

DOE/ID-22226

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

# **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**



Scientific Investigations Report 2013–5214

**Cover:** Photograph of the U.S. Geological Survey Idaho National Laboratory Project Office scientists setting up for water sample collection at well USGS 35. (Photograph courtesy of the USGS Idaho National Laboratory Project Office, October 22, 2003)

# **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**

By Linda C. Davis, Roy C. Bartholomay, and Gordon W. Rattray

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Scientific Investigations Report 2013–5214

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

**U.S. Department of the Interior**  
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U.S. Geological Survey, Reston, Virginia: 2013

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Suggested citation:

Davis, L.C., Bartholomay, R.C., and Rattray, G.W., 2013, 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: U.S. Geological Survey Scientific Investigations Report 2013–5214, (DOE/ID-22226), 90 p., <http://dx.doi.org/10.3133/sir20135214>.

ISSN -2328-0328 (online)

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# Conversion Factors, Datums, and Abbreviations and Acronyms

## Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m <sup>2</sup> )
square foot (ft <sup>2</sup> )	0.09290	square meter (m <sup>2</sup> )
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
Volume		
gallon (gal)	3.785	liter
million gallons (Mgal)	3,785	cubic meter (m <sup>3</sup> )
acre-foot (acre-ft)	1,233	cubic meter (m <sup>3</sup> )
Flow rate		
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m <sup>3</sup> /yr)
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
cubic foot per second per square mile [(ft <sup>3</sup> /s)/mi <sup>2</sup> ]	0.01093	cubic meter per second per square kilometer [(m <sup>3</sup> /s)/km <sup>2</sup> ]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m <sup>3</sup> /s)
Mass		
pound, avoirdupois (lb)	0.4536	kilogram (kg)
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Transmissivity*		
foot squared per day (ft <sup>2</sup> /d)	0.09290	meter squared per day (m <sup>2</sup> /d)

## Conversion Factors, Datums, and Abbreviations and Acronyms

SI to Inch/Pound

Multiply	By	To obtain
Volume		
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
Radioactivity		
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

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

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

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

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

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

### Datums

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

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

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

# Conversion Factors, Datums, and Abbreviations and Acronyms

## Abbreviations and Acronyms

Abbreviation or acronym	Definition
ATR Complex	Advanced Test Reactor Complex (formerly RTC, Reactor Technology Complex; and TRA, Test Reactor Area)
CFA	Central Facilities Area
Ci	Curie
DOE	Department of Energy
ESRP	eastern Snake River Plain
ICPP	Idaho Chemical Processing Plant
INEL	Idaho National Engineering Laboratory (1974–97)
INEEL	Idaho National Engineering and Environmental Laboratory (1997–2005)
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LRL	laboratory reporting level
LT-MDL	long-term method detection level
MCL	maximum contaminant level
MDL	method detection limit
MRL	minimum reporting level
MLMS	multilevel monitoring system
NAD	normalized absolute difference
NRF	Naval Reactors Facility
NRTS	National Reactor Testing Station (1949–74)
NWIS	National Water Information System
NWQL	National Water Quality Laboratory (USGS)
PBF	Power Burst Facility
QA	quality assurance
RESL	Radiological and Environmental Sciences Laboratory (DOE)
RSD	relative standard deviation
RWMC	Radioactive Waste Management Complex
RWMC PROD	RWMC Production Well
<i>s</i>	sample standard deviation
SDA	Subsurface Disposal Area
TAN	Test Area North
TRA DISP	TRA disposal well
TSF	Technical Support Facility
TOC	total organic carbon
USGS	U.S. Geological Survey
VOC	volatile organic compound

# 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

By Linda C. Davis, Roy C. Bartholomay, and Gordon W. Rattray

## Abstract

Since 1952, wastewater discharged to infiltration ponds (also called percolation ponds) and disposal wells at the Idaho National Laboratory (INL) has affected water quality in the eastern Snake River Plain (ESRP) aquifer and perched groundwater zones underlying the INL. The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy, maintains groundwater monitoring networks at the INL to determine hydrologic trends, and to delineate the movement of radiochemical and chemical wastes in the aquifer and in perched groundwater zones. This report presents an analysis of water-level and water-quality data collected from aquifer, multilevel monitoring system (MLMS), and perched groundwater wells in the USGS groundwater monitoring networks during 2009–11.

Water in the ESRP aquifer primarily moves through fractures and interflow zones in basalt, generally flows southwestward, and eventually discharges at springs along the Snake River. The aquifer primarily is recharged from infiltration of irrigation water, infiltration of streamflow, groundwater inflow from adjoining mountain drainage basins, and infiltration of precipitation.

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 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 groundwater from 50 of 127 aquifer wells were greater than or equal to the reporting level and ranged from  $200\pm 60$  to

$7,000\pm 260$  picocuries per liter. Tritium concentrations from one or more discrete zones from four wells equipped with MLMS were greater than or equal to reporting levels in water samples collected at various depths. Tritium concentrations in water from wells completed in shallow perched groundwater at the Advanced Test Reactor Complex (ATR Complex) were less than the reporting levels. Tritium concentrations in deep perched groundwater at the ATR Complex equaled or exceeded the reporting level in 12 wells during at least one sampling event during 2009–11 at the ATR Complex.

Concentrations of strontium-90 in water from 20 of 76 aquifer wells sampled during April or October 2011 exceeded the reporting level. Strontium-90 was not detected within the ESRP aquifer beneath the ATR Complex. During at least one sampling event during 2009–11, concentrations of strontium-90 in water from 10 wells completed in deep perched groundwater at the ATR Complex equaled or exceeded the reporting levels.

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. Concentrations of cesium-137 were equal to or slightly above the reporting level in 8 aquifer wells and from 2 wells equipped with MLMS.

The concentration of chromium in water from one well south of the ATR Complex was 97 micrograms per liter ( $\mu\text{g/L}$ ) in April 2011, just less than the maximum contaminant level (MCL) of  $100\ \mu\text{g/L}$ . Concentrations of chromium in water samples from 69 other wells sampled ranged from  $0.8\ \mu\text{g/L}$  to  $25\ \mu\text{g/L}$ . During 2009–11, dissolved chromium was detected in water from 15 wells completed in perched groundwater at the ATR Complex.

In 2011, concentrations of sodium in water from most wells in the southern part of the INL were greater than the background concentration of 10 milligrams per liter ( $\text{mg/L}$ ); the highest concentrations were at or near the Idaho Nuclear Engineering and Technology Center (INTEC). After the new

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percolation ponds were put into service in 2002 southwest of the INTEC, concentrations of sodium in water samples from the Rifle Range well rose steadily until 2008, when the concentrations generally began decreasing. The increases and decreases were attributed to disposal variability in the new percolation ponds. Concentrations of sodium in most wells equipped with MLMS generally were consistent with depth. During 2011, dissolved sodium concentrations in water from 17 wells completed in deep perched groundwater at the ATR Complex ranged from 6 to 146 mg/L.

In 2011, concentrations of chloride in most water samples from aquifer wells south of the INTEC and at the Central Facilities Area exceeded the background concentrations of 15 mg/L, but were less than the secondary MCL of 250 mg/L. Chloride concentrations in water from wells south of the INTEC have generally increased because of increased chloride disposal to the old percolation ponds since 1984 when discharge of wastewater to the INTEC disposal well was discontinued. After the new percolation ponds were put into service in 2002 southwest of the INTEC, concentrations of chloride in water samples from one well rose steadily until 2008 then began decreasing. Chloride concentrations in water from all but one well completed in the ESRP aquifer at or near the ATR Complex were less than background and ranged between 10 and 14 mg/L during 2011, similar to concentrations detected during the 2006–08 reporting period. During 2011, chloride concentrations in water from two aquifer wells at the Radioactive Waste Management Complex (RWMC) were slightly greater than concentrations detected during the 2006–08 reporting period. The vertical distribution of chloride concentrations in wells equipped with MLMS were generally consistent within zones during 2009–11 and ranged from about 8 to 20 mg/L. During April 2011, dissolved chloride concentrations in shallow perched groundwater at the ATR Complex ranged from 7 to 13 mg/L in water from three wells. Dissolved chloride concentrations in deep perched groundwater at the ATR Complex during 2011 ranged from 4 to 54 mg/L.

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. In 2011, sulfate concentrations in water samples from two wells near the RWMC were greater than background levels and could have resulted from well construction techniques and (or) waste disposal at the RWMC. The vertical distribution of sulfate concentrations in three wells near the southern boundary of the INL was generally consistent with depth, and ranged between 19 and 25 mg/L. The maximum dissolved sulfate concentration in shallow perched groundwater near the

ATR Complex was 400 mg/L in well CWP 1 in April 2011. During 2009–11, the maximum concentration of dissolved sulfate in deep perched groundwater at the ATR Complex was 1,550 mg/L in a well located west of the chemical-waste pond.

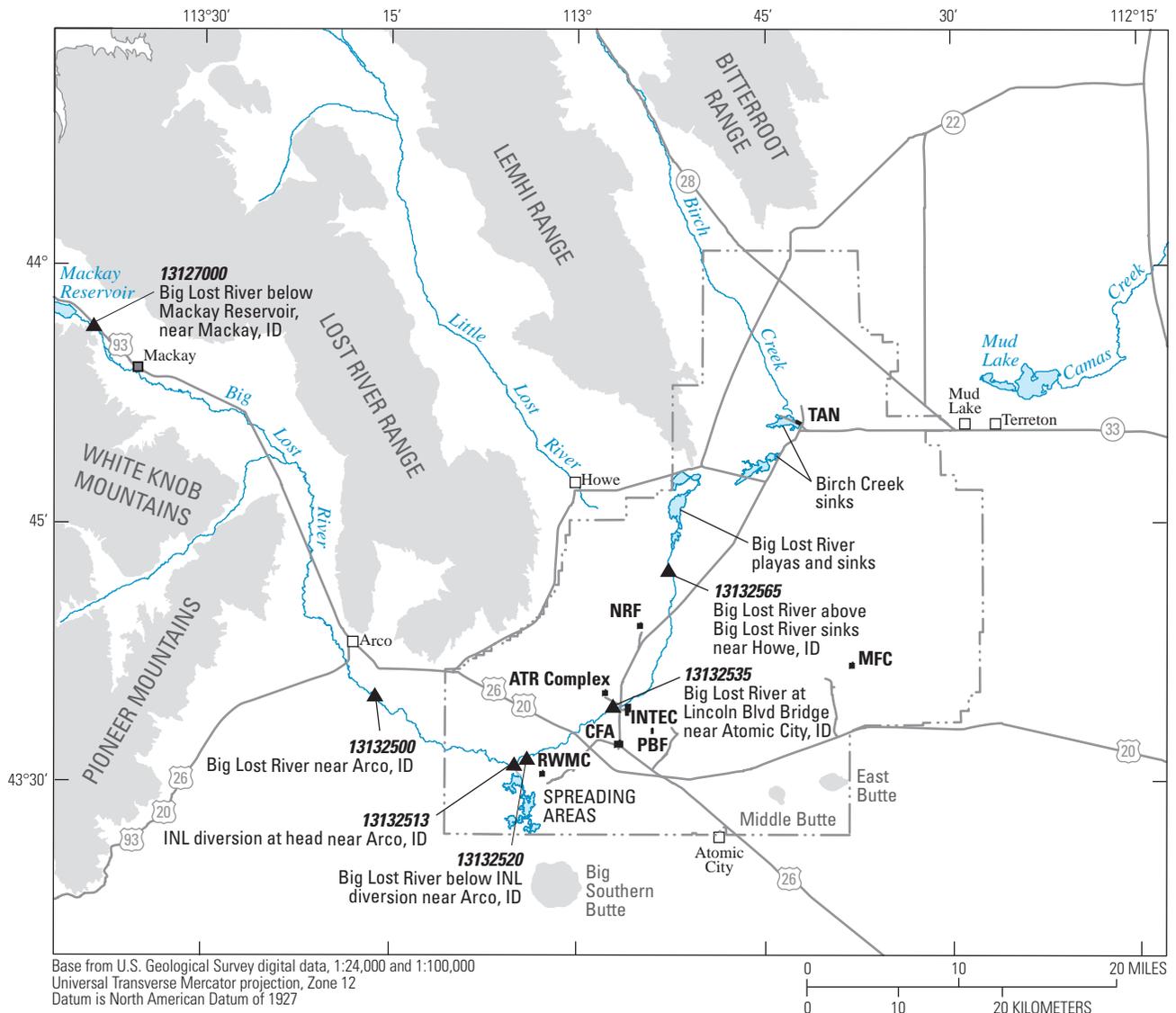
In 2011, concentrations of nitrate in water from most wells at and near the INTEC exceeded the regional background concentrations of 1 mg/L and ranged from 1.6 to 5.95 mg/L. Concentrations of nitrate in wells south of INTEC and farther away from the influence of disposal areas and the Big Lost River show a general decrease in nitrate concentrations through time.

During 2009–11, water samples from 30 wells were collected and analyzed for volatile organic compounds (VOCs). Six VOCs were detected. At least one and up to five VOCs were detected in water samples from 10 wells. The primary 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 were evaluated from 56 replicate and 16 blank quality-assurance samples. Results from replicate analyses were investigated to evaluate sample variability. Constituents with acceptable reproducibility were stable isotope ratios, major ions, nutrients, and VOCs. All radiochemical constituents and trace metals had acceptable reproducibility except for gross beta-particle radioactivity, aluminum, antimony, and cobalt. Bias from sample contamination was evaluated from 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.

## Introduction

The Idaho National Laboratory (INL), operated by the U.S. Department of Energy (DOE), encompasses about 890 mi<sup>2</sup> of the eastern Snake River Plain (ESRP) in southeastern Idaho ([fig. 1](#)). Names formerly used for this site, from earliest to most recent, were National Reactor Testing Station (NRTS, 1949–74), Idaho National Engineering Laboratory (INEL, 1974–97), and Idaho National Engineering and Environmental Laboratory (INEEL, 1997–2005). The INL facilities are used in the development of peacetime atomic-energy applications, nuclear safety research, defense programs, environmental research, and advanced energy concepts.



**EXPLANATION**

■	<b>Selected facilities at the Idaho National Laboratory</b>
MFC	Materials and Fuels Complex
CFA	Central Facilities Area
INTEC	Idaho Nuclear Technology and Engineering Center
NRF	Naval Reactors Facility
PBF	Power Burst Facility
RWMC	Radioactive Waste Management Complex
ATR Complex	Advanced Test Reactor Complex—formerly known as Reactor Technology Complex (RTC) and Test Reactor Area (TRA)
TAN	Test Area North
---	<b>Boundary of Idaho National Laboratory</b>
▲ 13132513	<b>USGS streamgage and number</b>

Figure 1. Location of the Idaho National Laboratory, USGS streamgages, and selected facilities, Idaho.

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Radiochemical and chemical wastewater generated at these facilities has been discharged to onsite infiltration ponds, evaporation ponds, disposal wells, or a combination thereof since 1952. Wastewater disposal has resulted in detectable concentrations of several waste constituents in water from the ESRP aquifer underlying the INL. Disposal of wastewater to infiltration ponds and infiltration of surface water at waste-burial sites resulted in the formation of perched groundwater in basalts and in sedimentary interbeds that overlie the ESRP aquifer (Cecil and others, 1991). Perched groundwater is an integral part of the pathway for waste-constituent migration to the aquifer.

The DOE requires information about the mobility of radiochemical- and chemical-waste constituents in the ESRP aquifer and in perched groundwater above the aquifer to assess the impact of INL facility operations on water quality, and to aid in remediation activities. Waste-constituent mobility is determined, in part, by (1) the rate and direction of groundwater flow, (2) the locations, quantities, and methods of waste disposal, (3) waste-constituent chemistry, and (4) the geochemical processes taking place in the aquifer. This study was conducted by the U.S. Geological Survey (USGS) in cooperation with the DOE Idaho Operations Office.

### Purpose and Scope

In 1949, the U.S. Atomic Energy Commission, which later became the DOE, requested that the USGS describe the water resources of the area now known as the INL. The purpose of the resulting study was to characterize these resources before the development of nuclear-reactor testing facilities. Since that time, the USGS has maintained water-level and water-quality monitoring networks at the INL to determine hydrologic trends and to delineate the movement of radiochemical and chemical wastes in the ESRP aquifer and in perched groundwater.

Most of the wells in the USGS monitoring network were constructed as open boreholes and are open to the aquifer through their entire depth below the water table. Beginning in 2005, the USGS and the INL contractor collaborated to instrument two wells (Middle 2050A and Middle 2051) with multilevel monitoring systems (MLMS) to collect water samples for analysis in order to describe the

vertical distribution of constituents in the ESRP aquifer. The USGS expanded the program during 2006–10 to include seven additional wells (USGS 103, 105, 108, 132, 133, 134, and 135). Water chemistry, vertical hydraulic head, and water temperature data were collected from the MLMS during 2005–11 (Bartholomay and Twining, 2010; Fisher and Twining, 2011; Twining and Fisher, 2012).

This report presents an analysis of water-level and water-quality data collected from wells in the USGS groundwater monitoring networks during 2009–11 as part of the continuing hydrogeologic investigations conducted by the USGS at the INL. This report describes the distribution and concentration of selected radiochemical and chemical constituents in groundwater and perched groundwater at the INL, the vertical distribution of selected constituents from samples collected with MLMS, and the changes in the regional water levels since 2008. The report also summarizes the history of waste disposal at the Advanced Test Reactor Complex (ATR Complex; formerly known as the Test Reactor Area, TRA), Idaho Nuclear Technology and Engineering Center (INTEC; formerly known as the Idaho Chemical Processing Plant, ICPP), Radioactive Waste Management Complex (RWMC), Test Area North (TAN), Naval Reactors Facility (NRF), and the Central Facilities Area (CFA).

### Previous Investigations

Hydrologic conditions and the distribution of selected wastewater constituents in groundwater and perched groundwater are discussed in a series of reports describing the INL. [Table 1](#) summarizes selected previous investigations of the geology, hydrology, and water characteristics at and near the INL, and periods included in those investigations. Numerous previous investigations of the hydrology and geology at the INL have been done by INL contractors, state agencies, and the USGS. Copies of most published reports for previous USGS studies at the INL are available from the USGS Publications Warehouse Web site at <http://pubs.er.usgs.gov/> (U.S. Geological Survey, 2013a). A list of all the reports published by the USGS on project work done at the INL can be found at <http://id.water.usgs.gov/projects/INL/pubs.html>. (U.S. Geological Survey, 2013b).

**Table 1.** Summary of selected previous investigations on geology, hydrology, and water characteristics of groundwater and perched groundwater, Idaho National Laboratory, Idaho, 1961–2012.

[Names for the Idaho National Laboratory have changed numerous times since 1949. Names formerly used for this site were: the National Reactor Testing Station (NRTS), 1949 to 1974; the Idaho National Engineering Laboratory (INEL), 1974–1997; the Idaho National Engineering and Environmental Laboratory (INEEL), 1997–2005; and the Idaho National Laboratory (INL), 2005 to present (2013). **Abbreviations:** TRA, Test Reactor Area; INTEC, Idaho Nuclear Technology and Engineering Center (formerly the ICPP, Idaho Chemical Processing Plant); RWMC, Radioactive Waste Management Complex (formerly the solid waste burial ground)]

Reference	Investigation period	Summary
Groundwater		
Jones (1961)		Hydrology of waste disposal at the NRTS, Idaho.
Olmsted (1962)		Chemical and physical character of groundwater at the NRTS, Idaho.
Morris and others (1963, 1964, 1965)		Hydrology of waste disposal at the NRTS, Idaho.
Barracough and others (1967a)	1965	Hydrology of the NRTS, Idaho.
Barracough and others (1967b)	1966	Hydrology of the NRTS, Idaho.
Nace and others (1975)		Generalized geologic framework of the NRTS, Idaho.
Robertson and others (1974)		Effects of waste disposal on the geochemistry of groundwater at the NRTS, Idaho.
Barracough and others (1976)		Hydrology of the solid waste burial ground (now the RWMC).
Barracough and Jenson (1976)	1971–73	Hydrologic data for the INEL, Idaho.
Barracough and others (1981)	1974–78	Hydrologic conditions for the INEL, Idaho.
Lewis and Jenson (1985) <a href="http://pubs.er.usgs.gov/publication/ha674">http://pubs.er.usgs.gov/publication/ha674</a>	1979–81	Hydrologic conditions for the INEL, Idaho.
Pittman and others (1988) <a href="http://pubs.er.usgs.gov/publication/wri894008">http://pubs.er.usgs.gov/publication/wri894008</a>	1982–85	Hydrologic conditions for the INEL, Idaho.
Orr and Cecil (1991) <a href="http://pubs.er.usgs.gov/publication/wri914047">http://pubs.er.usgs.gov/publication/wri914047</a>	1986–88	Hydrologic conditions and distribution of selected chemical constituents in water at the INEL, Idaho.
Bartholomay and others (1995)	1989–91	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in water, INEL, Idaho.
Bartholomay and others (1997) <a href="http://pubs.er.usgs.gov/publication/wri974086">http://pubs.er.usgs.gov/publication/wri974086</a>	1992–95	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in water, INEL, Idaho.
Bartholomay and others (2000) <a href="http://pubs.er.usgs.gov/publication/wri004192">http://pubs.er.usgs.gov/publication/wri004192</a>	1996–98	Hydrologic conditions and distribution of selected constituents in water, INEEL, Idaho.
Davis (2006b) <a href="http://pubs.er.usgs.gov/publication/sir20065088">http://pubs.er.usgs.gov/publication/sir20065088</a>	1999–2001	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in water, INL, Idaho.
Ackerman and others (2006) <a href="http://pubs.er.usgs.gov/publication/sir20065122">http://pubs.er.usgs.gov/publication/sir20065122</a>		Conceptual model of groundwater flow in the eastern Snake River Plain aquifer, INL, with implications for contaminant transport.
Davis (2008) <a href="http://pubs.er.usgs.gov/publication/sir20085089">http://pubs.er.usgs.gov/publication/sir20085089</a>	2002–05	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in groundwater and perched groundwater, INL, Idaho.

## 6 Hydrologic Conditions and Distribution of Selected Constituents in Water, Idaho National Laboratory, Idaho, 2009–11

**Table 1.** Summary of selected previous investigations on geology, hydrology, and water characteristics of groundwater and perched groundwater, Idaho National Laboratory, Idaho, 1961–2012.—Continued

[Names for the Idaho National Laboratory have changed numerous times since 1949. Names formerly used for this site were: the National Reactor Testing Station (NRTS), 1949 to 1974; the Idaho National Engineering Laboratory (INEL), 1974–1997; the Idaho National Engineering and Environmental Laboratory (INEEL), 1997–2005; and the Idaho National Laboratory (INL), 2005 to present (2013). **Abbreviations:** ATR Complex, Advanced Test Reactor Complex (formerly the TRA, Test Reactor Area and RTC, Reactor Technology Complex ); INTEC, Idaho Nuclear Technology and Engineering Center (formerly the ICPP, Idaho Chemical Processing Plant); RWMC, Radioactive Waste Management Complex (formerly the solid waste burial ground)]

Reference	Investigation period	Summary
Groundwater—Continued		
Davis (2010) <a href="http://pubs.er.usgs.gov/publication/sir20105197">http://pubs.er.usgs.gov/publication/sir20105197</a>	2006–08	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in groundwater and perched groundwater, INL, Idaho.
Bartholomay and Twining (2010) <a href="http://pubs.er.usgs.gov/publication/sir20105116">http://pubs.er.usgs.gov/publication/sir20105116</a>	2006–08	Vertical distribution of selected constituents in water from wells equipped with multilevel monitoring systems, INL, Idaho.
Fisher and Twining (2011) <a href="http://pubs.er.usgs.gov/publication/sir20105253">http://pubs.er.usgs.gov/publication/sir20105253</a>	2007–08	Multilevel groundwater monitoring of hydraulic head and temperature in the eastern Snake River Plain aquifer, INL, Idaho.
Twining and Fisher (2012) <a href="http://pubs.er.usgs.gov/publication/sir20125259">http://pubs.er.usgs.gov/publication/sir20125259</a>	2009–10	Multilevel groundwater monitoring of hydraulic head and temperature in the eastern Snake River Plain aquifer, INL, Idaho.
Bartholomay and others (2012) <a href="http://pubs.er.usgs.gov/publication/sir20125169">http://pubs.er.usgs.gov/publication/sir20125169</a>	1949–2009	Water-quality characteristics and trends for selected sites at and near the INL, Idaho.
Perched groundwater		
Barraclough and others (1967a)	1965	Extent of perched groundwater and distribution of selected wastewater constituents in perched groundwater at the TRA.
Barraclough and others (1967b)	1966	Extent of perched groundwater and distribution of selected wastewater constituents in perched groundwater at the TRA.
Robertson and others (1974)		Analysis of perched groundwater and conditions related to the disposal of wastewater to the subsurface at the INEL.
Barraclough and Jensen (1976)		Extent of perched groundwater and distribution of selected wastewater constituents in perched groundwater at the TRA.
Robertson (1977)		Numerical model simulating flow and transport of chemical and radionuclide constituents through perched groundwater at the TRA.
Barraclough and others (1981) <a href="http://pubs.er.usgs.gov/publication/wsp2191">http://pubs.er.usgs.gov/publication/wsp2191</a>	1974–78	Hydrologic conditions for the INEL, Idaho.
Lewis and Jensen (1985)	1979–81	Hydrologic conditions for the INEL, Idaho.
Pittman and others (1988) <a href="http://pubs.er.usgs.gov/publication/wri894008">http://pubs.er.usgs.gov/publication/wri894008</a>	1982–85	Hydrologic conditions for the INEL, Idaho.
Hull (1989)		Conceptual model that described migration pathways for wastewater and constituents from the radioactive-waste infiltration ponds at the TRA.

**Table 1.** Summary of selected previous investigations on geology, hydrology, and water characteristics of groundwater and perched groundwater, Idaho National Laboratory, Idaho, 1961–2012.—Continued

[Names for the Idaho National Laboratory have changed numerous times since 1949. Names formerly used for this site were: the National Reactor Testing Station (NRTS), 1949 to 1974; the Idaho National Engineering Laboratory (INEL), 1974–1997; the Idaho National Engineering and Environmental Laboratory (INEEL), 1997–2005; and the Idaho National Laboratory (INL), 2005 to present (2013). **Abbreviations:** ATR Complex, Advanced Test Reactor Complex (formerly the TRA, Test Reactor Area and RTC, Reactor Technology Complex ); INTEC, Idaho Nuclear Technology and Engineering Center (formerly the ICPP, Idaho Chemical Processing Plant); RWMC, Radioactive Waste Management Complex (formerly the solid waste burial ground)]

Reference	Investigation period	Summary
Perched groundwater—Continued		
Anderson and Lewis (1989) <a href="http://pubs.er.usgs.gov/publication/wri894065">http://pubs.er.usgs.gov/publication/wri894065</a>		Correlation of drill cores and geophysical logs to describe a sequence of basalt flows and sedimentary interbeds in the unsaturated zones underlying the RWMC.
Anderson (1991) <a href="http://pubs.er.usgs.gov/publication/wri914010">http://pubs.er.usgs.gov/publication/wri914010</a>		Correlation of drill cores and geophysical logs to describe a sequence of basalt flows and sedimentary interbeds in the unsaturated zones underlying the TRA and ICPP.
Ackerman (1991b) <a href="http://pubs.er.usgs.gov/publication/wri914058">http://pubs.er.usgs.gov/publication/wri914058</a>		Analyzed data from 43 aquifer tests conducted in 22 wells to estimate transmissivity of basalts and sedimentary interbeds containing perched groundwater beneath the TRA and ICPP.
Cecil and others (1991) <a href="http://pubs.er.usgs.gov/publication/wri914166">http://pubs.er.usgs.gov/publication/wri914166</a>	1986–88	Mechanisms for formation of perched groundwater at the TRA, ICPP, and RWMC, INEL, Idaho; distribution of chemical and radiochemical constituents in perched groundwater at the TRA, ICPP and RWMC.
Tucker and Orr (1998) <a href="http://pubs.er.usgs.gov/publication/wri984028">http://pubs.er.usgs.gov/publication/wri984028</a>		Hydrologic conditions and distribution of selected radiochemical and chemical constituents in perched groundwater, INEL, Idaho.
Bartholomay (1998) <a href="http://pubs.er.usgs.gov/publication/wri984026">http://pubs.er.usgs.gov/publication/wri984026</a>	1992–95	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in perched groundwater, INEL, Idaho.
Orr (1999) <a href="http://pubs.er.usgs.gov/publication/wri994277">http://pubs.er.usgs.gov/publication/wri994277</a>		Transient numerical simulation to evaluate a conceptual model of flow through perched groundwater beneath wastewater infiltration ponds at the TRA.
Bartholomay and Tucker (2000) <a href="http://pubs.er.usgs.gov/publication/wri004222">http://pubs.er.usgs.gov/publication/wri004222</a>	1996–98	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in perched groundwater, INEEL, Idaho.
Davis (2006a) <a href="http://pubs.er.usgs.gov/publication/sir20065236">http://pubs.er.usgs.gov/publication/sir20065236</a>	1999–2001	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in perched groundwater, INL, Idaho.
Davis (2008) <a href="http://pubs.er.usgs.gov/publication/sir20085089">http://pubs.er.usgs.gov/publication/sir20085089</a>	2002–05	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in groundwater and perched groundwater, INL, Idaho.
Davis (2010) <a href="http://pubs.er.usgs.gov/publication/sir20105197">http://pubs.er.usgs.gov/publication/sir20105197</a>	2006–08	Hydrologic conditions and distribution of selected radiochemical and chemical constituents in groundwater and perched groundwater, INL, Idaho.

## Groundwater Monitoring Networks

The USGS maintains groundwater monitoring networks at the INL to characterize the occurrence, movement, and quality of groundwater, and to delineate waste-constituent plumes in the ESRP aquifer and perched groundwater zones. Periodic water-level and water-quality data are obtained from these networks. In addition, data are collected from MLMS in order to describe the vertical distribution of selected constituents. Data from these monitoring networks are available through the USGS National Water Information System (NWIS) Web site at <http://waterdata.usgs.gov/id/nwis/nwis> (U.S. Geological Survey, 2013c).

### Water-Level Monitoring Network

The USGS aquifer water-level monitoring network was designed to determine hydraulic-gradient changes that affect the rate and direction of groundwater and waste-constituent movement in the ESRP aquifer, to identify sources of recharge to the aquifer, and to measure the effects of recharge. During 2005–10, nine wells were equipped with MLMS that allow pressure and temperature measurements to be acquired at isolated depths in each of the wells. This multilevel monitoring provided data that was used to describe the vertical distribution of pressure and temperature gradients in addition to the spatial distribution information previously gathered from open boreholes. A dual piezometer well (NRF 15) was completed in 2009 to provide additional pressure information upgradient from the NRF. As of December 2011, water levels were monitored in 185 aquifer wells. Water levels were measured annually in 31 wells, semiannually in 62 wells, triannually in 2 wells, quarterly in 71 wells, monthly in 15 wells, and continuously recorded in 4 aquifer wells. [Figures 2](#) and [3](#) show the locations of aquifer wells and the frequency of water-level measurements as of December 2011.

The USGS perched groundwater-level monitoring network was designed so that the extent and volume of perched groundwater in storage could be estimated. Perched groundwater occurs at the INL because unique features of the basalt layers and sedimentary interbeds in the unsaturated zones above the regional aquifer system that lie beneath some of the facilities provide a mechanism for the development of zones that hold water for a long time (Cecil and others, 1991, p. 17). As of December 2011, water levels in 29 wells ([fig. 4](#)) were monitored. At the ATR Complex, the network included 9 wells to monitor shallow perched groundwater levels and 18 wells to monitor deep perched groundwater levels. Shallow perched groundwater is considered to be

water perched in surficial sediment deposits, and deep perched groundwater is water perched at greater depth. Perching mechanisms are attributed to contrasting hydraulic properties between sedimentary interbeds and basalts or between low-permeability basalt-flow interiors and overlying fractured basalt. Southwest of the INTEC, the network included one well (ICPP-MON-V-200) to monitor perched groundwater levels around the new percolation ponds. Perched groundwater at the RWMC was measured in well USGS 92. Well locations and frequency of water-level measurements as of December 2011 are shown in [figure 4](#).

### Water-Quality Monitoring Network

The radiochemical and chemical character of groundwater and perched groundwater in the ESRP aquifer was determined from analyses of water samples collected as part of a comprehensive sampling program to identify contaminant concentrations and to define patterns of waste migration in the aquifer and perched groundwater zones. Water samples were collected and analyzed to identify trends in water quality from wells that penetrate the aquifer at various depths and with differing well completions (openhole, screened, or equipped with MLMS). Numerous water samples were collected from aquifer and perched groundwater wells near areas of detailed study, such as the ATR Complex, INTEC, RWMC, TAN, and CFA. Water samples from the NRF were collected and analyzed as part of a separate study (most recently, Bartholomay and others, 2001, 2002), and the results are available on the USGS NWIS Web site at <http://waterdata.usgs.gov/id/nwis/nwis> (U.S. Geological Survey, 2013c).

Beginning in 2005, the USGS and the INL contractor collaborated to equip two wells (Middle 2050A and Middle 2051; [figs. 5](#) and [6](#)) with MLMS to collect water samples for analysis in order to describe the vertical distribution of constituents in the ESRP aquifer. The USGS expanded the program from 2006 to 2010 to equip seven additional wells (USGS 103, 105, 108, 132, 133, 134, and 135; [figs. 5](#) and [6](#)). North Wind, Inc. (2006), Fisher and Twining (2011), and Twining and Fisher (2012) give detailed descriptions of the installation of each well. Bartholomay and Twining (2010, table 1) describe the water sample port depth and associated intervals sampled from six of MLMS-equipped wells (USGS 103, 132, 133, 134, Middle 2050A, and Middle 2051). Water chemistry, vertical hydraulic head, and water temperature data were collected from the MLMS during 2005–11 (Bartholomay and Twining, 2010; Fisher and Twining, 2011; Twining and Fisher, 2012).

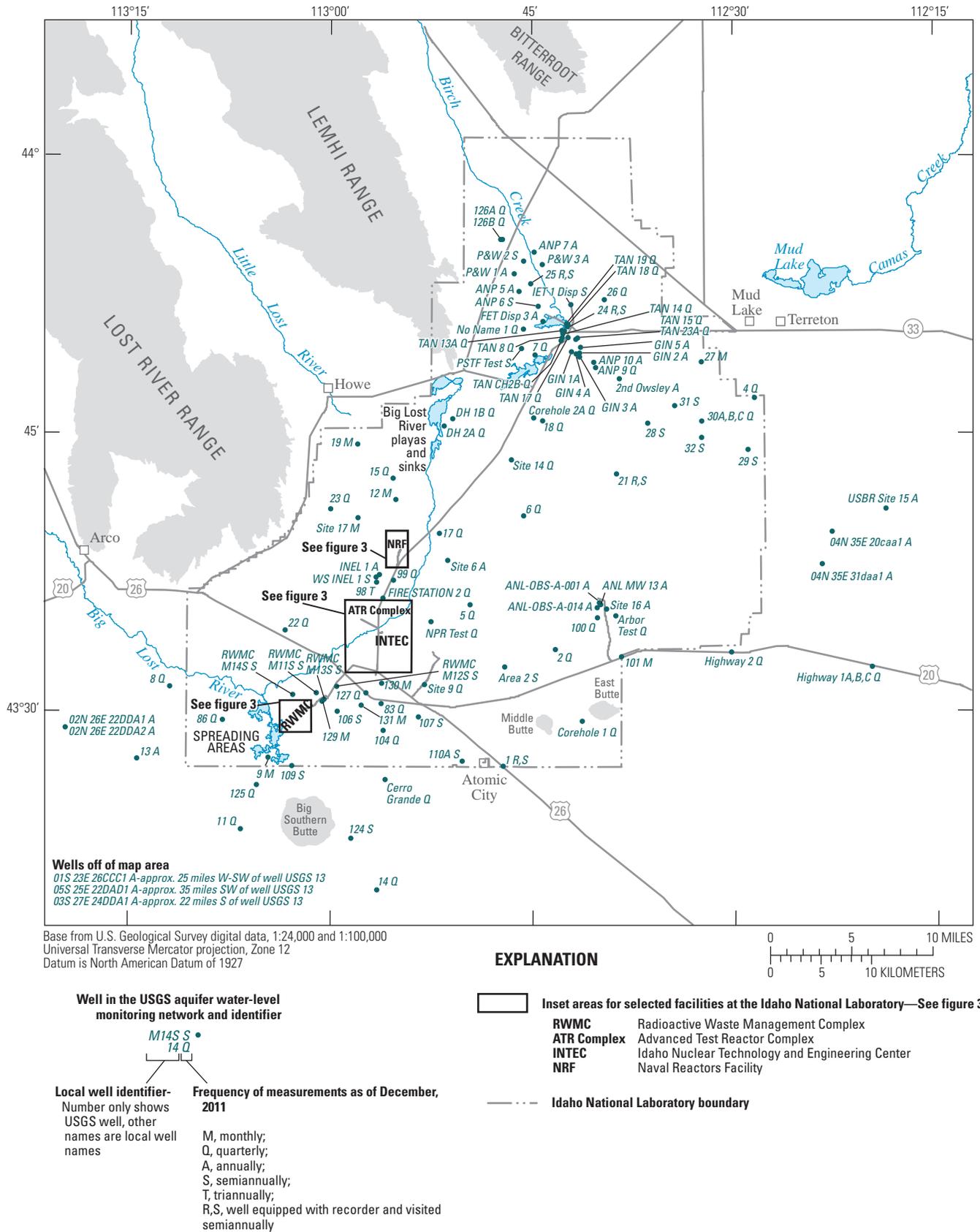
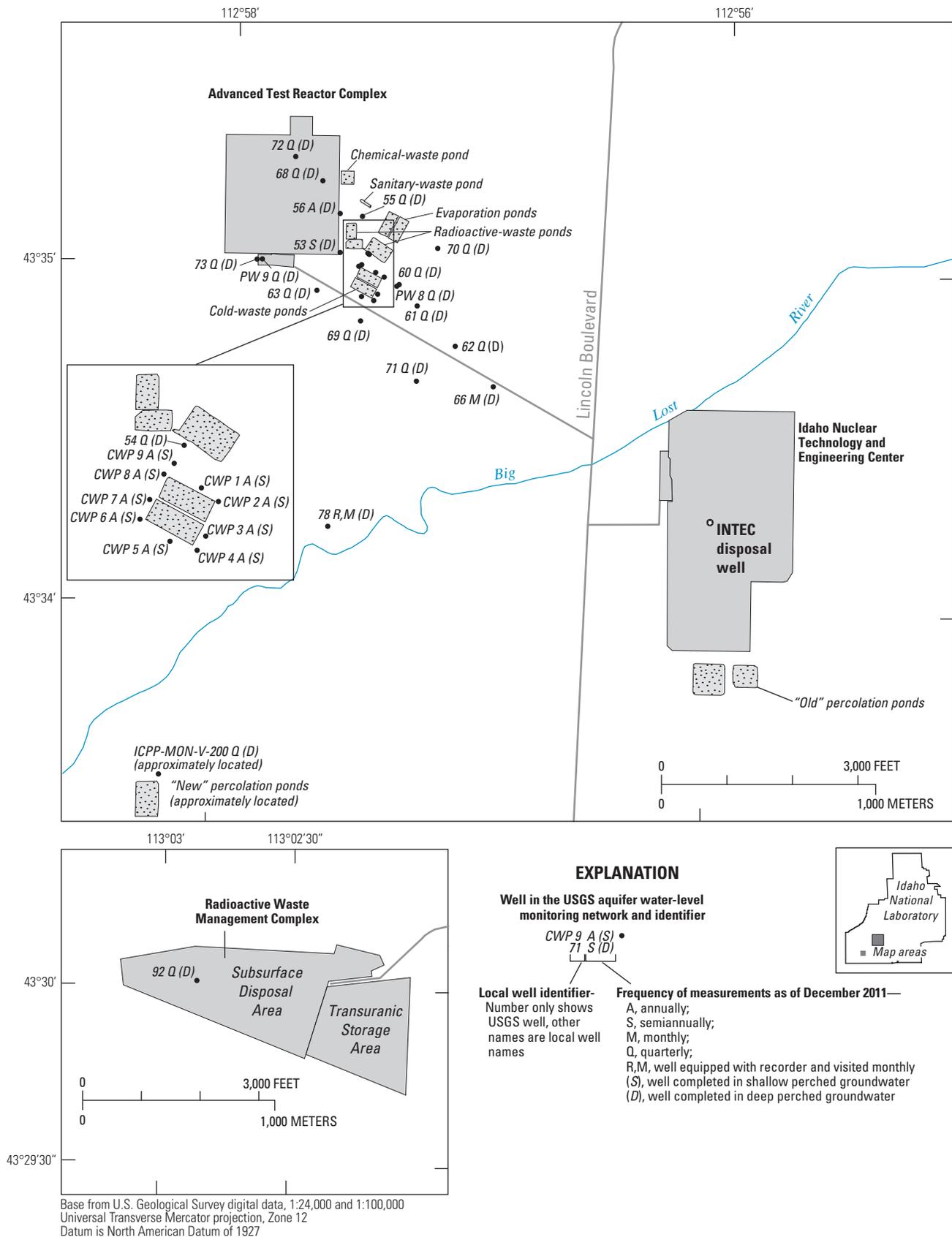


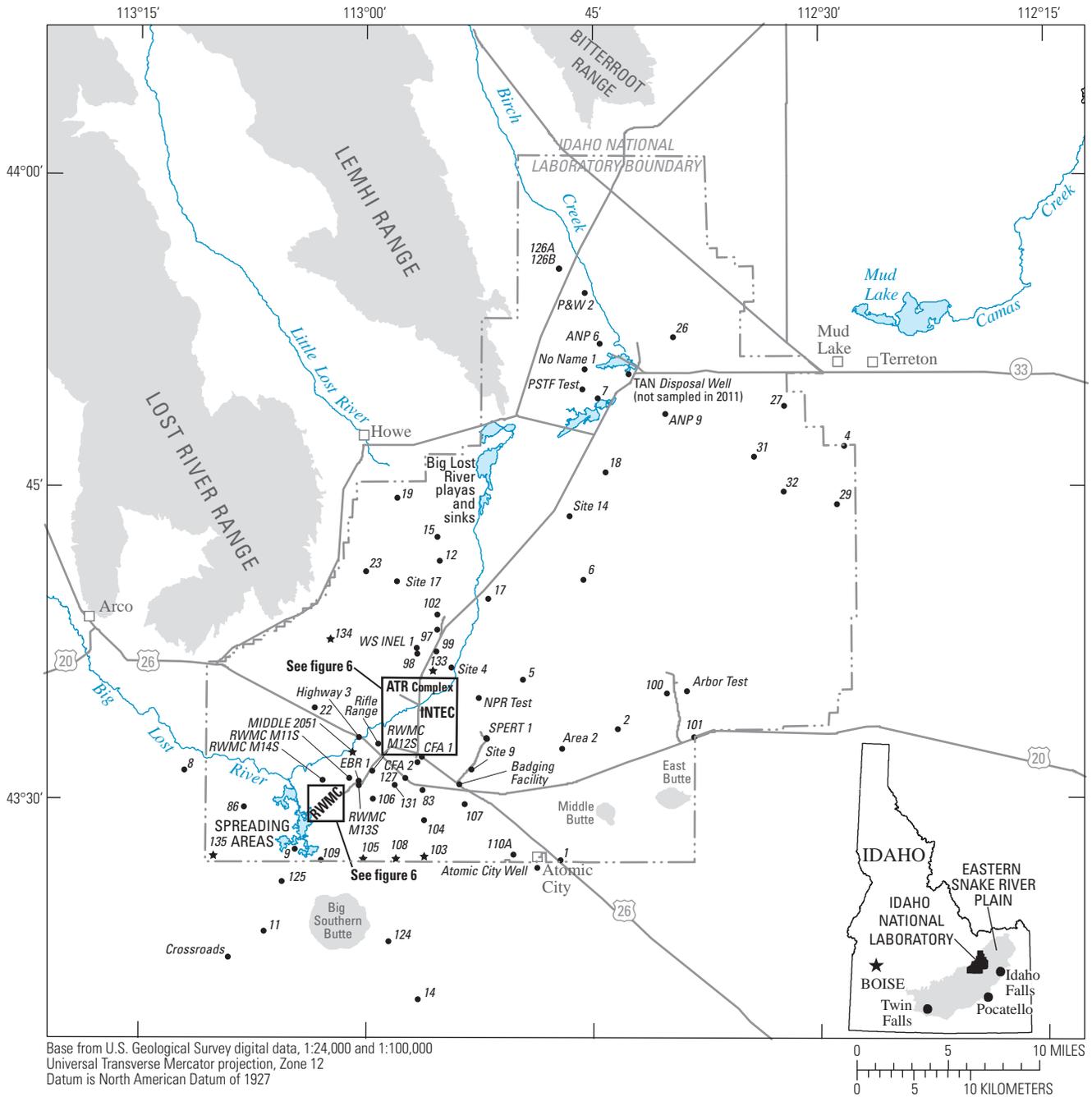
Figure 2. Location of wells in the U.S. Geological Survey aquifer water-level monitoring network at and near the Idaho National Laboratory, Idaho, and frequency of water-level measurements, as of December 2011.





**Figure 4.** Location of wells in the U.S. Geological Survey perched groundwater-level monitoring network at the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, and frequency of water-level measurements, as of December 2011.

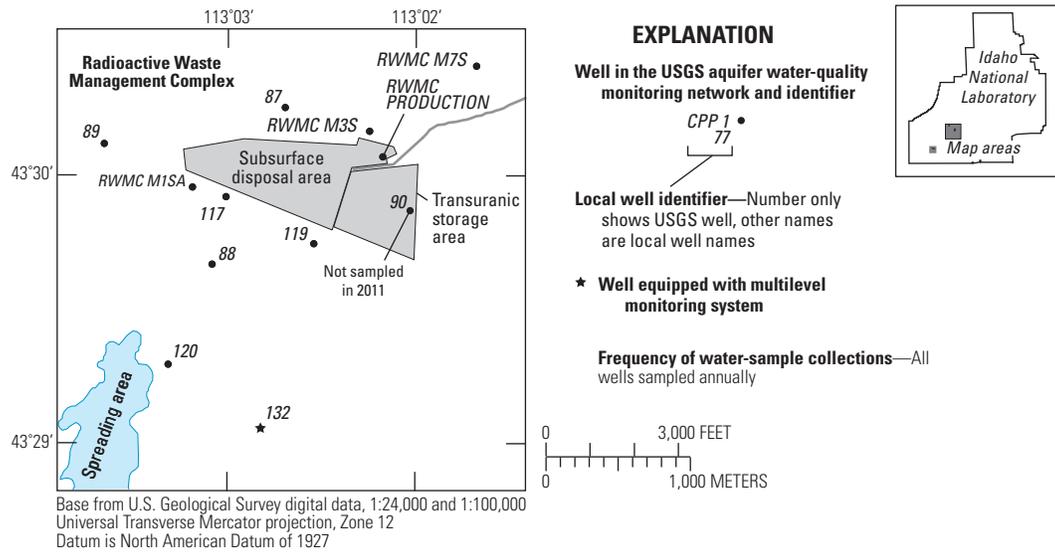
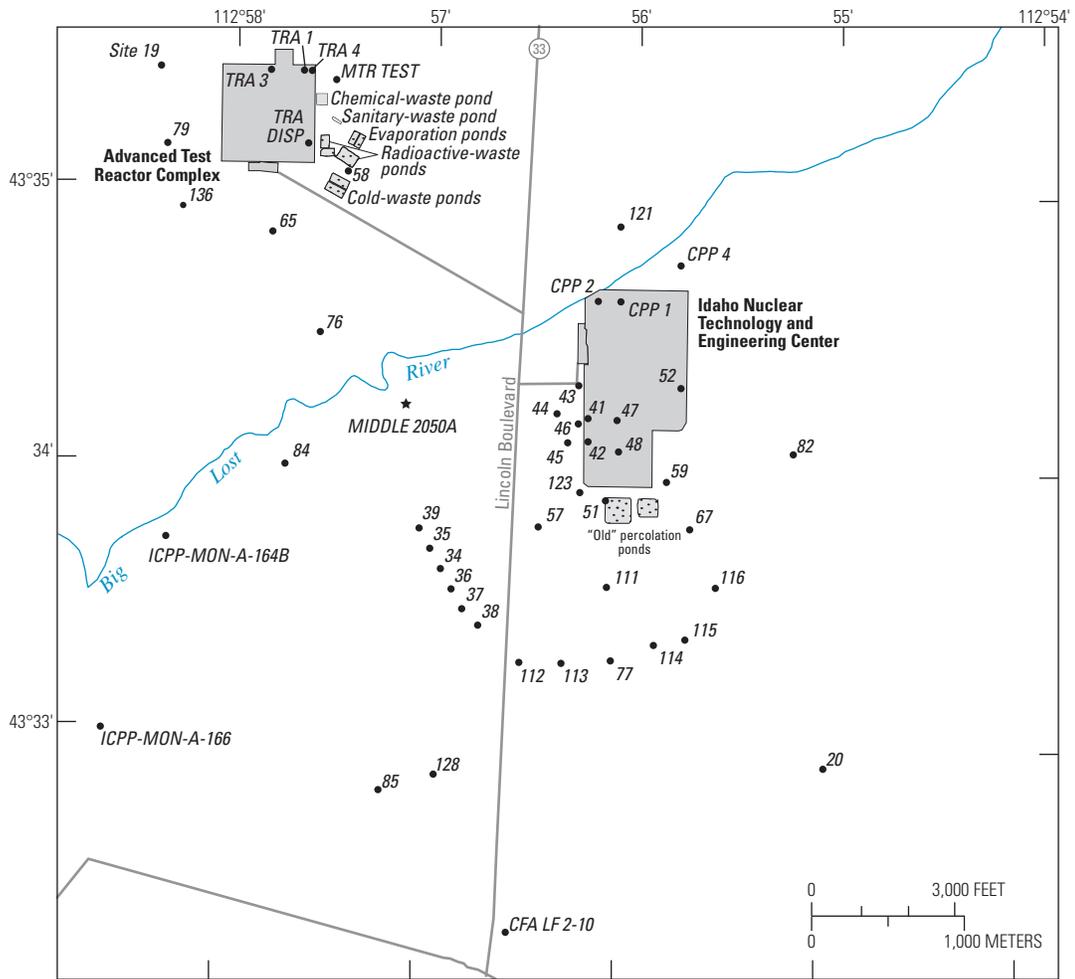
12 Hydrologic Conditions and Distribution of Selected Constituents in Water, Idaho National Laboratory, Idaho, 2009–11



**EXPLANATION**

- Well in the USGS aquifer water-quality monitoring network and identifier  
 RWMC M14S 14
- Local well identifier—Number only shows USGS well, other names are local well names
- ★ Well equipped with multilevel monitoring system
- Frequency of water-sample collections—All wells sampled annually
- Inset areas for selected facilities at the Idaho National Laboratory—See figure 6.
  - RWMC Radioactive Waste Management Complex
  - ATR Complex Advanced Test Reactor Complex
  - INTEC Idaho Nuclear Technology and Engineering Center
  - TAN Test Area North

**Figure 5.** Location of wells in the U.S. Geological Survey aquifer water-quality monitoring network, Idaho National Laboratory and vicinity, Idaho, as of December 2011.



**Figure 6.** Location of wells in the U.S. Geological Survey aquifer water-quality monitoring network at the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, and frequency of water-sample collections, as of December 2011.

## 14 Hydrologic Conditions and Distribution of Selected Constituents in Water, Idaho National Laboratory, Idaho, 2009–11

The type, frequency, and depth of groundwater sampling generally depend on the information needed in a specific area. Water samples were routinely collected and analyzed for some combination of concentrations of tritium, strontium-90, cesium-137, plutonium-238, plutonium-239, -240 (undivided), americium-241, gross alpha- and beta-particle radioactivity, chromium, sodium, chloride, sulfate, nutrients including nitrite plus nitrate (as nitrogen [N]), nitrite (as N), orthophosphate (as P), and ammonia (as N), volatile organic compounds (VOCs), total organic carbon (TOC), and measurements of specific conductance, pH, and temperature. Additionally, as part of the INL groundwater monitoring program adopted in 1994 (Sehlike and Bickford, 1993), water samples from several wells also were analyzed for fluoride, an extensive suite of trace elements, and TOC. When a new well is drilled by the

USGS at the INL, samples are collected and analyzed for all of the constituents previously listed, together with a full suite of cations and carbon, deuterium, oxygen, and uranium isotopes. A schedule listing the constituents that are typically analyzed is provided in a report by Knobel and others (2008, appendix A). The location and construction of wells, and the water sample collection method in the aquifer water-quality monitoring network as of December 2011, are shown in [figures 5](#) and [6](#), and in [table 2](#). Three new MLMS-equipped wells (USGS 105, 108, and 135) and well USGS 136 (Twining and others, 2012) were completed during 2009–11. Well location and construction of wells in the USGS water-quality monitoring network for perched groundwater beneath INL facilities as of December 2011 are shown in [figure 7](#) and [table 3](#). All wells were scheduled to be sampled annually.

**Table 2.** Construction of wells in the U.S. Geological Survey aquifer water-quality monitoring network and water sample-collection method, eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, as of December 2011.

[All wells are sampled annually except those whose sample-collection method is MLMS. MLMS sample schedule is subject to change from year to year.

**Well No. or name:** Well locations are shown in [figures 5](#) and [6](#). **Diameter:** //, hole diameter is not required for borehole volume calculations with multi-level thief samplers. **Sample-collection method:** Pump, sampled from pumping well (pumping rate in gallons per minute); Tap, sampled from faucet; MLMS (year installed), sampled with multilevel monitoring system. **Abbreviation:** USGS, U.S. Geological Survey]

Well No. or name	USGS site No.	Well construction		
		Diameter (inches)	Depth (feet)	Sample-collection method
ANP 6	435152112443101	10	295	Pump (25)
ANP 9	434856112400001	8	322	Pump (18)
Arbor test	433509112384801	10	790	Pump (20)
Area 2	433223112470201	16	877	Pump (18)
Atomic City	432638112484101	8	639	Tap
Badging Facility	433042112535101	8	644	Pump (35)
CFA 1	433204112562001	16	639	Pump (1,000)
CFA 2	433144112563501	16	681	Pump (1,400)
CFA LF 2-10	433216112563301	6	716	Pump (8.3)
CPP 1	433433112560201	16	586	Pump (3,000)
CPP 2	433432112560801	16	605	Pump (3,000)
CPP 4	433440112554401	16	700	Pump (400)
Crossroads	432128113092701	8	796	Pump (35)
EBR 1	433051113002601	10	1,075	Pump (25)
Highway 3	433256113002501	8	750	Pump (18)
ICPP-MON-A-164B	433338112581601	4	533	Pump (4)
ICPP-MON-A-166	433300112583301	6	527	Pump (3)
Middle 2050A-516.8 ft	433409112570515	//	539	MLMS 2005
Middle 2050A-643.9 ft	433409112570512	//	703	MLMS 2005
Middle 2050A-790.6 ft	433409112570509	//	807	MLMS 2005
Middle 2050A-999.3 ft	433409112570506	//	1,041	MLMS 2005
Middle 2050A-1180.3 ft	433409112570503	//	1,227	MLMS 2005
Middle 2051-602.9 ft	433217113004912	//	609	MLMS 2005
Middle 2051-749.0 ft	433217113004909	//	771	MLMS 2005
Middle 2051-826.8 ft	433217113004906	//	876	MLMS 2005
Middle 2051-1091.1 ft	433217113004903	//	1,128	MLMS 2005
Middle 2051-1140.9 ft	433217113004901	//	1,177	MLMS 2005
MTR test	433520112572601	8	588	Pump (26)
No name 1	435038112453401	12	500	Pump (42)

**Table 2.** Construction of wells in the U.S. Geological Survey aquifer water-quality monitoring network and water sample-collection method, eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, as of December 2011.—Continued

[All wells are sampled annually except those whose sample-collection method is MLMS. MLMS sample schedule is subject to change from year to year. **Well No. or name:** Well locations are shown in [figures 5](#) and [6](#). **Diameter:** //, hole diameter is not required for borehole volume calculations with multi-level thief samplers. **Sample-collection method:** Pump, sampled from pumping well (pumping rate in gallons per minute); Tap, sampled from faucet; MLMS (year installed), sampled with multilevel monitoring system. **Abbreviation:** USGS, U.S. Geological Survey]

Well No. or name	USGS site No.	Well construction		
		Diameter (inches)	Depth (feet)	Sample-collection method
NPR test	433449112523101	6	600	Pump (28)
PSTF test	434941112454201	10	319	Pump (30)
P&W 2	435419112453101	10	378	Pump (35)
Rifle range	433243112591101	5	620	Pump (25)
RWMC M1SA	432956113030901	6	638	Pump (6)
RWMC M3S	433008113021801	6	633	Pump (6)
RWMC M7S	433023113014801	6	628	Pump (5)
RWMC M11S	433058113010401	6	624	Pump (12)
RWMC M12S	433118112593401	6	572	Pump (6)
RWMC M13S	433037113002701	6	643	Pump (6)
RWMC M14S	433052113025001	6	635	Pump (14)
RWMC PROD	433002113021701	10, 14	685	Pump (200)
Site 4	433617112542001	8	495	Pump (500)
Site 9	433123112530101	10	1,057	Pump (30)
Site 14	434334112463101	8, 12	717	Pump (36)
Site 17	434027112575701	15	600	Pump (30)
Site 19	433522112582101	8, 10	860	Pump (15)
SPERT-1	433252112520301	14	653	Pump (400)
TRA 1	433521112573801	18	600	Pump (3,400)
TRA 3	433522112573501	20	602	Pump (3,800)
TRA 4	433521112574201	16, 18	965	Pump (2,000)
TRA DISP	433506112572301	6, 8	1,267	Pump (25)
USGS 1	432700112470801	5	630	Pump (22)
USGS 2	433320112432301	5	699	Pump (16)
USGS 4	434657112282201	6	553	Pump (36)
USGS 5	433543112493801	6	494	Pump (5)
USGS 6	434031112453701	4	620	Pump (30)
USGS 7	43491511243901	4, 6	903	Pump (45)
USGS 8	433121113115801	6	812	Pump (15)
USGS 9	432740113044501	6	654	Pump (15)
USGS 11	432336113064201	6	704	Pump (23)
USGS 12	434126112550701	10	563	Pump (35)
USGS 14	432019112563201	5	752	Pump (16)
USGS 15	434234112551701	10	610	Pump (30)
USGS 17	433937112515401	5, 6	498	Pump (15)
USGS 18	434540112440901	4	329	Pump (30)
USGS 19	434426112575701	6	399	Pump (17)
USGS 20	433253112545901	6	658	Pump (18)
USGS 22	433422113031701	6	657	Pump (2)
USGS 23	434055112595901	5, 6	458	Pump (25)
USGS 26	435212112394001	6	266	Pump (20)
USGS 27	434851112321801	6	312	Pump (20)
USGS 29	434407112285101	6	426	Pump (30)
USGS 31	434625112342101	8, 10	428	Pump (40)
USGS 32	434444112322101	5.5, 6	392	Pump (35)
USGS 34	433334112565501	10	700	Pump (30)
USGS 35	433339112565801	7	579	Pump (25)

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**Table 2.** Construction of wells in the U.S. Geological Survey aquifer water-quality monitoring network and water sample-collection method, eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, as of December 2011.—Continued

[All wells are sampled annually except those whose sample-collection method is MLMS. MLMS sample schedule is subject to change from year to year.

**Well No. or name:** Well locations are shown in [figures 5](#) and [6](#). **Diameter:** //, hole diameter is not required for borehole volume calculations with multi-level thief samplers. **Sample-collection method:** Pump, sampled from pumping well (pumping rate in gallons per minute); Tap, sampled from faucet; MLMS (year installed), sampled with multilevel monitoring system. **Abbreviation:** USGS, U.S. Geological Survey]

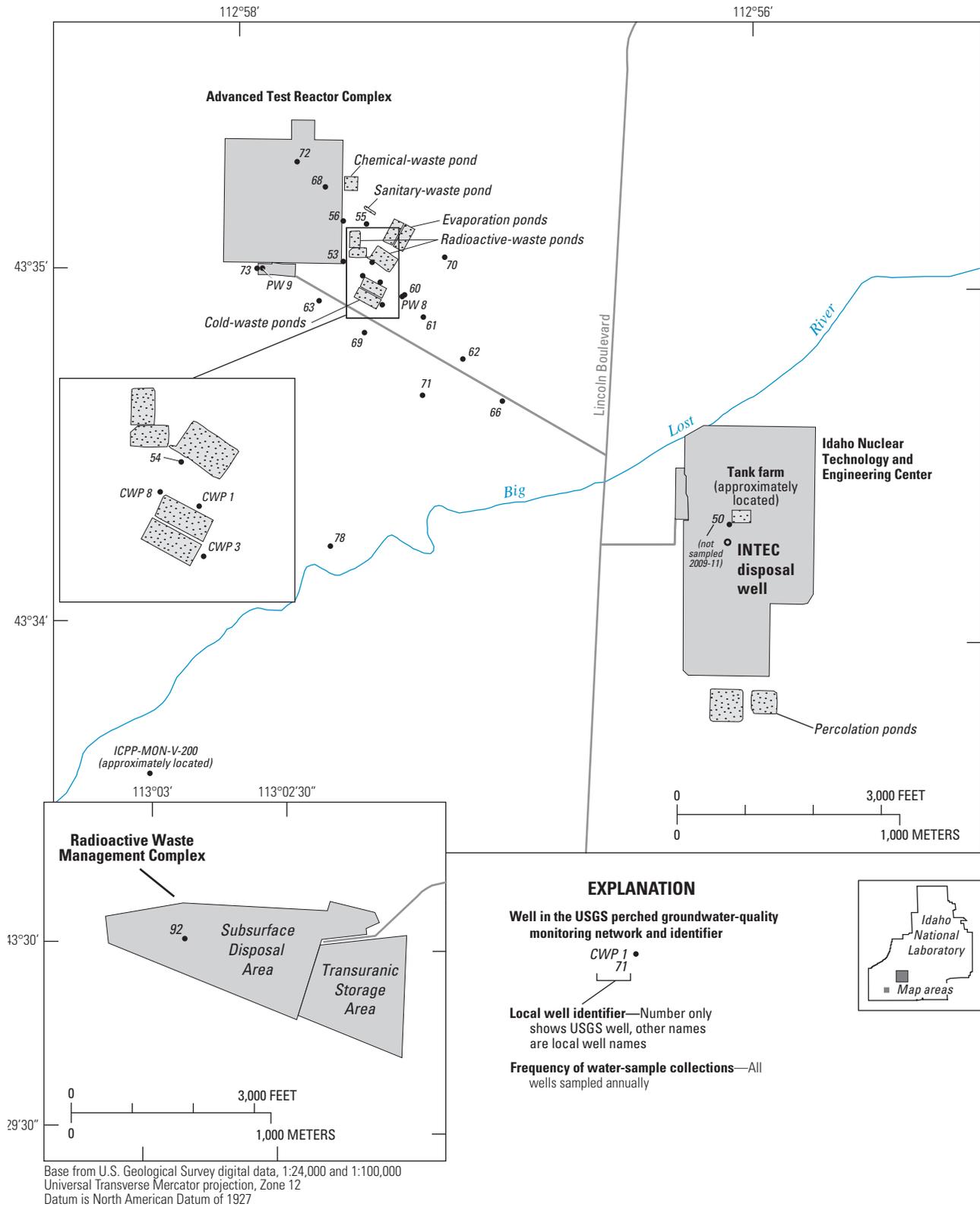
Well No. or name	USGS site No.	Well construction		
		Diameter (inches)	Depth (feet)	Sample-collection method
USGS 36	433330112565201	6	567	Pump (25)
USGS 37	433326112564801	6	572	Pump (25)
USGS 38	433322112564301	4	724	Pump (18)
USGS 39	433343112570001	8	492	Pump (25)
USGS 41	433409112561301	6	666	Pump (25)
USGS 42	433404112561301	6	678	Pump (25)
USGS 43	433415112561501	6	564	Pump (6)
USGS 44	433409112562101	6	650	Pump (25)
USGS 45	433402112561801	6	651	Pump (25)
USGS 46	433407112561501	6	651	Pump (25)
USGS 47	433407112560301	6	651	Pump (8)
USGS 48	433401112560301	6	750	Pump (29)
USGS 51	433350112560601	6	647	Pump (4)
USGS 52	433414112554201	6	602	Pump (30)
USGS 57	433344112562601	6	582	Pump (30)
USGS 58	433500112572502	6	503	Pump (26)
USGS 59	433354112554701	6	587	Pump (18)
USGS 65	433447112574501	4	498	Pump (8)
USGS 67	433344112554101	4, 6	694	Pump (8)
USGS 76	433425112573201	6	718	Pump (29)
USGS 77	433315112560301	6	586	Pump (25)
USGS 79	433505112581901	6	702	Pump (30)
USGS 82	433401112551001	6	693	Pump (25)
USGS 83	433023112561501	6	752	Pump (20)
USGS 84	433356112574201	6	505	Pump (20)
USGS 85	433246112571201	6	614	Pump (23)
USGS 86	432935113080001	8	691	Pump (19)
USGS 87	433013113024201	4	673	Pump (2)
USGS 88	432940113030201	4	663	Pump (8)
USGS 89	433005113032801	6	637	Pump (2)
USGS 97	433807112551501	4	510	Pump (27)
USGS 98	433657112563601	4	508	Pump (25)
USGS 99	433705112552101	4	440	Pump (25)
USGS 100	433503112400701	6	750	Pump (10)
USGS 101	433255112381801	4, 6	842	Pump (12)
USGS 102	433853112551601	6	445	Pump (30)
USGS 103-680.3 ft	432714112560723	//	691	MLMS 2007
USGS 103-801.9 ft	432714112560720	//	832	MLMS 2007
USGS 103-908.7 ft	432714112560716	//	920	MLMS 2007
USGS 103-992.9 ft	432714112560712	//	1,014	MLMS 2007
USGS 103-1086.8 ft	432714112560708	//	1,098	MLMS 2007
USGS 103-1209.7 ft	432714112560704	//	1,240	MLMS 2007
USGS 103-1258.0 ft	432714112560702	//	1,279	MLMS 2007
USGS 104	432856112560801	8	700	Pump (26)
USGS 105-727.6 ft	432703113001818	//	752	MLMS 2008
USGS 105-851.2 ft	432703113001815	//	862	MLMS 2008
USGS 105-951.6 ft	432703113001811	//	982	MLMS 2008
USGS 105-1071.6 ft	432703113001807	//	1,102	MLMS 2008

**Table 2.** Construction of wells in the U.S. Geological Survey aquifer water-quality monitoring network and water sample-collection method, eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, as of December 2011.—Continued

[All wells are sampled annually except those whose sample-collection method is MLMS. MLMS sample schedule is subject to change from year to year. **Well No. or name:** Well locations are shown in [figures 5](#) and [6](#). **Diameter:** //, hole diameter is not required for borehole volume calculations with multi-level thief samplers. **Sample-collection method:** Pump, sampled from pumping well (pumping rate in gallons per minute); Tap, sampled from faucet; MLMS (year installed), sampled with multilevel monitoring system. **Abbreviation:** USGS, U.S. Geological Survey]

Well No. or name	USGS site No.	Well construction		
		Diameter (inches)	Depth (feet)	Sample-collection method
USGS 105-1242.2 ft	432703113001803	//	1,276	MLMS 2008
USGS 106	432959112593101	8	760	Pump (24)
USGS 107	432942112532801	8	690	Pump (30)
USGS 108-661.1 ft	432659112582616	//	679	MLMS 2010
USGS 108-808.8 ft	432659112582613	//	830	MLMS 2010
USGS 108-887.7 ft	432659112582610	//	904	MLMS 2010
USGS 108-1028.8 ft	432659112582606	//	1,060	MLMS 2010
USGS 108-1171.8 ft	432659112582602	//	1,194	MLMS 2010
USGS 109	432701113025601	4	800	Pump (22)
USGS 110A	432717112501502	6	644	Pump (6)
USGS 111	433331112560501	8	560	Pump (12)
USGS 112	433314112563001	8	507	Pump (12)
USGS 113	433314112561801	6	556	Pump (15)
USGS 114	433318112555001	6	560	Pump (10)
USGS 115	433320112554101	6	581	Pump (5)
USGS 116	433331112553201	6	572	Pump (20)
USGS 117	432955113025901	6.5	655	Pump (12)
USGS 119	432945113023401	6.5	705	Pump (15)
USGS 120	432919113031501	6.5	705	Pump (18)
USGS 121	433450112560301	6	475	Pump (10)
USGS 123	433352112561401	6	515	Pump (12)
USGS 124	432307112583101	4	800	Pump (20)
USGS 125	432602113052801	5	774	Pump (18)
USGS 126A	435529112471301	5	648	Pump (30)
USGS 126B	435529112471401	6	472	Pump (10)
USGS 127	433058112572201	6	596	Pump (25)
USGS 128	433250112565601	4.5	615	Pump (23)
USGS 132-637.9 ft	432906113025022	//	660	MLMS 2006
USGS 132-765.4 ft	432906113025018	//	787	MLMS 2006
USGS 132-827.3 ft	432906113025014	//	864	MLMS 2006
USGS 132-918.7 ft	432906113025010	//	935	MLMS 2006
USGS 132-1011.6 ft	432906113025006	//	1,043	MLMS 2006
USGS 132-1173.0 ft	432906113025001	//	1,214	MLMS 2006
USGS 133-469.1 ft	433605112554312	//	480	MLMS 2006
USGS 133-569.6 ft	433605112554308	//	591	MLMS 2006
USGS 133-686.1 ft	433605112554305	//	696	MLMS 2006
USGS 133-745.5 ft	433605112554301	//	766	MLMS 2006
USGS 134-578.5 ft	433611112595819	//	590	MLMS 2006
USGS 134-645.5 ft	433611112595815	//	652	MLMS 2006
USGS 134-706.5 ft	433611112595811	//	720	MLMS 2006
USGS 134-806.6 ft	433611112595807	//	818	MLMS 2006
USGS 134-846.6 ft	433611112595804	//	868	MLMS 2006
USGS 135-737.9 ft	432753113093613	//	762	MLMS 2006
USGS 135-836.7 ft	432753113093609	//	861	MLMS 2006
USGS 135-988.1 ft	432753113093605	//	1,008	MLMS 2006
USGS 135-1116.4 ft	432753113093601	//	1,137	MLMS 2006
USGS 136	433447112581501	6	551	Pump (25)
WS INEL1	433716112563601	6	490	Pump (30)

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**Figure 7.** Location of wells in the U.S. Geological Survey perched groundwater-quality monitoring network at the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, and frequency of water-sample collections, as of December 2011.

**Table 3.** Construction of wells in the U.S. Geological Survey perched groundwater-quality monitoring network and water sample-collection method at the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, as of December 2011.

[Well No.: Well locations are shown in [figure 7](#). **Sample-collection method:** Pump, sample collected with a pump (pumping rate in gallons per minute); Bail, sample collected with a bailer (sample collection depth in feet below land surface). All wells sampled annually. **Abbreviation:** USGS, U.S. Geological Survey]

Well No.	USGS site No.	Well construction		
		Diameter (inches)	Depth (feet)	Sample-collection method
CWP 1	433459112572601	6	58	Bail (55)
CWP 3	433455112572501	6	55	Bail (50)
CWP 8	433500112573001	6	64	Bail (58)
ICPP-MON-V-200	433321112581501	4	127	Pump (1.5)
PW 8	433456112572001	6	166	Pump (8)
PW 9	433500112575401	6	200	Pump (5)
USGS 53	433503112573401	6	71	Bail
USGS 54	433503112572801	6	82	Pump (4)
USGS 55	433508112573001	6	81	Pump (1)
USGS 56	433509112573501	6	105	Bail (74)
USGS 60	433456112571901	6	117	Pump (6)
USGS 61	433453112571601	4	123	Pump (6)
USGS 62	433446112570701	8	165	Pump (5)
USGS 63	433455112574001	10	109	Pump (5)
USGS 66	433436112564801	4	202	Bail (195)
USGS 68	433516112573901	10	128	Pump (1)
USGS 69	433450112573001	4	115	Pump (5)
USGS 70	433504112571001	8	100	Pump (6)
USGS 71	433439112571501	5	171	Bail (165)
USGS 72	433519112574601	4	174	Bail (148)
USGS 73	433502112575401	6	127	Pump (6)
USGS 78	433413112573501	7	204	Bail (165)
USGS 92	433000113025301	3.5	214	Bail (213)

## Waste-Disposal Sites at the Idaho National Laboratory

Wastewater disposal at INL facilities ([fig. 1](#)) has been the principal source of radioactive- and chemical-waste constituents in water from the ESRP aquifer and in perched groundwater zones at and near the INL. In the past, wastewater disposal sites included infiltration ponds (percolation ponds) and ditches, evaporation ponds, drain fields, and disposal wells. Currently (2013), wastewater is being discharged to infiltration ponds, evaporation ponds, and ditches at the INL; and the effluent is sampled and analyzed by the INL contractor for radionuclides and various other

constituents prior to discharge. Solid and liquid wastes buried at the RWMC ([fig. 1](#)) also are sources of some constituents in groundwater.

Contractors at each INL facility collected and reported concentrations of radioactive- and chemical-waste-disposal data from 1976 to 1998 (French and others, 1999a, 1999b); however, prior to 1976 and since 1999, no formal program has been in place to compile annual amounts of constituents discharged at each facility (Richard Kauffman, U.S. Department of Energy, oral commun., 2005). Highlights of the waste disposal history at INL facilities are summarized here; a more comprehensive summary of waste disposal at the INL from 1952 through 1998 can be found in Bartholomay and others (2000).

## Advanced Test Reactor Complex

Since 1952, low-level radioactive, chemical, and sanitary wastewater has been discharged to infiltration and lined evaporation ponds located east of the ATR Complex (fig. 3). Nonradioactive cooling-tower wastewater was discharged to radioactive-waste infiltration ponds from 1952 to 1964, to the ESRP aquifer through a 1,267-foot-deep disposal well (TRA DISP, fig. 3) from 1964 until March 1982, and into two cold-waste infiltration ponds from 1982 to the present (2013). A more complete summary of potential groundwater contamination sources at the ATR Complex is found in U.S. Department of Energy (2011a, table 4-1).

In 1976, the DOE contractor at the ATR Complex began a three-phase program to reduce radioactivity in wastewater. The first phase was 1976–80 and the second phase was 1981–87. The contractor finished the final phase of the program in 1993. In August 1993, the radioactive-waste infiltration ponds at the ATR Complex were replaced with lined evaporation ponds. The evaporation ponds were designed to prevent radioactive wastewater from entering the aquifer.

During 1961–79, less than 25 percent of radioactivity in wastewater discharged was attributed to tritium; most other radioactivity consisted of radionuclides with half-lives of about several weeks, as well as small amounts of strontium-90, cesium-137, and cobalt-60 (Barraclough and others, 1981). In 1980, about 50 percent of radioactivity was attributed to tritium, and during 1981–93, over 90 percent was attributed to tritium (Bartholomay and others, 1997, fig. 6).

A chemical-waste infiltration pond was used for disposal of chemical wastewater from an ion-exchange system at the ATR Complex (fig. 3) from 1962 to 1999. The average annual discharge to this pond was about 17.5 million gallons (Mgal) during 1962–98. Sulfate and sodium hydrate were the predominant constituents in the chemical wastewater (Davis, 2010). In 1999, the chemical-waste infiltration pond was closed and covered with a protective cap (S.M. Stoller Corporation, 2002a).

From 1964 to March 1982, the TRA disposal well (TRA DISP, fig. 3) was used to inject nonradioactive wastewater from cooling-tower operations at the ATR Complex into the ESRP aquifer and also was used to discharge some radioactive wastewater from reactor operations (U.S. Department of Energy, 2011a). Since March 1982, wastewater from cooling-tower operations has been discharged to two cold-waste infiltration ponds (fig. 3). The TRA disposal well has been used as an observation well since 1982. Prior to 1964, well USGS 53 (fig. 4) also was used intermittently to discharge wastewater into the perched groundwater system (U.S. Department of Energy, 2011b) and has been used as an observation well since 1964.

Large quantities of chromate-contaminated wastewater were injected directly into the ESRP aquifer or infiltrated through the unsaturated zone beneath the radioactive-waste infiltration ponds (fig. 3). Between 1952 and 1972, an

estimated 17,790 lb of chromium was discharged to the radioactive-waste infiltration ponds and 31,131 lb of chromium was discharged to the TRA disposal well. In addition, approximately 8,920 curies (Ci) of tritium were discharged to the radioactive-waste infiltration ponds between 1952 and 1993. Other contaminants commonly associated with sanitary sewage in the sanitary waste pond (fig. 3) include nitrate, phosphate, and chloride (U.S. Department of Energy, 2011a).

## Idaho Nuclear Technology and Engineering Center

From 1952 to February 1984, the INTEC discharged most low-level radioactive, chemical, and sanitary wastewater into the ESRP aquifer through a 600-foot-deep disposal well (INTEC Disposal Well, fig. 4). Two percolation ponds (also called infiltration ponds) were used for wastewater disposal from 1984 through August 25, 2002 (fig. 4). The first pond was completed in February 1984 and the second pond was completed in October 1985. On August 26, 2002, the “old” percolation ponds were taken out of service and wastewater was discharged to the “new” percolation ponds about 2 mi southwest of INTEC (fig. 4). The new percolation ponds were designed to be a rapid infiltration system, and each pond can accommodate as much as 3 Mgal/d of continuous discharge (S.M. Stoller Corporation, 2004).

Tritium has accounted for most of the radioactivity in wastewater discharged to the disposal well and old percolation ponds at the INTEC (Davis, 2008, fig. 9). During 1953–2000, a total of about 21,135 Ci of tritium was discharged at the INTEC (Mann and Cecil, 1990; Davis, 2008). Other radionuclides discharged at INTEC include strontium-90, cesium-137, iodine-129, plutonium isotopes, uranium isotopes, neptunium-237, americium-241 and technetium-99 (U.S. Department of Energy, 2011a). In 1972, about 18,100 Ci of strontium-90 and 19,100 Ci of cesium-137 were released to soil at the INTEC Tank Farm (fig. 7) (Cahn and others, 2006). This accounts for about 88 percent (approximately 15,900 Ci) of the source of strontium-90 to groundwater at the INTEC Tank Farm (fig. 7). Three other locations at the INTEC Tank Farm are the source of the remaining 12 percent of strontium-90 (Cahn and others, 2006). In 1972, during a failed transfer of waste between two underground storage tanks, about 18,600 gal of sodium-bearing waste was leaked at an INTEC Tank Farm site (fig. 7).

Historically, chloride, fluoride, nitrate, sodium, and sulfate were the predominant chemical constituents in wastewater discharged at the INTEC (Pittman and others, 1988; Orr and Cecil, 1991; Bartholomay and others, 1995; Bartholomay and others, 1997; Bartholomay and others, 2000). Mercury also has been listed as a constituent that potentially could impact groundwater quality (U.S. Department of Energy, 2011a).

## Naval Reactors Facility

Wastewater at the NRF is discharged to a 1.65-mile-long industrial-waste ditch and sewage ponds (fig. 3). The waste ditch was first used in 1953 to dispose of non-radioactive, non-sewage industrial wastewater. Chloride, sulfate, and sodium have been the predominant chemical constituents in wastewater discharged to the ditch throughout its history of operation (Lewis and Jensen, 1985; Pittman and others, 1988; Orr and Cecil, 1991; Bartholomay and others, 1995; Bartholomay and others, 1997; Bartholomay and others, 2000).

## Radioactive Waste Management Complex

Solid and liquid radioactive- and chemical-wastes have been buried in trenches and pits at the Subsurface Disposal Area (SDA) at the RWMC (fig. 3) since 1952. These include transuranic wastes, other radiochemical and inorganic chemical constituents, and organic compounds. The transuranic wastes were buried in trenches until 1970, and stored above ground at the RWMC after 1970. Only low-level mixed waste has been buried at the RWMC since 1970. Before 1970, little or no sediment was retained between the excavation bottoms and the underlying basalt. Since 1970, a layer of sediment has been retained in excavations to inhibit downward migration of waste constituents.

About 17,100 Ci of plutonium-238, 64,900 Ci of plutonium-239, 17,100 Ci of plutonium-240, and 183,000 Ci of americium-241 were buried in the SDA during 1952–99 (Holdren and others, 2002, table 4-1). An estimated 88,400 gal of organic waste was buried before 1970 (Mann and Knobel, 1987, p. 1). These buried organic wastes included about 24,400 gal of carbon tetrachloride; 39,000 gal of lubricating oil; and about 25,000 gal of other organic compounds, including trichloroethane, trichloroethylene, perchloroethylene, toluene, and benzene.

## Test Area North

From 1953 to 1972, low-level radioactive, chemical, and sanitary wastewater was discharged at TAN (fig. 1) into the ESRP aquifer through a 310-foot-deep disposal well (TAN Disposal Well, fig. 5). In 1972, the disposal well was replaced by a 35-acre infiltration pond. Records are not available to indicate the amount of radioactivity in wastewater discharged at TAN before 1959. During 1959–93, about 61 Ci of radioactivity in wastewater were discharged to the disposal well and infiltration pond. Based on information available through 1998, radioactive wastewater has not been discharged since 1993 (Bartholomay and others, 2000).

Chemical wastewater containing predominantly chloride and sodium was discharged to the infiltration pond at the Technical Support Facility (TSF) near TAN during 1971–2007. Some low-level radioactive waste containing

approximately 0.039 Ci of strontium-90 also was released to the pond during 1972–85 (U.S. Department of Energy, 2011a). A closure plan for the pond was submitted to the Idaho Department of Environmental Quality in November 2007, and wastewater discharge to the pond ceased on November 29, 2007. All activities proposed in the plan were completed by February 2008 (S.M. Stoller Corporation, 2009).

## Central Facilities Area

About 65 Ci of radioactivity in about 1,500 Mgal of wastewater were discharged to the sewage-plant tile drain field at the CFA (fig. 1) during 1952–93. Most radioactive wastes discharged to this drain field were from aquifer water pumped from well CFA 1 (fig. 5), which obtains water from within the INTEC contaminant plume in the ESRP aquifer. Most radioactivity in wastewater discharged at the CFA was attributed to tritium.

Chloride and sodium were the predominant chemical constituents in wastewater at the CFA (Lewis and Jensen, 1984; Pittman and others, 1988; Orr and Cecil, 1991; Bartholomay and others, 1995; Bartholomay and others, 1997; Bartholomay and others, 2000). Nitrate in the southern part of the CFA has been attributed to wastewater disposal at the former CFA mercury pond (U.S. Department of Energy, 2011b).

## Hydrologic Conditions

The ESRP aquifer is one of the most productive aquifers in the United States (U.S. Geological Survey, 1985, p. 193). The aquifer consists of a thick sequence of basalts and sedimentary interbeds filling a large, arcuate, structural basin in southeastern Idaho (fig. 1). Recharge to the ESRP aquifer is primarily from infiltration of applied irrigation water, infiltration of streamflow, groundwater inflow from adjoining mountain drainage basins, and infiltration of precipitation.

## Surface Water

The Big Lost River drains more than 1,400 mi<sup>2</sup> of mountainous area that includes parts of the Lost River Range and the Pioneer Mountains west of the INL (fig. 1). Surface-water flow along the Big Lost River infiltrates to the ESRP aquifer through the river channel and at sinks and playas at its terminus (fig. 1). When flow in the Big Lost River exceeds 250 ft<sup>3</sup>/s in the river channel, excess streamflow is diverted to spreading areas, where it rapidly infiltrates into the spreading areas. This excess streamflow has been diverted since 1965 to spreading areas in the southwestern part of the INL to prevent potential flooding at the INL facilities (Bennett, 1990, p. 15). Other surface drainages that provide recharge to the ESRP aquifer at the INL include Birch Creek, the Little Lost River, and Camas Creek (fig. 1).

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The average streamflow recorded at USGS streamgaging station 13127000, Big Lost River below Mackay Reservoir near Mackay, Idaho (fig. 1) for complete water years (October 1–September 30) 1905–2011 was 219,000 acre-ft/yr (U.S. Geological Survey, 2011) (fig. 8). Streamflow at streamgaging stations at and downstream of streamgaging station 13127000 (fig. 1) for water years 2009–11 are shown in table 4 and figure 8. Most of the flow between Mackay Reservoir and Arco, Idaho, is diverted for irrigation and groundwater recharge, therefore, flow only reaches the INL during wet years or when heavy rainfall or rapid snowmelt warrant brief periods of high discharge out of Mackay Reservoir.

Recharge to the ESRP aquifer downstream of Arco, Idaho (fig. 1), is substantial during wet years because of streamflow infiltration from the Big Lost River channel, diversion areas, sinks, and playas. For example, infiltration losses at various discharges measured during 1951–85 ranged from 1 (ft<sup>3</sup>/s)/mi in the river channel to 28 (ft<sup>3</sup>/s)/mi in the sinks (Bennett, 1990, p. 24–26). Bennett (1990) considered streamflow losses to evapotranspiration minor as compared to infiltration losses. However, infiltration can be zero in years when there is little or no flow in the Big Lost River channel at or downstream of streamgaging station 13132500 (fig. 1), as was the case during 2002–04 (Davis, 2008, table 4) and 2008 (Davis, 2010, table 4). During 2009–11, there was measurable flow in the Big Lost River channel at and downstream of streamgaging station 13132500 (table 4).

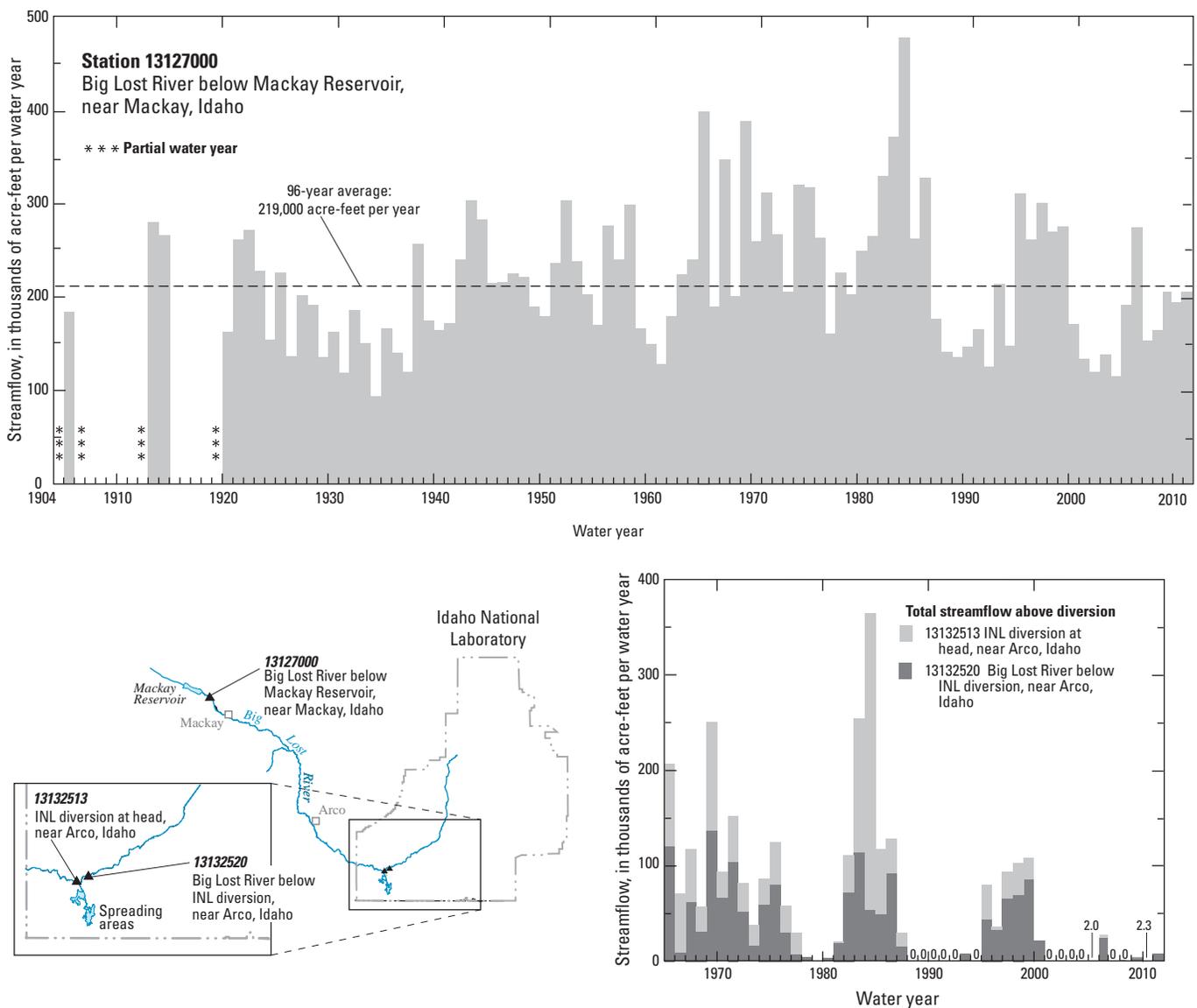


Figure 8. Streamflow at U.S. Geological Survey streamgaging stations along the Big Lost River: Big Lost River below Mackay Reservoir, near Mackay, Idaho, water years 1905, 1913–14, and 1920–2011; Big Lost River below the Idaho National Laboratory (INL) diversion, near Arco; and INL diversion at head, near Arco, Idaho, water years 1965–2011.

**Table 4.** Annual streamflow at U.S. Geological Survey streamgages along the Big Lost River, Idaho, water years 2009–11.[USGS streamgage: Station locations are shown in [figure 1](#). Streamflow: Data are from U.S. Geological Survey (USGS), 2009, 2010, and 2011.]

Abbreviations: INL, Idaho National Laboratory; WY, water year]

USGS streamgage		Streamflow (acre-feet)		
		WY 2009	WY 2010	WY 2011
13127000	Big Lost River below Mackay Reservoir, near Mackay, Idaho	209,700	193,200	213,700
13132500	Big Lost River near Arco, Idaho	9,200	3,830	12,300
13132513	INL diversion at head, near Arco, Idaho	158	0	0
13132520	Big Lost River below the INL Diversion, near Arco, Idaho	5,900	2,300	7,400
13132535	Big Lost River at Lincoln Blvd. Bridge, near Atomic City, Idaho	3,330	837	4,320
13132565	Big Lost River above Big Lost River Sinks, near Howe, Idaho	2,010	205	1,930

## Groundwater

Water in the ESRP aquifer primarily moves through interflow and fracture zones in the basalt. A large proportion of groundwater moves through the upper 200–800 ft of basaltic rocks (Mann, 1986, p. 21). Ackerman (1991a, p. 30) and Bartholomay and others (2000, p. 15) reported a range of transmissivity of basalt in the upper part of the aquifer of 1.1–760,000 ft<sup>2</sup>/d. Anderson and others (1999) reported a range of hydraulic conductivity at the INL of 0.01–32,000 ft/d. The hydraulic conductivity of rocks underlying the aquifer is from 0.002 to 0.03 ft/d (Mann, 1986, p. 21). The effective base of the ESRP aquifer probably ranges from about 815 to 1,710 ft below land surface in the western half of the INL based on data from wells that penetrate the base of the aquifer (Anderson and others, 1996, table 3). Wells in the eastern half of the INL do not penetrate the base of the aquifer, so the effective base of the aquifer cannot be estimated in that area.

Depth to water in wells completed in the ESRP aquifer ranges from about 200 ft in the northern part of the INL to more than 900 ft in the southeastern part. During March–May 2011, the altitude of the water table was about 4,560 ft in the northern part of the INL and about 4,410 ft in the southwestern part ([fig. 9](#)). Water flowed south and southwestward beneath the INL ([fig. 9](#)) at an average hydraulic gradient of about 4 ft/mi.

Water levels in wells generally declined 0.1–1.8 ft in the northern part of the INL from March–May 2009 to

March–May 2011 ([fig. 10](#)). In the central and eastern part of the INL, water levels generally rose from about 0.1 to 1.1 ft during the March to May 2009–11 reporting period ([fig. 10](#)). In the southwestern part of the INL, water levels generally rose or declined by approximately 1 ft during the March to May 2009 to March to May 2011 reporting period. However, the water level in well USGS 86 ([fig. 2](#)) rose 2.5 ft. The water level increases near wells along the Big Lost River can be attributed to periodic flow in the river and associated aquifer recharge during the 3 years of study.

Water levels monitored in wells USGS 12, 17, and 23 ([fig. 2](#)), and 20 ([fig. 3](#)) show long-term water-level changes in the ESRP aquifer in the central part of the INL in response to infiltration of streamflow ([fig. 11](#)). Long-term water-level fluctuations were about 18 ft in well USGS 20, 27 ft in well USGS 17, 33 ft in well USGS 23, and 37 ft in well USGS 12. Water levels in these wells varied, but generally rose slightly during 2009–11.

Groundwater moves southwestward from the INL and eventually discharges to springs along the Snake River near Twin Falls, Idaho, about 100 mi southwest of the INL. Discharge from the springs estimated by methods given by Kjelstrom (1995) was about 3.13 million acre-ft/yr for water year 2011, down slightly from the estimate of 3.64 million acre-ft/yr for water year 2008. Historically, the discharge to these springs has ranged from 2.97 million acre-ft/yr in 1904 to 4.94 million acre-ft/yr in 1951 (Daniel J. Ackerman, U.S. Geological Survey, written commun., 2007).

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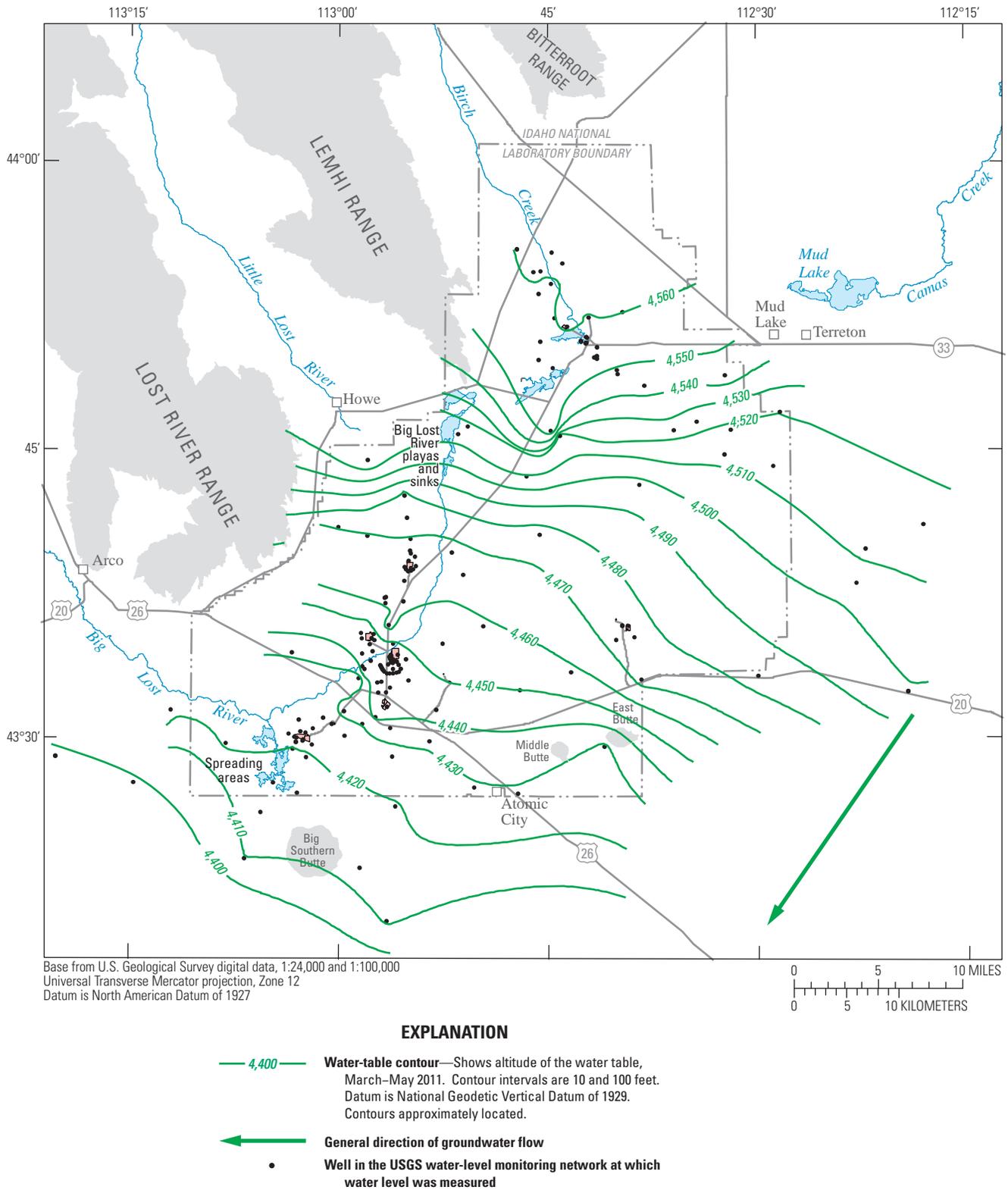
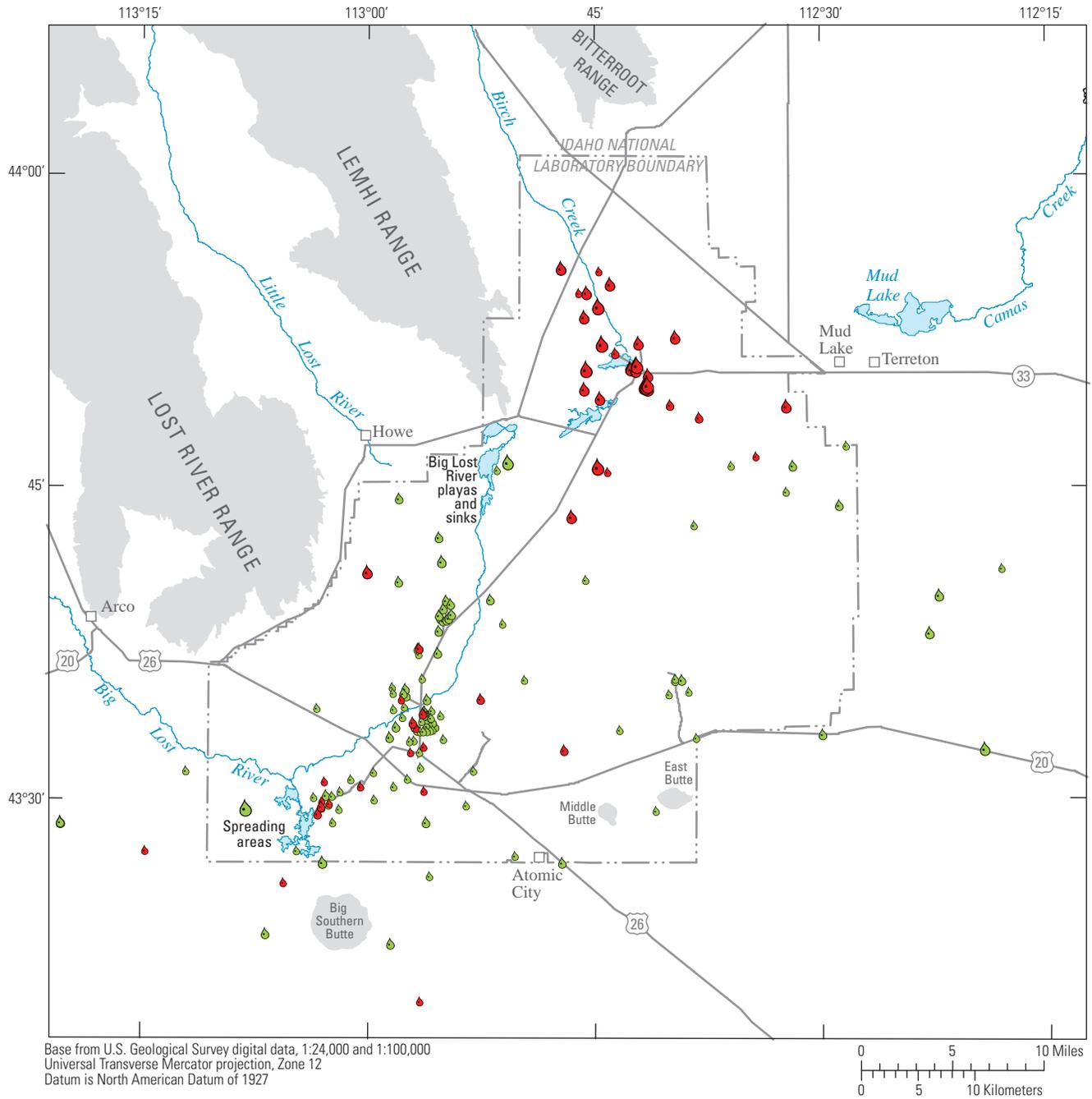


Figure 9. Altitude of the water table in the eastern Snake River Plain aquifer at and near the Idaho National Laboratory, Idaho, March–May 2011.



**EXPLANATION**

**Well at which there was a water level decline,  
 March-May 2009 to March-May 2011.**  
 Size of droplet indicates amount of decline, in feet.

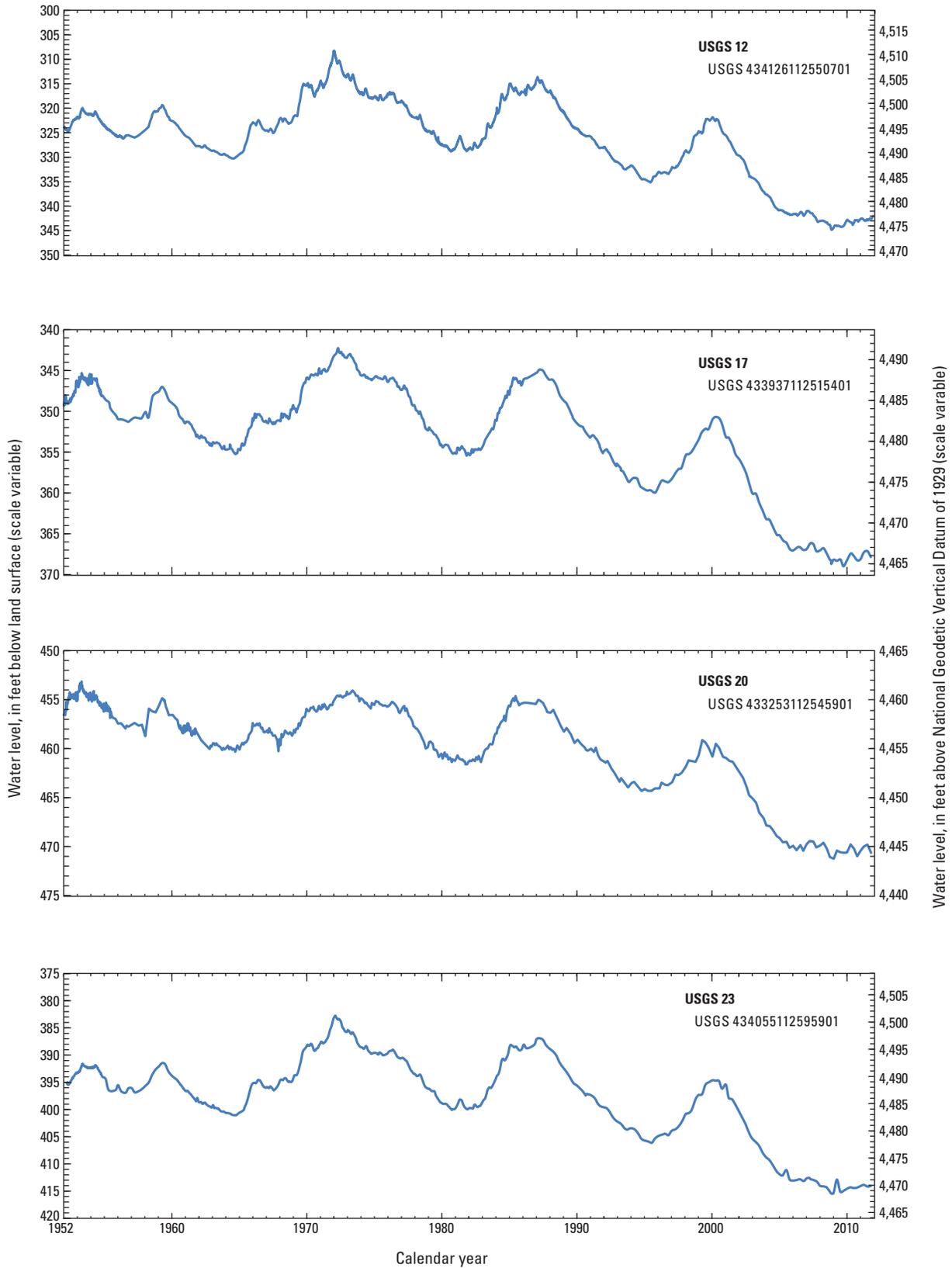
- 0.00 to -0.50
- 0.51 to -1.00
- 1.01 to -1.50
- 1.51 to -1.80

**Well at which there was a water level rise,  
 March-May 2009 to March-May 2011.**  
 Size of droplet indicates amount of rise, in feet.

- 0.00 to 0.50
- 0.51 to 1.00
- 1.01 to 1.50
- 1.51 to 2.00
- 2.01 to 2.50

**Figure 10.** Generalized rise or decline in groundwater levels in the eastern Snake River Plain aquifer at and near Idaho National Laboratory, Idaho, March–May 2009 to March–May 2011.

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**Figure 11.** Water levels in four U.S. Geological Survey (USGS) wells (USGS 12, 17, 20, 23) in the central part of the Idaho National Laboratory, Idaho, 1952–2011.

## Perched Groundwater

Disposal of wastewater to infiltration ponds and infiltration of surface water at waste-burial sites at the INL has resulted in the formation of perched groundwater in basalts and in sedimentary interbeds that overlie the ESRP aquifer (Cecil and others, 1991). Perched groundwater has formed in a complex sequence of basalt flow and sedimentary interbeds beneath the ATR Complex, the INTEC, and the RWMC. Perched groundwater also has been detected beneath infiltration ponds and ditches at other facilities at the INL in the past, but is not discussed in this report.

Anderson and Lewis (1989) and Anderson (1991) correlated geophysical logs to describe the stratigraphic sequences in which perched groundwater has formed at the ATR Complex, the INTEC, and the RWMC. Although the subsurface stratigraphy, geohydrologic characteristics, and waste disposal practices at each of these areas differs, the features controlling the formation of perched groundwater at these sites are similar (Cecil and others, 1991). Sedimentary interbeds in the subsurface may have smaller vertical hydraulic conductivities than overlying basalt flows, and alteration between basalt flows may contribute to reduced vertical hydraulic conductivity in the interflow rubble zones (Perkins and Winfield, 2007). Dense, unfractured basalt flows may have a decreased vertical hydraulic conductivity and may inhibit downward flow, and sedimentary or chemical infilling of fractures in basalt may reduce vertical hydraulic conductivity by limiting the interconnectivity of fractures reducing the water transmitting capability of the basalts (Cecil and others, 1991). Any combination of these factors may disrupt the downward vertical movement of water and contribute to the formation of perched groundwater zones.

At the ATR Complex, deep and shallow perched groundwater zones have formed in response to disposal of wastewater to infiltration ponds (Tucker and Orr, 1998). South of the INTEC, perched groundwater zones formed previously in response to wastewater disposal to the old percolation ponds, but have dried up since the ponds were taken out of use in 2002 (fig. 4). Perched groundwater also has been detected in other areas at the INTEC and may be attributed to leaking pipelines, leach fields, damaged casing in the upper part of the INTEC disposal well, other infiltration ponds, or landscape irrigation (Tucker and Orr, 1998). Perched groundwater also is present beneath the new percolation ponds (fig. 4) that were put in service during 2002. Perched groundwater beneath the RWMC formed from infiltration of snowmelt and rain, and recharge from the Big Lost River and INL spreading areas. This perched groundwater contains constituents leached from buried radioactive and organic-chemical wastes. Perched groundwater beneath wastewater infiltration ponds and buried waste is an integral part of the pathway for waste-constituent migration to the ESRP aquifer. The extent of perched groundwater is affected by the waste-disposal practices.

During March–May 2011, water levels in most deep perched groundwater wells around the ATR Complex rose since the March–May 2008 reporting period. Water-level rises ranged from about 0.7 ft in well USGS 72 to about 10.4 ft in well USGS 68 (fig. 4). Water-level rises may be attributed to variable recharge from ponds still in use, possible water leaks around the ATR Complex, infiltration of water from the Big Lost River channel during 2009–11 (table 4), or an overall increase in recharge at the INL during 2009–11 as compared to 2008, when there was zero flow in the Big Lost River channel at the INL (Davis, 2010, table 4). During March–May 2011, water levels completed in shallow perched groundwater wells rose and declined near the cold waste ponds (fig. 4); this could be due to variability in the amount of wastewater discharged to the ponds.

## Methods and Quality Assurance of Water Sample Analyses

Water samples were analyzed for radiochemical constituents at the DOE Radiological and Environmental Sciences Laboratory (RESL) at the INL and for chemical constituents at the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado. Until 2008, water samples analyzed by the RESL were entered into the USGS National Water Information System (NWIS) database with an uncertainty of  $2s$ , where  $s$  is the sample standard deviation. Beginning in 2008, data were entered into the NWIS database with an uncertainty of  $1s$ . Analytical uncertainties in this report are reported as  $1s$  for consistency with conventions used in previous USGS reports.

Methods used to sample and analyze for selected constituents generally follow the guidelines established by the USGS (Goerlitz and Brown, 1972; Stevens and others, 1975; Wood, 1976; Claassen, 1982; Wershaw and others, 1987; Fishman and Friedman, 1989; Faires, 1993; Fishman, 1993; Wilde and others, 1998). Water samples were collected according to a quality-assurance plan for water-quality activities conducted by personnel at the USGS INL Project Office. The plan was finalized in June 1989 and revised in March 1992, in 1996 (Mann, 1996), in 2003 (Bartholomay and others, 2003), and in 2008 (Knobel and others, 2008).

For the nine wells equipped with dedicated MLMS, water samples were collected using pre-cleaned, stainless-steel thief sampling bottles which were lowered to the zone to be sampled, connected to the sampling port, and filled with formation water. The stainless-steel bottles were then raised to the surface and emptied into a pre-cleaned container; the water was then processed to fill appropriate bottles for analyses. Field measurements also were taken from the pre-cleaned container and can be found for each well at <http://waterdata.usgs.gov/id/nwis/nwis> (U.S. Geological Survey, 2013c).

Field processing of water samples differed depending on the constituents for which analyses were requested. Water samples analyzed by the NWQL were placed in containers and preserved in accordance with laboratory requirements specified by Timme (1995) and Knobel and others (2008, appendix A). Containers and preservatives used for this study were supplied by the NWQL and were processed using a rigorous quality-control procedure (Pritt, 1989, p. 75) to minimize sample contamination. The process for water samples requiring filtration consisted of filtering the water through a disposable 0.45 micrometer filter cartridge that had been pre-rinsed with at least 1 L of deionized water. Water samples analyzed by the RESL were placed in containers and were preserved in accordance with laboratory requirements specified by Bodnar and Percival (1982) and Knobel and others (2008, appendix A).

## Guidelines for Interpreting Results of Radiochemical Analyses

Concentrations of radionuclides are reported with an estimated sample standard deviation,  $s$ , which is obtained by propagating sources of analytical uncertainty in measurements. The following guidelines for interpreting analytical results are based on an extension of a method proposed by Currie (1984).

In the analysis for a particular radionuclide, laboratory measurements are made on a target sample and a prepared blank. Instrument signals for the sample and the blank vary randomly. Therefore, it is essential to distinguish between two key aspects of the problem of detection: (1) the instrument signal for the sample must be greater than the signal observed for the blank before a decision can be made that the radionuclide was detected, and (2) an estimation must be made of the minimum radionuclide concentration that will yield a sufficiently large observed signal before a correct decision can be made for detection or nondetection of the radionuclide. The first aspect of the problem is a qualitative decision based on an observed signal and a definite criterion for detection. The second aspect of the problem is an estimation of the detection capabilities of a given measurement process.

In the laboratory, instrument signals must exceed a critical level of  $1.6s$ , where  $s$  is the sample standard deviation, before the qualitative decision can be made as to whether the radionuclide was detected. At  $1.6s$ , there is about a 95-percent probability that the correct conclusion—not detected—will be made. Given a large number of water samples, as many as 5 percent of the water samples with measured concentrations greater than or equal to  $1.6s$ , concluded as detected, might not contain the radionuclide. These measurements are referred to as false positives and are errors of the first kind in hypothesis testing.

Once the critical level of  $1.6s$  has been defined, the minimum detectable concentration may be determined. Concentrations that equal  $3s$  represent a measurement at the minimum detectable concentration. For actual concentrations equal to or greater than  $3s$ , there is a 95 percent or higher probability that the radionuclide was detected in a water sample. In a large number of water samples, the conclusion—not detected—will be made in 5 percent of the water samples that contain actual concentrations at the minimum detectable concentration of  $3s$ . These measurements are referred to as false negatives and are errors of the second kind in hypothesis testing.

Actual radionuclide concentrations between  $1.6s$  and  $3s$  have larger errors of the second kind. That is, there is a greater-than-5-percent probability of false negative results for water samples with actual concentrations between  $1.6s$  and  $3s$ . Although the radionuclide might have been detected, such detection may not be considered reliable; at  $1.6s$ , the probability of a false negative is about 50 percent.

The critical level and minimum detectable concentrations are based on counting statistics alone and do not include systematic or random errors inherent in laboratory procedures. The values  $1.6s$  and  $3s$  vary slightly with background or blank counts, with the number of gross counts for individual analyses, and for different radionuclides.

In this report, radionuclide concentrations less than  $3s$  are considered to be less than a “reporting level.” The critical level, minimum detectable concentration, and reporting level aid the reader to interpret analytical results and do not represent absolute concentrations of radioactivity, which may or may not have been detected. Analytical uncertainties in this report are reported as  $1s$  for consistency with conventions used in previous reports.

## Guidelines for Interpreting Results of Chemical Analyses

Historically, the NWQL has used a minimum reporting level (MRL) to report nondetected concentrations or concentrations less than the MRL. The MRL for chemical constituents is the lowest measured concentration of a constituent (the “less than” value reported by NWQL) that may be reliably reported using a given analytical method (Timme, 1995). However, NWQL determined that establishment of MRLs often was inconsistent, undefined, undocumented, and subjective (Childress and others, 1999). Therefore, in 1998, NWQL implemented new reporting procedures for some analytical methods based on long-term method detection levels (LT-MDLs). Childress and others (1999, p. 16) explained the new reporting procedures used by NWQL as:

“The USGS National Water Quality Laboratory collects quality-control data on a continuing basis to evaluate selected analytical methods to determine long-term method detection levels (LTMDLs) and laboratory reporting levels (LRLs). These values are re-evaluated each year on the basis of the most recent quality control data and, consequently, may change from year to year.

This reporting procedure limits the occurrence of false positive error. The chance of falsely reporting a concentration greater than the LT-MDL for a water sample in which the analyte is not present is 1 percent or less. Application of the LRL limits the occurrence of false negative error. The chance of falsely reporting a non-detection for a water sample in which the analyte is present at a concentration equal to or greater than the LRL is 1 percent or less.

Accordingly, concentrations are reported as less than the LRL for water samples in which the analyte was either not detected or did not pass identification. Analytes that are detected at concentrations between the LT-MDL and LRL and that pass identification criteria are estimated. Estimated concentrations will be noted with a remark code of “E.” These data should be used with the understanding that their uncertainty is greater than that of data reported without the “E” remark code.”

New LRLs were established for some analytical methods during 2009–11. In this report, concentrations determined using these methods are reported as greater than the LRL; concentrations determined using other methods are reported as greater than the MRL. Estimated concentrations less than the LRLs are treated as nondetected concentrations for consistency with treatment in previous publications, and because an estimated concentration is considered a “qualitatively detected analyte” (Childress and others, 1999, p. 7).

USGS Office of Water Quality Technical Memorandum 2010.07 (U.S. Geological Survey, 2010) outlines changes to data reporting by the NWQL for the inorganic and organic constituents that became effective October 1, 2010. Starting in October 2010, the reporting level was set at the LT-MDL concentration and concentrations less than the LT-MDL are reported as less than the LT-MDL for inorganic constituents. Results less than the LT-MDL for organic constituents are given a “t” qualifier code. The LRL convention as previously described is still used for organic constituents. Results between the LT-MDL and two times the LT-MDL (formerly the LRL for inorganic constituents) that were formerly reported with an “E” are now given an “n” qualifier code. Results for inorganic and organic constituents less than the lowest calibration standard are given a “b” qualifier code.

## Evaluation of Quality-Assurance Samples

Investigations to determine variability and bias for individual constituents were summarized by Wegner (1989), Williams (1996, 1997), and Rattray (2012). Additional quality-assurance (QA) studies by USGS INL Project Office personnel include:

- An evaluation of field sampling and preservation methods for strontium-90 (Cecil and others, 1989);
- A study comparing pump types used for sampling VOCs (Knobel and Mann, 1993);
- An analysis of tritium and strontium-90 concentrations in water from wells after purging different borehole volumes (Bartholomay, 1993);
- An analysis of effects of various preservation types on nutrient concentrations (Bartholomay and Williams, 1996);
- An analysis of two analytical methods to determine gross alpha- and beta-particle activity (Bartholomay and others, 1999);
- An evaluation of well-purging effects on water-quality results (Knobel, 2006); and
- An evaluation of the 2006–08 MLMS QA data (Bartholomay and Twining, 2010).

During 2009–11, variability and bias was evaluated from 56 replicate and 16 blank QA samples. Constituents analyzed from these samples included the constituents identified in section, [Water-Quality Monitoring Network](#).

## Variability

Results from replicate analyses were investigated to evaluate sample variability from field collection and processing, sample storage and shipping, and laboratory processing and analysis. Replicates consisted of two water samples, an environmental sample and a replicate sample, with the replicate sample collected immediately after collection of the environmental sample. Sources of variability include natural variability in groundwater chemistry, influences of sample collection and processing, and analytical uncertainty or error.

Sample variability was evaluated by calculating the reproducibility and reliability of individual constituents (Rattray, 2012). Reproducibility (the closeness of agreement between individual measurements) was calculated as normalized absolute difference (NAD) for radiochemical and stable isotope constituents (measurements that include analytical uncertainties) and relative standard deviation (RSD) for inorganic and organic constituents (measurements

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that do not include analytical uncertainties). Reliability (the error associated with a measurement) was calculated as a pooled RSD for each constituent except for the stable isotopes (because the stable isotope measurements are reported as isotope ratios, not concentrations). Equations for calculating the NAD and pooled RSD are presented in Rattray (2012).

### Reproducibility

Reproducibility of constituent measurements was considered acceptable if (Rattray, 2012, p. 10):

- The NAD was less than or equal to 1.96,
- The RSD was less than 14 percent (this corresponds to a relative percent difference of less than 20 percent),
- Both measurements were censored and (or) estimated because they were less than the reporting level for that analysis, or
- One measurement was censored or estimated and the other measurement was within one detection limit of the larger of the estimated value or the reporting level, or the measurements were within one detection limit of each other. For results reported using the LRL as the reporting level, the detection limit was the LT-MDL (one-half of the LRL). For results reported using the MRL as the reporting level, the detection limit was approximated as one-half of the MRL.

If the percentage of replicates with acceptable reproducibility for a constituent was greater than or equal to 90 percent, then the reproducibility for that constituent was considered acceptable for 2009–11.

Constituents with acceptable reproducibility were stable isotope ratios (100 percent), major ions (100 percent), nutrients (95–100 percent), and volatile organic compounds (100 percent). All radiochemical constituents (91–100 percent) and trace metals had acceptable reproducibility (91–100 percent) except for gross beta-particle radioactivity (88 percent), aluminum (80 percent), antimony (80 percent), and cobalt (60 percent). The percentage of replicates with acceptable reproducibility for TOC was 83 percent. The low reproducibility for gross beta-particle radioactivity, aluminum, antimony, cobalt, and TOC were probably a result of measured concentrations for these constituents that were all less than four times the method detection limit (MDL), LRL, or LT-MDL.

### Reliability

Reliability and RSDs are generally a function of concentration, where reliability increases and RSDs decrease with increasing concentration. Because pooled RSDs should be calculated from samples with similar variability, reliability was estimated for constituent concentration ranges with a similar range of RSDs (Rattray, 2012, p. 11).

[Table 5](#) shows pooled RSDs for discrete concentration ranges for each constituent (with calculated RSDs). RSDs were calculated for radiochemicals in order to calculate pooled RSDs, if both concentrations from a replicate sample pair equaled or exceeded the MDL and the reporting level of 3s. Pooled RSDs were calculated for every concentration range of each constituent; the pooled RSDs were less than or equal to 12 percent except for the 3 to less than 5 pCi/L concentration range for strontium-90 (32 percent), gross beta-particle radioactivity (22 percent), the 10 to less than 20 µg/L concentration range for ammonia (19 percent), aluminum (18 percent), cobalt (32 percent), and TOC (27 percent). The high RSDs and low reliability for these concentration ranges of strontium-90, ammonia, gross beta-particle radioactivity, aluminum, cobalt, and TOC were probably the result of measured concentrations that were all less than four times the MDL, LRL, or LT-MDL.

There were two replicate samples where high RSDs for nitrate were calculated because the environmental and replicate nitrate concentrations were very different (1.6 and 2.9 mg/L as N; 0.58 and 0.93 mg/L as N). The replicate with low concentrations had concentrations less than three times the reporting level, which explains why these concentrations were so different, but it is not known why concentrations from the other replicate were so different. Excluding these two high RSDs, results in a calculated pooled RSD for nitrate from 42 replicate sample pairs was 2.8 percent. Consequently, 95 percent of nitrate measurements appear to be very reliable.

The pooled RSDs in [table 5](#) are very similar to pooled RSDs determined from QA samples from 1996 to 2001 (Rattray, 2012, table 12). One notable difference, however, is the improved reliability of measurements for the lowest concentration range of orthophosphate during 2009–11 (2.6 percent) compared to 1996–2001 (16 percent). This was likely due to improved analytical performance.

### Bias

Bias from sample contamination was evaluated from equipment, field, container, and source solution blanks. Other sources of bias associated with field samples, such as matrix interference and sample degradation, were not evaluated. However, the NWQL and the RESL evaluate laboratory bias (including sample contamination, matrix interference, and sample degradation) with analysis of blank samples and reference materials. Equipment and field blanks were collected at field sites, the container blanks were collected at the USGS laboratory at the INL, and the deionized water source-solution blank was collected at the USGS Idaho Water Science Center, Idaho Falls Field Office. The equipment, field, and source solution blanks were collected as described by Rattray (2012, p. 7), and the container blank was collected in the same manner as equipment blanks.

**Table 5.** Ranges of concentrations, number of replicates with calculated relative standard deviations, and pooled relative standard deviations for radiochemical, inorganic, and organic constituents, Idaho National Laboratory, Idaho, 2009–11.

[**Abbreviations:** RSD, relative standard deviation; pCi/L, picocuries per liter; mg/L, milligrams per liter; µg/L, micrograms per liter; N, nitrogen; P, phosphorous. **Symbol:** <, less than]

Constituent	Concentration range	Number of replicates with calculated RSDs	Pooled RSD (percent)	Constituent	Concentration range	Number of replicates with calculated RSDs	Pooled RSD (percent)
Tritium (pCi/L)	600–4,000	13	5.0	Antimony (µg/L)	0.08–0.2	5	9.4
Strontium-90 (pCi/L)	3– <5	3	32	Arsenic (µg/L)	1–3	5	0.7
	5–10	5	12	Barium (µg/L)	30–100	5	0.7
	30–40	1	2.4	Boron (µg/L)	10–20	7	1.7
Gross-beta radioactivity (pCi/L as Cs-137)	4.0–12	9	22	Cadmium (µg/L)	0.05–0.06	1	8.2
Uranium-234 (pCi/L)	1–2	2	3.0	Cobalt (µg/L)	0.03–0.1	5	32
Uranium-235 (pCi/L)	0.04–0.05	1	3.2	Chromium (µg/L)	1– <5	12	8.9
Uranium-238 (pCi/L)	0.4–0.7	2	7.5		5–25	19	2.4
Sodium (mg/L)	5–50	50	1.8	Lithium (µg/L)	1–4	8	1.9
Calcium (mg/L)	30–50	4	1.7	Manganese (µg/L)	0.2–2	2	1.2
Magnesium (mg/L)	10–20	4	1.3	Molybdenum (µg/L)	1–3	5	0.6
Potassium (mg/L)	2–3	4	1.7	Nickel (µg/L)	0.1–0.5	4	2.3
Chloride (mg/L)	2–3	1	7.8	Selenium (µg/L)	1–2	4	1.7
	4–110	54	0.8	Strontium (µg/L)	200–250	4	0.2
Sulfate (mg/L)	10–300	29	1.2	Tungsten (µg/L)	0.09–0.2	4	2.5
Fluoride (mg/L)	0.1–0.3	5	2.3	Uranium (µg/L)	1–3	5	0.6
Bromide (µg/L)	30–50	4	4.8	Vanadium (µg/L)	4–6	4	0.7
Silica (mg/L)	20–30	4	0.4	Zinc (µg/L)	3–12	3	9.5
Ammonia (µg/L as N)	10– <20	2	19	Tetrachloromethane (µg/L)	0.5–0.6	1	2.5
	20–70	2	2.8	Toluene (µg/L)	0.1–0.2	1	2
Nitrate (mg/L as N)	0.1–6	44	12	Trichloroethene (µg/L)	0.4–0.5	1	1.5
	0.1–6	42	<sup>1</sup> 2.8	Trichloromethane (µg/L)	0.3–0.4	1	0.4
Nitrite (µg/L as N)	1–10	3	5.5	Total organic carbon (mg/L)	0.3–1.1	8	27
Orthophosphate (µg/L as P)	5–60	43	2.6				
	110–120	1	0.1				
Aluminum (µg/L)	4–7	4	18				

<sup>1</sup>Two replicates with high RSDs were excluded from this pooled RSD for nitrate.

Equipment blanks were collected to identify bias of environmental samples due to inadequate cleaning of portable sampling equipment (bailers, thief samplers, and stainless-steel sampling pipes). Inadequate cleaning of thief samplers and sampling pipes may cause cross-contamination between sample sites. Since 2008, each bailer has been designated for use at a specific well, so inadequate cleaning of a bailer will only affect the next sample collected from the specific well for which that particular bailer was designated.

Equipment blanks include bias from sources other than the equipment, such as field collection and processing, sample storage and shipping, and laboratory processing and analysis. Consequently, field and other blanks were collected to determine whether bias identified in equipment blanks may be from sources other than the equipment. The field blank was collected to identify all potential sources of bias in the equipment blanks except for bias from the equipment. The container blank was collected to identify bias from the 5-gallon plastic containers used to store deionized water. Source-solution blanks were collected to identify bias in the deionized water source solution collected from the USGS Idaho Water Science Center, Idaho Falls Field Office. Inorganic-free and organic-grade blank water, purchased from the NWQL, also were used as source solutions and were certified by NWQL to be free of the constituents of interest.

Bias was evaluated from results of 10 equipment blanks (sampling pipes [1], bailer [6], thief sampler [3]), 1 field blank, 1 container blank, and 4 source-solution blanks. Concentrations in blank samples were considered detected if (1) radiochemical constituents were greater than or equal to 3 $\sigma$  (the minimum detectable concentration) and (2) inorganic and organic constituents were greater than or equal to the largest reporting level for a constituent during 2009–11.

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.

The detectable concentration of dichloromethane in the container blank, which contains deionized water used for preparing blank samples, would not cause any bias in environmental sample concentrations of dichloromethane. All other detectable concentrations were from equipment blanks of bailers and had small concentrations of less than two times the MDL (2.5 $\pm$ 0.7 pCi/L, strontium-90) or less than two times the LRL (0.1 mg/L, sodium; 0.3 mg/L, sulfate; 0.1 mg/L, chloride) except for one chloride concentration (1.0 mg/L).

Sodium, sulfate, and chloride were detected in blanks from the bailer dedicated for use at well USGS 66. Minimum measured concentrations in water from this well during 2009–11 were 14.9, 188, and 17.6 mg/L for sodium, sulfate, and chloride, respectively. The largest potential bias for these constituents is 5.7 percent for chloride, which indicates that the potential bias of these constituents at well USGS 66 was not significant.

The blank with the detection of strontium-90 was from the bailer dedicated for use with well CWP 9. The only measured environmental sample concentration of strontium-90 in water from this well, 0.7 $\pm$ 0.7 pCi/L, during 2009–11 does not indicate any positive bias from sample contamination.

## **Selected Physical Properties of Water and Radiochemical and Chemical Constituents in the Eastern Snake River Plain Aquifer**

Physical properties of water measured during sampling events included specific conductance, temperature, and pH. Contaminant plumes of radiochemical and chemical constituents in the ESRP aquifer at the INL are attributed to waste-disposal practices. Areal distribution of the plumes was interpreted from analyses of water samples collected from a three-dimensional flow system. Concentrations of these constituents represent water samples collected during April or October 2011 from wells completed at various depths in the aquifer and with differing well completions; for example, single and multiple screened intervals and open boreholes. No attempt was made to determine the vertical extent and distribution of these plumes. However, beginning in 2006, selected wells were instrumented with dedicated MLMS. During 2011, water samples were collected from nine wells with dedicated MLMS that allow for some description of the vertical distribution of selected constituents in the aquifer. Radiochemical and chemical constituents analyzed for in groundwater samples collected from wells at the INL during 2009–11 include tritium, strontium-90, cesium-137, plutonium-238, plutonium-239, -240 (undivided), americium-241, gross alpha- and beta-particle radioactivity, chromium and other trace elements, sodium, chloride, sulfate, nitrate (as N), fluoride, VOCs, and TOC.

### **Specific Conductance, Temperature, and pH**

Specific conductance is a measure of the electrical conductivity of water and is proportional to the quantities of dissolved chemical constituents in the water. Dissolved chemical constituents such as chloride, sodium, and sulfate in wastewater discharged to disposal wells and infiltration ponds at INL facilities generally have increased the specific conductance of groundwater through time.

In 2011, the specific conductance of water from 134 wells ranged from 233 to 2,160  $\mu$ S/cm; the highest value was in water from well NRF 6 located adjacent to the industrial waste ditch ([fig. 3](#)). Specific conductance measurements for water from most wells around the NRF area were about 600  $\mu$ S/cm ([fig. 12](#)).

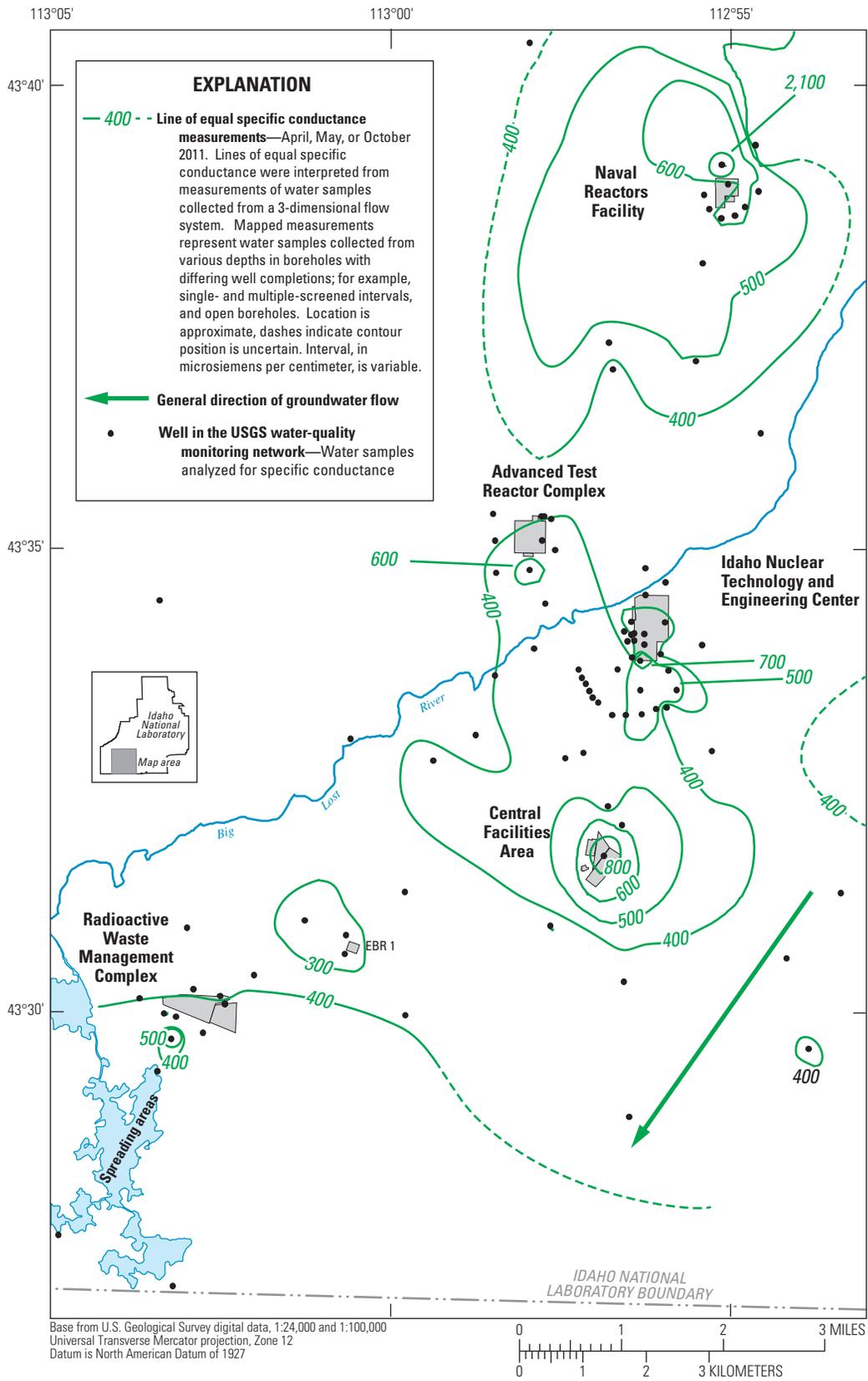


Figure 12. Distribution of specific conductance of water from wells at and near the Advanced Test Reactor Complex, Naval Reactors Facility, Idaho Nuclear Technology and Engineering Center, Central Facilities Area, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, April, May, or October 2011.

The general increase in specific conductance in groundwater attributed to wastewater discharged to the aquifer since the mid-1980s is apparent in groundwater downgradient from INL facilities. The background specific conductance of water in the ESRP aquifer is about 300–325  $\mu\text{S}/\text{cm}$  in the INTEC area (Robertson and others, 1974, p. 159). A plume of increased specific conductance originated from the INTEC old percolation ponds (fig. 6) and extended downgradient from the INTEC to the CFA (fig. 12). The specific conductance of water from several wells within this plume increased from about 500  $\mu\text{S}/\text{cm}$  in 1985 (Pittman and others, 1988, p. 64) to more than 1,000  $\mu\text{S}/\text{cm}$  in 1998 (Bartholomay and others, 2000, p. 37) and has decreased since then to 720  $\mu\text{S}/\text{cm}$  in 2011 (fig. 12).

The specific conductance of water from several wells at the ATR Complex exceeded 400  $\mu\text{S}/\text{cm}$  in 2011 (fig. 12). The maximum specific conductance measurement was from water from well USGS 65 (fig. 6), downgradient from the infiltration ponds at the ATR Complex. Well USGS 65 had a measurement of 614  $\mu\text{S}/\text{cm}$  in April 2011, about the same value as in April 2008.

At the CFA, the specific conductance of water from well CFA 1 decreased slightly from 609  $\mu\text{S}/\text{cm}$  in 2008 to 586  $\mu\text{S}/\text{cm}$  in April 2011; and in well CFA 2, the measurements increased from 810  $\mu\text{S}/\text{cm}$  in 2008 to 864  $\mu\text{S}/\text{cm}$  in 2011.

Near the RWMC, the maximum specific conductance measured was in water from well USGS 88, at 586  $\mu\text{S}/\text{cm}$  in October 2011, similar to the measurement of 580  $\mu\text{S}/\text{cm}$  in October 2008. Water from most other wells near the RWMC had measurements of about 250–400  $\mu\text{S}/\text{cm}$  (fig. 12).

Water temperature and pH were measured annually during 2009–11 in water from 126, 127, and 124 wells at the INL, respectively, for each year. The lowest water temperatures consistently were measured in well P&W 2, northwest of the TAN (fig. 5) and ranged from 9.0 to 10.0 °C, a slight increase from the 2006–08 reporting period when the temperatures ranged from 8.3 to 9.0 °C (Davis, 2008). The highest water temperatures consistently were measured in well USGS 7, ranging from 19.0 to 19.1 °C. The median water temperature for all wells sampled annually during 2009–11, was 12.8, 12.9, and 12.7 °C, respectively, for each year.

In 2009, pH ranged from 7.4 in water from well CFA 2 at the CFA to 9.1 in well USGS 119 south of the RWMC (fig. 6). In 2010, pH ranged from 7.2 in water from well USGS 4 on the eastern border of the INL (fig. 5) to 9.2 in water from well USGS 119, south of the RWMC (fig. 6). In 2011, pH ranged from 6.8 in water from the RWMC Production well and NPR Test (fig. 5) to 9.0 in water from well USGS 119 (fig. 6). The median pH in water from all wells sampled annually from 2009 to 2011 was 7.8, 7.7, and 7.9, respectively, for each year, similar to the 2006–08 reporting period when the median pH ranged from 7.8 to 7.9.

Field measurements of water temperature and pH were made in all wells equipped with MLMS during 2009–11. Twining and Fisher (2012) summarize temperature

measurements taken from different zones in these wells during 2009–10. During 2011, selected zones were measured for temperature and pH in existing MLMS equipped wells. Wells USGS 103, 105, and 108, which were equipped with MLMS during 2009–10, were measured for temperature and pH in most zones. In well USGS 103, the temperature ranged from 12.6 to 12.8 °C; pH ranged from 7.6 to 7.9. In well USGS 105 temperature ranged from 12.9 to 13.1 °C; pH ranged from 7.4 to 8.0. In well USGS 108, temperature ranged from 12.4 to 12.9 °C; pH ranged from 7.5 to 7.9.

## Tritium

A tritium plume has developed in the ESRP aquifer from discharge of wastewater at the INL since the 1950s. Tritium has a half-life of 12.3 years (Walker and others, 1989, p. 20). The maximum contaminant level (MCL) for tritium is 20,000 pCi/L (U.S. Environmental Protection Agency, 2013). About 31,810 Ci of tritium (Davis, 2006b) was discharged to wells and ponds at the INL from 1952 through 2000; no records are available since 2000. The primary sources of tritium in the aquifer have been the injection of wastewater through the disposal well at INTEC and the discharge of wastewater to percolation ponds at the INTEC and ATR Complex (fig. 4). Routine use of the disposal well at the INTEC ended in February 1984; subsequently, radioactive wastewater was discharged to the old percolation ponds until 1993 when discharge of low- and intermediate-level radioactive waste solutions ceased with the installation of the Liquid Effluent Treatment and Disposal Facility (U.S. Department of Energy, 2011a). Radioactive wastewater was discharged to the radioactive-waste ponds at the ATR Complex until 1993; since then, tritium at the ATR Complex has been discharged to lined evaporation ponds, which theoretically should prevent migration to the aquifer. Concentrations of tritium in water samples collected in 2011 from 50 of 127 aquifer wells exceeded the reporting level and ranged from 200±60 to 7,000±260 pCi/L. The tritium plume extended south-southwestward in the general direction of groundwater flow (fig. 13). Since 1997, tritium concentrations in water samples collected by the USGS from the ESRP aquifer have not exceeded the MCL.

Long-term radioactive-decay processes and an overall decrease in tritium disposal rates since the 1960s (Davis, 2008) contributed to decreased concentrations of tritium in water from most wells at the INL during 2009–11. Tritium concentrations in water from several wells at and south-southwest of the INTEC decreased or remained relatively constant during 2009–11 (fig. 14). Concentrations of tritium in well CFA 1 (figs. 5 and 14) south of the INTEC decreased from 6,300±200 pCi/L in April 2008 to 5,300±210 pCi/L in April 2011. The greatest decrease in tritium concentrations in wells south of the INTEC disposal well during the 2009–11 reporting period was in well USGS 77, which decreased from 5,620±150 pCi/L in October 2008 to 3,490±150 pCi/L in October 2011 (fig. 14).

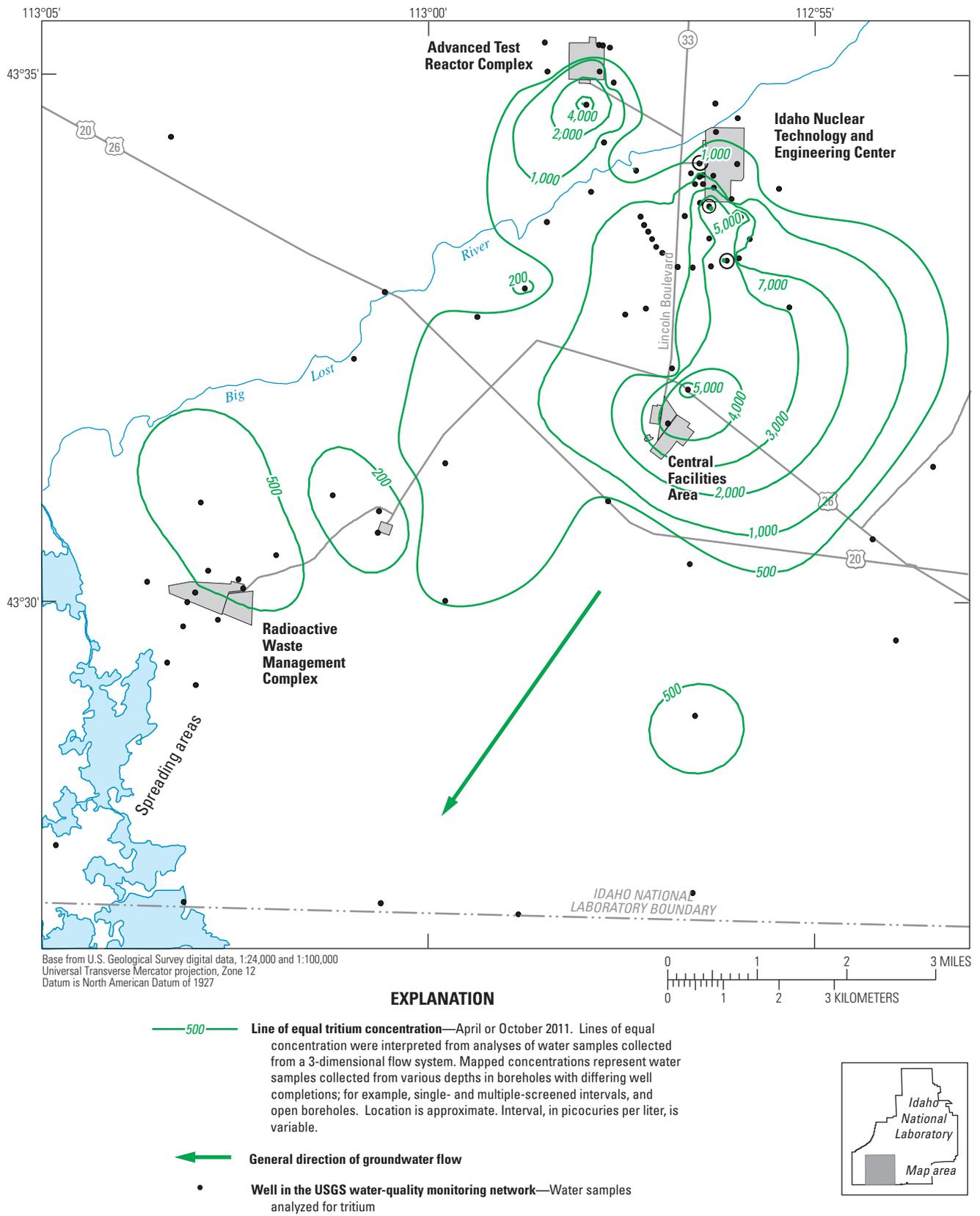


Figure 13. Distribution of tritium in water from wells at and near the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, Central Facilities Area, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, April or October 2011.

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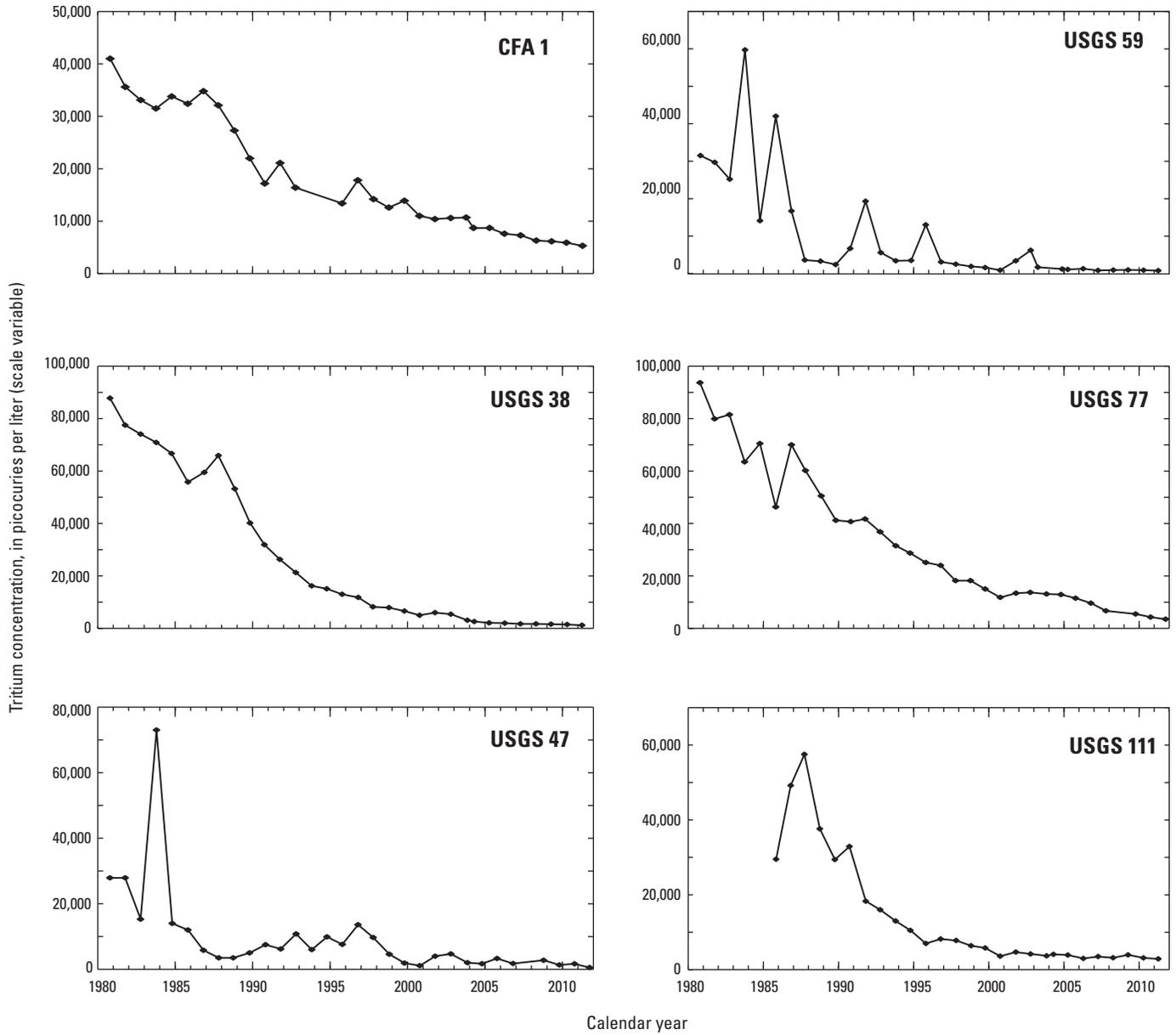


Figure 14. Tritium concentrations in water from six wells at and near the Central Facilities Areas and Idaho Nuclear Technology and Engineering Center, Idaho National Laboratory, Idaho, 1980–2011. Locations of wells are shown in [figures 5](#) and [6](#).

The overall decrease in tritium concentrations in water from wells at and south-southwest of the INTEC likely is the result of discontinued discharge of tritium in wastewater since the early 1990s (Davis, 2008, fig. 9).

Tritium concentrations in water from well USGS 59, near the old INTEC percolation ponds (figs. 6 and 14), have decreased since 1980, but were unusually high in October 1983, 1985, 1991, and 1995, and in 2002 (fig. 14). The higher concentrations in 1983 and 1985 correlate with higher annual discharge rates of tritium; however, annual discharge of tritium was low in 1991 and 1995 (Davis, 2008, fig. 9). In 1986, perched groundwater was detected outside the casing in well USGS 59. Following modifications to the well to prevent seepage of water into the well, a video log showed that some water from the perched groundwater zone was still seeping into the well. The higher concentrations in 1991, 1995, and 2002 probably resulted from seepage from a perched groundwater zone. The higher concentrations also correlate with the use of the old east percolation pond and with disposal of tritium to the ponds. The lower concentrations in water from well USGS 59 in 1989, 1993, 1994, and 1996–2000 correlate with years in which little or no tritium was discharged to the old percolation ponds (Davis, 2008, fig. 9). The slight increase in tritium concentrations in wells USGS 38, 47, 59, 77, and 111 between 2000 and 2001 (fig. 14), could have resulted from disposal of 0.03 Ci of tritium (S.M. Stoller Corporation, 2002b) to the old INTEC percolation ponds and from the lack of dilution by groundwater recharge because of low streamflows in the Big Lost River during 2000 (Davis, 2008). The overall decrease in tritium concentrations in water from wells at and south-southwest of the INTEC likely is the result of discontinued discharge of tritium in wastewater since the early 1990s (Davis, 2008, fig. 9). The lower concentrations in 2003–11 (fig. 14) occur after the old percolation ponds were taken out of service and replaced with the new percolation ponds about 2 mi southwest of the INTEC.

Tritium concentrations in water from wells USGS 83 and EBR 1 (fig. 5) and in and near the tritium plume (fig. 13) have been consistently less than the reporting level through time. Well USGS 83 penetrates about 250 ft of the ESRP aquifer and well EBR 1 penetrates about 490 ft of the aquifer. Most of the other wells in the tritium plume penetrate only the uppermost 50–200 ft of the aquifer. Tritium concentrations in water from wells USGS 83 and EBR 1 were less than the reporting level, possibly because of dilution by water from deeper zones, a phenomena described by Mann and Cecil (1990, p. 18) for these wells.

Prior to 1999, concentrations of tritium in water from wells near the southern boundary of the INL (USGS 1, 103, 105, 108, 109, 110A) (fig. 5), varied between exceeding and not exceeding the reporting levels (Pittman and others, 1988; Mann and Cecil, 1990; Bartholomay and others, 1997, 2000). During 1999–2005, concentrations of tritium in water from these wells and all wells sampled south of the INL boundary were less than the reporting level. Water from wells USGS 1, 109, and 110A had tritium concentrations below the reporting level during 2009–11.

Water from various depths in all nine wells equipped with the MLMS (figs. 5 and 6, table 6) was sampled and analyzed for tritium during 2009–11. During 2006 and 2007, water from well USGS 105 exceeded the reporting level with concentrations of  $210 \pm 60$  and  $270 \pm 80$  pCi/L, respectively. In 2008, well USGS 105 was deepened and equipped with a MLMS. Tritium concentrations in the uppermost sampling zone of well USGS 105 were less than the reporting level during 2009–10, but exceeded the reporting level in all lower zones during at least one sampling event from 2009 to 2011. Water sampled from the MLMS installed in well USGS 103 had tritium concentrations less than the reporting level in several of the upper zones but did show concentrations greater than the reporting level in deeper levels of the aquifer during 2009–11 (table 6). Well USGS 108 was equipped with a MLMS in 2010. One sample in 2010 (808.8 ft BLS) had a concentration greater than the reporting level; however, all other samples analyzed in 2010 and 2011 had tritium concentrations less than the reporting level in all zones sampled. Water from wells USGS 133 and 135 had concentrations of tritium that did not exceed the reporting level in any of the zones sampled during 2009–11. Other results showed that water from one or more zones in wells USGS 132, 134, Middle 2050A, and Middle 2051 contained concentrations of tritium greater than the reporting level during 2009–11. The tritium concentrations greater than the reporting levels are attributed to wastewater disposal at the INTEC and ATR Complex (Bartholomay and Twining, 2010). Bartholomay and Twining (2010) give a comprehensive analysis of the vertical variation in tritium concentrations for six of the wells previously described and possible sources of the tritium for the different zones in each well.

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**Table 6.** Tritium concentrations in water sampled at multiple depths in nine wells equipped with multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.

[Wells grouped by date sampled. **Well No.:** Well locations are shown in [figures 5](#) and [6](#). Concentrations and associated uncertainties in picocuries per liter. Analytical uncertainties are reported as 1 times the sample standard deviation. Concentrations equal to or greater than 3 times the sample standard deviation are considered greater than the reporting level and are **bold**. **Abbreviations:** ft BLS, feet below land surface; USGS, U.S. Geological Survey. **Symbol:** ±, plus or minus]

Well No.	Sampling port depth (ft BLS)	Date	Concentration	Well No.	Sampling port depth (ft BLS)	Date	Concentration
USGS 103	680.3	08-25-09	30±60	USGS 132	918.7	08-27-09	130±60
USGS 103	801.9	08-25-09	-40±60	USGS 132	1,011.6	08-27-09	<b>210±60</b>
USGS 103	908.7	08-25-09	30±60	USGS 132	1,173.0	08-26-09	<b>200±60</b>
USGS 103	992.9	08-24-09	80±60	USGS 132	637.9	06-30-10	<b>270±70</b>
USGS 103	1,086.8	08-24-09	<b>270±60</b>	USGS 132	765.4	06-30-10	<b>410±70</b>
USGS 103	1,209.7	08-24-09	<b>310±70</b>	USGS 132	827.3	06-30-10	<b>280±70</b>
USGS 103	1,258.0	08-25-09	<b>300±60</b>	USGS 132	918.7	06-30-10	<b>310±70</b>
USGS 103	680.3	06-27-10	50±60	USGS 132	1,011.6	06-30-10	<b>340±70</b>
USGS 103	801.9	06-25-10	100±60	USGS 132	1,173.0	06-30-10	<b>380±70</b>
USGS 103	908.7	06-23-10	140±60	USGS 132	637.9	07-06-11	<b>200±60</b>
USGS 103	992.9	06-23-10	<b>320±70</b>	USGS 132	765.4	07-06-11	<b>240±60</b>
USGS 103	1,086.8	06-23-10	<b>370±70</b>	USGS 133	469.1	08-20-09	80 ±60
USGS 103	1,209.7	06-29-10	<b>480±70</b>	USGS 133	569.6	08-20-09	-80±60
USGS 103	1,258.0	06-24-10	<b>510±70</b>	USGS 133	686.1	08-20-09	-40±60
USGS 103	992.9	06-21-11	130±60	USGS 133	745.5	08-20-09	-13±57
USGS 103	1,086.8	06-21-11	<b>290±60</b>	USGS 133	469.1	08-05-10	80±50
USGS 103	1,209.7	06-21-11	<b>350±70</b>	USGS 133	569.6	08-05-10	11±47
USGS 103	1,258.0	06-20-11	<b>380±70</b>	USGS 133	686.1	08-05-10	30±50
USGS 105	727.6	09-18-09	60±60	USGS 133	745.5	08-05-10	100±50
USGS 105	851.2	09-18-09	120±60	USGS 133	469.1	06-27-11	90±60
USGS 105	951.6	09-17-09	<b>200±60</b>	USGS 134	578.5	08-18-09	10±60
USGS 105	1,071.6	09-17-09	<b>270±60</b>	USGS 134	645.5	08-18-09	-50±60
USGS 105	1,242.2	09-16-09	80±60	USGS 134	706.5	08-18-09	<b>180±60</b>
USGS 105	727.6	09-16-10	140±50	USGS 134	806.6	08-17-09	-100± 60
USGS 105	851.2	09-16-10	<b>180±50</b>	USGS 134	846.6	08-17-09	11±58
USGS 105	951.6	09-15-10	<b>680±70</b>	USGS 134	578.5	06-22-10	50±60
USGS 105	1,071.6	09-15-10	<b>260±50</b>	USGS 134	645.5	06-22-10	<b>230±70</b>
USGS 105	1,242.2	09-15-10	<b>210±50</b>	USGS 134	706.5	06-21-10	130±60
USGS 105	851.2	07-13-11	140±60	USGS 134	806.6	06-21-10	130±60
USGS 105	951.6	07-11-11	<b>230±60</b>	USGS 134	846.6	06-21-10	90±60
USGS 105	1,071.6	07-11-11	<b>250±60</b>	USGS 134	578.5	06-29-11	-30±60
USGS 108	661.1	09-21-10	80±50	USGS 134	645.5	06-29-11	130±60
USGS 108	808.8	09-21-10	<b>190±50</b>	USGS 135	737.9	09-15-09	-60±60
USGS 108	887.7	09-20-10	130±50	USGS 135	836.7	09-15-09	-40±60
USGS 108	1,028.8	09-22-10	100±50	USGS 135	988.1	09-15-09	-40±60
USGS 108	1,171.8	09-20-10	160±50	USGS 135	1,116.4	09-14-09	-11±58
USGS 108	661.1	06-23-11	30±60	USGS 135	737.9	09-14-10	80±50
USGS 108	808.8	06-23-11	80±60	USGS 135	836.7	09-14-10	0±50
USGS 108	887.7	06-23-11	50±60	USGS 135	988.1	09-13-10	70±50
USGS 108	1,028.8	06-22-11	110±60	USGS 135	1,116.4	09-13-10	30±50
USGS 108	1,171.8	06-22-11	80±60	USGS 135	836.7	07-07-11	12±58
USGS 132	637.9	08-27-09	80±60				
USGS 132	765.4	08-27-09	<b>230±60</b>				
USGS 132	827.3	08-27-09	130±60				

**Table 6.** Tritium concentrations in water sampled at multiple depths in nine wells equipped with multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.—Continued

[Wells grouped by date sampled. **Well No.:** Well locations are shown in [figures 5](#) and [6](#). Concentrations and associated uncertainties in picocuries per liter. Analytical uncertainties are reported as 1 times the sample standard deviation. Concentrations equal to or greater than 3 times the sample standard deviation are considered greater than the reporting level and are **bold**. **Abbreviations:** ft BLS, feet below land surface; USGS, U.S. Geological Survey. **Symbol:** ±, plus or minus]

Well No.	Sampling port depth (ft BLS)	Date	Concentration	Well No.	Sampling port depth (ft BLS)	Date	Concentration
Middle 2050A	516.8	08-19-09	60±60	Middle 2051	602.9	07-01-10	<b>190±60</b>
Middle 2050A	643.9	08-19-09	-20±60	Middle 2051	749.0	07-01-10	<b>490±70</b>
Middle 2050A	790.6	08-19-09	20±60	Middle 2051	826.8	07-01-10	<b>640±80</b>
Middle 2050A	999.3	08-19-09	-90±60	Middle 2051	1,091.1	07-01-10	<b>370±70</b>
Middle 2050A	1,180.3	08-19-09	120±60	Middle 2051	1,140.9	07-01-10	<b>370±70</b>
Middle 2050A	516.8	06-28-10	160±60	Middle 2051	749.0	06-28-11	<b>320±70</b>
Middle 2050A	1,180.3	06-28-10	170±60	Middle 2051	826.8	06-28-11	<b>500±70</b>
Middle 2050A	643.9	06-28-10	<b>190±60</b>	Middle 2051	1,091.1	06-28-11	<b>290±60</b>
Middle 2050A	999.3	06-28-10	40±60	Middle 2051	1,140.9	06-28-11	<b>200±60</b>
Middle 2050A	790.6	06-28-10	-40±60				
Middle 2050A	516.8	06-27-11	170±60				
Middle 2051	602.9	09-03-09	-10±60				
Middle 2051	749.0	09-03-09	<b>400±70</b>				
Middle 2051	826.8	09-03-09	<b>440±70</b>				
Middle 2051	1,091.1	09-03-09	120±60				
Middle 2051	1,140.9	09-03-09	<b>190±60</b>				

### Strontium-90

A strontium-90 plume developed in the ESRP aquifer from wastewater disposal at the INL. Strontium-90 has a half-life of 29.1 years (Walker and others, 1989, p. 29). The MCL for strontium-90 in drinking water is 8 pCi/L (U.S. Environmental Protection Agency, 2013).

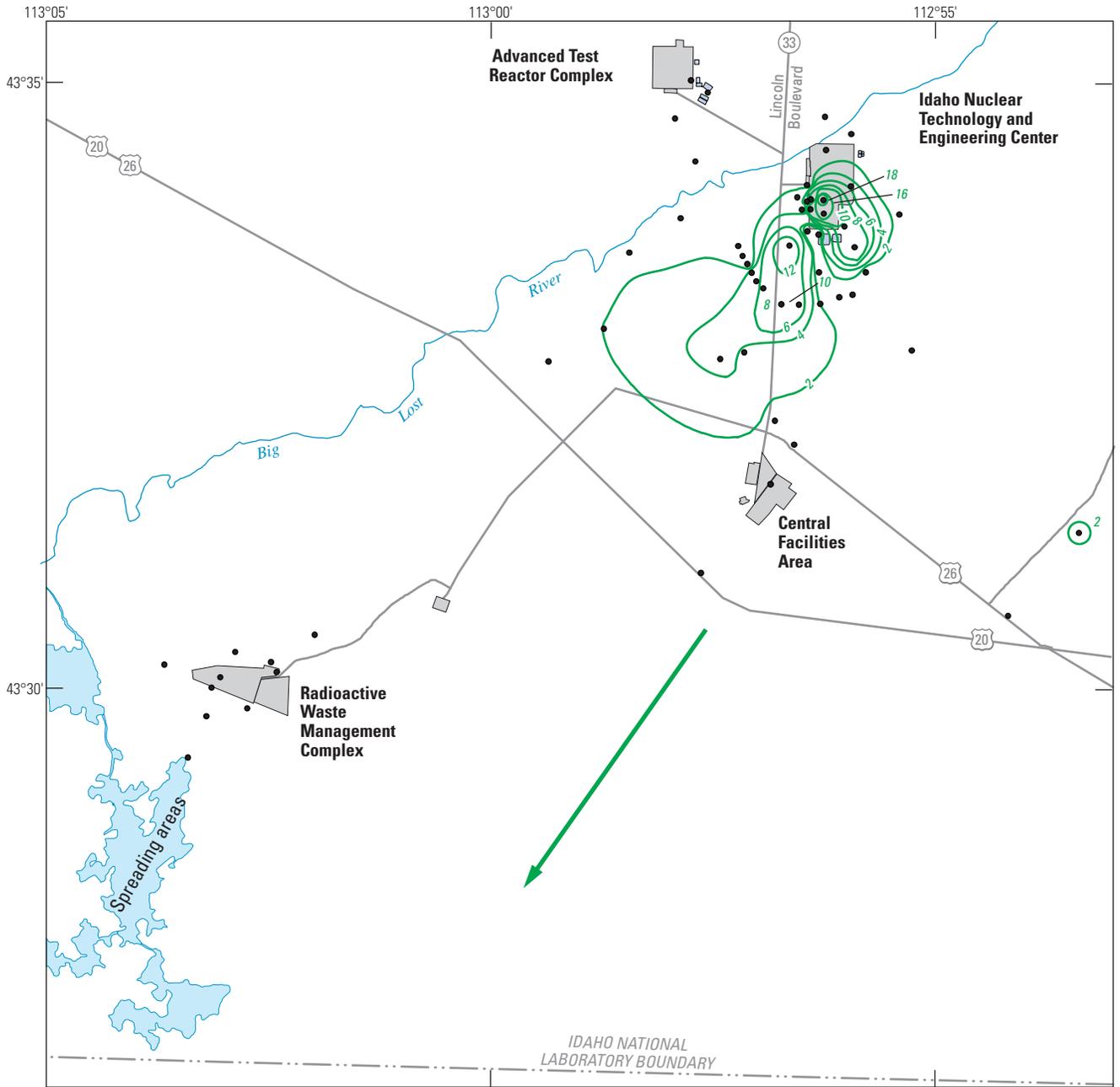
During 1952–98, about 24 Ci of strontium-90 was in wastewater that was injected directly into the aquifer through the disposal well and was discharged to the old percolation ponds at the INTEC (Bartholomay and others, 2000). During 1962–63, more than 33 Ci of strontium-90 in wastewater was discharged into a pit at the INTEC (Robertson and others, 1974, p. 117). In 1972, about 18,100 Ci of strontium-90 was leaked at the INTEC Tank Farm ([fig. 7](#)) (Cahn and others, 2006). During 1952–1998, about 93 Ci of strontium-90 also was discharged to radioactive-waste infiltration and evaporation ponds at the ATR Complex. During 2000, 0.21 Ci of strontium-90/yttrium-90 was discharged at the ATR Complex (S.M. Stoller Corporation, 2002b, table 6-2). Data are not available for strontium-90 discharged at either the INTEC or the ATR Complex during 2001–11.

During April or October 2011, water from 76 aquifer wells was sampled for strontium-90 throughout the INL. Concentrations of strontium-90 in water from 20 aquifer wells exceeded the reporting level. Concentrations of strontium-90

greater than the reporting level in samples from the aquifer wells ranged from 2.9±0.7 pCi/L in water from well Site 9, to 18.7±0.9 pCi/L in water from well USGS 47. The area of the strontium-90 plume near the INTEC extended south-southwestward in the general direction of groundwater flow ([fig. 15](#)). The concentrations of strontium-90 in water from wells near and southwest of INTEC have fluctuated and generally exceeded the reporting level since 1980; however, all wells have shown an overall decrease in strontium-90 concentration ([fig. 16](#)). Before 1989, strontium-90 concentrations in most wells had been decreasing likely because of factors including radioactive decay, diffusion, dispersion, changes in disposal methods, and dilution from natural recharge (Orr and Cecil, 1991, p. 35). The fluctuating concentrations of strontium-90 in water from most of the wells sampled during 2009–11 could have resulted, at least partly, from variations in recharge from the Big Lost River which flows near these wells south of the INTEC ([fig. 3](#)).

MLMS equipped wells USGS 105 and 135 near the southern boundary of the INL ([fig. 5](#)) were sampled for strontium-90 in September 2009 and 2010, and well USGS 108, also near the southern boundary of the INL ([fig. 5](#)) was sampled for strontium-90 in June 2010 and 2011. None of the water from any zones sampled contained concentrations of strontium-90 exceeding the reporting level.

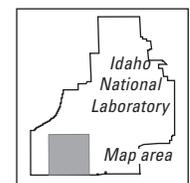
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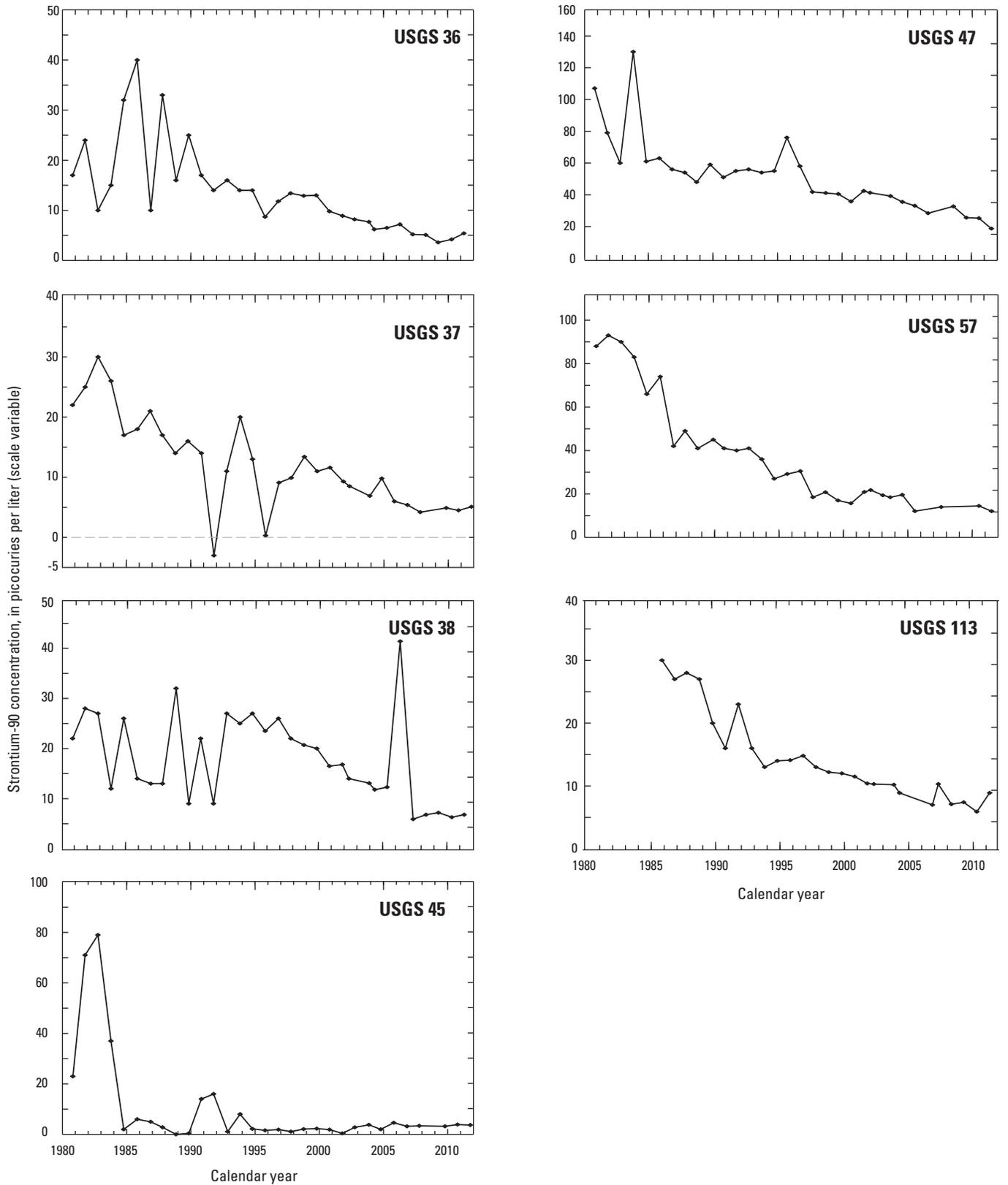
Base from U.S. Geological Survey digital data, 1:24,000 and 1:100,000  
 Universal Transverse Mercator projection, Zone 12  
 Datum is North American Datum of 1927

**EXPLANATION**

- 2— **Line of equal strontium-90 concentration**—April and October 2011. Lines of equal concentration were interpreted from analyses of water samples collected from a 3-dimensional flow system. Mapped concentrations represent water samples collected from various depths in boreholes with differing well completions; for example, single- and multiple-screened intervals, and open boreholes. Location is approximate. Interval, in picocuries per liter, is variable.
- ← **General direction of groundwater flow**
- **Well in the USGS water-quality monitoring network**—Water samples analyzed for strontium-90



**Figure 15.** Distribution of strontium-90 in water from wells at and near the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, Central Facilities Area, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, April or October 2011.



**Figure 16.** Strontium-90 concentrations in water from seven wells at and near the Idaho Nuclear Technology and Engineering Center, Idaho National Laboratory, Idaho, 1980–2011. Location of wells shown in [figure 6](#).

Strontium-90 has not been detected in the ESRP aquifer beneath the ATR Complex partly because of the exclusive use of waste-disposal ponds and lined evaporation ponds rather than the disposal well for radioactive-wastewater disposal at that facility. Sorption processes in sediments in the unsaturated zone beneath the radioactive waste-disposal pond could have minimized or prevented strontium-90 migration to the aquifer at the ATR Complex. Additionally, the stratigraphy beneath the ATR Complex includes more sedimentary interbeds than the stratigraphy beneath the INTEC (Anderson, 1991, p. 22–28).

## Cesium-137

From 1952 to 2000, about 138 Ci of cesium-137 in wastewater was discharged to the ATR Complex radioactive-waste infiltration and lined evaporation ponds and about 23 Ci was discharged to the INTEC disposal well and percolation ponds. In 1972, an additional 19,100 Ci of cesium-137 leaked at the INTEC Tank Farm (fig. 7) (Cahn and others, 2006). The half-life of cesium-137 is 30.17 years (Walker and others, 1989, p. 34).

During 2009–11, water from 72 aquifer wells was sampled and analyzed for cesium-137. Water from eight of these wells had cesium-137 concentrations that equaled or slightly exceeded the reporting level. Concentrations of cesium-137 exceeding the reporting level ranged from  $22\pm 7$  pCi/L to  $60\pm 20$  pCi/L. Concentrations of cesium-137 also equaled or slightly exceeded the reporting level in two wells equipped with MLMS. In well USGS 103 at 992.9 ft BLS, the concentration was  $39\pm 13$  pCi/L in August 2009. In September 2010, water from well USGS 105 had concentration of cesium-137 of  $25\pm 8$  pCi/L at 949.4 ft BLS, and in July 2011, the concentration of cesium-137 equaled the reporting level at  $30\pm 10$  pCi/L at 849.0 ft BLS. These concentrations that were slightly greater than the reporting level were not consistent with any distinct zone of water or area in the aquifer and could be attributed to false positives.

The absence of elevated concentrations of cesium-137 probably resulted from discontinuation of wastewater discharge to the INTEC disposal well and to sorption processes in the unsaturated and perched groundwater zones.

## Plutonium

In 1974, the USGS began monitoring plutonium-238 and plutonium-239, -240 (undivided) in wastewater discharged to the ESRP aquifer through the disposal well (fig. 6) at

the INTEC. During 1974–2000, approximately 0.26 Ci of plutonium in wastewater was discharged to the disposal well and percolation ponds at the INTEC (Davis, 2008). About 17,100 Ci of plutonium-238, 64,900 Ci of plutonium-239, and 17,100 Ci of plutonium-240 were buried in the SDA during 1952–99 (Holdren and others, 2002, table 4-1).

Before 1974, alpha radioactivity from disintegration of plutonium was not separable from the monitored, undifferentiated alpha radioactivity. The half-lives of plutonium-238, plutonium-239, and plutonium-240 are 87.7, 24,100, and 6,560 years, respectively (Walker and others, 1989, p. 46). Because of radioactive wastewater discharged to the disposal well at INTEC, concentrations of plutonium isotopes in some water samples from wells USGS 40 and 47 near INTEC (fig. 6) through January 1987 exceeded the reporting level (Orr and Cecil, 1991, p. 37). Concentrations in water samples collected from these wells since 1987 have been less than the reporting level.

During 2009–11, concentrations of plutonium-238 and plutonium-239, -240 (undivided) in water from all 23 aquifer wells sampled and all zones in 3 wells equipped with MLMS (USGS 105, 108, and 135) were less than the reporting level.

## Americium-241

Americium-241 is a decay product of plutonium-241. Plutonium isotopes have been detected in wastewater discharged to the ESRP aquifer at the INL and are in wastes buried at the RWMC. The half-life of americium-241 is 432.7 years (Walker and others, 1989, p. 46).

Concentrations of americium-241 in water samples collected between September 1972 and July 1982 from wells USGS 87, 88, 89, and 90 at the RWMC (fig. 6) and in water samples collected through 1988 from the TAN disposal well (fig. 5) exceeded the reporting level (Orr and Cecil, 1991, p. 38–39). During 1992–95, concentrations of americium-241 in water samples from two wells were equal to the reporting level. On October 2, 1992, the concentration in water from well USGS 37 was  $0.09\pm 0.03$  pCi/L; on April 20, 1993, the concentration in water from well USGS 120 was  $0.06\pm 0.02$  pCi/L (Bartholomay and others, 1997). The concentration in one water sample collected on April 12, 2001, from the RWMC Production Well (RWMC PROD) was  $0.003\pm 0.001$  pCi/L, equal to the reporting level (Davis, 2008). During 2009–11, concentrations in water from all 23 aquifer wells and all zones of the 3 MLMS-equipped wells sampled were less than the reporting level.

## 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. The radioactivity is usually reported as if it occurred as one radionuclide. Gross alpha and beta measurements are used to screen for radioactivity in the aquifer as a possible indicator of groundwater contamination. Water samples collected during 2009–11 were analyzed for gross alpha- and gross beta-particle radioactivity by RESL. In 2008, RESL increased the sensitivity of the gross alpha- and gross beta- particle radioactivity and changed the radionuclide 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, allowing for increased detectable concentrations (Bartholomay and Twining, 2010).

During 2009–11, water from 52 aquifer wells was sampled and analyzed for gross alpha-particle radioactivity. In 2009, concentrations of gross alpha-particle radioactivity exceeding the reporting level were detected in 13 wells, and ranged from  $2.7 \pm 0.9$  to  $4.3 \pm 1.4$  pCi/L. Additionally, in 2009, water from five wells equipped with MLMS had concentrations of gross alpha-particle radioactivity exceeding the reporting level that ranged from  $3.9 \pm 1.3$  to  $10.7 \pm 2.6$  pCi/L. This may be due to RESL increasing the sensitivity and changing the radionuclide reported for gross alpha-particle radioactivity from plutonium-239 to thorium-230 in 2008. During 2010–11, none of the water from aquifer wells or wells equipped with MLMS sampled contained concentrations of gross alpha-particle radioactivity exceeding the reporting level.

During 2009, concentrations of gross beta-particle radioactivity in water from 37 wells exceeded the reporting level and ranged from  $2.2 \pm 0.7$  to  $19 \pm 1.7$  pCi/L; in 2010, concentrations exceeded the reporting level in water from 43 wells and ranged from  $1.9 \pm 0.6$  to  $11.9 \pm 1.1$  pCi/L. During 2011, concentrations exceeded the reporting level in water from 16 wells and ranged from  $2.8 \pm 0.9$  to  $12.7 \pm 1.3$  pCi/L. All nine wells equipped with MLMS had gross beta-particle radioactivity concentrations greater than the reporting level in multiple zones during 2009–11. Concentrations ranged from  $2.2 \pm 0.7$  to  $16.3 \pm 1.4$  pCi/L. The increase in the number

of wells containing concentrations of gross beta-particle radioactivity exceeding the reporting level from previous reporting periods likely reflects the increase in sensitivity and change in the reporting radionuclide from cesium-137 to strontium-90/yttrium-90 by RESL in 2008.

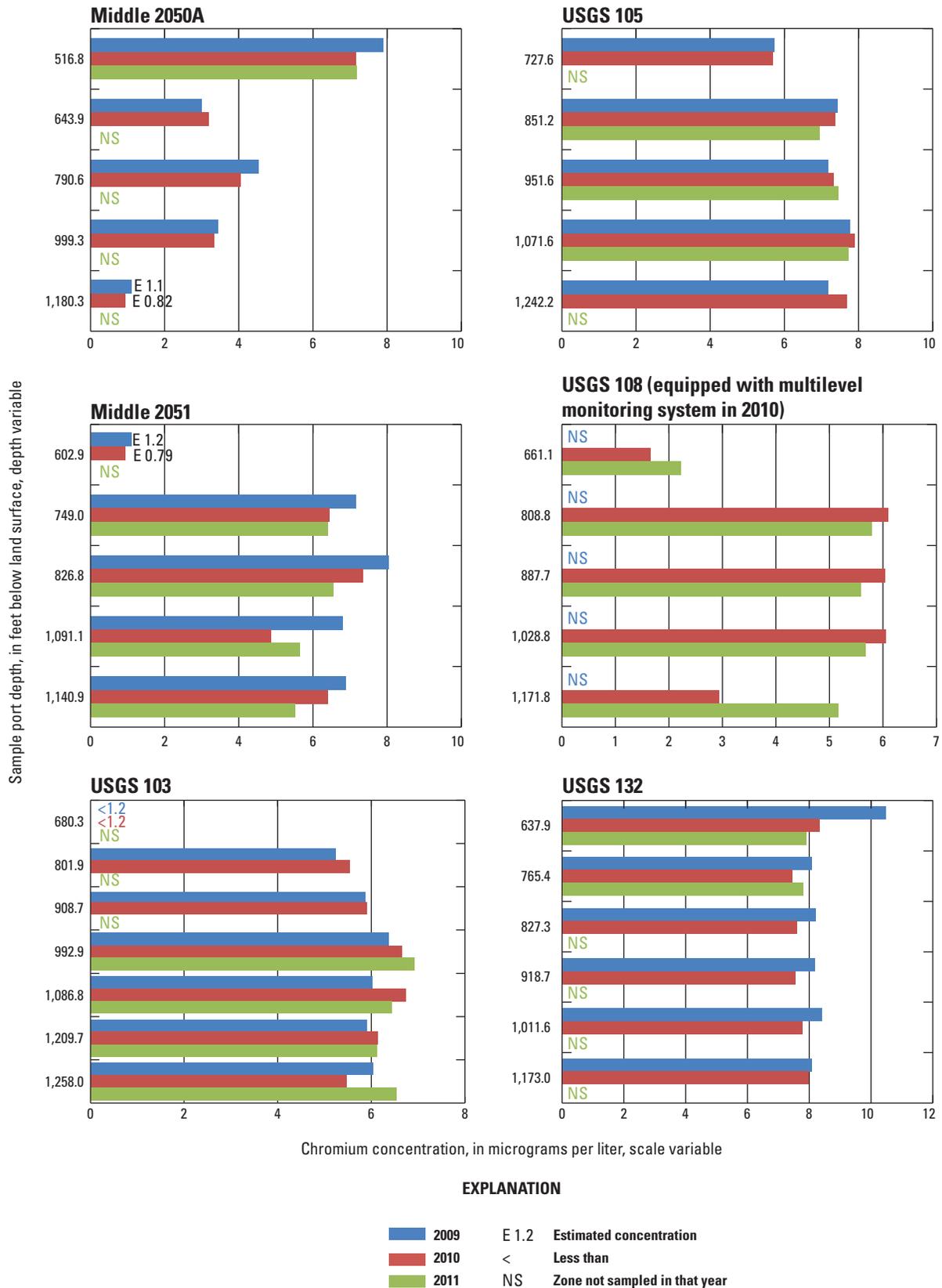
## Chromium

Between 1952 and 1972, an estimated 17,790 lb of chromium was discharged to the radioactive-waste infiltration ponds and 31,131 lb of chromium was discharged to the TRA disposal well (U.S. Department of Energy, 2011a). In October 1972, chromium used as a corrosion inhibitor in cooling-tower operations was replaced by a polyphosphate. No disposal of chromium to the subsurface at the ATR Complex was reported after 1972.

During 1971–83, about 265 lb of chromium in wastewater were discharged to the disposal well at INTEC and 720 lb of chromate were discharged at the Power Burst Facility (PBF, [fig. 1](#)) (Cassidy, 1984, p. 3). About 130 lbs of chromium were discharged to the old INTEC percolation ponds during 1992–98 (Bartholomay and others, 2000).

Background concentrations of chromium in the ESRP aquifer range from 2 to 3  $\mu\text{g/L}$  (Orr and others, 1991, p. 41). In April 2009, the dissolved chromium concentration in water from one well, USGS 65, south of ATR Complex ([fig. 6](#)) equaled the MCL of 100  $\mu\text{g/L}$  (U.S. Environmental Protection Agency, 2013) for total chromium in public drinking water supplies. In April 2011, the concentration of chromium in water from that well was 97  $\mu\text{g/L}$ , just less than the MCL. Concentrations in water samples from 69 other wells sampled ranged from 0.8 to 25  $\mu\text{g/L}$ .

Variation in chromium concentrations with depth in MLMS equipped wells during 2009–11 is shown in [figure 17](#). Most wells showed little vertical variation in chromium concentrations, with the exception of wells Middle 2051, USGS 103, and 108, which all had lower concentrations in the uppermost zones. Well Middle 2050A had higher concentrations in the uppermost zone. Concentrations in all wells and zones ranged from less than 1.2  $\mu\text{g/L}$  (well USGS 103) to 10.5 (well USGS 132)  $\mu\text{g/L}$ . Only well USGS 135 had consistent values right at background levels in all zones.



**Figure 17.** Vertical distribution of dissolved chromium in water from nine multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.

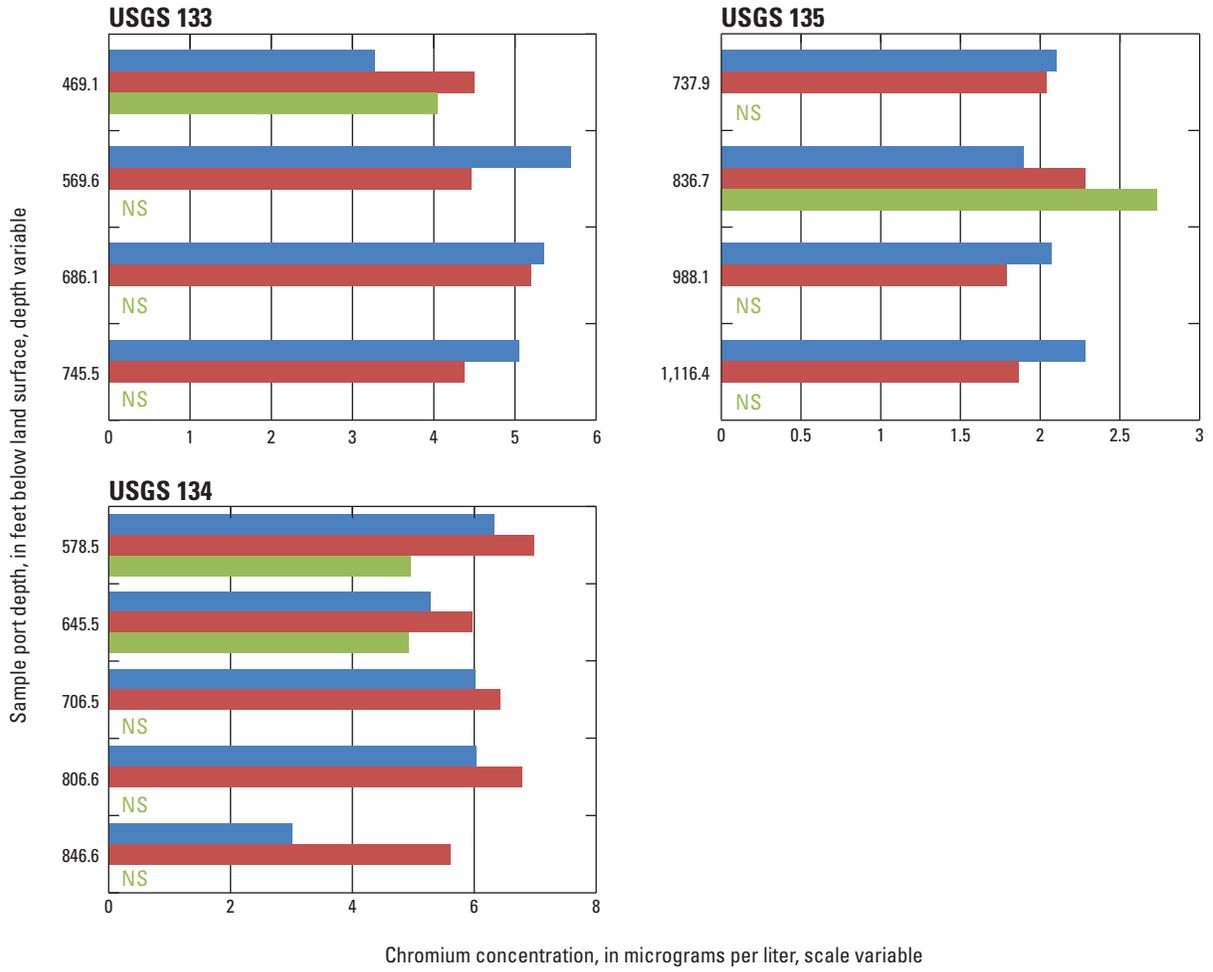


Figure 17.—Continued

## Sodium

During 1989–98, an estimated average annual 1.3 million lb/yr of sodium in wastewater were discharged at the INL (Bartholomay and others, 1995, 1997, 2000). During 1996–98, about 708,000 lb/yr of sodium were discharged to the INTEC percolation ponds; about 58,000 lb/yr were discharged to the ATR Complex chemical-waste infiltration pond; about 524,000 lb/yr were discharged to the NRF industrial-waste ditch; and about 5,000 lb/yr were discharged at CFA (Bartholomay and others, 2000). The background concentration of sodium in water from the ESRP aquifer near the INL generally is less than 10 mg/L (Robertson and others, 1974, p. 155). In 2011, concentrations in water from most wells in the southern part of the INL were greater than 10 mg/L.

Concentrations of dissolved sodium in water from wells near the INTEC generally have varied since 1984 when disposal practices were changed from injection to the disposal well to discharge to the old percolation ponds (figs. 6 and 18). During 1999–2011, the higher concentrations of sodium were in water from wells at or near INTEC (figs. 6 and 18). During 2011, the highest sodium concentration in water samples from aquifer wells near the INTEC was 35 mg/L in a water sample from well USGS 77 (fig. 6), a slight decrease from 2007 (40 mg/L). Concentrations of sodium in water from other wells south of the INTEC during 2009–11 generally were less than or equal to sodium concentrations detected during 2006–08 (fig. 18).

Installation and use of the new percolation ponds 2 mi southwest of the INTEC has contributed to increased concentrations of sodium in the Rifle Range well (fig. 5). In 1988, the concentration of sodium in this well was about 9 mg/L. After the new percolation ponds were put into service in 2002, concentrations of sodium increased steadily to a concentration of 16 mg/L until 2008, when the concentrations of sodium remained steady or decreased slightly (fig. 18), possibly due to episodic recharge from the Big Lost River or variable rates of discharge of sodium to the new percolation ponds during 2009–11.

In October 2011, the sodium concentration in water from well USGS 88 (fig. 6), near the RWMC, was 46 mg/L, about the same as the concentration as in 2008. In April 2011, the sodium concentration in water from well MTR Test at the ATR Complex near the chemical waste pond (fig. 6) was 10 mg/L,

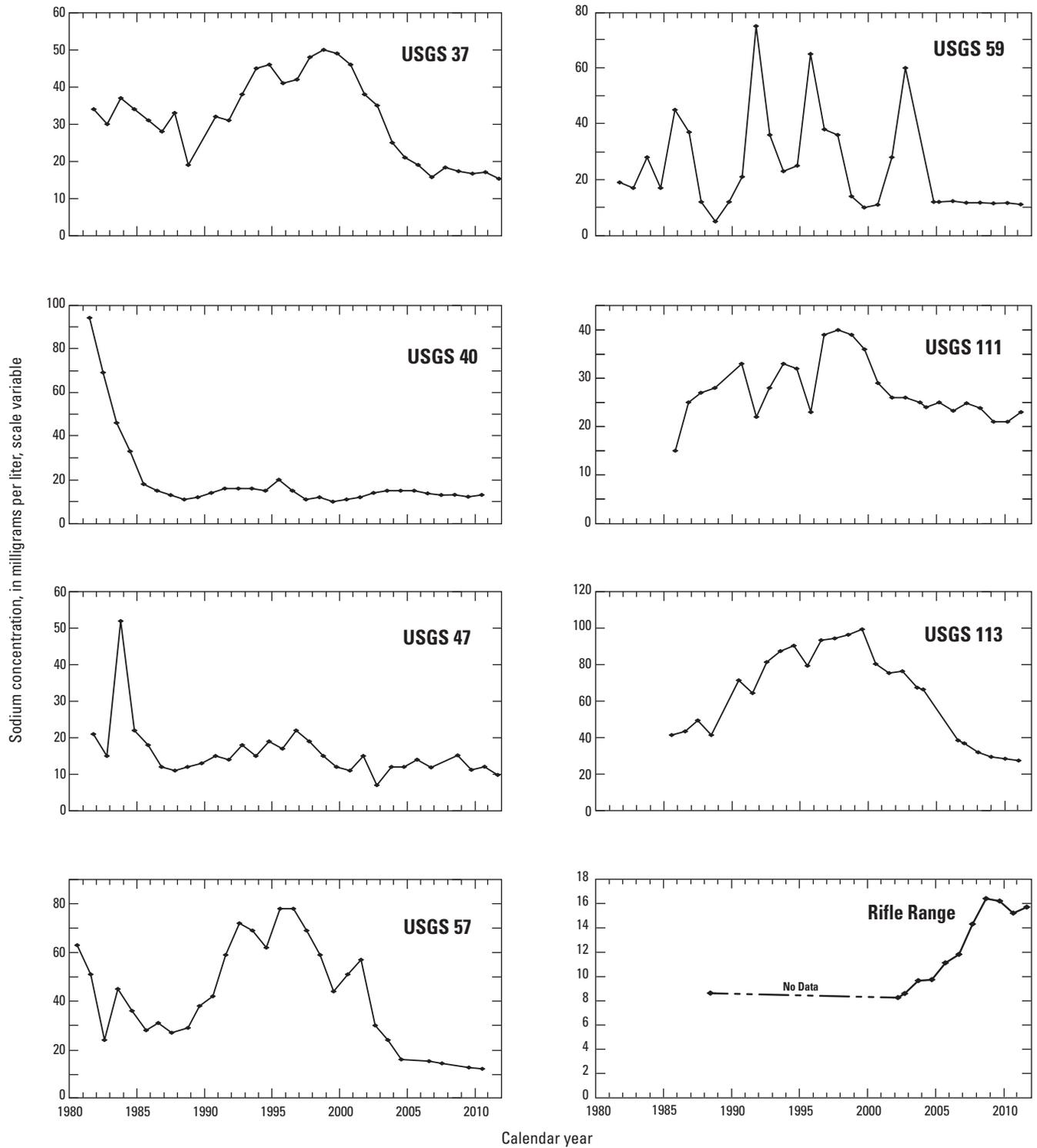
substantially less than the high concentration of 42 mg/L in 1998. Concentrations of sodium in this well have remained fairly constant at about 10 mg/L since about 2002. This concentration decrease from the high in 1998 may be a result of the discontinued use of the chemical waste pond in 1999.

The vertical distribution of sodium concentrations in wells equipped with MLMS are shown in figure 19. Concentrations in most wells generally were consistent with depth, although wells USGS 103, 108, and 132 had slightly higher concentrations in their uppermost zones (fig. 19).

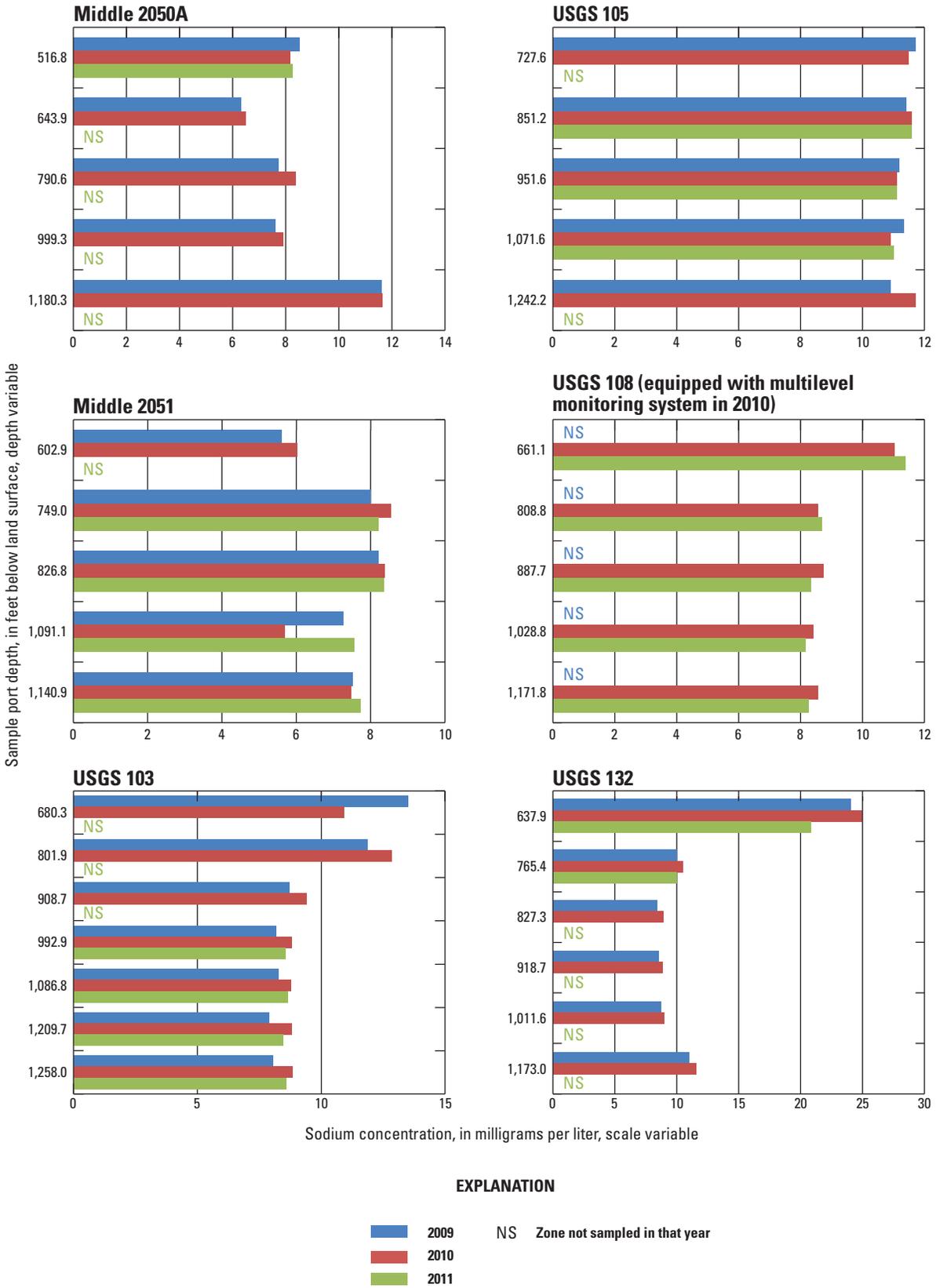
## Chloride

Chloride in wastewater has been discharged to infiltration ponds at the INL. The background chloride concentration in water from the ESRP aquifer at the INL generally is about 15 mg/L, the background chloride concentration near the INTEC is about 10 mg/L, and, near the Central Facilities Area (CFA), the ambient chloride concentration is about 20 mg/L (Robertson and others, 1974, p. 150). The secondary MCL for chloride in drinking water is 250 mg/L (U.S. Environmental Protection Agency, 2013). In 2011, concentrations of chloride in most water samples from wells south of the INTEC and at the CFA (figs. 20 and 21) exceeded 20 mg/L, but were less than the MCL.

Chloride concentrations in water from wells south of the INTEC generally were variable because of variable chloride disposal to the percolation ponds since 1984, when discharge of wastewater to the INTEC disposal well was discontinued. Although variable, the concentrations show an overall increase through the late 1990s, and an overall decrease since the late 1990s, with the exception of well USGS 59 (fig. 21). Chloride concentrations in water from USGS 59, near the INTEC percolation ponds, varied during 1984–2005; concentrations were unusually high in October 1991, 1995, and 2002 (fig. 21). The higher concentrations probably were caused by seepage down the well from the perched groundwater zone; chloride concentrations in perched groundwater wells near the percolation ponds were about 270 mg/L in 1991 and 1995 (Bartholomay and others, 1997) and averaged about 175 mg/L in five perched groundwater wells in 2002 (Davis, 2008, table 13). Since 2005, concentrations of chloride in well USGS 59 have remained constant (fig. 21).



**Figure 18.** Dissolved sodium concentrations in water from eight wells at and near the Idaho Nuclear Technology and Engineering Center, Idaho National Laboratory, Idaho, 1980–2011. Location of wells shown in [figure 6](#).



**Figure 19.** Vertical distribution of dissolved sodium in water from nine wells equipped with multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.

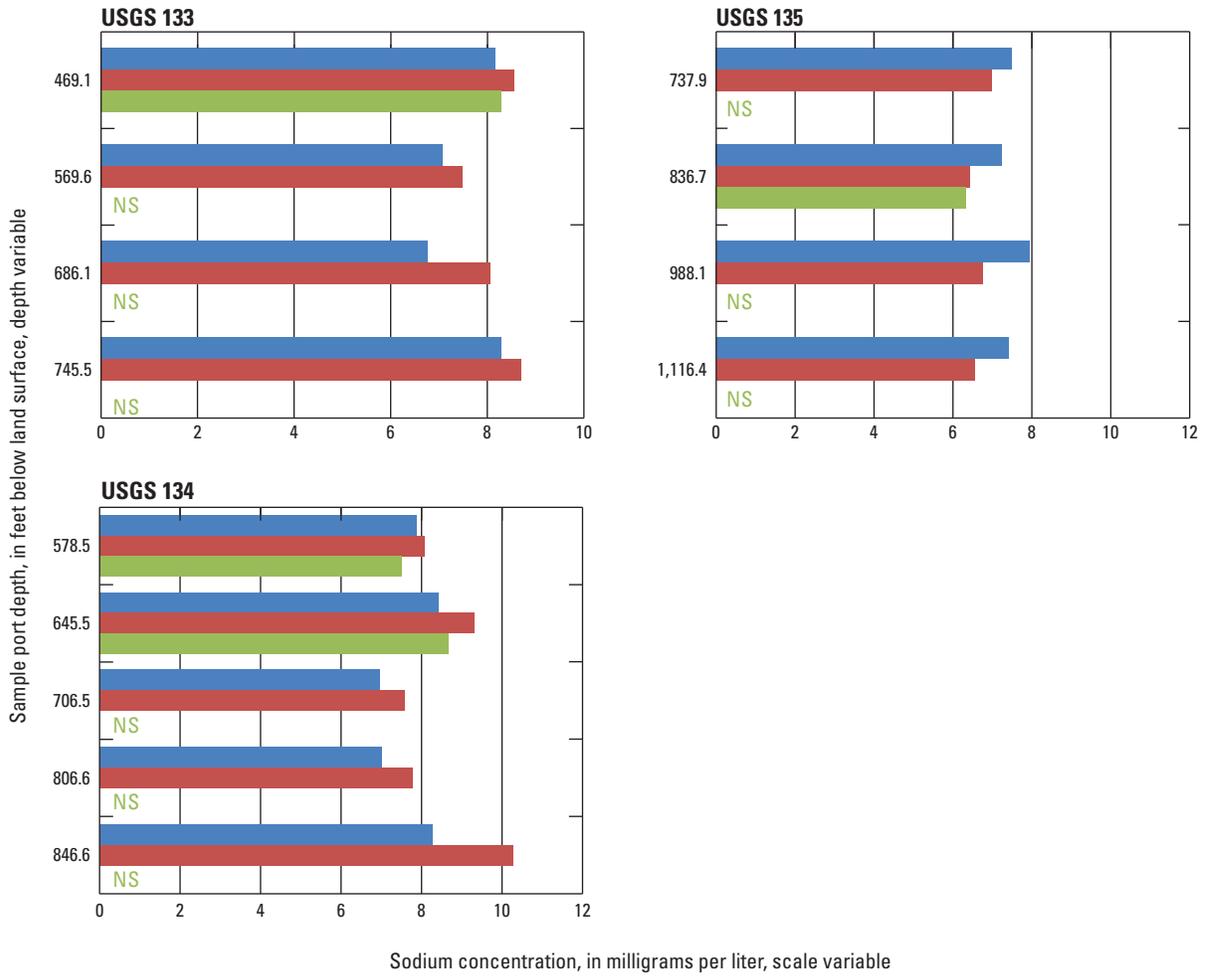
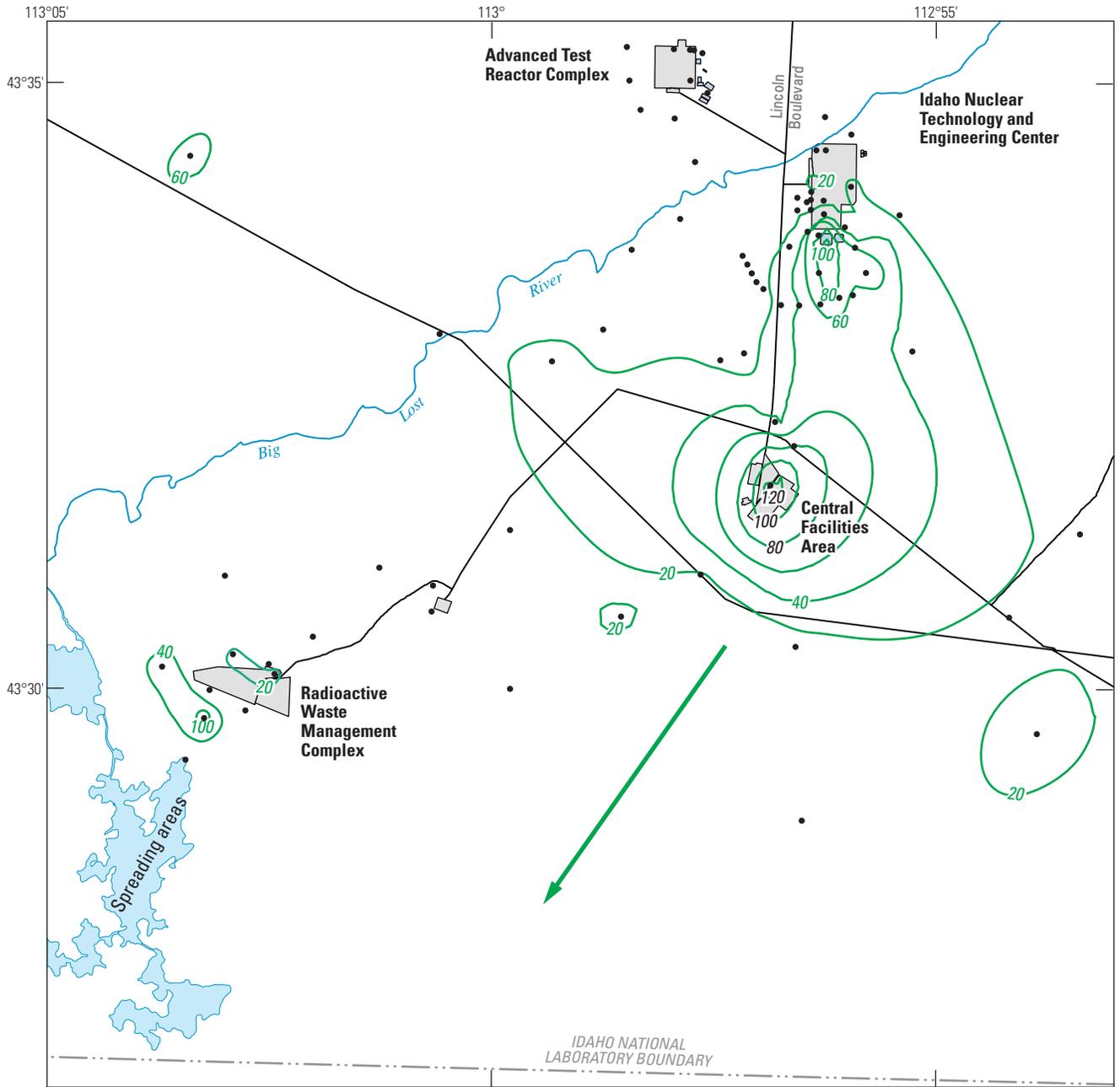


Figure 19.—Continued

50 Hydrologic Conditions and Distribution of Selected Constituents in Water, Idaho National Laboratory, Idaho, 2009–11



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

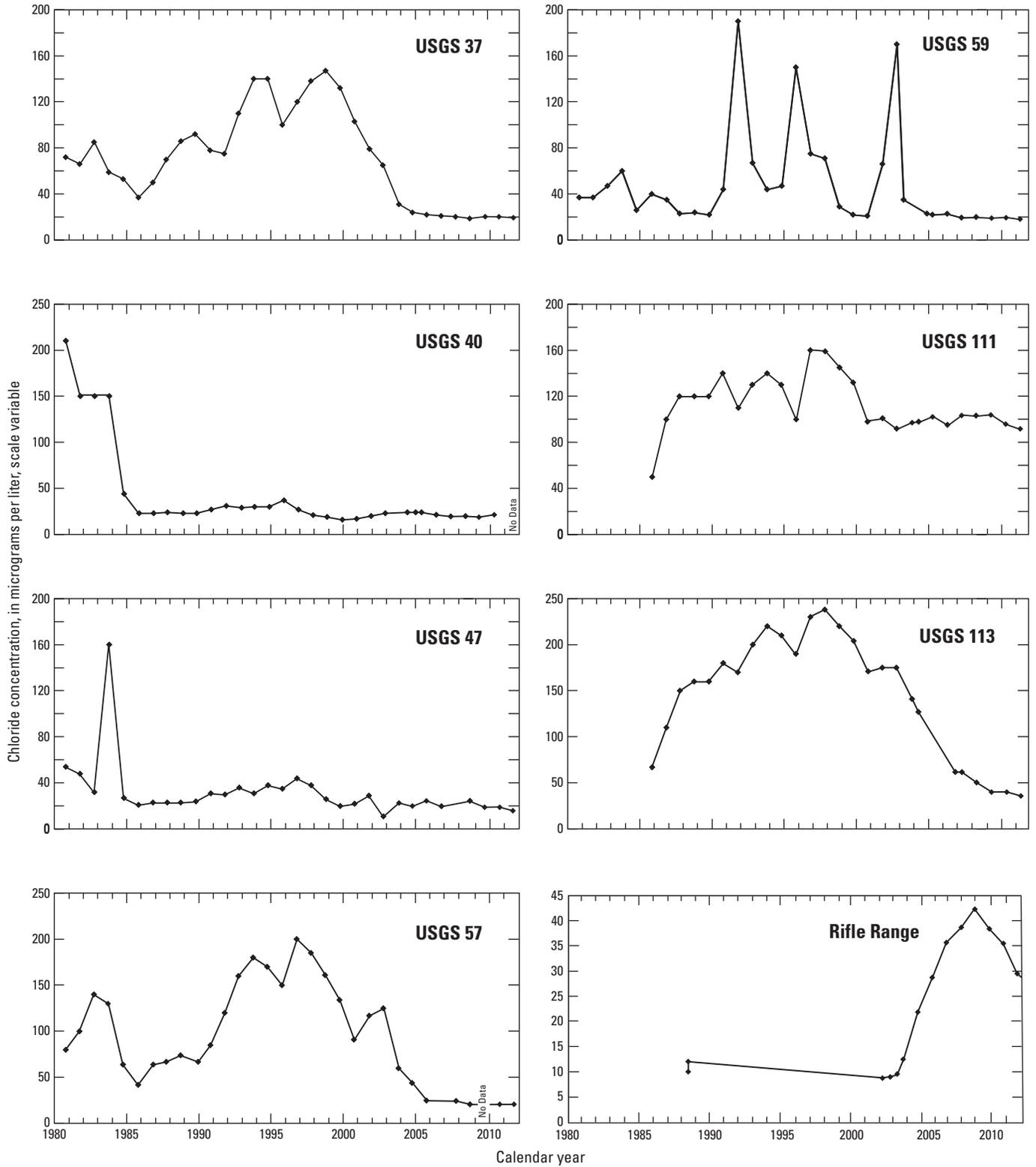


**EXPLANATION**

- 40— **Line of equal chloride concentration**—April and October 2011. Lines of equal concentration were interpreted from analyses of water samples collected from a 3-dimensional flow system. Mapped concentrations represent water samples collected from various depths in boreholes with differing well completions; for example, single- and multiple-screened intervals, and open boreholes. Location is approximate. Interval, in milligrams per liter, is variable.
- ← **General direction of groundwater flow**
- **Well in the USGS water-quality monitoring network**—Water samples analyzed for chloride



**Figure 20.** Distribution of chloride in water from wells at and near the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, Central Facilities Area, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, April or October 2011.



**Figure 21.** Dissolved chloride concentrations in water from eight wells at and near the Idaho Nuclear Technology and Engineering Center, Idaho National Laboratory, Idaho 1980–2011. Location of wells shown in [figure 6](#).

Trends in chloride concentrations in water from wells downgradient from the percolation ponds correlated with discharge rates into the old percolation ponds at the INTEC when travel time was considered. For example, chloride concentrations in water from wells USGS 37 and 57 (fig. 6) were lowest in 1985, during the period when the smallest amount of chloride was discharged to the ponds between 1984 and 1998 (fig. 22). Concentrations of chloride in water from well USGS 37 generally continued a decreasing or steady trend through 2011. Concentrations of chloride in water from well USGS 57 increased as discharge rates increased from 1985 through 1993; concentrations then decreased through 1995, increased in 1996, and decreased again in 1997 and 1998 (fig. 22). Concentrations continued decreasing through October 2000, and then increased through October 2003. Since 2003, chloride concentrations have decreased and remained steady in water from well USGS 57 (figs. 21 and 22). These decreasing or steady trends are due to discontinued disposal into the old percolation ponds and redirection of discharge to the new percolation ponds (fig. 4) to the southwest of these wells in 2002.

Chloride concentrations in water from well USGS 113, south of the INTEC, generally decreased from January 1998, when the concentration was 240 mg/L, through April 2011, when the concentration was 41 mg/L (fig. 21). Chloride concentrations in the Rifle Range well (figs. 5 and 21) increased from 9 mg/L in October 2002 to 42 mg/L in 2008 and decreased to 30 mg/L in October 2011. This well is downgradient from the new INTEC percolation ponds so the changes in concentrations are probably due to variable rates of chloride discharge to the ponds.

The chloride concentration in water from well CFA 2 at the CFA, increased slightly from 134 mg/L in October 2008 to 140 mg/L in October 2011. Concentrations of other wells in the CFA area ranged from 31 to 82 mg/L in 2011. The concentrations at CFA are attributed to past disposal at INTEC and increases in CFA 2 are probably representative of a period of increased wastewater disposal at INTEC during some previous timeframe.

In April 2011, the chloride concentration in water from well USGS 65 south of the ATR Complex (fig. 6) was greater than background at 19 mg/L. Chloride concentrations in water from all other wells completed in the ESRP aquifer at or near the ATR Complex were less than background and ranged between 10 and 14 mg/L during 2011, similar to the 2006–08 reporting period (Davis, 2010).

During 2011, chloride concentrations in water from wells USGS 88 and 89 at the RWMC were 102 and 46 mg/L, respectively, slightly higher than the 2006–08 reporting period. Concentrations of chloride in all other wells near the RWMC ranged from 11 to 24 mg/L.

The vertical distribution of chloride concentrations in wells equipped with MLMS was generally consistent within zones during 2009–11 (fig. 23). The highest concentrations

in water from well Middle 2050A were in the uppermost and lowermost zones at about 15–16 mg/L. Concentrations in the middle zones ranged from about 11 to 12 mg/L. Concentrations in well Middle 2051 were lowest in the uppermost zone, while concentrations in water from wells USGS 103 and 132 were highest in their uppermost zone. Chloride concentrations in water from wells USGS 133, 134, and 135 were near or below background in all zones (fig. 23).

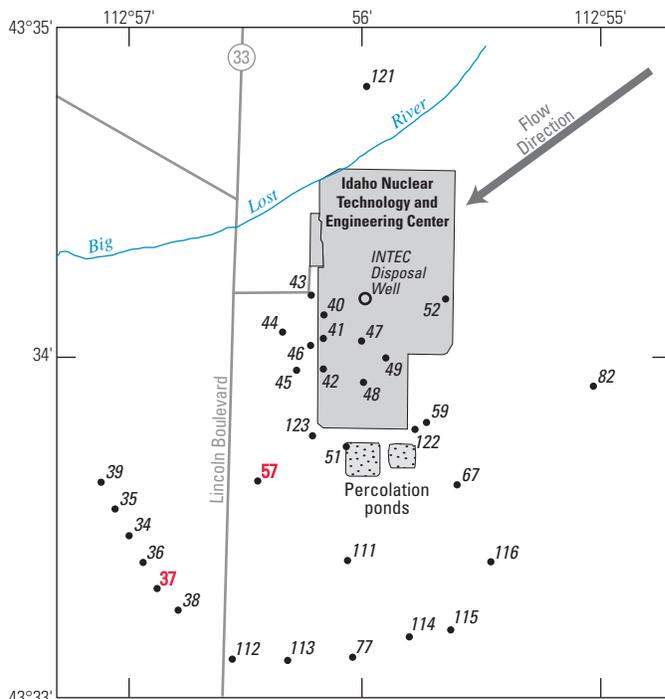
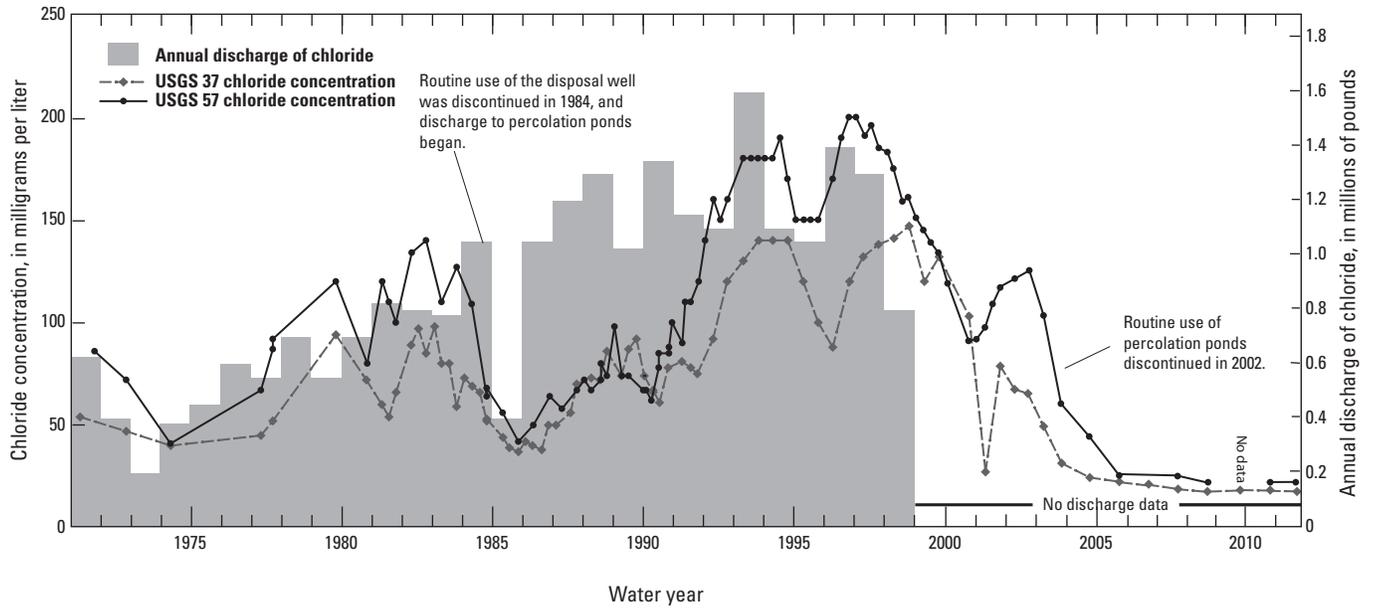
## Sulfate

Sulfate in wastewater has been discharged to percolation (infiltration) ponds at the INTEC, ATR Complex, and to the NRF industrial-waste ditch (Bartholomay and others, 2000). Background concentrations of sulfate in the ESRP aquifer in the south-central part of the INL range from about 10 to 40 mg/L (Robertson and others, 1974, p. 72). The secondary MCL for sulfate in drinking water is 250 mg/L (U.S. Environmental Protection Agency, 2013).

Because of the sulfate disposal history at the various facilities, water-sample collection for sulfate analyses at several wells was added to the USGS water-quality monitoring network in 1995. In 2011, sulfate concentrations in water samples from 11 wells in the south-central part of the INL equaled or exceeded the 40 mg/L background concentration of sulfate and ranged from 40 mg/L in well USGS 85 to 167 mg/L in well USGS 65 (fig. 6). In October 2011, the sulfate concentration in well CFA 2, south of INTEC (fig. 5), was 50 mg/L and was similar to the October 2008 sulfate concentration. During 2009–11, concentrations were 44, 44, and 45 mg/L in water from wells USGS 34, 35, and 39, respectively, southwest of INTEC, similar to the 2005–08 reporting period. Historically, concentrations in these wells were equal to or just less than the background value of 40 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.

In April or October 2011, sulfate concentrations in water samples from USGS 88 and USGS 119 (fig. 6), near the RWMC, were 47 and 39 mg/L, respectively, similar to concentrations in April or October 2008. The sulfate concentrations in water from these wells that were greater than the upper background limit of 40 mg/L could have resulted from the well construction techniques (Pittman and others, 1988, p. 57–61) and (or) waste disposal at the RWMC.

Three wells (USGS 105, 108, and 135) near the southern boundary of the INL that were equipped with MLMS were sampled for sulfate during 2009–11. Sulfate sampling is done the first 2 years after installation for MLMS to obtain baseline chemistry for the wells. The vertical distribution of sulfate in these wells is shown in figure 24. Sulfate concentrations were generally consistent with depth in all three wells, and ranged between 19 and 25 mg/L.

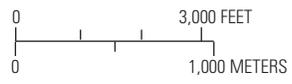


**EXPLANATION**

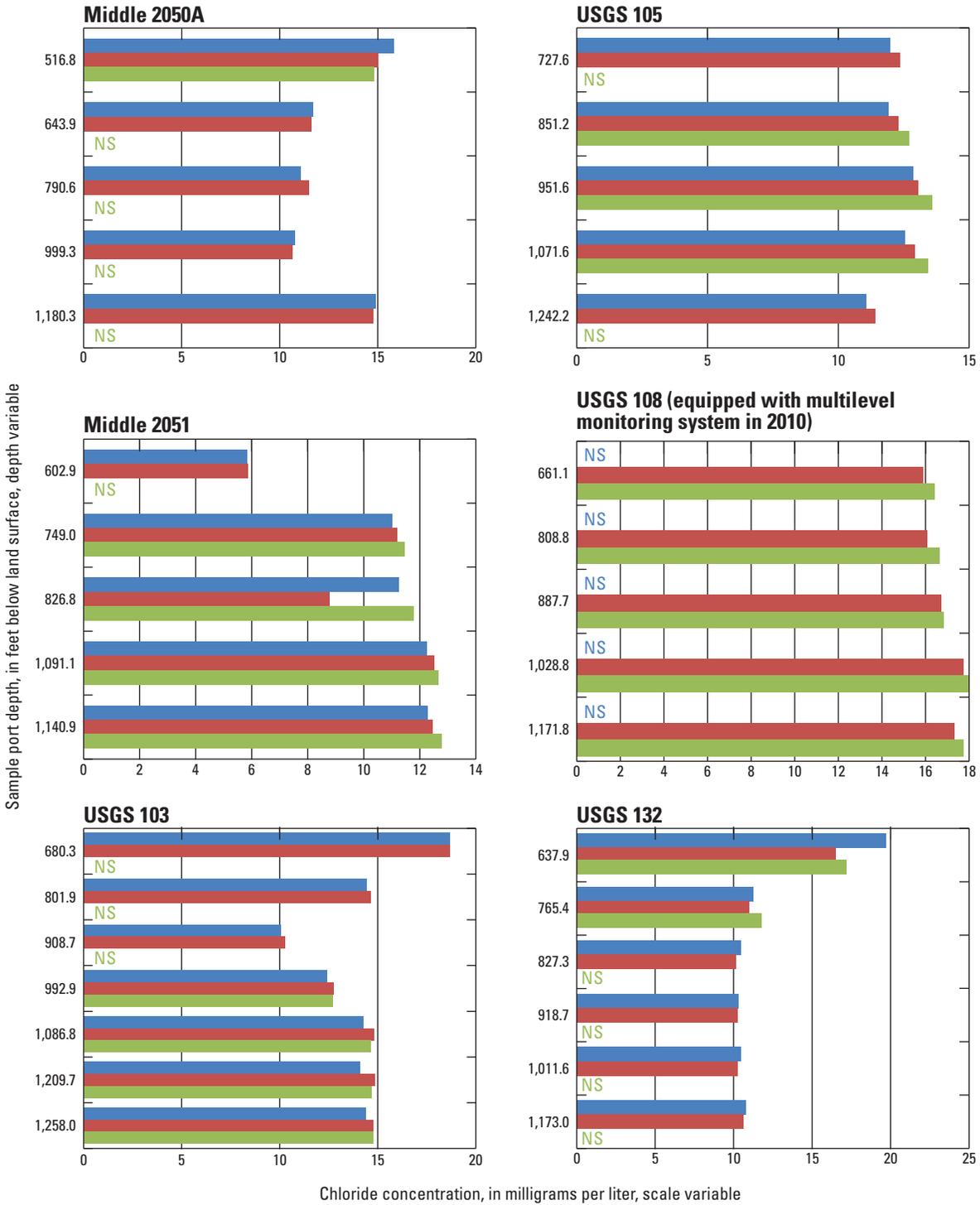
- Well in the USGS perched groundwater-quality monitoring network and identifier
- 82 Local well identifier—Number only shows USGS well, other names are local well names. Red well numbers indicate wells shown in chloride concentration graph.



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



**Figure 22.** Amount of chloride in wastewater discharged to the disposal well and percolation ponds at the Idaho Nuclear Technology and Engineering Center (INTEC), flow direction, and the location and amount of chloride in water from wells USGS 37 and USGS 57, Idaho National Laboratory, Idaho, 1971–2011.



EXPLANATION

- 2009
- 2010
- 2011
- NS Zone not sampled in that year

**Figure 23.** Vertical distribution of dissolved chloride in water from nine wells equipped with multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.

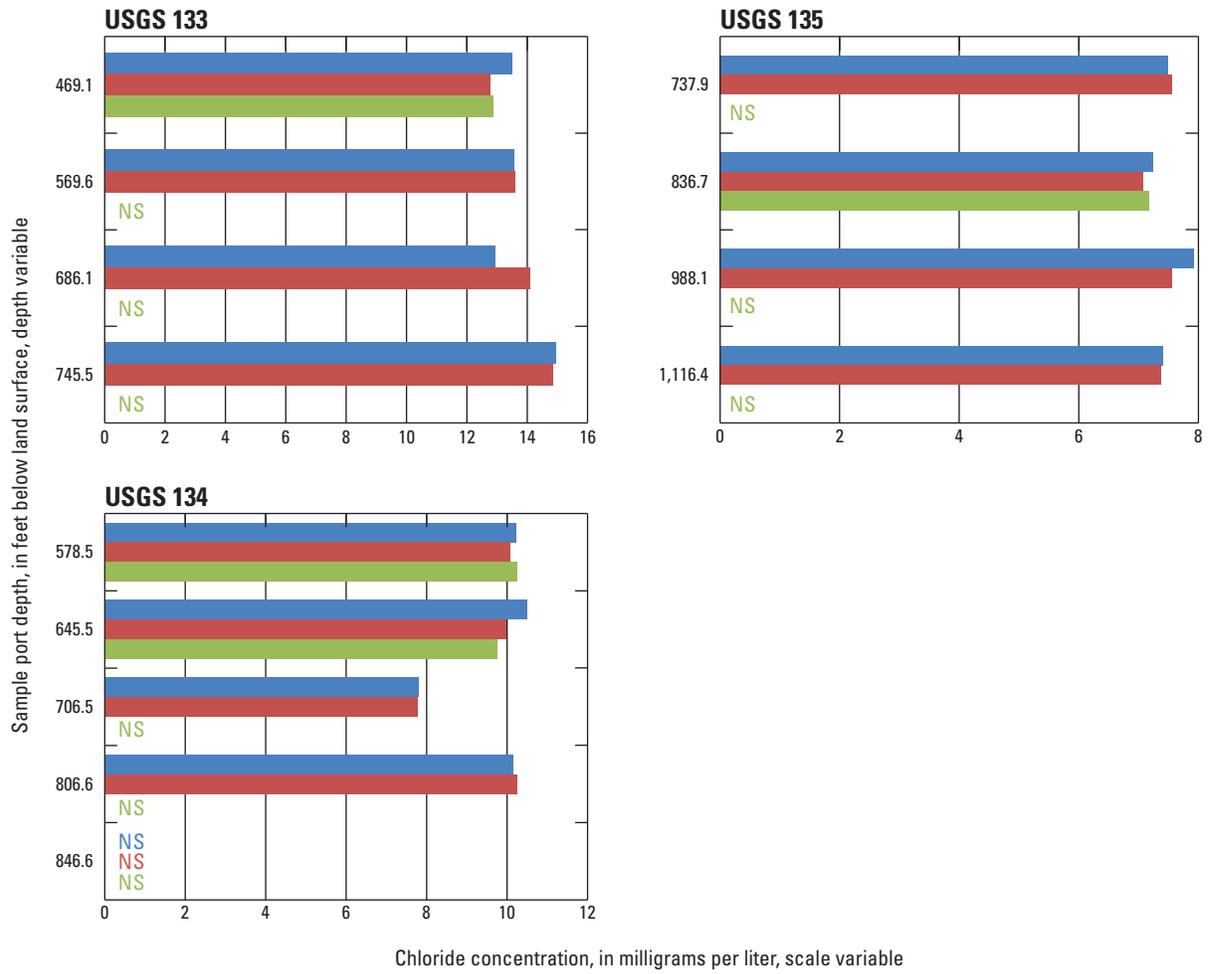


Figure 23.—Continued

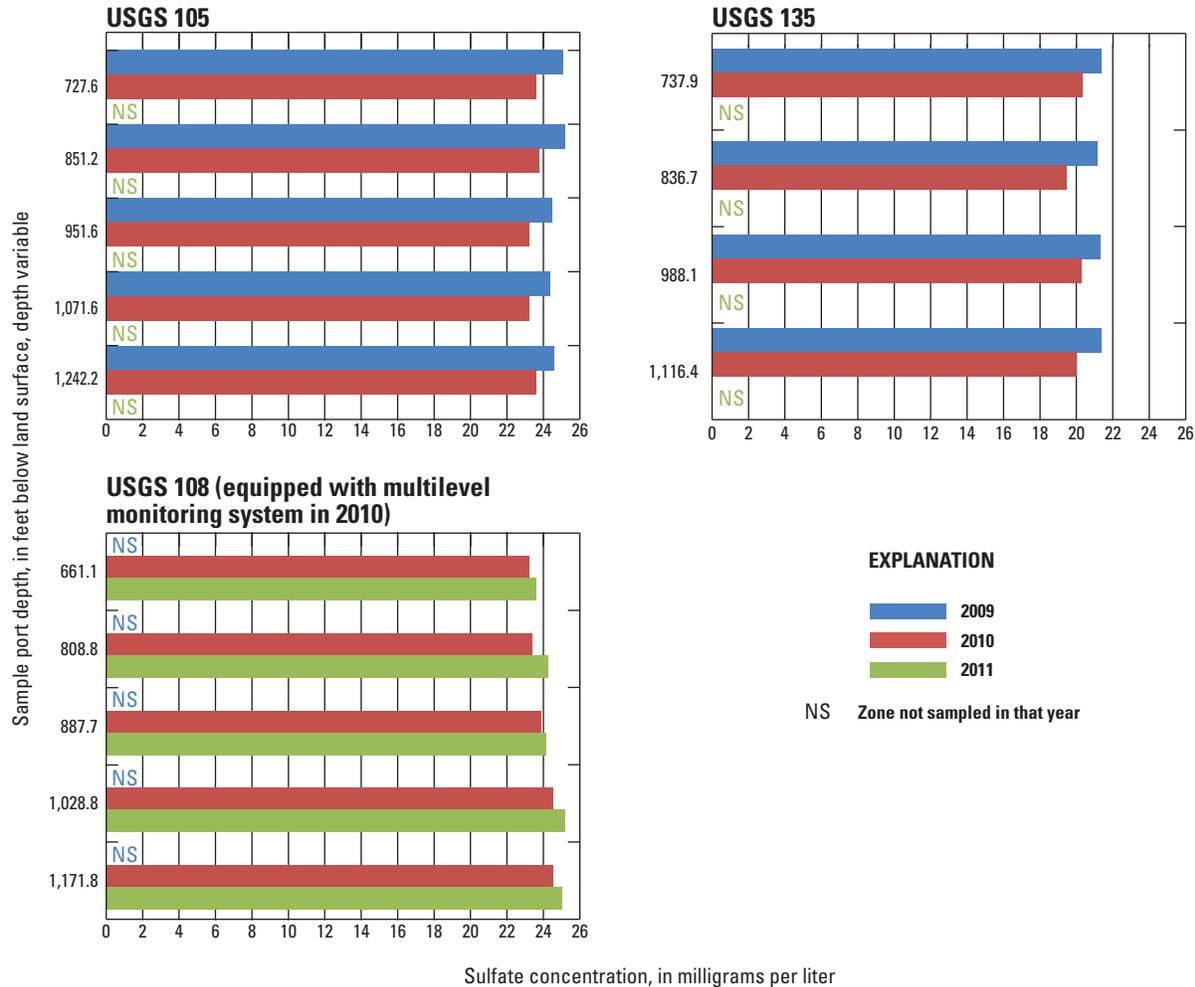


Figure 24. Vertical distribution of dissolved sulfate in water from three wells equipped with multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.

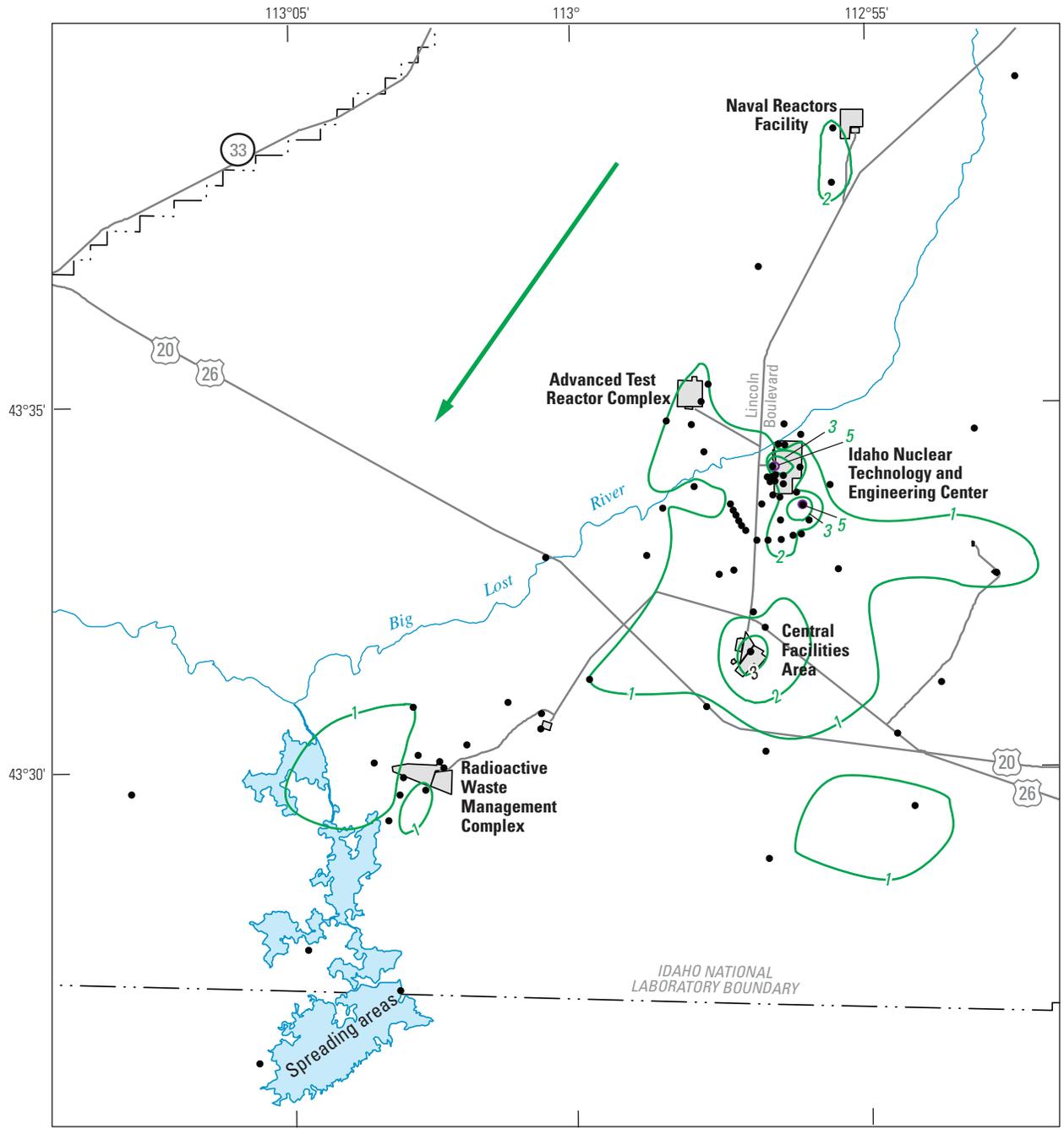
### Nitrate (as Nitrogen)

Wastewater containing nitrate was injected into the ESRP aquifer through the INTEC disposal well from 1952 to February 1984 and was discharged to the INTEC percolation ponds after February 1984 (Orr and Cecil, 1991). Concentrations of nitrate in groundwater not affected by wastewater disposal from INL facilities generally are less than the background of 1 mg/L (as nitrogen [N]) (Robertson and others, 1974, p. 73).

Concentrations of dissolved nitrate in this report are reported as nitrogen. Until the 2006–08 reporting period for publications in this series, nitrate was reported as nitrate. To convert concentrations as N to concentrations as  $\text{NO}_3^-$ , the nitrate (as N) concentration should be multiplied by 4.4266 (Hem, 1989, table 8) so that concentrations reported here can be compared with those given in previous reporting-period publications. Historical nitrite analyses indicate that almost all

nitrite concentrations are less than the LRL for analyses at the INL, so concentrations of nitrite plus nitrate are referred to as nitrate in this report.

The generalized distribution of nitrate concentrations in aquifer water samples collected in April or October 2011 are shown in figure 25. All nitrate concentrations measured in 2011 were less than the MCL for drinking water of 10 mg/L (U.S. Environmental Protection Agency, 2013). Nitrate concentrations at the INL have changed in response to reduced disposal rates and to the transition in 1984 from injection of wastewater to the INTEC disposal well to discharge to the old percolation ponds. In April or October 2011, concentrations of nitrate in water from most wells at and near the INTEC [wells USGS 40, 41, 43, 47, 48, 51, 52, 67, 77, 111, 113, 114, 116 (figs. 26 and 27)] exceeded the background concentration of 1 mg/L. Concentrations ranged from 1.6 mg/L in well USGS 41 to 5.95 mg/L in well USGS 40.



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

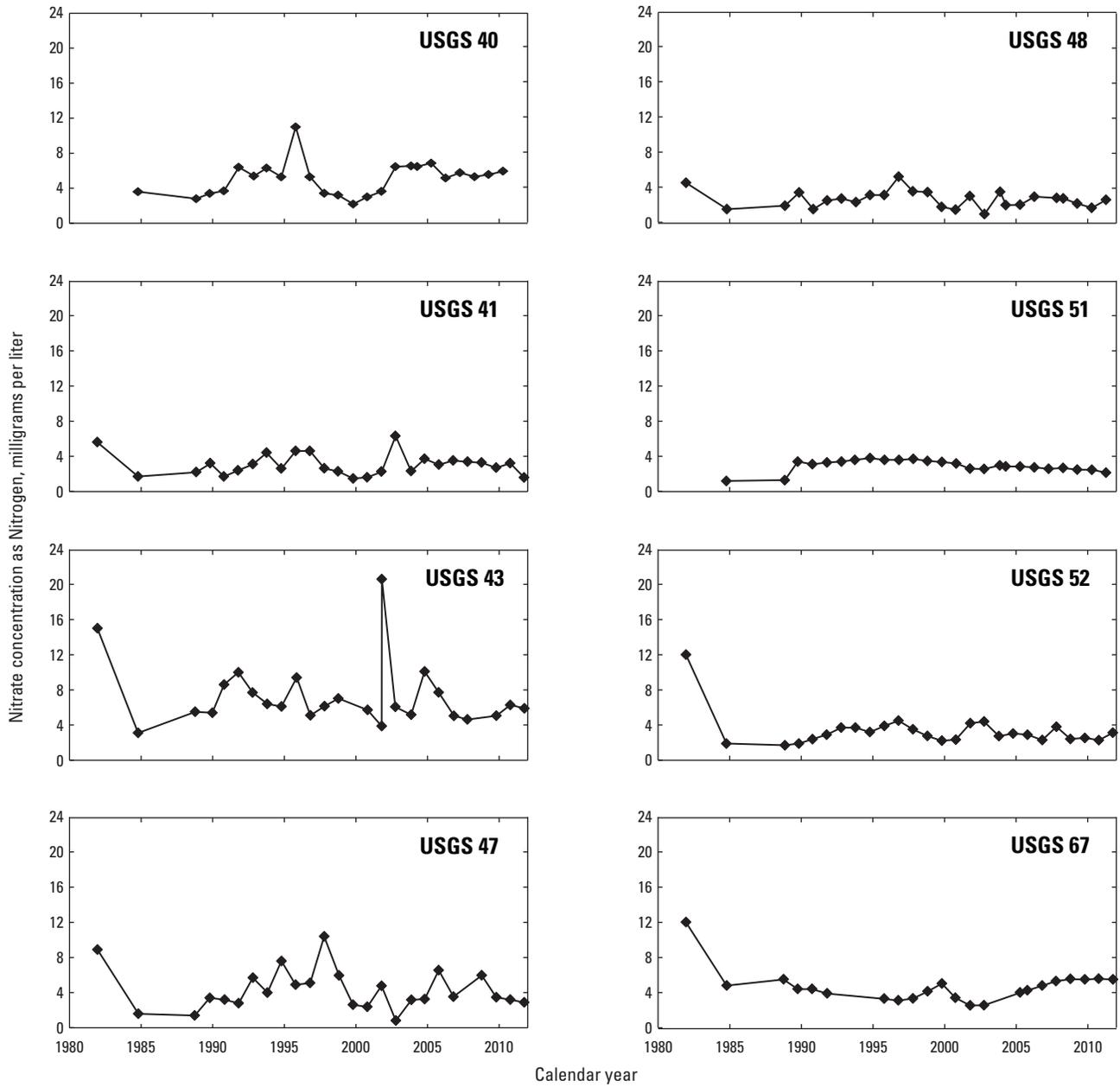


**EXPLANATION**

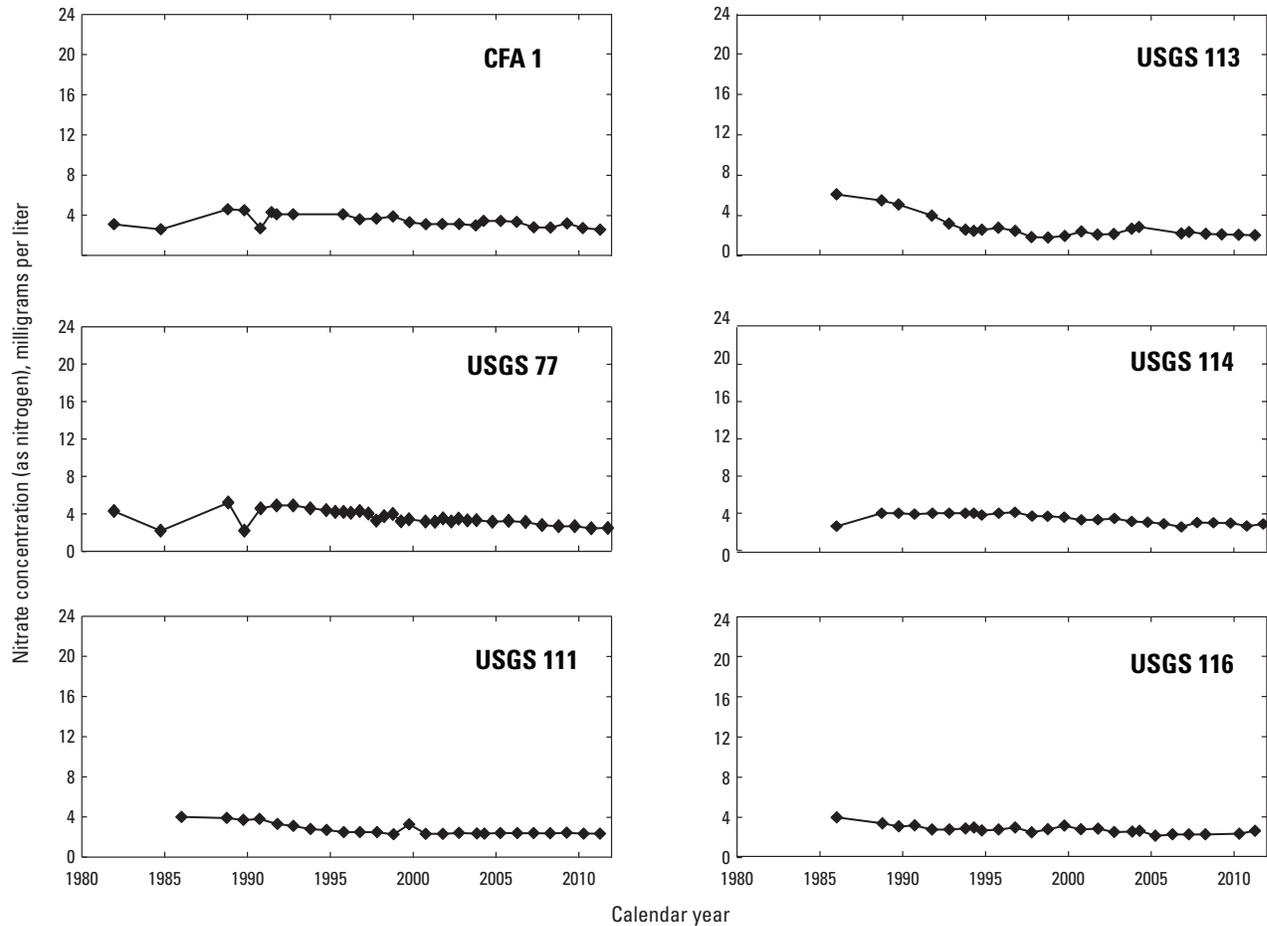
- 1 — **Line of equal nitrate (as N) concentration**—April and October 2011. Lines of equal concentration were interpreted from analyses of water samples collected from a 3-dimensional flow system. Mapped concentrations represent water samples collected from various depths in boreholes with differing well completions; for example, single- and multiple-screened intervals, and open boreholes. Location is approximate. Interval, in milligrams per liter as N, is variable.
- ← **General direction of groundwater flow**
- **Well in the USGS water-quality monitoring network**—Water samples analyzed for nitrate (as N)



**Figure 25.** Distribution of nitrate (as N) in water from wells at and near the Advanced Test Reactor Complex, Idaho Nuclear Technology and Engineering Center, Central Facilities Area, and Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, April or October 2011.



**Figure 26.** Concentration of nitrate (as N) in water from wells at and near the Idaho Nuclear Technology and Engineering Center, Idaho National Laboratory, Idaho, 1981–2011.



**Figure 27.** Concentration of nitrate (as N) in water from wells south of the Idaho Nuclear Technology and Engineering Center, Idaho National Laboratory, Idaho, 1981–2011.

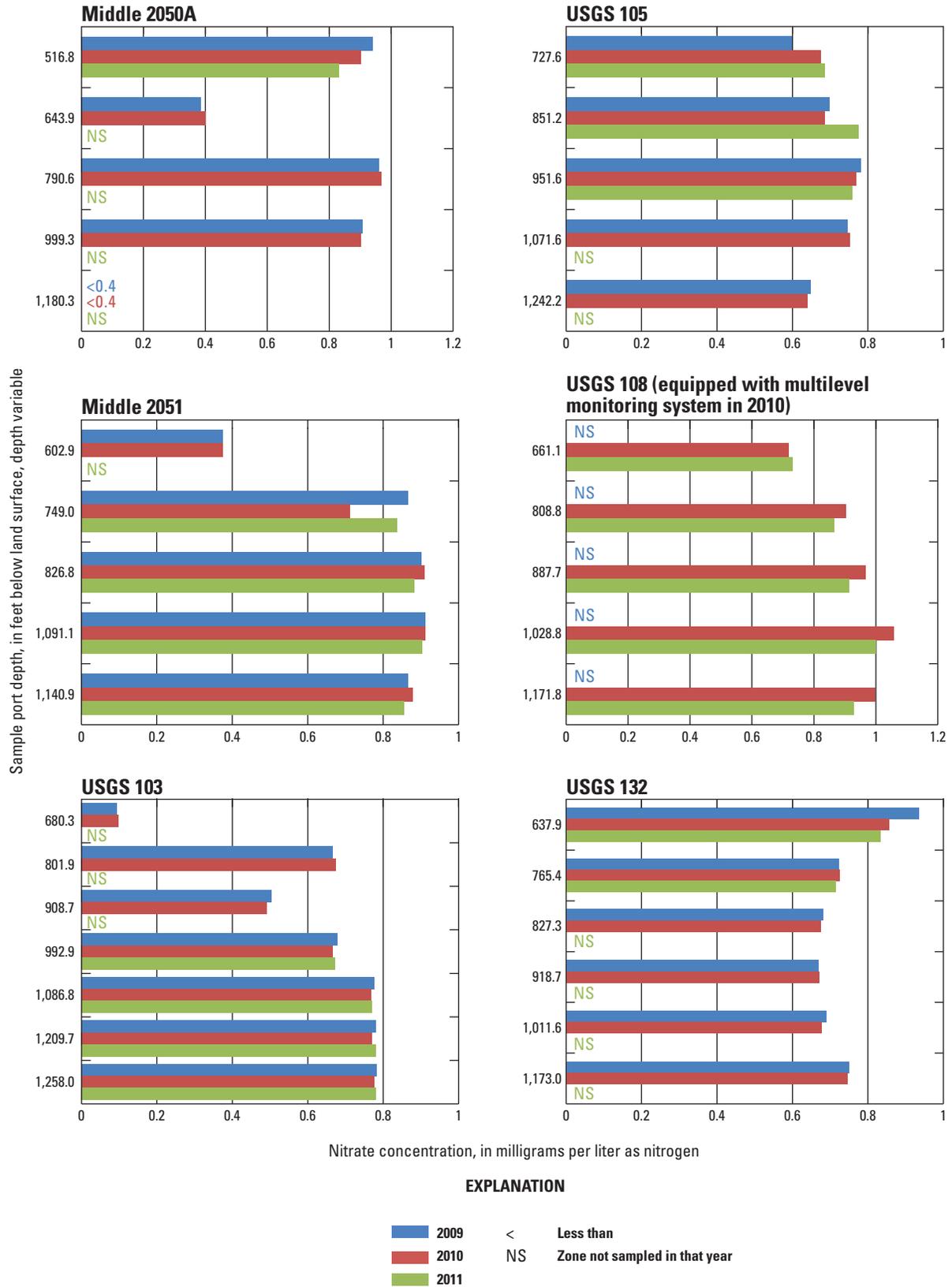
In 1981, the maximum nitrate concentration for wells near the INTEC was 15 mg/L in water from well USGS 43 at the INTEC just west of the INTEC Disposal well (figs. 6 and 26), and exceeded the MCL of 10 mg/L. Nitrate concentrations in water from wells in the vicinity of the INTEC disposal well and old percolation ponds (wells USGS 40, 41, 43, 47, 48, 51, 52, and 67) have been variable through time (fig. 26). The variability could have resulted from periodic dilution by recharge from the Big Lost River and variation in discharge rates to the injection well prior to 1984 or to the percolation ponds later. Concentrations of nitrate in wells south of INTEC and further away from the influence of disposal areas and the Big Lost River [wells CFA 1, USGS 77, 111, 113, 114, and 116 (figs. 5 and 6)] show much less variability and a general decrease in nitrate concentrations through time (fig. 27).

Historically, nitrate concentrations in water from wells near the RWMC have slightly exceeded the regional background concentration of about 1 mg/L (Robertson and others, 1974). In 1998, nitrate concentrations in water samples

from wells USGS 88, 89, and 119, near the RWMC (fig. 6), exceeded the background and were 1.6, 2.0, and 1.4 mg/L, respectively (Bartholomay and others, 2000). Concentrations have decreased slightly since 1998 and were 0.8, 1.6, and 1.3 mg/L, respectively, in 2011.

In 2011, near the ATR Complex, the concentration of nitrate in water from several wells was equal to or greater than the background concentration of 1 mg/L with the largest concentration of 1.5 mg/L in USGS 65. All concentrations measured in 2011 were less than the MCL for drinking water of 10 mg/L.

Figure 28 shows the vertical distribution of nitrate concentrations with depth in MLMS-equipped wells during 2009–11. The vertical distribution of nitrate in wells exhibited similar patterns to data from 2006–08 (Davis, 2010). Nitrate concentrations in wells Middle 2051 and USGS 103 were lower in the uppermost zone, and similar in all deeper zones in each well (fig. 28). Concentrations of nitrate from all zones in all wells were close to or less than the background of 1 mg/L.



**Figure 28.** Vertical distribution of nitrate in water from nine wells equipped with multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.

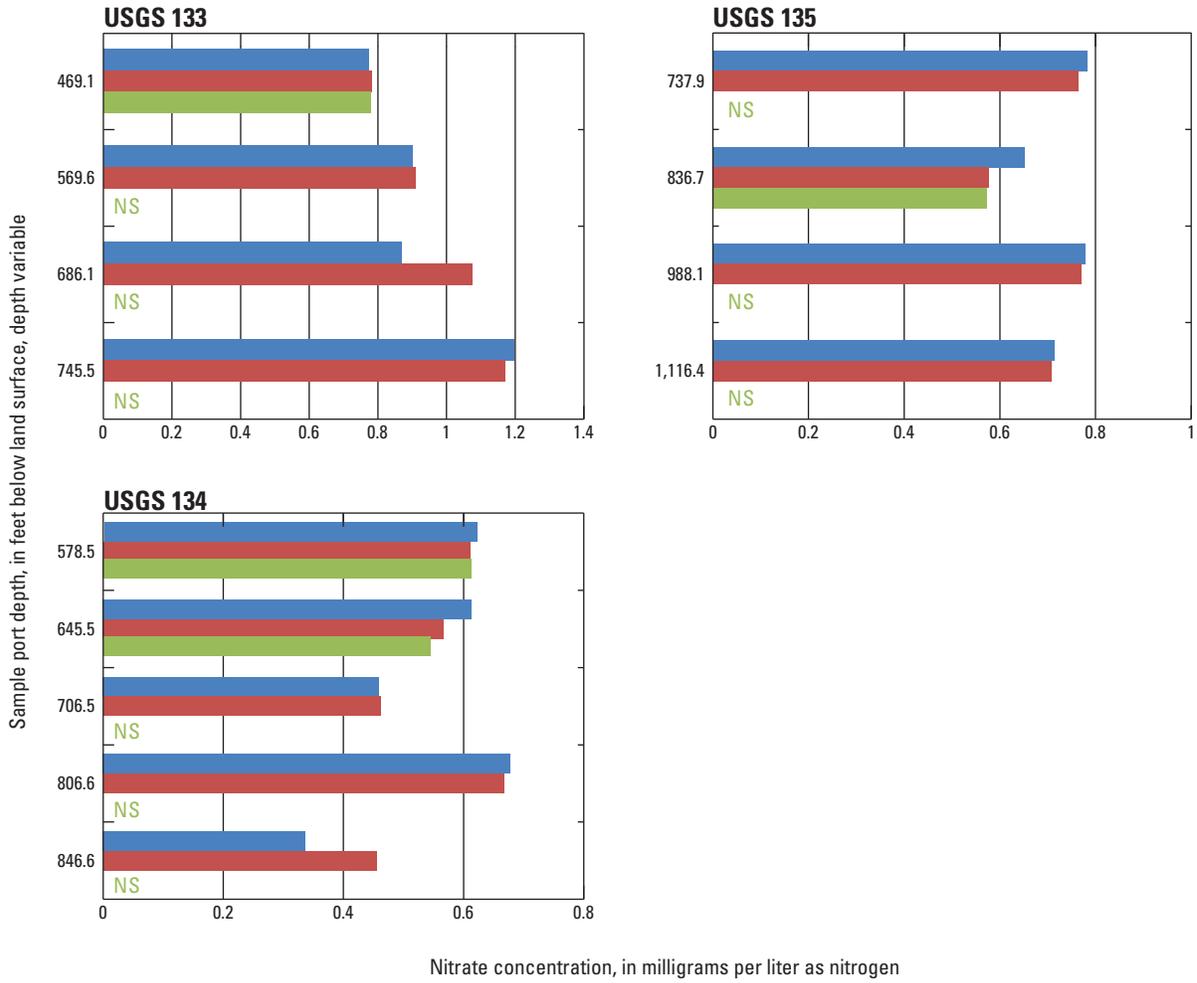


Figure 28.—Continued

## Fluoride

The USGS began analyzing water samples collected near the INTEC for fluoride in 1994, because fluoride in wastewater was being discharged to the old percolation ponds. During April or October 2011, water samples from five wells (CPP 1, USGS 34, 38, 77, and ICPP-MON-A-164B, [fig. 6](#)) were analyzed for fluoride; detected concentrations ranged from 0.2 to 0.3 mg/L. These concentrations are within the range of background concentrations of fluoride in the ESRP aquifer for the southwestern part of the INL reported by Robertson and others (1974, 0.1–0.3 mg/L, p. 75), which indicates that wastewater disposal has not had an appreciable effect on fluoride concentrations in the ESRP aquifer near the INTEC.

Fluoride concentrations in water samples collected from three wells equipped with MLMS (USGS 105, 108, and 135) during 2009–11 were within the range of background concentrations reported by Robertson and others (1974, p. 75) ([fig. 29](#)). Concentrations in all zones of each well ranged from 0.17 to 0.27 mg/L.

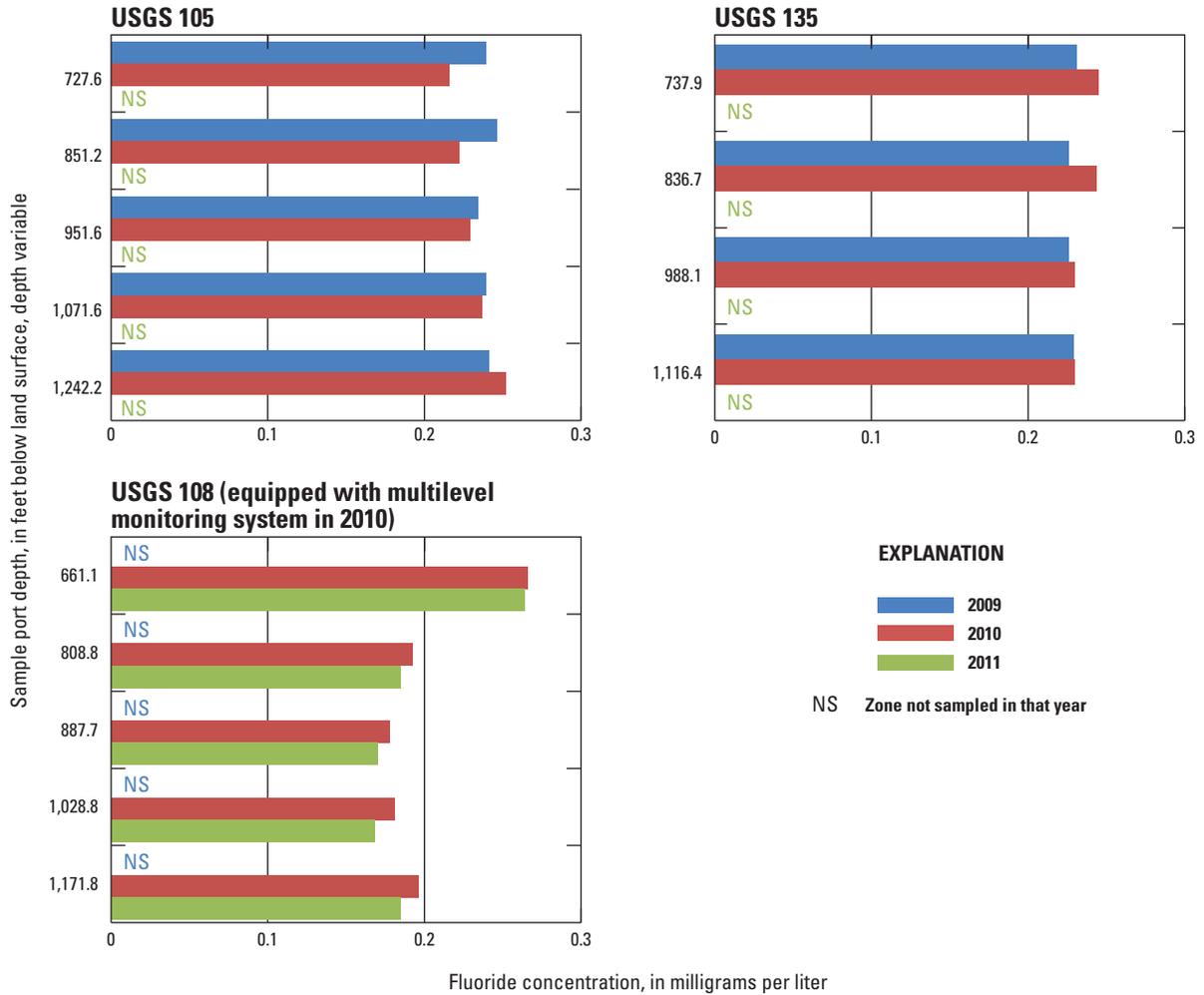
## Trace Elements

As part of the INL groundwater monitoring program adopted in 1994 and several special sampling programs, water samples from several wells were collected and analyzed for various trace elements during 2009–11. These trace elements were aluminum, antimony, arsenic, barium, beryllium, cadmium, cobalt, copper, iron, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium (stable), thallium, vanadium, and zinc. A summary of background concentrations of selected constituents in ESRP aquifer water samples is presented in Knobel and others (1992, p. 52). Bartholomay and others (2000, p. 32–34) give estimated disposal amounts of various trace elements in wastewater through 1998. Beginning in 1998, NWQL began implementing new reporting procedures based on long-term method detection levels (LT-MDLs) for some analytical methods (Childress and others, 1999). This change in LRLs (as opposed to MRLs) for some trace elements accounts for concentrations of some elements detected during 1999–2011, although historically the concentrations were less than the MRL. [Table 7](#) presents a summary of disposal data, disposal periods, and trace element concentration ranges in water samples analyzed during 2009–11 by the USGS. This table includes MLMS data for three new wells (USGS 105, 108, and 135). Bartholomay and Twining (2010, table 5) give a comprehensive summary of the vertical distribution of selected trace elements for each of the six wells equipped with MLMS prior to 2009.

## Volatile Organic Compounds

Volatile organic compounds (VOCs) are present in water from the ESRP aquifer because of waste-disposal practices at the INL. From 1987 to 2008, water samples from many wells completed in the ESRP aquifer at and near the INL were analyzed for VOCs for various water quality studies (Mann and Knobel, 1987; Mann, 1990; Liszewski and Mann, 1992; Greene and Tucker, 1998; Bartholomay and others, 2000; Davis, 2006b, 2008, 2010). Analyses from these studies indicated that from 1 to 19 VOCs in water samples from several wells exceeded their reporting levels during these years. The primary VOCs detected included carbon tetrachloride; 1,1-dichloroethane; 1,1,1-trichloroethane; trichloroethylene; tetrachloroethylene; chloroform; and toluene. During 2009–11, water samples from 30 wells were collected and analyzed for VOCs. Six different VOCs were detected. Water samples collected from 10 wells during 2009–11 each contained at least one and up to five of the different VOCs detected. [Table 8](#) shows the VOCs and concentrations detected in the 10 different wells. The primary VOCs detected included carbon tetrachloride, chloroform, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene. Toluene was detected in one well. Concentrations for all VOCs except carbon tetrachloride were less than the MCL for drinking water (U.S. Environmental Protection Agency, 2013).

Historically, concentrations of VOCs in water samples from several wells at and near the RWMC exceeded the reporting levels (Bartholomay and others, 2000). In December 2011, five VOCs were detected in water from the RWMC Production Well. The VOCs and concentrations detected in December 2011 were 7.27 µg/L of carbon tetrachloride, 2.10 µg/L of chloroform (trichloromethane), 0.50 µg/L of 1,1,1-trichloroethane, 3.91 µg/L of trichloroethylene, and 0.40 µg/L of tetrachloroethylene. A plot of carbon tetrachloride concentrations in water from the RWMC Production Well ([fig. 30](#)) indicates that concentration trends have increased with time from about 1 to 8 µg/L since 1987. The MCL for drinking water for carbon tetrachloride is 5 µg/L. Although the concentrations have been rising since, 1987, more recent data since 2005 may be starting to show that concentrations are leveling off ([fig. 30](#)) for the RWMC Production well. During 2009–11, water from well USGS 87, just north of the RWMC ([fig. 6](#)) had detectable concentrations of carbon tetrachloride, and exceeded the MCL of 5 µg/L for the first time in 2011. A plot of concentrations of carbon tetrachloride from this well also have increased with time from less than 1 µg/L in August 1987 to 5.1 µg/L in April 2011 ([fig. 30](#)). During 2009–11, carbon tetrachloride, chloroform, and trichloroethylene were detected in wells USGS 88 and 120 near the RWMC ([fig. 6](#)). Toluene also was detected in well USGS 88 in October 2011 ([table 8](#)).



**Figure 29.** Vertical distribution of fluoride in water from three wells equipped with multilevel monitoring systems, Idaho National Laboratory, Idaho, 2009–11.

**Table 7.** Trace elements disposed during various periods, number of wells sampled, and range of concentrations detected in water, Idaho National Laboratory, Idaho, 2009–11.

[Because the amounts of each constituent in wastewater discharged from INL facilities have not been compiled annually from monitoring data since 1998, no amounts are available for 1999–2011. Amount disposed, disposal period, and disposal facility from Bartholomay and others (2000). **Abbreviations:** INL, Idaho National Laboratory; INTEC, Idaho Nuclear Technology and Engineering Center; NR, none recorded; ND, not detected; lb, pound; µg/L, microgram per liter. **Symbol:** <, less than]

Constituent	Approximate amount disposed (lb)	Disposal period	Disposal facility	Number of wells sampled at the INL during 2009–11	Range of concentrations detected (µg/L)
Aluminum	117	1995–98	INTEC	12	2.35–9.50
Antimony	NR	NR	INL	12	0.1–0.22
Arsenic	11	1971–98	INL	12	1.21–5.88
Barium	4,740	1971–98	INL	12	16.17–157.4
Beryllium	<1	1971–98	INL	12	ND
Cadmium	22	1971–98	INL	12	0.04–0.37
Cobalt	NR	NR	INL	12	0.028–0.44
Copper	81	1995–98	INTEC	12	1.46–2.13
Iron	752	1995–98	INTEC	3	ND
Lead	556	1971–98	INL	12	0.02–0.12
Lithium	NR	NR	INL	3	1.53–3.24
Manganese	44	1995–98	INTEC	12	0.27–25.02
Mercury	141	1971–98	INL	10	0.006
Molybdenum	NR	NR	INL	12	1.23–6.01
Nickel	NR	NR	INL	12	0.09–1.53
Selenium	9	1971–98	INL	7	1.13–2.41
Silver	190	1971–98	INL	12	0.013
Strontium (stable)	NR	NR	INL	3	233.2–264.2
Thallium	NR	NR	INL	8	ND
Vanadium	NR	NR	INL	3	4.25–5.34
Zinc	5,240	1971–98	INL	12	1.40–7.59

**Table 8.** Concentrations of detected volatile organic compounds in aquifer wells at the Idaho National Laboratory, Idaho, 2009–11.

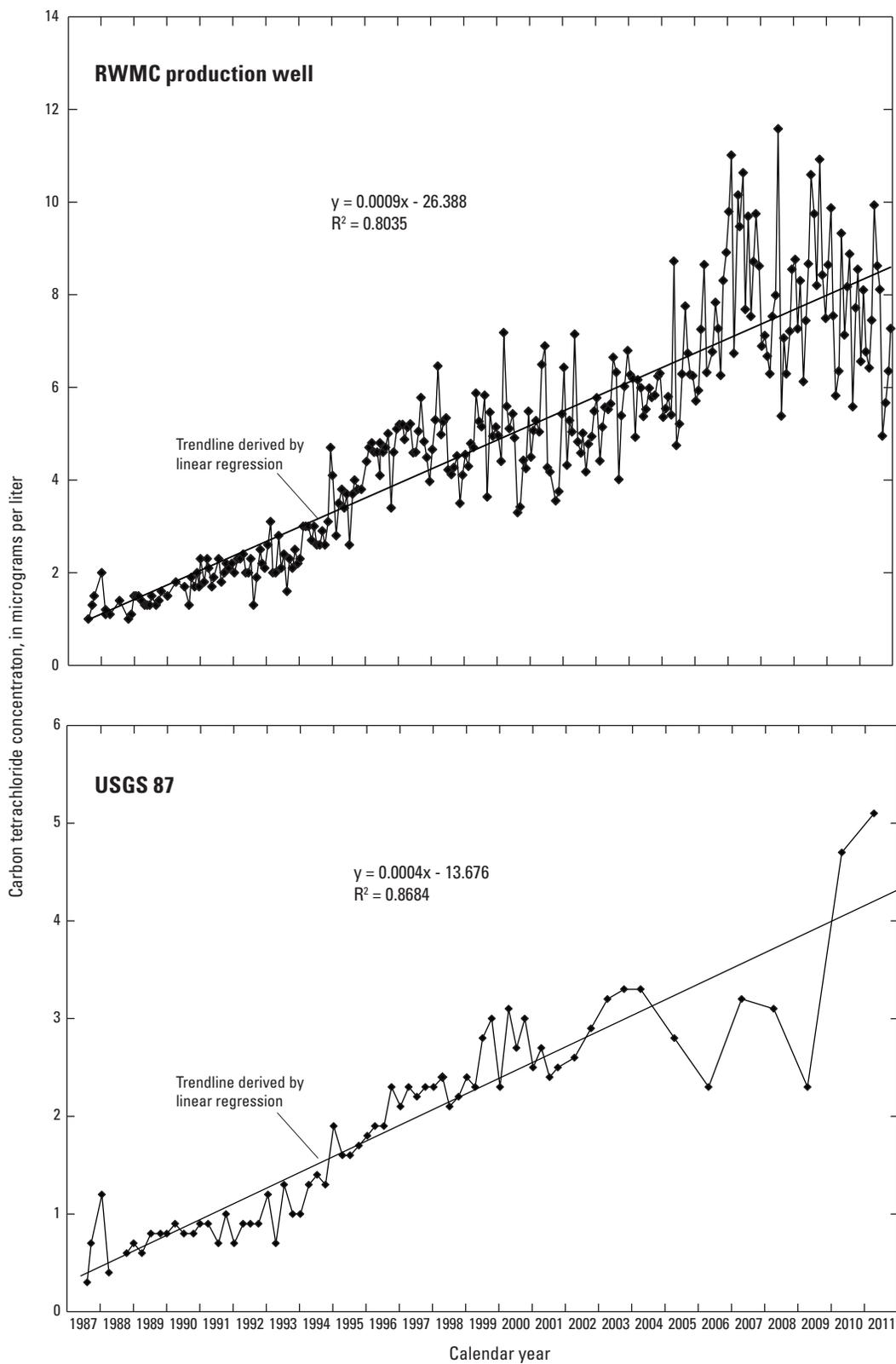
[Well No. or name: Location of wells are shown in figures 5 and 6. Analyses completed by the USGS National Water Quality Laboratory. **Abbreviations:** USGS, U.S. Geological Survey; NWIS, National Water Information System; µg/L, microgram per liter. **Symbol:** –, indicates concentration less than the reporting level]

Well No. or name	Date	Carbon Tetrachloride (Tetrachloromethane) (µg/L)	Chloroform (Trichloromethane) (µg/L)	Toluene (µg/L)	Tetrachloroethylene (Tetrachloroethene) (µg/L)	1,1,1-Trichloroethane (µg/L)	Trichloroethylene (Trichloroethylene) (µg/L)
NWIS Parameter code		32102	32106	34010	34475	34506	39180
EBR 1	04-21-09	–	0.12	–	–	–	–
HIGHWAY 3	10-27-09	–	0.24	–	–	–	–
USGS 38	04-06-09	–	–	–	–	0.11	–
USGS 65	04-13-09	–	–	–	–	0.12	–
USGS 65	04-28-10	–	–	–	–	0.11	–
USGS 65	04-18-11	–	–	–	–	0.11	–
USGS 77	10-07-09	–	–	–	–	0.12	–
USGS 87	04-16-09	2.27	0.35	–	–	0.13	0.58
USGS 87	04-28-10	4.67	0.29	–	0.11	0.18	0.64

**Table 8.** Concentrations of detected volatile organic compounds in aquifer wells at the Idaho National Laboratory, Idaho, 2009–11.—Continued

[Well No. or name: Location of wells are shown in figures 5 and 6. Analyses completed by the USGS National Water Quality Laboratory. **Abbreviations:** USGS, U.S. Geological Survey; NWIS, National Water Information System; µg/L, microgram per liter. **Symbol:** –, indicates concentration less than the reporting level]

Well No. or name	Date	Carbon Tetrachloride (Tetrachloro- methane) (µg/L)	Chloroform (Trichloro- methane) (µg/L)	Toluene (µg/L)	Tetrachloro- ethylene (Tetrachloro- ethene) (µg/L)	1,1,1-Trichloro- ethane (µg/L)	Trichloro- ethylene (Trichloro- ethylene) (µg/L)
NWIS Parameter code		32102	32106	34010	34475	34506	39180
USGS 87	04-18-11	5.07	0.31	–	0.15	0.22	1.03
USGS 88	10-26-09	0.50	0.51	–	–	–	0.37
USGS 88	10-26-10	0.52	0.38	–	–	–	0.38
USGS 88	10-24-11	0.58	0.39	0.16	–	–	0.43
USGS 98	10-05-09	–	0.10	–	–	–	–
USGS 120	10-26-09	1.15	0.13	–	–	–	0.16
USGS 120	10-13-10	0.69	–	–	–	–	–
USGS 120	10-18-11	0.65	–	–	–	–	–
RWMC PROD	01-15-09	8.76	1.98	–	0.38	0.60	3.90
RWMC PROD	02-12-09	7.26	1.85	–	0.35	0.54	3.51
RWMC PROD	03-12-09	8.30	1.88	–	0.38	0.55	3.65
RWMC PROD	04-16-09	6.13	1.79	–	0.33	0.47	3.16
RWMC PROD	05-14-09	7.44	1.85	–	0.36	0.49	3.54
RWMC PROD	06-11-09	8.66	2.17	–	0.40	0.57	4.08
RWMC PROD	07-09-09	10.59	2.13	–	0.41	0.65	4.09
RWMC PROD	08-13-09	9.74	1.85	–	0.41	0.55	3.76
RWMC PROD	09-10-09	8.20	1.75	–	0.36	0.52	3.32
RWMC PROD	10-13-09	10.92	2.48	–	0.47	0.64	4.44
RWMC PROD	11-12-09	8.43	2.21	–	0.40	0.59	3.73
RWMC PROD	12-17-09	7.49	1.97	–	0.37	0.53	3.56
RWMC PROD	01-14-10	8.64	2.10	–	0.40	0.53	3.76
RWMC PROD	02-16-10	9.87	2.33	–	0.45	0.61	4.31
RWMC PROD	03-11-10	7.55	2.06	–	0.38	0.50	3.77
RWMC PROD	04-08-10	5.82	2.38	–	0.43	0.61	4.26
RWMC PROD	05-13-10	6.35	1.80	–	0.34	0.47	3.43
RWMC PROD	06-10-10	9.33	2.74	–	0.43	0.62	4.68
RWMC PROD	07-15-10	7.13	1.84	–	0.30	0.51	3.42
RWMC PROD	08-16-10	8.17	1.84	–	0.35	0.54	3.78
RWMC PROD	09-09-10	8.88	1.81	–	0.39	0.54	3.79
RWMC PROD	10-14-10	5.58	1.40	–	0.29	0.38	2.88
RWMC PROD	11-16-10	7.71	2.21	–	0.39	0.54	4.12
RWMC PROD	12-09-10	8.55	2.14	–	0.40	0.53	4.12
RWMC PROD	01-12-11	6.56	1.89	–	0.30	0.42	3.40
RWMC PROD	02-10-11	8.10	2.09	–	0.33	0.52	3.99
RWMC PROD	03-10-11	6.77	1.73	–	0.32	0.44	3.44
RWMC PROD	04-14-11	6.42	2.75	–	0.40	0.61	4.77
RWMC PROD	05-12-11	7.45	2.46	–	0.38	0.53	4.75
RWMC PROD	06-09-11	9.93	2.46	–	0.41	0.50	4.49
RWMC PROD	07-14-11	8.62	1.86	–	0.37	0.43	3.86
RWMC PROD	08-11-11	8.11	1.41	–	0.28	0.34	2.88
RWMC PROD	09-08-11	4.95	2.02	–	0.30	0.54	3.91
RWMC PROD	10-13-11	5.67	2.48	–	0.38	0.49	4.57
RWMC PROD	11-15-11	6.35	2.25	–	0.40	0.42	4.18
RWMC PROD	12-08-11	7.27	2.10	–	0.40	0.50	3.91



**Figure 30.** Carbon tetrachloride concentrations in water from the Radioactive Waste Management Complex (RWMC) Production Well and well USGS 87, Idaho National Laboratory, Idaho, 1987–2011.

## Total Organic Carbon

Analyses of TOC are used to screen for organic compounds in the aquifer as a general indicator of groundwater contamination. As part of the INL groundwater monitoring program adopted in 1994, the USGS began collecting and analyzing water from several wells at the INL for TOC. During April or October 2011, water samples from 49 wells completed in the ESRP aquifer at the INL were analyzed for TOC; detected concentrations ranged from 0.31 to 0.96 mg/L. The majority of wells sampled had TOC concentrations below the LRL. The LRL for TOC ranged between 0.3 and 0.5 mg/L during 2011.

Water samples were collected and analyzed for TOC from nine wells equipped with MLMS. Results showed that the concentrations were variable between zones sampled in each well and ranged from less than the reporting level to 1.9 mg/L. Evaluations of quality assurance data for TOC indicated that the statistical equivalence of TOC concentrations from replicate pairs did not meet its data quality objective for completeness (Williams, 1996, 1997; Knobel and others, 1999; Bartholomay and Twining, 2010; Rattray, 2012). The NWQL presented laboratory results for organic constituents variable recovery of TOC indicative of reproducibility issues with the laboratory methods. Because of this reason, TOC will be discontinued from USGS sample schedules starting in 2012.

## Perched Groundwater at the Idaho National Laboratory

Disposal of wastewater to infiltration ponds and ditches, lined evaporation ponds, drain fields, and infiltration of surface water at waste-burial pits resulted in formation of perched groundwater in basalts and in sedimentary interbeds that overlie the ESRP aquifer (Cecil and others, 1991). Perched groundwater has formed in a complex sequence of basalt flow and sedimentary interbeds beneath the ATR Complex, the INTEC, and the RWMC. Anderson and Lewis (1989) and Anderson (1991) correlated geophysical logs to describe the stratigraphic sequences in which perched groundwater has formed. Although the subsurface stratigraphy, geohydrologic characteristics, and waste disposal practices at each of these areas differ, the features controlling the formation of perched groundwater at these sites are similar (Cecil and others, 1991). Sedimentary interbeds in the subsurface may have smaller vertical hydraulic conductivities than overlying basalt

flows, and alteration between basalt flows may contribute to reduced vertical hydraulic conductivity in the interflow rubble zones. Dense, unfractured basalt flows may have a decreased vertical hydraulic conductivity and inhibit downward flow, and sedimentary or chemical infilling of fractures in basalt may reduce vertical hydraulic conductivity by limiting the interconnectivity of fractures, reducing the water-transmitting capability of the basalts (Cecil and others, 1991). Any combination of these factors may disrupt the downward movement of water and contribute to the formation of perched groundwater zones.

Wastewater-disposal sites at INL facilities are the primary sources of radiochemical and chemical constituents in perched groundwater at the INL. During 2009–11, wastewater was discharged to infiltration and lined-evaporation ponds. Bartholomay and others (2000) provides a comprehensive summary of waste disposal at the INL through 1998.

## Advanced Test Reactor Complex

Bodies of shallow and deep perched groundwater formed at the ATR Complex in response to wastewater disposal into radioactive-, chemical-, cold-, and sanitary-waste ponds (Tucker and Orr, 1998) (fig. 6). Radiochemical and chemical constituents in wastewater migrate to the ESRP aquifer through perched groundwater beneath these wastewater infiltration ponds. The extent of perched groundwater is affected by the waste-disposal practices. Selected radiochemical and inorganic chemical constituents in wastewater have been monitored in the shallow and deep perched groundwater since the early 1960s.

Water samples from three wells (CWP 1, 3, and 8) completed in shallow perched groundwater near the ATR Complex (fig. 7) routinely were collected and analyzed for selected radiochemical and chemical constituents during 2009–11. Water samples were collected from 17 wells (PW 8, PW 9, USGS 54–56, 60–63, 66, 68–73, and 78) that were completed in deep perched groundwater beneath the ATR Complex. Sampling was discontinued at many perched groundwater wells during the 2002–05 reporting period because of lack of water in the wells (Davis, 2008, fig. 21).

Selection of radiochemical and chemical constituents for analyses was based on the waste-disposal history at the ATR Complex. Selected radiochemical constituents were tritium, strontium-90, and gamma analyses (which may yield detections of cesium-137, cobalt-60, or chromium-51); chemical constituents were dissolved chromium, sodium, chloride, and sulfate.

## Tritium

Wells CWP 1, 3, and 8 (fig. 4) are used to monitor shallow perched groundwater around the cold-waste ponds at the ATR Complex. During 2009–11, tritium concentrations in water samples collected from wells CWP 1, 3, and 8 were less than the reporting level.

Concentrations of tritium in deep perched groundwater near the ATR Complex during April or October 2011 are shown in figure 31. Concentrations of tritium in wells near the ATR Complex historically have been high compared to 2011 values. Tritium concentrations continued to decrease during the 2009–11 reporting period in all wells with the exception of well USGS 61 which had a concentration of  $2,890 \pm 130$  pCi/L, slightly higher than the 2008 concentration of  $2,610 \pm 120$  pCi/L. The decrease in tritium concentrations in water from wells near the ATR Complex likely is a result of changes in wastewater disposal practices near those wells. In some cases, the change in disposal practices also may have led to a decrease in the amount of perched groundwater available to sample.

Tritium concentrations in water from 12 wells completed in deep perched groundwater (PW 8, PW 9, USGS 54, 55, 56, 60, 61, 66, 68, 70, 71, and 73) near the ATR Complex generally were greater than or equal to the reporting level during at least one sampling event during 2009–11 (table 9). Tritium concentrations in water from five wells (USGS, 62, 63, 69, 72, and 78) were less than the reporting level during 2009–11 (table 9).

Tritium concentrations equal to or greater than the reporting level ranged from  $180 \pm 60$  pCi/L in water from well USGS 54 in 2009 to  $25,000 \pm 800$  pCi/L in water from well USGS 55 in 2010 (table 9). Water samples collected in October 2011 from well USGS 73 had a tritium concentration of  $3,300 \pm 150$  pCi/L, substantially less than the October 2008 concentration of  $13,100 \pm 300$  pCi/L. Well PW 9 had a concentration of  $14,500 \pm 500$  pCi/L, also substantially less than the October 2008 concentration of  $28,700 \pm 500$  pCi/L. Concentrations of tritium in these two wells have decreased appreciably since October 1993 when concentrations were  $296,000 \pm 10,000$  pCi/L in water from well USGS 73 and  $193,000 \pm 6,000$  pCi/L in water from well PW 9. These two wells are located more than 1,500 ft west of the radioactive-waste infiltration ponds (fig. 31). In 1993, the radioactive-waste infiltration ponds were taken out of service and wastewater was discharged to lined evaporation ponds (Davis, 2008). Historically, high tritium concentrations in water from wells USGS 73 and PW 9 wells indicate that the chemistry of perched groundwater west of the ATR Complex was affected by radioactive-waste infiltration pond disposals. Discontinuation of wastewater discharge to the radioactive-waste infiltration ponds and the subsequent use of

lined evaporation ponds, together with the radioactive decay process, may account for the decreased tritium concentrations in this area from 1993 to 2011.

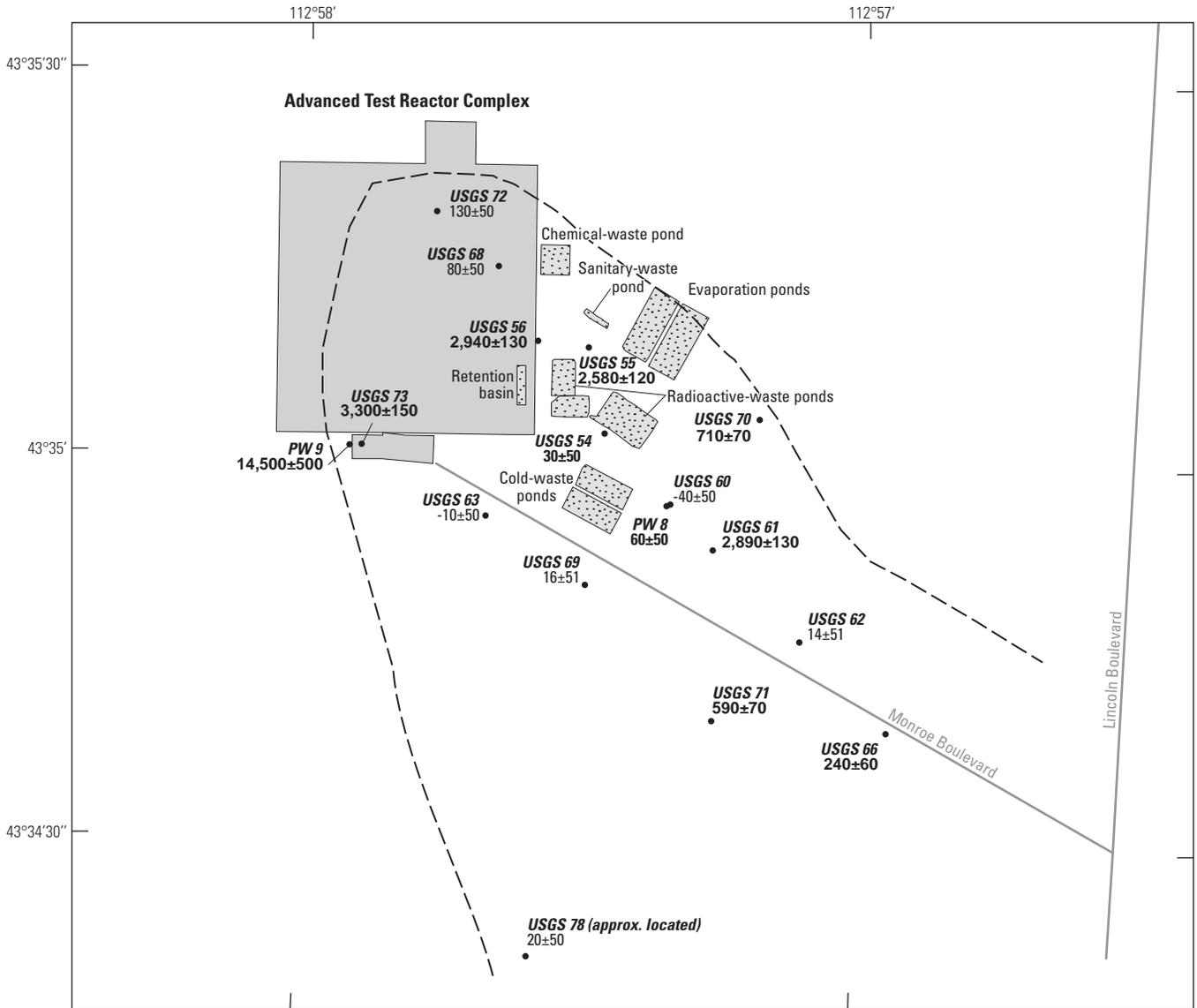
Tritium concentrations have fluctuated substantially in USGS 55 (located between the evaporation ponds and the radioactive-waste ponds [fig. 31]) during recent sampling periods with a larger concentration of  $25,000 \pm 800$  pCi/L in 2010, and a smaller concentration of  $2,580 \pm 120$  pCi/L in 2011. Similar large and small values were noted in Davis (2008, table 10; 2010, table 7). These variable changes may indicate remnant radioactive-waste pond wastewater is still present between the land surface and the perched groundwater zone, or there is possible leakage coming from the evaporation ponds or piping to the ponds.

Several factors affected the distribution of tritium in perched groundwater at the ATR Complex, including proximity of wells to the radioactive-waste infiltration ponds, depth of water below the ponds, variations in tritium disposal rate, and radioactive decay. Since 1982, tritium concentrations also have been affected by dilution from the cold-waste ponds. Replacement of the radioactive-waste infiltration ponds with the lined evaporation ponds in 1993 contributed to decreases in tritium concentrations in perched groundwater and decreases in perched groundwater in some wells. Infiltration from the Big Lost River during 1999, early 2000, 2005, and 2006 may have contributed to diluted tritium concentrations in perched groundwater southeast of the ATR Complex although a direct connection has never been documented.

## Strontium-90

Wells CWP 1, 3, and 8 (fig. 4) completed in shallow perched groundwater at the ATR Complex were sampled for strontium-90 during 2009–11. The concentrations of strontium-90 in wells CWP 1 and CWP 8 had varied between greater than and less than the reporting level during 2002–05 (Davis, 2008, table 10). Strontium-90 concentrations in water from wells CWP 1, 3, and 8 were less than the reporting level for all samples collected during 2006–08 Davis (2010, table 7). During 2009–11, concentrations of strontium-90 in one sample each from wells CWP 3 and 8 were greater than the reporting level (table 9).

During at least one sampling event in the period 2009–11, concentrations of strontium-90 in water from wells PW 8, USGS 54–56, 60–63, 70, and 73, completed in deep perched groundwater at the ATR Complex, were greater than or equal to reporting levels (table 9, fig. 32). Concentrations equal to or greater than the reporting level ranged from  $2.1 \pm 0.7$  pCi/L in well USGS 73 to  $65.5 \pm 1.8$  pCi/L in well USGS 56. The distribution of strontium-90 concentrations in perched groundwater from these wells during 2009–11 is attributed to exchange reactions between strontium-90 in solution and to sediments beneath the radioactive-waste infiltration ponds.



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

**EXPLANATION**

- Extent of deep perched groundwater—April–October 2011. Approximately located
- USGS 71**  
**590±70** Well completed in deep perched groundwater—Entry, PW 8, is local well identifier; 590±70, is tritium concentration and associated uncertainty in picocuries per liter. Concentration equal to or greater than the 3s reporting level in **bold**. Values represent most recent data collected during April or October 2011.



**Figure 31.** Concentrations of tritium in water from wells completed in deep perched groundwater, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, April or October 2011.

## 70 Hydrologic Conditions and Distribution of Selected Constituents in Water, Idaho National Laboratory, Idaho, 2009–11

Although strontium-90 has been detected in water from shallow and deep perched groundwater at the ATR Complex, it has not been detected in the ESRP aquifer beneath the ATR Complex. This may be because of the exclusive use of waste-disposal ponds and lined evaporation ponds rather than injection of waste directly to the aquifer (Bartholomay and others, 1997, p. 30). The absence of detectable concentrations

in the aquifer indicates that strontium-90 in solution is removed possibly by sorption and (or) exchange reactions in the unsaturated zone. Studies of strontium distribution coefficients for samples of surficial sediment, sedimentary interbeds, and sediment-filled fractures in basalts at the INL (Liszewski and others, 1997, 1998; Pace and others, 1999) support this theory.

**Table 9.** Concentrations of tritium, strontium-90, and cesium-137 in perched groundwater from selected wells, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, 2009–11.

[**Well No.:** Locations of wells are shown in [figure 7](#). Analyses completed by the Department of Energy’s Radiological and Environmental Sciences Laboratory. Analytical uncertainties are reported as 1 times the sample standard deviation. Concentrations equal to or greater than 3 times the sample standard deviation are considered to be greater than the reporting level and are **bold**. **Abbreviations:** USGS, U.S. Geological Survey; DP, well completed in deep perched groundwater; SP, well completed in shallow perched groundwater; NR, analysis not requested; pCi/L, picocurie per liter. **Symbol:** ±, plus or minus]

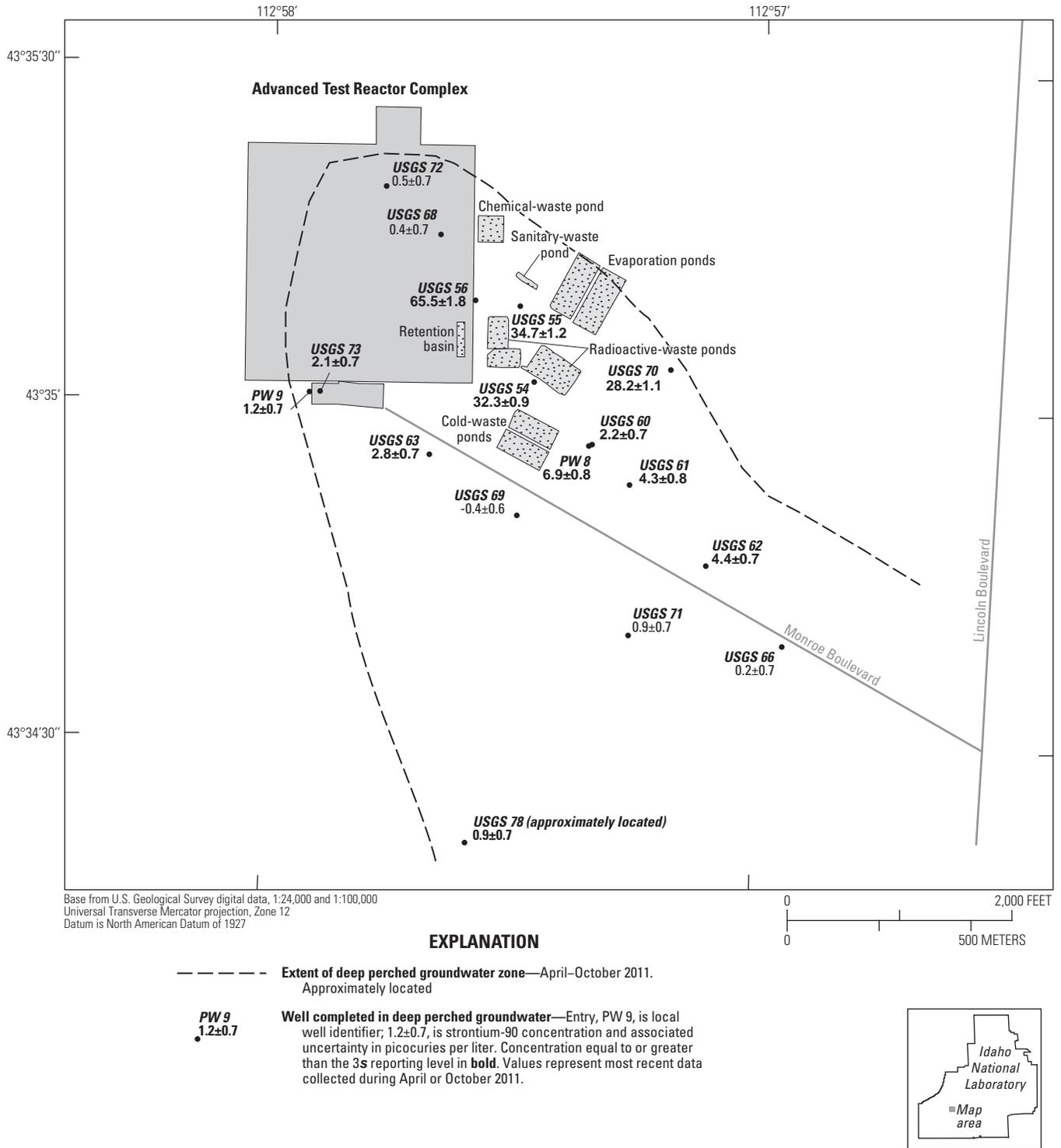
Well No.	Date sampled	Tritium (pCi/L)	Strontium-90 (pCi/L)	Cesium-137 (pCi/L)
CWP 1 (SP)	04-16-09	-30±60	0.1±0.7	NR
	04-22-10	60±60	1.7±0.7	NR
	04-18-11	10±50	0.9±0.7	NR
CWP 3 (SP)	04-16-09	-20±60	0.4±0.7	NR
	04-22-10	50±60	0.6±0.7	NR
	04-18-11	110±50	<b>3±0.7</b>	NR
CWP 8 (SP)	04-16-09	70±70	<b>5.4±0.8</b>	NR
	04-22-10	150±60	1.6±0.6	NR
	04-18-11	60±50	1.1±0.7	NR
PW 8 (DP)	04-13-09	<b>240±70</b>	<b>7.9±0.8</b>	8±10
	04-29-10	200±70	<b>9.3±0.8</b>	21±12
	04-04-11	60±50	<b>6.9±0.8</b>	12±8
PW 9 (DP)	10-14-09	<b>18,300±400</b>	0±0.7	9±11
	10-27-10	<b>22,800±700</b>	1.9±0.7	11±10
	10-05-11	<b>14,500±500</b>	1.2±0.7	29±10
USGS 54 (DP)	10-22-09	<b>180±60</b>	<b>34±1.2</b>	3±10
	10-28-10	140±50	<b>36.4±1.3</b>	26±11
	10-11-11	30±50	<b>32.3±0.9</b>	12±7
USGS 55 (DP)	04-29-10	<b>25,000±800</b>	<b>42.2±1.3</b>	28±13
	04-13-11	<b>2,580±120</b>	<b>34.7±1.2</b>	11±8
USGS 56 (DP)	10-17-11	<b>2,940±130</b>	<b>65.5±1.8</b>	12±8
USGS 60 (DP)	10-08-09	10.7±58.1	1.3±0.7	18±9
	10-28-10	<b>590±60</b>	<b>4±0.7</b>	21±10
	10-06-11	-40±50	<b>2.2±0.7</b>	7±6

**Table 9.** Concentrations of tritium, strontium-90, and cesium-137 in perched groundwater from selected wells, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, 2009–11.—Continued

[Well No.: Locations of wells are shown in [figure 7](#). Analyses completed by the Department of Energy's Radiological and Environmental Sciences Laboratory. Analytical uncertainties are reported as 1 times the sample standard deviation. Concentrations equal to or greater than 3 times the sample standard deviation are considered to be greater than the reporting level and are **bold**. **Abbreviations:** USGS, U.S. Geological Survey; DP, well completed in deep perched groundwater; SP, well completed in shallow perched groundwater; NR, analysis not requested; pCi/L, picocurie per liter. **Symbol:** ±, plus or minus]

Well No.	Date sampled	Tritium (pCi/L)	Strontium-90 (pCi/L)	Cesium-137 (pCi/L)
USGS 61 (DP)	04-13-09	<b>2,490±120</b>	1.5±0.6	22±10
	04-26-10	<b>2,070±120</b>	0.4±0.7	<b>12±4</b>
	04-05-11	<b>2,890±130</b>	<b>4.3±0.8</b>	20±9
USGS 62 (DP)	04-13-09	30±60	<b>3.3±0.7</b>	19±9
	04-29-10	120±60	<b>2.5±0.7</b>	13±13
	04-05-11	13.5±50.8	<b>4.4±0.7</b>	10±10
USGS 63 (DP)	10-14-09	80±60	0.6±0.7	-12±17
	10-28-10	90±50	<b>2.3±0.7</b>	8 ±8
	10-06-11	-10±50	<b>2.8±0.7</b>	29±10
USGS 66 (DP)	10-13-09	<b>440±70</b>	0.9±0.7	12±11
	10-21-10	<b>570±60</b>	1.3±0.8	24±12
	10-17-11	<b>240±60</b>	0.2±0.7	11±7
USGS 68 (DP)	04-20-09	<b>230±70</b>	1.4±0.7	15±11
	04-26-10	160±60	1.3±0.7	40±20
	04-27-11	80±50	0.4±0.7	20±30
USGS 69 (DP)	10-14-09	-50±60	-0.5±0.8	25±15
	10-14-10	50±50	0±0.6	5±7
	10-11-11	15.9±50.6	-0.4±0.6	4±6
USGS 70 (DP)	04-13-09	<b>3,290±130</b>	<b>36±1.3</b>	18±12
	04-12-10	<b>3,490±160</b>	<b>31.5±1.1</b>	35±15
	04-14-11	<b>710±70</b>	<b>28.2±1.1</b>	-15±10
USGS 71 (DP)	10-13-09	<b>780±80</b>	1±0.7	25±13
	10-21-10	<b>840±70</b>	0.5±0.7	21±11
	10-17-11	<b>590±70</b>	0.9±0.7	28±10
USGS 72 (DP)	04-20-09	-40±60	-0.6±0.6	17±9
	04-26-10	110±60	0.1±0.7	5±6
	04-27-11	130±50	0.5±0.7	9±10
USGS 73 (DP)	10-14-09	<b>2,960±120</b>	1.5±0.7	22±11
	10-28-10	<b>6,810±250</b>	1.2±0.7	-20±20
	10-05-11	<b>3,300±150</b>	<b>2.1±0.7</b>	16±8
USGS 78 (DP)	10-13-09	70±60	0.2±0.7	4±5
	10-21-10	70±50	0.3±0.7	30±20
	10-17-11	20±50	0.9±0.7	12±6

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**Figure 32.** Concentrations of strontium-90 in water from wells completed in deep perched groundwater, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, April or October 2011.

## Gamma Spectrometry

Water samples collected are routinely analyzed by gamma spectrometry and the results may yield concentrations of cesium-137, chromium-51, and cobalt-60. Water samples from wells completed in both shallow and deep perched groundwater at and near the ATR Complex have not yielded concentrations of cesium-137 greater than the reporting level since 1997; however, in April 2010, well USGS 61 had a concentration of cesium-137 that was equal to the reporting level ([table 9](#)). Water from wells at and near the ATR Complex has not had concentrations greater than the reporting level of chromium-51 since 1995, or cobalt-60 since 1998 (Davis, 2010).

## Chromium

In October 1972, chromium used as a corrosion inhibitor in cooling-tower operations was replaced by a polyphosphate. No disposal of chromium to the subsurface at the ATR Complex was reported after 1972 (Bartholomay and Tucker, 2000). The presence of dissolved chromium in water from wells completed in perched groundwater represents chromium in cooling-tower blowdown water that was discharged to the radioactive-waste infiltration ponds before 1965 when disposal practices changed to injection of water to the disposal well; concentrations in the perched groundwater zone are expected to continue to decrease in the future.

Historically, dissolved chromium concentrations in shallow perched groundwater at the ATR Complex have been very low (less than or slightly greater than the LRL) because of lack of disposal of chromium to the cold waste ponds. Over the past decade, several wells completed in shallow perched groundwater were not sampled because they were dry and were removed from the USGS sampling program. During 2009–11, three shallow perched groundwater wells (CWP 1, 3, and 8) were sampled for chromium. Chromium was detected in well CWP 1 in April of each year with a concentration of 3 µg/L ([table 10](#)). Chromium also was detected in well CWP 3 in April 2009 with a concentration of 2 µg/L. The reporting level for dissolved chromium varied from 0.6 (LT-MDL) to 1.2 (LRL) µg/L during 2009–11. Estimated concentrations ([table 10](#)) less than the LRLs are treated as nondetected concentrations, for consistency with treatment reported in previous publications and because an estimated concentration is considered a “qualitatively detected analyte” (Childress and others, 1999, p. 7).

Dissolved chromium was detected in water from all the wells sampled for chromium and completed in deep perched groundwater at the ATR Complex during 2009–11 ([table 10](#)). The highest concentrations during 2011 were in water from wells north and west of the radioactive-waste infiltration ponds (PW 9 and USGS 55, 56, and 73) ([table 10](#) and [fig. 33](#)).

During April or October 2011, detectable concentrations of dissolved chromium in wells completed in deep perched groundwater near the ATR Complex ranged from 1 µg/L in well USGS 78 to 43 µg/L in well USGS 56. The maximum concentration of chromium of 43 µg/L in well USGS 56 in October 2011 decreased from 125 µg/L in October 2006 ([table 10](#) and [fig. 33](#)).

## Sodium

Dissolved sodium was not sampled for in shallow perched groundwater at the ATR Complex ([table 10](#)). During April or October 2011, dissolved sodium concentrations in water from 17 wells completed in deep perched groundwater were determined. The sodium concentrations ranged from 6 to 146 mg/L ([table 10](#)). The highest concentration was in water from well USGS 68 ([table 10](#)); the sodium concentration in well USGS 68 decreased from 476 mg/L in April 2008 (Davis, 2010, table 8). Sodium concentrations in this well have varied through time and ranged from 146 to 431 mg/L during 2009–11. The reason for the variability of the concentrations in well USGS 68 probably is a result of movement of remnant water through the unsaturated zone from the chemical-waste pond which was closed in 1999.

## Chloride

Concentrations of dissolved chloride in most wells varied during 2009–11 ([table 10](#)). During April 2011, dissolved chloride concentrations in shallow perched groundwater ranged from 7 mg/L in well CWP 8 to 12 mg/L and 13 mg/L in wells CWP 1 and 3, respectively. Dissolved chloride concentrations in deep perched groundwater during April or October 2011 ranged from 4 mg/L in well USGS 78 to 54 mg/L in well USGS 73. Higher concentrations of chloride were in water from wells in the western part of the perched groundwater zone at the ATR Complex and may be a result of movement of remnant water through the unsaturated zone from the chemical-waste pond which was closed in 1999.

## Sulfate

The maximum dissolved sulfate concentration in shallow perched groundwater at the ATR Complex was 400 mg/L in well CWP 1 in April 2009. Concentrations of dissolved sulfate in this well vary greatly. During 2006–08, the concentrations ranged from 66 to 399 mg/L and during 2009–11 concentrations ranged from 34 to 400 mg/L ([table 10](#)). The variable concentrations are probably a result of changes in the amount of sulfate disposal to the cold-waste ponds.

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**Table 10.** Concentrations of selected dissolved ions in perched groundwater from selected wells, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, 2009–11.

[Well No.: Locations of wells are shown in [figure 7](#). Analyses completed by the USGS National Water Quality Laboratory. **Abbreviations:** DP, well completed in deep perched groundwater; SP, well completed in shallow perched groundwater; NR, analysis not requested; E, estimated, and followed by the estimated value; µg/L, microgram per liter; mg/L, milligram per liter; USGS, U.S. Geological Survey. **Symbol:** <, less than respective reporting level]

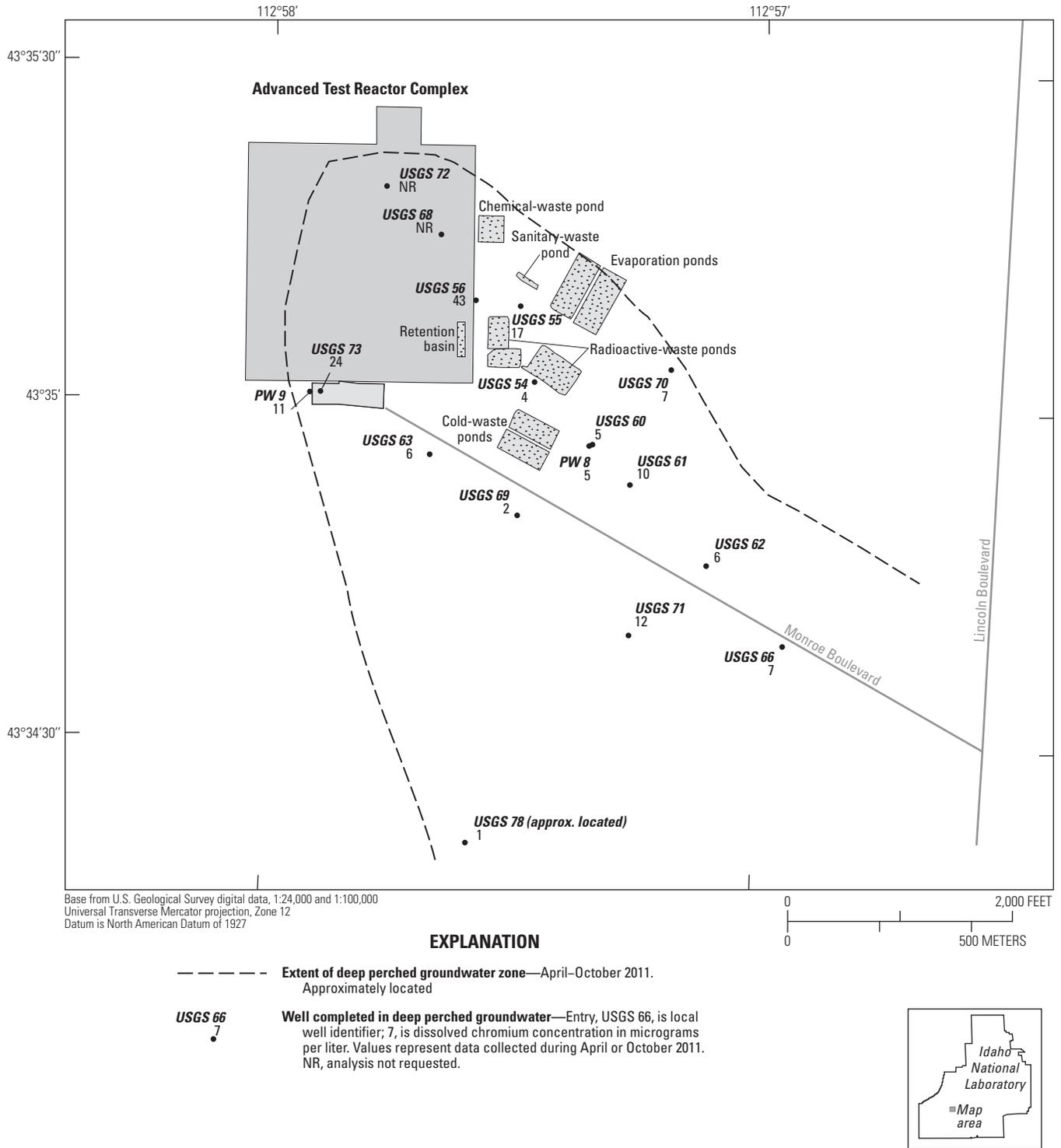
Well No.	Date sampled	Chromium, dissolved (µg/L)	Sodium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)
CWP 1 (SP)	04-16-09	3	NR	27	400
	04-22-10	3	NR	13	69
	04-18-11	3	NR	12	34
CWP 3 (SP)	04-16-09	2	NR	22	274
	04-22-10	<1.2	NR	18	193
	04-18-11	<0.6	NR	13	46
CWP 8 (SP)	04-16-09	E1	NR	5	28
	04-22-10	<1.2	NR	10	47
	04-18-11	<0.6	NR	7	31
PW 8 (DP)	04-13-09	7	16	19	230
	04-29-10	7	17	23	286
	04-04-11	5	18	18	181
PW 9 (DP)	10-14-09	7	21	37	83
	10-27-10	20	19	40	80
	10-05-11	11	20	40	75
USGS 54 (DP)	10-22-09	6	15	15	136
	10-28-10	7	15	19	203
	10-11-11	4	12	14	68
USGS 55 (DP)	04-29-10	29	17	18	164
	04-13-11	17	16	15	81
USGS 56 (DP)	10-17-11	43	35	15	41
USGS 60 (DP)	10-08-09	5	14	17	158
	10-28-10	6	16	22	274
	10-06-11	5	13	17	144
USGS 61 (DP)	04-13-09	12	13	17	146
	04-26-10	11	13	18	166
	04-05-11	10	14	18	163

**Table 10.** Concentrations of selected dissolved ions in perched groundwater from selected wells, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, 2009–11.—Continued

[**Well No.:** Locations of wells are shown in [figure 7](#). Analyses completed by the USGS National Water Quality Laboratory. **Abbreviations:** DP, well completed in deep perched groundwater; SP, well completed in shallow perched groundwater; NR, analysis not requested; E, estimated, and followed by the estimated value; µg/L, microgram per liter; mg/L, milligram per liter; USGS, U.S. Geological Survey. **Symbol:** <, less than respective reporting level]

Well No.	Date sampled	Chromium, dissolved (µg/L)	Sodium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Sulfate, dissolved (mg/L)
USGS 62 (DP)	04-13-09	8	17	20	255
	04-29-10	8	17	22	257
	04-05-11	6	18	20	218
USGS 63 (DP)	10-14-09	5	15	17	144
	10-28-10	9	17	22	272
	10-06-11	6	15	18	167
USGS 66 (DP)	10-13-09	<1.2	16	18	188
	10-21-10	2	15	18	190
	10-17-11	7	15	20	222
USGS 68 (DP)	04-20-09	NR	431	31	1,550
	04-26-10	NR	180	29	922
	04-27-11	NR	146	25	467
USGS 69 (DP)	10-14-09	E1	12	17	108
	10-14-10	1	11	18	119
	10-11-11	2	10	19	87
USGS 70 (DP)	04-13-09	19	16	17	165
	04-12-10	21	15	18	170
	04-14-11	7	15	15	91
USGS 71 (DP)	10-13-09	13	14	18	173
	10-21-10	10	14	19	176
	10-17-11	12	14	19	172
USGS 72 (DP)	04-20-09	NR	29	21	28
	04-26-10	NR	24	21	26
	04-27-11	NR	29	23	26
USGS 73 (DP)	10-14-09	15	16	41	56
	10-28-10	25	21	84	53
	10-05-11	24	19	54	56
USGS 78 (DP)	10-13-09	E1	7	4	21
	10-21-10	<0.6	5	5	20
	10-17-11	1	6	4	19

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**Figure 33.** Concentrations of dissolved chromium in water from wells completed in deep perched groundwater, Advanced Test Reactor Complex, Idaho National Laboratory, Idaho, April or October 2011.

Concentrations of dissolved sulfate in water from wells completed in deep perched groundwater at the ATR Complex near the cold-waste ponds (USGS 54, 60, 63, 69, and PW 8) ranged from 68 to 181 mg/L during April–October 2011 (table 10; fig. 7). These high concentrations indicate that water in the wells also was affected by discharge into the cold-waste ponds. During 2009–11, the maximum concentration of dissolved sulfate in deep perched groundwater was 1,550 mg/L in well USGS 68 (table 10), west of the chemical-waste pond (fig. 7). The dissolved sulfate concentration in this well varied from 467 to 1,550 mg/L during 2009–11 and is attributed to past disposal in the chemical-waste pond.

## Idaho Nuclear Technology and Engineering Center

Two percolation ponds were constructed south of the INTEC in 1984 and 1985 to replace the INTEC disposal well (fig. 7). Wastewater infiltrating from these ponds formed perched groundwater in the basalt and sedimentary interbeds above the ESRP aquifer in the southern part of INTEC. The old percolation ponds were taken out of service when new percolation ponds, located about 2 mi southwest of INTEC (fig. 4), were put into service in August 2002 (U.S. Department of Energy, 2011a). The USGS continued to monitor water from wells in the perched groundwater zone near the old percolation ponds until the last well (PW 4) went dry in 2008. Deeper perched groundwater near the center of the INTEC was monitored from samples collected from well USGS 50 (fig. 7) until the well was abandoned in 2009. Davis (2010) gives the final analyses of data collected from the USGS perched groundwater monitoring around the INTEC. Perched groundwater has been detected in other areas at the INTEC as well and may be attributed to leaking wastewater pipelines, leach fields, damaged casing in the upper part of the disposal well, other infiltration ponds, flow from the Big Lost River, precipitation recharge, or landscape irrigation (Tucker and Orr, 1998; Mirus and others, 2011). Information on water quality monitoring of perched groundwater wells in other areas of INTEC from monitoring performed by INL contractors was documented most recently by the U.S. Department of Energy (2011c).

Starting in April 2010, the USGS began to monitor perched groundwater in well ICPP-MON-V-200 (fig. 4), about 2 mi southwest of INTEC, for a general indication of water chemistry from the new percolation ponds installed in 2002 to better understand what effects the ponds may have on water quality in the ESRP aquifer. Results from water samples collected in 2010 and 2011 are given in table 11. Chemical constituent results from well ICPP-MON-V-200 compared with the water chemistry from CPP-1 (a production well at INTEC used to represent water quality before wastewater constituents are added) (Knobel and others, 1999) indicate that wastewater discharged to the new percolation ponds has elevated concentrations of chloride, sodium, and nitrate, and possibly barium and arsenic.

## Radioactive Waste Management Complex

Perched groundwater beneath the RWMC is in sedimentary interbeds in basalts and can be attributed primarily to local snowmelt and rain infiltration, and to recharge from the Big Lost River and the INL spreading areas. This perched groundwater contains constituents leached from buried radioactive and organic-chemical wastes. Liquid and solid waste materials buried at the RWMC (fig. 1) also are sources of some constituents in perched groundwater. Perched groundwater beneath buried waste can be an integral part of the pathway for waste-constituent migration to the ESRP aquifer. The extent of this perched groundwater is affected by the waste-disposal practices.

Well USGS 92 (fig. 4) is in the SDA at the RWMC and is completed in a sedimentary interbed (Anderson and Lewis, 1989, p. 29) at 214 ft BLS. Perched groundwater in this well has moved through overlying sediments and basalt and may contain waste constituents leached from radiochemical and organic-chemical wastes buried in the SDA.

During 2009–11, tritium concentrations in water samples from well USGS 92 (table 12) exceeded the reporting level and ranged from  $350 \pm 70$  pCi/L in April 2009 to  $410 \pm 60$  pCi/L in April 2011. Tritium concentrations in water from well USGS 92 have varied through time.

Historically, the concentration of americium-241 in water from well USGS 92 was greater than the reporting level in October 1992 and the concentration of plutonium-238 was greater than the reporting level in November 1994 (Bartholomay, 1998). Since the 1990s, concentrations of these constituents as well as strontium-90, cesium-137, and plutonium-239, 240 (undivided) have been less than the reporting levels.

Dissolved chloride concentrations in water from two water samples collected from well USGS 92 during 2010 and 2011 were 107 and 111 mg/L, respectively (table 12). These dissolved chloride concentrations are consistent with concentrations measured historically.

In 1987, nine VOCs were detected in water from well USGS 92 (Mann and Knobel, 1987, p. 16–17). Since then, from 6 to 18 different VOCs have been detected during various reporting periods. Water from well USGS 92 was sampled for VOCs in April 2010 and April 2011. Table 13 lists the concentrations of nine VOCs detected. All of the VOCs detected in April 2010 and April 2011 had been detected in 2007, except 1,2-dichloroethane was not detected in 2007. Toluene, which was detected in 2007, was not detected in 2010–11. Additionally, all of the VOC concentrations detected in 2010–11 were substantially lower than those detected in 2007 (table 11, this report; Davis, 2010, table 10). This decrease in VOC concentration may be a result of dilution by lateral infiltration of water flowing in the Big Lost River during water years 2009–11 (table 4) or removal of VOCs from the subsurface at the SDA by vapor vacuum extraction processes conducted by the INL contractor from 1996–present (2013).

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**Table 11.** Concentrations of selected chemical and radiochemical constituents in water from well ICPP-MON-V-200, Idaho National Laboratory, Idaho, 2010–11.

[See figure 4 for well location. Analytical results in micrograms per liter unless noted otherwise. Samples collected on April 27, 2010, and April 18, 2011, were from a submersible pump. Samples were analyzed at the U.S. Geological Survey (USGS) National Water Quality Laboratory in Lakewood, Colorado, unless indicated otherwise. Uncertainty of radiochemical constituents is one sample standard deviation. Concentrations that meet or exceed the reporting level of 3 times the sample standard deviation are in **boldface** type. **Abbreviations:** RESL, Radiological and Environmental Science Laboratory;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius;  $\text{mg}/\text{L}$ , milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter;  $^{\circ}\text{C}$ , degrees Celsius;  $\text{pCi}/\text{L}$ , picocuries per liter; N, Nitrogen; P, phosphorus; E, estimated; NC, not collected; NA, not analyzed. **Symbols:** <, less than;  $\pm$ , plus or minus]

	April 27, 2010	April 18, 2011		April 27, 2010	April 18, 2011
<b>Constituent or measurement and units</b>			<b>Constituent or measurement and units—Continued</b>		
Time	1025	0915	Tritium (pCi/L) (RESL)	110 $\pm$ 60	50 $\pm$ 50
Water temperature ( $^{\circ}\text{C}$ )	17.1	17.7	Strontium-90 (pCi/L) (RESL)	-0.3 $\pm$ 0.7	<b>2.4<math>\pm</math>0.7</b>
Air Temperature ( $^{\circ}\text{C}$ )	7.5	6.5	Cesium-137 (pCi/L) (RESL)	10 $\pm$ 9	15 $\pm$ 11
pH (field)	7.52	7.69	Gross alpha (pCi/L) (RESL)	2 $\pm$ 2	NC
pH (lab)	7.91	NA	Gross beta (pCi/L) (RESL)	<b>10.2<math>\pm</math>1.3</b>	NC
Specific conductance ( $\mu\text{S}/\text{cm}$ ) (field)	790	545	Americium-241 (pCi/L) (RESL)	0.01 $\pm$ 0.014	NC
Specific conductance ( $\mu\text{S}/\text{cm}$ ) (lab)	775	NA	Plutonium-238 (pCi/L) (RESL)	-0.006 $\pm$ 0.009	NC
Dissolved oxygen (mg/L)	6.57	6.61	Plutonium-239, 240 (pCi/L) (RESL)	0.003 $\pm$ 0.006	NC
Calcium (mg/L)	49.6	NC			
Magnesium (mg/L)	13.3	NC	<b>Volatile organic compounds (<math>\mu\text{g}/\text{L}</math>)</b>		
Potassium (mg/L)	2.98	NC	Acrylonitrile	<2.5	NC
Silica (mg/L)	22.5	NC	Benzene	<0.1	NC
Sodium (mg/L)	90.7	59.2	Bromobenzene	<0.2	NC
Bromide (mg/L)	0.036	NC	Bromochloromethane	<0.2	NC
Chloride (mg/L)	133	53.2	Bromomethane	<0.4	NC
Fluoride (mg/L)	0.245	NC	CFC-11	<0.2	NC
Sulfate (mg/L)	24.2	23.7	CFC-12	<0.2	NC
Ammonia as N (mg/L)	<0.02	<0.01	CFC-113	<0.1	NC
Nitrite as N (mg/L)	<0.002	<0.001	CHBrC12	<0.1	NC
Nitrate plus nitrite as N (mg/L)	2.74	3.43	Chlorobenzene	<0.1	NC
Orthophosphate as P (mg/L)	0.102	0.102	Chloroethane	<0.2	NC
Aluminum ( $\mu\text{g}/\text{L}$ )	E2.38	NC	Chloromethane	<0.2	NC
Antimony ( $\mu\text{g}/\text{L}$ )	0.225	NC	cis-1,2-dichloroethene	<0.1	NC
Arsenic ( $\mu\text{g}/\text{L}$ )	5.88	NC	cis-1,3-dichloropropene	<0.2	NC
Barium ( $\mu\text{g}/\text{L}$ )	157	NC	Dibromochloropropane	<0.5	NC
Beryllium ( $\mu\text{g}/\text{L}$ )	<0.2	NC	Dibromochloromethane	<0.2	NC
Boron ( $\mu\text{g}/\text{L}$ )	16.3	NC	Dibromomethane	<0.2	NC
Cadmium ( $\mu\text{g}/\text{L}$ )	0.036	NC	Dichloromethane	<0.2	NC
Chromium ( $\mu\text{g}/\text{L}$ )	4.66	4.07	Ethylbenzene	<0.1	NC
Cobalt ( $\mu\text{g}/\text{L}$ )	0.438	NC	Hexachlorobutadiene	<0.2	NC
Copper ( $\mu\text{g}/\text{L}$ )	2.13	NC	Isopropylbenzene	<0.2	NC
Iron ( $\mu\text{g}/\text{L}$ )	E4.00	NC	MTBE	<0.2	NC
Lead ( $\mu\text{g}/\text{L}$ )	E0.019	NC	Naphthalene	<0.5	NC
Lithium ( $\mu\text{g}/\text{L}$ )	3.24	NC	n-butylbenzene	<0.2	NC
Manganese ( $\mu\text{g}/\text{L}$ )	0.274	NC	n-propylbenzene	<0.2	NC
Mercury ( $\mu\text{g}/\text{L}$ )	NC	NC	sec-butylbenzene	<0.2	NC
Molybdenum ( $\mu\text{g}/\text{L}$ )	2.62	NC	Styrene	<0.1	NC
Nickel ( $\mu\text{g}/\text{L}$ )	1.53	NC	tert-butylbenzene	<0.2	NC
Selenium ( $\mu\text{g}/\text{L}$ )	1.32	NC	Tetrachloroethene	<0.1	NC
Silver ( $\mu\text{g}/\text{L}$ )	<0.01	NC	Tetrachloromethane	<0.2	NC
Strontium ( $\mu\text{g}/\text{L}$ )	253	NC	Toluene	<0.1	NC
Thallium ( $\mu\text{g}/\text{L}$ )	<0.02	NC	trans-1,2-dichloroethene	<0.1	NC
Tungsten ( $\mu\text{g}/\text{L}$ )	0.204	NC	trans-1,3-dichloropropene	<0.2	NC
Uranium ( $\mu\text{g}/\text{L}$ )	2.14	NC	Tribromomethane	<0.2	NC
Vanadium ( $\mu\text{g}/\text{L}$ )	4.25	NC	Trichloroethene	<0.1	NC
Zinc ( $\mu\text{g}/\text{L}$ )	<2.8	NC	Trichloromethane	<0.1	NC
Total organic carbon (mg/L)	<0.6	NC	Vinyl chloride	<0.2	NC

**Table 11.** Concentrations of selected chemical and radiochemical constituents in water from well ICPP-MON-V-200, Idaho National Laboratory, Idaho, 2010–11.—Continued

[See [figure 4](#) for well location. Analytical results in micrograms per liter unless noted otherwise. Samples collected on April 27, 2010, and April 18, 2011 were from a submersible pump. Samples were analyzed at the U.S. Geological Survey (USGS) National Water Quality Laboratory in Lakewood, Colorado, unless indicated otherwise. Uncertainty of radiochemical constituents is one sample standard deviation. Concentrations that meet or exceed the reporting level of 3 times the sample standard deviation are in **boldface** type. **Abbreviations:** RESL, Radiological and Environmental Science Laboratory;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius;  $\text{mg}/\text{L}$ , milligrams per liter;  $\mu\text{g}/\text{L}$ , micrograms per liter;  $^{\circ}\text{C}$ , degrees Celsius;  $\text{pCi}/\text{L}$ , picocuries per liter; N, Nitrogen; P, phosphorus; E, estimated; NC, not collected; NA, not analyzed. **Symbols:** <, less than;  $\pm$ , plus or minus]

	April 27, 2010	April 18, 2011		April 27, 2010	April 18, 2011
<b>Volatile organic compounds (<math>\mu\text{g}/\text{L}</math>)—Continued</b>			<b>Volatile organic compounds (<math>\mu\text{g}/\text{L}</math>)—Continued</b>		
Xylene	<0.2	NC	1,2-dibromoethane	<0.2	NC
1,1,1-trichloroethane	<0.1	NC	1,2-dichlorobenzene	<0.1	NC
1,1,1,2-tetrachloroethane	<0.2	NC	1,2-dichloroethane	<0.2	NC
1,1,2,2-tetrachloroethane	<0.2	NC	1,2-dichloropropane	<0.1	NC
1,1,2-trichloroethane	<0.2	NC	1,3-dichlorobenzene	<0.1	NC
1,1-dichloroethane	<0.1	NC	1,3-dichloropropane	<0.2	NC
1,1-dichloroethene	<0.1	NC	1,3,5-trimethylbenzene	<0.2	NC
1,1-dichloropropene	<0.2	NC	1,4-dichlorobenzene	<0.1	NC
1,2,3-trichloropropane	<0.2	NC	2-chlorotoluene	<0.2	NC
1,2,3-trichlorobenzene	<0.2	NC	2,2-dichloropropane	<0.2	NC
1,2,4-trichlorobenzene	<0.2	NC	4-chlorotoluene	<0.2	NC
1,2,4-trimethylbenzene	<0.2	NC	4-isopropyltoluene	<0.2	NC
1,2-Dibromo-3-chloropropane (DBCP)	<0.5	NC			

**Table 12.** Concentrations of tritium, strontium-90, cesium-137, selected transuranic elements, and dissolved chloride in perched groundwater from well USGS 92, Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, 2009–11.

[**Well No.:** Location of well is shown in [figure 7](#). Analyses completed by the Department of Energy's Radiological and Environmental Sciences Laboratory and the USGS National Water Quality Laboratory. Analyses for radionuclides, analytical uncertainties are reported as 1 times the sample standard deviation. Concentrations equal to or greater than 3 times the sample standard deviation are considered to be greater than the reporting level and are **bold**. **Abbreviations:** USGS, U.S. Geological Survey;  $\text{pCi}/\text{L}$ , picocurie per liter;  $\text{mg}/\text{L}$ , milligram per liter. NR, analysis not requested because of inadequate amount of water to sample. **Symbol:**  $\pm$ , plus or minus]

Well No.	Date sampled	Tritium ( $\text{pCi}/\text{L}$ )	Strontium-90 ( $\text{pCi}/\text{L}$ )	Cesium-137 ( $\text{pCi}/\text{L}$ )	Plutonium-238 ( $\text{pCi}/\text{L}$ )	Plutonium-239, 240 (undivided) ( $\text{pCi}/\text{L}$ )	Americium-241 ( $\text{pCi}/\text{L}$ )	Chloride (dissolved) ( $\text{mg}/\text{L}$ )
USGS 92	04-16-09	<b>350<math>\pm</math>70</b>	1.5 $\pm$ 0.7	60 $\pm$ 20	-0.006 $\pm$ 0.004	0.003 $\pm$ 0.007	-0.004 $\pm$ 0.014	NR
	04-08-10	<b>390<math>\pm</math>70</b>	1.7 $\pm$ 0.8	16 $\pm$ 19	0.01 $\pm$ 0.02	-0.005 $\pm$ 0.008	0.01 $\pm$ 0.02	107
	04-14-11	<b>410<math>\pm</math>60</b>	1.5 $\pm$ 0.7	30 $\pm$ 20	-0.011 $\pm$ 0.013	0.005 $\pm$ 0.012	0.01 $\pm$ 0.02	111

**Table 13.** Concentrations of selected volatile organic compounds in perched groundwater from well USGS 92, Radioactive Waste Management Complex, Idaho National Laboratory, Idaho, 2010–11.

[Location of well shown in [figure 7](#). Analyses completed by the U.S. Geological Survey's National Water Quality Laboratory using an analytical method that conforms to U.S. Environmental Protection Agency Method 524.2 (1995). Names in parentheses are alternate compound names. **Abbreviations:** NWIS, U.S. Geological Survey National Water Information System; µg/L, micrograms per liter]

Volatile organic compound name	NWIS parameter code	April 8, 2010	April 14, 2011
		Concentration (µg/L)	
1,2-Dichloroethane	32103	0.3	0.3
Carbon Tetrachloride (Tetrachloromethane)	32102	16.6	19.1
Chloroform (Trichloromethane)	32106	36.2	40.7
Tetrachloroethylene (Tetrachloroethene)	34475	4.4	3.4
1,1-dichloroethane	34496	0.5	0.4
1,1-dichloroethylene (1,1-dichloroethene)	34501	0.1	0.2
1,1,1-trichloroethane	34506	2.9	2.2
1,2-dichloropropane	34541	0.5	0.4
Trichloroethylene (Trichloroethene)	39180	21.3	23.9

## Summary

Radiochemical and chemical wastewater discharged since 1952 to infiltration ponds and disposal wells at the Idaho National Laboratory (INL) has affected water quality in the eastern Snake River Plain (ESRP) aquifer and in perched groundwater zones at the INL. The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy, maintains aquifer and perched groundwater monitoring networks at the INL to determine hydrologic trends and to delineate the movement of radiochemical and chemical wastes in the ESRP aquifer and in perched groundwater zones.

Water in the ESRP aquifer primarily moves through fractures and interflow zones in basalt, generally flows southwestward, and eventually discharges at springs along the Snake River near Twin Falls, Idaho, about 100 miles southwest of the INL. Estimated discharge from the springs was about 3.13 million acre-feet per year for water year 2011. The aquifer is recharged primarily from infiltration of irrigation water, infiltration of streamflow, groundwater inflow from adjoining mountain drainage basins, and infiltration of precipitation.

During March–May 2011, the altitude of the water table was about 4,560 feet (ft) in the northern part of the INL and about 4,410 ft in the southwestern part. Water flowed south and southwestward beneath the INL at an average hydraulic gradient of about 4 feet per mile.

Water levels in wells generally declined 0.1–1.8 ft in the northern part of the INL from March–May 2009 to March–May 2011. In the central and eastern part of the INL, water levels generally rose from about 0.1 to 1.1 ft during the March–May 2009 to March–May 2011 reporting period. In the

southwestern part of the INL, water levels generally rose or declined by approximately 1 ft during the March–May 2009 to March–May 2011 reporting period. However, water in well USGS 86 rose about 2.5 ft.

Disposal of wastewater to infiltration ponds and infiltration of surface water at the Advanced Test Reactor Complex (ATR Complex) and Idaho Nuclear Technology and Engineering Center (INTEC) resulted in formation of perched groundwater in basalts and in sedimentary interbeds that overlie the ESRP aquifer. Perched groundwater beneath the Radioactive Waste Management Complex (RWMC) formed from infiltration of snowmelt and rain and recharge from the Big Lost River and INL spreading areas. This perched groundwater contains constituents leached from buried radioactive and organic-chemical wastes. Perched groundwater is an integral part of the pathway for waste-constituent migration to the aquifer.

During 2005–10, nine wells were equipped with multilevel monitoring system (MLMS) that allow water samples and pressure and temperature measurements to be acquired at isolated depths in each of the wells. This multilevel monitoring helps to describe the vertical distribution of water chemistry and pressure and temperature gradients in addition to the horizontal distribution information previously gathered from open boreholes.

A tritium plume developed in the ESRP aquifer from discharge of wastewater at the INL since the 1950s. Concentrations of tritium in water samples collected in 2011 from 50 of 127 aquifer wells were greater than the reporting level and ranged from 200±60 to 7,000±260 picocuries per liter (pCi/L). The tritium plume extended south-southwestward in the general direction of groundwater flow. In 2011,

concentrations of tritium in water samples generally decreased from the 2006–08 reporting period and all concentrations were less than the maximum contaminant level (MCL) of 20,000 pCi/L.

Water from various depths in all nine wells equipped with the MLMS was sampled and analyzed for tritium during 2009–11. Tritium concentrations in the uppermost sampling zone of well USGS 105 were less than the reporting level during 2009–10, but exceeded the reporting level in all lower zones during at least one sampling event from 2009–11. Water sampled from well USGS 103 had concentrations less than the reporting level in the upper three zones in 2009–10, but did show concentrations greater than the reporting level in four deeper levels of the aquifer. Well USGS 108 was equipped with a MLMS in 2010. One zone sampled in 2010 had a concentration greater than the reporting level, but all samples analyzed in 2011 showed tritium concentrations less than the reporting level in all zones. Water from wells USGS 133 and 135 had concentrations of tritium that did not exceed the reporting level in any of the zones sampled. Other results showed that water from one or more zones in wells USGS 132, 134, Middle 2050A, and Middle 2051 contained concentrations of tritium greater than the reporting level during 2009–11. The tritium concentrations that were greater than the reporting levels are attributed to wastewater disposal at INTEC and ATR Complex.

Wells CWP 1, 3, and 8 were used to monitor shallow perched groundwater around the cold-waste ponds at the ATR Complex. During 2009–11, tritium concentrations in water samples collected from these wells were less than the reporting level. Tritium concentrations in water from 12 wells completed in deep perched groundwater near the ATR Complex generally were greater than or equal to the reporting level during at least one sampling event during 2009–11.

During 2011, water from 76 aquifer wells was sampled for strontium-90 throughout the INL. Concentrations of strontium-90 in water from 20 aquifer wells exceeded the reporting level. Concentrations that exceeded the reporting level in the aquifer wells ranged from  $2.9 \pm 0.7$  to  $18.7 \pm 0.9$  pCi/L. The area of the strontium-90 plume near the INTEC extended south-southwestward in the general direction of groundwater flow. Strontium-90 has not been detected in the ESRP aquifer beneath the ATR Complex partly because of the exclusive use of waste-disposal ponds and lined evaporation ponds rather than the disposal well for radioactive-wastewater disposal at that facility. Sorption processes in sediments in the unsaturated zone beneath the radioactive waste-disposal pond could have minimized or prevented strontium-90 migration to the aquifer at the ATR Complex. MLMS equipped wells USGS 105, 108, and 135 near the southern boundary of the INL were sampled for strontium-90 during 2009–11. None of the water from any zones sampled contained concentrations of strontium-90 greater than the reporting level.

Three wells completed in shallow perched groundwater at the ATR Complex were sampled for strontium-90 during 2009–11. During 2009–11, concentrations of strontium-90 in one sample each from two of the wells were greater than the reporting level.

During at least one sampling event in the period 2009–11, concentrations of strontium-90 in water from 10 wells completed in deep perched groundwater at the ATR Complex were greater than or equal to the reporting level. Concentrations equal to or greater than the reporting level ranged from  $2.1 \pm 0.7$  pCi/L to  $65.5 \pm 1.8$  pCi/L. The distribution of strontium-90 concentrations in perched groundwater from these wells during 2009–11 is attributed to exchange reactions between strontium-90 in solution and to sediments beneath the radioactive-waste infiltration ponds.

During 2009–11, water from 72 aquifer wells was sampled and analyzed for cesium-137. Water from eight of these wells had cesium-137 concentrations that equaled or slightly exceeded the reporting level. Concentrations of cesium-137 that exceeded the reporting level ranged from  $22 \pm 7$  pCi/L to  $60 \pm 20$  pCi/L. Concentrations of cesium-137 also equaled or slightly exceeded the reporting level in two wells equipped with MLMS. During 2009–11, concentrations of plutonium-238 and plutonium-239, -240 (undivided) in water from all 23 aquifer wells and all zones in 3 wells equipped with MLMS (USGS 105, 108, and 135) were less than the reporting level.

Gross alpha and beta measurements are used to screen for radioactivity in the aquifer as a possible indicator of groundwater contamination. During 2009–11, water from 52 aquifer wells was sampled and analyzed for gross alpha-particle radioactivity. In 2009, concentrations of gross alpha-particle radioactivity greater than or equal to the reporting level were detected in 13 wells. Also in 2009, water from five wells equipped with MLMS had concentrations of gross alpha-particle radioactivity equal to or greater than the reporting level. This likely is a result of RESL increasing the sensitivity and changing the radionuclide reported for gross alpha-particle radioactivity from plutonium-239 to thorium-230 in 2008. During 2010–11, water from all wells sampled and analyzed for concentrations of gross alpha-particle radioactivity was less than the reporting level.

During 2009, concentrations of gross beta-particle radioactivity in water from 37 wells exceeded the reporting level; in 2010, concentrations exceeded the reporting level in water from 43 wells; in 2011, concentrations exceeded the reporting level in water from 16 wells. All nine wells equipped with MLMS had gross beta-particle radioactivity concentrations greater than the reporting level in multiple zones during 2009–11.

In April 2009 and 2011, water from one well, south of ATR Complex, had chromium concentrations of 100 and 97  $\mu\text{g/L}$ , respectively, near the MCL of 100  $\mu\text{g/L}$  for total

chromium in drinking water. Concentrations in water samples from 69 other wells sampled ranged from 0.8 to 25 µg/L.

During 2009–11, three shallow perched groundwater wells (CWP 1, 3, and 8) were sampled for dissolved chromium. Chromium was detected in well CWP 1 in April of each year with a concentration of 3 µg/L. Chromium was also detected in well CWP 3 in April 2009 with a concentration of 2 µg/L.

Dissolved chromium was detected in water from 14 wells completed in deep perched groundwater at the ATR Complex during 2009–11. The highest concentrations were in water from wells north and west of the radioactive-waste infiltration ponds. The maximum concentration of chromium in well USGS 56 decreased from 125 µg/L in October 2006 to 43 µg/L in October 2011.

During 2011, the highest sodium concentration in water samples from aquifer wells near the INTEC was 35 mg/L in a water sample from well USGS 77. Concentrations of sodium in water from other wells south of the INTEC during 2009–11 generally were less than or equal to sodium concentrations detected during 2006–08. After the new percolation ponds were put into service in 2002 southwest of the INTEC, concentrations of sodium in water samples from the Rifle Range well rose steadily until 2008, when the concentrations generally began decreasing. Sodium concentrations in most MLMS-equipped wells generally were consistent with depth.

During 2011, dissolved sodium concentrations in water from 17 wells completed in deep perched groundwater ranged from 6 to 146 mg/L. The highest concentration was in water from well USGS 68; the sodium concentration in well USGS 68 decreased from 476 mg/L in April 2008, and is attributed to discontinued disposal in the former chemical-waste ponds.

In 2011, concentrations of chloride in most water samples from aquifer wells closest to the INTEC and the CFA exceeded background concentrations. Trends in chloride concentrations in water from wells downgradient from the old percolation ponds at the INTEC correlated with discharge rates into the ponds when travel time was considered. After the new percolation ponds were put into service in 2002 southwest of the INTEC, concentrations of chloride rose steadily in water samples from the Rifle Range well until 2008, when the concentrations began decreasing. The vertical distribution of chloride concentrations in wells equipped with MLMS was generally consistent between zones during 2009–11.

During April 2011, dissolved chloride concentrations in shallow perched groundwater ranged from 7 mg/L in well CWP 8 to 12 mg/L and 13 mg/L in wells CWP 1 and 3, respectively. Dissolved chloride concentrations in deep perched groundwater during April or October 2011 ranged from 4 to 54 mg/L. Higher concentrations of chloride in water from wells in the western part of the perched groundwater zone at the ATR Complex may be a result of movement of remnant water through the unsaturated zone from the chemical-waste pond which was closed in 1999.

Sulfate in wastewater has been discharged to percolation (infiltration) ponds at the INTEC, ATR Complex, and to the NRF industrial-waste ditch. In 2011, sulfate concentrations in water samples from 11 wells in the south-central part of the INL equaled or exceeded the 40 mg/L 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.

In 2011, sulfate concentration in water samples from a well near the RWMC was 47 mg/L and was similar to concentrations in October 2008. The greater-than-background sulfate concentration in water from this well could have resulted from the well construction techniques and (or) waste disposal at the RWMC.

Three wells near the southern boundary of the INL that were equipped with MLMS were sampled for sulfate during 2009–11. The vertical distribution of sulfate in these wells (USGS 105, 108, and 135) was generally consistent with depth in all three wells, and ranged between 19 and 25 mg/L.

The maximum dissolved sulfate concentration in shallow perched groundwater at the ATR Complex was 400 mg/L in well CWP 1 in April 2009. Concentrations of dissolved sulfate in this well vary greatly. The variable concentrations are probably a result of changes in the amount of sulfate disposal to the cold-waste ponds. Concentrations of dissolved sulfate in water from wells completed in deep perched groundwater at the ATR Complex near the cold-waste ponds ranged from 68 to 181 mg/L during April–October 2011. These high concentrations indicate that water in the wells also was affected by discharge into the cold-waste ponds. During 2009–11, the maximum concentration of dissolved sulfate in deep perched groundwater was 1,550 mg/L in well USGS 68, west of the chemical-waste pond and is attributed to past wastewater disposal to the pond.

Concentrations of nitrate (as nitrogen) in groundwater not affected by wastewater disposal from INL facilities generally are less than the regional background of 1 mg/L. In 2011, concentrations of nitrate in water from most wells at and near the INTEC exceeded the background concentration of 1 mg/L. Concentrations ranged from 1.6 mg/L in well USGS 41 to 5.95 mg/L in well USGS 40.

Historically, nitrate concentrations in water from wells near the RWMC have slightly exceeded the regional background concentration of about 1 mg/L. Since 1998, the concentrations of nitrate in water from wells USGS 89 and 119 remained relatively unchanged, with concentrations in 2011 of 1.6 and 1.3 mg/L, respectively.

In 2008, near the ATR Complex, the concentration of nitrate in water from well USGS 65 was 1.5 mg/L, and remained constant in 2011 with a concentration of 1.5 mg/L. All concentrations measured in 2011 were less than the MCL for drinking water of 10 mg/L.

During 2011, water samples from five wells were analyzed for fluoride; detected concentrations ranged from 0.2 to 0.3 mg/L. These concentrations were within the range of background concentrations of fluoride in the ESRP aquifer for the southwestern part of the INL, which indicates that wastewater disposal has not had an appreciable effect on fluoride concentrations in the ESRP aquifer near the INTEC.

Six volatile organic compounds (VOCs) were detected in water samples from 30 wells analyzed for VOCs during 2009–11. Water samples from 10 wells each contained at least one and up to five VOCs. The primary VOCs detected included carbon tetrachloride, chloroform, tetrachloroethylene, 1,1,1-trichloroethane, and trichloroethylene. The concentration of carbon tetrachloride was greater than the MCL for drinking water of 5 µg/L in two wells near RWMC in 2011. Carbon tetrachloride concentrations in water from the RWMC Production Well and well USGS 87 have increased with time since 1987.

Nine VOCs were detected in water from well USGS 92 near the RWMC in 2010 and 2011. All of the VOC concentrations detected were substantially lower than those detected in 2007. This decrease in VOC concentration may be a result of dilution by lateral infiltration of water flowing in the Big Lost River during water years 2009–11 or removal of VOCs from the subsurface at the SDA by vapor vacuum extraction processes conducted by the INL contractor from 1996–present (2013).

## Acknowledgments

The Department of Energy Radiological and Environmental Sciences Laboratory (RESL) at the Idaho National Laboratory provided radiochemical analyses of water samples. Aneta Bhatt, Director, supervised technical staff at the RESL during 2009–11.

## References Cited

- Ackerman, D.J., 1991a, Transmissivity of the Snake River Plain aquifer at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 914058 (DOE/ID-22097), 35 p. (Also available at <http://pubs.er.usgs.gov/publication/wri914058>.)
- Ackerman, D. J., 1991b, Transmissivity of perched aquifers at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 91-4114 (DOE/ID-22099), 27 p., <http://pubs.usgs.gov/wri/1991/4114/>.
- Ackerman, D. J., Rattray, G.W., Rousseau, J.P., Davis, L.C., and Orr, B. R., 2006, A conceptual model of ground-water flow in the eastern Snake River Plain aquifer at the Idaho National Laboratory and vicinity with implications for contaminant transport: U.S. Geological Survey Scientific Investigations Report 2006–5122 (DOE/ID-22198), 62 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20065122>.)
- Anderson, S.R., 1991, Stratigraphy of the unsaturated zone and uppermost part of the Snake River Plain aquifer at the Idaho Chemical Processing Plant and Test Reactors Area, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 91–4010 (DOE/ID-22095), 71 p. (Also available at <http://pubs.er.usgs.gov/publication/wri914010>.)
- Anderson, S.R., Ackerman, D.J., Liszewski, M.J., and Freiburger, R.M., 1996, Stratigraphic data for wells at and near the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 96–248 (DOE/ID-22127), 27 p., 1 diskette. (Also available at <http://pubs.er.usgs.gov/publication/ofr96248>.)
- Anderson, S.R., Kuntz, M.A., and Davis, L.C., 1999, Geologic controls of hydraulic conductivity in the Snake River Plain aquifer at and near the Idaho National Engineering and Environmental Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 99–4033 (DOE/ID-22155), 38 p. (Also available at <http://pubs.er.usgs.gov/publication/wri994033>.)
- Anderson, S.R., and Lewis, B.D., 1989, Stratigraphy of the unsaturated zone at the Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 89–4065 (DOE/ID-22080), 54 p. (Also available at <http://pubs.er.usgs.gov/publication/wri894065>.)
- Barraclough, J.T., and Jensen, R.G., 1976, Hydrologic data for the Idaho National Engineering Laboratory site, Idaho, 1971 to 1973: U.S. Geological Survey Open-File Report 75–318 (IDO-22055), 52 p.
- Barraclough, J.T., Lewis, B.D., and Jensen, R.G., 1981, Hydrologic conditions at the Idaho National Engineering Laboratory, Idaho, emphasis 1974–1978: U.S. Geological Survey Water-Resources Investigations Open-File Report 81–526 (IDO-22060), 116 p.
- Barraclough, J.T., Robertson, J.B., and Janzer, V.J., 1976, Hydrology of the solid waste burial ground, as related to the potential migration of radionuclides, Idaho National Engineering Laboratory, with a section on drilling and sample analyses, by L.G. Saindon: U.S. Geological Survey Open-File Report 76–471 (IDO-22056), 183 p.

- Barraclough, J.T., Teasdale, W.E., and Jensen, R.G., 1967a, Hydrology of the National Reactor Testing Station, Idaho, 1965: U.S. Geological Survey Open-File Report (IDO-22048), 107 p.
- Barraclough, J.T., Teasdale, W.E., Robertson, J.B., and Jensen, R.G., 1967b, Hydrology of the National Reactor Testing Station, Idaho, 1966: U.S. Geological Survey Open-File Report 67–12 (IDO-22049), 95 p.
- Bartholomay, R.C., 1993, Concentrations of tritium and strontium-90 in water from selected wells at the Idaho National Engineering Laboratory after purging one, two, and three borehole volumes: U.S. Geological Survey Water-Resources Investigations Report 93–4201 (DOE/ID-22111), 21 p. (Also available at <http://pubs.er.usgs.gov/publication/wri934201>.)
- Bartholomay, R.C., 1998, Distribution of selected radiochemical and chemical constituents in water from perched ground-water zones, Idaho National Engineering Laboratory, Idaho, 1992–95: U.S. Geological Survey Water-Resources Investigations Report 98–4026 (DOE/ID-22145), 59 p. (Also available at <http://pubs.er.usgs.gov/publication/wri984026>.)
- Bartholomay, R.C., Davis, Linda C., Fisher, Jason C., Tucker, Betty J., Raben, Flint A., 2012, Water-quality characteristics and trends for selected sites at and near the Idaho National Laboratory, Idaho, 1949–2009: U.S. Geological Survey Scientific Investigations Report 2012–5169 (DOE/ID-22219), 68 p. (Also available at <http://pubs.usgs.gov/sir/2012/5169/>.)
- Bartholomay, R.C., Hill, G.H., and Randolph, R.B., 1999, Statistical comparison of gross alpha- and gross beta-particle activity in water analyzed using two different laboratory methods, in 41st Rocky Mountain Conference on Analytical Chemistry, 41st, Denver, Colo., 1999, Final program and abstracts, p. 132.
- Bartholomay, R.C., Knobel, L.L., and Rousseau, J.P., 2003, Field methods and quality assurance plan for quality-of-water activities, U.S. Geological Survey, Idaho National Engineering and Environmental Laboratory, Idaho: U.S. Geological Survey Open-File Report 2003–42 (DOE/ID-22182), 45 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr0342>.)
- Bartholomay, R.C., Knobel, L.L., Tucker, B.J., and Twining, B.V., 2001, Chemical and radiochemical constituents in water from wells in the vicinity of the Naval Reactors Facility, Idaho National Engineering and Environmental Laboratory, Idaho, 1999: U.S. Geological Survey Open-File Report 2001–27 (DOE/ID-22172), 37 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr0127>.)
- Bartholomay, R.C., Knobel, L.L., Tucker, B.J., and Twining, B.V., 2002, Chemical and radiochemical constituents in water from wells in the vicinity of the Naval Reactors Facility, Idaho National Engineering and Environmental Laboratory, Idaho, 2000: U.S. Geological Survey Open-File Report 2002–148 (DOE/ID-22178), 34 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr02148>.)
- Bartholomay, R.C., Orr, B.R., Liszewski, M.J., and Jensen, R.G., 1995, Hydrologic conditions and distribution of selected radiochemical and chemical constituents in water, Snake River Plain aquifer, Idaho National Engineering Laboratory, Idaho, 1989 through 1991: U.S. Geological Survey Water-Resources Investigations Report 95–4175 (DOE/ID-22123), 47 p.
- Bartholomay, R.C., and Tucker, B.J., 2000, Distribution of selected radiochemical and chemical constituents in perched ground water, Idaho National Engineering and Environmental Laboratory, Idaho, 1996–98: U.S. Geological Survey Water-Resources Investigations Report 00–4222 (DOE/ID-22168), 51 p. (Also available at <http://pubs.er.usgs.gov/publication/wri004222>.)
- Bartholomay, R.C., Tucker, B.J., Ackerman, D.J., and Liszewski, M.J., 1997, Hydrologic conditions and distribution of selected radiochemical and chemical constituents in water, Snake River Plain aquifer, Idaho National Engineering Laboratory, Idaho, 1992 through 1995: U.S. Geological Survey Water-Resources Investigations Report 97–4086 (DOE/ID-22137), 57 p. (Also available at <http://pubs.er.usgs.gov/publication/wri974086>.)
- Bartholomay, R.C., Tucker, B.J., Davis, L.C., and Green, M.R., 2000, Hydrologic conditions and distribution of selected constituents in water, Snake River Plain aquifer, Idaho National Engineering and Environmental Laboratory, Idaho, 1996 through 1998: U.S. Geological Survey Water-Resources Investigations Report 00–4192 (DOE/ID-22167), 52 p. (Also available at <http://pubs.er.usgs.gov/publication/wri004192>.)
- Bartholomay, R.C., and Twining, B.V., 2010, Chemical constituents in groundwater from multiple zones in the eastern Snake River Plain aquifer at the Idaho National Laboratory, Idaho: U.S. Geological Survey Scientific Investigations Report 2010–5116 (DOE/ID-22211), 81 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20105116>.)
- Bartholomay, R.C., and Williams, L.M., 1996, Evaluation of preservation methods for selected nutrients in ground water at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 96–4260 (DOE/ID-22131), 16 p. (Also available at <http://pubs.er.usgs.gov/publication/wri964260>.)

- Bennett, C.M., 1990, Streamflow losses and ground-water level changes along the Big Lost River at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 90-4067 (DOE/ID-22091), 49 p. (Also available at <http://pubs.er.usgs.gov/publication/wri904067>.)
- Bodnar, L.Z., and Percival, D.R., eds., 1982, Analytical Chemistry Branch procedures manual—Radiological and Environmental Sciences Laboratory: U.S. Department of Energy Report IDO-12096 [variously pagged].
- Cahn, L.S., Abbott, M.L., Keck, J.F., Martian, Peter, Schafer, A.L., and Swenson, M.C., 2006, Operable Unit 3-14 Tank Farm soil and groundwater remedial investigation/baseline risk assessment: U.S. Department of Energy, Idaho Operations Office, DOE/NE-ID-11227 [variously pagged].
- Cassidy, G.B., 1984, Idaho National Engineering Laboratory industrial waste management information for 1983 and record-to-date: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication DOE/ID-10057 (83), 99 p.
- Cecil, L.D., Knobel, L.L., Wegner, S.J., and Moore, L.L., 1989, Evaluation of field sampling and preservation methods for strontium-90 in ground water at the Idaho National Engineering Laboratory: U.S. Geological Survey Water-Resources Investigations Report 89-4146 (DOE/ID-22083), 24 p. (Also available at <http://pubs.er.usgs.gov/publication/wri894146>.)
- Cecil, L.D., Orr, B.R., Norton, Teddy, and Anderson, S.R., 1991, Formation of perched ground-water zones and concentrations of selected chemical constituents in water, Idaho National Engineering Laboratory, Idaho, 1986-88: U.S. Geological Survey Water-Resources Investigations Report 91-4166 (DOE/ID-22100), 53 p. (Also available at <http://pubs.er.usgs.gov/publication/wri914166>.)
- Childress, C.J.O., Forman, W.T., Connor, B.F., and Maloney, T.J., 1999, New reporting procedures based on long-term method detection levels and some considerations for interpretations of water-quality data provided by the U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 99-193, 19 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr99193>.)
- Claassen, H.C., 1982, Guidelines and techniques for obtaining water samples that accurately represent the water chemistry of an aquifer: U.S. Geological Survey Open-File Report 82-1024, 49 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr821024>.)
- Currie, L.A., 1984, Lower limit of detection-definition and elaboration of a proposed position for radiological effluent and environmental measurements: U.S. Nuclear Regulatory Commission NUREG/CR-4007, 139 p.
- Davis, L.C., 2006a, An update of the distribution of selected radiochemical and chemical constituents in perched ground water, Idaho National Laboratory, Idaho, emphasis 1999-2001: U.S. Geological Survey Scientific Investigations Report 2006-5236 (DOE/ID-22199), 48 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20065236>.)
- Davis, L.C., 2006b, An update of hydrologic conditions and distribution of selected constituents in water, Snake River Plain aquifer, emphasis 1999-2001: U.S. Geological Survey Scientific Investigations Report 2006-5088 (DOE/ID-22197), 48 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20065088>.)
- Davis, L.C., 2008, An update of hydrologic conditions and distribution of selected constituents in water, Snake River Plain aquifer and perched-water zones, emphasis 2002-05: U.S. Geological Survey Scientific Investigations Report 2008-5089 (DOE/ID-22203), 74 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20085089>.)
- Davis, L.C., 2010, 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: U.S. Geological Survey Scientific Investigations Report 2010-5197 (DOE/ID-22212), 80 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20105197>.)
- Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determinations of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92-634, 28 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr92634>.)
- Fisher, J.C., and Twining, B.V., 2011, Multilevel groundwater monitoring of hydraulic head and temperature in the eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, 2007-08: U.S. Geological Survey Scientific Investigations Report 2010-5253 (DOE/ID-22213), 62 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20105253>.)
- Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr93125>.)
- Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p. (Also available at <http://pubs.er.usgs.gov/publication/twri05A1>.)

- French, D.L., Tallman, R.E., and Taylor, K.A., 1999a, Idaho National Engineering and Environmental Laboratory nonradiological waste management information for 1998 and record-to-date: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10057 (98) [variously paged].
- French, D.L., Tallman, R.E., and Taylor, K.A., 1999b, Radioactive waste management information for 1998 and record-to-date: U.S. Department of Energy, Waste Management Programs Division, Idaho Operations Office Publication, DOE/ID-10054 (98) [variously paged].
- Goerlitz, D.F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 40 p. (Also available at [http://pubs.er.usgs.gov/publication/twri05A3\\_1972](http://pubs.er.usgs.gov/publication/twri05A3_1972).)
- Greene, M.J., and Tucker, B.J., 1998, Purgeable organic compounds in water at or near the Idaho National Engineering Laboratory, Idaho, 1992–95: U.S. Geological Survey Open-File Report 98–51 (DOE/ID-22146), 21 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr9851>.)
- Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.
- Holdren, K.J., Becker, B.H., Hampton, N.L., Koeppen, L.D., Magnuson, S.O., Meyer, T.J., Olson, G.L., and Sondrup, A.J., 2002, Ancillary basis for risk analysis of the Subsurface Disposal Area: Idaho National Engineering and Environmental Laboratory, U.S. Department of Energy, Idaho Operations Office, INEEL/EXT-02-01125 [variously paged].
- Hull, L.C., 1989, Conceptual model and description of the affected environment for the TRA warm waste pond (Waste Management Unit TRA-03): EG&G Idaho Informal Report EGG-ER-8644, 125 p.
- Jones, P.H., 1961, Hydrology of waste disposal, National Reactor Testing Station, Idaho, an interim report: U.S. Atomic Energy Commission, Idaho Operations Office Publication IDO-22042-USGS, 152 p.
- Kjelstrom, L.C., 1995, Methods to estimate annual mean spring discharge to the Snake River between Milner Dam and King Hill, Idaho: U.S. Geological Survey Water-Resources Investigations Report 95–4055, 9 p. (Also available at <http://pubs.er.usgs.gov/publication/wri954055>.)
- Knobel, L.L., 2006, 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: U.S. Geological Survey Scientific Investigations Report 2006–5232 (DOE/ID-22200), 52 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20065232>.)
- Knobel, L.L., Bartholomay, R.C., Tucker, B.J., Williams, L.M., and Cecil, L.D., 1999, Chemical constituents in ground water from 39 selected sites with an evaluation of quality assurance data, Idaho National Engineering and Environmental Laboratory and vicinity, Idaho: U.S. Geological Survey Open-File Report 99–246 (DOE/ID-22159), 58 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr99246>.)
- Knobel, L.L., and Mann, L.J., 1993, Sampling for purgeable organic compounds using positive-displacement piston and centrifugal submersible pumps—A comparative study: Ground Water Monitoring Review, Spring 1993, p. 142–148.
- Knobel, L.L., Orr, B.R., and Cecil, L.D., 1992, Summary of background concentrations of selected radiochemical and chemical constituents in groundwater from the Snake River Plain aquifer, Idaho—Estimated from an analysis of previously published data: Journal of the Idaho Academy of Science, v. 28, no. 1, p. 48–61.
- Knobel, L.L., Tucker, B.J., and Rousseau, J.P., 2008, Field methods and quality-assurance plan for quality-of-water activities, U.S. Geological Survey, Idaho National Laboratory, Idaho: U.S. Geological Survey Open-File Report 2008–1165 (DOE/ID-22206), 36 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr20081165>.)
- Lewis, B.D., and Jensen, R.G., 1985, Hydrologic conditions at the Idaho National Engineering Laboratory, Idaho, 1979–1981 update: U.S. Geological Survey Hydrologic Investigations Atlas HA674, 2 sheets. (Also available at <http://pubs.er.usgs.gov/publication/ha674>.)
- Liszewski, M.J., and Mann, L.J., 1992, Purgeable organic compounds in ground water at the Idaho National Engineering Laboratory, Idaho, 1990 and 1991: U.S. Geological Survey Open-File Report 92–174 (DOE/ID-22104), 19 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr92174>.)
- Liszewski, M.J., Rosentreter, J.J., and Miller, K.E., 1997, Strontium distribution coefficients of surficial sediment samples from the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigative Report 97–4044 (DOE/ID-22140), 33 p. (Also available at <http://pubs.er.usgs.gov/publication/wri974044>.)

- Liszewski, M.J., Rosentreter, J.J., Miller, K.E., and Bartholomay, R.C., 1998, Strontium distribution coefficients of surficial and sedimentary interbed samples from the Idaho National Engineering and Environmental Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigative Report 98-4073 (DOE/ID-22149), 55 p. (Also available at <http://pubs.er.usgs.gov/publication/wri984073>.)
- Mann, L.J., 1986, Hydraulic properties of rock units and chemical quality of water for INEL-1—A 10,365-foot deep test hole drilled at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 86-4020 (DOE/ID-22070), 23 p. (Also available at <http://pubs.er.usgs.gov/publication/wri864020>.)
- Mann, L.J., 1990, Purgeable organic compounds in ground water at the Idaho National Engineering Laboratory, Idaho—1988 and 1989: U.S. Geological Survey Open-File Report 90-367 (DOE/ID-22089), 17 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr90367>.)
- Mann, L.J., 1996, Quality-assurance plan and field methods for quality-of-water activities, U.S. Geological Survey, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 96-615 (DOE/ID-22132), 37 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr96615>.)
- Mann, L.J., and Cecil, L.D., 1990, Tritium in ground water at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 90-4090 (DOE/ID-22090), 35 p. (Also available at <http://pubs.er.usgs.gov/publication/wri904090>.)
- Mann, L.J., and Knobel, L.L., 1987, Purgeable organic compounds in ground water at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 87-766 (DOE/ID-22074), 23 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr87766>.)
- Mirus, B.B., Perkins, K.S., and Nimmo, J.R., 2011, Assessing controls on perched saturated zones beneath the Idaho Nuclear Technology and Engineering Center, Idaho: U.S. Geological Survey Scientific Investigations Report 2011-5222, (DOE/ID-22216), 20 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20115222>.)
- Morris, D.A., Barraclough, J.T., Chase, G.H., Teasdale, W.E., and Jensen, R.G., 1965, Hydrology of subsurface waste disposal, National Reactor Testing Station, Idaho, annual progress report, 1964: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22047-USGS, 186 p.
- Morris, D.A., Barraclough, J.T., Hogenson, G.M., Shuter, Eugene, Teasdale, W.E., Ralston, D.A., and Jensen, R.G., 1964, Hydrology of subsurface waste disposal, National Reactor Testing Station, Idaho, annual progress report, 1963: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22046-USGS, 97 p.
- Morris, D.A., Hogenson, G.M., Shuter, Eugene, and Teasdale, W.E., 1963, Hydrology of waste disposal, National Reactor Testing Station, Idaho, annual progress report, 1962: U.S. Atomic Energy Commission, Idaho Operations Office Publication, IDO-22044-USGS, 99 p.
- Nace, R.L., Voegeli, P.T., Jones, J.R., and Deutsch, Morris, 1975, Generalized geologic framework of the National Reactor Testing Station, Idaho: U.S. Geological Survey Professional Paper 725-B, 48 p. (Also available at <http://pubs.er.usgs.gov/publication/pp725B>.)
- North Wind, Inc., 2006, Drilling, coring, and installation of two deep monitoring wells (Middle 2051 and Middle 2050A) in fiscal year 2005: Prepared under subcontract No. 00026016 for the U.S. Department of Energy, Rpt-178, revision 0 [variously paged].
- Olmsted, F.H., 1962, Chemical and physical character of ground water in the National Reactor Testing Station, Idaho: U.S. Atomic Energy Commission, Idaho Operations Office Publication IDO-22043-USGS, 142 p.
- Orr, B.R., 1999, A transient numerical simulation of perched ground-water flow at the Test Reactor Area, Idaho National Engineering and Environmental Laboratory, Idaho, 1952-94: U.S. Geological Survey Water-Resources Investigations Report 99-4277 (DOE/ID-22162), 54 p. (Also available at <http://pubs.er.usgs.gov/publication/wri994277>.)
- Orr, B.R., and Cecil, L.D., 1991, Hydrologic conditions and distribution of selected chemical constituents in water, Snake River Plain aquifer, Idaho National Engineering Laboratory, Idaho, 1986 to 1988: U.S. Geological Survey Water-Resources Investigations Report 91-4047 (DOE/ID-22096), 56 p. (Also available at <http://pubs.er.usgs.gov/publication/wri914047>.)
- Orr, B.R., Cecil, L.D., and Knobel, L.L., 1991, Background concentrations of selected radionuclides, organic compounds, and chemical constituents in ground water in the vicinity of the Idaho National Engineering Laboratory: U.S. Geological Survey Water-Resources Investigations Report 91-4015 (DOE/ID-22094), 52 p. (Also available at <http://pubs.er.usgs.gov/publication/wri914015>.)

- Pace, M.N., Rosentreter, J.J., and Bartholomay, R.C., 1999, Strontium distribution coefficients of basalt and sediment infill samples from the Idaho National Engineering and Environmental Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 99–4145 (DOE/ID-22158), 56 p. (Also available at <http://pubs.er.usgs.gov/publication/wri994145>.)
- Perkins, K.S., and Winfield, K.A., 2007, Property-transfer modeling to estimate unsaturated hydraulic conductivity of deep sediments at the Idaho National Laboratory, Idaho: U.S. Geological Survey Scientific Investigations Report 2007–5093 (DOE/ID-22202), 22 p.
- Pittman, J.R., Jensen, R.G., and Fischer, P.R., 1988, Hydrologic conditions at the Idaho National Engineering Laboratory, 1982 to 1985: U.S. Geological Survey Water-Resources Investigations Report 89–4008 (DOE/ID-22078), 73 p. (Also available at <http://pubs.er.usgs.gov/publication/wri894008>.)
- Pritt, J.W., 1989, Quality assurance of sample containers and preservatives at the U.S. Geological Survey National Water Quality Laboratory, in Pederson, G.L., and Smith, M.M., compilers, U.S. Geological Survey second national symposium on water quality—abstracts of the technical sessions: U.S. Geological Survey Open-File Report 89–409, 111 p. (Also available at <http://pubs.er.usgs.gov/publication/ofr89409>.)
- Rattray, G.W., 2012, 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: U.S. Geological Survey Scientific Investigations Report 2012–5270, (DOE/ID-22222), 74 p. (Also available at <http://pubs.er.usgs.gov/publication/sir20125270>.)
- Robertson, J.B., 1977, Numerical modeling of subsurface radioactive solute transport from waste- seepage ponds at the Idaho National Engineering Laboratory: U.S. Geological Survey Open File Report 76–717 (IDO-22057), 68 p.
- Robertson, J.B., Schoen, Robert, and Barraclough, J.T., 1974, The influence of liquid waste disposal on the geochemistry of water at the National Reactor Testing Station, Idaho, 1952–1970: U.S. Geological Survey Open-File Report 73–238 (IDO-22053), 231 p.
- Sehlke, Gerald, and Bickford, F.E., 1993, Idaho National Engineering Laboratory ground-water monitoring plan: EG&G Idaho, Inc., and Golder Associates, Inc., DOE/ID-10441, v. 1–2 [variously paged].
- Stevens, H.H., Jr., Ficke, J.F., and Smoot, G.F., 1975, Water temperature—Influential factors, field measurement, and data presentation: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D1, 65 p. (Also available at <http://pubs.er.usgs.gov/publication/twri01D1>.)
- S.M. Stoller Corporation, 2002a, Idaho National Engineering and Environmental Laboratory site environmental report, calendar year 1999: U.S. Department of Energy, Idaho Operations Office, DOE/ID-12082 (99) [variously paged].
- S.M. Stoller Corporation, 2002b, Idaho National Engineering and Environmental Laboratory site environmental report, calendar year 2000: U.S. Department of Energy, Idaho Operations Office, DOE/ID-12082 (00) [variously paged].
- S.M. Stoller Corporation, 2004, Idaho National Engineering and Environmental Laboratory site environmental report, calendar year 2003: U.S. Department of Energy, Idaho Operations Office, DOE/ID-12082 (03) [variously paged].
- S.M. Stoller Corporation, 2009, Idaho National Laboratory site environmental report, calendar year 2008: U.S. Department of Energy, Idaho Operations Office, DOE/ID-12082 (08) [variously paged].
- Timme, P.J., 1995, National Water Quality Laboratory, 1995 services catalog: U.S. Geological Survey Open-File Report 95–352, 120 p.
- Tucker, B.J., and Orr, B.R., 1998, Distribution of selected radiochemical and chemical constituents in perched ground water, Idaho National Engineering Laboratory, Idaho, 1989–91: U.S. Geological Survey Water-Resources Investigations Report 98–4028 (DOE/ID-22144), 62 p. (Also available at <http://pubs.er.usgs.gov/publication/wri984028>.)
- Twining, B.V., Bartholomay, R.C., and Hodges, M.K.V., 2012, Completion summary for borehole USGS 136 near the Advanced Test Reactor Complex, Idaho National Laboratory, Idaho: U.S. Geological Survey Scientific Investigations Report 2012–5230 (DOE/ID-22220), 32 p., plus appendixes. (Also available at <http://pubs.er.usgs.gov/publication/sir20125230>.)
- Twining, B.V., and Fisher, J.C., 2012, Multilevel groundwater monitoring of hydraulic head and temperature in the eastern Snake River Plain aquifer, Idaho National Laboratory, Idaho, 2009–10: U.S. Geological Survey Scientific Investigations Report 2012–5259 (DOE/ID-22221), 44 p., plus appendixes. (Also available at <http://pubs.er.usgs.gov/publication/sir20125259>.)
- U.S. Department of Energy, 2011c, Fiscal year 2010 annual report for operable unit 3-14, tank farm soil and INTEC groundwater, DOE/ID-11442, revision 0: U.S. Department of Energy Idaho Operations Office, May 2011, [variously paged].
- U.S. Department of Energy, 2011a, Idaho National Laboratory groundwater monitoring and contingency plan update: U.S. Department of Energy, DOE/ID-11034, revision 2, [variously paged].

- U.S. Department of Energy, 2011b, Five-year review of CERCLA response actions at the Idaho National Laboratory site—Fiscal years 2005–2009, DOE/ID-11429, Rev. 0, [variously paged].
- U.S. Environmental Protection Agency, 2013, Protection of environment—Code of Federal Regulations 40, Part 141, Subpart G, National Primary Drinking Water Regulations, Maximum Contaminant Levels and Maximum Residual Disinfectant Levels: Washington, D.C., Office of the Federal Register, National Archives and Records Administration, accessed August 21, 2013, at <http://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=3a944d5fa8add9792af65c5d71a0ccc&n=40y24.0.1.1.3&r=PART&ty=HTML#40:24.0.1.1.3.7>.
- U.S. Geological Survey, 1985, National water summary, 1984—Hydrologic events, selected water-quality trends, and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, 467 p. (Also available at <http://pubs.er.usgs.gov/publication/wsp2275>.)
- U.S. Geological Survey, 2011, 1312700 Big Lost River below Mackay Reservoir, near Mackay, ID—Upper Snake Basin, Big Lost Subbasin: U.S. Geological Survey Water-Data Report, WDR-US-2011, accessed February 4, 2013, at <http://wdr.water.usgs.gov/wy2011/pdfs/13127000.2011.pdf>.
- U.S. Geological Survey, 2010, Changes to the reporting convention and to data qualification approaches for selected analyte results reported by the National Water Quality Laboratory (NWQL): Office of Water Quality Technical Memorandum 2010.07, accessed February 4, 2013, at <http://water.usgs.gov/admin/memo/QW/qw10.07.html>.
- U.S. Geological Survey, 2013b, Idaho Water Science Center, Idaho National Laboratory Project Office—Publications: U.S. Geological Survey database, accessed August 27, 2013, at <http://id.water.usgs.gov/projects/INL/pubs.html>.
- U.S. Geological Survey, 2013c, National Water Information System—Web interface, USGS water data for Idaho: U.S. Geological Survey database, accessed February 4, 2013, at <http://waterdata.usgs.gov/id/nwis/nwis>.
- U.S. Geological Survey, 2013a, USGS Publications Warehouse: U.S. Geological Survey database, accessed February 4, 2013, at <http://pubs.er.usgs.gov/>.
- Walker, F.W., Parrington, J.R., and Feiner, Frank, 1989, Nuclides and isotopes, chart of the nuclides (14th ed.): General Electric Company, Nuclear Energy Operations, 57 p.
- Wegner, S.J., 1989, Selected quality assurance data for water samples collected by the U.S. Geological Survey, Idaho National Engineering Laboratory Idaho, 1980 to 1988: U.S. Geological Survey Water-Resources Investigations Report 89–4168 (DOE/ID-22085), 91 p. (Also available at <http://pubs.er.usgs.gov/publication/wri894168>.)
- Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A3, 80 p. (Also available at <http://pubs.er.usgs.gov/publication/twri05A3>.)
- Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., 1998, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations Report, book 9, chaps. A1–A5 [variously paged]. (Also available at <http://water.usgs.gov/owq/FieldManual/>.)
- Williams, L.M., 1996, Evaluation of quality assurance/quality control data collected by the U.S. Geological Survey for water-quality activities at the Idaho National Engineering Laboratory, Idaho, 1989 through 1993: U.S. Geological Survey Water-Resources Investigations Report 96–4148 (DOE/ID-22129), 116 p. (Also available at <http://pubs.er.usgs.gov/publication/wri964148>.)
- Williams, L.M., 1997, Evaluation of quality assurance/quality control data collected by the U.S. Geological Survey for water-quality activities at the Idaho National Engineering Laboratory, Idaho, 1994 through 1995: U.S. Geological Survey Water-Resources Investigations Report 97–4058 (DOE/ID-22136), 87 p. (Also available at <http://pubs.er.usgs.gov/publication/wri974058>.)
- Wood, W.W., 1976, Guidelines for collection and field analysis of ground-water samples for selected unstable constituents: U.S. Geological Survey Techniques of Water-Resources Investigations, book 1, chap. D2, 24 p. (Also available at <http://pubs.er.usgs.gov/publication/twri01D2>.)



Publishing support provided by the U.S. Geological Survey  
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