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Scientific Investigations Report 2017–5148

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

Cover: Photograph showing view of the Big Lost River flowing into the Idaho National Laboratory spreading areas, Idaho. Photograph by Roy Bartholomay, U.S. Geological Survey, June 22, 2017.

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U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Deputy Director
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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)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
	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)

Datums

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

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

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

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.

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

Activities for radioactive constituents in water are given in picocuries per liter (pCi/L).

Abbreviations

AEC	Atomic Energy Commission
ATR	Advanced Test Reactor
AVZ	Axial Volcanic Zone
CFA	Central Facilities Area
DOE	Department of Energy
EBB	Early Basal Brunhes
ESRP	Eastern Snake River Plain
ICPP	Idaho Chemical Processing Plant
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LBB	Late Basal Brunhes
M	Matuyama
Ma	million years
MBB	Middle Basal Brunhes
NPR	New Production Reactor
NRF	Naval Reactors Facility
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
SLM	South Late Matuyama
SRP	Snake River Plain
TAN	Test Area North
USGS	U.S. Geological Survey

Correlation between Basalt Flows with Radiochemical and Chemical Constituents in Selected Wells in the Southwestern Part of the Idaho National Laboratory, Idaho

By Roy C. Bartholomay, Mary K.V. Hodges, and Duane E. Champion

Abstract

Wastewater discharged to wells and ponds and wastes buried in shallow pits and trenches at facilities at the Idaho National Laboratory (INL) have contributed contaminants to the eastern Snake River Plain (ESRP) aquifer in the southwestern part of the INL. This report describes the correlation between subsurface stratigraphy in the southwestern part of the INL with information on the presence or absence of wastewater constituents to better understand how flow pathways in the aquifer control the movement of wastewater discharged at INL facilities. Paleomagnetic inclination was used to identify subsurface basalt flows based on similar inclination measurements, polarity, and stratigraphic position. Tritium concentrations, along with other chemical information for wells where tritium concentrations were lacking, were used as an indicator of which wells were influenced by wastewater disposal.

The basalt lava flows in the upper 150 feet of the ESRP aquifer where wastewater was discharged at the Idaho Nuclear Technology and Engineering Center (INTEC) consisted of the Central Facilities Area (CFA) Buried Vent flow and the AEC Butte flow. At the Advanced Test Reactor (ATR) Complex, where wastewater would presumably pond on the surface of the water table, the CFA Buried Vent flow probably occurs as the primary stratigraphic unit present; however, AEC Butte flow also could be present at some of the locations. At the Radioactive Waste Management Complex (RWMC), where contamination from buried wastes would presumably move down through the unsaturated zone and pond on the surface of the water table, the CFA Buried Vent; Late Basal Brunhes; or Early Basal Brunhes basalt flows are the flow unit at or near the water table in different cores.

In the wells closer to where wastewater disposal occurred at INTEC and the ATR-Complex, almost all the wells show wastewater influence in the upper part of the ESRP aquifer and wastewater is present in both the CFA Buried Vent flow and AEC Butte flow. The CFA Buried Vent flow and AEC Butte flow are also present in wells at and north of CFA and are all influenced by wastewater contamination. All wells with the AEC Butte flow present have wastewater influence and 83 percent of the wells with the more prevalent CFA Buried Vent flow have wastewater influence. South and southeast of CFA, most wells are not influenced by wastewater disposal and are completed in the Big Lost Flow and the CFA Buried Vent flow. Wells southwest of CFA are influenced by wastewater disposal and are completed in the Big Lost flow and CFA Buried Vent flow at the top of the aquifer. Basalt stratigraphy indicates that the CFA Buried Vent flow is the predominant flow in the upper part of the ESRP aquifer at and near the RWMC as it is present in all the wells in this area. The Late Basal Brunhes flow, Middle Basal Brunhes flow, Early Basal Brunhes flow, South Late Matuyama flow, and Matuyama flow are also present in various wells influenced by waste disposal.

Some wells south of RWMC do not show wastewater influence, and the lack of wastewater influence could be due to low hydraulic conductivities. Several wells south and southeast of CFA also do not show wastewater influence. Low hydraulic conductivities or ESRP subsidence are possible causes for lack of wastewater south of CFA.

Multilevel monitoring wells completed much deeper in the aquifer show influence of wastewater in numerous basalt flows. Well Middle 2051 (northwest of RWMC) does not show wastewater influence in its upper three basalt flows (CFA Buried Vent, Late Basal Brunhes, and Middle Basal Brunhes); however, wastewater is present in two deeper flows (the Matuyama and Jaramillo flows). Well USGS 131A (southwest of CFA) and USGS132 (south of RWMC) both show wastewater influence in all the basalt flows sampled in the upper 600 feet of the aquifer. Wells USGS 137A, 105, 108, and 103 completed along the southern boundary of the INL all show wastewater influence in several basalt flows including the G flow, Middle and Early Basal Brunhes flows, the South Late Matuyama flow and the Matuyama flow; however, the strongest wastewater influence appears to be in the South Late Matuyama flow. The concentrations of wastewater constituents in deeper parts of these wells support the concept of groundwater flow deepening in the southwestern part of the INL.

Introduction

The Idaho National Laboratory (INL), operated by the U.S. Department of Energy (DOE), encompasses about 890 mi^2 of the eastern Snake River Plain (ESRP) in southeastern Idaho (fig. 1). The INL was established in 1949 to develop atomic energy, nuclear safety, defense programs, environmental research, and advanced energy concepts. Wastewater disposal sites at the Test Area North (TAN), the Naval Reactors Facility (NRF), the Advanced Test Reactor Complex (ATR-Complex), and the Idaho Nuclear Technology and Engineering Center (INTEC) (fig. 1) have contributed radioactive- and chemical-waste contaminants to the ESRP aquifer. These sites incorporated various wastewater disposal methods, including lined evaporation ponds, unlined percolation (infiltration) ponds and ditches, drain fields, and injection wells. Waste materials buried in shallow pits and trenches within the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC) also have contributed contaminants to groundwater. Concern about subsurface movement of contaminants from these wastes increased the number and kinds of studies of subsurface geology and hydrology to provide information for conceptual and numerical models of groundwater flow and contaminant transport (Anderson and Lewis, 1989; Anderson, 1991; Anderson and Bartholomay, 1995; Anderson and Bowers, 1995; Anderson and Liszewski, 1997; Anderson, Ackerman, and others, 1996; Anderson, Liszewski, and Ackerman, 1996; Ackerman and others, 2006, 2010).

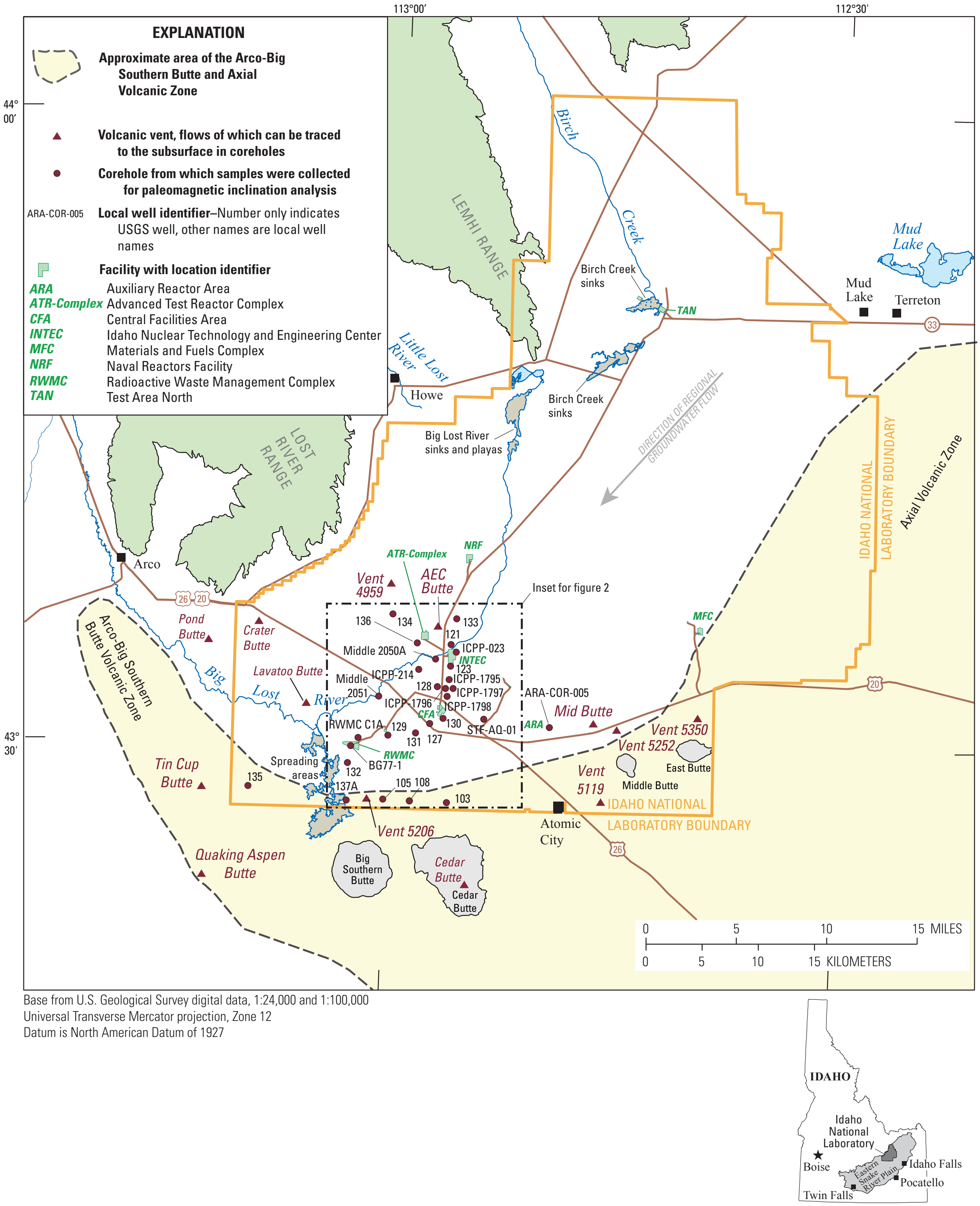
U.S. Geological Survey (USGS) scientists have been studying the geology, petrography, paleomagnetism, age of basalt flows, and hydrology of the ESRP for more than 100 years beginning with Russell (1902). Studies of the geologic framework of the ESRP at and near the INL intensified in 1949 when feasibility studies for siting of the INL began. Studies included evaluation of hydraulic properties of the aquifer, seismic and volcanic hazards, facility design and construction, and the evolution of basaltic volcanism on the ESRP.

Accumulations of basalt flows, eruptive fissures and vents, and fluvial and eolian sediments differ greatly in hydraulic conductivity, and the three-dimensional distribution of these materials control groundwater movement in the ESRP aquifer (Welhan and others, 2002). Basalt flows comprise more than 85 percent of the volume of the subsurface of the ESRP (Kuntz and others, 1992). Sedimentary interbeds comprise the rest. Paleomagnetic inclination and polarity studies on samples from subsurface drill cores and surface samples provide valuable data that can help constrain the age and extent of basalt flow groups. Data from paleomagnetic studies at and near the INL (Champion and Greeley, 1978; Champion and others, 1981; Champion and others, 1988) also have been used to document paleomagnetic secular variation (Hagstrum and Champion, 2002) during late Pliocene to Holocene time. The Big Lost Reversed Polarity Cryptochron (formerly referred to as the Big Lost Reversed Polarity Subchron (Champion and others, 1988) of the Brunhes Normal Polarity Chron was first identified in subsurface ESRP basalts at the INL (Champion and others, 1981, 1988).This study was done by the U.S. Geological Survey (USGS) in cooperation with the DOE Idaho Operations Office.

Purpose and Scope

Knowledge about the subsurface geologic framework of the ESRP aquifer is being used to aid in refining conceptual and numerical models of groundwater flow and contaminant transport at and near the INL. Better definition of wastewater constituent movement in the aquifer in relation to the geologic framework also will aid in creating a solute transport model. This report describes the correlation between subsurface stratigraphy in the southwestern part of the INL and presents information about the presence or absence of wastewater constituents to help develop a better understanding of how wastewater discharged at INL facilities is controlled by flow pathways in the aquifer. Paleomagnetic inclination data were used to identify subsurface basalt flows based on similar inclination measurements, polarity, and stratigraphic position. The subcore plugs collected from drill cores and used in this study yield only paleomagnetic-inclination data because the original declination of the drill cores is not preserved during drilling. Other data, such as lithology, petrology, geophysical logs, and geochemistry, can be used in conjunction with paleomagnetic inclination, stratigraphic, and age data to confirm or reject correlations. The presence or absence of wastewater constituents was determined using tritium concentrations or other constituents such as chloride concentrations or organic compounds. Tritium concentrations were used because they are sampled in every well at the INL and have established background concentrations. Wells with tritium concentrations less than 75 picocuries per liter (pCi/L) and (or) less than detection levels were not considered to be influenced by wastewater disposal unless organic compounds were present or chloride was present above background concentrations.

Paleomagnetic data were used to correlate surface and subsurface stratigraphy, determine relative ages, and, in conjunction with previous studies, determine the absolute age of certain basalt flows. Samples were collected from coreholes from depths of a few feet to 1,653 feet (ft). Drill core samples were selected from individual lava flow units based on identification of flow tops and bottoms in the coreholes. Well information was used to determine production zones that are correlated with the basaltic flow units. The wells considered for this study are in the southwestern part of the INL near and downgradient from the ATR Complex and INTEC (fig. 2).



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 the study area, selected facilities, volcanic vents, coreholes, and the Arco-Big Southern Butte and Axial volcanic zones, southwestern part of the Idaho National Laboratory, Idaho.

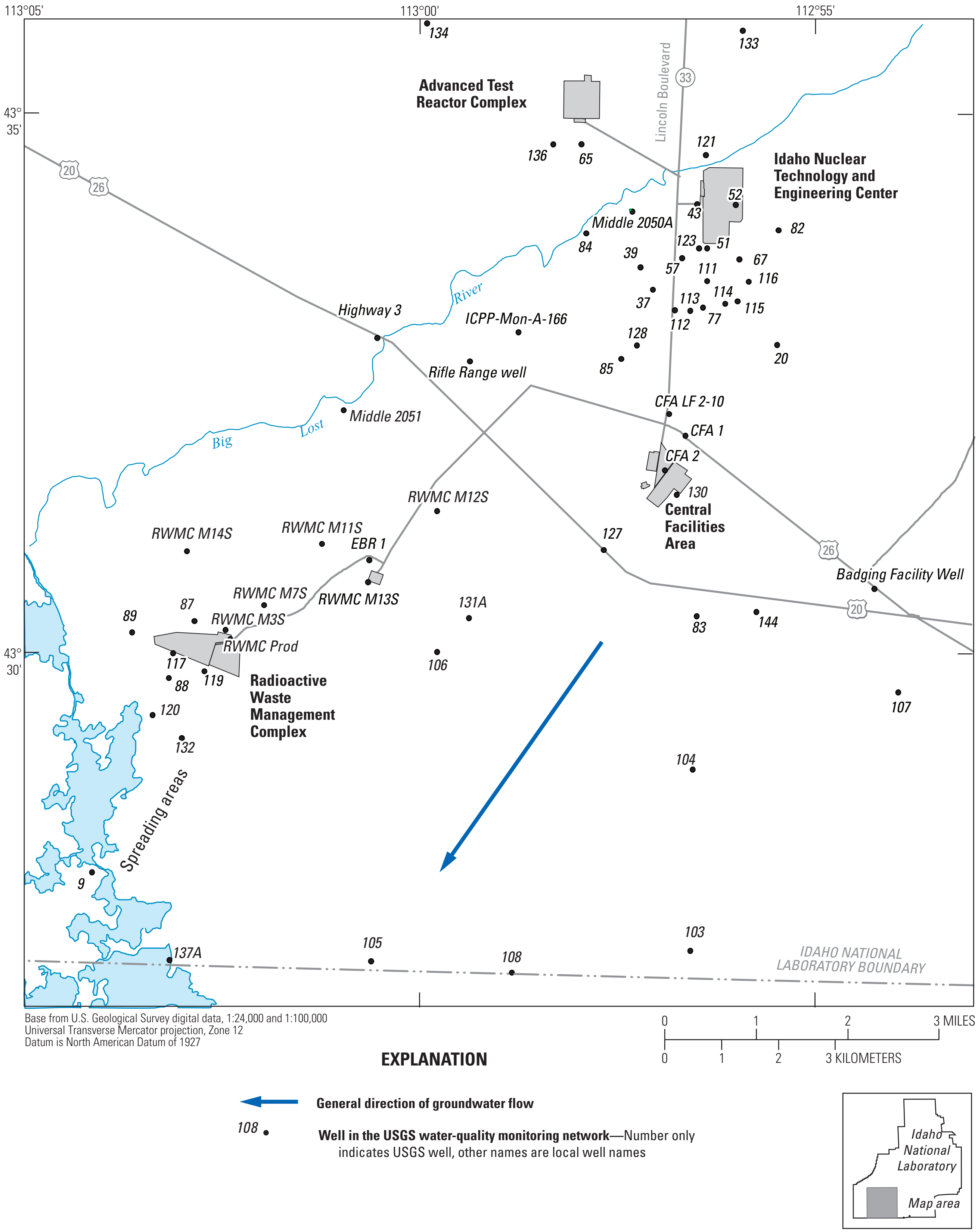


Figure 2. Location of wells sampled for radiochemical and chemical constituents, Idaho National Laboratory, Idaho.

Previous Investigations

Numerous investigations of water quality in the ESRP aquifer and geologic, paleomagnetic, and stratigraphic investigations on surface and subsurface basalts at and near the INL and the ESRP have been completed. Selected previous investigations and the areas of investigation are listed in table 1. Paleomagnetic data records the magnetic field at the time of eruption and is not unique. Other data such as lithology, petrology, geophysical logs, and geochemistry must be used in conjunction with paleomagnetic and age data to confirm or reject correlations.

The stratigraphic framework for the conceptual model for groundwater flow, published in 2006 (Ackerman and others, 2006) was based on a limited number of cores, and natural gamma geophysical logs from uncored wells (Anderson and Lewis, 1989; Anderson, 1991; Anderson and Bartholomay, 1995; Anderson and Bowers, 1995; Anderson, Ackerman, and others, 1996; Anderson, Liszewski, and Ackerman, 1996; Anderson and Liszewski, 1997; Anderson and others, 1999). The subsurface stratigraphy proposed by Anderson and his co-workers, has been largely confirmed by recent paleomagnetic stratigraphy studies (Champion and others, 2011, 2013; Hodges and Champion, 2016). This report presents a more detailed comparison of the stratigraphy through the southwestern part of the site with the location of groundwater contamination that was evaluated in several recent studies (Bartholomay and others, 2015, 2017; Davis and others, 2015; Bartholomay and Hall, 2016).

Table 1. Summary of selected previous investigations about geology, water quality, paleomagnetism, and stratigraphy of the eastern Snake River Plain and Idaho National Laboratory, Idaho.

[**Abbreviations:** ATR, Advanced Test Reactor; CFA, Central Facilities Area; ESRP, eastern Snake River Plain; INL, Idaho National Laboratory; INTEC, Idaho Nuclear Technology and Engineering Center (also known as ICPP [Idaho Chemical Processing Plant]); NPR, New Production Reactor; NRF, Naval Reactors Facility; RWMC, Radioactive Waste Management Complex; SRP, Snake River Plain; TAN, Test Area North; USGS; U.S. Geological Survey]

Reference	Area of investigation	Reference summary
Anders and Sleep, 1992	ESRP	Thermal and mechanical effects of the Yellowstone hotspot
Anderson, 1991	INTEC, ATR Complex	Stratigraphy of INTEC and the ATR Complex using geophysical logs
Anderson and Bowers, 1995	TAN	Stratigraphy of TAN using geophysical logs
Anderson and Lewis, 1989	RWMC	Stratigraphy of RWMC using geophysical logs
Anderson and Liszewski, 1997	INL	INL unsaturated and ESRP aquifer stratigraphy, based on core and natural gamma logs
Anderson, Ackerman, and others, 1996	INL	INL stratigraphy based on natural gamma logs
Anderson, Liszewski, and Ackerman, 1996	INL	INL surficial sediment thickness
Anderson and others, 1999	ESRP, INL and vicinity	Geologic controls on hydraulic conductivity
Bartholomay and Twining, 2010	Southwestern INL	Water quality of multilevel monitoring wells
Bartholomay and others, 2012	INL	Water-quality trends of wells not believed to be influenced by wastewater disposal
Bartholomay and others, 2015	Southwestern INL	Water quality of multilevel monitoring wells
Bartholomay and others, 2017	ESRP, INL and vicinity	Hydrologic conditions of the ESRP aquifer, 2012–15
Bestland and others, 2002	INL	Sedimentary interbeds in the Big Lost Trough, corehole 2-2A
Braile and others, 1982	ESRP	Seismic profiling of ESRP
Champion and others, 1981	INL	Radiometric ages and paleomagnetism at corehole Site E (NPR Test)
Champion and others, 1988	INL	Radiometric ages and paleomagnetism at corehole Site E (NPR Test), description of Big Lost cryptochron
Champion and Herman, 2003	INL, INTEC area	Paleomagnetism of basalt from drill cores
Champion and others, 2002	ESRP, INL and vicinity	Accumulation and subsidence based on paleomagnetism and geochronology
Champion and others, 2011	INL	Stratigraphic correlation of southern part of INL along with paleomagnetic information around TAN
Champion and others, 2013	NRF	Stratigraphic correlation of wells at NRF and to wells south of NRF

Table 1. Summary of selected previous investigations on water quality, geology, paleomagnetism, and stratigraphy of the eastern Snake River Plain and Idaho National Laboratory, Idaho.—Continued

Reference	Area of investigation	Reference summary
Davis and others, 2015	INL	Water-quality trends of wells possibly influenced by wastewater disposal
Geslin and others, 2002	Big Lost Trough, INL	Pliocene and Quaternary river drainage and sediment
Grimm-Chadwick, 2004	INL, CFA	Stratigraphy, geochemistry, and descriptions of high potassium oxide flow in cores
Hackett and Smith, 1992	ESRP	Description of ESRP volcanism including development of Axial Volcanic Zone
Hodges and others, 2012	INL	Construction diagrams, lithological, and geophysical logs for boreholes
Hodges and others, 2015	INL	Age dates of basalt flows in selected wells around the INL
Hodges and Champion, 2016	Southwestern INL	Paleomagnetic correlation of basalt flows in the southwestern part of INL
Kuntz, 1978	INL, RWMC	Geology of RWMC area
Kuntz and others, 1980	INL, RWMC	Radiometric dating, paleomagnetism of cores from RWMC
Kuntz and others, 1986	ESRP	Radiocarbon dates of Pleistocene and Holocene basalt flows
Kuntz and others, 1992	ESRP	ESRP basaltic volcanism, including eruption styles, landforms, petrology, and geochemistry
Kuntz and others, 1994	INL	Geologic map of INL, including radiometric ages and paleomagnetism
Lanphere and others, 1994	INL, at and near TAN	Petrography, age, and paleomagnetism of basalt flows at and near TAN
Lanphere and others, 1993	INL, at and near NRF	Petrography, age, and paleomagnetism of basalt flows at and near NRF
Mazurek, 2004	Central INL	Genetic alteration of basalt in ESRP aquifer
Miller, 2007	INL, RWMC	Geochemistry, descriptions of the B flow, and stratigraphy of corehole USGS 132
Morse and McCurry, 2002	INL	Base of the aquifer, alteration in basalts
Pierce and Morgan, 1992	ESRP	Age progression of Yellowstone hot spot
Pierce and others, 2002	ESRP	Age progression of Yellowstone hot spot
Reed and others, 1997	INL, ICPP	Geochemistry of lava flows in cores at ICPP
Rightmire and Lewis, 1987	INL, RWMC	Unsaturated zone geology, geochemistry of sediment and alteration products
Robertson and others, 1974	ESRP, INL and vicinity	Water quality and geochemistry of INL and vicinity
Russell, 1902	SRP	Geology and water resources of the Snake River Plain
Scarberry, 2003	INL, RWMC cores	Geochemistry of the F flow (now referred to as the Big Lost Reversed Polarity Cryptochron flows) and distribution in several coreholes at the INL
Shervais and others, 2006	INL, TAN cores	Cyclic geochemical variations in basalt in TAN drill cores
Stroup and others, 2008	INL	Statistical stationarity of sediment interbed thickness
Tauxe and others, 2004	SRP	Paleomagnetism of the Snake River Plain
Twining and others, 2008	INL	Construction diagrams, lithological, and geophysical logs for boreholes
Walker, 2000	ESRP	Volcanology of the Snake River Plain
Welhan and others, 2002	INL, ESRP	Morphology of inflated pahoehoe flows
Welhan and others, 2007	INL	Geostatistical modeling of sediment abundance
Wetmore and Hughes, 1997	INL	Model morphologies of subsurface lava flows
Wetmore and others, 1999	INL	Axial Volcanic Zone construction

Geohydrologic Setting

The INL is located on the west-central part of the ESRP. The ESRP developed when the North American tectonic plate moved southwestward over a fixed upper mantle-melting anomaly beginning about 17 million years ago (Pierce and Morgan, 1992; Pierce and others, 2002; Morgan and McIntosh, 2005). Thermal disruption resulted in a time transgressive series of silicic volcanic fields, characterized by positive geoid anomalies, rhyolitic resurgent caldera eruptions, emplacement of a mid-crustal mafic sill, and subsidence with later basaltic plains magmatism (Braile and others, 1982; Anders and Sleep, 1992; Peng and Humphries, 1998; Rodgers and others, 2002; Shervais and others, 2006). The part of the ESRP now occupied by the INL was the site of resurgent caldera activity, including the Picabo volcanic field from 10.2 ± 0.06 million years ago (Ma) to 7.9 ± 0.4 Ma (Kellogg and others, 1994; McCurry and Hughes, 2006), and the Heise volcanic field from 7.05 ± 0.04 Ma to 4.43 ± 0.08 Ma (Pierce and Morgan, 1992; Pierce and others, 2002; Morgan and McIntosh, 2005; McCurry and Hughes, 2006).

The ESRP is subsiding in the wake of the Yellowstone hot spot calderas (Braile and others, 1982; Anders and Sleep, 1992; McQuarrie and Rodgers, 1998; Rodgers and others, 2002). The ESRP subsided as it was filled, first with silicic material from the caldera eruptions, then later with tholeiitic basalt, and to a minor degree, with fluvial sediments washed out onto the ESRP (Blair, 2002; Bestland and others, 2002; Geslin and others, 2002). The total volume of basalt filling the ESRP is estimated to be 9,600 mi^3 (Kuntz, 1992).

The ESRP is an example of basaltic plains volcanism (Greeley, 1982). This form of basaltic volcanism is intermediate in style between flood basalts, such as the Columbia River Basalt Group, and shield volcano eruptions, such as those in Hawaii and Iceland. Basaltic eruptions on the ESRP generated a land surface formed from coalesced shield volcanoes that produced voluminous tube-fed pahoehoe flows and fissure eruptions (Greeley, 1982). Basaltic plains volcanism is characterized by relatively low effusion rates, long recurrence intervals, low total volumes of lava erupted, and the prevalence of monogenetic volcanoes (Kuntz, 1992). ESRP shield volcanoes produced flows that ranged from about 3 to 131 ft thick. The extent of some ESRP flows may be as large as 155 mi^2. The ESRP olivine tholeiite basalt flows may be as much as 22 mi long, and the accumulated volume of a shield volcano may be as large as 1.7 mi^3 (Kuntz and others, 1992). The flank areas of typical ESRP low shield volcanoes have slopes of less than 1 degree, and summit and vent areas have slopes of approximately 5 degrees (Greeley, 1982). Large, old vents are sometimes preserved as hills surrounded by basalt flows from younger vents; a good example is AEC Butte (fig. 1; Kuntz and others, 1994; Kuntz and others, 2003; Kuntz and others, 2007; Skipp and others, 2009).

More than 95 percent of the total volume of basalt in the ESRP is composed of tube-fed pahoehoe flows erupted from monogenetic shield volcanoes and lava cones (Kuntz and others, 1992). Basaltic lava fields, partially mantled with loess, cover the ESRP. The greatest numbers of eruptive centers are in the Axial Volcanic Zone ([AVZ]; fig. 1; Hackett and Smith, 1992). The AVZ is a constructional volcanic highland that parallels the long axis of the ESRP (Hackett and Smith, 1992; Kuntz and others, 1992, 1994; Anderson and Liszewski, 1997; Anderson, Ackerman, and others, 1996; Anderson and others, 1999; Hughes and others, 1999; Wetmore and others, 1999).

Basaltic eruptions have occurred on the ESRP about every 32,000–140,000 years over the entire INL (Champion and others, 2002). Eruptions in the northern part of the INL occur at longer intervals, and the shortest recurrence interval eruptions occur on or near the axis of the ESRP in the AVZ. Accumulation rates are highest in and around the AVZ (fig. 1; Champion and others, 2002). Most basalt flows and vents on the land surface in the southern part of the INL have normal magnetic polarity. These basalt flows and vents were erupted during the Brunhes Normal Polarity Chron and are less than 0.78 Ma. Some surface basalt flows and vents in the northern part of the INL have reversed magnetic polarity and erupted during the Matuyama Reversed Polarity Chron (2.581–0.78 Ma) (fig. 3; Ogg and Smith, 2004).

The basaltic flows and interbedded sediment combine to form the ESRP aquifer, which is one of the most productive aquifers in the United States (U.S. Geological Survey, 1985, p. 193). Water in the aquifer generally moves from northeast to southwest and eventually discharges to springs along the Snake River downstream of Twin Falls, Idaho, about 100 mi southwest of the INL. Water moves horizontally through basalt interflow zones and vertically through joints and interfingering edges of interflow zones. Infiltration of surface water, heavy pumpage, geologic conditions, and seasonal fluxes in recharge and discharge locally affect the movement of groundwater (Garabedian, 1986). The ESRP aquifer is recharged primarily from infiltration of applied irrigation water, infiltration of streamflow, groundwater inflow from adjoining mountain drainage basins, and infiltration of precipitation.

At the INL, depth to water in wells completed in the ESRP aquifer ranges from about 200 ft in the northern part of the site to more than 900 ft in the southeastern part. A significant proportion of the groundwater moves through the upper 200–800 ft of basaltic rocks (Mann, 1986, p. 21). Ackerman (1991, p. 30) and Bartholomay and others (1997, table 3) reported a range of transmissivity of basalt in the upper part of the aquifer of 1.1–760,000 ft^2/d. The hydraulic gradient at the INL ranges from 2 to 10 ft/mi, with an average of 4 ft/mi (Bartholomay and others, 2017, fig. 9). Horizontal flow velocities of about 2–26 ft/d have been calculated based on the movement of various constituents in different areas of the aquifer at and near the INL (Robertson and others, 1974; Mann and Beasley, 1994; Cecil and others, 2000; Plummer and others, 2000; Busenberg and others, 2001). These flow rates equate to a travel time of between 55 and 700 years for water beneath the INL to travel to springs that discharge at the terminus of the ESRP aquifer. Localized tracer tests at the INL have revealed vertical- and horizontal-transport rates as high as 60–150 ft/d (Nimmo and others, 2002; Duke and others, 2007).

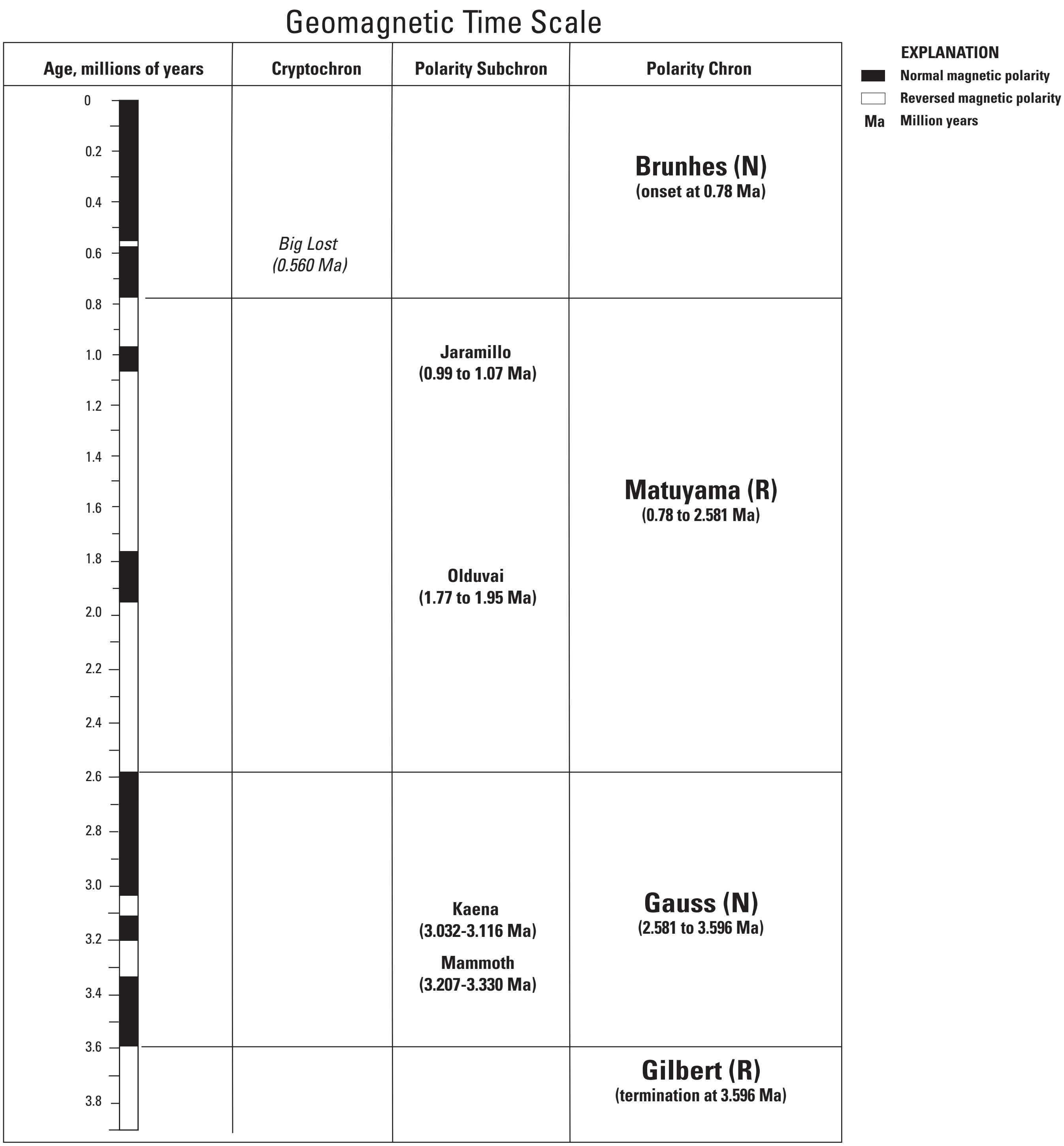


Figure 3. Geomagnetic time scale. Modified from Champion and others (1988), with new data from Ogg and Smith (2004).

Sampling and Analytical Techniques for Basalt Flows

The drill cores used for this study were carefully logged and sampled using INL Lithologic Core Storage Library protocols described in Davis and others (1997). Prior to sampling, the core material was described and the tops and bottoms of lava flows and flow units were identified. A lava flow unit is defined herein as the minimum subdivision of a lava flow, possessing quenched bottom and top surfaces, and typically part of a nearly contemporaneous group of other lava flow units. Basalt flow names used in this report were defined in more detail in Champion and others (2011) and Hodges and Champion (2016) and included labeling conventions, geomagnetic framework, sample collection, and correlation techniques. The basalt flow identified as being present in each well in the interval that the water samples are collected are given in table 2. Depths for basalt flows were measured by tape in feet and tenths of a foot from known marks recorded on wooden plugs or footage marked on the cores in the core boxes at the drill site. The wooden plugs are placed, or the drillers make marks on cores at the time of coring; the recorded measured depths are logged at the end of each core run. Descriptions of cores used to define the basalt flows in the aquifer are given in appendix A. Stratigraphy for wells used for wastewater determinations that did not have a core were interpreted from the nearest core to the well. Several wells at and downgradient of the ATR Complex and INTEC (see Bartholomay and others, 2017, fig. 6, for more information on wells not included) were not included in table 2 as they would have been determined to have the same stratigraphy because of similar distance to wells with known stratigraphy. The wells not included had open intervals (Bartholomay and others, 2017, table 2) similar to the wells used in this study and would not have contributed additional information to the study.

Sampling and Analytical Techniques for Tritium Concentrations

The tritium data used to determine whether or not wastewater influenced well water concentrations are from previously published data and includes data from the USGS National Water Information System database (accessible at https://maps.waterdata.usgs.gov/mapper/) (table 3). Tritium data from 11 multilevel monitoring well systems (MLMS) at the INL are reported in Bartholomay and Twining (2010) and Bartholomay and others (2015). The water samples collected from the MLMS were analyzed at the USGS Menlo Park Research Laboratory using electronic enrichment and liquid scintillation techniques to obtain lower detection levels (2.2 picocuries per liter [pCi/L]) than other data used for this study. Other tritium data used for this study were from wells completed in the upper part of the ESRP aquifer and were analyzed by the DOE Radiological and Environmental Sciences Laboratory with detection levels of about 200 pCi/L. Sampling methods and collection for water samples are described in Bartholomay and others (2014). Concentrations less than the detection level are labeled not detected (ND) in figure 4. The analytical results for tritium are presented with calculated analytical uncertainties (counting errors) in table 3. The probability is about 67 percent that the true radionuclide concentration is in a range of the reported concentrations plus or minus the uncertainty. Tritium data are compared to the estimated lower level of background (75 pCi/L) determined by Orr and others (1991) even though a more recent background level as reported by Bartholomay and Hall (2016) is about 35 pCi/L for groundwater in the southwestern part of the INL. The larger background is used to account for older water that would not have gone through as many half-life decay series as water samples collected more recently, because the data used for wastewater determination were collected between 1991 and 2016 (table 3). Chloride data also are listed in table 3 because chloride is another constituent commonly disposed of in wastewater at the ATR Complex and INTEC. Chloride readily moves in the aquifer system and is used to identify the presence or absence of wastewater in some of the wells with tritium concentrations less than the 200 pCi/L detection level.

Table 2. Data from selected coreholes and groundwater sampling sites at the Idaho National Laboratory, Idaho.

[Locations of wells are shown in figures 1 and 2. **Local name:** Local well identifier used in this study. **Site identifier:** The unique numerical identifiers used to access well data (https://waterdata.usgs.gov/nwis). **Land-surface altitude:** In feet above the vertical datum referenced to the North American Vertical Datum of 1988 (NAVD 88). **Site type:** Either a monitoring well (Well), multilevel monitoring system (MLMS), or corehole. **Open interval:** For multi-level systems the open interval is a hydraulically isolated depth interval. **Abbreviations:** AEC, Atomic Energy Commission; CFA, Central Facilities Area; ft bls, foot below land surface; ICPP, Idaho Chemical Processing Plant; NA, not applicable; RWMC, Radioactive Waste Management Complex; USGS, U.S. Geological Survey]

Local name	Site identifier	Land-surface altitude (ft)	Site type	Well depth (ft bls)	Hole depth (ft bls)	Open interval (ft bls)	Approximate water level (ft bls)		Basalt flow units and corehole used for open aquifer flow unit determination
							(ft bls)	Date	
Badging Facilty well	433041112535101	4,934	Well	644	644	533–644	488	September 2016	South CFA Buried Vent, Big Lost, CFA Buried vent; STF-AQ-1
BG-77-1	Not established		Corehole	NA	598	NA	596	April 2016	Early Basal Brunhes
CFA 1	433204112562001	4,928	Well	639	685	444–639	490	October 2016	CFA Buried Vent, AEC Butte; USGS 130 and ICPP-1798
CFA 2	433144112563501	4,931	Well	681	681	521–651 661–681	488	October 2016	CFA Buried Vent, AEC Butte; USGS 130
CFA LF 2-10	433216112563301	4,932	Well	716	816		490.21	10-20-16	CFA Buried Vent, AEC Butte; ICPP-1798
EBR-1	433051113002601	5,024	Well	1,075	1,075	600–750	607	September 2016	CFA Buried Vent, Middle Basal Brunhes, South Late Matuyama, Matuyama; RWMC C1A and USGS 129
						750–1,075			
Highway 3	433256113002501	4,981	Well	750	750	680–750	566	June 2016	Late Basal Brunhes, Middle Basal Brunhes, South Late Matuyama, Matuyama; Middle 2051
ICPP-023	Not established		Corehole	NA	739	NA	465	October 2016	CFA Buried Vent; AEC Butte
ICPP-214	Not established		Corehole	NA	498	NA	494	October 2016	CFA Buried Vent
ICPP-1795	Not established		Corehole	NA	648	NA	480	April 2016	CFA Buried Vent, AEC Butte
ICPP-1796	Not established		Corehole	NA	663	NA	490	October 2016	CFA Buried Vent, AEC Butte
ICPP-1797	Not established		Corehole	NA	648	NA	485	October 2016	CFA Buried Vent, AEC Butte
ICPP-1798	433216112562601	4,931	Corehole	NA	722	482–523	490	October 2016	CFA Buried Vent, AEC Butte
ICPP-Mon-A-166	433300112583301	4,956	Well	527	550	487–527	512.82	10-20-16	CFA Buried Vent, ICPP-214
Middle 2050A	433409112570515	4,928	MLMS	1,376	1,427	465–539	483.89	06-20-16	CFA Buried Vent, possibly AEC Butte or Middle Basal Brunhes
	433409112570512					643–703			AEC Butte, Late Basal Brunhes
	433409112570509					790–807			Matuyama
	433409112570506					999–1,041			Jaramillo
	433409112570503					1,180–1,227			Matuyama

Table 2. Data from selected coreholes and groundwater sampling sites at the Idaho National Laboratory, Idaho.—Continued

Local name	Site identifier	Land-surface altitude (ft)	Site type	Well depth (ft bls)	Hole depth (ft bls)	Open interval (ft bls)	Approximate water level (ft bls)		Basalt flow units and corehole used for open aquifer flow unit determination
							(ft bls)	Date	
Middle 2051	433217113004912 433217113004909 433217113004906 433217113004903 433217113004901	4,997	MLMS	1,175	1,179	562–609 748–771 826–876 1,090–1,128 1,140–1,176	566.05	06-07-16	CFA Buried vent, Late Basal Brunhes Matuyama Matuyama Jaramillo Matuyama
Rifle Range well	433243112591101	4,667	Well	620	626	600–620	513	October 2013	CFA Buried Vent; ICPP-214 and Middle 2051
RWMC C1A	433023113020301	5,025	Corehole	NA	1,805	NA	595	October 2016	CFA Buried Vent, Late Basal Brunhes, Middle Basal Brunhes, South Late Matuyama, Matuyama, Jaramillo
RWMC M3S	433008113021801	5,016	Well	633	660	603–633	596.61	10-13-16	CFA Buried Vent, Late Basal Brunhes; RWMC C1A
RWMC M7S	433023113014801	5,005	Well	628	638	598–628	584.95	10-12-16	CFA Buried Vent, Late Basal Brunhes; RWMC C1A
RWMC M11S	433058113010401	4,994	Well	624	626	559–624	572.96	10-19-16	CFA Buried Vent, Late Basal Brunhes; USGS 129 and USGS 131
RWMC M12 S	433118112593401	4,975	Well	572	586	528–572	543.67	10-20-16	CFA Buried Vent, Late Basal Brunhes; USGS 129 and USGS 131
RWMC M13S	433037113002701	5,027	Well	643	646	593–643	607.15	10-19-16	Big Lost, CFA Buried Vent, Middle Basal Brunhes; USGS 129
RWMC M14S	433052113025001	5,032	Well	635	645	584–635	611.70	10-20-16	CFA Buried Vent, Late Basal Brunhes; RWMC C1A and Middle 2051
RWMC Prod	433002113021701	5,005	Well	685	685	590–685	597	October 2016	CFA Buried Vent, Late Basal Brunhes, Middle Basal Brunhes; RWMC C1A and BG 77-1
STF-AQ-01	433112112535001	4,941	Corehole	558	713	538–558	483	October 2016	South CFA Buried Vent; Big Lost, Middle Basal Brunhes
USGS 9	432740113044501	5,030	Well	654	654	618–658	614.94;	10-17-16	Big Lost River, G Flow; USGS 137
USGS 20	433253112545901	4,915	Well	658	676	467–658	472.4	10-03-16	CFA Buried Vent, AEC Butte; ICPP-1797
USGS 37	433326112564801	4,929	Well	572	573	507–572	485.35	10-05-16	CFA Buried Vent; ICPP-1795
USGS 39	433343112570001	4,931	Well	492	572	47–492	486.34	07-19-16	CFA Buried Vent; Middle 2050A
USGS 43	433415112561501	4,915	Well	564	676	451–564	471.5	10-04-16	CFA Buried Vent; USGS 123

Table 2. Data from selected coreholes and groundwater sampling sites at the Idaho National Laboratory, Idaho.—Continued

Local name	Site identifier	Land-surface altitude (ft)	Site type	Well depth (ft bls)	Hole depth (ft bls)	Open interval (ft bls)	Approximate water level (ft bls)		Basalt flow units and corehole used for open aquifer flow unit determination
							(ft bls)	Date	
USGS 51	433350112560601	4,917	Well	647	659	475–647	471.14	04-06-16	CFA Buried Vent, AEC Butte; USGS 123
USGS 52	433414112554201	4,909	Well	602	650	450–602	465.01	10-05-16	CFA Buried Vent, AEC Butte; ICPP-023
USGS 57	433344112562601	4,922	Well	582	732	477–732	478.72	10-04-16	CFA Buried Vent, AEC Butte, Early Basal Brunhes; USGS 123
USGS 65	433447112574501	4,925	Well	498	498	456–498	477.00	10-19-16	CFA Buried Vent; USGS 136
USGS 67	433344112554101	4,913	Well	694	694	465–694	469.36	10-05-16	CFA Buried Vent, AEC Butte; USGS 123
USGS 77	433315112560301	4,921	Well	586	610	470–610	477.91	10-04-16	CFA Buried Vent, AEC Butte; ICPP-1795
USGS 82	433401112551001	4,907	Well	700	700	470–700	462.05	10-03-16	CFA Buried Vent, AEC Butte; ICPP-023
USGS 83	433023112561501	4,941	Well	752	752	516–752	507.28	10-17-16	Big Lost, CFA Buried Vent, Middle Basal Brunhes; USGS 144
USGS 84	433356112574201	4,938	Well	505	505	420–505	493.62	10-17-16	CFA Buried Vent; ICPP-214
USGS 85	433246112571201	4,939	Well	614	637	522–614	495.49	10-20-16	CFA Buried Vent; USGS 128
USGS 87	433013113024201	5,018	Well	673	673	568–673	596.29	04-13-16	CFA Buried Vent, Late Basal Brunhes, Middle Basal Brunhes; RWMC C1A and BG 77-1
USGS 88	432940113030201	5,021	Well	663	663	585-663	600.88	10-26-16	CFA Buried Vent, Middle Basal Brunhes; BG 77-1 and USGS 132
USGS 89	433005113032801	5,030	well	637	650	587-637	609.67	10-17-16	CFA Buried Vent, Middle Basal Brunhes; BG 77-1 and USGS 132
USGS 103	432714112560701 432714112560723 432714112560720 432714112560716 432714112560712 432714112560708 432714112560704 432714112560702	5,007	Well MLMS	760 1,297	760 1,307	575–760 670–691 767–832 892–920 958–1,014 1,063–1,098 1,184–1,240 1,257–1,279	588.89	06-14-16	Not identified Not identified Vent 5119 Unknown Middle Basal Brunhes South Late Matuyama Matuyama Post Jaramillo
USGS 104	432856112560801	4,988	Well	700	700	550–700	563.16	10-18-16	Big Lost, CFA Buried Vent; USGS 103

Table 2. Data from selected coreholes and groundwater sampling sites at the Idaho National Laboratory, Idaho.—Continued

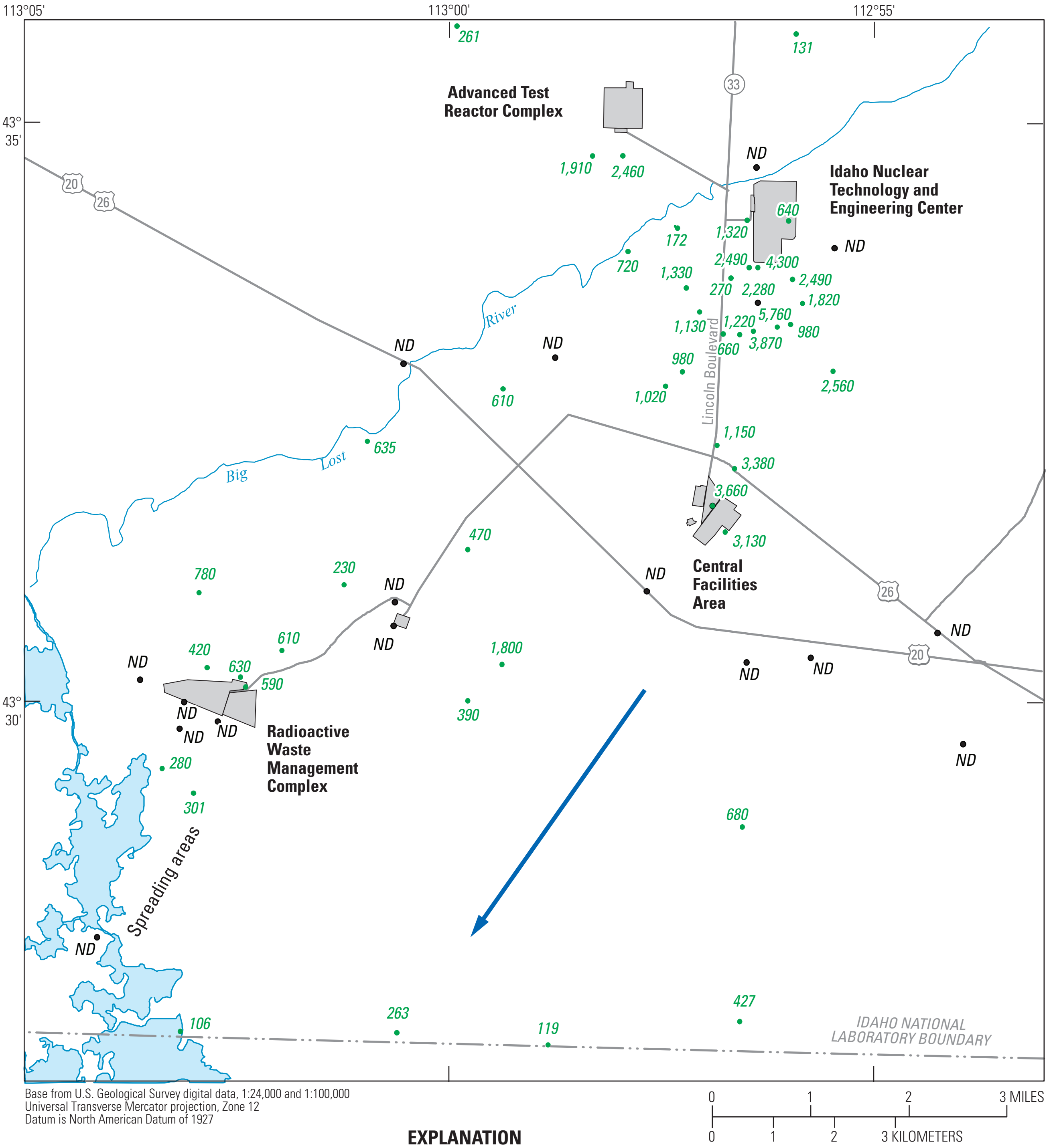
Local name	Site identifier	Land-surface altitude (ft)	Site type	Well depth (ft bls)	Hole depth (ft bls)	Open interval (ft bls)	Approximate water level (ft bls)		Basalt flow units and corehole used for open aquifer flow unit determination
							(ft bls)	Date	
USGS 105	432703113001801	5,095	Well	800	800	400–800			Unknown
	432703113001818		MLMS	1,300	1,409	707–752	677.73	06-16-16	Unknown
	432703113001815					830–862			Vent 5119
	432703113001811					929–982			Middle Basal Brunhes; Early Basal Brunhes
	432703113001807					1,035–1,102			South Late Matuyama
	432703113001803					1,225–1,276			Unknown, Matuyama
USGS 106	432959112593101	5,015	Well	760	760	400–760	595.89	10-20-16	CFA Buried Vent, Middle Basal Brunhes; USGS 131
USGS 107	432942112532801	4,918	Well	690	690	270–690	488.28	10-17-16	Big Lost, CFA Buried vent, Middle Basal Brunhes; STF-AQ-01
USGS 108	432659112582601	5,031	Well	765	765	400–760			Not identified
						755–765			Big Lost
	432659112582616		MLMS	1,218	1,218	642–679	613.60	06-15-16	Not identified
	432659112582613					791–830			G flow; Vent 5119
	432659112582610					872–904			Vent 5119, Middle Basal Brunhes
	432659112582606					1,018–1,060			South Late Matuyama
	432659112582602					1,161–1,192			Matuyama
USGS 111	433331112560501	4,920	Well	560	600	442–560	476.76	04-05-16	CFA Buried Vent; USGS 123
USGS 112	433314112563001	4,928	Well	507	563	432–444	484.15	10-03-16	CFA Buried Vent; ICPP-1795
						444–563			CFA Buried Vent; ICPP-1795
USGS 113	433314112561801	4,925	Well	556	564	445–564	479.68	04-05-16	CFA Buried Vent; ICPP-1795
USGS 114	433318112555001	4,920	Well	560	563	440–560	476.47	10-03-16	CFA Buried Vent; ICPP-1795
USGS 115	433320112554101	4,919	Well	581	581	437–581	475.09	10-03-16	CFA Buried Vent; ICPP-1795
USGS 116	433331112553201	4,916	Well	572	580	400–438	471.81	10-03-16	CFA Buried Vent; ICPP-1795
						438–572			CFA Buried Vent; ICPP-1795
USGS 117	432955113025901	5,012	Well	655	655	550–655	592.96	10-18-16	Early Basal Brunhes; Middle Basal Brunhes; BG 77-1 and USGS 132
USGS 119	432945113023401	5,032	Well	705	705	639–705	611.84	04-12-16	Early Basal Brunhes; Middle Basal Brunhes; BG 77-1 and USGS 132
USGS 120	432919113031501	5,040	Well	705	705	638–705	621.83	12-13-16	Middle Basal Brunhes, South Late Matuyama; USGS 132

Table 2. Data from selected coreholes and groundwater sampling sites at the Idaho National Laboratory, Idaho.—Continued

Local name	Site identifier	Land-surface altitude (ft)	Site type	Well depth (ft bls)	Hole depth (ft bls)	Open interval (ft bls)	Approximate water level (ft bls)		Basalt flow units and corehole used for open aquifer flow unit determination
							(ft bls)	Date	
USGS 121	433450112560301	4,910	Well	475	746	449–475	464.85	10-03-16	CFA Buried Vent
USGS 123	433352112561401	4,919	Well	515	744	450–475	475.43	10-04-16	CFA Buried Vent
USGS 127	433058112572201	4,956	Well	596	598	496–596	518.15	10-20-16	Big Lost, CFA Buried Vent
USGS 128	433250112565601	4,935	Well	615	768	457–615	490.9	10-26-16	CFA Buried vent, AEC Butte
USGS 129	433036113002701	5,026	Well	660	779	9–660	606.78	09-14-16	CFA Buried Vent, Middle Basal Brunhes, South Late Matuyama
USGS 130	433130112562801	4,928	Well	636	723	474–636	487.16	12-14-16	Big Lost, CFA Buried Vent, Middle Basal Brunhes
USGS 131	433036112581601	4,977	Well	797	808	537–797	548.25	12-13-16	Big Lost, CFA Buried Vent, Middle Basal Brunhes
USGS 131A	433036112581815	4,976	MLMS	1,177	1,198	562–632	546.29	06-28-16	Big Lost, CFA Buried Vent
	433036112581810					795–842			Middle Basal Brunhes, Early Basal Brunhes, South Late Matuyama
	433036112581806					956–1,058			Jaramillo
	433036112581803					1,120–1,157			Jaramillo
USGS 132	432906113025022	5,029	MLMS	1,238	1,238	624–660	610.58	06-07-16	CFA Buried Vent, Middle Basal Brunhes
	432906113025018					727 –787			South Late Matuyama
	432906113025014					812 –864			Matuyama
	432906113025010					911–935			Matuyama
	432906113025006					984 –1,043			Matuyama
	432906113025001					1,152 –1,214			Post Jaramillo
USGS 133	433605112554312	4,890	MLMS	798	818	448–480	430.03	06-13-16	AEC Butte
	433605112554308					556–591			AEC Butte, Late Basal Brunhes
	433605112554305					686–696			North Late Matuyama
	433605112554301					725–766			Matuyama

Table 2. Data from selected coreholes and groundwater sampling sites at the Idaho National Laboratory, Idaho.—Continued

Local name	Site identifier	Land-surface altitude (ft)	Site type	Well depth (ft bls)	Hole depth (ft bls)	Open interval (ft bls)	Approximate water level (ft bls)		Basalt flow units and corehole used for open aquifer flow unit determination
							(ft bls)	Date	
USGS 134	433611112595819	4,969	MLMS	894	949	554–590	517.66	06-06-16	Late Basal Brunhes
	433611112595815					639–652			Early Basal Brunhes
	433611112595811					691–720			Matuyama
	433611112595807					782–818			Post Jaramillo
	433611112595804					846–868			Jaramillo
	433611112595803					846–868			Jaramillo
USGS 135	432753113093613	5,150	MLMS	1,157	1,198	727–762	720.44	06-09-16	South Late Matuyama
	432753113093609					823–861			South Late Matuyama
	432753113093605					968–1,008			Matuyama
	432753113093601					1,106–1,137			Matuyama
USGS 136	433447112581501	4,935	Well	551	1,048	500–550	490.98	10-25-16	CFA Buried Vent, AEC Butte
USGS 137A	432701113025807	5,054	MLMS	895	1,058	640–718	629.11	06-13-16	Big Lost, G-flow
	432701113025805					721–784			Middle Basal Brunhes, Early Basal Brunhes
	432701113025803					787–862			Early Basal Brunhes, South Late Matuyama
	432701113025801					874–895			South Late Matuyama
USGS 144	433021112552501	4,954	Well	620	620	502–620	519.85	12-13-16	South CFA Buried Vent; Big Lost



EXPLANATION

680 — **Tritium concentration (in picocuries per liter) without uncertainty**—Date of collection given in table 3. Mapped concentrations represent water samples collected from various depths in boreholes with differing well completions; for example, single- and multiple-screened intervals, and open boreholes. Concentrations from multi-level monitoring wells is the largest reported concentration. Location is approximate

ND — **Concentrations less than laboratory detection levels**

General direction of groundwater flow

• or • — **Well in the USGS water-quality monitoring network**—Water samples analyzed for tritium

Figure 4. Tritium concentrations in water sampled from wells in the southwestern part of the Idaho National Laboratory, Idaho. See figure 2 for well numbers.

Table 3. Hydraulic conductivity, tritium, and chloride data for selected groundwater sampling sites at the Idaho National Laboratory, Idaho.

[Locations of wells are shown in figures 1 and 2. Hydraulic conductivity values are from Anderson and others (1999, table 2). Value for upper zones of multi-level wells USGS 103, 105, 108, and 137A are for open intervals in wells before multi-level systems were installed. USGS 109 is used for the upper level of USGS 137A because wells are at the same location. **Local name**: Local well identifier used in this study. **Site identifier:** Unique numerical identifier used to access well data (https://waterdata.usgs.gov/nwis). **Open interval:** For multi-level systems, the open interval is a hydraulically isolated depth interval. **Abbreviations:** ft bls, foot below land surface; ft/d, foot per day; mg/L, milligram per liter; NA, not available; pCi/L , picocuries per liter; >, greater than; ±, plus or minus]

Local name	Site identifier	Open interval (ft bls)	Hydraulic conductivity (ft/d as log K)	Tritium		Chloride		Wastewater present
				(pCi/L)	Date	(mg/L)	Date	
Badging Facility well	433041112535101	533–644	NA	15±55.6	04-20-15	16.4	04-20-15	No
CFA 1	433204112562001	444–639	1.08	3,380±110	04-20-15	87.7	04-20-15	Yes
CFA 2	433144112563501	521–651	1.04	3,660±100	10-13-15	134	10-13-15	Yes
		661–681						Yes
CFA LF 2-10	433216112563301	704–716	NA	1,150±80	04-13-15	26.7	04-13-15	Yes
EBR 1	433051113002601	600–750	0.43	-3.2±13	06-19-91	6.57	04-20-11	No
		750–1,075						
Highway 3	433256113002501	680–750	>0.52	100±50	10-19-15	6.00	10-19-15	No
ICPP-Mon-A-166	433300112583301	487–527	NA	-70±50	04-16-15	10.3	04-16-15	No
Middle 2050A	433409112570515	465–539	NA	172±5.4	08-27-08	12.3	06-23-15	Yes
	433409112570512	643–703	NA	93.8±3.5	08-26-08	11.6	06-28-10	Yes
	433409112570509	790–807	NA	60.9±2.9	08-26-08	11.5	06-28-10	No
	433409112570506	999–1,041	NA	5.4±1.9	08-26-08	10.6	06-28-10	No
	433409112570503	1,180–1,227	NA	97.6±3.5	08-26-08	14.8	06-28-10	Yes
Middle 2051	433217113004912	562–609	NA	51.7±2.9	08-25-08	5.9	07-01-10	No
	433217113004909	748–771	NA	475±13	08-25-08	10.5	06-10-15	Yes
	433217113004906	826–876	NA	635±19	08-21-08	11.0	06-18-14	Yes
	433217113004903	1,090–1,128	NA	292±8.6	08-21-08	11.5	06-10-15	Yes
	433217113004901	1,140–1,176	NA	300±8.9	08-21-08	11.9	06-20-13	Yes
Rifle Range well	433243112591101	600–620	NA	610±60	10-13-15	25.2	10-13-15	Yes
RWMC M3S	433008113021801	603–633	NA	630±60	10-20-15	15.7	10-20-15	Yes
RWMC M7S	433023113014801	598–628	NA	610±60	10-20-15	14.4	10-20-15	Yes
RWMC M11S	433058113010401	559–624	NA	230±50	10-22-15	7.87	10-22-15	Yes
RWMC M12S	433118112593401	528–572	NA	470±60	10-21-15	9.77	10-21-15	Yes
RWMC M13S	433037113002701	593–643	NA	-12.3±45.9	10-20-15	5.98	10-20-15	No
RWMC M14S	433052113025001	584–635	NA	780±60	10-20-15	16.1	10-20-15	Yes
RWMC Prod	433002113021701	590–685	2.36	590±60	10-14-15	25.8	10-14-15	Yes
USGS 9	432740113044501	618–658	3.32	-70±40	10-13-15	14.6	10-13-15	No
USGS 20	433253112545901	467–658	0.90	2,560±100	04-08-15	40.1	04-08-15	Yes
USGS 37	433326112564801	507–572	2.40	1,130±70	10-05-15	15.4	10-05-15	Yes
USGS 39	433343112570001	47–492	3.60	1,330±70	10-21-13	11.7	10-21-13	Yes
USGS 43	433415112561501	451–564	2.78	1,320±70	10-06-15	19.7	10-06-15	Yes
USGS 51	433350112560601	475–647	1.38	4,300±120	04-08-15	170	04-08-15	Yes
USGS 52	433414112554201	450–602	>3.52	640±60	10-05-15	19.6	10-05-15	Yes
USGS 57	433344112562601	477–732	2.18	270±50	10-07-15	14.7	10-07-15	Yes
USGS 65	433447112574501	456–498	2.45	2,460±100	04-02-15	19.5	04-02-15	Yes
USGS 67	433344112554101	465–694	NA	2,490±90	10-05-15	45.4	10-05-15	Yes
USGS 77	433315112560301	470–610	0.93	3,870±100	10-05-15	75.8	10-05-15	Yes
USGS 82	433401112551001	470–700	3.00	-60±50	04-07-15	17.4	04-07-15	No
USGS 83	433023112561501	516–752	0.58	70±110	04-24-07	10.2	04-25-11	No
USGS 84	433356112574201	420–505	>3.48	720±60	10-21-15	11.3	10-21-15	Yes
USGS 85	433246112571201	522–614	3.53	1,020±70	04-08-15	13.6	04-08-15	Yes
USGS 87	433013113024201	568–673	0.99	420±60	04-13-15	28.9	04-13-15	Yes
USGS 88	432940113030201	585–663	-0.77	0±50	10-13-15	109	10-13-15	Yes
USGS 89	433005113032801	587–637	-0.06	60±50	04-14-15	60.7	04-14-15	Yes

Table 3. Hydraulic conductivity, tritium, and chloride data for selected groundwater sampling sites at the Idaho National Laboratory, Idaho.—Continued

Local name	Site identifier	Open interval (ft bls)	Hydraulic conductivity (ft/d as log K)	Tritium		Chloride		Wastewater present
				(pCi/L)	Date	(mg/L)	Date	
USGS 103	432714112560723	670–691	2.94	8±1.9	08-20-08	18.7	06-24-10	No
	432714112560720	767–832	NA	16.9±1.9	08-19-08	14.7	06-23-10	No
	432714112560716	892–920	NA	72.4±2.9	08-19-08	10.3	06-23-10	No
	432714112560712	958–1,014	NA	275±8	08-18-08	12.5	06-16-15	Yes
	432714112560708	1,063–1,098	NA	434±13	08-18-08	14.4	06-16-15	Yes
	432714112560704	1,184–1,240	NA	427±12	08-18-08	14.4	06-16-15	Yes
	432714112560702	1,257–1,279	NA	405±13	08-19-08	14.6	06-16-15	Yes
USGS 104	432856112560801	550–700	-1.03	680±60	10-19-15	14.1	10-19-15	Yes
USGS 105	432703113001818	707–752	2.80	171.3±5.4	09-16-10	12.4	09-16-10	Yes
	432703113001815	830–862	NA	186.3±5.7	09-16-10	12.0	06-17-15	Yes
	432703113001811	929–982	NA	231.3±6.7	09-15-10	12.7	06-17-15	Yes
	432703113001807	1,035–1,102	NA	262.9±7.7	09-15-10	12.7	06-17-15	Yes
	432703113001803	1,225–1,276	NA	126.3±4.1	09-15-10	11.4	09-15-10	Yes
USGS 106	432959112593101	400–760	2.75	390±50	10-13-15	14.9	10-13-15	Yes
USGS 107	432942112532801	270–690	2.52	-70±50	04-20-15	22.6	04-20-15	No
USGS 108	432659112582616	642–679	2.98	58.8±3	06-23-11	12.4	09-16-10	No
	432659112582613	791–830	NA	119±3	06-23-11	16.2	06-18-15	Yes
	432659112582610	872–904	NA	79.3±2.4	06-23-11	16.6	06-26-13	Yes
	432659112582606	1,018–1,060	NA	83.6±3.1	06-22-11	17.4	06-26-13	Yes
	432659112582602	1,161–1,192	NA	97.4±3.3	06-22-11	17.1	06-18-15	Yes
USGS 111	433331112560501	442–560	-0.8	2,280±80	04-07-15	93.5	04-07-15	Yes
USGS 112	433314112563001	432–444	2.83	660±60	10-06-15	17.8	10-06-15	Yes
		444–563						Yes
USGS 113	433314112561801	445–564	3.30	1,220±80	04-07-15	29	04-07-15	Yes
USGS 114	433318112555001	440–560	-1.00	5,760±120	10-06-15	84.7	10-06-15	Yes
USGS 115	433320112554101	437–581	-0.58	980±60	10-06-15	41.2	10-06-15	Yes
USGS 116	433331112553201	400–438	0.08	1,820±90	04-07-15	95.0	04-07-15	Yes
		438–572						Yes
USGS 117	432955113025901	550–655	-0.72	-20±50	10-19-15	12.6	10-19-15	No
USGS 119	432945113023401	639–705	-2.00	-50±50	04-14-15	11.1	04-14-15	No
USGS 120	432919113031501	638–705	3.36	280±60	10-10-12	14.4	10-21-15	Yes
USGS 121	433450112560301	449–475	NA	-70±50	04-16-15	11.9	04-16-15	No
USGS 123	433352112561401	450–475	NA	2,490±90	10-07-15	24.8	10-07-15	Yes
USGS 127	433058112572201	496–596	NA	60±60	04-16-15	15.9	04-16-15	No
USGS 128	433250112565601	457–615	NA	980±60	10-07-15	12.9	10-07-15	Yes
USGS 130	433130112562801	474–636	NA	3,130±90	10-07-15	144	10-07-15	Yes
USGS 131	433036112581601	537–797	NA	1,800±400	04-12-07	20.9	05-25-10	Yes
USGS 131A	433036112581815	562–632	NA	983±26.3	07-17-13	17.1	06-15-15	Yes
	433036112581810	795–842	NA	1,454±38.5	07-16-13	26.4	06-15-15	Yes
	433036112581806	956–1,058	NA	149±4.86	07-16-13	13.3	06-15-15	Yes
	433036112581803	1,120–1,157	NA	133±4.51	07-16-13	13.6	06-15-15	Yes
USGS 132	432906113025022	624–660	NA	122±4.1	08-14-08	17.2	07-06-11	Yes
	432906113025018	727–787	NA	252±7.7	08-13-08	10.7	06-09-15	Yes
	432906113025014	812–864	NA	256±8	08-13-08	10.2	06-30-10	Yes
	432906113025010	911–935	NA	269±8.6	08-13-08	10.3	06-30-10	Yes
	432906113025006	984–1,043	NA	301±8.9	08-12-08	10.3	06-30-10	Yes
	432906113025001	1,152–1,214	NA	286±8.6	08-12-08	10.6	06-30-10	Yes
USGS 133	433605112554312	448–480	NA	131±4.1	09-02-08	11.7	06-09-15	Yes
	433605112554308	556–591	NA	6.9±1.8	09-02-08	13.6	08-05-10	No
	433605112554305	686–696	NA	7.9±1.7	09-02-08	14.1	08-05-10	No
	433605112554301	725–766	NA	12.4±2.2	09-02-08	14.9	08-05-10	No

Table 3. Hydraulic conductivity, tritium, and chloride data for selected groundwater sampling sites at the Idaho National Laboratory, Idaho.—Continued

Local name	Site identifier	Open interval (ft bls)	Hydraulic conductivity (ft/d as log K)	Tritium		Chloride		Wastewater present
				(pCi/L)	Date	(mg/L)	Date	
USGS 134	433611112595819	554–590	NA	17±1.9	09-04-08	9.47	06-08-15	No
	433611112595815	639–652	NA	261±7.3	09-04-08	9.7	06-29-11	Yes
	433611112595811	691–720	NA	9.1±1.7	09-03-08	7.28	07-10-13	No
	433611112595807	782–818	NA	3±1.8	09-03-08	10.3	06-21-10	No
	433611112595803	846–868	NA	88.7±3.2	09-03-08	8.4	06-21-10	No
USGS 136	433447112581501	500–550	2.4	1,910±100	10-25-11	14.0	10-15-15	Yes
USGS 137A	432701113025807	640–718	2.78	106±3.83	07-15-13	13.7	06-22-15	Yes
	432701113025805	721–784	NA	89.2±3.47	07-15-13	12.1	06-22-15	Yes
	432701113025803	787–862	NA	67.6±2.97	07-15-13	11.1	06-22-15	No
	432701113025801	874–895	NA	64.8±2.87	07-15-13	11.1	06-22-15	No
USGS 144	433021112552501	502–620	NA	80±60	12-07-16	17.8	12-07-16	No

Correlation between Basalt Flows and Wastewater Constituents in the Aquifer

Recent mapping of basalt flows at the INL using paleomagnetic inclination data (Champion and others, 2011; 2013; Hodges and Champion, 2016) has led to a better understanding and correlation of stratigraphic sequences at the INL. The extent of basalt flow units from youngest (Big Lost flow, fig. 5*A*) to oldest (Matuyama flow, fig. 5*H*) are shown in figure 5. The stratigraphic sequence of the flows from youngest to oldest is shown in table 4, which lists the percentage of wells that show wastewater influence compared with the wells with flows that do not show wastewater influence.

Table 4. Stratigraphic sequence and percentage of flows influenced by wastewater at the Idaho National Laboratory, Idaho.

[Basalt flow units were defined in Champion and others (2011) and Hodges and Champion (2016) and are arranged from youngest to oldest. The sequence for CFA Buried vent and G flow, AEC Butte and Vent 5119, North and South Late Matuyama, and the unknown flow in USGS 103, and Late Basal Brunhes are uncertain because these flows are not present together in any well to determine overlap and age dates that are available indicate that the flows are about the same age]

Basalt flow unit	Number of wells			Wastewater influence (percent)
	Flow identified	Wastewater detected	Wastewater not detected	
South CFA Buried Vents	2	0	2	0
Big Lost	13	5	8	38
CFA Buried Vent	52	43	9	83
G flow	2	2	2	100
Vent 5119	3	2	1	67
AEC Butte	14	14	0	100
Late Basal Brunhes	12	7	5	58
Unknown flow in USGS 103	1	0	1	0
Middle Basal Brunhes	20	11	9	55
Early Basal Brunhes	7	5	2	71
North Late Matuyama	1	0	1	0
South Late Matuyama	10	7	3	70
Unknown flow in USGS 105	1	1	1	100
Matuyama	11	5	6	45
Post Jaramillo	2	1	1	50
Jaramillo	4	3	1	75

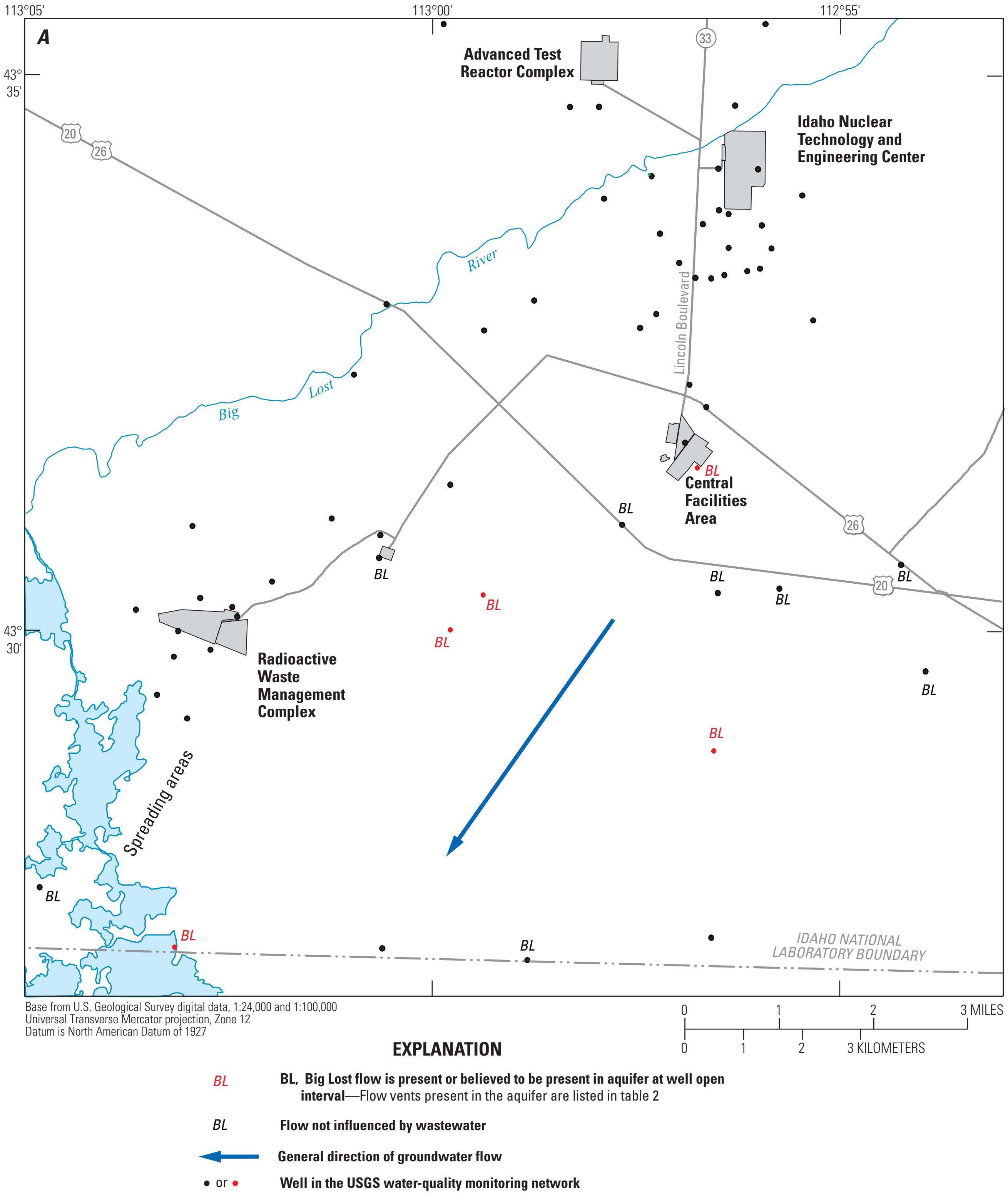


Figure 5. Occurrence of basalt flows (*A*) Big Lost, (*B*) CFA Buried Vent, (*C*) AEC Butte, (*D*) Late Basal Brunhes, (*E*) Middle Basal Brunhes, (*F*) Early Basal Brunhes, (*G*) South Late Matuyama, and (*H*) Matuyama in wells in the southwestern part of the Idaho National Laboratory, Idaho. See figure 2 for well numbers.

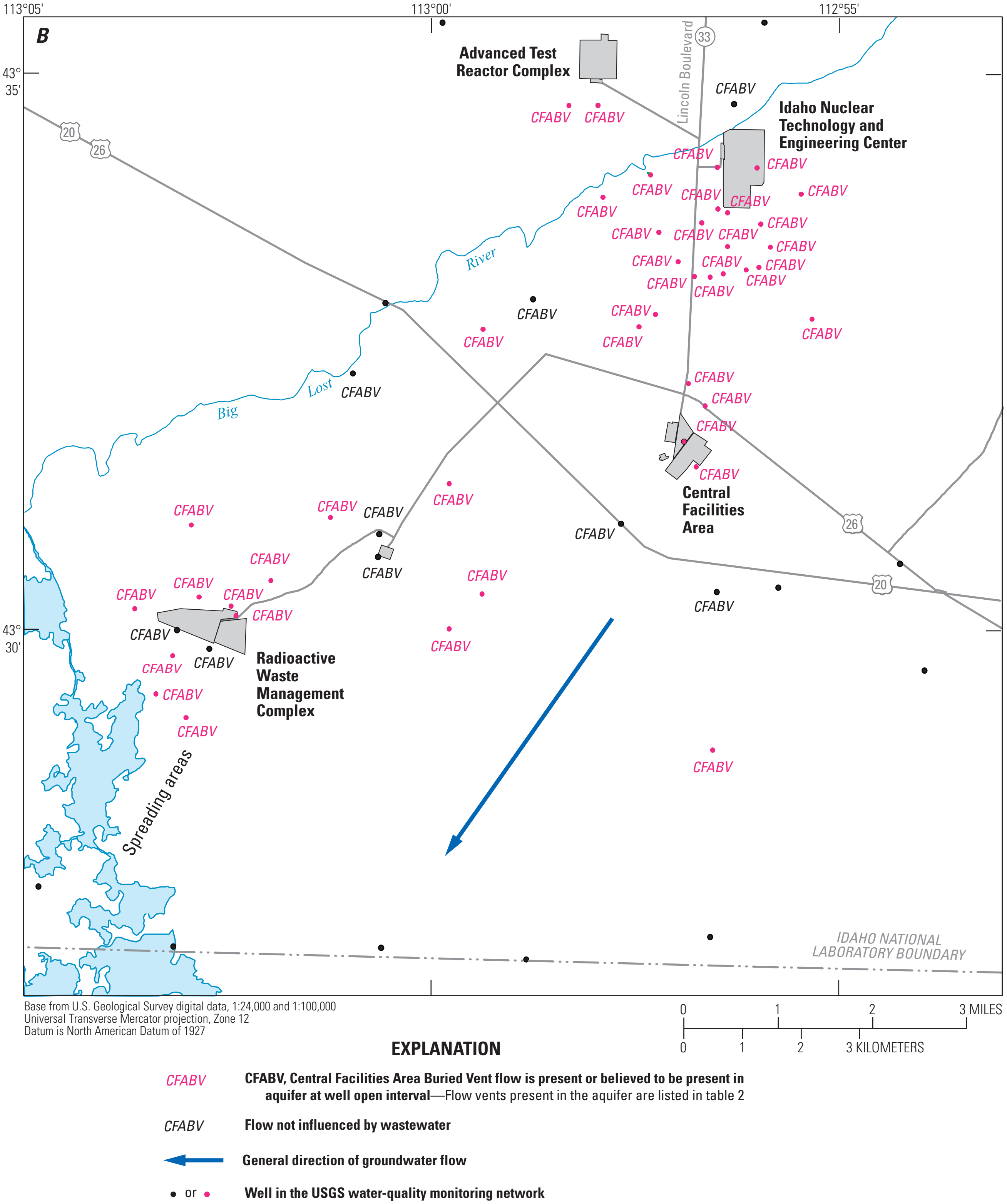
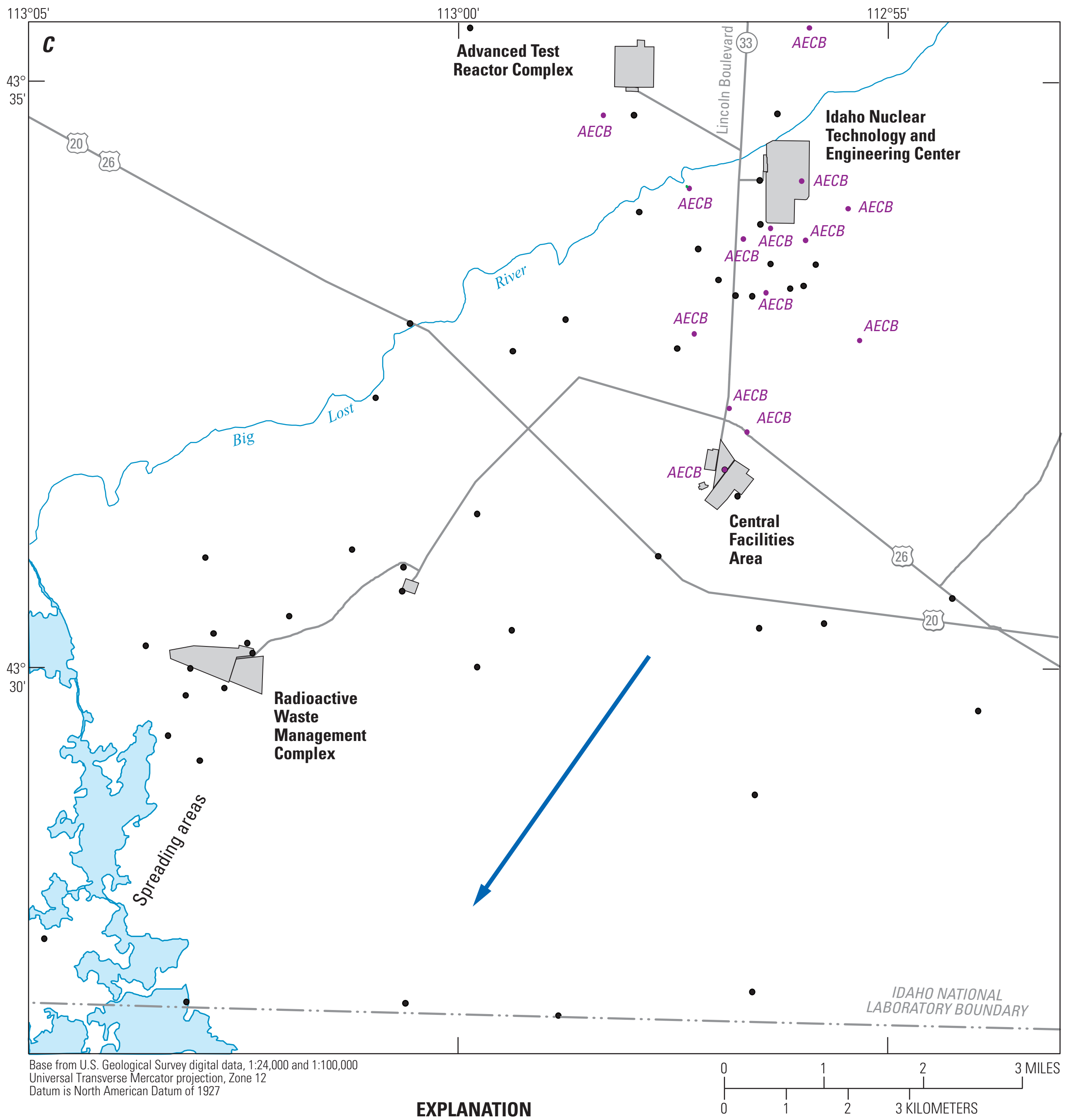


Figure 5.—Continued



EXPLANATION

AECB — **AECB, AEC Butte flow is present or believed to be present in aquifer at well open interval**—Flow vents present in the aquifer are listed in table 2

General direction of groundwater flow

• or • — **Well in the USGS water-quality monitoring network.**

Figure 5.—Continued

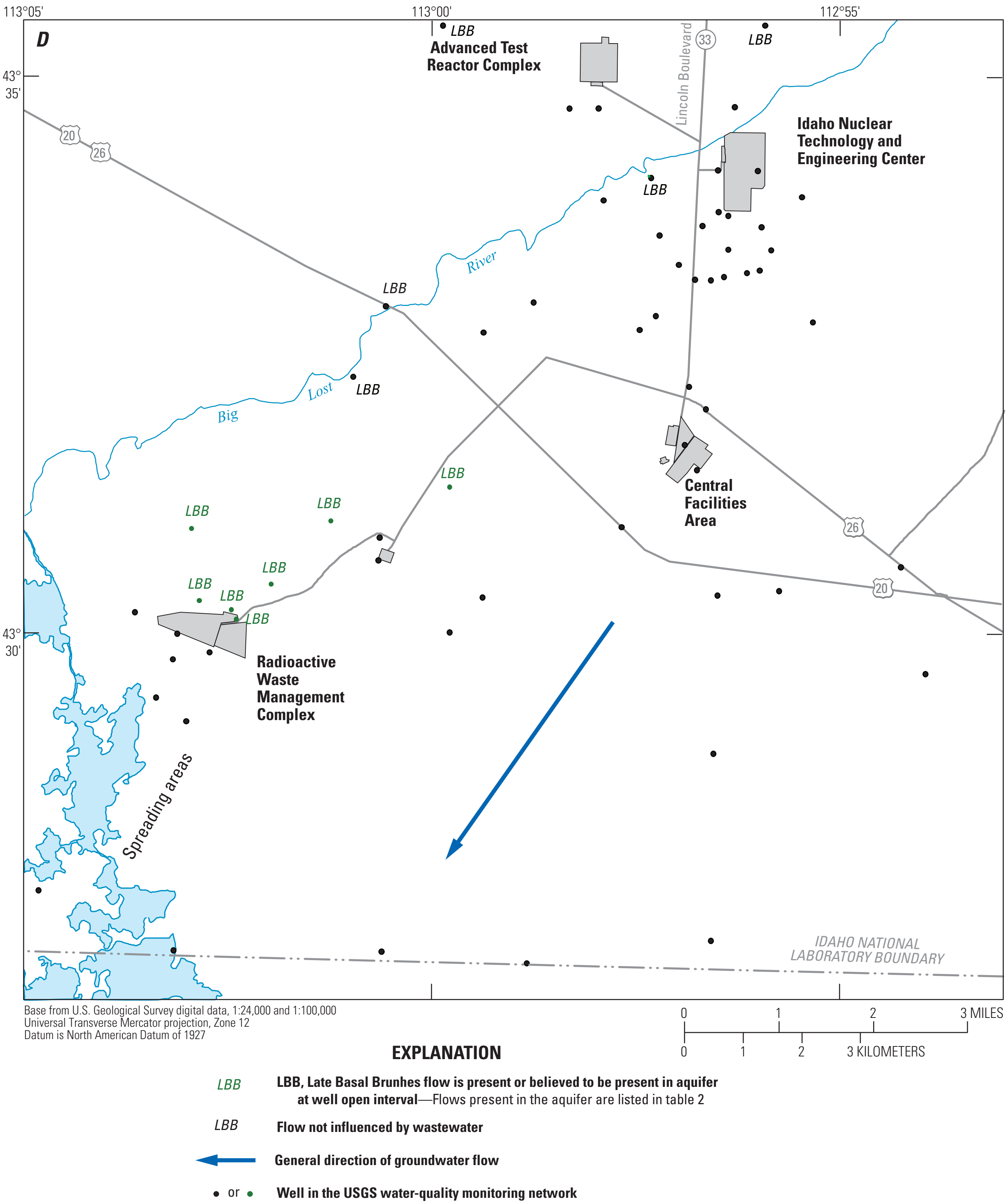


Figure 5.—Continued

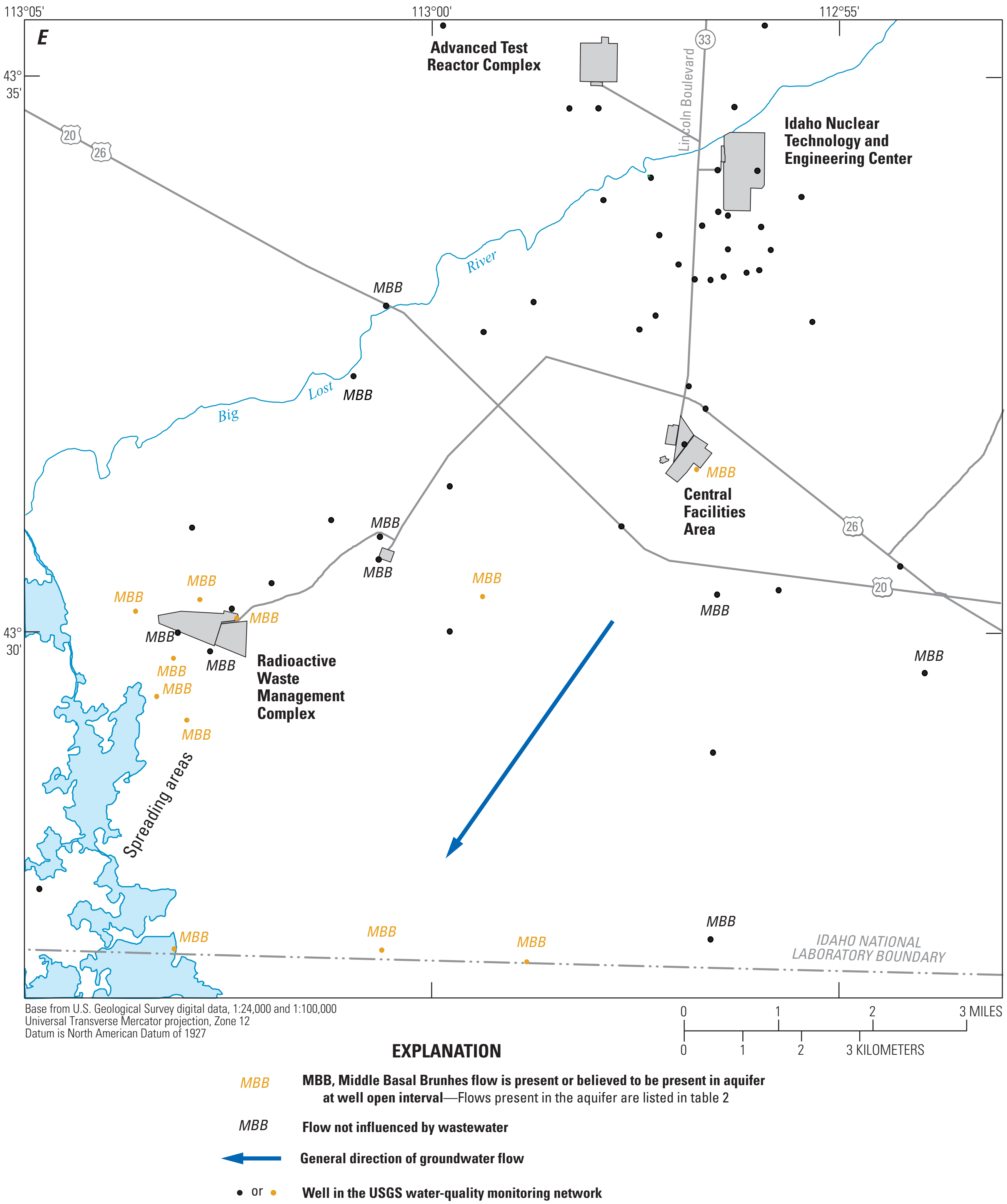
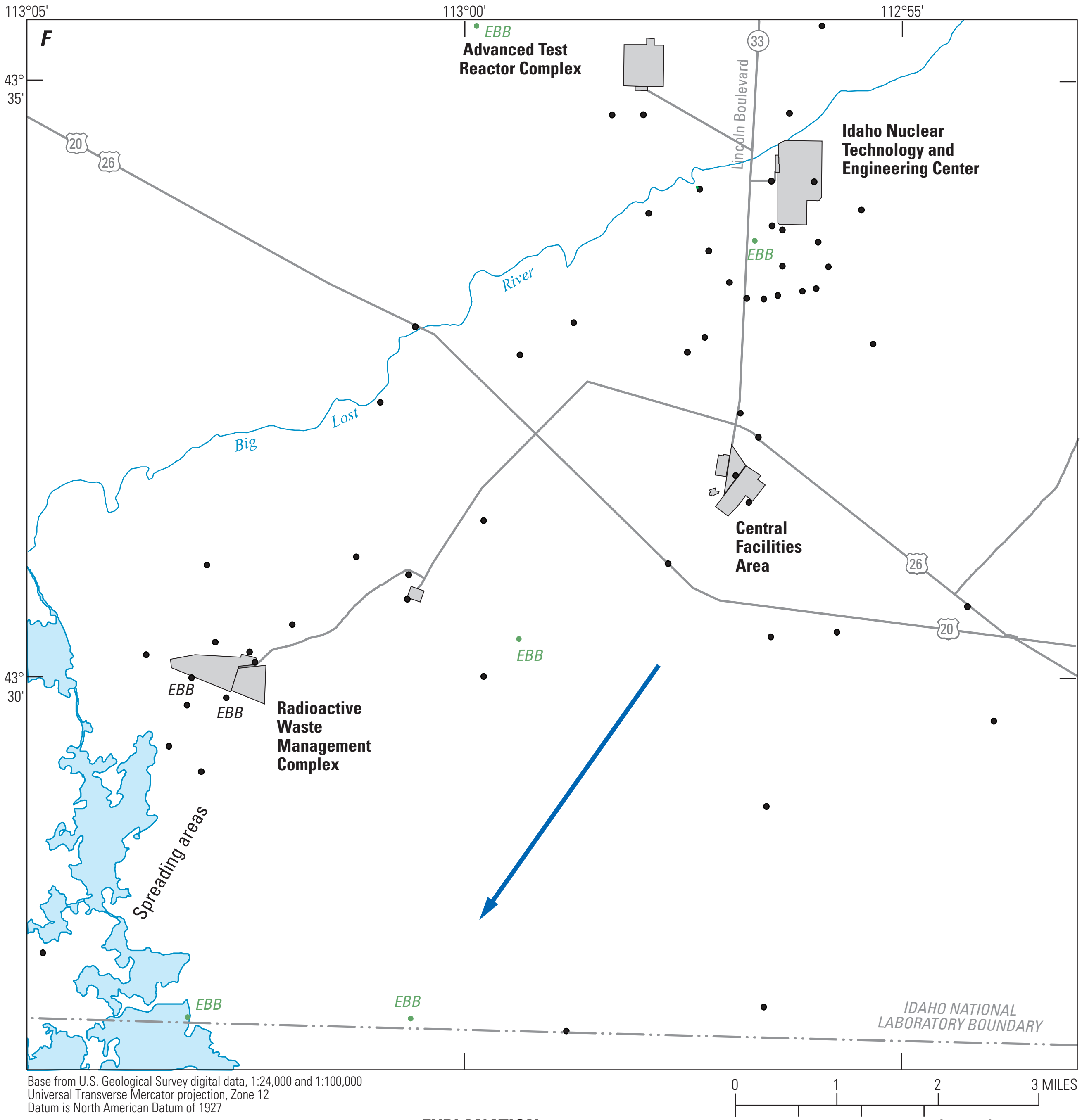


Figure 5.—Continued



EXPLANATION

EBB **EBB, Early Basal Brunhes flow is present or believed to be present in aquifer at well open interval**—Flows present in the aquifer are listed in table 2

EBB **Flow not influenced by wastewater**

General direction of groundwater flow

• or • **Well in the USGS water-quality monitoring network**

Figure 5.—Continued

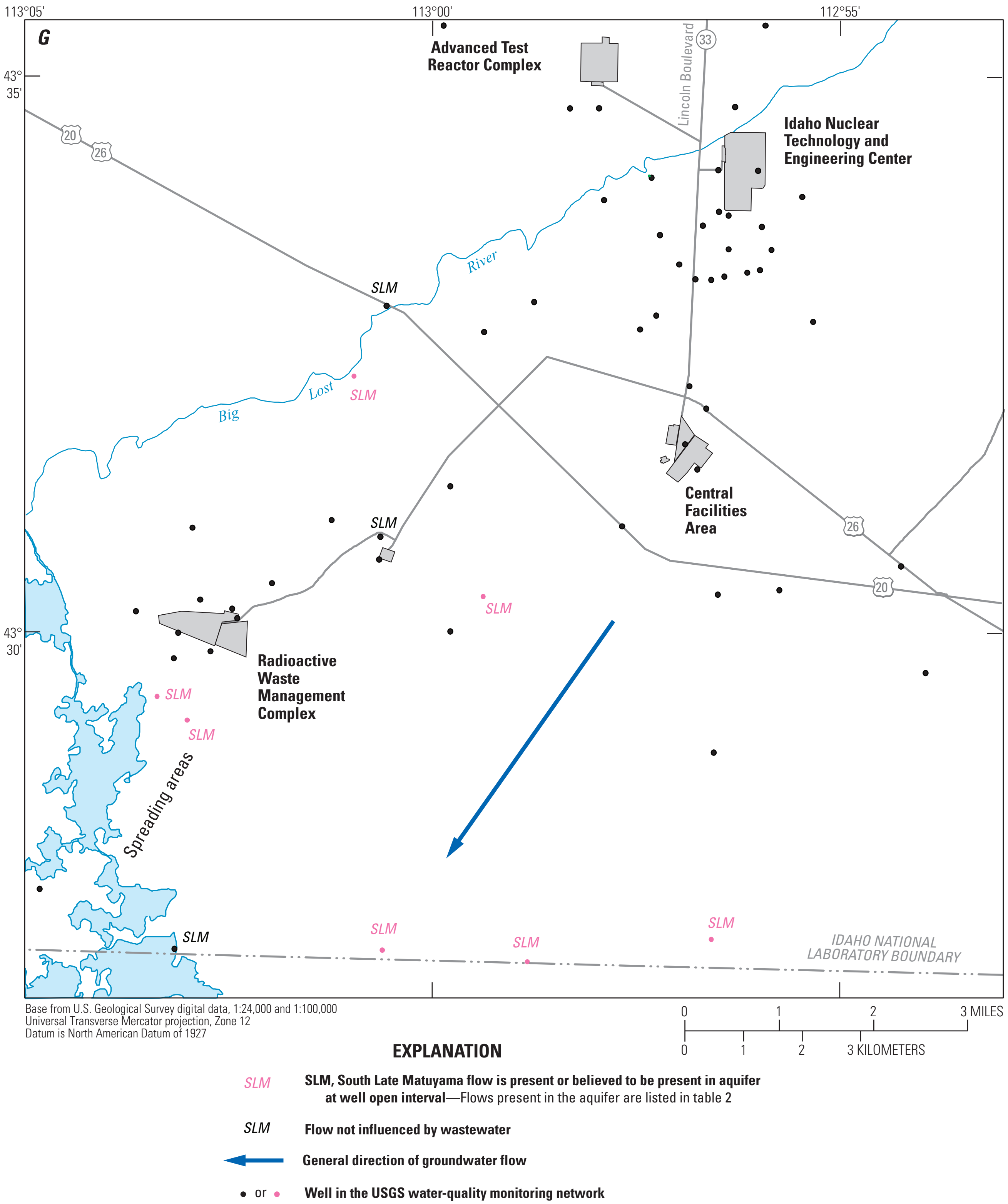


Figure 5.—Continued

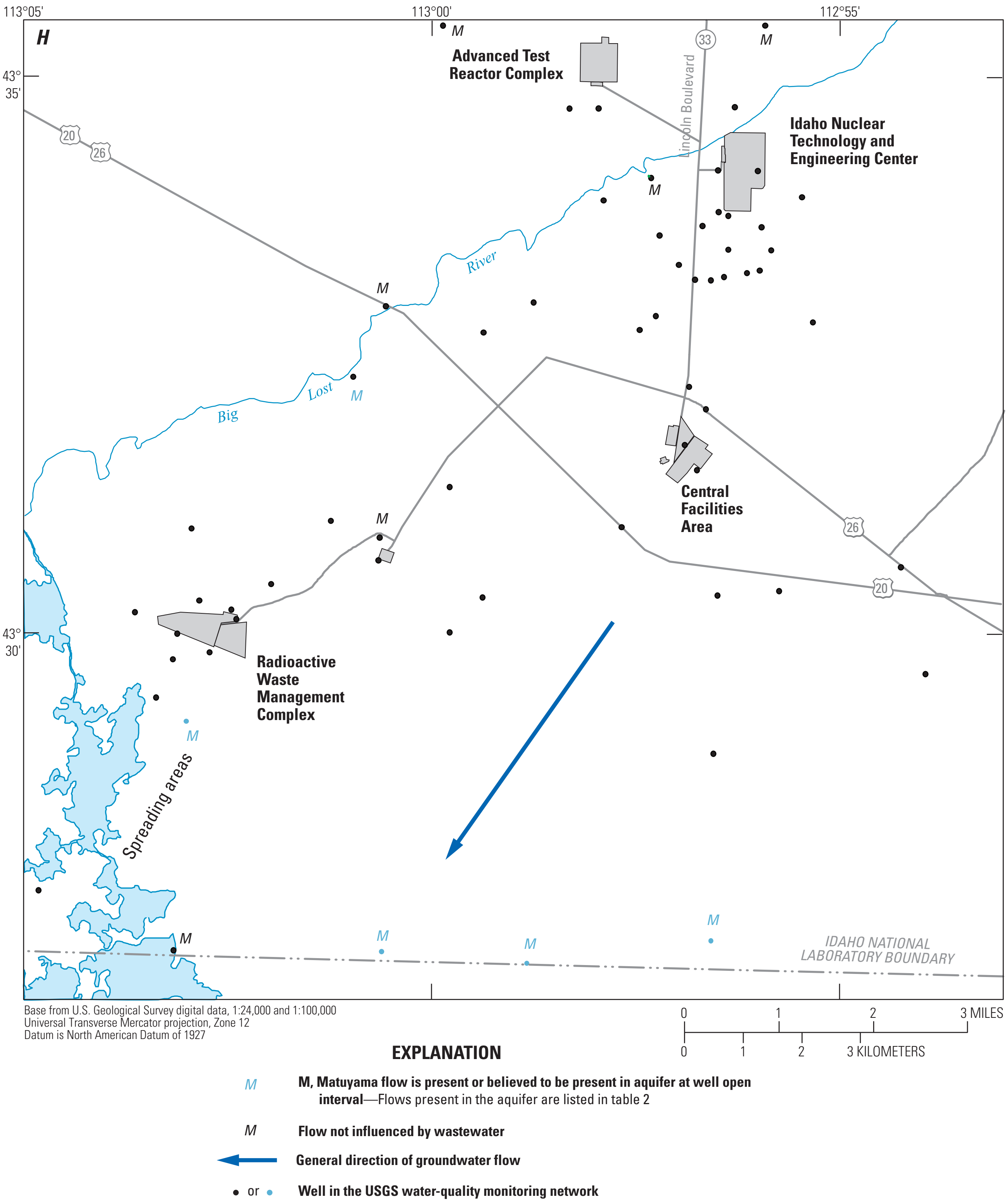


Figure 5.—Continued

Advanced Test Reactor Complex and Idaho Nuclear Technology and Engineering Center Area

The basalt flows in the upper 150 ft of the ESRP aquifer at INTEC (depth of the Idaho Chemical Processing Plant (ICPP) Disposal well where wastewater was discharged) consisted of the CFA Buried Vent flow and the AEC Butte flow. At the ATR Complex, where wastewater from long-term disposal in infiltration ponds would presumably move downward and intersect the top of the water table, the CFA Buried Vent flow probably occurs as the primary stratigraphic unit present; however, AEC Butte flow also could be present at some of the locations near the facility (Champion and others, 2011, pl. 1; Hodges and Champion, 2016, pl. 1).

Tritium concentrations greater than the lower estimated background concentration of 75 pCi/L (Orr and others, 1991) are assumed to indicate groundwater that has been influenced by wastewater disposal at the INL (fig. 4). Wells shown with tritium concentrations less than the laboratory detection level of 200 pCi/L have not been evaluated at a low enough detection level to determine whether wastewater constituents are influencing the water quality; however, evidence from concentrations of other chemical constituents such as chloride and volatile organic compounds mostly indicate that these wells probably are not affected by waste disposal. Almost all the wells at and near the ATR Complex and INTEC are influenced by wastewater disposal at the two facilities (this includes the wells north of highway 20/26 and north of CFA; fig. 4). An exception is ICPP Mon-A-166 (fig. 2), which was drilled as a downgradient monitoring well for new infiltration ponds southwest of INTEC, but does not show any influence from the ponds or from disposal from the ATR Complex, even though the Rifle Range well (fig. 2), farther downgradient and along the same flow path, does (Bartholomay and others, 2017). Both wells are presumed to have similar stratigraphy (CFA Buried Vent), but the Rifle Range Well is completed in more than 100 ft of the ESRP aquifer, whereas ICPP-Mon-A-166 is completed in the upper 15 ft of the aquifer (table 2).

Closer to where wastewater disposal occurred at INTEC and ATR Complex, almost all wells show wastewater influence in the upper part of the ESRP aquifer with wastewater present in both the CFA Buried Vent flow and AEC Butte flow (figs. 5B, 5C). Several wells near the ATR Complex and INTEC were not completed deep enough to sample more than the upper one or two basalt flows present in these areas. Well Middle 2050A is a multilevel monitoring well completed much deeper into the aquifer and located to the west of INTEC and southeast of the ATR Complex (fig. 1). Tritium data indicate minor wastewater influence in the areas of the aquifer that contain the CFA Buried Vent flow, the AEC Butte flow, and the Jaramillo flow (Bartholomay and others, 2015, fig. 19). Other data from well Middle 2050A indicate that the Late Basal Brunhes, Early Basal Brunhes, and Matuyama flows are not influenced by wastewater (figs. 5D, 5F, 5E; Bartholomay and others, 2015, fig. 19).

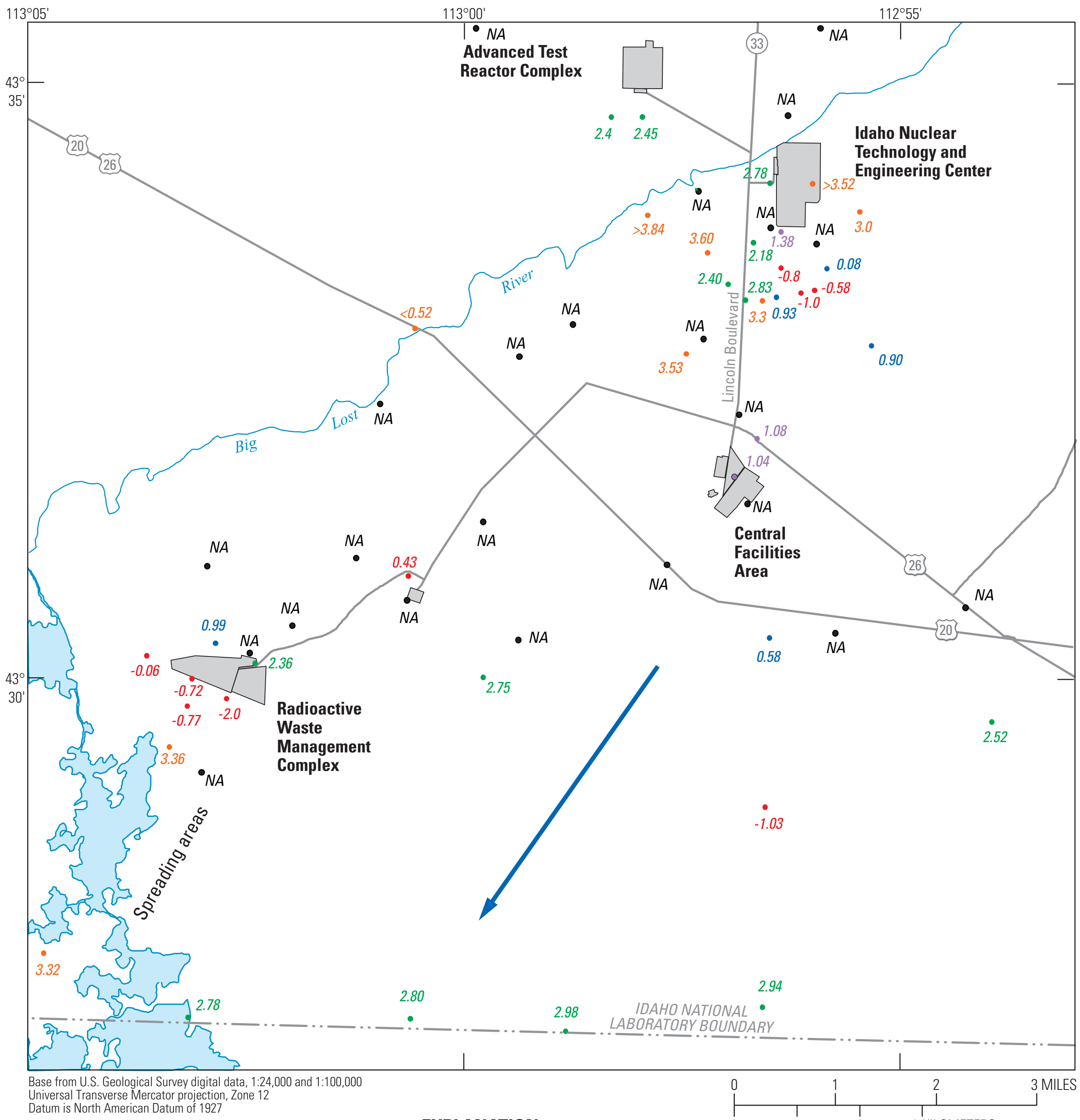
Central Facilities Area

Historically, wastewater contamination at the CFA is attributed to disposal activities at the INTEC that has moved downgradient and affected the water quality of the aquifer near the CFA, although some of the nitrate present in CFA 2 and USGS 130 has been attributed to disposal from CFA to the old mercury ponds south of the CFA (Bartholomay and others, 2017, p. 54). Figure 4 shows several of the wells south and southeast of CFA (USGS 127, 83, 144, and Badging Facility) are not influenced by wastewater; however, wells farther south and southwest (USGS 104, 131A, and 106) are influenced by wastewater disposal.

Basalt stratigraphy indicates that the CFA Buried Vent flow is the predominant flow in the upper part of the ESRP aquifer at and south of CFA (fig. 5*B*). This unit seems to pinch out southeast of CFA (Champion and others, 2011, pl. 1). The younger Big Lost flow is present in all of the wells south, southeast, and southwest of CFA, and the older AEC Butte flow is present in the wells at and north of CFA (figs. 5A, 5B, 5C, respectively).

The depth of open intervals in wells completed in the ESRP aquifer varies from about 100 to 250 ft (table 2) in most wells, so wastewater detection is independent of the amount of open interval sampled. Most of the wells (USGS 127, 144, and Badging Facility well) that are not influenced by wastewater disposal do not have a known hydraulic conductivity (fig. 6), so it is not certain if hydraulic conductivity plays a role in the absence of wastewater constituents. However, because the CFA Buried Vent flow originated somewhere near CFA (Hodges and Champion, 2016), it is reasonable to consider the most massive part of the flow and thus least conductive part of the aquifer could occur just south of CFA, which may be why wells in that area do not show influence from wastewater disposal. Additionally, because of subsidence in the ESRP, the upper part of the aquifer in this area is completed in the Big Lost Flow unit, which is above the CFA Buried Vent flow where wastewater was presumably discharged at INTEC and the ATR Complex. It may be that wastewater influenced groundwater flow occurs in the deeper parts of the ESRP aquifer in wells south of CFA.

Multilevel monitoring well USGS 131A shows wastewater influence in all four zones sampled and the zones are completed in the CFA Buried Vent flow, the Early Basal Brunhes flow and the Jaramillo flows (Bartholomay and others, 2015, fig. 19). The Big Lost, Middle Basal Brunhes, South Late Matuyama, and Matuyama flows are also present in the aquifer in this well (table A21), but the zones in those flows were not sampled. This well is completed in about the upper 600 ft of the aquifer and possibly is influenced by wastewater through its entire thickness.



EXPLANATION

Hydraulic conductivity, in Log K, in feet per day—Values from table 3 and Anderson and others (1999). Color indicates range of conductivity

-0.72	Less than 0
0.58	0 to 1
1.08	1 to 2
2.94	2 to 3
3.36	Greater than 3

General direction of groundwater flow

Well in the USGS water-quality monitoring network—Water samples analyzed for hydraulic conductivity. NA, not analyzed

Figure 6. Hydraulic conductivity measured in selected wells in the southwestern part of the Idaho National Laboratory, Idaho.

Radioactive Waste Management Complex Area

At the RWMC, where water with contaminants from buried wastes would presumably move down through the unsaturated zone and pond on the surface of the water table, the CFA Buried Vent, Late Basal Brunhes, and Early Basal Brunhes all have been identified as the flow units at or near the water table in different cores (Champion and others, 2011, pl. 1; Hodges and Champion, 2016, pl. 1; appendix A). Additionally, wastewater disposal from the ATR Complex and possibly INTEC also have contributed to some of the wastewater contamination in monitoring wells around the RWMC (Davis and others, 2015; Bartholomay and others, 2017). Tritium was not detected in wells USGS 88, 89, 117, and 119 directly south of RWMC and EBR 1 and RWMC M13S northeast of RWMC (figs. 2 and 4), but concentrations were not analyzed at a low enough detection level to determine whether or not wastewater constituents are influencing the water quality. However, evidence from concentrations of other chemical constituents such as chloride and volatile organic compounds (VOCs) indicate that these wells probably are not affected by waste disposal. An exception is well USGS 88 (table 3) that has VOCs present in samples that indicate movement of water originating from buried waste at the RWMC (Bartholomay and others, 2017, table 8). Additionally, USGS 88 and 89 have chloride concentrations that are greater than background and the high chloride concentrations have been attributed to waste disposal at the INL (table 3; Gordon Rattray, U.S. Geological Survey, written commun., 2017). All four wells south of RWMC that do not show influence from tritium (USGS 88, 89, 117, and 119) all have low hydraulic conductivities (fig. 6), which may be limiting the movement of water into these wells.

Basalt stratigraphy indicates that the CFA Buried Vent flow is the predominant flow in the upper part of the ESRP aquifer at and near the RWMC because it is present in all the wells (fig. 5*B*). The Late Basal Brunhes flow is present in most wells north and northeast of RWMC (fig. 5*D*). The Middle Basal Brunhes flow is present in the ESRP aquifer in all but one of the wells near the RWMC and in two upgradient wells (fig. 5*E*). The Early Basal Brunhes flow is present in USGS 117 and 119 (fig. 5*F*). The South Late Matuyama flow is present in EBR 1, USGS 120 and 132, and the Matuyama flow is present in Middle 2051, EBR 1 and USGS 132 (fig. 5G, 5H; table 2).

Two multilevel monitoring wells completed in the upper 600–700 ft of the ESRP aquifer show wastewater-influenced water in several zones of the aquifer both northwest of RWMC (Middle 2051) and south of RWMC (USGS 132). Well Middle 2051 shows wastewater influence in the Matuyama and Jaramillo flows (Bartholomay and others, 2015, fig. 19) and probably would have wastewater influence in the South Late Matuyama and Post Jaramillo flows if water samples were collected from those zones, given the nature of the stratigraphy in that well. The geology above a large sedimentary interbed in this well has the CFA Buried Vent flow, Late Basal Brunhes flow, and Middle Basal Brunhes flows that make up the upper part of the ESRP aquifer in this location. The water in this part of the aquifer is believed to be influenced by Big Lost River surface recharge (Bartholomay and Twining, 2010; Bartholomay and others, 2015) and no wastewater influence seems to be affecting the upper part of this well. USGS 132 shows wastewater influence in all 6 zones sampled; the zones are completed in the Middle and Early Basal Brunhes flows and the Matuyama flow (Bartholomay and others, 2015, fig. 19). The CFA Buried Vent flow is also present in the upper part of the aquifer in this well (table A22) and because wastewater is present in all the zones, wastewater is probably present in this flow unit.

Southern Boundary of the Idaho National Laboratory

Movement of buried wastes at the RWMC and wastewater disposal from the ATR Complex and INTEC have probably contributed to some of the wastewater contamination in the monitoring wells at the southern boundary of the INL (Bartholomay and Twining, 2010; Bartholomay and others, 2015; Davis and others, 2015). Basalt flows that show some wastewater influence along the southern boundary are in the G flow, Middle and Early Basal Brunhes flows, the South Late Matuyama flow and the Matuyama flow; however, the greatest influence appears to be in the South Late Matuyama flow (Bartholomay and others [2015, fig. 20]). Revised interpretation of the flows present in USGS 137A (Hodges and Champion, 2016) indicate the Big Lost flow, G flow, and the Early Basal Brunhes flows are influenced by wastewater, but not the South Late Matuyama as indicated by Bartholomay and others (2015). Wells USGS 137A, 105, 108, and 103 all show wastewater influence in several zones; however, well USGS 135 (fig. 1) west of these wells does not show wastewater influence in any of the well zones in the over 400 ft of ESRP aquifer in which it was completed. All four zones of USGS 135 were completed in the South Late Matuyama and Matuyama flows (table A25). The concentrations of wastewater constituents in deeper zones in wells USGS 105, 108, and 103 support the concept of groundwater flow deepening in the southwestern part of the INL as indicated by Ackerman and others (2010).

Summary and Conclusions

Wastewater discharged to wells and ponds at the Advanced Test Reactor Complex (ATR Complex) and Idaho Nuclear Technology and Engineering Center (INTEC) and wastes buried in shallow pits and trenches at the Radioactive Waste Management Complex (RWMC) have contributed contaminants to the eastern Snake River Plain (ESRP) aquifer in the southwestern part of the Idaho National Laboratory (INL). This report investigated the correlation between subsurface stratigraphy in the southwestern part of the INL with information on the presence or absence of wastewater constituents to better understand how wastewater discharged at INL facilities are controlled by flow pathways in the aquifer. Paleomagnetic inclination was used to identify subsurface basalt flows based on similar inclination measurements and polarity. Tritium concentrations were used to determine wastewater influence and were analyzed at two different laboratories using two different detection levels. For wells with tritium concentrations below detection levels, other chemical constituents also were examined to make a determination as to whether or not the well was influenced by wastewater disposal.

Drill cores were used to understand the basalt stratigraphy and some of the cored holes were completed as monitoring wells. For wells not cored, nearby core information was used to interpret local stratigraphy.

The basalt flows in the upper 150 ft of the ESRP aquifer where wastewater was discharged at INTEC consisted of the CFA Buried Vent flow and the AEC Butte flow. At the ATR Complex, where wastewater would presumably pond on the surface of the water table, the CFA Buried Vent flow probably occurs as the primary stratigraphic unit present, although the AEC Butte flow also could be present at some of the locations. In wells closer to where wastewater disposal occurred at INTEC and ATR Complex, almost all the wells show wastewater influence in the upper part of the ESRP aquifer with wastewater present in the CFA Buried Vent flow and AEC Butte flow. The CFA Buried vent flow was present in the most wells analyzed in this study (52) and wastewater constituents were present in 83 percent of the wells. The AEC Butte flow was present in 14 of the wells analyzed and all 14 have wastewater influence. Several wells at and around the ATR Complex and INTEC were not completed deep enough to sample more than just the upper one or two flows (CFA Buried Vent and AEC Butte) present in these areas. The predominance of wastewater movement in these flow units is expected because they were the units that wastewater was discharged. A multilevel monitoring well completed in several basalt flows (Middle 2050A) has data that indicates minor wastewater influence in parts of the aquifer comprised of the CFA Buried Vent flow, the AEC Butte flow, and the Jaramillo flow. Other data from this well shows that the Late Basal Brunhes, Early Basal Brunhes, and Matuyama flows are not influenced by wastewater.

Several of the wells south and southeast of CFA (USGS 127, 83, 144, and the Badging Facility well) are not influenced by wastewater; however, wells farther south and southwest (USGS 104, 131A, and 106) are influenced by wastewater disposal. Basalt stratigraphy indicates that the CFA Buried Vent flow is the predominant flow in the upper part of the ESRP aquifer at and south of CFA. The younger Big Lost flow is present in all of the wells south, southeast, and southwest of CFA, and the AEC Butte flow is present in the wells at CFA and north of CFA. Most of the wells that are not influenced by wastewater disposal do not have a measured hydraulic conductivity, so whether hydraulic conductivity plays a role in the absence of wastewater constituents is not certain. However, given that the CFA Buried Vent flow originated somewhere around CFA, the most massive part of the flow and thus the least conductive part of the aquifer likely could occur just south of CFA. This may be why wells in that area do not show influence from wastewater disposal. Because of subsidence in the ESRP, the upper part of the aquifer in this area also is completed in the younger Big Lost Flow, which overlies the CFA buried Vent flow in which wastewater was presumably discharged at INTEC and the ATR Complex. It may be that wastewater influenced groundwater flow would occur in the deeper parts of the ESRP aquifer in wells south of CFA. A multilevel monitoring well USGS 131A completed in the upper 600 feet of the aquifer shows wastewater influence in all four zones sampled, and the zones are completed in the CFA Buried Vent flow along with the Early Basal Brunhes and the Jaramillo flows. The Big Lost, Middle Basal Brunhes, South Late Matuyama, and Matuyama flows also are present in the aquifer in this well, but no samples were collected from zones in those flows.

At the RWMC, where buried wastes presumably would move through the unsaturated zone and pond on the surface of the water table, CFA Buried Vent, Late Basal Brunhes, and Early Basal Brunhes all have been the basalt flow at or near the water table in different cores. All four wells south of RWMC that do not show influence from tritium (USGS 88, 89, 117, and 119) all have low hydraulic conductivities, which may be limiting the movement of water into these wells. Basalt stratigraphy indicates that the CFA Buried Vent flow is the predominant flow in the upper part of the ESRP aquifer at and near the RWMC because it is present in all the wells. The Late Basal Brunhes flow, Middle Basal Brunhes flow, Early Basal Brunhes flow, South Late Matuyama flow, and Matuyama flow also are present in various wells influenced by waste disposal. Two multilevel monitoring wells completed in the upper 600–700 ft of the ESRP aquifer show wastewater influenced water in several zones completed in the ESRP aquifer both northwest of RWMC (Middle 2051) and south of RWMC (USGS 132).

Basalt flows that show some wastewater influence along the southern boundary are in the G flow, Middle and Early Basal Brunhes flows, the South Late Matuyama flow, and the Matuyama flow; however, the South Late Matuyama flow shows the most wastewater influence. Wells USGS 137A, 105, 108, and 103 all show wastewater influence in several basalt flows; however, USGS 135 west of these wells does not show any wastewater influence in any of the basalt flows in the more than 400 ft of ESRP aquifer that it was completed. All four zones of USGS 135 were completed in the South Late Matuyama and Matuyama flows. The concentrations of wastewater constituents in deeper zones in wells USGS 105, 108, and 103 support the concept of groundwater flow deepening in the southwestern part of the INL.

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Appendix A. Paleomagnetic Inclination Values and Basalt Flows from Coreholes in the Eastern Snake River Plain Aquifer at the Idaho National Laboratory

Corehole paleomagnetic information for tables A1–A27 was originally published in Champion and others (2011) and Hodges and Champion (2016). Previously unpublished flow unit determinations for basalt that makes up the aquifer are presented in tables A1–A27; depth and paleomagnetic data for corehole USGS 144 are presented in table A28. Tables are organized alphabetically by corehole name. Appendix A tables are Microsoftt®. Excel files and are available for download at https://doi.org/10.3133/sir20175148.

Information in the tables includes sample depth for flow units that make up the eastern Snake River Plain aquifer, and identifies sample groups that were used to determine average inclination for flows and 95 percent uncertainty. Each sample has a characteristic remanent inclination in degrees and an alternating-field demagnetization level in milliTeslas or an alternative demagnetization approach. Positive inclination values indicate normal paleomagnetic polarity, and negative inclination values indicate reversed paleomagnetic polarity.

Some coreholes are not vertical. In cases where the corehole deviates from vertical to the north or south, deviation correction values were obtained from geophysical deviation logs and applied to the paleomagnetic inclination data obtained from deviated samples to account for this variation from the vertical. Paleomagnetic inclination data, which were corrected for borehole deviation are in parenthesis, and the corrected values presented in the column to the right of the measured values. Deviation corrections were applied to the average paleomagnetic inclination of sample groups.

Petrographic boundaries denote a significant change in mineralogy in a flow. Unrecovered core and sediment intervals also were recorded in the depth column. Samples that are labeled “NIIA” were not included in the average. The NIIA samples may have been thermally overprinted by overlying flows, tilted by endogenous inflation, struck by lightning when on the surface, or otherwise had their orientations disturbed so that they do not yield usable paleomagnetic inclination data.

Stepwise thermal demagnetizations were done only on samples of particular interest.

The paleomagnetic line fit (Li) indicates values derived from a line fit performed from a vector component diagram using a sequence, or all of the demagnetizations steps from each sample from that site. A Li is accomplished through the simultaneous inspection of both horizontal and vertical 2D planes representing the diminishing of the remanent magnetic vector of a sample created through either progressive alternating field (AF) or thermal (Th) demagnetization. A straight line is regressed through those demagnetization steps which align toward a zero strength magnetization in both 2D planar views (Kirschvink, 1980).

Measurements are in feet and milliteslas because the raw data were collected using these units of measure.

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