DOE/ID-22220

Prepared in cooperation with the U.S. Department of Energy

# Completion Summary for Borehole USGS 136 near the Advanced Test Reactor Complex, Idaho National Laboratory, Idaho

Scientific Investigations Report 2012–5230

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

**Cover:** Photograph of basalt core (foreground) and U.S. Geological Survey drilling crew and drill rig at a drill site on the Idaho National Laboratory, Idaho. Photograph taken by Brian V. Twining, Hydrologist, U.S. Geological Survey Idaho National Laboratory Project Office, Idaho Falls, Idaho.

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KEN SALAZAR, Secretary

**U.S. Geological Survey**
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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# Conversion Factors, Datums, and Abbreviations and Acronyms

## Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| square foot ($ft^2$) | 0.09290 | square meter ($m^2$) |
| | Volume | |
| ounce, fluid (fl. oz) | 0.02957 | liter (L) |
| gallon (gal) | 3.785 | liter (L) |
| cubic foot ($ft^3$) | 28.32 | cubic decimeter ($dm^3$) |
| cubic foot ($ft^3$) | 0.02832 | cubic meter ($m^3$) |
| liter (L) | 33.82 | ounce, fluid (fl. oz) |
| | Flow rate | |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| gallon per minute (gal/min) | 0.06309 | liter per second (L/s) |
| | Pressure | |
| atmosphere, standard (atm) | 101.3 | kilopascal (kPa) |
| pound per square inch ($lb/in^2$) | 6.895 | kilopascal (kPa) |
| | Radioactivity | |
| picocurie per liter (pCi/L) | 0.037 | becquerel per liter (Bq/L) |
| | Hydraulic conductivity | |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| | Hydraulic gradient | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer (m/km) |
| | Transmissivity* | |
| foot squared per day ($ft^2/d$) | 0.09290 | meter squared per day ($m^2/d$) |

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

°F=(1.8×°C)+32.

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

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

*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.

# Conversion Factors, Datums, and Abbreviations and Acronyms—Continued

## Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

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

## Abbreviations and Acronyms

| Abbreviation or acronym | Definition |
|---|---|
| ATA | Aquifer test archive |
| ATRC | Advanced Test Reactor Complex |
| BEA | Battelle Energy Alliance |
| BLS | below land surface |
| CFA | Central Facilities Area |
| DOE | U.S. Department of Energy |
| ESRP | eastern Snake River Plain |
| GWSI | Groundwater site inventory |
| LRL | Laboratory reporting level |
| INL | Idaho National Laboratory |
| INTEC | Idaho Nuclear Technology and Engineering Center |
| LT-MDL | Long-term method detection level |
| MFC | Materials and Fuels Complex |
| MRL | Minimum reporting level |
| N | Nitrogen |
| NOSAMS | National Ocean Sciences Accelerator Mass Spectrometry |
| NWQL | National Water Quality Laboratory (USGS) |
| P | Phosphorus |
| PS | Pipe size |
| RESL | Radiological and Environmental Sciences Laboratory (DOE) |
| RWMC | Radioactive Waste Management Complex |
| SS | Stainless Steel |
| s | Sample standard deviation |
| TAN | Test Area North |
| TRA | Test Reactor Area |
| USGS | U.S. Geological Survey |
| VOC | Volatile organic compound |

# Completion Summary for Borehole USGS 136 near the Advanced Test Reactor Complex, Idaho National Laboratory, Idaho

By Brian V. Twining, Roy C. Bartholomay, and Mary K.V. Hodges

## Abstract

In 2011, the U.S. Geological Survey, in cooperation with the U.S. Department of Energy, cored and completed borehole USGS 136 for stratigraphic framework analyses and long-term groundwater monitoring of the eastern Snake River Plain aquifer at the Idaho National Laboratory. The borehole was initially cored to a depth of 1,048 feet (ft) below land surface (BLS) to collect core, open-borehole water samples, and geophysical data. After these data were collected, borehole USGS 136 was cemented and backfilled between 560 and 1,048 ft BLS. The final construction of borehole USGS 136 required that the borehole be reamed to allow for installation of 6-inch (in.) diameter carbon-steel casing and 5-in. diameter stainless-steel screen; the screened monitoring interval was completed between 500 and 551 ft BLS. A dedicated pump and water-level access line were placed to allow for aquifer testing, for collecting periodic water samples, and for measuring water levels.

Geophysical and borehole video logs were collected after coring and after the completion of the monitor well. Geophysical logs were examined in conjunction with the borehole core to describe borehole lithology and to identify primary flow paths for groundwater, which occur in intervals of fractured and vesicular basalt.

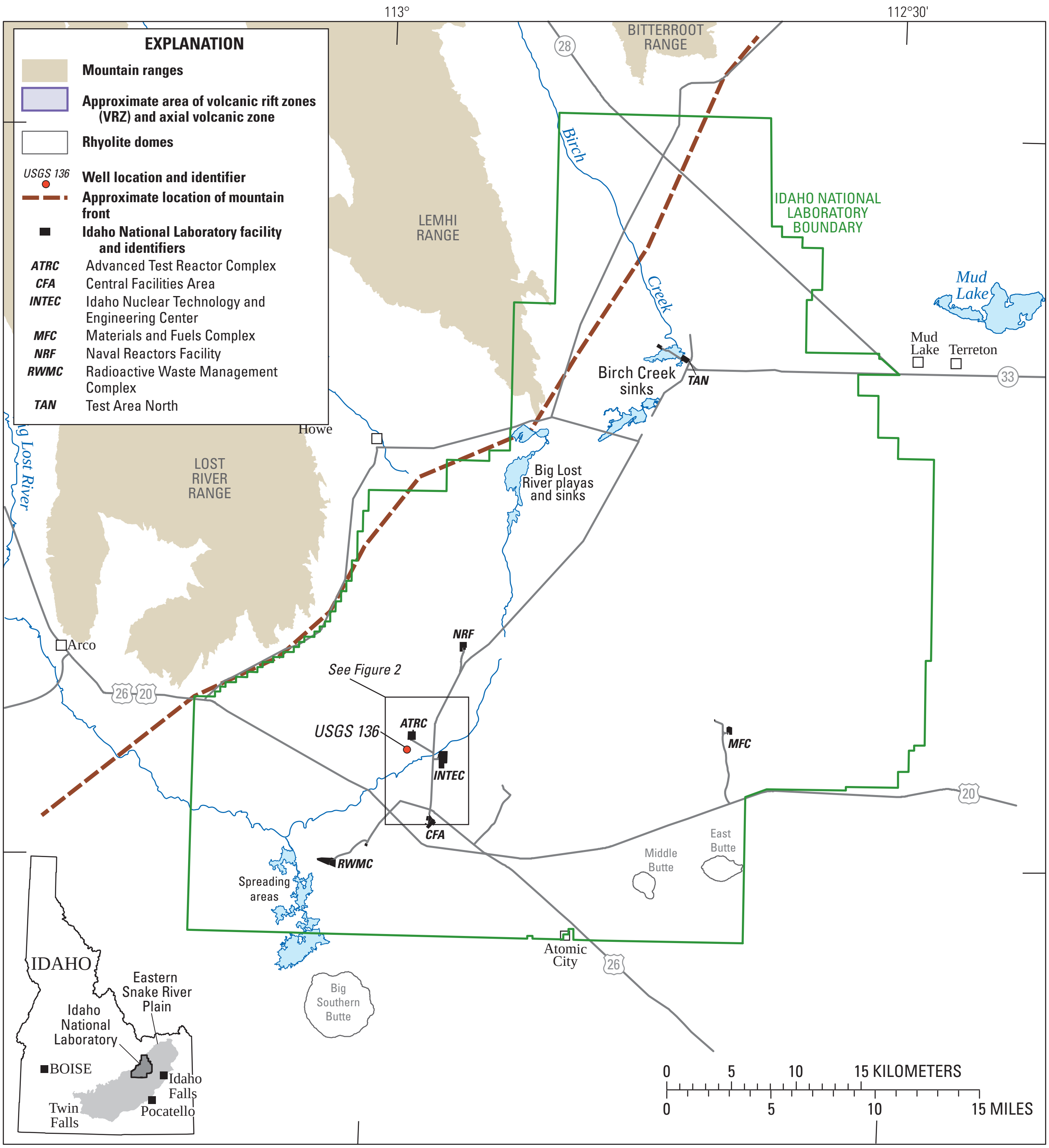
A single-well aquifer test was used to define hydraulic characteristics for borehole USGS 136 in the eastern Snake River Plain aquifer. Specific-capacity, transmissivity, and hydraulic conductivity from the aquifer test were at least 975 gallons per minute per foot, $1.4 \times 10^5$ feet squared per day ($ft^2/d$), and 254 feet per day, respectively. The amount of measureable drawdown during the aquifer test was about 0.02 ft. The transmissivity for borehole USGS 136 was in the range of values determined from previous aquifer tests conducted in other wells near the Advanced Test Reactor Complex: $9.5 \times 10^3$ to $1.9 \times 10^5$ $ft^2/d$.

Water samples were analyzed for cations, anions, metals, nutrients, total organic carbon, volatile organic compounds, stable isotopes, and radionuclides. Water samples from borehole USGS 136 indicated that concentrations of tritium, sulfate, and chromium were affected by wastewater disposal practices at the Advanced Test Reactor Complex. Depth-discrete groundwater samples were collected in the open borehole USGS 136 near 965, 710, and 573 ft BLS using a thief sampler; on the basis of selected constituents, deeper groundwater samples showed no influence from wastewater disposal at the Advanced Test Reactor Complex.

## Introduction

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (DOE), has collected borehole information at the Idaho National Laboratory (INL) since 1949 to provide baseline data concerning the migration and disposition of radioactive and chemical wastes in the eastern Snake River Plain (ESRP) aquifer. The USGS identified the need for additional geohydrologic and corehole information near the Advanced Test Reactor Complex (ATRC) for evaluating numerical and stratigraphic framework models. Additionally, the INL groundwater monitoring plan update (U.S. Department of Energy, 2003) suggested the need for additional monitor wells (screened in the upper 50 ft of the aquifer) downgradient from the ATRC (fig. 1) to better monitor radiochemical and chemical waste discharged to infiltration ponds at the ATRC (Davis, 2010).

On October 27, 2010, the USGS INL Project Office began coring borehole USGS 136 (fig. 2). The USGS collected data and completed borehole USGS 136 in two stages. In the first stage, the borehole was cored continuously to a depth of 1,048 ft below land surface (BLS). Geophysical and water-quality data were collected to that depth before the borehole was backfilled with cement and drill cuttings from about 560 to 1,048 ft BLS. In the second stage, the borehole was reamed in stages to the total completion depth of 560 ft BLS to allow for setting casing, annular seal, and well screen before a submersible pump was installed for long-term water-quality monitoring. The final design for borehole USGS 136 allows for sampling and aquifer testing of approximately 50 ft of the ESRP aquifer, about 0.5 mi southwest of the ATRC. The final monitor well, including an aquifer test, was completed September 22, 2011.




Base from U.S. Geological Survey digital data, 1:24,000 and 1:100,000Universal Transverse Mercator projection, Zone 12Datum is North American Datum of 1927

**Figure 1.** Location of selected facilities and borehole USGS 136, Idaho National Laboratory, Idaho.

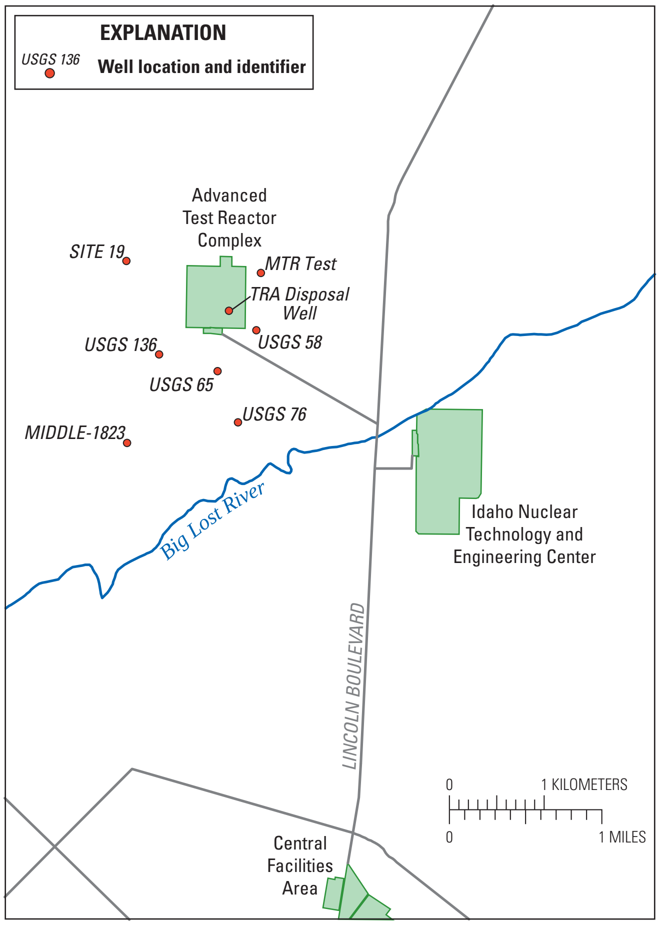



**Figure 2.** Location of borehole USGS 136 and selected monitor wells, Advanced Test Reactor Complex and vicinity, Idaho National Laboratory, Idaho.

## Purpose and Scope

In 2011, the USGS, in cooperation with the DOE, cored and completed borehole USGS 136 for stratigraphic framework analyses and long-term groundwater monitoring of the ESRP aquifer. This report presents information collected during the drilling, completion, and water testing of borehole USGS 136, a new aquifer monitor well drilled south of the ATRC for downgradient monitoring of the facility. Drilling methods and construction of borehole USGS 136 are presented for the cored borehole drilled to 1,048 ft BLS and the final monitor-well construction completed near 551 ft BLS. General lithologic descriptions of the drill core to 1,048 ft BLS along with geophysical data from the land surface to 560 ft BLS are presented; additional geophysical data are included in an appendix. The results for a single-well aquifer test conducted in borehole USGS 136 are presented and analyzed. Results of a comprehensive suite of water samples collected after the well was completed and analyzed for inorganic, organic, stable isotopes, and radionuclide constituents are presented. Additionally, depth-discrete groundwater samples collected with a thief sampler near 965, 710, and 573 ft BLS are included in an appendix, and results from a routine water-quality sample collected from the well after completion are provided for comparison.

## Geohydrologic Setting

The INL is in the west-central part of the ESRP (fig. 1). The ESRP is a northeast-trending structural basin about 200 mi long and 50–70 mi wide. The ESRP was caused by the passage of the North American tectonic plate over the Yellowstone Hot Spot (Pierce and Morgan, 1992). The ESRP is subject to continuing basaltic volcanism and subsidence, because disruption to the crust resulted in increased heat flow (Blackwell and others, 1992) and emplacement of a dense, mid-crustal sill (Shervais and others, 2006). The subsiding ESRP basin was filled with interbedded terrestrial sediments and Pleistocene to late Pliocene basalt, 0.6 to 1.2 mi thick (Whitehead, 1992). The basaltic rocks and sedimentary deposits make up the ESRP aquifer.

The ESRP is composed mostly of olivine tholeiite basalt flows, which erupted as tube-fed, inflated, pahoehoe flows that make up more than 85 percent of the subsurface volume of the ESRP at the INL (Anderson and Liszewski, 1997). A diagram of a lobe of a tube-fed pahoehoe ESRP basalt flow, showing cooling fractures that develop perpendicular to the exterior surfaces, vesicle zones and sheets, pipe vesicles, interior mega vesicles, and a diktytaxitic to massive core, is presented in figure 3. The distribution of basalt flows is controlled by topography, rate of effusion, and duration of eruption. Near-vent flows are thinner than distal flows, and accumulations of thin flows have a larger volume of high conductivity zones than the same volume of thick flows (Anderson and others, 1999).

The part of the Snake River Plain aquifer that underlies the ESRP is one of the most productive aquifers in the United States (U.S. Geological Survey, 1985, p. 193). Groundwater in the ESRP aquifer generally moves from northeast to southwest, eventually discharging to springs along the Snake River downstream from Twin Falls, Idaho—about 100 mi southwest of the INL (Whitehead, 1992). Water moves through basalt fracture zones at the tops, bases, and sides of basalt flows. Infiltration of surface water, groundwater pumping, geologic conditions, and seasonal fluxes of recharge and discharge locally affect the movement of groundwater (Garabedian, 1986). Recharge to the ESRP aquifer is primarily from infiltration of applied irrigation water, streamflow, precipitation, and groundwater inflow from adjoining mountain drainage basins (Ackerman and others, 2006).

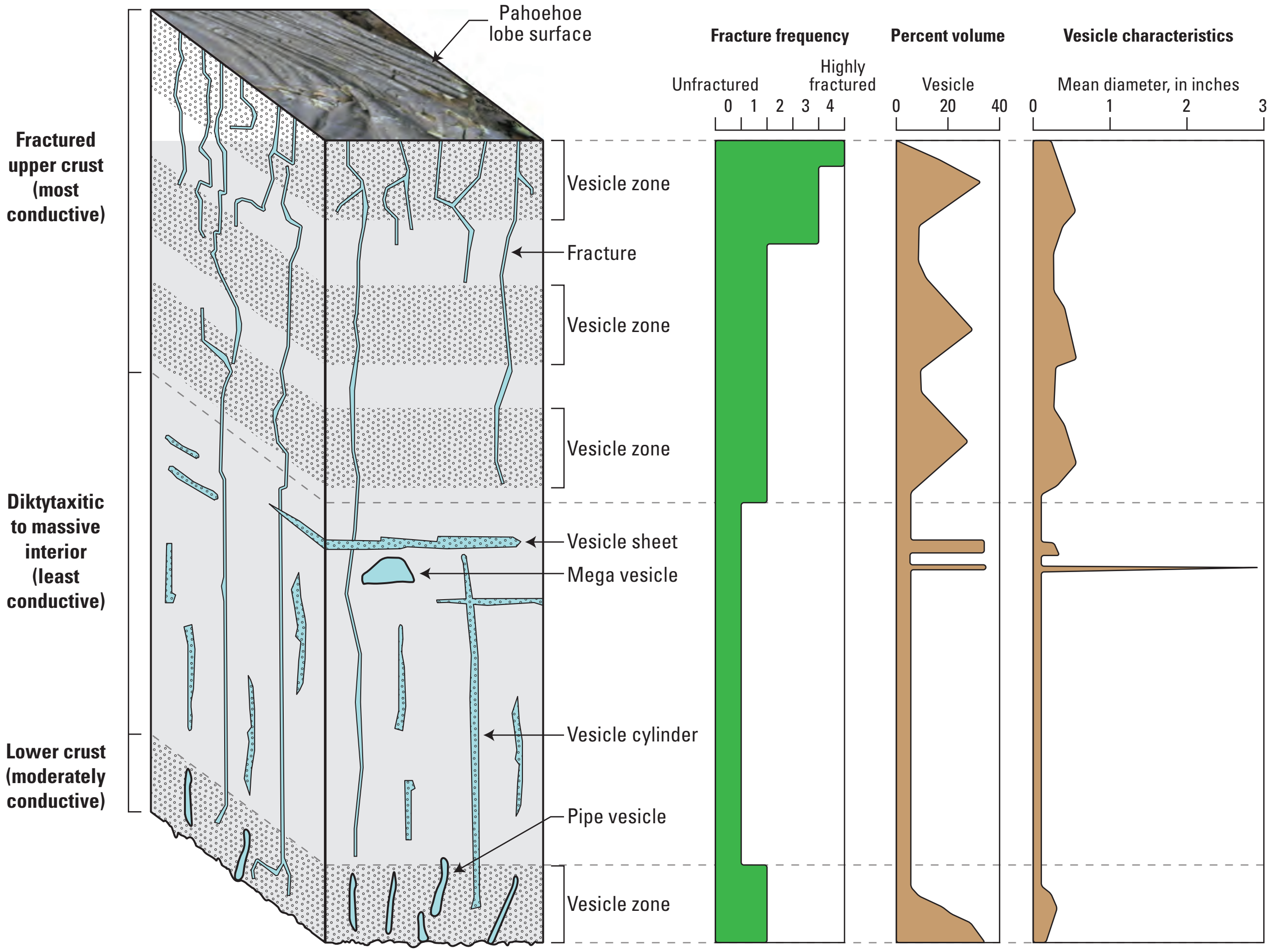



**Figure 3.** Idealized typical olivine tholeiite pahoehoe basalt flow (modified from Self and others, 1998, fig. 3, p. 90). The basalt flow is divided into three sections on the basis of vesicle characteristics and fracture frequency. Hydraulic conductivity is highest for the fractured upper crust, moderate for the lower crust, and lowest for the diktytaxitic to massive interior. The photograph of the pahoehoe lobe surface is courtesy of Scott Hughes, Emeritus Professor, Idaho State University, Pocatello, Idaho.

Across the INL, the March 2010 altitude of the water table ranges from about 4,560 to 4,390 ft (fig. 4); at borehole USGS 136, the altitude of the water table is about 4,447 ft. Depth to water ranges from about 200 ft BLS in the northern part of the INL to more than 900 ft BLS in the southeastern part; depth to water near the ATRC is about 490 ft BLS. A major portion of the groundwater moves through the upper 200–800 ft of basaltic rocks (Mann, 1986, p. 21). The estimated transmissivity for the upper part of the ESRP aquifer is 1.1 to 760,000 $ft^2/d$ reported by Ackerman (1991, p. 30) and Bartholomay and others (1997, table 3). The hydraulic gradient at the INL ranges from 2 to 10 ft/mi; the average is about 4 ft/mi (Davis, 2010, fig. 9). Horizontal flow velocities of 2 to 20 ft/d have been calculated on the basis of the movement of various chemical/radiochemical constituents in different areas of the ESRP aquifer at the INL (Robertson and others, 1974; Mann and Beasley, 1994; Cecil and others, 2000; Busenberg and others, 2001). These flow rates equate to a travel time of about 70–700 years for water beneath the INL to travel to springs that discharge at the terminus of the ESRP aquifer near Twin Falls, Idaho (fig. 1). Localized tracer tests at the INL have shown vertical and horizontal transport rates as high as 60 to 150 ft/d (Nimmo and others, 2002; Duke and others, 2007).

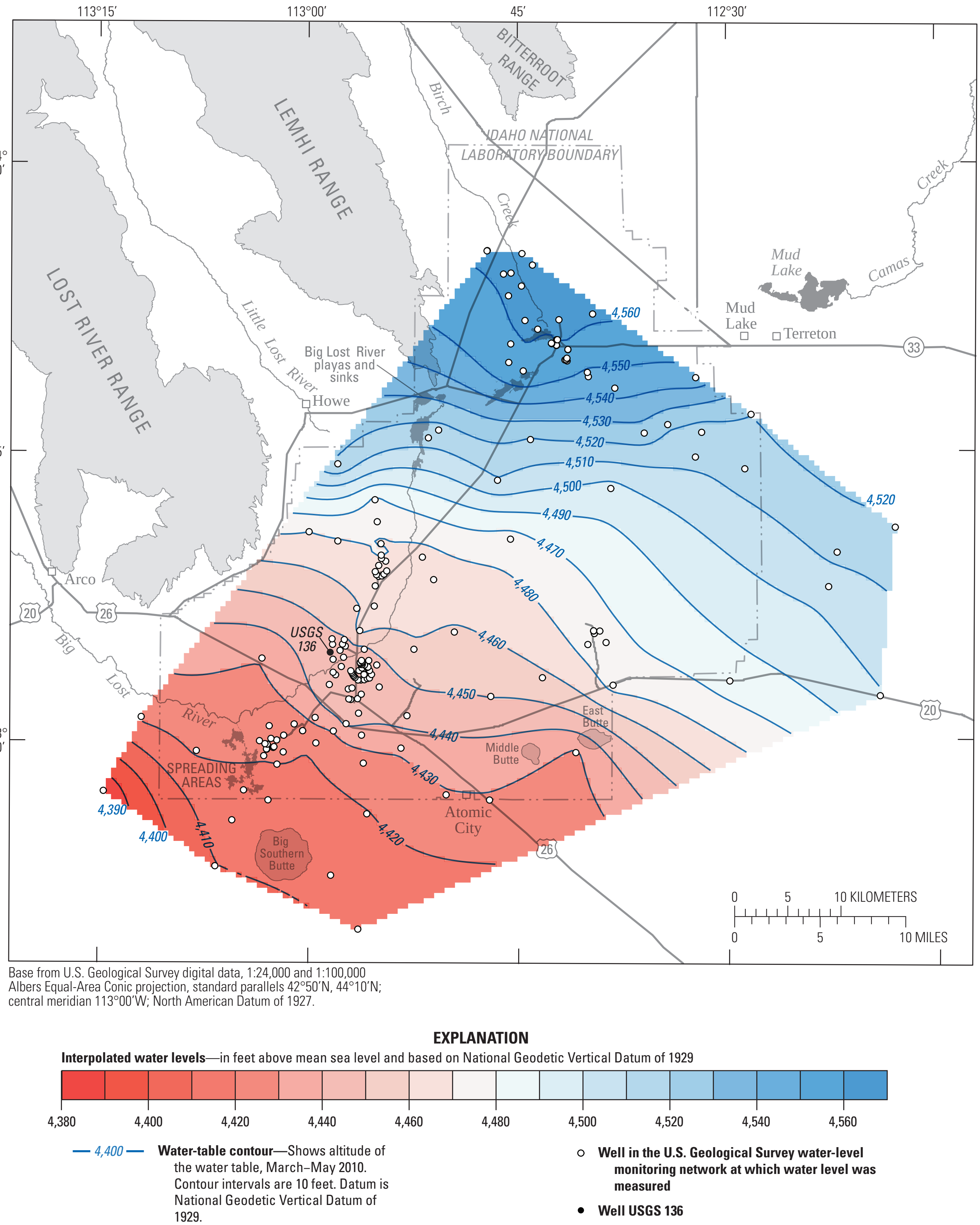



**Figure 4.** Water-table contours, measured March–May 2010, and monitor wells at and near the Idaho National Laboratory, Idaho.

# Drilling and Borehole Construction Methodology

The USGS determined the location and final design of borehole USGS 136 in discussion with DOE and the INL contractor Battelle Energy Alliance (BEA). Drilling, well construction, and hydraulic testing by the USGS INL Project Office took place between October 27, 2010, and September 22, 2011. All activities were performed in accordance with the USGS INL Site Safety Plan and the INL Environmental Checklist (INL-10-063); additionally, the USGS performed and documented regular safety inspections and safety briefings.

Prior to drilling startup, all drill rods, casing components, screen(s), pump, and drilling equipment were cleaned using a Hotsy® HSS-80389E diesel pressure washer. Protective tarps were placed under the drill rig, and equipment was checked on a daily basis for signs of hydraulic leaks. No reportable spills occurred while drilling at this location.

## USGS 136 Drilling Methods and Completion

Borehole USGS 136 was continuously cored using a Christensen™ CS 1500 rotary drilling rig and PQ- and HQ-size coring systems, where PQ refers to core rod sizing (pipe size about 4.6-in. outside diameter and drill-bit size about 4.8 in.) and HQ refers to core rod sizing (pipe size about 3.5-in. outside diameter and drill-bit size about 3.8 in.). The coring system uses Crisdrill™ and diamond drill bit(s), core catchers, and latch assembly (fig. 5). Core was retrieved in 5- and 10-ft sections using a four-part wireline latching mechanism (quadlatch) at the top of the core-barrel assembly. After removal from the borehole, core was marked for vertical direction and depth in the field before boxing. Cores were photographed and archived at the INL Lithologic Core Storage Library (Davis and others, 1997), which is operated by the USGS INL Project Office at the Central Facilities Area (CFA) (fig. 1).

On October 28, 2010, surface casing was driven using a casing driver mounted to a MOBILE™-B80 drill rig; a hydraulically operated downhole hammer was used to advance the 10-in. surface casing through surficial alluvium to about 48 ft BLS. Reaming, setting steel casing, and setting well screen were performed using a GEFCO™ SD-300 drill rig; tri-cone drill bits were used to enlarge (ream) sections of the borehole prior to setting the casing and screen.

Drilling fluids included water and pressurized air supplied using a Sullair™ diesel air compressor. Air and water mist were supplied continuously during coring and reaming of borehole USGS 136 to cool the bit face and to evacuate drill cuttings. Water used for drilling was transported from well MTR Test using a water truck with a capacity of 3,000 gal; approximately 7,500 gal of water was consumed for coring and reaming. Groundwater from well MTR Test was used because the well is close to borehole USGS 136 (fig. 2) but upgradient from the ATRC; it was believed that the water chemistry of the drill water was not affected by recent ATRC wastewater disposal. During drilling, the rate of water usage ranged from 2 to 7 gal/min, and air pressures ranged from 90 to 350 lb/in$^2$.

The annular space in the 7.9-in. diameter borehole between the 6-in. casing and the borehole wall was sealed by pressure grouting a Portland Type II cement/bentonite mixture (about 5 percent bentonite) down the annular space using 1-in. diameter tremmie pipe. The mixture of cement and bentonite was mixed at the job site and pumped down the annular space until the cement/bentonite mixture reached land surface. Approximately 45 ft$^3$ of the cement/bentonite mixture were used to seal the annular space from land surface to about 486 ft BLS.

## Borehole USGS 136 Construction

Borehole USGS 136 was PQ-cored from 48 to 563 ft BLS and HQ-cored from 563 to 1,048 ft BLS. Before coring, 10-in. diameter carbon-steel surface casing was set through 48 ft of surficial sediment that included calcified gravel and sand layers. Calcite-cemented sediment made setting surface casing difficult; therefore, compressed air was introduced to blow cuttings while simultaneously driving the casing.

Starting November 2, 2010, borehole USGS 136 was drilled and PQ-cored from 48 to 364 ft BLS. A winter storm with drifting snow and sub-zero temperatures made road and equipment access difficult, so drilling and coring were halted after November 18, 2010. Equipment was removed from the drill site, and the borehole was secured for about 5 months.

Drilling and coring were resumed after April 12, 2011, and continued through April 19, 2011. PQ-size core was obtained from 364 to 563 ft BLS. From April 20, 2011, through May 5, 2011, HQ-size core was obtained from 563 to 1,048 ft BLS. Drilling and coring were halted at 1,048 ft BLS, about 5 ft into a sediment layer consisting of silt and clay. This silt and clay layer is also found in borehole MIDDLE-1823 (fig. 2), which is less than 1 mi south of borehole USGS 136. Neutron, temperature logs, and core collected from borehole MIDDLE-1823 indicate the bottom of the ESRP aquifer to be near 1,030 ft BLS (Helm-Clark and others, 2005). For the purpose of hydraulic testing in borehole USGS 136, the sediment layer near 1,043 ft BLS represents the base of the ESRP aquifer.

Geophysical logs of USGS 136 were collected through steel drill pipe on May 5, 2011; open-hole logs were collected for several days starting May 11, 2011 (table 1). Details of the geophysical logging operations are provided in table 1 and in the section “Geologic and Geophysical Data.”

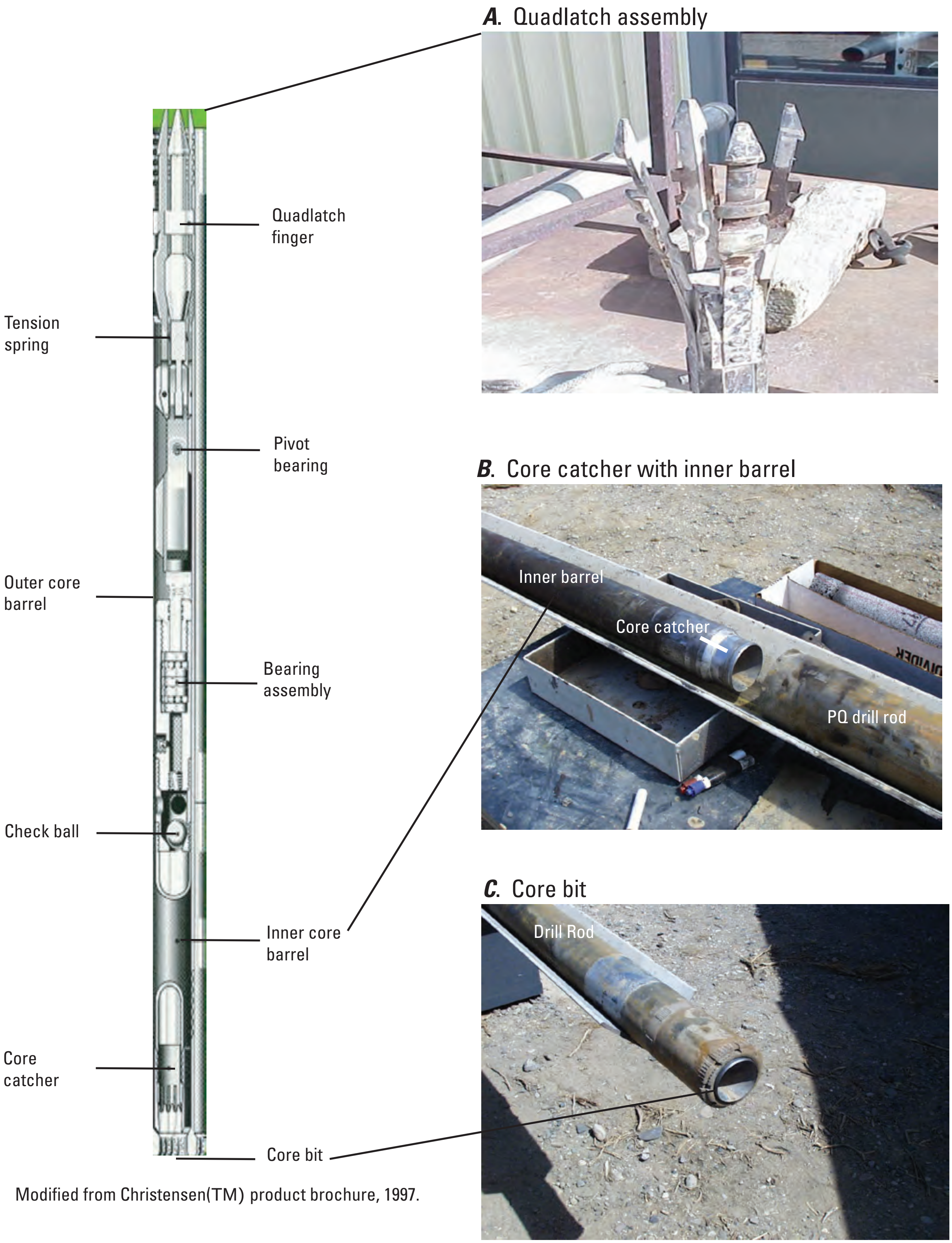



**Figure 5.** PQ-size coring system similar to one used for coring borehole USGS 136, Idaho National Laboratory, Idaho.

**Table 1.** Summary of geophysical and video logs collected at borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

[Geophysical data presented in this report were taken from one or more of the following logging tools listed below. **Log type:** Description of geophysical log trace presented. **Logging tool identifier:** Century™ tool number as referenced on web site http://www.century-geo.com/; B&W Cam, black and white camera. **Depth:** Refers to logging depths that data were collected; ft BLS, feet below land surface. **Hole condition:** Open, refers to logging without casing; Cased, specifies that casing was present when logging; Screened, specifies that well screen was present during logging. **Log direction:** Logs generally were run from total depth to land surface. **Comments:** Explanations where needed. **Abbreviations:** ft, foot; ft/min, foot per minute; gal/min, gallon per minute; in., inch. NA, not applicable]

| U.S. Geological Survey geophysical logging files | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Log type | Logging tool identifier | Depth (ft BLS) | | Date | Hole condition | Log direction | Logging tool uncertainty | Comments |
| | | Top | Bottom | | | | | |
| Natural gamma | 9057A | 0 | 1,044 | 05-05-11 | Cased | Down | ±5 percent | Run after coring, casing set on bottom |
| Caliper | 9065A | 455 | 731 | 05-11-11 | Cased/Open | Up | ±0.15 in. | Run after coring, casing set near 480 ft BLS |
| | 9065A | 709 | 1,046 | 05-12-11 | Cased/Open | Up | ±0.15 in. | Run after coring, casing set near 727 ft BLS |
| Neutron | 9057A | 0 | 1,043 | 05-05-11 | Cased | Down | ±5 percent | Run after coring, casing set on bottom |
| Normal resistivity and spontaneous potential | 9057A | 460 | 730 | 05-11-11 | Open | Down | ±5 percent | Casing set near 480 ft BLS—see appendix B |
| | 9057A | 0 | 1,046 | 05-11-11 | Open | Down | ±5 percent | Casing set near 727 ft BLS—see appendix B |
| Gamma-gamma density | 0024A | 0 | 1,043 | 05-05-11 | Cased | Up | ±5 percent | Run after coring, casing set on bottom |
| Temperature and specific conductance | 9042A | 0 | 730 | 05-11-11 | Cased/Open | Down | ±5 percent | Casing set near 480 ft BLS—see appendix B |
| | 9042A | 0 | 1,045 | 05-11-11 | Cased/Open | Down | ±5 percent | Casing set near 727 ft BLS—see appendix B |
| Gyro deviation | 9095 | 0 | 1,032 | 05-05-11 | Cased | Down | NA | Run after coring, casing set on bottom |
| | 9095 | 0 | 1,032 | 05-05-11 | Cased | Up | NA | Run after coring, casing set on bottom |
| Electromagnetic flow (EM) meter | 9741 | 736 | 1,038 | 05-16-11 | Open | Down | ±0.005 gal/min | Ambient log run trolling down 10 ft/min—see appendix B |
| | 9741 | 736 | 1,038 | 05-16-11 | Open | Up | ±0.005 gal/min | Ambient log run trolling up 10 ft/min—see appendix B |
| | 9741 | 736 | 1,037 | 05-16-11 | Open | Stations | ±0.005 gal/min | Ambient log station measurements—see appendix B |
| | 9741 | 489 | 550 | 09-08-11 | Screened | Stations | ±0.005 gal/min | Ambient log station measurements—see appendix B |
| Borehole video | B&W Cam | 480 | 727 | 05-10-11 | Open | Down | NA | Run after coring, casing set near 480 ft BLS |
| | B&W Cam | 729 | 1,044 | 05-11-11 | Open | Down | NA | Run after coring, casing set near 727 ft BLS |
| | R-2000 | 0 | 551 | 08-24-11 | Cased/Open | Down | NA | Installed 6 in. casing—no screen |
| | R-2000 | 0 | 551 | 09-08-11 | Cased | Down | NA | Installed 6 in. casing and screen |

Borehole video logs were collected during the removal of the drill pipe to identify obstructions in the borehole. Analysis of geophysical log data, core material, and drilling notes indicated the location of unstable layers in the aquifer (zones that have the potential to collapse); neutron log traces were used to confirm zones of increased porosity for collection of groundwater samples.

Depth-discrete groundwater thief samples were collected within the open borehole on May 10, 2011. To prevent borehole collapse and to limit mixing with the upper parts of the aquifer, drill pipe was positioned just below unstable zones near 950, 690, and 460 ft BLS; depth-discrete groundwater thief samples were collected from 965, 710, and 573 ft BLS, respectively. Therefore, analytical results of the water chemistry may represent mixing within the aquifer from the location where the rods were set to the bottom of the hole. No efforts were made to purge water from the borehole prior to sample collection. After logging and sampling, the borehole was backfilled with a mixture of cement and drill cuttings from about 560 to 1,048 ft BLS on May 16, 2011.

Starting May 17, 2011, the drill pipe was removed from borehole USGS 136, and the borehole was reamed from 48 to 486 ft BLS using a 7.8-in. diameter tri-cone bit. Reaming to 486 ft BLS was completed on August 10, 2011, and 6-in. diameter carbon-steel casing was placed near the bottom of the reamed hole. The annular space in the 7.9-in. diameter borehole between the 6-in. casing and the borehole wall was sealed by pressure grouting a cement/bentonite mixture on August 15, 2011. The annular seal was allowed to cure for about 1 week before reaming into the aquifer.

A 6-in. diameter tungsten and carbide tri-cone drill bit was used to ream borehole USGS 136 from 486 to 551 ft BLS on August 23, 2011. On August 24, 2011, after removing the drill bit and drill rods, a borehole video was recorded between 486 and 551 ft BLS to confirm that the reamed borehole section was clear from obstructions prior to setting well screen. A 5-in. diameter wire-wrap stainless steel (SS) screen was placed in borehole USGS 136 on August 24, 2011 (fig. 6). Drill rod was used to lower the screen assembly to the bottom of the borehole on a reverse threaded casing adapter. After the drill rod was removed, a final borehole video was recorded to examine the condition of the casing and screen.

A temporary pump, discharge line, and water-level measuring line were set to run a 24-hour aquifer test starting August 31, 2011. After the results of the aquifer test were examined, the temporary pump and measurement line were removed. The temporary submersible pump was used to evacuate drill cuttings and purge the well prior to setting the final submersible pump.

The final submersible pump, pump wire, discharge line, and water-level measurement line included a Grundfos™ 5-horsepower SS submersible pump, 4-wire (7 gauge) pump wire, 1.25-in. SS discharge line, and 1-in. SS water-level line placed September 22, 2011 (fig. 6). The submersible pump intake was set near 528 ft BLS, and the 1-in. measuring line was capped at about 520 ft BLS; the top of the ESRP aquifer was measured near 488 ft BLS.

The configuration of the completed monitor well (fig. 6 and table 2) includes (1) 10-in. diameter steel casing extending from 1 ft above land surface to 48 ft BLS; (2) 6-in. diameter steel casing extending from 2 ft above land surface to 486 ft BLS; (3) figure k-packer with 6-in. diameter rubber sealing wipers by 5-in. diameter pipe size from 439 to 440 ft BLS; (4) 5-in. diameter PS 304 SS casing blank extending from 440 to 500 ft BLS; and (5) 5-in. diameter PS 304 SS wire-wrap well screen (20-slot) equipped with a screen bottom cap extending from 500 to 551 ft BLS (fig. 6). Below 551 ft, drill cuttings prevent the screen from moving deeper.

Surface completion consisted of a 4-ft diameter concrete pad complete with a brass survey marker, steel impingement guard posts around the well, and a locking wellhead. Drilling equipment was demobilized September 22, 2011.

**Table 2.** Location and completion of well used in the aquifer tests.

[**Local name:** Local well identifier used in this study. Location of well is shown in figure 1. **Site identifier:** Unique numerical identifier used to access well data (http://waterdata.usgs.gov/nwis). **Aquifer thickness:** Aquifer base estimated from MIDDLE-1823 (Helm-Clark and others, 2005). BLS, below land surface; NAD 27, North American Datum of 1927; NGVD 29, National Geodetic Vertical Datum of 1929. ft, feet; in., inch]

| | |
|---|---|
| **Local name** | USGS 136 |
| **Site identifier** | 433447112581501 |
| **Longitude** | 112°58'12.0" (NAD 27) |
| **Latitude** | 43°34'47.7" (NAD 27) |
| **Measurement point elevation** | 4935.0 ft (NGVD 29) |
| **Aquifer thickness** | 550 ft, estimated distance between top of aquifer (near 490 ft BLS) and estimated aquifer base (near 1,040 ft BLS) |
| **Drilled borehole depth** | 1,048 ft BLS |
| **Completion depth** | 551 ft BLS |
| **Borehole diameter (485–551 ft BLS)** | 6.25 in. |
| **Well screen diameter** | 5 in. |
| **Well screen slot size** | 20-slot (0.020-in. openings) |
| **Top of screen** | 500 ft BLS |
| **Bottom of screen** | 550 ft BLS |
| **Depth to water** | 488.17 ft BLS, measured August 31, 2011, at 10:27 a.m. prepumping |

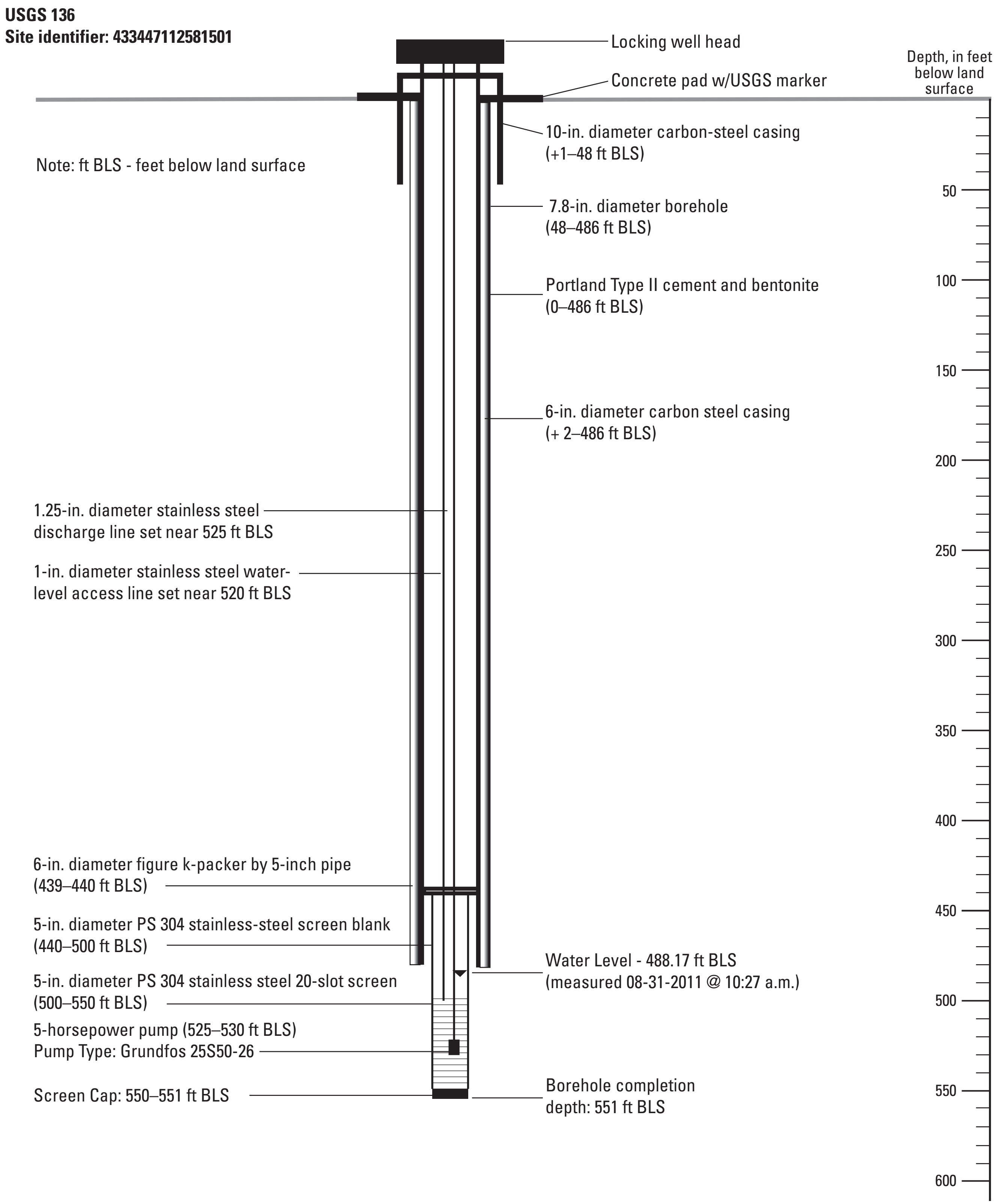



**Figure 6.** Final constructed borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

# Geologic and Geophysical Data

Geologic and geophysical data were collected from core material and geophysical logs. Core material from borehole USGS 136 was photographed and described to provide detailed lithologic descriptions from 48 to 1,048 ft BLS. Geophysical data were collected from land surface to 1,048 ft BLS; select geophysical logs are presented from land surface to 560 ft BLS, which were used to provide data for the final borehole construction and aquifer test. Core photographs and lithologic logs are presented in appendix A. Additional geophysical data, not described below but included in table 1, are presented in appendix B and include a composite of geophysical log traces extending from 485 to 1,040 ft BLS.

Geologic contacts were taken from geophysical traces and reported in feet BLS. Missing intervals and sediment zones not recovered, along with human error marking the core depths correctly, may cause discrepancies in the location of geologic contacts on core material; geophysical traces provide a continuous unbiased log that better represents the location of geologic contacts.

Borehole geophysical logs included natural gamma, neutron, gamma-gamma dual density, and caliper log traces. Gyro deviation surveys were run from 0 to 1,040 ft BLS to determine the direction and magnitude of borehole deviation. Several borehole video logs were recorded to look at the condition of the drilled borehole and final monitor well. Geophysical data were displayed using WellCAD™ software and were used to describe geologic and hydrologic features. Raw geophysical data are available upon request through the USGS INL Project Office.

## Geology

The sparsely vegetated surface at borehole USGS 136 is underlain by 48 ft of surficial sediment. Geoprobe® cores were collected to the point of refusal in plastic liner sleeves down to about 25 ft BLS (Geoprobe® cores were not logged for this report, but were collected within a 30 ft radius of borehole USGS 136 and are available for inspection at the INL Lithologic Core Storage Library). Sediment descriptions were from Geoprobe® cores, driller notes, and sediment returns observed while driving 10-in. diameter surface casing to the top of the first basalt contact. Surficial materials consisted of (1) loess exposed at the surface; (2) about 39 ft of sand, gravel, and cobble material from about 5 to 44 ft BLS; and (3) about 4 ft of fine sand mixed with silt and clay just above the upper basalt contact at about 44 to 48 ft BLS.

Excluding surficial sediment, seven sediment layers were described from 48 to 551 ft BLS in borehole USGS 136; where core material was not recovered, sediment layers were described from examination of geophysical and video logs. Sediment-layer boundary depths were reported near 96, 159, 189, 210, 253, 329, and 503 ft BLS. Borehole USGS 136 sediment, including surficial sediment, makes up about 15 percent of the unsaturated zone by volume (0 to 488 ft BLS). Composition of the sediment layer ranged in grain size from fine silt to coarse sand. In the completed borehole USGS 136 (0 to 551 ft BLS), excluding surficial sediment, the thickness of the sediment layer ranged from 1 to 22 ft.

On the basis of a visual inspection of core and geophysical data, about 25 basalt flows were observed from 48 to 551 ft BLS (appendix A). In the completed borehole USGS 136 (0 to 551 ft BLS), Quaternary olivine tholeiite basalt flows ranged in thickness from 1 to 75 ft (average 18 ft) and varied from highly fractured to dense, with high to low vesiculation and aphanitic to fine-grained texture. The basalt is mostly medium to dark gray in color. Detailed core descriptions and photographs, from 48 ft to 1,048 ft BLS, are included in appendix A.

## Geophysical Logs

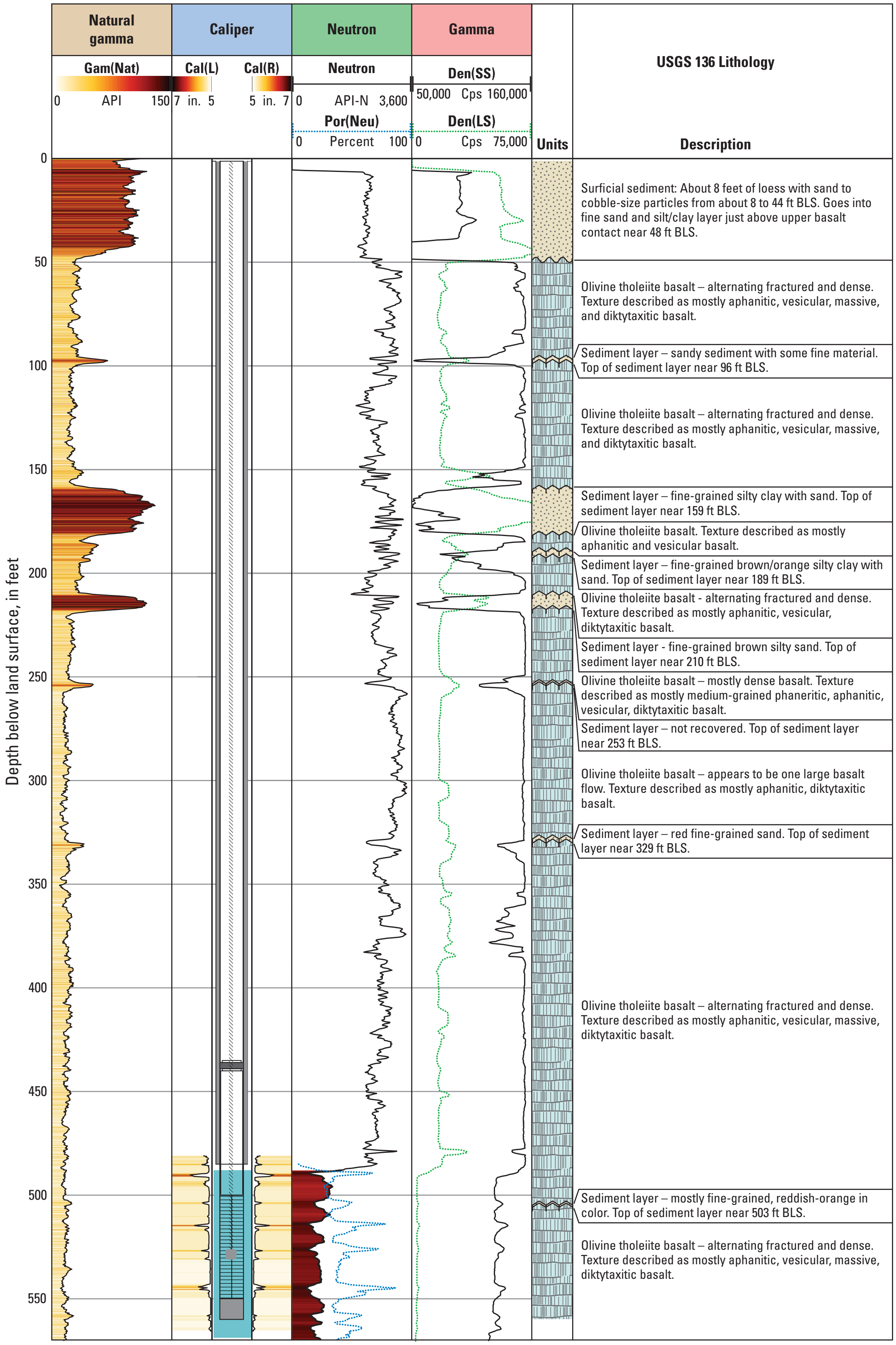
Wireline geophysical logs were run after completion of coring and during construction of borehole USGS 136. Geophysical data were collected using Century Geophysical Corporation™ logging equipment, and the resulting data files were processed using WellCAD™ analytical software. Borehole video log(s) were recorded using one of two cameras: a Laval Underground Surveys™ black and white camera or a Laval Underground Surveys™ R-2000 downhole color camera system. USGS INL Project Office calibrates geophysical logging equipment annually using modified procedures established by Century™ Geophysical Corporation; tool uncertainty is specified in table 1.

Natural gamma, caliper, neutron, gamma-gamma dual density, gyro deviation, and borehole video logs were collected during various drilling stages at borehole USGS 136 (table 1). A composite of natural gamma, caliper, neutron, and gamma-gamma dual density logs and general lithology from land surface to 560 ft BLS is shown in figure 7.

### Natural Gamma Logs

Natural gamma logs record gamma radiation emitted by naturally occurring radioisotopes. The USGS uses these logs at the INL to identify sedimentary layers in boreholes and to distinguish between basalt flows that display different amounts of potassium-40. The natural gamma detector measures total gamma radiation without distinguishing between individual contributions of the various isotopes.

Natural gamma logs were collected after coring on May 5, 2011, and displayed for the interval 0 to 560 ft BLS




**EXPLANATION**

**Definition of terms**

- **API** - American Petroleum Institute
- **BLS** - below land surface
- **Cal(L)** - left-side caliper
- **Cal(R)** - right-side caliper
- **Cps** - counts per second
- **Den(SS)** - short-spaced density
- **Den(LS)** - long-spaced density
- **ft** - feet
- **Gam(Nat)** - natural gamma radiation
- **in.** - inches
- **Neutron** - hydrogen index
- **Por(Neu)** - liquid-filled porosity

**Figure 7.** Geophysical and lithologic logs run from total depth to land surface for borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

(fig. 7). The log trace depicts a 48-ft surficial sediment layer and confirms the tops of six sediment-layer contacts near 96, 159, 189, 210, 253, and 329 ft BLS. One sediment layer near 503 ft BLS was not depicted in the natural gamma traces, but it was described in the core lithologic log from small amounts of sediments in the overlying and underlying basalt core. Because there was little or no natural gamma response at or near this depth, the sediment on the basalt core at this depth may have been deposited there during drilling and does not represent an actual stratigraphic layer. Alternatively, the sediment may contain very little radiogenic material, making it indistinguishable from the basalt above and below it (appendix A). The thickness of the sediment layers ranged from about 1 to 22 ft.

### Caliper Logs

The caliper tool makes a continuous log of the drill-hole diameter by using three extendable, spring-loaded arms that press against the sides of the borehole and detect changes in the diameter as the tool is brought up from the bottom of the borehole. The caliper tool can detect changes in borehole diameter greater than or equal to 0.15 in.

Open-hole caliper logs were collected after coring on May 11, 2011, and were displayed between 485 and 560 ft BLS (fig. 8); emphasis was placed on the screened interval 500 to 551 ft BLS. Caliper logs were used to confirm the presence of fractured and (or) vesicular basalt areas; fractured and (or) vesicular zones correlate with elevated neutron porosity traces. Dense, fractured, and sediment zones make up about 60, 38, and 2 percent, respectively, of the lithology within the screened interval (500 and 551 ft BLS) in borehole USGS 136. Groundwater flow is expected to occur more readily in the zones identified as either fractured and (or) vesicular basalt.

### Neutron Logs

Neutron measurements are a general indicator of hydrogen content; when they are combined with natural gamma logs for sediment location, they can be used to identify perched water zones in the unsaturated zone. The neutron log records the continuous measurement of the induced radiation produced by bombarding surrounding media (casing, formation, and fluid) with fast neutrons (energies greater than $10^5$ electron volts (eV)) from a sealed neutron source, which collide with surrounding atomic nuclei until they are captured (Keys, 1990, section 5, p. 95). The neutron tool used by the USGS INL Project Office has an americium/beryllium neutron source and a Helium-3 detector that counts slow (thermal) neutrons (those that have energies less than 0.025 eV).

Neutron logs were run through casing on May 5, 2011, and displayed for the interval 0 to 560 ft BLS (fig. 7). Review of the neutron trace revealed no evidence of perched water in the unsaturated zone (land surface to about 488 ft BLS). Neutron logs, examined for the section of aquifer extending from about 488 to 560 ft BLS, were used to identify areas of high and low hydrogen content in borehole USGS 136 (fig. 8). A vertical gradient, ranging from red (higher hydrogen content) to white (lower hydrogen content), was applied using WellCAD™ software to estimate areas containing fractured and (or) vesicular basalt. The neutron log shows good agreement with the drill-core lithology log (fig. 8, appendix B) once depths were adjusted vertically down about 3 ft because of discrepancies between core depth and geophysical data depth. Areas of low hydrogen content correlate with areas of dense and massive basalt, and areas of high hydrogen content correlate with areas of fractured and vesicular basalt. On the basis of basalt-hydrogen correlations, neutron logs show evidence for fractured and vesicular basalt, indicative of more productive water-producing zones, within the screened intervals from 504 to 506, 513 to 518, 523 to 527, and 543 to 549 ft BLS in borehole USGS 136.

### Gamma-Gamma Dual Density Logs

The gamma-gamma dual density log, also known as the induced gamma-density log, measures bulk density of the formation in the immediate vicinity of the borehole. Two separately spaced detectors record induced gamma-radiation intensity from an encapsulated radioactive source after it is backscattered or absorbed in a drill hole, borehole fluid, or surrounding media (Chase and others, 1964). Very dense materials increase scatter and cause increased absorption of gamma radiation; the increased absorption of gamma radiation results in fewer particles returning to the detector. The opposite is true for fractured and low-density materials. The induced gamma signal is attenuated in direct proportion to the bulk density of a formation.

Gamma-gamma dual density logs were run through casing on May 5, 2011, and displayed for the interval 0 to 560 ft BLS (fig. 7). Density logs were used to reference areas of dense as opposed to fractured basalt, and they correlate well with the depth-adjusted lithology log (figs. 7 and 8). Density logs confirm the presence of fractured basalt within the intervals from 504 to 506, 513 to 518, 523 to 527, and 543 to 549 ft BLS in borehole USGS 136 (fig. 8).

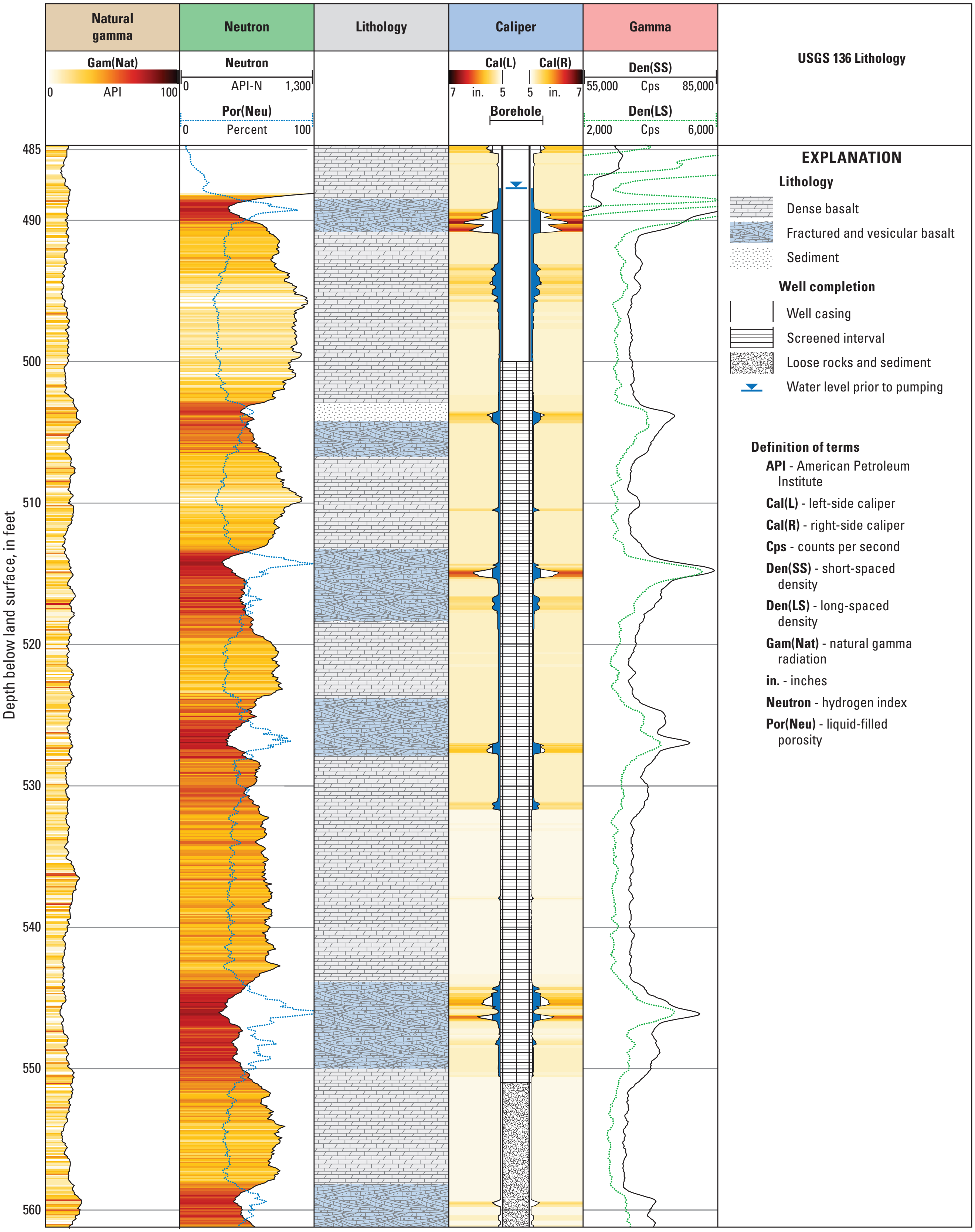



**Figure 8.** Expanded geophysical and lithologic logs with focus on depths 485–560 feet below land surface for borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

## Gyro Deviation Survey

A borehole gyroscopic deviation survey was run through casing on May 5, 2011, before the borehole was backfilled from 560 to 1,048 ft BLS. The gyroscopic deviation survey measures the change in horizontal deviation from vertical through drill steel or casing where magnetic rocks occur. Deviation was measured every 0.1 ft and displayed in 50 ft increments from 50 to 1,000 ft BLS; deviation measurements below 551 ft BLS are represented by a dashed line because this portion of borehole USGS 136 was backfilled (fig. 9). The lowest measurement in the completed portion of borehole USGS 136 (near 550 ft BLS) indicates a 16.3 ft (1.8 degree) horizontal deviation from vertical (fig. 9). To account for deviation near the water table in borehole USGS 136 (near 488 ft BLS), a deviation correction of -0.22 ft was applied to water-level measurements during the aquifer test and ongoing water-level measurements. A summary of borehole-deviation measurements is presented in table 3.

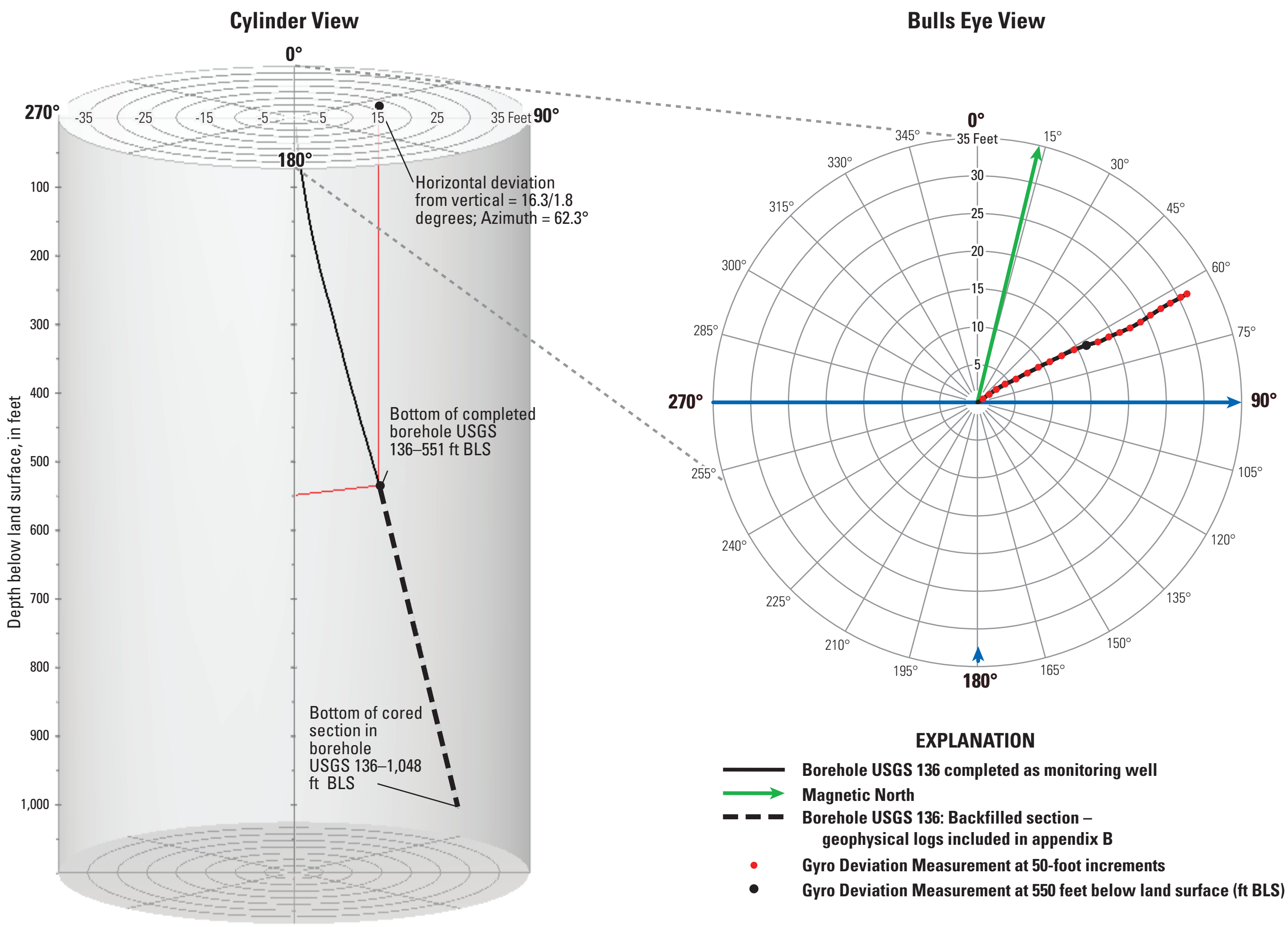



**Figure 9.** Gyroscopic deviation data collected for borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

**Table 3.** Gyroscopic deviation survey summary from borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

[Borehole USGS 136 deviation profile shown in figure 9; red circles represent measurements taken at 50-ft increments. Survey performed using a Century Geophysical Corporation™ 9095 logging tool. A tripod was used to hold the tool vertical during warmup. During warmup, the following information was noted: reference sighting azimuth, land surface drilling datum height, and magnetic declination (13.9 degrees). ft, foot; BLS, foot below land surface]

| USGS 136 measurement depth (ft BLS) | Horizontal deviation from vertical (ft) | Deviation from vertical (degrees) | True drillhole depth (ft) | Drillhole azimuth (ft) |
|---|---|---|---|---|
| 50 | 0.9 | 1.1 | 49.99 | 58.2 |
| 100 | 1.9 | 0.9 | 99.98 | 55.2 |
| 150 | 3.1 | 1.6 | 149.97 | 55.4 |
| 200 | 4.4 | 1.8 | 199.95 | 56.9 |
| 250 | 6.0 | 2.0 | 249.92 | 58.7 |
| 300 | 7.7 | 1.9 | 299.89 | 59.6 |
| 350 | 9.3 | 1.7 | 349.87 | 60.2 |
| 400 | 11.0 | 1.7 | 399.84 | 60.6 |
| 450 | 12.8 | 2.0 | 449.81 | 61.0 |
| 500 | 14.6 | 2.0 | 499.77 | 61.5 |
| 550 | 16.3 | 1.8 | 549.74 | 62.3 |
| 600 | 17.8 | 1.9 | 599.72 | 63.4 |
| 650 | 19.4 | 1.8 | 649.69 | 63.6 |
| 700 | 21.0 | 1.8 | 699.67 | 63.8 |
| 750 | 22.5 | 1.9 | 749.65 | 64.0 |
| 800 | 24.1 | 1.7 | 799.62 | 63.7 |
| 850 | 25.7 | 1.8 | 849.59 | 63.3 |
| 900 | 27.2 | 1.7 | 899.57 | 62.9 |
| 950 | 28.7 | 1.8 | 949.55 | 62.8 |
| 1,000 | 30.3 | 1.8 | 999.52 | 62.7 |

# Aquifer Test

A single-well aquifer test was conducted in the ESRP aquifer to define the hydraulic characteristics of borehole USGS 136 once it was completed as a monitor well. The aquifer test started at 1101 on August 31, 2011, and ended at 1134 on September 1, 2011. Results from the test were used to determine the average hydraulic properties of rock material for the screened portion of borehole USGS 136. A memorandum, dated March 21, 2012, from the USGS Western Region Groundwater Specialist states that the aquifer-test package is adequately documented and the analyses are technically sound (see appendix C). The hydraulic-property estimates were recorded in the USGS Groundwater Site Inventory (GWSI) database, and data collected during the aquifer test were archived in the USGS Idaho Water Science Center Aquifer Test Archive (ATA).

The aquifer-test data were analyzed for relative trends. Prolonged aquifer tests confirmed that borehole USGS 136 met sustained discharge rates of about 20 gal/min. Water samples, collected after purging the well for about 24 hours, indicate that no residual drilling fluid was introduced during construction of borehole USGS 136.

## Aquifer-Test Procedures

Fluid pressure head, barometric head pressure, fluid temperature, and air temperature were measured continuously throughout the test. The fluid pressure head, $\Psi_w$, and water temperature were measured with a Solinst® Levelogger®, a self-contained water level and temperature datalogger suspended on a wireline and positioned below the water table (fig. 10). The barometric head pressure, $\Psi_{atm}$, and air temperature were measured with a Solinst® Barologger®, a self-contained atmospheric pressure and temperature datalogger suspended on a wireline and positioned above the water table (fig. 10). The pressure head was compensated for changes in atmospheric pressure (fig. 11) and calculated by using the following equation:

$$\Psi = \Psi_w - \Psi_{atm} \quad (1)$$

where

$\Psi$ is compensated pressure head,
$\Psi_w$ is fluid pressure head, and
$\Psi_{atm}$ is barometric head pressure.

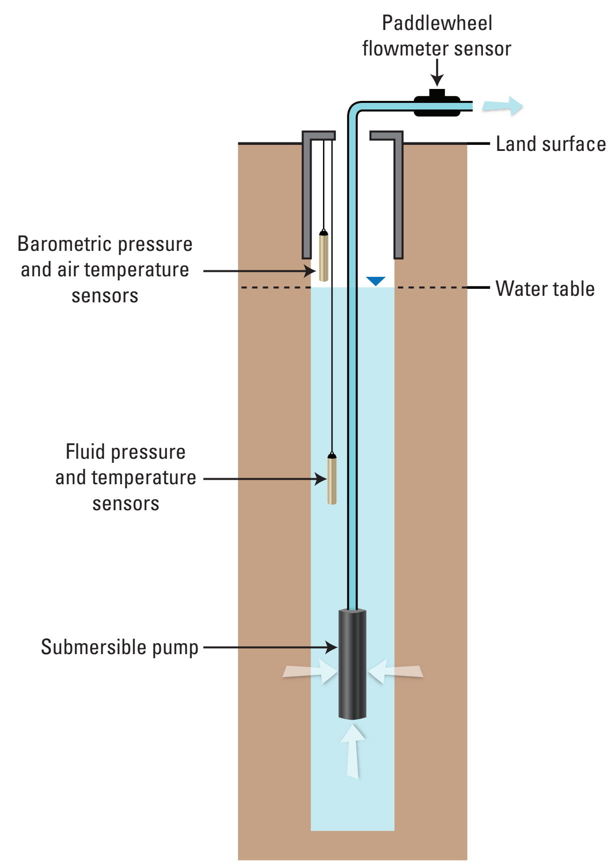



**Figure 10.** Idealized placement of sensors during aquifer testing at borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

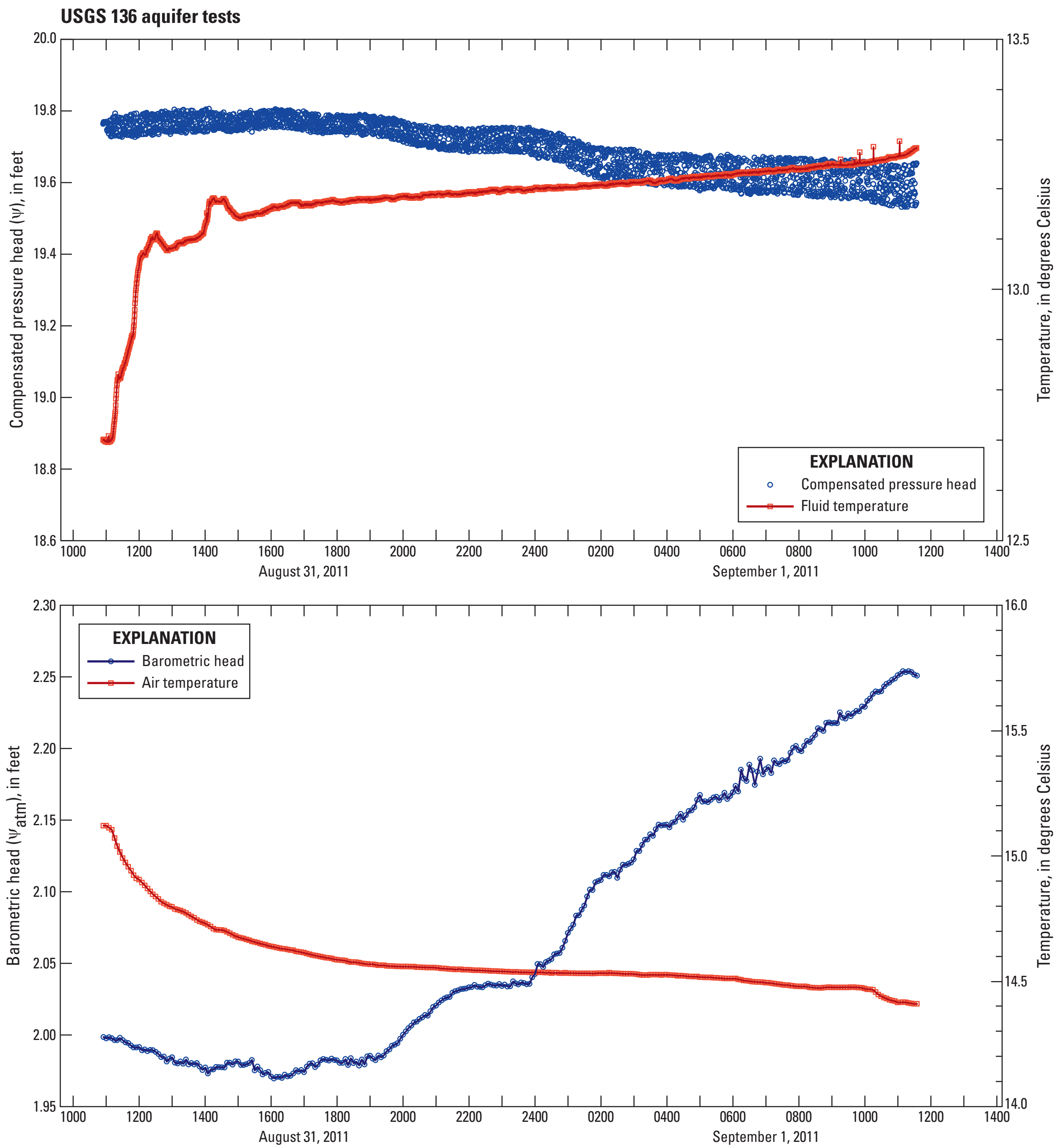



**Figure 11.** Changes in compensated pressure head, fluid temperature, barometric head, and air temperature through time during aquifer testing at borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, August 31, 2011, through September 1, 2011.

After the pump was turned off, aquifer-test recovery data were collected, but they were not analyzed.

The flow rate, $Q$, associated with well discharge was monitored periodically using a Blue-White Industries® F-2000 paddlewheel flowmeter (figs. 10 and 12). Measured flow rates remained relatively constant throughout the tests and ranged from 19.3 to 20.0 gal/min (fig. 12).

## Analysis of Aquifer-Test Data

The data from the single-well aquifer test at borehole USGS 136 were analyzed using a specific-capacity method to estimate transmissivity (Ackerman, 1991). This method uses linear regression to estimate transmissivity in the vicinity of the well from specific capacity (fig. 13). The specific-capacity method uses a modified Theis equation (Theis and others, 1963, p. 332, eqn. 1) and assumes constant values for the storage coefficient and the effective well radius to estimate transmissivity. Because of the limited drawdown response (less than 0.1 ft) and no observation well data, the specific-capacity method was the only method considered for estimating the hydraulic properties of the aquifer near borehole USGS 136.

Specific capacity (SC) is an expression of the productivity of a well commonly expressed as the ratio of the flow rate (Q) in gallons per minute to the total measured drawdown (Δs) in feet; however, in this case, average drawdown was determined only for the data between 10 and 500 minutes. Early time data (less than 10 min) were not considered because of variations in discharge rates and possible borehole storage effects. Late time data (greater than 500 min) were not considered because of the substantial rise in barometric pressure that occurred at about the same time as the water-level rise in borehole USGS 136. Additional data from longer-term water-level trends in response to changes in barometric pressure should be examined for this area to develop a water-level response model. Borehole USGS 136 displays small changes in water levels in response to pumping; this response is common for fractured basalt media that displays high transmissivities (Ackerman, 1991).

The specific-capacity method estimates transmissivity (*T*) through the use of the following equation(s):

$$SC = \left(\frac{Q}{\Delta s}\right) \tag{2}$$

$$T = (SC)^{1.1853} \times 40.62 = \left(\frac{Q}{\Delta s}\right)^{1.1853} \times 40.62 \tag{3}$$

where

$T$ is the transmissivity, in feet per day;
$SC$ is the specific capacity, in gallons per minute per foot;
$Q$ is the pumping rate, in gallons per minute; and
$\Delta s$ is the average drawdown, in feet.

The drawdown in the well, $s$, at any given time, $t$, is determined by subtracting the compensated pressure head at time $t$ from the initial compensated pressure head prior to pumping, $\Psi_0$. Drawdown as a function of time is expressed as:

$$s(t) = \psi_0 - \psi(t) \tag{4}$$

Estimates of horizontal hydraulic conductivity were based on the aquifer thickness, $b$, rather than the screen length because Halford and others (2006) found that in most cases using aquifer thickness as the divisor gave better estimates of transmissivity for unconfined aquifers with partial penetration. The horizontal hydraulic conductivity, $K$, was calculated using the following equation:

$$K = \frac{T}{b} \tag{5}$$

where

$T$ is aquifer transmissivity, and
$b$ is aquifer thickness.

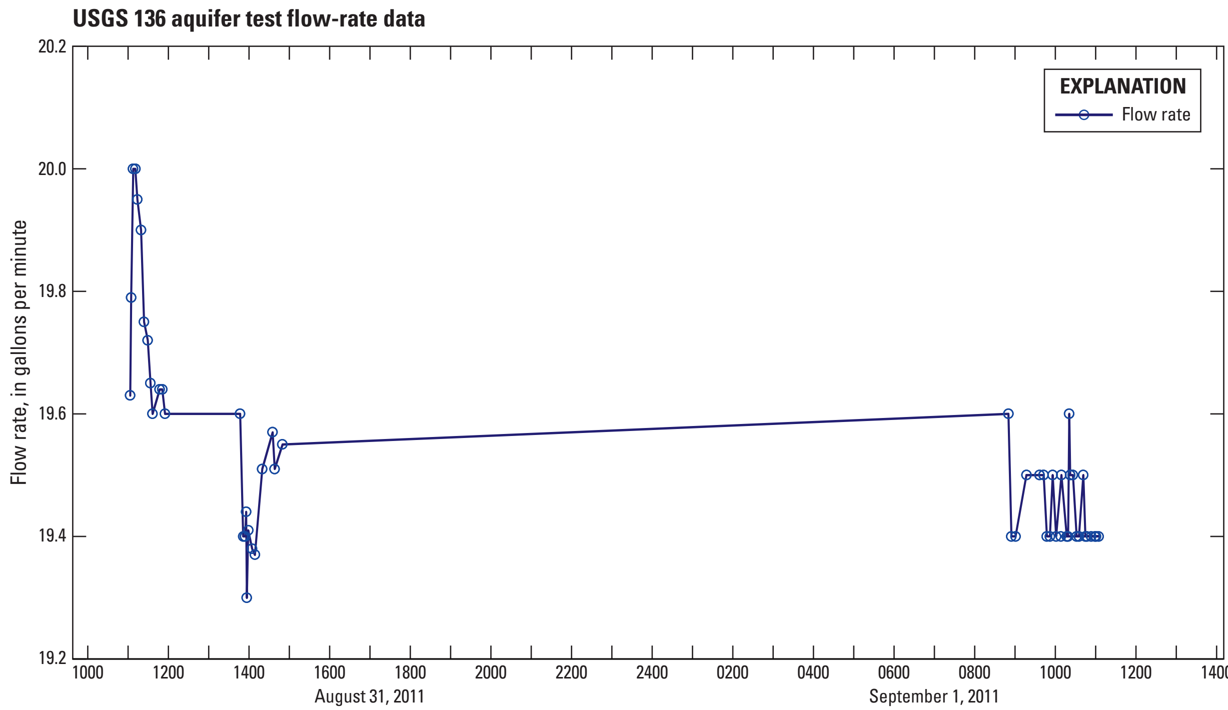



**Figure 12.** Pumping rates during aquifer testing at borehole USGS 136, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, August 31, 2011, through September 1, 2011.

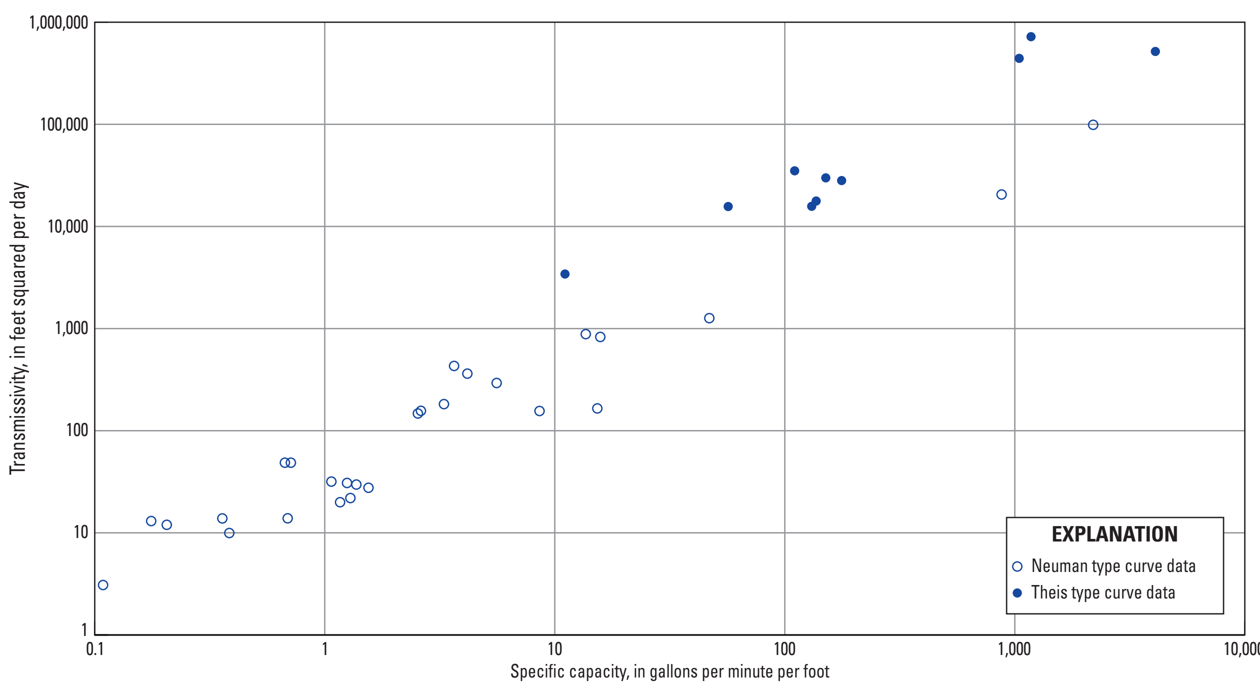



**Figure 13.** Relation between transmissivity and specific capacity as applied to the aquifer test in borehole USGS 136 (modified from Ackerman, 1991).

## Hydraulic Property Estimates

The hydraulic properties of the geohydrologic column at borehole USGS 136 were defined with transmissivity and horizontal hydraulic conductivity (conductivity). Transmissivity was estimated by an interpretive approach; all data were not honored and only relevant data were used. The specific-capacity method applied to the aquifer test is shown in figures 13 and 14. The specific capacity, transmissivity, and conductivity were estimated at 975 (gal/min)/ft, 1.4 × $10^5$ $ft^2$/d, and 254 ft/d, respectively. Calculations of these three parameters are as follows:

$$SC = \left(\frac{Q}{\Delta s}\right) = \frac{19.5\,\text{gal/min}}{0.02\,\text{ft}} = 975\,(\text{gal/min})/\text{ft} \quad (6)$$

$$T = (SC)^{1.1853} \times 40.62 = (975\,(\text{gal/min})/\text{ft})^{1.1853} \times 40.62 = 1.4\times10^5\ \text{ft}^2/\text{d} \quad (7)$$

$$K = \frac{T}{b} = \frac{1.4\times10^5\ \text{ft}^2/\text{day}}{550\,\text{ft}} = 254\,\text{ft}/\text{d} \quad (8)$$

A comparison between the estimated USGS 136 transmissivity and transmissivity values determined from past aquifer tests conducted at wells in the vicinity of the ATRC shows the transmissivity of borehole USGS 136 is in the range of other wells in this area (table 4). The estimated transmissivity values from these past aquifer tests (Ackerman, 1991; Bartholomay and others, 1997) ranged from 9.5 × $10^3$ to 1.9 × $10^5$ $ft^2$/d (table 4). The average hydraulic conductivity for borehole USGS 136 was well within the range of values reported in the literature for similar rock types; Freeze and Cherry (1979) report hydraulic conductivity values for permeable basalt ranging from 5.7 × $10^{-2}$ to 5.7 × $10^3$ ft/d. The hydraulic conductivity of the ESRP aquifer at or near the INL ranges from about 1.0 × $10^{-2}$ to 3.2 × $10^4$ ft/d (Anderson and others, 1999).

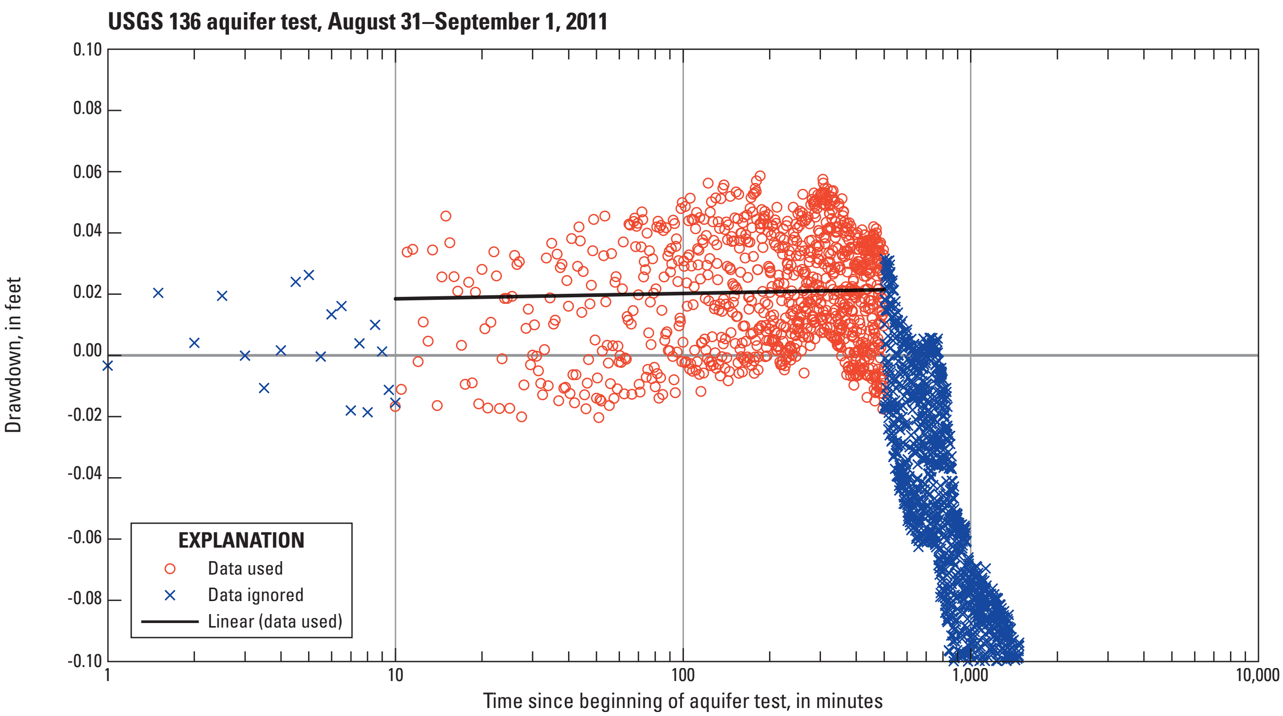



**Figure 14.** Analyses of drawdown time series for aquifer test at borehole USGS 136 (August 31 through September 1, 2011), Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

**Table 4.** Comparison of transmissivity values estimated from aquifer tests conducted at wells within the vicinity of borehole USGS 136, near the Advanced Test Reactor Complex, Idaho National Laboratory, Idaho.

[Data from Ackerman (1991) and Bartholomay and others (1997). **Local name:** Local well identifier used in this study. Locations of wells are shown in figure 2. **Site identifier** is the unique numerical identifier used to access well data (http://waterdata.usgs.gov/nwis). **Longitude, Latitude:** Referenced to NAD 27 (North American Datum of 1927). **Distance to borehole USGS 136:** Straight line distance within the aerial dimension to borehole USGS 136. **Abbreviations:** $ft^2/d$, foot squared per day; mi, mile]

| Local name | Site identifier | Longitude | Latitude | Transmissivity ($ft^2/d$) | Distance to borehole USGS 136 (mi) |
|---|---|---|---|---|---|
| USGS 76 | 433425112573201 | 112°57'32" | 43°34'25" | $1.9\times10^5$ | 0.7 |
| USGS 58 | 433500112572502 | 112°57'25" | 43°35'00" | $3.7\times10^4$ | 0.6 |
| USGS 65 | 433447112574501 | 112°57'47" | 43°34'47" | $9.5\times10^3$ | 0.5 |
| Site 19 | 433522112582101 | 112°58'21" | 43°35'22" | $3.1\times10^4$ | 0.7 |
| TRA disposal | 433506112572301 | 112°57'37" | 43°35'06" | $6.2\times10^4$ | 0.5 |

# Water-Sample Collection

## Sample Collection Methods

Water-sample collection at borehole USGS 136 generally followed guidelines documented in the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, variously dated) and in Knobel and others (2008); water-quality samples were collected during three sampling events. After coring to 1,048 ft BLS on May 10, 2011, initial water-quality samples were collected near 573, 710, and 965 ft BLS using a pre-cleaned SS thief sampling bottle that was opened at intervals within the open borehole to test if chemical constituents discharged into the Test Reactor Area (TRA) Disposal well from 1964 to 1982 (Davis, 2010) (fig. 2) at deeper parts of the ESRP aquifer were present in groundwater at borehole USGS 136. Discussion of the analytical results from the thief samples is given in appendix D.

After the monitor well was completed and the 24-hour aquifer test was performed, water-quality samples were collected on September 1, 2011. Water samples were collected from a 0.25-in. SS sample port installed off piping at the wellhead after the well was purged with a submersible pump and field measurements were stable. The constituents sampled after well completion were selected to provide a characterization of baseline water chemistry and radionuclide concentrations. Sample results are given in table 5.

A third round of water samples was collected on October 25, 2011, after a permanent submersible pump was installed near 525 ft BLS; results of these samples are also given in table 5. The constituents selected for the third round of sampling were based on the needs for long-term monitoring downgradient from the ATRC. Field measurements of pH, specific conductance, water temperature, and dissolved oxygen were collected during all three sample rounds, and alkalinity was measured after well completion; results are presented in table 5.

Samples were processed in the field according to protocols for the constituents for which analyses were requested. Samples to be analyzed for chemical constituents by the USGS National Water Quality Laboratory (NWQL) were placed in containers and preserved in accordance with laboratory requirements specified by Knobel and others (2008, appendix D). Containers and preservatives used were supplied by the NWQL and had gone through a rigorous quality-control procedure (Pritt, 1989, p. 75) to minimize sample contamination. Samples requiring field filtration were filtered through a disposable 0.45-µm cartridge that had been pre-rinsed with at least 1 L of deionized water. Samples to be analyzed for radionuclides by the Radiological and Environmental Sciences Laboratory (RESL) at the INL were placed in containers and preserved in accordance with laboratory requirements specified by Bodnar and Percival (1982) and Knobel and others (2008, appendix D). Samples for isotopes of oxygen and hydrogen were containerized in bottles provided by the USGS Reston Stable Isotope Laboratory - Isotope Fractionation Project in Reston, Va., and analyzed by that laboratory. Samples for isotopes of carbon were containerized in bottles provided by the NWQL, and these samples were analyzed at the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) (http://www.whoi.edu/nosams/page.do?pid=40137, accessed June 5, 2012) in Woods Hole, Mass.

**Table 5.** Concentrations of selected chemical and radiochemical constituents in water from borehole USGS 136, Idaho National Laboratory, Idaho.

[Location of well is shown in figure 1. Analytical results in micrograms per liter unless otherwise noted. Thief samples from USGS 136 were collected on May 10, 2011, from 965, 710, and 573 feet below land surface (BLS). Samples collected on September 1, 2011, and October 25, 2011, were from a 5-horsepower submersible pump at 525 feet below land surface. Samples were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colo., unless otherwise noted. **Abbreviations:** NOSAMS, National Ocean Sciences Accelerator Mass Spectrometry Laboratory in Woods Hole, Mass.; RSIL, USGS Reston Stable Isotope Laboratory in Reston, Va.; ºC, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; pCi/L, picocuries per liter; N, nitrogen; P, phosphorus; RESL, Radiological and Environmental Sciences Laboratory; E, estimated; NC, not collected; NA, not analyzed. <, less than; ±, plus or minus. Uncertainty of radiochemical constituents is 1 standard deviation. Uncertainity of deuterium and oxygen-18 is ±1.5 per mil. Uncertainty of carbon-13 is ±0.3 per mil. Concentrations that meet or exceed the reporting level of 3 times the 1 standard deviation value are shown in **bold** type]

| Constituent or measurement | May 10, 2011, at | | | September 11, 2011, at | October 25, 2011, at |
|---|---|---|---|---|---|
| | 965 ft BLS | 710 ft BLS | 573 ft BLS | 525 ft BLS | 525 ft BLS |
| Time | 1025 | 1305 | 1524 | 1058 | 1041 |
| Water temperature (ºC) | 13.2 | 13.4 | 13.7 | 13.5 | 13.1 |
| Air Temperature (ºC) | 9.2 | 11.4 | 13.4 | 17.4 | 4.0 |
| pH | 7.84 | 7.93 | 7.96 | 7.49 | 7.93 |
| Specific conductance (µS/cm) (field) | 377 | 377 | 376 | 438 | 429 |
| Specific conductance (µS/cm) (lab) | NA | NA | NA | 415 | 427 |
| Dissolved oxygen (mg/L) | 10.3 | 10.9 | 9.8 | 9.04 | 7.69 |
| Alkalinity (mg/L as $CaCO_3$) | NC | NC | NC | 168 | NC |
| Total dissolved solids (mg/L) | NC | NC | NC | 252 | NA |
| Calcium (mg/L) | NC | NC | NC | 50 | NC |
| Magnesium (mg/L) | NC | NC | NC | 17.4 | NC |
| Potassium (mg/L) | NC | NC | NC | 1.95 | NC |
| Silica (mg/L) | NC | NC | NC | 22.2 | NC |
| Sodium (mg/L) | 8.66 | 8.76 | 8.78 | 11 | 11 |
| Bromide (mg/L) | NC | NC | NC | 0.027 | NC |
| Chloride (mg/L) | 10.4 | 10.5 | 10.6 | 12.9 | 13 |
| Fluoride (mg/L) | NC | NC | NC | 0.143 | NC |
| Sulfate (mg/L) | 21 | 20.8 | 21.5 | 32.4 | 32.8 |
| Ammonia as N (mg/L) | <0.010 | E0.012 | E0.011 | <0.010 | <0.010 |
| Nitrite as N (mg/L) | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Nitrate plus nitrite as N (mg/L) | 0.895 | 0.886 | 0.911 | 1.13 | 1.09 |
| Orthophosphate as P (mg/L) | 0.025 | 0.022 | 0.024 | 0.023 | 0.022 |
| Aluminum | NC | NC | NC | 6.84 | 6.35 |
| Antimony | NC | NC | NC | 0.088 | 0.094 |
| Arsenic | NC | NC | NC | 1.55 | 1.69 |
| Barium | NC | NC | NC | 48.1 | 57.6 |
| Beryllium | NC | NC | NC | <0.1 | <0.006 |
| Boron | NC | NC | NC | 21.9 | NC |
| Cadmium | NC | NC | NC | <0.016 | <0.016 |
| Chromium | 3.58 | 2.8 | 3.93 | 13.3 | 15.1 |
| Cobalt | NC | NC | NC | E0.031 | 0.047 |
| Copper | NC | NC | NC | <0.5 | <0.8 |
| Iron | NC | NC | NC | E4.97 | NC |
| Lead | NC | NC | NC | <0.015 | 0.032 |
| Lithium | NC | NC | NC | 2.04 | NC |
| Manganese | NC | NC | NC | 0.404 | 0.399 |
| Mercury | NC | NC | NC | <0.005 | <0.005 |
| Molybdenum | NC | NC | NC | 1.16 | 1.24 |
| Nickel | NC | NC | NC | E0.154 | 0.425 |
| Selenium | NC | NC | NC | 1.22 | 1.36 |
| Silver | NC | NC | NC | <0.005 | <0.005 |
| Strontium | NC | NC | NC | 241 | NC |
| Thallium | NC | NC | NC | <0.010 | NC |
| Tungsten | NC | NC | NC | 0.18 | NC |

**Table 5.** Concentrations of selected chemical and radiochemical constituents in water from borehole USGS 136, Idaho National Laboratory, Idaho.—Continued

[Location of well is shown in figure 1. Analytical results in micrograms per liter unless otherwise noted. Thief samples from USGS 136 were collected on May 10, 2011, from 965, 710, and 573 feet below land surface. Samples collected on September 1, 2011 and October 25, 2011, were from a 5-horsepower submersible pump at 525 feet below land surface. Samples were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado, unless otherwise noted. **Abbreviations:** NOSAMS, National Ocean Sciences Accelerator Mass Spectrometry Laboratory in Woods Hole, Mass.; RSIL, USGS Reston Stable Isotope Laboratory in Reston, Va.; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; pCi/L, picocuries per liter; N, nitrogen; P, phosphorus; RESL, Radiological and Environmental Sciences Laboratory; E, estimated; NC, not collected; NA, not analyzed. <, less than; ±, plus or minus. Uncertainty of radiochemical constituents is 1 s. Uncertainity of deuterium and oxygen-18 is ±1.5 per mil. Uncertainty of carbon-13 is ±0.3 per mil. Concentrations that meet or exceed the reporting level of 3 times the 1s value are shown in boldface type]

| Constituent or measurement | May 10, 2011, at | | | September 11, 2011, at | October 25, 2011, at |
|---|---|---|---|---|---|
| | 965 ft BLS | 710 ft BLS | 573 ft BLS | 525 ft BLS | 525 ft BLS |
| Uranium | NC | NC | NC | 1.53 | 1.76 |
| Vanadium | NC | NC | NC | 3.78 | NC |
| Zinc | NC | NC | NC | <1.4 | 2.9 |
| Total organic carbon (mg/L) | NC | NC | NC | E0.472 | <0.5 |
| Tritium (pCi/L) (RESL) | 80±50 | -40±50 | 50±50 | **2,260±120** | **1,910±100** |
| Strontium-90 (pCi/L) (RESL) | 1.0±0.6 | 1.4±0.6 | 1.3±0.6 | 0.1±0.8 | 0.5±0.6 |
| Technetium-99 (pCi/L) (RESL) | NC | NC | NC | 0±0.03 | NC |
| Iodine-129 (pCi/L) (RESL) | NC | NC | NC | 0.01±0.011 | NC |
| Carbon-14 (pCi/L) (RESL) | NC | NC | NC | -20±70 | NC |
| Cesium-137 (pCi/L) (RESL) | 80±50 | 20±20 | 8±8 | 13±6 | 18±9 |
| Gross alpha (pCi/L) (RESL) | NC | NC | NC | -2±3 | 3±2 |
| Gross beta (pCi/L) (RESL) | NC | NC | NC | **3.8±0.9** | 2.0±0.8 |
| Americium-241 (pCi/L) (RESL) | NC | NC | NC | 0.003±0.012 | -0.003±0.012 |
| Plutonium-238 (pCi/L) (RESL) | NC | NC | NC | -0.003±0.003 | -0.006±0.004 |
| Plutonium-239,240 (pCi/L) (RESL) | NC | NC | NC | 0.003±0.012 | -0.003±0.003 |
| Uranium-234 (pCi/L) | NC | NC | NC | **1.37±0.12** | NC |
| Uranium-235 (pCi/L) | NC | NC | NC | **0.047±0.019** | NC |
| Uranium-238 (pCi/L) | NC | NC | NC | **0.423±0.067** | NC |
| Carbon-13 (per mil) (NOSAMS) | NC | NC | NC | -8.33 | NC |
| Carbon-14 (percent modern) (NOSAMS) | NC | NC | NC | 1,747±6.10 | NC |
| Deuterium (per mil) (RSIL) | NC | NC | NC | -136.9 | NC |
| Oxygen-18 (per mil) (RSIL) | NC | NC | NC | -17.90 | NC |
| Volatile organic compounds | | | | | |
| Acrylonitrile | NC | NC | NC | <2.5 | <2.5 |
| Benzene | NC | NC | NC | <0.1 | <0.1 |
| Bromobenzene | NC | NC | NC | <0.2 | <0.2 |
| Bromochloromethane | NC | NC | NC | <0.2 | <0.2 |
| Bromomethane | NC | NC | NC | <0.4 | <0.4 |
| CFC-11 | NC | NC | NC | <0.2 | <0.2 |
| CFC-12 | NC | NC | NC | <0.2 | <0.2 |
| CFC-113 | NC | NC | NC | <0.1 | <0.1 |
| CHBrC12 | NC | NC | NC | <0.1 | <0.1 |
| Chlorobenzene | NC | NC | NC | <0.1 | <0.1 |
| Chloroethane | NC | NC | NC | <0.2 | <0.2 |
| Chloromethane | NC | NC | NC | <0.2 | <0.2 |
| cis-1,2-dichloroethene | NC | NC | NC | <0.1 | <0.1 |
| cis-1,3-dichloropropene | NC | NC | NC | <0.2 | <0.2 |
| Dibromochloropropane | NC | NC | NC | <0.5 | <0.5 |
| Dibromochloromethane | NC | NC | NC | <0.2 | <0.2 |
| Dibromomethane | NC | NC | NC | <0.2 | <0.2 |
| Dichloromethane | NC | NC | NC | <0.2 | <0.2 |
| Ethylbenzene | NC | NC | NC | <0.1 | <0.1 |
| Hexachlorobutadiene | NC | NC | NC | <0.2 | <0.2 |

**Table 5.** Concentrations of selected chemical and radiochemical constituents in water from borehole USGS 136, Idaho National Laboratory, Idaho.—Continued

[Location of well is shown in figure 1. Analytical results in micrograms per liter unless otherwise noted. Thief samples from USGS 136 were collected on May 10, 2011, from 965, 710, and 573 feet below land surface. Samples collected on September 1, 2011 and October 25, 2011, were from a 5-horsepower submersible pump at 525 feet below land surface. Samples were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado, unless otherwise noted. **Abbreviations:** NOSAMS, National Ocean Sciences Accelerator Mass Spectrometry Laboratory in Woods Hole, Mass.; RSIL, USGS Reston Stable Isotope Laboratory in Reston, Va.; ºC, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; pCi/L, picocuries per liter; N, nitrogen; P, phosphorus; RESL, Radiological and Environmental Sciences Laboratory; E, estimated; NC, not collected; NA, not analyzed. <, less than; ±, plus or minus. Uncertainty of radiochemical constituents is 1 s. Uncertainity of deuterium and oxygen-18 is ±1.5 per mil. Uncertainty of carbon-13 is ±0.3 per mil. Concentrations that meet or exceed the reporting level of 3 times the 1s value are shown in boldface type]

| Constituent or measurement | May 10, 2011, at | | | September 11, 2011, at | October 25, 2011, at |
|---|---|---|---|---|---|
| | 965 ft BLS | 710 ft BLS | 573 ft BLS | 525 ft BLS | 525 ft BLS |
| Volatile organic compounds—Continued | | | | | |
| Isopropylbenzene | NC | NC | NC | <0.2 | <0.2 |
| MTBE | NC | NC | NC | <0.2 | <0.2 |
| Naphthalene | NC | NC | NC | <0.5 | <0.5 |
| *n*-butylbenzene | NC | NC | NC | <0.2 | <0.2 |
| *n*-propylbenzene | NC | NC | NC | <0.2 | <0.2 |
| *sec*-butylbenzene | NC | NC | NC | <0.2 | <0.2 |
| Styrene | NC | NC | NC | <0.1 | <0.1 |
| *tert*-butylbenzene | NC | NC | NC | <0.2 | <0.2 |
| Tetrachloroethene | NC | NC | NC | <0.1 | <0.1 |
| Tetrachloromethane | NC | NC | NC | <0.2 | <0.2 |
| Toluene | NC | NC | NC | 0.28 | <0.1 |
| *trans*-1,2-dichloroethene | NC | NC | NC | <0.1 | <0.1 |
| *trans*-1,3-dichloropropene | NC | NC | NC | <0.2 | <0.2 |
| Tribromomethane | NC | NC | NC | <0.2 | <0.2 |
| Trichloroethene | NC | NC | NC | <0.1 | <0.1 |
| Trichloromethane | NC | NC | NC | <0.1 | <0.1 |
| Vinyl chloride | NC | NC | NC | <0.2 | <0.2 |
| Xylene | NC | NC | NC | <0.2 | <0.2 |
| 1,1,1-trichloroethane | NC | NC | NC | <0.1 | <0.1 |
| 1,1,1,2-tetrachloroethane | NC | NC | NC | <0.2 | <0.2 |
| 1,1,2,2-tetrachloroethane | NC | NC | NC | <0.2 | <0.2 |
| 1,1,2-trichloroethane | NC | NC | NC | <0.2 | <0.2 |
| 1,1-dichloroethane | NC | NC | NC | <0.1 | <0.1 |
| 1,1-dichloroethene | NC | NC | NC | <0.1 | <0.1 |
| 1,1-dichloropropene | NC | NC | NC | <0.2 | <0.2 |
| 1,2,3-trichloropropane | NC | NC | NC | <0.2 | <0.2 |
| 1,2,3-trichlorobenzene | NC | NC | NC | <0.2 | <0.2 |
| 1,2,4-trichlorobenzene | NC | NC | NC | <0.2 | <0.2 |
| 1,2,4-trimethylbenzene | NC | NC | NC | <0.2 | <0.2 |
| 1,2-Dibromo-3-chloropropane (DBCP) | NC | NC | NC | <0.5 | <0.5 |
| 1,2-dibromoethane | NC | NC | NC | <0.2 | <0.2 |
| 1,2-dichlorobenzene | NC | NC | NC | <0.1 | <0.1 |
| 1,2-dichloroethane | NC | NC | NC | <0.2 | <0.2 |
| 1,2-dichloropropane | NC | NC | NC | <0.1 | <0.1 |
| 1,3-dichlorobenzene | NC | NC | NC | <0.1 | <0.1 |
| 1,3-dichloropropane | NC | NC | NC | <0.2 | <0.2 |
| 1,3,5-trimethylbenzene | NC | NC | NC | <0.2 | <0.2 |
| 1,4-dichlorobenzene | NC | NC | NC | <0.1 | <0.1 |
| 2-chlorotoluene | NC | NC | NC | <0.2 | <0.2 |
| 2,2-dichloropropane | NC | NC | NC | <0.2 | <0.2 |
| 4-chlorotoluene | NC | NC | NC | <0.2 | <0.2 |
| 4-isopropyltoluene | NC | NC | NC | <0.2 | <0.2 |

## Analytical Methods

Analytical methods used by the USGS for selected organic, inorganic, and radionuclide constituents are described by Goerlitz and Brown (1972), Thatcher and others (1977), Wershaw and others (1987), Fishman and Friedman (1989), Faires (1993), Fishman (1993), Rose and Schroeder (1995), and McCurdy and others (2008). Analytical methods used for selected isotopic constituents were summarized by Busenberg and others (2000). A discussion of procedures and methods used by the RESL for the analysis of radionuclides in water is provided by Bodnar and Percival (1982), Sill and Sill (1994), and the U.S. Department of Energy (1995).

## Guidelines for Interpretation of Analytical Results

Concentrations of radionuclides are reported with an estimated sample standard deviation, ***s***, which is obtained by propagating sources of analytical uncertainty in measurements. McCurdy and others (2008) provided details on interpreting radiological data used by the USGS. The guidelines for interpreting analytical results are based on an extension of a method proposed by Currie (1984) that is given in Davis (2010). In this report, radionuclide concentrations less than 3***s*** are considered to be less than a "reporting level." The reporting level should not be confused with the analytical method detection limit, which is based on laboratory procedures.

Concentrations of inorganic and organic constituents are reported with reference to laboratory reporting levels (LRLs) or with reference to minimum reporting levels (MRLs). Childress and others (1999) provide details about the approach used by the USGS regarding detection levels and reporting levels. USGS Office of Water Quality Technical Memorandum 2010.07 (U.S. Geological Survey, 2010) outlines changes to data reporting by the NWQL for the inorganic and organic constituents. The method detection limit is the minimum concentration of a substance that can be measured and reported with 99-percent confidence that the concentration is greater than zero. The LRL is the concentration at which the false negative error rate is minimized to be no more than 1 percent of the reported results. The MRL uses a censor-limit based reporting level below which no data are reported and is set at a concentration greater than the detection limit of the analyte. The LRL generally is equal to twice the yearly determined long-term method detection level (LT-MDL), which is a detection level derived by determining the standard deviation of a minimum of 24 MDL spike-sample measurements over an extended time. These reporting levels may be described as preliminary for a developmental method if the levels have been based on a small number of analytical results. These levels also may vary from sample to sample for the same constituent and the same method, if matrix effects or other factors arise that interfere with the analysis. Concentrations measured between the LT-MDL and the LRL may be described as estimated values. For most of the constituents in this report, reported concentrations generally are greater than the LRLs or MRLs, but some concentrations are given as less than the LRL or MRL, and some concentrations are estimated.

As a matter of convention, concentrations of stable isotopes are reported as relative isotopic ratios (Toran, 1982). Busenberg and others (2000) described stable isotope data in more detail.

### Inorganic Chemistry Data

Water samples collected in September from borehole USGS 136 were sent to the NWQL to be analyzed for dissolved concentrations of cations of calcium, potassium, magnesium, silica, and sodium; anions of bromide, chloride, fluoride, and sulfate; and trace elements of aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, tungsten, uranium, vanadium, and zinc. In addition, samples were collected and sent to the NWQL to be analyzed for dissolved concentrations of ammonia as nitrogen (N), nitrite as N, nitrate plus nitrite as N, and orthophosphate as phosphorus (P) (table 5).

A comparison of the data for the sample collected after well completion in September 2011 and the sample collected for the routine water-quality sampling program in October 2011 indicates very similar chemistry of the aquifer water between sample periods (table 5). Background concentrations of dissolved chromium in the ESRP aquifer are generally around 2-3 µg/L (Orr and others, 1991; Knobel and others, 1992), so concentrations of 13.3 and 15.1 µg/L in this well in September and October, respectively (table 5), can probably be attributed to wastewater disposal at the ATRC. Sulfate concentrations of 32.4 and 32.8 mg/L (table 5) were about 10 mg/L higher than background concentrations around the ATRC (20 to 25 mg/L; Robertson and others, 1974, fig. 27). Concentrations of chloride, sodium, and nitrate plus nitrite as N were near background levels for the aquifer in the vicinity of the ATRC but were slightly higher than concentrations from thief samples collected from deeper in the aquifer at this borehole prior to well completion (table 5).

## Organic Chemistry Data

The water samples collected in September and October 2011 from USGS 136 were analyzed at the NWQL for total organic carbon and volatile organic compounds (VOCs). Concentrations of VOCs were all below the LRL except toluene, which was detected in the sample collected in September at a concentration of 0.28 µg/L but was below the LRL in the sample collected in October (table 5). Toluene is a product of grease used on pipe threads and is a product in fuels, so the small September concentration may have been a remnant of drilling activities.

## Stable Isotope Data

Water samples collected in September 2011 were analyzed for relative concentrations of stable isotopes of hydrogen (H), oxygen (O), and carbon (C). Because the absolute measurement of isotopic ratios is analytically difficult, relative isotopic ratios were measured instead (Toran, 1982). For example, $^{18}O/^{16}O$ of a sample is compared with $^{18}O/^{16}O$ of a standard:

$$\text{Delta}\,^{18}O = (R_{sample} / R_{standard} - 1) \text{ X } 1{,}000 \qquad (9)$$

where

$R_{sample}$ is the $^{18}O/^{16}O$ ratio in the sample,

$R_{standard}$ is the $^{18}O/^{16}O$ ratio in the standard, and

Delta $^{18}O$ is the relative concentration, in units of parts per thousand.

Delta $^{18}O$ is referred to as delta notation; it is the value reported by isotopic laboratories for stable isotope analysis. $^{2}H/^{1}H$ and $^{13}C/^{12}C$ are defined in a similar manner with the respective ratios replacing $^{18}O/^{16}O$ in $R_{sample}$ and $R_{standard}$. The standard used for determining Delta $^{18}O$ and Delta $^{2}H$ in water is standard mean ocean water as defined by Craig (1961). The PeeDee Belemnite reference standard was used to determine Delta $^{13}C$ in water (Timme, 1995, p. 71). The carbon-14 was measured by accelerator mass spectrometry, and concentrations are given as percent modern carbon.

Stable isotope concentration data for deuterium, oxygen-18, and carbon-13 samples collected in September 2011 from USGS 136 were similar to concentrations of those constituents in two other wells (Site 19 and USGS 76; fig. 2) sampled in the vicinity of the ATRC (Busenberg and others, 2000), but concentrations were quite different from samples collected from USGS 65 (Knobel and others, 1999). For example, concentrations in USGS 136 (table 5) were -8.33, -136.9, and -17.9 per mil for carbon-13, deuterium, and oxygen-18, respectively. For Site 19, the respective concentrations were -8.35, -139.0, and -18.04; for USGS 76, the respective concentrations were not collected, -138.3, and -18.0 (Busenberg and others, 2000, table 11). Concentrations in USGS 65, which is relatively close to USGS 136 (fig. 1), were -10.4, -133, and -16.9 for carbon-13, deuterium, and oxygen-18, respectively.

The stable isotope data, along with other water-chemistry information, indicate that groundwater at USGS 136 is not being affected by wastewater disposal nearly to the extent that USGS 65 is but that the groundwater is affected (based on concentrations of tritium, sulfate, and chromium) to some extent by wastewater disposal at the ATRC. Historically, water samples from Site 19 and USGS 76 have not shown concentrations of constituents such as tritium, chromium, and sulfate at levels representative of wastewater disposal at the ATRC. However, water samples from USGS 65 (http://nwis.waterdata.usgs.gov/id/nwis/qwdata/?site_no=433447112574501&agency_cd=USGS& accessed April 17, 2012) have shown measurable concentrations of tritium, chromium, and sulfate through the entire history of sampling (Davis, 2010).

## Radiochemical Data

Water samples were collected from borehole USGS 136 after well completion in September 2011 and analyzed at the RESL for tritium; strontium-90; gross alpha, beta, and gamma radioactivity; iodine-129, technetium-99, carbon-14, plutonium-238, and plutonium-239, -240 (undivided); and americium-241. In addition, samples were collected for uranium isotopes and analyzed by a USGS NWQL contract laboratory (table 5). Results for all the radionuclides analyzed by the RESL were below the reporting level, except for tritium in samples collected in September and October 2011 and gross beta collected in September 2011 (table 5). Uranium isotope concentrations in samples collected from USGS 136 were within the range of other uranium isotope concentrations in the ESRP aquifer in other samples collected from wells in the southwestern part of the INL (Bartholomay and Twining, 2010). The elevated tritium concentrations indicate some influence from past wastewater disposal at the ATRC.

In addition to the carbon-14 sample analyzed by the RESL (table 5), a sample was sent to the NOSAMS facility to radiocarbon date the water sample. The sample result for carbon-14 of 1,747 percent modern carbon indicates that levels in this well are greater than what would be expected in nature, but they should not be confused with radioactivity in the sample, which is below the reporting level (table 5).

## Summary

In 2011, the USGS, in cooperation with the DOE, cored and completed borehole USGS 136 for stratigraphic framework analyses and long-term groundwater monitoring of the ESRP aquifer. The borehole was initially cored to a depth of 1,048 ft BLS to collect core, open-borehole water samples, and geophysical data. Following data collection, borehole USGS 136 was cemented and backfilled between 560 and 1,048 ft BLS. The final construction of borehole USGS 136 required the borehole to be reamed to allow for 6-in. and 5-in. diameter casing and screen, respectively; the screened monitoring interval was completed between 500 and 551 ft BLS. A dedicated pump and water-level access line were installed to allow for aquifer testing and for collecting water samples and water-level data.

Borehole video and logs for natural gamma, caliper, neutron, gamma-gamma dual density, and gyro deviation were collected after coring and after the final completion of the monitor well. Geophysical logs were examined in conjunction with the borehole core to confirm the presence of fractured and (or) vesicular basalt areas where groundwater flow is expected to occur more readily and to describe borehole lithology.

A single-well aquifer test was used to define hydraulic characteristics for borehole USGS 136 in the ESRP aquifer. Specific-capacity, transmissivity, and hydraulic conductivity from the aquifer tests were at least 975 (gal/min)/ft, $1.4 \times 10^5$ ft$^2$/d, and 254 ft/d, respectively. Transmissivity was estimated by an interpretative approach in which all data were not honored and only relevant data were used. The amount of measureable drawdown reported during the aquifer test was about 0.02 ft. The transmissivity for borehole USGS 136 was in the range of values determined from past aquifer tests in other wells near the ATRC—$9.5 \times 10^3$ to $1.9 \times 10^5$ ft$^2$/d.

Water samples collected after well completion were analyzed for cations, anions, metals, nutrients, total organic carbon, VOCs, stable isotopes, and radionuclides. Water samples collected within the screened interval (500 to 550 ft BLS) indicate concentrations of tritium, sulfate, and chromium were affected by past wastewater-disposal practices at the ATRC. Depth-discrete groundwater samples were collected within the open borehole near 965, 710, and 573 ft BLS using a thief sampler; selected constituents in the deeper groundwater samples showed no influence from wastewater disposal at the ATRC.

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# Appendixes

Appendixes A–D are available for download as a PDF at http://pubs.usgs.gov/sir/2012/5230/.

## Appendix A. Core Logs for Borehole USGS 136 (0–1,048 ft BLS)

## Appendix B. Borehole USGS 136 Geophysical Logs (480–1,048 ft BLS)

## Appendix C.  Memorandum: Aquifer Test Borehole USGS 136

## Appendix D.  Water-Chemistry Data

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