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Delineation of Areas Having Elevated Electrical Conductivity, Orientation and Characterization of Bedrock Fractures, and Occurrence of Groundwater Discharge to Surface Water at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund Site Near McCormick, South Carolina

Scientific Investigations Report 2015–5084

U.S. Department of the Interior
U.S. Geological Survey

Cover. Drilling equipment used by U.S. Environmental Protection Agency contractors during the construction of well BH66 in October 2012.

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By Melinda J. Chapman, Brad A. Huffman, and Kristen Bukowski McSwain

Prepared in cooperation with the U.S. Environmental Protection Agency, Region 4, Superfund Section

Scientific Investigations Report 2015–5084

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2015

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
gallon (gal)	3.785	cubic decimeter (dm^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic feet (ft^3)	0.0283168	cubic meters (m^3)
	Flow or movement rate	
foot per day (ft/d)	0.3048	meter per day (m/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
kilometers per hour (km/h)	0.621371	miles per hour (mi/hr)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Frequency	
Hertz (Hz)	1	cycle per second
millimhos per meter	1,000/mmhos/m	ohm-meters
millimhos per meter	1	millisiemens per meter

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)

Conversion Factors—Continued

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Specific conductance as recorded during water-quality profiles was measured using a calibrated probe. However, specific conductance logs presented in borehole geophysical tools are considered qualitative because the tool was not calibrated in the field.

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

ATV	acoustic televiewer image log
EM	electromagnetic
DTS	distributed temperature sensing
EPA	U.S. Environmental Protection Agency
FLASH	Flow-Log Analysis of Single Holes
GPS	global positioning system
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
PVC	polyvinyl chloride
OTV	optical televiewer image log
START	EPA Superfund Technical Assessment and Response Team
USGS	U.S. Geological Survey

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Delineation of Areas Having Elevated Electrical Conductivity, Orientation and Characterization of Bedrock Fractures, and Occurrence of Groundwater Discharge to Surface Water at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund Site Near McCormick, South Carolina

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Abstract

During October 2012 through March 2013, the U.S. Geological Survey (USGS), in cooperation with the U.S. Environmental Protection Agency (EPA) Region 4, Superfund Section, conducted borehole geophysical logging, surface geophysical surveys, and water-quality profiling in selected wells and areas to characterize or delineate the extent of elevated subsurface electrical conductivity at the EPA Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina. Elevated electrical conductivity measured at the site may be related to native rock materials, waste rock disposal areas used in past operations, and (or) groundwater having elevated dissolved solids (primarily metals and major ions) related to waste migration. Five shallow screened wells and four open-borehole bedrock wells were logged by using a suite of borehole tools, and downhole water-quality profiles were recorded in two additional wells. Well depths ranged from about 26 to 300 feet below land surface. Surface geophysical surveys based on frequency-domain electromagnetic and distributed temperature sensing (DTS) techniques were used to identify areas of elevated electrical conductivity (Earth materials and groundwater) and potential high dissolved solids in groundwater and surface water on land and in areas along the northern unnamed tributary at the site.

Results from the electromagnetic-induction logging of four selected wells near the Main Pit and one well located about 800 feet southeast of the Main Pit lake indicate that elevated electrical conductivity extends to a depth of about 110 feet below land surface. Groundwater-quality properties recorded in eight selected wells were highly variable, suggesting a broad spectrum of geochemical conditions and contaminant concentrations within the groundwater system. Ranges of field water-quality properties recorded from water-profiling of groundwater in all wells logged were as follows: pH, 3.1 to 9.2; specific conductance, 48 to 5,300 microsiemens per centimeter; dissolved oxygen, 0.2 to 4.4 milligrams per liter; and water temperature, 17.0 to 18.0 degrees Celsius. The highest specific conductance and lowest pH measurements were made in boreholes located between the Main Pit lake and the northern unnamed tributary. Conceptually, these wells may intercept elevated dissolved solids in groundwater leaking from the Main Pit lake along a flow path that discharges into the unnamed tributary to the north. Results from surface geophysical electromagnetic and fiber-optics surveys confirm areas of focused discharge of groundwater near the Main Pit lake along the northern unnamed tributary. The frequency-domain surface electromagnetic surveys also identified an area with higher levels of elevated electrical conductivity located northwest of the former Rainsford Pit area.

Bedrock properties were characterized from borehole geophysical logs collected from three open-borehole bedrock wells. The mean strike azimuth of the borehole foliation data measured in bedrock well IR-1 was 221° (N. 41° E.), and the mean dip angle was 78° to the northwest. Dominant strike azimuth orientations of primary fractures measured in three boreholes were from 210° to 250° (N. 30° E. to N. 70° E.) with a mean dip of 68° northwest. Transmissivity estimates interpreted from the heat-pulse flowmeter data from bedrock well IR-1 were about 69 feet squared per day, and the radius of influence was estimated at about 640 feet.

Introduction

The U.S. Environmental Protection Agency (EPA) has created a National Priority List (NPL) of abandoned hazardous waste sites to determine which sites require additional investigation or remediation. A former gold mine near McCormick, South Carolina (fig. 1), was officially placed on the NPL in 2009 as a result of the presence of elevated heavy metal concentrations (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc) and cyanide in soil, sediment, groundwater, and surface water onsite and in tributaries. The site, named the Barite Hill/Nevada Goldfields, covers approximately 795 acres, with former mining operations encompassing approximately 135 acres. The site was operated from 1989 until 1995 as a conventional open-pit mine using cyanide heap-leaching processes for gold recovery. During operation, the site included two open mine pits: the 20-acre Main Pit and the former 4-acre Rainsford Pit areas

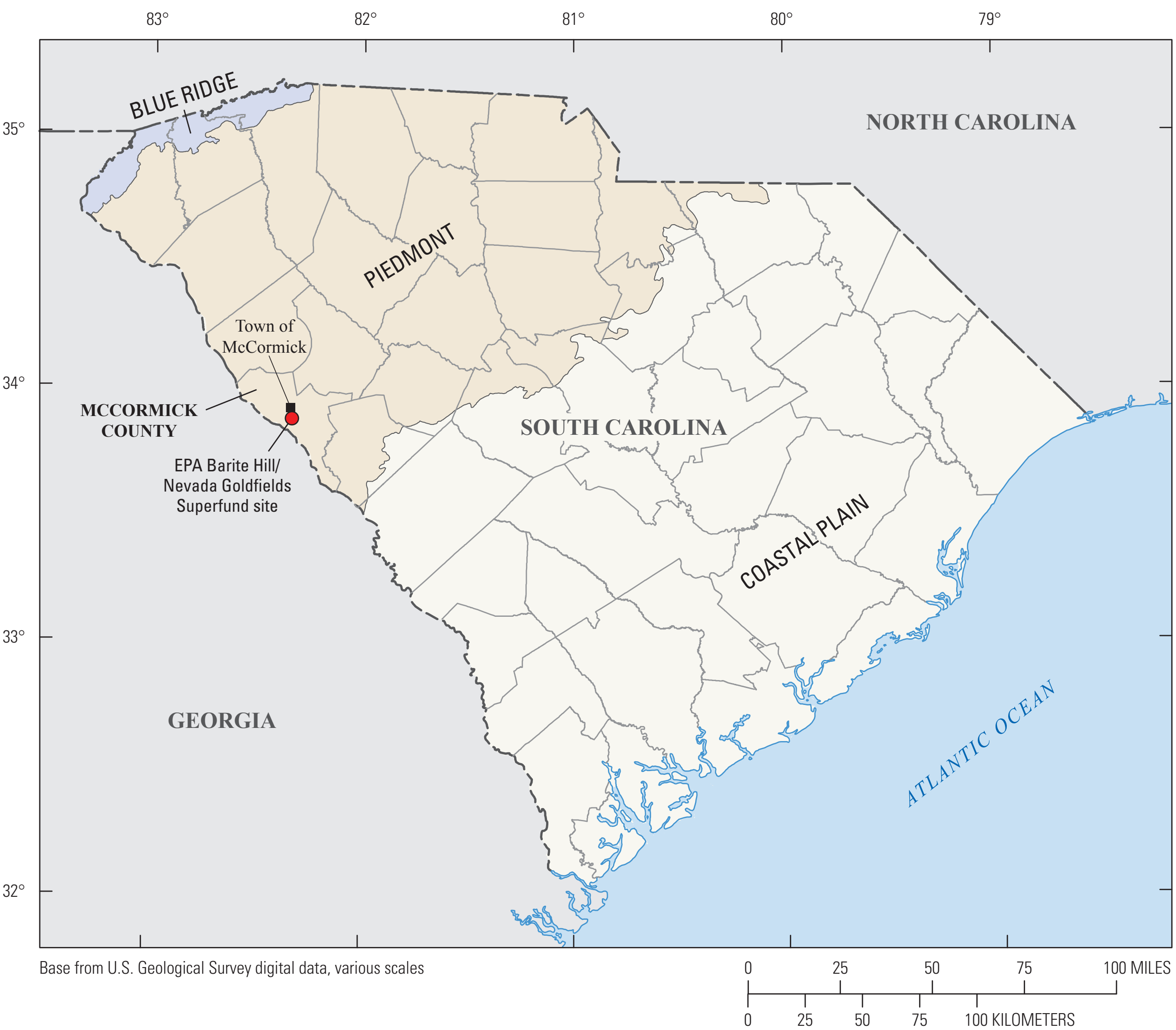


Figure 1. Physiographic provinces and location of the U.S. Environmental Protection Agency (EPA) Barite Hill/Nevada Goldfields Superfund site within McCormick County and the Piedmont Physiographic Province in South Carolina.

(fig. 2). In addition to the mine pits, the site also included a processing plant, a reusable heap-leach facility that consisted of an asphalt-lined leach pad, a permanent leach pad, seven ponds, and two waste disposal areas (U.S. Environmental Protection Agency, 2012).

Mining operations ceased in 1995, at which time Nevada Goldfields, Inc., (the operational company) began reclaiming the site (restoring the site to natural or less disturbed conditions). Site reclamation continued until 1999 when the company filed for bankruptcy. At that time, the site was abandoned, and the facility was taken over by the South Carolina Department of Health and Environmental Control. Prior to site abandonment, the company treated the Main Pit lake water with sodium hydroxide to reduce the acidity (U.S. Environmental Protection Agency, 2007).

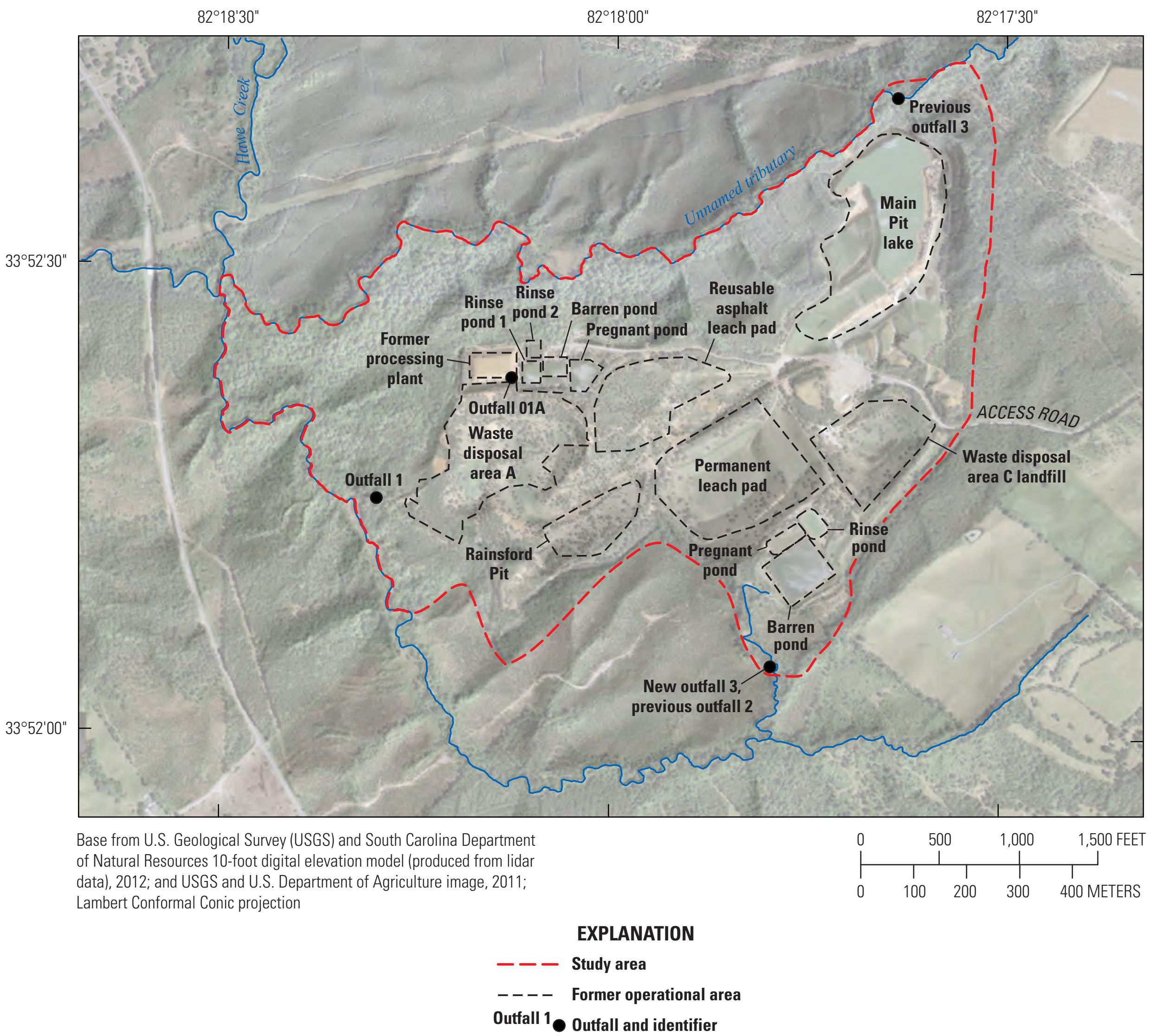


Figure 2. Former operational areas of the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina (Candice Teichert, U.S. Environmental Protection Agency, written commun., 2012).

When the mine was abandoned, the Main Pit slowly filled up with water (runoff and groundwater inflow). Much of this water was in contact with acid-producing minerals in surrounding waste rock, resulting in approximately 60 million gallons of acidic water (pH of approximately 2) and a high dissolved inorganic content in the Main Pit, now referred to as the Main Pit lake (Oneida Total Integrated Enterprises, 2009). Acidic water and dissolved inorganic constituents seeped from the site into unnamed tributaries to Hawe Creek that border the pit, flowed to Hawe Creek, and eventually flowed to the Savannah River and J. Strom Thurmond Dam and Clarks Hill Lake, approximately 2 miles (mi) downstream (figs. 3 and 4).

Figure 3. Location of the town of McCormick, McCormick County, the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site, Hawe Creek, and J. Strom Thurmond Dam and Clarks Hill Lake, South Carolina.

In February 2012, EPA Region 4, Superfund Section staff requested assistance from the U.S Geological Survey (USGS) in order to better delineate areas of elevated electrical conductivity in the subsurface and water, characterize subsurface fracture orientations in the bedrock, and identify areas of increased groundwater discharge to the unnamed northern tributary to Hawe Creek. The USGS study used a combination of surface and borehole geophysical techniques to delineate areas of elevated electrical conductivity and characterize the groundwater system. A history of site operations and remedial investigations is provided online at http://www.epa.gov/region4/superfund/sites/npl/southcarolina/bhilngldflsc.html (U.S. Environmental Protection Agency, 2013).

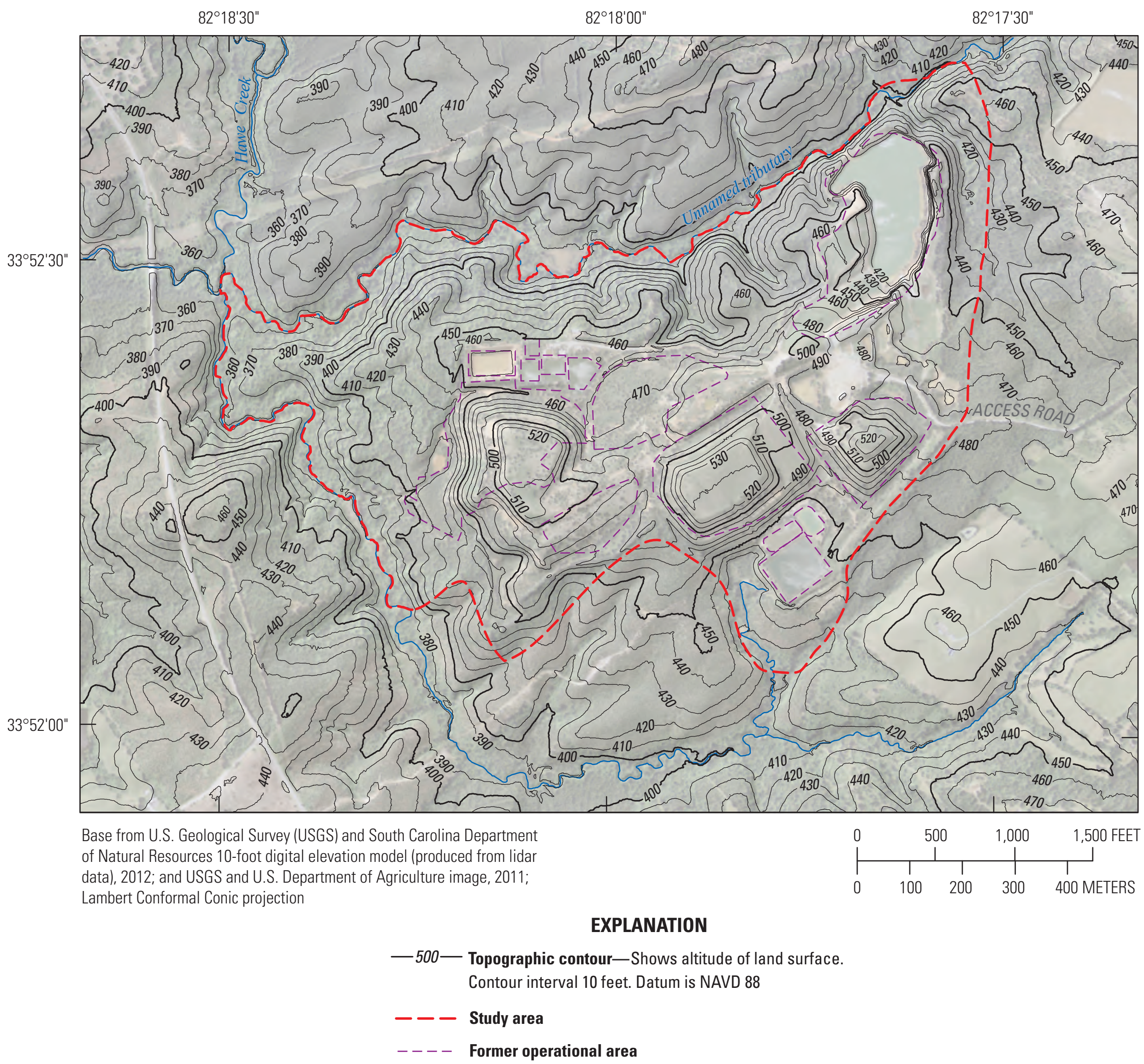


Figure 4. Topography and surrounding surface-water features at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site, near McCormick, South Carolina.

Purpose and Scope

The purpose of this report is to describe the results of the study conducted by the USGS at the EPA Barite Hill/Nevada Goldfields Superfund site during October 2012 through March 2013. Surface and borehole geophysical methods were used to delineate areas of elevated electrical conductivity at the site and assist with the characterization of the groundwater system. The scope of this report includes the documentation of delineation of areas of elevated conductivity in selected wells and other locations, bedrock fracture characteristics and orientations, and identification of areas of groundwater discharge in the northern unnamed tributary to Hawe Creek.

During October–November 2012, borehole geophysical logs were collected in three newly drilled wells, which were installed as part of this study by EPA contractors, and in six existing wells (table 1; fig. 5). In addition, groundwater-quality profiles of water temperature, pH, specific conductance, and dissolved oxygen were recorded at selected intervals in 11 wells (8 existing and 3 newly drilled). The

Table 1. Construction data for wells logged using borehole geophysical equipment at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

[USGS, U.S. Geological Survey; datum for latitude and longitude is North American Datum of 1983 (NAD 83); NAVD 88, North American Vertical Datum of 1988; BH, horehole; PVC, polyvinyl chloride; —, not applicable; ?, unknown, not observed during camera logging]

USGS site number	Station name and aquifer section tapped	Latitude (decimal degrees)	Longitude (decimal degrees)	Land-surface altitude (feet above NAVD 88)	Well depth (feet below land surface)	Casing material
335216082173601	BH33 (Regolith)	33.87122375	–82.29349583	469.18	161	PVC
335216082173602	BH34 (Regolith)	33.87122248	–82.29349842	468.71	96	PVC
335224082174301	BH49 (Regolith)	33.87324912	–82.29538085	486.25	70	PVC
335224082174302	BH50 (Regolith)	33.8732842	–82.29538039	487.16	142	PVC
335224082174303	BH51 (Regolith)	33.87321735	–82.29538297	485.99	192	PVC
335236082174401	BH55 (Regolith)	33.8767932	–82.29582214	408.34	36	PVC
335240082173801	BH56 (Regolith)	33.8777949	–82.2938855	419.43	26	PVC
335232082174901	BH65 (Regolith)	33.875475	–82.296856	422.19	89	Steel[1]
335226082173701	BH66 (Regolith)	33.873958	–82.293478	456.33	85	Steel[1]
335221082175301	BH67 (Regolith)	33.872628	–82.298169	495.28	146	Steel[1]
335224082172101	IR-1 (Bedrock)	33.873367	–82.289067	475	300	Steel

[1]Temporary casing or open-hole diameter installed during drilling activities.

[2]At the time of geophysical logging. Wells later completed as 2-inch PVC screened finishes.

borehole geophysical logs were collected to delineate areas of elevated electrically conductive materials above and below the water table in the regolith and bedrock that may be associated with past mining operations or natural conditions within the ore rock.

Surface geophysical surveys were conducted across the site to delineate areas of elevated conductivity in areas where subsurface information was lacking and to delineate zones of groundwater discharge to the unnamed northern tributary to Hawe Creek (fig. 6). During December 2012, surface electrical conductivity surveys were used to delineate areas across the site where the presence of conductive material in unsaturated zone materials or below the water table was not known or the outer boundaries of the elevated conductivity were not known. A fiber-optic distributed temperature survey was conducted in the unnamed northern tributary from late February to early March 2013, for a period of about 7 days, to identify potential groundwater discharge reaches of the unnamed northern tributary.

Table 1. Construction data for wells logged by borehole geophysical equipment at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.—Continued

[Datum for latitude and longitude is North American Datum of 1983 (NAD 83); NAVD 88, North American Vertical Datum of 1988; BH, horehole; PVC, polyvinyl chloride; —, not applicable; ?, unknown, not observed during camera logging]

Casing diameter (inches)	Screened interval	Open-hole interval	Geophysical logging date	Water level recorded prior to geophysical logging (depth below land surface, in feet)	Remarks	USGS site number
	(depth below land surface, in feet)					
2	150.6–160.6	—	October 11, 2012	41.11	—	335216082173601
2	?	—	October 11, 2012	40.79	Casing pinched at bottom; no screen observed	335216082173602
2	60.9–69.9	—	October 11, 2012	47.06	—	335224082174301
2	132.7–141.7	—	October 11, 2012	47.47	—	335224082174302
2	?	—	October 11, 2012	46.28	No screen observed	335224082174303
4	—	—	October 18, 2012	21.39	—	335236082174401
4	—	—	October 18, 2012	17.03	—	335240082173801
[1]6	—	[2]57–90	October 18, 2012	—	—	335232082174901
[1]6	—	[2]51.5–87	October 16, 2012	—	—	335226082173701
[1]6	—	[2]37.5–147	October 17, 2012	—	—	335221082175301
6	—	28–300	October 9, 2012	25.94	—	335224082172101

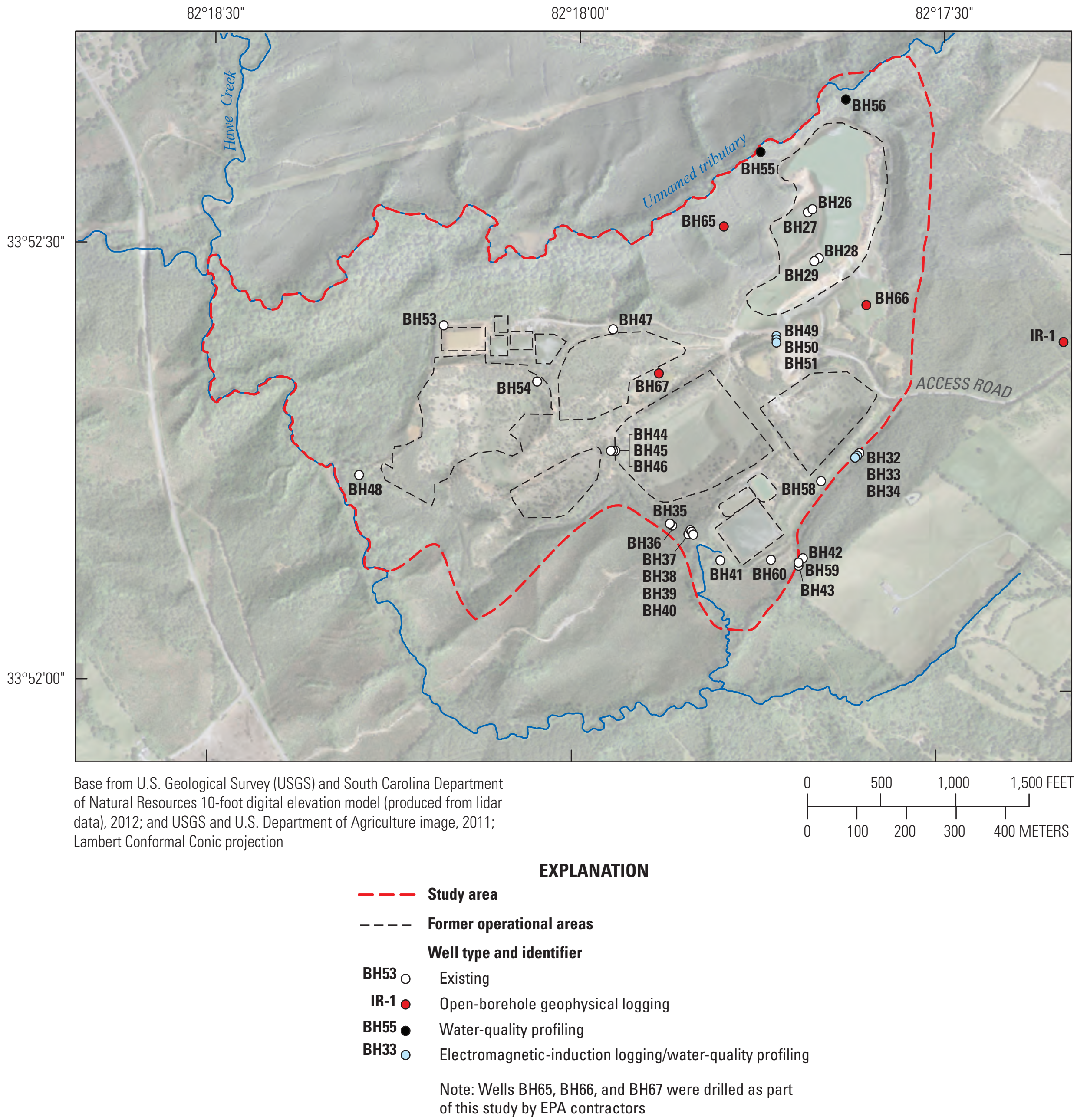


Figure 5. Wells logged using borehole geophysical methods at the U.S. Environmental Protection Agency (EPA) Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

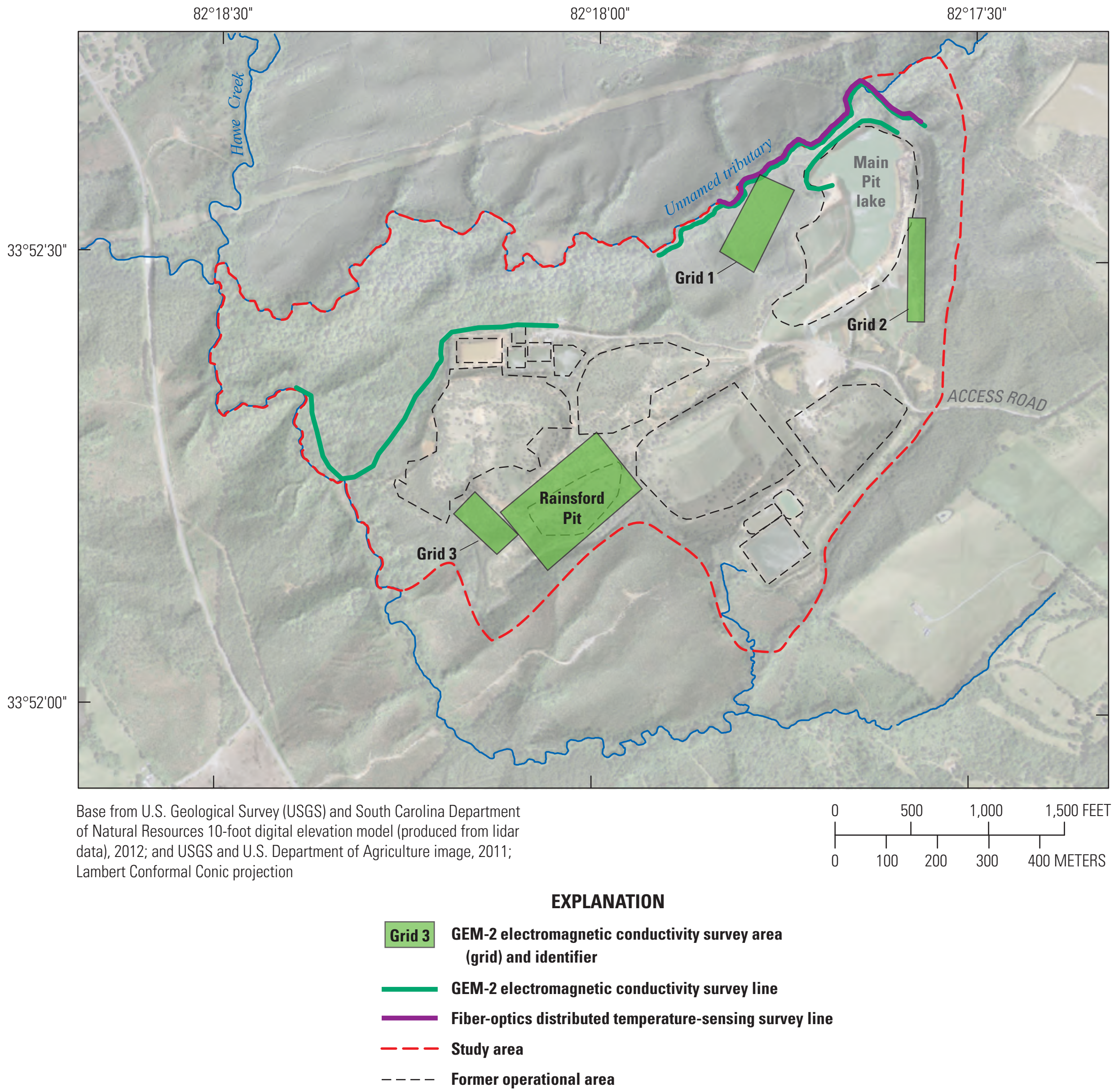


Figure 6. Location of the GEM-2 (electromagnetic) and fiber-optic distributed temperature sensing surveys at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

Study Area

The EPA Barite Hill/Nevada Goldfields Superfund site is located in McCormick County and is approximately 3 mi south of McCormick, South Carolina (fig. 1). The site is located in a relatively remote area, with no homes or commercial buildings closer than 0.5 mi of the site (U.S. Environmental Protection Agency, 2004). The topography of the area consists of rolling hills with land surface altitudes ranging from about 360 to 530 feet above the North American Vertical Datum of 1988 (NAVD 88) (fig. 4). The site is located along a topographic high that forms the headwaters of two unnamed tributaries to Hawe Creek (fig. 2). Clarks Hill Lake, a recreational lake created by the J. Strom Thurmond Dam on the Savannah River is about 3 mi west of the site (fig. 3).

The EPA Barite Hill/Nevada Goldfields Superfund site includes an area of about 795 acres. The former operational area of gold mining, leaching, and processing was about 135 acres, with a designated buffer area of about 660 acres (U.S. Environmental Protection Agency, 2011, 2013). To extract gold from ore, the facility used a cyanide solution in a heap-leach process that required several ponds for processing—three rinse ponds, two barren ponds, and two pregnant ponds (fig. 2). These ponds currently (2014) contain an unknown volume of liquids potentially contaminated with inorganics and cyanide. Additionally, the site includes three large, multi-acre waste-rock piles (also contaminated with cyanide), which have the potential for producing acidic water when the waste rocks come into contact with rainfall, surface-water runoff, and groundwater. Over time, the Main Pit, created by the past mining operations, filled in with approximately 60 million gallons of water (Oneida Total Integrated Enterprises, 2010). This water had a pH of 2 and high dissolved metals concentrations a few years (2003) after the mine closed in 1999 (U.S. Environmental Protection Agency, 2004), although treatment processes used the addition of sodium hydroxide, which periodically raised the pH to 4 or 5 (Oneida Total Integrated Enterprises, 2010).

Stormwater runoff is largely uncontrolled at the site, although four National Pollutant Discharge Elimination System (NPDES) monitoring sites are located within the unnamed tributaries to Hawe Creek (labeled as outfalls on fig. 2). Runoff from the site could contain a cyanide-bearing solution or acidic water with high dissolved metal content, and thus potentially affect nearby wetlands and the unnamed tributaries of Hawe Creek that surround the site (U.S. Environmental Protection Agency, 2004).

Geologic Setting

The EPA Barite Hill/Nevada Goldfields site is located within the southern part of the Carolina Slate Belt, more recently referred to as the Carolina terrane (Hibbard and others, 2002) in the Piedmont Physiographic Province of South Carolina (fig. 1), immediately north of the South Carolina-Georgia State line. As described by Clark (1999a, b), the geologic setting of the Barite Hill/Nevada Goldfields site is within metavolcanic host rocks (stratiform deposits), geographically within the Lincolnton-McCormick historic mining district. Foley and Ayuso (2012) describe gold deposits within the Carolina Slate Belt as ore-hosted within quartz-sericite-pyrite-altered volcanic rocks and juvenile metasedimentary rocks and in associated shear zones. At the Barite Hill/Nevada Goldfields site, associated shear zones are described as sheared and deformed auriferous massive sulfide deposits.

Clark (1999a, b) describes the host rocks at the Barite Hill/Nevada Goldfields site as sericitically-altered felsic metavolcanic and metasedimentary rocks of the Late Proterozoic Persimmon Fork Formation. The geologic history of the site consists of at least six stages (Clark, 1999a, b): (1) submarine volcanism/hydrothermal fluid migration/seafloor exhalation; (2) later hydrothermal activity within a failed massive sulfide system or epithermal event; (3) green schist facies metamorphism, folding, and thrust faulting; (4) late- to post-tectonic remobilization of quartz, barite, and gold; (5) high-angle faulting; and (6) deep weathering/oxidation. The geologic map presented by Clark (1999a, b) describes the Persimmon Fork Formation as primarily felsic-vitric and vitric-crystal metatuff, including lithic and lithic-lapilli tuff, agglomerate, welded tuff, and mafic tuff, as well as the felsic pyroclastic sequence (Carpenter, 1976).

The upper and lower mapped pyroclastic units within the Persimmon Fork Formation at the site are differentiated in the geologic map and block diagrams of the Main Pit and Rainsford Pit areas (Clark, 1999a, b). The upper pyroclastic unit consists of metadacite porphyry, such as weakly foliated, altered volcanic rock, and metavolcanic/metasedimentary rocks that are thin-bedded to finely laminated, composed of varying grain size, chlorite and alteration minerals, such as talc, tremolite, and actinolite. Regional bedding trends about N. 30°–50° E., dipping 52°–85° to the northwest or southeast (Clark, 1999a). The lower pyroclastic unit contains submassive sulfide or gossan, siliceous barite-rich rock, metasedimentary rock (chloritic, finely laminated), meta-keratophyre, and felsic metavolcanic rock (well foliated, metapyroclastic, altered, and mineralized). Northwest-trending normal faults also were mapped within the Main Pit area.

In 2008, the EPA Superfund Technical Assessment and Response Team (START) conducted a geologic assessment of the Barite Hill/Nevada Goldfields site. Rock units cropping out along the Main Pit wall and the northern tributary were described as a tan to light-orange, well-foliated felsic metavolcanic unit and a greenish-gray, thinly bedded, interlayered metavolcanic and metasedimentary unit (U.S. Environmental Protection Agency Superfund Technical Assessment and Response Team, 2008). Both units (felsic metavolcanic and interlayered metavolcanic/metasedimentary units) were described as competent rock, which means the rock is more resistant to weathering than other rock units. The dominant fracture sets measured were 40–60° and 310–330° azimuths. The mean fracture set measured for the felsic metavolcanic unit was 45° and 325°. The mean fracture set strike azimuth measured for the interlayered metavolcanic and metasedimentary unit was 52° and 313°.

Surface Water

McCormick County Water and Sewer supplies the majority of the population within a 4-mi radius of the study site with water from J. Strom Thurmond Reservoir, which is slightly upstream of the Hawe Creek discharge point (U.S. Environmental Protection Agency, 2004). Sections of Hawe Creek that flow into Strom Thurmond Reservoir (Clarks Hill Lake) are accessible for recreational activities such as fishing and swimming. Surface-water-quality and sediment samples have been collected at the site since the two original outfalls were permitted (NPDES Outfalls 1 and 2; fig. 2). Known groundwater seeps in the unnamed northern tributary near the Main Pit area at the Barite Hill/Nevada Goldfields site also have been sampled. Macroinvertebrate studies were conducted from 1992 to 1998 on a biannual basis in surface-water bodies at the site as a requirement of the NPDES permits. Elevated concentrations of metals discharging to the Outfall 1 receiving stream resulted in a reduction of habitat (including fish) downstream in the tributary to near its confluence with Hawe Creek (U.S. Environmental Protection Agency, 2004). Elevated concentrations of barium, copper, lead, selenium, and zinc that exceeded State of South Carolina and (or) EPA freshwater–surface-water chronic screening criteria for hazardous waste sites were detected in surface-water samples from the tributaries to Hawe Creek in March 2007 (U.S. Environmental Protection Agency, Region 4, Science and Ecosystem Division, 2013). Stream habitat surveys conducted in March 2007 indicated that groundwater seeps have a major effect, reducing biodiversity almost to the point of extinction (Lockheed Martin Technology Services, 2007). Surface-water-quality samples continue to be collected by EPA personnel and their consultants from the Main Pit lake and surrounding tributaries.

Groundwater

The aquifer system at the study site is complex, as is common in the Piedmont Physiographic Province of the southeastern United States. The complexity of the aquifer system is related to the fact that the rocks have undergone multiple periods of structural deformation, metamorphism, and igneous intrusion. The deep bedrock component has little primary porosity, and groundwater flow is controlled by secondary fractures and other complex discontinuities, such as differential weathering along lithologic contacts (Chapman and others, 2005). In some areas, a transition zone may be present, consisting of a partially weathered, more intensely fractured zone near the top of bedrock. Private groundwater-supply wells in the area are completed in the bedrock part of the aquifer. The shallow regolith is the primary storage reservoir and is the source of recharge to the deeper bedrock fractures (Heath, 1980).

At the Barite Hill/Nevada Goldfields site, at least three zones of groundwater have been identified and characterized: (1) a shallow, upper zone of saprolite, which is described as degraded, but retaining bedrock-like structures and fractures, and colluvial soils (regolith) with some relic structures and fractures; (2) an intermediate zone within the upper fracture system of the saprolite (likely the transition zone); and (3) deep competent bedrock (U.S. Environmental Protection Agency, 2004). The three zones are reported to be hydraulically connected, exhibiting no isolated or perched water-table conditions. The mean hydraulic conductivity within the shallow upper zone of saprolite was reported to be about 0.05 foot per day (ft/d), with the hydraulic conductivity of the uppermost section of colluvial clay reported to be as much as one or two orders of magnitude lower. Within the intermediate zone, the weathered rock retains some structure and is reported to have a mean hydraulic conductivity of 0.18 ft/d. The deep, lowermost competent bedrock zone is reported to have hydraulic conductivities of 0.019 ft/d and 0.09 ft/d (estimated from two wells). Vertical gradients were reported to be downward from the saprolite zone to the intermediate zone and upward from the deep bedrock zone to the intermediate zone (U.S. Environmental Protection Agency, 2004).

Methods

Borehole geophysical logs and surface geophysical surveys were used in this study to characterize subsurface electrical conductivity, characterize the fractured bedrock, and identify areas of groundwater discharge in the northern unnamed tributary at the EPA Barite Hill/Nevada Goldfields Superfund site. Borehole geophysical logs and groundwater-quality profiles were collected in 11 wells at the site from October through November 2012 (fig. 5; table 1). Surface electrical conductivity surveys were conducted at selected locations (fig. 6) across the site in December 2012. Fiber-optic distributed temperature-sensing (DTS) surveys recorded continuous water temperature along the fiber and air temperature from February 28 to March 4, 2013, in a section of the northern unnamed tributary near the Main Pit area.

Borehole Geophysical Logs

Borehole geophysical logs collected in selected wells at the site as part of this study included

- Downhole water-quality properties (temperature, pH, specific conductance, and dissolved oxygen) were measured in vertical profiles of seven wells and during heat-pulse flowmeter stress testing in one well (fig. 5; table 2);
- Electromagnetic-induction and natural gamma logs in the five shallow screened wells (BH33, BH34, BH49, BH50, and BH51);
- Caliper, electrical resistivity, natural gamma, fluid temperature, and resistivity in the four open-hole bedrock wells (existing well IR-1 and newly drilled wells BH65, BH66, and BH67);
- Optical televiewer (OTV) or acoustic televiewer (ATV) logs in the four open-hole bedrock wells (existing well IR-1 and newly drilled wells BH65, BH66, and BH67; note, well BH65 had cloudy water after drilling activities);
- Heat-pulse flowmeter (both ambient and stressed) in one existing bedrock well (well IR-1); and

Well depths where borehole geophysical logs and (or) water-quality profiles were collected ranged from about 26 to 300 ft below land surface (table 1). Traditional camera logs also were collected in the five accessible screened wells (wells BH33, BH34, BH49, BH50, and BH51) to check well integrity, including depths of casing and screened intervals and the presence of sediment infilling (appendix 1). Borehole geophysical logging field notes, which include field calibration checks, are included in appendix 1. Downhole camera well inspection logging notes for five wells are listed in appendix 2. Rinse samples from borehole logging tools were collected prior to geophysical logging, between the logging of selected wells, and subsequent to the completion of logging. These rinse samples were analyzed for major ions and metals to ensure that cross contamination did not occur from well to well as part of the geophysical logging process (appendix 3).

Geophysical logging was used to characterize (1) shallow, electrically conductive zones in the regolith and bedrock and (2) fractures (including other structures) in the bedrock. The electromagnetic (EM) induction logging tool can log through polyvinyl chloride (PVC) well casings and screens to a radial distance of about 4 ft surrounding the well (Century Geophysical Corporation, 2014). In the unsaturated zone above the water table, electrically conductive zones potentially represent native conductive geologic materials, such as ore deposits. Conductive materials below the water table may represent zones of conductive ore material and (or) groundwater that has elevated specific conductance related to elevated dissolved ions and metals. Fracture zones and other structural characteristics delineated in the four bedrock wells logged as part of this study include depth, degree of relative openness (open, partially open, or weathered only), and orientation (strike azimuth and dip angle). Depth to fracture zones within individual open boreholes was determined from traditional caliper, electrical resistivity, and fluid resistivity/temperature logs. Natural gamma logs also were collected for lithologic characterization and correlation. OTV or ATV image logs were collected to determine degree of relative fracture openness and orientation. Heat-pulse flowmeter logging was conducted in one open-borehole bedrock well to measure vertical flow near each delineated fracture zone relative to logging performed during the drilling of the well.

Continuous, oriented digital color images of the bedrock in the subsurface were recorded from OTV image logs. These logs were oriented by using a magnetometer built into the borehole tool, and thus, the orientation of features such as fractures, foliation (bedrock fabric), and lithologic contacts can be determined by using adjustments for local magnetic declination. Where the water in the well was too cloudy, an ATV tool was used to image the fractures and determine orientations.

Orientations of subsurface fractures (both open and sealed), foliation, and lithologic contacts were determined from the OTV and ATV image logs for three bedrock wells using WellCad software (Advanced Logic Technology, 2011). Fracture orientations were determined from OTV and ATV images, which were corrected for magnetic declination (National Oceanic and Atmospheric Administration, 2015) and borehole deviation. Additionally, the optical televiewer image can be used to characterize rock type, orientation of foliation/bedding, and geologic texture. Orientations interpreted from the OTV image logs were adjusted for a local magnetic declination of 6° west and for measured borehole deviation. Subsurface geologic features were compiled for statistical analyses using rose diagrams and three-dimensional display of fracture planes at depth. The fracture orientation data were compared to surface geologic mapping data to build a conceptual model of flow in the bedrock part of the aquifer at the study site.

Table 2. Physical properties and constituents of groundwater measured during well water-quality profiling during December 2012 at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; ?, unknown, no observation during camera logging; na, camera logging could not be conducted. Note: Values are average representations of vertical profile data]

Station name and aquifer section tapped	Logged depth (feet below land surface)	Screened or open interval (feet below land surface)	pH	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Temperature (°C)
BH33 (Regolith)	161	150.6–160.6	7.9	390	0.6	17.3
BH34 (Regolith)	96	?	7.6	571	0.2	17.0
BH49 (Regolith)	69.9	60.9–69.9	5.1	48	4.0	18.0
BH50 (Regolith)	141.7	132.7–141.7	9.2	170	0.2	17.7
BH51 (Regolith)	192	?	9.1	156	0.3	17.7
BH55 (Regolith)	35.72	na	3.8	3,410	0.2	17.3
BH56 (Regolith)	25.75	na	3.1	5,300	0.2	17.3
IR-1 (Bedrock)	300	28–300	6.7	315	4.4	18.0

Fracture zones were selected for heat-pulse flowmeter logging (that is, stationary measurements of vertical borehole flow above and below the fracture zone) based on interpretations from caliper, electrical resistivity, and fluid (temperature and specific conductance) logs, and OTV/ATV image logs and interpretations. Results from ambient (natural flow) and stressed (pumped flow) measurements from heat-pulse flowmeter logs were modeled for aquifer properties (hydraulic head differences, transmissivity, and radius of influence) by using the recently published USGS Flow-Log Analysis of Single Holes (FLASH) program (Day-Lewis and others, 2011; U.S. Geological Survey, 2014). Positive heat-pulse flow measurements indicated upward flow, and negative heat-pulse flow measurements indicated downward flow. In the one bedrock well where the heat-pulse flowmeter tool was used, modeled hydraulic characteristics (head and transmissivity) were estimated from flow measurements by using the FLASH model (Day-Lewis and others, 2011).

Surface Electromagnetic Conductivity Surveys

The surface EM conductivity surveys at the EPA Barite Hill/Nevada Goldfields Superfund site were conducted during December 2012 in areas of known elevated electrical conductivity near the Main Pit (fig. 6) and in areas where elevated constituent concentrations in groundwater may have migrated, such as west of the former Rainsford Pit area and in the western part of the site. The surface EM conductivity surveys were conducted by using a portable GEM-2 digital, multi-frequency electromagnetic sensor that recorded continuous walk-along profiles (horizontal instrument orientation) at selected locations. The GEM-2 sensor transmits an EM wave at seven combined frequencies ranging between about 330 and 48,000 hertz (Hz) (Geophex, Ltd., 2004) and induces a secondary magnetic field in the Earth. The instrument measures in-phase and quadrature data, which can later be converted to magnetic susceptibility and electrical conductivity, respectively. The instrument is portable, weighs about 9 pounds, is about 5 ft long, and has transmit and receive coils separated by a fixed offset distance within the same plane. The depth of investigation of the GEM-2 is related to the EM waveform skin depth, which is a function of the Earth's electrical conductivity, magnetic permeability, and the angular frequency of the EM plane wave propagating through the subsurface as described in equation 1 (Huang, 2005):

$$\delta = \sqrt{\frac{2}{\sigma\mu\omega}}, \qquad (1)$$

where

- σ is electrical conductivity of Earth material;
- μ is magnetic permeability of free space (vacuum); and
- ω is angular frequency.

At low frequencies, the waveform produced by the GEM-2 penetrates relatively deep into the Earth, compared to the higher frequencies (Geophex, Ltd., 2004). Surface EM induction surveys measure a bulk conductivity of the subsurface that extends from the land surface to a maximum depth of investigation that is a fraction of the skin depth, which is the total depth of penetration of the EM wave.

The GEM-2 EM surveys were collected by using the frequency-domain method in which variable frequencies and, therefore, variable depths of penetration are achieved in either predefined survey grid areas or along profile lines. The frequencies used were one of two preconfigured sets—

high and low—that contained seven frequencies each. The high frequency set ranged from 1,530 to 93,090 Hz, and the low frequency set ranged from 1,530 to 47,970 Hz. The frequency set used in the field in a particular survey area was dependent upon observed return signal strength and consistency. Data were collected during the survey by using WinGEM2 software on a handheld Trimble personal digital assistant. Surveys were performed by carrying the GEM-2 at about 1 meter (m) (3.28 ft) above land surface and walking at a regular pace of about 2.8 miles per hour (mi/h) (4.5 kilometers per hour [km/h]). The GEM-2 was equipped with a global positioning system (GPS) that allowed simultaneous time and positioning data to be collected and stored along with the data. Closed-canopy conditions in some areas (particularly in Grids 1 and 3, fig. 6) restricted the collection of location data, and limited GPS reception required spatial interpolation along sections of the grid layout. Surface EM conductivity survey data collected without GPS were not used in this report. The GEM-2 profile-line data were collected typically in open fields or along existing open paths or roads—along benches (topographically raised areas) west of the former Rainsford Pit area, along an old road on the west side of the site, along drainage areas and old logging roads near Grid 1, along the banks of a section of the northern unnamed tributary to Hawe Creek, and along the northern rim of the Main Pit lake. A few survey locations (Grids 1 and 3) were fairly wooded with no paths or roads. For these areas, dead-reckoning location methods were used to collect data along straight profile lines, and deviations were made only to avoid trees. In addition, a profile was collected within a selected stretch of the northern unnamed tributary near the Main Pit lake. Specific conductance and pH measurements also were recorded during the survey of the unnamed northern tributary.

Post-processing of the EM survey data was performed to remove noise and transient spikes in the data. Post-processing consisted of “despiking” the data by removing anomalies with short temporal and (or) spatial extents and applying a moving median filter by using Microsoft Excel. Surface EM survey data are presented in this report as electrical conductivity readings in units of millisiemens per meter.

Fiber-Optic Distributed Temperature Sensing Survey

Areas of groundwater discharge at the groundwater/surface-water interface generally are not readily discernible and often require measurement of a tracer or surrogate that differentiates between groundwater and surface water. Temperature has been shown to be an excellent tracer of groundwater movement along aquifer/surface-water interfaces near streams (Stonestrom and Constantz, 2003). Natural variations in stream water temperature patterns can be used to assess the interaction of surface water with shallow groundwater. The temperatures of surface-water bodies are variable and change daily in response to seasonal and meteorological changes, whereas groundwater temperatures are relatively stable year round. During the winter, groundwater discharge into surface water can be recognized as a warm thermal signature. During this study, methods were used that are intended to ensure measurement of differences in temperature and qualitative identification of areas of groundwater discharge, but these methods cannot be used to distinguish between no-flow and losing reaches.

Fiber-optic distributed temperature sensing (DTS) can be used to determine differences in the temperature of surface water along a profile. This relatively new technology is well suited for monitoring groundwater/surface-water interactions. With DTS, surface-water temperatures are measured for several days along a fiber-optic cable that may extend a mile or more with a spatial resolution of less than 1 m (1 ft). Temperature precisions of 0.1 degree Celsius (°C) and a temporal resolution of 90 seconds can be obtained (Selker and others, 2006). The differences in measured temperatures can often reveal locations of groundwater discharge.

From February 26 to March 7, 2013, a fiber-optic DTS survey was completed by using a Sensornet ORYX DTS to delineate areas of groundwater discharge along the northern unnamed tributary to Hawe Creek. About 725 m (2,400 ft) of fiber-optic cable were deployed in the bed of the stream channel in the tributary, which forms the northern hydrologic boundary of the site (fig. 6). GPS location measurements were collected every 5 m (about 16 ft) along the cable during deployment. Unfortunately, at 2:00 a.m. on the first night of data collection (February 27, 2013), the cable was severed, presumably by wildlife, which resulted in a loss of about 25 m (about 82 ft) of deployed cable and 2 days of data collection. The cable was repaired at the site by USGS personnel, and hence, the temperature data collection reported here began on February 28, 2013.

Temperature data obtained by using the ORYX DTS and analyzed for this study were collected beginning at 5:04 p.m. on February 28, 2013, and ending at 8:04 p.m. on March 7, 2013. Data were recorded every 1.5 minutes (min) at intervals of about 1 m (3.28 ft) along the length of the fiber-optic cable. Ten consecutive temporal measurements made by the DTS over a 15-minute period were averaged to obtain 1 temperature measurement, for a total of 684 measurements collected over about 7 days. Analysis of the thermal data after field deployment and retrieval of the fiber-optic cable was conducted by using the DTS graphical user interface (GUI) beta program, currently under development by the USGS (Martin Briggs, U.S. Geological Survey, written commun., 2013). The DTS GUI is a Python-based software package that provides tools to import and visualize DTS data superimposed on maps or satellite imagery. The user can also calculate and plot summary statistics of temperature time series and profiles. Air temperature also was measured with an independent thermometer. On February 13, 2013, a surface-water discharge measurement was made near the downstream end of the survey line using an acoustic Doppler velocimeter and the mid-point method (Turnipseed and Sauer, 2010).

Borehole Geophysical Logging and Imaging Data

During October 2012, borehole geophysical logs were collected from five shallow screened wells and four open-borehole bedrock wells (three newly drilled [BH65, BH66, and BH67] and one existing [IR-1]) at the EPA Barite Hill/Nevada Goldfields Superfund site (fig. 5). Groundwater-quality profiles were collected in seven wells. These data were collected to assist the EPA with the delineation of electrically conductive material (native geologic materials, mine waste rock, and groundwater having elevated dissolved solids and metals) within the regolith both above and below the water table and with the characterization of secondary fracture orientations and other structural features within the bedrock. The casing depths (depths to the top of the open-hole interval) for wells selected for borehole geophysical logging at the site indicate that the inferred regolith thickness ranges from about 28 to 57 ft (table 1). Groundwater levels measured in all 11 wells during geophysical logging and water-quality profile logging in October 2012 ranged from 17.03 to 47.47 ft below land surface.

Delineation of Shallow Conductivity from Electromagnetic-Induction Logs

Downhole EM-induction tools respond to the presence of conductive contaminants and sample the material in a 4-ft radius surrounding the open borehole or PVC-cased well. Electromagnetic-induction logs were collected in five selected wells—BH33, BH34, BH49, BH50, and BH51—during October 2012 (appendix 4). Natural gamma logs also were collected by using the same borehole geophysical tool. Wells BH49, BH50, and BH51 are located about 650 ft south of the Main Pit lake, and wells BH33 and BH34 are located about 1,300 ft south of the Main Pit lake (fig. 5).

The EM-induction logs for wells BH33 and BH34 indicate that high conductivity material is present to a depth of about 72 ft below land surface (fig. 7). The EM-induction log for well BH51 indicates high conductivity material to a depth of about 110 ft below land surface (fig. 8). These depths likely correspond to areas of low resistivity values (high conductivity material) delineated in the southwestern end of the resistivity sounding surveyed east of the Main Pit lake by GEL Geophysics, LLC (2012). The conductive zones within the wells generally were delineated as having elevated electrical conductivity (about 1,300 to greater than 6,000 millisiemens per meter [mS/m]) above and below the water table and higher specific conductance and lower pH values for the water in the well (figs. 7 and 8; appendix 4). (Note: millisiemens per meter borehole electrical conductivity units are equivalent to the surface electrical conductivity units of millimhos per meter.)

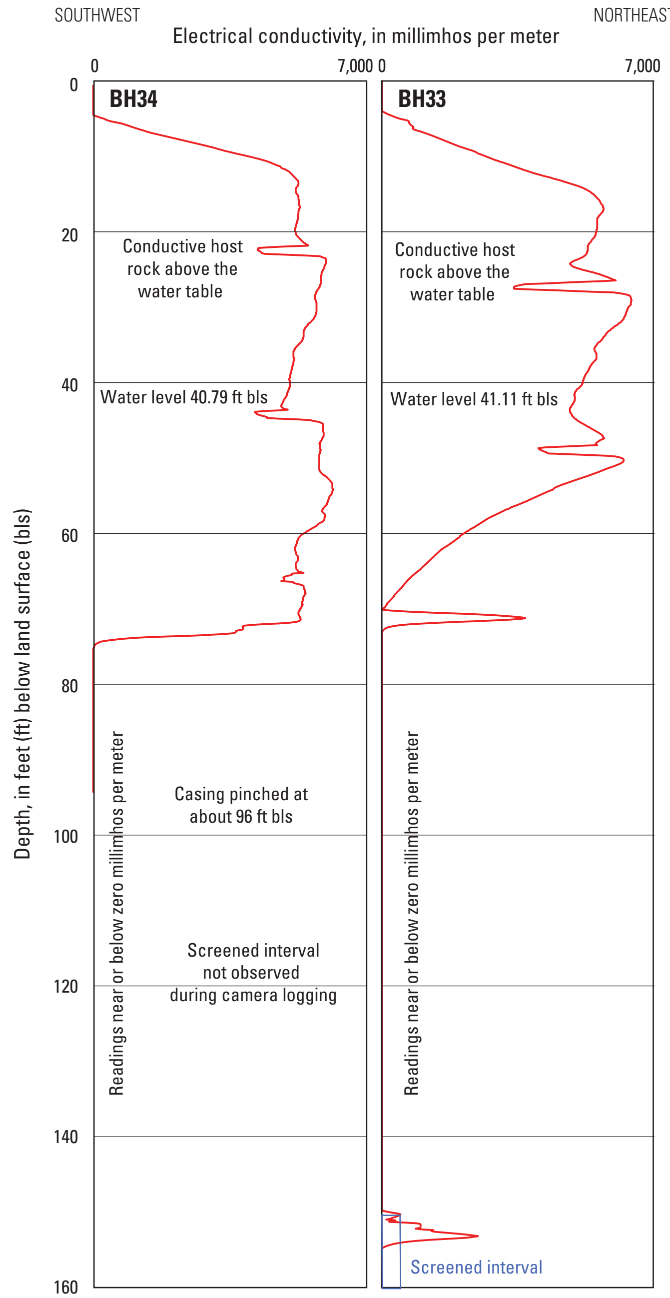


Figure 7. Electrical conductivity logs of regolith wells BH33 and BH34 showing a shallow area of high conductivity from land surface to about 72 feet and at depth within the screened interval for well BH33, October 2012, at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

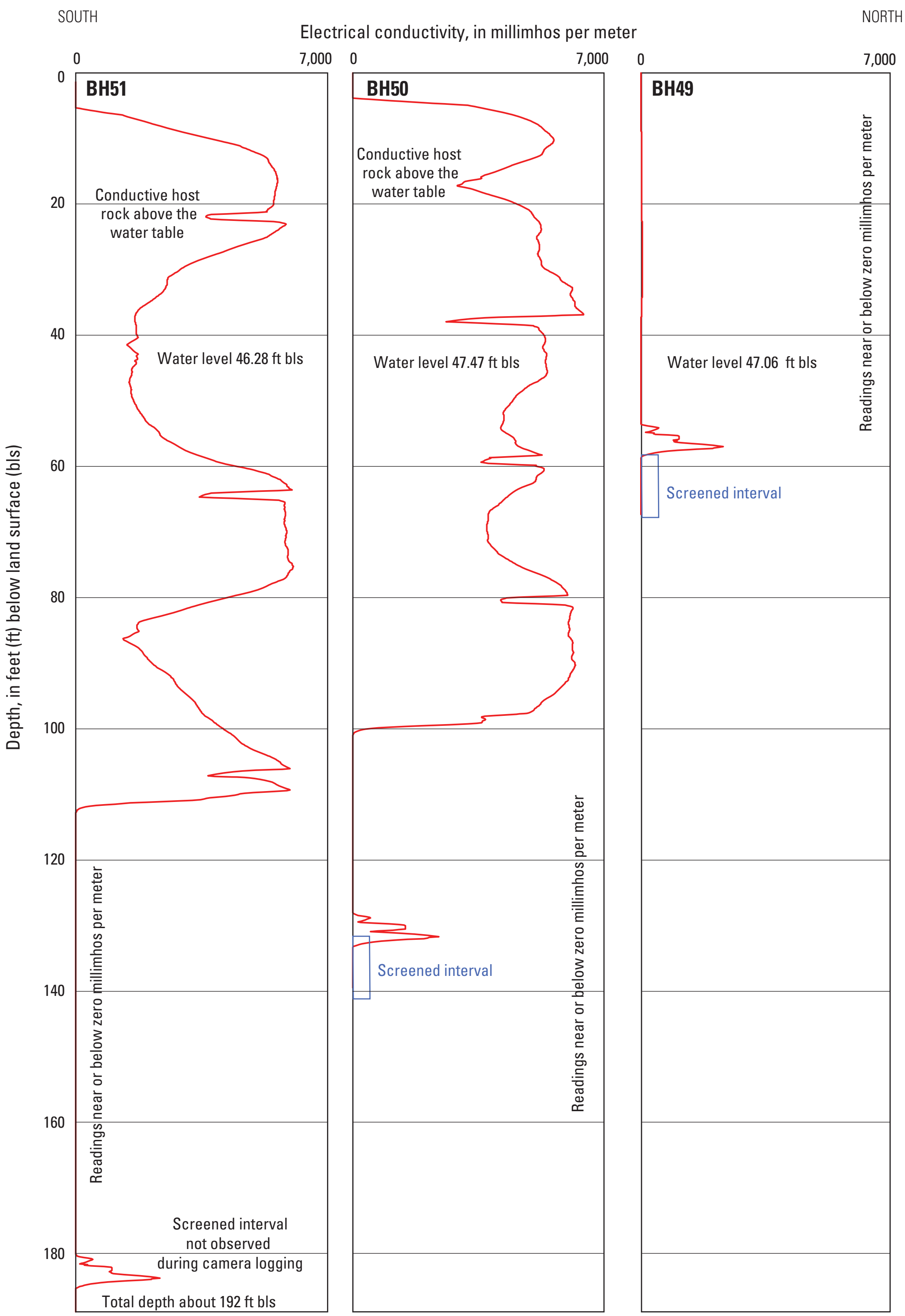


Figure 8. Electrical conductivity logs of regolith wells BH51, BH50, and BH49 showing a shallow area of high conductivity from land surface to about 110 feet in wells BH51 and BH50 and at depth within the screened interval for all three wells, October 2012, at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

The deep part of the EM induction log (figs. 7 and 8, wells BH33, BH34, BH50, and BH51) appears to reflect a sharp decrease in electrical conductivity that is most likely explained by a change in geologic materials, such as a reduction in the presence of conductive ore materials, or a reduction in porosity below the saturated zone (water table) in the transition zone or bedrock. The lower conductivity zone shown in figures 7 and 8 likely corresponds to the 100- to 200-ohmmeter "green" zone or deeper yellow and red zones delineated on the resistivity surveys conducted east of the Main Pit lake by GEL Geophysics LLC (2012). If this contrast in geologic materials is related to a porosity and permeability reduction in the transition zone or bedrock, it may be an important factor in controlling downward migration of elevated dissolved ions and metals in the groundwater system at the EPA Barite Hill/Nevada Goldfields Superfund site.

A comparison of water-quality profile data and properties recorded as part of this study in seven screened wells (BH33, BH34, BH 49, BH 50, BH 51, BH 55, and BH 56) and in open-hole bedrock well IR-1 indicates much higher specific conductance values (3,410 and 5,300 µS/cm, respectively) and much lower pH values (3.8 and 3.1, respectively) for wells BH55 and BH56 than for the other five wells (table 2; fig. 5; appendix 4). The higher specific conductance and lower pH measurements are the results of elevated concentrations of conductive dissolved ions and metals in groundwater at the site. Wells BH55 and BH56 are between the Main Pit lake and the northern unnamed tributary. Conceptually, these wells may intercept high conductivity/low pH groundwater leaking from the Main Pit area along a flow path discharging to the northern unnamed tributary (fig. 5). Results from well sampling conducted by EPA, Region 4, Science and Ecosystem Support Division (Athens, Ga.) during December 2012 also indicated that wells BH55 and BH56 had the highest specific conductance readings, the lowest pH readings, and the highest concentrations of major ions (calcium, sodium, magnesium, potassium, and sulfate) and inorganics (aluminum, cadmium, copper, iron, manganese, nickel, and zinc) of the five wells where EM-induction logs were collected or where groundwater-quality profiles were recorded (U.S. Environmental Protection Agency Region 4 Science and Ecosystem Division, 2013).

A variable range of water-quality properties was recorded in the seven screened wells: pH ranged from 3.1 to 9.2; specific conductance from 48 to 5,300 µS/cm; dissolved oxygen from 0.2 to 4.4 milligrams per liter (mg/L); and temperature from 17.0 to 18.0 °C (table 2). Well BH49 had anomalously low specific conductance values and high dissolved oxygen concentrations, suggesting enhanced recharge from precipitation as a result of either being shallow in the groundwater system or having potential well casing leakage over time. Wells BH33 and BH34 have elevated pH values, which could be a result of sodium hydroxide, which was used to treat the Main Pit lake water, leaking into the groundwater system. Bedrock well IR-1 had elevated dissolved oxygen concentrations, indicating a connection of deeper fractures to shallow groundwater recharge; no well casing leakage was detected during the ambient heat-pulse flowmeter logging. These data suggest a wide range of geochemical conditions within the groundwater system at the site.

Characterization of Bedrock Fractures and Foliation from Borehole Geophysical Logs

Open-hole borehole geophysical logs were collected in bedrock wells IR-1, BH65, BH66, and BH67 during October 2012 at the EPA Barite Hill/Nevada Goldfields Superfund site (figs. 9–12). Fracture zones are indicated by caliper "breakouts" or open-borehole enlargements and lower resistivity zones. Inflow from fracture zones was noted where inflections occur in fluid resistivity (calculated specific conductance) and temperature logs, such as near 150 ft in well IR-1 (fig. 9).

OTV or ATV images were used to determine orientations of secondary fractures and other planar features in three bedrock wells at the site during October 2012 (appendix 5). Additionally, the OTV images can be used to characterize rock type, orientation of foliation/bedding, and geologic texture. Figures 13*A*–*E* show examples of typical images of the bedrock foliation and fractures. Fractures were characterized as either primary (open), secondary (partially open or weathered), or sealed, as shown in appendix 5. Typical cross-cutting (against foliation) secondary fractures can be seen in well IR-1 (fig. 13*A*). Increased fracture density near the top of bedrock, which may be considered the transition zone in well IR-1, can be seen in figure 13*B*. Filled cross-cutting mineral veins or fractures in well IR-1 can be seen in figure 13*C*. A primary fracture is present at about 85.5 ft below land surface in well BH67, with other secondary fractures at depth (fig. 13*D*). Primary fractures are visible in the OTV image of well BH66 shown in figure 13*E* and are confirmed by an increase in borehole diameter on the caliper log.

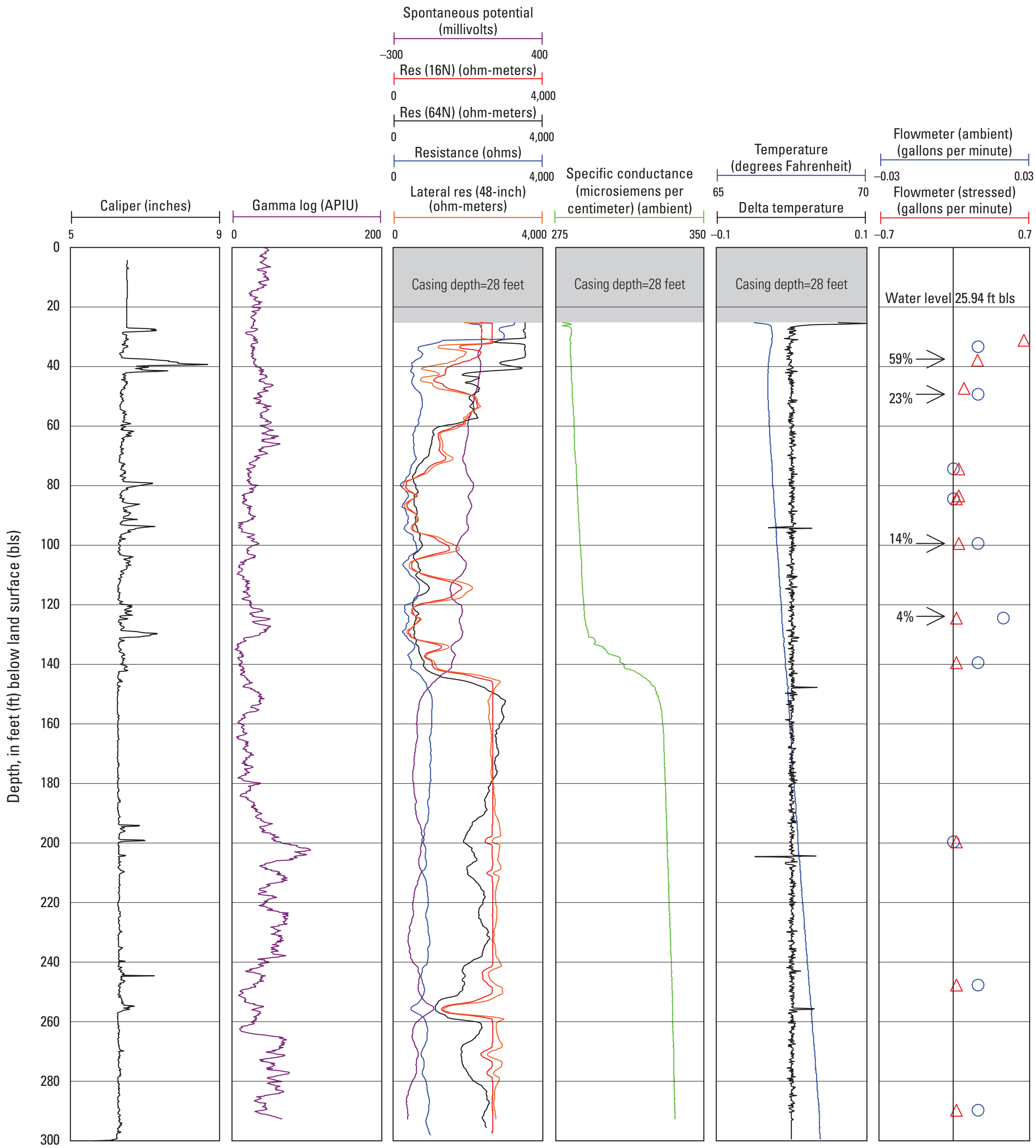


Figure 9. Borehole geophysical logs showing depth of fracture zones and vertical flow in bedrock well IR-1, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina. Arrows show zones of inflow and modeled FLASH percentage (appendix 5). [Note: Electric logs collected under ambient conditions; lithology information was not available; APIU, American Petroleum Institute units; Res (16N), 16-inch normal resistivity; Res (64N), 64-inch normal resistivity]

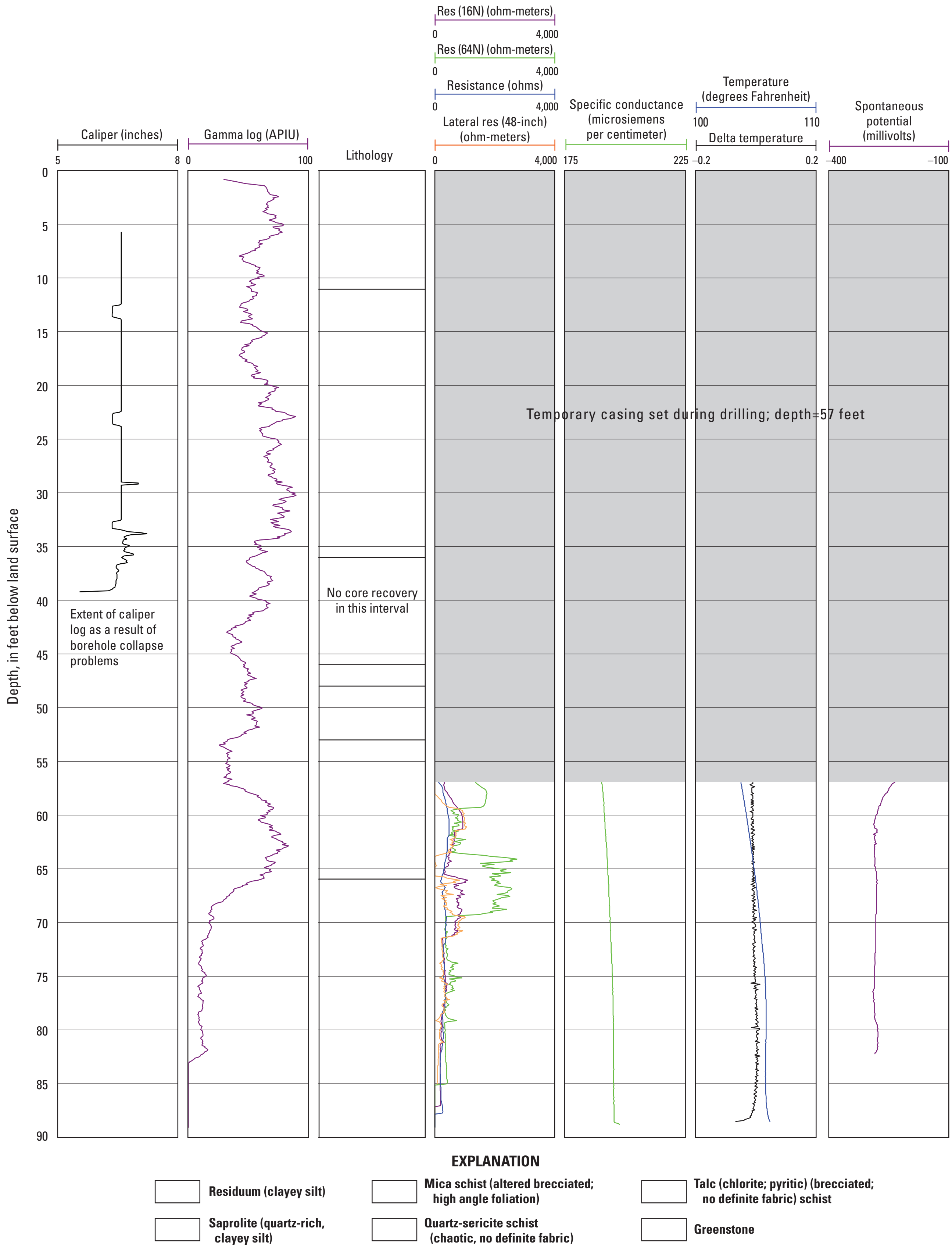


Figure 10. Borehole geophysical logs showing depth of fracture zones and lithologic log (Black and Veatch, Inc., written commun., 2012) in bedrock well BH65, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina. [APIU, American Petroleum Institute units; Res, resistivity]

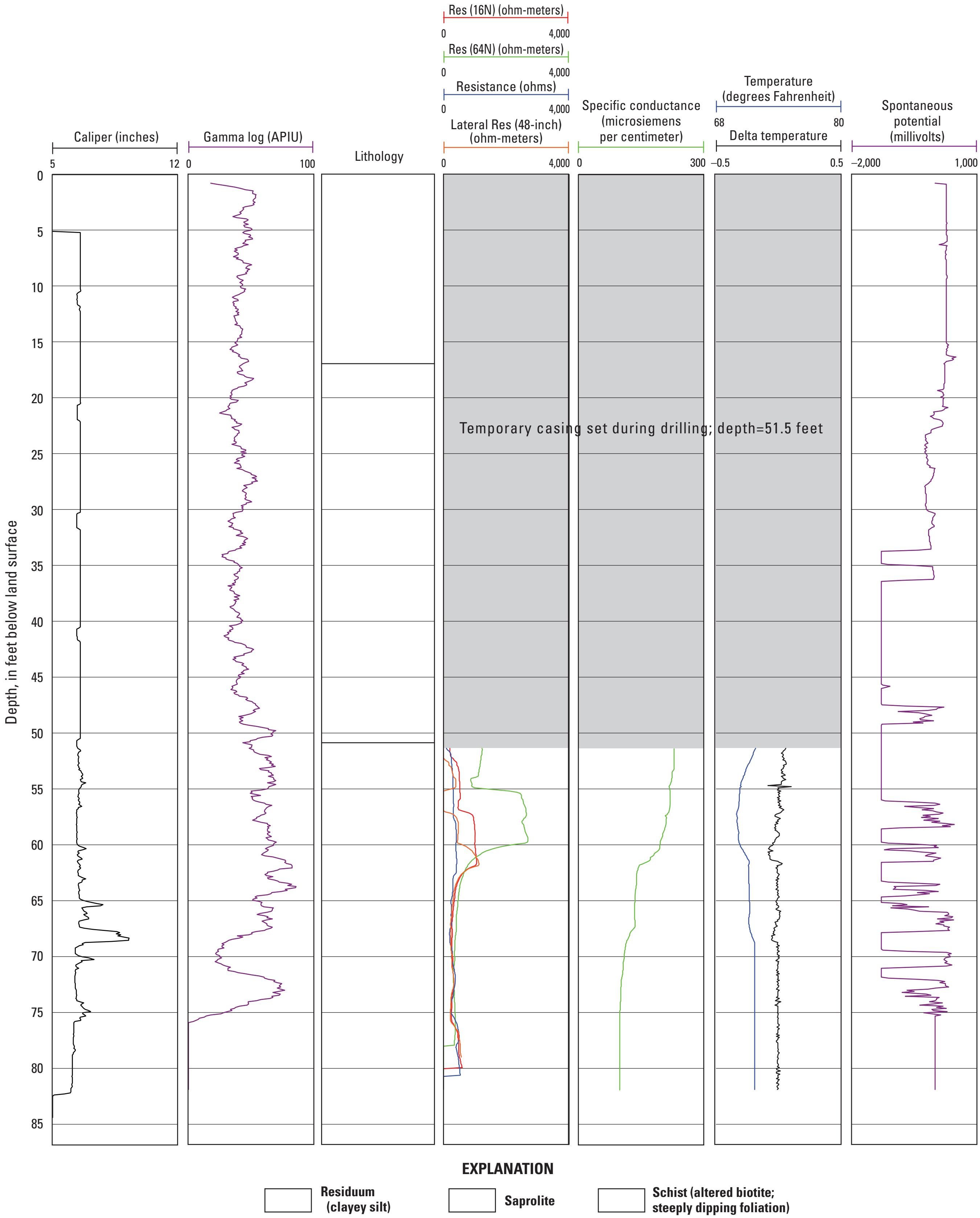


Figure 11. Borehole geophysical logs showing depth of fracture zones and lithologic log (Black and Veatch, Inc., written commun., 2012) in bedrock well BH66, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina. [APIU, American Petroleum Institute units; Res, resistivity]

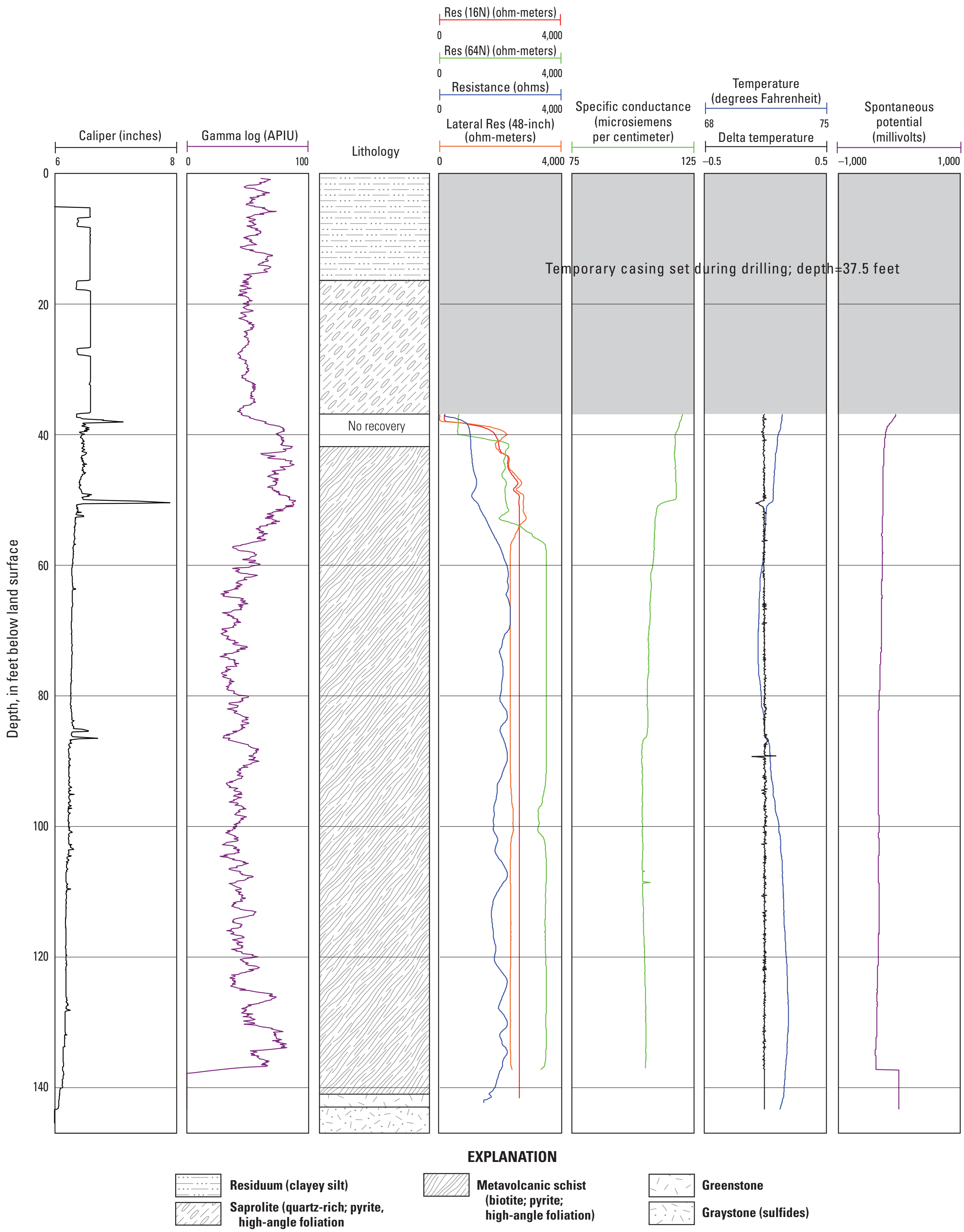


Figure 12. Borehole geophysical logs showing depth of fracture zones and lithologic log (Black and Veatch, Inc., written communication, 2012) in bedrock well BH67, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina. [APIU, American Petroleum Institute units; Res, resistivity]

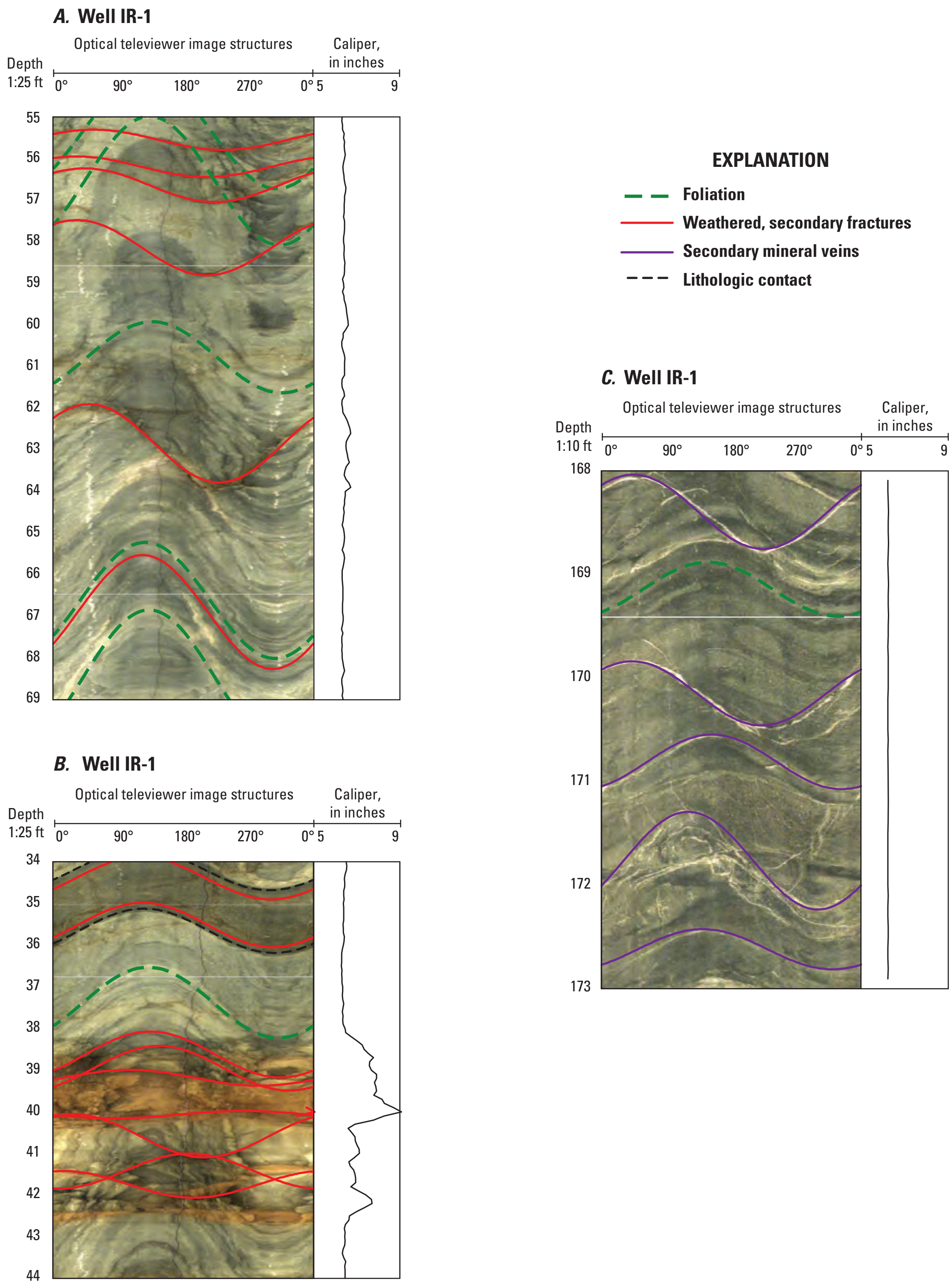


Figure 13. Optical and acoustic televiewer images showing (*A*) foliation and secondary fractures in bedrock well IR-1, (*B*) fractures within the transition zone in bedrock well IR-1, (*C*) secondary mineral veins in bedrock well IR-1, (*D*) primary and secondary fractures in bedrock well BH67, and (*E*) primary and secondary fractures in bedrock well BH66, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

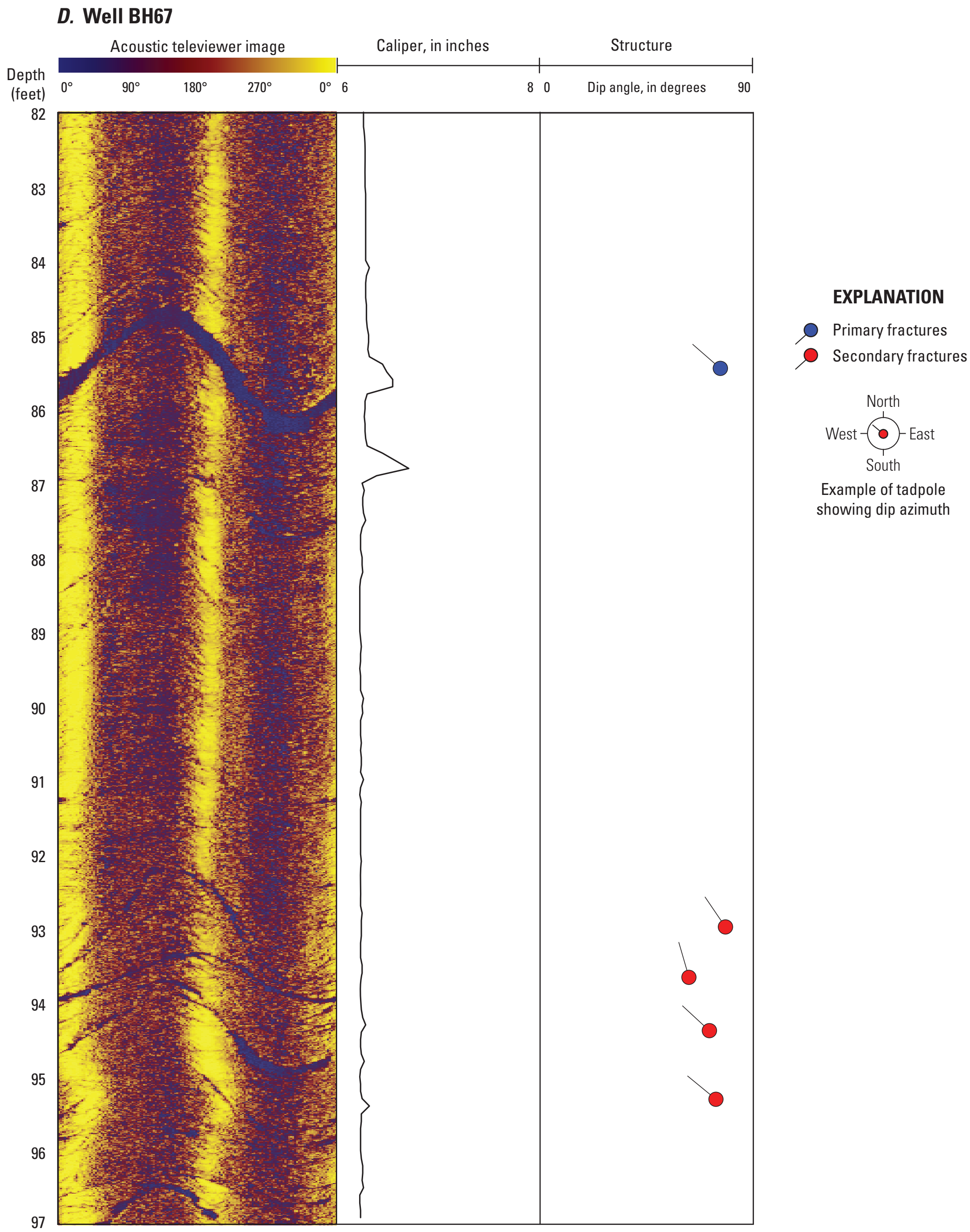


Figure 13. Optical and acoustic televiewer images showing (*A*) foliation and secondary fractures in bedrock well IR-1, (*B*) fractures within the transition zone in bedrock well IR-1, (*C*) secondary mineral veins in bedrock well IR-1, (*D*) primary and secondary fractures in bedrock well BH67, and (*E*) primary and secondary fractures in bedrock well BH66, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.—Continued

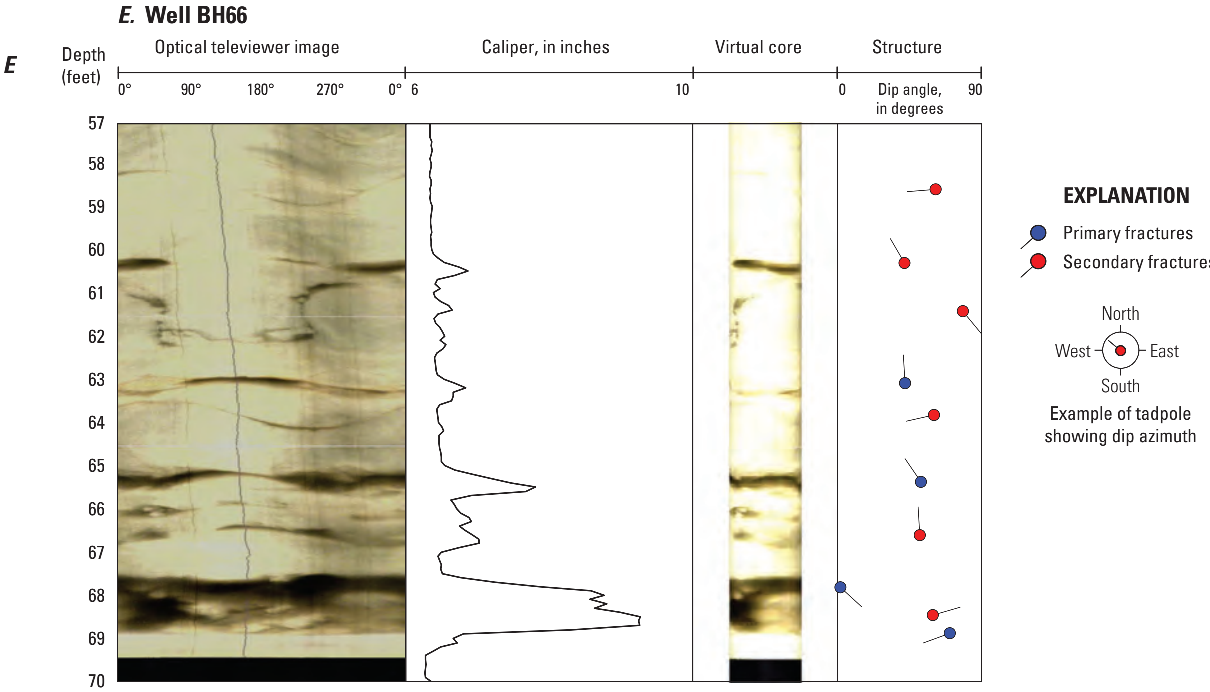


Figure 13. Optical and acoustic televiewer images showing (*A*) foliation and secondary fractures in bedrock well IR-1, (*B*) fractures within the transition zone in bedrock well IR-1, (*C*) secondary mineral veins in bedrock well IR-1, (*D*) primary and secondary fractures in bedrock well BH67, and (*E*) primary and secondary fractures in bedrock well BH66, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.—Continued

More than 300 subsurface structural measurements (orientations) were interpreted from OTV and ATV images collected from bedrock wells IR-1, BH66, and BH67. Primary and secondary fractures were delineated, and respective orientations of the fractures were characterized for all three wells (appendix 5). Bedrock well IR-1 was the only well of the three with water that was clear enough on the OTV image to allow for delineation of foliation or bedrock fabric, lithologic contacts, sealed fractures, and other features. Wells BH66 and BH67 installed during October 2012 for this study by EPA contractors were drilled into partially weathered shallow bedrock (or potentially the transition zone) and thus had cloudy water. (An image log was not collected in well BH65 because of potential wall collapse during logging.) Rose diagrams show strike azimuth orientations of all structures delineated in the three bedrock wells (fig. 14). The number of measurements delineated per well were as follows: 276 structural features for well IR-1; 10 structural features for well BH66; and 33 structural features for well BH67. Structural data from wells IR-1 and BH67 had similar dominant strike azimuth orientations of 210° to 240° and northwest dip directions. Dominant strike azimuth orientations measured in well BH66 were 160–170° with a southwest dip direction and 260–270° with a northwest-north dip direction. An aerial comparison of the structures delineated in the three bedrock wells across the site is shown in figure 15.

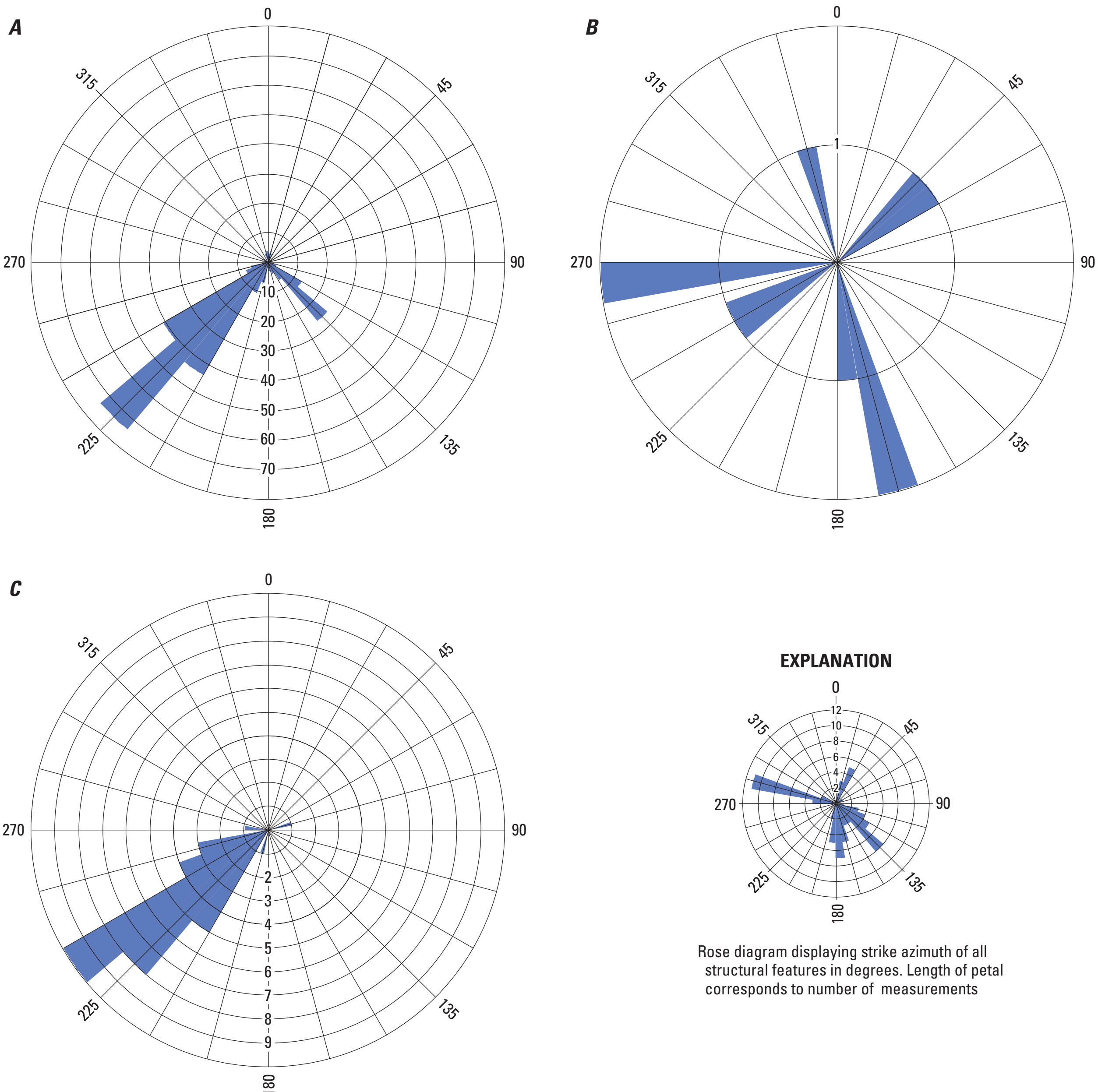


Figure 14. Rose diagrams showing strike azimuths of all structural features characterized by using either optical or acoustic televiewer images of bedrock wells (*A*) IR-1, (*B*) BH66, and (*C*) BH67, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

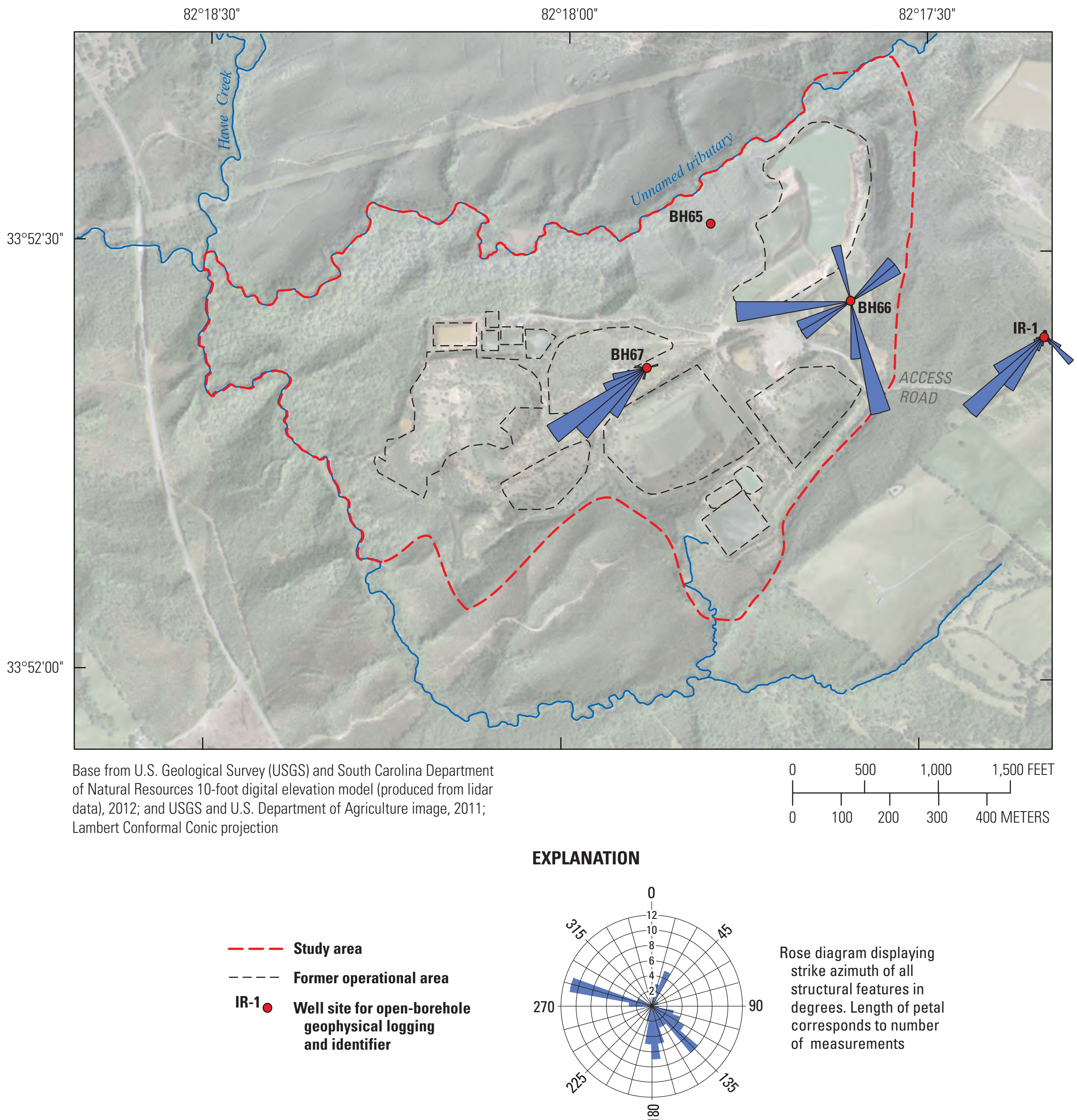


Figure 15. Areal distribution of structural features delineated in bedrock wells IR-1, BH66, and BH67, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

As previously stated, foliation or bedding (rock fabric) could only be measured from the OTV image of well IR-1 (fig. 16 and appendix fig. 5–1). The mean strike azimuth of the bedrock foliation data was 222° (N. 42° E.), with strike azimuths ranging from 146° to 241°, southwest or northwest dip direction, respectively, and the mean dip angle was 78° to the northwest, with dip angles ranging from 53° to 85°. The mean foliation of N. 42° E. is within the range of regional bedding reported by Clark (1999a) of N. 30°–50° E., with dip angles ranging from 52° to 85° to the northwest or southeast.

Rose diagrams of measured primary fractures in the three bedrock wells are shown in figure 17, and the areal distribution at the site is shown in figure 18. A composite rose diagram of strike azimuths of primary fractures measured in all three open-borehole bedrock wells is shown in figure 19. Dominant fracture strike azimuth orientations were from 210° to 250° (N. 30° E. to N. 70° E.) with a mean dip of 68° northwest. This orientation confirms a dominant fracture set striking N. 40° E. –N. 60° E. measured by the EPA START (U.S. Environmental Protection Agency Superfund Technical Assessment and Response Team, 2008).

Ambient and stressed vertical flow were measured in the open borehole near fracture zones delineated in bedrock well IR-1 by using a heat-pulse flowmeter tool on October 10, 2012 (figs. 5 and 9). The lower range of flow for this borehole geophysical tool is 0.01 gallon per minute (gal/min) in a 6-inch-diameter borehole, and the upper range is about 2 gal/min. Slight upflow (0.01–0.02 gal/min at 140 ft, near the minimum resolution of the tool) was measured in well IR-1 during the ambient heat-pulse logging (fig. 9). The initial drilling report (South Carolina Department of Health and Environmental Control, 2008) indicated the presence of two fracture zones at depths of 140 and 250 ft. No measureable difference was noted at these two depths during the stressed heat-pulse logging. Results from the FLASH modeling of the heat-pulse flowmeter data are included in appendix 6. The model resolved four fracture zones at 38.5, 50, 100, and 125 ft, primarily based on inflow changes during the stressed heat-pulse test. The transmissivity estimate calculated by the FLASH model was about 69 feet squared per day (ft^2/d), and the radius of influence was estimated to be about 640 ft. The shallowest fracture zone modeled was at 38.5 ft with a 59-percent contribution and is potentially part of the transition zone because of the greater fracture density observed in the OTV image (appendix fig. 5–1).

A three-dimensional diagram of bedrock structures (mostly fractures including foliation and sealed fractures in well IR-1) is shown in figure 20. The three-dimensional diagram illustrates the potential interconnectivity of fracture zones between bedrock wells at the site. Fractures having similar dip azimuths and angles are shown as parallel fracture images. The distribution of subsurface fractures and their associated three-dimensional orientations likely control the direction of groundwater flow and the transport of any elevated dissolved ions and metals related to the former mining operations, depending on the location of source areas and hydraulic head distributions between fracture zones.

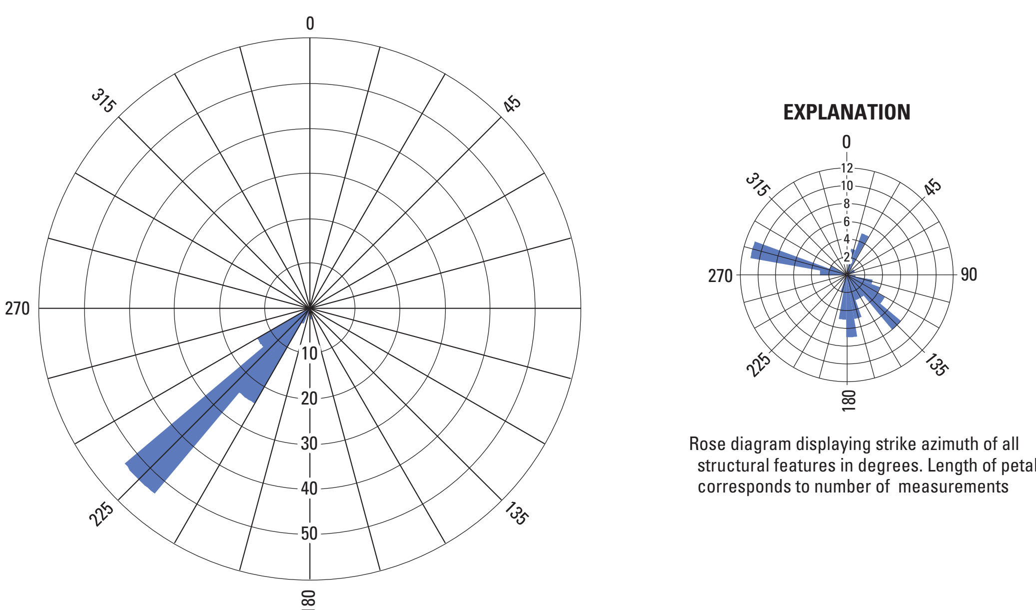


Figure 16. Rose diagram showing strike azimuths of foliation measured in bedrock well IR-1, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

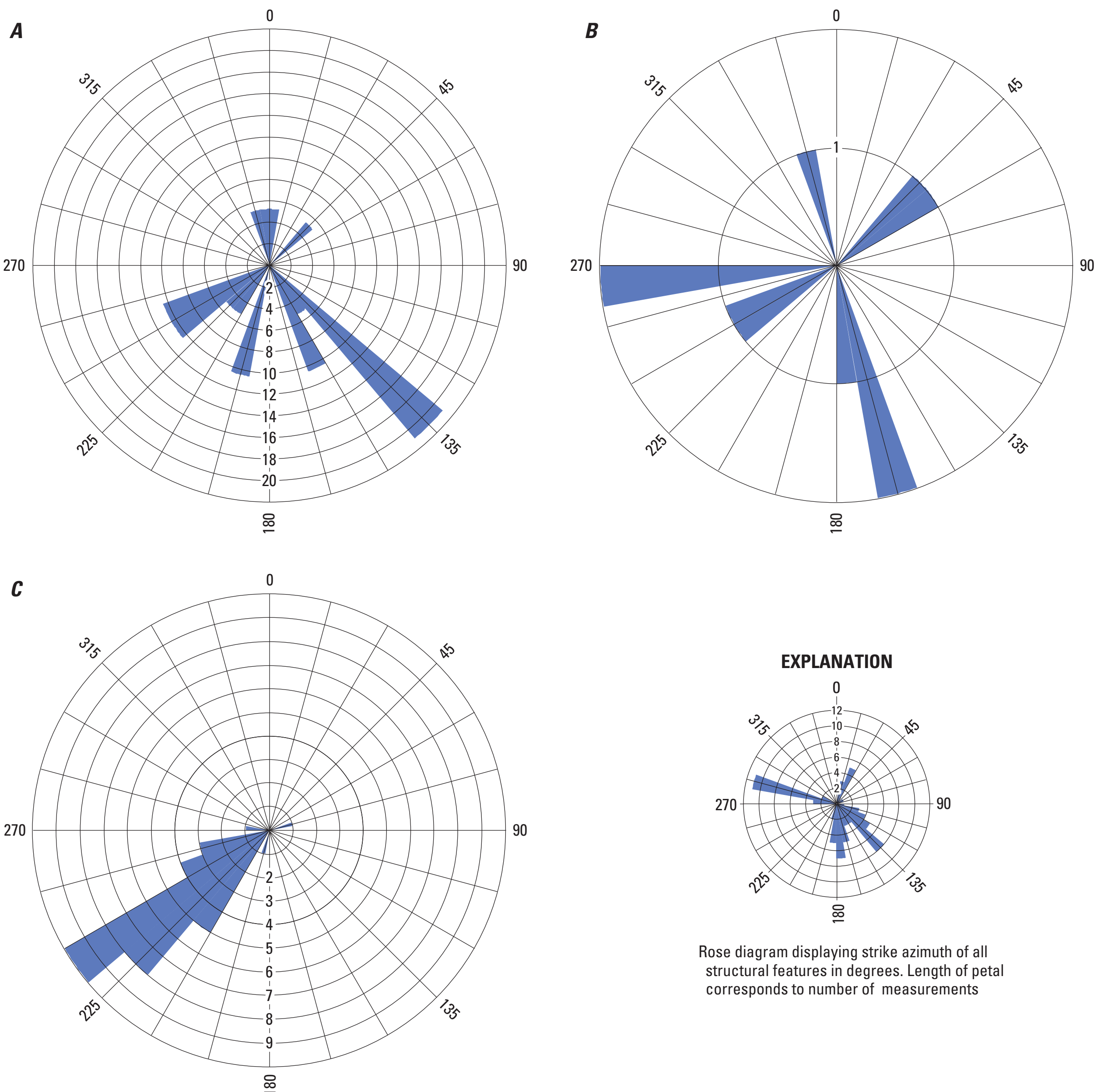
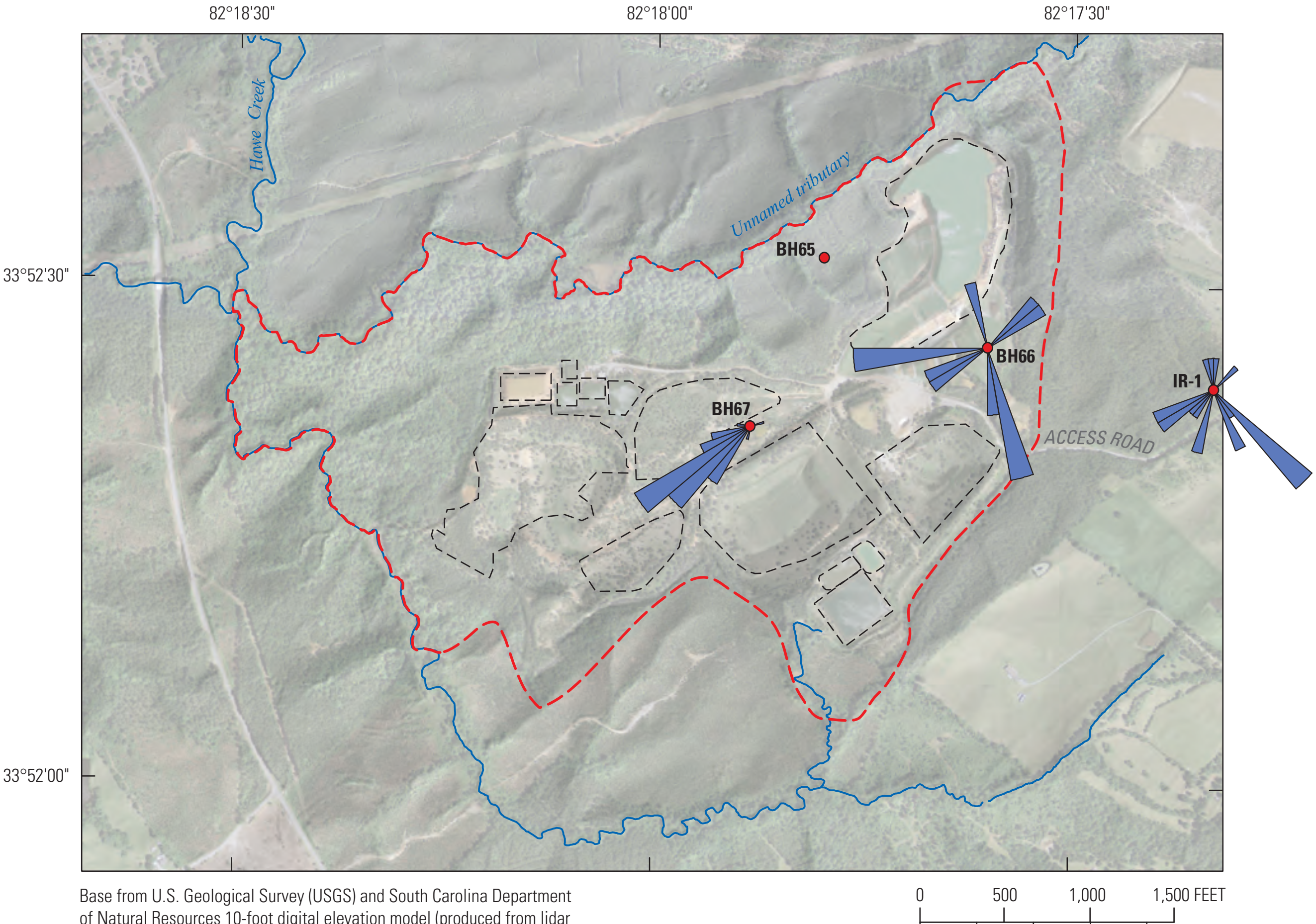


Figure 17. Rose diagrams showing strike azimuths of primary factures characterized by using either optical or acoustic televiewer images of bedrock wells (*A*) IR-1, (*B*) BH66, and (*C*) BH67, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.



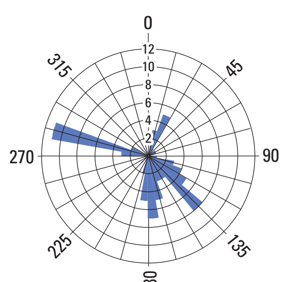
Base from U.S. Geological Survey (USGS) and South Carolina Department of Natural Resources 10-foot digital elevation model (produced from lidar data), 2012; and USGS and U.S. Department of Agriculture image, 2011; Lambert Conformal Conic projection

EXPLANATION

Study area

Former operational area

IR-1 **Well site for open-borehole geophysical logging and identifier**



Rose diagram displaying strike azimuth of all structural features in degrees. Length of petal corresponds to number of measurements

Figure 18. Areal distribution of open (primary) fractures delineated in bedrock wells IR-1, BH66, and BH67 at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

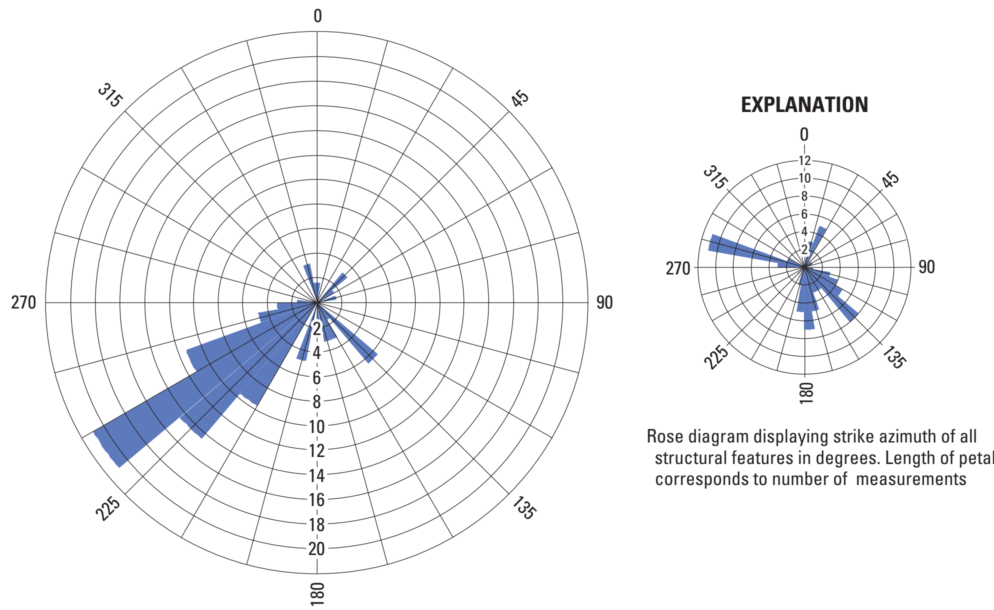


Figure 19. Composite rose diagram showing strike azimuths of all fractures measured in bedrock wells IR-1, BH66, and BH67 at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

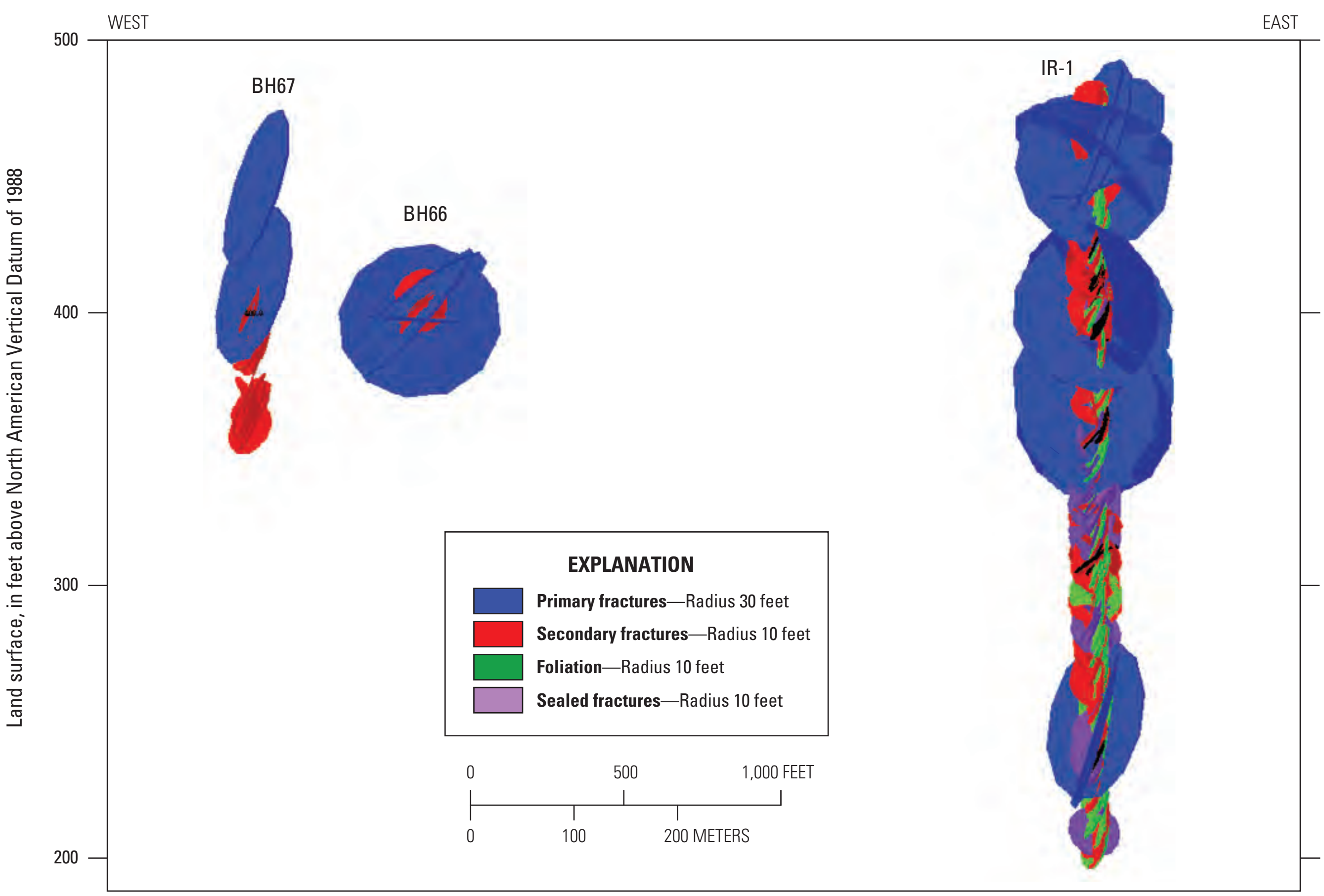


Figure 20. Schematic cross-section view of three-dimensional fractures and foliation in bedrock wells IR-1, BH66, and BH67 at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

Surface Geophysical Surveys

Surface geophysical surveys provide areal readings of differences in Earth properties. These properties include those of the materials, such as regolith and bedrock, and the groundwater contained within those materials. Conductive materials, such as those observed at the EPA Barite Hill/Nevada Goldfields Superfund site, typically are highly contrasting with surrounding materials and native groundwater, and electrical geophysical surveys often are used to delineate these contrasts from land surface and at depth within Earth materials, including groundwater. Temperature measurements within surface water can be used to detect differences within the water column (distributed temperature sensing), and waterborne resistivity methods can be used to sample through and below the water column. The surface geophysical methods applied at the EPA Barite Hill/Nevada Goldfields Superfund site as part of this study consisted of surface electromagnetic conductivity surveys and fiber-optic DTS surveys.

Delineation of Areas of Elevated Conductivity

Surface electrical conductivity surveys were conducted in four areas of the site during December 2012: near the northern unnamed tributary to Hawe Creek (Grid 1, fig. 6), the Main Pit area (Grid 1 to the west, north rim, and Grid 2 to the southeast, fig. 6), the former Rainsford Pit area, and the western area of the site. Four common intermediate frequencies recorded during all surveys were, with respect to relative depths of signal penetration, 7,970 hertz (Hz) (shallow) and 33,030 Hz (shallow), 8,250 Hz (intermediate), and 1,530 Hz (deep). The results of electrical conductivity surveys from the four areas for total electrical conductivity and separate datasets per frequency are shown in figures 21–25. High electrical conductivity values greater than 90 mS/m above or below the water table (fig. 25), are possibly indicative of buried waste materials or native unsaturated geologic materials, and low conductivity values (less than 10 to near 0 mS/m) are possibly indicative of bedrock.

Interpretation of the electrical conductivity surveys indicates that areas of highest electrical conductivity readings tend to be clustered in localized areas and may represent elevated conductivity related to natural geologic materials and (or) waste materials from the former mining operations. For all four electrical conductivity frequencies used in the surface investigation, and the corresponding ranges in relative depth penetration, areas north and west of the Main Pit lake along the northern unnamed tributary and areas northwest of the former Rainsford Pit area appear to have the highest readings (greater than about 50 to more than 90 mS/m; figs. 2 and 21–25). Intermediate conductivity levels (greater than 20 to about 50 mS/m) were delineated along a section of the northern unnamed tributary between areas of previously identified groundwater seeps (Oneida Total Integrated Enterprises, 2009), north-northwest and southeast of the Main Pit lake, and within and southwest and northwest of the former Rainsford Pit area/southeast of Waste Disposal Area A (fig. 2). These elevated conductivity readings in the area of the Main Pit lake may be related to the leakage of high conductivity surface-water and groundwater flow discharging to specific areas along the tributary and southeast of the lake. This conclusion is supported by the fact that the areas of elevated conductivity along the northern unnamed tributary correspond to known seep areas that have been sampled in previous investigations at the site (Oneida Total Integrated Enterprises, 2009). Elevated electrical conductivity readings southeast of Waste Disposal Area A and northwest of the former Rainsford Pit area may indicate the presence of conductive waste rock and (or) the migration of elevated dissolved ions and metals in groundwater flowing in that direction, potentially along a flow path.

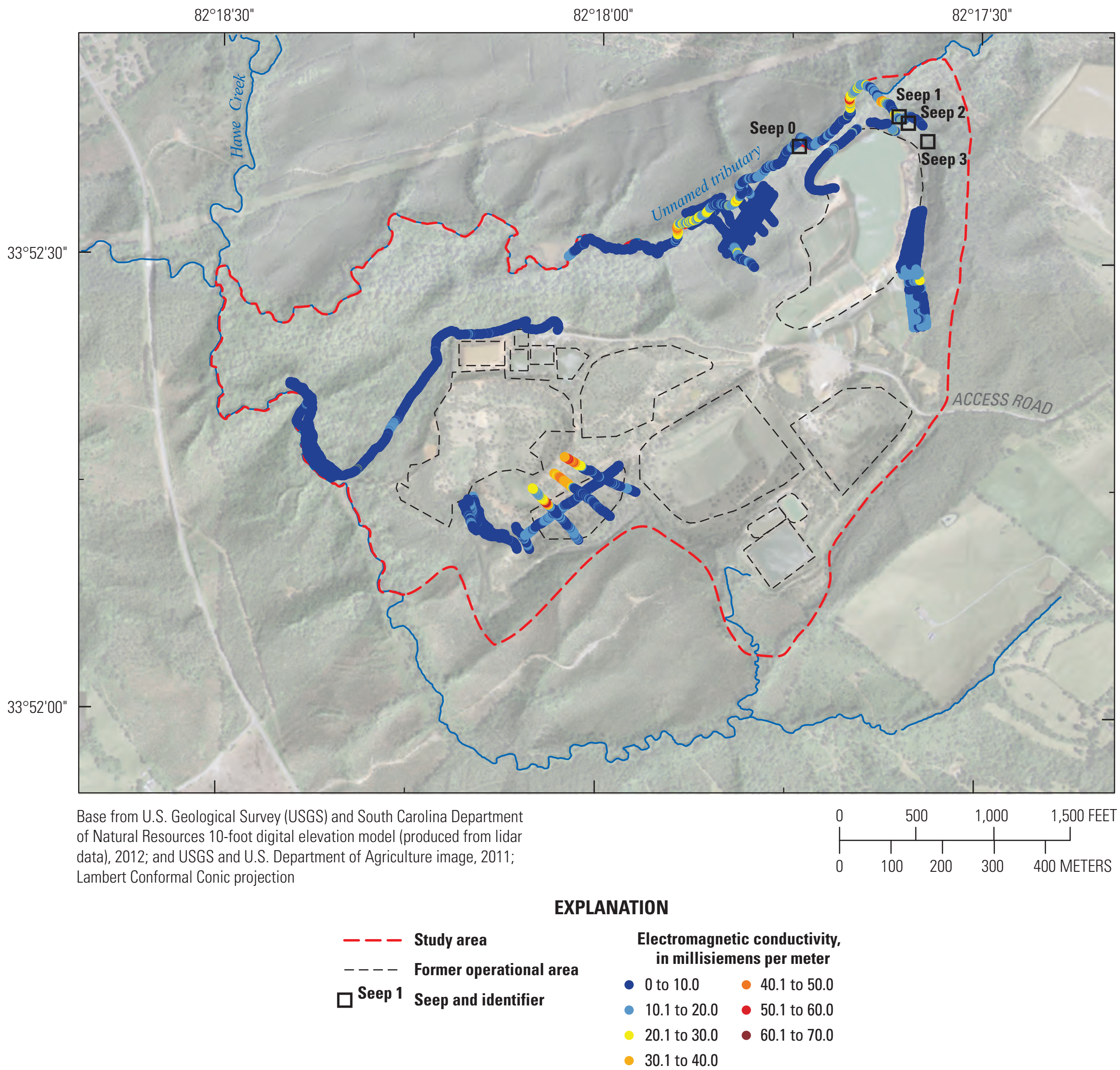


Figure 21. Location of seeps identified in June 2009 (Oneida Total Integrated Enterprises, 2009) and total surface electrical conductivity survey results collected during December 2012 at selected areas across the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

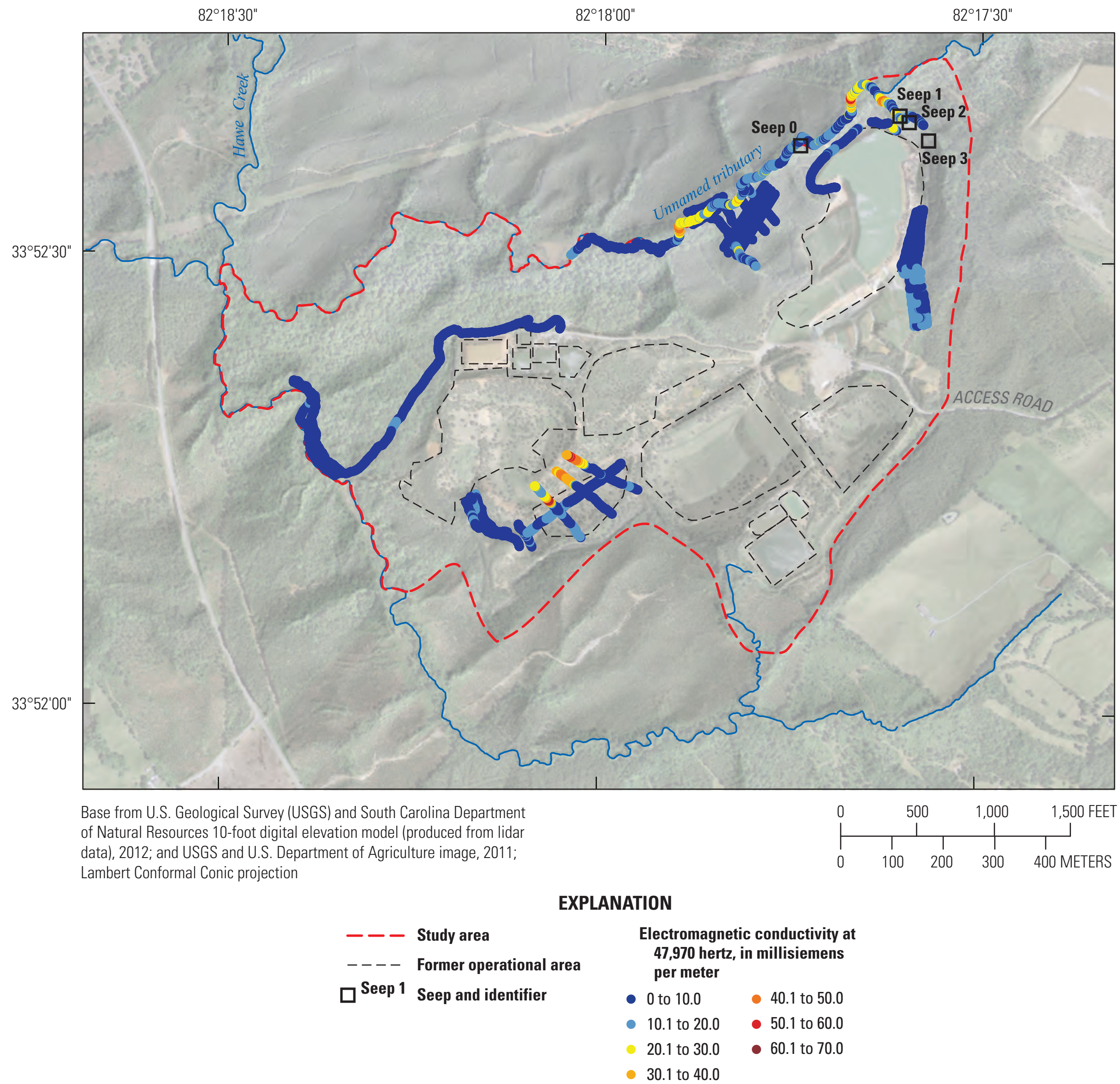


Figure 22. Location of seeps identified in June 2009 (Oneida Total Integrated Enterprises, 2009) and surface electrical conductivity survey results when using the shallow 47,970-hertz frequency during December 2012 at selected areas across the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

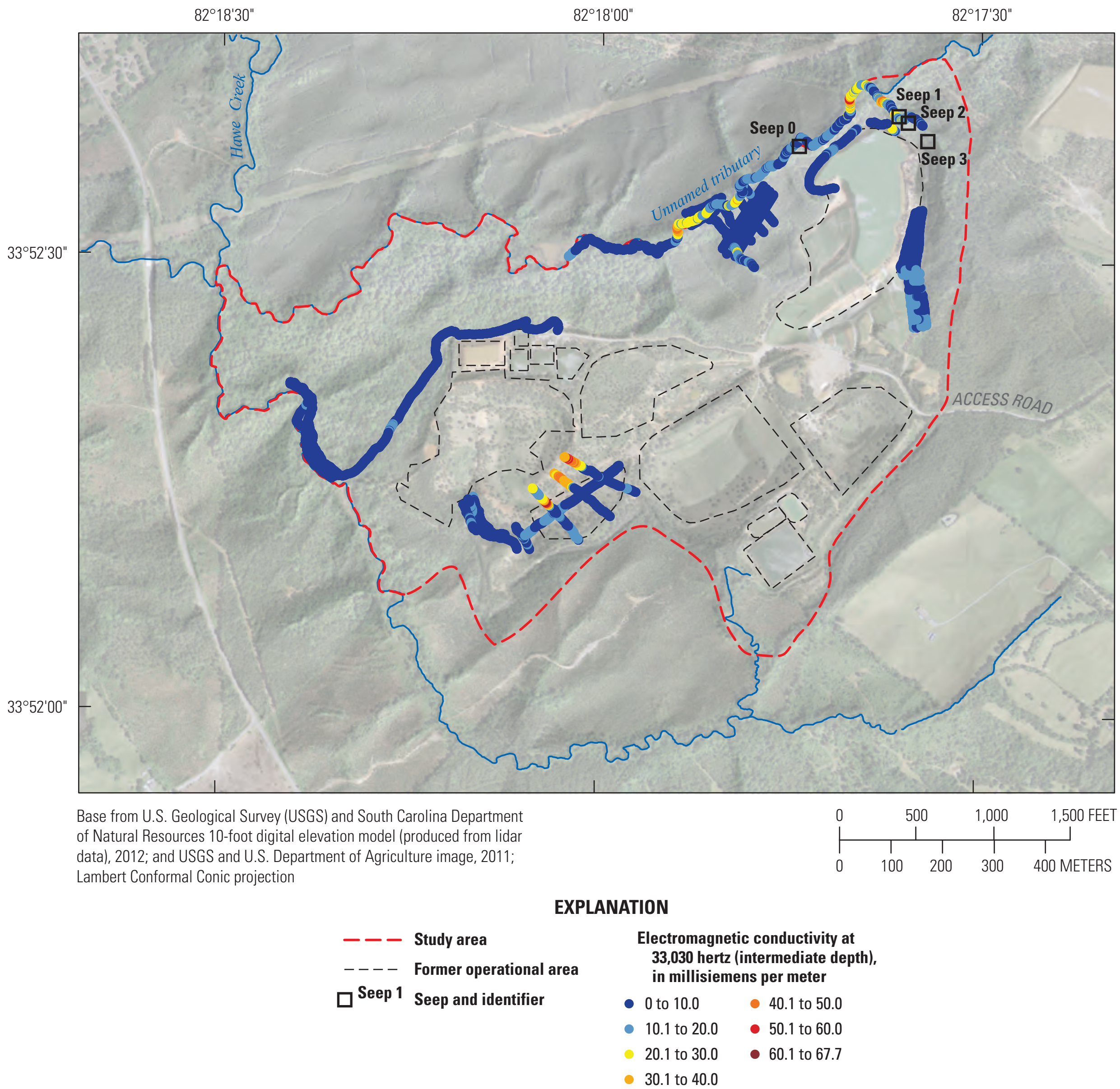


Figure 23. Location of seeps identified in June 2009 (Oneida Total Integrated Enterprises, 2009) and surface electrical conductivity survey results when using the shallow 33,030-hertz frequency during December 2012 at selected areas across the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

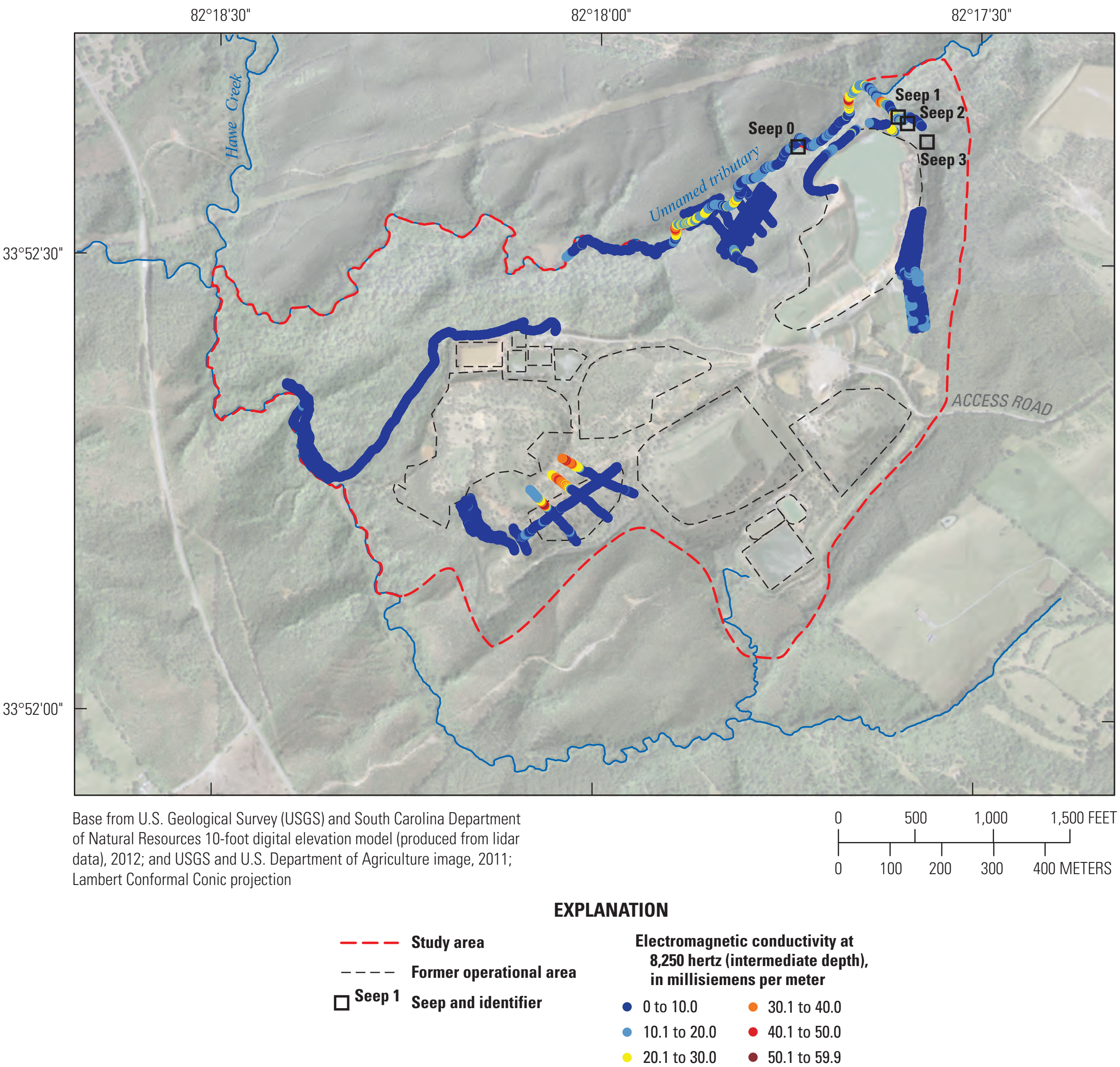


Figure 24. Location of seeps identified in June 2009 (Oneida Total Integrated Enterprises, 2009) and surface electrical conductivity survey results when using the intermediate 8,250-hertz frequency during December 2012 at selected areas across the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

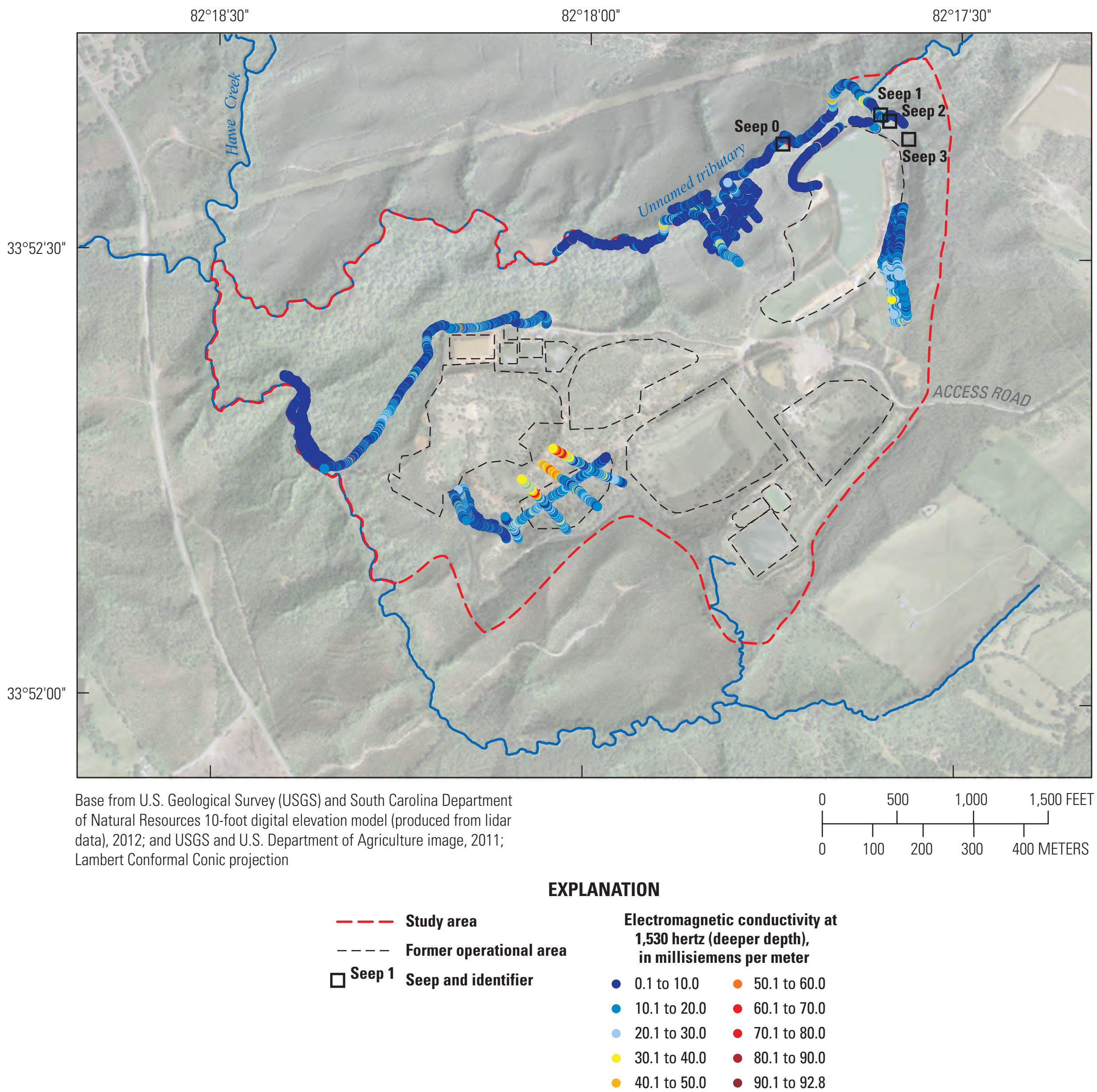


Figure 25. Location of seeps identified in June 2009 (Oneida Total Integrated Enterprises, 2009) and surface electrical conductivity survey results when using the deep 1,530-hertz frequency during December 2012 at selected areas across the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

Delineation of the four electrical conductivity frequencies along their respective profile lines shows that each frequency is sensing to different depth levels. For the area southeast of the Main Pit, most of the seven frequencies measured along the westernmost profile line had similar patterns and ranges of data fluctuation, whereas the deeper, lower frequency 1,530-Hz data exhibited a somewhat different pattern with a larger range of fluctuation, which is indicative of low bedrock electrical conductivity and high resistivity (fig. 26). These patterns and ranges of data are typical responses where high electrically conductive material appears to be present in the shallow subsurface (unsaturated ore/mine waste material and [or] porous regolith groundwater having elevated dissolved metals concentrations) and low electrical conductivity material (low porosity resistive bedrock) in the deeper subsurface. The surface survey conducted along the northern unnamed tributary had similar electrical conductivity readings at all frequencies, suggesting the potential for signal attenuation from elevated specific conductance in surface water or thicker zones of higher electrical conductivity at depth (fig. 27). A different response was recorded in the former Rainsford Pit area where the high electrical conductivity readings were recorded by using the lower frequency values. The high electrical conductivity readings indicated conductive materials at greater depth, such as buried waste rock, conductive native ore rock, or elevated dissolved ions and metals within the groundwater system where the water table is deeper near a topographically high area of the site (figs. 4, 28).

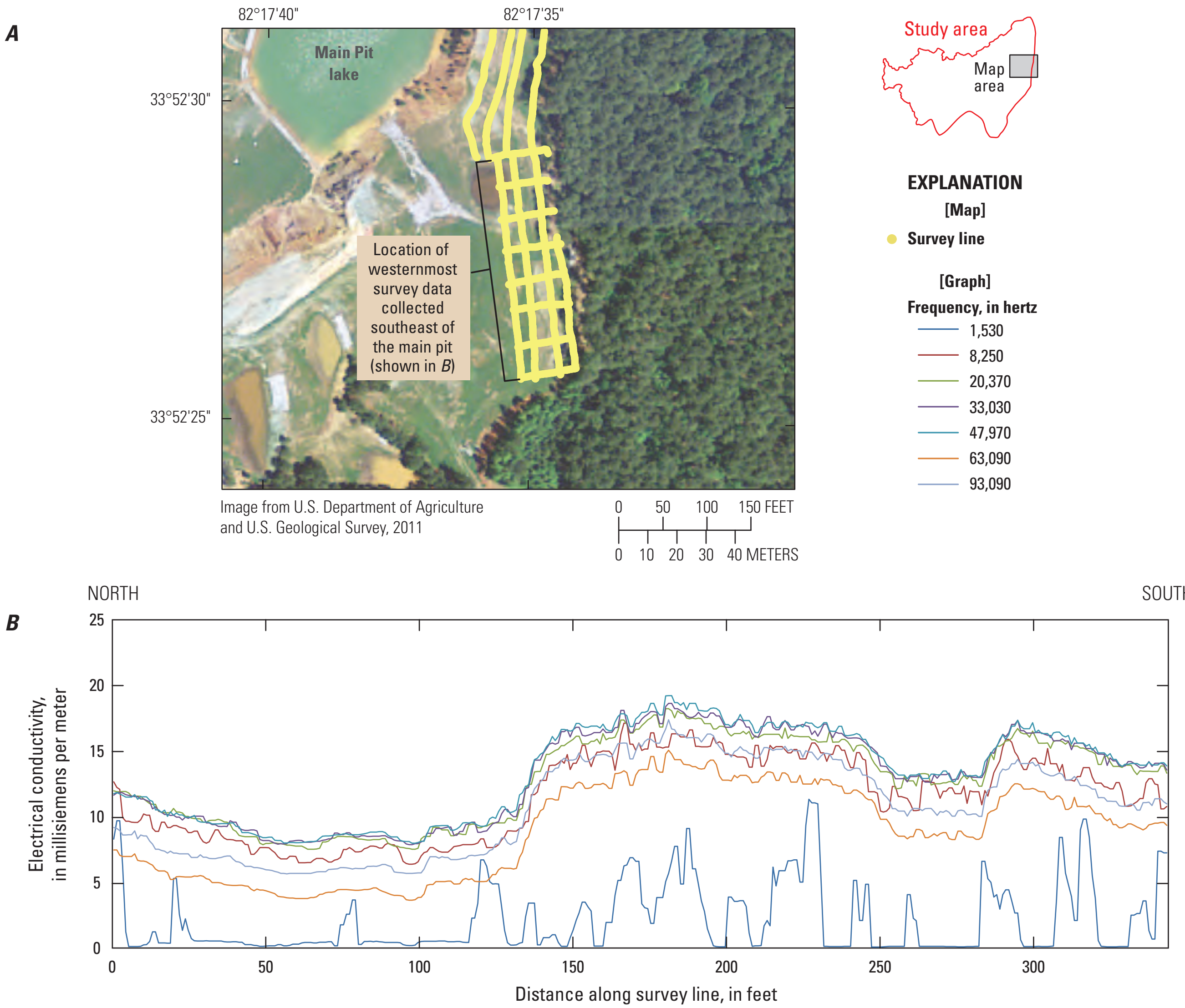


Figure 26. (*A*) Location of electromagnetic conductivity data collected along the westernmost survey line southeast of the Main Pit lake and (*B*) corresponding frequency profiles recorded during December 2012 at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

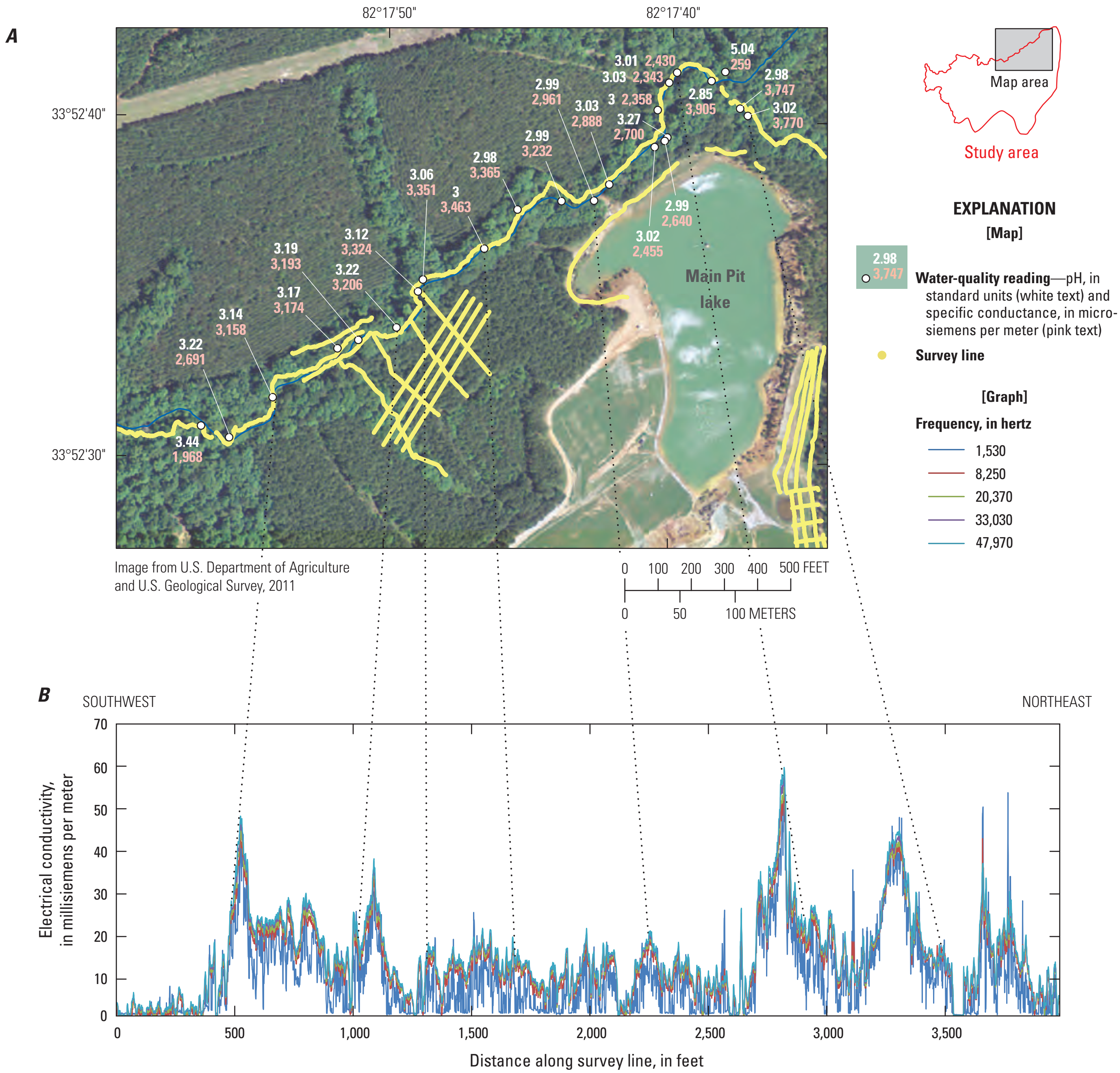


Figure 27. (*A*) Location of surface electromagnetic conductivity data and water-quality readings along the northern unnamed tributary and (*B*) corresponding frequency profiles recorded during December 2012 at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

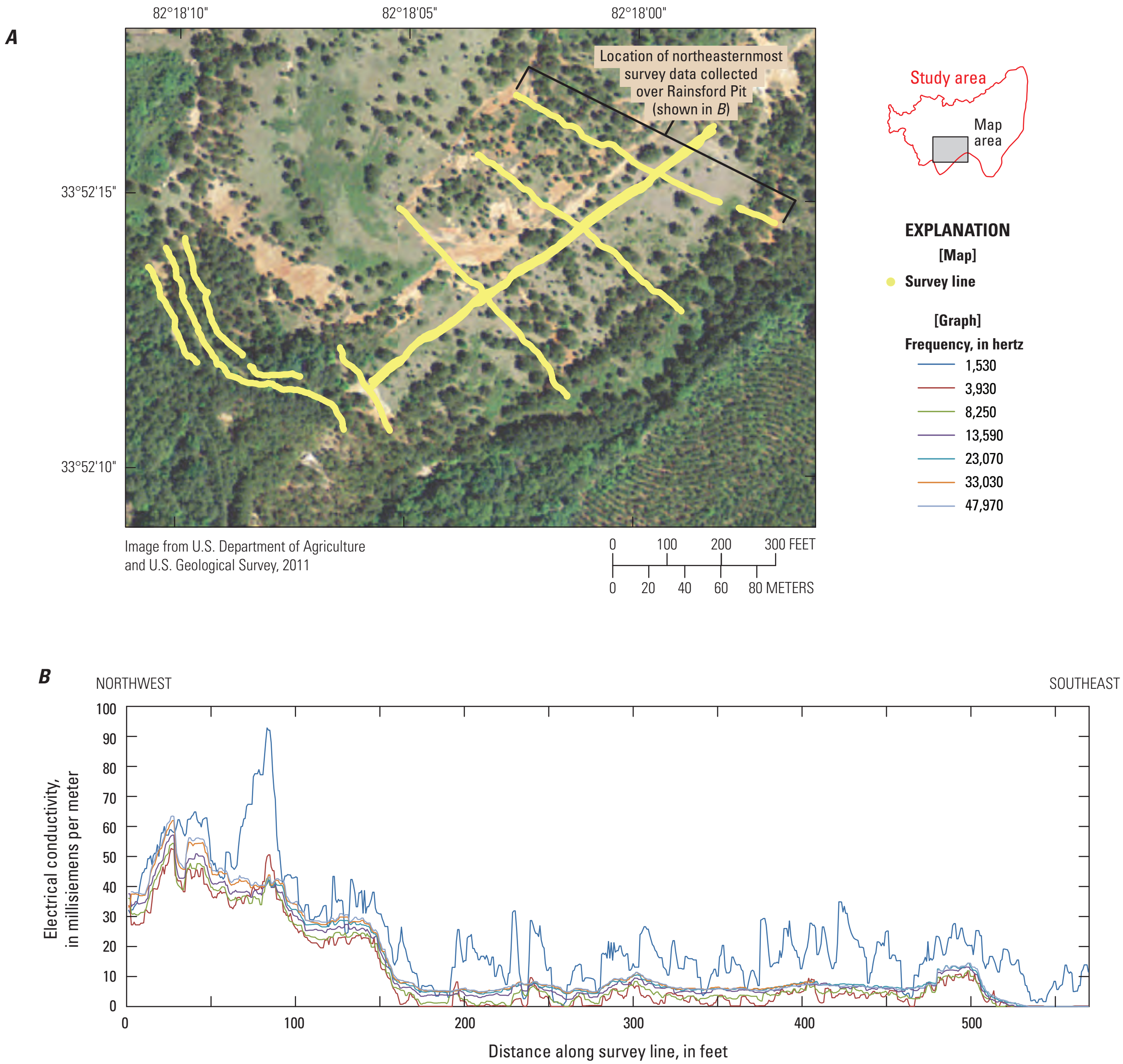


Figure 28. (*A*) Location of surface electromagnetic conductivity data collected along the northeasternmost survey line over Rainsford Pit and (*B*) corresponding frequency profiles recorded during December 2012 at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

Estimates of depth of penetration from the surface electrical conductivity surveys were calculated by using equation 1 in the Methods section of this report. By using a constant of 1.26×10^{-6} for magnetic permeability, which is representative of free space or a vacuum, the maximum estimated depth of penetration for the higher frequencies of 47,090 and 33,030 Hz was about 1 to 10 m (about 3 to 33 ft) for the higher 70-mS/m readings and about 10 to 90 m (about 33 to 300 ft) for the lower 1-mS/m readings. For the intermediate frequency of 8,250 Hz, depths of penetration estimates were about 20 m (about 65 ft) for the higher readings near 60 mS/m and about 170 m (about 560 ft) for the lower readings near 1 mS/m. For the lowest frequency of 1,530 Hz, depths of penetration were estimated at 40 m (about 130 ft) for the higher readings near 90 mS/m and about 400 m (about 1,300 ft) for the lower readings near 1 mS/m. For magnetic materials such as those containing high amounts of iron, the depth of penetration would likely be reduced.

Delineation of Areas of Groundwater Discharge

Areas of low pH and elevated specific conductance at the EPA Barite Hill/Nevada Goldfields Superfund site were detected in the northern unnamed tributary surface water during previous work conducted by EPA and their contractors and in December 2012 as part of this study (fig. 27*A*). The low pH/high specific conductance is likely attributed to elevated dissolved ions and metals flowing out of the Main Pit lake into the groundwater system, and then discharging into the tributary (fig. 2).

From February 26 to March 7, 2013, a DTS survey was conducted by using a Sensornet Oryx DTS sensor to delineate areas of groundwater discharge along the streambed of the northern unnamed tributary at the site (fig. 29). At that time of year, groundwater temperatures generally are much warmer than surface-water temperatures and generally are not subject to diurnal fluctuations.

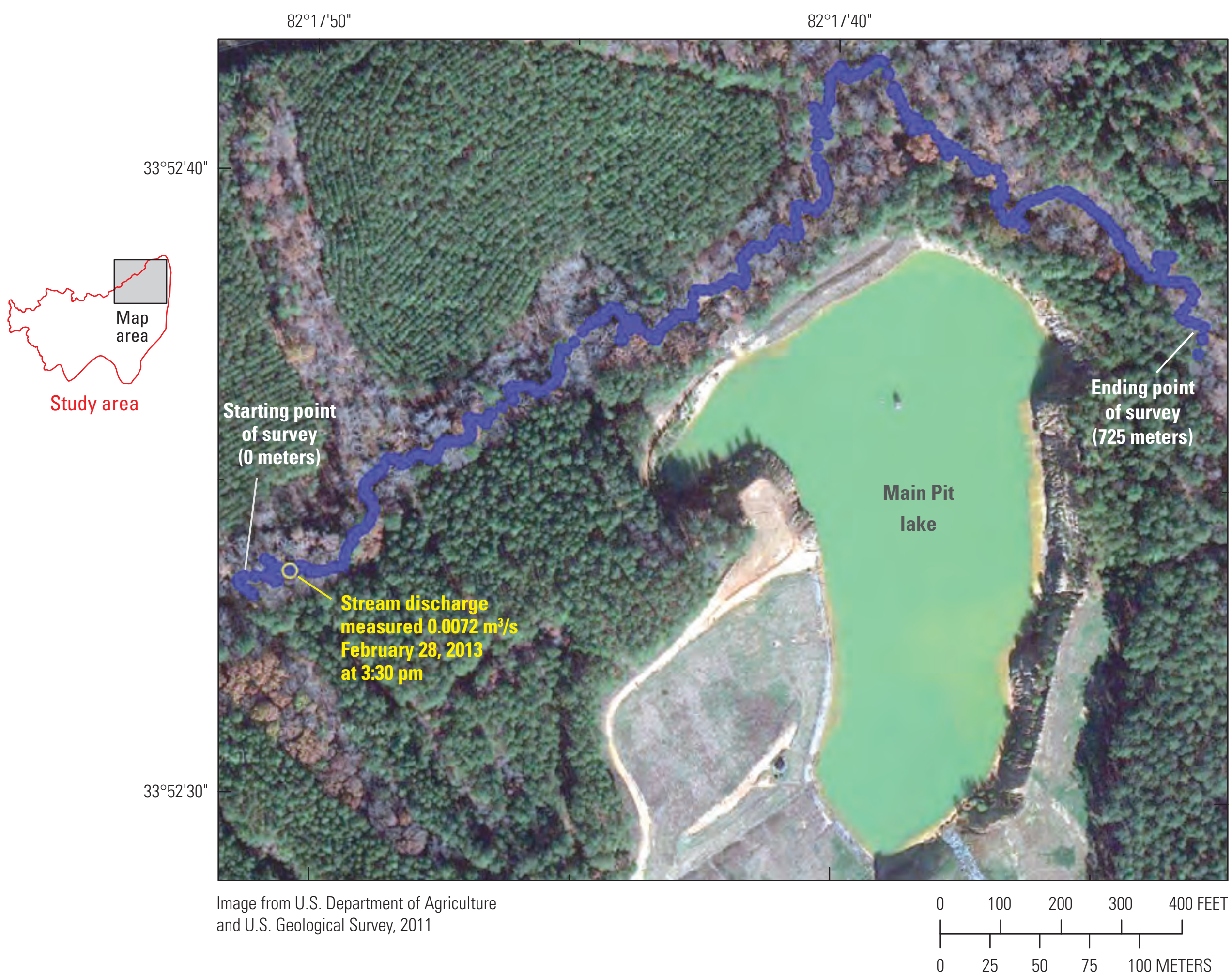


Figure 29. Location of the distributed temperature sensing survey near the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site, northern unnamed tributary, February 26–March 7, 2013. [m^3/s, cubic meter per second]

The streambed was generally composed of exposed bedrock and large cobbles, with the exception of a limited quantity of sand- and silt-sized particles that had accumulated around boulders. Tributary discharge was low and stable (base-flow conditions) during the majority of the 7-day survey, measuring 0.25 cubic foot per second (ft^3/s) (0.0072 cubic meter per second [m^3/s]) on February 28, 2013, at 3:30 p.m. The majority of the tributary is quite shallow, with water depths less than 0.5 m interspersed with a few 1-m-deep pools. One precipitation event occurred during the survey. On March 5, 2013, 0.43 inch (1.1 centimeters) of precipitation was recorded (Brian Striggow, U.S. Environmental Protection Agency, Athens, Ga., written commun., 2013).

The DTS surface-water and air temperature data collected are displayed as a continuous thermogram in figure 30. Surface-water temperatures measured by the DTS along the streambed during the survey ranged from about 3 to 14 ºC, and air temperature (fig. 30*A*) measured at the tributary bank ranged from a low of about –6 ºC on March 4, 2013, at 7:34 a.m. to a high of about 23 ºC on March 5 at 3:49 p.m. A diurnal thermal signature within the surface water is visible on the thermogram, displaying warmer surface-water temperatures from solar radiation in the afternoon followed by cooling during the night (figs. 30*A* and *B*). Areas with an influx of groundwater typically exhibit reduced fluctuations in temperature cycles compared to areas with only surface water, which is influenced directly by air temperature fluctuations (fig. 30*B*).

A thermal trace of surface-water temperatures measured on March 4, 2013, at 7:34 a.m., the time of coldest measured air temperature, is displayed in figure 30*C*. The groundwater discharge areas identified at 549 and 645 m along the cable were located to the north-northeast of the Main Pit lake and upstream of the confluence with a second tributary to the north (fig. 31). Both of these identified areas are within shallow pools below rock ledges controlling surface-water movement. The groundwater discharge areas identified at 417 and 438 m along the cable were located along a straight section of the tributary to the north-northwest of the Main Pit, downstream from the confluence.

Each temperature measurement recorded using the DTS at the site was compared to the calculated 7-day average, along with a variance, for that respective location (fig. 29). Each temperature measurement made in the same area as groundwater discharge will be thermally buffered (have a low variance) compared to temperature measurements in areas where the cable is exposed or groundwater is not discharging. The temperature data were recorded every 15 minutes for 7 days at each point along the cable. The sum of the temperature measurements made at one specific location was then divided by the number of measurements to obtain a 7-day average. Spatially, these 7-day averages can be plotted in relation to the length of the cable for comparison of any temperature time trace with the average temperature. Where the thermogram was comparable to the 7-day average temperature, groundwater inflow is indicated as light green areas in figure 30*C*. This lack of variability in the temperature data, which represents areas of groundwater discharge, is particularly noticeable when measurements collected at the warmest and coolest part of one diurnal cycle are compared to the 7-day average (fig. 30*C*).

Of the area surveyed along the northern unnamed tributary, four separate locations were delineated as areas of groundwater discharge, corresponding to distances of about 417, 438, 549, and 645 m (1,370, 1,440, 1,800, and 2,120 ft, respectively) along the fiber-optic cable (fig. 30*C*). Locations of inferred groundwater discharge identified by DTS measurements correlate with areas of increased electrical conductivity measured in the surface EM surveys during December 2012 (figs. 21–25) and the locations of four seeps delineated near the creek in previous sampling efforts (fig. 31). One seep (seep 0, fig. 31) located further downstream and west of the Main Pit lake was identified in the electrical conductivity survey and in previous investigations, but not during the fiber-optic DTS survey.

No obvious geologic anomalies, such as differences in materials or bedrock outcrops, were noted in the groundwater discharge areas identified along the unnamed northern tributary at the site as part of this study. Locations of groundwater discharge identified by DTS measurements correlate with areas of increased electrical conductivity measured in the surface surveys during December 2012 (figs. 21–25) and groundwater seeps delineated in previous sampling efforts at the EPA Barite Hill/Nevada Goldfields Superfund site (fig. 31).

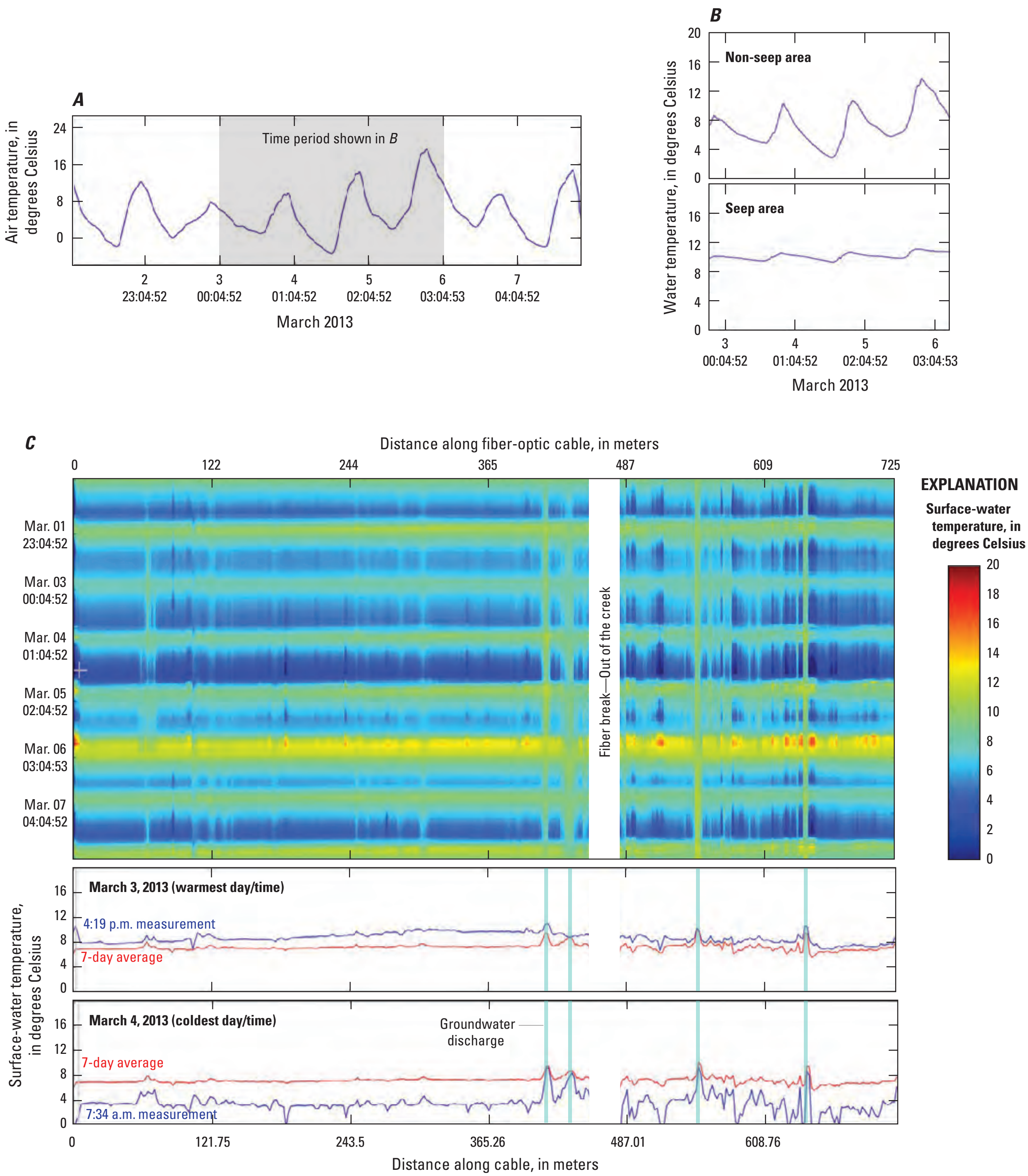


Figure 30. Distributed temperature sensing measurements collected in the northern unnamed tributary at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site from February 28 to March 7, 2013: (*A*) recorded air temperature cycles; (*B*) water temperature in previously identified seep and non-seep areas; and (*C*) thermogram images during the monitoring period and graphs showing the 7-day mean surface-water temperatures on the warmest and coldest days/times.

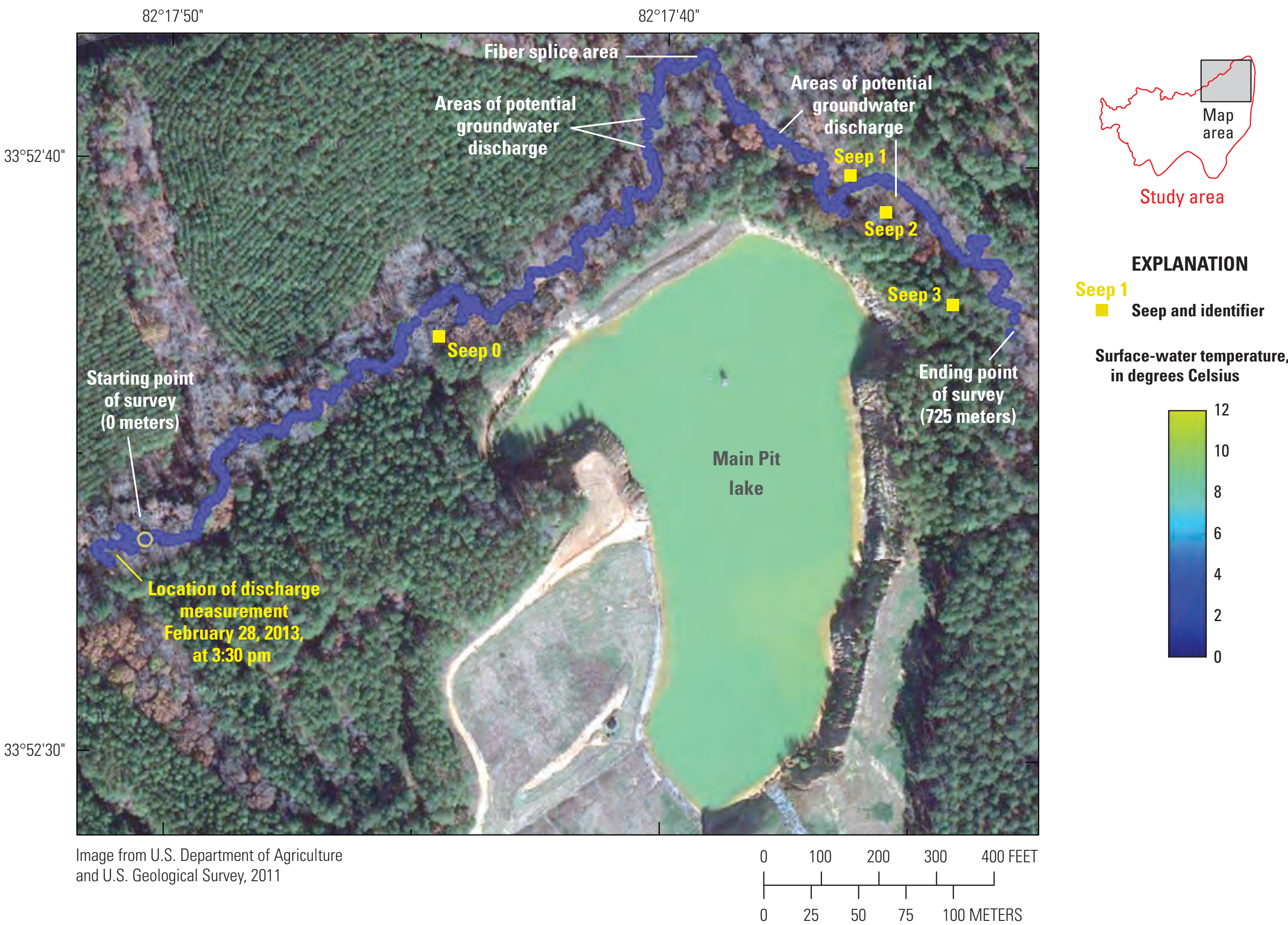


Figure 31. Location of seeps identified in June 2009 (Oneida Technical Integrated Enterprises, 2009) and line of distributed temperature sensing measurements and areas of interpreted groundwater discharge in the unnamed northern tributary measured March 4, 2013, at 7:34 a.m. at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

Summary

The U.S. Geological Survey conducted borehole geophysical logging and water-quality profiling in selected wells and conducted surface geophysical surveys at the U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina, from October 2012 through March 2013. Borehole geophysical logs were collected from seven shallow screened wells and four open-borehole bedrock wells at the site to delineate zones of elevated electrical conductivity above and below the water table and to characterize the fractured bedrock part of the groundwater system. Well depths ranged from about 26 to 300 feet below land surface. Surface geophysical surveys were collected to delineate areas of elevated electrical conductivity that are related to native geologic materials, mine waste rock, and elevated dissolved ions and metals in groundwater and to delineate areas of groundwater discharge by using the fiber-optic distributed temperature sensing method in the northern unnamed tributary at the site.

Results of electromagnetic-induction logging of five selected wells about 1,300 feet south of the Main Pit lake suggest elevated electrical conductivity extends to depths of as much as 110 feet below land surface. From water-quality profiles conducted in the seven screened wells, the highest specific conductance and the lowest pH readings were noted for two wells located between the Main Pit lake and the northern unnamed tributary. Conceptually, these wells may intercept groundwater with elevated conductivity that is leaking from the Main Pit along a flowpath discharging to the tributary. The range in groundwater-quality properties recorded in the selected wells varied as follows: pH ranged from 3.1 to 9.2; specific conductance from 48 to 5,300 microsiemens per centimeter at 25 degrees Celsius; dissolved oxygen from 0.2 to 4.4 milligrams per liter; and water temperature from 17.0 to 18.0 degrees Celsius. These data suggest a wide range of geochemical conditions and elevated concentrations of dissolved ions and metals within the groundwater system at the site.

Bedrock structural interpretations were measured for three bedrock wells where image logs were collected. The mean strike azimuth of the bedrock foliation data measured in well IR-1 was 221° (N. 41° E.), and the mean dip angle was 78° to the northwest. The mean foliation of N. 41° E. is within the range of regional bedding of N. 30–50° E. with the dip angle ranging from 52° to 85° to the northwest or southeast. Dominant strike azimuth orientations of primary fractures measured in three bedrock wells were 210–250° (N. 30° E. to N. 70° E.) with a mean dip of 68° northwest. This orientation parallels the regional bedding strike of N. 30–50° E. and a dominant fracture set striking N. 40° E.–N. 60° E. measured by the U.S. Environmental Protection Agency Superfund Technical Assessment and Response Team in 2008.

Results from the modeling of the heat-pulse flowmeter data collected in bedrock well IR-1 resolved four fracture zones at 38.5, 50, 100, and 125 feet below land surface. The transmissivity estimate calculated by the FLASH model was about 69 feet squared per day, and the radius of influence was estimated to be about 640 feet. The shallowest fracture zone modeled at 38.5 feet had the largest contribution to flow in the well at about 59 percent and is potentially part of the transition zone because a greater fracture density was observed in the optical televiewer image log at this depth.

Interpretation of surface electromagnetic surveys conducted in December 2012 indicates that the highest readings representing areas of elevated electrical conductivity were delineated in specific areas along the northern unnamed tributary and northwest of the former Rainsford Pit. Surface geophysical electromagnetic readings greater than 90 millisiemens per meter were recorded at the site. Elevated electrical conductivity in the Main Pit area appears to be discharging through the groundwater system to specific areas along the northern unnamed tributary. Elevated electrical conductivity in the Rainsford Pit area appears to be in an area to the northwest and may represent either conductive native or waste-rock materials and (or) elevated concentrations of dissolved ions and metals in the groundwater system in that area.

Results from the fiber-optic distributed temperature system survey conducted from February 26 to March 7, 2013, indicated groundwater discharge at four separate areas along the northern unnamed tributary, north of the Main Pit lake. These areas correspond to higher surface electrical conductivity readings noted as part of this study and areas where groundwater seeps were sampled during previous investigations at the site.

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Appendixes 1–6

Appendix 1. Borehole Geophysical Logging Field Notes

USGS
science for a changing world

Century / Caliper log

Tool serial number: **9065a** S/N 609

WELL NAME: IR-1

Date: 10/9/2012

NWIS 15-digit id:

Operators: WSC/BAH

Location:

Project:

watch time: 1524
computer time: 3:24 pm

Well information:
Describe measurement point (MP): TOP OF PVC CASING
Depth of well: 306 ft below MP
Height of MP above land surface: 1.15 ft
Water level from MP 27.09 ft @ 1530
Depth to bottom of casing: 28 ft
Nominal diameter 6.25 inches PVC

Notes on well (water quality, need for PPE, or problem areas: Length 5.13 ft

Top of tool zeroed to land surface: ☑ (check) TOP of TOOL

295.13
5.13
300.26

Starting time of log: 1607 Depth Start: 295.13 ft

Ending time of log: 1632 Depth End: 184.32 ft

Logging speed: ~3-6 ft/min * Depth Bottom: 300.26 ft
Logging direction: UP

Sampling rate: 0.10

Round trip error check of depth: should be <2% of the total depth

2-pt Calibration:
Point 1: 6.31 inch CPS: 31509.5 31558.500
Point 2: 8.625 inch CPS: 40351.5 40157.901

Note any problems or points of interest:

WELL TAG: DRILLED 4-10-2008 REGISTRATION # 167
DEPTH 300 ft DRILLER: LANGFORD
CASING 28 ft
6.25 in diam
YIELD 6PM

33.873368
-82.289068
Lat/Long NOT in the HEADER

* PROCESSOR - LOCKS UP: invalid 20" points
No clean up between tools
RINSED cable DOWN

35°52 24.1
082°17'20.9
FROM GARMIN 60CSX

33.873368
-82.289068

USGS
science for a changing world

SN:609

Century / Caliper log

Tool serial number: **9065a**

WELL NAME: IR-1

Date: 10-9-2012

NWIS 15-digit id:

Operators: WSC / BAH

Location: SECOND (Well 25)

watch time: 15:24
computer time: 3:24pm

Project:

Well information:
Describe measurement point (MP): TOP OF PVC CASING

Depth of well: 300 ft below MP

Well Tag info:

Height of MP above land surface: 1.15 ft
Water level from MP 27.09 ft @ 1530
Depth to bottom of casing: 28 ft
Nominal diameter 6.25 inches

Notes on well (water quality, need for PPE, or problem areas:
Tool Length 5.13 ft

ZEROED TOLL ☐ NO - Started @ 184.32 ft TOP OF TOOL

Starting time of log: 1640 Depth Start: 184.32 ft

Ending time of log: 1700 Depth End: -0.19 ft

Logging speed: ~10 ft/min Depth Bottom: 300.26 ft
Logging direction: UP

Sampling rate: .10

Round trip error check of depth: -0.19 ft should be <2% of the total depth

2-pt Calibration:

			NEW	PREVIOUS
Point 1:	6.31	inch	CPS: 31509.5	CPS:
Point 2:	8.625	inch	CPS: 40351.5	CPS:

Note any problems or points of interest:

Second portion of LOG

possible breakout
52-53 depth ft 15.1 IN. ?
38-43 ft 9 in
CASING confirmed 28 ft

USGS
science for a changing world

S/N 886 ✓

Century / Combo tool log

Tool serial number: **8143a** ✓

WELL NAME: IR-1

Date: 10/9/2012

NWIS 15-digit id: ______

Operators: WSC/BAH

Location: ______

watch time: 1703

Project: ______

computer time: 5:03 pm

Geophysical log reference: measuring pt or land surface

Well information:

Describe measurement point (MP): TOP OF PVC CASING

Depth of well: 300 ft below land surface

Height of MP above land surface: 1.15 ft

Water level from MP 27.09 ft @ 1530

Depth to bottom of casing: 28 ft

Nominal diameter 6.25 inches steal PVC

Notes on well (water quality,need for PPE, or problem areas:

Tool length 7.50 ft

Top of tool zeroed to land surface: ☑ (check)

299.
~~300.00~~
7.50
292.50

E-log mud-probe grounded: ☑ (check)

CLEANED CABLE ON UP ☑

Log Down

Start time of log: 1711

End time of log: 1734

Logging speed: ~15 ft/min

Bottom of tool 7.50 ft

Depth Start: 0.00 TOP of TOOL

300 ft

Depth End: 292.49 ft

Log Up

Start time of log: 1735

End time of log: 1757

Logging speed: ~15 ft/min

Depth Bottom: 300.26 ft

Sampling rate: 0.10

Round trip error check of depth: ~0.16 ft should be <2% of the total depth

Note any problems or points of interest:

PAUSED After entering water: to Stabilize ~61.5°F

USGS
science for a changing world

Mount Sopris / ALT OTV log (OBI 40)

Tool serial number: **5023 / 102611**

WELL NAME: IR-1

Date: 10-10-2012

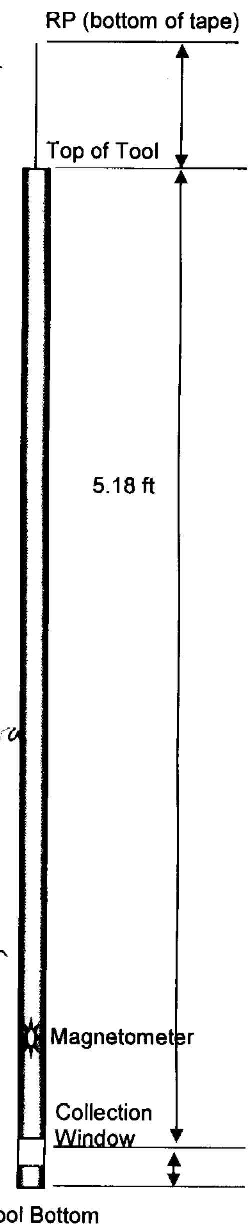
NWIS 15-digit id: ____

Operators: WSC / BAH

Location: ____

watch time:
computer time:

Project: ____



Well information:

Describe measurement point (MP): TOP of PVC CASING

Depth of well: 300 ft below MP

Height of MP above land surface: 1.15 ft

Water level from MP 27.12 ft @ 0750

Depth to bottom of casing: 28 ft

Nominal diameter 6.25 inches

Notes on well (water quality, need for PPE, or problem areas:

Magnetometer/Inclinometer check:

Tilt check (~45°): ☑ OK Directional (N,S,E,&W) tilt check: ☑ OK

North check (placing object in front of camera window at north): ☑ OK

Top of tool zeroed to land surface: ☑ (check)

Depth of camera

Starting time of log: ~ 0826 Depth Start: 5.18 ft

Ending time of log: ____ ? Depth End: ____ ft ?

Logging speed: ~ 8 (<5 ft/min) Depth Bottom: 300.7 ft Finish 5.07 ft

Logging direction: ~~UP~~ DOWN

Sampling rate:

Round trip error check of depth: 0.11 ft should be <2% of the total depth

Note any problems or points of interest:

CASING - 28

✓ 39-42 ✓ 120

✓ 130

135-136 ([illegible])

✓ 80 - 219

90 252-256

✓ 94

99

Checks:

1. Data sampling interval: 0.015 ft Pts/turn: 360 Light: 6 or 8
   in dark rocks choose a higher light intensity -- 8 -10.
2. Prior to actual data collection you can do the real-time mode data collection as a check.
   Be sure to record the depth before you start the time drive!!
3. Bottom of lower centralizer minimum of 20 inches from tool bottom
4. Note the version and build of MS log that was used and consider archiving a copy of the tol file

Ambient

HPFM "~~LOW RATE~~" PUMPING

Well: IR-1 Tool serial no. Operators: WSC/BAH

NWIS 15-digit id. (c1): Describe MP: TOP of PVC casing

Date 10 / 10 / 2012 Pump set at ____feet Watch time: 0932

Pumping Rate ________ gal/min WL at start of HPFM 27.12 at 0750 Computer time: 0932

Pump Started _____ Start 3.18 ft WL at end of HPFM _______ at ______

Initial Water Level _____ feet End 3.29 ft Δ in WL during test _______ ft

Pump Stopped _____ WL after test: _______ at ______

Fluid Res. & Temp: yes ____ or no ____ Rnd-trip depth error: 0.11 ft

Depth (in feet)	Flow Direction	Flow Rate (in gallons per min) Note direction with - or + or with up or down arrow				Time	Diff. in flow rate	Notes - include interpretation (see below)
27.50	NO FLOW	0	0			1000	—	AUTO PICK NOT WORKING PROPERLY?
34.00	↑	.01/35.05	.01/37.55	.01/36.1		1008		WL=27.12
50.00	↑	.01/35.9	.01/36.4	.01/33.6		1019		WL=27.12
75.00		0	0			1048		WL=27.12
85.00		0	0	0		1059		WL=27.12
100	↑	.01/26	.01/23	.01/28.7	.01/36	1110		WL=27.12
125.03	↑	.01/24	.01/27	.06/2.1	.01/32 0	1135		WL=27.12
140.07	↑	.01/31	0/40	.01/27	.01/27			
200.02	↑	.01/28	.01/30 +			1206		FIRST RUN G @ 1220
248.03	↑	.01/32	.01/25	.01/36	.01/29	1244		
290.01	↑	.01/32	.01/39	.01/36		1259		

Remember to record the calibration values of the flowmeter. You can do a screen grab of the calibration page on MsHeat or record values.

transient flow means that the flow rate is changing, typically it occurs in response to the effects of tool movement, which causes an apparent vertical flow.

Late-time flow means that the heatpulse has arrived after the GP, but the computer has picked the GP. Be sure to note this occurrence!

check measurement indicates that a duplicate measurement was made to check the consistency of an earlier measurement.

umbrella marks: indicate the way that the diverters were set - it may help with the interpretatiton of the data for anticipated upflow and for downflow

Potential zones

source: 1/24/2011 cjohnson@usgs.gov 83 9 Low Rate Pumping Forms 58 62-64

HPFM "LOW RATE" PUMPING

NWIS 15-digit id. (c1):

Date 10 / 10 / 12

Pumping Rate ~0.8 gal/min

Pump Started ____

Initial Water Level 27.12 feet @1306

Pump Stopped ____

Well: IR-1

Tool serial no.

Describe MP: TOP of PVC casing

Pump set at 44 **feet** below TOC

WL at start of HPFM 27.12 at 1330

WL at end of HPFM ____ at ____

Δ in WL during test ____ ft

WL after test: ____ at ____

Operators: WSC/BAH

Watch time: 1306

Computer time: 1306

Fluid Res. & Temp: yes ____ or no ____

Rnd-trip depth error: ft

Depth (in feet)	Flow Direction	Flow Rate (in gallons per min) Note direction with - or + or with up or down arrow				Time	Diff. in flow rate	Notes - include interpretation (see below)
290.01		.01/28	.01/32	.01/33		1401		
248		.01/~~35~~ 37	.01/25	.01/33				
200.01		.01/29	.01/28	.01/26		1427		
140.01		.01/23	.01/31	.01/35	.01/35	1440		
125.00		.01/24	.01/25			1450		
100.00		.02/17	.02/17	.02/17		1454		
85.01		.01/26	.01/25	.01/34	.01/40	1505		0/40 (BYPASS?)
~~75~~ 84		.02/20	.02/21	.02/22		1515		moved up 1 foot
~~50~~ 75.01		.02/20	.02/21			1523		
49.99		.04/8.5	.04/8.5	.04/8.6		1531		
38.48		.09/4.35	.09/4.2	.1/3.9				★ RAISED PUMP to ~32' BMP
31.85		.39/1.40	1.39/0.6	0.3/1.85		1557		Experiment/HP near pump

Remember to record the calibration values of the flowmeter. You can do a screen grab of the calibration page on MsHeat or record values.

transient flow means that the flow rate is changing, typically it occurs in response to the effects of tool movement, which causes an apparent vertical flow.

Late-time flow means that the heatpulse has arrived after the GP, but the computer has picked the GP. Be sure to note this occurrence!

check measurement indicates that a duplicate measurement was made to check the consistency of an earlier measurement.

umbrella marks: indicate the way that the diverters were set - it may help with the interpretatiton of the data for anticipated upflow and for downflow

source: 1/24/2011 cjohnson@usgs.gov

Low Rate Pumping Forms

AMBIENT HP FLOWMETER

Field form for recording discharge and drawdown data used to compute open hole specific capacity

WELL IR-1 Date: 10/10/12 Operators: RGH / JWSC
Pumping rate 0 gpm watch time:
Height of MP 1.15 computer time:

These data are used to compute the open hole specific capacity. With additional programs you can calculate the open hole transmissivity. (see Bradbury and Rothschild, 1985)

Pump set at ____ **ft below MP**
Note any observations in the discharged water: smell, turbidity, color...

SET PUMP @ ~44' BMP

Be sure to note when the pump was turned on, changes in pumping rate, pump off, etc. These data along with fluid temp and resistivity data collected after pumping may help in the interpretation the flow meter data and the hydraulics of the borehole.

Watch time	water level	drawdown rate	TROLL	Discharge rate measurement vol (gal)	time (s)	Q (gpm)	Comments:
1009	27.12						
1019	27.12						
1048	27.12						
1059	27.12						
1133	27.12						
1222	27.11						PLACED PUMP @ ~44' BMP @ 1220
1330	27.12						
1331	PUMP ON						
1333	27.32			~0.12 GPM		~0.52 GPM	
1338	27.40						INCREASED RATE @1339
1343	27.55						19 SECS / 1 LITER
1351	27.6					0.79	
1403	27.66		27.659			0.79	
1413	27.70						
1424	27.73						19 sec / 1 LITER
1437	27.76		27.737				
1447	27.79					0.79	
1457	27.81		27.779				
1540	27.89						TURNED TROLL OFF

MP=measuring point, dd= drawdown, Q=discharge (or injection rate), vol= volume
We want to run the HPFM test under pumping conditions once we hit quasi-steady state, which is defined as the amount of water coming out of storage is <10% of the pumping. That is we start the HPFM under pumping conditions when the drawdown rate per minute (converted to the borehole storage) is less than the resolution of the tool. So for example: dd at 0.01 ft in a 6-in hole--> is 0.015 gpm and we can just bearly measure that with the HPFM tool. So dd has to be <0.01ft/min

*DURING 'PUMPING' HP FLOWMETER

WELL PURGE LOG FIELD ID IR-1 10/10/12

Allowable Drawdown: ________ *ft* **Purge method:** STANDARD LOW-FLOW OTHER ____________

START TIME:________________ END TIME______________

Time	Water Level blw MP LSD	Draw-down ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity ns/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1406	27.67		~~0.8~~	0.8	17.99	315	6.73	4.46			
1415					18.0	315	6.73	4.45			
1430					18.04	315	6.73	4.39			
1440					18.1	315	6.73	4.39			
											MEDIAN VALUES
											QUIESCENT pH
											FINAL FIELD MEASURE-

Well Volume (gal) = $V = 0.0408\,HD^2$ or Well Volume = $H \times F$

where:
- V is volume of water in the well, in gallons
- H is height of water column, in feet
- D is inside Diameter of well, in inches
- F is casing Volume Factor (see table)

H = Well depth - Static water level = ________ feet

Diameter, inside (D) = ________ inches

1 well volume (V) = ________ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = (n)(V) = ________ **gallons [Actual =** ________ **gal]**

where:
- n is number of well volumes to be removed during purging
- V is volume of water in the well, in gallons

Q = estimated pumping rate = ______ gallons per minute

Approximate purge time = (purge volume)/Q = ______ minutes

	VOLUME FACTORS												
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Screened/Open Interval: TOP ________.____ ft blw LSD MSL

Bottom ________.____ ft blw LSD MSL

Depth to Top of Sampling Interval ______.____ft blw LSD MSL

Depth to Bottom of Sampling Interval ______.____ ft blw LSD MSL

Depth to set pump from MP (all units in feet except where noted) :	
Distance to top of screen from LSD	
+ MP (- if MP below LS)	
– (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	
Depth to pump from LSD (all units in feet) :	
– MP	
= Depth pump set from LSD MSL	

Notes/Calculations:

MONITORED DURING "PUMPING" HP FLOWMETER

GW Form version 8.0

USGS
science for a changing world

Century / Combo tool log

Tool serial number: ~~S/N 886~~ 988 ~~8143a~~ 9511A

WELL NAME: BH33

Date: 10-11-2012

NWIS 15-digit id:

Operators: WSC/BAH

Location: MW-02

watch time: 1523

Project:

computer time: 1523

Geophysical log reference: measuring pt or land surface

Well information:

Describe measurement point (MP):

Depth of well: 163.2 ft below land surface

Height of MP above land surface: 2.65 ft

Water level from MP 43.95 ft @ 1523

Depth to bottom of casing: ft

Nominal diameter 2 inches steal PVC

Notes on well (water quality,need for PPE, or problem areas:

Tool length ~~7.50 ft~~ 7.8 ft 4.99 to sensor

	CALIBRATION	New	Previous
Top of tool zeroed to land surface: ☑ (check)	0.00	61041.5	60678.699
E-log mud-probe grounded: ☐ (check) N/A	690	137889.3	138047.703

CLEANED CABLE ON UP ☑

152.
-44
108

44.00
-5.00
39.00

Log Down

Start time of log: 1537

End time of log: 1603

Logging speed: ~8-9 ft/min

Log Up

Start time of log: 1604

End time of log: 1622

Logging speed: ~8-9 ft/min

163.2
-7.8
155.4

152.76
7.80
160.56

Depth Start: 0.0 Top of Tool

Depth Bottom: 160.56

Depth End: 152.76

Sampling rate: 0.10

Round trip error check of depth: -0.08 should be <2% of the total depth

Note any problems or points of interest:

Sensor Lowered ~ 1.5 ft prior to recording start

Sensor in ~ 4 ft water held for Temp Stabilize

Lat 33.871224
Long -82.293496

Groundwater-quality profile

10-11-2012 HYDROLAB PROFILE

WELL PURGE LOG FIELD ID BH33

Allowable Drawdown: ______ ft **Purge method:** STANDARD LOW-FLOW OTHER ______

START TIME: ______ END TIME ______

Time	HYDROLAB ~~Water~~ Level blw MP ~~LSD~~	Draw-down ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity ms/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1640	45				18.27	319	8.09	2.89			
1643	55				17.60	316	8.10	2.41			
1644	65				17.32	316	8.11	1.59			
1646	75				17.24	316	8.13	0.79			
1648	85				17.19	318	8.15	0.34			
1649	95				17.22	321	8.14	0.24			
1653	105				17.15	338	8.04	0.16			
1654	115				17.15	370	7.89	0.14			
1655	125				17.18	400	7.76	0.13			
1657	135				17.20	436	7.65	0.13			
1700	145				17.22	486	7.45	0.14			
1702	155				17.25	563	7.35	0.24			
1704	163				17.26	571	7.36	0.18			BOTTOM OF WELL
											MEDIAN VALUES
											QUIESCENT pH
											FINAL FIELD MEASURE-

Well Volume (gal) = $V = 0.0408\,HD^2$ or Well Volume = $H \times F$

where:
- *V* is volume of water in the well, in gallons
- *H* is height of water column, in feet
- *D* is inside Diameter of well, in inches
- *F* is casing Volume Factor (see table)

H = Well depth - Static water level = ______ feet

Diameter, inside (*D*) = ______ inches

1 well volume (*V*) = ______ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = (*n*)(*V*) = ______ **gallons [Actual =** ______ **gal]**

where:
- *n* is number of well volumes to be removed during purging
- *V* is volume of water in the well, in gallons

Q = estimated pumping rate = ______ gallons per minute

Approximate purge time = (purge volume)/*Q* = ______ minutes

	VOLUME FACTORS												
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Depth to set pump from MP (all units in feet except where noted) :

Distance to top of screen from LSD	
+ MP (- if MP below LS)	
− (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	

Depth to pump from LSD (all units in feet) :

− MP	
= Depth pump set from LSD MSL	

Screened/Open Interval: TOP ______.____ ft blw LSD MSL

Bottom ______.____ ft blw LSD MSL

Depth to Top of Sampling Interval ______.____ ft blw LSD MSL

Depth to Bottom of Sampling Interval ______.____ ft blw LSD MSL

Notes/Calculations:

USGS
science for a changing world

Century / Combo tool log

Tool serial number: ~~S/N 886~~ 988 ~~8143a~~ 9511A

WELL NAME: BH34

Date: 10-11-2012

NWIS 15-digit id:

Operators: WSC/BAM

Location: MW-D1

watch time: 1626

Project:

computer time: 1626

87.6
-44.0
43.6

Geophysical log reference: measuring pt or land surface

Well information:

Describe measurement point (MP):

Depth of well: 98.9 ft below land surface

Height of MP above land surface: 2.65 ft

Water level from MP 43.78 ft @ 1629

Depth to bottom of casing: ft

Nominal diameter 2 inches steal PVC

41.00
+5.80
46.80
43.78
3.02

Notes on well (water quality, need for PPE, or problem areas:

Tool length ~~7.50~~ ft 7.8 ft 4.99 to Sensor

33.8
5.0
38.8

Top of tool zeroed to land surface: ☑ (check)

98.9
7.8
91.1

E-log mud-probe grounded: ☐ (check) N/A

CLEANED CABLE ON UP ☐

87.57
+7.8
95.37

Log Down

Start time of log: 1635

End time of log: 1653

Logging speed: ~8-9 ft/min

Log Up

Start time of log: 1654

End time of log: 1705

Logging speed: ~8-9 ft

Depth Start: 0.00 Top of Tool

Depth Bottom: 95.37

Depth End: 87.57

Sampling rate: 0.10

Round trip error check of depth: -0.11 should be <2% of the total depth

Note any problems or points of interest:

held sensor in ~2.2 ft water to stabilize temp ~1641-1643

Lat 33.871222
long -82.293498

Groundwater-quality profile

10-11-2012 Hydrous Profile

WELL PURGE LOG FIELD ID BH 34

Allowable Drawdown: ________ *ft* **Purge method:** STANDARD LOW-FLOW OTHER ____________

Hydrous START TIME:______________ END TIME______________

Time	Water Level blw MP LSD	Draw-down ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity ms/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1717	45				17.59	551	7.56	~~[illegible]~~ 0.67			
1718	50				17.15	551	7.55	0.33			
1720	55				17.02	552	7.56	0.19			
1721	60				16.99	557	7.60	0.15			
1722	65				17.00	569	7.73	0.14			
1723	70				17.00	580	7.82	0.15			
1724	75				17.01	584	7.87	0.14			
1725	80				17.02	584	7.89	0.15			
1726	85				17.04	584	7.90	0.15			
1727	90				17.07	585	7.91	0.12			
1728	95				17.09	584	7.91	0.14			
											MEDIAN VALUES
											QUIESCENT pH
											FINAL FIELD MEASURE

Well Volume (gal) = $V = 0.0408\ HD^2$ or Well Volume = $H \times F$

where:
- V is volume of water in the well, in gallons
- H is height of water column, in feet
- D is inside Diameter of well, in inches
- F is casing Volume Factor (see table)

H = Well depth - Static water level = __________ feet

Diameter, inside (D) = __________ inches

1 well volume (V) = __________ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = (n)(V) = __________ **gallons [Actual =** __________ **gal]**

where:
- n is number of well volumes to be removed during purging
- V is volume of water in the well, in gallons

Q = estimated pumping rate = _______ gallons per minute

Approximate purge time = (purge volume)/Q = _______ minutes

	VOLUME FACTORS											
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Depth to set pump from MP (all units in feet except where noted) :	
Distance to top of screen from LSD	
+ MP (- if MP below LS)	
− (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	
Depth to pump from LSD (all units in feet) :	
− MP	
= Depth pump set from LSD MSL	

Screened/Open Interval: TOP _________._____ ft blw LSD MSL

Bottom _________._____ ft blw LSD MSL

Depth to Top of Sampling Interval _______.____ ft blw LSD MSL

Depth to Bottom of Sampling Interval _______.____ ft blw LSD MSL

Notes/Calculations:

USGS
science for a changing world

Em conductivity

Century / ~~Combo tool log~~

Tool serial number: ~~S/N 886~~ 988 ~~8143a~~ 9511A

WELL NAME: BH49

Date: 10/11/2012

NWIS 15-digit id:

Operators: WSC/BAH

Location: MW-A3

watch time: 0945

Project:

computer time: 0945

Geophysical log reference: measuring pt ~~or~~ land surface

Well information:

Describe measurement point (MP): TOP of PVC casing

Depth of well: 73.9 ft below land surface

Height of MP above land surface: 2.35 ft

Water level from MP 49.43 ft @ 0948

Depth to bottom of casing: ft

Nominal diameter 2 inches steal PVC

Notes on well (water quality,need for PPE, or problem areas:

Tool length ~~7.50 ft~~ 7.8 ft

Top of tool zeroed to land surface: ☑ (check)

E-log mud-probe grounded: ☐ (check) N/A

CLEANED CABLE ON UP ☑

61
73.9
7.8
66.1
62.86
7.8
70.66

Log Down

Start time of log: 0949

End time of log: 1004

Logging speed: ~8 ft/min

Log Up

Start time of log: 1025

End time of log: ? Brad

Logging speed: ~8 ft/min

Bottom Tool 7.8 ft
70.66

Depth Start: 0.00 Top of Tool

Depth Bottom: 70.66

Depth End: 62.86

Sampling rate: 0.10

Round trip error check of depth: 0.09 should be <2% of the total depth

Note any problems or points of interest:

TOP of TOOL = 47.00
Sensor AT = 52.00 ft WS = 49.43 holding for stabilization

USED GETAC DOWN
USED EEE Notebook UP

Depth Drilled MAY be wrong IN Header, ON UP sample should be 73.9 ft

33.873249
-82.295381

Groundwater-quality profile

10-11-2012 Hydrolab Profile

~~WELL PURGE LOG~~ FIELD ID BH49

Allowable Drawdown: ______ **ft** **Purge method:** STANDARD LOW-FLOW OTHER ______

START TIME: ______ **END TIME** ______

Time	~~Water~~ Hydrolab Level blw MP ~~LSD~~	Draw-down ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity µs/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1242	50				18.57	52	5.31	3.99			
1243	55				18.15	47.4	5.11	3.92			
1244	60				18.08	46.7	4.97	4.00			
1246	65				18.00	47.1	4.94	4.09			
1247	70				17.92	48.0	4.96	4.01			
											MEDIAN VALUES
											QUIESCENT pH
											FINAL FIELD MEASURE-

Well Volume (gal) = $V = 0.0408\ HD^2$ or Well Volume = $H \times F$

where:
V is volume of water in the well, in gallons
H is height of water column, in feet
D is inside Diameter of well, in inches
F is casing Volume Factor (see table)

H = Well depth - Static water level = ______ feet

Diameter, inside (D) = ______ inches

1 well volume (V) = ______ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = (n)(V) = ______ **gallons [Actual =** ______ **gal]**

where:
n is number of well volumes to be removed during purging
V is volume of water in the well, in gallons
Q = estimated pumping rate = ______ gallons per minute
Approximate purge time = (purge volume)/Q = ______ minutes

VOLUME FACTORS													
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Screened/Open Interval: TOP ______.____ ft blw LSD MSL

Bottom ______.____ ft blw LSD MSL

Depth to Top of Sampling Interval ______.____ ft blw LSD MSL

Depth to Bottom of Sampling Interval ______.____ ft blw LSD MSL

Depth to set pump from MP (all units in feet except where noted) :	
Distance to top of screen from LSD	
+ MP (- if MP below LS)	
– (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	
Depth to pump from LSD (all units in feet) :	
– MP	
= Depth pump set from LSD MSL	

Notes/Calculations:

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USGS
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EM Induction

Century / ~~Combo tool~~ log

~~S/N 886~~ 988
Tool serial number: ~~8143a~~ 9511A

WELL NAME: BH50

Date: 10-~~10~~ 11-2012

NWIS 15-digit id:

Operators: WSC/BAH

Location:

watch time: 0801

Project:

computer time: 0801

Geophysical log reference: measuring pt or land surface

Well information:

Describe measurement point (MP): Top of PVC casing

Depth of well: 148.1 ft below land surface

Height of MP above land surface: 2.52 ft

Water level from MP 49.95 ft @ 1727

10/11/12 50.03 @ 0756

Depth to bottom of casing: ft

Nominal diameter 2 inches steal PVC

Notes on well (water quality, need for PPE, or problem areas:

Tool length 7.50 ft

	Cal	New	Previous
	0.00	60628.7	61799.500
	690.00	138047.7	138711.094

Top of tool zeroed to land surface: ☑ (check)

E-log mud-probe grounded: ☐ (check) N/A

CLEANED CABLE ON UP ☐

Log Down

Start time of log: 0818

End time of log: 0841

Logging speed: ~8 ft/min

Log Up

Start time of log:

End time of log:

Logging speed:

Depth Start: 0.00

Depth End: ~~134.85 - top of tool~~

Depth Bottom: 134.85 - TOP OF TOOL * SOFTWARE INDICATES BOTTOM OF SENSOR at 4.99 ft.

TOOL LENGTH IS =

Sampling rate: 0.1

Round trip error check of depth: -0.09 should be <2% of the total depth

Note any problems or points of interest:

* ~~APPEARS TO BE~~ IS SOMETHING CAUSING SPIKES (NEGATIVE COND MMHO/M, POSITIVE RES OHM/M EVERY ~20 ft (CASING JOINTS? SPACERS?)

* BELOW 100 ft: COND (MMHO/M) WENT FROM 5000-6000 DOWN TO NEGATIVE READINGS
RES (OHM/M) WENT FROM ~0.16 TO NEGATIVE VALUES

lat 33.873284
long -82.295380

Groundwater-quality profile

10-11-2012 HYDROLAB PROFILE

~~WELL PURGE LOG~~ FIELD ID BH 50

Allowable Drawdown: _________ ***ft*** **Purge method:** STANDARD LOW-FLOW OTHER ________________________

START TIME:____________________ **END TIME**______________

Time	~~Water~~ HYDROLAB Level blw MP ~~LSD~~	Draw-down ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity µs/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1218	140				17.54	257	6.07	0.68			
1222	130				17.55	184	6.50	0.18			
1224	120				17.57	156	7.18	0.16			
1225	110				17.60	138	9.37	0.16			
1226	100				17.63	148	10.11	0.13			
1228	90				17.69	171	10.42	0.12			
1229	80				17.76	181	10.49	0.12			
1230	70				17.87	184	10.51	0.14			
1233	60				18.03	184	1052	0.13			
1234	55				18.14	183	1051	0.15			
											MEDIAN VALUES
											QUIESCENT pH
											FINAL FIELD MEASURE-

Well Volume (gal) = *V* = 0.0408 *HD*² or **Well Volume = *H* x *F***

where:

V is volume of water in the well, in gallons
H is height of water column, in feet
D is inside Diameter of well, in inches
F is casing Volume Factor (see table)

H = Well depth - Static water level = __________ feet

Diameter, inside (*D*) = __________ inches

1 well volume (*V*) = __________ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = (*n*)(*V*) = __________ **gallons [Actual =**__________ **gal]**

where:

n is number of well volumes to be removed during purging
V is volume of water in the well, in gallons

Q = estimated pumping rate = _______ gallons per minute

Approximate purge time = (purge volume)/*Q* = ________ minutes

VOLUME FACTORS													
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Depth to set pump from MP (all units in feet except where noted) :	
Distance to top of screen from LSD	
+ MP (- if MP below LS)	
– (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	
Depth to pump from LSD (all units in feet) :	
– MP	
= Depth pump set from LSD MSL	

Screened/Open Interval: TOP _________.____ ft blw LSD MSL

Bottom __________.____ ft blw LSD MSL

Depth to Top of Sampling Interval _______.____ft blw LSD MSL

Depth to Bottom of Sampling Interval _______.____ ft blw LSD MSL

Notes/Calculations:

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Century / Combo tool log

Tool serial number: ~~S/N 686~~ 988 ~~8143a~~ 9511A

WELL NAME: BH51

Date: 10-11-2012

NWIS 15-digit id:

Operators: WSC/BAH

Location: MW-A1

watch time: 1104
computer time: 1104

Project:

18

Geophysical log reference: measuring pt or land surface

Well information:
Describe measurement point (MP): TOP of PVC CASING
Depth of well: 199.9 ft below land surface
Height of MP above land surface: 2.37 ft
Water level from MP 48.72 ft @ 1054
Depth to bottom of casing: ft
Nominal diameter 2 inches steal PVC

Notes on well (water quality,need for PPE, or problem areas:
Tool length ~~7.50 ft~~ 7.8 ft Sensor at 4.99 ft

Top of tool at WS
48.72
−7.80
40.92
48.72
−4.99
43.73 Top of Tool at sensor at WS

Top of tool zeroed to land surface: ☑ (check)

199.9
−7.8
192.1

E-log mud-probe grounded: ☐ (check) N/A

CLEANED CABLE ON UP ☐

183.04
+7.8
190.84

Log Down

Start time of log: 1105
End time of log: ~1130
Logging speed: ~8 ft/min

Log Up

Start time of log: 1132
End time of log: 1156
Logging speed: ~8 ft/min

Bottom TOOL 7.8 ft
190.84

Depth Start: 0.00 TOP of TOOL
Depth End: 183.04

Depth Bottom: 190.84
Sampling rate: 0.10

Round trip error check of depth: 0.18 should be <2% of the total depth

Note any problems or points of interest:

Positioned sensor in water Top of tool @ 45.00 ft to stabilize temp.

Lat 33.87317
Long −82.295383

Groundwater-quality profile

10-11-2012 Hydrolab Profile

WELL PURGE LOG FIELD ID BH51

Allowable Drawdown: ______ ***ft*** **Purge method:** STANDARD LOW-FLOW OTHER ______________

Hydrolab **START TIME:**______________ **END TIME**______________

Time	~~Water~~ Level blw MP ~~LSD~~	Draw-down ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity ms/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1302	50				18.85	131	10.02	0.80			
1304	60				18.21	135	10.14	0.15			
1307	70				17.94	136	10.19	0.14			
1308	80				17.84	136	10.23	0.13			
1309	90				17.71	136	10.24	0.13			
1310	100				17.66	135	10.25	0.13			
1311	110				17.62	132	10.22	0.13			
1312	120				17.58	126	10.15	0.13			
1313	130				17.55	117	9.91	0.13			
1314	140				17.53	114	9.58	0.13			
1315	150				17.51	122	9.00	0.13			
1316	160				17.51	139	7.96	0.13			
1317	170				17.50	177	6.71	0.15			
1318	180				17.50	233	6.37	0.24			
1319	190				17.50	367	6.11	1.72			
											MEDIAN VALUES
											QUIESCENT pH
											FINAL FIELD MEASURE-

Well Volume (gal) = $V = 0.0408\,HD^2$ or **Well Volume =** $H \times F$

where:
- V is volume of water in the well, in gallons
- H is height of water column, in feet
- D is inside Diameter of well, in inches
- F is casing Volume Factor (see table)

H = Well depth - Static water level = __________ feet

Diameter, inside (D) = __________ inches

1 well volume (V) = __________ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = $(n)(V)$ = __________ **gallons [Actual =**__________ **gal]**

where:
- n is number of well volumes to be removed during purging
- V is volume of water in the well, in gallons

Q = estimated pumping rate = _______ gallons per minute

Approximate purge time = (purge volume)/Q = _______ minutes

VOLUME FACTORS													
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Depth to set pump from MP (all units in feet except where noted) :	
Distance to top of screen from LSD	
+ MP (- if MP below LS)	
– (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	
Depth to pump from LSD (all units in feet) :	
– MP	
= Depth pump set from LSD MSL	

Screened/Open Interval: TOP _________._____ ft blw LSD MSL

Bottom __________._____ ft blw LSD MSL

Depth to Top of Sampling Interval _______._____ft blw LSD MSL

Depth to Bottom of Sampling Interval _______._____ ft blw LSD MSL

Notes/Calculations:

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Groundwater-quality profile

10/18/2012

WELL PURGE LOG

FIELD ID RH55

Allowable Drawdown: ________ *ft* **Purge method:** STANDARD LOW-FLOW OTHER ____________

START TIME:________________ END TIME________________

Time	Water Level blw MP LSD	~~Draw-down~~ ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity ns/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1110	24.49	HYDROLAB (BMP)									
1112	~~25~~	25			18.52?	1797?	3.38	6.02?			MAY NOT BE FULLY SUBMERGED
1114		30			17.65	3338	3.70	0.36			
1116		35			17.25	3445	3.80	0.21			
1118		37			17.07	3447	3.83	0.16			BOTTOM
											MEDIAN VALUES
											QUIESCENT PH
											FINAL FIELD MEASURE-

Well Volume (gal) = $V = 0.0408\ HD^2$ or Well Volume = $H \times F$

where:
- V is volume of water in the well, in gallons
- H is height of water column, in feet
- D is inside Diameter of well, in inches
- F is casing Volume Factor (see table)

H = Well depth - Static water level = ________ feet

Diameter, inside (D) = ________ inches

1 well volume (V) = ________ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = (n)(V) = ________ **gallons [Actual =**________ **gal]**

where:
- n is number of well volumes to be removed during purging
- V is volume of water in the well, in gallons

Q = estimated pumping rate = ______ gallons per minute

Approximate purge time = (purge volume)/Q = ______ minutes

VOLUME FACTORS												
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Screened/Open Interval: TOP ________.____ ft blw LSD MSL

Bottom ________.____ ft blw LSD MSL

Depth to Top of Sampling Interval ______.____ft blw LSD MSL

Depth to Bottom of Sampling Interval ______.____ ft blw LSD MSL

Depth to set pump from MP (all units in feet except where noted) :	
Distance to top of screen from LSD	
+ MP (- if MP below LS)	
− (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	
Depth to pump from LSD (all units in feet) :	
− MP	
= Depth pump set from LSD MSL	

Notes/Calculations:

MP = 3.12 ft

SWL = 24.49 ft @1110

GW Form version 8.0

Groundwater-quality profile Last well near Lake NR EHSS

10/18/2012

WELL PURGE LOG

FIELD ID BA56

Allowable Drawdown: ________ *ft* **Purge method:** STANDARD LOW-FLOW OTHER ____________

START TIME: ____________ END TIME ____________

Time	Water Level blw MP LSD	Draw-down ft	Well Yield gpm	Pumping Rate gpm	Water Temp °C	Conduc-tivity ms/cm	pH units	Dis-solved oxygen	Turbidity		Comments [clarity, etc.]
1130	79.65	HYDROLAB (BMP)									
1132		20			18.57	5253	2.80	~~1.0~~ 0.80			
1134		25			18.11	5200	2.92	0.19			
1139		27.7			17.84	5470	3.50	0.14			Bottom
											MEDIAN VALUES
											QUIESCENT pH
											FINAL FIELD MEASURE-

Well Volume (gal) = $V = 0.0408\ HD^2$ or **Well Volume =** $H \times F$

where:
V is volume of water in the well, in gallons
H is height of water column, in feet
D is inside Diameter of well, in inches
F is casing Volume Factor (see table)

H = Well depth - Static water level = ________ feet
Diameter, inside (D) = ________ inches
1 well volume (V) = ________ gallons

Parameter	Stability Criteria* (for more information see NFM Table 6.0-1)
pH	± 0.1 units (± 0.05 units if instrument display 2 or more digits to the right of the decimal) ± 0.3 if SC <~75µS/cm
Temperature (T)	± 0.2° C (thermistor)
Specific Conductivity (SC)	± 5%, of SC < 100 µS/cm ± 3%, for SC > 100 µS/cm
Dissolved Oxygen (DO)	± 0.2 mg/L
Turbidity (TU)	± 10%, for TU< 100: ambient TU is < 5 or most ground-water systems (visible TU > 5)

*allowable variation among 5 or more sequential field-measurement values

Purge Volume = $(n)(V)$ = ________ **gallons [Actual =** ________ **gal]**
where:
n is number of well volumes to be removed during purging
V is volume of water in the well, in gallons
Q = estimated pumping rate = ______ gallons per minute
Approximate purge time = (purge volume)/Q = ______ minutes

VOLUME FACTORS													
DIAMETER (in.)	1.0	1.5	2.0	3.0	4.0	4.5	5.0	6.0	8.0	10.0	12.0	24.0	36.0
CASING VOL.	0.04	0.09	0.16	0.37	0.65	0.83	1.02	1.47	2.61	4.08	5.88	23.5	52.9

Depth to set pump from MP (all units in feet except where noted) :	
Distance to top of screen from LSD	
+ MP (- if MP below LS)	
– (7 to 10 x diameter (inches) of the well) [convert to feet]	
= Depth to pump intake from MP	
Depth to pump from LSD (all units in feet) :	
– MP	
= Depth pump set from LSD MSL	

Screened/Open Interval: TOP ________.____ ft blw LSD MSL
Bottom ________.____ ft blw LSD MSL
Depth to Top of Sampling Interval ______.____ft blw LSD MSL
Depth to Bottom of Sampling Interval ______.____ ft blw LSD MSL

Notes/Calculations:
MP = 2.70 4 Rough estimate

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S/N 886

Century / Combo tool log

Tool serial number: **8143a**

WELL NAME: BH65

Date: 10-18-2012

NWIS 15-digit id: ____________

Operators: WSC/BAH

Location: ____________

watch time: 1704
computer time: 1705

Project: ____________

Geophysical log reference: measuring pt or land surface

Well information:

Describe measurement point (MP): Top of temporary Steel Casing

Depth of well: ~90 ft below land surface

Height of MP above land surface: 9 ft

Water level from MP ______ ft @ ______

Depth to bottom of casing: ~57 ft

Nominal diameter ______ inches steal PVC

Notes on well (water quality,need for PPE, or problem areas:

Tool length 7.50 ft

Top of tool zeroed to land surface: ☑ (check)

E-log mud-probe grounded: ☑ (check)

CLEANED CABLE ON UP ☐

90.0
7.5
82.5

81.63
7.50
89.13

Log Down

Start time of log: 1745

End time of log: 1757

Logging speed: ~5-8 ft/min

Log Up

Start time of log: 1759

End time of log: 1808

Logging speed: 5-10 ft/m

Depth Start: 0.00 TOP of TOOL

Depth Bottom: 89.13

Depth End: 81.63

Sampling rate: 0.10

Round trip error check of depth: 0.06 should be <2% of the total depth

Note any problems or points of interest:

USGS
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Century / Caliper log

SN:609 ✓
Tool serial number: **9065a** ✓

WELL NAME: BH65

Date: 10-18-2012

NWIS 15-digit id: ____________

Operators: WSC/BAH

Location: ____________

watch time: 1359
computer time: 1400

Project: ____________

Well information:

Describe measurement point (MP): Top of Temporary Steel Casing

Depth of well: ________ ft below MP

Well Tag info:

Height of MP above land surface: 7.5 ft

Water level from MP ________ ft @ ________

Depth to bottom of casing: ________ ft

Nominal diameter ________ inches

Notes on well (water quality, need for PPE, or problem areas:

Tool Length 5.13 ft

ZEROED TOLL ☑

Starting time of log: 1410

Depth Start: 34.12 ft

Top of tool

34.12
+ 5.13
39.25

Ending time of log: 1416

Depth End: 0.38 ft

Logging speed: ________

Depth Bottom: 39.25 ft

Logging direction: UP

Sampling rate:

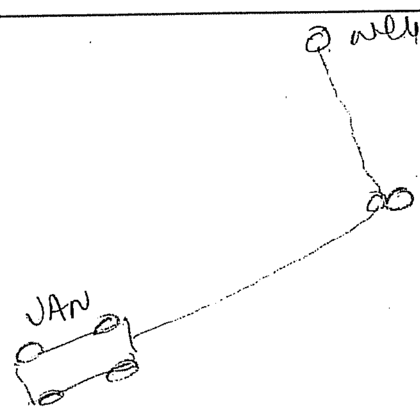
Round trip error check of depth: 0.38 ft should be <2% of the total depth due to slack in pully system

2-pt Calibration:

			NEW	PREVIOUS
Point 1:	6.31	inch	CPS:	CPS: 29194.7
Point 2:	8.625	inch	CPS:	CPS: 37821.8

Note any problems or points of interest:

When boring; No Rock but losing mud & sediment in core.



BH66DOWN20121016.
BH66UP20121016

USGS science for a changing world

Mount Sopris / ALT OTV log (OBI 40) Tool serial number: **5023 / 102611**

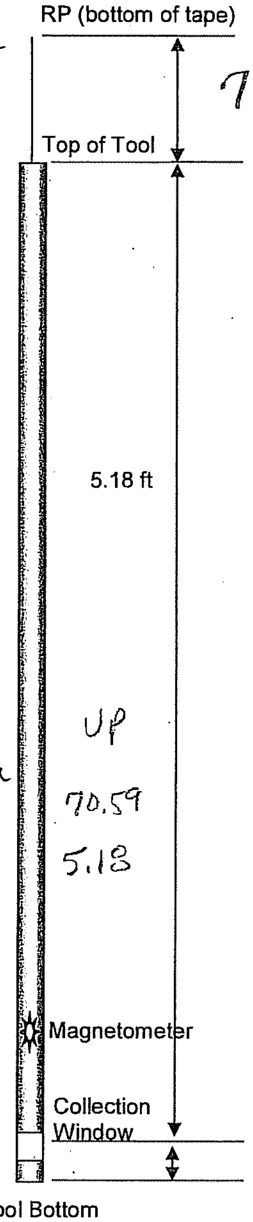
WELL NAME: BH66 Date: 10-16-2012

NWIS 15-digit id: ______ Operators: WSC/BAH

Location: ______

Project: ______

watch time: 0742
computer time: 0742



7 ft

UP
70.59
5.18

Well information:
Describe measurement point (MP): TOP of ~~Temp~~ temporary Steel CASING
Depth of well: 87 ~~ft below MP~~
Height of MP above land surface: 7 ft
Water level from MP 33.20 ft @ 0742
Depth to bottom of casing: 53 / 51.6 ft
Nominal diameter 6 inches / OTV Land surface

Notes on well (water quality,need for PPE, or problem areas:

Magnetometer/Inclinometer check:
Tilt check (~45°): ☑ OK Directional (N,S,E,&W) tilt check: ☑ OK
North check (placing object in front of camera window at north): ☑ OK

Top of tool zeroed to land surface: ☑ (check)

Starting time of log: ~0748 Depth Start: 5.18 ft AT camera

Ending time of log: 0808 Depth End: 70.59 ft

Logging speed: ~5 (<5 ft/min) Depth Bottom: 84.63 ft
Logging direction: UP DOWN

Sampling rate: 0.10

Round trip error check of depth: 0.0 ft should be <2% of the total depth

Note any problems or points of interest:

Checks:
1. Data sampling interval: 0.015 ft Pts/turn: 360 Light: 6 or 8
   in dark rocks choose a higher light intensity -- 8 -10.
2. Prior to actual data collection you can do the real-time mode data collection as a check.
   Be sure to record the depth before you start the time drive!!
3. Bottom of lower centralizer minimum of 20 inches from tool bottom
4. Note the version and build of MS log that was used and consider archiving a copy of the tol file

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Century / Caliper log

SN 609 ✓
Tool serial number: 9065a ✓

WELL NAME: BH66

Date: 10-15-2012

NWIS 15-digit id:

Operators: WSC / BAH

Location:

watch time: 1421

Project:

computer time: 2:21 pm

Well information:

Describe measurement point (MP): Top of temporary Steel Collar

Depth of well: 87 ft below MP

Height of MP above land surface: 7.00 ft

Water level from MP ~ 33.4 ft RISING ft @

Water Level from Tom

Depth to bottom of casing: 53 ft

Nominal diameter 6 inches steel

Notes on well (water quality,need for PPE, or problem areas:

TOOL 5.13 ft

Top of TOOL 79.50 + 5.13 = 84.63

Starting time of log: 1605

Depth Start: 79.50 ft

Ending time of log:

Depth End: 8 ft

Logging speed: ~ 9-10 ft/min

Depth Bottom: 84.63 ft

Logging direction: UP

Sampling rate: .10

Round trip error check of depth: 0

should be <2% of the total depth

Note any problems or points of interest:

Newly drilled

Lat N33° 52' 26.3"

LONG W-82° 17' 36.5"

404 245 8191

50

58 64

72.5

80

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science for a changing world

Mount Sopris / ALT OTV log (OBI 40)

Tool serial number:

WELL NAME: BH 66

Date: 10-15-2012

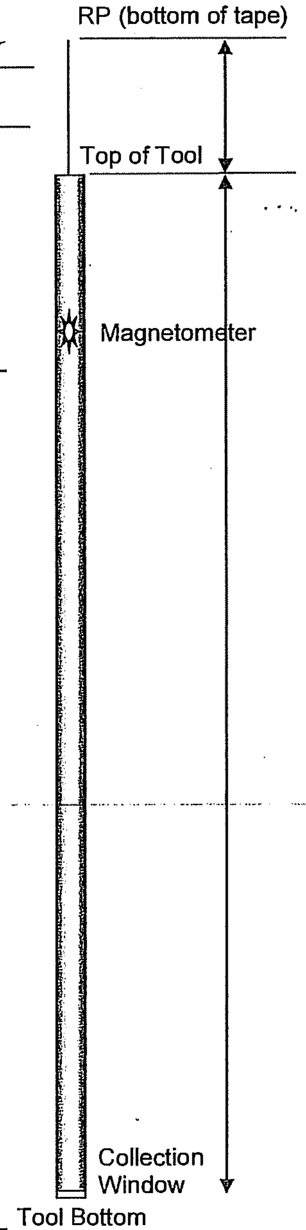
NWIS 15-digit id: ______

Operators: USC/BAH

Location: ______

watch time: 1650
computer time: 4:50 pm

Project: ______



Well information:

Describe measurement point (MP): TOP OF TEMPORARY STEEL CASING

Depth of well: 87 ft below ~~MP~~ LSD?

Height of MP above land surface: 7.0 ft

Water level from MP 33.2 ft @ 0742

Depth to bottom of casing: ______ ft

Nominal diameter 6 inches

Notes on well (water quality, need for PPE, or problem areas:

Magnetometer/Inclinometer check:

Tilt check (~45°): ☐ OK Directional (N,S,E,&W) tilt check: ☐ OK

North check (placing object in front of camera window at north): ☐ OK

TESTED ON 10/16/12 + ALL PASSED

Top of tool zeroed to land surface: ☐ (check) Camera

Starting time of log: ? / 1654 Depth Start: 5.18 ft

Ending time of log: 1654 / 1703 Depth End: 81.47 ft

Logging speed: ______ (<8 ft/min) Depth Bottom: 84.63 ft

Logging direction: ______

Round trip error check of depth: 0.07 ft should be <2% of the total depth

Note any problems or points of interest:

TWO LOGS

FIRST LOG FROM LAND SURFACE TO 32 feet

– STOPPED + TURNED LIGHT INTENSITY UP

SECOND LOG FROM 32 feet to 81.47 feet

VERY MURKY

USGS
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Century / Combo tool log

Tool serial number: **8043a**

WELL NAME: BH 66

Date: 10-15-2012

NWIS 15-digit id: ____________

Operators: BA Hessman / WS Caldwell

Location: Barre Hall

watch time: ________
computer time: ________

Project: ____________

Well information:
Describe measurement point (MP): TOP OF TEMPORARY STEEL CASING
Depth of well: 87 ft below MP
Height of MP above land surface: 7.0 ft
Water level from MP ~33.49 (RISING) ft @ ________
Depth to bottom of casing: 53 ft
Nominal diameter 6 inches

Notes on well (water quality,need for PPE, or problem areas:

Top of tool zeroed to land surface: ☑ (check)

Log Down	**Log Up**
Start time of log: 1614	Start time of log: 1629
End time of log: \	End time of log: ________
Logging speed: ~10 ft/min	Logging speed: ~10 ft/min

Depth Start: ________	Depth Bottom: ________
Depth End: ________	Sampling rate: ________

Round trip error check of depth: oK should be <2% of the total depth

Note any problems or points of interest:

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S/N 886 ✓

Century / Combo tool log

Tool serial number: **8143a** ✓

WELL NAME: BH67

Date: 10-17-12

NWIS 15-digit id: ____

Operators: WSC/BAH

Location: ____

watch time: 1159

Project: ____

computer time: 1159

Geophysical log reference: measuring pt or land surface

Well information:

Describe measurement point (MP): TOP of steel temporary Casing

Depth of well: 147 ft below land surface

Height of MP above land surface: 6 ft

Water level from MP 29.10 ft @ 1118

Depth to bottom of casing: ~37 ft

Nominal diameter 6 inches steel PVC

Notes on well (water quality, need for PPE, or problem areas:

Tool length 7.50 ft

Top of tool zeroed to land surface: ☑ (check)

E-log mud-probe grounded: ☑ (check)

CLEANED CABLE ON UP ☑

145.00
7.5
137.5

136.11
7.50
143.61

Log Down

Start time of log: 1150

End time of log: 1204

Logging speed: ~14-15 ft/min

Depth Start: 0.00 TOP OF TOOL

Depth End: 136.11

Bottom Tool
7.50
143.61

Log Up

Start time of log: 1205

End time of log: 1216

Logging speed: ~14 ft/min

Depth Bottom: 145.76

Sampling rate: 0.10

Round trip error check of depth: 0.12 ft should be <2% of the total depth

Note any problems or points of interest:

Slowed tool when in water → casing ~37 ft to stabilize temp.

HCN 0 PPm @ 1208

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Mount Sopris / ALT ~~OTV~~ ATV log (~~OBI~~ ABI 40)

Tool serial number: ~~5023 / 102611~~

WELL NAME: BH67

Date: 10 - ~~16~~ 17 -12

NWIS 15-digit id:

Operators: WSC/BAH

Location:

watch time:

Project:

computer time:

RP (bottom of tape)

6ft

Top of Tool

5.09

~~5.18~~ ft

Magnetometer

Collection Window

Tool Bottom

Well information:

Describe measurement point (MP): TOP of Steel temporary Casing

Depth of well: 147 ft below MP

Height of MP above land surface: 6 ft

Water level from MP 29.10 ft @ 1118

Depth to bottom of casing: 37 ft

Nominal diameter 6 inches Steel

Notes on well (water quality,need for PPE, or problem areas:

Magnetometer/Inclinometer check:

Tilt check (~45°): ☑ OK Directional (N,S,E,&W) tilt check: ☑ OK

North check (placing object in front of camera window at north): ☐ OK CAN'T SEE

Top of tool zeroed to land surface: ☑ (check)

Starting time of log:

Depth Start: 17.94 ft

Ending time of log: 1311

Depth End: 140.59 ft

Logging speed: ~3.5 (<5 ft/min)

Depth Bottom: 145.76 ft

Logging direction: ~~UP~~ Down

Sampling rate: .01

Round trip error check of depth: 0.01

should be <2% of the total depth

Note any problems or points of interest:

- RESTARTED LOG @ 17.94 ft
- possible high angle fracture ~92'-110'
- fracture @ 131-132 that did not show on caliper
  → ZONE from 131-134

5.09 ft to sensor

Checks:

1. Data sampling interval: 0.015 ft Pts/turn: 360 Light: 6 or 8
   in dark rocks choose a higher light intensity -- 8 -10.
2. Prior to actual data collection you can do the real-time mode data collection as a check.
   Be sure to record the depth before you start the time drive!!
3. Bottom of lower centralizer minimum of 20 inches from tool bottom
4. Note the version and build of MS log that was used and consider archiving a copy of the tol file

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SN:609 ✓

Century / Caliper log

Tool serial number: **9065a** ✓

WELL NAME: BH67

Date: 10-~~16~~ 17-12

NWIS 15-digit id:

Operators: INSC/BAH

Location: New well this day

watch time: ~~1443~~ 1107

computer time: ~~2:44 pm~~ 1107

Project:

Well information:

Describe measurement point (MP): Top of Steel temporary Casing

Depth of well: 147 ft below MP

Well Tag info: New

Height of MP above land surface: 6 ft

Water level from MP 29.10 ft @ 1118

Depth to bottom of casing: ~37 ft

Nominal diameter 6 inches

Notes on well (water quality,need for PPE, or problem areas:

Tool Length 5.13 ft

ZEROED TOLL ☑

~147
~152

140.63
5.13
145.76

Starting time of log: 1128

Depth Start: 140.63 ft

Ending time of log: 1144

Depth End: -.03 ft

Logging speed: ~10 ft/min

Depth Bottom: 145.76 ft

Logging direction: UP

Sampling rate: 0.10

Round trip error check of depth: -.03 should be <2% of the total depth

2-pt Calibration:

		NEW	PREVIOUS
Point 1:	6.31 inch	CPS: 29194.7	CPS: 31558.5
Point 2:	8.625 inch	CPS: 37821.8	CPS: 40157.801

Note any problems or points of interest:

Just drilled, water in well is artificial due to drilling

~23 false Reading

37-51 w/ breakouts & Rough

✓ 38 breakout 7.1"

✓ ~~x~~50 breakout 7.9"

63 Minor 6.3"

✓ 85-~~x~~87 breakout 6.7" and 6.5"

95-105 Rough zone

110 ~6.2"

✓ 128 ~6.2"

N 33° 52′ 21.5″ 33.87263

W 082° 17′ 53.4 -82.29817

Appendix 2. Downhole Camera Well Inspection Logging Notes

Table 2–1. Downhole camera well inspection logging notes.

Well BH33		Well BH34		Well BH49	
Depth below land surface, in feet	Remarks	Depth below land surface, in feet	Remarks	Depth below land surface, in feet	Remarks
6.1	Casing joint	6.6	Casing joint	0.9	Surface casing joint
20.6	Casing joint	16.6	Casing joint	10.9	Casing joint
30.6	Casing joint	26.6	Casing joint	20.9	Casing joint
40.6	Casing joint	36.6	Casing joint	30.9	Casing joint
41.1	Water surface	41.1	Water surface	40.9	Casing joint
50.6	Casing joint	41.6	Casing joint	48.4	Water surface
60.6	Casing joint	46.6	Casing joint	50.9	Casing joint
70.6	Casing joint	56.6	Casing joint	60.9	Screen starts
80.6	Casing joint	66.6	Casing joint	65.9	Joint
90.6	Casing joint	76.6	Casing joint	69.9	Bottom (sediment)
100.6	Casing joint	86.6	Casing joint		
110.6	Casing joint	95.6	Casing pinched[1]		
120.6	Casing joint				
130.6	Casing joint				
140.6	Casing joint				
150.6	Screen starts				
160.6	Bottom (sediment)				

Table 2–1. Downhole camera well inspection logging notes.—Continued

Well BH50		Well BH51	
Depth below land surface, in feet	**Remarks**	**Depth below land surface, in feet**	**Remarks**
3.2	Casing joint	3.3	Casing joint
12.7	Casing joint	12.8	Casing joint
22.7	Casing joint	22.8	Casing joint
32.7	Casing joint	32.8	Casing joint
42.7	Casing joint	42.8	Casing joint
48.5	Water surface	47.4	Water surface
52.7	Casing joint	62.8	Casing joint
62.7	Casing joint	72.8	Casing joint
72.7	Casing joint	82.8	Casing joint
82.7	Casing joint	82.8	Casing joint
92.7	Casing joint	92.8	Casing joint
102.7	Casing joint	102.8	Casing joint
112.7	Casing joint	112.8	Casing joint
122.7	Casing joint	122.8	Casing joint
131.7	Casing stained orange below 131 feet	132.8	Casing joint
132.7	Screen starts	142.8	Casing joint
141.7	Screen ends	152.8	Casing joint
142.2	Bottom (sediment)	162.8	Casing joint
		165.8	Water blurry (cloudy) below 165 feet
		172.8	Casing joint
		182.8	Casing joint; distinct color change
		191.8	Distinct color change
		192.0	Bottom (sediment)[1]

[1]Screened interval was not observed.

Appendix 3. Water-Quality Results of Borehole-Tool Rinse-Water Samples

Table 3–1. Water-quality results of borehole-tool rinse-water samples, U.S. Environmental Protection Agency (EPA) Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina, October–November 2012.

[Notes: All samples were unfiltered. Station numbers are database quality-assurance identifiers not associated with a geographic location. mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; na, not analyzed]

Sample type	Station number	Sample date	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Silica (mg/L)	Aluminum (µg/L)
USGS tool rinse	10100023	10/9/2012	0.187	0.185	<0.06	0.128	1.59	212
USGS tool rinse	10100023	10/11/2012	0.339	0.0671	0.196	0.151	0.332	76.9
USGS tool rinse	10100023	11/5/2012	0.271	0.0431	0.074	0.119	0.347	110
USGS tool rinse[1]	10100023	11/5/2012	<0.021	<0.007	<0.06	<0.015	<0.018	<50
Reporting limit			0.021	0.007	0.06	0.015	0.018	50
Blank value			<0.021	<0.0070	<0.060	<0.0150	0.018	<50.0
EPA groundwater sample range for wells logged as part of this study[2]		12/2012	<0.25–390	<0.25–93	3.4–120	<1.0–12	na	<100–150,000
Reporting limit			0.25	0.25	1.0	1.0	na	100

Sample type	Station number	Sample date	Arsenic (µg/L)	Barium (µg/L)	Berryllium (µg/L)	Boron (µg/L)	Cadmium (µg/L)	Chromium (µg/L)
USGS tool rinse	10100023	10/9/2012	3.64	<0.19	32.3	<0.4	1.99	8.65
USGS tool rinse	10100023	10/11/2012	3.16	<0.19	33.6	<0.4	1.29	4.28
USGS tool rinse	10100023	11/5/2012	<0.3	<0.19	31.2	<0.4	3.01	6.98
USGS tool rinse[1]	10100023	11/5/2012	<0.3	<0.19	31.8	<0.4	<0.6	<1.4
Reporting limit			0.3	0.19	2.4	0.4	0.6	1.4
Blank value			<0.300	<0.190	<2.40	<0.400	<0.600	<1.40
EPA groundwater sample range for wells logged as part of this study[2]		12/2012	<5.0–140	<0.5–<2.5	na	<0.5–1,400	<5.0–52	<10–92,000
Reporting limit			5.0	0.5, 2.5	na	0.5	5.0	10

Sample type	Station number	Sample date	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Lithium (µg/L)	Manganese (µg/L)	Thallium (µg/L)
USGS tool rinse	10100023	10/9/2012	8.65	4,060	3.75	0.513	17.4	<0.06
USGS tool rinse	10100023	10/11/2012	4.28	150	149	0.232	2.92	<0.06
USGS tool rinse	10100023	11/5/2012	6.98	<4.6	7.09	0.241	14.4	<0.06
USGS tool rinse[1]	10100023	11/5/2012	<1.4	<4.6	<0.04	<0.04	<0.2	<0.06
Reporting limit			1.4	4.6	0.04	0.04	0.2	0.06
Blank value			<1.40	<4.60	<0.040	<0.040	<0.200	<0.060
EPA groundwater sample range for wells logged as part of this study[2]		12/2012	<10–92,000	<100–1,100,000	<1.0–24	na	<5.0–15,000	<1.0
Reporting limit			10	100	1.0	na	5.0	1.0

Sample type	Station number	Sample date	Molybdenum (µg/L)	Nickel (µg/L)	Silver (µg/L)	Strontium (µg/L)	Vanadium (µg/L)	Zinc (µg/L)
USGS tool rinse	10100023	10/9/2012	<1.4	2.51	<0.6	0.804	<0.6	28.2
USGS tool rinse	10100023	10/11/2012	<1.4	<1.1	<0.6	1.6	<0.6	42.1
USGS tool rinse	10100023	11/5/2012	<1.4	4.91	<0.6	0.938	<0.6	21.5
USGS tool rinse[1]	10100023	11/5/2012	<1.4	<1.1	<0.6	<0.18	<0.6	<2.0
Reporting limit			1.4	1.1	0.6	0.18	0.6	2
Blank value			<1.40	<1.10	<0.600	<0.180	<0.600	<2.00
EPA groundwater sample range for wells logged as part of this study[2]		12/2012	na	<10–590	<0.5–<5.0	na	<5.0–91	<10–37,000
Reporting limit			na	10	0.5, 2.5, 5.0	na	5	10

[1]Bottle field blank.

[2]Results from December 2012 sampling. Well IR-1 not sampled (U.S. Environmental Protection Agency, Region 4, Science and Ecosystem Division, 2013).

Appendix 4. Borehole Geophysical Logs and Water-Quality Profiles

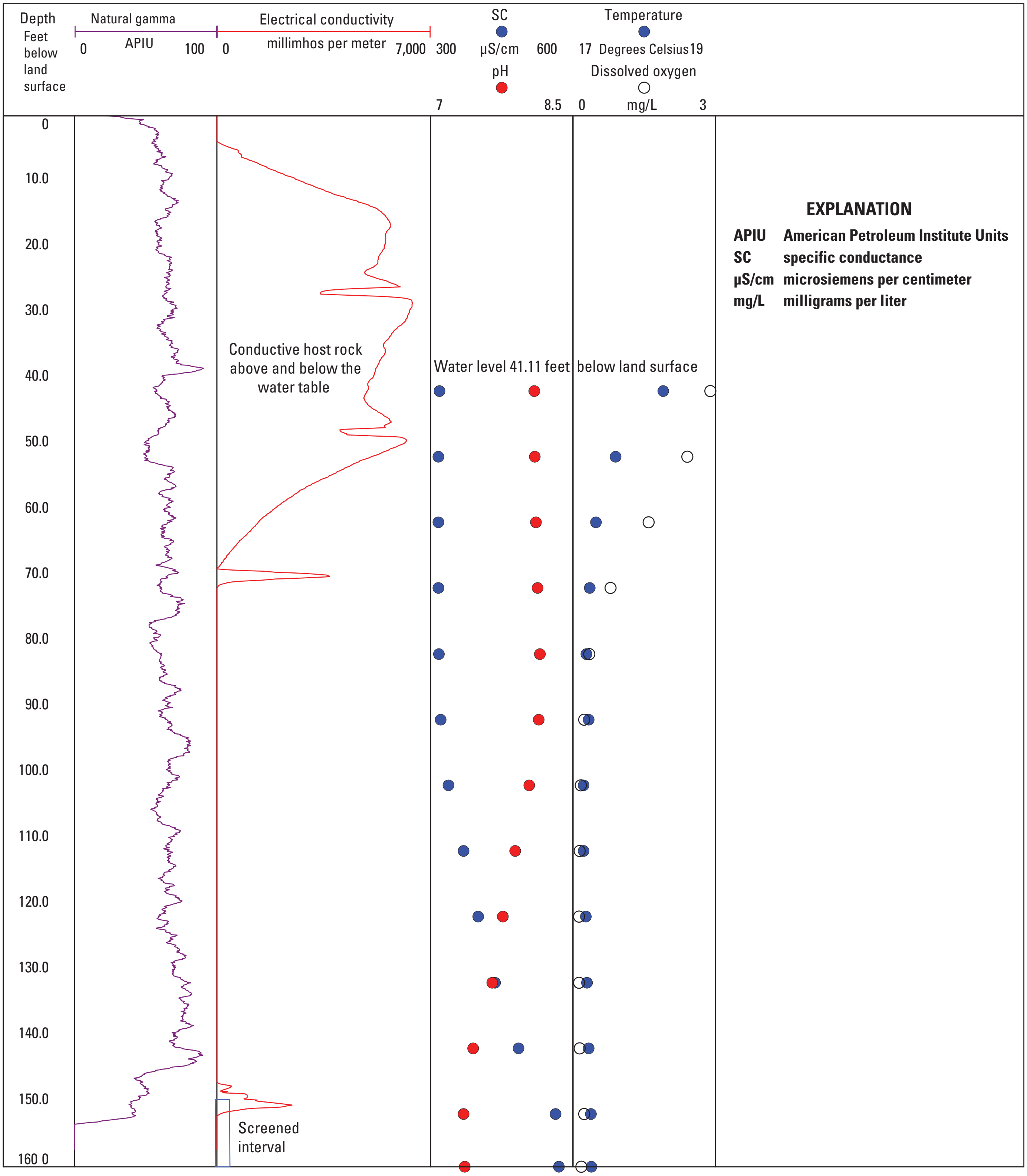

Figure 4–1. Borehole geophysical logs and water-quality profile in regolith well BH33, October 2012, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

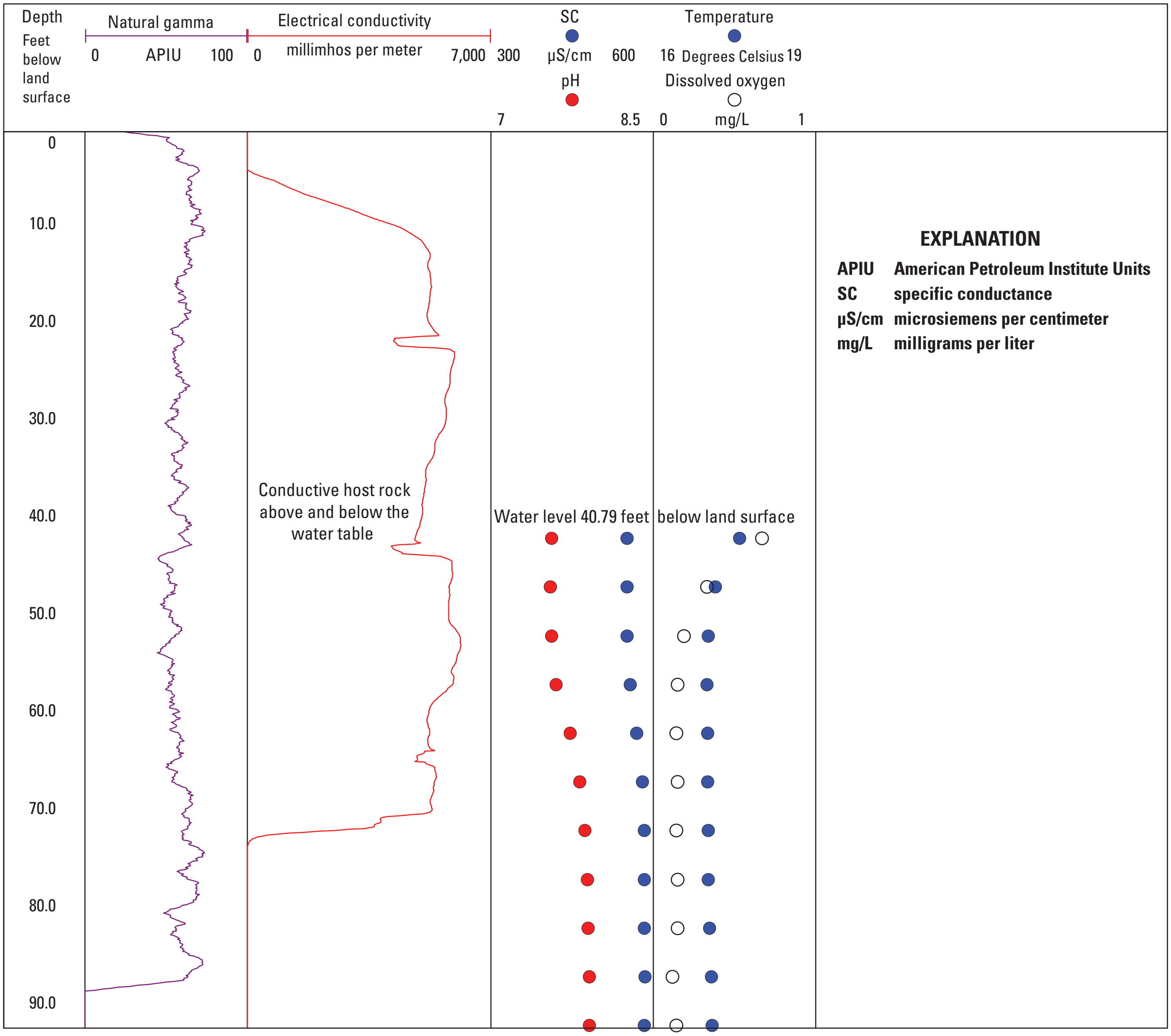

Figure 4–2. Borehole geophysical logs and water-quality profile in regolith well BH34, October 2012, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

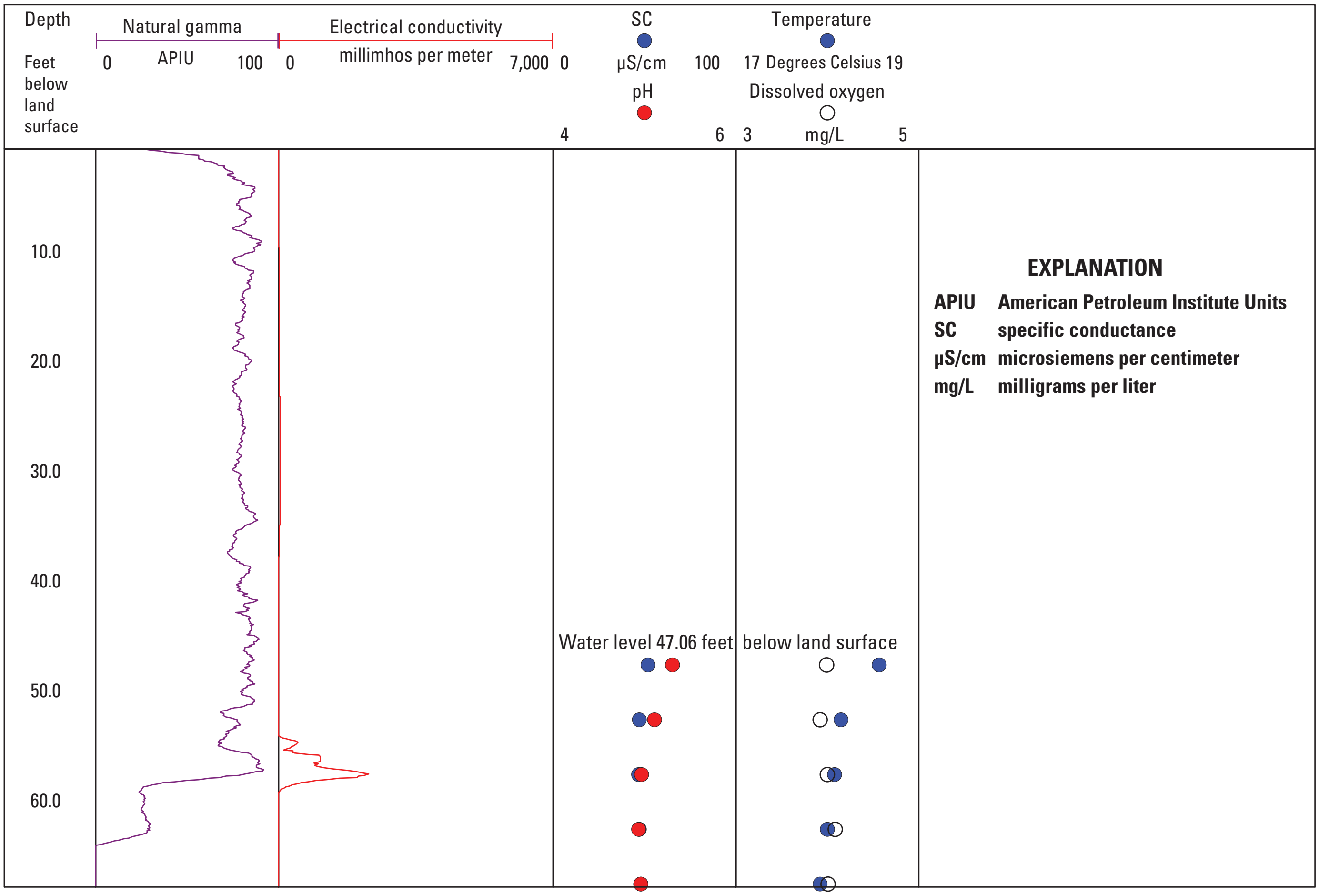

Figure 4–3. Borehole geophysical logs and water-quality profile in regolith well BH49, October 2012, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

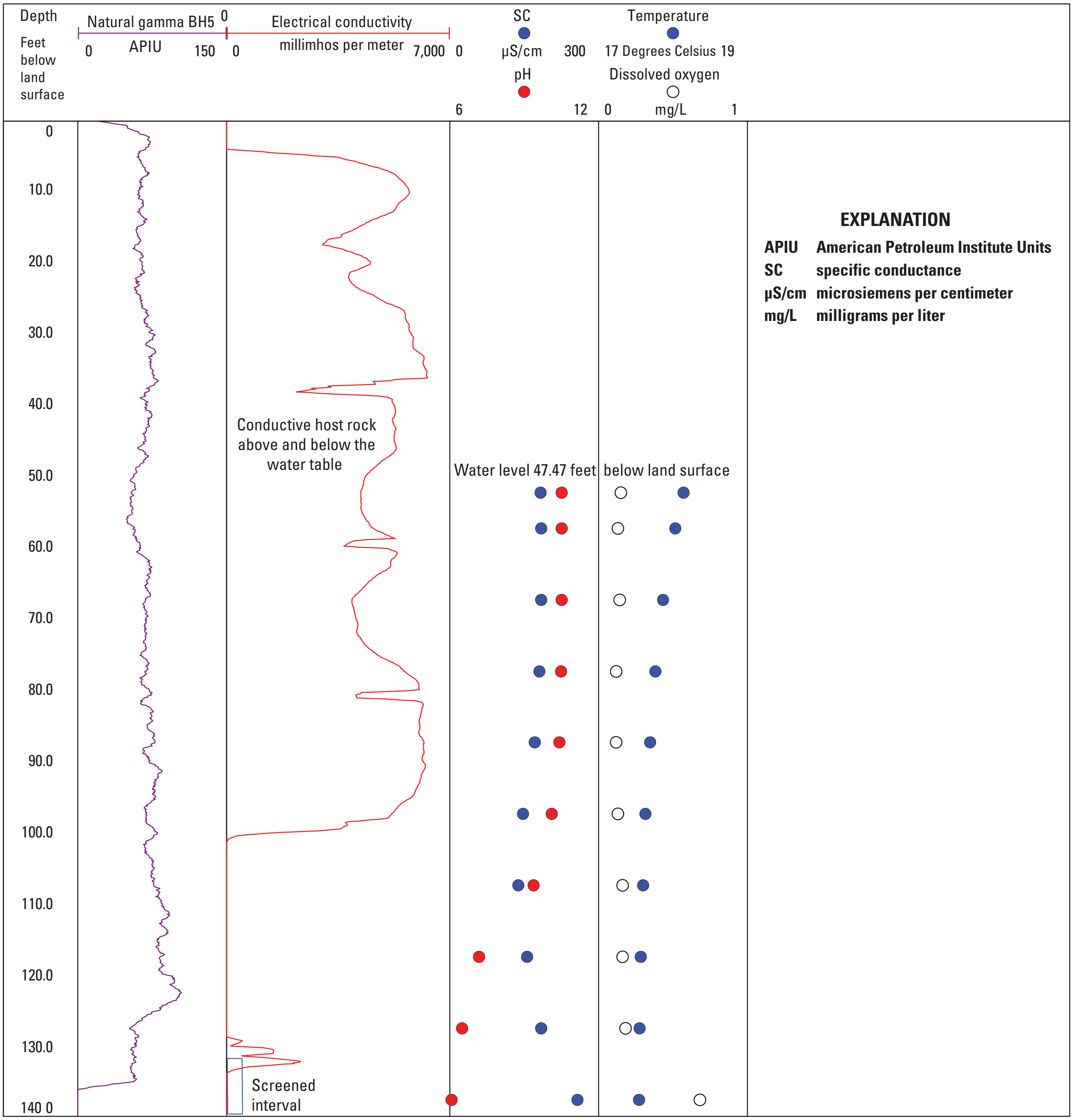

Figure 4–4. Borehole geophysical logs and water-quality profile in regolith well BH50, October 2012, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

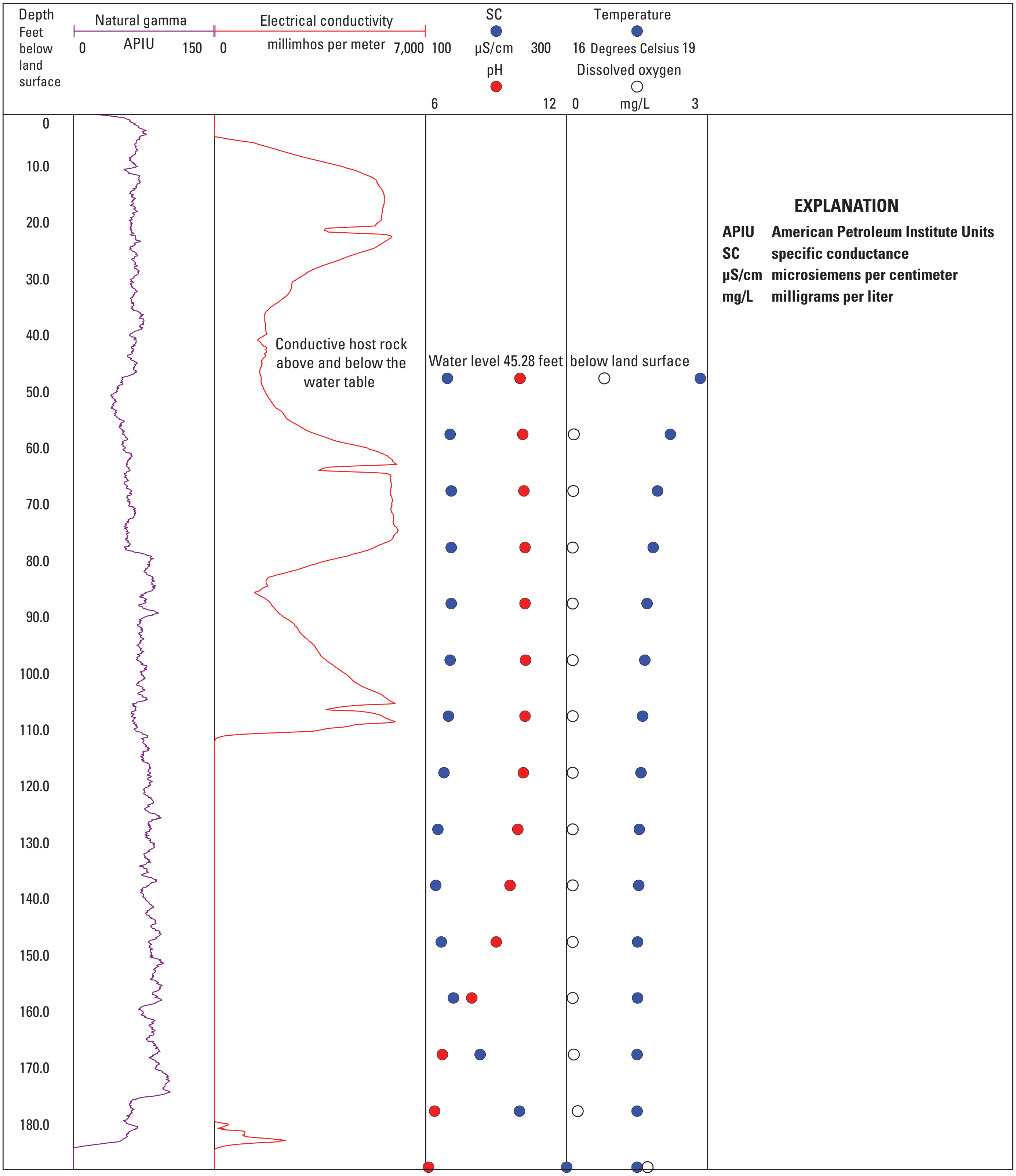

Figure 4–5. Borehole geophysical logs and water-quality profile in regolith well BH51, October 2012, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

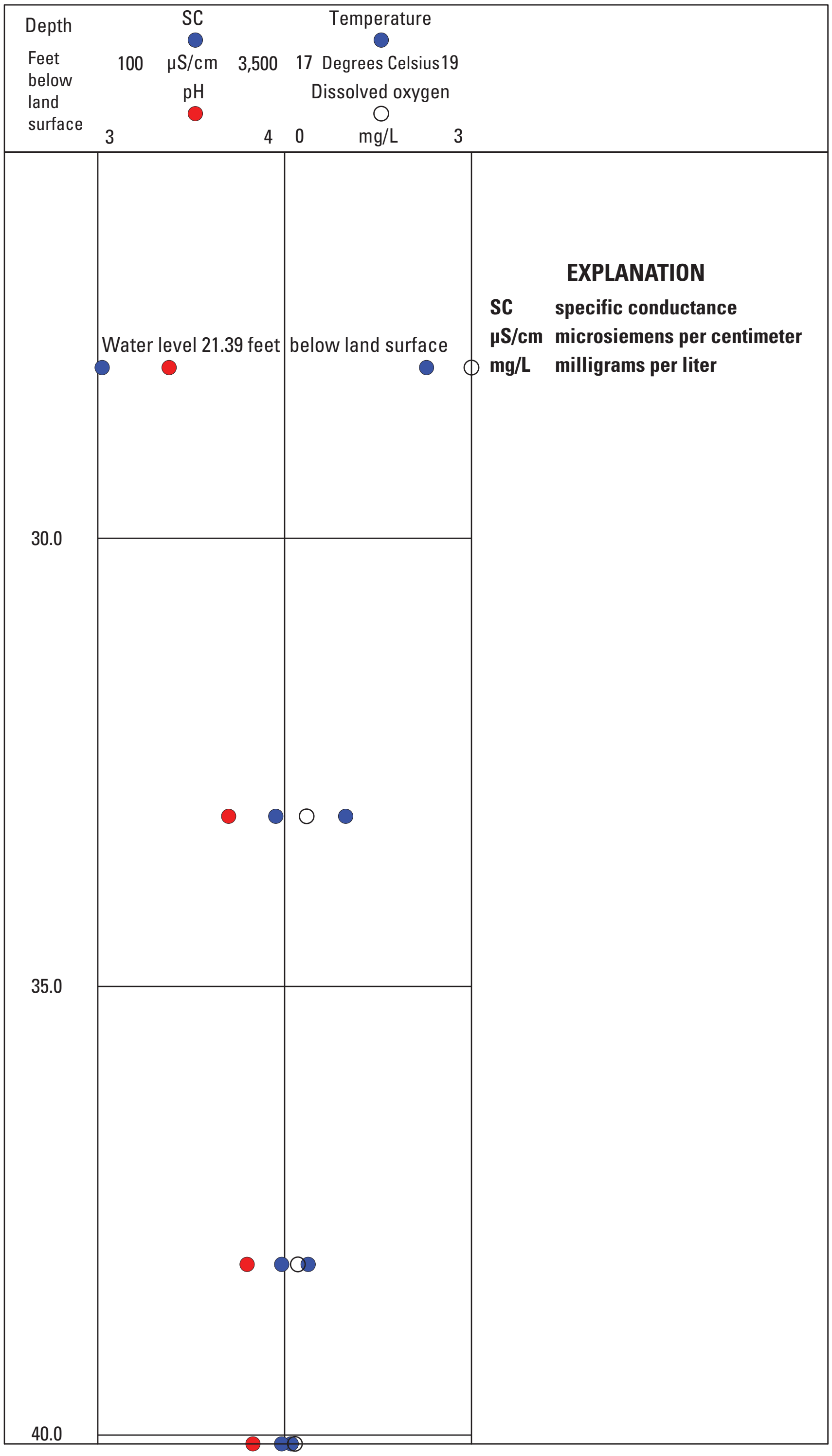

Figure 4–6. Groundwater-quality profile in regolith well BH55, October 2012, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

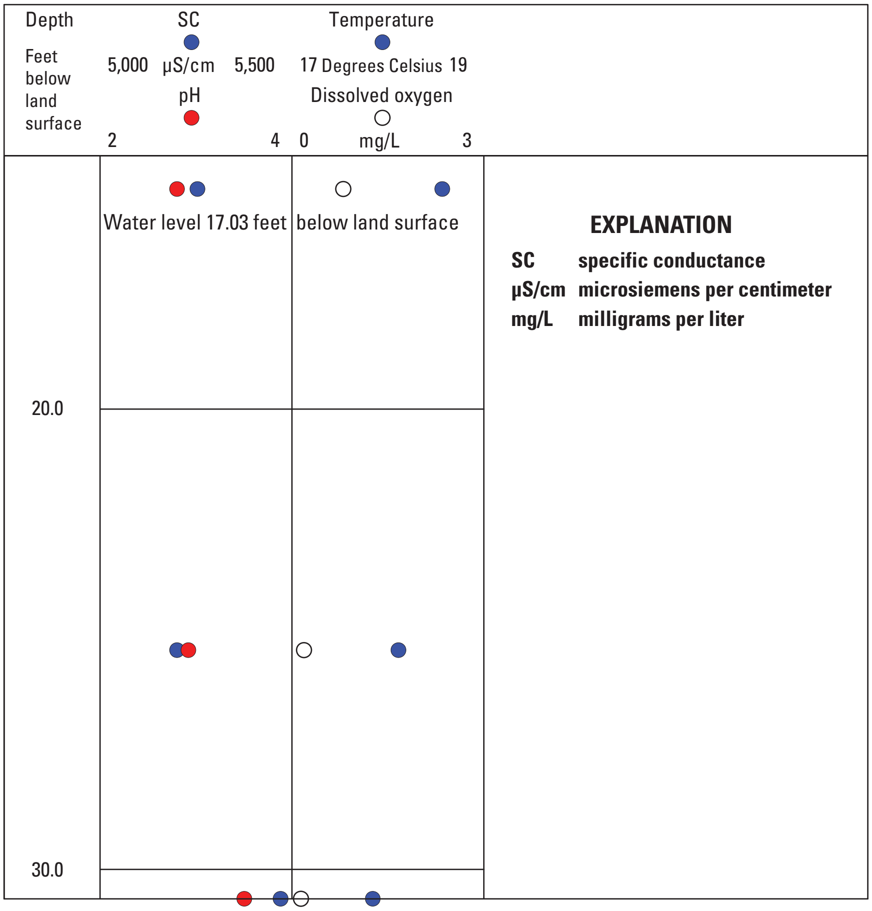

Figure 4–7. Groundwater-quality profile in regolith well BH56, October 2012, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

Appendix 5. Borehole Geophysical Logs Showing Depth of Fracture Zones and Structural Feature Orientation

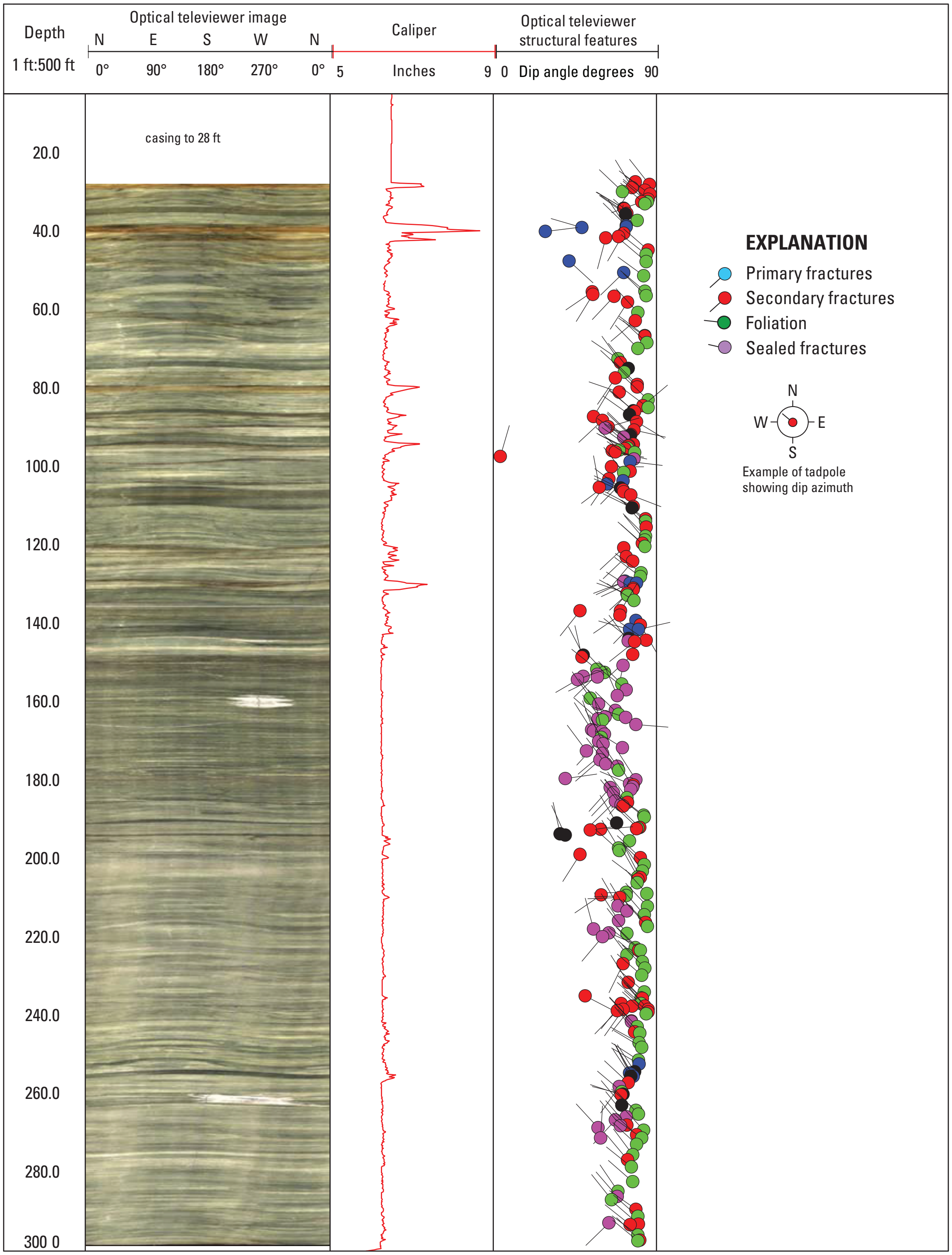

Figure 5–1. Borehole geophysical logs showing depth of fracture zones and structural feature orientation in bedrock well IR-1, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

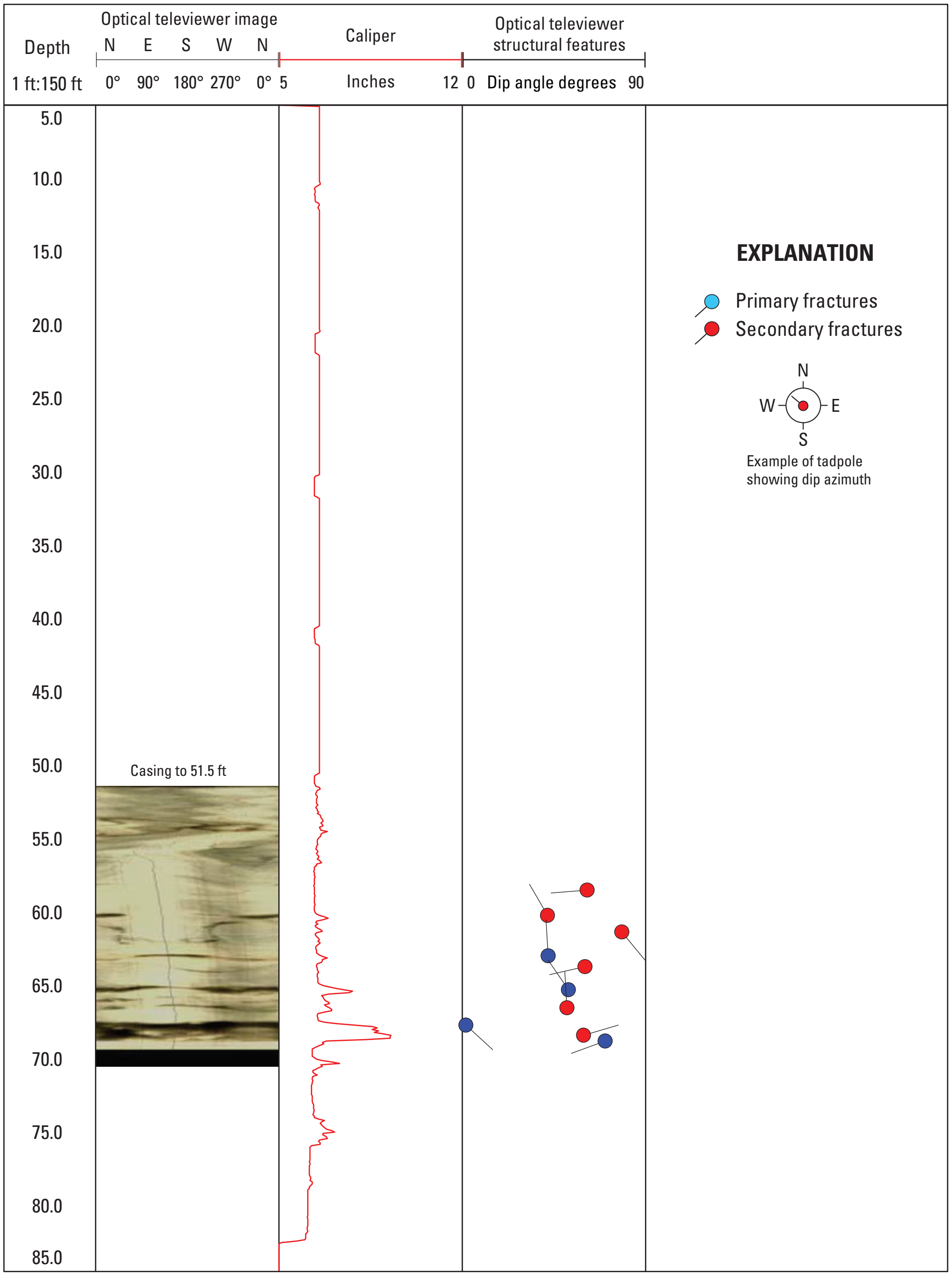

Figure 5–2. Borehole geophysical logs showing depth of fracture zones and structural feature orientation in bedrock well BH66, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

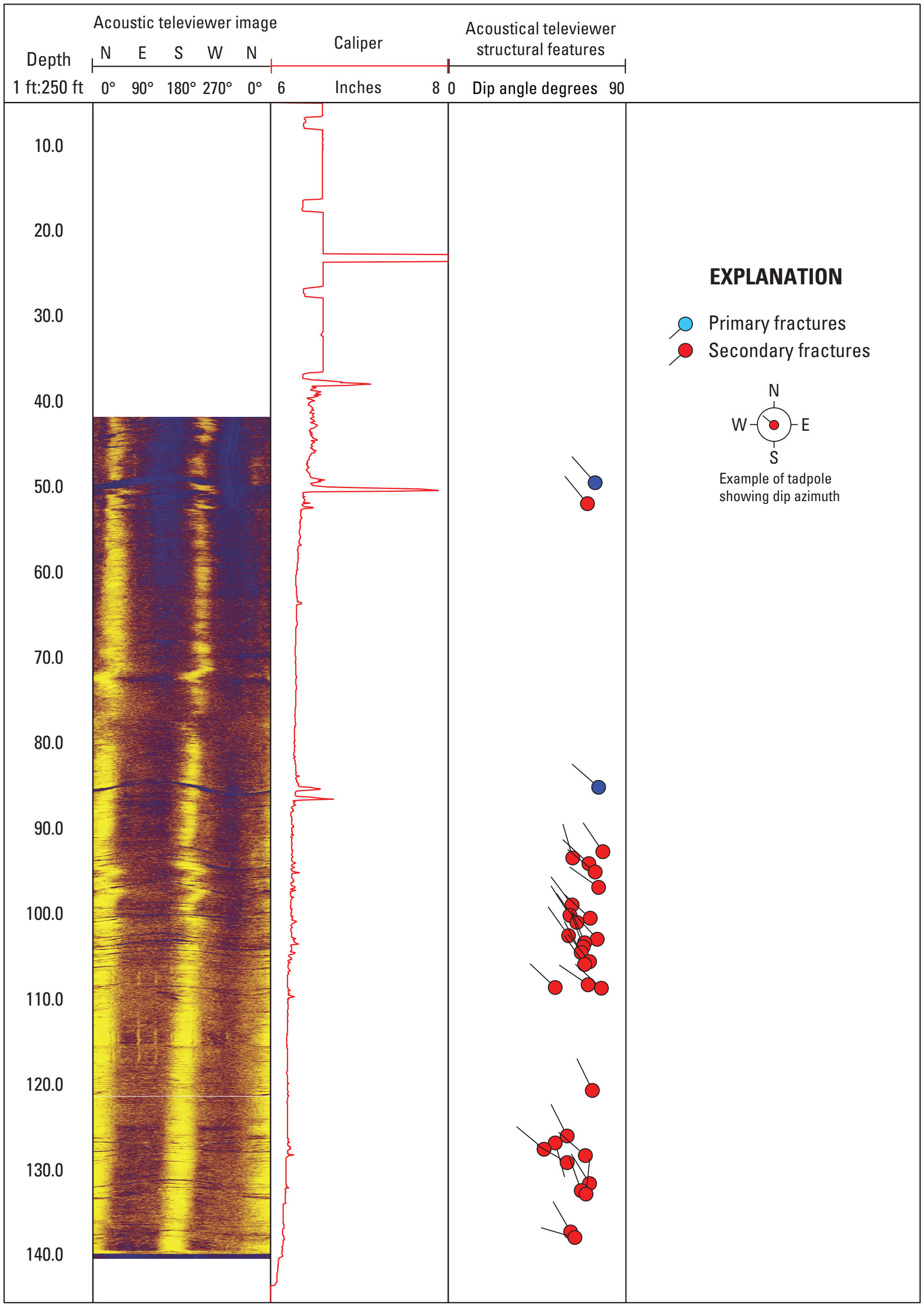

Figure 5–3. Borehole geophysical logs showing depth of fracture zones and structural feature orientation in bedrock well BH67, U.S. Environmental Protection Agency Barite Hill/Nevada Goldfields Superfund site near McCormick, South Carolina.

Appendix 6. Flow-Log Analysis of Single Holes Model of Bedrock Well IR-1 Heat-Pulse Flowmeter Logs

FLASH (Flow-Log Analysis of Single Holes)

by F.D. Day-Lewis, C.D. Johnson, F.L. Paillet, and K.J. Halford

Contact Info:

http://water.usgs.gov/ogw/bgas

Last updated: 04/09/2010

This program was designed to run in Excel- Microsoft Office 2007.

Summary

FLASH (Flow-Log Analysis of Single Holes) is a spreadsheet-based graphical user interface (GUI) for a multi-layer Thiem solution for steady-state flow to a borehole. The software allows for analysis of data from boreholes in which step increases in flow (from discrete fractures or zones) or linear increases in flow (over multiple aquifer layers) are observed. Data are entered in the worksheet “FIELD DATA.” Interpretations of ambient and stressed flow are enetered along with physical parameters and water-level measurements on the “INPUTS” sheet. Visual Basic for Applications (VBA) routines provide an interface to the Excel Solver, which can be used for model calibration.

This spreadsheet uses a multi-layer Thiem analytical model to generate a borehole flow log representing the flow that would be measured in a borehole with a specified number of aquifers for a given set of values for the water levels in each of the aquifers, and the difference between the open-hole water level under static and steady pumping (or injection) conditions. The program is used in a forward modeling mode (that is, trial and error) until a satisfactory match between measured and computed flow is achieved for a given set of input parameters. In the GUI, the input parameters, which generally include transmissivity and head, can be changed; the simulated flow profiles are updated automatically. The GUI also supports use of the Excel Solver for automated calibration.

Installation

Use the spreadsheet available online at http://water.usgs.gov/ogw/flash/ (accessed July 2015). You may need to reset macro security to include the location of this file as a “trusted site.” Go to “Excel Options” under the “Office Button.” Also, it may be necessary to install the Solver add-in. The spreadsheet is designed for use in Excel 2007 or later.

Input

1. Data points may be entered in columns of the worksheet “FIELD DATA;” however, the program may be run without entering measurements. You can either type the values for depth and flow rate, or you can open the output file from the flowmeter collection program in Excel and copy the appropriate data fields into the “FIELD DATA” worksheet. Remember, by convention, downflow is shown as negative, and upflow is positive. Be sure to make all corrections to flow data including normalization of pumping flow, if necessary.
2. The user’s interpretation of the field data (for example, fracture depths, flow rates) is entered on the worksheet “INPUTS.” Avoid interpreting all variations in flowmeter measurements; rather fit an interpretation to the scatter in the data. Consider borehole diameter and data quality. The code allows for up to 10 flow zones (aquifer layers or fractures).
3. Model calibration parameters (Zone Tfactor and Zone H) are adjusted manually to improve the fit to the data.
4. As an alternative to manual calibration, the Excel Solver may be used to estimate the model parameters that result in the best match to the data, in a least-squares sense.

Output

The simulated log is plotted automatically on the same graphs as the interpreted logs and the measured point data. The input and output data, measured and modeled flow profiles, and additional supporting data or documentation can be stored in the spreadsheet. The Excel file can be “saved as” a new filename. It can be reopened (like any normal Excel file), and provided you enable the macros upon opening, the model can be revised.

Model Parameters

Be careful to use inch/pound parameters -- feet, inches, gallons per minute.

Elevation of measuring point - elevation used for calculation of water levels based on drawdown and depths entered below, in feet.

Number of flow zones - number of transmissive zones (layers or fractures) up to a maximum of 10.

Well diameter - diameter of well in the interval over which drawdown occurs, in inches.

Drawdown - the distance between the ambient and the quasi-steady state water level measured under stressed (pumping or injection conditions), in feet.

Depth to ambient water level - depth from measurement point to water level in well in absence of stress, in feet.

Depth at bottom of casing - depth at which the well is open to the formation, in feet. The hydraulic solution will be plotted from this depth down to the depth at the bottom of the well.

Depth at bottom of well - depth at the bottom of the well, in feet. The hydraulic solution will be plotted to this depth.

Radius of influence - the radial distance from the well at which all transmissive zones remain at equilibrium condition, in feet.

Total transmissivity - the transmissivity based on an open-hole pump test, used for a starting value, in feet squared per day (ft^2/d).

Fracture or layer information - For each zone the following is specified: depth, in feet, below the reference point. Fractures are numbered automatically; fractures are numbered from bottom to top:

- **Ambient flow above** - the flow in the well above the given zone, with upward flow positive, in gallon per minute (gal/min).
- **Pumped flow above** - the flow in the well above the given zone, under stressed conditions, with upward flow positive, in gpm (or injected flow rate in the case of an injection test).
- **Tfactor** - the proportion of the given zone's transmissivity to the total transmissivity of the well; that is, if the estimate is 4 ft^2/d, you would enter a 0.04 zone's Tfactor for a total transmissivity of 100 ft^2/d, and for a total transmissivity of 40 ft^2/d, you would enter 0.10 for the Tfactor; in decimal fraction of total, dimensionless.
- **Dh** - an estimate of the head for the zone relative to ambient water level, in feet.
- **Farfield head** - the head of the given zone at large distance from the well, in feet. Note that this is calculated and not entered directly by the user.

ABS(Dh) maximum - inversion constraint on the maximum absolute difference between the head of any zone and the water level in the well, in feet.

Regularization weight - weight applied to the regularization term in the inversion when "Solve with Regularization" is specified, dimensionless. Note, regularization is useful in cases where the inversion converges to unrealistic head or transmissivity values, but giving too much weight to the regularization term will degrade the match to the data.

Tfactor minimum - inversion constraint on the minimum TFactor; this is useful in cases where the inversion converges to unrealistically small transmissivity values for certain zones.

Simulation Output

MSE - Mean squared error, in square gallons per minute ($[gal/min]^2$); this quantifies the misfit between the interpreted and simulated flows.

Ambient WL - Calculated water level for ambient conditions subtracted from the elevation of the reference point, in feet.

Pumped WL - Calculated water level for stressed conditions subtracted from the elevation of the reference point, in feet.

Sum Tfactor - Sum of the TFactor estimates, dimensionless. If this value is 1.0, then the total transmissivity in cell D13 is honored.

Estimated Ttotal - The total transmissivity estimated for the well, in ft^2/d.

Sum Dh^2 - The sum of squared differences between simulated and interpreted heads.

Regularized misfit - The combined, weighted misfit for regularized inversion, equal to the MSE plus the regularization weight multiplied by the Sum Dh^2.

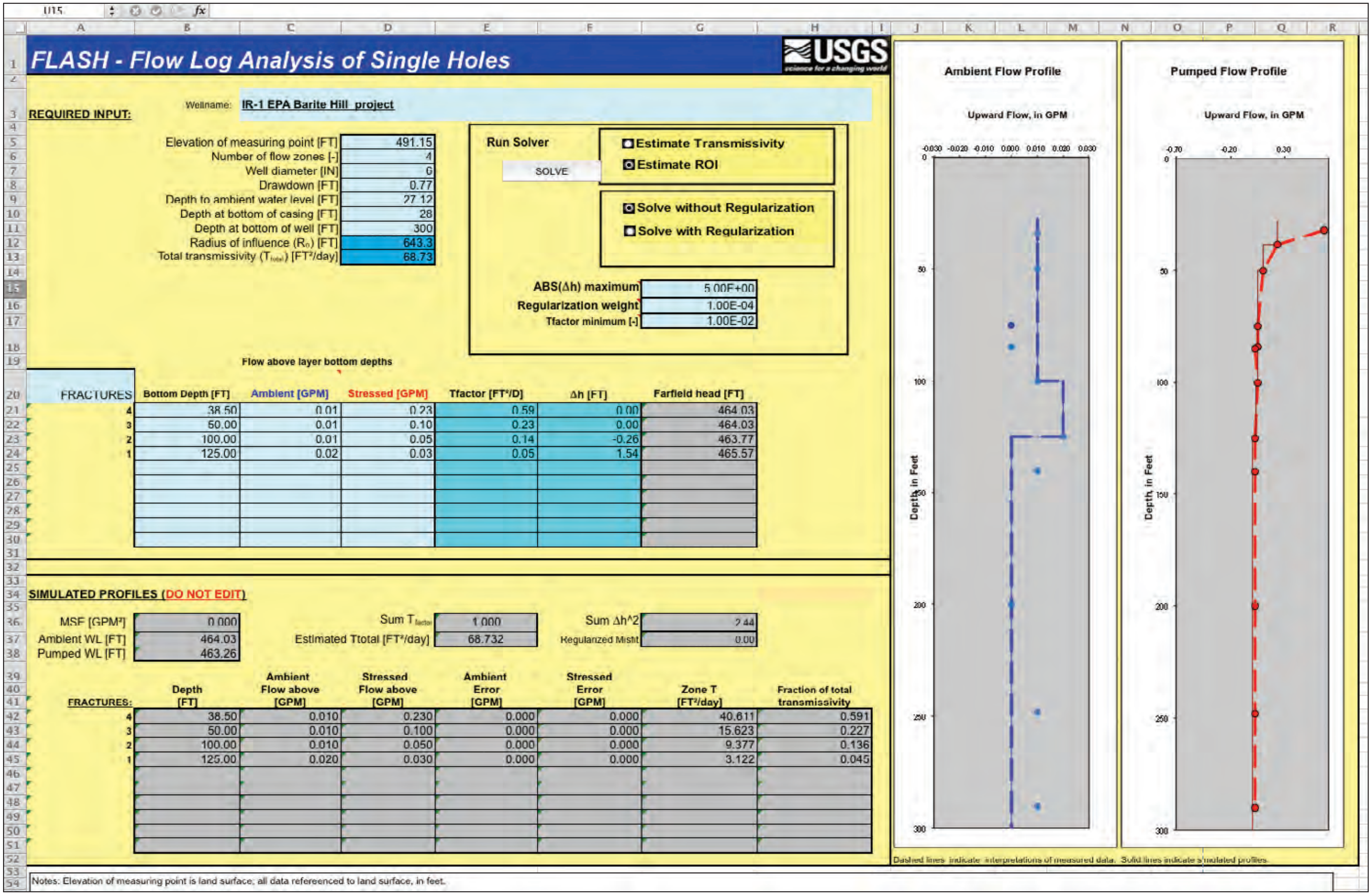

Figure 6–1. Screen capture of Inputs sheet of FLASH model for bedrock well IR-1 at the EPA Barite Hill/Nevada Goldfields Superfund site.

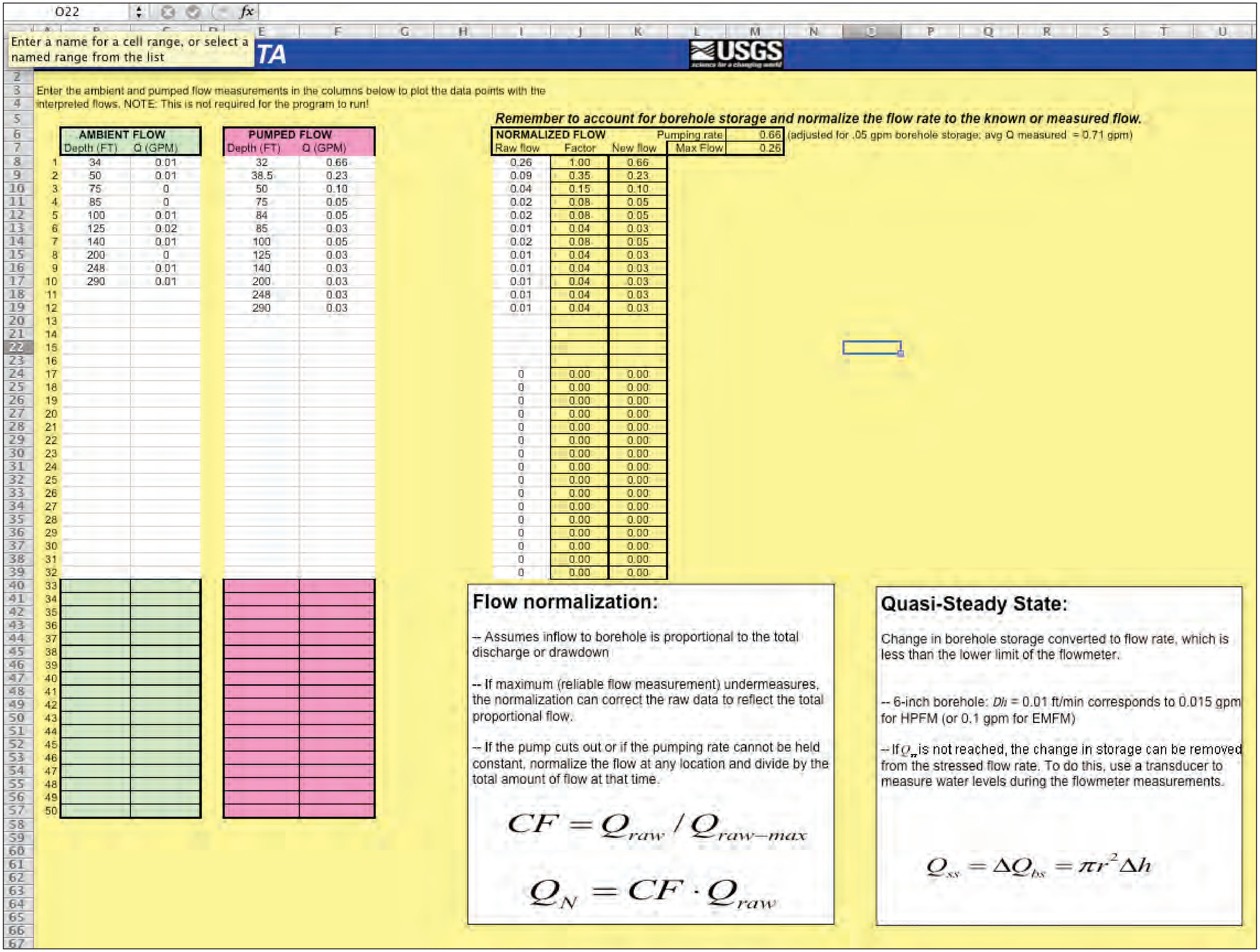

Figure 6–2. Screen capture of Field_Data sheet of FLASH model for bedrock well IR-1 at the EPA Barite Hill/Nevada Goldfields Superfund site.

Comparison of Measured and Simulated Flowmeter Data

PLOTTING: DO NOT CHANGE THIS

FRACTURES	*28.00*						
	Bottom Depth [FT]	DATA			SIMULATED		
ROW OFFSET	Depth	Ambient	Pumped	Depth	Ambient	Pumped	
	28.00	0.01	0.23	28.00	0.01	0.23	
0	38.50	0.01	0.23	38.50	0.01	0.23	
0	38.50	0.01	0.10	38.50	0.01	0.10	
1	50.00	0.01	0.10	50.00	0.01	0.10	
1	50.00	0.01	0.05	50.00	0.01	0.05	
2	100.00	0.01	0.05	100.00	0.01	0.05	
2	100.00	0.02	0.03	100.00	0.02	0.03	
3	125.00	0.02	0.03	125.00	0.02	0.03	
3	125.00	0.00	0.00	125.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4	300.00	0.00	0.00	300.00	0.00	0.00	
4							

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