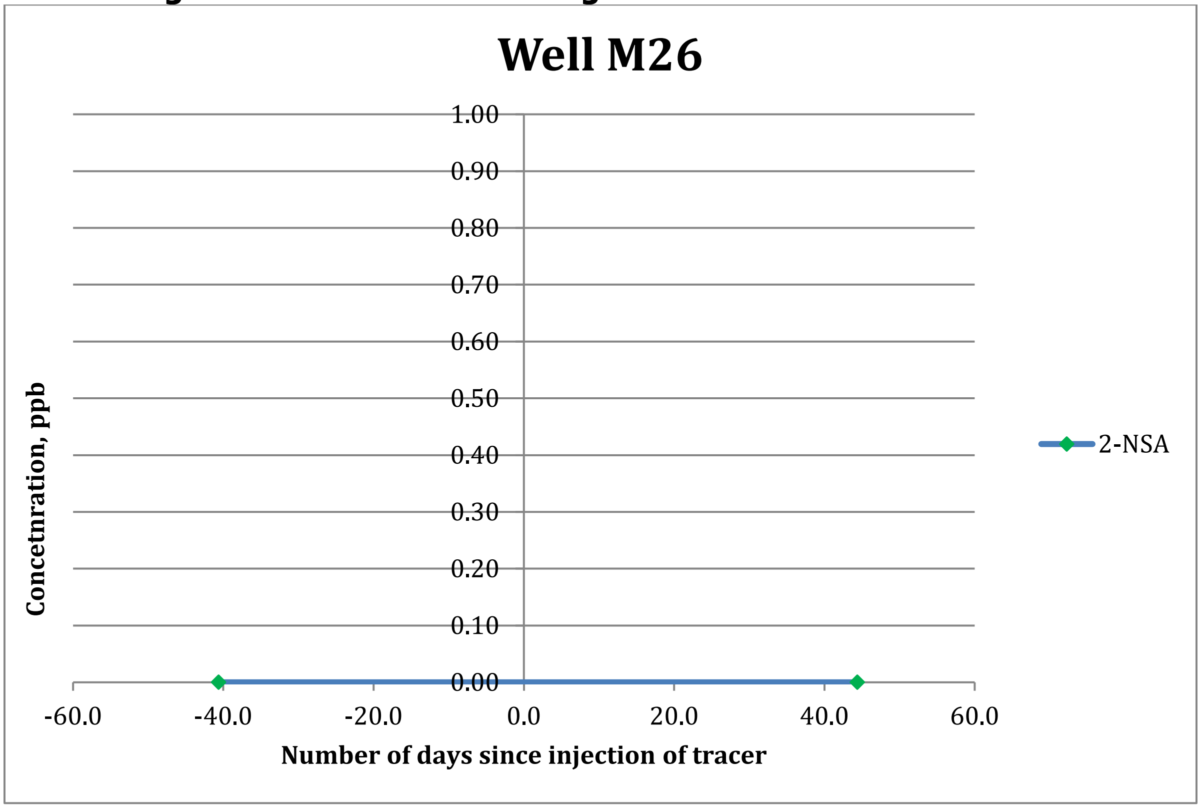
Figure 18: USGS Sampled Tracer Return Curves for MCWD Production Wells



Tracer return curves for MCWD production wells sampled by the USGS prior to and after the LTFT.

Source: Ormat

Figure 19: MCWD Monitoring Well 26 Tracer Return Curve



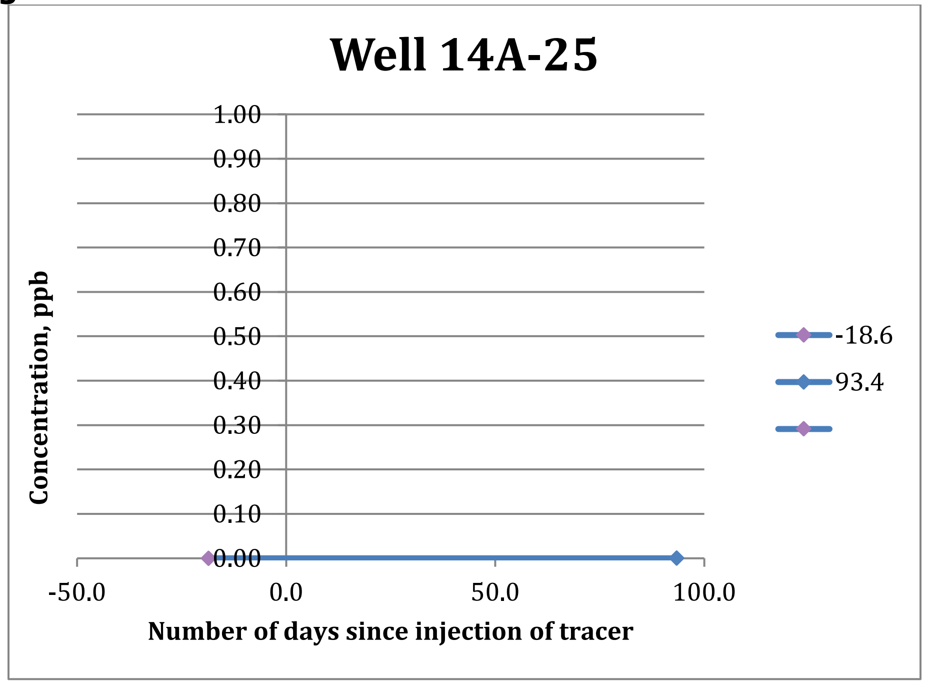
Tracer return curve for MCWD Monitoring Well 26 sampled by the USGS prior to and after the LTFT.

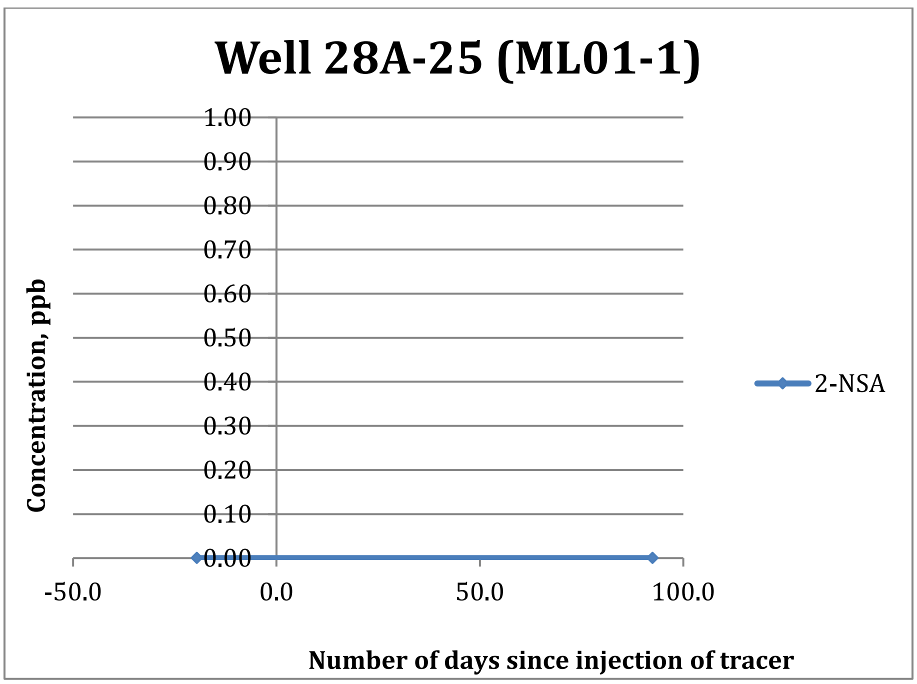
Source: Ormat

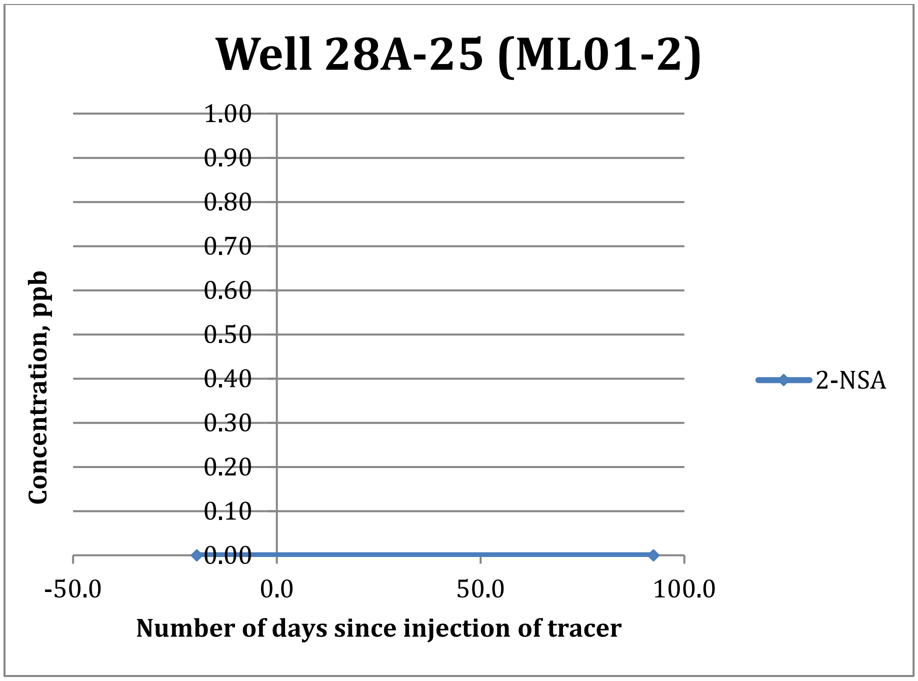
Monitoring Wells 14A-25 and 28A-25

The USGS collected tracer samples from Wells 14A-25 and 28A-25 (ML01-1 and ML01-2) before and after the LTFT as part of their regular quarterly sampling. Neither well was equipped with a permanent pump and therefore could not be pumped/sampled during the 28-day test. Only one completion of Well 14A-25 was sampled for tracer (ML02-1). Completion ML02-2 had no geochemical or pressure monitoring since August 2016 when tubing was dropped downhole blocking the borehole. No tracer was detected in Wells 14A-25 and 28A-25 (Figure 20).

Figure 12: Tracer Return Curves for Wells 14A-25 and 28A-25







Tracer return curves for Wells 14A-25 and 28A-25.

Source: Ormat

Discussion

Injection of tracer into Well 12-25 at the start of the LTFT was implemented to assess the hydraulic connection between Wells 12-25 and 14-25 within the geothermal reservoir. The return curve of Well 14-25 indicated there was a strong connection between Wells 12-25 and 14-25, likely along a fault as evidenced from the strong peak associated with the first arrival of the tracer. The return rate could be used in additional reservoir modeling to calibrate the model and for finalizing locations of geothermal wells in the Basalt Canyon area. The lack of tracer returns to any of the MCWD wells or to Wells 14A-25 and 28A-25 confirmed the lack of hydraulic connection between the geothermal reservoir and the shallower systems directly above the geothermal reservoir (Well 14A-25), to the southeast (Monitoring Wells 28A-25 and MCWD 26), and to the southwest (MCWD production wells). Well 14A-25 saw a minor pressure response to the LTFT (see the Water Level Analysis subsection), but the warm fluids measured in Well 14A-25 were not immediately connected to the geothermal fluids in Well 14-25, as observed by the lack of tracer returns and from the geochemical analysis. (See the Chemistry Analysis subsection.)

Water-Level Analysis

Observing and measuring changes in water levels in the shallow monitoring wells before, during, and after the LTFT allowed for assessment of the pressure response between them and the geothermal reservoir when natural and unnatural causes were eliminated. Changes in water level can occur due to natural recharge from increased precipitation, barometric effects, or improper calculation of depth-to-water level from the raw pressure data (an unnatural cause). The assessment of pressure response does not allow for the assessment of hydraulic connection between the shallow monitoring wells and the deeper geothermal system. Ormat had access to water-level data for both Wells 14A-25 and 28A-25, but data for the MCWD wells were not provided.

Data

Water-level data for the two monitoring wells were downloaded from the NWIS website: https://nwis.waterdata.usgs.gov/nwis. No corrections were made to the data and are presented here verbatim. Cyclic fluctuations associated with changes in barometric pressure in all datasets were not corrected for and, in the case of Well 14A-25, mask the exact water levels at the start and finish of the Well 14A-25 LTFT. To remove the barometric effects, a record of atmospheric pressure is required.[7] The water level for the shallow Well 14A-25 was only recorded and reported for the ML02-1 completion; the USGS has not recorded or reported data for the ML02-2 completion since mid-2016 because tubing dropped downhole and blocked the wellbore. Water levels for shallow Well 28A-25 were recorded and reported for both completions (ML01-1 and ML01-2). See Appendix F for the complete record of water levels recorded and reported by the USGS.

On August 26, 2017, before the start of the pump in Well 14-25, Well 14A-25 (ML02-1) was estimated to have a water level of 357.74 ft below ground surface. At the completion of the test for Well 14A-25 (ML02-1), the estimated water level was 358.16 ft below ground surface, equal to an estimated 0.42-ft decrease in water level during the 28-day period (Table 7). This amount of decrease was the maximum estimate of decrease but could be much less if the barometric effects were corrected for a more accurate reading. A decrease in 0.42 ft of water level equates to approximately 0.18 change in pressure (psi). The water-level trend before the test showed a slight rise, but is nearly static (when barometric effects are ignored), similar to the trend observed during the Well 14-25 LTFT (Figure 21). After the completion of the LTFT, the water level rose approximately 0.25 ft. Noncyclic fluctuations in water level at the very beginning of the test, at the time of the temporary shut-in September 19, 2017, and at the completion of the test were also observed in Well 14A-25 (Figure 21).

On August 26, 2017, Well 28A-25 had water levels of about 333.03 ft (ML01-1) and 333.02 ft (ML01-2) below ground surface. At the completion of the test, Well 28A-25 had water levels of about 332.65 ft (ML01-1) and 332.63 ft (ML01-2) below ground level, equal to 0.38 ft and 0.39 ft increase in water level, respectively, during the 28-day period (Table 7). The rise in water level observed in Well 28A-25 was on trend with the rising trend observed prior to and after the LTFT (Figure 21). No change in water level was observed related to the temporary shut-in of the test September 19, 2017 (Figure 21).

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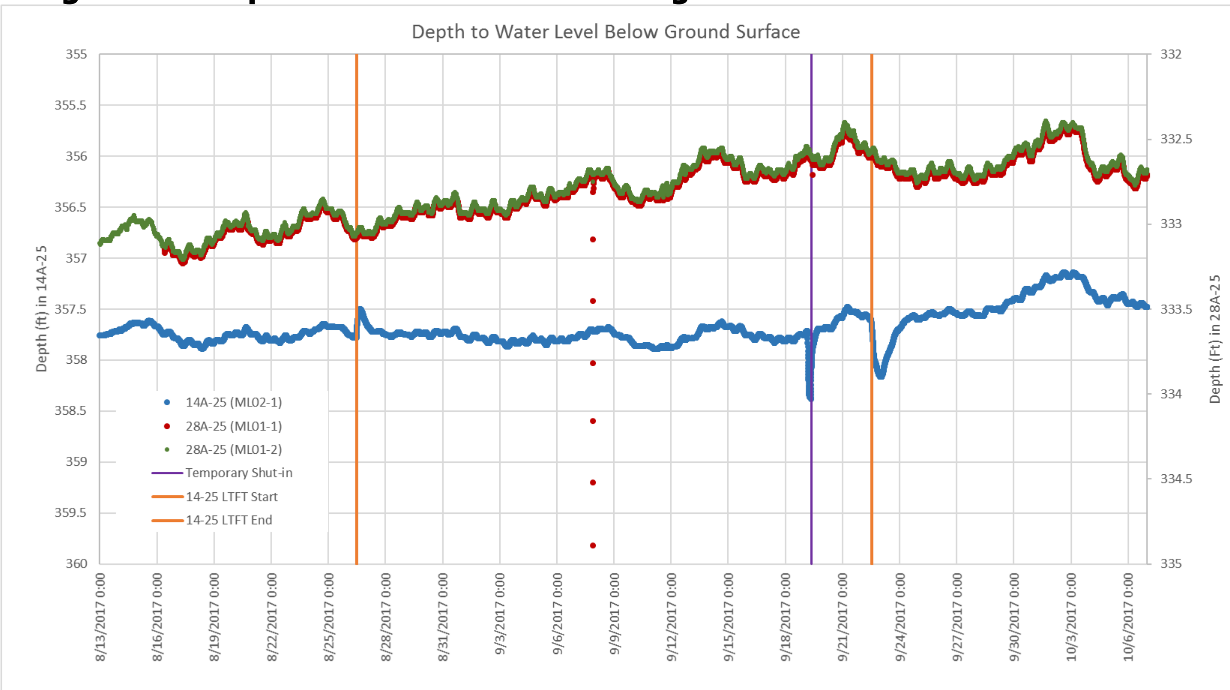
7 Spane, Jr., F.A. 1999. *Effects of Barometric Fluctuations on Well Water-Level Measurements and Aquifer Test Data*. Richland: Pacific Northwest National Laboratory, https://www.osti.gov/servlets/purl/15125.

Figure 13: Reported Water Levels During the LTFT for Wells 14A-25 and 28A-25



Reported water levels from the USGS before, during, and after the Well 14-25 LTFT.

Source: Data downloaded from https://nwis.waterdata.usgs.gov/nwis

Table 7: Depth-to-Water Level from Ground Surface Before and After the LTFT

Date	Well 14A-25 (ML02-1)	Well 14A-25 (ML02-2)	Well 28A-25 (ML01-1)	Well 28A-25 (ML01-2)
8/26/2017	357.74	NR	333.03	333.02
9/22/2017	358.16	NR	332.65	332.63
Difference:	0.42	N/A	-0.38	-0.39

Depth-to-water level in each monitoring well before and after the LTFT. All depths are in feet. Positive difference in depths equate to a decrease in water level and negative difference in depths equate to a rise in water level.

Source: Ormat Nevada, Inc.

Discussion

Natural fluctuations in water level were seen in both Wells 14A-25 and 28A-25, including barometric effects and recharge of the system. The recharge or rise in water level was easily observed in Well 28A-25 but less obvious in Well 14A-25. Because of barometric changes, the exact depth-to-water level in both monitoring wells at the start and completion of the LTFT was masked and can only be estimated. Verification of the calculated depth-to-water levels could not be performed by Ormat because the raw pressure data for the monitoring wells were not available.

With Ormat's best attempt to ignore natural variations, Well 14A-25, which is approximately 100 ft from Well 14-25, showed a very minor decrease in water level during the test. The total decrease in water level was estimated to be 0.42 ft at 0.18 psi, assuming 1ft of water column exerts a pressure of 0.433 psi. A more reliable indicator of pressure response in Well 14A-25 was the noncyclic fluctuation observed at the start of the test August 26, 2017. This response was likely due to the formation of gas bubbles within the geothermal reservoir when the pump was turned on. Startup of the pump formed a low-pressure regime immediately surrounding the wellbore in which bubbles were formed. This phenomenon was short-lived and didn't extend for the duration of the test. A response to the temporary shut-in was not witnessed at Well 28A-25, located approximately 2477 ft southeast of Well 14-25. The small change in water level observed in Well 14A-25 and the lack of response in Well 28A-25 indicated the limited area impacted by production of the geothermal reservoir and that of Well 28A-25. Despite no response to the LTFT, Well 28A-25 was completed within a heated system and could serve as a monitoring location southeast of Well 14-25 during the development of the CD IV project.

Chemistry Analysis

Geochemical sampling was conducted on Well 14-25 near the beginning and at the end of the LTFT. The USGS collected samples from Wells 14A-25 and 28A-25 before and after the LTFT; these data were not yet available upon completion of this grant. Instead, earlier analyses of Wells 14A-25 and 28A-25 and their relationship to the Basalt Canyon geothermal wells are presented here.

See Appendix G for a complete geochemistry table.

Geothermal Well 14-25: Major Chemistry

Well 14-25 was sampled for full geochemical analyses at the start and completion of the LTFT. Results were compared to chemical profiles from the rig test conducted after the completion of drilling in October 2010 (which was flowed for four hours) and with historic chemistry of current Geothermal Production Well 57-25 (Well 57-25) and Production Well 66-25 (Well 66-25). Major dissolved constituents are shown in Table 8 below.

Comparisons between geochemistry at the beginning of the LTFT and the end of the test show a slight decrease in common drilling mud contaminant elements — such as sodium (Na), chloride (Cl) and potassium (K) — which makes sense as the well continues to clean up from continuous flow (Figure 22)**.** Geothermal constituents, such as boron (B), lithium (Li), and fluoride (F), actually increase slightly during the test in response to continuous flow and recharge from the geothermal reservoir (Figure 23)**.** A lack of notable dilution or decline in uniquely geothermal constituents suggests that no freshwater component was being contributed to the flow of Well 14-25 as demonstrated over the course of the test. When compared to the geochemistry of Wells 57-25 and 66-25, Well 14-25 has comparable concentrations of major dissolved constituents matching that of the known geothermal reservoir (Table 8).

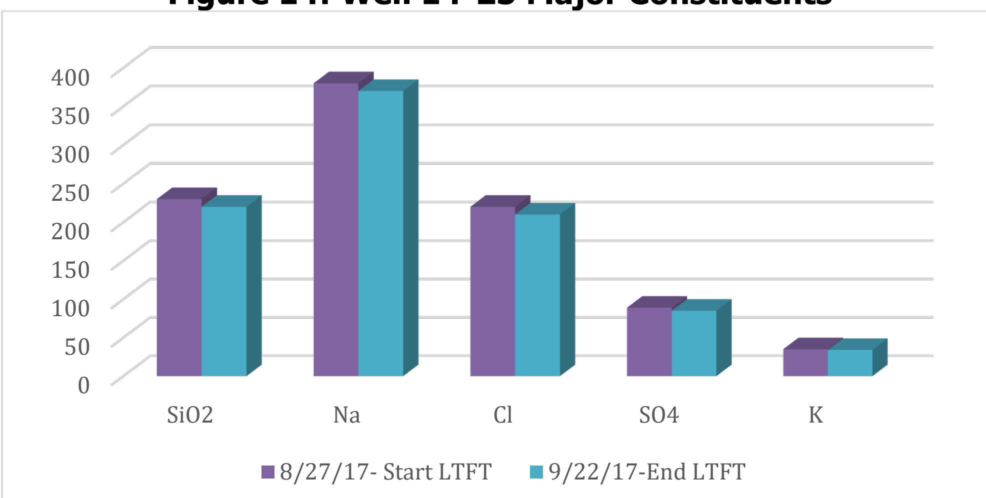
Table 8: Major Geochemical Analyses for Wells 14-25, 57-25, and 66-25

Well	Sample Date	Silicon dioxide (SiO_2)	Na	Cl	Sulfate (SO_4^{2-})	K	F	B	Li	Arsenic (As)
14-25	8/27/2017	230	380	220	89	35	10	8.9	2.5	0.84
14-25	9/22/2017	220	370	210	85	34	10	9	2.7	0.62
57-25	2/25/2015	300	420	280	110	42	9.6	11	3.1	0.5
57-25	07/29/15	250	391	256	118	39.8	11.4	9.53	2.3	0.934
57-25	04/27/16	293	407	250	118	42.1	10.3	10.4	2.62	1.18
57-25	8/25/2017	280	380	260	120	43	12	10	3.2	1.1
66-25	2/25/2015	250	410	250	90	34	10	10	2.6	0.47
66-25	07/29/15	227	379	230	101	32.4	11.2	8.15	2.4	0.831
66-25	10/12/16	229	380	230	100	32	11.4	9.8	2.41	1.07
66-25	8/25/2017	220	370	240	100	34	13	8.9	2.5	0.84

All values reported in milligrams per kilogram (mg/kg), or parts per million (ppm).

Source: Ormat

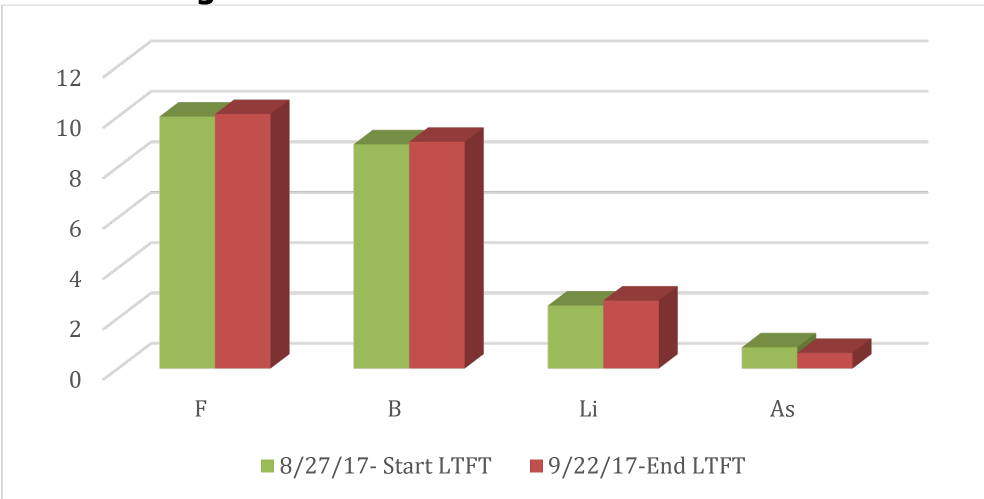
Figure 14: Well 14-25 Major Constituents



Major constituents found in Well 14-25.

Source: Ormat

Figure 15: Well 14-25 Minor Constituents



Minor constituents found in Well 14-25.

Source: Ormat

Monitoring Wells 14A-25 and 28A-25: Geochemical Characteristics

Well 14A-25 represents a unique, relatively dilute composition with elevated geothermal constituents such as B, Li. As, and SiO_2. For comparison, Monitoring Wells 28A-25-deep (ML01-1) and 28A-25-shallow (ML01-2) represent more dilute, nongeothermal fluid; however, they still contain some evidence of a geochemical component with measurable B and Cl/B ratios approaching that of typical geothermal fluids (approximately 20 to 30). Fluids from Well 14A-25 fall along a trend with other equilibrated geothermal brines in the Basalt Canyon reservoir, suggesting a primary geothermal source (Figure 24). Conversely, fluids from Well 28A-25 do not plot along this trend, which is characteristic of groundwaters and nongeothermal brines below 212°F (100°C).

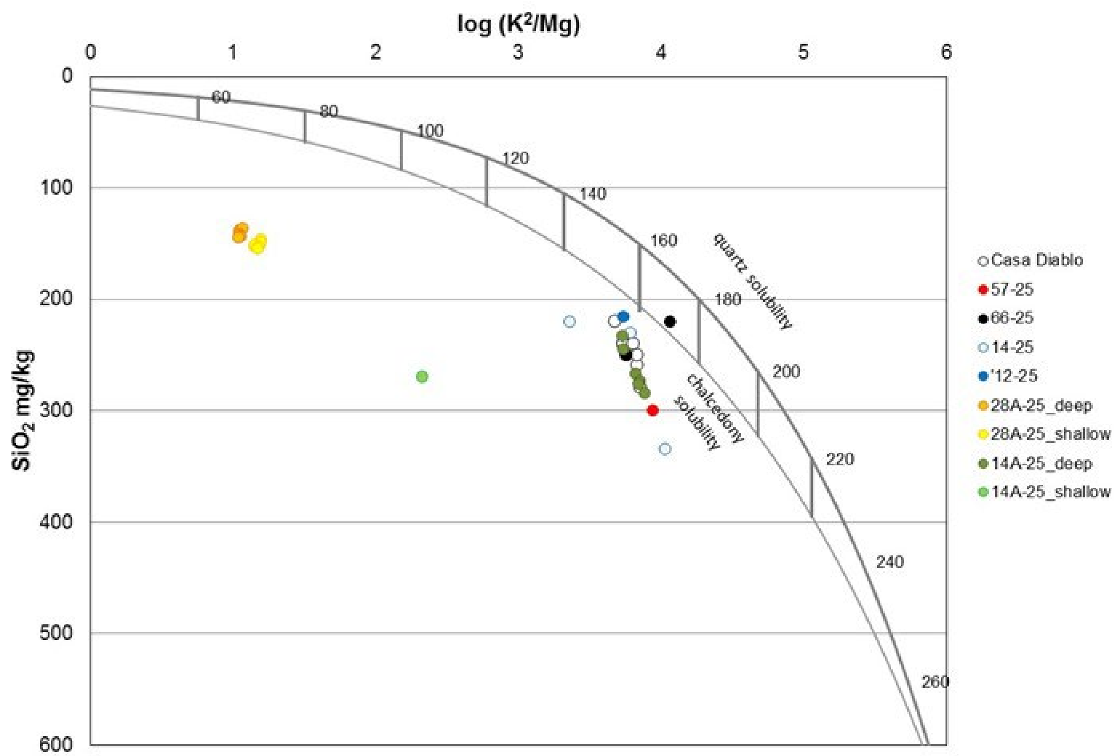
Plots of Cl/B versus Cl (Figure 25) allows for detailed mixing, dilution, and fractionation analysis due to the conservative nature of chloride and the volatile nature of boron under boiling conditions. Well 14A-25 fluids appear to derive along a distillation trend sourcing from reservoir fluids similar to Well 14-25 in Basalt Canyon; condensation of boiled geothermal fluid with enhanced boron concentrating in the vapor phase results in a low Cl/B ratio. This observation makes sense for a shallow, high-temperature fluid perched just above the producing Well 14-25. Monitoring Wells 28A-25 deep (ML01-1) and 28A-25 shallow (ML01-2) share similar Cl/B ratios and plot very close to nearby Monitoring Well M26. These fluids likely represent a thermally reactive dilute fluid sourced from the same recharge as Well M26.

A mixing trend calculated between Well 28A-25 and various low-Cl MCWD wells suggest that Well M26 lies along a geochemical gradient between the lower Mammoth dilute fluids and the more thermally reactive fluids near Well 28A-25. A similar mixing line was attempted between Well 14A-25 and the MCWD wells; however, Wells 28A-28 and M26 did not plot on this trend, indicating that they are not the product of direct mixing between shallow geothermal fluids in Basalt Canyon and dilute lower Mammoth fluids.

Chloride/SiO_2-enthalpy diagrams also confirmed a distillation relationship between Well 14A-25 and Basalt Canyon geothermal fluids. This monitoring well falls along the boiling trend of increased SiO_2 with decreased chloride as demonstrated in Figure 26. Well 28A-25 did not plot along any dilution, boiling, or distillation trends; however, this plot represents a powerful tool for identifying future mixing or comingling between the various end members with the hydrologic system. Plots of stable isotopes d18O and d2H (Figure 27) help delineate the original places of the various freshwater, geothermal, and recharge sources within the Mammoth system. Well 14A-25 fluids that appear to plot very closely to other geothermal fluids in Basalt Canyon, however, are unique enough to suggest some modification from the original source. Well 14A-25 fluids were possibly derived from fractionation of a primary geothermal endmember in Basalt Canyon such as fluids near Wells RDO-8 and 57-25, associating with the Cl/B ratios and Cl-SiO_2 relationships described above. Fluids from Well 14A-25-shallow plot along a similar trend of boiling, which supports this assumption.

Well 28A-25 fluids were plotted along the meteoric water line grouped with other dilute lower Mammoth fluids. Based on isotopic mapping of surface waters, the meteoric recharge source from these waters could derive from the northwest highlands above the Long Valley Caldera, or the lower elevation catchment within the southern rim of the caldera.

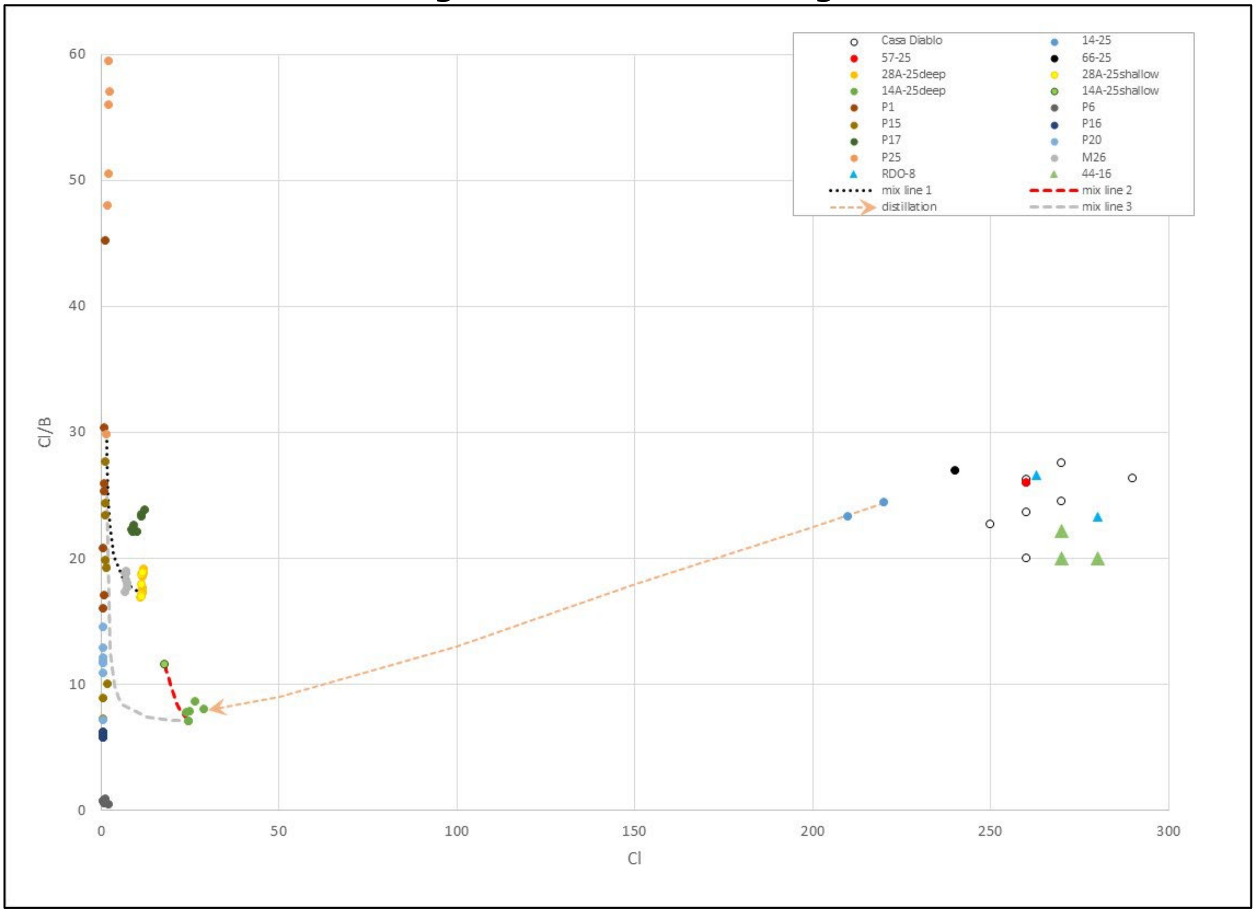
Figure 16: Plot of SiO_2 Versus K/Mg Geothermometers



Plot of SiO_2 vs K/Mg geothermometers demonstrating grouping and near equilibrium between Well 14A-25 monitoring wells and Basalt Canyon and Casa Diablo production wells.

Source: Ormat Nevada, Inc.

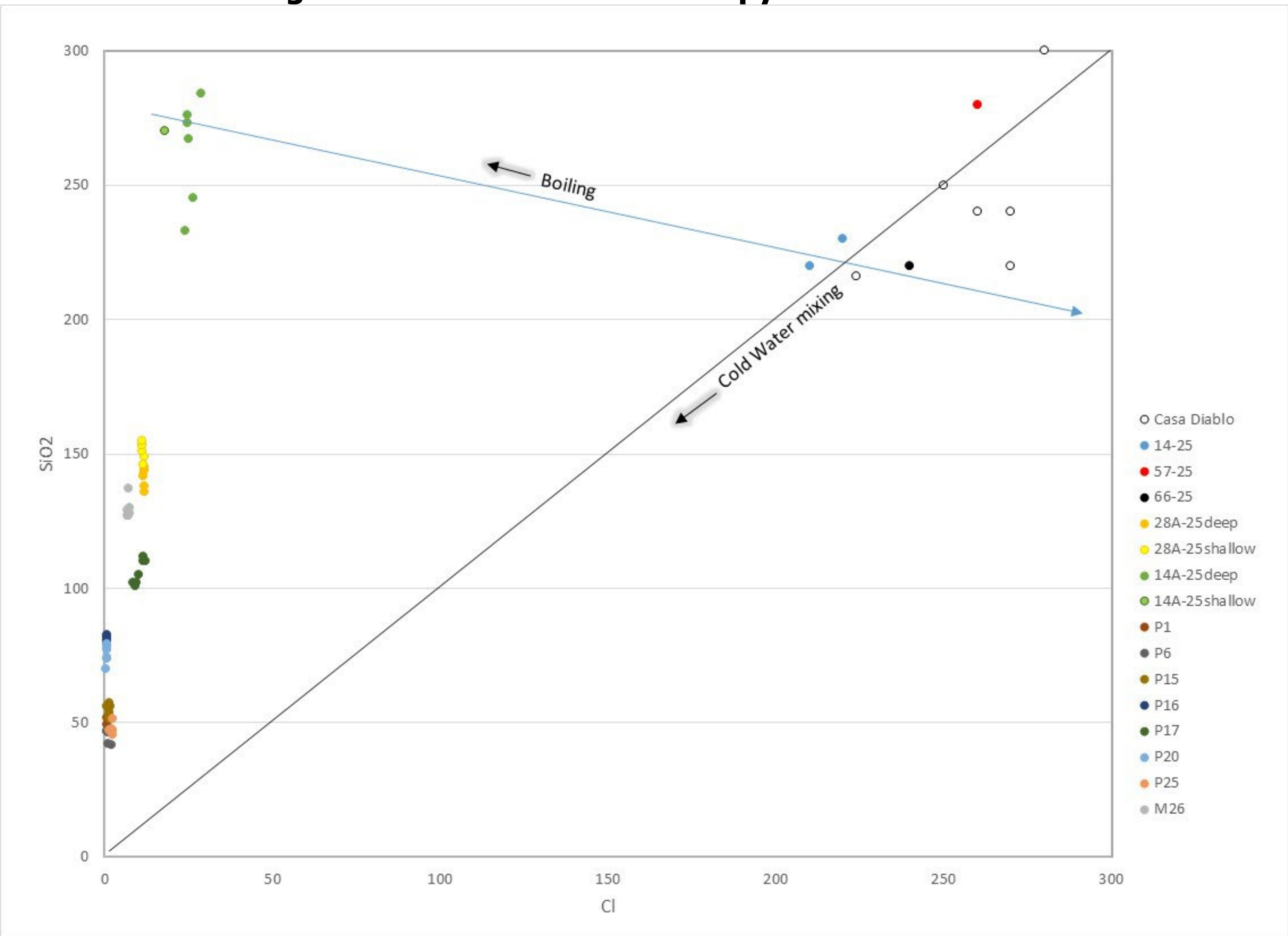
Figure 17: Plot of Cl/B Versus Cl for 14A-25, 28A-25, Basalt Canyon, Casa Diablo, and Regional MCWD Monitoring Wells



Plot of Cl/B versus Cl for 14A-25, 28A-25, Basalt Canyon, Casa Diablo, and regional MCWD monitoring wells demonstrating (1) genetic relationship between Wells 14A-25 and 14-25-type fluids (pink distillation trend), (2) mixing relationship between 28A-25, M26, and other MCWD-type fluids (mixing line 1), (3) lack of mixing relationship between Wells 14A-25 and 28A-25 or other MCWD fluids (mixing line 3).

Source: Ormat Nevada, Inc.

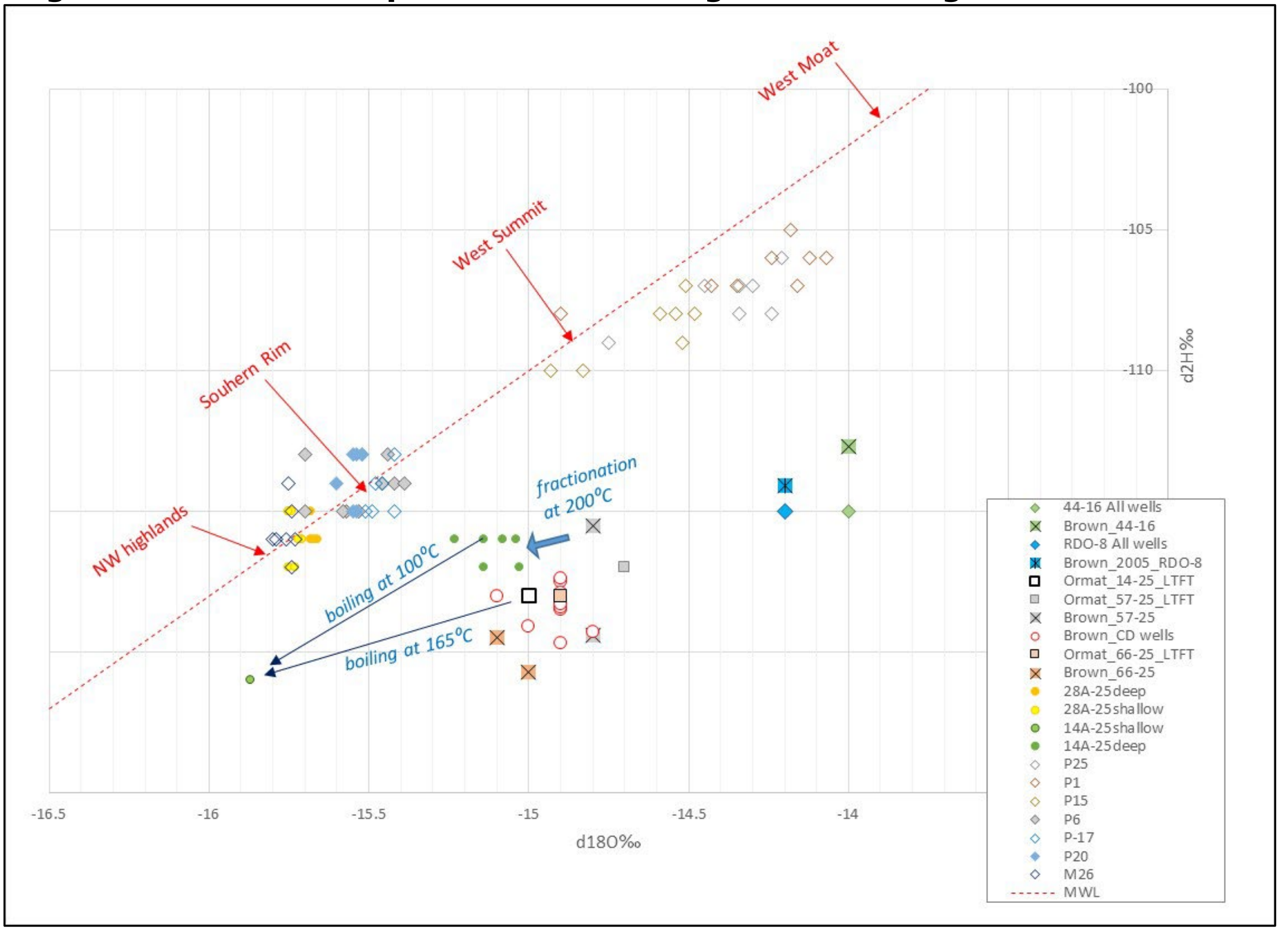
Figure 18: Plot of Silica-Enthalpy Versus Chloride



Silica-enthalpy vs. Chloride plot demonstrating distillation/boiling relationship between Well 14A-25 and other Basalt Canyon fluids.

Source: Ormat Nevada, Inc.

Figure 19: Stable Isotope Plot of Monitoring Wells and Regional Endmembers



Stable isotope plot of monitoring wells and regional endmembers demonstrating the places of origin for fluids from Wells 14A-25 and 28A-25.

Source: Ormat Nevada, Inc.

CHAPTER 5: Conclusions on Expansion of the Shallow Monitoring Program

The expansion of the shallow monitoring program was successfully completed by a collaboration of multiple entities participating in the Long Valley Hydrologic Advisory Committee. This collaboration led to two new monitoring wells in the Long Valley Caldera. One monitoring well is located within the extents of the known thermal area but at a shallow depth, and the second well is located between the Town of Mammoth Lakes and the Known Geothermal Resource Area. The assessment of initial data collected from these wells established a baseline that would be referenced for the CD IV project.

These initial data have already shown that the monitoring wells respond to natural variations such as drought, recharge, barometric effects, and a possible minor response in Well 14A-25 due to the geothermal long term flow test. The analyzed data associated with the Well 14-25 LTFT provided an initial assessment of how the geothermal reservoir will or will not affect the shallow regime. This initial assessment will be incorporated in the baseline. This baseline is useful for all entities to understand whether or not the geothermal reservoir is connected to the groundwater aquifer used by the Town of Mammoth Lakes.

Assessment of the Well 14-25 LTFT data concluded that Wells 14A-25 and 28A-25 were not hydraulically connected to the geothermal reservoir. The same was concluded for groundwater aquifer used by MCWD. The lack of tracer returns to any nongeothermal well, in addition to the unique geochemical signature that isolated the groundwater aquifers from the geothermal reservoir, prove the lack of hydraulic connection. The minor water level change seen in Well 14A-25 associated with the LTFT was not due to a direct connection with the geothermal reservoir, but instead a pressure response caused by a pressure change in the geothermal reservoir. This pressure response was not observed in Well 28A-25, indicating the limited area impacted by the pressure change.

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GLOSSARY

Abbreviation, Acronym, or Term	Definition
basalt	A dark, fine-grained volcanic rock that sometimes displays a columnar structure.
BLM	Bureau of Land Management
caldera	A large volcanic crater
CD IV	Casa Diablo IV – fourth phase of expanding the Casa Diablo power plant in Mono County, California
EC	Electrical conductivity
ft	foot, feet
GMRP	Groundwater Monitoring and Response Plan
gpm	gallons per minute
in	inch
LTFT	long term flow test
LVHAC	Long Valley Hydrologic Advisory Committee
MCWD	Mammoth Community Water District
mg/kg	milligram per kilogram (equals 1 ppm)
MPLP	Mammoth Pacific, L.P. (limited partnership)
NAD	North American Datum
NWIS	National Water Information System
Ormat	Ormat Nevada, Inc.
ppb; ppm	parts per billion, parts per million
psig	pounds per square inch gauge (relative to atmospheric pressure)
Renewable Portfolio Standard	Policies designed to increase the use of renewable energy sources for electricity generation
SiO_2	silicon dioxide
SO_4^{2-}	sulfate ion
spud	To start the well drilling process by removing rock, dirt, and other sedimentary material with the drill bit.

Abbreviation, Acronym, or Term	Definition
tuff	A light, porous rock formed by consolidation of volcanic ash
USGS	United States Geological Survey
Well RDO-8	Existing Exploration Geothermal Well RDO-8, drilled in 2986
Well 12-25	Existing Geothermal Injection Well 12-25
Well 14-25	Existing Geothermal Well 14-25 (idle), drilled in 2010
Well 14A-25	New Monitoring Well 14A-25
Well 28A-25	New Monitoring Well 28A-25
Well 57-25	Existing Geothermal Production Well
Well 66-25	Existing Geothermal Production Well
Well M26	Existing MCWS Monitoring Well
Well 16	Existing MCWS Production Well
Well 17	Existing MCWS Production Well
Well 25	Existing MCWS Production Well
2-NSA	2-Naphthalene sulfate

APPENDICES

Appendix A: USGS 14A-25 Completion Report

Appendix B: USGS 28A-25 Completion Report

Appendix C: Testing Equipment Photos

Appendix D: Geothermal Well 14-25's Long Term Flow Test Readings

Appendix E: Tracer Return Dataset

Appendix F: Water Level Data

Appendix G: Geochemistry Data Table

Appendix H: Earthquake Activity Report

These appendices are publicly available upon request. Please contact Geothermal Grant and Loan Program at geothermal@energy.ca.gov