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

Completion Summary for Borehole TAN-2312 at Test Area North, Idaho National Laboratory, Idaho

Scientific Investigations Report 2018–5118

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

Cover: U.S. Geological Survey hydrologic technician pulling drill core from borehole TAN-2312 at the Idaho National Laboratory, Idaho. Photograph by Brian V. Twining, U.S. Geological Survey, August 3, 2017.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
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 minute (ft/min)	0.3048	meter per minute (m/min)
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)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]
	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.

Supplemental Information

*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 at 25 °C).

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 National Geodetic Vertical Datum of 1929 (NGVD 29).

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

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

Abbreviations

ATR Complex	Advanced Test Reactor Complex (formerly RTC, Reactor Technology Complex and TRA, Test Reactor Area)
API	American Petroleum Institute
BLS	below land surface
CFA	Central Facilities Area
CPS	counts per second
CTF	Contained Test Facility
DLDQ	detection limit by DQCALC
DOE	U.S. Department of Energy
DQCALC	detection and quantitation calculation
EMFM	electromagnetic flow meter
EPA	Environmental Protection Agency
ESRP	eastern Snake River Plain
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MFC	Materials and Fuels Complex
MRL	minimum reporting level
N	nitrogen
NRF	Naval Reactors Facility
NWQL	National Water Quality Laboratory (USGS)
P	phosphorus
HQcore	rod sizing
RESL	Radiological and Environmental Sciences Laboratory (DOE)
RSIL	Reston Stable Isotope Laboratory
RWMC	Radioactive Waste Management Complex
s	sample standard deviation
TAN	Test Area North
USGS	U.S. Geological Survey
VOC	volatile organic compound

Completion Summary for Borehole TAN-2312 at Test Area North, Idaho National Laboratory, Idaho

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

Abstract

In 2017, the U.S. Geological Survey, in cooperation with the U.S. Department of Energy, drilled and constructed borehole TAN-2312 for stratigraphic framework analyses and long-term groundwater monitoring of the eastern Snake River Plain aquifer at the Idaho National Laboratory in southeast Idaho. The location of borehole TAN-2312 was selected because it was downgradient from TAN and believed to be the outer extent of waste plumes originating from the TAN facility. Borehole TAN-2312 initially was cored to collect continuous geologic data, and then re-drilled to complete construction as a monitor well. The final construction for borehole TAN-2312 required 16- and 10-inch (in.) diameter carbon-steel well casing to 37 and 228 feet below land surface (ft BLS), respectively, and 9.9-in. diameter open-hole completion below the casing to 522 ft BLS. Depth to water is measured near 244 ft BLS. Following construction and data collection, a temporary submersible pump and water-level access line were placed near 340 ft BLS to allow for aquifer testing, for collecting periodic water samples, and for measuring water levels.

Borehole TAN-2312 was cored continuously, starting at the first basalt contact (about 37 ft BLS) to a depth of 568 ft BLS. Not including surface sediment (0–37 ft), recovery of basalt and sediment core at borehole TAN-2312 was about 93 percent; however, core recovery from 170 to 568 ft BLS was 100 percent. Based on visual inspection of core and geophysical data, basalt examined from 37 to 568 ft BLS consists of about 32 basalt flows that range from approximately 3 to 87 ft in thickness and 4 sediment layers with a combined thickness of approximately 76 ft. About 2 ft of total sediment was described for the saturated zone, observed from 244 to 568 ft BLS, near 296 and 481 ft BLS. Sediment described for the saturated zone were composed of fine-grained sand and silt with a lesser amount of clay. Basalt texture for borehole TAN-2312 generally was described as aphanitic, phaneritic, and porphyritic. Basalt flows varied from highly fractured to dense with high to low vesiculation.

Geophysical and borehole video logs were collected after core drilling and after final construction at borehole TAN-2312. Geophysical logs were examined synergistically with available core material to suggest zones where groundwater flow was anticipated. Natural gamma log measurements were used to assess sediment layer thickness and location. Neutron and gamma-gamma source logs were used to identify fractured areas for aquifer testing. Acoustic televiewer logs, fluid logs, and electromagnetic flow meter results were used to identify fractures and assess groundwater movement when compared against neutron measurements. Furthermore, gyroscopic deviation measurements were used to measure horizontal and vertical displacement for borehole TAN-2312.

After construction of borehole TAN-2312, a single-well aquifer test was completed September 27, 2017, to provide estimates of transmissivity and hydraulic conductivity. Estimates for transmissivity and hydraulic conductivity were 1.51×10^{2} feet squared per day and 0.23 feet per day, respectively. During the 220-minute aquifer test, well TAN-2312 had about 23 ft of measured drawdown at sustained pumping rate of 27.2 gallons per minute. The transmissivity and hydraulic conductivity estimates for well TAN-2312 were lower than the values determined from previous aquifer tests in other wells near Test Area North.

Water samples were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Water samples for most of the inorganic constituents showed concentrations near background levels for eastern regional groundwater. Water samples for stable isotopes of oxygen, hydrogen, and sulfur indicated some possible influence of irrigation on the water quality. The volatile organic compound data indicated that this well had some minor influence by wastewater disposal practices at Test Area North.

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 is refining numerical models for the movement of groundwater and contaminants in the ESRP aquifer. Additional hydrogeologic and borehole information downgradient from Test Area North (TAN) is needed to understand groundwater flow for ongoing studies (fig. 1). Borehole TAN-2312 was located as a downgradient well for monitoring radiochemical and chemical constituents that were previously discharged from TAN. Geologic data along with hydraulic properties (transmissivity and hydraulic conductivity) are needed to define groundwater movement as it relates to contaminant transport of waste plumes at TAN.

The week of July 17, 2017, the USGS mobilized equipment to TAN to begin drilling for borehole TAN-2312 (fig. 2). Borehole TAN-2312 was cored from the first basalt contact to a depth of 568 ft below land surface (BLS) and constructed as a monitor well at completion of coring. Borehole TAN-2312 was constructed with 16-in. diameter surface casing to 37 ft BLS (first basalt contact), 10-in. well casing to 228 ft BLS, and 9.9-in. open-hole to 522 ft BLS. The section of borehole from 522 to 568 ft BLS was not re-drilled and borehole video, collected after construction, shows that section of borehole had filled with drill cuttings. Drilling and construction were completed September 20, 2017, for aquifer testing and groundwater sampling.

Various data were collected throughout the drilling process and compiled within this report. Geophysical data and downhole video were collected and examined to confirm open borehole conditions and identify areas of fractured and dense basalt. After construction, aquifer testing was done for well TAN-2312 on September 27, 2017. Additionally, an extensive suite of groundwater samples was collected after purging to examine water chemistry.

Purpose and Scope

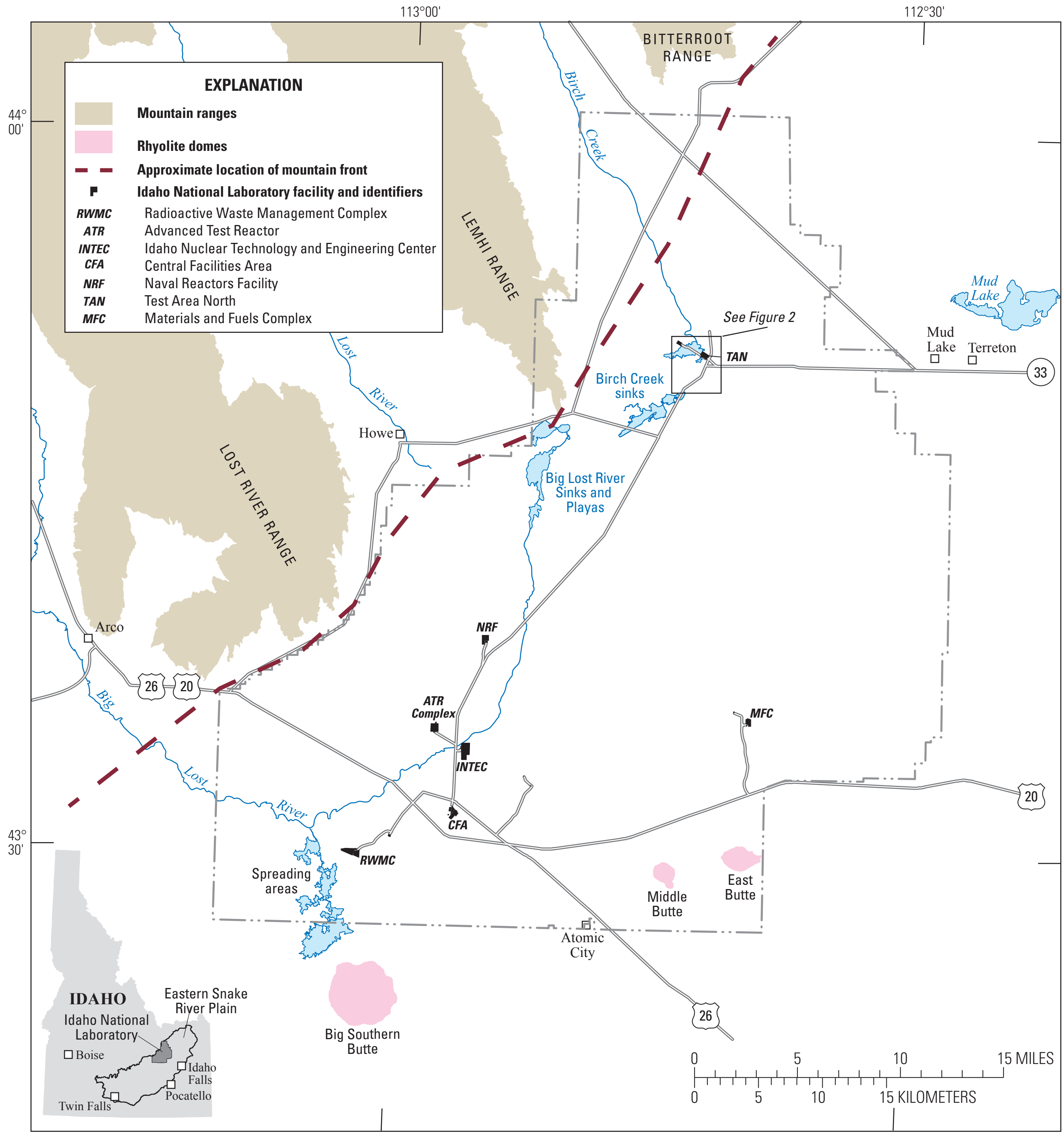
The purpose of this study is to better understand the hydrogeology in the northern part of the INL, specifically at TAN. Borehole TAN-2312 was located downgradient from the TAN facility; data collected will be used to characterize both radiochemical and chemical waste plumes that are currently undergoing treatment. Geologic, geophysical, and aquifer test data were collected and analyzed to determine lithologic and hydraulic properties. Additionally, water samples were collected and analyzed to provide water-quality data after construction. This report presents results of the drilling, coring, construction, geophysical logging, aquifer testing, and water sampling for borehole TAN-2312. General lithologic descriptions of the drill core for borehole TAN-2312 are provided and detailed descriptions are included in appendixes 1–3. This report presents a comprehensive suite of water samples analyzed for inorganic, organic, stable isotopes, and radionuclide constituents, and results.

Hydrogeologic Setting

The INL is in the west-central part of the ESRP (fig. 1). The ESRP is a northeast-trending structural basin about 200 miles (mi) long and 50–70 mi wide. Formation of 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, 0.6–1.2 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). Figure 3 includes 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. 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 of 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).



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

Figure 1. Location of selected facilities at the Idaho National Laboratory, Idaho.

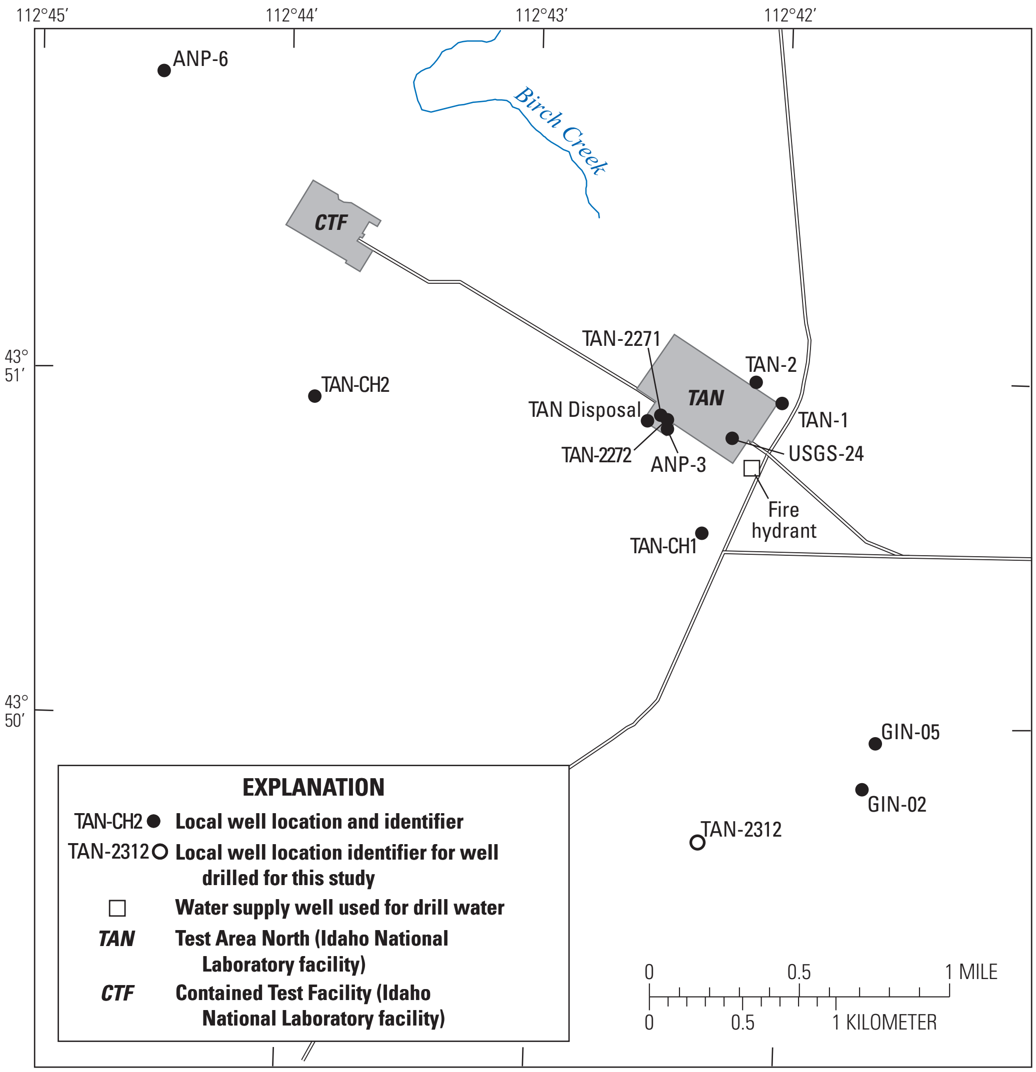


Figure 2. Location of well TAN-2312 and selected monitor wells, Test Area North, Idaho National Laboratory, Idaho.

Throughout the INL, the March–May 2015 water-table altitude ranged from about 4,560 to 4,410 ft (Bartholomay and others, 2017, fig. 9); at borehole TAN-2312, the altitude of the water table is about 4,544 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 measured in borehole TAN-2312 is about 244 ft BLS. Most 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 1.1–760,000 feet squared per day (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 feet per mile (ft/mi); the average is about 4 ft/mi (Bartholomay and others, 2017, fig. 9). Horizontal flow velocities of 2–20 feet per day (ft/d) have been calculated based on the movement of various chemical and 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 and 150 ft/d, respectively (Nimmo and others, 2002; Duke and others, 2007).

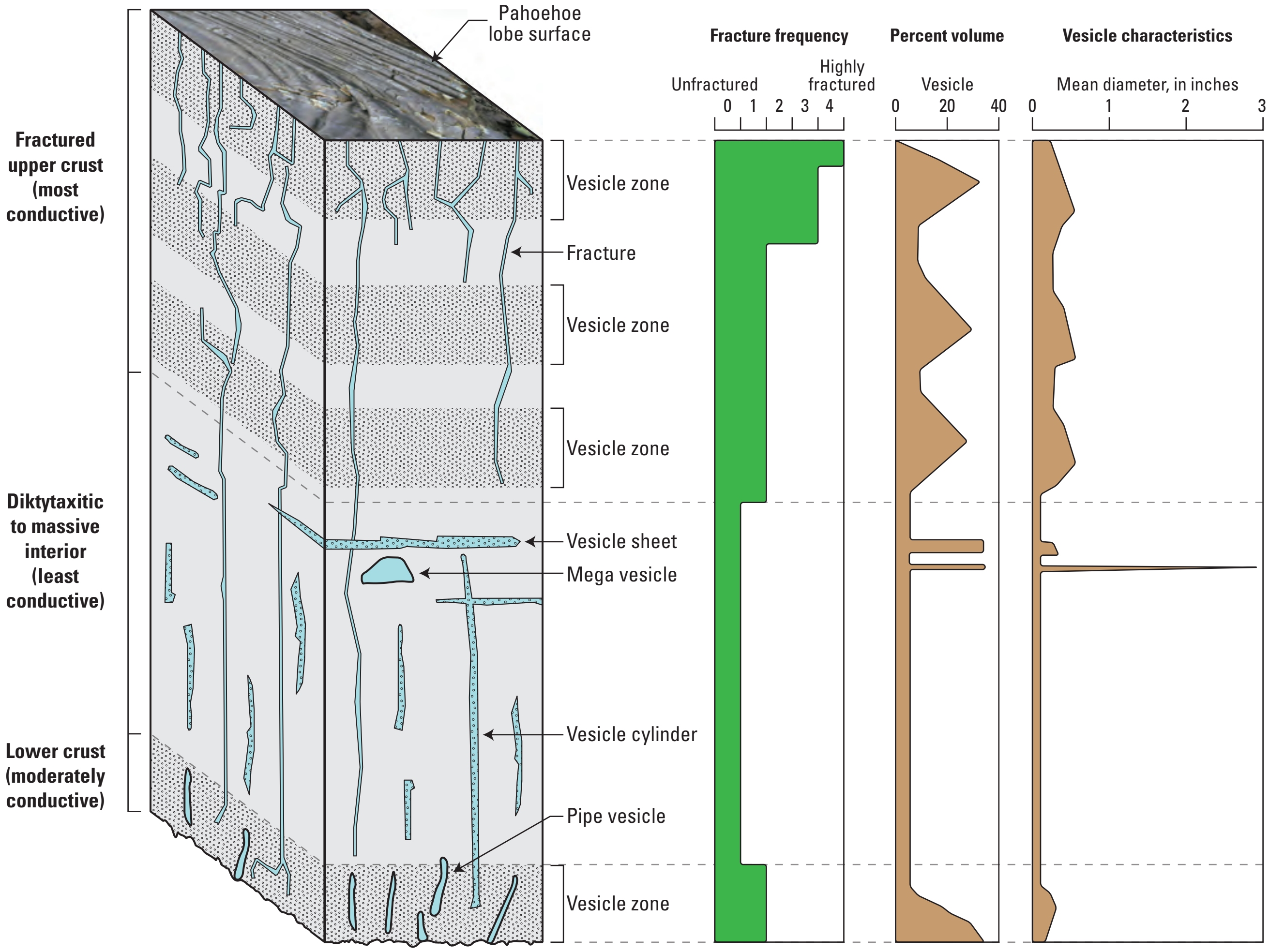


Figure 3. Idealized typical olivine tholeiite pahoehoe basalt flow (modified from Self and others, 1998, fig. 3, p. 90). The basalt flow is divided into three sections based on vesicle characteristics and fracture frequency. Hydraulic conductivity is highest for the fractured upper crust, moderate for 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.

Previous Investigations

The USGS INL Project Office has been involved with providing completion reports for special studies addressing drilling and testing of wells for the ESRP aquifer at the INL. USGS INL Project Office has also been involved with the collection and interpretation of geophysical data collected throughout the INL and surrounding area. A comprehensive listing of publications by the USGS is available through weblink—https://www.usgs.gov/centers/id-water/science/publications-idaho-national-laboratory?qt-science_center_objects=0#qt-science_center_objects.

Twining (2016) investigates borehole deviation data for wells constructed within the ESRP aquifer. This well completion summary report examines deviation data collected through gyroscopic and magnetic methods and presents correction factors for water-level observations at well sites at and near the INL.

Twining and others (2016) summarizes the data collected during the drilling, construction, and testing of boreholes TAN-2271 and TAN-2272. Data collected include: geophysical logging data, aquifer testing data, and groundwater sampling data. The collection methods and analysis described for boreholes TAN-2271 and TAN-2272 are very similar methods and analysis used for borehole TAN-2312. The reported data were provided to DOE and the supporting contractor for ongoing monitoring at the TAN facility.

Drilling and Borehole Construction Methods

Drilling, well construction, and hydraulic testing by the USGS took place between July 25, 2017, and September 27, 2017. All activities were in accordance with the USGS INL Site Safety Plan (Roy Bartholomay, U.S. Geological Survey, written commun., December 16, 2016) and the INL Environmental Checklist requirements. Prior to drilling startup, construction barriers were established and a job-site, pre-job, safety briefing was held July 25, 2017. Regular equipment inspections and safety discussions were documented and weekly drilling updates were distributed by email during the project. Safety Data Sheets for chemicals used during drilling are included in appendix 1. A summary of driller notes along with daily activity are included in appendix 2.

Where drilling was done downgradient of the TAN facility (fig. 1), State regulatory agencies required drill fluid returns to be diverted to holding tanks (frac-tanks) after 244 ft BLS, approximate depth to ESRP aquifer. Drill cuttings and fluid returns, diverted to frac-tanks, were handled by Waste Generator Services at the INL for disposal. Water used during coring, reaming, and well construction was supplied from a fire hydrant located at TAN (fig. 2).

Drilling Techniques and Equipment

Borehole TAN-2312 was continuously cored from about 37 to 568 ft using a Christensen™ CS 1500 rotary drilling rig and HQ-size coring system, where HQ refers to core rod sizing (drill-bit size about 3.8-in. diameter). The core system was setup with carbide and diamond core bits, core catchers, and latch assembly for core retrieval (fig. 4). Core was retrieved in 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 orientation and depth in the field before boxing. Once cleared, the cores where taken to CFA-663 to be photographed and archived at the INL Lithologic Core Storage Library (appendix 3), which is operated by the USGS at the Central Facilities Area (CFA) (fig. 1).

Rotary tri-cone drilling, downhole hammer (DHH) drilling, and setting well casing segments were performed using a GEFCO™ SD-300. The rig was initially used to tri-cone drill and drive 16-in. diameter casing to the first basalt contact in borehole TAN-2312. Additionally, the SD-300 drill rig was used to re-drill (ream) 15-in, 13-in., and 9.9-in. diameter borehole sections during the construction phase. Spiral stabilizers, sized to the drill bit diameter, were used to keep the borehole straight and plumb while reaming. Air and water were the primary fluids while reaming; however, Baroid® Quik-Foam® (foam) was introduced to improve cutting returns to surface, when necessary (appendix 1).

Pressurized air and water were used to complete HQ-coring for borehole TAN-2312 from about 37 to 568 ft BLS. Water and air usage ranged from 2 to 5 gallons per minute (gal/min), with air pressures ranging from 100 to 350 lb/in^2. Core drilling fluid from land surface to about 244 ft BLS was disposed to the ground; however, drill fluid returns from about 244 to 568 ft BLS were diverted to frac-tanks for later disposal. Core drilling for borehole TAN-2312 generated approximately 4,000 gal of drill fluid returns.

Pressurized air, water, and drill foam were used during reaming 15-in., 13-in., and 9.9-in. diameter sections in borehole TAN-2312. Drilling fluid was continuously injected at rates of about 2–4 gal/min. Reaming was completed and well casing placed down to 228 ft BLS before core drilling into the aquifer. Borehole TAN-2312 was constructed as open hole (9.9-in. diameter) between 228 and 522 ft BLS, see fig. 5. Drill fluid and cutting material for the 9.9-in. diameter borehole were diverted to 21,000 gal frac-tanks. Approximately 38,000 gal of fluid returns were generated during reaming and approximately 3,000 gal of water were generated during development of borehole TAN-2312 from 244 to 522 ft BLS.

Detailed Drilling Activity

Drilling at borehole TAN-2312 started July 25, 2017, using a modified tri-cone to drill to the first basalt. After removing the bit assembly, 16-in. diameter well casing was placed to a depth of 37 ft on July 26, 2017, and about 5 ft^3 of granular bentonite casing seal was set behind the casing on July 31, 2017. Once the surface casing was in the ground, the SD-300 drill rig was changed out for the CS-1500 core rig.

Core drilling (HQ-size) in borehole TAN-2312 was done in two stages, stage 1 involved coring from about 37 to 227 ft BLS (August 1–3, 2017) and stage 2 included core drilling from 228 to 568 ft BLS (August 17–30, 2017). Reaming for borehole TAN-2312 was completed following coring for both stage 1 (unsaturated zone) and stage 2 (saturated zone).

On completion of stage 1 core drilling, borehole TAN-2312 was reamed to 15-in. diameter from 37 to 84 ft BLS on August 7, 2017 (appendix 2). Afterwards, temporary well casing (14-in. diameter) was placed down to 84 ft BLS to hold back an unstable sediment layer that existed from about 52 to 82 ft BLS (appendix 2). The 14-in. diameter well casing was placed as a precautionary measure to prevent potential problems when reaming to 13-in. diameter. The 14-in. diameter well casing was removed August 14, 2017.

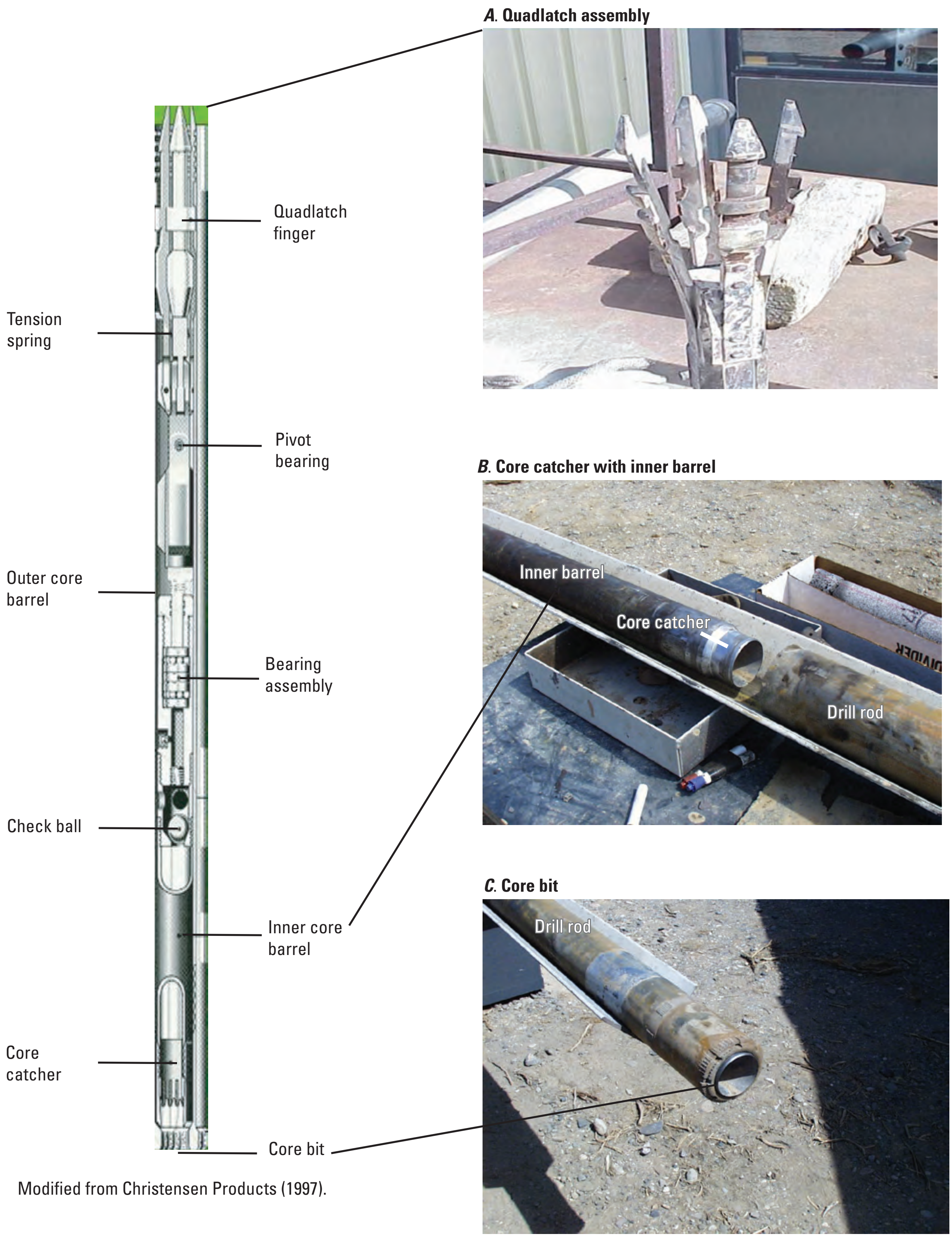


Figure 4. HQ-size coring system similar to one used for coring. HQ refers to core rod sizing (drill-bit size about 3.8-in. outer diameter).

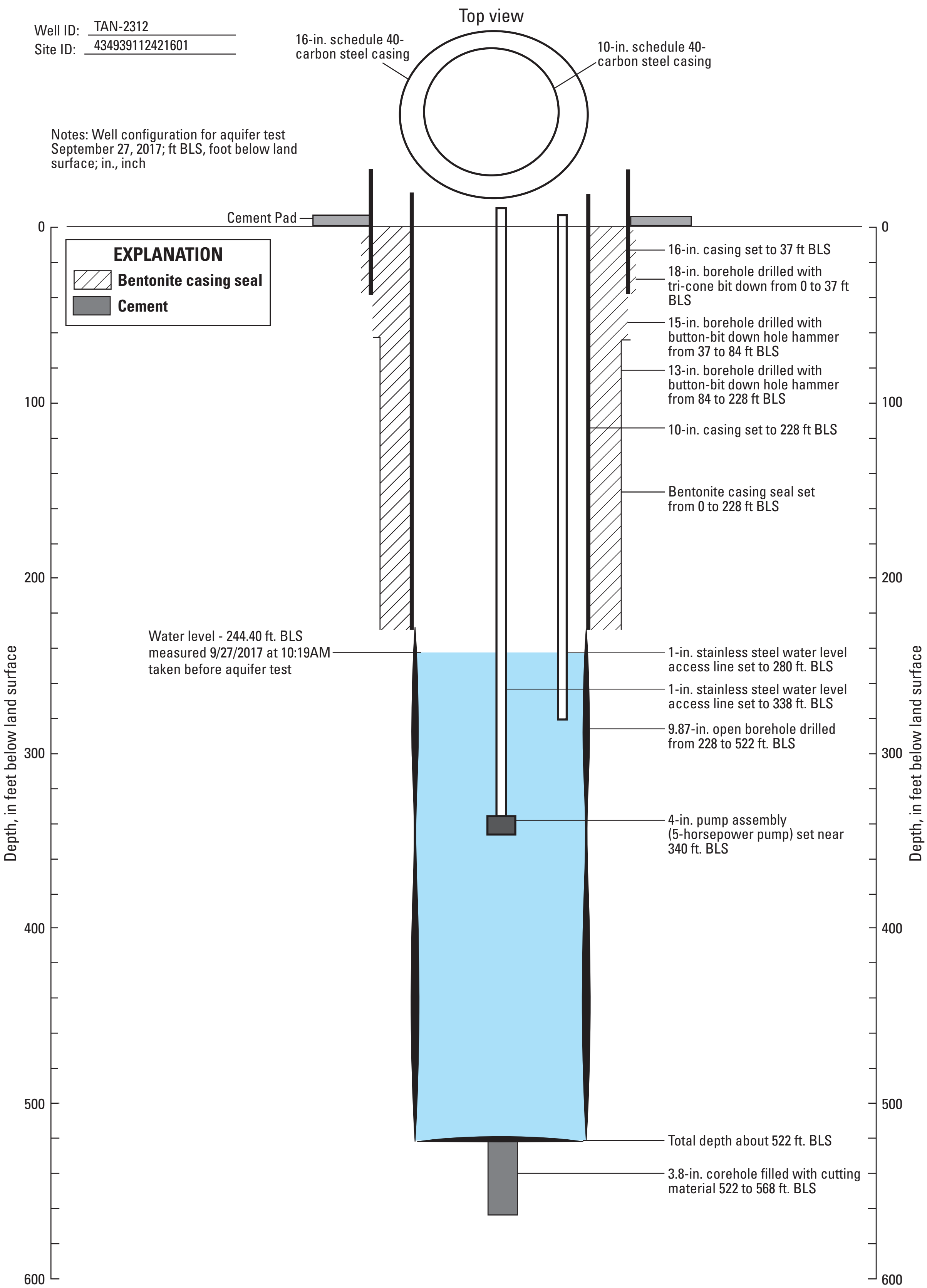


Figure 5. Final constructed well TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

Starting August 9, 2017, borehole TAN-2312 was reamed to 13-in. diameter from 84 to 228 ft BLS, 1 ft past where core drilling stopped. Afterwards, 10-in. diameter well casing was placed down to 228 ft BLS and the borehole annular space was filled in with approximately 42 ft^3 of bentonite casing seal on August 15, 2017 (fig. 5). The bentonite casing seal was installed dry; Izbiki and others (2000) have shown through repeated neutron logging that bentonite hydrates and forms an effective low-permeability seal after installation within the borehole. Frequent sounding measurements along with approximated material volume calculations were used to confirm accurate backfill material placement.

The second stage of coring, followed by reaming, required fluids to be placed in frac-tanks. Core drilling was halted at a depth of 568 ft BLS, stopping in dense basalt. Reaming was completed from 228 to 522 ft BLS (September 6–20, 2017). Reaming was halted at 522 ft BLS, completing the well about 278 ft into the ESRP aquifer (244 to 522 ft BLS). Near 500 ft BLS, reaming to 9.9-in. diameter started to slow because of fluid pressure over the DHH bit. At a depth of 518 ft BLS, drilling was halted and the DHH was changed out for a tri-cone bit assembly on August 19, 2017. Reaming using a 9.9-in. diameter tri-cone bit assembly was resumed from 518 to 522 ft BLS; however, progress was very slow through dense basalt sections. After reaming and before removing the tri-cone assembly, borehole TAN-2312 was developed by blowing air to develop from the bottom of the borehole, this generated approximately 3,000 gal of water. The afternoon of August 20, 2017, drilling was stopped and the tri-cone drilling assembly was removed from borehole TAN-2312 to allow it to sit and clear up over the weekend. A borehole video, taken August 25, 2017, confirmed the completion depth of 522 ft BLS and that the cored section, from 522 to 568 ft BLS, was filled with drill cutting material and was not accessible (fig. 5, appendix 2).

On September 27, 2017, borehole TAN-2312 was configured with a temporary Grundfos™ 5-horsepower SS submersible pump, 4-wire (7 gauge) pump wire, 1-in. diameter SS discharge line, and 1-in. diameter SS water-level line placed (fig. 5). The submersible pump intake was set near 340 ft BLS for aquifer testing and well development, and the 1-in. diameter measuring line was installed down to about 280 ft BLS. The final construction of borehole TAN-2312 (fig. 5) includes (1) 16-in. diameter carbon steel casing extending from 3.5 ft above land surface to 37 ft BLS, (2) 10-in. diameter threaded carbon steel casing extending from 2.8 ft above land surface to 228 ft BLS, and (3) 9.9-in. inside diameter open borehole from 228 to 522 ft BLS. Surface completion includes a 4-ft diameter concrete pad complete with a brass survey marker, and a locking wellhead (table 1).

Table 1. Location and completion information for well TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

[Location of well is shown in figure 2. **Local name:** Local well identifier used in this study. Site identifier: Unique numerical identifier used to access well data (http://waterdata.usgs.gov/nwis). Longitude, Latitude, and Measurement point elevation: Survey taken at brass survey marker (brass cap) located adjacent to well head on cement pad. Aquifer thickness: The altitude of the base of the aquifer as interpreted from geophysical surveys (Whitehead, 1992) subtracted from the measured depth to water (altitude of water table). Open borehole diameter: Based on drilled diameter of open borehole interval. **TAN-2312:** NAD 27, North American Datum of 1927; NGVD 29, National Geodetic Vertical Datum of 1929; AMSL, above mean sea level; BLS, below land surface; ft, foot; in., inch]

Local name	TAN-2312
Site identifier	434939112421601
Longitude	112°42'16.6" (NAD 27)
Latitude	43°49'39.7" (NAD 27)
Measurement point elevation	4,796 ft (NGVD 29) AMSL (approximate)
Aquifer thickness	700 ft
Completion depth	522 ft BLS
Drill depth	568 ft BLS
Open borehole diameter	9.9 in.
Casing diameter	10 in.
Top of open borehole	228 ft BLS
Bottom of open borehole	522 ft BLS
Depth to water	244.40 ft BLS, measured September 27, 2017, at 10:19 a.m.

Geologic and Geophysical Data

Geologic data were collected and analyzed from core material to provide rock and sediment properties; additionally, geologic and hydrologic data, including geologic contacts, were interpreted from geophysical logs collected and analyzed for borehole TAN-2312. Geophysical logs provide a complete and continuous formation representation adjacent to the well bore and offer more consistency when selecting depths for geologic contacts, when core recovery is sometimes incomplete. Rock and sediment core recovered from borehole TAN-2312 was photographed and labeled to provide detailed lithologic descriptions from 37 to 568 ft BLS. Core photographs and lithologic descriptions are presented in appendix 3.

The wireline geophysical logging equipment, operated by the USGS, was used to collect data in borehole TAN-2312. Geophysical data were collected during various stages of drilling and construction; additionally, video data were collected and used to evaluate the condition of borehole TAN-2312. Geophysical log data included: natural gamma, neutron, gamma-gamma dual density, acoustic caliper, temperature, specific conductance, electromagnetic flow meter (EMFM), acoustic televiewer, and gyroscopic deviation. Geophysical log data were collected and saved as electronic files in the form of physical measurement and depth and processed using WellCAD™ software. Geophysical data, once processed, were used to suggest geologic and hydrologic characteristics. The geophysical and video log data collected are summarized in table 2. Geophysical data are available upon request through the USGS INL Project Office or through weblink—https://webapps.usgs.gov/GeoLogLocator/#!/.

Geology

The land surface at borehole TAN-2312 is sparsely vegetated loess. Surface sediment was not cored, but described in drill cuttings as an unconsolidated mixture of poorly developed soil consisting of fine to coarse sand to the first basalt contact, near 37 ft BLS. Surface materials were described from drill cuttings observed while drilling and driving 16-in. diameter surface casing (appendix 2).

Table 2. Summary of geophysical and video log data collected from borehole TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

[Geophysical data presented in this report were collected using one or more of the following logging tools listed below. **Log type:** Description of geophysical log trace presented. **Tool ID:** Century Geophysical Corporation ™ tool number as referenced on web site http://www.century-geo.com/; WC-1750 camera designed by Aries™ Industry. **Depth:** Logging depth reported from land surface measurement point. **Date** and **Time:** Refers to date and local time the log was time stamped in month-day-year and hours:minutes. **Sensor uncertainty:** Uncertainty specfied by tool manufacturer. **Comments:** explanations where needed. **Abbreviations:** ID, Identifier; NA, not applicable; BLS, below land surface; in., inch; ft, foot; ft/min, foot per minute; gal/min, gallon per minute]

U.S. Geological Survey geophysical logging files							
Log type	Tool ID	Depth (ft BLS)		Date	Time	Sensor uncertainty	Comments
		Top	Base				
Natural Gamma	9057A	0	567	09-05-17	11:07	±5 percent	Run after coring HQ-size (3.8-in.) drill rod set at 568 ft BLS
Acoustic Caliper	9804C	230	522	09-25-17	11:30	±0.1 in.	Run after reaming to 9.9-in., open hole from 228–522 ft BLS
Neutron	9057A	0	567	09-05-17	11:30	±5 percent	Run after coring HQ-size (3.8-in.) drill rod set at 568 ft BLS
Gamma-gamma density	0024A	0	566	09-05-17	13:22	±5 percent	Run after coring HQ-size (3.8-in.) drill rod set at 568 ft BLS
Temperature and specific conductance	9042A	0	521	09-26-17	08:35	±5 percent	Run after reaming to 9.9-in., open hole from 228–522 ft BLS
Gyroscopic deviation	9095	0	553	09-05-17	11:23	±0.5 degree	Down log, run after coring HQ-size (3.8-in.) drill rod set at 568 ft BLS
	9095	0	553	09-05-17	11:51	±0.5 degree	Up log, run after coring HQ-size (3.8-in.) drill rod set at 568 ft BLS
Electromagnetic flow meter (EMFM)	9721	250	500	09-25-17	13:51	±5 percent	Ambient stations - run after reaming to 9.9-in. open hole 228–522 ft BLS
	9721	250	513	09-26-17	10:13	±5 percent	Trolling up at 5 ft/min - run after reaming to 9.9-in. open hole 228–522 ft BLS
	9721	250	514	09-26-17	11:18	±5 percent	Trolling up at 10 ft/min - run after reaming to 9.9-in. open hole 228–522 ft BLS
Acoustic Televiewer	9804C	0	522	09-25-17	11:30	±5 percent	Run after reaming to 9.9-in., open hole from 228–522 ft BLS
Borehole Video	WC-1750	0	522	09-25-17	11:30	±0.15 in.	Run after reaming to 9.9-in., open hole from 228–522 ft BLS - cloudy
	WC-1750	225	523	10-10-17	11:30	±0.15 in.	Run after reaming to 9.9-in., open hole from 228–522 ft BLS - mostly clear

Excluding surficial sediment (0–37 ft BLS), four sediment layers were observed between 37 and 568 ft BLS in borehole TAN-2312 (appendix 3). Including surficial sediment, sediment constitutes about 14 percent (77 of 568 ft) by volume of borehole TAN-2312. Most of the sediment for borehole TAN-2312 was described for the unsaturated zone, above 244 ft BLS. Sediment layer(s) described for the saturated zone were minor and makeup a very small percentage of the saturated zone. Sediment layers described for borehole TAN-2312 consist of fine sand, silt, and clay.

Upon inspection of geophysical data, about 32 basalt flows were observed in borehole TAN-2312 (appendix 3). Core material presented in appendix 3 confirms location of most basalt flows; however, some material was missing and not all flow contacts were labeled. Basalt textures for borehole TAN-2312 varied between aphanitic, phaneritic, diktytaxitic, and porphyritic. In general, the basalts are medium to dark gray in color. Basalt flows in borehole TAN-2312 ranged in thickness from about 3 to 82 ft and varied from massive to fractured, with varying degrees of vesiculation. Detailed core descriptions and photographs for borehole TAN-2312 (37–568 ft BLS) are included in appendix 3.

Geophysical Logs

Geophysical data were collected using Century Geophysical Corporation™ logging equipment, and the resulting data files were processed using WellCAD™ analytical software. Borehole video logs were recorded using an Aries Industry™ WC-1750 downhole color camera. The USGS calibrates geophysical logging equipment annually; logging equipment sensor uncertainty is specified on table 2. A composite of natural gamma, neutron, and gamma-gamma dual density along with well design and general lithology from land surface to completion depth are shown in figure 6.

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 contain varying 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 to 568 ft BLS, with drill rods placed on the bottom (fig. 6). Excluding surface sediment, the tops of sediment layers were at approximately 52, 159, 296, and 481ft BLS in borehole TAN-2312 (fig. 6 and appendix 3). Sediment layer thickness ranges from 37 ft (surface sediment) to less than 2 ft and mostly consisted of fine grained sand, silt, and some clay. Most of the sediment reported in borehole TAN-2312 is present within the unsaturated zone, above 244 ft BLS. Approximately 3 ft of sediment resides in the saturated zone described at this well location. Fine grained sediment fill, described in borehole TAN-2312 fractures, did now show up in natural gamma traces (fig. 6); however, sediment was described in core material (appendix 3).

Caliper Logs

The acoustic caliper log scans the borehole and converts the reflected travel time to distance between the sonde and the borehole wall. The acoustic caliper log uses acoustic transit and velocity data to generate directional caliper in the X and Y directions, noted as ATV X and ATV Y respectively (fig. 7). The acoustic caliper log generates a continuous profile of the borehole diameter as the tool is raised from the bottom of the borehole. The acoustic caliper tool can detect subtle changes in borehole diameter, greater than or equal to 0.1-in.

Acoustic caliper logs were collected after reaming borehole TAN-2312 to 9.9 in. (fig. 7) and used to confirm rock property changes, such as fractured and vesicular to dense basalt. Acoustic caliper data collected for borehole TAN-2312 show remnant traces of the drilled HQ-size corehole, drilled before reaming (fig. 7). The drilled corehole trace is detected as noise recorded in the acoustic caliper data. Fractured and (or) vesicular zones, identified in caliper logs, correlate with elevated neutron porosity data and changes in density. Fracture and (or) vesiculated zones are considered the primary water producing zones where groundwater flow is expected.

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. 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 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.

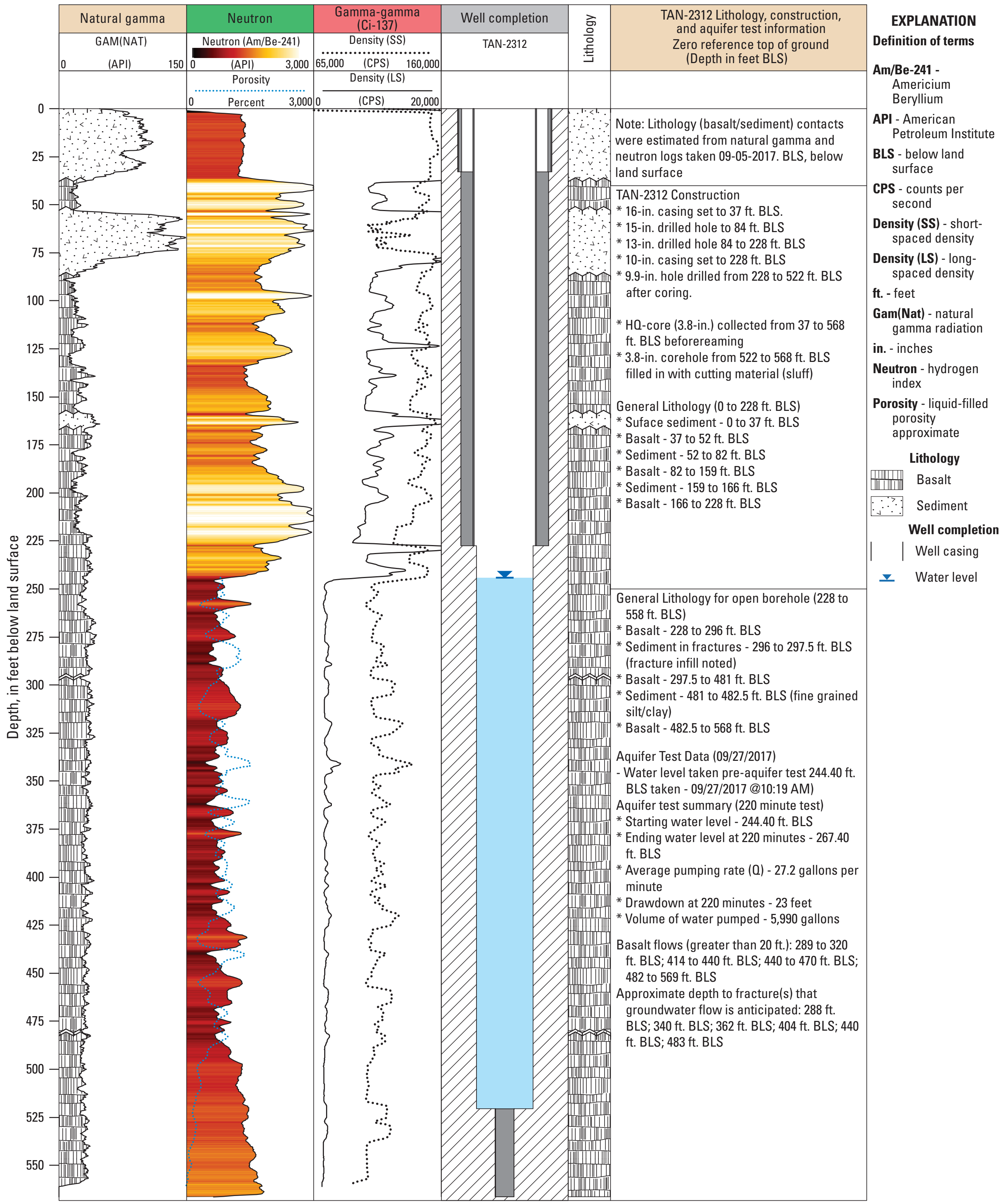


Figure 6. Geophysical logs run from total depth to land surface and lithologic logs described from cores, video logs, and geophysical logs for borehole TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

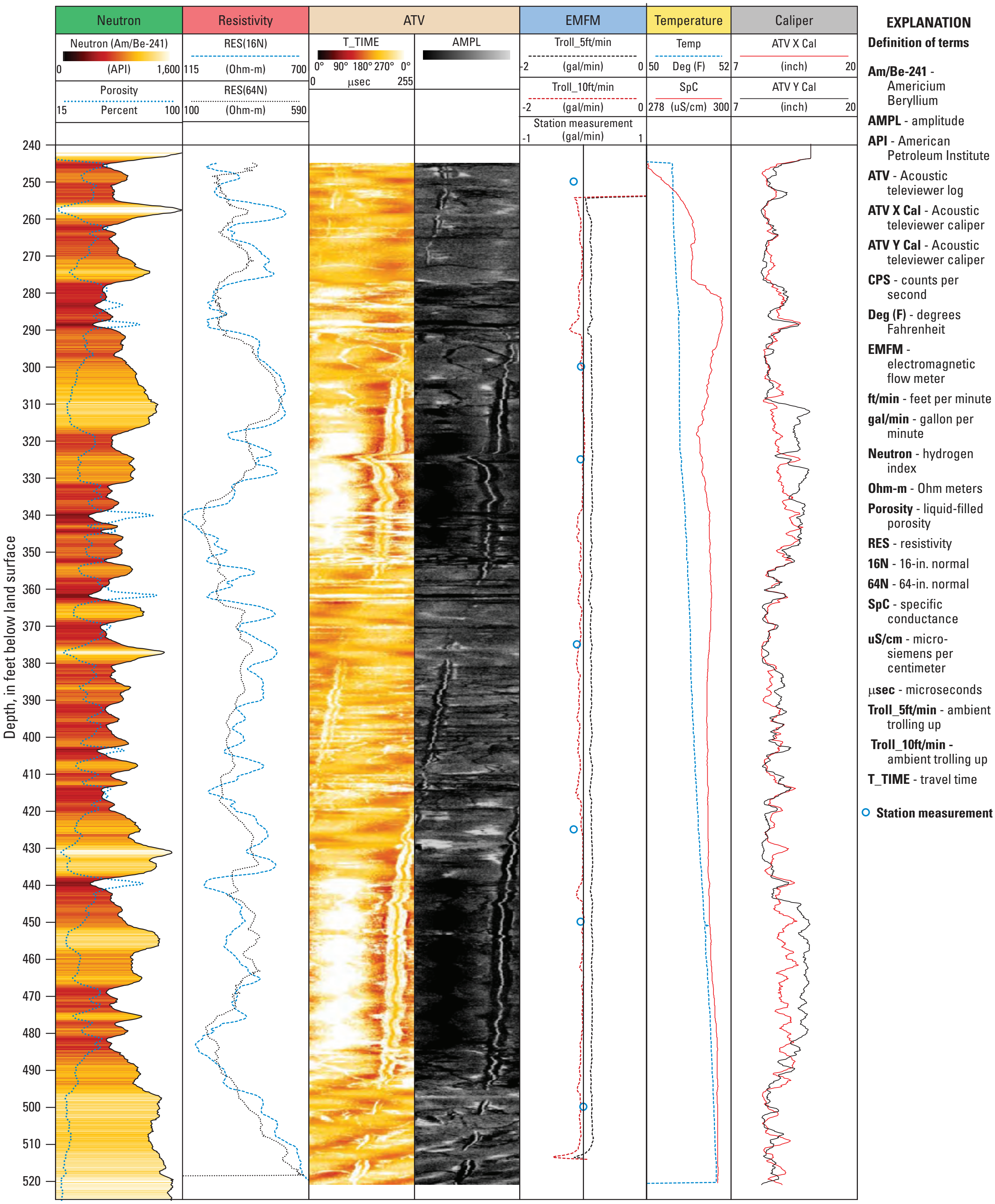


Figure 7. Expanded geophysical and lithologic logs with focus on depths 240–525 feet below land surface for borehole TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

Neutron logs were collected after HQ-size coring (borehole 3.8-in. diameter) and with temporary drill casing extended to bottom of the borehole. Review of the neutron data indicated no evidence of perched water (land surface to about 244 ft BLS). Neutron logs were examined for the open-hole section of aquifer to identify areas of high and low hydrogen content in borehole TAN-2312 (fig. 7). A color gradient, ranging from red (high hydrogen content) to white (low hydrogen content), was applied to approximate the location of water-producing zones in figure 7. The neutron logs show good agreement with HQ-size core collected from borehole TAN-2312 (fig. 7, appendix 3), where 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. Based on basalt-hydrogen correlations, neutron logs show evidence for fractured and vesicular basalt, indicative of more productive water-producing zones, within the open-hole intervals at these approximate depth(s): 282–288; 339–342; 360–363; 402–406; 438–441; and 481–484 ft BLS (figs. 6 and 7).

Gamma-Gamma Dual Density Logs

The principle behind density logging is the detection of Compton-scattered gamma rays that originate from a small radioactive source. The intensity of the gamma radiation reflected to the probe is primarily a function of electron density of the media after it is backscattered or absorbed in a drill hole, borehole fluid, or surrounding media. The type of density probe used for this investigation is the omni-directional, dual detector sonde that responds to density variation in counts per second (CPS), registering higher CPS counts for lower density material.

Gamma-gamma dual density logs were collected after coring to 568 ft BLS in borehole TAN-2312 (fig. 6). Density logs were used to identify areas of dense, as opposed to fractured, basalt. The location of fracture zones indicated by gamma-gamma logs are consistent with zones indicated by other geophysical methods.

Fluid Logs

Fluid specific conductance and temperature were measured after reaming borehole TAN-2312 to 9.9-in. (fig. 7). Specific conductance and temperature were measured within the fluid column, from 244 to 522 ft BLS, after the boreholes had about 6 days to stabilize from drilling activity. Specific conductance measures the ability of a fluid to conduct electric current; changes in specific conductance are generally related to amount of dissolved solids in a fluid. Specific conductance and temperature provide a general indicator for changing water chemistry and can indicate where groundwater is moving through factures and (or) sediments to a borehole in a basalt-sediment aquifer system.

Specific conductance in borehole TAN-2312 ranged from about 278 to 298 microsiemens per centimeter (µS/ cm; fig. 7). Specific conductance data suggest fractures near 288 and 340 ft BLS indicate a 20 µS/cm and 10 µS/cm conductance increase, respectively, likely from groundwater inflow. Fractures near 288 and 340 ft BLS were also identified by neutron logging. Specific conductance does not change much, if any, for fractures below 340 ft BLS. In general, the specific conductance profile for borehole TAN-2312 suggests that the groundwater chemistry is very similar throughout the water column, but the upper 100 ft of the aquifer appears to be where most groundwater movement occurs.

Water temperature in borehole TAN-2312 ranged from 50.1 to 51.7 °F (fig. 7). Water temperature changes about 1.6 °F over 278 ft, suggesting a temperature gradient of approximately 0.6 °F per 100 ft. The temperature data suggest that groundwater inflow and outflow within the fluid column profiled are minimal for borehole TAN-2312.

Electric Logs

Electric logs were collected after reaming borehole TAN-2312 out to 9.9-in. diameter. These electric logs include normal resistivity logs (16-in. normal and 64-in. normal). The normal-resistivity logs record the electrical resistivity of the surrounding rocks and groundwater as measured by variably spaced potential electrodes, located on the logging probe. Normal resistivity logs were used to confirm stratigraphic layering in basalt flow units within borehole TAN-2312 (fig. 7).

Acoustic Televiewer Logs

Acoustic televiewer (ATV) logs display high resolution images of the borehole wall by rotating a transducer that transmits digital ultrasonic pulses. The transit time (T_Time) and amplitude (AMPL) of the reflected acoustic signal are recorded as photographic-like images (fig. 7). The image data are captured once the probe enters the saturated zone and can be run within water or light drilling mud filled borehole(s). Lithologic changes, foliations, bedding, and sealed fractures may be detected even when there is no change in the borehole diameter if there is sufficient acoustic contrast (Williams and Johnson, 2004). The USGS uses the ATV log data along with the borehole core to determine the location of fractures, fracture thickness, and sediment zones.

The ATV logs for borehole TAN-2312 were run after reaming to 9.9-in. diameter using centralizers for positioning the tool. The 9.9-in. diameter was outside of the diameter suggested for running ATV logs, where the suggested diameter range is 2.9–9.0-in. (Williams and Johnson, 2004); however, the tool was run slowly (3–4 feet per minute) and the data collection interval was set to 0.02 ft. The ATV image data for borehole TAN-2312 appear to correlate well with neutron logs displayed in figure 7. Flow contacts and areas of dense basalt were imaged for the section between 244 and 522 ft BLS. The line that appears throughout the ATV image is remnant of the corehole drilled prior to reaming. The ATV data indicate location of basalt fractures and correlates with flow contacts identified in neutron logs (fig. 7).

Electromagnetic Flow Meter Logs

The design of the EMFM is based on Faraday's Law of Induction: voltage induced by a conductor moving at right angles through a magnetic field is directly proportional to the velocity of the moving conductor. The EMFM measures the voltage generated by an electrical conductor (water) passing through the inside of a hollow cylindrical section, within the flowmeter, that is surrounded by electromagnets. Groundwater flow through this magnetic field induces voltage that is measured by electrodes and then used to calculate a volumetric flow rate (Paillet, 2000). EMFM logs were used to identify vertical flow and to identify fractures and zones that contribute groundwater, or both; negative (-) values represent groundwater moving down (down flow) and positive (+) values represent groundwater moving up (up flow). Data were collected in unpumped (ambient) conditions using EMFM methods described by Paillet (2000).

Ambient wellbore flow was collected for borehole TAN-2312; wellbore flow under stressed conditions was not collected. The large diameter (9.9-in.) of borehole TAN-2312 made for non-ideal conditions to collect EMFM data; however, EMFM logs were primarily used to suggest the location of fractures where groundwater is flowing. Groundwater inflow and outflow are the result of vertical differences in water pressure (head). To examine ambient wellbore flow, EMFM logs were collected in the upward direction at two trolling speeds (5 and 10 ft/min) for borehole TAN-2312; additionally, stationary measurements were collected at seven discrete depth stations, between 250 and 500 ft BLS (fig. 7). The EMFM trolling data were collected without the use of a diverter, but centralizers, fitted to the borehole diameter, were used to center the tool within the borehole. Station measurements required a rubber diverter, fitted to the borehole diameter, along with centralizers. All seven stationary measurements were adjusted for zero-flow response at 500 ft BLS, a section of borehole considered dense basalt where groundwater flow was considered zero, but was measured as -0.9 gal/min. Adjusted stationary measurements ranged from 0.00 to -0.15 gal/min for borehole TAN-2312 and EMFM data suggest minimal groundwater inflow and outflow from fractures throughout the water column (fig. 7). Trolling and station measurements were collected by sending the tool to the bottom, allowing it to sit for about 15 min, and collecting data while moving the tool at a constant speed in the upward direction.

Five zones of groundwater movement were identified from the EMFM trolling and stationary measurements, near: 288 ft BLS, 340 ft BLS, 362 ft BLS, 440 ft BLS, and 483 ft BLS (fig. 7). Groundwater inflow and outflow were measured near fractured flow contacts also identified in neutron and acoustic logs (figs. 6 and 7). EMFM data are consistent with fluid logs and suggest fractures within the upper 100 ft of the aquifer appear to be where most groundwater flow occurs. Borehole TAN-2312 EMFM data suggest minimal change in head pressure throughout the fluid column (244–522 ft BLS) and slight downward flow that ranges from 0.00 to -0.15 gal/min.

Gyroscopic Deviation Survey

A borehole gyroscopic deviation survey was run after coring to total depth for borehole TAN-2312 (fig. 8). The gyroscopic deviation survey procedure and equations used to compute calculated offset, northing, easting, distance, and azimuth are explained in Twining (2016). Gyroscopic deviation data are continuously collected at regular spaced intervals (0.20 ft) and post-processing software, proprietary to Century™, is used to compute the wellbore path using reference angles SANG and SANGB, referred to as the slant angle (inclination) and slant angle bearing (azimuth), respectively.

Deviation survey data used to compute the wellbore path are shown in 50-ft increments from 0 to 550 ft BLS in borehole TAN-2312 (table 3; fig. 8). The calculated offset for borehole TAN-2312 accounts for horizontal and vertical displacements at various depths; however, at a survey depth near 244 ft (approximate depth to water), the calculated offset is 0.01 ft (table 3). The USGS uses a water-level correction when the gyroscopic deviation survey suggests the calculated offset exceeds 0.20 ft (Twining, 2016); therefore, no water-level correction was necessary for borehole TAN-2312. The borehole-deviation survey results are summarized in table 3.

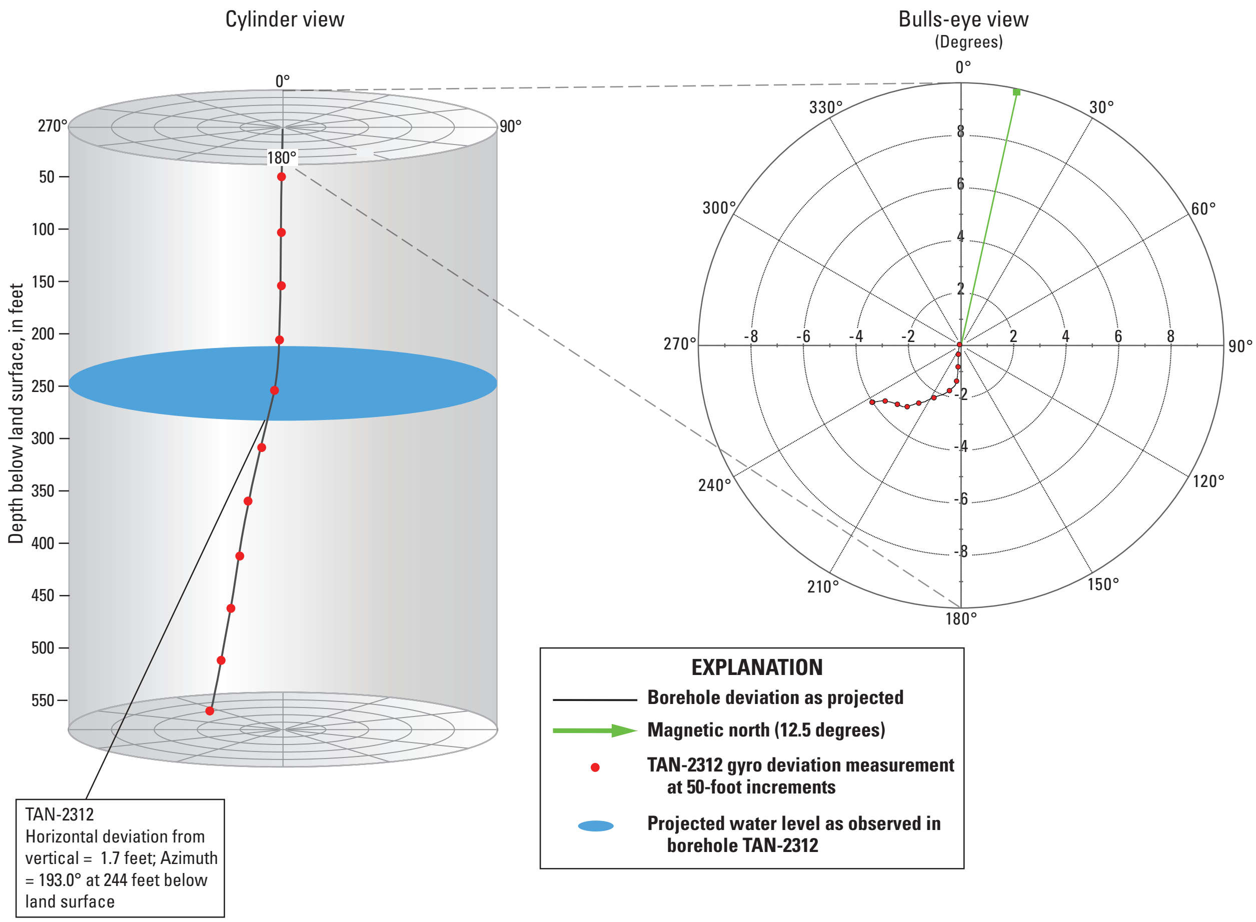


Figure 8. Gyroscopic deviation data collected for borehole TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

Table 3. Gyroscopic deviation data from processed survey for borehole TAN-2312, Idaho National Laboratory, Idaho.

[Borehole deviation profile shown in figure 8. Survey performed using a Century Geophysical Corporation™ 9095 logging tool with magnetic declination was set at constant 12.5 degrees. **Local name:** The local well identifier used in this study. **CD:** Cable depth (CD) is reported from wireline depth. TVD: True vertical depth (TVD) is computed depth using average angles equation (Twining, 2016). CO: Calculated offset (CO) is computed CD minus TVD (CD - TVD). **Northing, Easting**, **Distance,** and **Azimuth:** Computed from the well path survey using SANG and SANGB data. **Abbreviations:** BLS, below land surface; ft, foot; deg, degrees; SANG, refers to inclination or slant angle; SANGB, refers to azimuth or slant angle bearing from well survey].

Local name	CD (ft BLS)	TVD (ft BLS)	CO (CD - TVD) (ft)	Northing (ft)	Easting (ft)	Distance (ft)	Azimuth (deg)	SANG (deg)	SANGB (deg)
TAN-2312	50	50.00	0.00	0.0	-0.1	0.1	298.6	0.2	194.4
	100	100.00	0.00	-0.3	-0.1	0.4	196.2	0.5	187.0
	150	150.00	0.00	-0.8	-0.1	0.8	187.8	0.6	179.9
	200	199.99	0.01	-1.4	-0.2	1.4	187.0	0.4	189.4
	244	243.99	0.01	-1.7	-0.4	1.7	193.0	0.7	233.2
	250	249.99	0.01	-1.7	-0.5	1.8	194.6	0.8	220.7
	300	299.99	0.01	-2.0	-1.0	2.2	207.5	0.8	245.9
	350	349.98	0.02	-2.2	-1.6	2.7	216.2	0.6	258.5
	400	399.98	0.02	-2.3	-2.1	3.1	221.3	0.4	266.3
	450	449.98	0.02	-2.2	-2.4	3.3	227.3	0.6	289.6
	500	499.98	0.02	-2.1	-2.9	3.6	233.7	0.6	270.1
	550	549.97	0.03	-2.2	-3.4	4.0	237.3	0.6	263.0

Aquifer Test

A 220-minute (min) single well aquifer test was conducted in well TAN-2312 on September 27, 2017, starting at 10:20 AM and ending at 2:00 PM. The hydraulic-property estimates were reviewed and recorded in the USGS Groundwater Site Inventory database and data collected during the aquifer test were archived in the USGS Idaho Water Science Center Aquifer Test Archive (appendix 4).

The aquifer-test data were analyzed for pressure change in response to groundwater pumping and atmospheric conditions. Well TAN-2312 shows 23 ft of drawdown at average sustained discharge rates of 27.2 gal/min after 220 min of pumping. Groundwater samples were collected at about 160 min into the aquifer test, with analytical results summarized in the section that follows.

Aquifer-Test Procedures

During the aquifer test in well TAN-2312, fluid pressure head (water + atmosphere), water temperature, and barometric pressure were measured continuously. The fluid pressure head, Ψ_{w+atm}, and temperature were measured with an absolute (non-vented) Solinst® Levelogger®, a self-contained water level and temperature datalogger suspended on a wireline beneath the water table (fig. 9); Solinst® Levelogger® (F65/M20) has a stated full-scale range and accuracy of 65.6 and ±0.032 ft, respectively. The barometric head, Ψ_{atm}, and air temperature were measured with a Solinst® Barologger®, a self-contained atmospheric pressure and temperature datalogger suspended on a wireline above the water table (fig. 9). The fluid pressure head was compensated for changes in atmospheric pressure during the aquifer test and calculated using the following equation:

$$\Psi = \Psi_{w+atm} - \Psi_{atm} \qquad (1)$$

where

Ψ	is the compensated pressure head;
Ψ_{w+atm}	is the fluid pressure head; and
Ψ_{atm}	is the barometric pressure.

Barometric head ranged from 12.46 to 12.49 pounds per square inch (psi) (28.74–28.81 ft of water equivalent) during the 220-min test, the weather was mostly clear, sunny, and with minimal wind (fig. 10). Recovery data was collected but not analyzed.

The pumping rate, Q, associated with well discharge was monitored periodically using a Blue-White® F-2000 paddlewheel flowmeter sensor (figs. 9 and 10). Measured pumping rates remained relatively constant throughout the test, averaging 27.2 gal/min. Pumping rates during the aquifer test in well TAN-2312 ranged from 25.6–28.6 gal/min with time (fig. 10). Total discharge was measured prior to pumping and after turning the pump off, total discharge during the 220-minute test was 5,990 gal. Totalizer readings pre- and post-test were 101,320 and 107,260 gal; approximately 50 gal were diverted for sampling and calibrating meters for groundwater quality samples presented in this summary. Totalizer readings and flowmeter sensor readings agree well at 27.2 gal/min.

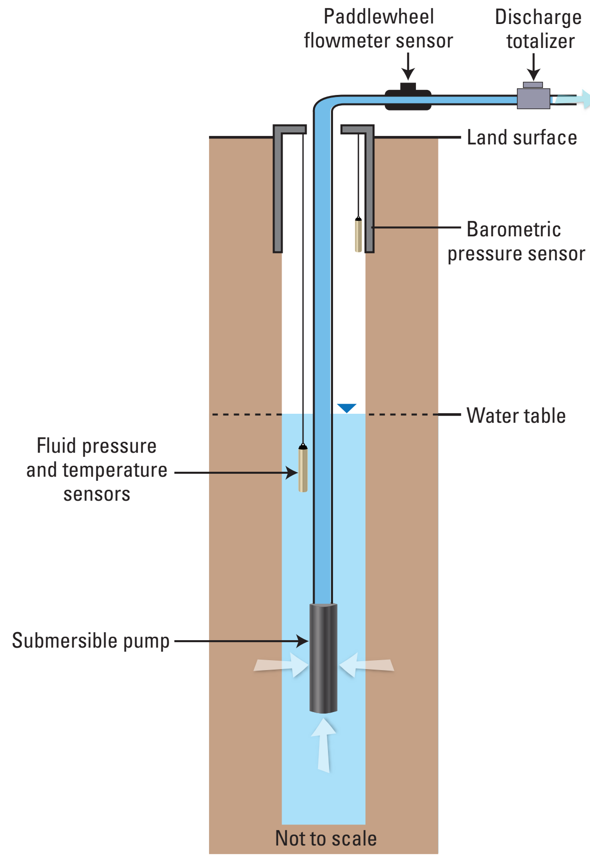


Figure 9. Idealized schematic showing pressure sensor(s) and pump placements during the aquifer test at well TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

Analysis of Aquifer-Test Data

Aquifer test results were analyzed using the Cooper-Jacob (Cooper and Jacob, 1946) method. The Cooper-Jacob method uses an approximation of the Theis solution. As with the Theis solution, it assumes a pumping well that fully penetrates a confined, homogeneous, and isotropic aquifer of infinite extent. Conditions for well TAN-2312 aquifer testing depart greatly from the Theis (1935) model given that the well partially penetrates an unconfined heterogeneous anisotropic aquifer. Furthermore, the test was short (less than 4 hours), where water had to be containerized in holding tanks and discharge volume was limited. The Cooper-Jacob method was

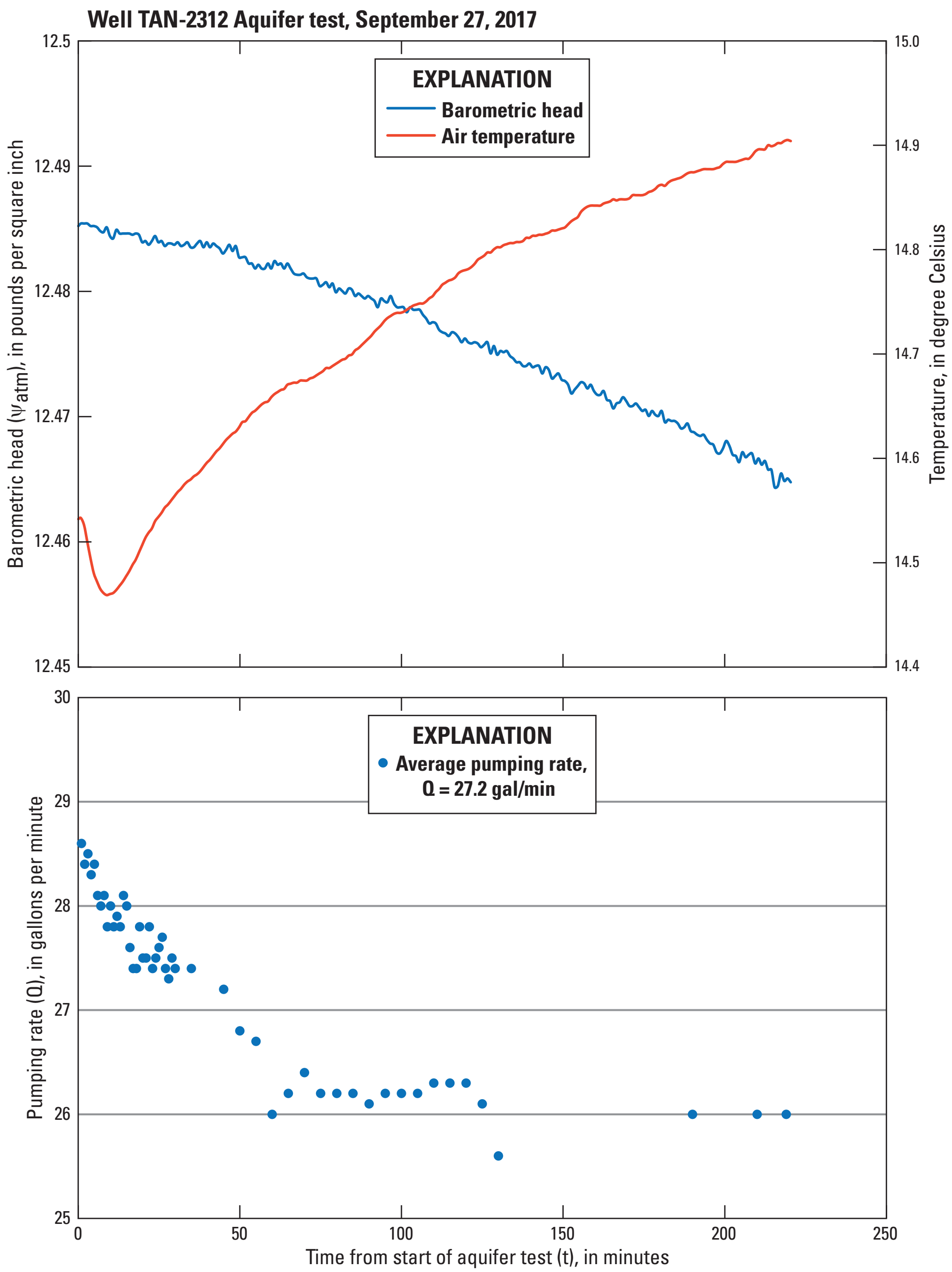


Figure 10. Barometric pressure, air temperature, and discharge rate measured during the aquifer test in well TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

used, regardless of the differences between field conditions and theory, because of its simplicity. An analysis of single-well tests by Halford and others (2006) indicated that estimating hydraulic properties from a single-well pumping test with anything other than the Cooper-Jacob method is unnecessary and that transmissivity is the only hydraulic property that could be estimated uniquely.

The Cooper-Jacob method estimates transmissivity by fitting a straight line to drawdowns in the pumping well on an arithmetic axis versus time on a log-arithmetic axis. Transmissivity, T, is determined from the slope of the straight line using the following equation:

$$T = \frac{2.3Q}{4\pi}\frac{1}{\Delta s} \tag{2}$$

where

Q is the pumping rate, and

Δs is the drawdown across one log cycle of time from the onset of pumping.

The drawdown in the well, Δs, at any given time, t, is determined by subtracting the compensated pressure head at t from the initial compensated pressure head prior to pumping, Ψ_0. Drawdown as a function of time was calculated using the following equation:

$$s(t) = \psi_0 - \psi(t) \tag{3}$$

Estimations of horizontal hydraulic conductivity, K, were based on the aquifer thickness, b, rather than the screen length and calculated using equation 4. Halford and others (2006) determined that in most cases using aquifer thickness as the divisor gave better estimates of transmissivity for unconfined aquifers with partial penetration. Aquifer thickness was approximated at 700 ft BLS, this estimate is based on interpolated electrical resistivity surveys and data collected from limited deep boreholes at the INL (Whitehead, 1986, sheet 2; Ackerman and others, 2010, fig. 13). Horizontal hydraulic conductivity (K) was calculated using the following equation:

$$K = \frac{T}{b} \tag{4}$$

Hydraulic Property Estimates

The hydraulic properties of the geohydrologic column were defined with T and K based on single-well analysis from data collected from the pumping well (fig. 11). The transmissivity estimated with the Cooper-Jacob method was estimated by an interpretive approach, all data were not used and only relevant data were used to fit the semi-log slopes. For example, the analysis excluded the first 10 min of aquifer test to avoid early-time complications, such as wellbore storage effects. Data collected in the pumping well are compensated pressure head measurements (fig. 11), collected every 60 seconds from pressure transducers. Electronic tape (e-tape) manual measurements were also collected and compared to compensated pressure head measurements from transducers, and the data agreed within the level of accuracy of the transducers and e-tape (±0.03 ft). Starting and ending e-tape water levels were 244.40 and 267.40 ft BLS; starting and ending head pressure readings were 30.61 ft and 7.59 ft.

The aquifer test (TAN-2312), T and K were estimated at 1.51×10^2 ft²/d and 0.23 ft/d, respectively. Calculations of these parameters using a combination of equations 2 and 4 are shown here:

$$T = \frac{2.3Q}{4\pi}\frac{1}{\Delta s} = \frac{2.3\times3.64\,\text{ft}^3/\text{min}}{4\pi\times6.34\,\text{ft}} = 0.11\,\text{ft}^2/\text{min}$$

$$\text{or}\quad 1.51\times10^2\ \text{ft}^2/\text{d}$$

$$K = \frac{T}{b} = \frac{0.11\,\text{ft}^2/\text{min}}{700\,\text{ft}} = 1.6\times10^{-4}\ \text{ft/min}$$

$$\text{or}\quad 2.3\times10^{-1}\ \text{ft/d}$$

The amount of drawdown at the end of the aquifer test at well TAN-2312 was about 23.0 ft for an average discharge of 27.2 gal/min. This is significant for a well that penetrates 278 ft into a basalt aquifer and was drilled out to 9.9-in. in diameter. A comparison between the estimated TAN-2312 transmissivity and values determined from past aquifer tests conducted at wells within the vicinity of TAN show reasonable agreement, but on the lower end of the spectrum (fig. 2, table 4). The estimated transmissivity values from these past aquifer tests (Ackerman, 1991; Twining and others, 2016) ranged from 3.0×10^1 to 5.0×10^5 ft²/d. The average hydraulic conductivity for well TAN-2312 was on the lower end of the range reported in the literature for similar rock types. Domenico and Schwartz (1990) and Freeze and Cherry (1979) report a range of hydraulic conductivity values for permeable basalt from 5.7×10^{-2} to 5.7×10^3 ft/d; and 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).

Table 4. Comparison of transmissivity values estimated from aquifer tests conducted at wells within the vicinity of well TAN-2312, Idaho National Laboratory, Idaho.

[Locations of wells shown in figure 2. **Local name:** The local well identifier used in this study. **Site identifier:** The unique numerical identifiers used to access well data (http://waterdata.usgs.gov/nwis). **Longitude and Latitude:** Referenced to North American Datum of 1927 (NAD 27). **Distance to wells:** Straight line distance within the aerial dimension to well TAN-2312. **Abbreviations:** ft²/d, foot squared per day; mi, mile]

Local name	Site identifier	Longitude	Latitude	Transmissivity (ft²/d)	Distance to well (mi)
ANP 3	435053112423201	112°42'31.4"	43°50'52.5"	3.0×10^{1}	1.4
ANP 6	435152112443101	112°44'31.4"	43°51'51.6"	5.0×10^{5}	3.0
TAN 1	435056112420001	112°42'00.0"	43°50'56.0"	2.9×10^{4}	1.5
TAN 2	435100112420701	112°42'07.0"	43°51'00.0"	1.6×10^{4}	1.6
TAN-2271	435053112423101	112°42'30.9"	43°50'53.3"	4.1×10^{3}	1.5
TAN-2272	435053112423001	112°42'30.3"	43°50'52.9"	8.1×10^{3}	1.5
USGS 24	435053112420801	112°42'12.3"	43°50'50.8"	1.4×10^{4}	1.4

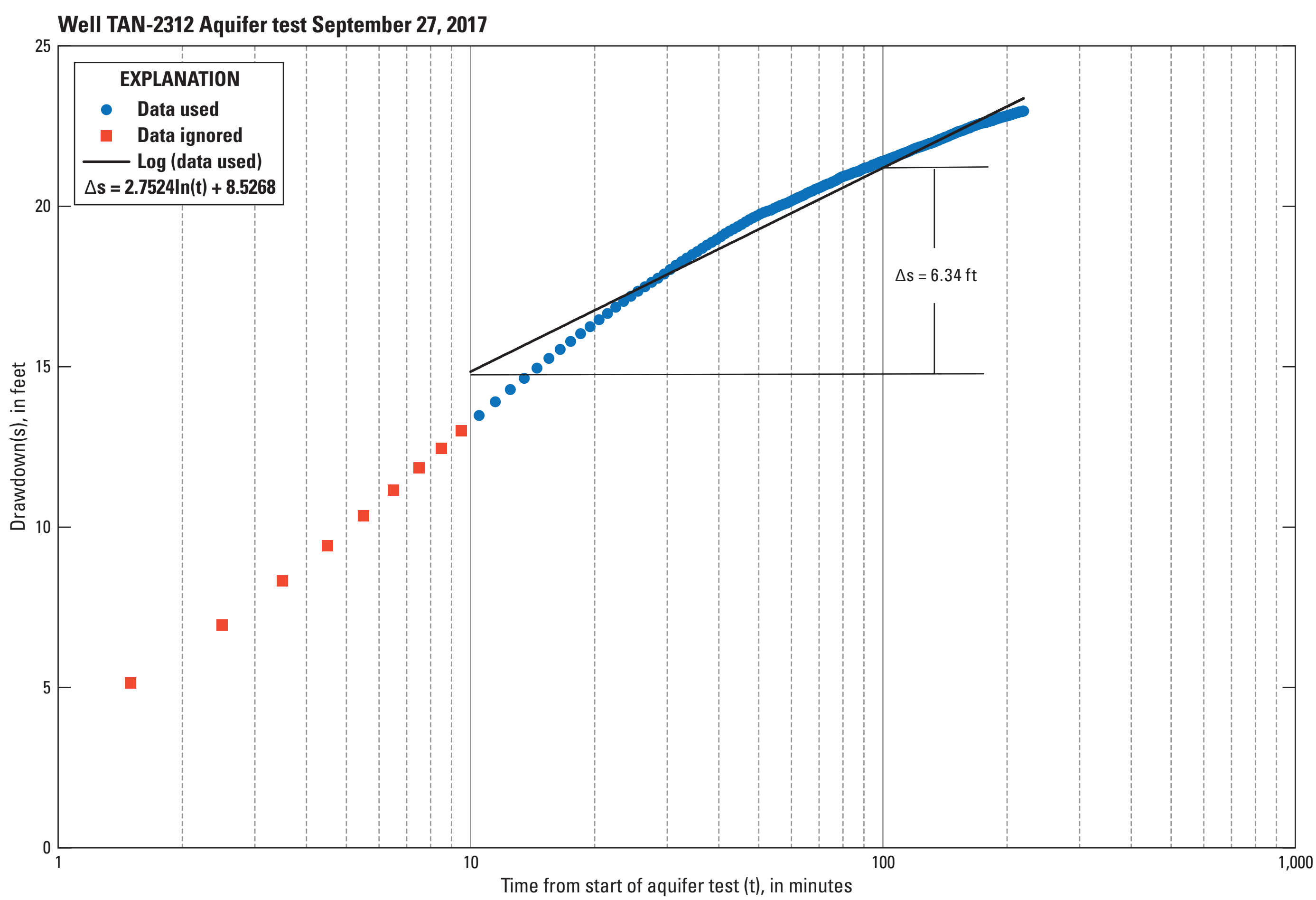


Figure 11. Aquifer test data for well TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

Water-Sample Collection

Sample Collection Methods

Water-sample collection at well TAN-2312 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 Bartholomay and others (2014); water-quality samples were collected at the end of aquifer testing in well TAN-2312, after the well was purged for about 160 minutes. Water-quality samples were collected from well TAN-2312 on September 27, 2017, from a 0.25-in. diameter SS sample port installed off of 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. Field measurements of water temperature, pH, specific conductance, dissolved oxygen, and alkalinity were collected prior to sampling (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 Bartholomay and others (2014, appendix A). Containers and preservatives 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 2 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 Bartholomay and others (2014, appendix A). Samples for the stable isotopes of oxygen, hydrogen, and sulfur were collected in bottles provided by NWQL and shipped to the USGS Reston Stable Isotope Laboratory (RSIL)–Isotope Fractionation Project in Reston, Virginia, for analysis. The sample for tritium was collected in bottles provided by NWQL and shipped to the USGS Menlo Park Research Laboratory for analysis.

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 Bartholomay and others (2017). In this report, radionuclide concentrations less than 3**s** are considered to be less than the "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 reporting limits determined using detection and quantitation calculation (DQCALC) software and are reported as detection limits from DQCALC (DLDQC) for inorganic constituents and minimum reporting levels (MRL) for organic constituents. The MRL is the smallest measured constituent concentration that can be reliably reported using a specific analytical method (Timme, 1995). The DLDQC is one of four new report level codes adopted by the NWQL to replace the long-term method detection limit (U.S. Geological Survey, 2015). DLDQC is described as the lowest concentration that with 90 percent confidence will be exceeded no more than 1 percent of the time when a blank sample is measured (≤ 1 percent false positive risk; U.S. Geological Survey, 2015, p. 11). DQCALC is a Microsoft Excel®-based software package used to compute a method detection estimate (Standard Practice D7510-10; American Society for Testing and Materials International, 2010). See U.S. Geological Survey (2015) for a more detailed explanation of the DQCALC procedures. Childress and others (1999) provide details about the approach used by the USGS regarding detection levels and reporting levels. For most of the constituents in this report, reported concentrations generally are greater than the DLDQCs or MRLs, but some are given as less than.

Table 5. Concentrations of selected chemical and radiochemical constituents in water from well TAN-2312, Test Area North, Idaho National Laboratory, Idaho.

[See figure 1 for TAN-2312 location. Date format is (mm/dd/yy). Analytical results in micrograms per liter unless noted otherwise. Samples were analyzed at the USGS National Water Quality Laboratory in Lakewood, Colorado, unless otherwise indicated. **Constituent or measurement:** Menlo, USGS Menlo Park Research Laboratory, Menlo Park, California; RSIL, USGS Reston Stable Isotope Laboratory in Reston, Virginia.; deg C, degrees Celsius; NTU, Nephlometric turbiditiy units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram 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 1s. Uncertainity of deuterium and oxygen-18 is ±1.5 per mil. Concentrations that meet or exceed the reporting level of 3 times the 1s value are shown in boldface type.]

Constituent or measurement	TAN-2312 (09/27/17)
Time	13:05
Water temperature (deg C)	11.4
Air temperature (deg C)	16.8
pH (field)	7.88
pH (lab)	8.1
Specific conductance (µS/cm) (field)	333
Specific conductance (µS/cm) (lab)	342
Dissolved oxygen (mg/L)	11.01
Turbidity (NTU)	73.2
Alkalinity (mg/L as $CaCO_3$)	138
Hardness (mg/L as $CaCO_3$)	144
Calcium (mg/L)	34.1
Magnesium (mg/L)	14.2
Potassium (mg/L)	3.67
Silica (mg/L)	30.2
Sodium (mg/L)	11.5
Bromide (mg/L)	E0.02
Chloride (mg/L)	11.3
Fluoride (mg/L)	0.32
Sulfate (mg/L)	27.9
Ammonia as N (mg/L)	<0.01
Nitrite as N (mg/L)	E0.001
Nitrate plus nitrite as N (mg/L)	0.56
Orthophosphate as P (mg/L)	0.022
Aluminum	7.3
Antimony	0.222
Arsenic	2.3
Barium	61.1
Beryllium	<0.19
Boron	23
Cadmium	<0.03
Chromium	4.4
Cobalt	0.131
Copper	0.25
Iron	<10
Lead	<0.02
Lithium	2.4
Manganese	3.55
Mercury	<0.005
Molybdenum	3.94
Nickel	0.4
Selenium	1.4
Silver	<1
Strontium	175
Thallium	<0.02
Tungsten	1.13
Uranium	2.18
Vanadium	4.5
Zinc	2.1
Tritium (pCi/L) (Menlo)	2.32±2.11
Strontium-90 (pCi/L) (RESL)	0.5±0.7
Cesium-137 (pCi/L) (RESL)	-21±0.9
Gross alpha (pCi/L) (RESL)	0.6±1.5
Gross beta (pCi/L) (RESL)	2.2±0.8
Americium-241 (pCi/L) (RESL)	0.013±0.014
Plutonium-238 (pCi/L) (RESL)	-0.006±0.005
Plutonium-239,240 (pCi/L) (RESL)	-0.003±0.006
Uranium-234 (pCi/L)	**1.20±0.122**
Uranium-235 (pCi/L)	0.044±0.017
Uranium-238 (pCi/L)	**0.702±0.080**
Deuterium (per mil) (RSIL)	-133
Oxygen-18 (per mil) (RSIL)	-17.13
Sulfur-34/32 (per mil) (RSIL)	8.38
Volatile organic compounds	
Acrylonitrile	<2.5
Benzene	<0.1
Bromobenzene	<0.2
Bromochloromethane	<0.2
Bromomethane	<0.4
CFC-11	<0.2
CFC-12	<0.2
CFC-113	<0.1
CHBrC12	<0.1
Chlorobenzene	<0.1
Chloroethane	<0.2
Chloromethane	<0.2
cis-1,2-dichloroethene	<0.1
cis-1,3-dichloropropene	<0.2
Dibromochloropropane	<0.5
Dibromochloromethane	<0.2
Dibromomethane	<0.2

Table 5. Concentrations of selected chemical and radiochemical constituents in water from well TAN-2312, Test Area North, Idaho National Laboratory, Idaho.—Continued

Constituent or measurement	TAN-2312 (09/27/17)
Dichloromethane	<0.2
Ethylbenzene	<0.1
Hexachlorobutadiene	<0.2
Isopropylbenzene	<0.2
MTBE	<0.2
Naphthalene	<0.5
n-butylbenzene	<0.2
n-propylbenzene	<0.2
sec-butylbenzene	<0.2
Styrene	<0.1
tert-butylbenzene	<0.2
Tetrachloroethene	0.169
Tetrachloromethane	<0.2
Toluene	1.37
trans-1,2-dichloroethene	<0.1
trans-1,3-dichloropropene	<0.2
Tribromomethane	<0.2
Trichloroethene	0.636
Trichloromethane	<0.1
Vinyl chloride	<0.2
Xylene	<0.2
1,1,1-trichloroethane	<0.1
1,1,1,2-tetrachloroethane	<0.2
1,1,2,2-tetrachloroethane	<0.2
1,1,2-trichloroethane	<0.2
1,1-dichloroethane	<0.1
1,1-dichloroethene	<0.1
1,1-dichloropropene	<0.2
1,2,3-trichloropropane	<0.2
1,2,3-trichlorobenzene	<0.2
1,2,4-trichlorobenzene	<0.2
1,2,4-trimethylbenzene	<0.2
1,2-dibromoethane	<0.2
1,2-dichlorobenzene	<0.1
1,2-dichloroethane	<0.2
1,2-dichloropropane	<0.1
1,3-dichlorobenzene	<0.1
1,3-dichloropropane	<0.2
1,3,5-trimethylbenzene	<0.2
1,4-dichlorobenzene	<0.1
2-chlorotoluene	<0.2
2,2-dichloropropane	<0.2
4-chlorotoluene	<0.2
4-isopropyltoluene	<0.2

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 from well TAN-2312 were sent to the NWQL to be analyzed for dissolved concentrations of (1) cations of calcium, magnesium, potassium, silica, and sodium; (2) anions of bromide, chloride, fluoride, and sulfate; and (3) 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. Additionally, 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).

Sample data collected from well TAN-2312 indicate: calcium concentrations were 34.1 mg/L, potassium concentrations were 3.67 mg/L, silica concentrations were 30.2 mg/L, chloride concentrations were 11.3 mg/L, fluoride concentrations were 0.32, and sulfate concentrations were 27.9 mg/L (table 5). Nitrate plus nitrite as N concentrations were lower than background water in the ESRP aquifer at the INL (Bartholomay and Hall, 2016). The water chemistry of this well is mostly representative of eastern regional background water for the ESRP at the INL (Bartholomay and Hall, 2016), except for the small lithium concentration (2.4 µg/L) and the small nitrate concentration (0.56 mg/L) which are more representative of western tributary water. This well is near the mixing line of water types as described in Fisher and others (2012) and its chemistry supports a mixture of western tributary water and eastern regional water.

Organic Chemistry Data

Water samples collected from well TAN-2312 were analyzed at the NWQL for volatile organic compounds (VOCs). Most of the VOCs had concentrations less than their laboratory MRL. Exceptions include trichloroethene (0.636 µg/L); toluene (1.37 µg/L); and tetrachloroethene (0.169 µg/L) (table 5). None of the concentrations exceeded the Environmental Protection Agency (EPA) maximum contaminant level for drinking water (U.S. Environmental Protection Agency, 2017). Toluene is an organic compound found in grease used in the drilling operation and trichloroethene and tetrachloroethene were discharged in the TAN Disposal well (Bartholomay and others, 2017).

Stable Isotope Data

Water samples collected from well TAN-2312 were analyzed at the RSIL for relative concentrations of the stable isotopes of deuterium (^2H) oxygen-18 (^{18}O), and sulfur-34 (^{34}S). Because the absolute measurement of isotopic ratios is analytically difficult, relative isotopic ratios were measured instead (Toran, 1982) and are expressed in delta notation as part per mil (part per thousand difference). For example, $^{18}O/^{16}O$ of a sample is compared with $^{18}O/^{16}O$ of a standard:

$$\delta\, ^{18}O = (R_{sample}/R_{standard}-1) \times 1{,}000 \qquad (5)$$

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. $^2H/^1H$ is 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 ^2H in water is standard mean ocean water as defined by Craig (1961). The standard used for Delta ^{34}S is IAEA-S-1, which has a consensus value of -0.3 per mil relative to the Vienna Canyon Diablo Troilite reference standard (Révész and others, 2012).

Stable isotope concentration data for deuterium and oxygen-18 samples collected from TAN-2312 were -133 and -17.13 per mil, respectively (table 5). Concentrations of deuterium and oxygen-18 isotopes were most similar to stable isotopes in Mud Lake surface water (Ott and others, 1994, table 4) as compared to Birch Creek surface water and concentrations in other wells in the northern part of the INL (figs. 1 and 2). Mud Lake water is more enriched with these isotopes because of recirculation of irrigation water (Rattray, 2018). Rattray (2018) indicated that most eastern regional influenced water had sulfur isotope concentrations greater than 10 per mil; although a couple of wells (Park Bell and USGS 4, Knobel and others, 1999) did have sulfur isotopes similar to the concentration of 8.38 per mil in TAN-2312 (table 5). Rattray (2018) attributed the lower sulfur isotope concentrations to geothermal influence in the case of Park Bell and irrigation influence in the case of USGS 4. The stable isotope data for TAN-2312 probably indicate the water is influenced by irrigation in the Mud Lake area.

Radiochemical Data

Water samples collected from well TAN-2312 were analyzed at the RESL for strontium-90; gross alpha, beta, and gamma radioactivity; plutonium-238, and plutonium-239, -240 (undivided); and americium-241 and Menlo Park for tritium. Additionally, samples were collected for uranium isotopes and analyzed by a USGS NWQL contract laboratory (table 5). Concentrations of all the radionuclides analyzed were less than the reporting level except for uranium-234 and 238 (table 5). The concentration of uranium-234 was at the background level for the eastern Snake River Plain aquifer water at the INL, whereas the uranium-238 concentration of 0.702±0.08 pCi/L was larger than background (Bartholomay and Hall, 2016, table 1).

Summary

In 2017, the U.S. Geological Survey, in cooperation with the U.S. Department of Energy, drilled and constructed borehole TAN-2312 for stratigraphic framework analyses and long-term groundwater monitoring of the eastern Snake River Plain aquifer at the Idaho National Laboratory. Borehole TAN-2312 initially was cored to collect continuous geologic data and then re-drilled to complete construction as a monitoring well. The final construction for borehole TAN-2312 required 10-inch (in.) diameter carbon-steel well casing to 228 feet below land surface (ft BLS) and 9.9-in. diameter open-hole construction to 522 ft BLS. Following construction and data collection, a submersible pump and water-level access line were placed to allow for aquifer testing, water sampling, and for measuring water levels.

Geophysical and borehole video logs were collected after core drilling and after reaming during the drilling and construction process at borehole TAN-2312. Geophysical logs were examined in conjunction with the core material for borehole TAN-2312 and suggest the occurrence of fractured and (or) vesiculated basalt, dense basalt, and sediment layering in both the saturated and unsaturated zone. Gyroscopic deviation measurements were used to measure horizontal and vertical deviation in borehole TAN-2312.

A single-well aquifer test was conducted following construction at well TAN-2312 and data were used to provide estimates of transmissivity and hydraulic conductivity. The transmissivity and hydraulic conductivity for well TAN-2312 were estimated at 1.51×10^2 square feet per day (ft^2/d), and 0.23 feet per day (ft/d), respectively. Measured discharge rates remained relatively constant during the testing at well TAN-2312, with average pumping rates of 27.2 gallons per minute. The estimated transmissivity for well TAN-2312 was on the low range of expected values (3.0×10^1 to 5.0×10^5 ft^2/d) determined from previous aquifer tests conducted in other wells near Test Area North.

Water samples were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Water samples for most of the inorganic constituents showed concentrations near background levels for eastern regional groundwater. Water samples for stable isotopes of oxygen, hydrogen, and sulfur indicated some possible influence of irrigation on the water quality. The volatile organic compound data indicated that this well had some minor influence by wastewater disposal practices at Test Area North.

References Cited

Ackerman, D.J., 1991, Transmissivity of the Snake River Plain aquifer at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 91–4058 (DOE/ID-22097), 35 p. [Also available at https://pubs.er.usgs.gov/publication/wri914058.]

Ackerman, D.J., Rattray, G.W., Rousseau, J.P., Davis, L.C., and Orr, B.R., 2006, A conceptual model of ground-water flow in the eastern Snake River Plain aquifer at the Idaho National Laboratory and vicinity with implications for contaminant transport: U.S. Geological Survey Scientific Investigations Report 2006–5122, 62 p. [Also available at https://pubs.usgs.gov/sir/2006/5122/.]

Ackerman, D.J., Rousseau, J.P., Rattray, G.W., and Fisher, J.C., 2010, Steady-state and transient models of groundwater flow and advective transport, Eastern Snake River Plain aquifer, Idaho National Laboratory and vicinity, Idaho: U.S. Geological Survey Scientific Investigations Report 2010–5123, 220 p.

American Society for Testing and Materials (ASTM) International, 2010, Standard practice for performing detection and quantitation estimation and data assessment utilizing DQCALC software, based on ASTM practices D6091 and 20 D6512 of Committee D19 on water: ASTM D7510-10, 2 p. [Also available at http://www.astm.org/Standards/D7510.htm.]

Anderson, S.R., Kuntz, M.A., and Davis, L.C., 1999, Geologic controls of hydraulic conductivity in the Snake River Plain aquifer at and near the Idaho National Engineering and Environmental Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 99–4033 (DOE/ID-22155), 38 p. [Also available at https://pubs.er.usgs.gov/publication/wri994033.]

Anderson, S.R., and Liszewski, M.J., 1997, Stratigraphy of the unsaturated zone and the Snake River Plain aquifer at and near the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 97–4183 (DOE/ID-22142), 65 p. [Also available at https://pubs.er.usgs.gov/publication/wri974183.]

Bartholomay, R.C., and Hall, L.F., 2016 Evaluation of background concentrations of selected chemical and radiochemical constituents in water from the eastern Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho: U.S. Geological Survey Scientific Investigations Report 2016-5056, (DOE/ID-22237), 19 p., https://doi.org/10.3133/sir20165056.

Bartholomay, R.C., Maimer, N.V., Rattray, G.W., and Fisher, J.C., 2017, An update of hydrologic conditions and distribution of selected constituents in water, eastern Snake River Plain aquifer and perched groundwater zones, Idaho National Laboratory, Idaho, emphasis 2012–15: U.S. Geological Survey Scientific Investigations Report 2017-5021, (DOE/ID-22242), 87 p., https://doi.org/10.3133/sir20175021.

Bartholomay, R.C., Maimer, N.V., and Wehnke, A.J., 2014, Field methods and quality-assurance plan for water-quality activities and water-level measurements, U.S. Geological Survey, Idaho National Laboratory, Idaho: U.S. Geological Survey Open-File Report 2014–1146 (DOE/ID-22230), 66 p. [Also available at https://pubs.usgs.gov/of/2014/1146/.]

Bartholomay, R.C., Tucker, B.J., Ackerman, D.J., and Liszewski, M.J., 1997, Hydrologic conditions and distribution of selected radiochemical and chemical constituents in water, Snake River Plain aquifer, Idaho National Engineering Laboratory, Idaho, 1992 through 1995: U.S. Geological Survey Water-Resources Investigations Report 97–4086 (DOE/ID-22137), 57 p. [Also available at https://pubs.er.usgs.gov/publication/wri974086.]

Blackwell, D.D., Kelley, S., and Steele, J.L., 1992, Heat flow modeling of the Snake River Plain, Idaho: Idaho National Engineering Laboratory, Department of Energy contractor report no. EGG-NPR-10790, 109 p.

Bodnar, L.Z., and Percival, D.R., eds., 1982, RESL Analytical Chemistry Branch procedures manual: U.S. Department of Energy Report IDO-12096, 364 p.

Busenberg, E., Plummer, L.N., and Bartholomay, R.C., 2001, Estimated age and source of the young fraction of ground water at the Idaho National Engineering and Environmental Laboratory: U.S. Geological Survey Water-Resources Investigations Report 2001–4265 (DOE/ID-22177), 144 p.

Busenberg, E., Plummer, L.N., Doughten, M.W., Widman, P.K., and Bartholomay, R.C., 2000, Chemical and isotopic composition and gas concentrations of ground water and surface water from selected sites at and near the Idaho National Engineering and Environmental Laboratory, Idaho, 1994–97: U.S. Geological Survey Open-File Report 2000–81 (DOE/ ID-22164), 51 p. [Also available at http://pubs.er.usgs.gov/publication/ofr0081.]

Cecil, L.D., Welhan, J.A., Green, J.R., Frape, S.K., and Sudicky, E.R., 2000, Use of chlorine-36 to determine regional-scale aquifer dispersivity, eastern Snake River Plain aquifer, Idaho/USA *in* Nuclear instruments and methods in physics research section B—Beam interactions with materials and atoms: International Conference on Accelerator Mass Spectrometry, 8th, Vienna, Austria, 1999, v. 172, p. 679–687.

Childress, C.J.O., Foreman, W.T., Conner, B.F., and Maloney, T.J., 1999, New reporting procedures based on long-term method detection levels and some considerations for interpretations of water-quality data provided by the U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 99–193, 19 p. [Also available at https://water.usgs.gov/owq/OFR_99-193/.]

Christensen Products, 1997, C Wireline System: Christensen Products Web page, accessed May 2008, at http://christensenproducts.com.

Cooper, H.H., Jr., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, v. 27, no. 4, p. 526–534, https://doi.org/10.1029/TR027i004p00526.

Craig, Harmon, 1961, Isotopic variation in meteoric water: Science, v. 133, p. 1,702–1,703.

Currie, L.A., 1984, Lower limit of detection—Definition and elaboration of a proposed position for radiological effluent and environmental measurements: U.S. Nuclear Regulatory Commission NUREG/CR-4007, 139 p.

Domenico, P.A., and Schwartz, F.W., 1990, Physical and Chemical Hydrogeology: New York, John Wiley & Sons, Inc., 824 p.

Duke, C.L., Roback, R.C., Reimus, P.W., Bowman, R.S., McLing, T.L., Baker, K.E., and Hull, L.C., 2007, Elucidation of flow and transport processes in a variably saturated system of interlayered sediment and fractured rock using tracer tests: Vadose Zone Journal, v. 6, no. 4, p. 855–867, https://doi.org/10.2136/vzj2006.0102.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92–634, 28 p. [Also available at http://pubs.er.usgs.gov/publication/ofr92634.]

Fisher, J.C., Rousseau, J.P., Bartholomay, R.C., and Rattray, G.W., 2012, A comparison of U.S. Geological Survey three-dimensional estimates of groundwater source areas and velocities to independently derived estimates, Idaho National Laboratory and vicinity, Idaho: U.S. Geological Survey Scientific Investigations Report 2012-5152 (DOE/ID-22218), 130 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments, U.S. Geological Survey Open-File Report 93–125, 217 p. [Also available at https://pubs.er.usgs.gov/publication/ofr93125.]

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p. [Also available at https://pubs.usgs.gov/twri/twri5-a1/.]

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice Hall, Inc., 604 p.

Garabedian, S.P., 1986, Application of a parameter-estimation technique to modeling the regional aquifer underlying the eastern Snake River Plain, Idaho: U.S. Geological Survey Water-Supply Paper 2278, 60 p. [Also available at https://pubs.er.usgs.gov/publication/wsp2278.]

Goerlitz, D.F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 40 p. [Also available at http://pubs.er.usgs.gov/publication/twri05A3_1972.]

Halford, K.J., Weight, W.D., and Schreiber, R.P., 2006, Interpretation of transmissivity estimates from single-well pumping aquifer tests: Ground Water, v. 44, no. 3, p. 467–471, https://doi.org/10.1111/j.1745-6584.2005.00151.x.

Izbicki, J.A., Clar, D.A., Pimentel, M.I., Land, M.T., Radyk, J., and Michel, R.L., 2000, Data from a thick unsaturated-zone underlying Oro Grande and Sheep Creek washes in the western part of the Mojave Desert, near Victorvill, San Bernardino County, California: U.S. Geological Survey Open-File Report 00–262, 133 p.

Keys, W.S., 1990, Borehole geophysics applied to ground-water investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 2, chap. E2, 150 p.

Knobel, L.L., Bartholomay, R.C., Tucker, B.J., Williams, L.M., and Cecil, L.D., 1999, Chemical constituents in ground water from 39 selected sites with an evaluation of associated quality assurance data, Idaho National Engineering and Environmental Laboratory and vicinity, Idaho: U.S. Geological Survey Open-File Report 99-246, (DOE/ID-22159), 58 p. [Also available at http://pubs.er.usgs.gov/publication/ofr99246.]

Mann, L.J., 1986, Hydraulic properties of rock units and chemical quality of water for INEL-1—A 10,365-foot deep test hole drilled at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 86–4020 (IDO-22070), 23 p. [Also available at https://pubs.er.usgs.gov/usgspubs/wri/wri864020.]

Mann, L.J., and Beasley, T.M., 1994, Iodine-129 in the Snake River Plain aquifer at and near the Idaho National Engineering Laboratory, Idaho, 1990–91: U.S. Geological Survey Water-Resources Investigations Report 94–4053 (DOE/ID-22115), 27 p. [Also available at http://pubs.er.usgs.gov/usgspubs/wri/wri944053.]

McCurdy, D.E., Garbarino, J.R., and Mullin, A.H., 2008, Interpreting and reporting radiological water-quality data: U.S. Geological Survey Techniques and Methods, book 5, chap. B6, 33 p. [Also available at https://pubs.usgs.gov/tm/05b06/.]

Nimmo, J.R., Perkins, K.S., Rose, P.E., Rousseau, J.P., Orr, B.R., Twining, B.V., and Anderson, S.R., 2002, Kilometer-scale rapid transport of naphthalene sulfonate tracer in the unsaturated zone at the Idaho National Engineering and Environmental Laboratory: Vadose Zone Journal, v. 1, no. 1, p. 89–101, https://doi.org/10.2136/vzj2002.8900.

Ott, D.S., Cecil, L.D., and Knobel, L.L., 1994, Stable isotopes of hydrogen and oxygen in surface water and ground water at selected sites on or near the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 94–55 (DOE/ID-22112), 14 p., https://pubs.er.usgs.gov/usgspubs/ofr/ofr9455.

Paillet, F.L., 2000, Flow logging in difficult boreholes—Making the best of a bad deal, *in* Proceedings of the 7th International Symposium on Borehole Geophysics for Minerals, Geotechnical, and Groundwater Applications, Denver, Colo., 2000: Houston, Texas, The Minerals and Geotechnical Logging Society, A Chapter at Large of the Society of Professional Well Log Analysts, p. 125–135.

Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hot spot, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1–53, https://doi.org/10.1130/MEM179-p1.

Pritt, J.W., 1989, Quality assurance of sample containers and preservatives at the U.S. Geological Survey National Water Quality Laboratory, *in* Pederson, G.L., and Smith, M.M., comps., U.S. Geological Survey second national symposium on water quality—Abstracts of the technical sessions: U.S. Geological Survey Open-File Report 89–409, 111 p. [Also available at https://pubs.er.usgs.gov/publication/ofr89409.]

Rattray, G.W., 2018, Geochemistry of groundwater in the eastern Snake River Plain aquifer, Idaho National Laboratory and vicinity, eastern Idaho: U.S. Geological Survey Professional Paper 1837-A (DOE/ID-22246), 198 p., https://doi.org/10.3133/pp1837A.

Révész, Kinga, Qi, Haiping, and Coplen, T.B., 2012, Determination of the δ 34S of sulfate in water; RSIL lab code 1951, chap. 10 *of* Stable isotope-ratio methods, sec. C of Révész, Kinga, and Coplen, T.B. eds., Methods of the Reston Stable Isotope Laboratory (slightly revised from version 1.1 released in 2007): U.S. Geological Survey Techniques and Methods, book 10, 33 p., available only at https://pubs.usgs.gov/tm/2006/tm10c10/. (Supersedes versions 1.0 and 1.1 released in 2006 and 2007, respectively.)

Robertson, J.B., Schoen, Robert, and Barraclough, J.T., 1974, The influence of liquid waste disposal on the geochemistry of water at the National Reactor Testing Station, Idaho, 1952–1970: U.S. Geological Survey Open-File Report 73–238 (IDO-22053), 231 p.

Rose, D.L., and Schroeder, M.P., 1995, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of volatile organic compounds in water by purge and trap capillary gas chromatography/mass spectrometry: U.S. Geological Survey Open-File Report 94–708: W, 26 p. [Also available at https://pubs.er.usgs.gov/publication/ofr94708W.]

Self, S., Keszthelyi, L., and Thordarson, T., 1998, The importance of pahoehoe: Annual Review of Earth and Planetary Sciences, v. 26, no. 1, p. 81–110, https://doi.org/10.1146/annurev.earth.26.1.81.

Shervais, J.W., Vetter, S.K., and Hanan, B.B., 2006, Layered mafic sill complex beneath the eastern Snake River Plain—Evidence from cyclic geochemical variations in basalt: Geology, v. 34, no. 5, p. 365–368, https://doi.org/10.1130/G22226.1.

Sill, D.S., and Sill, C.W., 1994, Simultaneous determination of the actinides in small environmental samples: Radioactivity and Radiochemistry, v. 5, no. 2, p. 8–19.

Thatcher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A5, 95 p. [Also available at https://pubs.usgs.gov/twri/twri5a5/.]

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: Transactions-American Geophysical Union, v. 16, no. 2, p. 519–524, https://doi.org/10.1029/TR016i002p00519.

Timme, P.J., 1995, National Water Quality Laboratory, 1995 services catalog: U.S. Geological Survey Open-File Report 95–352, 120 p. [Also available at https://pubs.er.usgs.gov/publication/ofr95352.]

Toran, L., 1982, Isotopes in ground-water investigations: Ground Water, v. 20, no. 6, p. 740–745, https://doi.org/10.1111/j.1745-6584.1982.tb01394.x.

Twining, B.V., 2016, Borehole deviation and correction factor data for selected wells in the eastern Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho: U.S. Geological Survey Scientific Investigations Report 2016–5163 (DOE/ID-22241), 23 p., plus appendixes, https://doi.org/10.3133/sir20165163.

Twining, B.V., Bartholomay, R.C., and Hodges, M.K.V., 2016, Completion summary for boreholes TAN-2271 and TAN-2272 at Test Area North, Idaho National Laboratory, Idaho: U.S. Geological Survey Scientific Investigations Report 2016-5088 (DOE/ID-22239), 37 p., plus appendixes, https://doi.org/10.3133/sir20165088.

U.S. Department of Energy, 1995, Radiochemistry manual, rev. 10: Idaho Falls, Idaho, U.S. Department of Energy, Radiological and Environmental Sciences Laboratory [variously paged].

U.S. Environmental Protection Agency, 2017, Protection of environment—Code of Federal Regulations 40, part 141: Washington, D.C., Office of Federal Archives and Records Administration [variously paged].

U.S. Geological Survey, 2015, Changes to National Water Quality Laboratory (NWQL) procedures used to establish and verify laboratory detection and reporting limits: National Water Quality Laboratory Technical Memorandum 15.02., accessed January 26, 2016, at http://wwwnwql.cr.usgs.gov/rapi-notes/15-14_NWQL_TM_15-02_(DQCALC).pdf.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9. [Also available at https://water.usgs.gov/owq/FieldManual/.]

U.S. Geological Survey, 1985, National water summary 1984—Hydrologic events, selected water-quality trends, and ground-water resources: U.S Geological Survey Water-Supply Paper 2275, 467 p. [Also available at https://pubs.er.usgs.gov/publication/wsp2275.]

Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., eds., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 80 p. [Also available at https://pubs.er.usgs.gov/publication/twri05A3.]

Whitehead, R.L., 1986, Geohydrologic framework of the Snake River Plain, Idaho and eastern Oregon: U. S. Geological Survey Hydrologic Investigations Atlas HA-681, scale 1:1,000,000, 3 sheets.

Whitehead, R.L., 1992, Geohydrologic framework of the Snake River Plain regional aquifer system, Idaho and eastern Oregon: U. S. Geological Survey Professional Paper 1408-B, 32 p. [Also available at https://pubs.er.usgs.gov/publication/pp1408B.]

Williams, J.H., and Johnson, C.D., 2004, Acoustic and optical borehole-wall imaging for fractured-rock aquifer studies: Journal of Applied Geophysics, v. 55, no. 1-2, p. 151–159, https://doi.org/10.1016/j.jappgeo.2003.06.009.

Appendixes

Appendixes 1–4 are .PDF files available for download at https://doi.org/10.3133/sir20185118.

Appendix 1. Material Safety Data Sheets for Drilling Mud

Appendix 2. Driller Log for TAN-2312

Appendix 3. Core Logs and Photographs for Borehole TAN-2312

Appendix 4. Archive Approval Memo

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