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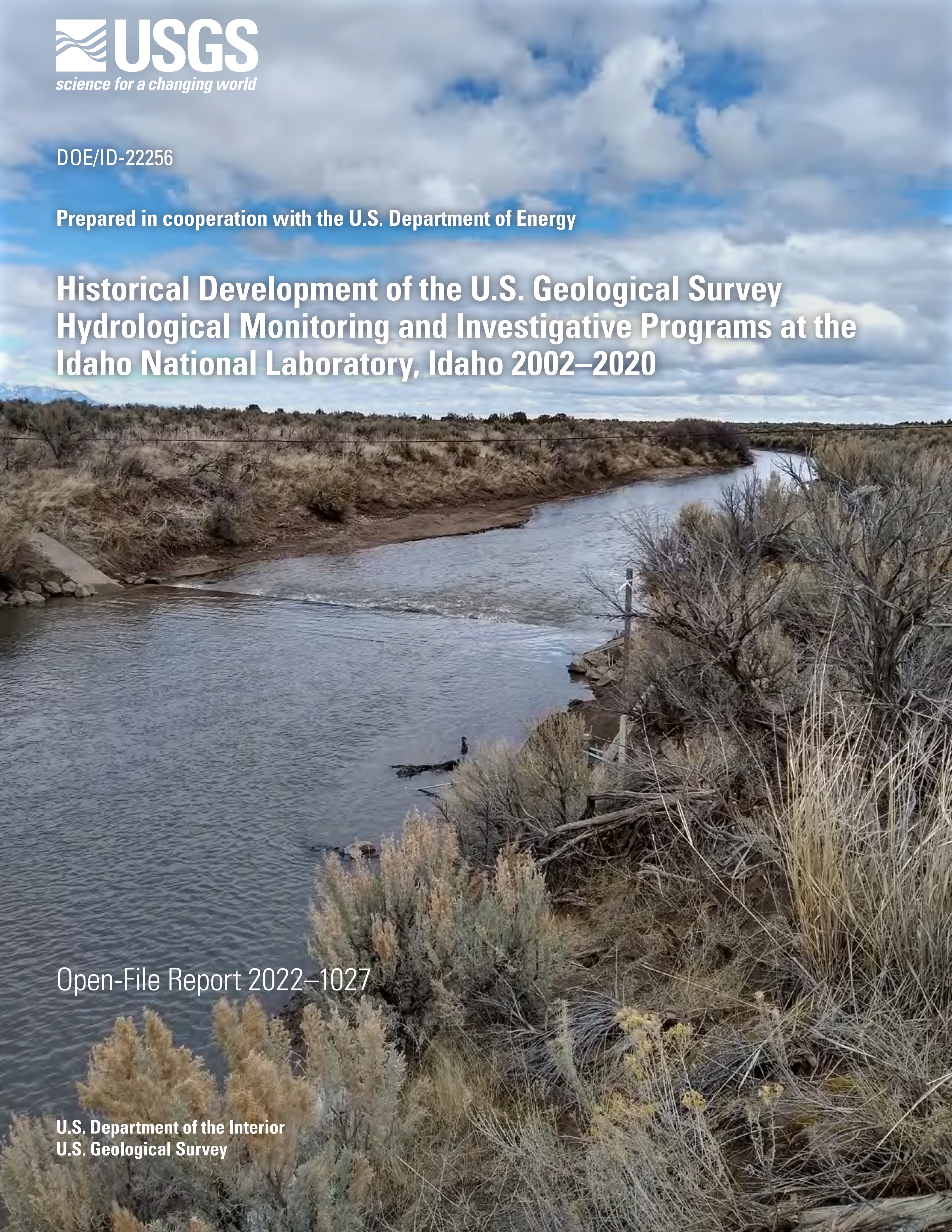
Prepared in cooperation with the U.S. Department of Energy

Historical Development of the U.S. Geological Survey Hydrological Monitoring and Investigative Programs at the Idaho National Laboratory, Idaho 2002–2020



Open-File Report 2022–1027

U.S. Department of the Interior
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Cover. North facing view of the Big Lost River at U.S. Geological Survey (USGS) streamgage 13132520, Big Lost River below INL Diversion, near Arco, Idaho. Photograph by Roy Bartholomay, U.S. Geological Survey, April 10, 2019.

Historical Development of the U.S. Geological Survey Hydrological Monitoring and Investigative Programs at the Idaho National Laboratory, Idaho, 2002–2020

By Roy C. Bartholomay

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U.S. Geological Survey, Reston, Virginia: 2022

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Conversion Factors

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.09290	square meter (m^2)
gallon (gal)	3.785	liter (L)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile ($[ft^3/s]/mi^2$)	0.01093	cubic meter per second per square kilometer ($[m^3/s]/km^2$)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
Curie (Ci)	$3.7X10^{10}$	becquerel (bq)
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)
millirem per hour	0.010	millisievert per hour

Conversion Factors—Continued

Multiply	By	To obtain
gallon per minute per foot ([gal/min]/ft)	0.2070	liter per second per meter ([L/s]/m)

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Datums

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

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

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

Supplemental Information

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 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).

Results for measurements of stable isotopes of an element (with symbol E) in water, solids, and dissolved constituents commonly are expressed as the relative difference in the ratio of the number of the less abundant isotope (iE) to the number of the more abundant isotope of a sample with respect to a measurement standard.

Abbreviations

AEC	Atomic Energy Commission
BFW	Badging Facility well
BLR	Big Lost River
CFA	Central Facilities Area
CPP	Chemical Processing Plant
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ESRP	eastern Snake River Plain
GIN	Gas Injection Test site
INEL	Idaho National Engineering Laboratory
INEEL	Idaho National Engineering and Environmental Laboratory
NRTS	National Reactor Testing Station
ppm	parts per million
RESL	Radiological and Environmental Sciences Laboratory
RHLLW	Remote Handled Low-level Waste facility
USGS	U.S. Geological Survey

Historical Development of the U.S. Geological Survey Hydrological Monitoring and Investigative Programs at the Idaho National Laboratory, Idaho, 2002–2020

By Roy C. Bartholomay

Abstract

This report summarizes the historical development and operations, from 2002 to 2020, of the U.S. Geological Survey's (USGS) hydrologic monitoring and investigative programs at the Idaho National Laboratory in cooperation with the U.S. Department of Energy. The report covers the USGS's programs for water-level monitoring, water-quality sampling, geochemical studies, geophysical logging, geologic framework development, groundwater-flow modeling, drilling, surface-water monitoring, and unsaturated zone studies. The report provides physical information about wells, information about changes and frequencies of sampling and measurements, and management decisions for changes. Brief summaries of USGS reports published from 2002 through 2020 (with U.S. Department of Energy report numbers) are provided in an appendix.

Introduction

In 1949, the National Reactor Testing Station (NRTS), an 890- square mile (mi^2) site on the eastern Snake River Plain (ESRP) in southeastern Idaho (fig. 1), was established by the U.S. Atomic Energy Commission (AEC), which later became the U.S. Department of Energy (DOE), for the development of peacetime atomic-energy applications, nuclear safety research, defense programs, and advanced energy concepts. To account for changing priorities of the Station, the NRTS was successively renamed the Idaho National Engineering Laboratory (INEL) in 1974, the Idaho National Engineering and Environmental Laboratory (INEEL) in 1997, and the Idaho National Laboratory (INL) in 2005. Current (2020) programs and priorities at the Laboratory include nuclear energy research; spent nuclear-fuel management; hazardous and mixed-waste management and minimization; national security; cultural resources preservation; and environmental engineering, protection, and remediation.

The United State Geological Survey (USGS) has conducted research activities at the INL since 1949, its employees first traveling from district and regional offices to conduct studies and then working from Central Facilities Area (CFA) offices starting in 1959 (Knobel and others, 2005, p.1). The USGS still performs field operations out of offices at CFA, but since 1998, USGS INL Project Office personnel have been stationed at offices in Idaho Falls, most recently at the Willow Creek Building. One employee also has an office at Idaho State University (ISU) in Pocatello for periodic interaction with ISU research assistants.

Initially, the USGS studies characterized the water resources of the INL area before the development of nuclear-reactor testing facilities. The USGS since has maintained groundwater -quality and water-level measurement monitoring networks at the INL to provide data on hydrologic trends and document the movement of radioactive and chemical wastes in the unsaturated zone and the ESRP aquifer. The USGS has published numerous reports on the geology and hydrology of the INL, and a list of those publications is provided on the INL Project website at U.S. Geological Survey (2018). Brief summaries of USGS DOE/ID reports published from 1949–2001 are included in appendix 1 of Knobel and others (2005). Brief summaries of reports published from 2002 through 2020 are provided in appendix 1 here.

The USGS, in cooperation with DOE's Idaho Operations Office, has studied the hydrology and geology at the INL to better understand the movement of water (and included chemical and radioactive wastes) through the ESRP aquifer and the effects of historical waste disposal practices. Wastewater disposal sites at Test Area North (TAN), the Naval Reactors Facility (NRF), the Advanced Test Reactor (ATR) Complex, and the Idaho Nuclear Technology and Engineering Center (INTEC) (fig. 1) have been the principal sources of radioactive- and chemical- waste contaminants to water in the ESRP aquifer (Bartholomay and others, 2020). These disposal sites have included lined evaporation ponds, unlined infiltration ponds and ditches, drain fields, and injection wells. Waste materials buried in shallow pits and trenches within the Subsurface Disposal Area at the Radioactive Waste Management Complex (RWMC) also have contributed contaminants to the groundwater. As a result of these waste-disposal practices, water in several monitoring wells at the INL contains elevated concentrations of several radiochemical constituents, chromium, sodium, chloride, sulfate, nitrate, and purgeable organic compounds (Mann and Beasley, 1994; Beasley and others, 1998; Cecil and others, 1998; Bartholomay and others 2020).

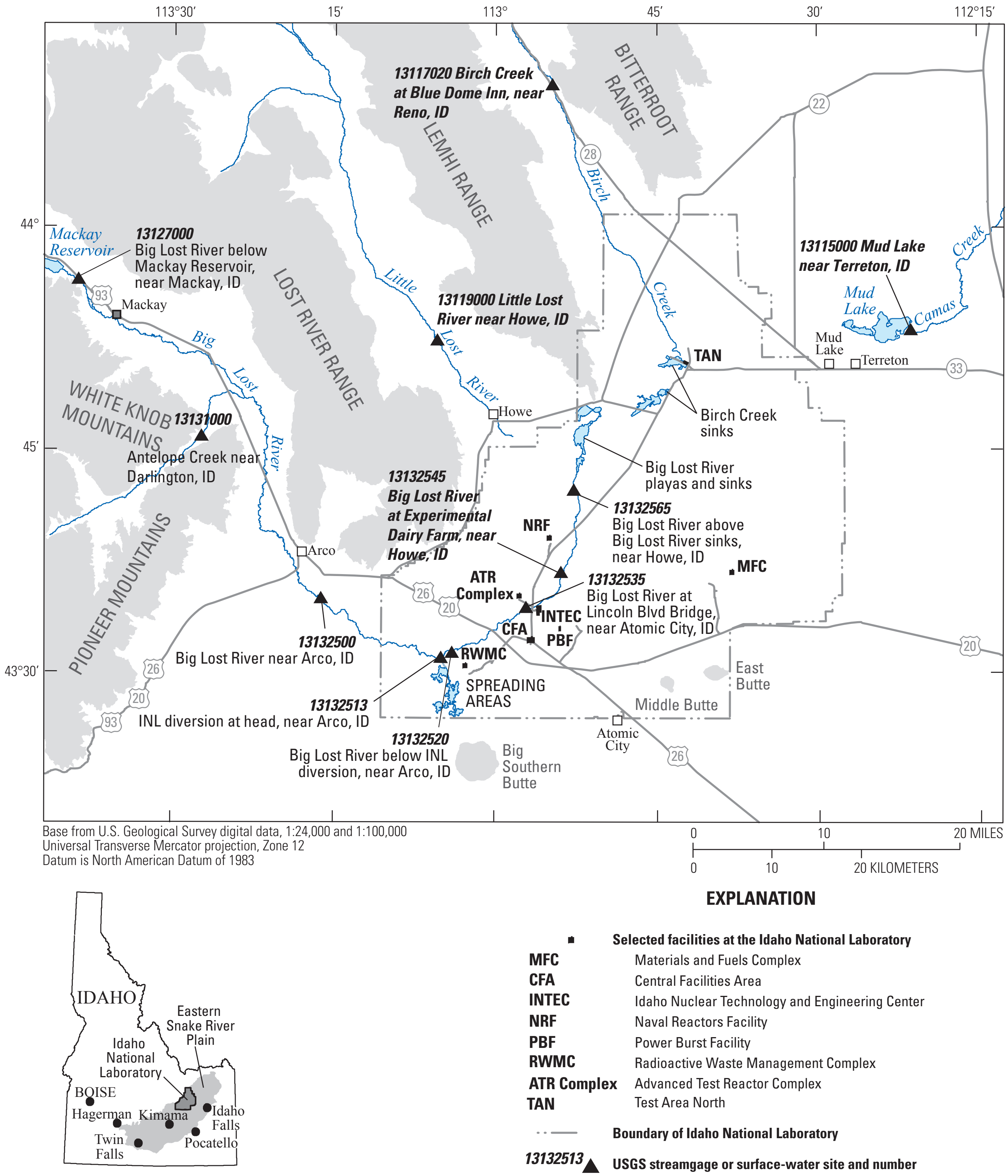

Figure 1. Locations of the Idaho National Laboratory, U.S. Geological Survey streamgaging stations and other surface-water data-collection sites, and selected Idaho National Laboratory facilities.

Purpose and Scope

This report presents a summary of the historical development and operations of the USGS hydrologic monitoring and investigative programs at the INL during the period 2002 through 2020. The development and evolution of several programs, focused on water-level monitoring, water-quality sampling, geochemical studies, geophysical logging, geologic framework, groundwater-flow modeling, drilling, surface water, and the unsaturated zone to their current configurations are described. This compilation of information is important to document managerial decision-making over the past 19 years with a focus toward informing decisions for future monitoring and investigative programs at the INL.

Geohydrologic Setting

The INL is located on the west-central part of the ESRP. The ESRP is a northeast-trending structural basin about 200 miles (mi) long and 50–70 mi wide (fig. 1). The basin, bounded by faults on the northwest and by down warping and faulting on the southeast, has been filled with basaltic lava flows interbedded with terrestrial sediments. Hundreds of basalt flows, basalt flow groups, and sedimentary interbeds are present at the INL; basalt flows make up about 85 percent of the volume of deposits in the unsaturated zones and underlying aquifer (Anderson and Liszewski, 1997). The basaltic rocks and sedimentary deposits combine to form the ESRP aquifer, which is the primary source of groundwater in the basin.

Rhyolitic lava flows and tuffs are exposed locally at the surface and may also be present at depth under most of the ESRP. A 10,365-ft-deep test hole at the INL penetrated about 2,160 feet (ft) of basalt and sediment and 8,205 ft of tuffaceous and rhyolitic volcanic rocks (Mann, 1986).

The ESRP aquifer is one of the most productive in the United States (U.S. Geological Survey, 1985, p. 193). Groundwater at the INL 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 (fig. 1). The water moves horizontally through basalt interflow zones and vertically through joints and interfingering edges of basalt flows. Infiltration of surface water, heavy pumpage, geohydrologic conditions, and seasonal fluxes of recharge and discharge locally affect the movement of groundwater (Garabedian, 1986). The ESRP aquifer is recharged primarily by infiltration of applied irrigation water, infiltration of streamflow, inflow of groundwater from adjoining mountain drainage basins, and infiltration of precipitation (Ackerman and others, 2006).

At the INL, depth to water in wells completed in the ESRP aquifer ranges from about 200 ft below land surface in the northern part of the INL to more than 900 ft below land surface in its southeastern part. (Bartholomay and others, 2020, fig. 9). Most of the groundwater moves through the upper 200–800 ft of basaltic rock (Mann, 1986, p. 21). Ackerman (1991, p. 30), Bartholomay and others (1997, table 3), and Twining and Maimer (2019, table 2) reported transmissivity values for basalt in the upper part of the aquifer ranging from 1.1 to 760,000 ft^2/d. The hydraulic gradient at the INL ranges from 2 to 10 feet per mile, with an average of 4 feet per mile (Bartholomay and others, 2020, fig. 9). Horizontal flow velocities of 2–26 feet per day (ft/d) have been calculated on the basis of 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; and Busenberg and others, 2001). These flow rates are equivalent to a travel time of about 50–700 years for water beneath the INL to reach springs that discharge at the terminus of the ESRP groundwater- flow system near Twin Falls, Idaho. Localized groundwater-tracer tests at the INL have shown that vertical- and horizontal-transport rates are as high as 60–150 ft/d (Nimmo and others, 2002; Duke and others, 2007). The effective base of the aquifer ranges in depth from about 815 to 1,710 ft below land surface in the western half of the INL and could be greater than 1,900 ft below land surface in the eastern half (Anderson and Liszewski, 1997, p. 11).

Historical Development of Hydrologic Monitoring and Investigative Programs

The monitoring networks and investigative programs at the INL have evolved to their current schedules of monitoring because wells were installed for various reasons; for example, the need to estimate the volume of the ESRP aquifer, or to document and understand changes in water quality. Well names, locations, and use; and construction and completion data for selected wells the USGS has sampled or measured at INL between 2002 and 2020 are given in tables 1–2 and on figures 2–4. In 2020, the USGS INL Project Office updated its National Water Information System (NWIS) database to change all measurements for latitude and longitude from North American Datum (NAD) of 1927 to NAD 1983 and land- surface altitude from North American Vertical Datum (NAVD) of 1929 to NAVD 1988. The current datums are the datums of reference for this report, but reports published prior to 2020 used the prior datums. Details on many of the wells sampled and measured are given in tables 1–3 in Knobel and others (2005), therefore the wells presented in this report are just new wells incorporated into the USGS monitoring program between 2002–2020. The following is a synopsis of when and why newer wells were drilled and added to the current monitoring network.

Table 1. Monitoring wells added to the U.S. Geological Survey monitoring program, Idaho National Laboratory, Idaho, 2002–2020.

[**Local well name**: The local identifier used in this study. **Well number**: Township, range, section. **Site identifier**: The unique numerical identifier used to access well data from the U.S. Geological Survey National Water Information System (U.S. Geological Survey, 2022a). **Well use**: CO, Contractor observation; O, observation; WL, water-level measurement; MM, multilevel monitoring; A, abandoned; piezo., piezometer. See figures 2 and 3 for well locations.]

Local well name	Well number	Site identifier	Latitude/longitude	Well use
ARA-MON-A-002	2N 30E 12acd2	433054112492102	433054 1124924	O
CFA 1932	3N 29E 36cdc1	433214112570101	433214 1125704	WL
Cross Road	1S 28E 02cdc1	432128113092701	432128 1130930	O
ICPP-MON-A-164B	3N 29E 26bca1	433338112581601	433339 1125817	WL
ICPP-MON-A-166	3N 29E 34aad1	433300112583301	433300 1125833	WL
ICPP-MON-A-167	3N 29E 26cab1	433331112580701	433330 1125810	O
ICPP-MON-V-200	3N 29E 26cbd1	433321112581501	433321 1125818	O
Middle 1823	3N 29E 23cba1	433418112581701	433419 1125818	WL
Middle 2050A	3N 29E 24cca1	433409112570500	433409 1125705	MM
Middle 2051	3N 29E 33ccc1	433217113004900	433217 1130049	MM
NRF 14	4N 30E 30aad3	433856112545901	433857 1125459	O
NRF 15-A	4N 30E 20bbcb4	433942112545002	433942 1125451	piezo.
NRF 15-B	4N 30E 20bbcb3	433942112545001	433942 1125451	piezo.
NRF 16	4N 30E 17cbc1	434018112545101	434018 1125451	O
PBF-MON-A-003	2N 30E 03aba1	433203112514201	433203 1125146	O
TAN-2271	6N 31E 13cab1	435053112423101	435053 1124231	O
TAN-2272	6N 31E 13cab2	435053112423001	435053 1124230	CO
TAN-2312	6N 31E 24cdd1	434939112422001	434939 1124220	O
USBR Site 15	4N 35E 14aaa1	434102112180701	434102 1121810	WL
USGS 103	2N 30E 31cbc1	432714112560700	432713 1125610	MM
USGS 105	2N 29E 33dcc1	432703113001800	432703 1130018	MM
USGS 108	2N 29E 35ccc1	432659112582600	432658 1125829	MM
USGS 128	3N 29E 36bdb3	433250112565601	433250 1125656	O
USGS 129	2N 29E 09cda2	433036113002701	433037 1130027	WL
USGS 130	2N 29E 01dda1	433130112562801	433131 1125628	O
USGS 131	2N 29E 11cca1	433036112581601	433036 1125816	WL
USGS 131A	2N 29E 11cca2	433036112581800	433037 1125816	MM
USGS 132	2N 29E 19cab1	432906113025000	432907 1130251	MM
USGS 133	3N 30E 07cab1	433605112554300	433606 1125544	MM
USGS 134	3N 29E 09adc1	433611112595800	433611 1125958	MM
USGS 135	2N 28E 30ddc1	432753113093600	432753 1130936	MM
USGS 136	3N 29E 23bab1	433447112581501	433448 1125812	O
USGS 137	2N 29E 31cdc3	432701113025701	432702 1130257	A
USGS 137A	2N 29E 31cdc3	432701113025800	432703 1130256	MM
USGS 138	5N 30E 07cac1	434615112553501	434615 1125535	WL
USGS 139A	4N 31E 28cda2	433823112460402	433823 1124604	piezo.
USGS 139B	4N 31E 28cda1	433823112460401	433823 1124604	piezo.
USGS 140	3N 29E 23bac1	433441112581201	433441 1125812	O
USGS 141	3N 29E 23bbd1	433441112581601	433441 1125816	CO
USGS 142	4N 29E 29dad1	433837113010901	433837 1130109	WL
USGS 142A	4N 29E 29dad2	433837113010902	433838 1130109	WL
USGS 143	3N 33E 03baa1	433736112341301	433736 1123413	O

Table 1. Monitoring wells added to the U.S. Geological Survey monitoring program, Idaho National Laboratory, Idaho, 2002–2020.—Continued

[**Local well name**: The local identifier used in this study. **Well number**: Township, range, section. **Site identifier**: The unique numerical identifier used to access well data from the U.S. Geological Survey National Water Information System (U.S. Geological Survey, 2022a). **Well use**: CO, Contractor observation; O, observation; WL, water-level measurement; MM, multilevel monitoring; A, abandoned; see figures 2 and 3 for well locations.]

Local well name	Well number	Site identifier	Latitude/longitude	Well use
USGS 144	2N 30E 18abb1	433021112552501	433021 1125528	O
USGS 145A	3N 28E 24ccd3	433358113042702	433358 1130427	piezometer
USGS 145B	3N 28E 24ccd2	433358113042701	433358 1130427	piezometer
USGS 146	3N 28E 24ccd1	433359113042501	433359 1130425	O
USGS 147	2N 29E 21dcb1	432851113001401	432851 1130014	O
USGS 148A	3N 32E 13bdb1	433535112390801	433535 1123908	O
USGS 149	3N 32E 13cab1	433524112390800	433524 1123908	MM
01S 23E 26CCC1	01S 23E 26CCC1	431810113413601	431810 1134139	WL
03S 27E 24DDA1	03S 27E 24DDA1	430836113143401	430836 1131434	WL
05S 25E 22DAD1	05S 25E 22DAD1	425812113271201	425811 1132715	WL
02N 26E 22DDA1	02N 26E 22DDA1	432854113201001	432854 1132013	WL
02N 26E 22DDA2	02N 26E 22DDA2	432854113201002	432854 1132013	WL

Wells ARA-MON-A-002 and PBF-MON-A-003 were drilled by the INL contractor in 1994 (table 2) to provide monitoring for Waste Area Group (WAG) 5 at the Critical Infrastructure Test Range Complex/Auxiliary Reactor Area (ARA) in the Power Burst Facility (PBF) area of the INL (fig. 1). Enough data were collected from (WAG) 5 so that the Record of Decision that the facility operations had no adverse effects on water quality were met for a clean-up decision for the facility and the INL contractor discontinued sampling these wells in 2007 (Department of Energy report number DOE/ID-2018). Analyses of trends for groundwater samples reported by Bartholomay and others, (2012) indicated increasing concentrations in some constituents downgradient from the PBF, so starting in 2012, the USGS added two wells (ARA-MON-A-002 and PBF-MON-A-003) to their monitoring program to establish more long-term trend information in the vicinity of the ARA.

Well CFA 1932 was drilled by the INL contractor in 2004 for monitoring around the CFA landfill. The USGS started collecting water level measurements at this well in 2005 (table 1).

The Cross Road well was drilled in 1958 for stock water needs downgradient of the INL and was added to the USGS monitoring program in 2005 as an additional off-site downgradient monitoring well. Prior to 2005, the Cross Road well was sampled for the Magic Valley sampling program from 1993 to 1998.

Wells ICPP-MON-A-164B, 166, and 167; and well ICPP-MON-V-200 were drilled in 2000 as monitoring wells for new infiltration ponds (called New Percolation ponds on fig. 4) that were installed in 2002 to replace the infiltration ponds south of INTEC (table 1). ICPP-MON-A-167 and 164B were upgradient monitoring wells for the ponds from 2002 to 2004 and 2010 and 20ll, respectively. ICPP-MON-A-167 was sampled until the pump failed. ICPP-MON-A-164B was used as a replacement upgradient well six years later until monitoring was discontinued when it was decided that well USGS 84 gave similar information. In 2010, the USGS began to collect samples from well ICPP-MON-V-200, completed in perched groundwater below the new infiltration ponds, to monitor the influence of the ponds on the underlying aquifer. In 2002, ICPP-MON-A-166 was added to the sampling program as a downgradient monitoring well for groundwater beneath the ponds and has been sampled ever since.

Well Middle 1823 was cored and drilled in 2003 for a geologic study for WAG 2. The USGS monitored water levels in the well from 2007 to 2012 before discontinuing measurements because a water-level optimization study (Fisher, 2013) indicated the measurements added little information to the water table configuration at the site. Wells Middle 2050A and Middle 2051 were cored and drilled in 2005 to enhance understanding of the geology of the ESRP aquifer; multilevel monitoring systems were installed in these wells and have been monitored since 2005.

Well NRF-14 was completed in 2008 and is used to monitor the Naval Reactors Facility's drinking water program. Well NRF 15 was cored and sampled in 2008 to replace NRF 13 and serve as an upgradient monitoring well for NRF's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) monitoring program. When analysis of a water sample collected from NRF 15 after it was cored (Twining and others, 2010) indicated the well was influenced by the NRF waste ditch, the well was completed as a dual piezometer water-level monitoring well (NRF 15 A and B, fig. 3). NRF-16 was then drilled and completed in 2009 and is used for upgradient monitoring for the NRF CERCLA monitoring program. NRF-13 was replaced because it showed influence from the waste ditch that precluded it from being used as an upgradient well.

Table 2. Completion and construction data for monitoring wells at the Idaho National Laboratory, Idaho, 2002–2020.

[**Local well name**: The local identifier used in this study. **Completion date**: month/date/year. **Well depth** and **water level** in feet below land surface. Hole and casing diameter below water table in inches. **Casing**: Top and bottom in feet below land surface. **Opening**: Range of opening in feet below land surface followed by type abbreviations O, open hole; P, perforated or slotted; S, screen unknown. **Water level**: approximate and based on first measurement. **Symbols**: negative sign indicates above land surface. **Abbreviations**: mm, millimeter; piezo., piezometer; unk, unknown; #, indicates well was deepened and recompleted as a multilevel monitoring well. See figures 2–4 for well locations.]

Local well name	Completion date	Well depth	Hole diameter	Casings	Opening	Water level
ARA-MON-A-002	7/29/1994	620	10	11-629; 10	600-620 S	594
CFA 1932	3/16/2005	525	548.5	*-2.5-485; 6.5	485-525 S	491
Cross Road	9/24/1958	796	6	748-774, 7	774-796 O	582
ICPP-MON-A-164B	3/15/2000	533	8	0-493,4	493-533 S	502
ICPP-MON-A-166	4/7/2000	527	12	-2.0-487, 6	487-527 S	490
ICPP-MON-A-167	6/8/2000	504	8	*-2.0-462, 6	462-502 S	455
ICPP-MON-V-200	10/20/2000	127	4	2-122, 4	122-127 S	108
Middle 1823	2/28/2003	720	6	*-2.5-680, 6	680-720 P	483
Middle 2050A	7/1/2005	1376	6	*-2.2-420, 7; MP55, 0-1376, 100 mm	15 measurement ports	481
Middle 2051	10/3/2005	1177	6	*-2.3-430, 7; MP55, 0-1177, 100 mm	12 measurement ports	571
NRF 14	8/26/2008	550	12	8-550; 8	420-549; S	386
NRF 15-A	10/27/2008	759	5,4	2-128, 5	128-759; O	378
NRF 15-B	10/27/2008	759	5,4	2-128, 5	128-759; O	366
NRF 16	11/4/2009	422	6	302-362, 5	362-422, S	360
PBF-MON-A-003	0/0/1994	575	10	0-545, 5	545-575, S	522
TAN-2271	5/20/2015	280	10	*-2-211; 10	211-280; O	228
TAN-2272	5/27/2015	281	9	*-2.5-209; 10	209-281; O	228
TAN-2312	7/25/2017	522	10	*-2-228, 10	228-522, O	241
USGS 103#	8/1/2007	1297	8,5,4	0-575, 8, 1.5-1290, 100 mm MP-55	23 measurement ports	587
USGS 105#	7/25/2009	1293	5,4	*-0.5-800, 5, MP-55, 0-1,290, 100 mm	18 measurement ports	675
USGS 108#	8/27/2010	1198	5,4	*-1-760, 5, MP-55, -3.5-1191, 100 mm	16 measurement ports	611
USGS 128	8/19/2002	615	5	*-1-457; 5	457-615; O	480
USGS 129	4/12/2005	660	5	*-1-9; 6	9-779; O	601
USGS 130	7/22/2003	636	6,4	*-1-474, 5	474-636; S	482
USGS 131	10/22/2003	797	5	*-1.5-537; 6	537-797; O	545
USGS 131A	8/7/2012	1198	5	*-2.5-536, 5, MP-55, 0-1188; 100 mm	16 measurement ports	547
USGS 132	7/25/2006	1238	9	*-1-188, 9, MP-55, 0-1,214; 100 mm	23 measurement ports	608
USGS 133	8/18/2004	798	6,5	1-663, 5, MP-55, 0-766; 100 mm	13 measurement ports	429
USGS 134	8/16/2006	894	4.5	1-544, 4.5, MP-38, 0-887; 100 mm	20 measurement ports	515
USGS 135	7/13/2009	1157	5	*-1-698, 5, MP-55, 0-1137, 100 mm	14 measurement ports	718

Table 2. Completion and construction data for monitoring wells at the Idaho National Laboratory, Idaho, 2002–2020.—Continued

[**Local well name**: The local identifier used in this study. **Completion date**: month/date/year. **Well depth** and **water level** in feet below land surface. Hole and casing diameter below water table in inches. **Casing**: Top and bottom in feet below land surface. **Opening**: Range of opening in feet below land surface followed by type abbreviations O, open hole; P, perforated or slotted; S, screen unknown. **Water level**: approximate and based on first measurement. **Symbols**: negative sign indicates above land surface. **Abbreviations**: mm, millimeter; piezo., piezometer; unk, unknown; #, indicates well was deepened and recompleted as a multilevel monitoring well. See figures 2–4 for well locations.]

Local well name	Completion date	Well depth	Hole diameter	Casings	Opening	Water level
USGS 136	8/25/2011	560	6,5,4	539-550; 5	500-550, P	487
USGS 137	3/19/2013	994	4	0-222, 8	abandoned	628
USGS 137A	7/19/2012	1317	5	*-3-331, 5, MP-55, 0-895; 100 mm	8 measurement ports	637
USGS 138	12/5/2012	325	4	*-3-325; 2.5	302-322, S	185
USGS 139A	6/11/2014	603	8,4	*-1-485, 6	754-774; S	480
USGS 139B	6/11/2014	603	8,4	*-1-485, 6	590-610; S	482
USGS 140	7/10/2013	546	8,6	*-2-483, 6	496-546, S	490
USGS 141	8/29/2013	546	8,6	*-2-485, 6	496-546, S	492
USGS 142	8/11/2016	840	8,6	*-1-506, 6	810-840, S	445
USGS 142A	8/11/2016	560	8	0-40,8	40-560, O	531
USGS 143	5/23/2016	801	6	*-2-490, 6	490-801, O	725
USGS 144	12/7/2016	620	6	*-1-502,6	502-620, O	518
USGS 145A	11/15/2018	1037	4	*-2-413, 6	1277-1297, S	708
USGS 145B	11/15/2018	1037	4	*-2-413, 6	1017-1037, S	700
USGS 146	6/5/2017	800	6	*-2-591, 6	591-800, O	707
USGS 147	9/4/2018	729	8	*-3.5-272, 8	272-729, O	657
USGS 148A	6/12/2019	759	5	*-1-5, 5	314-759, O	654
USGS 149	4/24/2019	973	5	0-974, MP 55	15 measurement ports	653

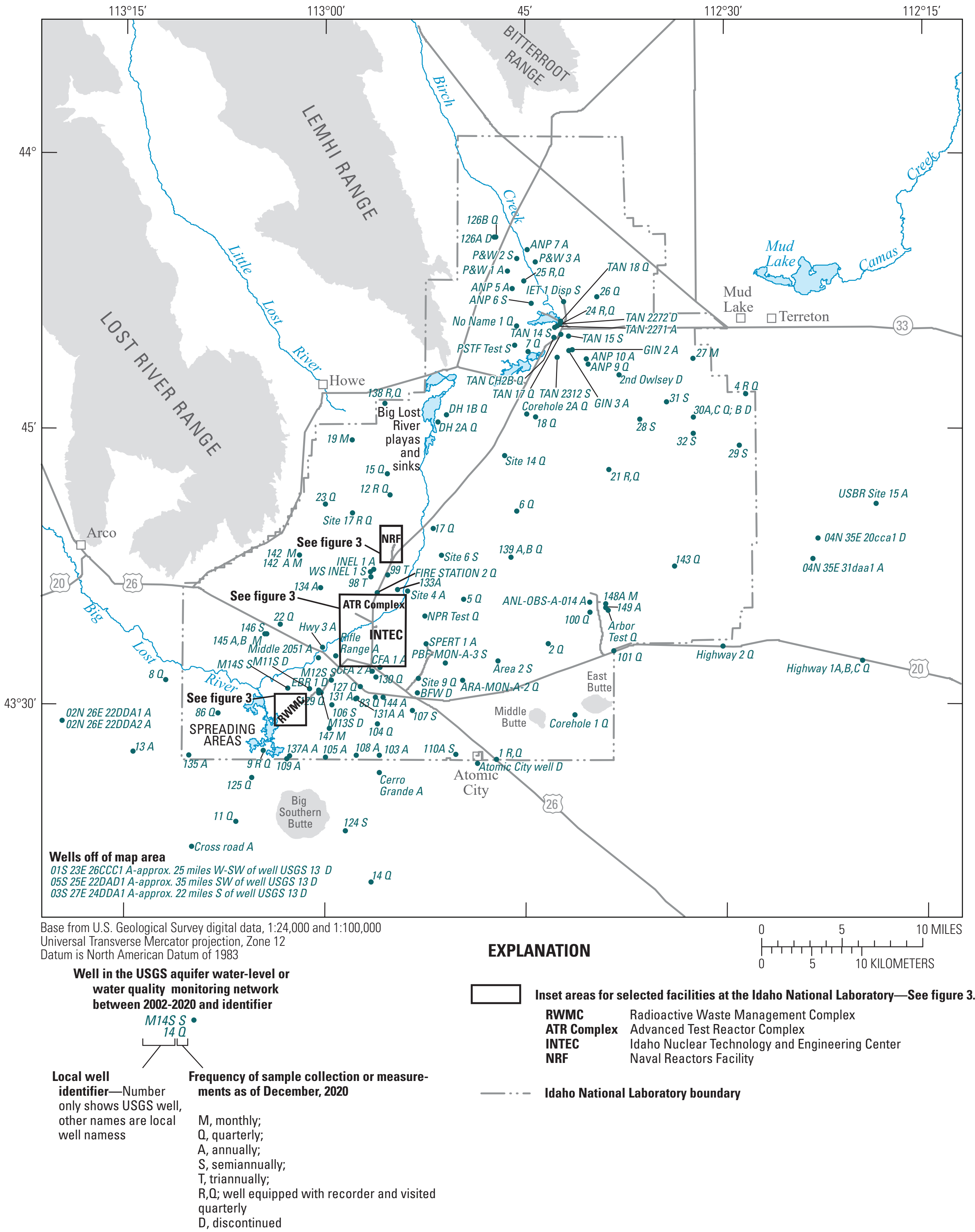

Figure 2. Locations of wells sampled or measured by the U.S. Geological Survey, 2002–2020, Idaho National Laboratory, Idaho.

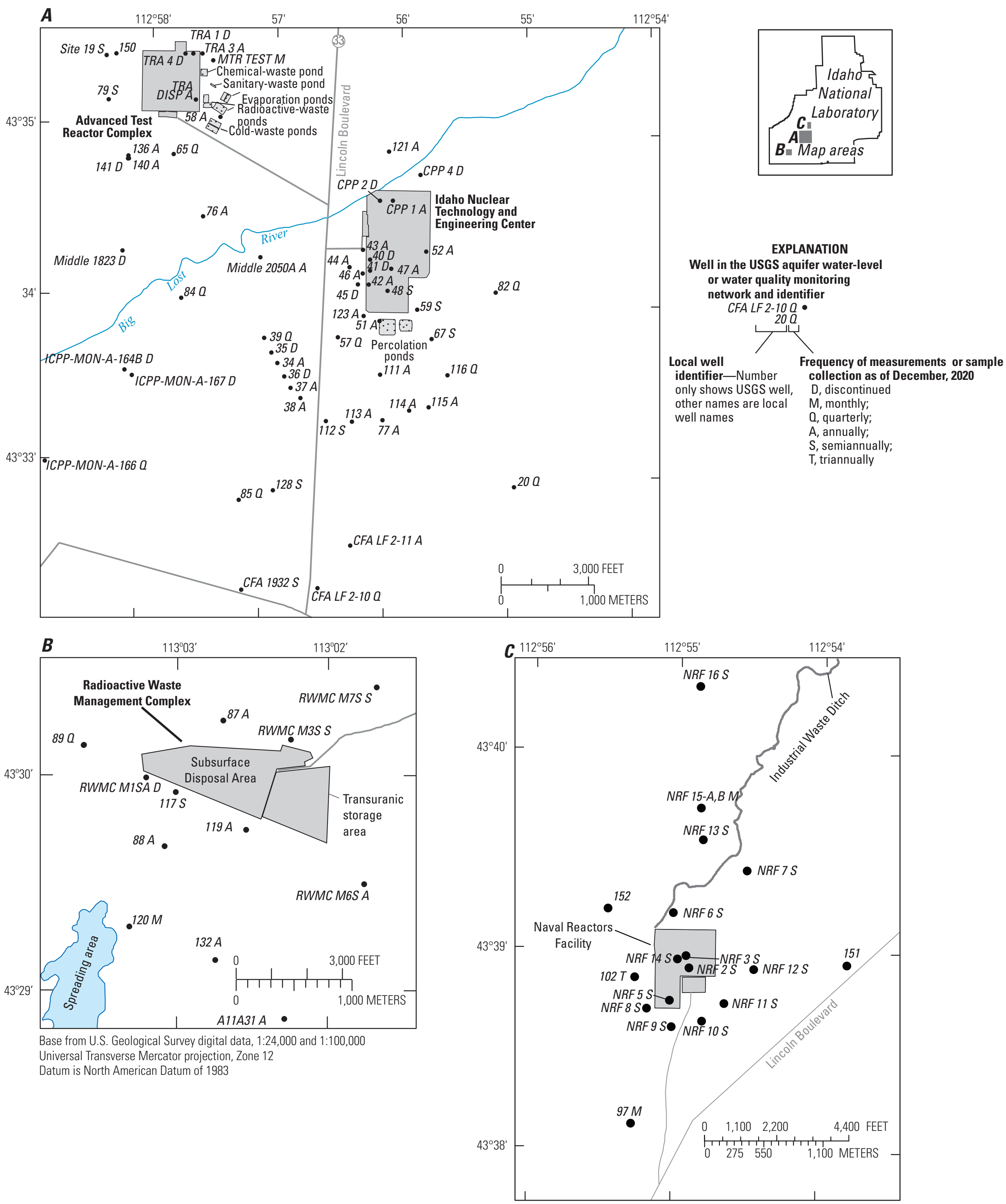

Figure 3. Locations of wells sampled or measured by the U.S. Geological Survey 2002–2020, at selected facilities at the Idaho National Laboratory: Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, Radioactive Waste Management Complex, and the Naval Reactors Facility.

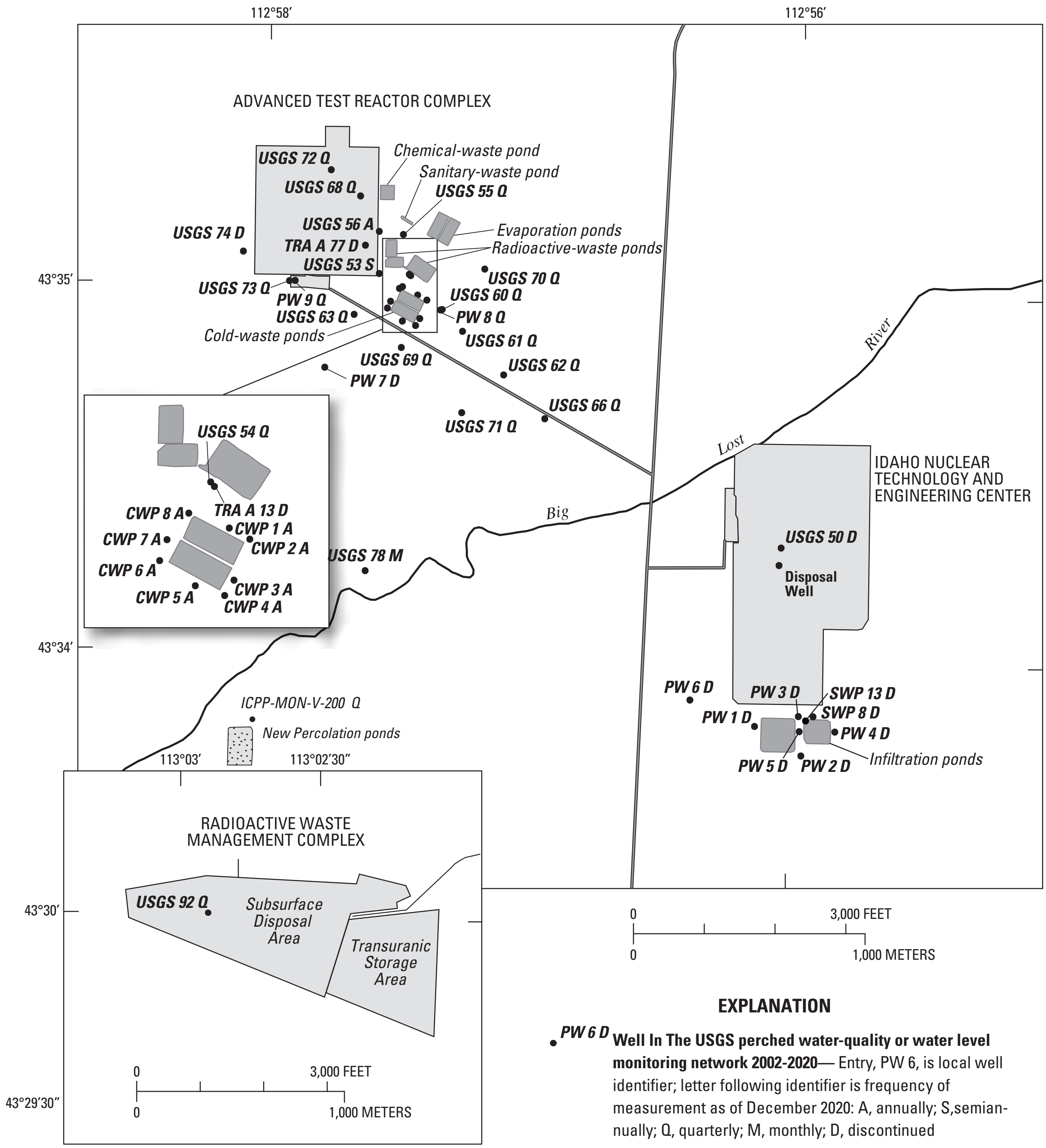

Figure 4. Locations of wells completed in perched aquifers sampled or measured by the U.S. Geological Survey, 2002–2020, at selected facilities at the Idaho National Laboratory: Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, and Radioactive Waste Management Complex.

Table 3. Surface-water sites and wells removed from the sampling program in 2020 at the Idaho National Laboratory and vicinity, Idaho.

[**Local name**: is the local identifier used in this study. **Site identifier**: is the unique numerical identifiers used to access well data (https://waterdata.usgs.gov/nwis). **Abbreviations**: BLR, Big Lost River, INL Idaho National Laboratory. Old water is groundwater that is older than the onset of atmospheric bomb testing (pre-1952) (Rattray, 2018, p.177]

Local name	Site identifier	Justification for removal
Atomic City	432638112484101	No long-term trends in the data, mostly all eastern regional water, well identified for removal by optimization, and data from nearby wells USGS 110A and USGS 1 indicate similar water chemistry.
BFW	433042112535101	No long-term trends in the data and well identified for removal by optimization study.
Big Lost River near Arco	13132500	No long-term trends, water chemistry similar to BLR at INL diversion.
Big Lost River at experimental dairy farm	13132545	No long-term trends, water chemistry similar to that at BLR at INL diversion.
CPP 2	433432112560801	Similar water chemistry to CPP 1, well identified for removal by optimization study.
CWP 3	433455112572501	Similar water chemistry to CWP 1.
RWMC M1SA	432956113030901	Old water with no concentration trends.
RWMC M11S	433058113010401	Old water with no concentration trends.
RWMC M13S	433037113002701	Old water with no concentration trends.
Site 14	434334112463101	Old water with no trends and well identified for removal by optimization study.
Site 19	433522112582101	Old water with no trends and well identified for removal by optimization study.
TRA 4	433552112574201	Similar water chemistry to TRA 3, well identified for removal by optimization study.
USGS 26	435212112394001	Old water with no trends and well identified for removal by optimization study.
USGS 29	434407112285101	Eastern regional water with no trends.
USGS 35	433339112565801	Similar water chemistry to USGS 34, well identified for removal by optimization.
USGS 36	433330112565201	Similar water chemistry to USGS 37, well identified for removal by optimization.
USGS 39	433343112570001	Similar water chemistry to USGS 34, well identified for removal by optimization, well collapse causes well to be dry during low aquifer levels.
USGS 41	433409112561301	Similar water chemistry to USGS 42, well identified for removal by optimization.
USGS 45	433402112561801	Similar water chemistry to USGS 44, well identified for removal by optimization.
USGS 78	433413112573501	All Big Lost River water, No trends.
USGS 109	432701113025601	Similar water chemistry to USGS 137A, well identified for removal by optimization.
USGS 121	433450112560301	Similar water chemistry to Site 4, well identified for removal by optimization.
USGS 125	432602113052801	Similar water chemistry and trends as USGS 11; well identified for removal by optimization.
USGS 126 B	435529112471401	No trends and well identified for removal by optimization.
USGS 134	433611112595800	No trends, mostly old water.
USGS 135	432753113093600	No trends, mostly old water.

Wells TAN-2271 and TAN 2272 were cored and completed in 2015 to provide geologic information for the USGS program in the TAN area and for use by the contractor for their ongoing WAG 1 cleanup work. TAN 2272 was sampled after drilling (Twining and others, 2016) and has not been monitored since by the USGS; well TAN 2271 was added to the USGS monitoring program after it was completed. TAN-2312 was cored and completed in 2017 to provide additional geologic information for the USGS program in the TAN area and also to be used by the contractor for their ongoing WAG 1 cleanup work. It is currently being used as a downgradient monitoring well for the TAN area.

Wells USGS 103, 105, and 108 were initially drilled in 1980 through approximately 150 ft of the top of the ESRP aquifer to enable collection of water-level and water-quality information along the southern boundary of the INL (fig. 2). From 2007 to 2010, these wells were cored several hundred feet deeper to improve geologic understanding of the aquifer, and after deepening, multilevel monitoring systems were installed and have been monitored since installation. Well USGS 128 was cored and drilled in 2002 as a replacement monitoring well for CFA LF 3-11, which had to be abandoned. Well USGS 129 was cored and drilled in 2005 to provide additional geologic and water-table information east of RWMC. Well USGS 130 was cored and drilled in 2003 near CFA to provide an open hole well that could be used for geophysical log testing and calibrations. In 2012, a pump was installed in this well, and it was added to the monitoring program. Well USGS 131 was cored and drilled in 2003 to provide additional geologic information and monitoring south of CFA. In 2010, this well was cored deeper for an installation of a multilevel monitoring system, but when drill rod became stuck in the hole from 381 to 741 ft, coring efforts were suspended, and the well is now used for water level measurements. A new well (USGS 131A) was drilled at the site in 2012 and a multilevel monitoring system was installed. Between 2004 and 2009, wells USGS 132-135 were cored and completed as multi-level monitoring wells at different areas in the southwestern part of the INL (figs. 2–3). In 2011, USGS 136 was cored and completed as a monitoring well south of the ATR Complex to eventually become an upgradient monitoring well for the Remote Handled Low-Level Waste (RHLLW) Facility (Twining and others, 2012). In 2013, wells USGS 140 and 141 were drilled for monitoring water quality downgradient of the RHLLW by the INL contractor (Twining and others, 2014). Additionally, cores from USGS 140 were used for unsaturated zone studies (Perkins and other, 2014; Nimmo and others, 2017). USGS 137 was cored with the intent to complete it as a multilevel monitoring well; however, drill rod and the drill hammer became stuck in the hole and it had to be abandoned. USGS 137A was then cored and completed as a multilevel monitoring well in 2012.

Several wells were drilled primarily, though not exclusively, to provide information needed to improve the groundwater-flow model. In 2012, USGS 138 was cored and completed as a water-level monitoring well in the NW corner of the INL. In 2014, USGS 139A and B were cored and completed as water-level monitoring wells at different levels in the aquifer in the center of the INL. In 2016, USGS 142 and 142A were cored and completed as water-level monitoring wells in different depths in the west-central part of the INL (Twining and others, 2017). Additionally, USGS 142 was cored deeper into rhyolite for an INL geothermal study. Also in 2016, USGS 143 was cored and completed as a monitoring well northeast of the Materials and Fuels Complex (MFC), both to provide additional information to improve the groundwater flow model and to provide an upgradient monitoring well for MFC. USGS 144 was cored and completed as a monitoring well in 2016 south of CFA to further track the extent of the nitrate plume that originated from the old mercury waste pond south of CFA. In 2018, USGS 145A and B were cored to provide additional geologic information in the southwestern part of the INL and completed as a dual piezometer well to provide additional information for the groundwater flow model.

In 2017, USGS 146 was drilled to supply water for coring operations in USGS 145 and is now used for water-level and water-quality monitoring in the southwestern part of the INL. In 2018, USGS 147 was cored and drilled to provide additional geologic and water quality information southwest of CFA. In 2020, this well was cored further to enable collection of water-quality information from a deeper part of the aquifer. In 2019, USGS 148A and 149 were cored and drilled for a seismic study and water-quality monitoring on the east side of MFC. USGS 149 was completed as a multi-level monitoring well (Twining and others, 2021). Also in 2019, USGS 150, west of the ATR Complex (fig. 3), was cored for geologic information and for an INL seismic study. As of 2020, the well is awaiting final decision for abandonment. In 2020, USGS 151 and 152 (fig. 3) were cored northeast and northwest, respectively, of the NRF for geologic information and for an INL seismic study. At the end of 2020, these holes were backfilled to a depth of about 600 ft and were awaiting a decision as to whether they would be completed as monitoring wells for the NRF program.

Wells 01S 23E 26CCC1, 03S 27E 24DDA1, 05S 25E 22DAD1, 02N 26E 22DDA1, and 02N 26E 22DDA2 were added to the water-level monitoring program at INL in 2009 when they were discontinued from the statewide water-level monitoring network. When water-level measurements at two of these wells (03S 27E 24DDA1 and 05S25E 22DAD1) were begun by another organization in 2019, they were discontinued from the USGS INL monitoring network.

Water-Level Monitoring Program

The USGS water-level monitoring program was designed to identify and document changes in storage and the general direction of groundwater flow within the ESRP aquifer. The data collected have subsequently been used to determine changes in hydraulic gradient that affect the rate and direction of groundwater and waste-constituent movement, to identify sources of recharge, and to measure the effects of that recharge to the aquifer. The water-level monitoring network continued to expand as new wells were drilled so that at the end of 2012, 778 measurements were made during that year from 216 wells, both those completed in the ESRP aquifer and in perched groundwater zones above the aquifer. To eliminate the collection of redundant data and increase the overall efficiency of the monitoring network, the USGS conducted an optimization study that was completed in 2013 (Fisher, 2013). Results of the study led to the decision to decrease the number of measurements and the number of wells monitored to the current (December 2020) schedule of 664 measurements from 200 wells (Appendix 2 in Bartholomay and others, 2021). In their report on the groundwater-flow model, Ackerman and others (2010) indicated some areas where the collection of additional water-level data could improve the predictive capability of the model and as a result, a network of 12 multilevel monitoring systems along with 5 additional piezometer nests and 6 transducer sites were added to the water-level monitoring program between 2005 and 2020 (fig. 2–4). All USGS water-level data are available at https://waterdata.usgs.gov/id/nwis.

Water-Quality Sampling Program

The radiochemical and chemical character of water in the ESRP aquifer is determined from analyses of water samples collected as part of a comprehensive sampling program to identify contaminants, determine long-term trends in the concentrations of those contaminants, and define patterns of waste migration in the aquifer. At the end of 2001, the USGS was collecting samples either quarterly, semiannually, or annually from 129 wells that were completed in the ESRP aquifer, 38 wells completed in perched groundwater zones above the aquifer at the ATR Complex, INTEC, and RWMC, and 7 surface-water sites (Davis, 2006a, 2006b). At the end of 2020, the number of routine sampling sites had been reduced to 100 wells completed in the ESRP aquifer, 35 wells completed in perched groundwater zones, and 5 surface-water sites (appendix 1 in Bartholomay and others, 2021).

In 2002, quarterly collection of water samples was discontinued, and the sampling schedules for wells that had been sampled quarterly were changed to semiannual collection, in April and October; wells that had been sampled annually (though in various months) were now all to be sampled in July. Beginning in 2004, however, sampling of all wells in the monitoring program was changed to an annual schedule, with the samples collected in either April or October. The sampling operations were divided up so that wells near each other were sampled in either April or October. For example, well USGS 112 is sampled in October, and nearby well USGS 113 is sampled in April, so that continuous coverage and monitoring of aquifer conditions is maintained in the vicinity of those two wells.

In June 2003, a conditional “no-longer-contained-in” determination for an area at and downgradient from INTEC was withdrawn, which resulted in the requirement that purge water (water pumped from a well before samples are collected) from 30 of the wells sampled by the USGS be containerized (Knobel, 2006). Starting with the October 2003 sampling period, sampling protocol for all wells in the routine monitoring program was modified from the purging of three wellbore volumes and three stable readings of pH, specific conductance and water temperature to just one wellbore volume (and three stable readings) before collecting samples to minimize the amount of water that needed to be containerized.

After the use of two infiltration ponds south of INTEC was discontinued in 2002, several of the perched-aquifer wells near the infiltration ponds (SWP-8 and 13; and PW 1, 2, 3, 4, 5, and 6 (fig. 4)) dried up between 2002 and 2008 and were subsequently abandoned. Wells TRA A-13, A-77, PW-7, and USGS 74 near the ATR Complex also dried up after remediation of the radioactive waste ponds in the early 1990s and they, too, were abandoned. Well USGS 50 at INTEC was sampled until 2008 and was abandoned in 2009 (Davis and others, 2013).

In 2010, the DOE requested that the USGS evaluate their long-term water-quality monitoring network to determine if redundancy existed with some of the wells being sampled and to determine if any of the data collection could be discontinued. Results of that evaluation were described in two reports (Bartholomay and others, 2012; and Davis and others, 2015) and the optimization of the network is described in a more recent report (Fisher and others, 2021).

In 2012, four new wells (ARA-MON-A-002, GIN-2, PBF-MON-A-003 and USGS 130) were added to the sampling program to better document trends in constituent concentrations in groundwater beneath the PBF, TAN, and CFA areas. Additionally, fourteen wells (ANP 9, Arbor Test, EBR-1, IET Disposal, PSTF Test, TRA 1, USGS 4, USGS 6, USGS 15, USGS 22, USGS 40, USGS 83 and USGS 126A) were removed from the sampling schedule because long-term trend information indicated no significant changes in constituent concentrations in the water for their period of record and because of the need to decrease the number of monitoring sites because of budget reductions. Sampling at well ICPP-MON-A-164B was discontinued because data were similar to the data collected at well USGS 84. Sample collection at USGS 40 was discontinued and the well was subsequently abandoned after the pump failed and got stuck while attempts were made to replace it. Sample collection at well CPP 4 was discontinued in 2017 because its water chemistry is similar to that at other INTEC production wells.

In 2012, the collection of samples for analysis of total organic carbon was discontinued owing to a combination of factors: poor laboratory reproducibility, no significant trends in the data, and budget reductions. In 2016, sample collection for strontium-90 and gamma analyses was discontinued for wells not near INTEC or the ATR Complex. Samples for analyses of gamma, strontium-90, and plutonium and americium isotopes were no longer collected for wells CPP-1, USGS 84, 89, 97, 98, 117, and 119. Additionally, samples for analysis of plutonium and americium isotopes were no longer collected from wells USGS 34 and USGS 38. All the radiochemical constituents for which analyses were discontinued in samples from the select wells had long-term concentrations below reporting levels and analytical results showed no significant trends (Davis and others, 2015).

In 2020, sample collection was discontinued at 26 wells because optimization and geochemistry studies indicated that water-chemistry data from the sites added little information to the extent and migration of wastewater-contaminant plumes at the INL, or that data on their water type and long-term trends indicated future monitoring would not add beneficial information. A list of wells and surface-water sites and justification for their removal from the network are given in table 3. Sampling of wells USGS 5, 12, and 107 for analysis of volatile organic compounds was discontinued because of an entire history of non-detections for all such compounds in these wells. A historical perspective of selected constituents and gross radioactivity in groundwater at INL follows.

Tritium

Tritium (symbol **T** or **^{3}H**) is a radioactive isotope of hydrogen. It occurs naturally in the atmosphere in trace amounts and is a low-abundance byproduct in normal operations of nuclear reactors. The USGS has monitored for tritium at the INL since 1956 (Knobel and others, 2005). Tritium has been, by far, the most abundant radioactive constituent in wastewater discharged at the INL and is the most widespread in the ESRP aquifer. About 31,620 curies (Ci) of tritium was discharged at the ATR Complex and INTEC through 1998 (Bartholomay and others, 2000), but no known releases have occurred since 1998 (other than to evaporation ponds at the ATR Complex). Because of the amount of tritium released, the USGS continues to monitor for tritium at wells and surface water sites sampled between 2002 and 2020. Tritium is analyzed by the DOE's Radiological and Environmental Sciences Laboratory (RESL) in Idaho Falls ID at a detection level of 200 pCi/L (Bartholomay and others, 2014). Analytical methods that achieve lower detection levels have been used by other laboratories, including at the USGS Menlo Park tritium lab from 2016 to 2018 (Bartholomay and others, 2020, table 7). Additionally, ARS International, LLC provides low-level tritium analyses for the NRF program at the INL.

Strontium-90

Strontium-90 is a radioactive form of strontium found in waste from nuclear reactors. The USGS has routinely monitored for strontium-90 around INTEC and the ATR Complex since the early 1960s (Knobel and others, 2005). Strontium-90 has been an abundant radioactive-waste product at the ATR Complex, INTEC, and TAN. Bartholomay and others (2000) determined that about 57 Ci of strontium-90 had been discharged in wastewater at INTEC through 1998; about 93 Ci was discharged to ponds at the ATR Complex. In 1972, about 18,100 Ci of strontium-90 was leaked at the INTEC Tank Farm (Cahn and others, 2006). No known releases have occurred since 2000 (other than to evaporation ponds at the ATR Complex).

Most of the samples for analysis of strontium-90 were collected at wells completed in the ESRP aquifer and in perched aquifers at and near INTEC, the ATR Complex, and TAN. In 1995, some additional sampling was added to several regional monitoring wells to verify strontium-90 concentrations were below the detection limit. Because analyses indicated that concentrations were indeed below the detection limits, sampling was discontinued at the regional wells in 2016. All the strontium-90 samples are analyzed at RESL.

Cesium-137 / Gamma Radiation

Since 1962, the USGS has routinely monitored groundwater at the INL for gamma emissions by radioactive nuclides. Cesium-137 is the primary radionuclide detected (by gamma spectroscopy), although historically cobalt-60 and chromium-51 also have been identified in some samples. From 1952 to 2000, about 138 Ci of cesium-137 in wastewater was discharged at the ATR Complex, and about 23 Ci was discharged at the INTEC disposal well and infiltration ponds. In 1972, an additional 19,100 Ci of cesium-137 leaked at the INTEC tank farm (Cahn and others, 2006). No known releases have occurred since 2000, other than to the ATR Complex evaporation ponds.

Most of the samples analyzed for gamma emissions were collected from wells completed in the ESRP aquifer and in perched aquifers at and near INTEC, the ATR Complex, and TAN. In 1995, some additional sampling for gamma analysis was added to several regional monitoring wells. Data indicated that regional concentrations were mostly below the analytical detection limits, so sampling was discontinued from most of these wells in 2016. All the samples for gamma spectroscopy are analyzed at RESL.

Plutonium-238, Plutonium-239, -240 (undivided), and Americium-241

The USGS has routinely monitored groundwater at the INL for the radionuclides plutonium-238, plutonium-239, -240 (undivided), and americium-241 beginning in 1971 at the RWMC and in 1974 at INTEC (Knobel and others, 2005). Thousands of curies of plutonium isotopes have been buried at RWMC, and about 0.26 Ci has been discharged in wastewater at INTEC (Bartholomay and others, 2000). Beginning in 1974, samples for analyses of these radionuclides have been collected on a routine schedule at selected wells at INTEC and RWMC and at one well downgradient of the ATR Complex. Sample collection from most wells with no history of detection of these constituents was discontinued in 2016.

Gross Alpha- and Beta-Particle Radioactivity

Gross alpha- and beta-particle radioactivity is a measure of the total radioactivity given off as alpha and beta particles during the radioactive decay process. Such measurements have been used at INL since 1955 to screen for radioactivity in the ESRP aquifer as a general indicator of contamination (Nace, 1961). In 1994, gross alpha-particle and gross beta-particle radioactivity measurements were added to the sampling schedules of several regionally monitored wells. In 2008, the RESL increased the sensitivity of their gross alpha- and gross beta-particle radioactivity measurement methods and changed the radionuclides reported for gross alpha-particle radioactivity from plutonium-239 to thorium-230, and for gross beta-particle radioactivity from cesium-137 to strontium-90/yttrium-90. The minimum detectable activity decreased from about 1.6 to 1.5 pCi/L for gross alpha-particle radioactivity and from about 6.4 to 3.4 pCi/L for gross beta-particle radioactivity, which resulted in an increase in the number of detections (Bartholomay and Twining, 2010). In October 2016, samples for alpha- and beta-particle radioactivity analyses for some of the wells were sent to the USGS National Water Quality Laboratory (NWQL) because of a pending change in the laboratory to be used for such analyses; however, a decision to return to the use of RESL for the analyses was made after only a few sets of samples had been sent to the NWQL. The samples analyzed at the NWQL also had increased sensitivity compared to samples analyzed at RESL.

Iodine-129

The USGS first monitored for iodine-129 in the ESRP aquifer at the INL in April 1977 (Barraclough and others, 1981). Small concentrations (about 0.941 Ci) of I-129 have been discharged at INTEC from 1953 through 1988. Iodine-129 is not routinely monitored by the USGS at the INL, but more recent samples were collected in 2003 and 2007 (Bartholomay 2009); in 2011–12 (Bartholomay 2013), and in 2017–18 (Maimer and Bartholomay 2019). The analyses of all samples collected during the past 4 sampling periods have been done by Accelerator Mass Spectroscopy at the Purdue Rare Isotope Measurement Laboratory so results could be comparable using the same methods.

Chloride

Peckham (1959) conducted the first extensive study of the occurrence of chloride in the ESRP aquifer at the INL. Sodium chloride has been the most abundant chemical constituent discharged in wastewater to the subsurface at the INL, and consequently sodium and chloride are among the most widespread chemical constituents in regional groundwater (Robertson and others, 1974). Chloride continues to be monitored at all wells sampled by the USGS as part of their routine monitoring program, and the samples have been analyzed at the NWQL since 1989 (Bartholomay and others, 2012). No changes have occurred to chloride sampling protocols other than the addition to and deletion of wells from the monitoring program, as indicated earlier in this report.

Sodium

Sodium contamination at the INL was first studied by the USGS in 1958 (Knobel and others, 2005). Sodium chloride has been the most abundant chemical constituent discharged in wastewater to the subsurface at the INL, and consequently sodium and chloride are among the most widespread chemical constituents in regional groundwater (Robertson and others, 1974). Sodium continues to be monitored at most of the wells at the INL; samples have been analyzed at the NWQL since 1989 (Bartholomay and others, 2012). No changes have occurred to sodium sampling protocols other than the addition to and deletion of wells from the monitoring program as indicated, earlier in this report.

Sulfate

Sulfate has been discharged in wastewater at several of the INL facilities, including the ATR Complex, INTEC, and the NRF; however, USGS monitoring of sulfate in groundwater has been inconsistent because concentrations were historically near background levels (Knobel and others, 2005). Monitoring for sulfate was expanded in 1995 to be included at most wells and continues to be analyzed at the NWQL (Bartholomay and others, 1997). No changes have occurred to sulfate sampling other than the addition and deletion of wells to the monitoring program, as indicated earlier in this report.

Chromium

The disposal of chromium in wastewater at INL has been documented at the ATR Complex, INTEC, and the PBF (Davis, 2010, p. 37). Chromium has been monitored at selected wells at and near the ATR Complex since the 1960s (Mann and Knobel, 1988). Since the introduction of the INL groundwater monitoring program in 1994 (Sehlke and Bickford, 1993), chromium has been monitored at most wells at the INL and the samples analyzed at the NWQL. No changes have occurred to chromium sampling other than the addition and subtraction of wells to the monitoring program as indicated earlier in this report.

Nitrate

The disposal of nitrate in wastewater at the INTEC since 1952 has been documented. The first study of nitrate in the ESRP aquifer at the INL, in 1973, consisted of the interpretation of analyses of water samples downgradient of the INTEC, and the first comprehensive regional study of nitrate in groundwater was conducted in January 1979 (Barraclough and others, 1981). Water samples collected at the INL since 1989 have been analyzed at the NWQL for nitrite plus nitrate (as N), but because nitrite analyses have historically shown that the nitrite plus nitrate concentration value is virtually all nitrate, that value has been referred to as nitrate in most of the USGS INL publications. Nitrate was added to analyses for many wells in the regional part of the aquifer at the INL in 1994, and no changes have occurred to nitrate sampling other than the addition and subtraction of wells to the monitoring program, as indicated earlier in this report.

Fluoride

About 39,700 pounds of fluoride was discharged in wastewater at INTEC from 1971 through 1998 (Bartholomay and others, 1997). Fluoride was added to the list of constituents analyzed in samples from selected monitoring wells around INTEC in 1994 and continues to be included as part of first-time sample analyses at new wells drilled at the INL by the USGS. Fluoride is analyzed at the NWQL and no changes have been made to the monitoring program since 1994.

Trace Elements

Selected trace elements including aluminum, antimony, arsenic, barium, beryllium, bromide, cadmium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, uranium, vanadium, and zinc have been analyzed in water samples collected throughout the history of USGS involvement at INL as part of several special studies (Knobel and others, 1995). As part of the INL groundwater monitoring program adopted in 1994, samples from selected wells in the vicinity of the ATR Complex and TAN are analyzed for selected trace elements at the NWQL and those wells continue to be sampled at the end of 2020. Trace elements are also included as part of the first-time sample analyses at new wells drilled at the INL by the USGS.

Total Organic Carbon

As part of the INL groundwater monitoring program adopted in 1994, the USGS began collecting water samples at selected wells completed in the ESRP aquifer for analysis of total organic carbon (TOC) to screen for organic compounds in the aquifer as a general indicator of groundwater contamination. Analyses for TOC continued through 2011. In 2012, laboratory analyses were discontinued because of budget reductions to the USGS program, the lack of noticeable trends, and the variable recovery of TOC and issues with the reproducibility of analytical results (Davis and others, 2013, p. 67).

Purgeable Organic Compounds

Purgeable organic compounds (POCs) are present in water from the ESRP aquifer as a consequence of waste-disposal practices at the INL. The first extensive sampling for POCs was completed by Leenheer and Bagby (1982). Mann and Knobel (1987) followed up that earlier work with a comprehensive study in 1987. Routine analyses of samples for POCs at RWMC began after completion of the 1987 study, and sampling of selected wells was expanded in 1994 following the publication of the INL groundwater monitoring plan (Sehlke and Bickford 1993). No changes have occurred to POC sampling other than the addition and subtraction of wells to the monitoring program, as indicated earlier in this report, and the discontinuation of sample collection at USGS wells 5, 12 and 107 in 2020. POCs are also included as part of the first-time sample analyses at new wells drilled at the INL by the USGS.

Quality-Assurance Program

The first study by the USGS at the INL documenting results of quality assurance data was published by Wegner (1989) and documented quality assurance data collected between 1980 through 1988. A formalized quality-assurance plan for the USGS INL Project was implemented in 1989 and was revised in 1992, 1996 (Mann, 1996), 2003 (Bartholomay and others, 2003), 2008 (Knobel and others, 2008), 2014 (Bartholomay and others, 2014), and in 2021 (Bartholomay and others, 2021).

Since 2002, the USGS has continued to analyze and interpret the quality-assurance data collected in the routine water-sampling program. Evaluations of older quality-assurance data (1996-2008) were published in 2012 and 2014 (Rattray, 2012, 2014) to determine reproducibility and bias of the data. Starting with 2009 data, the reproducibility and bias of routine quality-assurance data were described in the hydrologic conditions reports (Davis and others, 2013; Bartholomay, Maimer, and others, 2017; Bartholomay and others, 2020). Quality-assurance data collected for the multilevel monitoring program and for iodine-129 studies have been published in the reports covering their different period of records (Bartholomay, 2009; Bartholomay and Twining, 2010; Fisher and Twining, 2011; Bartholomay, 2013; Bartholomay and others, 2015; Twining and Fisher, 2015; Maimer and Bartholomay, 2019; and Twining and others, 2021). A special quality-assurance study described by Knobel (2006) evaluated if a change in sampling protocol from purging of three casing volumes of water to just one casing volume prior to sample collection would affect data quality. Such a change would reduce the amount of purge water from wells sampled at and near INTEC that would have to be containerized. The results showed no significant change in data quality so changes to the sample program were implemented.

Special Water-Quality Studies

Naval Reactors Facility Sampling

In 1989, the Idaho Branch Office (IBO) of the Pittsburgh Naval Reactors (NRF) Office, U.S. DOE, requested that the USGS initiate a water-quality data collection program in the vicinity of NRF. The purpose of the data-collection program is to provide the IBO with a consistent set of data to evaluate the effects of NRF activities on the chemical characteristics of water in the ESRP aquifer. The water sampling program has continued from 2002 through 2020 with some changes in the laboratories that perform the analyses, changes in the frequency of the sampling, and changes to the number of wells sampled.

Samples collected for the USGS NRF program were analyzed by the Severn Trent Laboratories through the USGS Department of Defense Environmental Conservation (DODEC) Program in 2002; in December of 2006, Severn Trent was acquired by TestAmerica Laboratories, Inc. (2021). TestAmerica Laboratories, Inc., were used for inorganic, organic, and some radiochemical analyses until 2015, when GEL laboratories became the primary laboratory used for analyses. Tritium analyses were made by USGS contract laboratories through the DODEC program until 2010, and subsequently by Brigham Young University's laboratory of isotope geochemistry. Since 2015, samples for tritium analyses have been sent to ARS International, LLC.

In 2002, water samples were collected quarterly from wells USGS 12, 97, 98, 99, 102, NRF 6, 7, 8, 9, 10, 11, 12, and 13 and analyzed for selected inorganic, organic, and radiochemical constituents for the NRF sampling program (figs. 2, 3). In 2003, the sampling schedule shifted to collection three times each year, and in 2007, to collection just twice a year. In 2010, well NRF 16 was added to the sampling program and well NRF 13 was discontinued. In 2011, sampling was discontinued at well USGS 12, and began at wells NRF 3 and NRF 14. Beginning in 2012, samples were collected once every other year at wells USGS 97, 98, and 99. In 2020, Site 6, Site 17, and USGS 12 were added to the sampling program.

Downgradient Sampling

In 1988, the USGS began collecting samples for analysis of tritium in spring discharge to the Snake River at 19 sites between Twin Falls and Hagerman, Idaho. This sampling program continued through 2001, with the last set of results published in Twining and others (2003). The program was discontinued because of budget reductions to the USGS monitoring program.

In 1989, the USGS initiated a routine water-sampling program in the area from the southern boundary of the INL to the Hagerman, ID area known as the Magic Valley program. Fifty-five sites were sampled during the initial year of this program, and subsequently about a third of the sites were sampled annually through 2003. The samples were analyzed for selected radionuclides, trace elements, common ions, nutrients, purgeable organic compounds and pesticides. The analytical results for each year of sampling were published in USGS Open-File Reports, with the last set of results published by Rattray and others (2005). The program was discontinued by the USGS in 2004 because of funding cuts; however, the Idaho Department of Environmental Quality INL oversight program has continued the sampling program.

In 2010, the USGS collected water samples and geophysical logs from a deep research well near the center of the ESRP, near Kimama, Idaho, for additional water-chemistry and hydrogeologic data downgradient of the INL. Water samples were collected and analyzed for common ions; selected trace elements; nutrients; isotopes of hydrogen, oxygen, and carbon; and selected radionuclides. Results for the geophysical logs and the water chemistry analyses are given in Twining and Bartholomay (2011).

Site Characterization Studies

Starting in 2008, the USGS, in cooperation with the NRF, cored and drilled NRF 15 as a potential upgradient monitoring well for the NRF's CERCLA sampling program (fig. 3). When analyses of water samples from this well indicated possible influence on groundwater chemistry from the nearby NRF waste ditch, it was decided to finish the well as a dual piezometer water-level measurement site. Subsequently, the USGS drilled NRF-16 further upgradient to replace NRF 13 as a monitoring well for the CERCLA program. Results from the drilling, geophysical logging, aquifer test, and the analyses of initial water samples for NRF 16 are given in Twining and others (2011). The report also includes results of sample analyses for NRF-15.

In 2011, the USGS drilled, cored, and completed well USGS 136 for stratigraphic framework analyses and long-term groundwater monitoring of the eastern Snake River Plain aquifer downgradient of the ATR Complex at the INL (Twining and others, 2012). This well was drilled as an upgradient monitoring well for the contractor for the proposed RHLLW Repository. Geophysical logs were acquired, and an aquifer test was completed at the well. Water samples were collected and analyzed for cations, anions, metals, nutrients, total organic carbon, volatile organic compounds, stable isotopes, and radionuclides. Analytical results showed that concentrations of tritium, sulfate and chromium were affected by upgradient disposal of wastewater at the ATR Complex. Analyses of samples collected with a thief sampler from deep in the aquifer indicated no influence from the wastewater disposal from the TRA disposal well.

In 2013, the USGS cored and drilled USGS 140 and 141 to collect data for stratigraphic framework analyses, hydrologic property analyses, and aquifer properties south of the ATR Complex; the wells were to be used as downgradient monitoring wells by the INL contractor for the RHLLW Disposal Facility (Twining and others, 2014). In well USGS 140, sediment interbeds were cored and sampled for an unsaturated zone study (Perkins and others, 2014). Geophysical logs were obtained in both wells and single aquifer tests were conducted at each well following their completion. Water samples were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Analyses of the samples from both wells indicated that concentrations of tritium, sulfate, and chromium were affected by wastewater disposal practices at the ATR Complex.

In 2015, TAN 2271 and TAN 2272 (fig. 2) were drilled to collect data for the monitoring program near TAN in addition to providing information needed for the INL contractor's cleanup program (Twining and others, 2016). Wells TAN 2271 and TAN 2272 (fig. 2) were cored and constructed to characterize the hydrogeology of the area using data collected from geophysical logs, aquifer properties, and water chemistry. Water samples from TAN 2271 and TAN 2272 were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Concentrations of strontium-90, trichloroethene, and vinyl chloride in samples from one or both wells exceeded maximum contaminant levels for public drinking water supplies.

In 2017, well TAN 2312 was drilled south of TAN to collect additional information for the monitoring program near TAN along with information for the INL contractor cleanup program (Twining and others, 2018). Well TAN 2312 was cored and constructed to characterize the hydrogeology of the area using data collected from geophysical logs, aquifer properties, and water chemistry. Water samples collected from this well were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Analyses of the samples for stable isotopes of oxygen, hydrogen, and sulfur indicated possible influence of nearby irrigation on the water chemistry. The volatile organic compound data indicated that the water at this well also was affected by wastewater disposal practices at TAN.

In 2019, wells USGS 148A and USGS 149 were drilled east of MFC to collect additional data for groundwater monitoring around the MFC as well as to support an INL seismic hazards study by the INL contractor (Twining and others, 2021). Well USGS 148A was completed for monitoring the upper part of the aquifer system; USGS 149 was completed as a multilevel monitoring well. Cores from both wells were analyzed for paleomagnetic properties and water samples were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. The chemical character of water in well USGS 148A and in all four zones in USGS 149 was similar, indicating mostly regional background concentrations of constituents, with a small influence from irrigation water and with no apparent affect from wastewater disposal at MFC.

Geochemical Studies

The USGS has conducted interpretive studies to describe the processes affecting the distribution of chemical constituents in the subsurface at and near the INL since 1949. Prior to 2002, several studies were conducted to understand the natural geochemistry of the ESRP aquifer system (Knobel and others, 2005, p. 14–15). In 2002, continuation of studies reported in Knobel and others, 2005 to understand the natural geochemistry of drainages contributing groundwater and surface-water recharge to the ESRP aquifer were done with a description of the Little Lost River and Birch Creek drainage basins by Swanson and others (2002, 2003). After these studies, geochemistry was put on hold for a couple years while priorities for the project shifted to the revision of the groundwater flow model. From 2005 to 2012, 11 new multilevel monitoring wells were instrumented at the INL with from 4 to 7 sampling ports that sampled the upper 250 to 750 ft of the aquifer; a full suite of geochemical constituents were collected and analyzed from these 11 wells starting in 2006 (Bartholomay and Twining, 2010; Bartholomay and others, 2015). In 2011, drainage basin studies that recharge the ESRP aquifer at the INL restarted. Ginsbach (2013) completed an analysis of the geochemical evolution of water in the Medicine Lodge Creek drainage basin. Rattray and Ginsbach (2014) and Rattray (2015) analyzed the geochemistry of the groundwater in the Beaver Creek, Camas Creek, and Mud Lake Basin areas.

In 2017, a four-part USGS Professional Paper series was started to fully describe the sources and chemical reactions taking place in the ESRP aquifer at and around the INL. The first chapter on the geochemistry of the source water was published in 2018 (Rattray, 2018). The second chapter summarized results of the geochemical modeling of the upper part of the aquifer (Rattray, 2019). The third chapter modeled the water collected from multiple levels of the aquifer (Gordon Rattray, USGS, written commun., 2021) in the SW corner of the INL. The fourth chapter (Gordon Rattray, written commun., 2021) used uranium and strontium isotopes to further describe the source waters of the hydrologic system at the INL.

Geophysical Logging Program

The USGS has been involved with the collection of geophysical logs and analyses of geophysical log data at INL extending back to 1952. Geophysical logs commonly acquired include neutron, gamma-gamma (density), natural gamma, mechanical caliper, acoustic caliper, temperature, resistivity (electric), specific conductance, magnetic deviation, gyroscopic deviation, electromagnetic flowmeter, and acoustic televiewer (obtained in 2015). The USGS also has the capacity to run borehole videos using a variety of color and black and white video. Geophysical logs have been saved and archived in various formats throughout the years (Knobel and others, 2005, p. 18–19), and since 1991, all logs have been saved in electronic/digital format. Starting in 2009, geophysical log data were made available for public access using a database repository named USGS GeoLog archiver. This repository continues to be updated with new and selected historical logs collected before 2009.

Geophysical logs have been included and described in the papers referenced in the downgradient studies and site characterization studies sections earlier in this report. Additional logs for several selected wells were published in USGS Data Series reports (Twining and others, 2008; Hodges and others, 2012; and Twining and others, 2017). Geophysical logs were used for a study that evaluated declining water levels at INL and the effect of such declines on wells (Bartholomay and Twining, 2015). Deviation logs were used in a well deviation study (Twining, 2016), and geophysical logs were used to define the transmissivity changes for the aquifer (Twining and Maimer, 2019).

Geologic Framework Program

The USGS has conducted studies of the geologic framework at the INL since the site was established in 1949. Since 2002, the geologic framework studies have mostly focused on refining the subsurface stratigraphic correlation of basalt flows and sedimentary interbeds. Some additional studies have characterized the geologic framework at new facilities. Geophysical logs, along with lithological data from cores, petrographic descriptions, radiometric age dating, and geochemical data were used to create a two-dimensional geologic framework of the INL, and the stratigraphic information was used to develop the conceptual framework (Ackerman and others, 2006) for the USGS groundwater-flow and contaminant-transport model (Ackerman and others, 2010). After the conceptual model was completed, the USGS began using paleomagnetic and age dating information to further refine the stratigraphic framework (Champion and others, 2011; Champion and others, 2013; Hodges and others, 2015; and Hodges and others 2016),

Drilling Program

Well and core drilling initiated in the 1990s at the INL has continued from 2002 to 2020, with the addition of new monitoring wells, piezometer wells, and multilevel monitoring wells. Wells were first cored then repurposed for monitoring based on scientific research needs for the area (table 1). To acquire hydraulic head, water temperature, and water-chemistry data that describe the vertical distribution of constituents in the ESRP aquifer, the USGS collaborated with the INL contractor in 2005 to develop a multilevel monitoring network. Through 2020, 12 wells were instrumented with multi-level Westbay™ packer sampling systems to collect data at isolated depths in each well. Other wells drilled since 2002 have been for: (1) site characterization studies noted previously in this report, (2) monitoring waste constituent movement in the southwestern part of the INL, and (3) additional water level information to improve the groundwater flow model.

Groundwater-Flow Modeling Program

Groundwater flow is a critical component of understanding how wastewater disposal and buried waste from the various INL facilities will move through the ESRP aquifer in the future. Prior to 2002, several modeling studies were completed (Knobel and others, 2005, p. 21–22), and the USGS INL Project Office personnel were working on a conceptual model, a steady-state model, a transient model, and a solute-transport model of the aquifer. The conceptual model was published in 2006 (Ackerman and others, 2006), and a three-dimensional steady-state and transient model of flow and advective transport was published in 2010 (Ackerman and others, 2010). A study to compare the simulated three-dimensional model estimates of groundwater source areas and velocities to independently derived estimates was completed in 2012 (Fisher and others, 2012). Current work (2020) is combining revisions to the geologic framework along with updated information from multilevel hydraulic-head measurements and geochemical modeling efforts to produce reproducible groundwater-flow and solute-transport models for the ESRP aquifer at and near the INL.

Surface-Water Program

The USGS surface-water program at the INL has consisted of collection of flow data at a stream-gaging network on the Big Lost River; operation of gaging-stations in three small (2 to 20 mi^2) closed drainage basins within INL boundaries, studies of infiltration (seepage) through the channel of Big Lost River to the underlying groundwater system; and flood hazard studies on the Big Lost River and Birch Creek (Knobel and others, 2005., p. 22–23). Since 2002, the USGS has completed studies to (a) estimate the magnitude of the 100-year peak flow in the Big Lost River at the INL (Hortness and Rousseau, 2003), (b) determine the extent and severity of flooding at INL facilities along the Big Lost River (Berenbrock and Doyle, 2003), and (c) evaluate the effects of streambed erosion and bedrock constrictions along a reach of the Big Lost River on model predictions of water-surface elevations (Berenbrock and others, 2007). In addition, surface-water data collected from the gaging station network has been presented and discussed as part of the periodic hydrologic conditions update reports.

From 2002 through 2009, the USGS Idaho Water Science Center's Idaho Falls Field Office operated a hydrologic network in the Big Lost River Basin that consisted of eight continuous-record stream-gaging stations, six crest-stage gages in the spreading areas and playas, and one lake-stage gage in playa 1. In FY 2009, however, the USGS and the DOE decided to reduce the number of data-collection sites in the network to seven continuous-record stations (gage 13132514 at outlet of spreading area A was discontinued) and one stage-measurement only site on Mackay reservoir. Those data are available at (U.S. Geological Survey, 2022b). Data-collection platforms equipped with satellite telemetry are installed at all seven of the continuous-record stations to provide real-time hydrologic information. Data have been collected continuously at two of the three most upstream stations since the early 1900s; data collection at the third upstream station started in the 1940s. Data from the current hydrologic network in the Big Lost River Basin are used to determine annual snowmelt runoff, to calculate infiltration (seepage) losses from the main channel and diversions, to estimate infiltration in ponded areas, and to support flood-control studies. In addition, the telemetry at gaging stations in the basin provides the INL facilities immediate access to storage and flow conditions in the Big Lost River. In 2016, the USGS installed two new gaging stations in the Little Lost River Basin to better monitor flow. In 2017, a new station was installed in Antelope Creek near Darlington, ID (13131000, fig. 1). In 2020, the USGS installed radar telemetry at the Big Lost River station below the INL diversion near Arco (13132520, fig. 1) to reduce measurement error resulting from sedimentation at that site. Funding for the stream gaging network has been shared between DOE, the USGS, and other cooperators.

Unsaturated-Zone Program

Prior to 2002, several studies were completed within the unsaturated-zone program. These included the construction and instrumentation of a test-trench facility to determine hydraulic and solute-transport characteristics of the unsaturated zone underlying the RWMC, a tracer study to define long-range flowpaths through the unsaturated zone, and an investigation of the hydraulic properties of the sedimentary interbeds within the basalts at several locations. (Knobel and others, 2005, p. 23). Since 2002, the USGS continued to evaluate the properties of the unsaturated zone at the INL by quantifying groundwater flow and contaminant transport. Efforts focused on the effects of sedimentary interbeds to either enhance or retard the spread of contaminants. Extensive measurements of the hydraulic and bulk properties of the unsaturated zone have been completed and published in four reports (Perkins, 2003; Winfield, 2003; Perkins, 2008; and Perkins and others, 2014). Sediment property-transfer models, which simulate the hydraulic properties of INL sediments on the basin of more easily measured bulk properties, were subsequently developed and tested using these data recovered from drill cores and measured in laboratory experiments. The results were published in three reports (Winfield, 2005; Perkins and Winfield, 2007; and Perkins and others, 2014). The hydraulic-property measurements and property-transfer models provide a firm foundation for large-scale simulations of water and contaminant transport at the INL using conventional numerical models based on diffuse flow theory. In recognition of the importance of preferential flow through the fractured basalts at the INL, efforts in 2010 shifted toward evaluating correlations among perched-well water levels, weather conditions, and fluctuating inputs of water at the land surface to assess the sensitivity of water movement to preferential-flow behaviors. Because complex preferential-flow behaviors are not typically considered in conventional flow models, parallel efforts also focused on establishing means for incorporating preferential flow into conceptual and numerical models of contaminant transport. Preliminary work with a source-responsive model demonstrated that a simple approach can be applied to quantify the effects of preferential flow at the INTEC. Water-level analysis and modeling work demonstrated the potential utility of the approach, which was summarized in two reports (Mirus and others, 2011; Mirus and Nimmo, 2013). In 2016, USGS personnel completed analyses of interbed material below the RHLLW Facility (Nimmo and others, 2017. Currently (2020), no further study of the unsaturated zone at the INL is planned unless additional funds or a specific need can be identified.

Summary

In 1949, the National Reactor Testing Station (NRTS), an 890-mi^2 site on the Eastern Snake River Plain (ESRP) in southeastern Idaho, was established by the U.S. Atomic Energy Commission for the development of peacetime atomic-energy applications, nuclear safety research, defense programs, and advanced energy concepts. To account for changing priorities of the Station, the NRTS was renamed several times, and in 2005 became the Idaho National Laboratory (INL), whose functions are currently administered by the Nuclear Regulatory Commission. Current (2020) programs and priorities at the Laboratory include nuclear energy research; spent nuclear-fuel management; hazardous and mixed-waste management and minimization; national security; cultural resources preservation; and environmental engineering, protection, and remediation.

This report summarizes the historical development and operations, from 2002 to 2020, of the U.S. Geological Survey's (USGS) hydrologic monitoring and investigative programs at the INL in cooperation with the U.S. Department of Energy. The report covers the USGS's programs and how they have evolved for water-level monitoring, water-quality sampling, geochemical studies, geophysical logging, geologic framework development, groundwater-flow modeling, drilling, surface-water monitoring, and unsaturated zone studies.

The water-level program changed from a maximum of 778 measurements from 216 wells in 2012 to 664 measurements from 200 wells at the end of 2020. The water quality monitoring network changed from sampling 129 wells in the ESRP aquifer, 38 wells that penetrated perched groundwater zones at the ATR Complex, INTEC, and RWMC, and 7 surface water sites either quarterly, semiannually, or annually as part of the routine sample program at the end of 2001 to sampling 100 wells in the ESRP aquifer, 35 wells that penetrated perched groundwater zones, and 5 surface-water sites annually at the end of 2020. Surface-water flow measured in the Big Lost River drainage basin changed from eight streamgages, six crest-stage gages, and one lake-stage gage site in 2009 to seven streamgages and one stage site on Mackay Reservoir at the end of 2020.

Brief summaries of USGS-published reports from 2002 through 2020, listed by U.S. Department of Energy report numbers, are provided in the appendix.

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Winfield, K.A., 2003, Spatial variability of sedimentary interbed properties near the Idaho Nuclear Technology and Engineering Center at the Idaho National Engineering and Environmental Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 2003-4142, DOE/ID-22187, 36 p. [Also available at https://doi.org/10.3133/sir20055114.]

Winfield, K.A., 2005, Development of property-transfer models for estimating the hydraulic properties of deep sediments at the Idaho National Engineering and Environmental Laboratory, Idaho: U.S. Geological Survey Scientific Investigations Report 2005–5114, DOE/ID-22196, 49 p. [Also available at https://doi.org/10.3133/sir20055114.]

Appendix 1. Summaries of U.S. Geological Survey reports, 2002–2020 (listed by U.S. Department of Energy report numbers)

Throughout the history of the INL, many facility-related acronyms have been used and frequently have been changed. Many of the historic well names were based on the current (at the time) facility name or the proposed name of a research facility that was never completed. Please see Knobel and others, 2005 acronym list or the abbreviations section of this report for a list of many of the acronyms. For complete citations for the reports summarized in this section, please see the references cited section of this report.

DOE/ID-22178 Chemical and radiochemical constituents in water from wells in the vicinity of the Naval Reactors Facility, Idaho National Engineering and Environmental Laboratory, Idaho 2000**,** Open-File Report (OFR) 2002-148, by R.C. Bartholomay, L.L. Knobel, B.J., Tucker, and B.V., Twining, 2002, 34 p. This is the eighth in the series of reports describing the chemical characteristics of water samples from wells in the vicinity of the Naval Reactors Facility at the INEEL. A total of 52 samples were collected from 13 monitoring wells on a quarterly basis. Laboratory analyses indicated detectable concentrations of total cations, dissolved anions, some trace elements, and nitrite plus nitrate as nitrogen were determined along with concentrations of gross alpha- and gross beta-particle radioactivity and tritium. Four field blanks and four replicates were collected as a measure of quality assurance. Ranges of concentrations for most of the data are given.

DOE/ID-22179 Geochemistry of the Little Lost River drainage basin, Idaho, Water-Resources Investigations Report (WRIR) 2002-4120, by Shawn A. Swanson, Jeffrey J. Rosentreter, Roy C. Bartholomay, and LeRoy L. Knobel, 2002, 29 p. The purpose of this study was to better define the geochemical character of water in the Little Lost River drainage basin and to determine its effect on the geochemistry of the eastern Snake River plain aquifer at and near the INL. Water samples were collected from 6 wells and 2 surface-water sites and analyzed for selected inorganic constituents, dissolved organic carbon, stable isotopes, tritium, and gross measurements of radioactivity. Four duplicates were collected for quality assurance. Results show that most water has a calcium-magnesium bicarbonate character. Water from two sites had elevated chloride concentrations. The computer code NETPATH was used to evaluate geochemical mass-balance reactions in the Little Lost River basin. The two most down-gradient wells, at Ruby farms and Mays, were much deeper than the other wells and it was concluded that those two wells probably represent eastern Snake River Plain aquifer water. Of all the sites sampled, only two upgradient wells were representative of the Little Lost River basin alluvial aquifer Mass-balance modeling of the system indicated that dissolution of dolomite is the major reaction taking place there. Nitrification of ammonium ion to nitrate and dissolution of inorganic fertilizers are chemical processes that also occur in the system. The study indicated that more samples would be needed to better represent the natural geochemistry of the Little Lost River basin.

DOE/ID-22180 Tritium in flow from selected springs that discharge to the Snake River, Twin Falls-Hagerman area, Idaho 1994-99, OFR-02-185, by Brian V. Twining, 2002, 12 p. From 1994-99, the USGS collected samples for tritium analyses from 19 springs along the north side of the Snake River near Twins Falls and Hagerman, Idaho, to address public concern over migration of tritium from the INL. This study publishes new results from a long-term study that started in 1990. Concentrations of tritium ranged from 6.5+/-0.6 to 65.0+/-4.5 picocuries per liter (pCi/L) during 1994-99, and mean concentrations measured from 1990 through 1999 in selected springs showed decreasing trends in tritium values, which is likely the result of natural radioactive decay.

DOE/ID-22181 Estimating the magnitude of the 100-year peak flow in the Big Lost River at the Idaho National Engineering and Environmental Laboratory, Idaho, WRIR 02-4299, by Jon E. Hortness and Joseph P. Rousseau, 2003, 36 p. This study assessed the effects of flooding on INL facilities and attempted to better define a large difference of 4,350 cubic feet per second (ft^3/s) in the peak flows estimated in two previous studies. Regression models were used to compare annual peak flows, and the attenuation of annual peak flows between successive stream-gaging stations for the same flow event were used to estimate the magnitude of the 100-year peak flow in the Big Lost River. The 100-year peak flow of 4,790 ft^3/s at the Howell Ranch gaging station was used as a starting point. Analyses of flow in the Big Lost River immediately upstream of the diversion dam indicated a peak flow of 3,750 ft^3/s, with upper and lower 95% confidence limits of 6,250 ft^3/s and 1,300 ft^3/s, respectively. The study concluded the high intensity, localized rainfall was not likely to produce large peak flows at the INL because of high loss rates from infiltration, bank storage, and channel storage along much of the stream channel. The study also considered the effect of the magnitude 7.3 Borah peak earthquake in 1983 with a joint occurrence of a 100-year peak flow and determined the joint occurrence could significantly increase the magnitude of the peak flow.

DOE/ID-22182 Field methods and quality-assurance plan for quality-of-water activities, U.S. Geological Survey, Idaho National Engineering and Environmental Laboratory, Idaho, OFR 03-42, by Roy C. Bartholomay, LeRoy L. Knobel, and Joseph P. Rousseau, 2003, 45 p. This report is the fourth update of the INL Projects' quality-assurance plan. The report outlines responsibilities of the USGS - INL Project Office Staff in maintaining and improving the quality of technical products and providing a formal standardization, documentation, and review of activities that lead to these products. Data-quality objectives, methods for the collection, handling, and analysis of water samples, review of analyses, performance audits, corrective actions, information on water-quality sampling schedules, and water-quality field equipment are listed. A table on analytical methods used by the Severn Trent Laboratories, which is the lab used for Naval Reactor Facility analyses at the time of the study, is presented. The introduction of the sampler auditor checklist is given as an attachment at the end of the document. Annual field audits of the USGS INL staff that collect water quality samples started to occur around the 2001 timeframe.

DOE/ID-22183 Measurement of sedimentary interbed hydraulic properties and their hydrologic influence near the Idaho Nuclear Technology and Engineering Center at the Idaho National Engineering and Environmental Laboratory, WRIR 03-4048, by Kim S. Perkins, 2003, 19 p. This study examined the hydraulic properties of sedimentary interbeds below the two new percolation ponds near the INTEC at the Vadose Zone Research Park. Hydraulic properties, including saturated and unsaturated hydraulic conductivity and water retention, were measured on 12 cores recovered from 2 interbeds from borehole ICPP-SCI-V-215 near INTEC. The two interbeds have saturated hydraulic conductivity values that range over four orders of magnitude, from 1.42 x 10^{-03} (centimeters per second (cm/s) for loamy sand to 1.66 x 10^{-07} cm/s for silt loam. The upper interbed exhibits hydraulic properties consistent with higher clay contents than those of the lower interbed and contains low permeability layers that could enhance perching of groundwater. The two sedimentary interbeds are separated by a relatively thin basalt flow that exhibits distinctly different baked-zone features. The baked zone of the upper interbed is macroporous, containing highly cemented aggregates, whereas the baked zone of the lower interbed contains highly oxidized, mainly unconsolidated sand. The baked-zone sediments from both interbeds, although texturally and structurally different, have comparable, relatively high saturated hydraulic conductivities. In order to quantify the effect of the microporous structure of the baked material in the upper interbed, water retention was measured on 2 undisturbed cores in addition to the 12 cores used for hydraulic property measurements. The calculated distributions indicated a decrease in the mean pore size and a narrower range of grain sizes in the repacked samples, which resulted in the steepening of the drainage retention curve. The results of the study reiterated the need for analysis of additional samples from various locations and interbeds across the INL.

DOE/ID-22184 Stage-discharge relations for selected culverts and bridges in the Big Lost River flood plain at the Idaho National Engineering and Environmental Laboratory, Idaho, WRIR 03-4066, by Charles Berenbrock and Jack D. Doyle, 2003, 62 p. This study was done to determine the extent and severity of flooding at INL facilities along the Big Lost River. Two computer programs-the Culvert Analysis Program (CAP) and the HEC-RAS model-were used to define stage-discharge relations for 31 culverts and 2 bridge sites in a 10-mile reach of the river, from the INL diversion dam to 1 mile downstream of INTEC. The relations can be used to improve surface-water-flow models to evaluate potential flooding. Discharge through culverts ranged from zero to as much as could be conveyed. Discharge through bridges ranged from 0 to 7,000 cubic feet per second. Tailwater elevations ranged from 0 to 30 feet for both culverts and bridges. More than 40 pages of data are presented in the appendixes of the paper. Stage-discharge relations can be incorporated into the numerical surface-water-flow models to simulate the effects of the structures on flood flows. One limitation of the models is that changes in flow conditions, such as obstruction by sediment or debris, are not simulated.

DOE/ID-22185 Radiochemical and chemical constituents in water from selected wells and springs from the southern boundary of the Idaho National Engineering and Environmental Laboratory to the Hagerman Area, Idaho, 2001, OFR 03-168, by Brian V. Twining, Gordon Rattray, and Linford J. Campbell, 2003, 32 p. This report presents results from the collection of groundwater samples from 16 sites in the Twin Falls-Hagerman study area in 2001 as part of the 5th round of sampling of these sites. along with two quality assurance samples. Two sample sites were discontinued from the program. Water samples were analyzed for selected radionuclides, trace elements, common ions, nutrients, purgeable organic compounds and pesticides. Additionally, results of the analyses of tritium in samples from 19 springs were presented along with analyses of 2 quality-assurance samples. These tritium analyses represented the last year of the tritium springs sampling study. Results showed similar concentrations to in previous sample periods: no significant concentrations were detected. The tritium sampling was discontinued because of budget reductions to the USGS INL Project Office program.

DOE/ID-22186 Reevaluation of background iodine-129 concentrations in water from the Snake River Plain aquifer, Idaho, WRIR 03-4106, by L. Dewayne Cecil, L. Flint Hall, and Jaromy R. Green, 2003, 18 p. The background concentrations of iodine-129 in the Snake River Plain aquifer were reevaluated on the basis of analyses of 52 groundwater and surface water samples collected from the eastern Snake River Plain. The background concentration estimate, using the results of a subset of 30 groundwater samples. is 5.4 attocuries per liter (aCi/L), and the 95-percent nonparametric confidence interval is 5.2–10 aCi/L. The background concentration determined in a previous study was less than or equal to 8.2 aCi/L.

DOE/ID-22187 Spatial variability of sedimentary interbed properties near the Idaho Nuclear Technology and Engineering Center at the Idaho National Engineering and Environmental Laboratory, Idaho, WRIR-4142, by Kari A. Winfield, 2003, 36 p. As part of the characterization of the subsurface and the perching mechanisms below the Vadose Zone Research Park (VZRP), unsaturated and saturated properties, including particle size, bulk density, particle density, and specific surface area, were determined for material from the same depth intervals as the core samples, with an additional 66 particle-size distributions measured on bulk samples from the same boreholes. Three relatively thick interbeds (in places 10 meters [m] thick) were identified at depths of 35, 45, and 55 m below land surface. The 35-m interbed is uniform in texture and extends from the Big Lost River to the new percolation ponds. The 45-m interbed coarsens upward, and the 55-m interbed contains alternating coarse and fine layers. Seventy-one of the 90 samples collected were silt loams. The coarsest samples were within the 45-m and 55-m thick interbeds of borehole ICPP-SCI-V-215, near the southeast corner of the new percolation ponds. Baked zones were at the top of some intervals, and the average geometric mean particle diameter of baked-zone intervals was only slightly coarser, in some cases, than the underlying non-baked sediment. The hydraulic properties in core samples from baked zones within the different interbeds did not show effects from alteration caused during basalt deposition but differed mainly by texture. Saturate hydraulic conductivities for 10 core samples ranged from 10^{-7} to 10^{-4} cm/s. Low- permeability layers within the 35-m and 45-m interbeds may cause perched groundwater zones to form beneath the new percolation pond area, leading to possibly lateral movement of water away from the VZRP.

DOE/ID-22188 Geochemistry of the Birch Creek Drainage Basin, Idaho, WRIR 03-4272, by Shawn A. Swanson, Jeffrey J. Rosentreter, Roy C. Bartholomay and LeRoy L. Knobel, 2003, 36 p. The purpose of this study was to better define the chemical character of water coming out of the Birch Creek basin, both from the surface and as underflow, to be used as a source input to understand the geochemistry at the INL. During 2000, water samples were collected from five wells and one surface-water site in the Birch Creek drainage basin and analyzed for selected inorganic constituents, nutrients, dissolved organic carbon, tritium, measurements of gross alpha and beta radioactivity, and stable isotopes. Four duplicate samples were collected for quality assurance. Results, which include Analytical results, including those for previously collected samples from four other sites in the basin, show that most water from the Birch Creek drainage has a calcium-magnesium bicarbonate character. The study concluded that the Birch Creek valley can be divided into three hydrologic areas. In the northern part, groundwater is forced to the surface by a basalt barrier, and the sampling sites were either surface water or shallow wells. The water chemistry in this area was characterized by simple evaporative models, simple calcite-carbon dioxide models, or complex models involving carbonate and silicate minerals. The central part of the study area is filled by sedimentary material and the sampling sites were wells that were deeper than those in the northern part. Water chemistry is characterized by calcite-dolomite-carbon dioxide models. In the southern part of the drainage basin, the groundwater enters the eastern Snake River Plain aquifer, and the wells were much deeper than in the other two areas of the study. The calcium and carbon water chemistry in this area was characterized by a simple calcite-carbon dioxide model, but calcite-silicate models more accurately accounted for mass transfer here. The study concluded that the water chemistry in well USGS 126B best represents the chemistry of water recharging the eastern Snake River Plain aquifer by means of underflow from the Birch Creek drainage basin.

DOE/ID-22189 Paleomagnetism of basaltic lava flows in coreholes ICPP-213, ICPP-214, ICPP-215, and USGS 128 near the Vadose Zone Research Park, Idaho Nuclear Technology and Engineering Center, Idaho National Engineering and Environmental Laboratory, Idaho, OFR 03-483, by Duane E. Champion and Theodore C. Herman, 2003, 15 p. This study presented paleomagnetic analyses on basalt from 41 lava flows represented in about 2,300 feet of core from coreholes ICPP-213, ICPP-214, ICPP-215, and USGS 128. These wells are near the Idaho Nuclear Technology and Engineering Center Vadose Zone Research Park at the INL. Measurements were made on 508 samples and are compared between wells and to surface outcrops of basalt in the study area. In general, sub-horizontal lines of correlation can be drawn (?) between sediment layers and between basalt layers in the area of the new percolation ponds. Some of the flows and flow sequences are strongly correlative at different depths and represent good stratigraphic markers. This study showed that a more distant correlation of more than a mile to well USGS 128 is possible for several of the basalt flows, especially at greater depth. This study marked the transition in the INL program from using geophysical logs to correlate basalt flows to using paleomagnetic analyses.

DOE/ID-22190 Radiochemical and chemical constituents in water from selected wells and springs from the southern boundary of the Idaho National Engineering and Environmental Laboratory to the Hagerman area, Idaho, 2002, OFR 2004-1004, by Gordon W. Rattray and Linford J. Campbell, 2004, 22 p. This report presents results from the 2002 collection of samples from wells and springs at 17 sites in the Twin Falls-Hagerman study area as part of the 6th round of sampling along with one quality assurance replicate sample. Water samples were analyzed for selected radionuclides, trace elements, common ions, nutrients, purgeable organic compounds and pesticides. Statistical analyses of replicate pairs indicated 132 of the 135 constituent concentrations were equivalent. Analytical results showed similar concentrations to previous sample periods and no significant concentrations were detected.

DOE/ID-22191 Development of a local meteoric water line for Southeastern Idaho, Western Wyoming, and South-central Montana, Scientific Investigations Report (SIR) 2004-5126, by Lyn Benjamin, LeRoy L. Knobel, L. Flint Hall, L. DeWayne Cecil, and Jaromy R. Green, 2005, 17 p. This study used linear regression analysis on stable hydrogen (H) and oxygen (O) isotope data from 68 snow-core and precipitation samples collected during 1999-2001 to determine the Local Meteoric Water Line (LMWL) for southeastern Idaho, western Wyoming, and south-central Montana. Regression analysis of the isotope data for the samples yielded a LMWL defined by the equation $\delta 2H = 7.95\ \delta 18O + 8.09$ ($r2 = 0.98$). This equation will be useful as a reference for future studies in this area that use stable isotopes of H and O to determine sources of groundwater recharge, to determine water-mineral exchange, to evaluate surface-water and groundwater interaction, and to analyze other geochemical and hydrologic issues.

DOE/ID-22192 Review of the transport of selected radionuclides in the interim risk assessment for the Radioactive Waste Management Complex, Waste Area Group 7 Operable Unit 7-13/14, Idaho National Engineering and Environmental Laboratory, Idaho, Volume 1, SIR 2005-5026, by Joseph P. Rousseau, Edward R. Landa, John R. Nimmo, L. DeWayne Cecil, LeRoy L. Knobel, Pierre D. Glynn, Edward M. Kwicklis, Gary P. Curtis, Kenneth G. Stollenwerk, Steven R. Anderson, Roy C. Bartholomay, Clifford R. Bossong, and Brennon R. Orr, vol I, 211 p. vol II, 2005, 72 p. This study presents results from the USGS's independent technical review of the Interim Risk Assessment and Contaminant Screening for the Waste Area Group 7 Remedial Investigation. The review assessed the data and geotechnical approaches that were used to estimate future risks associated with the release of the actinides americium, uranium, neptunium, and plutonium to the Snake River Plain aquifer from wastes buried in pits and trenches at the Subsurface Disposal Area (SDA) in the Radioactive Waste Management Complex at the INL. Five specific tasks were defined for the study: (1) to review the radionuclide sampling data to determine how reliable and significant are the reported radionuclide detections and how reliable is the ongoing sampling program, (2) to assess the physical and chemical processes that logically can be invoked to explain true detections, (3) to determine if distribution coefficients that were used in the IRA are reliable and if they have been applied properly, (4) to determine if transport model predictions are technically sound, and (5) to identify issues needing resolution to determine technical adequacy of the risk assessment analysis, and what additional work is required to resolve those issues. The reviewers indicated that some constituents, such as neptunium-137, should be added to the sample program and that uncertainties associated with radionuclide values should be rounded to appropriate significant figures. Better marking radionuclides in the INL database was another finding. The distribution coefficients used in the analyses had some limitations and the review team recommended that better distribution coefficient data are needed to justify predictions of contaminant transport. The review team feels that more rigorous definition of the hydrologic properties of the sedimentary interbeds and the actinide distribution coefficients associated with these geologic units are needed. Another finding was the considerable uncertainty over how the exclusion of lateral flow of water from outside the SDA affects actinide predictions. Lateral migration from the Big Lost River in the spreading areas needs to be incorporated into future flow and transport modeling to improve the technical defensibility.

DOE/ID-22193 Radiochemical and chemical constituents in water from selected wells and springs from the southern boundary of the Idaho National Laboratory to the Hagerman area, Idaho, 2003, OFR 2005-1125 version 2.1, by Gordon W. Rattray, Amy J. Wehnke, L. Flint Hall, and Linford J. Campbell, 2005, 32 p. This report presents results from the 2003 sampling of 14 sites in the Twin Falls-Hagerman study area as part of the 6th round of sampling along with two quality assurance replicate samples. Water samples were analyzed for selected radionuclides, trace elements, common ions, nutrients, purgeable organic compounds and pesticides. The number of sampling sites was reduced because of budget considerations for the program; 2003 was the last year the USGS was involved with this sampling program, but the Idaho Department of Environmental Quality's INL oversight program has continued the program. Statistical analyses of the data for replicate pairs of samples indicated 267 of the 270 constituent concentrations were equivalent. Results showed similar concentrations to those for previous sample periods. One significant result was that the concentration of nitrate in the sample from site MV-43 was 20 mg/L, which exceeds the maximum contaminant level for public drinking water of 10 mg/L for that constituent.

DOE/ID-22194 Hydraulic characteristics of bedrock constrictions and an evaluation of one- and two-dimensional models of flood flow on the Big Lost River at the Idaho National Engineering and Environmental Laboratory, Idaho, SIR 2007-5080, by Charles Berenbrock, Joseph P. Rousseau, and Brian V. Twining, 2007, 208 p. This study examined the 1.9-mile reach of the Big Lost River between the diversion dam and the Pioneer Diversion structures to evaluate the effects of streambed erosion and bedrock constrictions on model predictions of water-surface elevations. A fixed-bed surface-water flow model (HEC-RAS) and a moveable-bed surface-water flow and sediment-transport model (HEC-6), were used to evaluate these effects. The results of simulations made with these models were compared to the results of a two-dimensional (TRIM2-D) fixed-bed model that had been previously used to predict water-surface elevations for peak flows with sufficient stage and stream power to erode floodplain terrain features dated at 300 and 500 years old, and an unmodified Pleistocene surface dated at 10,000 years old; and to extend the period of record at the Big Lost River gaging station near Arco for flood-frequency analyses. The extended record was used to estimate the magnitude of the 100-year recurrence interval flood and the magnitude of floods with return periods as long as 10,000 years. Results showed that in most cases the TRIM2-D model simulated higher water-surface elevations, shallower flow depths, higher flow velocities and higher stream powers than the two 1-D models for the same peak flows. A field survey of the 1.9-mile saddle area indicated that the elevation of the lowest point on the saddle area was 1.2 ft higher than indicated on the 2-ft contour map that was used in the TRIM2D model. Because of this elevation discrepancy, HEC-RAS model simulations indicated that a peak flow of at least 210 m^3/s would be needed to initiate flow across the 10,000-year-old Pleistocene surface. The differences in simulated water-surface elevations between the 3 models are attributed primarily to differences in topographic relief and to differences in the channel and floodplain geometries used in these models.

DOE/ID-22195 Historical development of the U.S. Geological Survey hydrologic monitoring and investigative program, Idaho National Engineering and Environmental Laboratory, Idaho, 1949–2001, OFR 2005-1223, by LeRoy L.

Knobel, Roy C. Bartholomay, and Joseph P. Rousseau, 2005, 93 p. This report is a summary of the historical development, from 1949 to 2001, of the U.S. Geological Survey's (USGS) hydrologic monitoring and investigative programs at the INL. The report covers the USGS's water-level monitoring program, water-quality sampling program, geophysical program, geologic framework program, drilling program, modeling program, surface-water program, and unsaturated-zone program. The report provides physical information about the wells and information about the frequencies of sampling and measurement. Summaries of USGS published reports listed by U.S. Department of Energy (DOE) report numbers also are provided in an appendix. This report, which covers the period 1949 to 2001, is the precursor to this current report, which covers USGS activities at INL from 2002 through 2020.

DOE/ID-22196 Development of property-transfer models for estimating the hydraulic properties of deep sediments at the Idaho National Engineering and Environmental Laboratory, Idaho, SIR 2005-5114, by Kari A. Winfield, 2005, 49 p. Values for hydraulic properties of sediments were developed from easily measured bulk-physical properties for deep interbeds at the INL. Determining the hydraulic properties of the unsaturated zone is one step in understanding water flow and unsaturated flow processes through the complex system. Multiple linear regression was used to construct the property-transfer models for estimating the water-retention curve and the saturated hydraulic conductivity of the deep sedimentary interbeds. The models were developed from laboratory measurements of hydraulic and bulk-physical properties for 109 core sample subsets. The samples were collected from depths of 9 to 175 meters in cores from near RWMC and the INTEC Vadose Zone Research Park. Four regression models were developed using bulk-physical property measurements (bulk density, particle density, and particle size) as the potential explanatory variables. Comparison of root-mean-square-error distributions for each alternative particle-size model showed that the estimated water-retention curves were insensitive to the way the particle size distribution was represented. Bulk density, the median particle diameter, and the uniformity coefficient were chosen as input parameters for the final models. The property-transfer models developed in this study allow easy determination of hydraulic properties without need for their direct measurement. Additionally, the models provide the basis for development of theoretical models that rely on physical relations between the pore-size distribution and the bulk-physical properties of the media. With this adaptation, the property-transfer models should have greater application throughout the Idaho National Engineering and Environmental Laboratory and other geographic locations.

DOE/ID-22197 An update of hydrologic conditions and distribution of selected constituents in water, Snake River Plain Aquifer, Idaho National Laboratory, Idaho, Emphasis 1999-2001, SIR 2006-5088, by Linda C. Davis, 2006, 48 p. This is the 10th in the series of reports covering the effects of waste disposal on the distribution of constituents in the eastern Snake River Plain aquifer. The report presents an analysis of water-level and water-quality data collected from 1999 through 2001. Water levels in wells rose in the northern and west-central parts of the INL by 1–3 feet and declined in the southwestern parts of the INL by up to 4 feet during 1999–2001. Detectable concentrations of radiochemical constituents in water samples from wells in the Snake River Plain aquifer at the INL generally decreased or remained constant during this same period. Tritium concentrations decreased as much as 8.3 pCi/mL during 1999-2001, ranging from 0.43+/-0.14 to 13.6+/-0.6 pCi/mL in October 2001. Strontium-90 concentrations decreased or remained constant, ranging from 2.1 +/-0.6 to 42.4 +/-1.4 pCi/L. Concentrations of Cesium-137 and plutonium were less than the reporting level in samples from all wells. The concentration of americium-241 in one of the samples collected from RWMC Production wells was 0.003+/-0.001p/Ci/L; concentrations in other samples were all less than the reporting level. Chromium in well USGS 65 decreased from 168 micrograms per liter (µg/L) in 1998 to 139 µg/L in 2001, but still was greater than the maximum contaminant level of 100 µg/L. Analyses of the samples for most of the other chemical constituents also showed declining concentrations. The concentration of carbon tetrachloride in the RWMC Production well continued to show an upward trend, but the concentration in October 2001 was less than the concentration in October 1998.

DOE/ID-22198 A conceptual model of groundwater flow in the eastern Snake River Plain aquifer at the Idaho National Laboratory and vicinity with implications for contaminant transport, SIR 2006-5122, by Daniel J. Ackerman, Gordon W. Rattray, Joseph P. Rousseau, Linda C. Davis, and Brennon R. Orr, 2006, 62 p. A conceptual model of groundwater flow in west-central part of the INL was developed to simulate and evaluate contaminant transport at the INL and vicinity. The model domain encompasses about 1,940 square miles of the eastern Snake River Plain. Three hydrologic units were used to define the complex stratigraphy, which consisted of at least 65 basalt-flow groups, 5 andesite-flow groups, and 61 sedimentary interbeds. Younger rocks, primarily thin, densely fractured basalt, compose hydrogeologic unit 1; younger rocks, primarily of massive, less densely fractured basalt, compose hydrogeologic unit 2; and intermediate-age rocks, primarily of slightly-to-moderately altered, fractured basalt, compose hydrogeologic unit 3. Differences in hydraulic properties among adjacent hydrogeologic units result in much of the large-scale heterogeneity and anisotropy of the aquifer in the model area, and differences in horizontal and vertical hydraulic conductivity in individual hydrogeologic units result in much of the small-scale heterogeneity and anisotropy of the aquifer in the model area. The geometry of the aquifer over the model area is highly irregular. Its thickness increases from north to south, and older rocks that underlie the aquifer indicates large changes in saturated thickness.

Physical boundaries of the model include the water table, the base of the aquifer, and the northwest mountain front. Artificial boundaries include the northeast boundary, southeast-flowline boundary, and southwest boundary. Water flows into the model area as (1) underflow (1,225 cubic feet per second [ft^3/s]) from the regional aquifer (northeast boundary—constant and nonuniform), (2) underflow (695 ft^3/s) from the tributary valleys and mountain fronts (northwest boundary—constant and nonuniform), (3) precipitation recharge (70 ft^3/s) (constant and uniform), (4) streamflow-infiltration recharge (95 ft^3/s) (variable and nonuniform), (5) wastewater return flows (6 ft^3/s) (variable and nonuniform), (6) irrigation-infiltration recharge (24 ft^3/s) (variable and nonuniform) across the water table (water-table boundary—variable and nonuniform), and (7) upward flow across the base of the aquifer (44 ft^3/s) (uniform and constant). The southeast-flowline boundary is represented as a no-flow boundary. Water flows out of the model area as underflow (2,037 ft^3/s) to the regional aquifer (southwest boundary—variable and nonuniform) and as groundwater withdrawals (45 ft^3/s) (water table boundary—variable and nonuniform).

Groundwater flow increases progressively in a direction downgradient of the northeast boundary. This increased flow is the result of tributary-valley and mountain-front underflows along the northwest boundary and precipitation recharge and streamflow-infiltration recharge across the water-table boundary. Groundwater flows in all three hydrogeologic units beneath the INL. South of the INL, the younger rocks, hydrogeologic units 1 and 2, are either not present or are above the water table, and all flow occurs through the intermediate-age rocks, hydrogeologic unit 3.

Long-term monitoring of contaminant movement in the aquifer at the INL indicates that groundwater velocities in the thin, fractured basalts of hydrogeologic unit 1, the uppermost hydrogeologic unit of the aquifer, range from 4 to 20 feet per day (ft/d) south of the Test Reactor Area and the Idaho Nuclear Technology and Engineering Center. These velocities probably indicate preferential flow along the many interflow zones of the thin, fractured basalt flows composing the uppermost hydrogeologic unit. Hydraulic conductivities (500–5,000 ft/d) estimated from velocity measurements were consistent with those derived from aquifer tests conducted in this hydrogeologic unit. Almost two-thirds of the hydraulic conductivity values derived from aquifer-test measurements in hydrogeologic unit 1 were larger than 100 ft/d and about one-third were larger than 1,000 ft/d. The first indications of contaminants moving downward near the southern boundary of the site are introduced in this report.

DOE/ID-22199 An update of the distribution of selected radiochemical and chemical constituents in perched groundwater, Idaho National Laboratory, Idaho, Emphasis 1999-2001, SIR 2006-5236, by Linda C. Davis, 2006, 48 p. This report is the companion to the update of the hydrologic conditions of the aquifer and was the fifth report published on just the perched aquifer systems at the INL; the report presents a compilation of data collected between 1999 and 2001. At the Reactor Technology Complex (RTC), tritium, strontium-90, cesium-137, dissolved chromium, chloride, sodium, and sulfate were monitored in shallow and deep perched groundwater. In samples of deep perched groundwater, tritium concentrations generally decreased or varied randomly during 1999–2001. During October 2001, tritium concentrations ranged from less than the reporting level to 39.4±1.4 picocuries per milliliter (pCi/mL). Strontium-90 (Sr-90) concentrations in water samples from wells completed in deep perched groundwater at the RTC varied randomly with time. During October 2001, concentrations of Sr-90 in water from five wells exceeded the reporting level and ranged from 2.8±0.7 picocuries per liter (pCi/L) in well USGS 63 to 83.8±2.1 pCi/L in well USGS 54. No reportable concentrations of cesium-137, chromium-51, or cobalt-60 were present in water samples from any of the shallow or deep wells at the RTC during 1999–2001. Concentrations of dissolved chromium during July–October 2001 in deep perched groundwater near the RTC ranged from 10 micrograms per liter (µg/L) in well USGS 61 to 82 µg/L in well USGS 55. The largest concentrations were in water from wells north and west of the radioactive-waste infiltration ponds. During July–October 2001, dissolved sodium concentrations ranged from 7 milligrams per liter (mg/L) in well USGS 78 to 20 mg/L in all wells except well USGS 68 (413 mg/L). Dissolved chloride concentrations in deep perched groundwater ranged from 5 mg/L in well USGS 78 to 91 mg/L in well USGS 73. The maximum dissolved sulfate concentration in shallow perched groundwater was 419 mg/L in well CWP 1 during July 2000. Concentrations of dissolved sulfate in water from wells USGS 54, 60, 63, 69, and PW 8, completed in deep perched groundwater near the cold-waste ponds, ranged from 115 to 285 mg/L in July–October 2001. The maximum concentration of dissolved sulfate in water during July–October 2001 was 1,409 mg/L in well USGS 68 west of the chemical-waste pond.

At the INTEC, tritium, strontium-90, cesium-137, dissolved sodium, chloride, sulfate, and nitrite plus nitrate (as nitrogen) were monitored in shallow and deep perched groundwater. The tritium concentration in water from wells completed in deep perched groundwater beneath the infiltration ponds ranged from less than the reporting level in wells PW 1 and PW 5 to 9.7±0.5 pCi/mL in well PW 6. Dissolved sodium, chloride, and sulfate concentrations in shallow and deep perched groundwater at the INTEC infiltration ponds during 1999–2001 were similar to or less than the average annual effluent monitoring data.

At the RWMC, tritium, strontium-90, cesium-137, plutonium-238, plutonium-239, -240 (undivided), americium-241, dissolved chloride, and a suite of volatile organic compounds were monitored in deep perched groundwater at well USGS 92. Samples contained concentrations greater than the minimum reporting levels of 15 volatile organic compounds.

DOE/ID-22200 Evaluation of well-purging effects on water-quality results for samples collected from the eastern Snake River Plain aquifer underlying the Idaho National Laboratory, Idaho, SIR 2006-5232, by LeRoy L Knobel, 2006, 58 p. This report presents qualitative and quantitative comparisons of water-quality data from the Idaho National Laboratory to determine if the change from purging three wellbore volumes to purging of only one wellbore volume prior to collection of water samples for analysis has a discernible effect on the comparability of the data. Historical chemical analysis data for 30 wells were visually compared to the analytical data for samples collected after purging only 1 wellbore volume from the same wells. Of the 322 qualitatively examined constituent plots, 97.5 percent met 1 or more of the criteria established for determining data comparability. A simple statistical equation used to determine if water-quality data collected from 28 wells at the INL with long purge times (after pumping 1 and 3 wellbore volumes of water) were statistically the same at the 95-percent confidence level, indicated that 97.9 percent of 379 constituent pairs were equivalent.

Comparability of the analytical data for samples from both the qualitative (97.5 percent comparable) and quantitative (97.9 percent comparable) evaluations after purging 1 and 3 wellbore volumes of water indicates that the reductions in purging volume had no discernible effect on comparability of water-quality data at the INL. The qualitative evaluation was limited, however, because only October-November 2003 data were available for comparison to historical data.

DOE/ID-22201 Geostatistical modeling of sediment abundance in a heterogeneous basalt aquifer at the Idaho National Laboratory, Idaho, SIR 2006-5316, by John A. Welhan, Renee L. Farabaugh, Melissa J. Merrick, and Steven R. Anderson, 2006, 32 p. The spatial distribution of sediment in the eastern Snake River Plain aquifer was evaluated and modeled to improve the parameterization of hydraulic conductivity (K) for the USGS subregional-scale groundwater- flow model being developed for the INL. The sediments have K values as much as six orders of magnitude lower than the most permeable basalt, and previous flow-model calibrations have shown that hydraulic conductivity is sensitive to the proportion of intercalated sediment. Stratigraphic data in the form of sediment thicknesses from 333 boreholes in and around the Idaho National Laboratory were evaluated as grouped subsets of lithologic units (composite units) corresponding to their relative time-stratigraphic position. That evaluation indicated that median sediment abundances of the stratigraphic units below the water table are statistically invariant (stationary) in a spatial sense and provide evidence of stationarity across geologic time as well. On the basis of these results, the borehole data were kriged as two-dimensional spatial datasets representing the sediment content of the layers that discretize the groundwater-flow model in the uppermost 300 feet of the aquifer. Multiple- indicator kriging was used to model the geographic distribution of median sediment abundance within each layer by defining the local cumulative frequency distribution (CFD) of sediment via indicator variograms defined at multiple thresholds. A methodology is proposed for delineating and constraining the assignment of hydraulic conductivity zones for parameter estimation, based on the locally estimated CFDs and relative kriging uncertainty. A kriging-based methodology improves the spatial resolution of hydraulic property zones that can be considered during parameter estimation and should improve calibration performance and sensitivity by more accurately reflecting the nuances of sediment distribution within the aquifer.

DOE/ID 22202 Property-transfer modeling to estimate unsaturated hydraulic conductivity of deep sediments at the Idaho National Laboratory, Idaho, SIR 2007-5093, by Kim S. Perkins and Kari A Winfield, 22. The results of this study improved understanding of the highly nonlinear relation between water content and hydraulic conductivity within the sedimentary interbeds to better predict water flow and solute transport processes at the INL. A capillary bundle model was used to estimate unsaturated hydraulic conductivity values for 40 samples from sedimentary interbeds using water-retention parameters and saturated hydraulic conductivity values derived from (1) laboratory measurements on core samples, and (2) site-specific property transfer regression models developed for the sedimentary interbeds. Four regression models were previously developed using bulk-physical property measurements (bulk density, the median particle diameter, and the uniformity coefficient) as the explanatory variables. The response variables, estimated from linear combinations of the bulk physical properties, included saturated hydraulic conductivity values and three parameters that define the water-retention curve.

The degree to which the unsaturated hydraulic conductivity curves estimated from property-transfer-modeled water-retention parameters and saturated hydraulic conductivity approximated the laboratory-measured data was evaluated using a goodness-of-fit indicator, the root-mean-square error. Because numerical models of variably saturated flow and transport require parameterized hydraulic properties as input, simulations were run to evaluate the effect of the various parameters on model results. Results show that the property transfer models based on easily measured bulk properties perform nearly as well as curves fit to laboratory-measured water retention for the estimation of unsaturated hydraulic conductivity.

DOE/ID-22203 An update of hydrologic conditions and distribution of selected constituents in water, Snake River Plain aquifer and perched-water zones, Idaho National Laboratory, Idaho, emphasis 2002-05, SIR 2008-5089, by Linda C. Davis, 2008, 74 p. This report is the eleventh in the series of hydrologic conditions reports and focuses on water-level and water-quality data from 2002 through 2005 from both the aquifer and the perched groundwater zones at the INL. Water levels in wells declined throughout the INL area, with declines of 3–8 ft in the southwestern part of the INL, about 10–15 feet in the west central part of the INL, and about 6–11 ft in the northern part of the INL. Water levels also declined in most of the perched zones, with some water levels declining below pumps. In October 2005, reportable concentrations of tritium in groundwater ranged from 0.51±0.12 to 11.5±0.6 picocuries per milliliter, and the tritium plume extended south southwestward in the general direction of groundwater flow. Tritium concentrations in water from several wells southwest of the Idaho Nuclear Technology and

Engineering Center (INTEC) decreased or remained constant as they had during 1998–2001, except for concentrations in well USGS 47, which increased a few picocuries per milliliter. Most wells completed in shallow perched groundwater at the Reactor Technology Complex (RTC) were dry during 2002–05. The tritium concentration in water from one deep perched water well exceeded the reporting level at the INTEC. Concentrations of strontium-90 in water from 14 of 34 wells sampled during October 2005 exceeded the reporting level and ranged from 2.2±0.7 to 33.1±1.2 picocuries per liter. During 2002–05, concentrations of plutonium-238, and plutonium-239, -240 (undivided), americium-241 and cesium-137 were less than the reporting level in water from all wells sampled at the INL.

In April 2005, water from well USGS 65, south of the RTC, contained 100 micrograms per liter (µg/L) of chromium, a decrease from the concentration of 139 µg/L detected in October 2001. During 2002–05, the largest concentration of sodium in water samples collected from wells at the INL was 76 milligrams per liter (mg/L), in a sample from well USGS 113, south of INTEC. During April–October 2005, chloride concentrations in shallow perched water from three wells at the RTC ranged from 10 to 32 mg/L, and from 3 to 35 mg/L in deep perched groundwater. At the INTEC, dissolved chloride concentrations in deep perched water in wells closest to the percolation ponds ranged from 118 to 332 mg/L. In 2005, sulfate concentrations in water from wells USGS 34, 35, and 39, southwest of INTEC, were 42, 46, and 46 mg/L, respectively. The maximum sulfate concentration in water from wells completed in shallow perched water at the RTC was 396 mg/L. During April–October 2005, concentrations of dissolved sulfate in water from wells completed in deep perched water at the RTC ranged from 66 to 276 mg/L. In October 2005, concentrations of nitrate in water from wells USGS 41, 43, 45, 47, 52, 57, 67, 77, 112, 114, and 115 near the INTEC, exceeded the regional background of 5 mg/L (as nitrate) and concentrations ranged from 6 mg/L in well USGS 45 to 34 mg/L in well USGS 43. During 2002–05, 12 volatile organic compounds (VOCs) were detected in water from wells at the INL. Concentrations of from 1 to 9 VOCs were detected in water samples from 13 wells. The principal VOCs detected included carbon tetrachloride, chloroform, 1,1-dichloroethane, 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene.

DOE/ID-22204 Statistical stationarity of sediment interbed thicknesses in a basalt aquifer, Idaho National Laboratory, eastern Snake River Plain, Idaho, SIR 2008-5167, by Caleb N. Stroup, John A. Welhan, and Linda C. Davis, 2008, 20 p. The statistical stationarity of distributions of sedimentary interbed thicknesses within the southwestern part of the Idaho National Laboratory (INL) was evaluated within the stratigraphic framework of Quaternary sediments and basalts. The thicknesses of 122 sedimentary interbeds observed in 11 coreholes were documented from lithologic logs and independently inferred from natural-gamma logs. Lithologic information was grouped into composite time-stratigraphic units based on correlations with existing composite-unit stratigraphy near these holes. The assignment of lithologic units to an existing chronostratigraphy on the basis of nearby composite stratigraphic units may introduce error where correlations with nearby holes are ambiguous or the distance between holes is great, but this technique was considered the best technique for grouping stratigraphic information at the INL at the time.

Nonparametric tests of similarity were used to evaluate temporal and spatial stationarity in the distributions of sediment thickness. Four statistical tests were applied to the data: (1) the Kolmogorov-Smirnov (K-S) two-sample test to compare distribution shape, (2) the Mann-Whitney (M-W) test for similarity of two medians, (3) the Kruskal-Wallis (K-W) test for similarity of multiple medians, and (4) Levene's (L) test for the similarity of two variances. Results of these analyses corroborate previous work that concluded the thickness distributions of Quaternary sedimentary interbeds are locally stationary in space and time. The dataset used in this study was relatively small, so the results presented should be considered preliminary, pending incorporation of data from more coreholes. Statistical tests also demonstrated that natural-gamma logs consistently fail to detect interbeds less than about 2–3 ft thick, although these interbeds are observable in lithologic logs. This finding should be taken into consideration when modeling aquifer lithology or hydraulic properties based on lithology.

DOE/ID-22205 Construction diagrams, geophysical logs, and lithologic descriptions for boreholes USGS 126a, 126b, 127, 128, 129, 130, 131, 132, 133, and 134, Idaho National Laboratory, Idaho, Data Series (DS) 350, by Brian V. Twining, Mary K.V. Hodges, and Stephanie Orr, 2008, 22 p. This report summarizes construction, geophysical, and lithologic data collected from ten USGS boreholes completed between 1999 and 2006 at the INL. Nine boreholes were continuously cored; USGS 126b had 5 ft of core. Completion depths range from 472 to 1,238 ft. Geophysical data were collected from each borehole, and those data are summarized in this report. Cores were photographed and digitally logged using commercially available software. Digital core logs are included in appendixes to this report. Borehole descriptions summarize location, completion date, and amount and type of core recovered.

DOE/ID-22206 Field methods and quality-assurance plan for quality-of-water activities, U.S. Geological Survey, Idaho National Laboratory, Idaho, OFR 2008-1165, by LeRoy L. Knobel, Betty J. Tucker, and Joseph P. Rousseau, 2008, 36 p. This report is the fifth revision that outlines responsibilities of the INL Project Office Staff in maintaining and improving the quality of technical products and providing a formal standardization, documentation, and review of activities that lead to these products. Data-quality objectives, methods for sample collection and preservation, review of analyses, performance audits, corrective actions, and information on sampling schedules and field equipment are listed. A table of data-quality objectives for TestAmerica Laboratories, the lab used for Naval Reactor Facility analyses at the time of the study, is presented.

DOE/ID-22207 Laboratory-measured and property-transfer modeled saturated hydraulic conductivity of the Snake River Plain aquifer sediments at the Idaho National Laboratory, Idaho, SIR 2008-5169, by Kim S. Perkins, 2008, 14 p. This study evaluates the nature of the sedimentary material within the Snake River Plain aquifer and tests the applicability of a site-specific property-transfer model developed for the sedimentary interbeds of the unsaturated zone to deeper sedimentary interbeds within the aquifer itself. The study was done to determine if values of hydraulic properties for the deep sediments could be improved for use in the groundwater-flow model. Saturated hydraulic conductivity (*Ksat*) was measured for 10 core samples from sedimentary interbeds within the Snake River Plain aquifer and estimated using the property-transfer model. The property-transfer model for predicting *Ksat* was previously developed using a multiple linear-regression technique with bulk physical-property measurements (bulk density [ρ*bulk*], the median particle diameter, and the uniformity coefficient) as the explanatory variables. The model systematically underestimates *Ksat*, typically by about a factor of 10, which likely is due to higher bulk-density values for the aquifer samples compared to the samples from the unsaturated zone upon which the model was developed. Linear relations between the logarithm of *Ksat* and ρ*bulk* also were explored for comparison. The data presented in this report provides information useful in refining understanding of the hydraulic influence of sediments in the current subregional scale groundwater-flow model either by scaling existing values for each of the three units in the model or by explicit incorporation of sedimentary units.

DOE/ID-22208 Iodine-129 in the Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho, 2003 and 2007, SIR 2009-5088, by Roy C. Bartholomay, 2009, 28 p. This study highlights results for periodic sampling at the INL for low-level iodine-129 concentrations. Samples for analysis of ^{129}I were collected in 2003 from 36 wells used to monitor the Snake River Plain aquifer, and from one well used to monitor a perched zone at the INTEC. Concentrations of ^{129}I in the samples ranged from 0.0000066 ± 0.0000002 to 0.72 ± 0.051 picocuries per liter (pCi/L). Many wells within a 3-mile radius of the INTEC showed decreases of as much as one order of magnitude in concentration from samples collected during 1990–91, and all the samples had concentrations less than the Environmental Protection Agency's Maximum Contaminant Level (MCL) of 1 pCi/L. The average concentration of ^{129}I in 19 wells sampled during both collection periods decreased from 0.975 pCi/L in 1990–91 to 0.249 pCi/L in 2003. These decreases are attributed to the discontinuation of disposal of ^{129}I in wastewater after 1988 and to dilution and dispersion in the aquifer.

Although water from wells sampled in 2003 near the INTEC showed decreases in concentrations of ^{129}I compared with concentrations in samples collected in 1990–91, some wells south and east of the Central Facilities Area, near the site boundary, and south of the INL showed slight increases in ^{129}I levels. These slight increases may be related to variable discharge rates of wastewater that eventually moved to these well locations as a mass of water from a particular disposal period.

In 2007, the USGS collected samples for analysis of ^{129}I from 36 wells that are used to monitor the aquifer south of INTEC and from 2 wells that are used to monitor perched water zones at INTEC. Concentrations of ^{129}I in the eastern Snake River Plain aquifer ranged from 0.000026 ± 0.000002 to 1.16 ± 0.04 pCi/L, and the concentration at one well exceeded the maximum contaminant level (1 pCi/L) for public drinking-water supplies. The average concentration of ^{129}I in 19 wells sampled in 2003 and 2007 did not differ; however, slight increases and decreases of concentrations in several areas around the INTEC were evident in the aquifer. The decreases are attributed to the discontinued disposal and to dilution and dispersion in the aquifer. The increases may be due to the movement into the aquifer of remnant perched water below the INTEC.

In 2007, the USGS also collected samples from 31 zones in 6 wells equipped with multi-level Westbay™ packer sampling systems to help define the vertical distribution of ^{129}I in the aquifer. Concentrations ranged from 0.000011 ± 0.0000005 to 0.0167 ± 0.0007 pCi/L. For three wells, concentrations of ^{129}I between zones varied one to two orders of magnitude. For two wells, concentrations varied for one zone by more than an order of magnitude from the wells' other zones. Similar concentrations were measured from all five zones sampled in one well. Samples from all 31 zones had concentrations of ^{129}I two or more orders of magnitude below the maximum contaminant level.

DOE/ID-22209 Steady-state and transient models of groundwater flow and advective transport, eastern Snake River Plain aquifer, Idaho National Laboratory and vicinity, Idaho, SIR 2010-5123, by Daniel J. Ackerman, Joseph P. Rousseau, Gordon W. Rattray, and Jason C. Fisher, 2010, 220 p. Saturated flow in the eastern Snake River Plain aquifer was simulated using the MODFLOW-2000 groundwater-flow model. Steady-state flow was simulated to represent conditions in 1980 with average streamflow infiltration from 1966 through 1980 for the Big Lost River, the major variable inflow to the groundwater system. The transient flow model simulates groundwater flow between 1980 and 1995, a period that included a 5-year wet cycle (1982–86) followed by an 8-year dry cycle (1987–94). Specified flows into or out of the active model grid define the conditions on all boundaries except the southwest (outflow) boundary, which is simulated with head-dependent flow. In the transient flow model, streamflow infiltration was the major stress, and was variable in time and location. The model was calibrated by adjusting aquifer hydraulic properties to match simulated and observed heads or head differences using the parameter-estimation program incorporated in MODFLOW-2000. Various summary, regression, and inferential statistics, in addition to comparisons of model properties and simulated head to measured properties and head, were used to evaluate the model calibration.

Model parameters estimated for the steady-state calibration included hydraulic conductivity for seven of nine hydrogeologic zones and a global value of vertical anisotropy. Parameters estimated for the transient calibration included specific yield for five of the seven hydrogeologic zones. The zones represent five rock units and parts of four rock units with abundant interbedded sediment. All estimates of hydraulic conductivity were nearly within 2 orders of magnitude of the maximum expected value in a range that exceeds 6 orders of magnitude. The estimate of vertical anisotropy was larger than the maximum expected value. All estimates of specific yield and their confidence intervals were within the ranges of values expected for aquifers, the range of values for porosity of basalt, and other estimates of specific yield for basalt.

The steady-state model reasonably simulated the observed water-table altitude, orientation, and gradients. Simulation of transient flow conditions accurately reproduced observed changes in the flow system resulting from episodic infiltration from the Big Lost River and facilitated understanding and visualization of the relative importance of historical differences in infiltration in time and space. As described in a conceptual model, the numerical model simulations demonstrate that flow is (1) dominantly horizontal through interflow zones in basalt and vertical anisotropy resulting from contrasts in hydraulic conductivity of various types of basalt and the interbedded sediments, (2) temporally variable due to streamflow infiltration from the Big Lost River, and (3) moving downward downgradient of the INL.

The numerical models were reparametrized, recalibrated, and analyzed to evaluate alternative conceptualizations or implementations of the conceptual model. The analysis of the reparametrized models revealed that little improvement in the model would be realized from alternative descriptions of sediment content, simulated aquifer thickness, streamflow infiltration, and vertical head distribution on the downgradient boundary of the model. Of the alternative estimates of flow to or from the aquifer, only a 20 percent decrease in the largest inflow, the northeast boundary underflow, resulted in a recalibrated parameter value just outside the confidence interval of the base-case calibrated value.

Particle-tracking calculations made with the particle-tracking program MODPATH were used to evaluate (1) how simulated groundwater flow paths and travel times differ between the steady-state and transient flow models, (2) how wet- and dry-climate cycles affect groundwater flow paths and travel times, and (3) how well model-derived groundwater flow directions and velocities compare to independently derived estimates. Particle tracking also was used to simulate the growth of tritium (^{3}H) plumes originating at the Idaho Nuclear Technology and Engineering Center and the Reactor Technology Complex over a 16-year period under steady-state and transient flow conditions (1953–68). The shape, dimensions, and areal extent of the ^{3}H plumes were compared to a map of the plumes for 1968 from ^{3}H releases at the Idaho Nuclear Technology and Engineering Center and the Reactor Technology Complex that began in 1952.

Collectively, the particle-tracking simulations indicate that average linear groundwater velocities, based on estimates of porosity, and flow paths are influenced by two primary factors: (1) the dynamic character of the water table, and (2) the large contrasts in the hydraulic properties of the media, primarily hydraulic conductivity. The simulated growth and decay of groundwater mounds as much as 34 ft above the steady-state water table beneath the Big Lost River spreading areas, sinks, and playas, and to a lesser extent beneath the Big Lost River channel led to non-uniform changes in the altitude of the water table throughout the model area. These changes affect the orientation and magnitude of water-table gradients and affect groundwater flow directions and velocities to a greater or lesser degree, depending on the magnitude, duration, and proximity of the transient stress. Simulation results also indicate that temporal changes in the local hydraulic gradient can account for some of the observed dispersion of contaminants in the aquifer near the major sources of contamination at the INTEC and the RTC and perhaps most observed dispersion several miles downgradient of these facilities. The distance downgradient of the INTEC that simulated particle plumes were able to reasonably reproduce the shape and dimensions of the 1968 ^{3}H plume extended only to the boundary of zones of abundant sediment, about 4 miles downgradient of the INTEC. This boundary encompasses the entire area represented by the 25,000 picocuries/liter ^{3}H isopleths for 1968. Particle plumes simulated beyond this boundary were narrow and long, and did not reasonably reproduce the shape, dimensions, or position of the leading edge of the ^{3}H plume as shown in earlier reports; however, as noted in an assessment of the interpreted plume, few data were available in 1968 to characterize its true areal extent and shape.

DOE/ID-22210 Completion summary for well NRF-16 near the Naval Reactors Facility, Idaho National Laboratory, Idaho, SIR 2010-5101, by Brian V. Twining, Jason C. Fisher, and Roy C. Bartholomay, 2010, 36 p. This report summarizes completion information for well NRF-16 which was drilled as an upgradient monitoring program well for the NRF's Comprehensive Environmental Response Compensation and Liability Act sampling program. The borehole was cored to 425 ft below land surface. The core was logged, and geophysical logs were collected, and the core and log description were used to identify primary flow paths for groundwater. Video logs (presented in an appendix to the report) were collected to confirm that no perched water existed and to examine the well bore before and after final installation of the screen. Two consecutive single-well aquifer tests to define hydraulic characteristics for well NRF-16 were conducted in the eastern SRP aquifer. Transmissivity and hydraulic conductivity averaged from the aquifer tests were 4.8×10^{3} ft^{2}/d and 9.9 ft/d respectively. These tests indicated that the well was within the range of productivity of other wells near the NRF. Water samples from this well were analyzed for metals, nutrients, total organic carbon, volatile organic compounds, semi-volatile organic compounds, herbicides, pesticides, polychlorinated biphenols, and radionuclides. All chloride, nitrate, and sulfate concentrations were less than background concentrations for the eastern SRP aquifer north of the NRF. Concentrations for most of the organic compounds and radionuclides in the samples were less than the laboratory reporting limits and levels. The main conclusion from the study is that that water at well NRF-16 would be a good representation of upgradient aquifer water not influenced by NRF facility disposal. NRF-16 was drilled after coring NRF 15, which was drilled initially but showed effects of wastewater disposal from NRF in its water chemistry, which prompted the drilling of the new well, NRF-16. Water chemistry analysis results for NRF-15 are presented in a tabular form in the report. NRF-15 was later completed as a duel-piezometer water-level monitoring well for the NRF program.

DOE/ID-22211 Chemical constituents in groundwater from multiple zones in the eastern Snake River Plain aquifer at the Idaho National Laboratory, Idaho, 2005-08, SIR 2010-5116, by Roy C. Bartholomay and Brian V. Twining, 2010, 82 p. This study presents the first water chemistry results from multilevel monitoring wells that were installed at the INL between 2005 and 2008. Water samples were collected from six monitoring wells completed in about 350–700 feet of the upper part of the aquifer, and the samples were analyzed for major ions, selected trace elements, nutrients, selected radiochemical constituents, and selected stable isotopes. Each well was equipped with a multilevel monitoring system containing four to seven sampling ports that were each isolated by permanent packer systems. The sampling ports were installed in aquifer zones that were highly transmissive and that represented the water chemistry in the top four to five layers of a steady-state and transient groundwater-flow model. The model's water chemistry and particle-tracking simulations are being used to better define movement of wastewater constituents in the aquifer.

The results of the water chemistry analyses indicated that, in each of four separate wells, one zone of water differed markedly from the other zones in the well. In four wells, one zone to as many as five zones contained radiochemical constituents that originated from wastewater disposal at selected laboratory facilities. The multilevel sampling systems are defining the vertical distribution of wastewater constituents in the eastern Snake River Plain aquifer, and the concentrations of wastewater constituents in deeper zones in wells Middle 2051, USGS 132, and USGS 103 support the concept of groundwater flow deepening in the southwestern part of the INL as presented in the groundwater flow model report published in 2010 (DOE/ID-22209).

DOE/ID-22212 An update of hydrologic conditions and distribution of selected constituents in water, Snake River Plain aquifer and perched groundwater zones, Idaho National Laboratory, Idaho, emphasis 2006-08, SIR 2010-5197, by Linda C. Davis, 2010, 80 p. This report is the twelfth in the series of hydrologic conditions reports and focuses on water level and water quality data from 2006 through 2008 from both the aquifer and the perched groundwater zones at the INL. From March–May 2005 to March–May 2008, water levels in wells generally remained constant or rose slightly in the southwestern corner of the INL. Water levels declined in the central and northern parts of the INL. The declines ranged from about 1 to 3 feet in the central part of the INL, to as much as 9 feet in the northern part of the INL. Water levels in wells completed in perched water around the Advanced Test Reactor Complex (ATRC) also declined.

In April or October 2008, reportable concentrations of tritium in groundwater ranged from 810 ± 70 to 8,570 ± 190 picocuries per liter (pCi/L). Tritium concentrations in deep, perched groundwater exceeded the reporting level in 11 wells during at least one sampling event during 2006–08 at the ATRC. Tritium concentrations from one or more zones in each well were reportable in water samples collected from various depths in six wells equipped with multi-level Westbay™ packer sampling systems.

Concentrations of strontium-90 ranged from 2.2 ± 0.7 to 32.7 ± 1.2 pCi/L. During at least one sampling event during 2006–08, concentrations of strontium-90 in water samples from nine wells completed in deep perched groundwater at the ATRC were greater than reporting levels, and concentrations ranged from 2.1±0.7 to 70.5±1.8 pCi/L. During 2006–08, concentrations of cesium-137, plutonium-238, and plutonium-239, -240 (undivided), and americium-241 were less than the reporting level in water samples from all wells and all zones in wells equipped with multi-level packer sampling systems at the INL.

The concentration of chromium in water from one well south of the ATRC steadily decreased from 2006 to 2008 and was 93 micrograms per liter (µg/L) in 2008, just less than the maximum contaminant level (MCL). Chloride concentrations in wells near INTEC generally decreased. In 2008, sulfate concentrations ranged from 40 to 157 mg/L in nine wells in the south-central part of the INL. Nitrate concentrations (as N) in INTEC area ranged from 2.2 to 5.97 mg/L. Concentrations of from 1 to 10 volatile organic compounds (VOCs) were detected in water samples from 11 wells. The principal VOCs detected included carbon tetrachloride, trichloromethane, 1,1-dichloroethane, 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene. Nine VOCs were detected in perched water at well USGS 92, which was a decrease from the 15 compounds detected in 2002–03. Additionally, all VOC concentrations detected in 2007 were significantly lower than those detected during 2002–03, except for toluene, which was not detected in 2002–03.

DOE/ID-22213 Multilevel groundwater monitoring of hydraulic head and temperature in the eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, 2007-08, SIR 2010-5253, by Jason C. Fisher and Brian V. Twining, 2011, 62 p. This report describes the installation process for the first six multilevel wells installed at the INL and presents quarterly depth-discrete measurements of fluid pressure and temperature collected in 2007 and 2008. Each borehole was instrumented with a multilevel monitoring system consisting of a series of valved measurement ports, packer bladders, casing segments, and couplers. Hydraulic heads (head) and water temperatures in boreholes were monitored at 86 hydraulically isolated depth intervals, from 448.0 to 1,377.6 feet below land surface.

The vertical hydraulic gradients in each borehole remained relatively constant over time, with minimum Pearson correlation coefficients between head profiles ranging from 0.72 at borehole USGS 103 to 1.00 at boreholes USGS 133 and MIDDLE 2051. Major inflections in the head profiles almost always coincided with low permeability sediment layers. The vertical hydraulic gradients were defined for the major inflections in the head profiles and were as much as 2.2 feet per foot. Head gradients generally were downward in boreholes USGS 133, 134, and MIDDLE 2050A, zero in boreholes USGS 103 and 132, and exhibited a reversal in direction in borehole MIDDLE 2051. Water temperatures in all boreholes ranged from 10.2 to 16.3 degrees Celsius. Boreholes USGS 103 and 132 are in an area of concentrated volcanic vents and fissures, and measurements show water temperature decreasing with depth. All other measurements in boreholes show water temperature increasing with depth. A comparison among boreholes of the normalized mean head over time indicated a moderately positive correlation.

DOE/ID-22214 Paleomagnetic correlation of surface and subsurface basaltic lava flows and flow groups in the southern part of the Idaho National Laboratory, Idaho, with paleomagnetic data tables for drill cores, SIR 2011-5049, by Duane E. Champion, Mary K.V. Hodges, Linda C. Davis, and Marvin A. Lanphere, 2011, 34 p. 1 plate. This report presents results of paleomagnetic inclination and polarity studies on thousands of subcores collected from 51 coreholes at the INL. These studies are used to paleomagnetically characterize and correlate successive stratigraphic intervals in each corehole to similar depth intervals in adjacent coreholes. Paleomagnetic results from 83 surface paleomagnetic sites, within and near the INL, are used to correlate these buried lava flow groups to basaltic shield volcanoes still exposed on the surface of the eastern Snake River Plain (ESRP). Sample handling and demagnetization protocols are described as well as the paleomagnetic data averaging process. Paleomagnetic inclination comparisons between coreholes located only a few kilometers apart show comparable stratigraphic successions of mean inclination values over tens of meters of depth. At greater distance between coreholes, comparable correlation of mean inclination values is less consistent because flow groups may be missing, or additional flow groups may be present and found at different depth intervals.

Two shallow intersecting cross-sections, oriented southwest-northeast and northwest-southeast, respectively, drawn through southwest Idaho National Laboratory coreholes show the corehole to corehole or surface to corehole correlations derived from the paleomagnetic inclination data. A description of several of the predominant flows in the southwestern part of the INL are presented. Evidence of progressive subsidence of the axial zone of the ESRP is shown in these cross sections, distorting the original attitudes of the lava flow groups and interbedded sediments. A deeper cross-section, oriented west to east, spanning the entire southern Idaho National Laboratory shows correlations of the lava flow groups in the saturated part of the ESRP aquifer.

Areally extensive flow groups in the deep subsurface (from about 100–800 meters (330–2,625 feet) below land surface) can be traced over long distances. In the west to east cross-section, the flow group labeled “Matuyama” can be correlated from corehole USGS 135 to corehole NPR Test/W-02, about 28 kilometers (17 miles). The flow group labeled “Matuyama 1.21 Ma” can be correlated from corehole Middle 1823 to corehole ANL-OBS-A-001, 26 kilometers (16 miles). Other flow groups correlate over distances of up to about 18 kilometers (11 miles).

DOE/ID-22215 Geophysical logs and water-quality data collected for boreholes Kimama-1A and -1B, and Kimama Water Supply Well near Kimama, Southern Idaho, Data Series 622, by Brian V. Twining and Roy C. Bartholomay, 2011, 18 p. A deep research well drilled near the center of the eastern Snake River Plain, presented an opportunity to collect water chemistry data and geophysical logs from a deep corehole. Wireline geophysical logs were collected for the diverging borehole, Kimama-1A and -1B, from land surface to 976 and 2,498 feet below land surface (BLS), respectively. Water samples were collected from Kimama-1A at depths near 460 and 830 feet BLS, and from the Kimama Water Supply (KWS) well located about 75 feet away. About 155 individual basalt flows were identified, ranging from less than 3 feet to more than 175 feet in thickness (averaging 15 feet) for borehole Kimama-1B (0–2,498 feet BLS). Sediment and basalt contacts were identified on the basis of geophysical traces and were confirmed with visual inspection of core photographs. Temperature logs from the water table surface (about 260 feet BLS) to the bottom of borehole Kimama-1B (2,498 feet BLS) were nearly isothermal, ranging from about 62 to 64 degrees Fahrenheit. Gyroscopic data revealed that borehole Kimama-1B begins to separate from borehole Kimama-1A near a depth of 676 feet BLS. Drill hole azimuth and horizontal deviation at total logged depth for boreholes Kimama-1A and -1B were 172.6 and 188.3 degrees and 25.9 and 82.0 feet, respectively.

Water samples were collected and analyzed for common ions; selected trace elements; nutrients; isotopes of hydrogen, oxygen, and carbon; and selected radionuclides. One set of water samples was collected from the KWS well and the two other sample sets were collected from borehole Kimama-1A near 460 and 830 feet BLS. With one exception, analyses of samples collected from all three zones near Kimama generally indicated that the water chemistry was similar. The exception was found in the deepest zone in borehole Kimama-1A (830 feet BLS), where concentrations of constituents probably were affected by the drilling mud. A comparison of analyses for inorganic and organic constituents, and for stable isotopes between the KWS well and the 460-foot zone in borehole Kimama-1A indicated similar chemistry of the aquifer water, except for some variability in concentrations of nitrate plus nitrite, orthophosphate, iron, zinc, and carbon-14.

Radionuclide concentrations were either less than reporting levels or at background levels for the eastern Snake River Plain aquifer.

DOE/ID-22216 Assessing controls on perched saturated zones beneath the Idaho Nuclear Technology and Engineering Center, Idaho, SIR 2011-5222, by Ben B. Mirus, Kim S. Perkins, and John R. Nimmo, 2011, 20 p. Because of waste disposal history at INTEC and the formation of perched groundwater zones, more work was needed in this area to better understand water movement in the unsaturated zone. During 2009–2011, the USGS employed data analysis and numerical simulations with a recently developed model of preferential flow to evaluate the sources and quantity of recharge to the perched zones at INTEC. Piezometer, tensiometer, temperature, precipitation, and stream-discharge data were analyzed, with focus on the possibility of contributions to the perched zones from infiltration of snowmelt and of flow in the neighboring Big Lost River (BLR). Analysis of the timing and magnitude of subsurface dynamics indicate that streamflow provides local recharge to the shallow, intermediate, and deep perched saturated zones within 150 m of the BLR; at greater distances from the BLR, the influence of streamflow on recharge is unclear. Perched water-level dynamics in most wells analyzed were consistent with findings from previous geochemical analyses, which suggest that a combination of the infiltration of snowmelt and water from anthropogenic sources (for example, leaky pipes and drainage ditches) contributed to recharge of shallow and intermediate perched zones throughout much of INTEC. The source-responsive fluxes model was parameterized to simulate recharge via preferential flow associated with intermittent episodes of streamflow in the BLR. The simulations correspond reasonably well to the observed hydrologic response within the shallow perched zone. Good model performance indicates that source-responsive flow through a limited number of connected fractures contributes substantially to the perched-zone dynamics. The agreement between simulated and observed perched-zone dynamics suggest that the source-responsive fluxes model can provide a valuable tool for quantifying rapid preferential flow processes that may result from different land-management scenarios. As a consequence of budget reductions, this study concluded work by the USGS unsaturated zone research group at the INL.

DOE/ID-22217 Construction diagrams, geophysical logs, and lithologic descriptions for boreholes USGS 103, 105, 118, 131, 135, NRF-15, and NRF-16, Idaho National Laboratory, Idaho, Data Series 660, by Mary K.V. Hodges, Stephanie M. Orr, Katherine E. Potter, and Tynan LeMaitre, 2012, 34 p. This report summarizes construction, geophysical, and lithologic data collected from about 4,509 feet of core from seven boreholes deepened or drilled by the U.S. Geological Survey (USGS), Idaho National Laboratory (INL) Project Office, from 2006 to 2009 at the INL. USGS 103, 105, 108, and 131 were deepened and cored from 759 to 1,307 feet, 800 to 1,409 feet, 760 to 1,218 feet, and 808 to 1,239 feet, respectively. Boreholes USGS 135, NRF-15, and NRF-16 were drilled and continuously cored from land surface to 1,198, 759, and 425 feet, respectively. Cores were photographed and digitally logged by using commercially available software. Borehole descriptions summarize location, completion date, and amount and type of core recovered. Core logs are given in appendixes to the report.

DOE/ID-22218 A comparison of U.S. Geological Survey three-dimensional model estimates of groundwater source areas and velocities to independently derived estimates, Idaho National Laboratory and vicinity, Idaho, SIR-2012-5152, by Jason C. Fisher, Joseph P. Rousseau, Roy C. Bartholomay, and Gordon W. Rattray, 2012, 130 p. This study evaluated the three-dimensional model of groundwater flow in the fractured basalts and interbedded sediments of the eastern Snake River Plain aquifer at and near the INL to determine if model-derived estimates of groundwater movement are consistent with (1) results from previous studies on water chemistry type, (2) the geochemical mixing at an example well, and (3) independently derived estimates of the average linear groundwater velocity. Simulated steady-state flow fields were analyzed using backward particle-tracking simulations that were based on a modified version of the particle-tracking program MODPATH. Model results were compared to the 5-microgram-per-liter lithium contour interpreted to represent the transition from a water type that is primarily composed of tributary valley underflow and streamflow-infiltration recharge to a water type primarily composed of regional aquifer water. This comparison indicates several shortcomings in the way the model represents flow in the aquifer. The eastward movement of tributary valley underflow and streamflow-infiltration recharge is overestimated in the north-central part of the model area and underestimated in the central part of the model area. Model inconsistencies can be attributed to large contrasts in hydraulic conductivity between hydrogeologic zones.

Sources of water at well NPR-W01 were identified using backward particle tracking, and they were compared to the relative percentages of source-water chemistry determined using geochemical mass balance and mixing models. The particle tracking results compare reasonably well with the chemistry results for groundwater derived from surface-water sources (–28 percent error), but overpredict the proportion of groundwater derived from regional aquifer water (108 percent error) and underpredict the proportion of groundwater derived from tributary valley underflow from the Little Lost River valley (–74 percent error). These large discrepancies may be attributed either to large contrasts in hydraulic conductivity between hydrogeologic zones or a short-circuiting of underflow from the Little Lost River valley to an area of high hydraulic conductivity, or to a combination of these factors.

Independently derived estimates of the average groundwater velocity at 12 well locations within the upper 100 feet of the aquifer were compared to model-derived estimates. Agreement between velocity estimates was good at wells with travel paths located in areas of sediment-rich rock (root-mean-square error [RMSE] = 5.2 feet per day [ft/d]) and poor in areas of sediment-poor rock (RMSE = 26.2 ft/d); simulated velocities in sediment-poor rock were 2.5–4.5 times larger than independently derived estimates at wells USGS 1 (less than 14 ft/d) and USGS 100 (less than 21 ft/d). The models overprediction of groundwater velocities in sediment-poor rock may be attributed to large contrasts in hydraulic conductivity and a very large, model-wide estimate of vertical anisotropy (14,800).

DOE/ID-22219 Water-quality characteristics and trends for selected sites at and near the Idaho National Laboratory, Idaho, 1949-2009, SIR 2012-5169, by Roy C. Bartholomay, Linda C. Davis, Jason C. Fisher, Betty J. Tucker, and Flint A. Raben, 2012, 68 p. As the first part of a three-phase study to optimize the water quality monitoring network, the USGS analyzed water-quality data collected from 67 wells and 7 surface-water sites at the Idaho National Laboratory (INL) from 1949 through 2009, sites believed not to be influenced by INL waste disposal activities. Water samples were analyzed for major cations, anions, nutrients, trace elements, and total organic carbon. The analytical data enabled examination of water-quality trends that might inform future management decisions about the number of wells to sample at the INL and the type of constituents to monitor. Water-quality trends were determined using (1) the nonparametric Kendall's tau correlation coefficient, p-value, Theil-Sen slope estimator, and summary statistics for uncensored data; and (2) the Kaplan-Meier method for calculating summary statistics, Kendall's tau correlation coefficient, p-value, and Akritas-Theil-Sen slope estimator for robust linear regression for censored data.

Statistical analyses of chloride concentrations indicate downward trends in chloride levels in groundwater influenced by Big Lost River seepage or, in some cases, variable chloride concentrations that correlate with above-average and below-average periods of recharge. Analyses of trends in concentrations in chloride in water samples from four sites along the Big Lost River indicate a downward trend or no trend for chloride, and chloride concentrations generally are much lower at these four sites than those in the aquifer. Above-average and below-average periods of recharge also affect concentration trends for sodium, sulfate, nitrate, and a few trace elements in several wells. Analyses of trends for constituents in water from several of the wells that is mostly regionally derived groundwater generally indicate upward trends for chloride, sodium, sulfate, and nitrate concentrations. These trends are attributed to agricultural or other anthropogenic influences on the aquifer upgradient of the INL.

Statistically defined trends in concentrations of chemical constituents from several wells near the Naval Reactors Facility may be influenced by wastewater disposal at the facility or by anthropogenic influence from the Little Lost River basin. Groundwater samples from three wells downgradient of the Power Burst Facility area show upward trends for chloride, nitrate, sodium, and sulfate concentrations. The increases could be caused by wastewater disposal in the Power Burst Facility area.

Some groundwater samples in the southwestern part of the INL and southwest of the INL show concentration trends for chloride and sodium that may be influenced by wastewater disposal. Downward trends in some of the groundwater samples could be attributed to the decreasing concentrations in the wastewater from the late 1970s to 2009. The young fraction of groundwater in many of the wells is more than 20 years old, so samples collected in the early 1990s are more representative of groundwater discharged in the 1960s and 1970s, when concentrations of sodium and chloride in wastewater were much higher. Groundwater sampled in 2009 would be representative of the lower concentrations of chloride and sodium in wastewater discharged in the late 1980s. Analyses of trends for sodium in several groundwater samples from the central and southern part of the eastern Snake River aquifer show increasing trends. In most cases, however, the sodium concentrations are less than background concentrations measured in the aquifer. Many of the wells are open to larger mixed sections of the aquifer, and the trends indicate that in the long history of wastewater disposal in the central part of the INL, sodium concentrations in the groundwater have increased.

DOE/ID-22220 Completion summary for borehole USGS 136 near the Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, SIR 2012-5230, by Brian V. Twining, Roy C. Bartholomay, and Mary K.V. Hodges, 2012, 32 p. In 2011, the U.S. Geological Survey cored and completed borehole USGS 136 for stratigraphic framework analyses and long-term groundwater monitoring of the eastern Snake River Plain aquifer at the Idaho National Laboratory. This well was drilled as an upgradient monitoring well for the contractor at the Remote Handled Low-level Waste Repository. The borehole was initially cored to a depth of 1,048 feet (ft) below land surface (BLS) to collect core, open-borehole water samples, and geophysical data. After these data were collected, the borehole was cemented and backfilled between 560 and 1,048 ft BLS. The final construction of borehole USGS 136 required that the borehole be reamed to allow for installation of 6-inch (in.) diameter carbon-steel casing and 5-in. diameter stainless-steel screen; the screened monitoring interval was completed between 500 and 551 ft BLS. A dedicated pump and water-level access line were placed to allow for aquifer testing, for collecting periodic water samples, and for measuring water levels.

Geophysical and borehole video logs were collected after coring and after the completion of the monitor well. A single-well aquifer test was used to define hydraulic characteristics for well USGS 136. Specific-capacity, transmissivity, and hydraulic conductivity from the aquifer test were at least 975 gallons per minute per foot, 1.4×10^5 feet squared per day (ft^2/d), and 254 feet per day, respectively. Drawdown during the aquifer test was about 0.02 ft. The transmissivity for borehole USGS 136 was in the range of values determined from previous aquifer tests conducted in other wells near the Advanced Test Reactor Complex: 9.5×10^3 to 1.9×10^5 ft^2/d.

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

DOE/ID-22221 Multilevel groundwater monitoring of hydraulic head and temperature in the eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, 2009-10 SIR 2012-5259, by Brian V. Twining and Jason C. Fisher, 2012, 44 p. This report is the second in the series of reports on the fluid pressure and temperature data collected from the multilevel monitoring systems. This report includes data collected in 2009 and 2010 from 9 multilevel monitoring wells, including data from 120 hydraulically isolated depths intervals ranging from 448 to 1378 feet below land surface. Detailed descriptions of the geophysical traces, lithology log, completion log, and profiles are provided for boreholes USGS 105, 108, and 135.

Head and temperature profiles recorded quarterly reveal unique patterns for vertical examination of the aquifer's complex basalt and sediment stratigraphy, proximity to aquifer recharge and discharge, and groundwater flow. These features contribute to some of the local variability even though the general profile shape remained consistent over the period of record. Major inflections in the head profiles almost always coincided with low-permeability sediment layers and occasionally thick sequences of dense basalt. Temperature profiles for boreholes completed within the Big Lost Trough indicate linear conductive trends; whereas temperature profiles for boreholes completed within the axial volcanic high indicate mostly convective heat transfer resulting from the vertical movement of groundwater. Additionally, temperature profiles provide evidence for stratification and mixing of water types along the southern boundary of the Idaho National Laboratory.

Vertical head and temperature change were quantified for each of the nine multilevel monitoring systems. The vertical head gradients were defined for the major inflections in the head profiles and were as high as 2.1 feet per foot. Low vertical head gradients indicated potential vertical connectivity and flow, and large gradient inflections indicated zones of relatively low vertical connectivity. Large head differences were attributed to poor vertical connectivity between fracture units because of sediment layering and/or dense basalt. Groundwater temperatures in all boreholes ranged from 10.2 to 16.3˚C.

Normalized mean hydraulic head values for all nine multilevel monitoring wells for the period of record (2007–10) were analyzed. The mean head values indicate a moderately positive correlation among all boreholes, which reflects regional fluctuations in water levels in response to seasonality. However, this temporal trend is slightly different when the location of the wells is considered; wells along the southern boundary, within the axial volcanic high, show a strongly positive correlation with seasonal recharge.

DOE/ID-22222 Evaluation of quality-control data collected by the U.S. Geological Survey for routine water-quality activities at the Idaho National Laboratory, Idaho, 1996-2001, SIR 2012-5270, by Gordon W. Rattray, 2012, 74 p. This report is a continuation of the evaluation of the USGS INL Project Office quality-assurance data and covers the quality assurance data collected for the routine site-wide INL monitoring program from 1996-2001. From 1996 to 2001, quality-control samples consisting of 204 replicates and 27 blanks were collected. Paired measurements from replicates were used to calculate variability (as reproducibility and reliability) from sample collection and analysis for concentrations of radiochemical, chemical, and organic constituents. Measurements from field and equipment blanks were used to estimate the potential contamination bias of constituents.

The reproducibility of measurements of constituents was calculated from paired measurements as the normalized absolute difference (NAD) or the relative standard deviation (RSD). If the percentage of paired measurements with acceptable reproducibility for a constituent was greater than or equal to 90 percent, then the reproducibility for that constituent was considered acceptable for the period 1996–2001. The percentage of paired measurements with acceptable reproducibility was greater than or equal to 90 percent for all constituents except orthophosphate (89 percent), zinc (80 percent), hexavalent chromium (53 percent), and total organic carbon (TOC; 38 percent). The low reproducibility of analytical results for orthophosphate and zinc was attributed to calculation of RSDs for replicates with low concentrations of these constituents. The low reproducibility for hexavalent chromium and TOC was attributed to the inability to preserve hexavalent chromium in water samples and high variability with the analytical method for TOC.

The reliability of measurements of constituents was estimated from pooled RSDs that were calculated for discrete concentration ranges for each constituent. Pooled RSDs of 15–33 percent were calculated for low concentrations of gross-beta radioactivity, strontium-90, ammonia, nitrite, orthophosphate, nickel, selenium, zinc, tetrachloroethene, and toluene. Lower pooled RSDs of 0–12 percent were calculated for all other concentration ranges of these constituents, and for all other constituents, except for one concentration range for gross-beta radioactivity, chloride, and nitrate + nitrite; two concentration ranges for hexavalent chromium; and TOC. Pooled RSDs for the 50–60 picocuries per liter concentration range of gross-beta radioactivity (reported as cesium-137) and the 10–60 milligrams per liter (mg/L) concentration range of nitrate + nitrite (reported as nitrogen [N]) were 17 percent. Chloride had a pooled RSD of 14 percent for the 20 to less than 60 mg/L concentration range. High pooled RSDs of 40 and 51 percent were calculated for two concentration ranges for hexavalent chromium and of 60 percent for TOC.

Measurements from (1) field blanks were used to estimate the potential bias associated with environmental samples from sample collection and analysis, (2) equipment blanks were used to estimate the potential bias from cross contamination of samples collected from wells where portable sampling equipment was used, and (3) a source-solution blank was used to verify that the deionized water source-solution was free of the constituents of interest. The source-solution blank had a detectable concentration of hexavalent chromium of 2 micrograms per liter. If this bias was from a source other than the source solution, then about 84 percent of the 117 hexavalent chromium measurements from environmental samples could have a bias of 10 percent or more. Of the 14 field blanks that were collected, only chloride (0.2 milligrams per liter) and ammonia (0.03 milligrams per liter as nitrogen), in one blank each, had detectable concentrations. With an estimated confidence level of 95 percent, at least 80 percent of the 1,987 chloride concentrations measured from all environmental samples had a potential bias of less than 8 percent. The ammonia bias, which may have occurred at the analytical laboratory, could produce a potential bias of 5–150 percent in eight potentially affected ammonia measurements. Of the 12 equipment blanks that were collected, chloride was detected in 4 of these blanks, sodium in 3 blanks, and sulfate and hexavalent chromium were each detected in 1 blank. The concentration of hexavalent chromium in the equipment blank was the same as that in the source-solution blank collected on the same day, which indicates that the hexavalent chromium in the equipment blank is probably from a source other than the portable sampling equipment, such as the sample bottles or the source-solution water itself. The potential bias for chloride, sodium, and sulfate measurements was estimated for environmental samples that were collected using portable sampling equipment. For chloride, it was estimated with 93 percent confidence that at least 80 percent of the measurements had a bias of less than 18 percent. For sodium and sulfate, it was estimated with 91 percent confidence that at least 70 percent of the measurements had a bias of less than 12 and 5 percent, respectively.

DOE/ID-22223 Paleomagnetic correlation and ages of basalt flow groups in coreholes at and near the Naval Reactors Facility, Idaho National Laboratory, Idaho, SIR 2013-5012, by Duane E. Champion, Linda C. Davis, Mary K.V. Hodges, and Marvin A Lanphere, 2013, 48 p. Paleomagnetic inclination and polarity studies were conducted on sub-core samples from eight coreholes at and near the NRF at the INL. These studies were used to characterize and to correlate successive stratigraphic basalt flow groups in each corehole to basalt flow groups with similar paleomagnetic inclinations in adjacent coreholes. Results were used to extend the subsurface geologic framework at the INL previously derived from paleomagnetic data for south INL coreholes. Geologic framework studies are used in conceptual and numerical models of groundwater flow and contaminant transport. Sample handling and demagnetization protocols are described, as well as the paleomagnetic data averaging process.

Paleomagnetic inclination comparisons among NRF coreholes show comparable stratigraphic successions of mean inclination values over tens to hundreds of meters of depth. Corehole USGS 133 is more than 5 kilometers from the nearest NRF area corehole, and the mean inclination values of basalt flow groups in that corehole are somewhat less consistent than with NRF area basalt flow groups. Some basalt flow groups in USGS 133 are missing, additional basalt flow groups are present, or the basalt flow groups are at depths different from those of NRF area coreholes.

Age experiments on young, low-potassium olivine tholeiite basalts may yield inconclusive results; paleomagnetic and stratigraphic data were used to choose the most reasonable ages. Results of age experiments using conventional potassium argon and argon-40/argon-39 protocols indicate that the youngest and uppermost basalt flow group in the NRF area is 303 ± 30 ka and that the oldest and deepest basalt flow group analyzed is 884 ± 53 ka.

A south to north line of cross-section drawn through the NRF coreholes shows corehole-to-corehole basalt flow group correlations derived from the paleomagnetic inclination data. Key stratigraphic results for significant flows are presented.

DOE/ID-22224 Optimization of water-level monitoring networks in the eastern Snake River Plain aquifer using a kriging-based genetic algorithm method, SIR-2013-5020, by Jason C. Fisher, 2013, 74 p. This study evaluated long-term water-level monitoring networks in both the entire eastern Snake River Plain and at the INL monitoring network to see to what extent the network could be reduced without affecting the definition of the water-table surface. A network design tool, distributed as an R package, was developed to determine which wells to exclude from a monitoring network because they add little or no beneficial information. A kriging-based genetic algorithm method was used to optimize the monitoring network. The algorithm was used to identify the set of wells whose removal from the network would result in the smallest increase in the weighted sum of the (1) mean standard error at all nodes in the kriging grid where the water table is estimated, (2) root-mean-squared-error between the measured and estimated water-level elevation at the discontinued wells, (3) mean standard deviation of measurements across time at the discontinued wells, and (4) mean measurement error of wells in the reduced network. The solution to the optimization problem (the best wells to retain in the monitoring network) depends on the total number of wells removed; this number is a management decision. The network design tool was applied to optimize two observation-well networks monitoring the water table of the eastern Snake River Plain aquifer, Idaho; these networks include the 2008 Federal-State Cooperative water-level monitoring network (Co-op network) with 166 wells, and the 2008 U.S. Geological Survey-Idaho National Laboratory water-level monitoring network (USGS-INL network) with 171 wells. Each network was optimized five times: by successively removing (1) 10, (2) 20, (3) 40, (4) 60, and (5) 80 observation wells from the original network. An examination of the trade-offs associated with increases in the number of wells removed indicates that 20 wells can be removed from the Co-op network with a relatively small "degradation" of the estimated water table map, and 40 wells can be removed from the USGS-INL network before the water table map degradation accelerates. The optimal network designs indicate the robustness of the network design tool. Observation wells were removed from high well-density areas of the network while retaining the spatial pattern of the existing water-table map.

DOE/ID-22225 Iodine-129 in the eastern Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho, 2010-12, SIR 2013-5195, by Roy C. Bartholomay, 2013, 22 p. During 2010–12, the U.S. Geological Survey collected groundwater samples for analysis of ^{129}I from 62 wells in the ESRP aquifer to track concentration trends and changes for ^{129}I in the aquifer as part of the periodic monitoring done at the INL. Concentrations of ^{129}I ranged from 0.0000013±0.0000005 to 1.02±0.04 picocuries per liter (pCi/L), and generally decreased in wells near the INTEC relative to concentrations detected in previous sampling events. The average concentration of ^{129}I in groundwater from 15 wells sampled during four different sample periods decreased from 1.15 pCi/L in 1990–91 to 0.173 pCi/L in 2011–12. All but two wells within a 3-mile radius of the INTEC showed decreases in ^{129}I concentrations, and all but one sample had concentrations less than the U.S. Environmental Protection Agency maximum contaminant level of 1 pCi/L. These decreases are attributed to the discontinuation of disposal of ^{129}I in wastewater and to dilution and dispersion in the aquifer. The decreases in ^{129}I concentrations, in areas around INTEC where concentrations increased between 2003 and 2007, were attributed to less recharge near INTEC owing either to less flow in the Big Lost River or less local snowmelt and anthropogenic sources.

Although samples collected from wells near INTEC in 2011–12 showed decreases in ^{129}I concentrations compared with previously collected data, some wells south and east of the Central Facilities Area, near the site boundary, and south of the INL showed small increases. These slight increases are attributed to variable discharge rates of wastewater that eventually moved to these well locations as a pulse of water from a disposal period.

Wells sampled for the first time around the Naval Reactors Facility had ^{129}I concentrations slightly greater than background concentrations in the ESRP aquifer. These concentrations are attributed to either seepage of unknown wastewater sources discharged at the Naval Reactors Facility or seepage from air emission deposits from INTEC, or both.

In 2012, the U.S. Geological Survey collected discrete groundwater samples from 25 zones in 11 wells equipped with multilevel monitoring systems to help define the vertical distribution of ^{129}I in the aquifer. Concentrations ranged from 0.000006±0.000004 to 0.082±0.003 pCi/L. Concentrations of ^{129}I in samples collected from two new wells completed in 2012 showed variability in the concentrations of up to one order of magnitude among various zones. Two other wells showed similar concentrations of ^{129}I in all three zones sampled. Concentrations were considerably less than the maximum contaminant level in all zones.

DOE/ID-22126 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 2009-11, SIR 2013-5214, by Linda C. Davis, Roy C. Bartholomay, and Gordon W. Rattray, 2013, 90 p. This report is the thirteenth in the series of hydrologic conditions reports and focuses on water level and water quality data from 2009 through 2011 from both the aquifer and the perched groundwater zones at the INL. From March–May 2009 to March–May 2011, water levels in wells generally declined in the northern part of the INL. Water levels generally rose in the central and eastern parts of the INL. Detectable concentrations of radiochemical constituents in water samples from aquifer wells or multilevel monitoring system (MLMS) equipped wells in the ESRP aquifer at the INL generally decreased or remained constant during 2009–11. Decreases in concentrations were attributed to radioactive decay, changes in waste-disposal methods, and dilution from recharge and underflow. In 2011, concentrations of tritium in water samples from 50 of 127 aquifer wells were greater than or equal to the reporting level and ranged from 200±60 to 7,000±260 picocuries per liter. During 2009–11, concentrations of plutonium-238, and plutonium-239, -240 (undivided), and americium-241 were less than the reporting level in water samples from all aquifer wells and in all wells equipped with MLMS.

The concentration of chromium in water from one well south of the ATR Complex was 97 micrograms per liter (μg/L) in April 2011, which is slightly less than the maximum contaminant level (MCL) of 100 μg/L. After the new percolation ponds were put into service in 2002 southwest of the INTEC, concentrations of sodium and chloride in water samples from the Rifle Range well rose steadily until 2008, after which the concentrations generally began decreasing. The increases and decreases were attributed to the variability in the volume of wastewater disposal in the new percolation ponds. In 2011, sulfate concentrations in water samples from 11 aquifer wells in the south-central part of the INL equaled or exceeded the background concentration of sulfate and ranged from 40 to 167 mg/L. The greater-than-background concentrations in water from these wells probably resulted from sulfate disposal at the ATR Complex infiltration ponds or the old INTEC percolation ponds. During 2009–11, the maximum concentration of dissolved sulfate detected in deep perched groundwater at the ATR Complex was 1,550 mg/L, in a sample from a well located west of the chemical-waste pond. In 2011, concentrations of nitrate in water from most wells at and near the INTEC exceeded the regional background concentrations of 1 mg/L and ranged from 1.6 to 5.95 mg/L. At least one and as many as five volatile organic contaminants (VOCs) were detected in water samples from 10 wells. The principal VOCs detected include carbon tetrachloride, chloroform, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene. In 2011, concentrations for all VOCs were less than their respective MCL for drinking water, except carbon tetrachloride in water from two wells.

During 2009–11, variability and bias in results of analyses of 56 replicate and 16 blank quality-assurance samples were evaluated. Constituents with acceptable reproducibility were stable isotope ratios, major ions, nutrients, and VOCs. Results for all radiochemical constituents and trace metals had acceptable reproducibility except those for gross beta-particle radioactivity, aluminum, antimony, and cobalt. Bias from sample contamination was evaluated for equipment, field, container, and source-solution blanks. No detectable constituent concentrations were reported for equipment blanks of the thief samplers and sampling pipes or for the source-solution and field blanks. Equipment blanks of bailers had detectable concentrations of strontium-90, sodium, chloride, and sulfate, and the container blank had a detectable concentration of dichloromethane.

DOE/ID-22227 Geochemistry of groundwater in the Beaver and Camas Creek drainage basins, eastern Idaho, SIR 2013-5226, by Gordon W. Rattray and Michael L. Ginsbach, 2014, 70 p. As part of the ongoing efforts to define the geochemical character of source water to eastern Snake River Plain (ESRP), this study applied geochemical modeling to investigate the geochemistry of groundwater in the Beaver and Camas Creek drainage basins, which provide groundwater recharge to the ESRP aquifer underlying the northeastern part of the INL. Data used in this study include petrology and mineralogy from 2 sediment samples and 3 rock samples, and chemical analyses of 4 surface-water and 18 groundwater samples. The mineralogy of the sediment and rock samples was analyzed with X-ray diffraction, and the mineralogy and petrology of the rock samples was examined in thin sections. The water samples were analyzed for field parameters, major ions, silica, nutrients, dissolved organic carbon, trace elements, tritium, and the stable isotope ratios of hydrogen, oxygen, carbon, sulfur, and nitrogen.

Groundwater geochemistry was influenced by reactions with rocks of the geologic terranes—carbonate rocks, rhyolite, basalt, evaporite deposits, and sediment that composed of all these rocks. Agricultural practices near and south of Dubois and the application of road anti-icing liquids on U.S. Interstate Highway 15 were likely sources of nitrate, chloride, calcium, and magnesium to groundwater.

Groundwater geochemistry in the alluvial aquifer in Camas Meadows and the ESRP fractured basalt aquifer was successfully simulated using the geochemical modeling code PHREEQC. The primary geochemical processes appear to be precipitation or dissolution of calcite and dissolution of silicate minerals. Dissolution of evaporite minerals, associated with Pleistocene Lake Terreton, is an important contributor of solutes in the Mud Lake-Dubois area. Oxidation-reduction reactions are important influences on the chemistry of groundwater at Camas Meadows and the Camas National Wildlife Refuge. In addition, mixing of different groundwaters or surface water with groundwater appears to be an important physical process influencing groundwater geochemistry in much of the study area, and evaporation may be an important physical process influencing the groundwater geochemistry of the Camas National Wildlife Refuge. The mass-balance modeling results from this study provide an explanation of the natural geochemistry of water in the ESRP aquifer northeast of the INL, and thus provide a starting point for evaluating the natural and anthropogenic geochemistry of groundwater at the INL.

DOE/ID-22228 Evaluation of quality-control data collected by the U.S. Geological Survey for routine water-quality activities at the Idaho National Laboratory and vicinity, Southeastern Idaho, 2002-08, SIR 2014-5027, by Gordon W. Rattray, 2014, 66 p. This report is a continuation of the evaluation of the USGS INL Project Office quality-assurance data and covers the data collected for the routine site wide INL monitoring program from 2002 to 2008. After this publication, the quality-assurance data for subsequent years was included in the hydrologic conditions report. Quality-control samples consisted of 139 replicates and 22 blanks (approximately 11 percent of the number of environmental samples collected). Measurements from replicates were used to estimate variability (from field and laboratory procedures and sample heterogeneity), as reproducibility and reliability, of water-quality measurements of radiochemical, inorganic, and organic constituents. Measurements from blanks were used to estimate the potential contamination bias in analytical results for selected radiochemical and inorganic constituents in the environmental samples, with an emphasis on identifying any cross contamination of samples collected with portable sampling equipment.

The reproducibility of water-quality measurements was estimated with calculations of normalized absolute difference for radiochemical constituents and relative standard deviation (RSD) for inorganic and organic constituents. The reliability of water-quality measurements was estimated with pooled RSDs for all constituents. Reproducibility was acceptable for all constituents except dissolved aluminum and total organic carbon. Pooled RSDs were equal to or less than 14 percent for all constituents except for total organic carbon, which had pooled RSDs of 70 percent for the low concentration range and 4.4 percent for the high concentration range.

Source-solution and equipment blanks were analyzed for concentrations of tritium, strontium-90, cesium-137, sodium, chloride, sulfate, and dissolved chromium. Field blanks were analyzed for the concentration of iodide. No detectable concentrations of these constituents were reported for the blanks except for strontium-90 in one source solution and one equipment blank collected in September and October 2004, respectively. The detectable concentrations of strontium-90 in the blanks probably were from a small source of strontium-90 contamination or large measurement variability, or both.

Order statistics and the binomial probability distribution were used to estimate the magnitude and extent of any potential contamination bias of tritium, strontium-90, cesium-137, sodium, chloride, sulfate, dissolved chromium, and iodide in the environmental samples. These statistical methods indicated that, with (1) 87 percent confidence, contamination bias of cesium-137 and sodium in 60 percent of water quality samples was less than the minimum detectable concentration or reporting level; (2) 92–94 percent confidence, contamination bias of tritium, strontium-90, chloride, sulfate, and dissolved chromium in 70 percent of water-quality samples was less than the minimum detectable concentration or reporting level; and (3) 75 percent confidence, contamination bias of iodide in 50 percent of water-quality samples was less than the reporting level for iodide. These results support the conclusion that any contamination bias introduced by the collection, processing, storage, and analysis of water samples was insignificant, and that any cross-contamination of perched groundwater samples collected with bailers during 2002–08 was insignificant.

DOE/ID-22229 Completion summary for boreholes USGS 140 and USGS 141 near the Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, SIR 2014-5098, by Brian V. Twining, Roy C. Bartholomay, and Mary K.V., Hodges, 2014, 40 p. Two wells were drilled for the INL contractor to be used as downgradient monitoring wells for the Remote Handled Low-Level Waste Disposal Facility. USGS 140 was cored and sediment interbeds were sampled for an unsaturated zone study. Both wells were completed about 50 ft into the eastern Snake River Plain aquifer, to depths of between 496 and 546 ft below land surface. Thirty-two basalt flows and 4 sedimentary layers were identified in cores from well USGS 140. Geophysical logs were collected from both wells and single aquifer tests were done at each well following completion. The specific capacity, transmissivity, and hydraulic conductivity for well USGS 140 were estimated at 2,370 gallons per minute per foot [(gal/min)/ft)], 4.06 × 105 feet squared per day (ft^2/d), and 740 feet per day (ft/d), respectively. The specific capacity, transmissivity, and hydraulic conductivity for well USGS 141 were estimated at 470 (gal/min)/ft, 5.95 × 104 ft^2/d, and 110 ft/d, respectively.

Water samples were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Analyses of the samples from both wells indicated that concentrations of tritium, sulfate, and chromium were affected by wastewater disposal practices at the Advanced Test Reactor Complex. Most constituents in water from wells USGS 140 and USGS 141 had concentrations like concentrations in well USGS 136, which is upgradient from wells USGS 140 and USGS 141.

DOE/ID-22230 Field methods and quality-assurance plan for water-quality activities and water-level measurements, U.S. Geological Survey, Idaho National Laboratory, Idaho, OFR 2014-1146, by Roy C. Bartholomay, Neil V. Maimer, and Amy J. Wehnke, 2014, 66 p. This report is the sixth revision that outlines responsibilities of the USGS INL Project Office staff in maintaining and improving the quality of technical products and providing a formal standardization, documentation, and review of activities that lead to these products. Data-quality objectives, methods for the collection and preservation of water samples, review of analyses, performance audits, corrective actions, information on water sampling and water-level measurement schedules, and water-quality field equipment are listed. A Personal Computer Field Form table is first introduced. This report was the first to present the quality-assurance (QA) practices used for the water-level monitoring program and discussed QA for the multi-level monitoring network.

DOE/ID-22231 Measurement of unsaturated hydraulic properties and evaluation of property-transfer models for deep sedimentary interbeds, Idaho National Laboratory, Idaho, SIR 2014-5206, by Kim S. Perkins, Ben B. Mirus, and Brittany D. Johnson, 2014, 16 p. During 2013-14, information on the unsaturated zone was collected below the proposed Remote Handled Low-Level Waste Facility. Twelve core samples from the sedimentary interbeds in a borehole near the proposed facility were collected for laboratory analysis of hydraulic properties, which also allowed further testing of the property-transfer modeling approach. For each core sample, the steady-state centrifuge method was used to measure relations between matric potential, saturation, and conductivity. These measurements were compared to water-retention and unsaturated hydraulic conductivity parameters estimated using the established property-transfer models. For each core sample, the agreement between measured and estimated hydraulic parameters was evaluated quantitatively using the Pearson correlation coefficient (r). The highest correlation is for saturated hydraulic conductivity (Ksat) with an r value of 0.922. The saturated water content (qsat) also exhibits a strong linear correlation with an r value of 0.892. The curve shape parameter (λ) has a value of 0.731, whereas the curve scaling parameter (y_o) has the lowest r value of 0.528. The r values demonstrate that model predictions correspond well to the laboratory measured properties for most parameters, which supports the value of extending this approach for quantifying unsaturated hydraulic properties at various sites throughout INL.

DOE/ID-22232 Chemical constituents in groundwater from multiple zones in the eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, 2009-13, SIR 2015-5002, by Roy C. Bartholomay, Candice B. Hopkins, and Neil V. Maimer, 2015, 110 p. This report was the second in the series on the chemical character of the water in the eastern Snake River Plain aquifer on the basis of the analyses of samples collected from multi-level monitoring wells. From 2009 to 2013, water samples were collected from 11 monitoring wells completed in about 250–750 feet of the upper part of the aquifer, and samples were analyzed for selected major ions, trace elements, nutrients, radiochemical constituents, and stable isotopes.

The water-chemistry composition of all sampled zones for the five new multilevel wells is calcium plus magnesium bicarbonate. One of the zones in well USGS 131A has a slightly different chemistry from that in the rest of the zones and wells, and the difference is attributed to more wastewater influence from the Idaho Nuclear Technology and Engineering Center. The water in one well, USGS 135, was not influenced by wastewater disposal; it consisted of mostly older water in all its zones.

Tritium concentrations in relation to basaltic flow units indicate the influence of wastewater in multiple basalt flow groups; however, tritium is most abundant in the South Late Matuyama flow group in the southern boundary wells. The concentrations of wastewater constituents in deep zones in wells Middle 2051, USGS 132, USGS 105, and USGS 103 support the concept of groundwater flow deepening in the southwestern corner of the INL, as indicated by the INL groundwater-flow model.

DOE/ID-22233 Water-quality characteristics and trends for selected wells possibly influenced by wastewater disposal at the Idaho National Laboratory, Idaho 1981-2012, SIR 2015-5003, by Linda C. Davis, Roy C. Bartholomay, Jason C. Fisher, and Neil V. Maimer, 2015, 105 p. This is the second report on water quality trends and focuses on data collected from 1981 through 2012 from 35 perched aquifer wells and 64 wells believed to be influenced by wastewater disposal at the INL. The samples were analyzed for tritium, strontium-90, major cations, anions, nutrients, trace elements, total organic carbon, and volatile organic compounds. Results of the analyses allowed examination of any water-quality trends that might influence future management decisions about the number of wells to sample at the INL and the type of constituents to monitor. The data were processed using custom computer scripts developed in the R programming language. Water-quality trends were determined using a parametric survival regression model to fit the observed data, including left-censored, interval-censored, and uncensored data.

Trend test results for tritium and strontium-90 in aquifer wells indicated that the concentrations in nearly all wells had downward or showed no trends. Similarly, trends in perched groundwater wells were mostly decreasing or no trends; trends were increasing in two perched groundwater wells near the Advanced Test Reactor Complex. Decreasing trends generally are attributed to the absence of recent wastewater disposal and to radioactive decay. Trend test results for chloride, sodium, sulfate, nitrite plus nitrate (as nitrogen), chromium, trace elements, and total organic carbon in aquifer wells indicated that concentrations in most wells had either decreasing or no trends. The decreasing trends in these constituents are attributed to decrease in disposal of these constituents, as well as discontinued use of the old percolation ponds south of the Idaho Nuclear Technology and Engineering Center (INTEC) and redirection of wastewater to the new percolation ponds 2 miles southwest of the INTEC in 2002. Chloride (along with sodium, sulfate, and some nitrate) concentrations in wells south of the INTEC may be influenced by episodic recharge from the Big Lost River. These constituent concentrations decrease during wetter periods, when there is probably more dilution from infiltration recharge from the Big Lost River, and increase during dry periods, when there is less recharge from the river. Concentrations in sodium in wells downgradient of the Central Facilities Area and near the southern boundary of the INL showed increasing trends in sodium concentration, whereas there was no trend in the concentrations of chloride. The increasing trend for sodium could be due to the long-term influence of wastewater disposal from upgradient facilities and the lack of trend for chloride could be because chloride is more mobile than sodium and more dispersed in the aquifer system. Volatile organic compound concentration trends were analyzed for nine aquifer wells. Trend test results indicated an increasing trend for carbon tetrachloride for the Radioactive Waste Management Complex Production Well for the period 1987–2012; however, trend analyses of data collected since 2005 show no statistically significant trend, indicating that engineering practices designed to reduce movement of volatile organic compounds to the aquifer may be having a positive effect on the aquifer.

DOE/ID-22234 New argon-argon (40Ar/39Ar) radiometric age dates from selected subsurface basalt flows at the Idaho National Laboratory, Idaho, SIR 2015-5028, 2015, 25 p. This report presents an age-dating method for basalt and provides results for 11 samples. Paleomagnetic and stratigraphic data were used to constrain the results of the age-dating experiments to derive the preferred age for each basal flow. Knowledge of the ages of subsurface basalt flows is needed to improve numerical models of groundwater flow and contaminant transport in the eastern Snake River Plain aquifer. The age of the flows can be used for correlation in the subsurface and in volcanic recurrence and landscape evolution studies that are important to better understand possible future volcanic hazards at the Idaho National Laboratory. Results indicate that ages ranged from 60 ± 16 thousand years for Quaking Aspen Butte to 621 ± 9 thousand years for State Butte.

DOE/ID-22235 Multilevel groundwater monitoring of hydraulic head and temperature in the eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, 2011-13, SIR 2015-5042, by Brian V. Twining and Jason C. Fisher, 2015, 49 p. This report is the third in the series of reports that present information on the fluid pressure and temperature in 11 multilevel monitoring wells and presents this data for 2011 through 2013. Hydraulic head (head) and groundwater temperature data were collected from 11 multilevel monitoring wells, including 177 hydraulically isolated depth intervals from 448.0 to 1,377.6 feet below land surface. Twenty-two major head inflections were described for 9 of 11 MLMS boreholes and almost always coincided with low-permeability sediment layers and occasionally thick layers of dense basalt. Vertical head gradients defined for the major inflections in the head profiles were as high as 2.9 feet per foot. Poor connectivity between fractures and higher vertical gradients were generally attributed to sediment layers and layers of dense basalt, or both. Groundwater temperatures in all boreholes ranged from 10.8 to 16.3 °C.

Boreholes in the Big Lost Trough display variations in temporal correlations in hydraulic head that may result from proximity to the mountain front to the northwest and episodic flow in the Big Lost River drainage system. For example, during June 2012, boreholes MIDDLE 2050A and MIDDLE 2051 showed head buildup within the upper zones when compared to the June 2010 profile event. This event correlates to years when surface flow was reported for the Big Lost River several months preceding the measurement period.

DOE/ID-22236 Hydrologic influences on water-level changes in the eastern Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho, 1949-2014, SIR 2015-5085, by Roy C. Bartholomay and Brian V. Twining, 2015, 36 p. This study was done to assess the effect that future water-level declines may have on wells and pumps. Water-level data were compared with pump-setting depth to determine the hydraulic head above the current pump setting. Additionally, geophysical logs were examined to address changes in well productivity with water-level declines. Furthermore, hydrologic factors that affect water levels in different areas of the INL were evaluated to help understand why water-level changes occur.

Review of pump intake placement and 2014 water-level data indicates that 40 wells completed within the ESRP aquifer at the INL have 20 feet (ft) or less of head above the pump. Nine of these wells are in the northeastern and northwestern areas of the INL, where recharge is predominantly affected by irrigation, wet and dry cycles of precipitation, and flow in the Big Lost River. Water levels in northeastern and northwestern wells generally show fluctuations of as much as 4.5 ft seasonally and declines as much as 25 ft during the past 14 years.

In the southeastern area of the INL, seven wells were identified as having less than 20 ft of water remaining above the pump. Most of the wells in the southeast show less decline over the period of record compared with wells in the northeast; the smaller declines are probably attributable to less withdrawal from wells for irrigation. In addition, most of the southeastern wells show only about a 1–2 ft fluctuation seasonally because they are less influenced by withdrawals for irrigation. In the southwestern area of the INL, 24 wells were identified as having less than 20 ft of water remaining above the pump. Wells in the southwest also only show small 1–2 ft fluctuations seasonally because of a lack of irrigation influence. Wells show larger fluctuation in water levels closer to the Big Lost River and fluctuate in response to wet and dry cycles of recharge to the river.

Geophysical logs indicate that most of the wells evaluated will maintain their current production until the water level declines to the depth of the pump. A few of the wells may become less productive once the water level gets to within about 5 ft from the top of the pump. Wells most susceptible to future drought cycles are those in the northeastern and northwestern areas of the INL.

DOE/ID-22237 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, DIR 2016-5056, by Roy C. Bartholomay and L. Flint Hall, 2016, 19 p. Although two previous background studies of groundwater chemistry had been made by the USGS at the INL, they were completed in the early 1990s and did not incorporate as much data that was available for this study and they also did not include all the same constituents as this study. Chemical and radiochemical constituents including calcium, magnesium, sodium, potassium, silica, chloride, sulfate, fluoride, bicarbonate, chromium, nitrate, tritium, strontium-90, chlorine-36, iodine-129, plutonium-238, plutonium-239, -240 (undivided), americium-241, technetium-99, uranium-234, uranium-235, and uranium-238 were selected for analysis in this background study. Samples of water collected from wells and springs at and near the INL that were not believed to be influenced by wastewater disposal were used to identify background concentrations. Water in the eastern Snake River Plain aquifer at and near the INL was divided into two major water types (western tributary and eastern regional) on the basis of concentrations of lithium less than and greater than 5 micrograms per liter (μg/L). Median concentrations for each constituent were used to define the upper limit of background. The upper limits for background for the two different water types are given in the paper for the constituents included in the study.

DOE/ID-22238 Purgeable organic compounds at or near the Idaho Nuclear Technology and Engineering Center, Idaho National laboratory, Idaho, 2015, OFR 2016-1083, by Neil V. Maimer and Roy C. Bartholomay, 2016, 17 p. For this study, samples collected from 31 wells at or near the Idaho Nuclear Technology and Engineering Center (INTEC) at the Idaho National Laboratory were analyzed for purgeable organic compounds (POCs). The samples were collected and analyzed for the purpose of evaluating whether purge water collected from sampled wells located within an aerial polygon established downgradient of the INTEC must be treated as a Resource Conservation and Recovery Act listed waste. The samples were analyzed using a method with a lower detection level than samples normally collected at the INL.

POC concentrations in water samples from 29 of 31 wells completed in the eastern Snake River Plain aquifer were greater than their detection limit, determined from detection and quantitation calculation software, for at least one to four POCs. Of the 29 wells with POC concentrations greater than their detection limits, only 20 had concentrations greater than the laboratory reporting limit. None of the concentrations exceeded any maximum contaminant levels established for public drinking water supplies. The most commonly detected compounds were 1,1,1-trichoroethane, 1,1-dichloroethene, and trichloroethene.

DOE/ID-22239 Completion summary for boreholes TAN-2271 and TAN-2272 at Test Area North, Idaho National Laboratory, Idaho, SIR 2016-5088, by Brian V. Twining, Roy C. Bartholomay, and Mary K.V. Hodges, 2016, 37 p. This report presents well completion information, geophysical logs, aquifer test results, water chemistry and a core description for two wells drilled at Test Area North (TAN) for additional information for the monitoring program near TAN along with information for the INL contractor cleanup program. Electromagnetic flow meter results were used to identify downward flow conditions that exist for boreholes TAN-2271 and TAN-2272. The transmissivity and hydraulic conductivity were estimated for the pumping well and observation well during the aquifer tests conducted on August 25 and August 27, 2015. Estimates for transmissivity range from 4.1×10^3 feet squared per day (ft^2/d) to 8.1×10^3 ft^2/d; estimates for hydraulic conductivity range from 5.8 to 11.5 feet per day (ft/d). Both TAN-2271 and TAN-2272 show sustained pumping rates of about 30 gallons per minute (gal/min) with measured drawdown in the pumping well of 1.96 ft and 1.14 ft, respectively. Water samples were collected from both wells and were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Results of analyses of the samples for strontium-90, trichloroethene, and vinyl chloride indicated that those constituents exceeded maximum contaminant levels for public drinking water supplies in one or both wells.

DOE/ID-22240 Paleomagnetic correlation of basalt flows in selected coreholes near the Advanced Test Reactor Complex, the Idaho Nuclear Technology and Engineering Center, and along the southern boundary, Idaho National Laboratory, Idaho: SIR 2016-5131, by Mary K. V. Hodges and Duane E. Champion, 2016, 65 p. This report was done as a continuation of using paleomagnetic data to better define the stratigraphy at the INL. Data for 18 coreholes was used to construct 3 cross sections in the southwestern part of the INL. Some new age dates were also used in the correlations. Flows from the surface volcanic vents Quaking Aspen Butte, Vent 5206, Mid Butte, Lavatoo Butte, Crater Butte, Pond Butte, Vent 5350, Vent 5252, Tin Cup Butte, Vent 4959, Vent 5119, and AEC Butte are found in coreholes, and were correlated to the surface vents by matching their paleomagnetic inclinations, and in some cases, their stratigraphic positions.

Some subsurface basalt flows that do not correlate to surface vents, do correlate over several coreholes, and may correlate to buried vents. Subsurface flows which correlate across several coreholes, but not to a surface vent include the D3 flow, the Big Lost flow, the CFA buried vent flow, the Early, Middle, and Late Basal Brunhes flows, the South Late Matuyama flow, the Matuyama flow, and the Jaramillo flow. The location of vents buried in the subsurface by younger basalt flows can be inferred if their flows are penetrated by several coreholes, by tracing the flows in the subsurface, and determining where the greatest thickness occurs.

DOE/ID-22241 Borehole deviation and correction factor data for selected wells in the eastern Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho, SIR 2016-5163, by Brian V. Twining, 2016, 23 p. The USGS INL Project Office has been collecting borehole deviation data as part of the geophysical logging program for many years. This paper summarizes all the information compiled for 177 wells. As of 2016, the database includes: 57 wells with gyroscopic survey data; 100 wells with magnetic deviation survey data; 11 wells with erroneous gyroscopic data that were excluded; and 68 wells with no deviation survey data available. Of the 57 wells with gyroscopic deviation surveys, correction factors for 16 wells ranged from 0.20 to 6.07 ft and inclination angles (SANG) ranged from 1.6 to 16.0 degrees. Of the 100 wells with magnetic deviation surveys, a correction factor for 21 wells ranged from 0.20 to 5.78 ft and SANG ranged from 1.0 to 13.8 degrees, not including the wells that did not meet the correction factor criteria of greater than or equal to 0.20 ft.

Both gyroscopic and magnetic deviation survey data were available for 47 wells. Datasets for both survey types were compared for the same well to determine whether magnetic survey data were consistent with gyroscopic survey data. Of those 47 wells, 96 percent showed similar correction factor estimates (≤ 0.20 ft) for both magnetic and gyroscopic well deviation surveys. A linear comparison of correction factor estimates for both magnetic and gyroscopic deviation well surveys for all 47 wells indicate good linear correlation, represented by an r-squared of 0.88. The correction factor difference between the gyroscopic and magnetic surveys for 45 of the 47 wells ranged from 0.00 to 0.18 ft. The difference in magnetic and gyroscopic well deviation SANG measurements, for all wells, ranged from 0.0 to 0.9 degrees. These data indicate good agreement between SANG data measured using the magnetic deviation survey methods and SANG data measured using gyroscopic deviation survey methods, even for surveys collected years apart.

DOE/ID-22242 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, SIR 2017-5012, by Roy C. Bartholomay, Neil V. Maimer, Gordon W. Rattray, and Jason C. Fisher, 2017, 87 p. This report is the 14th in the series on hydrologic conditions and focuses on water quality and water level data for 2012 through 2015 for aquifer and perched-water wells. Statistically significant trend graphs for concentrations are given for the first time in several of the figures; in previous reports, graphs were presented for concentration only. From March–May 2011 to March–May 2015, water levels in wells completed in the ESRP aquifer declined in all wells at the INL. Water-level declines were largest in the northern part of the INL and smallest in the southwestern part.

In 2015, concentrations of tritium in water from 49 of 118 ESRP aquifer wells were greater than or equal to the reporting level and ranged from 230±50 to 5,760±120 picocuries per liter. Concentrations of strontium-90 in water from 18 of 67 ESRP aquifer wells sampled during April or October 2015 exceeded the reporting level. During 2012–15, concentrations of cesium-137 were less than the reporting level in all but eight ESRP aquifer wells, and concentrations of plutonium-238, plutonium-239, -240 (undivided), and americium-241 were less than the reporting level in water samples from all ESRP aquifer wells and all zones in wells equipped with MLMS.

In April 2015, the concentration of chromium in water from well USGS 65 was 72.8 µg/L, considerably less than the MCL. Sodium, chloride, sulfate, and nitrate in wells near INTEC continued to show mostly decreasing trends. Eighteen volatile organic compounds (VOCs) were detected. At least 1 and up to 7 VOCs were detected in water samples from 14 wells. The principal VOCs detected include carbon tetrachloride, trichloromethane, tetrachloroethene, 1,1,1-trichloroethane, and trichloroethene. In 2015, concentrations for all VOCs were less than their respective MCL for drinking water, except carbon tetrachloride in water from two wells, trichloroethene in three wells and vinyl chloride in one well.

During 2012–15, variability and bias were evaluated from 54 replicate and 33 blank quality-assurance samples. All radiochemical constituents and trace metals had acceptable reproducibility except for gross alpha- and beta-particle radioactivity, cesium-137, antimony, cobalt, iron and manganese. Bias from sample contamination was evaluated on the basis of analyses of equipment, field, container, and source solution blanks. Some of the constituents were found at small concentrations near reporting levels, but analyses indicate that no sample bias was likely for any of the sample periods.

DOE/ID-22243 Drilling, construction, geophysical log data, and lithologic log for boreholes USGS 142 and USGS 142A, Idaho National Laboratory, Idaho, Data Series 1058, by Brian V. Twining, Mary K.V. Hodges, Kyle Schusler, and Christopher Mudge, 2017, 21 p. These wells were drilled in the west-central part of the INL to provide data for the stratigraphic framework and long-term groundwater monitoring for the western part of the aquifer. Well USGS 142 was deepened to provide research information for a possible geothermal research site that the INL was competing for; however, the INL was not selected for the second phase of funding for the project. Geophysical logs, construction information and a core log with photos of the core are presented for USGS 142. Borehole USGS 142 initially was cored to collect rock and sediment core, then re-drilled to complete construction as a screened water-level monitoring well. Borehole USGS 142A was drilled and constructed as a monitoring well after construction problems with borehole USGS 142 prevented access to the upper 100 feet (ft) of the aquifer. Boreholes USGS 142 and USGS 142A are separated by about 30 ft and have similar geology and hydrologic characteristics. Water level was first measured at nearly 530 feet below land surface (ft BLS) at both borehole locations and water levels indicate upward hydraulic gradients at this location.

Borehole USGS 142 was cored continuously, starting at the first basalt contact (about 4.9 ft BLS) to a depth of 1,880 ft BLS. Excluding surface sediment, approximately 89 percent, or 1,666 ft, of the total core from this well was recovered. The material in well USGS 142 consists of approximately 45 basalt flows, 16 sediment and (or) sedimentary rock layers, and rhyolite welded tuff. Rhyolite was encountered at approximately 1,396 ft BLS. Sediment layers comprise a large percentage of the borehole between 739 and 1,396 ft BLS, with grain sizes ranging from clay and silt to cobble size. Sedimentary rock layers had calcite cement. Basalt flows ranged in thickness from about 2 to 100 ft and varied in nature from highly fractured to dense, and ranged from massive to diktytaxitic to scoriaceous, in texture.

DOE/ID-22244 Updated procedures for using drill cores and cuttings at the lithologic core storage library, Idaho National Laboratory, Idaho, OFR 2018-1001, by Mary K.V. Hodges, Linda, C. Davis, and Roy C. Bartholomay, 2018, 48 p. This report provides an update to procedures and researchers' responsibilities for access to the facility and for examination, sampling, and return of materials. It also describes the facility and cores and cuttings stored at the facility. Descriptions of cores and cuttings include the corehole names, corehole locations, and depth intervals available in appendixes at the back of the report. As of this report, about 73,000 ft of core is housed in the core library at building CF 663 and the additional space provided in building CF 674.

DOE/ID-22245 Correlation between basalt flows and radiochemical and chemical constituents in selected wells in the southwestern part of the Idaho National Laboratory, Idaho, SIR 2017-5148, by Roy C. Bartholomay, Mary K.V. Hodges, and Duane E. Champion. 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 in water in the eastern Snake River Plain (ESRP) aquifer to better understand how flow pathways in the aquifer control the movement of wastewater discharged at INL facilities. Paleomagnetic inclination data were used to identify subsurface basalt flows on the basis of similar inclination measurements, polarity, and stratigraphic position. Tritium concentrations in the water, along with other chemical information for wells for which tritium data 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 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. The water in all the wells in which the AEC Butte flow is present is influenced by wastewater, 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.

DOE/ID-22246 Geochemistry of groundwater in the eastern Snake River Plain aquifer, Idaho National Laboratory and vicinity, eastern Idaho, Professional Paper (PP) 1837-A, by Gordon W. Rattray, 2018, 198 p. This report is the first chapter of four planned chapters on the INL geochemistry of the eastern Snake River Plain (ESRP) aquifer and focuses mostly on all the different sources of recharge, mixing of water and directions of groundwater flow that make up the aquifer water at the INL. The geochemistry data from 167 sample sites at and near the INL were analyzed. The sites included 150 groundwater, 13 surface-water and 4 geothermal sites. Data were collected between 1952 and 2012, although most data used in the analyses were collected from 1989 to 1996. Water samples were analyzed for selected constituents including dissolved gases, major ions, dissolved metals, isotope ratios, and environmental tracers.

Sources of recharge to the ESRP aquifer identified at the INL were regional groundwater, groundwater inflow from the Little Lost River (LLR) and Birch Creek (BC) valleys, groundwater from the Lost River Range, geothermal water, and the infiltration of surface water from the Big Lost River (BLR), LLR, and BC. Recharge from the BLR that may have occurred during the last glacial epoch, or paleorecharge, may be present at several wells in the southwestern part of the INL. Mixing of water at the INL primarily included mixing of surface water with groundwater from the tributary valleys and mixing of geothermal water with regional groundwater. Additionally, a zone of mixing between tributary valley water and regional groundwater, trending southwesterly, extended from near the northeastern boundary of the INL to the southern boundary of the INL. Flow directions for regional groundwater were southwesterly, and flow directions for tributary groundwater were southeasterly upon entering the ESRP aquifer, but the water eventually began to flow southwesterly in a direction parallel with regional groundwater.

Several discrepancies were identified from comparison of sources of recharge determined from geochemistry data and backward particle tracking with a groundwater-flow model. Some discrepancies observed in the particle-tracking results included representation of recharge from BC near the north INL boundary, groundwater from the BC valley not extending far enough south, regional groundwater that extends too far west in the southern part of the INL, and no representation of recharge from geothermal water in the upper groundwater flow model layer or recharge from the BLR in the southwestern part of the INL.

DOE/ID-22247 Completion summary for borehole TAN-2312 at Test Area North, Idaho National Laboratory, Idaho, SIR-2018-5118, by Brian V. Twining, Roy C. Bartholomay, and Mary K.V. Hodges, 2018, 29 p. This report presents well completion information, geophysical logs, aquifer test results, water chemistry and a core description of one well drilled at Test Area North (TAN) for additional information for the monitoring program near TAN along with information for the INL contractor cleanup program. Well TAN 2312 was drilled as a downgradient monitoring well for wastewater constituents discharged at TAN. It was continuously cored to 568 ft below land surface (BLS) and completed as a monitoring well at a depth of 522 ft BLS. The water level was measured at about 244 ft BLS.

The transmissivity and hydraulic conductivity were estimated for the pumping well from a single well aquifer test completed on September 27, 2017. The estimate for transmissivity was 1.51×10^2 feet squared per day (ft^2/d); estimate for hydraulic conductivity was 0.23 feet per day (ft/d). During the 220-minute aquifer test, well TAN-2312 had about 23 ft of measured drawdown at a sustained pumping rate of 27.2 gallons per minute. Groundwater samples were collected and were analyzed for cations, anions, metals, nutrients, volatile organic compounds, stable isotopes, and radionuclides. Analyses of the samples for stable isotopes of oxygen, hydrogen, and sulfur indicated some possible influence of irrigation on the water chemistry. The volatile organic compound data indicated that this well had some minor influence by wastewater disposal practices at Test Area North.

DOE/ID-22248 Evaluation of chemical and hydrologic processes in the eastern Snake River Plain aquifer based on results from geochemical modeling, Idaho National laboratory, eastern Idaho, PP 1837-B, by Gordon W. Rattray, 2019, 85 p. This report is the second in the series of chapters of Professional Papers on the USGS study program at INL and focuses on the geochemical modeling aspect of the program. The models were developed on the basis of the chemistry of 127 water samples collected from sites at and near the INL. The samples were collected between 1952 and 2017 with most of the samples collected during the mid-1990s. Geochemistry and isotopic data used in geochemical modeling consisted of concentrations of dissolved oxygen, carbon dioxide, major ions, silica, aluminum, iron, and the stable isotope ratios of hydrogen, oxygen, and carbon. Geochemical modeling results indicated that the primary chemical reactions in the aquifer were precipitation of calcite and dissolution of plagioclase (An60) and basalt volcanic glass. Secondary minerals other than calcite included calcium montmorillonite and goethite. Reverse cation exchange, consisting of sodium exchanging for calcium on clay minerals, occurred near site facilities where large amounts of sodium were released to the ESRP aquifer in wastewater discharge. Reverse cation exchange acted to retard the movement of wastewater-derived sodium in the aquifer.

Regional groundwater inflow was the primary source of recharge to the aquifer underlying the Northeast and Southeast INL Areas. Birch Creek (BC), the Big Lost River (BLR), and groundwater from BC valley provided recharge to the North INL Area, and the BLR and groundwater inflow from BC and Little Lost River (LLR) valleys provided recharge to the Central INL Area. The BLR, groundwater from the BLR and LLR valleys and the Lost River Range, and precipitation provided recharge to the Northwest and Southwest INL Areas. The primary source of recharge west and southwest of the INL was groundwater inflow from BLR valley. Upwelling geothermal water was a small source of recharge at two wells. Aquifer recharge from surface water in the northern, central, and western parts of the INL indicated that the aquifer in these areas was a dynamic, open system, whereas the aquifer in the eastern part of the INL, which receives little recharge from surface water, was a relatively static and closed system.

Sources of recharge identified with a groundwater flow model (using particle tracking) and geochemical modeling were similar for the Northeast and Southeast INL Areas. However, differences between the models were that the geochemical model represented (1) recharge of groundwater from the Lost River Range in the western part of the INL, whereas the flow model did not, (2) recharge of groundwater from the BC and BLR valleys extending farther south and east, respectively, than in the flow model, and (3) more recharge from the BLR in the Southwest INL Area than in the flow model. Mixing of aquifer water beneath the INL included (1) mixing of regional groundwater and water from the BC valley in the Northeast and Southeast INL Areas and (2) mixing of surface water (primarily from the BLR) and groundwater across much of the North, Central, Northwest, and Southwest INL Areas. Local recharge from precipitation mixed with groundwater in the Northwest and Southwest INL Areas, and local upwelling geothermal water mixed with groundwater in the Central and Northeast INL Areas. Flow directions of regional groundwater were southward in the eastern part of the INL and south-southwesterly at downgradient locations. Groundwater from the BC and LLR valleys initially flowed southeasterly before changing to south-southwest flow directions that paralleled regional groundwater, and groundwater from the BLR valley initially flowed south before changing to a south-southwest direction.

Wastewater-contaminated groundwater flowed south from the Idaho Nuclear Technology and Engineering Center (INTEC) infiltration ponds in a narrow plume, with the percentage of wastewater in groundwater decreasing due to dilution, dispersion, and (or) degradation from about 60–80 percent wastewater 0.7–0.8-mile (mi) south of the INTEC infiltration ponds to about 1.4 percent wastewater about 15.5 mi south of the INTEC infiltration ponds. Wastewater contaminated groundwater flowed southeast and then southwest from the Naval Reactors Facility industrial waste ditch, with the percentage of wastewater in groundwater decreasing from about 100 percent wastewater adjacent to the waste ditch to about 2 percent wastewater about 0.6 mi south of the waste ditch.

DOE/ID-22249 Transmissivity and geophysical data for selected wells at and near the Idaho National Laboratory, Idaho, 2017-18, SIR 2019-5134, by Brian V. Twining and Neil V. Maimer, 2019, 30 p. This paper is an update to the transmissivity study completed in the early 1990s using similar methods. Aquifer water levels had decreased from 10 to 35 ft since previous tests and many new wells had been drilled since the first sitewide tests. Geophysical log data for several wells is given to better show fracture density and flow movement in the aquifer. Aquifer tests were conducted during 2017–18 on 101 wells at and near the INL. These were short-duration aquifer tests, conducted with a limited number of water-level and discharge rate observations during routine sampling. Pumped intervals (water columns) for individual wells ranged from 12 to 790 feet (ft). Semi-constant discharge rates during aquifer testing ranged from 1 to 45 gallons per minute (gal/min), water-level response to pumping ranged from no observed drawdown to 52.4 ft, and length of aquifer tests for individual wells ranged from 10 to 160 minutes. Estimates of specific capacity for individual wells ranged from less than (<) 1.0 to greater than (>) 3.0×10^3 gallons per minute per foot; estimates of transmissivity for individual wells ranged from 2.0 to $>5.4 \times 10^5$ feet squared per day (ft^2/d).

Review of well productivity included examination of aquifer test data for 65 wells collected during this investigation and previous investigations spanning about 30 years. Additionally, hydrograph data were presented for a similar period of record at four selected well locations to provide a snapshot of the general water-level change along the north end of the INL, the center of the INL, and along the south end of the INL. Eleven of the 65 wells showed a change in productivity—six wells with increased productivity and five wells with decreased productivity. Declines in water levels and changes in well conditions seemed to affect about 17 percent of individual wells.

Estimates of transmissivity were divided into five categories, ranging from very low to very high values. About 53 percent of the wells tested suggest high or very high transmissivity (>10,000 ft^2/d), about 23 percent of the wells tested show low or very low (referred to as “lower”) transmissivity (≤1,000 ft^2/d), and about 24 percent of wells tested suggest moderate transmissivity (>1,000–10,000 ft^2/d). Location of volcanic vent corridors along with dike systems under the subsurface were examined in conjunction with wells that indicate lower transmissivity (≤1,000 ft^2/d) to develop inferred areas of lower transmissivity. Based on data from 24 individual wells, eight inferred regions were identified that show low and very low transmissivity. The largest inferred area of lower transmissivity (≤1,000 ft^2/d) seems to extend from the Lost River Range through the center of the INL and crosses the southern INL boundary near Atomic City. Seven other inferred regions of lower transmissivity (>1,000 ft^2/d) were identified in areas where volcanic vent corridors were previously identified.

DOE/ID-22250 Iodine-129 in the eastern Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho 2017-18, SIR 2019-5133, by Neil V. Maimer and Roy C. Bartholomay, 2019, 20 p., As a continuation of attempting to collect samples of water from the eastern Snake River Plain aquifer for analysis of ^{129}I about every 5 years, the USGS sampled 30 wells during 2017 and 2018. Concentrations of ^{129}I in the samples ranged from 0.000016 ± 0.000001 to 0.88+/- 0.03 picocuries per liter (pCi/L), and concentrations generally decreased in wells near the INTEC as compared with concentrations in previously collected samples. The average concentration of ^{129}I in 15 wells sampled during 5 different sample periods decreased from 1.15 pCi/L in 1990–91 to 0.168 pCi/L in 2017–18, but average concentrations were similar to 2011–12 within analytical uncertainty. All but four wells within a 3-mile radius of the INTEC showed decreases in concentration, and all samples had concentrations less than the U.S. Environmental Protection Agency’s maximum contaminant level of 1 pCi/L. These decreases are attributed to the discontinuation of disposal of ^{129}I in wastewater and to dilution and dispersion in the aquifer. Some wells southeast of INTEC showed increasing trends; these increases were attributed to variable transmissivity. Although wells near INTEC sampled in 2017–18 showed decreases in concentrations compared with data collected previously, some wells south of the INL boundary showed small increases. These increases are attributed to historical variable discharge rates of wastewater that eventually moved to these well locations as a pulse of water from a particular disposal period.

DOE/ID-22251 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 2016-18, SIR 2019-5149, by Roy C. Bartholomay, Neil V. Maimer, Gordon W. Rattray, and Jason C. Fisher, 2020, 82 p. This report is the 15th in the series on hydrologic conditions and focuses on water quality and water level data for 2016 through 2018 for aquifer and perched wells. From March–May 2015 to March–May 2018, water levels in wells completed in the eastern Snake River Plain (ESRP) aquifer declined from 0.5 to 3 ft in wells in the northern part of the INL and increased from 0.5 to 3 ft in the southwestern.

In 2018, concentrations of tritium in water from 46 of 111 ESRP aquifer wells were greater than or equal to the reporting level and ranged from 260±50 to 5,100±190 picocuries per liter. Table 7 of this report gives several low-level tritium concentrations. Concentrations of strontium-90 in water from 17 of 60 ESRP aquifer wells sampled during April or October 2018 exceeded the reporting level and ranged from 2.2+/-0.7 to 363+/-19 pCi/L in a new well near Test Area North. During 2016–18, concentrations of cesium-137 were less than the reporting level in all but one ESRP aquifer well, and concentrations of plutonium-238, plutonium-239, -240 (undivided), and americium-241 were less than the reporting level in water samples from all ESRP aquifer wells.

In April 2018, the concentration of chromium in water from well USGS 65 was 76 μg/L, less than the MCL. Concentrations of sodium, chloride, sulfate, and nitrate in wells near INTEC continued to show mostly downward trends. Sulfate concentrations in southwestern part of the INL ranged from 22 to 151 mg/L. Two wells near INTEC showed increasing trends possibly due to tank farm waste being mobilized to the aquifer. Sixteen volatile organic compounds (VOCs) were detected. At least 1 and up to 7 VOCs were detected in water samples from 15 wells. The principal VOCs detected include carbon tetrachloride, trichloromethane, tetrachloroethene, 1,1,1-trichloroethane, and trichloroethene. In 2018, concentrations for all VOCs were less than their respective MCL for drinking water, except carbon tetrachloride in water from two wells, trichloroethene in one well.

During 2016–18, variability and bias were evaluated from 37 replicate and 15 blank quality-assurance samples. Constituents with acceptable reproducibility were major ions, trace elements, nutrients and VOCs. All radiochemical constituents had acceptable reproducibility except for gross-alpha and beta radioactivity. Bias from sample contamination was evaluated from equipment, field, and source solution blanks. Some of the constituents were found at small concentrations near reporting levels, but analyses indicate that no sample bias was likely for any of the sample periods.

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