GTHT - ____1____

WELL INSTALLATION, MONITORING, SAMPLING & ANALYSIS PLAN

DATE:

September 13, 2013

State of New Mexico
Energy, Minerals and Natural Resources Department

Susana Martinez
Governor

David Martin
Cabinet Secretary Designate

Brett F. Woods, Ph.D.
Deputy Cabinet Secretary

Jami Bailey
Division Director
Oil Conservation Division

OCTOBER 17, 2013

Mr. Nick Goodman
Lightning Dock Geothermal HI-01, LLC
136 South Main Street, Suite 600
Salt Lake City, Utah 84101

RE: Lightning Dock Geothermal Project (GTHT-001): "Water Quality Monitoring Program WP" dated September 13, 2013, from Lightning Dock Geothermal HI-01, LLC in Hidalgo County, New Mexico

Dear Mr. Goodman:

The Oil Conservation Division (OCD) is in receipt of the operator's "Water Quality Monitoring Program Work Plan" (WP) dated September 13, 2013 to address the OCD Order (Case No. 14246 & Order No. R-13127) issued on May 29, 2009 and Oil Conservation Commission (OCC) Order (Case No. 14948 & Order No. R-13675-B) issued on May 9, 2013.

Lightning Dock Geothermal HI-01, LLC (operator) stated in the WP that it was satisfying the GTHT-001 Discharge Permit (WQCC permit) dated July 1, 2009. The WP included: 1) Monitor well installation, 2) Monitoring Plan, and 3) Sampling and Analysis Plan for Ground Water and Surface Water.

OCD has completed its review of the WP. The WP is the revised monitoring plan allowed by the OCD in the meeting (meeting) in Santa Fe on August 7, 2013 due to changes in the project, since OCD issued the permit in 2009. The changes will likely be incorporated into any WQCC permit renewal before August 4, 2014, if an application for renewal is submitted. OCD's review of the WP with recommended changes for a revised WP is provided below.

OCD Observations:

1) The operator (formerly Los Lobos Renewable Power, LLC) did not complete all proposed exploratory well test for the project. By receipt of the WP, OCD concludes that the operator has decided to proceed at its own risk to commercially produce geothermal power without conducting well testing.
2) The operator's cover letter statement, "satisfying the permit dated July 1, 2009" is not entirely accurate because Section 20 (Additional Site Specific Conditions Water Quality Monitoring Program (A-F)) requirements were not completely addressed in the WP. OCD conducted its review of the WP based on the WQCC permit Section 20(A-F) conditions. OCD comments and recommendations on the WP indicate where the

operator must revise its WP. Any changes will likely be reflected in any permit renewal issued by the OCD before the WQCC permit expires on August 4, 2014.

OCD Comments:

1) The WP must address OCD's 2009 Order, which is essentially the OCD WQCC permit issued in 2009, and the most recent OCC Order (2013) which reflects changes (i.e., injection/production well locations, well identifications, depths, etc.) from the original WQCC permit. OCD does not anticipate that the WP and changes recommended herein will require a "Modification" to the WQCC permit pursuant to 20.6.2.3108 NMAC.

2) The determination of "background" is critical to the project and determination of whether the production/injection operations will be acceptable under the WQCC Regulations. The depth of the fresh water (e.g., < 10,000 ppm TDS) bearing zone has not been determined at the project location and water quality data collected to date indicates some WQCC water quality exceedances, i.e., Aluminum, Boron, Fluoride, Iron, Manganese, pH, TDS, and Uranium. Therefore, the operator must meet the greater of WQCC water quality standards or background. Water quality exceedances will likely require a modification to the WQCC permit to address water quality, i.e., treatment of injected fluids, and/or termination of the project if water quality standards are not met.

WQCC Permit Review of Section 20(A-F) Recommendations:

1) **Section A: Aquatic Toxicity Testing**

    a. This subsection needs to be addressed in the WP. The operator may state that aquatic toxicity testing shall be conducted if chemical additions are made to the system to treat scale, iron, and other problems.
    b. The 6-month water quality monitoring period after system startup of injection fluid (influent) into the injection wells is still require (See Section 2e below). The surface management, i.e., aeration, oxidation, temperature and pressure change(s), residence time at surface before injection, etc. could adversely affect the metals quality of the injected fluids above WQCC water quality standards and/or "background".

2) **Section B: Ground Water & Surface Water Sampling and Monitoring Requirements**

    a. The operator shall follow EPA Quality Assurance and Quality Control (QA/QC) and Data Quality Objectives (DQOs) during environmental sampling and laboratory analysis aspects of the sampling and analysis plan. Laboratory detection limits that exceed WQCC water quality standards present DQO issues and are not acceptable to the OCD.
    b. Monitor wells and sampling equipment shall be designed and properly constructed to withstand geothermal temperatures of the reservoir(s) for the project.
    c. The operator shall analyze environmental samples collected in accordance with the Tables and references to analytical requirements (e.g., sample frequency, etc.) listed in the discharge permit.

d. The OCD Low-Flow Sampling Program in the permit requires that screen length in monitor wells be less than 15 feet. OCD notices that the water supply and some of the existing monitoring wells have screen lengths larger than 15 feet. In cases where screens are larger than 15 ft., sampling shall occur near the bottom of the well screen and/or open borehole using the OCD approved ASTM Sampling Procurement Method (Section 20Bi). The WP includes the sample methods.

e. If multiple fresh water bearing aquifers are identified, the operator shall install additional monitor wells to monitor for contamination in each different fresh water aquifer (Section 20Bi).

f. A "Background and Compliance Report" must be submitted within 30-days of completion of the first 6 months of sampling to OCD that reflects the first 6 months of sampling (Section 20Bii). Thereafter, the injected fluids **must** be sampled regularly (e.g., to be determined based on 6 month sampling events with results) to ensure it meets WQCC water quality standards and/or background concentrations before injection into wells.
    i. The report shall include: static water level (SWL) data collection method(s); piezometric/potentiometric map generation based on SWL data measurements; hydrogeology; ground water flow direction(s); hydraulic gradient; and water quality, etc. Well SWLs are typically measured at least 24 hours in advance of monitor well sampling (Sections 20Bii & 20Biii).
    ii. There is no mention of notifications within 24 hours after having knowledge that a well(s) water table drops below the monitoring well screen, and/or written statement of whether the water resource in the Animas Valley is or is not adequate to sustain steady-state production of the geothermal resources within 60 days of the above (Section 20Biii).

g. While the installation of one nested well (NW-1) is proposed, there is no mention of well depth and/or monitoring of "head" to determine the vertical hydrogeologic gradient, but should be specified with a "rationale" in the WP (Section 20Biv). The nested well may establish the natural hydrogeologic gradient (HG) before production and injection occurs, and under an operational HG when operations begin. Also, it could be used to monitor water quality at deeper depth in the reservoir.

h. There is no mention of shut-down procedures or contingency plan (e.g., treatment system installation, shut-down for assessment of situation, etc.) to protect the underground source of drinking water (USDW) if water quality exceeds the WQCC water quality standards and/or background concentrations in a well (Sections 20Bv & 20Bviii). Section 2(f) above is a critical element of the WP.

i. Section 4.3 (Water Supply Wells) in the WP does not propose annual monitoring. The required monitoring frequency is "annual" (Sections 20Bvi & 20Ci). The WP table and sample frequency shall conform to the applicable tables. If the standard "three well casing volumes" evacuation method before sample collection is used, then stabilization parameters before sample collection are not required.

j. Similar to Section 2(f)i above, quarterly piezometric/potentiometric surface flow across the facility is required (Section 20.Bvii).

k. After the background water quality for the facility is determined, the cause of ground water exceedances shall be determined. This will also help to verify that the monitor well network is adequate for ground water quality monitoring (Section 20Bviii).

l. Section 6.2 (Production and Injection Wells) shall conform to the sample frequency outlined in Table 2. Similar to Section 4 below, some of the Table 2 Injection and Production Well IDs have changed. The WP shall reflect that all production and development wells will conform to the Table 2 requirements.

3) Section C: Water Supply Wells Monitoring Program

a. OCD had recommended that the AmeriCulture State Well No.1 also be included in Table 3 when the LDG 63-7 injection well casing depth was not increased to at least 100 ft. deeper than the nearest water supply well within one-half mile from an injection well.
b. Similar to Section 2(h) above, notification within 72 hours of determination of a water quality exceedance is required in the WP.

4) Section D: Holding Ponds, Drainage Ditches, Pits and Ponds Monitoring Program

a. Section 5 of the WP states conformance with Table 4 sample requirements; however, many of the locations with reference to well IDs have changed. The WP shall include a provision that sampling in conformance with Table 4 criteria shall occur at any Table 4 location where fluids are present at the facility.
b. The WP shall reflect that OCD shall be notified within 72 hours of the operator's determination that the WQCC water quality standards (general chemistry and metals) and/or "background" have been exceeded at the Table 4 locations.

5) Section E: Spent Produced Water and Cooling-Tower Blow-Down Water Monitoring Program

a. This statement shall be included in the WP under the caveat, "only applicable if a water-based cooling tower system is installed at the facility." Section 1 (Introduction) of the WP states, "LDG has eliminated the use of water-cooling tower to cool its working fluid as described in the permit; therefore, the WQMP excludes cooling tower-blow-down monitoring."
b. OCD requires that a flow diagram of the surface handling units of produced fluids be included in the WP (Section 20Ei) to understand surface fluid management operations. This should also assist the operator to provide the OCD will a facility diagram of constructed units associated with the commercial geothermal power generation facility. Perhaps some construction diagrams submitted to the Regulations and Licensing Department Construction Industries Division may be provided to OCD.
c. The former referenced "3D Tresar Control Monitoring System" and/or its replacement shall be identified and similar to Section 5(b) above (Section 20Eii). It is not clear if the operator intends to use such a system for monitoring influent before injection into wells during operations.
d. The injected fluids shall meet the standards for ground water specified in 20.6.2.3103 NMAC, no presence of any 20.6.2.7(WW) NMAC toxic constituents, and or exceedance of the OCD approved background concentration as established from the first sampling event (Section 20Eiii) and/or other proposed statistically valid method of facility background determination approved by the OCD.

6) **Section F: Annual Water Quality Monitoring Program Report**

   a. The operator shall continue to submit this report annually by January 31st.

OCD Conclusions:

1) The operator needs to address all permit Section 20(A-F) provisions in the WP because it is the document where changes to the WQCC permit will likely occur during renewal.
2) Due to the scope of changes that have occurred since the OCD issued the WQCC permit (GTHT-001) in 2009, and due to the upcoming permit expiration date, OCD will likely modify the permit to reflect the changes documented in this letter in any renewed WQCC permit, if an application for permit renewal is submitted to OCD.
3) OCD has determined that the WP and changes from the permit to not require a "modification" under WQCC Regulations.
4) OCD reserves the right to issue a "Modification" to the permit at any time.
5) OCD reserves the right to "Terminate" the permit if and/or when conditions warrant.

If you have any questions, please contact Carl Chavez of my staff at (505) 476-3490, mail at the address below, or email at CarlJ.Chavez@state.nm.us. Thank you.

Sincerely,

Scott Dawson

Scott Dawson
Deputy Director

SD/cjc

cc: Mr. Daniel Sanchez, OCD Santa Fe
Mr. David Brooks, OCD Santa Fe
Mr. Glenn von Gonten, OCD Santa Fe
OCD Artesia Office

Chavez, Carl J, EMNRD

From: Chavez, Carl J, EMNRD
Sent: Thursday, October 10, 2013 9:19 AM
To: Janney, David (david.janney@amec.com)
Cc: Nick Goodman (Nick.Goodman@cyrqenergy.com); Dawson, Scott, EMNRD; Sanchez, Daniel J., EMNRD; VonGonten, Glenn, EMNRD; Dade, Randy, EMNRD; Shapard, Craig, EMNRD; Lindeen, Christopher, OSE; Jackson, Charles L., OSE; Mcmillan, Martin, OSE
Subject: FW: Datarequestforgeothermalproject OSE Impairment Analysis.doc
Attachments: Datarequestforgeothermalproject OSE Impairment Analysis.doc

David:

Good morning. Yesterday the OCD met with Nick Goodman and Tom Carroll to discuss the project and basically any outstanding issues that may prevent the Lightning Dock Geothermal HI-01, LLC's (LDG) proclaimed deadline of 12/31/2013 from being met.

Please find attached the information (remember House Bill 201?) that LDG will need to provide to the OCD for review and basically completeness before submitting it to the Office of State Engineer for a "Water Impairment Analysis" (analysis) for the project.

The OCD recommends that LDG complete an information package that addresses the OSE's attached outline. Please contact the OSE if you have questions on the attachment. You may also contact the OCD if you have questions and/or the OCD needs to coordinate with the OSE and LDG to facilitate communication to help LDG provide the analysis information. It may also help LDG to address any project related water diversion issues discussed during yesterday's meeting.

Thank you.

Carl J. Chavez, CHMM
New Mexico Energy, Minerals & Natural Resources Department
Oil Conservation Division, Environmental Bureau
1220 South St. Francis Drive, Santa Fe, New Mexico 87505
Office: (505) 476-3490
E-mail: CarlJ.Chavez@State.NM.US
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"Why Not Prevent Pollution; Minimize Waste; Reduce the Cost of Operations; & Move Forward With the Rest of the Nation?" To see how, please go to: "Pollution Prevention & Waste Minimization" at http://www.emnrd.state.nm.us/ocd/environmental.htm#environmental

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From: Lindeen, Christopher, OSE
Sent: Thursday, March 14, 2013 4:23 PM
To: Brooks, David K., EMNRD; Chavez, Carl J, EMNRD
Subject: Datarequestforgeothermalproject OSE Impairment Analysis.doc

Gentlemen – I have attached a general list of information that would be needed for the OSE to form an opinion as to whether the diversion and injunction of water for a proposed geothermal project would impair existing ground water rights. Please let me know if you have any questions.

Thanks – Chris

Chris Lindeen
New Mexico Office of the State Engineer
Administrative Litigation Unit
P.O. Box 25102
Santa Fe, New Mexico 87504-5102
(505) 827-3518
Fax (505) 827-3520
christopher.lindeen@state.nm.us

To render an opinion on whether existing groundwater rights may be impaired by the proposed diversion and reinjection of groundwater for a geothermal project, the OSE requests that a report be provided containing the following information:

1) A description of the proposed diversion and reinjection of groundwater for a geothermal project including:
    a. For each of the proposed pumping and injection wells:
        i. X and Y locations (UTM NAD83, meters, Zone13) at the land surface
        ii. Proposed depth and screened interval (ft)
        iii. Proposed pumping rate and injection rate (gpm)
        iv. A proposed pumping and injection schedule (afy)
        v. If wells have been horizontally drilled (or are less than vertical), provide information on the location of the production zone
2) A description of the geologic unit(s) from which the geothermal resource is to be pumped and reinjected, and a description of geologic units that are hydrologically connected to it. The description should include the thickness, and composition of each. Also provide information concerning the data sources that were relied upon.
3) Lithologic logs for the project pumping and injection wells and the interpreted geologic unit(s) to which the lithology in the logs corresponds.
4) A description of geologic structures in the area that may affect groundwater flow, including fractures, faults, and folds. Also include a description of what their identification is based on.
5) Figures showing 1) a geologic map and 2) geologic cross-sections (at least two). If existing cross-sections for the area of interest are appropriate and available in the literature, they may be used and cited.
6) A description of aquifer properties for the geologic units of interest in the area, noting their location and the geologic unit to which they pertain, and provide information about the source of the aquifer property data. If an aquifer test or tests have been performed at the project site, provide a description the test(s), the data collected, and the interpreted aquifer properties based on the test(s).
7) A description of the conceptual understanding of flows into and out of the project area and how the conceptual model was developed.
8) Identify groundwater rights sharing the same groundwater source as the geothermal project that may be impacted by the proposed project operations. OSE water right files, the WATERS database and any publically-available hydrographic survey may be used to identify groundwater rights in the area and their associated points of diversion.
9) A description of the water levels in the “geothermal” aquifer and the hydrologically-connected aquifers. Include hydrographs and water-level contours based on observed data where data are available.
10) A description of the analytical or numerical model to be used to evaluate the hydrologic effects of the application.

   a. A numerical model will be preferred in situations where the effects to more than one geologic unit are to be evaluated, or whenever use of analytical methods would be considered inappropriate.
   b. Describe the model and the basis for its construction.
   c. Aquifer properties used in the model should be based on aquifer tests of geologic units in the area of the proposed project. If an aquifer property is unavailable based on testing, values based on literature estimates may be used and cited.
   d. For situations where data are limited, it is encouraged that the property value or model structure used be conservative (i.e., which errs on the side of overestimating drawdown)
   e. Provide model files.

11) Calculation of drawdown due to the proposed pumping and reinjection using an analytical or numerical model. The following should be described or considered in the evaluation:
   a. A summary of the simulated pumping and reinjection in the model.
   b. All known wells that may be hydrologically impacted by the project based on the modeling. Present a table of the wells in which drawdown may occur, that includes:
      i. the OSE point of diversion (POD) number (well),
      ii. the OSE designated use,
      iii. the well location (in UTM NAD83)
      iv. date the well was drilled,
      v. water-bearing formation,
      vi. the depth to water (based on either when the well was drilled or the most recent measurement available),
      vii. the total depth of the well,
      viii. the estimated water column (based on either when the well was drilled or the most recent measurement available).
      ix. The drawdown results:
         1. If it is a permanent project, present the drawdown results at 40 years for each existing well.
         2. If it is a temporary project, evaluate the maximum drawdown that will occur within a 40-year period and report the time of maximum drawdown for each existing well.
      x. The projected drawdown due to existing water rights for the time period evaluated (either at 40 years, or at the time of the maximum drawdown) for each existing well.
      xi. The dynamic drawdown (the self-induced drawdown inside the well due to the pump turning on and off) for each existing well.
      xii. For those fields that may be time dependent (such as depth to water and water column) provide information concerning the time the data were collected.
   c. Provide an excel spreadsheet of the table described in 11b.

WATER QUALITY MONITORING PROGRAM WORK PLAN

INCLUDING THE
WELL INSTALLATION AND MONITORING PLAN
AND THE
SAMPLING AND ANALYSIS PLAN FOR GROUNDWATER AND SURFACE WATER

LIGHTNING DOCK GEOTHERMAL, HI-01
HIDALGO COUNTY, NEW MEXICO

Submitted To:

The New Mexico Oil Conservation Division
1220 South Saint Francis Drive
Santa Fe, New Mexico 87505

Submitted By

Cyrq
energy

Prepared By:

amec

AMEC Environment & Infrastructure, Inc.
8519 Jefferson N.E.
Albuquerque, New Mexico 87113

September 13, 2013

amec

RECEIVED OCD

2013 SEP 17 A 10:48

September 13, 2013

Mr. Carl Chavez, CHMM
New Mexico Oil Conservation Division
1220 South Saint Francis Drive
Santa Fe, NM 87505
505-476-3490
CarlJ.Chavez@state.nm.us

RE: Monitoring Program Work Plan for Lightning Dock Geothermal Hi-01, LLC, Hidalgo County, New Mexico

Dear Mr. Chavez:

On behalf of Lightning Dock Geothermal HI-01, LLC (LDG), and pursuant to the requirement in the Lightning Dock Geothermal No. 1 (HI-01) Discharge Permit (GTHT-001) dated July 1, 2009, AMEC Environment & Infrastructure, Inc. hereby submits the Monitoring Program Work Plan that includes the well installation and monitoring plan and the sampling and analysis plan for groundwater and surface water for the above referenced site. In fulfillment of the terms in GTHT-001, this plan is being submitted more than three (3) months prior to the startup of the geothermal power plant.

Thank you very much for your assistance in the development of this important energy project. Should you have questions regarding this form, please do not hesitate to contact me by email at David.Janney@amec.com or by phone at (505) 821-1801. Mr. Dade will also receive a copy of the document.

Respectfully submitted,

David W. Janney

David W. Janney, PG
Agent for Los Lobos Renewable Power, LLC

Cc: Randy Dade, - NMOCD
Chuck Smiley – Lightning Dock Geothermal HI-01, LLC
Michelle Henrie – Lightning Dock Geothermal HI-01, LLC

Attachments

One (1) Monitoring Program Work Plan

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LIST OF ACRONYMS

ASTM	American Society for Testing and Materials
Cyrq	Cyrq Energy
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
L	liter
LDG	Lightning Dock Geothermal HI-01, LLC
mg/L	milligrams per liter
ml/min	milliliters per minute
OCD	New Mexico Oil Conservation Division
ORP	oxygen-reduction potential
PAH	polynuclear aromatic hydrocarbon
ppm	parts per million
PVC	polyvinyl chloride
SC	specific conductivity
SVOC	semivolatile organic compound
TDS	total dissolved solids
TPH	total petroleum hydrocarbon
VOC	volatile organic compound
WQMP	Water Quality Monitoring Program

1.0 INTRODUCTION

Lightning Dock Geothermal HI-01, LLC (LDG), a wholly owned subsidiary of Cyrq Energy (Cyrq), is pleased to present this document to define its water quality monitoring program (WQMP) for the Lightning Dock Geothermal Project (the " LDG Project") located in Hidalgo County, New Mexico. The WQMP is required by the New Mexico Oil Conservation Division (OCD) to satisfy the requirements of the Lightning Dock Geothermal No.1 (HI-01) Discharge Permit (GTHT-001), dated July 1, 2009.

The purpose of this document is to define the monitoring program. This document meets the requirements of Section 20.B.i of GTHT-001 that specifies the need for the preparation of a groundwater monitoring program work plan including a well installation and monitoring plan and a sampling and analysis plan for the monitoring wells, water supply wells, holding ponds, and pits. This WQMP also addresses the sampling aspects of Oil Conservation Commission Order No. R-13675-B, dated May 9, 2013.

The objective of this document is to provide written procedures for the sampling events required by OCD and the acquisition of groundwater quality data that will permit background concentrations to be established for a number of constituents.

LDG has eliminated the use of water-cooling tower to cool its working fluid as described in GTHT-001; therefore, the WQMP excludes cooling tower-blow-down monitoring.

1.1 Site Location and Description

The LDG Project is located in Section 7, Township 25, South Range 19 west of Hidalgo County, New Mexico. LDG is located along the east side of the Animas Valley approximately 13 miles north of Animas, New Mexico, and approximately 18 miles southwest of Lordsburg, New Mexico. LDG Energy owns 160 acres upon which some of its geothermal wells are located. Rosette, Inc., owns the adjoining property to the east upon which three of the LDG geothermal wells are located. The Project area is relatively flat and is has a natural soil surface. The Project location is depicted in Figure 1 and the Project layout is shown on Figure 2.

1.2 Site Background

The Lightning Dock geothermal system is a blind system with no surface manifestations, discovered during cable tool drilling of an irrigation well in 1948. The system takes its name from Lightning Dock Peak, located in the Pyramid Mountains just east of the Project area. Since 1948 a number of investigators have conducted geochemical sampling of fluids, electrical and gravity geophysical surveys, temperature gradient drilling, shallow production well drilling of the resource for direct-use heating for green-housing and aquaculture, and deep geothermal exploratory drilling.

Early geothermal and geophysical data suggested that the Lightning Dock resource was perhaps the best prospective geothermal resource for commercial electrical power production in New Mexico, but little was known about the lateral and vertical extent or characteristics of the reservoir. The first deep geothermal well (TFD 55-7, now referred to as LDG 55-7) was drilled by Steam Reserve Corporation in 1984 and it found high temperatures (>150°F) with significant water flow at a depth of about 1,150 feet. Since that date, a number of operators have drilled additional production or injection wells near LDG 55-7.

Multiple isolated fresh water aquifers do not exist in the project area but there are two distinct water qualities in the project area, including groundwater in alluvium or valley fill sediments with temperatures below 250°F and upwelling geothermal water in bedrock that is generally above 250°F. Groundwater in the alluvium is found approximately 60 feet below ground surface and the alluvium may be up to 600 feet thick in the project area. Alluvial groundwater in the project area is a blend of cold groundwater moving from southeast to northwest in the alluvial aquifer that is recharged by precipitation and hotter geothermal water upwelling from the bedrock geothermal system. The bedrock geothermal system consists of Tertiary volcanic or volcaniclastic rocks and the underlying Paleozoic sedimentary rocks. Precambrian granitic basement rocks are present at depth below the Paleozoic sedimentary rocks. Geothermal water rises through fractures in the Paleozoic rocks and silicified and fractured Tertiary volcaniclastic rocks and enters the alluvial groundwater system. LDG's geothermal production and injection wells are completed in the bedrock system at depths as great as 4,441 feet. The existing production and injection wells are presented n the table below.

Production and Injection Wells

WELL NAME	WELL TYPE	TOTAL DEPTH
LDG 45-7	Production	2,900 Feet
LDG 47-7	Injection	2,963 Feet
LDG 53-7	Injection	4,491 Feet
LDG 55-7	Injection	2,349 Feet
LDG 63-7	Injection	3,400 Feet

Both the alluvial and bedrock waters are of good quality and contain less than 10,000 parts per million (ppm) total dissolved solids (TDS). Generally, the mixed alluvial water contains fluoride concentration ranging between 8 and 10 ppm and the bedrock water contains fluoride concentration ranging between 9 and 14 ppm fluoride. Other constituents in these waters are largely the same.

2.0 SCOPE OF WORK

The water quality monitoring program for the LDG Project includes this groundwater monitoring program work plan as well as the sampling and analysis plan for groundwater and surface water. It includes a description of the methods used for the installation of new monitoring wells and, if necessary, the plugging and abandonment of monitoring wells that have become unusable because the depth-to-groundwater has fallen below the bottom of the screened interval in the well.

3.0 MONITORING WELLS

This section describes the methods and procedures that will be utilized to construct and develop the groundwater monitoring wells.

3.1 Monitoring Well Installation

LDG will contract with a New Mexico-licensed driller to install the required groundwater monitoring wells. Prior to installing the wells, LDG will obtain the required well permits from the New Mexico Office of the State Engineer and obtain access agreements, if necessary, for the properties on which the wells may be installed. LDG will contact the New Mexico ONE-CALL system at least 48-hours in advance of any drilling so nearby subsurface utilities are located prior to drilling. LDG will use hollow-stem auger drilling methods to advance the boreholes for well installations with depths up to 100 feet. Wells deeper than 100 feet will be advanced with air- or mud-rotary methods. Drill cuttings will not be sampled during well installations.

GTHT-001 specifies locations for each of the monitoring wells based on the production and injection well network that was approved in 2008. The existing production and injection well network currently includes the wells listed in the table. Proposed monitoring wells locations are shown in Figure 2.

Groundwater monitoring wells will be constructed from threaded, 2-inch diameter, schedule 40 polyvinyl chloride (PVC) pipe. Well screen sections will be schedule 40 PVC mill slot with a 0.010 to 0.020-inch slot width. The screen section of each well will extend 20 feet into the aquifer, and approximately 5 feet of screen will span the air/water interface. The sand or filter pack around the screened interval will consist of the appropriate-sized clean silica sand. The filter pack sand will be placed 3 feet above the screen section. A minimum 3-foot thick bentonite plug will be placed above the filter pack and hydrated using tap water. Expansive neat cement grout will be placed to within 2 feet of the surface above the bentonite plug. Surface completions may be a flush-mount, traffic-grade manhole or PVC risers contained inside a protective steel well riser installed in a concrete pad. The well seal will be allowed to bond to the casing for a minimum of 72 hours prior to well development.

3.2 Monitoring Well Development

Monitoring wells will be developed to clean the well and to stabilize the filter pack and aquifer materials around the slotted casing. Well development will be accomplished by bailing, mechanical pumping, surging or swabbing, and will continue until the well is thoroughly developed and as free of sand, silt, and turbidity as possible. Water samples will be collected and analyzed for field parameters (pH, temperature, dissolved oxygen [DO], oxygen-reduction potential [ORP] and specific conductivity [SC]) every three (3) casing volumes. When stabilized parameters (+/- 25%), have been achieved for three (3) consecutive measurements, well development operations will cease.

In some cases, initial development pumping may immediately dewater the well casing and thereby inhibit well development. When this occurs, laboratory-clean water can be introduced into the well, followed by surging of the waters introduced with a swab or surge block, followed by pumping or bailing. This procedure would be repeated until full development of the well is established as described above. Development water will be labeled and contained in 55-gallon drums pending the receipt of laboratory analyses of the groundwater samples. Disposal of the development water will conform to applicable hazardous waste requirements. Well purging and sampling will not occur until at least 72 hours after the completion of development.

3.3 Low Flow Monitoring Well Purging and Sampling

Purging and sampling by low flow methods is preferred. Monitoring well purging and sampling (pursuant to EPA Region I Low Stress Purging and Sampling Procedure for the Collection of Ground Water Samples from Monitoring Wells [EPA Region I 2010]) steps are described below.

- Arrive at the well and confirm the well identification number.
- Unlock the well and open the well protective cover.
- Using a properly decontaminated water-level probe, measure the water level from the top of the well casing to the nearest 0.01 foot and record the measurement on the well sampling log to the nearest 0.01 foot.

- Keep the water-level probe in the well.
- Lower the properly decontaminated low-flow bladder pump into the well and set it in the middle of the screened interval. Connect the flow-through cell to the sample pump discharge tubing, preferably with a "T" fitting, and lower the intake into the well, with the end of the intake at the mid-screen position.
- Begin pumping the well at 0.1 to 0.5 liters (L) per minute (100 to 500 milliliters per minute [ml/min]). Check the water level in the well and measure the discharge rate of the pump by using a graduated cylinder every minute for the first five (5) minutes. Ideally, the pumping rate should equal the well recharge rate with little or no water level drawdown in the well (drawdown should be less than 0.3 foot). If drawdown is greater than 0.33 foot, lower the flow rate.
- Measure and record the water level, discharge rate, and water quality indicator parameters on the well sampling log every five (5) minutes during purging.
- If drawdown exceeds 0.33 foot, a minimum of three (3) volumes of the sampling system from each well will be purged, followed by sample collection. The liquid volume of the sampling system consists of the volume of the pump intake chamber, discharge tubing, and flow-through cell attached to the water quality meter.
- Check the discharge tubing for air bubbles during the purging process. If bubbles are visible, tap the tubing where the bubble is located to enable the bubble to pass through the tubing and into the flow-through cell.
- During purging, monitor pH, temperature, ORP, DO, and SC approximately every five (5) minutes with a calibrated water quality meter.
- The groundwater should be purged until indicator parameters have stabilized. The well will be considered stabilized and ready for sample collection when the indicator parameters have stabilized for three (3) consecutive readings, as follows:
  - Consecutive readings within ± 10% standard units for pH
  - Consecutive readings within ±10% degree Celsius (°C) for temperature
  - Consecutive readings within ± 10 % micromhos per centimeter (μmhos/cm) for specific conductance
  - Consecutive readings within ±10% millivolts for ORP
  - Consecutive readings within ± 10% milligrams per liter (mg/L) for DO
- If stabilization is not occurring and the procedure has been strictly followed, then sample collection can take place once a minimum of three to a maximum of six (6) casing volumes have been removed. The pumping rate may be increased in order to remove the required casing volumes. Record the specific information on purging in the field logbook or on the groundwater sampling field form.
- Once field water quality parameters have stabilized, flow will be directed from the T-fitting into the sample containers.
- Containers with preservative will not be overfilled to the point where overflow occurs, because overfilling may result in a loss of preservative.

- Sample containers will be kept capped, except when being filled.
- Vials for volatile organic compound (VOC) analysis will be filled by initially tilting the vials, allowing the pump discharge to flow gently down the inside of the vial with minimal turbulence. Each vial will be filled until a positive meniscus is formed at the top of the volatile organic amplifier vial. After the vial is full, it will be capped immediately, inverted, tapped lightly, and checked for the presence of air bubbles. If air bubbles are present, the sample will be discarded and resampled using a new vial.
- Collect samples for the remaining organic constituents such as semi-volatile organic compounds (SVOCs), polynuclear aromatic hydrocarbons (PAHs), phenols, total petroleum hydrocarbons (TPHs), general chemistry anions, TDS, and pH.
- Place a 0.45-micron filter online and collect samples for dissolved metals, general chemistry cations, and radiological parameters.
- Affix a completed sample label to the sample container and cover with clear packaging tape.
- Purge water will be contained in labeled 55-gallon drums pending receipt of laboratory results on groundwater samples. Purge water will be disposed of into the centralized line pond at LDG 55-7 if analytical parameters are within the acceptable limits.

3.4 Conventional Monitoring Well Purging

If low-flow purging and sampling methods cannot be used on a well, the well will be purged by bailing or pumping to remove three (3) well volumes prior to sample collection. If the well column is evacuated by bailing or pumping, samples will be collected after approximately 80 percent of the initial water level has returned. A field log will be maintained by the sampler that includes observations of conditions prior to purging (e.g., odor, turbidity, color), amount of water purged, measurements of water quality parameters (pH, temperature, ORP, DO, and SC), the stability of the aforementioned parameters, and the recharge rate of the well. Purge water will be labeled and contained in 55-gallon drums pending receipt of laboratory results on groundwater samples. Purge water will be disposed of into the centralized line pond at LDG 55-7 if analytical parameters are within the acceptable limits.

3.5 Conventional Monitoring Well Water Sampling

Where low-flow sampling is not applicable, groundwater samples may be collected in a conventional manner using a submersible pump or a new disposable plastic bailer. The wells will be purged of three (3) well volumes as described in Section 3.4 and sampling will be collected following stabilization of the field parameters (pH, temperature, ORP, DO, and SC).

3.6 Sample Packaging and Shipment

All glass sample containers will be wrapped in bubble wrap packaging material, placed into resealable plastic bags, and placed into a cooler containing ice. Ice is to be contained in double one-gallon resealable plastic bags and placed into the cooler. Cooler space will be filled with as much ice as is possible and additional bubble wrap will be used as necessary. The completed chain-of custody will also be placed in a resealable plastic bag and taped to the underside of the cooler lid. Coolers will be sealed with packaging tape and a custody seal will affixed between the cooler and the cooler lid.

3.7 Chain-of-Custody and Laboratory Receipt

Once samples are collected, a completed chain-of-custody form containing the following information will accompany all samples: sample name, sample date and time, sample matrix, total number of bottles for each sample, requested analyses, special instructions for the laboratory, as well as the signature of the person collecting the samples. Samples are considered "in custody" if the following conditions are true:

- The responsible person (either the person collecting the sample or the person designated on the chain-of-custody form as having custody) maintains possession of the samples.
- After the samples are collected by or relinquished to a responsible person, they must remain in view of, or in the physical possession of the responsible person.
- Samples are sealed so that no one can tamper with them.
- Samples are maintained in an area restricted to authorized personnel.

Samples will be maintained in the custody of the sampling personnel during daily sample activities. As each sample is collected, field personnel will complete a chain-of-custody form for that sample that includes sample name, sample date and time, sample matrix, total number of bottles for each sample, and requested analyses, as well as the signature of the person collecting the samples.

On transfer of custody to a new responsible person, the sampling personnel will sign and date the relinquishment of custody and the recipient of custody will sign and date acknowledgement of receipt. If samples are shipped by a common carrier, then the receiving agent will not sign the chain-of-custody form and, instead, the signed relinquishment will be sealed in the cooler.

On receipt by the laboratory, the receiving agent (custodian) will document the condition of the cooler, the integrity of the custody seal, the internal temperature of the cooler and the condition of the sample containers. After the samples are logged in, the laboratory custodian will sign and date the chain-of-custody form. The original form will be retained by the laboratory and a copy of the form will be provided to LDG to be included in the project files.

3.8 Monitoring Well Surveying

LDG will contract with a New Mexico-licensed surveyor to establish horizontal and vertical coordinates for monitoring, production, injection, and water supply wells as necessary. The datum of the survey will be the nearest US Geodetic Survey benchmark with a referencing above mean sea level. The top of each well casing will be surveyed with an accuracy of 0.01 foot. A notch with a permanent black mark will be made on the north side of the top of each well casing riser and this will serve as the reference point for all subsequent depth to water measurements.

3.9 Field Equipment Calibration Procedures

The water quality meter used to record these field parameters will be calibrated against known standards on a weekly basis and checked against the standards daily. Water quality meter calibration will be conducted according to the manufacturer's specifications. Documentation of equipment calibration will be recorded in a field book and a written record of the daily field water quality parameters will be recorded on field data sheets for inclusion into the permanent record.

3.10 Drilling and Field Equipment Decontamination Procedures

Drilling equipment, including augers and other related drilling equipment, will be decontaminated (via steam cleaning or equivalent method) between each well location. Drill cuttings will be disposed of by spreading on LDG property. Potable water will be used for decontamination of drilling equipment.

Sampling equipment, including submersible pumps, bladder pumps, and flow through cells or other water quality instruments, will be decontaminated between each use. The exterior of all sampling pumps will be scrubbed with a brush using a solution of deionized water and tri-sodium phosphate followed by triple rinse using deionized water. Submersible pumps will also be decontaminated by pumping one (1) gallon of deionized water and tri-sodium phosphate solution through the pump followed by pumping one (1) gallon of deionized water through the pump. Bladder pumps will be disassembled and scrubbed with a brush using a solution of deionized water and tri-sodium phosphate. Bladders and pump tubing may be dedicated to individual wells, in which case they will be triple rinsed with deionized water after each use and stored in double sealable plastic bags clearly labeled with the well number.

All rinseate water used in the decontamination process and all purge water from the wells will be stored on-site in steel DOT approved drums. Drums will be labeled as to contents, date container filled, company name, and sealed. The drums will be left onsite for subsequent disposal pending analytical results.

3.11 Well Plugging and Abandonment

If the groundwater level drops below a monitoring well's screened interval, well plugging and abandonment may be required. The appropriate methodology for abandoning boreholes and decommissioning groundwater monitoring wells is described in the New Mexico Office of the State Engineer regulations and in detail in the American Society for Testing and Materials (ASTM) Guidance D 5299-92. The practices described in these references will be followed.

4.0 PRODUCTION, INJECTION AND WATER SUPPLY WELL SAMPLING

This section describes the sampling procedures for production, injection, and water supply wells. Each production and injection well will be sampled prior to placing it on production or injection.

4.1 Production Wells

Production wells will be sampled prior to placing the well into production; after 15 days of production, and after 30 days of production. Three (3) casing volumes will be removed from the well with the production pump prior to sampling. The production pump will also be used to bring the sample to the surface where it will be collected from a sampling port in the pump discharge line. The samples will be collected according to ASTM Method E-947-83 or E-1675-95a. During the first 30 days of production, field water quality parameters (pH, temperature, ORP, SC, and DO) will be measured on a daily basis at the sampling port. If daily field parameters experience a substantial change (+/- 25 percent), LDG will collect an additional sample for laboratory analysis.

4.2 Injection Wells

Each injection well will be sampled before placing it on injection. Since injection wells are not equipped with pumps, low-flow methods will be used to collect samples from the water column within the well. The low-flow bladder pump body will set within 100 feet of the groundwater surface and the suction or inlet tubing of the bladder pump will be placed into the lined or screened interval of the well. At this point, the low-flow sampling methods described in Section 3.3, with a few minor revisions, will be utilized to collect the sample. Due to the temperature limitations of the water quality probes in all water quality meters, the samples will be brought to the surface and run through the ice bath described in ASTM Method E-947-83 or E-1675-95a. The sample will flow through the ice bath and then through the flow-through cell on the water quality meter. Temperature will be recorded in line prior to passing the sample through the ice bath.

Each injection wellhead will be equipped with a sampling port that will allow sample collection before the spent geothermal fluid from the power plant heat exchanger is injected back into formation. These samples will also be collected according to ASTM Method E-947-83 or E-1675-95a as appropriate. During the first 30 days of injection, injectate water quality parameters (pH, temperature, ORP, SC, and DO) will be measured on a daily basis from a single sampling port in the spent geothermal water discharge line of the power plant. Temperature will be measured directly in-line and the other parameters will be measured with an appropriate water quality meter after the samples have been cooled to avoid damage to the probes. If daily field parameters experience a substantial change (+/- 25 percent), LDG will collect a sample for laboratory analysis.

4.3 Water Supply Wells

Prior to startup of the geothermal power plant, LDG will sample each of the water supply wells for the constituents listed in Table 3. Well owners will receive a written request to access the well for sample collection. If well owners deny access, LDG will notify OCD in writing and the well will not be sampled.

Wells equipped with pumps will be purged of three (3) well volumes prior to sample collection. Measurements of field water quality parameters (pH, temperature, ORP, DO, and SC) will be collected using a flow-through cell where applicable; purge water will be discharged to the surface in a manner that does not create a nuisance for the property owner. If water temperature is above boiling, the samples will be collected according to ASTM Method E-947-83 or E-1675-95a. If sample temperatures are below boiling they will be collected without the ice bath called for in these ASTM methods. At the end of the first 30 days of production, field water quality parameters (pH, temperature, ORP, SC, and DO) will be measured again on each water supply well. If these field parameters exhibit a substantial change (+/- 25 percent), LDG will collect an additional sample from the well for laboratory analysis.

5.0 HOLDING PONDS, BLOW-DOWN PONDS, DRAINAGE DITCHES AND RESERVE PITS

During operation of the geothermal power plant, LDG will collect samples from each of the locations in Table 4. Samples will be collected using sampling containers supplied by the laboratory. Field water quality parameters will not be collected on these samples.

6.0 SAMPLING FREQUENCY AND ANALYSIS

This section describes the sampling frequency and analytical methods that will be applied to each of the samples. The appropriate US Environmental Protection Agency or Standard Methods analytical methods with appropriate detection limits will be used to analyze the samples and standard laboratory quality assurance/quality control data will be submitted to OCD with the analytical results. Trip blanks and duplicate samples will be submitted as appropriate for the organic analytes. All samples will be submitted to the laboratory for analysis on a standard 10-day analytical reporting turnaround time.

6.1 Monitoring Wells

Sampling frequency for the monitoring wells will be conducted according to the frequency and analyte list indicated in Table 1. Assuming that organic constituents are not detected in the samples collected prior to plant start up and in the first monthly sampling events following plant startup, subsequent samples will be analyzed only for the inorganic constituents listed in Table 1.

6.2 Production and Injection Wells

Sampling frequency for the production and injection wells will be conducted according to the frequency indicated on Table 2. During the first round of sampling prior to plant startup, and for the first three (3) monthly sampling events after plant startup, samples will be analyzed for the inorganic and organic constituents listed in Tables 2. After plant startup, the samples from each injection well (LDG 47-7, LDG 55-7, LDG 54-7, and LDG 63-7) will be collected from a sampling port at the wellhead prior to spent geothermal water being injected back into formation. The boiling points of the organic constituents listed in Tables 2 are above 250°F). Assuming that organic constituents are not detected in the samples collected prior to plant start up and in the first 3 monthly sampling events following plant startup, subsequent samples will be analyzed only for the inorganic constituents listed in Table 2.

6.3 Water Supply Wells

Sampling frequency for the water supply wells will be conducted according to the frequency indicated on Table 3. The first sample will be collected prior to plant startup and these wells will be sampled annually thereafter.

6.4 Ponds, Pits, and Drainage Ditches

Sampling frequency for the holding ponds, pits, and other surface-water features will be conducted according to the frequency indicated on Table 4. Samples are to be collected on a quarterly basis if the ponds, pits, and ditches are in use. When these locations are not in use, a time and date stamped photograph will be taken of the location and this will be included in the Annual Water Quality Monitoring Program Report.

FIGURES

AMEC Environmental & Infrastructure
8519 Jefferson, NE
Albuquerque, NM 87113

amec

Cyrq
Lightning Dock
geothermal

PROJECT:
Lightning Dock Geothermal HI-01, LLC

TITLE:
PROJECT LOCATION

DWN BY: KP	DATUM:	DATE: SEPTEMBER 2013
CHK'D BY: DJ	REV. NO.:	CONTRACT NO.: 11517000102
PROJECTION:	SCALE: 1" = 5 miles	FIGURE NO.: 1

AMEC Environmental & Infrastructure
8519 Jefferson, NE
Albuquerque, NM 87113

amec

Cyrq
Lightning Dock
geothermal

PROJECT: Lightning Dock Geothermal Hi-01, LLC	DWN BY: KP	DATUM:	DATE: SEPTEMBER 2013
	CHK'D BY: DJ	REV. NO.:	CONTRACT NO.: 11517000102
TITLE: PROJECT LAYOUT	PROJECTION:	SCALE: 1" ≈ 700'	FIGURE NO.: 2

TABLES

TABLE 1

Ground Water Monitoring Program

ID*	Frequency	Media	Analytical Suite/Method	Approximate Well Location
MW-1[1]	Annual	GW	Analyze for dissolved fraction of all 20.6.2.3 103 NMAC Constituents VOCs (8260B) SVOCs (8270C) PAHs (8310) TPH (418.1) Metals- dissolved (6010B/6020) including Bromide, Lithium, Rubidium, and Tungsten (by approved EPA methods), Mercury (7470A/7471A) General Chemistry (Methods specified at 40 CFR 136.3) Uranium (6010B/6020), Radioactivity (E903/E904) Radon (by EPA Method or method approved by OCD)	Shallow MW (water table) located ~ 100' downgradient (North) of Class V IW 55-07 and associated pits (OCD)
MW-2[1]	Annual	GW		Shallow MW (water table) located ~ 100' downgradient (North) of Class V IW 53-07 and associated pits (OCD)
MW-3[1]	Annual	GW		Shallow MW (water table) located ~ 100' downgradient (North) of Class V IW 63-12 and associated pits (OCD)
MW-4[1]	Annual	GW		Shallow MW located ~ 1500' (Northwest) of DW 45-07 directly downgradient from facility (OCD)
MW-5[1]	Annual	GW		Shallow MW (water table) located ~1000' upgradient (South) of the nursery greenhouses 3 & 4 to monitor background (OCD)
MW-6[1]	Annual	GW		Shallow MW (water table) located ~ 100' downgradient (North) of Class V IW 47-7 and associated pits (OCD)
MW-7[1]	Annual	GW		Shallow MW (water table) located ~ 100' downgradient (North) of the next production well to be drilled and associated pits (OCD)
MW-8[1]	Annual	GW		Shallow MW (water table) located ~ 100' downgradient (North) of the next production well to be drilled and associated pits (OCD)
NW-1[1]	Annual	GW		Located between DW 45-07 and IW 55-07 drilled to a depth of approximately 600 feet.

Table Notes:

BODs: Biochemical Oxygen Demand
COD: Chemical Oxygen Demand
DW: Development/Production Well
DWL: Dynamic Water Level
GH: Greenhouse
GW: Groundwater
IW: Injection Well

MSL: Mean Sea-Level
MW: Monitoring Well
NW: Nested Well
SW: Surface Water
SWL: Static Water Level

*Quarterly Static Water Level (SWL): MSL to nearest 0.01 feet prior to sampling event

1. Wells must be installed in advance of system startup and sampled.

2. Semi-Annual groundwater monitoring event must be completed no more than 30 days prior to the start of the irrigation season but no later than April 30 of each year. Monitoring must be conducted no later than 30 days after the conclusion of the irrigation season but no later than November 15 of each year.

3. One time sampling event with static water level (SWL) mean sea-level (0.01 ft. accuracy) measurements in advance of system start-up. Thereafter, monthly sampling for the first six months with dynamic water level (DWL) recording equipment is required. After six months of monthly monitoring, the sampling shall be conducted at least annually.

4. Sample quarterly while in use. If organics are evident, sampling with analytical methods similar to MWs shall be implemented during the sampling event.

5. Daily for 10 business days at system start up; thereafter weekly for two months; thereafter based on establishing correlation with the 3D Tresar Control Monitoring System.

Note: All wells with phase-separated hydrocarbons (PSHs) must be checked at a minimum of once per month and recorded on a spreadsheet. The data must be presented in table form listing all of the impacted wells, date inspected, product thickness measured to 0.01 of a foot, and amount of product/water recovered. If PSHs are observed in a monitoring well, then appropriate steps must be taken to recover the PSHs using the best available technology.

TABLE 2

Geothermal Injection Wells and Production/Development Wells Monitoring Program

ID*	Frequency	Media	Analytical Suite/Method	Approximate Well Location
DW 45-07 [1,3]	Annual	GW	Analyze for dissolved fraction of all 20.6.2.3 103 NMAC Constituents VOCs (8260B) SVOCs (8270C) PAHs (8310) TPH (418.1) Metals- dissolved (6010B/6020) including Bromide, Lithium, Rubidium, and Tungsten (by approved EPA methods) Mercury (7470A/7471A) General Chemistry (Methods specified at 40 CFR 136.3) Uranium (6010B/6020), Radioactivity (E903/E904) Radon (by EPA Method or method approved by OCD)	See Figure 2.
IW 47-07 [1,3]	Annual	GW		
IW 53-07 [1,3]	Annual	GW		
IW 55-07 [1,3]	Annual	GW		
IW 63-07 [1,3]	Annual	GW		

Table Notes:

BODs: Biochemical Oxygen Demand
COD: Chemical Oxygen Demand
DW: Development/Production Well
DWL: Dynamic Water Level
GH: Greenhouse
GW: Groundwater
IW: Injection Well
MSL: Mean Sea-Level
MW: Monitoring Well
NW: Nested Well
SW: Surface Water
SWL: Static Water Level

*Quarterly Static Water Level (SWL): MSL to nearest 0.01 feet prior to sampling event

[1] Wells must be installed in advance of system startup and sampled.

[2] Semi-Annual groundwater monitoring event must be completed no more than 30 days prior to the start of the irrigation season but no later than April 30 of each year. Monitoring must be conducted no later than 30 days after the conclusion of the irrigation season but no later than November 15 of each year.

[3] One time sampling event with static water level (SWL) mean sea-level (0.01 ft. accuracy) measurements in advance of system start-up. Thereafter, monthly sampling for the first six months with dynamic water level (DWL) recording equipment is required. After six months of monthly monitoring, the sampling shall be conducted at least annually.

[4] Sample quarterly while in use. If organics are evident, sampling with analytical methods similar to MWs shall be implemented during the sampling event.

[5] Daily for 10 business days at system start up; thereafter weekly for two months; thereafter based on establishing correlation with the 3D Tresar Control Monitoring System.

Note: All wells with phase-separated hydrocarbons (PSHs) must be checked at a minimum of once per month and recorded on a spreadsheet. The data must be presented in table form listing all of the impacted wells, date inspected, product thickness measured to 0.01 of a foot, and amount of product/water recovered. If PSHs are observed in a monitoring well, then appropriate steps must be taken to recover the PSHs using the best available technology.

TABLE 3

Water Supply Wells Monitoring Program

ID*	Frequency	Media	Analytical Suite/Method	Approximate Well Location
TG 52-07	Annual	GW	Analyze for dissolved fraction of all 20.6.2.3 103 NMAC Constituents VOCs (8260B) SVOCs (8270C) PAHs (8310) TPH (418.1) Metals- dissolved (6010B/6020) including Bromide, Lithium, Rubidium, and Tungsten (by approved EPA methods) Mercury (7470A/7471A) General Chemistry (Methods specified at 40 CFR 136.3) Uranium (6010B/6020), Radioactivity (E903/E904), Radon (by EPA Method or method approved by OCD)	See Figure 2.
AmeriCulture No. 1 Federal	Annual	GW		
AmeriCulture State Well No. 2	Annual	GW		
McCants No. 1 State	Annual	GW		
Burgett No. 1 State	Annual	GW		
Burgett Greenhouse No.2	Annual	GW		

Table Notes:

BODs:	Biochemical Oxygen Demand
COD:	Chemical Oxygen Demand
DW:	Development/Production Well
DWL:	Dynamic Water Level
GH:	Greenhouse
GW:	Groundwater
IW:	Injection Well
MSL:	Mean Sea-Level
MW:	Monitoring Well
NW:	Nested Well
SW:	Surface Water
SWL:	Static Water Level

*Quarterly Static Water Level (SWL): MSL to nearest 0.01 feet prior to sampling event

1. Wells must be installed in advance of system startup and sampled.

2. Semi-Annual groundwater monitoring event must be completed no more than 30 days prior to the start of the irrigation season but no later than April 30 of each year. Monitoring must be conducted no later than 30 days after the conclusion of the irrigation season but no later than November 15 of each year.

3. One time sampling event with static water level (SWL) mean sea-level (0.01 ft. accuracy) measurements in advance of system start-up. Thereafter, monthly sampling for the first six months with dynamic water level (DWL) recording equipment is required. After six months of monthly monitoring, the sampling shall be conducted at least annually.

4. Sample quarterly while in use. If organics are evident, sampling with analytical methods similar to MWs shall be implemented during the sampling event.

5. Daily for 10 business days at system start up; thereafter weekly for two months; thereafter based on establishing correlation with the 3D Tresar Control Monitoring System.

Note: All wells with phase-separated hydrocarbons (PSHs) must be checked at a minimum of once per month and recorded on a spreadsheet. The data must be presented in table form listing all of the impacted wells, date inspected, product thickness measured to 0.01 of a foot, and amount of product/water recovered. If PSHs are observed in a monitoring well, then appropriate steps must be taken to recover the PSHs using the best available technology.

TABLE 4

Holding Ponds, Drainage Ditches, Pits and Ponds Monitoring Program

ID*	Frequency	Media	Analytical Suite/Method	Approximate Well Location
GH Holding Pond No. 1	Quarterly [4]	SW	Metals- dissolved (6010B/6020) including Bromide, Lithium, Rubidium, and Tungsten (by approved EPA methods) General Chemistry (Methods specified at 40 CFR 136.3)	See Figure 2 for well locations.
Drainage Ditch No. 1 (East)	Quarterly [4]	SW		
Retention Pond No. 1	Quarterly [4]	SW		
Bermed Canal No. 1	Quarterly [4]	SW		
Pit Associated with DW 45-07	Within 30 days of use	SW		
Pit Associated with any additional Production Wells	Within 30 days of use	SW		
Pit Associated with IW 53-07	Within 30 days of use	SW		
Pit Associated with IW 55-07	Within 30 days of use	SW		
Pit Associated with IW 63-07	Within 30 days of use	SW		
Pit Associated with IW 47-07	Within 30 days of use	SW		
Pit Associated with any additional Injection Wells	Within 30 days of use	SW		

Table Notes:

BODs: Biochemical Oxygen Demand
COD: Chemical Oxygen Demand
DW: Development/Production Well
DWL: Dynamic Water Level
GH: Greenhouse
GW: Groundwater
IW: Injection Well
MSL: Mean Sea-Level
MW: Monitoring Well
NW: Nested Well
SW: Surface Water
SWL: Static Water Level

*Quarterly Static Water Level (SWL): MSL to nearest 0.01 feet prior to sampling event

[1] Wells must be installed in advance of system startup and sampled.

[2] Semi-Annual groundwater monitoring event must be completed no more than 30 days prior to the start of the irrigation season but no later than April 30 of each year. Monitoring must be conducted no later than 30 days after the conclusion of the irrigation season but no later than November 15 of each year.

[3] One time sampling event with static water level (SWL) mean sea-level (0.01 ft. accuracy) measurements in advance of system start-up. Thereafter, monthly sampling for the first six months with dynamic water level (DWL) recording equipment is required. After six months of monthly monitoring, the sampling shall be conducted at least annually.

[4] Sample quarterly while in use. If organics are evident, sampling with analytical methods similar to MWs shall be implemented during the sampling event.

[5] Daily for 10 business days at system start up; thereafter weekly for two months; thereafter based on establishing correlation with the 3D Tresar Control Monitoring System.

Note: All wells with phase-separated hydrocarbons (PSHs) must be checked at a minimum of once per month and recorded on a spreadsheet. The data must be presented in table form listing all of the impacted wells, date inspected, product thickness measured to 0.01 of a foot, and amount of product/water recovered. If PSHs are observed in a monitoring well, then appropriate steps must be taken to recover the PSHs using the best available technology.

Appendix A

ASTM E947-83

Designation: E 947 – 83 (Reapproved 1996)$^{\epsilon 1}$

An American National Standard

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Specification for Sampling Single-Phase Geothermal Liquid or Steam for Purposes of Chemical Analysis[1]

This standard is issued under the fixed designation E 947; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Keywords were added editorially in April 1996.

1. Scope

1.1 This specification covers the basic requirements for equipment to be used for the collection of uncontaminated and representative samples from single-phase geothermal liquid or steam. Geopressured liquids are included. Fig. 1

2. Application

2.1 This specification covers only that equipment which is commonly used for the sampling of single-phase geothermal liquid or steam. It does not cover specialized equipment required for, and unique to, a specific test or method of analysis. The specification covers items such as valves, fittings, tubing, cooling coils and condensers, pumps, degassers, sample containers, sample probes, and packaging materials, but excludes equipment used in specific testing and analysis.

2.2 This procedure applies to single-phase steam or liquid streams prior to separation and to separated single-phase steam or liquid streams.

2.3 For most geothermal and geopressured fluids tested by the procedures outlined in this specification, both liquid and gas samples may be collected.

3. Sample Probes

3.1 Sample probes shall be used to extract liquid or steam from the main part of the geothermal flow rather than using a wall-accessing valve and pipe arrangement.

3.1.1 The probe permits the sampling of various positions within the flow to determine whether stratified or annular two-phase flow is present which would bias a single-point sample.

3.2 Sample probes shall be designed to extract representative samples from flowing systems. Special attention during construction of the probe shall be given to the stresses that the probe will later be subjected to during insertion into, and operation in, a pressurized flowing system.

3.3 The sampling probe (Fig. 2) passes through the sliding seal and access valve in order that liquid or steam can be sampled from the mainstream of the flow line. Thereafter, the sample contacts only surfaces that the operator can verify are noncontaminating and nonabsorbing.

3.3.1 Moving the probe tip across the diameter of the pipe may allow the operator to determine the existence of stratification or multiphase sampling problems.

3.3.2 Flow regulation is accomplished downstream of the cooling coils in order to avoid residual flashing into steam at the point of pressure reduction. Flashing may cause scale deposition which would preclude the accurate determination of certain constituents.

4. Sampling Lines

4.1 *Safety*—Sampling lines shall be as short as practical and of sufficient strength to prevent structural failure.

4.2 *Construction*—All sample lines shall be constructed to eliminate traps in which condensate, entrained particulates, or scale precipitates might settle since they may be partially emptied with changes in flow conditions and may result in sample contamination. Allow for thermal expansion.

5. Valves, Fittings, and Gages

5.1 Valves which control access to the sampling point shall have straight throats (frequently designated as ball, plug, and gate valves). For flexibility of sampling, a minimum of |n#-in. diameter throat is recommended. This permits a probe to be inserted directly into the flow.

5.2 It is recommended that at least one full-port shut-off valve be placed on the downstream end of the sample probe so that the sampling line may be isolated when desired.

5.3 Throttling devices such as valves, capillary tubes, or orifices, if used, shall be placed at the sample outlet of the cooler or condenser. This practice will ensure cooling at the highest pressure and will minimize the possibility of fluid flashing or scale forming in the cooling coil. A head column such as that recommended for normal water and steam sampling (Specification D 1192, for Equipment for Sampling Water and Steam[2]) shall not be used because it provides a mechanism for gas separation and escape prior to sample collection.

5.4 Equipment adequate to determine the pressure and

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[1] This specification is under the jurisdiction of ASTM Committee E-44 on Solar, Geothermal, and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.15 on Field Development.

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[2] *Annual Book of ASTM Standards*, Vol 11.01.

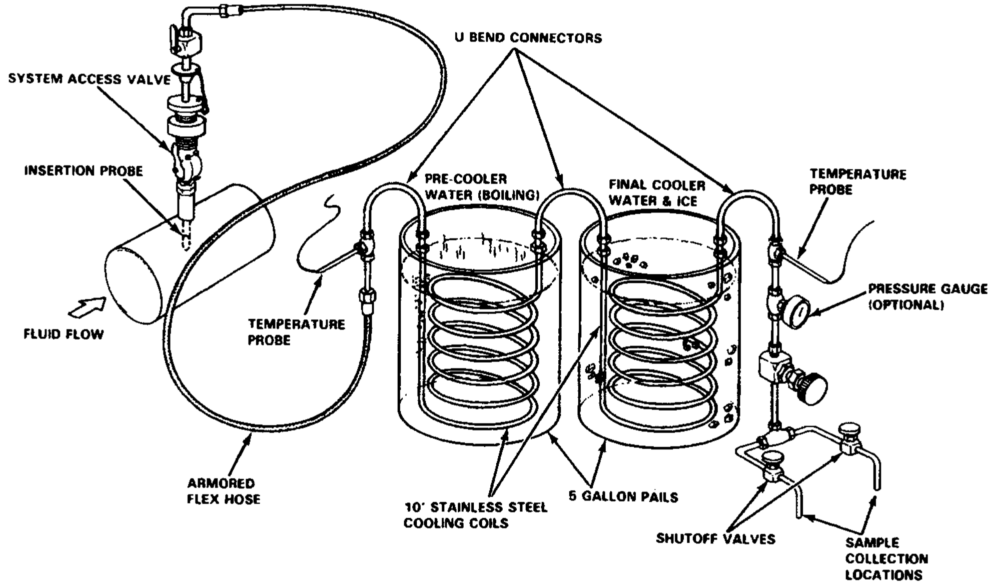

FIG. 1 Example Assembly (Particularly Suited for Liquid Flows)

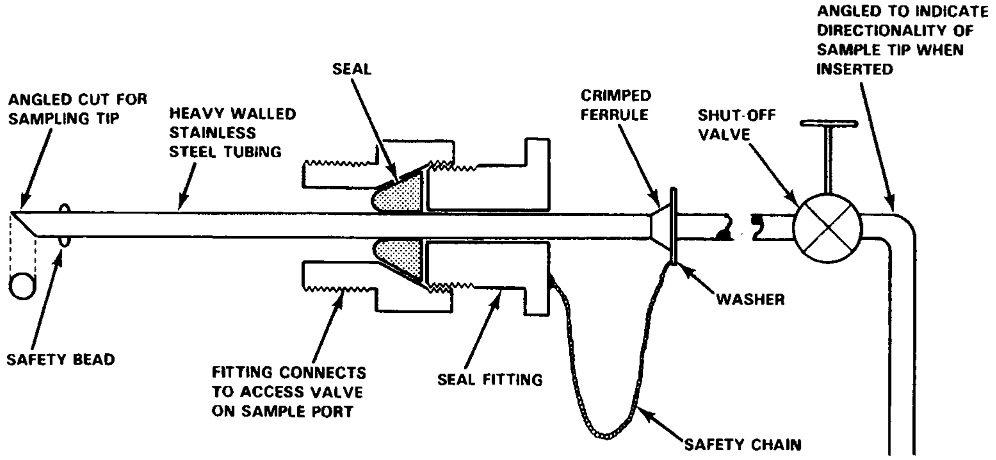

FIG. 2 Sample Probe

temperature of the mainstrem liquid or steam flow shall be utilized.

6. Sample Cooler

6.1 The tube through which the sample flows shall be continuous through the cooling location so there will be no possibility of sample contamination or dilution from the cooling water. The internal diameter of the tube is suggested to be no larger than that of the sample probe so that storage within the coil is low and the time lag of sample through the cooling phase will be a minimum.

6.2 When the temperature of the sample is above the boiling point of water, it may be advantageous, in order to conserve ice, to use a precooler containing water to lower the temperature of the sample before it enters the cooler. The temperature of the sample can then be controlled by the flow rate and the temperature of the final cooling bath (frequently an ice water bath).

7. Materials and Lubricants

7.1 *Lubricants*:

7.1.1 No lubricant shall be used in the collection containers, or their valves and seals, where it could contact the sample and bias the components of interest. This is particularly important if minor constituents are to be measured.

7.1.2 Other valves and moving parts in the sampling equipment that contact the sample should be lubricated to the minimum extent consistent with service life.

7.2 *Materials*:

7.2.1 In all cases, the sampling equipment shall be made of materials resistant to corrosion by the sample and that will not bias the results. Stainless steel, glass, and polymers are examples of materials that are generally satisfactory.

7.2.2 Copper-based alloys should be avoided.

8. Liquid Sample Containers

8.1 Liquid sample containers and compatible closures shall not bias the sample components of interest. Sample containment shall conform to EPA guidelines.[3] These guidelines recommend the collection of liquid samples in either plastic or glass containers. Boron and silica samples should be collected in plastic containers.

8.2 The closures of the filled sample containers shall be fixed in place to prevent accidental opening in transit. Alternatively, the sample containers may be secured inside a shipping container designed to prevent disturbance of the inner container.

9. Gas Sample Containers

9.1 Devices used to collect and transport the gas component of the samples (as shown in Fig. 3) shall be resistant to chemical reactions and to gaseous diffusion or adsorption. They should be filled to equal or exceed atmospheric pressure to prevent air from leaking into the sample container.

10. Filters

10.1 Filters, when used, shall be housed in a pressure-tight container assuring that the full flow passes through the filter.

11. Cleaning

11.1 The sampling apparatus shall be kept clean.

11.2 When finished sampling, or when the sampling apparatus will be idle, the interior of the apparatus shall be rinsed with distilled water to minimize corrosion and contamination.

11.3 It may be necessary to disassemble and clean new equipment prior to initial use.

12. Example of Sampling Train

12.1 Examples of a sampling train are shown in Fig. 3 and Fig. 1. Consideration should be given to the force generated by any specific combination of probe diameter and system pressure and to the limitations and safety of sliding seals. A combination of probe tip bead and safety chain are recommended to restrict forcible ejection of the probe from the line being sampled. In unsafe cases, a fixed connection is preferred.

13. Keywords

13.1 chemical analysis; geopressured liquid; geothermal liquid; geothermal steam; single-phase geothermal liquid; single-phase geothermal steam

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[3] *Federal Register*, Vol 44, No. 244, pp. 75050–75052.

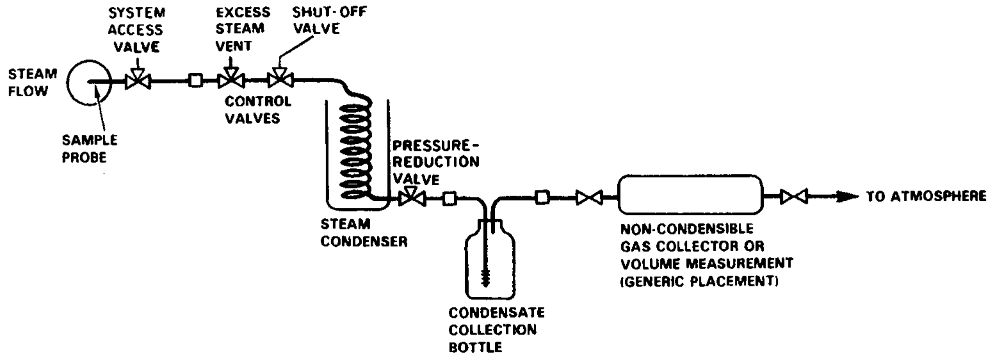

FIG. 3 Example Assembly (Particularly Suited for Steam Flows)

Appendix B

ASTM 1675-95a

Designation: E 1675 – 95a

An American National Standard

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Practice for Sampling Two-Phase Geothermal Fluid for Purposes of Chemical Analysis[1]

This standard is issued under the fixed designation E 1675; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The purpose of this practice is to obtain representative samples of liquid and steam as they exist in a pipeline transporting two-phase geothermal fluids.

1.1.1 The liquid and steam samples are collected and properly preserved for subsequent chemical analysis in the field or an off-site analytical laboratory.

1.1.2 The chemical composition data generated from the analysis of liquid and steam samples may be used for many applications important to geothermal energy exploration, development, and the long-term managed exploitation of geothermal resources. These applications include, but are not limited to, resource evaluations such as determining reservoir temperature and the origin of reservoir fluids, compatibility of produced fluids with production, power generation and reinjection hardware exposed to the fluids (corrosivity and scale deposition potential), long-term reservoir monitoring during field exploitation, and environmental impact evaluations including emissions testing.

1.1.2.1 To fully utilize the chemical composition data in the applications stated in 1.1.2, specific physical data related to the two-phase discharge, wellbore, and geothermal reservoir may be required. Mathematical reconstruction of the fluid chemistry (liquid and steam) to reservoir conditions is a primary requirement in many applications. At a minimum, this requires precise knowledge of the total fluid enthalpy and pressure or temperature at the sample point. Fluid reconstruction and computations to conditions different from the sample collection point are beyond the scope of this practice.

1.2 This practice is limited to the collection of samples from two-phase flow streams at pressures greater than 10 psig and having a volumetric vapor fraction of at least 20 %. This practice is not applicable to single-phase flow streams such as pumped liquid discharges at pressures above the flash point or superheated steam flows. Refer to Specification E 947 for sampling single-phase geothermal fluids.

1.3 The sampling of geothermal fluid two-phase flow streams (liquid and steam) requires specialized sampling equipment and proper orientation of sample ports with respect to the two-phase flow line. This practice is applicable to wells not equipped with individual production separators.

1.4 In many cases, these techniques are the only possible way to obtain representative steam and liquid samples from individual producing geothermal wells. The sampling problems that exist include the following:

1.4.1 Unstable production flow rates that have a large degree of surging,

1.4.2 Unknown percentage of total flow that is flashed to steam or is continuously flashing through the production system,

1.4.3 Mineral deposition during and after flashing of the produced fluid in wellbores, production piping, and sampling trains,

1.4.4 Stratification of flow inside the pipeline and unusual flow regimes at the sampling ports, and

1.4.5 Insufficient flash fraction to obtain a steam sample.

1.5 This practice covers the sample locations, specialized sampling equipment, and procedures needed to obtain representative liquid and steam samples for chemical analysis.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Section 7.

2. Referenced Documents

2.1 *ASTM Standards:*

E 947 Specification for Sampling Single-Phase Geothermal Liquid or Steam for Purposes of Chemical Analysis[2]

2.2 *Other Document:*

ASME Code Section VIII, Division 1(1986), Pressure Vessel Design, Fabrication and Certification[3]

3. Summary of Practice

3.1 Samples are collected from a pipeline carrying two-phase geothermal fluids by using a sampling separator that separates liquid and steam phases through centrifugal force. A

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[1] This practice is under the jurisdiction of ASTM Committee E-44 on Solar, Geothermal, and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.15 on Geothermal Field Development.

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[2] *Annual Book of ASTM Standards*, Vol 12.02.

[3] Available from American Society of Mechanical Engineers 345 E. 47th St. New York, NY 10017.

fraction of the separated steam is condensed and a fraction of the separated liquid is cooled. Portions of the condensed steam and cooled liquid are collected in appropriate sample containers for subsequent chemical analysis.

4. Significance and Use

4.1 The objective of this practice is to obtain representative samples of the steam and liquid phases as they exist in the pipeline at the sample point, without allowing steam condensation or additional liquid flashing in the separator. A significant feature of the practice is the use of a cyclone-type separator for high-efficiency phase separation which is operated at flow rates high enough to prevent significant heat loss while maintaining an internal pressure essentially the same as the pipeline pressure.

4.2 Another significant feature of the practice is to locate the sampling separator at a point on the pipeline where the two-phase flow is at least partially stratified to aid in the separation process. It is neither necessary nor possible to pass representative proportions of each phase through the sampling separator to obtain representative samples. The separator is usually attached to an appropriately oriented port to collect each specific phase—normally on top of the line for steam and at the bottom for liquid. In some cases, piping configurations can generate unusual flow regimes where the reverse is required. If the ratio of one phase to another is not extreme, representative samples of each phase can often be obtained from a horizontal port on the side of the pipeline.

4.3 This practice is used whenever liquid or steam samples, or both, must be collected from a two-phase discharge for chemical analysis. This typically includes initial well-testing operations when a well is discharged to the atmosphere or routine well production when a well discharges to a fluid gathering system and power plant. The combined two-phase flow of several wells producing through a common gathering system may also be sampled in accordance with this practice.

4.4 This practice is not typically employed when individual wells produce to dedicated production separators. In these cases, the separated steam and liquid at the outlet of the production separator is sampled in accordance with single-phase sampling methods (Specification E 947).

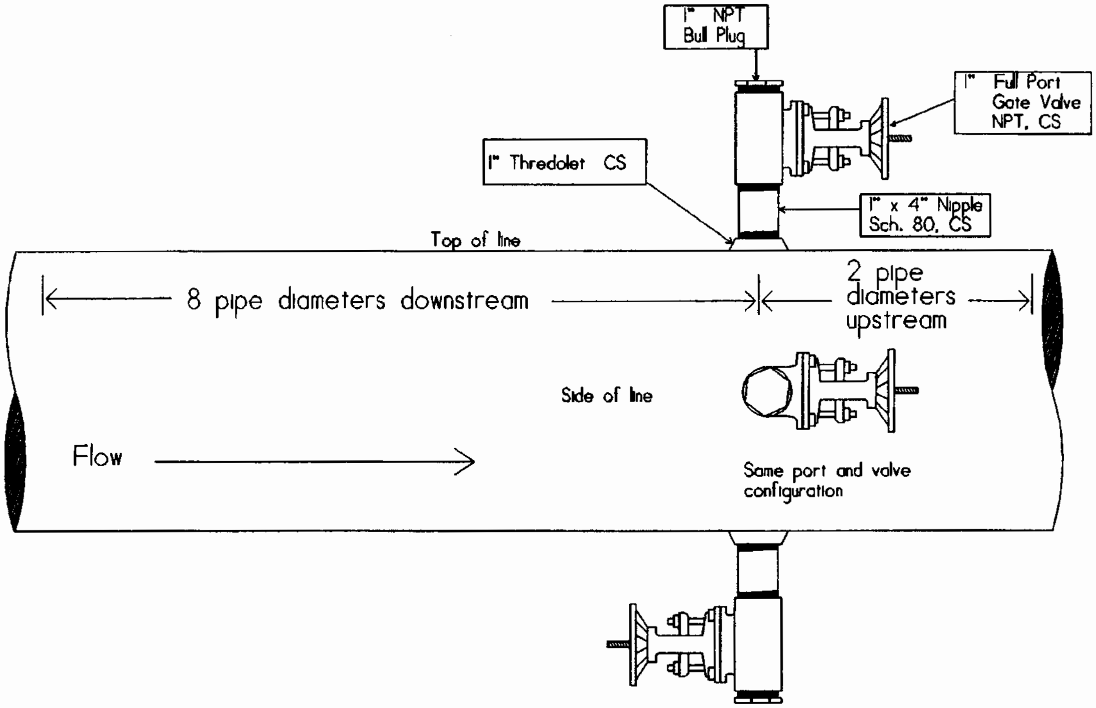
5. Sample Location

5.1 Sample locations vary and are dependent upon the gross quantities of each phase at the sample point. If sample ports are properly oriented on the two-phase pipeline, a certain degree of phase stratification will have occurred prior to sampling, facilitating further separation of the target phase through the sampling separator.

5.2 Ports are ideally located on the top and bottom of the pipeline at least eight diameters downstream and two diameters upstream of major flow disturbances such as pipe bends, reductions, valving, etc. (see Fig. 1).

5.2.1 In cases where the fluid contains substantial quantities of solid debris that may plug the sample port, the liquid port can be located at a 45° angle from the bottom, provided that a sufficient liquid phase is present.

5.2.2 If the flow regime is known, the number of ports may possibly be reduced to a single port located either on the side, top, or bottom of the two-phase pipeline. Sufficient quantities of each phase must be available at the single port to allow collection of representative steam and liquid samples.



NOTE 1—Minimum pipe diameters required upstream and downstream of major flow disturbances (piping bends, reductions).

FIG. 1 Two-Phase Flowline Sampling Separator Ports

5.2.3 The sample ports must be at least 1-in. diameter and configured with a full-open port ball or gate valve. This requirement is necessary to ensure that only a minimal pressure drop occurs through the port valve and associated piping. Scale and debris often reduce the effective inner diameter of the port, therefore smaller ports are not recommended. The port size restriction also provides a safety margin given the weight of the separator and force needed to install and remove fittings from the port.

5.3 Sample ports should never be located on side-stream piping from the main flow line unless only the side-stream fluids are to be characterized. The proportions of each phase are not likely to remain the same in a flow stream split off from the main flow line. Any pressure reduction in the side stream piping will change the steam and liquid compositions to an unknown degree.

6. Equipment

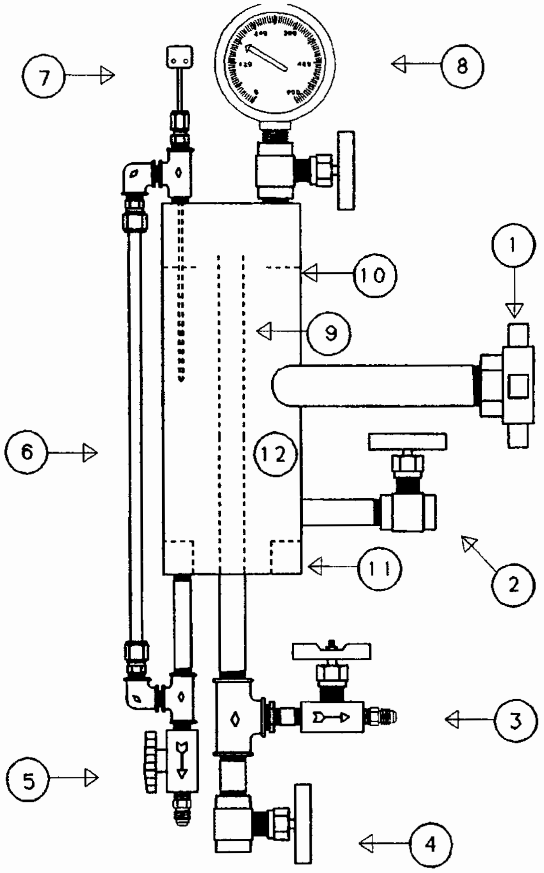
6.1 *Sampling Separator*—A cyclone-type separator rated to the pipeline pressure at the sample point, including a pressure gage, temperature probe, and sight glass (optional). The separator should be designed to attach directly to the sample port to minimize heat loss and pressure drop.

6.1.1 A typical sampling separator is shown in Fig. 2. This is a cyclone-type separator with a 1-in. pipe inlet attached at a tangent to the separator body. The separator is rated to 500 psig at 500°F. A pressure gage and thermocouple are located at the top of the separator, and steam and liquid sample valves are located at the bottom. Steam is drawn from the top of the separator through an axial pipe extending up from the bottom of the vessel. Liquid is drawn directly off the bottom. Internal baffles prevent liquid films from rising up the inner walls of the vessel with the steam flow to the sample valves. Vortex breakers are placed in the bottom of the vessel to prevent steam entrainment in the liquid flow to the sample valves.

6.1.1.1 The vent valve on the side of the sampling separator (No. 2 in Fig. 2) can be used to maintain an excess flow of steam and liquid through the separator, beyond the amount needed for sample collection. If sufficient quantities of each phase are present, the side vent valve will maintain a liquid level about 2 in. above the liquid sample valve (No. 5 in Fig. 2). This allows collection of both steam and liquid samples from the separator without the need to adjust the liquid level.

6.1.1.2 An optional sight-glass (PFA-fluorocarbon) for liquid level is located along one side of the separator to aid in proper separator operation and confirm the position of the liquid level. The sight glass is only rated to 250 psig and must be removed for higher pressure operation.

6.2 *Sample Hoses*—Sample hoses are PFA-lined stainless steel braided hoses rated to 500 psig and 450°F. JIC type fittings or quick-disconnect fittings attach hoses to the separator and condenser. Hoses are dedicated to either steam or liquid service to prevent cross-contamination. The inner diameter of the hose should not exceed 0.375 in. Stainless steel tubing may also be used (0.25 to 0.375-in. outside diameter), although it is less convenient. Convoluted, flexible stainless steel hose is specifically excluded due to potential entrapment and contamination problems caused by the internal convolutions.

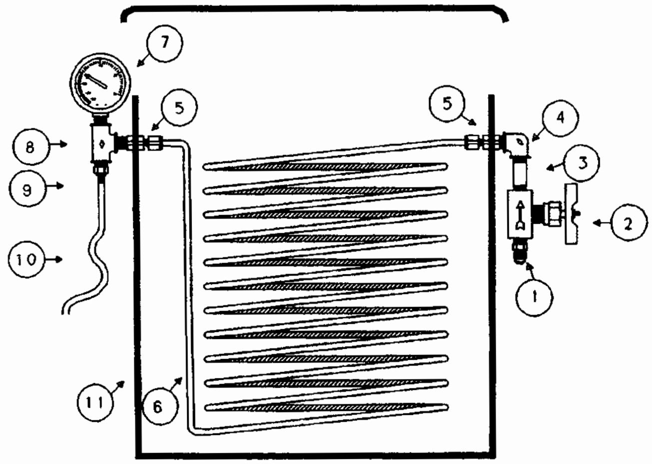


1) 1 in. Two-Phase Inlet (Hammer Union)
2) ½ in. Vent Valve (Regulating Valve or Ball Valve)
3) ¼ in. Steam Sample Valve (Regulating Valve)
4) ½ in. Steam Bleed Valve (Regulating Valve)
5) ¼ in. or ⅜ in. Liquid Sample Valve (Ball Valve)
6) ⅜ in. Teflon Sight Glass (250 psi limit: 1⁄16 in. wall, Teflon PFA)
7) ¼ in. × 12 in. Type K Thermocouple
8) Pressure Gage with Surge Protector Valve
9) ½ in. × Steam Outlet Pipe
10) Baffle Ring
11) Vortex Breaker Plates
12) Separator Body, 4 in. I.D. × 12 in.
Material specification: All metal components 304 or 316 stainless steel

FIG. 2 Sampling Separator

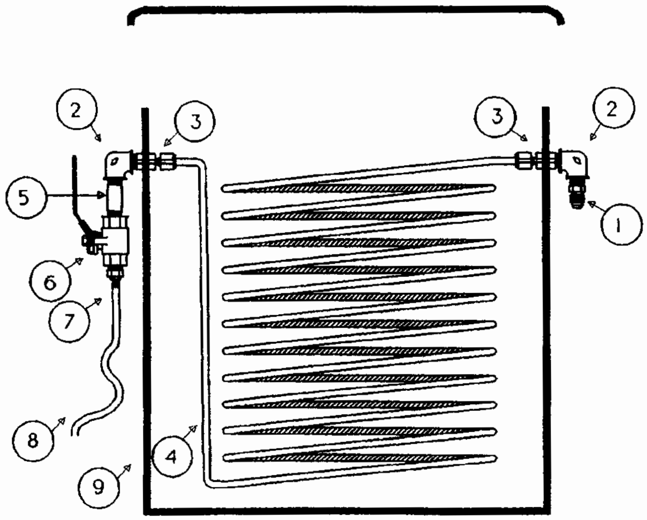
6.3 *Condenser*—A sample condenser configuration with two sets of stainless steel tubing coils is recommended. One set of coils is dedicated for condensing steam and the other is dedicated for cooling liquid. The steam condenser coil has a pressure/vacuum gage located at the sample outlet and a regulating valve at the inlet. The steam flow can be precisely regulated at the inlet as opposed to regulating the flow of condensate and gas at the outlet that can result in large pressure surges and the hold-up of gas or condensate phases in the coils. The liquid cooling coil has a regulating valve at the outlet and an optional pressure gage. Regulating the outlet flow prevents flashing of liquid at the inlet to the condenser where chemical deposition could occur. Dedicated condensers with single sets of tubing coils for sampling either steam or liquid also can be used (see Fig. 3 and Fig. 4).

6.3.1 The condenser coil tubing must not exceed 0.25-in. outside diameter to prevent the segregation of gas and condensate phases during sampling of steam. Larger tubing sizes also



1) JIC Fitting (¼ in. NPT × S.A.E. 37°)
2) Regulating Valve (¼ in. NPT)
3) Pipe Nipple (¼ in. NPT)
4) Pipe Elbow (¼ in. NPT)
5) Bulkhead Fitting (¼ in. NPT × ¼ in. Swagelok)
6) 20 ft. × ¼ in. O.D. Stainless Steel Tubing (0.035 in. wall)
7) 30 in. Hg × 30 psi Vacuum/Pressure Gage
8) Gage Tee (¼in. NPT)
9) Hose Adapter (¼in. NPT × ¼in. Hosebarb)
10) Plastic[5] Tubing (⅜ in. O.D., 5⁄16in. I.D.)
11) 8- to 20-Gallon Drum with Lid
Material specification: All metal components 304 or 316 stainless steel

FIG. 3 Steam Sample Condenser



1) JIC Fitting (¼ in. NPT × S.A.E. 37°)
2) Pipe Elbow (¼ in. NPT)
3) Bulkhead Fitting (¼ in. NPT × ¼ in. or ⅜ in. Swagelok)
4) 20 ft. × ¼ in. or ⅜ in. O.D. Stainless Steel Tubing (0.035 in. wall)
5) Pipe Nipple (3 in. × ¼ in. NPT)
6) Sample Valve (Ball Valve, ¼ in. NPT)
7) Hose Adapter (¼ in. NPT × ¼ in. Hosebarb)
8) Plastic[5] Tubing (⅜ in. O.D., 5⁄16 in. I.D.)
9) 8- to 20-Gallon Drum with Lid
Material specification: All metal components 304 or 316 stainless steel

FIG. 4 Liquid Sample Cooler

increase the risk of contamination and chemical deposition during liquid sampling due to low fluid velocities and longer residence times within the tubing. In cases where the liquid contains substantial quantities of particulate matter, 0.375-in. outside diameter tubing coils may be used to minimize cooling coil plugging problems.

6.3.2 In cases where the noncondensible gas concentration in steam exceeds approximately 5 % by weight, the outlet of the steam condenser coil should be at an elevation below the inlet with a continuous down-slope in the tubing from inlet to outlet. This allows the small volume of condensate to freely drain out of the condenser and prevents hold-up within the coils.

6.4 Condenser cooling can be achieved by an ice/water bath surrounding the coils or by a continuous overflow of cooling water running into the vessel holding the coils (configuration shown in Fig. 3 and Fig. 4). Alternate configurations may include a water-tight jacket around the coils through which a constant source of cooling water flows. A source of coolant may be a glycol/water mixture circulated through the condenser jacket and an external fan-cooled heat exchanger.

6.5 *Pressure Gage*—For the measurement of separator pressure. Bourdon-tube type gages or pressure transducers may be used. A pressure-snubbing device is recommended to minimize the pressure spikes and surges common in two-phase flow lines. The full-scale pressure range of the gage should not exceed two times the measurement reading. The gage should be calibrated at monthly intervals when in routine use and every six months for intermittent use. The measurement accuracy of the gage should be at least ±1 % of full-scale. All gages require permanent identification numbers so that field data and calibration data can be traced to each specific instrument.

6.6 *Temperature Meter and Thermocouple Probes*—For the measurement of separator temperature. Temperature meters are the digital readout style with plug-in thermocouple probes. Type K thermocouples are preferred due to the corrosion resistance of the exposed electrical connectors. The meter accuracy should be at least ±1°F. Meters and thermocouple probes should be calibrated at the same intervals as the pressure gages to ensure consistency between the measurements of pressure and temperature. All meters and probes require permanent identification numbers so that field data and calibration data can be traced to each specific instrument.

6.7 *Fittings*—Sample ports often need to be replumbed, and fittings may need to be replaced. A selection of pipe fittings including reducer bushings, pipe nipples, couplings and elbows, plus those needed for sample equipment maintenance, are required on site.

6.8 *Plastic*[4]— Sample Tubing Located at the exit of the condenser for gas and liquid sample collection (5⁄16-in. inside diameter by ⅜-in. outside diameter). Heavy wall plastic[4] tubing is required for use under vacuum during gas sample collection and pressure during in-line filtration of liquid samples.

6.9 *Filter Holder*—High-pressure stainless steel (47 mm diameter) with 0.45 micron or smaller membrane filters for use at the condenser inlet. Polycarbonate membranes are required

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[4] Tygon, a registered trademark product of Norton Co., has been used for this purpose.

at high temperatures (up to 300°F). The same filter holder can be used at the outlet side or a low-pressure plastic filter holder may be substituted.

6.10 *Tool Kit*—Includes at a minimum several pipe wrenches (sizes 24-, 18-, and 14-in.), crescent wrenches (sizes 8- and 12-in.), and a hammer.

7. Hazards

7.1 Hydrogen sulfide gas is present in most geothermal steam. Typically the steam itself and the surrounding air are sufficient to dilute H_2S below hazardous levels. For wells that produce high concentrations of H_2S (>500 ppm_w in steam), a personal H_2S air monitor is required to verify that safe ambient air levels of H_2S are not exceeded. This is very important during sampling of shut-in wells or wells on bleed flows which tend to build high gas concentrations.

7.2 Hydrogen sulfide gas is concentrated during sampling as the steam is condensed to a liquid. Care must be taken when sampling high-gas wells to make sure that the gas is allowed to dissipate. If this sampling is done in an enclosed building or confined area, a properly sized fan or hood must be used. A personal H_2S air monitor is also required.

7.3 Geothermal steam or water temperatures can exceed 450°F. Dry superheated steam is generally less of a hazard than saturated steam and boiling water. Leather gloves must be worn when working on hot piping, sample hoses, fittings and valves.

7.4 Use extreme caution when attempting to vent geothermal fluids through sample ports to the atmosphere. Ports may be plugged with scale or rocks which can be released explosively and unexpectedly after the sample valve has been opened. Warn any assistants or workers nearby to stand clear.

7.5 Sample port valves and associated plumbing can be severely corroded or eroded. Extra care must be taken when operating old valves. If the valves are frozen or operate abnormally, they must not be used. Sample port fittings may be too weak to support the weight of the sampling separator. Schedule 80 sample port piping is the minimum grade needed to attach the separator.

7.5.1 Do not force valves or fittings with large pipe wrenches. Ruptures and uncontrolled steam releases may result. When tightening fittings with a pipe wrench, verify that the pipe wrench has a "bite" before exerting force and make sure footing is secure.

7.6 The noise from geothermal steam bleeds may be above the safe working levels. Ear plugs should be worn during operation of the separator.

7.7 Goggles or a face shield must be worn during sampling. An eye hazard exists from debris entrained in venting geothermal fluid and from corrosive chemicals used in sample bottles.

7.8 Gas bottles usually contain sodium hydroxide that is hazardous to the skin and eyes. A face shield and eye goggles must be worn when sampling. Gas bottles also may contain cadmium chloride which is poisonous and carcinogenic. Latex gloves should also be worn when handling gas sample bottles.

8. Procedure

8.1 *Installation and Set-Up of the Sampling Separator*:

8.1.1 Install a Schedule 80, 1-in. pipe nipple, with one part of the connecting hammer union attached to the sample port. Use an elbow fitting and second nipple if the port is vertical. Nipples should be only 4 to 6 in. long. At least a 1-in. size port is needed to support the weight of the separator and to allow sufficient flow without a pressure drop through the separator.

8.1.2 Orient the nipple so that it is pointing away from personnel and equipment, downwind if possible. Verify that the path is clear, then open the sample valve to blow out any debris. A qualitative check on the amount of liquid and steam discharged may be made to verify your choice of sample port location. Close the valve.

8.1.3 Connect the separator to the 1-in. pipe. Use the hammer to secure the union tightly. Insulate the attached inlet piping and fittings.

8.1.4 Close all valves on the separator except the isolation valve to the pressure gage.

8.1.5 Open the sample port valve completely and record the pressure reading. This pressure represents the static line pressure.

8.1.6 Slowly open the ½-in. vent valve (No. 2 in Fig. 2). Open the valve until the pressure on the gage starts to drop, then shut the valve slightly so that the pressure is maintained at the original static line pressure. Maximize the vent without significantly dropping the pressure (<2 % of reading), so that the relative heat loss between the pipeline and the separator is minimized.

8.2 *Operation of the Sampling Separator to Sample Steam*:

8.2.1 Open the steam bleed valve (No. 4 in Fig. 2) one-half to one turn. Adjust the ½-in. vent valve as needed to maintain static line pressure. Check the sight glass (if available) to verify that the liquid level is lower than the separator inlet. Let the separator level, pressure and temperature stabilize for 5 min. A transparent or bluish steam vent indicates that dry steam is exiting the steam bleed valve. Excess moisture is usually visible as white spray or streaks in the steam plume.

8.2.2 Open the steam sample valve (No. 3 in Fig. 2). Allow the steam to blow out any impurities, close the valve and connect the dedicated steam sample hose to this valve. Connect the other end of the hose to the steam condenser coil.

8.2.3 Open the steam sample valve 100 % and throttle the sample flow using the regulating valve on the condenser. Adjust the ½-in. vent valve as needed to maintain static line pressure. Allow the condensate to flush for 5 min through the condenser before sampling. Collect all samples as needed using the referenced methods. Record the separator pressure and temperature before and after collecting samples and monitor during sampling.

8.2.4 Prior to and during steam sampling, the separator liquid level should remain below the separator inlet pipe. If this level rises, reduce the steam bleed and steam sample flow rates and open the ½-in. vent valve as much as possible without allowing a significant pressure drop. If the level still rises, another sample port location may be required.

8.2.5 If the optional sight glass is not installed, excessive liquid level can be observed when white spray or streaks are present in the steam plume from the steam bleed valve. A surging flow (alternating hissing sound) from the ½-in. vent valve usually indicates that both liquid and steam are venting and the liquid level is at the ½-in. vent valve. A transparent or bluish steam vent indicates dry steam is exiting the steam bleed valve and the liquid level is not too high.

8.3 *Operation of the Sampling Separator to Sample Liquid*:

8.3.1 Open the steam bleed valve (No. 4 on Fig. 2) 100 %. Adjust the ½-in. vent valve as needed to maintain static line pressure. The separator liquid level should rise and may flood the separator, venting liquid and steam from the steam bleed valve. This ensures that pure liquid will be obtained from the liquid sample valve. Let the separator level, pressure and temperature stabilize for 5 min.

8.3.2 If liquid is scarce at the chosen sample port, both the steam bleed and steam sample valves may be opened (while maintaining line pressure) and the ½-in. vent valve shut completely in order to flood the separator. Let the separator level, pressure and temperature stabilize for 5 min.

8.3.3 Open the liquid sample valve (No. 5 on Fig. 2). Allow the water to blow out any impurities that may have settled there. Close the valve and connect one end of the dedicated liquid sample hose to the valve. Connect the other end to the liquid cooling coil.

8.3.4 Open the liquid sample valve 100 % and throttle the sample flow using the liquid sample cooler valve. Adjust the ½-in. vent valve or the steam bleed/sample valves, or both, as needed to maintain static line pressure. Allow the condenser to flush for 5 min before collecting samples. Collect all samples as needed using the referenced methods. Record the separator pressure and temperature before and after sampling and monitor during sampling.

8.3.5 Prior to and during liquid sampling, the separator liquid level should remain at or above the ½-in. vent valve as observed on the sight glass. If a sight glass is not installed, the separator should remain flooded as evidenced by liquid present in the steam bleed. If the level falls, operate the separator as described in 8.3.2. The liquid sample rate may also have to be reduced. If the level still falls, another sample port location may be required.

8.4 *Collection of Noncondensible Gas Samples*:

8.4.1 *Stem-Type Gas Bottle*—The term "stem-type" refers to the type of inlet system used on the gas bottle to collect the sample. A typical stem-type gas bottle is shown in Fig. 5. Stems are usually 5 in. long, having a small hole in the side 3 in. down from the top inlet. The end of the stem tube inside the bottle is sealed shut. The stem is secured to the bottle by a threaded packing nut with silicon and O-rings.[5] Tightening the packing nut compresses the O-ring which holds the stem in place with the side hole above the O-rings, maintaining the bottle vacuum. The stem is ridged near the inlet to allow a firm grip with fingers and to prevent it from being sucked completely into the bottle. The sealed end of the stem is enlarged slightly to impede blowout through the O-rings under pressure. Obtain a sample as follows:

8.4.1.1 Place the discharge end of the plastic[4] tubing from the condenser gage tee over the end of the stem ¼ to ½-in., using care not to push the stem in or twist and break it. Make sure the condenser valve is throttled sufficiently, so as not to over-pressure the tubing. The pressure gage on the outlet of the condenser should not read greater than 15 psig to start. If it does, turn down the sample flow rate. Remember the stem purge pressure at this point; this is the reference pressure when filling the bottle.

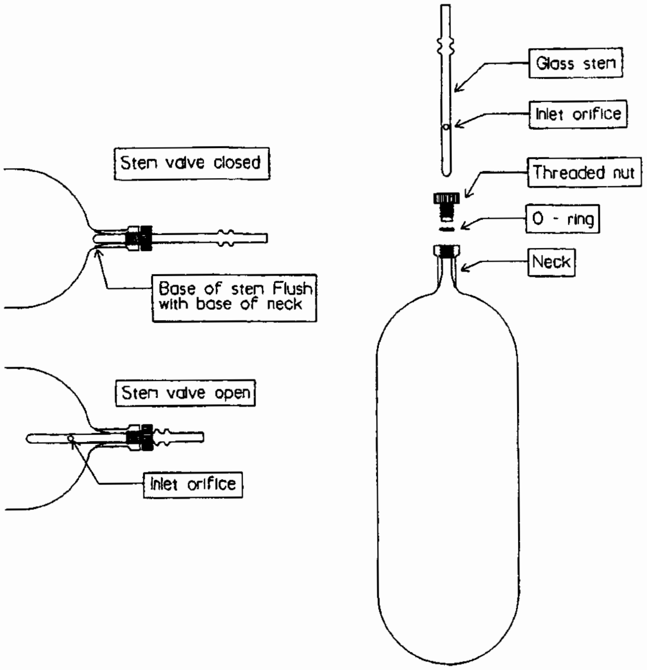

FIG. 5 Stem Type Gas Bottle

8.4.1.2 Condensate and noncondensible gas will purge the stem and escape to the atmosphere past the packing nut. As long as the small hole in the stem is above the O-rings, condensate and gas will purge to the atmosphere. When the stem is inserted below the O-rings, the sample is allowed into the container. Gently rotate the stem within the O-rings to loosen and slide the stem into the bottle. Loosen the packing nut one-eighth turn only if the stem does not slide easily.

8.4.1.3 After stem insertion, the bottle is turned stem down so that gases and liquids mix. The gage on the condenser should show an increase in vacuum or a drop in pressure, and the sample rate should increase slightly. Due to the small side-hole restriction in the stem, the condenser gage does not read the actual bottle pressure, but rather a relative pressure given the sample flow rate.

(*1*) During sampling, the bottle inlet pressure may rise sharply if particulate matter enters the stem and plugs the side-hole. Withdraw the stem before the pressure exceeds 15 psig and try to dislodge the particle, then resume sampling.

(*2*) It is desirable to maintain the bottle inlet pressure above atmospheric when sampling by adjusting the sample flow rate. This eliminates the potential for in-leakage of air through the sampling train.

8.4.1.4 As sampling progresses, condensate and gases fill the container and the vacuum will slowly decrease back to zero or the pressure will increase back to the initial stem purge pressure. Gently shake the bottle to facilitate absorption of CO_2. When the initial stem purge pressure is reached, sampling

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[5] Viton O-rings, available from Ace Glass, Inc., 1430 Northwest Blvd., Vineland, NJ 08360, have been found sutiable for this purpose.

is completed, and the stem should be withdrawn. Slide the stem back up until the side-hole is above the O-rings and condensate/gas is purging again to the atmosphere. The bottom end of the stem should be at the shoulder of the bottle neck, about ½-in. below the O-rings. Tighten the nut firmly.

8.4.1.5 If the vacuum does not return to zero or the pressure does not increase to the original stem purge pressure, fill the container to approximately three-fourth full with total liquid, but no more than three-fourth full. Those wells producing larger quantities of gas relative to steam will pressurize the bottles much faster and with less liquid volume.

(*1*) Although it may be possible to fill the bottle more than three-fourth full with liquid, do not fill bottles beyond this point, regardless of the vacuum remaining in the bottle.

8.4.2 *Single Stopcock Valve Gas Bottle*—Single stopcock valve gas bottles have a sampling nipple to attach the plastic[4] tubing directly to a valve mounted on the bottle. No initial purge is possible—the nipple has a minimal dead volume. A typical stopcock valve gas bottle is shown in Fig. 6.

8.4.2.1 Place the discharge end of the plastic[4] tubing from the condenser gage tee over the end of the nipple ¼ to ½in. Make sure the regulating valve on the condenser is throttled sufficiently to not over-pressure the tubing. The pressure gage on the outlet of the condenser will continue to increase until the stopcock valve is opened. If the sample rate is too high or if the valve is not opened quickly enough, the plastic[4] tubing will pop off the condenser or the bottle nipple. This usually occurs at approximately 30 psig.

8.4.2.2 Upon opening the stopcock valve, condensate and non-condensible gas will rapidly enter the bottle. The vacuum gage will show an increase in vacuum, usually much more than the stem–type bottle due to the larger opening of the stopcock valves. The stopcock valve can be throttled to reduce the sample rate and decrease the inlet vacuum.

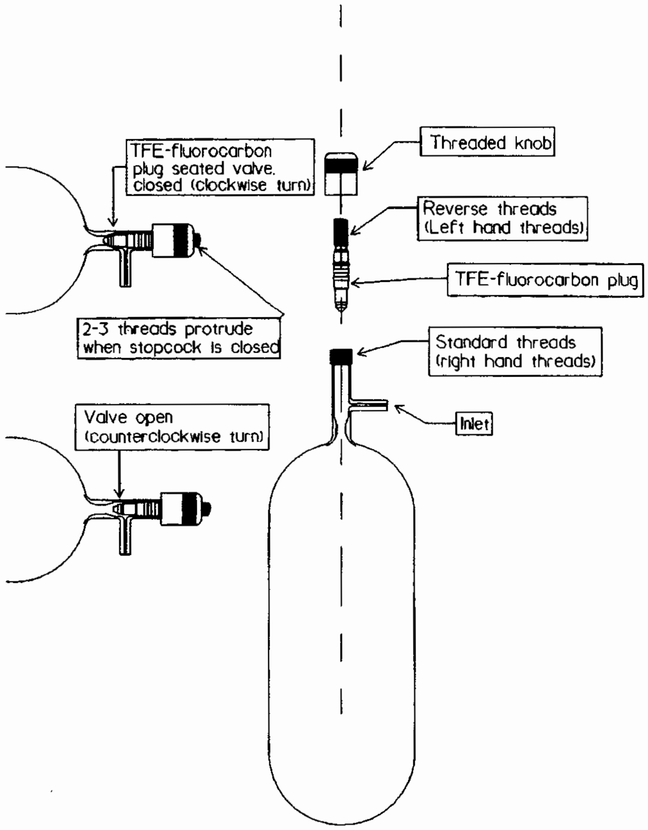


FIG. 6 Stopcock Valve Gas Bottle

8.4.2.3 It is desirable to maintain the bottle inlet pressure above atmospheric when sampling by adjusting the sample flow rate. This eliminates the potential for in-leakage of air through the sampling train.

8.4.2.4 Invert the container valve down to allow the gas and liquid to mix. Gently shaking the bottle will help dissolve CO_2 in the liquid and allow more sample to enter the bottle before the pressure increases.

(*1*) If the sample flow rate is too low, the absorbing solution in the bottle may back-flow into the plastic[4] tubing when the bottle is inverted. Increase flow or keep the bottle upright.

8.4.2.5 As sampling progresses, condensate and gases fill the container. The vacuum will slowly decrease back to zero and then the bottle will reach a slight positive pressure. Sampling is completed at this point, and the stopcock valve should be closed. If the vacuum does not return to zero or positive pressure, fill the container approximately three-fourths full with total liquid, but no more than three-fourths full. Slide the plastic[8] tubing off the nipple immediately after the bottle valve is closed. Those wells producing larger quantities of gas relative to steam will pressurize the bottles much faster and with less liquid volume.

8.5 *Collection of Steam Condensate and Geothermal Liquid Samples*:

8.5.1 *Steam Condensate* (see Table 1)—Steam condensate is collected in polyethylene, polypropylene, TFE-fluorocarbon, or glass bottles. Sample bottles not containing preservatives are rinsed at least twice with sample and the end of the plastic[4] tubing is rinsed with condensate from the bottle. The cap is rinsed twice with condensate before tightening onto the bottle.

8.5.1.1 If acid or other preservatives are present in the bottles, care must be taken not to spill or overfill the bottles. The condensate temperature should not exceed 80°F during

TABLE 1 Steam Sample Collection

Sample Type	Parameter
Gas bottle, evacuated glass containing NaOH/$CdCl_2$	Ar, O_2, N_2, CH_4, H_2, He, CO_2, H_2S, NH_3, saturated hydrocarbons, radon-222, freon and SF_6 tracers
Gas bottle, evacuated glass containing deionized water/$CdCl_2$	Unsaturated hydrocarbons, aromatic hydrocarbons, CO
Impinger, gas scrubbing bottle containing NaOH/$CdCl_2$; 0.1 *N* H_2SO_4	H_2S, NH_3
Raw, unacidified (RU) condensate in polyethylene bottle, 250–500 mL	Cl^-, F^-, B, SiO_2, Na, As, Se
Raw, acidified HNO_3(RA) or filtered acidified HNO_3(FA) in polyethylene or TFE-fluorocarbon bottle, 250 mL + 5 mL HNO_3	Fe, Mn, other heavy metals
Raw, $HNO_3/K_2Cr_2O_7$ preserved in glass bottle, 125 to 250 mL + 25 to 50 mL preservative solution	Hg
Raw, unacidified (RU) condensate in glass vial containing copper wire, 25 to 50 mL	Stable isotopes

collection, minimizing loss of dissolved gases, and water vapor.

8.5.2 *Geothermal Liquid* (see Table 2)—Liquid sample bottles are filled in the same manner as steam condensate sample bottles.

8.5.3 Liquid samples are normally filtered for silica and metals analysis. The filter holder is assembled with a 0.45 µm or smaller membrane filter. Attach the filter holder directly to the discharge end of the plastic[8] tubing from the liquid cooling coils. Reduce the sample flow rate as needed to prevent the tubing from popping off under pressure. Verify that the filter has not ruptured during sampling by inspecting the membrane after the samples have been collected.

8.5.3.1 In cases where the suspended matter to be removed may dissolve upon cooling through the coils (calcite) or where precipitates may form upon cooling, the high-pressure stainless steel filter holder can be installed directly at the inlet to the coils using stainless steel JIC fittings. Only polycarbonate membrane filters should be used on the high temperature side. Verify that the filter has not ruptured during sampling by inspecting the membrane after the samples have been collected.

8.5.4 Dilution and preservation of liquid samples with HNO_3, deionized water or dilute NaOH may be required for silica analysis. Dilution with HNO_3 or deionized water may also be required for the analysis of metals and other species in highly saline brines. The dilutions are best performed gravimetrically by adding an approximate amount of geothermal liquid directly from the condenser to a pre-weighed sample bottle containing a known amount of preservative. The exact sample volume and dilution factor can be precisely determined later in the laboratory before analysis.

TABLE 2 Geothermal Liquid Sample Collection

Sample Type	Parameter
Raw, unacidified (RU) brine in polyethylene bottle, 500 to 1000 mL	Cl^-, F^-, B, $SO_4^{=}$, TDS, TSS, pH, alkalinity, As, Se
Raw, acidified HNO_3(RA) or filtered acidified HNO_3(FA) in polyethylene bottle, 250 mL, 5 mL HNO_3	Na, K, Ca, Mg, Sr, Li, SiO_2(by ICP), Fe, Mn, other heavy metals
Filtered, acidified,~$\frac{1}{10}$dilution of sample with 2 % HNO_3, in polyethylene bottle, 100 to 250 mL	SiO_2(by ICP), other high-level metals
Raw, NaOH/$CdCl_2$ preserved in polyethylene bottle, 500 to 1000 mL, 25 mL preservative solution	H_2S, $SO_4^{=}$
Raw, HNO_3/$K_2Cr_2O_7$ preserved in glass bottle, 125 to 250 mL, 25 to 50 mL preservative solution	Hg
Raw, unacidified (RU) condensate in glass vial, 125 mL	NH_3, total inorganic carbon
Raw, unacidified (RU) condensate in glass vial containing copper wire, 25 to 50 mL	Stable isotopes
Filtered, 0.1 *N* NaOH preserved (~$\frac{1}{10}$dilution of sample with NaOH) in polyethylene bottle, 100 to 250 mL	SiO_2

9. Quality Control

9.1 *Separator Operation*—Carefully compare static line pressure to the separator pressure to ensure that there is no significant difference. Reduce vent and bleed flows temporarily to check for an increase in separator pressure.

9.1.1 Ensure that the maximum allowable flow is being passed through the separator without a pressure drop and that connected inlet piping and fittings are insulated.

9.1.2 Compare separator pressure and temperature readings to steam tables to verify proper instrument operation.

9.1.3 Be certain that there is no liquid carry-over into steam samples and no steam entrainment into liquid samples by the techniques described in 8.2 and 8.3.

9.2 *Gas Bottle Sampling*—Whenever possible, gas bottle samples are collected with back-pressure at the bottle inlet as described in the procedure, but no more than 10 psig. By collecting samples in this manner, air contamination from condenser fitting leaks can be minimized. Stem bottles usually are best suited for sampling with back-pressure, but stopcock bottles can also be used in this manner by throttling the stopcock valve. The steam condenser should be leak-checked regularly by drawing a 20-in. Hg vacuum on the condenser, shutting off the vacuum source, and verifying the system will maintain this vacuum for 10 min.

9.3 *Condensate Samples*—Properly cleaned and prepared sample bottles are obtained from qualified laboratories and are rinsed with condensate in the field when appropriate. Only condenser trains and sample hoses dedicated strictly for steam sampling are used. Steam samples are not collected with geothermal liquid sampling equipment.

9.3.1 Sample train equipment must be sufficiently flushed between wells and upon initial sampling to prevent cross-contamination. Typically, a 5-min condensate flush at full flow is required before any samples are obtained.

9.4 *Geothermal Liquid Samples*—Properly cleaned and prepared sample bottles are obtained from qualified laboratories and are rinsed with liquid in the field when appropriate.

9.4.1 Sample train equipment must be sufficiently flushed between wells and upon initial sampling to prevent cross-contamination. Typically, a 5-min liquid flush at full flow is required before any samples are obtained.

9.4.2 Check filter membranes after collecting filtered samples to ensure that the filter is intact.

9.4.3 Check for excessive gas bubbles in the liquid sample stream which may indicate steam entrainment.

10. Keywords

10.1 chemical analysis; fluid chemistry; geothermal resources; two-phase geothermal fluids

Appendix C

Low-Flow Purging and Sampling Groundwater

Low-Flow Purging and Sampling Ground Water

Evolution of Technology and Standards

BY JOE RITCHEY

The human suffering caused by groundwater contamination has been dramatized in films such as "Erin Brockovich" and "A Civil Action." Joe Ritchey describes the ASTM standards behind the scenes that help ensure safe drinking water and provide proof of contamination when necessary.

Throughout history a safe drinking water supply has been among the top criteria for the sustained development of a community. As such, it is not surprising that successful ancient civilizations engineered their water supplies to get a safe source to their citizenry. Evidence of ancient wells as a source of water is present today at least in the Middle East and Central America and probably many other locations. Although something was known then about what made water good or bad to drink, much of what we know today has been learned in the past 50 years.

We now understand the mechanics of ground-water flow and contaminant transport even if we are unable to describe subsurface conditions sufficiently to determine the contamination's exact whereabouts. Often contamination occurs from unidentified sources so that even an understanding of the mechanisms of transport leaves us unsure of the extent of migration. Monitoring wells are one of the tools to examine subsurface conditions. Collecting groundwater samples from several wells at nearly the same time and then repeating the sampling procedure several months later may enable the investigator to interpolate between past and current conditions and even extrapolate to some future time.

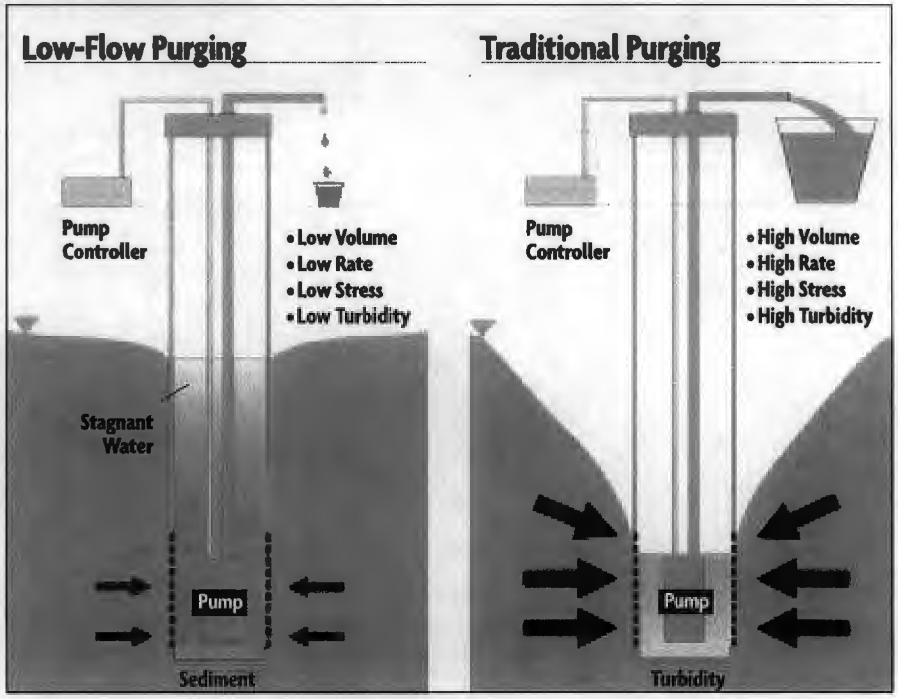
To make a valid comparison between past and present, the samples need to be representative of the water in the soil and rock. In addition the samples need to be evaluated in a consistent manner so as to eliminate effects due to sampling procedures or chemical analysis techniques. Changing the sampling procedure is done at risk of changing some characteristic of the samples. Knowing the cause and effect relationship of each procedure helps the investigator focus on eliminating the significant impacts first.

A REVIEW OF GROUND-WATER PURGING METHODS

The usual purpose of collecting ground water samples is to determine the concentration of a particular dissolved chemical in the geologic formation. Getting the ground water from the formation in to the sample bottle without changing it is crucial and you don't need to be trained in hydrology to immediately identify obstacles. The water to be sampled may be several metres to tens of metres below the ground-water surface so that it may be pressurized above atmospheric pressure. The distance from the water surface to the ground surface may also be significant, requiring a pumping device. The ground water temperature (usually the annual average air temperature at the ground surface) may be warmer or colder than the temperature at the ground surface at the time of sampling. Warmer temperatures at the ground surface are usually more problematic. Ultimately ground water must pass through a sand pack surrounding the well screen, the well screen itself, well casing, and sampling device before it is placed in a container for shipment to a laboratory.

Changes in the pressure and temperature will affect the sample and so will the presence of air or gases and contact with foreign materials such as the sand pack and well casing. To minimize this possible effect specific recommendations for material-chemical compatibility were established. Beyond the materials, ground water itself will often reside in the well casing exposed to the atmosphere for months if not years between subsequent sampling events. This passage of time further affects the sample such that the water in the well is clearly not representative of the formation water. Hence the procedure was instituted of purging "stag-

FIGURE 1



Low-flow purging extracts much less water than traditional purging.

Apparatus for collecting a groundwater sample – from left to right: purging and sampling pump controller, air tank for pump, bucket to contain purge water, and flow-through cell to measure indicator parameters.

nant" water from the well so that representative ground water is sampled.

In the late 1970s, purging three to five times the volume of water initially in the well was arbitrarily considered adequate to produce samples representative of formation water. However, calculation of the percent formation water with volume purged was recommended to provide a more rational basis to determine the amount of purging required. The rate and volume of ground water pumped was to be determined on the basis of soil or rock properties and the well diameter. Wells were purged in the minimum time required to produce "representative" ground water samples.

The 1980s brought an enormous number of site investigations for soil and ground water contamination in response to regulations by national agencies such as the U.S. Environmental Protection Agency. Monitoring well technology, sampling procedures, and analytical techniques were developed and many were defined in ASTM standards.

Through the decade of the 1990s industries frequently complained about the expense of continued monitoring of a large number of wells, while regulators saw little progress in cleanup. The goal of corrective actions was changed to include an evaluation of risk at the point of exposure rather than cleanup to an arbitrary cleanup value for a particular chemical, and efforts were focused on reducing costs in monitoring programs and the waste generated by environmental investigations. One of the activities that was scrutinized was the volume of water purged from a well prior to sampling that had to be disposed of as a waste. In many municipalities wastewaters from well purging and corrective actions were specifically excluded from publicly owned treatment works because of the fear of violating of their own discharge permit. Along with the expenses of investigating an ever-increasing number of sites came extensive research that, in part, showed what was happening in a well during purging and sampling by different methods. Purging a fixed volume of water was usually done as quickly as possible, which usually re-suspended sediments that had settled to the bottom of the well. In particular, acid added as a preservative, would leach metals from any suspended sediment, exaggerating the metals results. To address problems such as these, a method called "low-flow" purging proved effective at enabling collection of representative samples while reducing the volume of water extracted.

WHAT IS LOW-FLOW PURGING?

"Low flow" refers to the movement of ground water from the formation through the well screen. Flow must be minimized to preclude the entrainment of sediment in the water to be collected as a sample. Some researchers refer to the method as "low-stress" purging, where "low stress" refers to the impact of pumping the well on the formation. Water-level drawdown and turbidity provide measurable indicators of the stress on a given formation imparted by a pumping device operated at a given flow rate.

Low-flow purging directly followed by sampling is a method of collecting samples from a well that does not require the removal of large volumes of water from the well (Figure 1, previous page). Low-flow purging differs from previously developed methods of purging because "stagnant" water is left in the well and the turbidity is minimized. The method depends on moving ground water through the well screen at approximately the same rate as it flows through the formation. This enables significant reduction in the volume of water extracted before sampling. For the natural movement of ground water to flow through the well, the well must have been properly designed, constructed, and developed such as described in ASTM standards D 5092, Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers, and D 5521, Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aqufiers.

Typically, flow rates on the order of 0.1 to 0.5 L/min are used; however, this is dependent on site-specific and well-specific factors. Some very coarse textured formations have been successfully purged and sampled in this manner at flow rates up to 1 L/min. Pumping water levels in the well and water-quality indicator parameters should be monitored during pumping, with stabilization indicating that purging is completed and sampling can begin. Because the flow rate used for purging is, in most cases, the same or only slightly higher than the flow rate used for sampling, and because purging and sampling are conducted as one continuous operation in the field, the process is referred to as low-flow purging and sampling.

Low-flow purging and sampling can be used to collect samples for aqueous-phase contaminants and naturally occurring analytes, including volatile and semi-volatile organic compounds, metals and other inorganics, pesticides, PCBs, other organic compounds, radionuclides and microbiological constituents. Low-flow purging and sampling is effective with aqueous-phase constituents that may sorb or partition to particulate matter. Low-flow purging and sampling is not applicable to sampling either light or dense non-aqueous-phase liquids.

BENEFITS OF LOW-FLOW PURGING AND SAMPLING

Purging and sampling at a low-flow rate offers a number of benefits over traditional methods including:

- Improved sample quality and reduced (or eliminated) need for sample filtration, through elimination of mixing of the water column in the well and minimized disturbance of the well and the formation, which result in greatly reduced sample turbidity and minimization of false positives for analytes associated with particulate matter.
- Improved sample accuracy and precision and greatly reduced sample variability as a result of reduced stress on the formation, reduced mixing and dilution of analytes, and reduced potential for sample agitation, aeration and degassing or volatilization.
- Samples represent a smaller section or volume of the formation, representing a significant improvement in the ability to detect and resolve contaminant distributions, which may vary greatly over small distances in three-dimensional space.
- Overall, improved sample consistency, especially when using dedicated pump.
- Ability to directly quantify the total mobile contaminant load (including mobile colloid-sized particulate matter) without the need for sample filtration.

Ground-Water Sciences on the Big Screen

IN YEARS PAST THE FLAVOR OF BEER WAS ADVERTISED AS IMPROVED WITH GROUND WATER DERIVED FROM springs. You often can find advertising that exemplifies the virtues of "artesian" water in bottled drinking water. Within the last several years contaminated ground water has been the subject of two popular movies: **"A Civil Action"** (1998, Touchstone Pictures and Paramount Pictures) and **"Erin Brockovich"** (2000, Universal Pictures and Columbia Pictures). Both movies portray the tragedy of families suffering due to contact with contaminated ground water and difficulty in identifying its source, path, and effect.

"A Civil Action" is about the Woburn, Mass., case in which chlorinated solvents from two industries contaminated wells G and H in the city's well field. As is sometimes the situation, an investigation was carried out in the course of a legal battle between citizens against the industries rather than by compliance between the industry and state or federal environmental protection agencies. Whether the investigation is carried out at the direction of legal counsel or a regulatory authority, the engineers and geologists doing the work are anxious to perform the work in a logical manner, trying to balance the cost of additional samples verses the increased uncertainty of fewer samples. Either way the representativeness of the samples is crucial.

In "Erin Brockovich," groundwater contamination in Hinkley, Calif., is caused by release of hexavalent chromium, an additive to inhibit corrosion in a compressor station cooling tower water. Spent cooling water was placed in lagoons that leaked impacting residential wells. As with many contamination cases, the releases to groundwater began before there was a real awareness of environmental management. Unfortunately even after the releases were identified and the risk was assessed, the ramifications were ignored.

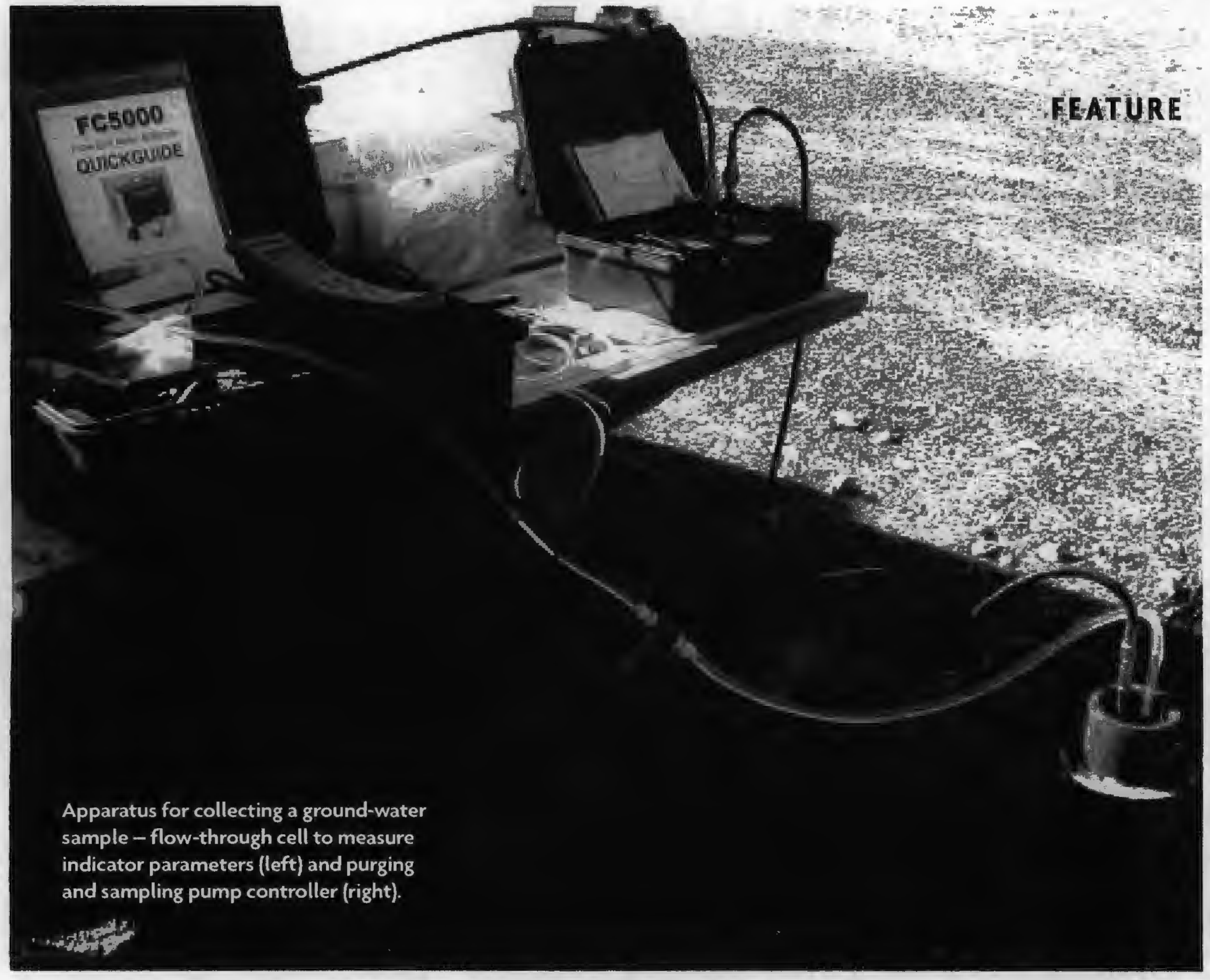
Neither movie is on the list of 100 top grossing films of all time, however, "A Civil Action" grossed over $55 million and "Erin Brockovich" over $125 million. These numbers indicate that the movies were well received by the public. The impact of sampling techniques in the cases portrayed in these movies were not shown on screen, however, they most likely were an important part of the legal proceedings; they always are.

Installing the purging/ sampling pump.

Chronology of a Sampling Event

A SAMPLING EVENT IS THE STEPS FOLLOWED FROM PLANNING THE activity to submitting the samples to the laboratory performing the analyses. The steps are outlined below:

- **Perform calibration checks** on field monitoring instruments.
- **Inspect the well** and surrounding site for security, damage, and evidence of tampering.
- **If volatile organic compound (VOC)** contamination is present or suspected, determine ambient VOC background levels in the immediate vicinity of the well with an appropriate instrument. Then remove the well cap and immediately measure VOCs at the rim of the well and record the readings in the field logbook or on the well data sheet.
- **Locate** the well survey reference point.
- **Measure** the static water level in the well.
- **Containerize wastewater** until analytical data are available to determine the proper disposal process.
- **Purging (with an installed dedicated purging and sampling device) -** Start the pump at a low flow rate until surface discharge occurs. Check water level. If no drawdown occurs, gradually increase the pump rate until flow is optimized with minimal drawdown.
- **Connect the pump discharge tubing directly to the flow-through-cell.** Monitor and record water level and pumping rate every three to five minutes (or as appropriate) during purging.
- **Monitor Indicator Field Parameters -** During well purging, monitor selected indicator field parameters (e.g., turbidity, temperature, specific conductance, pH, oxidation-reduction potential, dissolved oxygen) every three to five minutes.
- **Collect Water Samples -** Disconnect the flow cell from the water path before collecting samples. Water samples for laboratory analyses must be collected before the water has passed through the cell to prevent cross contamination or chemistry changes.
- **Add the preservative** as required by analytical methods.
- **Label each sample** as it is collected. Samples requiring cooling (e.g., VOCs and cyanide) are to be placed into a cooler with ice or refrigerant for delivery to the laboratory.
- **Post Sampling Activities -** Measure the final flow rate and record on the field data sheet and measure the final depth to water and total well depth, if required and not previously measured during this sampling event, and record.
- **Secure the well.**



Apparatus for collecting a ground-water sample – flow-through cell to measure indicator parameters (left) and purging and sampling pump controller (right).

- Increased well life through reduced pumping stress on the well and formation, resulting in greatly reduced movement of fine sediment into the filter pack and well screen.
- Greatly reduced purge-water volume (often 90 to 95 percent), resulting in significant savings of cost related to purge water handling and disposal or treatment, and reduced exposure of field personnel to potentially contaminated purge water.
- Reduced purging and sampling time (much reduced at sites using dedicated pumps), resulting in savings of labor cost.

STANDARDS DEVELOPMENT

The expansion of environmental activities in the 1980s and early 1990s led to new products, methods, and standards. One of the early standards developed was D 4448, Standard Guide for Sampling Ground Water Monitoring Wells, developed by Committee D34 on Waste Management. In 1987 Subcommittee D18.21 on Ground Water and Vadose Zone Investigations was formed under Committee D18 on Soil and Rock. A D18 task group on ground water sample collection and handling then assisted D34 in revising D 4448 in 1995, and most recently in 2001.

Standard D 4448 describes the general options available for sampling ground water. Additional standards have been developed to provide more detail on many of the options presented in D 4448. Related standards include:

- D 5903, Guide for Planning and Preparing for a Ground-Water Sampling Event;
- D 6634, Guide for Selection of Purging and Sampling Devices for Ground-Water Monitoring Wells;
- D 6564, Guide for Field Filtration of Ground-Water Samples;
- D 6517, Guide for Field Preservation of Ground-Water Samples;
- D 6089, Guide for Documenting a Ground-Water Sampling Event.

Recently D34 and D18 worked cooperatively to develop a new standard Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations. Although initially developed independently, a joint committee week meeting in January 2002 resulted in a committee approval of the standard. D18 and D34 are committed to working together on the development of future standards for ground-water investigations. //

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