Prepared in cooperation with the Jackson Hole Airport Board and the Teton Conservation District

Hydrogeology and Water Quality in the Snake River Alluvial Aquifer at Jackson Hole Airport, Jackson, Wyoming, September 2008–June 2009

Scientific Investigations Report 2010–5172

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

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KEN SALAZAR, Secretary

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

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Conversion Factors and Datums

Multiply	**By**	**To obtain**
	Length	
inch (in.)	25.40	millimeter (mm)
inch (in.)	2.540	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	Volume	
ounce, fluid (fl. oz)	0.02957	liter (L)
	Flow rate	
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Concentration	
part per million (ppm)	1.0	milligram per liter (mg/L)
part per billion (ppb)	1.0	microgram per liter (µg/L)

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) as follows:

$$°F = 9/5\ (°C) + 32$$

$$°C = 5/9\ (°F - 32)$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), with the exception of figure 5, which is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83), with the exception of table 1, which is referenced to both NAD 83 and the North American Datum of 1927 (NAD 27).

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

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).

Abbreviations, Initialisms, and Acronyms

ADAF	aircraft deicing/anti-icing fluid
BTEX	benzene, toluene, ethylbenzene, xylene
$CaCO_3$	calcium carbonate
COD	chemical oxygen demand
$\delta^{18}O$	oxygen-18/oxygen-16 isotopic ratio
$\delta^{2}H$	deuterium/protium isotopic ratio
DOC	dissolved organic carbon
DRO	diesel-range organics
DWA	Drinking Water Advisory
e-tape	electric tape
GMWL	Global Meteoric Water Line
GPS	global positioning system
GRO	gasoline-range organic
HAL	Lifetime Health Advisory Level
IRL	interim reporting level
JHA	Jackson Hole Airport
LMWL	Local Meteoric Water Line
LRL	laboratory reporting level
MCL	Maximum Contaminant Level
MRL	minimum reporting level
NTRU	nephelometric turbidity ratio units
NWQL	National Water Quality Laboratory
PVC	polyvinyl chloride
RPD	relative percent difference
RSD4	Risk-Specific Dose at 10^{-4} Cancer Risk
RSIL	Reston Stable Isotope Laboratory
SMCL	Secondary Maximum Contaminant Level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound

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By Peter R. Wright

Abstract

The hydrogeology and water quality of the Snake River alluvial aquifer, at the Jackson Hole Airport in northwest Wyoming, was studied by the U.S. Geological Survey in cooperation with the Jackson Hole Airport Board and the Teton Conservation District during September 2008–June 2009. Hydrogeologic conditions were characterized using data collected from 14 Jackson Hole Airport wells. Groundwater levels are summarized in this report and the direction of groundwater flow, hydraulic gradients, and estimated groundwater velocity rates in the Snake River alluvial aquifer underlying the study area are presented. Analytical results of chemical, dissolved gas, and stable isotopes are presented and summarized.

Seasonally, the water table at Jackson Hole Airport was lowest in early spring and reached its peak in July, with an increase of 12 to 14 feet between April and July 2009. Groundwater flow was predominantly horizontal but had the hydraulic potential for downward flow. The direction of groundwater flow was from the northeast to the west-southwest. Horizontal groundwater velocities within the Snake River alluvial aquifer at the airport were estimated to be about 26 to 66 feet per day. This indicates that the traveltime from the farthest upgradient well to the farthest downgradient well was approximately 53 to 138 days. This estimate only describes the movement of groundwater because some solutes may move at a rate much slower than groundwater flow through the aquifer.

The quality of the water in the alluvial aquifer generally was considered good. The alluvial aquifer was a fresh, hard to very hard, calcium carbonate type water. No constituents were detected at concentrations exceeding U.S. Environmental Protection Agency Maximum Contaminant Levels, and no anthropogenic compounds were detected at concentrations greater than laboratory reporting levels. The quality of groundwater in the alluvial aquifer generally was suitable for domestic and other uses; however, dissolved iron and manganese were detected at concentrations exceeding the U.S. Environmental Protection Agency Secondary Maximum Contaminant Levels for drinking water in two monitoring wells. These secondary standards are esthetic guidelines only and are nonenforceable. Iron and manganese are likely both natural components of the geologic materials in the area and may have become mobilized in the aquifer due to reduction/oxidation (redox) processes. Additionally, measurements of dissolved-oxygen concentrations and analyses of major ions and nutrients indicate reducing conditions exist at two of the seven wells sampled. Reducing conditions in an otherwise oxic aquifer system are indicative of an upgradient or in-situ source of organic carbon. The nature of the source of organic carbon at the airport could not be determined.

Measurements of dissolved-oxygen concentrations (0.1 to 8.1 milligrams per liter) indicated some variability in the oxygen content of the aquifer. Five of the seven wells showed oxic conditions in the aquifer, whereas two wells had low concentrations of dissolved oxygen (less than 1 milligram per liter), indicating anoxic conditions. Nutrients were found in low concentrations in all samples collected. Nitrate plus nitrite was detected in samples from five of the seven monitored wells, whereas dissolved ammonia was detected only in the two wells where anoxic conditions were present in the aquifer. Dissolved organic carbon (DOC) concentrations generally were low. Only samples from three wells had DOC concentrations that were not estimated; one concentration, an order of magnitude higher than other detected DOC concentrations, slightly exceeded the estimated range for natural groundwater.

Samples of dissolved gases were collected, and field analyses of ferrous iron, manganous manganese, hydrogen sulfide, and low-level dissolved oxygen were done to better understand the redox conditions of the alluvial aquifer. Dissolved gas analyses confirmed low concentrations of dissolved oxygen in samples from wells where reducing conditions exist and showed the presence of methane gas in samples from both wells. The redox processes occurring in the alluvial aquifer at these two wells were identified by using a model designed to use a multiple-lines-of-evidence approach to distinguish reduction processes. Results of analyses from May and June indicate iron reduction was the dominant redox process occurring in the aquifer.

Generally, the results of samples collected to determine the presence of anthropogenic compounds showed these compounds were not present. No gasoline-range organics or glycols were detected at concentrations greater than the laboratory reporting levels used for this study. Small concentrations of diesel-range organics were detected in four samples during this study; all detected concentrations were reported as "estimated" and were less than the laboratory reporting level. Concentrations of diesel-range organics were less than the laboratory reporting level in all samples collected during the last sampling event, indicating that the diesel-range organics (if present, and not due to field or laboratory contamination) were not from a persistent source during this study.

Samples of stable hydrogen and oxygen isotopes were collected from all seven wells and an irrigation ditch that crosses the airport to assess the source of water to the aquifer. Analysis of stable hydrogen and oxygen isotope data indicated the source of groundwater likely is meteoric, and water from all the sampled wells underwent similar recharge and evolution paths.

Introduction

The Snake River alluvial aquifer is located in the Snake River Valley in northwestern Wyoming, including Grand Teton National Park, in an area known as Jackson Hole. This alluvial aquifer is used for domestic, public supply, commercial, livestock, and irrigation purposes (Nolan and Miller, 1995). In 2005, the U.S. Geological Survey (USGS) estimated that 98 percent of the water used for domestic and public supply in Teton County was groundwater (U.S. Geological Survey, 2005). Water from this aquifer is used for both domestic and commercial purposes by the Jackson Hole Airport (JHA) and nearby residents. Airport activities and facilities have the potential to affect water quality in the aquifer. JHA is located in an area of high vulnerability to groundwater contamination due to a high water table, coarse soils, and high rates of hydraulic conductivity (Hamerlinck and Arneson, 1998).

Of particular interest is whether deicing and anti-icing compounds used at the airport are being transported into the alluvial aquifer. Studies of water quality near other airports in the United States have found components of aircraft deicing/anti-icing fluids (ADAFs) in airport snowbanks (Corsi and others, 2006a), surface-water runoff (Corsi and others, 2001), and shallow groundwater (Cancilla and others, 1998). Reduced dissolved-oxygen conditions were found to be associated with ADAF (Cancilla and others, 1998; Corsi and others, 2001; Corsi and others, 2006a, 2006b). These studies have found that glycols, the primary ingredient in ADAFs, have very high biochemical oxygen demand, creating the potential for oxygen depletion in receiving waters (Corsi and others, 2001). In addition to glycols, ADAFs contain various performance-enhancement additives, which also can be isolated in environmental waters. Although previous groundwater studies have been completed in Teton County, little groundwater flow and water-quality information is available in the vicinity of the airport. To address these concerns, the USGS, in cooperation with the Jackson Hole Airport Board and Teton Conservation District, conducted a study to characterize groundwater conditions at the airport.

The objective of this study was to characterize the hydrogeology and groundwater quality of the Snake River aquifer in upgradient and downgradient parts of the aquifer underlying the airport and facilities. Groundwater levels (referred to as water levels in this report) were measured during each visit to the airport and continuously at several wells to determine the direction of groundwater flow, calculate hydraulic gradients, and estimate groundwater velocity at the airport. Water-quality samples were collected at airport wells at four different times to characterize groundwater quality.

Purpose and Scope

The purpose of this report is to describe the hydrogeology and water quality within the alluvial aquifer underlying the JHA during September and October 2008 and March, May, and June 2009. These four time periods reflect different hydrogeologic conditions and different airport-use periods. Hydrogeologic characteristics including the direction of groundwater flow, hydraulic gradients, estimated flow rates of the alluvial aquifer, and water-quality conditions for major-ion chemistry, nutrients, trace elements, volatile organic compounds (VOCs), gasoline-range organics (GRO), diesel-range organics (DRO), and glycols upgradient and downgradient from airport activities and facilities are described. The implications of these results are described. Additionally, reduction and oxidation processes (redox) are characterized, and the source of water to the aquifer is evaluated by using stable-isotope data.

Description of Study Area

The JHA is located in the southern part of Jackson Hole, a semiarid, high-altitude valley in northwestern Wyoming (fig. 1). Located approximately 8 miles (mi) north of the town of Jackson, JHA is the busiest commercial airport in Wyoming; 3,904 flights carried more than 600,000 passengers during 2008 (Michelle Buschow, Jackson Hole Airport, written commun., 2009). The airport is unique in that it is located within Grand Teton National Park, along the park's southwestern boundary. The airport is at an altitude of about 6,400 feet (ft) above the North American Vertical Datum of 1988 (NAVD 88), covers an area of 533 acres, and has one runway and one taxiway (Jackson Hole Airport, 2009).

The JHA is located east of the Snake River on relatively thick Snake River terrace deposits (Pierce and Good, 1992). These terrace deposits consist of Quaternary-age unconsolidated gravel, pediment, and fan deposits that are saturated and collectively constitute a relatively large water-table aquifer

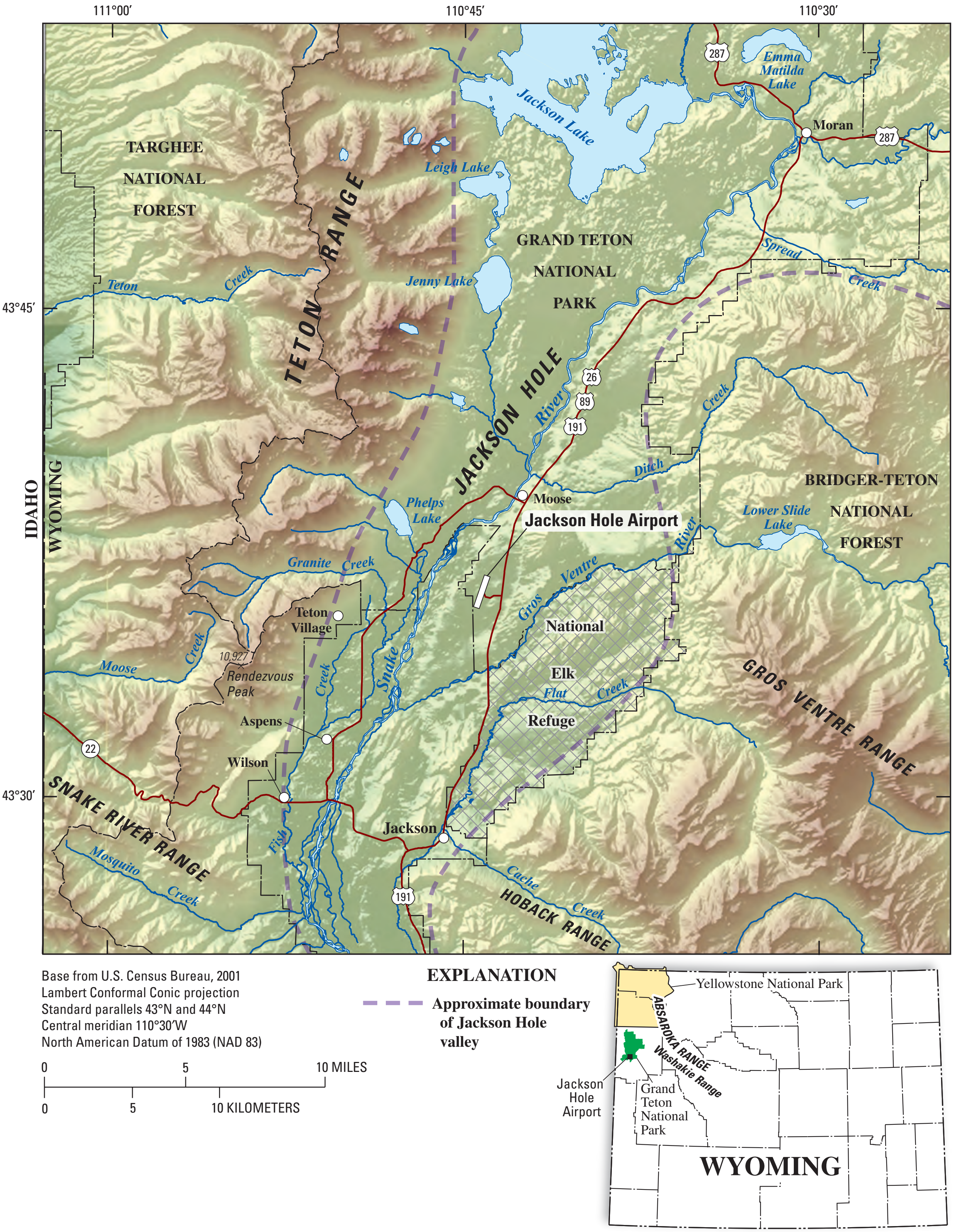


Figure 1. Location of Jackson Hole Airport in the Jackson Hole valley, Wyoming.

throughout the eastern part of Grand Teton National Park and the Jackson Hole area (Nolan and Miller, 1995; Nolan and others, 1998). The aquifer is informally named the "Jackson aquifer" (Nolan and Miller, 1995) and is referred to as the "Snake River alluvial aquifer" in this report. The thickness of the Snake River alluvial aquifer in the vicinity of the airport is estimated to be 200 to 250 ft (Nolan and others, 1998, their fig. 5) and is the primary water supply for JHA and area residents.

The Snake River alluvial aquifer is unconfined, and depth to water ranged from less than 1 ft to 233.91 ft below land surface with a median depth to water of 10.78 ft below land surface (Nolan and Miller, 1995). Depth to water varies with topography and is shallowest near bodies of surface water. Groundwater in the Snake River alluvial aquifer generally follows the topography, moving from high areas toward the Snake River and southwest through the Snake River valley (Nolan and Miller, 1995). The direction of groundwater flow in the Snake River alluvial aquifer at the JHA is from the northeast to the southwest (Kumar and Associates, written commun., 1993; Nolan and Miller, 1995).

The study area is in the Middle Rockies ecoregion, which is a temperate, semiarid steppe regime (Chapman and others, 2004). Climate conditions in the Jackson Hole area vary with changes in season and altitude. Mean monthly temperatures at the Moose, Wyo., climate station, located approximately 4 mi north of JHA, ranged from 0.9 degree Fahrenheit (°F) in January to 80.6°F in July with an annual average of 36.9°F during the period 1958–2009 (Western Regional Climate Center, 2009). Mean monthly precipitation data, also collected at the Moose, Wyo., climate station ranged from 1.1 inches (in.) in July to 2.6 in. during January with an annual average of 21.0 in. for the period 1958–2009 (Western Regional Climate Center, 2009). Much of the precipitation in the Jackson Hole area is snowfall. On average, snowfalls occur 10 months of the year with an average snowfall of 171.4 in. at Moose, Wyo. (Western Regional Climate Center, 2009). For the period September 2008 to August 2009, average air temperature was 37.9°F and total precipitation was 25.7 in., which included a snowfall total of 180.5 in.

Study Design

Existing production wells in the study area were inventoried to determine if any could be used for collection of hydrogeologic and water-quality data. Nine existing production wells were selected for water-level monitoring and two of these wells (Hangar 1 and Hangar 5) also were selected for water-quality sampling. Five additional monitoring wells were installed to help understand local hydrogeologic and water-quality characteristics (fig. 2). The hydrogeology of the Snake River alluvial aquifer underlying the Jackson Hole Airport was characterized from the collection of water levels from 14 wells by using discrete measurements and continuous recorders for a subset of wells from September 2008 to February 2010. The water quality of the Snake River alluvial aquifer was determined from water-quality samples collected at 7 of the 14 wells (fig. 2, table 1).

Four of the five monitoring wells installed were screened near the water table, and one well (JH–3D) was completed in the deeper part of the aquifer (table 1). These wells were installed along the direction of groundwater flow based on published potentiometric-surface contour maps (Kumar and Associates, written commun., 1993; Nolan and Miller, 1995). Well JH–1 was installed north and east of current (2010) airport operations (upgradient), just east of the Teton Interagency Helitack Crew operations center (fig. 2). Three wells (JH–2, JH–3, and JH–4) were installed along the south and west airport boundary to represent downgradient conditions of current and planned airport operations, and a deep well (JH–3D) was installed adjacent to well JH–3 along the south and west airport boundary (fig. 2).

Groundwater samples were collected four times from each of seven wells with the exception of well JH–4 (fig. 2; table 1). During the March sampling there was not enough water in well JH–4 to collect a sample. Results described in this report are for data collected during sampling done between September 2008 and June 2009. In order to understand the general water quality of the aquifer, samples were analyzed for constituents that naturally occur in water, including major ions and trace elements. Samples also were analyzed for many compounds found in products that are used at the airport such as VOCs, GRO, and DRO (found in fuels) and glycols (the primary ingredient in deicer and anti-icer products). Because low dissolved-oxygen concentrations were measured at wells JH–3 and JH–3D during the first two sampling events, additional water-quality data were collected to better understand the redox processes occurring at these wells.

Methods of Data Collection and Analysis

Methods used for collection and analysis of hydrogeologic and water-quality data are described in this section. Quality-assurance and quality-control data collected for the water-quality samples also are described in this section.

Well Construction and Ancillary Information

The wells installed for this study were drilled using a dual rotary rig during July and August of 2008. Water-table wells were constructed with 2-in.-diameter, flush-jointed polyvinyl chloride (PVC) casing and well screen. Well screens used to construct the wells were 15 or 20 ft long (table 1) and set at depths about 10 ft below and 5 ft above the water-table surface. This allowed the wells to "straddle" the water

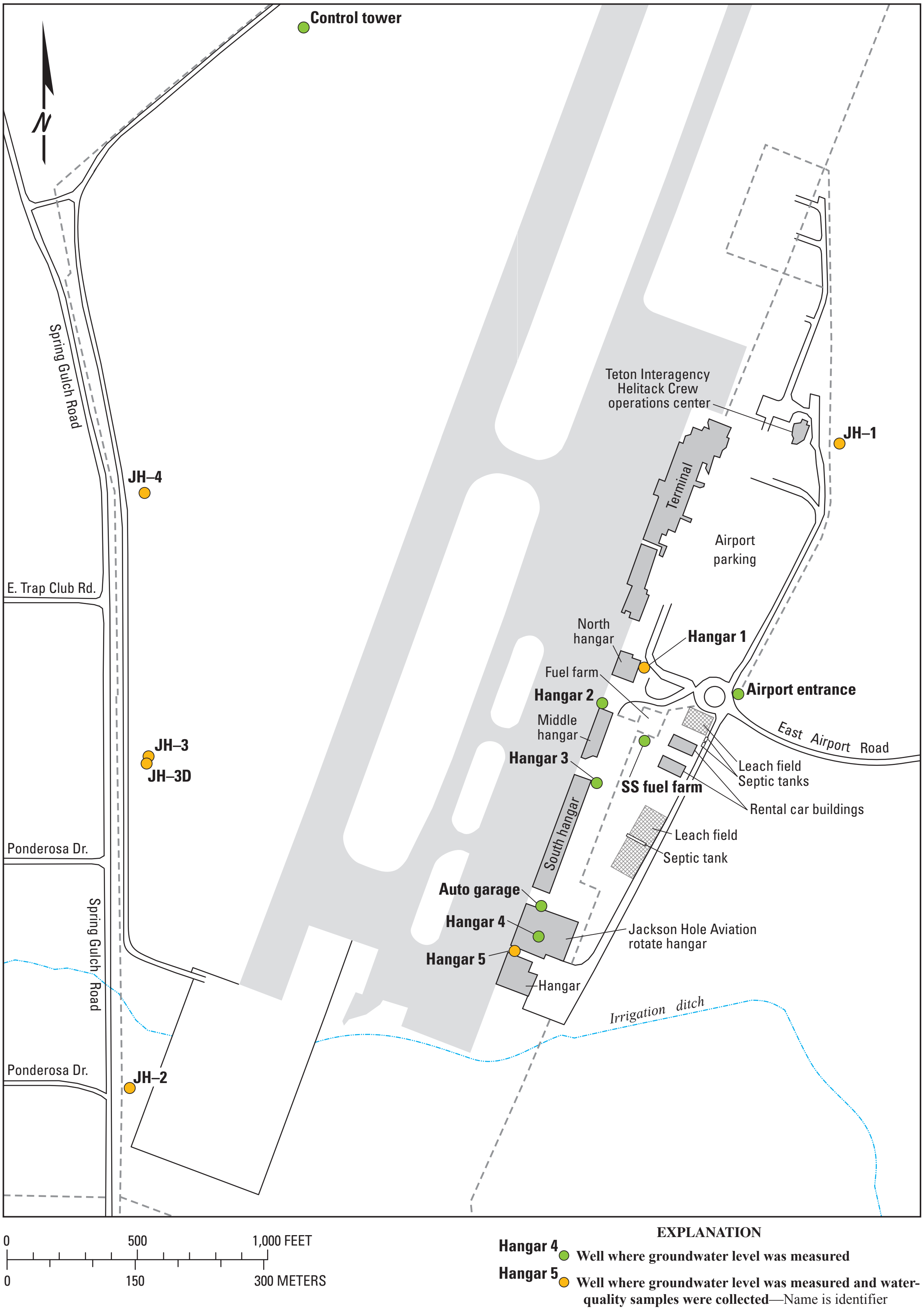


Figure 2. Location of wells used in the study area for data collection, Jackson Hole Airport, Jackson, Wyoming.

Table 1. Well construction and related ancillary information for wells used for data collection at the Jackson Hole Airport, Jackson, Wyoming, September 2008–June 2009.

[USGS, U.S. Geological Survey; NAD 27, North American Datum of 1927; NAD 83, North American Datum of 1983; ft, feet; NAVD 88, North American Vertical Datum of 1988; bls, below land surface; MP, measuring point; M, measured; S, Wyoming State Engineer's Office well permit database; --, not able to measure or find listed; -XX, a negative MP indicates a measurement above land surface; TOPC, top of polyvinyl chloride casing; TOSC, top of steel casing; TOWC, top of well cap]

USGS site-identification number	Well identifier (fig. 2)	Latitude (NAD 27)	Longitude (NAD 27)	Latitude (NAD 83)	Longitude (NAD 83)	Land-surface altitude (ft above NAVD 88)	Well depth (ft bls)	Well screen interval (ft bls)	Source of well construction data	Height of MP above land surface (ft)	Altitude of MP (ft above NAVD 88)	Description of MP
Water quality and water levels												
433615110440001	JH–1	43°36′14.80″	110°43′59.56″	43°36′14.55″	110°44′2.31″	6,422.46	60.36	30–50	M	0.55	6,421.91	TOPC
433551110443501	JH–2	43°35′50.94″	110°44′34.79″	43°35′50.69″	110°44′37.54″	6,406.59	59.45	30–55	M	.32	6,406.27	TOPC
433603110443501	JH–3	43°36′03.17″	110°44′34.56″	43°36′2.92″	110°44′37.31″	6,412.22	60.23	40–60	M	.28	6,411.94	TOPC
433603110443502	JH–3D	43°36′02.90″	110°44′34.7″	43°36′2.65″	110°44′37.45″	6,411.99	102.58	[1]--	M	–1.97	6,413.96	TOSC
433613110443501	JH–4	43°36′12.73″	110°44′34.95″	43°36′12.48″	110°44′37.70″	6,418.06	58.87	40–55	M	.32	6,417.74	TOPC
433607110440901	Hangar 1	43°36′06.65″	110°44′09.20″	43°36′6.40″	110°44′11.94″	6,418.51	65	43–65	S	–1.24	6,419.75	TOWC
433556110441601	Hangar 5	43°35′56.19″	110°44′16.01″	43°35′55.94″	110°44′18.76″	6,409.86	92	43–92	S	.25	6,409.61	TOSC
Water levels only												
4336301104427	Control tower	43°36′29.7″	110°44′27.27″	43°36′29.45″	110°44′30.02″	6,427.55	100	53–100	S	–1.07	6,428.62	TOWC
4336041104410	SS fuel farm	43°36′03.61″	110°44′10.06″	43°36′3.36″	110°44′12.81″	6,416.63	55.70	--	M	.12	6,416.51	TOWC
4336061104405	Airport entrance	43°36′05.89″	110°44′05.19″	43°36′5.64″	110°44′7.94″	6,417.17	81	48–81	S	–1.17	6,418.34	TOWC
4336051104412	Hangar 2	43°36′05.18″	110°44′11.76″	43°36′4.93″	110°44′14.51″	6,416.83	89	35–89	S	–1.26	6,418.09	TOWC
4336021104412	Hangar 3	43°36′02.26″	110°44′11.75″	43°36′2.01″	110°44′14.50″	6,414.09	--	--	--	–1.02	6,415.11	TOWC
4335581104415	Auto garage	43°35′57.82″	110°44′14.68″	43°35′57.57″	110°44′17.43″	6,412.57	--	--	--	.26	6,412.31	TOSC
4335561104415	Hangar 4	43°35′56.69″	110°44′14.79″	43°35′56.44″	110°44′17.54″	6,411.26	--	--	--	.16	6,411.10	TOSC

[1] This well was drilled to 115 feet below land surface and cased down to 105 feet. Field measurements of well depth indicate the open borehole collapsed and partially filled the borehole.

table, allowing for some seasonal changes in the water-table altitude and allowing for determination of the presence of possible groundwater contaminants, such as petroleum fuels that can float on or near the water-table surface. The deep well (JH–3D) installed adjacent to well JH–3 was drilled to 115 ft of depth. This well was constructed with 105 ft of 6-in steel casing. The open borehole collapsed when the drill stem was removed and partially filled the lower end of the casing, leaving well JH–3D approximately 103 feet deep, which is about 43 ft deeper than well JH–3. Well JH–3D is not perforated or screened, is bottom fed, and acts as a piezometer. Prior to sampling, all five of the new monitoring wells were pumped or “developed” using methods described in Lapham and others (1995) to remove artifacts associated with drilling, such as drilling fluids, to provide water representative of the aquifer being sampled, and to improve movement of water to the well.

Well locations and altitudes were determined during September and October 2008. Well locations were determined using a global positioning system (GPS) reporting latitude and longitude (table 1) using the North American Datum of 1927 (NAD 27), with a horizontal accuracy of about ±16 ft (5 meters). All latitudes and longitudes were converted to the North American Datum of 1983 (NAD 83) and are presented in table 1. Altitudes for three wells had been determined by a private surveying firm previously. Well altitudes for the remaining 11 wells were determined by a private surveying firm during October 2008 using the North American Vertical Datum of 1988 (NAVD 88) and established airport benchmarks. Altitudes for all of the wells described above were determined using conventional surveying methods.

Water Levels

Discrete water levels were measured during each visit to the airport (table 2), and hourly water levels were collected at selected wells during and after other field activities were completed. Discrete water levels were measured with a calibrated electric tape (e-tape) when the well casing was clear or with a calibrated steel tape when well pump and power cables were present. Multiple “replicate” measurements were made during each visit to ensure the water level measured was the correct water level. Water levels were measured to one one-hundredth of a foot. The qualities of water-level measurements were not always excellent, even if multiple measurements were the same. If a water-level measurement was questionable due to measuring conditions (weather or suspected recent pumping), an “E” was included with the measurement to indicate it was an estimate. The quality of water-level measurements was a consideration during data analysis.

During February 2009, continuous water-level recorders were installed in the five new monitoring wells. These self-contained pressure transducer/temperature/data logging units are vented, allowing for changes in barometric pressure, and are accurate to ±0.012 ft (In-Situ, Inc., 2007, p. 23). Discrete water-level measurements were collected each time data were downloaded (during each airport visit) (table 2) to verify proper reading of the instrument. When logged instrument readings did not match discrete water-level measurements, a datum correction was applied to the applicable period of record.

Water-Table Contours, Hydraulic Gradient, and Groundwater Velocity

Water-table contours were constructed, and direction of groundwater flow and hydraulic gradient were calculated using methods described in Heath (1983, p. 11). Each set of calculations for direction of groundwater flow and hydraulic gradient required water-level data from three wells (“three-point calculation,” [Heath, 1983, p. 11]) located in a triangular arrangement. Data necessary for these calculations included water-level altitude (table 2) and the linear distance between wells (approximated from topographic map). Data collected from wells JH–1, JH–2, and JH–4 during October 2008 are used herein as an example of how these hydrogeologic characteristics were determined.

The first step was to identify the well with the intermediate water-level altitude (well JH–4). Once this well was identified, the point of contour or position between the well with the highest water-level altitude (JH–1) and the well with the lowest water-level altitude (JH–2) at which the water-level altitude was the same as in the intermediate well (JH–4) was determined using equation 1 (Heath, 1983, p. 11) and was solved using equations 2–3 for water-level data collected on October 15, 2008 (table 2).

$$\frac{(A-B)}{x}=\frac{(A-C)}{D} \tag{1}$$

where

A is the highest water-level altitude,
B is the intermediate water-level altitude,
C is the lowest water-level altitude,
D is the distance between wells with the highest and lowest water-level altitudes, and
x is the point of contour.

$$\frac{(6,380.92\,ft-6,364.41\,ft)}{x}=\frac{(6,380.92\,ft-6,358.81\,ft)}{3,542\,ft} \tag{2}$$

$$x=2,645\,ft \tag{3}$$

The point of contour is located x feet from the well with the highest water-level altitude. In this case, the point of contour was about 2,645 ft from well JH–1 along the path between wells JH–1 and JH–2 (fig. 3). Next, a straight line was drawn between well JH–4 and the point of contour (fig. 3). This

Table 2. Water-level data and related ancillary information for measurements collected at the Jackson Hole Airport, Jackson, Wyoming, September 2008–June 2009.

[BMP, below measuring point; NAVD 88, North American Vertical Datum of 1988; e-tape, calibrated electric tape; E, estimated value; --, not applicable]

Well identifier (fig. 2)	Date	Time (24 hour)	Water level (feet BMP)	Water-level method	Water-level altitude, feet above NAVD 88)
JH–1	09/16/2008	1646	39.56	e-tape	6,382.35
	10/15/2008	1435	40.99	e-tape	6,380.92
	03/03/2009	1145	46.10	e-tape	6,375.81
	05/05/2009	1520	43.97	e-tape	6,377.94
	06/16/2009	1400	36.80	e-tape	6,385.11
JH–2	09/15/2008	1500	45.74	e-tape	6,360.53
	10/15/2008	1005	47.46	e-tape	6,358.81
	03/05/2009	0842	53.21	e-tape	6,353.06
	05/07/2009	0856	49.88	e-tape	6,356.39
	06/18/2009	825	40.28	e-tape	6,365.99
JH–3	09/16/2008	0745	48.62	e-tape	6,363.32
	10/15/2008	0947	50.19	e-tape	6,361.75
	03/04/2009	1020	55.45	e-tape	6,356.49
	05/06/2009	1136	52.28	e-tape	6,359.66
	06/17/2009	1102	44.09	e-tape	6,367.85
JH–3D	09/16/2008	0953	51.88	e-tape	6,362.08
	10/15/2008	0949	52.37	e-tape	6,361.59
	03/04/2009	1157	57.69	e-tape	6,356.27
	05/06/2009	1406	54.53	e-tape	6,359.43
	06/17/2009	1110	46.15	e-tape	6,367.81
JH–4	09/16/2008	1450	51.75	e-tape	6,365.99
	10/15/2008	0937	53.33	e-tape	6,364.41
	03/04/2009	0945	58.22	e-tape	6,359.52
	05/06/2009	0920	55.09	e-tape	6,362.65
	06/17/2009	0840	47.93	e-tape	6,369.81
Hangar 1	10/15/2008	1250	47.22	steel tape	6,372.53 E
	03/03/2009	0930	49.10	steel tape	6,370.65
	05/05/2009	0910	46.82	steel tape	6,372.93
	06/16/2009	0836	39.57	steel tape	6,380.18
Hangar 5	10/15/2008	1135	38.78	e-tape	6,370.83
	03/05/2009	1130	44.08	e-tape	6,365.53
	05/05/2009	1210	41.53	e-tape	6,368.08
	06/16/2009	1020	33.62	e-tape	6,375.99

Table 2. Water-level data and related ancillary information for measurements collected at the Jackson Hole Airport, Jackson, Wyoming, September 2008–June 2009.—Continued

[BMP, below measuring point; NAVD 88, North American Vertical Datum of 1988; e-tape, calibrated electric tape; E, estimated value; --, not applicable]

Well identifier (fig. 2)	Date	Time (24 hour)	Water level (feet BMP)	Water-level method	Water-level altitude, feet above NAVD 88)
Control tower	10/15/2008	0920	58.17	steel tape	6,370.45 E
	03/04/2009	1133	60.21	steel tape	6,368.41
	05/05/2009	1310	57.29	steel tape	6,371.33
	06/16/2009	0925	51.70	steel tape	6,376.92
SS fuel farm	10/15/2008	1030	41.55	steel tape	6,374.96 E
	[1]03/05/2009	--	--	--	--
	05/05/2009	1350	40.24	e-tape	6,376.27
	06/16/2009	1140	37.50	e-tape	6,379.01
Airport entrance	10/15/2008	1410	41.92	steel tape	6,376.42 E
	03/03/2009	1025	46.60	steel tape	6,371.74
	05/05/2009	0945	44.34	steel tape	6,374.00
	06/16/2009	0915	36.78	steel tape	6,381.56
Hangar 2	10/15/2008	1225	44.75	steel tape	6,373.34 E
	03/05/2009	1315	47.95	steel tape	6,370.14
	05/05/2009	1310	45.59	steel tape	6,372.50
	06/16/2009	1200	38.09	steel tape	6,380.00
Hangar 3	10/15/2008	1047	41.30	steel tape	6,373.81 E
	03/05/2009	1300	46.45	steel tape	6,368.66
	05/05/2009	1340	44.05	steel tape	6,371.06
	06/16/2009	1105	36.49	steel tape	6,378.62
Auto garage	10/15/2008	1110	40.89	e-tape	6,371.42
	03/05/2009	1154	46.08	e-tape	6,366.23
	05/05/2009	1245	43.62	e-tape	6,368.69
	06/16/2009	1040	35.81	e-tape	6,376.50
Hangar 4	10/15/2008	1128	38.50	e-tape	6,372.60 E
	03/05/2009	1330	42.72	e-tape	6,368.38 E
	05/05/2009	1500	41.23	e-tape	6,369.87 E
	06/16/2009	1030	33.39	e-tape	6,377.71 E

[1] Could not access well, under snow pile.

line is a segment of contour and represents the water-level altitude of the Jackson Hole alluvial aquifer. A line was then drawn perpendicular to the water-level contour and through well JH–1 (fig. 3). This line also could be drawn through well JH–2 and parallels the direction of groundwater flow.

The hydraulic gradient is the change in hydraulic head (*dh*; change in water-level altitude) per unit distance (*dl*) in a given direction (Lohman and others, 1972):

$$Hydraulic\,gradient = \frac{dh}{dl} \tag{4}$$

To aid in the construction of contours, hydraulic gradient was calculated as the difference between the water-level altitude of the well and the water-level altitude of the contour, divided by the distance between the well and the contour. Equations 5 and 6 show the calculation of the hydraulic gradient using the water-level altitude of JH–1, the water-level altitude of the contour (same as well JH–4), and the linear distance between the well and contour:

$$Hydraulic\,gradient = \frac{6{,}380.92\,ft - 6{,}364.41\,ft}{2{,}477\,ft} \tag{5}$$

$$Hydraulic\,gradient = 0.0067\,ft/ft \tag{6}$$

Three-point calculations, such as those just described in the previous examples, were made for many different combinations of wells and were determined for each of five rounds of water-level measurements. Evaluation of water-level measurements identified irregularities with measurements from production wells. These production wells were regularly pumped, and it was difficult to determine if water-level measurements were affected by recent pumping. Consequently, only water levels measured in monitoring wells were used in three-point calculations. However, water levels measured in all wells were used to construct the water-table contour maps. Water-table contours were drawn (figs. 4*A*–*D*) using both discrete water-level measurements and contours determined using multiple three-point calculations to assist with “bending” of contours. A water-table contour map was constructed for four water-level measurement events: October 2008, March 2009, May 2009, and June 2009 (figs. 4*A*–*D*). Contour construction was straightforward for all measurement events except May 2009, where it was recognized that one water-level measurement collected at the SS fuel farm well was anomalous compared to all the other groundwater levels. This was assumed to be a measurement error, was not considered, and the water-table contour map was constructed as shown in figure 4*C*.

An average groundwater velocity can be estimated if the horizontal hydraulic conductivity, effective porosity, and hydraulic gradient are known, with the assumption that groundwater flow is perpendicular to the water-table contours and the aquifer is homogeneous and isotropic. The groundwater velocity was estimated using the average hydraulic gradient calculated for each water-level measurement event (table 3) by using equation 7 (Heath, 1983, p. 25):

$$v = \frac{Kdh}{ndl} \tag{7}$$

where

v is groundwater velocity, in feet per day;
K is horizontal hydraulic conductivity, in feet per day;
n is effective porosity, in percent, expressed as a decimal ratio;
$\frac{dh}{dl}$ is the hydraulic gradient, in foot per foot.

Hydraulic conductivity estimates for the Snake River alluvial aquifer at the airport were not available and were not determined during this study. To estimate groundwater velocities at the airport, hydraulic conductivity values from published aquifer tests of the Snake River alluvial aquifer at Teton Village and the Aspens in southern Jackson Hole were used (Nelson Engineering, 1992). The surficial geology of the area surrounding JHA is similar to the surficial geology at Teton Village and the Aspens (fig. 5), so it was assumed that the hydraulic conductivity at JHA would be similar to the hydraulic conductivities at Teton Village and the Aspens. The hydraulic conductivity of 22,000 gallons per day per square foot, or 2,900 feet per day (ft/d), for Teton Village is more than twice the hydraulic conductivity of 9,000 gallons per day per square foot, or 1,200 ft/d, for the Aspens (Nelson Engineering, 1992). Hydraulic conductivity estimates for Teton Village (2,900 ft/d) and the Aspens (1,200 ft/d) were high owing to the coarse-grained deposits of the system. Drillers’ logs for the airport monitoring wells installed for this study indicated that the aquifer is composed of a sand and gravel mixture. The porosity range for mixed sand and gravel is 20–35 percent (Fetter, 1988, table 4.2). An effective porosity of 30 percent (or 0.30) was used for all groundwater-velocity calculations (table 4).

Groundwater Sampling and Analysis

Groundwater samples were collected and processed in a mobile water-quality laboratory in accordance with standard USGS methods described in the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997–2010). Water was pumped from each well through a sampling manifold and a flow-through chamber in the mobile laboratory until at least three well-casing volumes had been removed and measurements of physical properties of dissolved oxygen, pH, specific conductance, temperature, and turbidity stabilized. These physical properties (table 5) were measured in the field as part of sample collection using

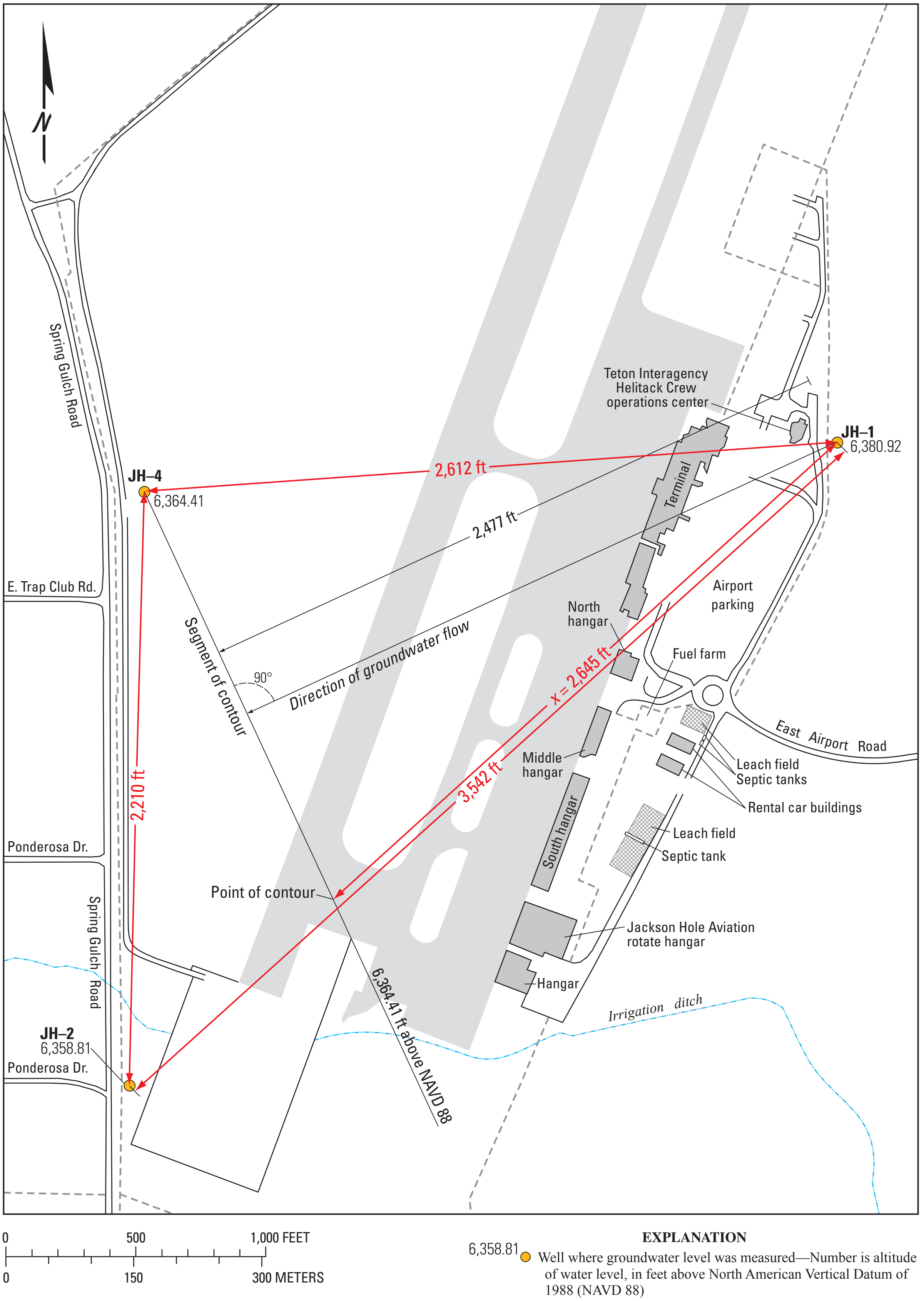
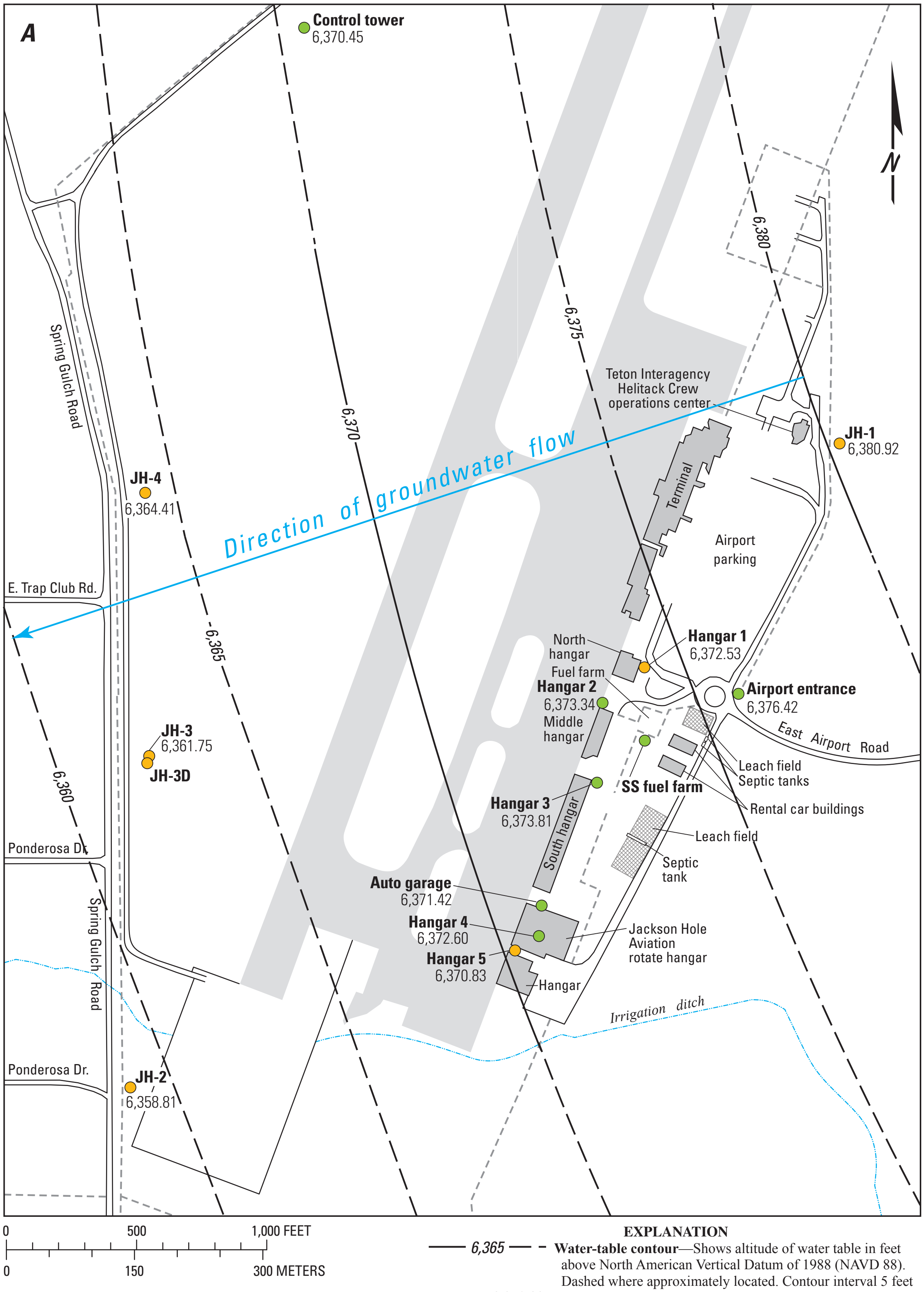


Figure 3. Example of a “three-point calculation” for determining direction of groundwater flow and hydraulic gradient, Jackson Hole Airport, Jackson, Wyoming.



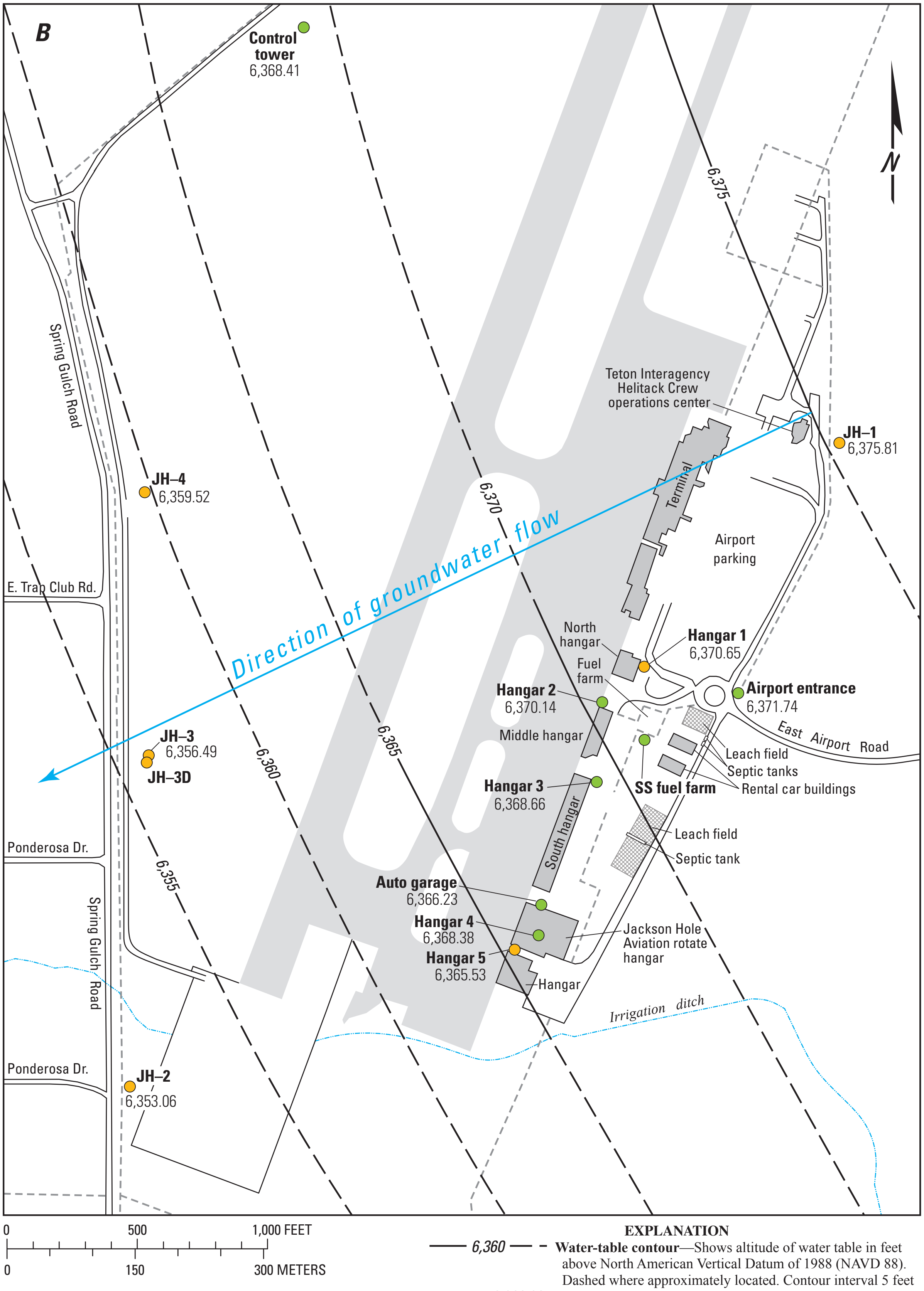
EXPLANATION

6,365 Water-table contour—Shows altitude of water table in feet above North American Vertical Datum of 1988 (NAVD 88). Dashed where approximately located. Contour interval 5 feet

● 6,372.60 Well where groundwater level was measured—Number is altitude of water level in feet above NAVD 88

● 6,370.83 Well where groundwater level was measured and water-quality samples were collected—Number is altitude of water level in feet above NAVD 88

Figure 4. Water-table contours and estimated direction of groundwater flow, Jackson Hole Airport, Jackson, Wyoming. *A*, October 2008.



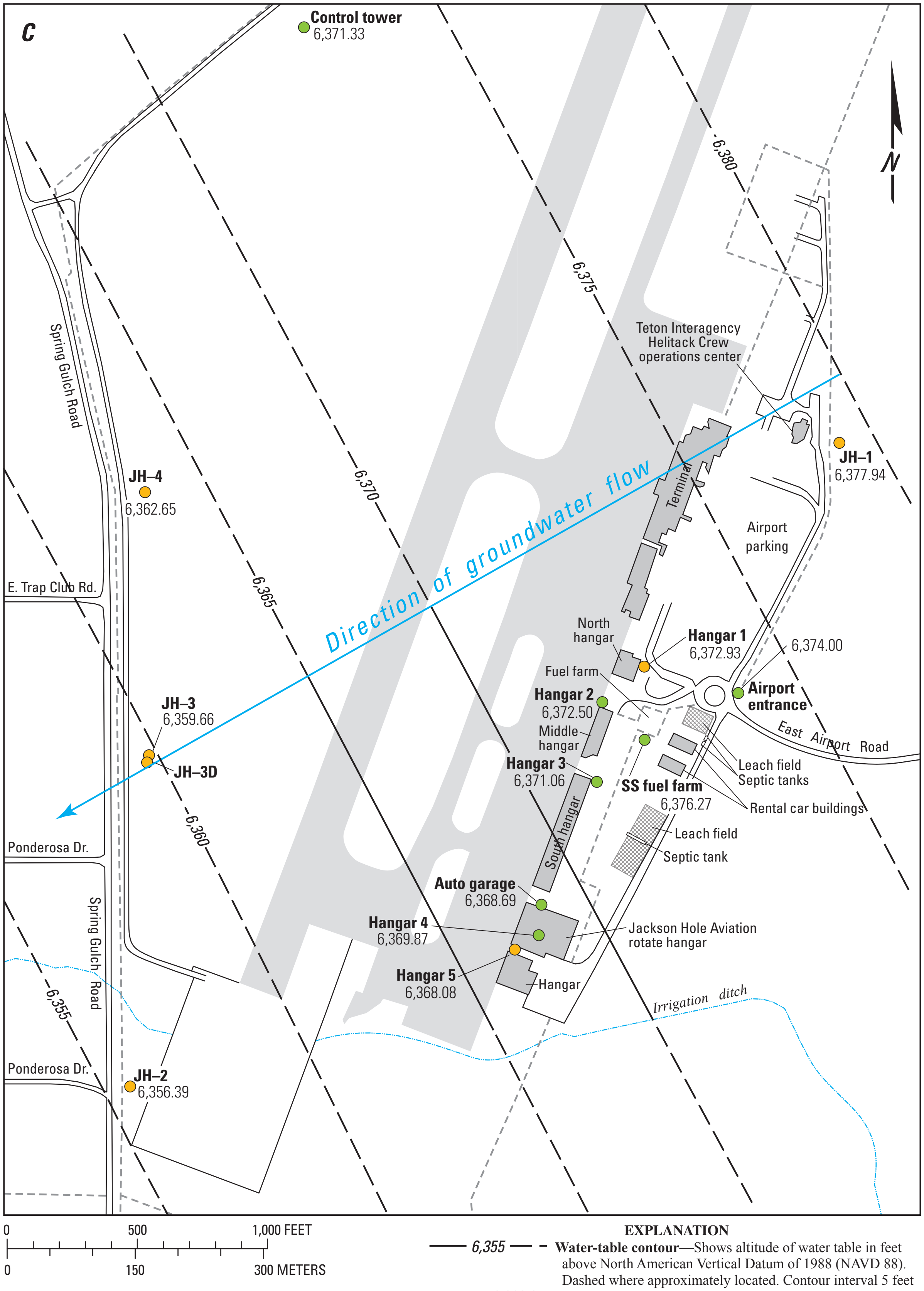
EXPLANATION

6,360 — Water-table contour—Shows altitude of water table in feet above North American Vertical Datum of 1988 (NAVD 88). Dashed where approximately located. Contour interval 5 feet

● 6,368.38 — **Well where groundwater level was measured**—Number is altitude of water level in feet above NAVD 88

● 6,365.53 — **Well where groundwater level was measured and water-quality samples were collected**—Number is altitude of water level in feet above NAVD 88

Figure 4. Water-table contours and estimated direction of groundwater flow, Jackson Hole Airport, Jackson, Wyoming.—Continued. *B*, March 2009.



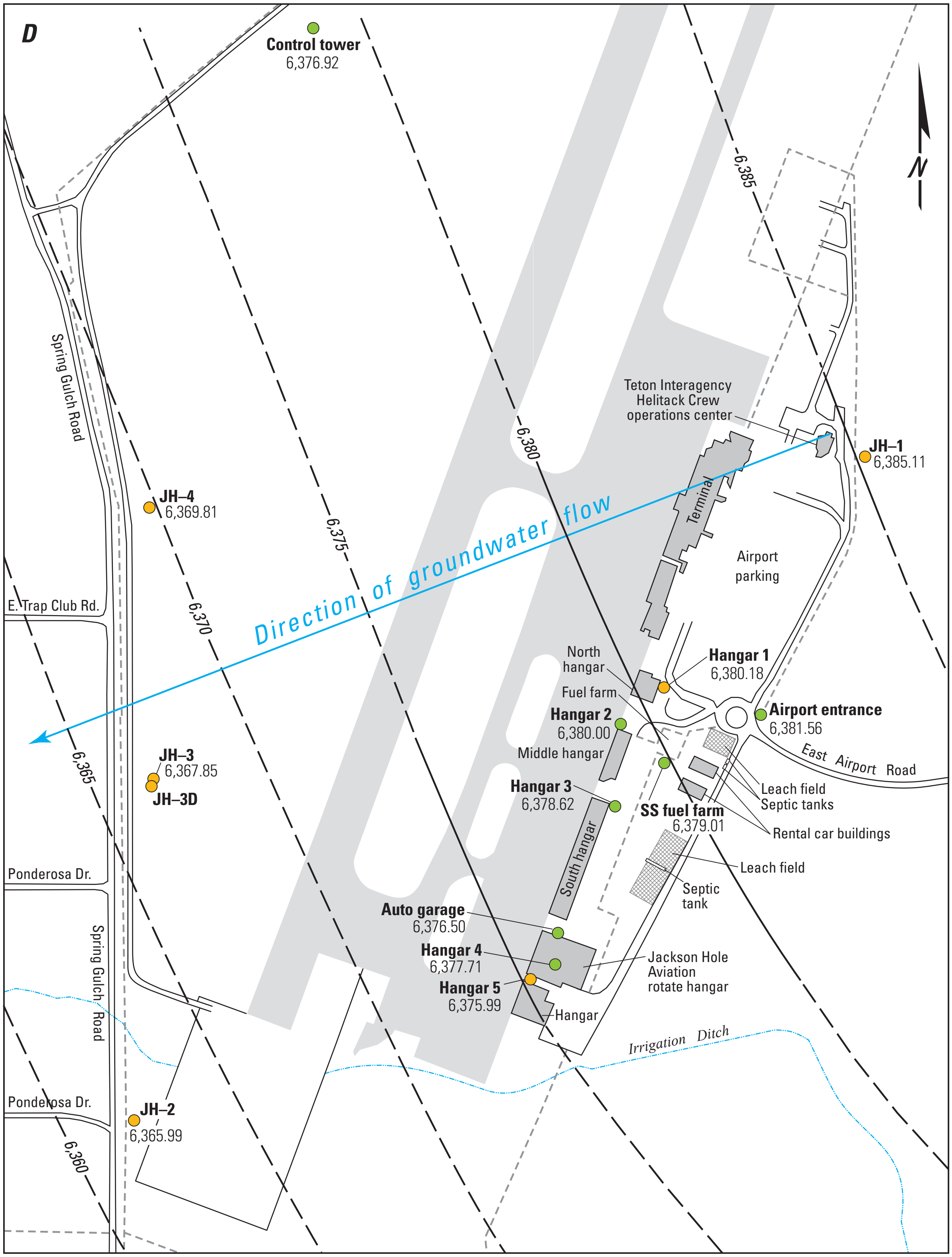
EXPLANATION

6,355 — Water-table contour—Shows altitude of water table in feet above North American Vertical Datum of 1988 (NAVD 88). Dashed where approximately located. Contour interval 5 feet

● 6,369.87 **Well where groundwater level was measured**—Number is altitude of water level in feet above NAVD 88

● 6,368.08 **Well where groundwater level was measured and water-quality samples were collected**—Number is altitude of water level in feet above NAVD 88

Figure 4. Water-table contours and estimated direction of groundwater flow, Jackson Hole Airport, Jackson, Wyoming.—Continued. *C*, May 2009.



EXPLANATION

6,360 — **Water-table contour**—Shows altitude of water table in feet above North American Vertical Datum of 1988 (NAVD 88). Dashed where approximately located. Contour interval 5 feet

● 6,377.71 **Well where groundwater level was measured**—Number is altitude of water level in feet above NAVD 88

● 6,375.99 **Well where groundwater level was measured and water-quality samples were collected**—Number is altitude of water level in feet above NAVD 88

Figure 4. Water-table contours and estimated direction of groundwater flow, Jackson Hole Airport, Jackson, Wyoming.—Continued. *D*, June 2009.

Table 3. Horizontal hydraulic gradients calculated for five water-level measurement events at the Jackson Hole Airport, Jackson, Wyoming, September 2008–June 2009.

Wells used in three-point calculation to determine hydraulic gradient	Horizontal hydraulic gradient (foot per foot)					
	September 2008	October 2008	March 2009	May 2009	June 2009	Average
JH–1, JH–2, JH–4	0.0066	0.0066	0.0068	0.0063	0.0066	0.0066
JH–1, JH–3, JH–4	.0067	.0067	.0069	.0064	.0061	.0066
JH–1, JH–2, JH–3	.0067	.0068	.0068	.0065	.0065	.0067
Average by month	.0067	.0067	.0068	.0064	.0064	.0066

methods described in U.S. Geological Survey (1997–2010). Alkalinity was determined using incremental titration of a filtered water sample with sulfuric acid as described in U.S. Geological Survey (1997–2010).

For samples collected for analyses of major ions, selected nutrients, selected trace elements, and dissolved organic carbon, filtration was performed by passing sample water through a pre-conditioned 0.45-micrometer, nominal-pore-size, baked glass-fiber filter. In this report, constituents in filtered water samples are referred to as “dissolved.” Constituents in unfiltered water samples are referred to as “total.”

The USGS National Water Quality Laboratory (NWQL) in Denver, Colo., analyzed groundwater samples for chemical oxygen demand (COD), major ions, nutrients, trace elements, and dissolved organic carbon (DOC). Major ions and trace elements (table 5) were analyzed using ion-exchange chromatography or inductively coupled plasma-atomic-emission spectroscopy (Fishman and Friedman, 1989; Fishman, 1993). Nutrients and COD (table 5) were analyzed using colorimetry (Fishman, 1993). DOC (table 5) was analyzed using ultraviolet light-promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993).

TestAmerica Laboratories, Inc., was contracted to analyze water samples for VOCs, GRO, glycols, and DRO (table 6) using U.S. Environmental Protection Agency (USEPA) methods. VOC samples were sent to TestAmerica in Savannah, Ga., and were analyzed using USEPA method 524.2 (Munch, 1995). Analyses for GRO using USEPA SW846 method 8021/8015B (U.S. Environmental Protection Agency, 1996a; 1996b) and DRO using USEPA SW846 method 8015B (U.S. Environmental Protection Agency, 1996a) in the C10–C32 and C10–C36 carbon ranges (table 6) were performed by TestAmerica in Denver, Colo. Glycol samples were sent to TestAmerica in Austin, Tex., and analyzed using USEPA SW846 method 8015B (U.S. Environmental Protection Agency, 1996a).

The USGS Reston Stable Isotope Laboratory (RSIL) in Reston, Va., analyzed seven groundwater samples and one surface-water sample for stable isotopes of hydrogen (δ^2H or deuterium (hydrogen-2)/protium (hydrogen-1) isotopic ratio) and oxygen (δ^{18}O or oxygen-18/oxygen-16 isotopic ratio) (table 5). The samples for determination of stable isotopes of hydrogen were analyzed using a gaseous hydrogen equilibrium procedure (Coplen and others, 1991), and the samples for determination of stable isotopes of oxygen were analyzed using the carbon dioxide-water equilibration technique of Epstein and Mayeda (1953). The USGS Reston Chlorofluorocarbon Laboratory in Reston, Va., analyzed groundwater samples for dissolved gases (argon, carbon dioxide, methane, nitrogen, and oxygen) (table 5) using gas chromatography (Busenberg and others, 2001).

Low-range dissolved oxygen, sulfide, and ferrous iron analyses were performed in the field laboratory using a HACH DR 2000 spectrophotometer (HACH, 1996). Methods of analyses included HACH method 8316, the indigo carmine method using AccuVac ampoules for low-range dissolved oxygen; HACH method 8146, the 1,10-phenanthroline method using AccuVac ampoules for ferrous iron; and HACH method 8131, a methylene blue method for sulfide (HACH, 1996).

Water-quality results collected during this study are presented in tables in the “Supplemental Information” section at the back of this report. Some water-quality results, especially those for organic compounds in this study, are reported as a less than (<) value or are qualified with an “E” meaning estimated. The < symbol indicates that the chemical was not detected. The value following the < symbol is the laboratory reporting level (LRL) or interim reporting level (IRL) associated with that analysis. The LRL can have various definitions, depending on the laboratory, but for water-quality data reported by the NWQL, the LRL generally is equal to twice the yearly determined long-term method detection level (Childress and others, 1999). The IRL, such as for dissolved nitrite and bromide (table 5), is a temporary reporting level used for new or custom schedules when long-term method detection level data are unavailable and a laboratory reporting level has not yet been established (U.S. Geological Survey, 2004). Values commonly are estimated when the value is greater than the minimum reporting level (MRL), defined by the NWQL as the smallest measured concentration of a substance that can be measured reliably by using a given analytical method (Timme, 1995), but less than the LRL. Generally, concentrations that are less than the LRL have more uncertainty in their quantification than concentrations larger than LRLs.

Quality Assurance/Quality Control

In addition to collection of environmental groundwater samples, three quality-control samples were collected, including a field-equipment blank, a trip blank, and a replicate sample. Analyses of these sample data are necessary to determine the quality of field and laboratory procedures and results. Quality-control samples were collected, processed, and analyzed using the same methods as environmental samples, and the results were used in this study to estimate the bias and variability that may have resulted from sample collection, processing, and analysis.

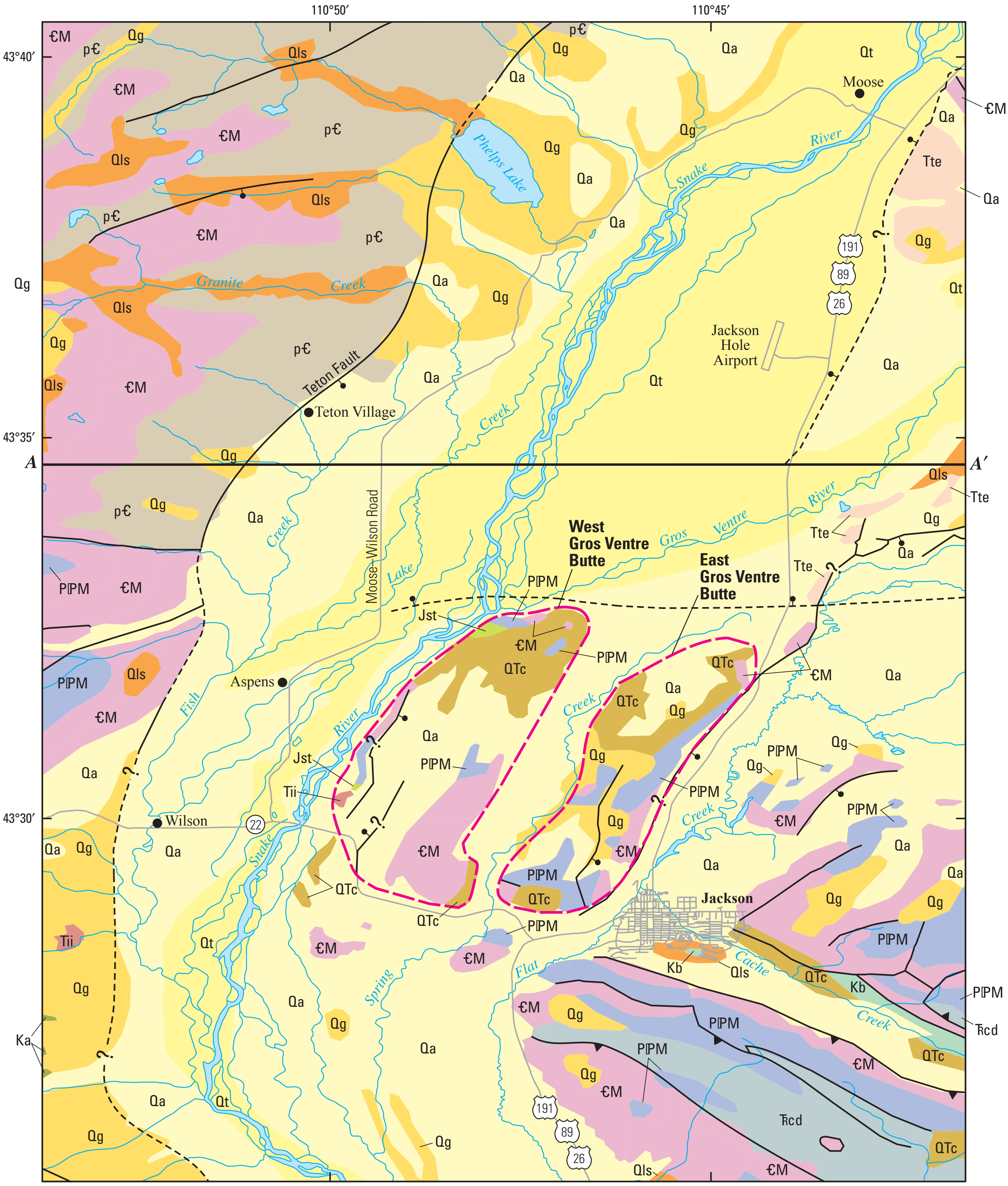
A field-equipment blank was collected between samples; that is, after the collection of an environmental sample and cleaning of the sampling equipment, and just before the collection of the next environmental sample. The field-equipment blank is a measure of sampling bias, providing data used to determine if cleaning procedures removed constituents from sampling equipment between sites and if sampling and laboratory methods were appropriate to prevent contamination of environmental samples (Mueller and others, 1997). Upon completion of cleaning, the field-equipment blank was collected by passing specially prepared blank water through all the sampling equipment. Inorganic-free and organic-free blank water was obtained from the NWQL and is certified to be free of inorganic and organic constituents, respectively. Trip blanks for this study were VOC vials of organic-free blank water filled and sealed by TestAmerica Laboratories. These trip blanks accompanied environmental sample vials to verify that VOC contamination did not occur during storage, sampling, or shipment to or from TestAmerica. A replicate sample was collected immediately after the primary environmental sample and was analyzed for the same constituents as the primary sample, to provide a measure of variability due to the effects of field and laboratory procedures.

The field equipment blank was analyzed for COD, major ions, trace elements, nutrients, DOC (table 11), VOCs, GRO (table 12), glycols and DRO (table 13). Tables 11, 12, 13, and 14 are located in the "Supplemental Information" section at the back of the report. All of the major ions except calcium and bromide were detected in the field blank; concentrations of detected major ions were very low and much smaller than concentrations measured in the environmental samples. None of the nutrients, trace elements, VOCs, GRO, glycols, or DRO was detected in the field equipment blank. Field equipment blank results indicate decontamination procedures were adequate and field and laboratory contamination of the environmental samples was minimal.

One trip blank was collected during the study for analysis of VOCs. Methylene chloride was detected at a small and estimated concentration of 0.61 microgram per liter (µg/L) in the trip blank (table 12). Because methylene chloride is a common solvent used by laboratories (U.S. Environmental Protection Agency, 2009a) and was the only VOC detected in the trip blank, this sample may have been contaminated at the laboratory. However, it also is possible that contamination could have occurred during transport of the trip blank. Therefore, the detection of methylene chloride found in an environmental sample at similar small, estimated concentration was considered to be due to sample contamination and not as a detection for this study.

One replicate sample was collected during this study. The relative percent difference (RPD) was calculated by comparing constituent concentrations measured in both the primary environmental sample and the replicate sample. The RPD was calculated using equation 8.

$$RPD = absolute\,value\left(\frac{concentration_{environmental\ sample} - concentration_{replicate\ sample}}{\left(\frac{concentration_{environmental\ sample} + concentration_{replicate\ sample}}{2}\right)}\right)\times 100 \qquad (8)$$



Base from Wyoming Gap Analysis digital data, 1996, 1:100,000
Albers Equal-area Conic projection
Standard parallels 41°N and 45°N, central meridian 110°30′W

0 2 4 MILES
0 2 4 KILOMETERS

Geology modified from Case and others, 1998; Love and Christiansen, 1985; Love and others, 1992; and Love and others, 2003

Figure 5. Generalized geology and geologic section in the vicinity of the Jackson Hole Airport, Jackson, Wyoming.

EXPLANATION

Quaternary unconsolidated deposits

Qa	Alluvium and colluvium
Qt	Gravel, pediment, and alluvial fan deposits
Qg	Gravel, pediment, talus, and alluvial fan deposits—May include some glacial deposits (fill and outwash) and Tertiary gravels
Qtc	Conglomerate Jackson Hole (Pleistocene or Pliocene)
Qls	Landslide deposits

Tertiary sedimentary and igneous rocks

Tte	Teewinot Formation
Tii	Intrusive and extrusive igneous rocks

Mesozoic and Paleozoic rocks

Kb	Bacon Ridge Sandstone
Ka	Aspen Shale
Jst	Stump Formation
₮cd	Chugwater and Dinwoody Formations
P₽M	Phosphoria Formation, Wells Formation, Tensleep Sandstone, and Amsden Formation
ЄM	Flathead Sandstone, Gros Ventre Formation, Gallatin Limestone, Bighorn Dolomite, Darby Formation, and Madison Limestone

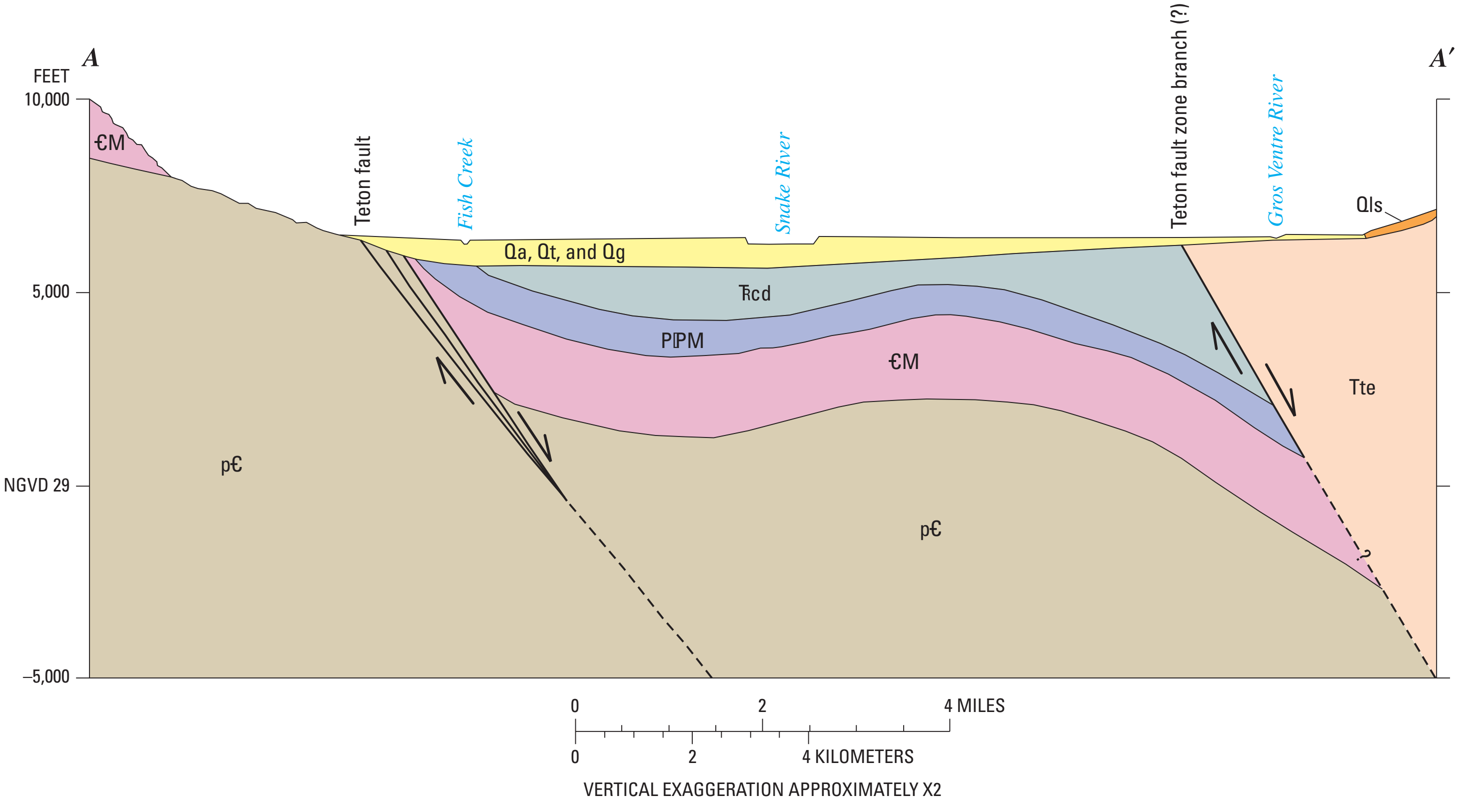
Precambrian rocks

pЄ	Granitic and basaltic rocks, granite gneiss, metasedimentary and metavolcanic rocks, metasedimentary and metamorphosed mafic and ultramafic rocks

Fault—Dashed where concealed and(or) approximately located. Bar and ball on downthrown side

Thrust fault (concealed)—Saw teeth on upper plate

Relative fault movement



Details of fault and buried strata are approximate and largely diagrammatic. For simplicity, Quaternary deposits are not distinguished in the geologic section. Schematic based on a nearby cross section in Love and others, 2003.

Figure 5. Generalized geology and geologic section in the vicinity of the Jackson Hole Airport, Jackson, Wyoming.—Continued

Table 4. Results of groundwater-velocity calculations using hydraulic conductivity values of the Snake River alluvial aquifer at Teton Village and the Aspens.

[*K*, horizontal hydraulic conductivity; ft/d, feet per day; *dh*, change in hydraulic head; *d*l, change in linear distance; ft/ft, foot per foot; *n*, porosity; ft/d, feet per day]

Date	Horizontal hydraulic conductivity (*K*) (ft/d)	Average hydraulic gradient (*dh/dl*) (ft/ft)	Porosity from Heath, 1983 (*n*) (percent)	Velocity estimate (ft/d)
Hydraulic conductivity at Teton Village (Nelson Engineering, 1992)				
September 2008	2,900	0.0067	0.3	65
October 2008	2,900	.0067	.3	65
March 2009	2,900	.0068	.3	66
May 2009	2,900	.0064	.3	62
June 2009	2,900	.0064	.3	62
Average	2,900	.0066	.3	64
Hydraulic conductivity at the Aspens (Nelson Engineering, 1992)				
September 2008	1,200	0.0067	0.3	27
October 2008	1,200	.0067	.3	27
March 2009	1,200	.0068	.3	27
May 2009	1,200	.0064	.3	26
June 2009	1,200	.0064	.3	26
Average	1,200	.0066	.3	26

The replicate sample was analyzed for COD, major ions, trace elements, nutrients, DOC (table 11), VOCs, GRO (table 12), glycols, and DRO (table 13). RPDs were calculated only for constituents with detections, which for this replicate sample included only inorganic constituents. RPDs were not calculated for inorganic sample pairs where one value was reported as less than the MRL or LRL and the other value was reported as greater than the MRL or LRL or was estimated. RPDs for most constituents were less than or equal to 10 percent (table 14, in back of report), indicating results were reproducible for most inorganic constituents. Five of the constituents had RPDs greater than 10 percent (bromide, ammonia, phosphorus, total nitrogen and iron; table 14); however, both the environmental and replicate sample concentrations were very small, causing small concentration differences to result in relatively large RPDs.

Although important in the quality-assurance/quality-control process, the collection and analysis of blanks and replicates were not the only methods used to assess the quality of the dataset. The accuracy of major-ion analyses was checked by calculating a cation-anion balance. The sum of concentrations of dissolved cations in milliequivalents per liter should equal the sum of concentrations of dissolved anions in milliequivalents per liter (Hem, 1985). The percent difference between the sum of concentrations of cations and anions in milliequivalents per liter was calculated using equation 9.

$$Percent\ difference = \left(\frac{sum\ of\ dissolved\ cations - sum\ of\ dissolved\ anions}{sum\ of\ dissolved\ cations + sum\ of\ dissolved\ anions} \right) \times 100 \qquad (9)$$

The calculated cation-anion balances for all groundwater samples were less than 5 percent and were considered to be of good quality.

Table 5. Physical properties, inorganic constituents, and other constituents analyzed in groundwater samples in the field or at the U.S. Geological Survey National Water Quality Laboratory. Samples collected at Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

[--, not applicable; MRL, minimum reporting level; LRL, laboratory reporting level; IRL, interim reporting level]

Physical property or inorganic constituent	Unit of measure	Reporting level (unit of measure)	Reporting level type
Physical properties (field analyses)			
Dissolved oxygen	milligrams per liter	--	--
pH	standard units	--	--
Specific conductance	microsiemens per centimeter at 25 degrees Celsius	--	--
Water temperature	degrees Celsius	--	--
Turbidity	nephelometric tubidity ratio units	--	--
Major ions and related water-quality characteristics			
Dissolved solids, residue on evaporation at 180 degrees Celsius	milligrams per liter	10	MRL
Calcium, dissolved	milligrams per liter	.044	LRL
Magnesium, dissolved	milligrams per liter	.016	LRL
Potassium, dissolved	milligrams per liter	.064	LRL
Sodium, dissolved	milligrams per liter	.1	LRL
Alkalinity, dissolved	milligrams per liter, as calcium carbonate	--	--
Bicarbonate, dissolved	milligrams per liter	--	--
Hardness, total	milligrams per liter, as calcium carbonate	--	--
Bromide, dissolved	milligrams per liter	.02	IRL
Chloride, dissolved	milligrams per liter	.12	LRL
Fluoride, dissolved	milligrams per liter	.08	LRL
Silica, dissolved	milligrams per liter	.058	LRL
Sulfate, dissolved	milligrams per liter	.18	LRL
Nutrients			
Ammonia, dissolved	milligrams per liter as nitrogen	.02	LRL
Nitrate plus nitrite, dissolved	milligrams per liter as nitrogen	.04	LRL
Nitrite, dissolved	milligrams per liter as nitrogen	.002	IRL
Orthophosphate, dissolved	milligrams per liter as phosphorus	.008	LRL
Phosphorus, total	milligrams per liter	.008	LRL
Nitrogen, total	milligrams per liter	.1	LRL
Trace elements			
Iron, dissolved	micrograms per liter	6	LRL
Manganese, dissolved	micrograms per liter	.2	LRL
Other analyses			
Chemical oxygen demand (COD)	milligrams per liter	10	MRL
Organic carbon, dissolved (DOC)	milligrams per liter	.66	LRL

Table 6. Volatile organic compounds, gasoline-range organics, glycols, and diesel-range organics analyzed in groundwater samples at TestAmerica Laboratories, Inc., laboratory reporting levels, and related U.S. Environmental Protection Agency drinking water standards.

[Compounds detected during study are shown in **bold** type. All units in micrograms per liter (µg/L) unless otherwise noted. USEPA, U.S. Environmental Protection Agency; mg/L, milligrams per liter; --, not applicable; DRO, diesel-range organics; C10–C32 and C10–C36, ranges of carbon compounds included in the analysis]

Compound	Common name/synonym	Chemical Abstract Service (CAS) registry number[1]	Laboratory reporting level	USEPA standard or health advisory
		Volatile organic compounds		
1,1-Dichloroethane	Ethylidene dichloride	75-34-3	0.50	--
1,1-Dichloroethene	Vinylidene chloride	75-35-4	.50	[2]7
1,1-Dichloropropene	--	563-58-6	.50	--
1,1,1-Trichloroethane	Methylchloroform	71-55-6	.50	[2]200
1,1,1,2-Tetrachloroethane	--	630-20-6	.50	[3]100
1,1,2-Trichloroethane	Vinyl trichloride	79-00-5	.50	[2]5
1,1,2,2-Tetrachloroethane	--	79-34-5	.50	[3]20
1,2-Dibromo-3-chloropropane	DBCP, Nemagon	96-12-8	.50	[2].2
1,2-Dibromoethane	Ethylene dibromide (EDB)	106-93-4	.50	[2].05
1,2-Dichlorobenzene	*o*-Dichlorobenzene	95-50-1	.50	[2]600
1,2-Dichloroethane	Ethylene dichloride	106-06-2	.50	[2]5
1,2-Dichloropropane	Propylene dichloride	78-87-5	.50	[2]5
1,2,3-Trichlorobenzene	--	87-61-6	.50	--
1,2,3-Trichloropropane	Allyl trichloride	96-18-4	.50	[4]4
1,2,4-Trichlorobenzene	--	120-82-1	.50	[2]70
1,2,4-Trimethylbenzene	Pseudocumene	95-63-6	.50	--
1,3-Dichlorobenzene	*m*-Dichlorobenzene	541-73-1	.50	[4]600
1,3-Dichloropropane	Trimethylene dichloride	142-28-9	.50	--
1,3,5-Trimethylbenzene	Mesitylene	108-67-8	.50	--
1,4-Dichlorobenzene	*p*-Dichlorobenzene	106-46-7	.50	[2]75
2-Chlorotoluene	1-chloro-2-methylbenzene	95-49-8	.50	[4]100
2,2-Dichloropropane	--	594-20-7	.50	--
4-Chlorotoluene	1-chloro-4-methylbenzene	106-43-4	.50	[4]100
4-Isopropyltoluene	4-Cymene	99-87-6	.50	--
Benzene	Pyobenzol	75-43-2	.50	[2]5
Bromobenzene	Phenyl bromide	108-86-1	.50	[4]70
Bromochloromethane	Methylene chlorobromide	74-97-5	.50	[4]90
Bromodichloromethane	Dichlorobromomethane	75-27-4	.50	[2,5]80
Bromoform	Tribromomethane	75-25-2	.50	[2,5]80
Bromomethane	Methyl bromide	74-83-9	1.0	[4]10
Carbon tetrachloride	Tetrachloromethane	56-23-5	.50	[2]5
Chlorobenzene	Monochlorobenzene	108-90-7	.50	[2]100
Chloroethane	Ethyl chloride	75-00-3	1.0	--
Chloroform	Carbon trichloride	67-66-3	.50	[2,5]80
Chloromethane	Methyl chloride	74-87-3	.50	[4]30
cis-1,2-Dichloroethene	(Z)-1,2-Dichloroethene	156-59-2	.50	[2]70
cis-1,3-Dichloropropene	(Z)-*cis*-1,3-Dichloropropene	542-75-6	.50	[3]40
Dibromochloromethane	Chlorodibromomethane	124-48-1	.50	[2,5]80
Dibromomethane	Methylene dibromide	74-95-3	.50	--

Table 6. Volatile organic compounds, gasoline-range organics, glycols, and diesel-range organics analyzed in groundwater samples at TestAmerica Laboratories, Inc., laboratory reporting levels, and related U.S. Environmental Protection Agency drinking water standards.—Continued

[Compounds detected during study are shown in **bold** type. All units in micrograms per liter (µg/L) unless otherwise noted. USEPA, U.S. Environmental Protection Agency; mg/L, milligrams per liter; --, not applicable; DRO, diesel-range organics; C10–C32 and C10–C36, ranges of carbon compounds included in the analysis]

Compound	Common name/synonym	Chemical Abstract Service (CAS) registry number[1]	Laboratory reporting level	USEPA standard or health advisory
Volatile organic compounds—Continued				
Dichlorodifluoromethane	CFC-12, Freon 12	75-71-8	0.50	[4]1,000
Ethylbenzene	Phenylethane	100-41-4	.50	[2]700
Hexachlorobutadiene	Perchlorobutadiene	87-68-3	.50	[4]90
Isopropylbenzene	(1-methylethyl)benzene	98-82-8	.50	--
Methylene chloride	Dichloromethane	75-09-2	.50	[2]5
Methyl tert-butyl ether	MTBE	1634-04-4	.50	[6]20–40
Naphthalene	Naphthene	91-20-3	1.0	[4]100
n-Butylbenzene	1-Phenylbutane	104-51-8	.50	--
n-Propylbenzene	Isocumene	103-65-1	.50	--
o-Xylene	1,2-Dimethylbenzene	95-47-6	.50	[2,7]10,000
sec-Butylbenzene	(1-Methylpropyl)benzene	135-98-8	.50	--
Styrene	Ethenylbenzene	100-42-5	.50	[2]100
tert-Butylbenzene	(1,1-Dimethylethyl)benzene	98-06-6	.50	--
tert-Butyl ethyl ether	Ethyl *tert*-butyl ether (ETBE)	637-92-3	.50	--
Tetrachloroethene	Perchloroethene (PCE), tetrachloroehtylene	127-18-4	.50	[2]5
Toluene	Methylbenzene	108-88-3	.50	[2]1,000
trans-1,2-Dichloroethene	(E)-1,2-Dichloroethene	156-60-5	.50	[2]100
trans-1,3-Dichloropropene	(E)-1,3-Dichloropropene	10061-02-6	.50	[3]40
Trichloroethene	TCE, trichloroethylene	79-01-6	.50	[2]5
Trichlorofluoromethane	CFC-11, Freon 11	75-69-4	.50	[4]2,000
Vinyl chloride	Choroethene	75-01-4	.50	[2]2
Xylene, total	Dimethylbenzene	1330-20-7	.50	[2,7]10,000
Gasoline-range organics	GRO	--	10	--
Glycols and diesel-range organics				
Diethylene glycol	Ethanol, 2,2'-oxybis-	111-46-6	25 mg/L	--
Diethylene glycol monobutyl ether	Ethanol, 2-butoxy-	111-76-2	10 mg/L	--
Ethylene glycol	1,2-Ethanediol	107-21-1	25 mg/L	--
Propylene glycol	1,2-Propanediol	57-55-6	25 mg/L	--
Triethylene glycol	Triglycol	112-27-6	25 mg/L	--
DRO, C10–C32	--	--	25 mg/L	--
DRO, C10–C36	--	--	25 mg/L	--

[1] This report contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. The CAS recommends the verification of the CAS Registry Numbers through CAS Client Services℠.

[2] U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2009b).

[3] U.S. Environmental Protection Agency Risk-Specific Dose at 10^{-4} Cancer Risk (RSD4) (U.S. Environmental Protection Agency, 2009b, 2010).

[4] U.S. Environmental Protection Agency Lifetime Health Advisory Level (HAL) (U.S. Environmental Protection Agency, 2009b).

[5] Total for all trihalomethanes cannot exceed 80 µg/L (U.S. Environmental Protection Agency, 2009b).

[6] The U.S. Environmental Protection Agency Drinking-Water Advisory ranges from 20 to 40 µg/L (U.S. Environmental Protection Agency, 2009b).

[7] The total for all xylenes combined cannot exceed 10,000 µg/L (U.S. Environmental Protection Agency, 2009b).

Hydrogeology

The study area lies within Jackson Hole, a geological depression, or "structural basin," formed by a large block of the Earth's crust that dropped down along a fault at the base of the Teton Range with its hinge point in the highlands to the east (Love and Reed, 1971). Jackson Hole is bounded on the west by the Teton Range, to the south by the Snake River and Hoback Ranges, to the east by the Gros Ventre Range, and to the north-northeast by the Washakie and Absaroka Ranges which extend north along the eastern boundary of both Grand Teton and Yellowstone National Parks. The geology around the study area is complex with strata ranging from Precambrian basement rocks to Quaternary unconsolidated surficial deposits (fig. 5).

Surficial deposits in the vicinity of the JHA consist of unconsolidated Quaternary gravel, pediment, and fan deposits, whereas surficial deposits at the airport are predominantly terrace gravels underlain by siltstone deposits of the Chugwater and Dinwoody Formations (fig. 5) (Love and others, 2003). Lithologic logs of wells installed for this study indicate the Quaternary deposits range in size from sand to cobble with most deposits primarily consisting of coarse gravel (Jack Weber, Weber Well Drilling, written commun., 2009).

Water levels in unconfined aquifers like the Snake River alluvial aquifer commonly vary seasonally. Graphical representations of water levels (hydrographs) measured during the study are presented in figure 6 for each of the new monitoring wells, except well JH–3D for which the transducer did not operate properly and only discrete water levels are presented. These hydrographs indicate that the water levels in the Snake River alluvial aquifer vary seasonally, reflecting a pattern influenced by precipitation driven recharge (primarily snowmelt) during April–June and irrigation-induced recharge during June–October and minimal aquifer recharge during November–March. The water table was at its lowest level in mid-April 2009, at the beginning of spring, and at its highest level in mid-July 2009 at the end of the peak of snowmelt. The water level increased about 12 to 14 ft between April and July 2009 (fig. 6). Well JH–1 consistently had the highest water-level altitudes (table 2, fig. 6) ranging from a low, discrete measurement of 6,375.81 ft above NAVD 88 in March to a high, discrete measurement of 6,385.11 ft above NAVD 88 in June. Well JH–2 had the lowest water-level altitudes (table 2, fig. 6), with discrete measurements ranging from 6,353.06 ft above NAVD 88 to 6,365.99 ft above NAVD 88. On average, the water-table altitude between wells JH–1 and JH–2 (a distance of about 3,542 ft) dropped a little more than 22 feet.

The direction of groundwater movement and the hydraulic gradient were determined using techniques described in the "Methods of Data Collection and Analysis" section of this report. The direction of groundwater flow is generally to the west-southwest, assuming groundwater flow is perpendicular to water-table contours (figs. 4*A–D*). Seasonal variations in the direction of groundwater flow appear to be minimal. Horizontal hydraulic gradients were calculated for several combinations of monitoring wells and ranged from 0.0061 foot per foot (ft/ft) to 0.0069 ft/ft, with an average of 0.0066 ft/ft (table 3). The relative spatial uniformity of calculated hydraulic gradients across the airport indicates that the hydraulic gradient of the aquifer at the airport is relatively uniform, in spite of regular pumping of production wells in the study area.

Monitoring wells JH–3 and JH–3D (well cluster 3) were located adjacent to each other and completed at different depths to evaluate the hydraulic potential (differences in hydraulic head or groundwater level) for vertical groundwater flow at the location. There was a relatively small vertical gradient in the Snake River alluvial aquifer at well cluster 3. Calculations of the vertical hydraulic gradient at well cluster 3 indicated this gradient varied throughout the year, ranging from a high of 0.005 ft/ft in March and May to a low of 0.0009 ft/ft in June, with an average of 0.0037 ft/ft. The decreasing water-level altitude with depth (table 2) indicates a hydraulic potential for downward groundwater flow in the Snake River alluvial aquifer at this location. The ratio of the average horizontal hydraulic gradient to the average vertical hydraulic gradient is 1.78. This means that for every 1.78 ft water moves horizontally, water is also likely to move 1 ft vertically (downward), assuming horizontal and vertical conductivities of aquifer materials are the same.

Horizontal groundwater velocities were calculated for each airport visit using hydraulic conductivity values from both Teton Village and the Aspens (table 4) and an estimated porosity as described previously in the "Methods of Data Collection and Analysis" section. The groundwater velocity was estimated as high as 66 ft/d using average hydraulic gradients calculated for March 2009 and the hydraulic conductivity for Teton Village; the groundwater velocity was estimated to be as low as 26 ft/d using the average hydraulic gradient calculated for May and June 2009 and the hydraulic conductivity for the Aspens (table 4). Using an estimated linear distance of 3,540 feet from well JH–1 to well JH–2, it would take approximately 53 to 138 days for water in the aquifer to travel from well JH–1 (upgradient from airport operations) to the southwest boundary of the airport.

The calculated rates of horizontal groundwater velocity (table 4) are estimates and could vary at different locations at the JHA. Horizontal hydraulic conductivity differs from point to point and along a flow path because lithology is typically heterogeneous and anisotropic. The actual groundwater velocity may be different between two points depending on the heterogeneity of the aquifer. The direction of flow also might not be perpendicular to water-table contours as shown in figures 4 *A–D* (due to anisotropy) and likely is not in a straight line. These factors, and the estimated porosity value chosen, could substantially affect the groundwater velocity estimates.

Groundwater velocity estimates (table 4) only describe movement of groundwater in the Snake River alluvial aquifer and are not applicable to soluble contaminant movement. Solute movement through saturated media, such as an aquifer, is influenced by advection as well as other physical processes such as diffusion and dispersion and chemical processes such as sorption, precipitation, oxidation and reduction, and biodegradation (Fetter, 1993). Consequently, some solutes may move at a rate much slower than groundwater flow through the aquifer.

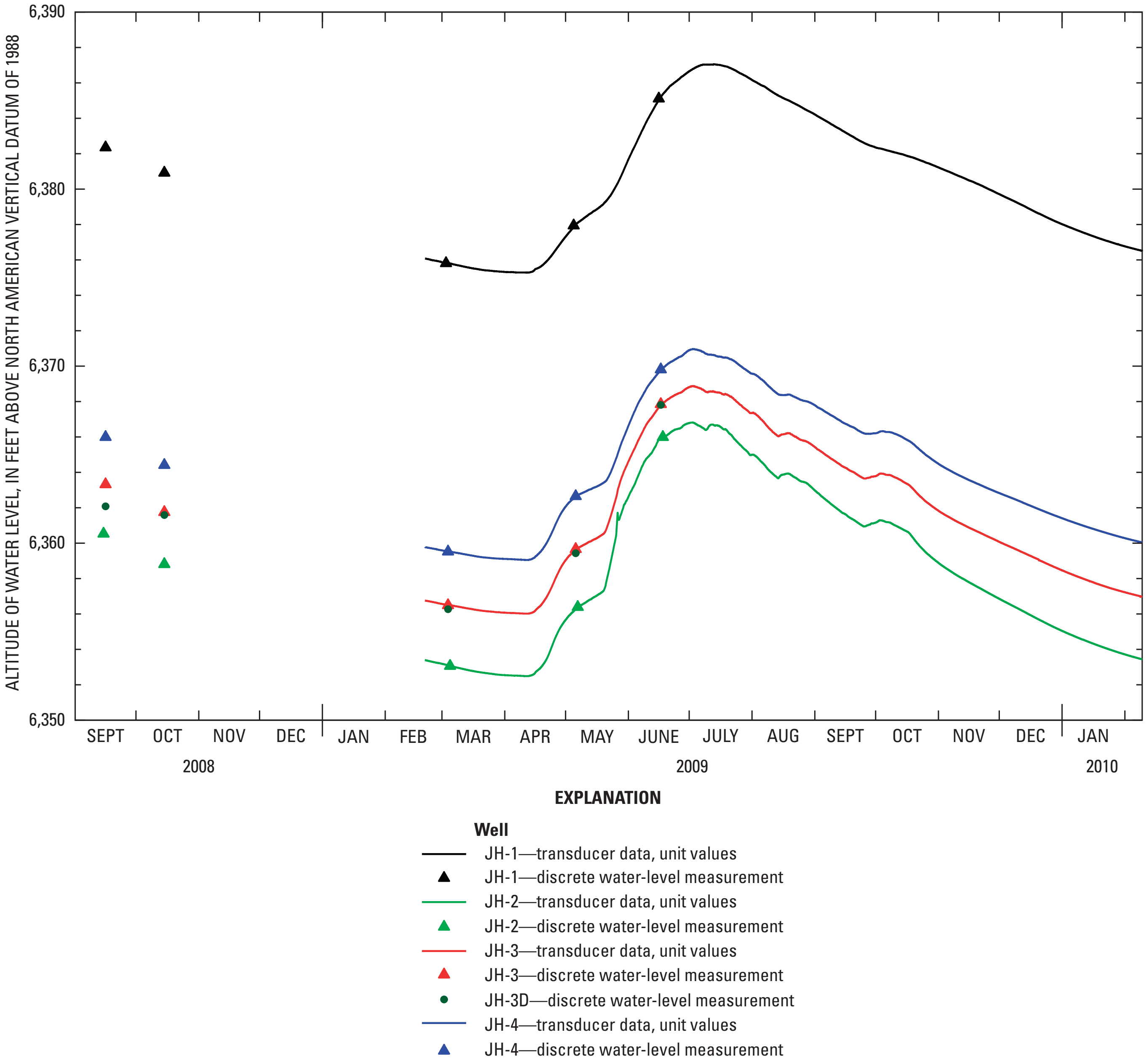


Figure 6. Water levels for selected wells sampled at the Jackson Hole Airport, Jackson, Wyoming, September 2008–February 2010.

Water Quality

The groundwater in the study area was generally of good quality. No constituents were detected at concentrations exceeding the USEPA Maximum Contaminant Levels (MCLs). However, reduction/oxidation (redox) measurements indicate oxygen-poor conditions in two wells (JH–3 and JH–3D). Many anthropogenic constituents were included in sample analyses and only DRO compounds were detected (in qualified concentrations).

Chemical Composition

Natural waters, such as groundwater, contain a wide variety of dissolved substances. These dissolved substances are derived from many sources, a few of which include atmospheric gases, weathering and erosion of rocks and soils the water has contacted, solution and precipitation of minerals, and biochemical processes (Hem, 1985). Many common physical and chemical properties were measured during this study. These properties are summarized in table 7 with all physical property data presented in table 11 and table 8, included in the "Supplemental Information" section at the back of this report. The properties that best describe the groundwater composition in the Snake River alluvial aquifer are described further in this section of the report.

The groundwater was near neutral to alkaline (pH values ranged from 7.4 to 8.1) with concentrations of alkalinity as calcium carbonate ($CaCO_3$) ranging from 109 to 210 milligrams per liter (mg/L). Groundwater at the airport was freshwater, having dissolved-solids concentrations (ranging from 140 to 255 mg/L) less than 1,000 mg/L (Heath, 1983, p. 65, table 2). Specific-conductance values were relatively low, ranging from 234 to 420 microsiemens per centimeter at 25 degrees Celsius (µS/cm). These values were similar to the range of values for dissolved solids (91 to 538 mg/L) and specific conductance (112 to 863 µS/cm) reported by Nolan and Miller (1995) for water from wells producing from Quaternary alluvium, colluvium, and gravel, pediment, fan, and glacial deposits in Teton County, Wyoming. Dissolved-solids concentrations and specific-conductance values in samples from wells at JHA were highest along the southwest boundary of the airport (wells JH–2, JH–3, and JH–3D) and generally followed a seasonal pattern, with concentrations and values increasing with recharge during March–June and then decreasing with reduced recharge during the rest of the year (tables 11 and 8). Calculated hardness concentrations ranged from 110 to 200 mg/L (as $CaCO_3$), making water at the airport moderately hard (61 to 120 mg/L as $CaCO_3$) to very hard (121 to 180 mg/L as $CaCO_3$) (Hem, 1985, p. 159).

The major ion composition of groundwater in the study area largely resulted from chemical reactions between water and sediments in the soil and aquifer and, to a lesser extent, from ions in precipitation. The relative proportions of the major cations (calcium, magnesium, potassium, and sodium) and the major anions (bicarbonate, carbonate [based on alkalinity], chloride, fluoride, and sulfate) were used to describe the water type at each well. The average ion composition for samples from each well was plotted on a trilinear diagram (fig. 7). The triangles on the bottom left and right show the relative percentages of cations and anions, whereas the quadrangle in the center is a combination of all the ion data (Piper, 1944). Calcium was the dominant cation, and bicarbonate was the dominant anion; thus, the water type for all the wells sampled at the airport was calcium bicarbonate (fig. 7).

Redox Conditions

The chemical quality of groundwater commonly is affected by redox processes (Chapelle and others, 2009). Although most groundwater at the JHA was oxic (oxygenated), two wells (JH–3 and JH–3D) were found to have reducing (oxygen-poor) conditions. Reduction reactions generally are sequential and occur in a specific order as long as reactants are available. The sequence starts with the reduction of oxygen and progresses through nitrate reduction, reduction of manganese oxides, reduction of iron oxides, sulfate reduction, and finally methanogenesis (Appelo and Postma, 2005; U.S. Geological Survey, 2009). Each of these reactions either causes the disappearance of a reactant or the appearance of a reaction product, changing the groundwater composition. This section presents results for dissolved oxygen, nutrients, trace elements, dissolved gases, DOC, and COD in an effort to highlight the effect reducing conditions have had on the groundwater composition at wells JH–3 and JH–3D.

The dissolved-oxygen concentration was measured each time a well was sampled and was the first indication of the redox condition of water in each well. Dissolved-oxygen concentrations measured using a field meter ranged from 0.13 mg/L to 8.1 mg/L (table 7, table 8), with a median concentration of 6.8 mg/L. Although the water sampled in most of the wells was oxic, dissolved-oxygen concentrations indicative of reducing (anoxic or anaerobic) conditions (a dissolved-oxygen concentration of less than 1 mg/L was considered indicative of reducing conditions for this study) were measured in water from wells JH–3 and JH–3D (fig. 8). Dissolved-oxygen concentrations in oxic water from the other wells generally averaged greater than 7.0 mg/L in all the wells except JH–2, which had concentrations ranging from 6.0 to 6.7 mg/L. In addition to field measurements, dissolved-oxygen concentrations also were measured in water from wells JH–3 and JH–3D using spectrophotometry and gas chromatography. These methods consistently reported slightly lower concentrations of dissolved oxygen than the field meter (table 8).

Nutrients were detected at low concentrations in all 27 samples, with all concentrations less than applicable USEPA standards (table 11; table 7). Dissolved nitrite as nitrogen (nitrite) was not detected in any samples, whereas total nitrogen was detected in all of the samples except those from well JH–3D. Dissolved nitrate plus nitrite as nitrogen (referred

Table 7. Summary of physical properties and inorganic constituent data for groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

[USEPA, U.S. Environmental Protection Agency; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTRU, nephelometric turbidity ratio units; DWA, Drinking Water Advisory; $CaCO_3$, calcium carbonate; HCO_3, bicarbonate; MCL, Maximum Contaminant Level; E, estimated concentration; <, less than; HAL, Health Advisory Level]

Physical property or constituent	Number of detections/ number of samples	Minimum value or concentration	Median value or concentration[1]	Maximum value or concentration	USEPA drinking-water standards[1,2] or health advisories[3,4]
Physical properties					
Dissolved oxygen (mg/L)	27/27	0.13	6.8	8.1	--
pH, unfiltered, field (standard units)	27/27	7.4	7.9	8.1	[2]6.5–8.5 (SMCL)
Specific conductance, field (µS/cm)	27/27	234	295	420	--
Water temperature, field (°C)	27/27	7.3	8.8	11.6	--
Turbidity (NTRU)	27/27	.2	.7	4.6	[2]5.0 (SMCL)
Major ions and related water-quality characteristics, in milligrams per liter, dissolved unless otherwise noted					
Dissolved solids	27/27	140	174	255	[2]500 (SMCL)
Calcium	27/27	32.5	40.4	62.8	--
Magnesium	27/27	6.63	8.13	11.8	--
Potassium	27/27	1.77	1.97	2.29	--
Sodium	27/27	5.86	7.28	8.73	[4]30–60 (DWA)
Alkalinity, field, as $CaCO_3$	27/27	109	123	210	--
Bicarbonate	27/27	133	150	256	--
Hardness, total, as $CaCO_3$	27/27	110	130	200	--
Bromide	25/27	E.01	.02	.03	--
Chloride	27/27	3.06	4.00	11.20	[2]250 (SMCL)
Fluoride	27/27	.33	.41	.48	[3]4 (MCL), [2]2 (SMCL)
Silica	27/27	17.5	18.8	21.9	
Sulfate	27/27	1.65	10.7	13	[2]250 (SMCL), [4]500 (DWA)
Nutrients, in milligrams per liter, dissolved unless otherwise noted					
Ammonia, as nitrogen	4/27	E0.012	0.02	0.388	[5]30 (HAL)
Nitrate plus nitrite, as nitrogen	19/27	E.04	.22	1.27	[3]10 (MCL)
Nitrite, as nitrogen	0/27	<.002	<.002	<.002	[3]1 (MCL)
Orthophosphate, as phosphorus	27/27	.011	.019	.067	--
Phosphorus, total, as phosphorus	26/27	.010	.015	.076	--
Total nitrogen (nitrate + nitrite + ammonia + organic-nitrogen), unfiltered	21/27	E.08	0.22	1.32	--
Trace elements, in micrograms per liter					
Iron	17/27	E2	E3	563	[2]300 (SMCL)
Manganese	22/27	<.2	.4	1,740	[2]50 (SMCL)
Other analyses					
Chemical oxygen demand, unfiltered	0/27	<10	<10	<10	--
Dissolved organic carbon	27/27	E.3	E.3	3.1	--

[1] Median values were determined using detections and non-detections.

[2] U.S. Environmental Protection Agency Secondary Maximum Contaminant Level (SMCL) (U.S. Environmental Protection Agency, 2009b).

[3] U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2009b).

[4] The U.S. Environmental Protection Agency Drinking-Water Advisory (DWA) ranges from 20 to 40 µg/L (U.S. Environmental Protection Agency, 2009b).

[5] U.S. Environmental Protection Agency Lifetime Health Advisory Level (HAL) (U.S. Environmental Protection Agency, 2009b).

Table 8. Physical properties measured in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

[USGS, U.S. Geological Survey; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTRU, nephelometric turbidity ratio units; --, no data collected]

USGS site-identification number	Well identifier	Date	Sample time (24 hour)	Air temperature (°C)	Dissolved oxygen (mg/L)	pH, field (standard units)	Specific conductance, field (µS/cm)	Water temperature (°C)	Turbidity (NTRU)
433615110440001	JH–1	10/15/2008	1630	10.0	7.8	8.0	248	7.3	0.3
		03/03/2009	1345	10.0	8.1	8.0	244	9.2	4.6
		05/05/2009	1700	10.0	7.9	8.0	247	8.2	1.0
		06/16/2009	1530	19.0	8.1	8.0	270	9.9	.7
433551110443501	JH–2	10/17/2008	1100	8.5	6.0	7.7	318	10.0	3.0
		03/05/2009	1020	–1.0	6.7	7.8	295	7.5	1.0
		05/07/2009	1030	8.0	6.7	7.6	341	9.6	1.0
		06/18/2009	0940	11.0	6.4	7.5	420	9.2	.7
433603110443501	JH–3	10/16/2008	1330	11.0	.4	7.4	394	9.5	1.4
		03/05/2009	1200	8.0	.3	7.4	336	8.2	2.0
		03/05/2009	1230	8.0	[1].2	7.4	353	8.8	.5
		03/05/2009	1630	16.0	[1]1.1	7.4	410	11.6	.6
433603110443502	JH–3D	10/16/2008	1630	11.5	.7	7.5	340	8.5	1.0
		03/05/2009	1500	7.5	.2	7.7	296	7.6	4.0
		03/05/2009	1600	11.0	[2].1	7.6	301	8.1	.7
		03/05/2009	1345	19.0	[3].5	7.6	344	9.5	.7
433613110443501	JH–4	10/16/2008	1000	7.5	7.2	8.0	237	9.0	1.0
		03/05/2009	0950	--	--	--	--	--	--
		03/05/2009	1030	10.5	7.1	8.0	234	9.7	2.3
		03/05/2009	0945	17.0	8.0	8.0	264	10.1	.3
433607110440901	Hangar 1	10/17/2008	1630	11.0	7.8	8.1	248	8.4	.3
		03/05/2009	1030	9.0	6.9	8.1	248	7.6	.2
		03/05/2009	1030	5.0	7.1	8.1	247	7.7	.6
		03/05/2009	1010	13.5	7.5	8.1	264	8.7	.2
433556110441601	Hangar 5	10/17/2008	1400	10.5	7.0	7.9	273	10.3	.3
		03/05/2009	1300	–0.5	7.2	8.0	266	8.0	.2
		03/05/2009	1345	9.5	6.8	7.9	295	8.8	2.2
		03/05/2009	1250	17.5	6.8	7.9	314	9.6	.2
433553110443601	Irrigation ditch	06/18/2009	1050	12.0	9.3	8.5	259	10.4	--

[1] Dissolved-oxygen concentration measured by spectrophotometer was 0.17 mg/L.

[2] Dissolved-oxygen concentration measured by spectrophotometer was 0.11 mg/L.

[3] Dissolved-oxygen concentration measured by spectrophotometer was 0.19 mg/L.

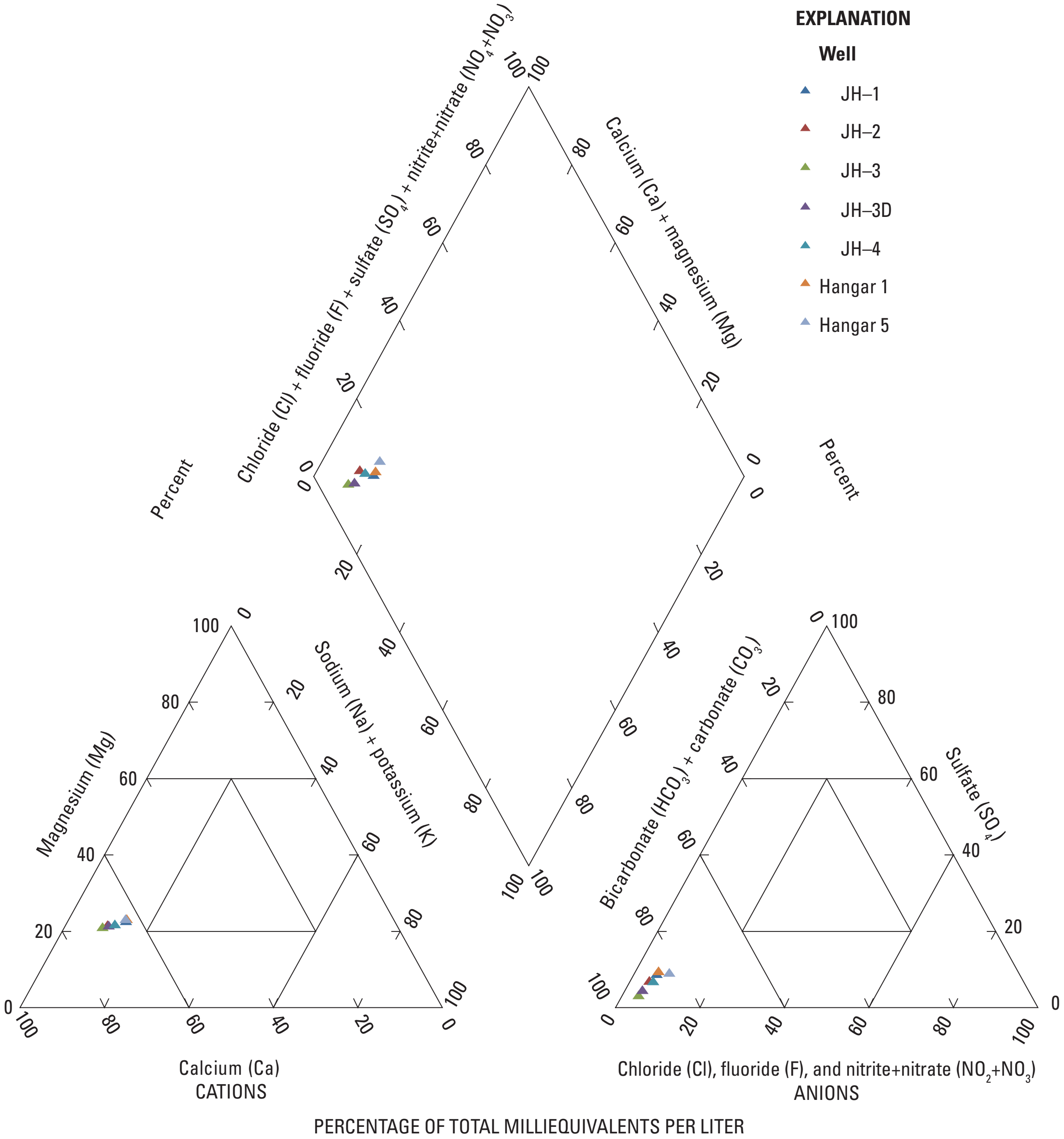


Figure 7. Trilinear diagram showing proportional mean major-ion composition for groundwater samples collected from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

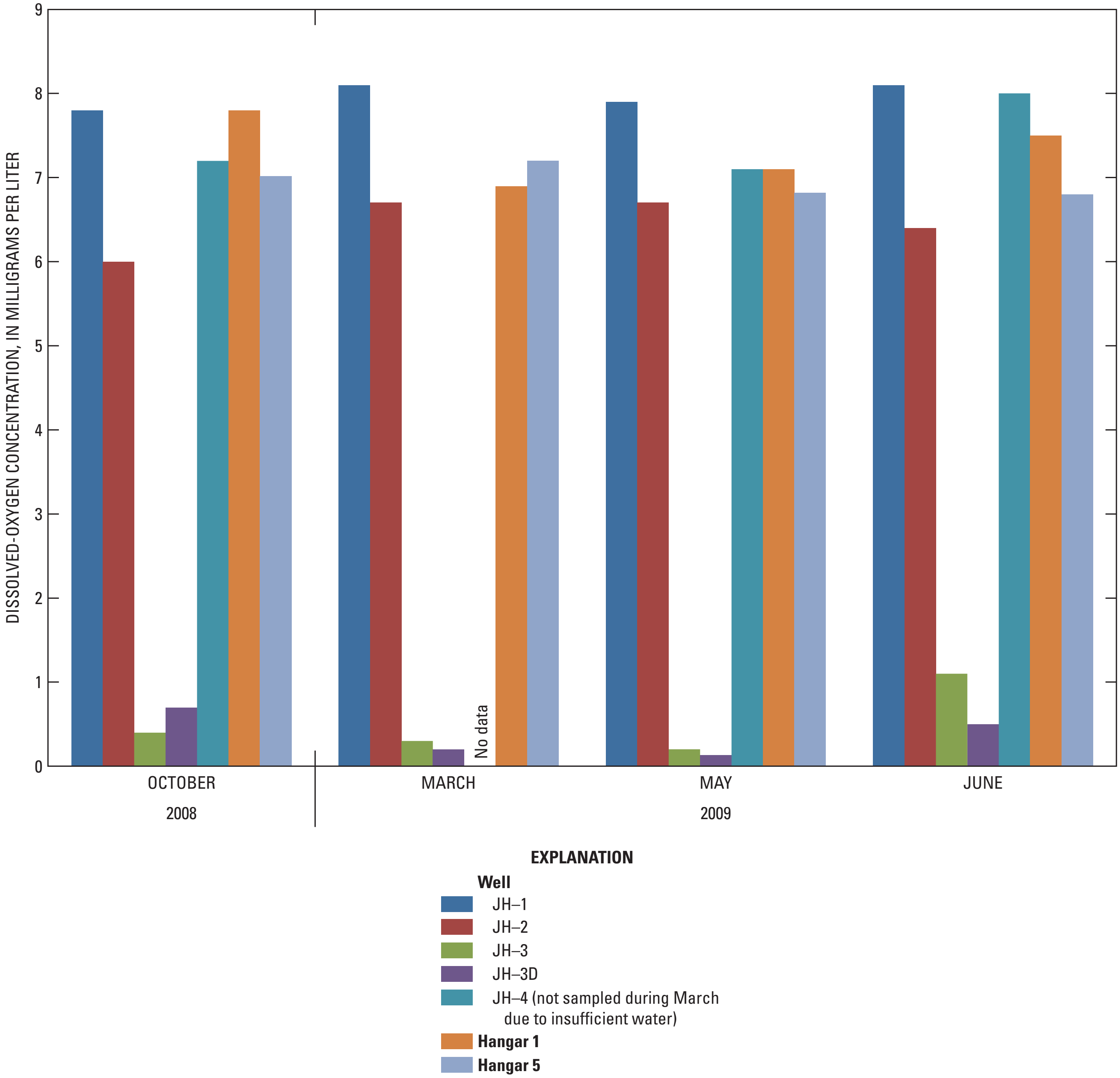


Figure 8. Dissolved-oxygen concentrations for groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

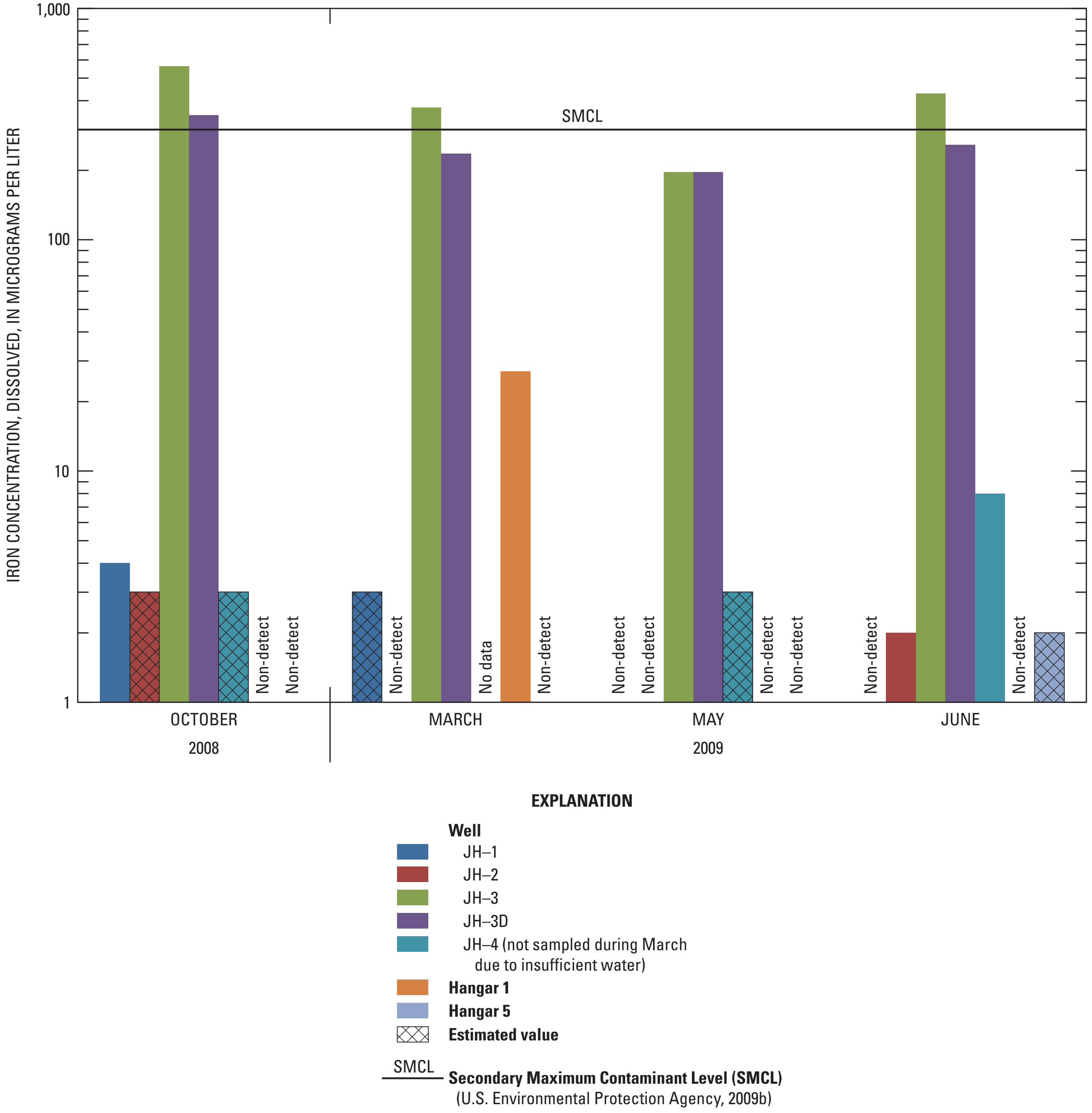


Figure 9. Dissolved iron concentrations for groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

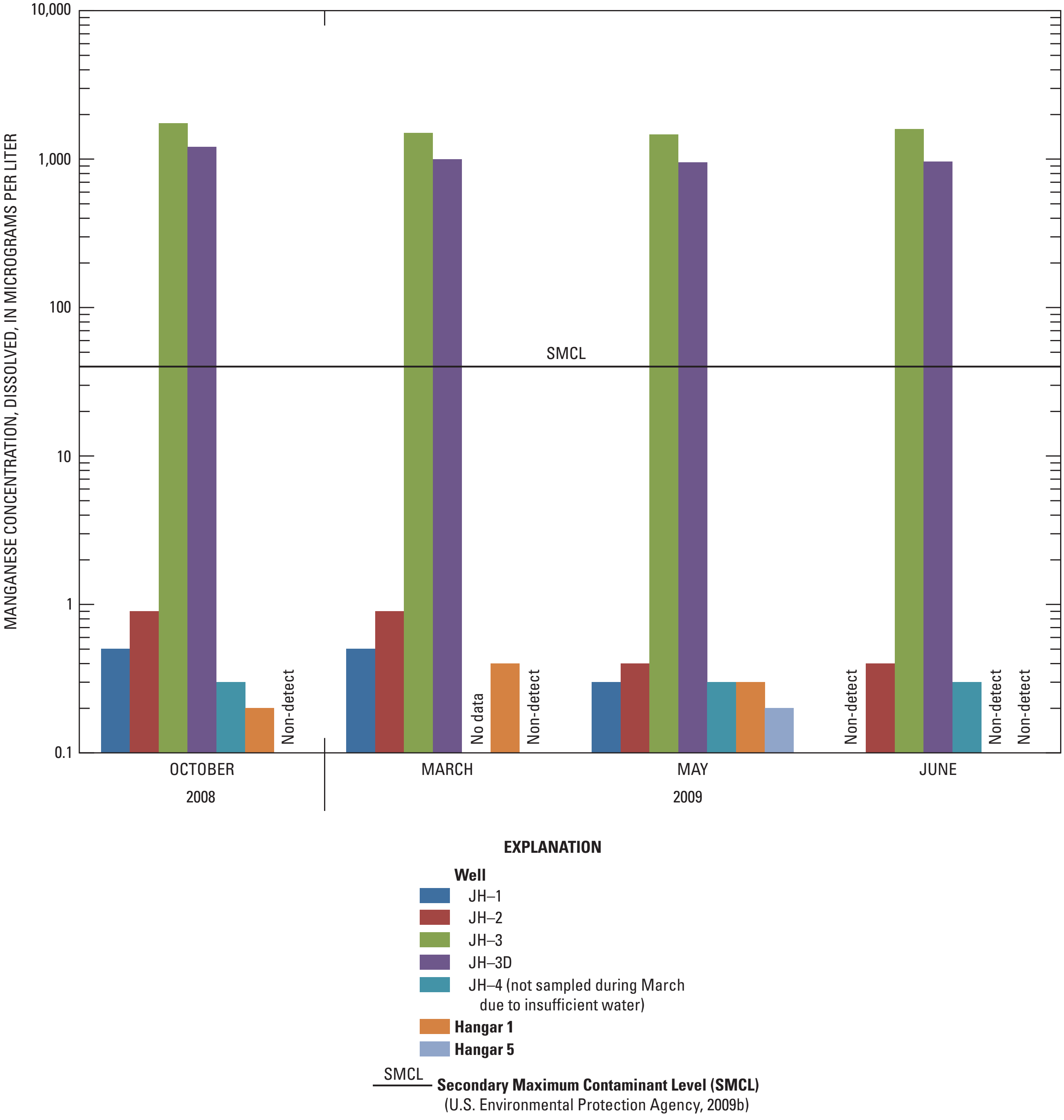


Figure 10. Dissolved manganese concentrations for groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

to as nitrate in this report) was detected in samples from all wells except JH–3 and JH–3D, indicating nitrate was the primary nitrogen species in the alluvial aquifer. Ammonia as nitrogen was detected in samples from wells JH–3 and JH–3D. Nitrate can be reduced by bacteria to nitrous oxide, ammonia, and nitrogen gas (Hem, 1985) when exposed to anaerobic conditions; therefore, the occurrence of ammonia instead of nitrate is another indicator of reducing conditions at wells JH–3 and JH–3D. Two samples collected during June 2009 had higher concentrations of nitrate (1.27 mg/L at well JH–2 and 0.97 mg/L at well Hangar 5) and total nitrogen (1.32 mg/L at well JH–2 and 0.98 mg/L at well Hangar 5) than were detected in samples from other airport wells. These elevated concentrations could be a result from these wells being directly downgradient from the septic leach field at the airport (fig. 4). The elevated nitrate concentrations are not alarming as they are slightly greater than the median concentration (0.69 mg/L as nitrogen) reported for nitrite plus nitrate in groundwater samples from Quaternary deposits within Teton County, Wyoming (Nolan and Miller, 1995), and fall within the range of concentrations (0 to 2 mg/L) that can be expected in the absence of human influence (Mueller and Helsel, 1996). Total phosphorus and dissolved orthophosphate (as phosphorus) were detected in water from all seven wells (table 11; table 7). The median value for total phosphorus (0.015 mg/L) was slightly greater than the median value (0.010 mg/L) reported for total phosphorus in groundwater samples from Quaternary deposits within Teton County, Wyoming (Nolan and Miller, 1995) and was within the range (0 to 0.1 mg/L total phosphorus) of concentrations that Mueller and Helsel (1996) reported as could be expected in groundwater in the absence of human influence.

The dissolved trace elements iron and manganese were detected in samples from all seven wells and in 23 of the 27 samples collected. Concentrations of dissolved iron and manganese were low and near LRLs in samples collected from all wells except JH–3 and JH–3D. High concentrations of dissolved iron (196–563 µg/L) and manganese (947–1,740 µg/L) (table 11) are additional indicators of reducing conditions (McMahon and Chapelle, 2008). Dissolved-iron concentrations exceeded the USEPA Secondary Maximum Contaminant Level (SMCL) of 300 µg/L (U.S. Environmental Protection Agency, 2009b) in three out of four samples from well JH–3 and one out of four samples from well JH–3D (fig. 9; table 11; table 7). Dissolved-manganese concentrations in samples from wells JH–3 and JH–3D exceeded the SMCL in all samples collected during the four sampling events (fig. 10; table 11; table 7). The SMCLs are nonenforceable standards for constituents that may cause cosmetic effects (discoloration of teeth or skin) or esthetic effects (undesirable taste, odor, or color) in drinking water (U.S. Environmental Protection Agency, 2009b). Neither well JH–3 nor JH–3D is used to supply drinking water.

Several additional analyses were performed during May and June to better define the water-quality conditions at wells JH–3 and JH–3D. During June, samples for analyses of dissolved gases (argon, carbon dioxide, methane, nitrogen, and oxygen) were collected from wells JH–3 and JH–3D and, as a point of comparison, well JH–2, to assist in sourcing the water from the Snake River alluvial aquifer and better understand ongoing chemical and biological processes occurring at well cluster 3. During May and June, samples for analyses of ferrous iron (Fe^{2+}), hydrogen sulfide (H_2S) measured as sulfide (S^{2-}), and a more accurate quantification of low-level dissolved oxygen were collected to identify the types of redox processes occurring in the Snake River alluvial aquifer at and upgradient from well cluster 3 using a framework designed by McMahon and Chapelle (2008) and modified by Chapelle and others (2009).

The dissolved gas data provided an additional confirmation of reducing conditions at wells JH–3 and JH3–D. The concentrations of dissolved oxygen detected in the dissolved gas samples were even lower (0.2 mg/L in water from both wells JH–3 and JH–3D) (table 9) than those measured using the field meter (table 8). Additionally, methane gas (CH_4) was detected in samples from wells JH–3 (3.9 mg/L) and JH–3D (2.7 mg/L) and not in the sample from well JH–2 (table 9). Methane gas is produced by methanogenic microorganisms under anaerobic conditions (U.S. Geological Survey, 2009). These methanogenic conditions generally occur after all the other possible “reduction reactants” have been used up and indicate extremely reducing conditions.

Concentrations of the redox-sensitive species of ferrous iron (Fe^{2+}), sulfide (sum of H_2S, HS^-, and S^{2-}), and dissolved oxygen, along with nitrate (NO_3^-), manganous manganese (Mn^{2+}), sulfate (SO_4^{2-}), and methane (CH_4) were used to assess redox processes using the classification scheme of McMahon and Chapelle (2008). Because redox processes in groundwater tend to segregate into zones dominated by a single electron-accepting process, the redox framework uses the concentrations of the redox-sensitive species to assign the predominant redox process to groundwater samples. An automated spreadsheet program was used to assign the redox classification to each sample (table 10) (Jurgens and others, 2009). The October 2008 and March 2009 samples for wells JH–3 and JH–3D indicated either sulfate or iron reduction were the dominant processes occurring (table 10). The samples from both wells in May and June had iron-to-sulfide ratios greater than 10, indicating that iron reduction was the dominant redox process occurring at that time (Chapelle and others, 2009).

Concentrations of DOC, which commonly is considered a food source for reducing bacteria, generally were low in samples from all seven wells, ranging from an estimated 0.3 to 3.1 mg/L, with a median value of estimated 0.3 mg/L (table 11; table 7). Only samples from wells JH–2, JH–3, and JH–3D had DOC concentrations that were not estimated, and the DOC concentration of 3.1 mg/L in the March 2009 sample from well JH–3 was an order of magnitude higher than other detected DOC concentrations. As previously mentioned, various water-quality constituents indicate reducing conditions at wells JH–3 and JH–3D so higher DOC concentrations at these wells than at others is not surprising. The DOC

Table 9. Analyses for dissolved gases in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, June 2009.

[USGS, U.S. Geological Survey]

USGS site-identification number	Well identifier	Sample date	Sample time (24 hour)	Water temperature, field (degrees Celsius)	Dissolved-gas concentration, in milligrams per liter									
					Methane (CH_4)		Carbon dioxide (CO_2)		Nitrogen (N_2)		Oxygen (O_2)		Argon (Ar)	
					Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2
433551110443501	JH–2	06/18/2009	0940	9.22	0	0	17.6	17.4	20.2	20.2	4.9	4.6	0.72	0.72
433603110443501	JH–3	06/17/2009	1630	11.60	3.88	3.96	17.4	17.1	18.3	18.5	.23	.19	.66	.66
433603110443502	JH–3D	06/17/2009	1345	9.50	2.67	2.68	9.3	9.3	17.4	17.3	.23	.20	.62	.62

Table 10. Assignment of redox categories and processes for groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

[mg/L, milligrams per liter; NO_3^-, nitrate; Mn^{2+}, manganous manganese; µg/L, micrograms per liter; Fe^{2+}, ferrous iron; SO_4^{2-}, sulfate; --, not applicable; Redox process: O_2, oxygen reduction; Fe(III), iron reduction; SO_4, sulfate reduction]

Sample date	Sample time (24 hour)	Dissolved oxygen (mg/L)	NO_3^- (as nitrogen) (mg/L)	Mn^{2+} (µg/L)	Fe^{2+} (µg/L)	SO_4^{2-} (mg/L)	Sulfide (sum of H_2S, HS^-, and S^{2-}) (mg/L)	General redox category	Redox process	Fe^{2+}/ sulfide ratio
Well JH–1										
10/15/2008	1630	7.8	0.18	0.5	4	10.7	--	oxic	O_2	--
03/03/2009	1345	8.1	.24	.5	3	11.4	--	oxic	O_2	--
05/05/2009	1700	7.9	.22	.3	4	10.7	--	oxic	O_2	--
06/16/2009	1530	8.1	.23	.2	4	9.87	--	oxic	O_2	--
Well JH–2										
10/17/2008	1100	6.0	0.26	0.9	3	12.4	--	oxic	O_2	--
03/05/2009	1020	6.7	.22	.9	4	11.7	--	oxic	O_2	--
05/07/2009	1030	6.7	.4	.4	4	11.0	--	oxic	O_2	--
06/18/2009	940	6.4	1.27	.4	2	11.9	--	oxic	O_2	--
Well JH–3										
10/15/2008	1330	0.4	0.04	1,740	563	4.27	--	anoxic	Fe(III)/SO_4	--
03/04/2009	1200	.3	.04	1,500	373	8.45	--	anoxic	Fe(III)/SO_4	--
05/06/2009	1230	.2	.04	1,460	196	7.38	0.001	anoxic	Fe(III)	196
06/17/2009	1630	.2	.04	1,590	428	1.65	.034	anoxic	Fe(III)	12.6
Well JH–3D										
10/15/2008	1630	0.3	0.04	1,210	346	6.58	--	anoxic	Fe(III)/SO_4	--
03/04/2009	1500	.2	.04	994	236	9.51	--	anoxic	Fe(III)/SO_4	--
05/06/2009	1600	.1	.04	947	196	7.88	0.005	anoxic	Fe(III)	39.2
06/17/2009	1345	.2	.04	964	257	3.78	.007	anoxic	Fe(III)	36.7
Well JH–4										
10/16/2008	1000	7.2	0.39	0.3	3	8.03	--	oxic	O_2	--
05/06/2009	1030	7.1	.59	.3	3	8.16	--	oxic	O_2	--
06/17/2009	945	8.0	.38	.3	8	7.75	--	oxic	O_2	--
Well Hangar 1										
10/17/2008	1630	7.8	0.16	0.2	4	11.5	--	oxic	O_2	--
03/03/2009	1030	6.9	.22	.4	27	11.9	--	oxic	O_2	--
05/05/2009	1030	7.1	.22	.3	4	11.5	--	oxic	O_2	--
06/16/2009	1010	7.5	.21	.2	4	11.3	--	oxic	O_2	--
Well Hangar 5										
10/17/2008	1400	7.0	0.25	0.2	4	12.7	--	oxic	O_2	--
03/05/2009	1300	7.2	.25	.2	4	13	--	oxic	O_2	--
05/05/2009	1345	6.8	.52	.2	4	12.4	--	oxic	O_2	--
06/16/2009	1250	6.8	.97	.2	2	12.6	--	oxic	O_2	--

concentrations in samples from all seven wells were within the estimated range of 0 to about 3 mg/L considered natural in groundwater (Drever, 1997, fig. 6–1, p. 108), with the exception of the maximum concentration of 3.1 mg/L at JH–3, which was only slightly greater. Chemical oxygen demand was not detected in samples at concentrations greater than the MRL of 10 mg/L.

Anthropogenic Compounds

Samples from each of the seven wells were analyzed for many anthropogenic compounds found in products used at JHA. VOCs, GRO, and DRO are all chemical compounds found in fuel and cleaning products, and the glycols are used in deicing and anti-icing products. Concentrations of GRO and glycols in all samples were less than the LRLs used for this study. One VOC of the 63 included in the VOC analysis, methylene chloride (also known as dichloromethane), was detected at small (estimated) concentrations in one environmental sample from well JH–3 during May 2009. The quality-control trip blank analysis indicated that the detection in the environmental samples was likely due to laboratory contamination as described previously in the “Quality Assurance/Quality Control” section.

A small concentration of DRO in the C10–C36 range was detected in one sample collected during March 2009 from well Hangar 1 (table 13). Small concentrations of DRO in the C10–C36 and C10–C32 ranges were detected in three samples collected during May 2009 from wells JH–1, JH–2, and JH–4. Snowmelt runoff was recharging the aquifer during this period (fig. 6), which may have flushed some surface contaminants to the groundwater. All detected concentrations were reported as “estimated” as they were less than the LRL. The source of the low-level DRO concentrations in samples from the four wells, including well JH–1, which is upgradient from all airport operations, is not known. The sampled wells are relatively close to public roads, and diesel-run vehicles are operated on airport roads. Concentrations of DRO in the C10–C36 and C10–C32 ranges in all seven samples collected during the last sampling event in June 2009 were less than the LRL (0.25 mg/L). This indicates that during this study the DRO contamination (if present, and not due to field or laboratory contamination) was not from a persistent source.

Hydrogen and Oxygen Isotopes

To better understand the source of water in the alluvial aquifer, additional water samples were collected from all seven wells and the irrigation ditch flowing across the southern end of the airport. Samples were analyzed for stable isotopes of hydrogen and oxygen (table 11). Figure 11 shows paired δ^2H and $\delta^{18}O$ values in water samples collected during June 2009. Two lines are plotted on this graph: the Global Meteoric Water Line (GMWL), which represents the approximate global isotope compositions of precipitation (rain and snow) (Craig, 1961), and the Local Meteoric Water Line (LMWL), which represents the approximate isotope compositions of precipitation for southeastern Idaho, western Wyoming, and south-central Montana (Benjamin and others, 2004). The $\delta^{18}O$ and δ^2H values for the sample collected from the irrigation ditch plotted on the GMWL and above the LMWL. The $\delta^{18}O$ and δ^2H values for groundwater samples grouped closely together and plotted below both the LMWL and the GMWL, indicating the source of water to the aquifer likely is meteoric but has undergone some fractionation, possibly due to evaporation or chemical exchange with the aquifer matrix (Drever, 1997). The differences in the δ^2H and $\delta^{18}O$ values among the samples from wells were minimal, indicating the sampled waters were likely subject to similar recharge and(or) evolution paths. However, the δ^2H and $\delta^{18}O$ values for samples from wells JH–2 and JH–3D plotted slightly away from the other groundwater samples, indicating small differences in recharge and(or) evolution paths for these waters.

Implications of Study Findings and Further Study Needs

The Jackson Hole Airport (JHA) is a critical transportation hub for visitors to Jackson Hole and Grand Teton National Park. Airport usage numbers indicate that continued operation and growth of the airport are likely. Similar to other airports, JHA uses many chemicals to accomplish day-to-day operations. Fuels, degreasers, cleaners, and aircraft deicing and anti-icing fluids (ADAFs) are stored, transported, and used regularly. Use of these chemicals is of concern to JHA operators, the National Park Service, and local residents. ADAFs are somewhat unique in that they are applied in the open airport environment and typically necessitate subsequent containment to avoid their further migration to other mediums such as surface water or groundwater. Although airport staff have recently begun efforts to contain ADAF waste products by using a suction truck, a dedicated ADAF application and recovery area has not yet been constructed (Raymond C. Bishop, Jackson Hole Airport, oral commun., 2010). Although this report provides an improved understanding of the groundwater flow direction and velocity and geochemical processes occurring at the airport, this section of the report describes implications of study findings that bear further scrutiny and needs for further study.

At the airport, groundwater flows horizontally west-southwest at an estimated rate of 26 to 66 ft/d, with a downward vertical gradient equal to about one-half of the gradient measured for horizontal flow. The estimated rate of horizontal flow was calculated using published values, and the vertical gradient data are based on data from one pair of wells (JH–3 and JH–3D). Understanding the movement of water in the aquifer is critical when evaluating the movement of soluble contaminants, which typically move at much slower rates than the rate of groundwater flowing through the aquifer. This

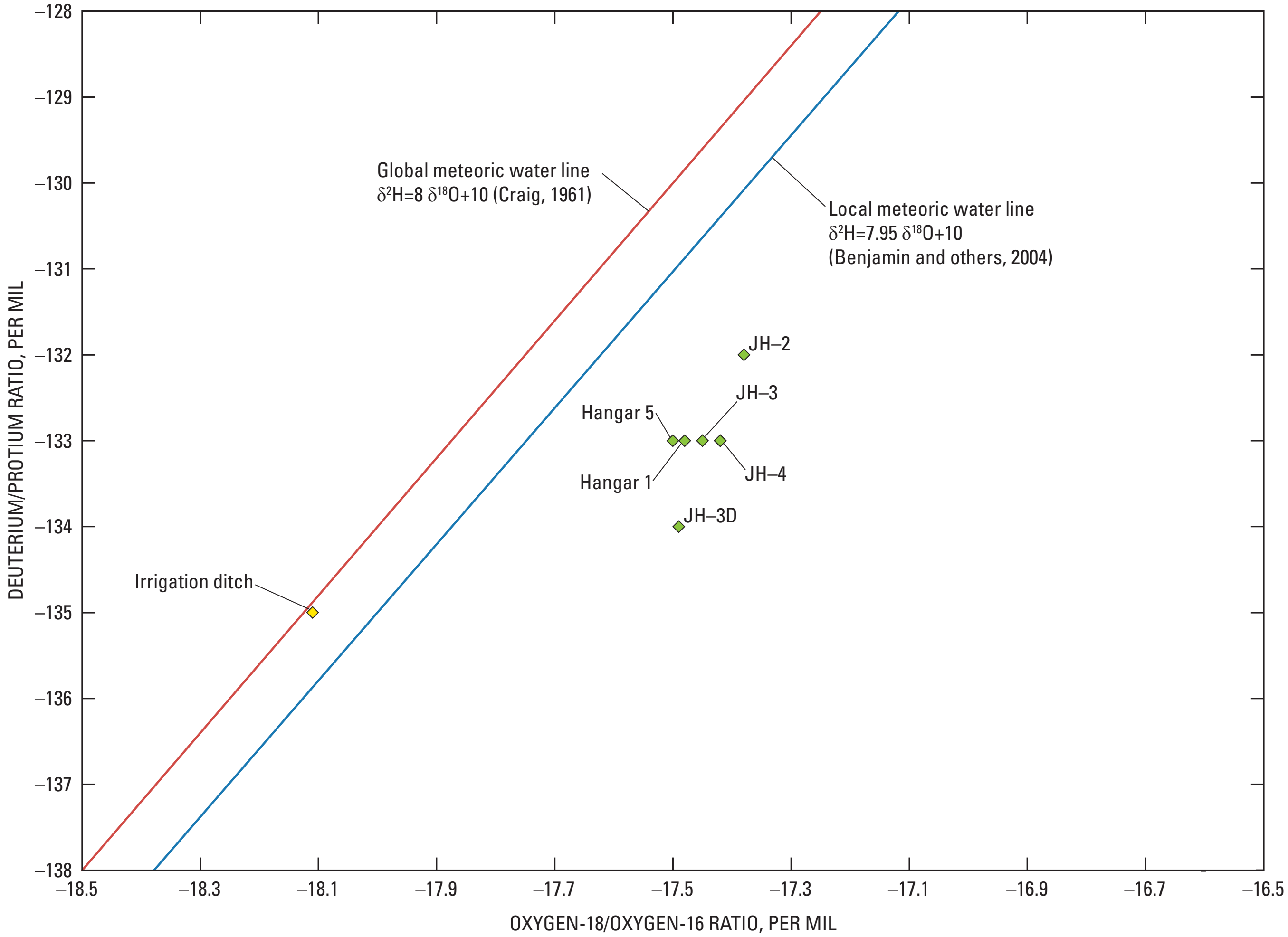


Figure 11. Relation between oxygen-18/oxygen-16 isotopic ratio and deuterium/protium ratio for groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, June 2009.

slower movement is due to the many physical, chemical, and biological processes by which solutes are affected as they move through the aquifer. Additional research could be done to better characterize local flow rates in the Snake River alluvial aquifer in the JHA study area. Aquifer tests using wells at JHA to determine hydraulic conductivity of aquifer materials in the study area would provide airport managers with more accurate contaminant transport information that would be valuable in the event of a contaminant spill. The addition of another well pair would provide additional information about the movement and quality of groundwater in the study area.

The water quality in the Snake River alluvial aquifer at the airport generally is high quality and considered to be generally suitable for domestic and other uses without treatment when compared to USEPA water-quality standards (U.S. Environmental Protection Agency, 2009). However, water-quality results for samples from wells JH–3 and JH–3D commonly were very different from samples from other wells at the airport. Dissolved-solids concentrations were slightly higher in samples from wells JH–3 and JH–3D than in samples from other airport wells. The highest DOC concentration was in a sample from well JH–3. Concentrations of dissolved oxygen and other dissolved gases indicated that reducing conditions exist in the groundwater in this part of the aquifer near wells JH–3 and JH–3D. Some natural constituents can be mobilized from aquifer materials under reducing conditions. Dissolved iron and manganese concentrations in samples from wells JH–3 and JH–3D exceeded USEPA SMCLs and were substantially higher than iron and manganese concentrations in samples from other airport wells. Ammonia, a byproduct of nitrate reduction, was the dominant form of dissolved nitrogen in samples from wells JH–3 and JH–3D, whereas nitrate was the dominant form of dissolved nitrogen in samples from all the other airport wells.

Reducing conditions in an otherwise oxic aquifer system are indicative of an upgradient or in-situ source of organic carbon or oxidizable minerals (Appelo and Postma, 2005; Drever, 1997; Hem, 1985). The nature of the source of organic carbon and the source of the reducing conditions at wells JH–3 and JH–3D could not be determined. The breakdown of organic contaminants, which can act as a nutrient source for aquifer bacteria, is one process that can cause reducing conditions in the aquifer. It is important to note that reducing conditions can be the result of natural processes in local zones of aquifers; however, samples of natural background conditions for those wells prior to development of JHA were not available. Therefore, it is assumed that the background water quality of the aquifer is represented by the other airport wells.

It is feasible that the deicer-derived glycols could have produced the reducing conditions observed at wells JH–3 and JH–3D; however, glycols exceeding LRLs were not detected in any of the samples from airport wells. The absence of glycols in the groundwater at the airport may be because of one or a combination of the following: (1) glycols break down rapidly in water and soil (Klecka and others, 1993), (2) glycol concentrations in water downgradient from the airport may be diluted, (3) analytical methods used had relatively high LRLs, and (4) glycols are not present in the aquifer.

Additional water-quality research may help to determine the extent and cause of the reducing conditions in the aquifer beneath JHA. To determine the extent of the reduced zone of groundwater, additional wells upgradient from and lateral to well cluster 3 would be needed. The reduced zone of groundwater did not laterally extend out to wells JH–2 and JH–4 during the study; therefore, the lateral extent exists between well cluster 3 and these wells. Additional samples for major ions and trace elements would help to characterize the variability of water-quality conditions of the aquifer, including potential for a natural localized, reducing groundwater zone. Additional water-quality sampling in the reduced zone of groundwater could be used to target some of the ADAF additives that might be more persistent in groundwater than glycols, which may help determine if deicers in groundwater are causing the reducing conditions.

Summary

Groundwater-level measurements and groundwater-quality samples were collected from wells completed in the Snake River alluvial aquifer at the Jackson Hole Airport in northwestern Wyoming during September 2008–June 2009 to characterize the hydrogeology and groundwater quality upgradient and downgradient from airport operations. The U.S. Geological Survey, in cooperation with the Jackson Hole Airport Board and Teton Conservation District, characterized groundwater conditions with groundwater-level measurements from 14 wells and groundwater-quality analyses from a subset of 7 of these wells. Data, including groundwater levels, field measurements, major ions, nutrients, volatile organic compounds, gasoline-range organics (GRO), glycols, diesel-range organics (DRO), dissolved gases, stable isotopes of hydrogen and oxygen, and a few miscellaneous field and laboratory analytical results are presented and summarized in this report. The direction of groundwater flow, hydraulic gradients, and estimated groundwater velocity rates of the Snake River alluvial aquifer underlying the study area also are presented, and the reduction/oxidation (redox) condition is characterized for selected well locations.

Water levels collected throughout the study indicate the water table was lowest in the early spring and reached its peak in July, with an increase of 12 to 14 feet between April and July of 2009. Water-table contour maps show that the water table was highest in the northeast part of the airport and lowest in the southwest, indicating that the direction of groundwater flow generally was to the west-southwest. The water table dropped about 22 feet across the airport (between wells JH–1 and JH–2) with an average hydraulic gradient of 0.0066 foot/foot. Water levels in wells JH–3 and JH–3D indicate a small downward vertical-flow gradient at well cluster 3. Lithologic data for monitoring wells JH–1 through JH–4, coupled with a fairly narrow range of hydraulic gradients for these wells, indicate the Snake River alluvial aquifer at the airport is relatively homogeneous. Using hydraulic conductivity estimates calculated for two locations in southern Jackson Hole, horizontal groundwater velocity in the alluvial aquifer was estimated to be 26 to 66 feet per day. Using an estimated linear distance of 3,540 feet from well JH–1 to well JH–2, it would take approximately 53 to 138 days for water in the aquifer to travel from well JH–1 (upgradient from airport operations) to the southwest boundary of the airport. This estimate of groundwater velocity only describes the movement of water through the aquifer because some solutes may move at a much slower rate.

Generally, water in the Snake River alluvial aquifer was found to be of good quality. No constituents were detected at concentrations exceeding U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Levels, and no anthropogenic compounds were detected at concentrations greater than laboratory reporting levels. Although the quality of groundwater in the shallow aquifer generally was suitable for domestic and other uses without treatment, two inorganic constituents (dissolved iron and dissolved manganese) were detected in concentrations exceeding USEPA Secondary Maximum Contaminant Levels (SMCLs) in some samples. It is important to note that these SMCLs are nonenforceable standards for constituents that may cause cosmetic effects (discoloration of teeth or skin) or esthetic effects (undesirable taste, odor, or color) in drinking water.

Field measurements of pH were near neutral to alkaline with a median value of 7.9, and specific-conductance measurements ranged from 234 to 420 microsiemens per centimeter at 25 degrees Celsius. Dissolved solids and major-ion data indicated the groundwater sampled at the airport is considered hard to very hard, fresh, calcium bicarbonate water. Measurements of dissolved-oxygen concentrations ranged from 0.1 to 8.1 milligrams per liter (mg/L) and indicated some variability in the oxygen content of the aquifer. Although oxic aquifer conditions were indicated for five of the wells, dissolved-oxygen concentrations indicated reducing conditions at the two wells at cluster 3, JH–3 and JH–3D.

Nutrients were detected at low concentrations in all samples collected. Dissolved nitrate plus nitrite was detected in samples from wells JH–1, JH–2, JH–4, Hangar 1, and Hangar 5, indicating nitrate is the primary dissolved-nitrogen species in the aquifer. Nitrate plus nitrite was not detected in samples from wells JH–3 or JH–3D; however, ammonia was detected in samples from these wells. The absence of nitrate plus nitrite in samples from wells JH–3 and JH–3D was not unexpected because nitrate and nitrite commonly are reduced by bacteria when exposed to anaerobic conditions such as those at these wells. Dissolved organic carbon was detected in all of the wells at concentrations within the estimated range for natural groundwater (0 to 3 milligrams per liter) except one sample, which was slightly greater than the estimated range and had a concentration a magnitude higher than other detected dissolved organic carbon concentrations. Chemical oxygen demand exceeding the laboratory reporting level was not detected in any samples.

Dissolved iron concentrations in many of the samples from wells JH–3 and JH–3D exceeded the SMCL of 300 micrograms per liter, whereas dissolved manganese concentrations exceeded the SMCL of 50 micrograms per liter in all of the samples collected from both wells. Iron and manganese likely are both natural components of the geologic materials in the area that became dissolved in the aquifer due to redox processes. Both of these constituents, when found in drinking water, can cause cosmetic or esthetic effects, potentially requiring treatment. Neither well JH–3 nor JH–3D is used for drinking water.

Dissolved gas samples were collected and field analyses were performed for ferrous iron, manganous manganese, hydrogen sulfide, and low-level dissolved oxygen to better understand the redox conditions of the alluvial aquifer. These additional analyses confirmed that samples from wells JH–3 and JH–3D had low concentrations of dissolved oxygen and showed the presence of low concentrations of methane gas in samples from both wells. The redox processes occurring in the Snake River alluvial aquifer at wells JH–3 and JH–3D were identified using a spreadsheet model designed to use a multiple line of evidence approach to distinguish the source of reduction. Results from May and June, which include a full set of data, indicate that iron reduction is the dominant process occurring in the aquifer at these wells.

Each well was sampled for many anthropogenic compounds including volatile organic compounds, GRO, glycols, and DRO, which are used at the Jackson Hole Airport. Methylene chloride, a volatile organic compound, was detected at an estimated concentration in a groundwater sample from well JH–3 but was attributed to sample contamination because an estimated concentration of methylene chloride was measured in a trip blank. No gasoline-range organics or glycols were detected at concentrations greater than laboratory reporting levels used for this study. A small concentration of DRO, in the C10–C36 range, was detected in one sample collected from Hangar 1, and small concentrations of DRO in the C10–C32 and DRO C10–C36 ranges were detected in three samples collected from wells JH–1, JH–2, and JH–4; all detected concentrations of DRO were reported as “estimated” and were less than the laboratory reporting level. Concentrations of DRO in all samples collected from all seven wells during the last sampling event were less than the laboratory reporting level (0.25 mg/L), which indicates that the DRO contamination (if present, and not due to field or laboratory contamination) was not from a persistent source during this study.

Samples of stable hydrogen and oxygen isotopes were collected to assess the source of water to the aquifer. Samples were collected from all seven wells and an irrigation ditch that crosses the southern edge of the airport. Analysis of δ^2H and $\delta^{18}O$ stable isotope data indicate the source of water to the aquifer likely is meteoric and that sampled water is subject to similar recharge and evolution paths.

In general, the low dissolved-oxygen concentrations and iron reduction occurring at wells JH–3 and JH–3D are not uncommon in groundwater. However, the dissolved-oxygen concentrations in water from the other five wells sampled at the Jackson Hole Airport were 6 mg/L or higher, indicating the Snake River alluvial aquifer is naturally oxic in the vicinity of the airport. It is possible there is a natural cause for higher rates of reduction upgradient from well cluster 3; however, lithologic logs and hydraulic gradient data indicate the Snake River alluvial aquifer is relatively homogeneous, making a natural cause less likely. Reducing conditions in an otherwise oxic aquifer system are indicative of an upgradient or in-situ source of organic carbon. The nature of the source of organic carbon at the airport was not determined.

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References Cited

Appelo, C.A.J., and Postma, Dieke, 2005, Geochemistry, groundwater and pollution (2d ed.): Leiden, The Netherlands, A.A. Balkema Publishers, 649 p.

Benjamin, Lyn, Knobel, L.L., Hall, L.F., Cecil, L.D., and Green, J.R., 2004, Development of a local meteoric water line for southeastern Idaho, western Wyoming, and south-central Montana: U.S. Geological Survey Scientific Investigations Report 2004–5126, 17 p.

Brenton, R.W., and Arnett, T.L., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of dissolved organic carbon by UV-promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92–480, 12 p.

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

Cancilla, D.A., Martinez, Jennifer, and Van Aggelen, G.C., 1998, Detection of aircraft deicing/antiicing fluid additives in a perched water monitoring well at an international airport: Environmental Science and Technology, v. 32, no. 23, p. 3834–3835.

Case, J.C., Arneson, C.S., and Hallberg, L.L., 1998, Preliminary 1:500,000-scale digital surficial geology map of Wyoming: Wyoming State Geological Survey Digital Product HDSM 98–1.

Chapelle, F.H., Bradley, P.M., Thomas, M.A., and McMahon, P.B., 2009, Distinguishing iron-reducing from sulfate-reducing conditions: Ground Water, v. 47, no. 2, p. 300–305.

Chapman, S.S., Bryce, S.A., Omernik, J.M., Despain, D.G., ZumBerge, J.R., and Conrad, M., 2004, Ecoregions of Wyoming (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey, scale 1:1,4000,000, *http://www.epa.gov/wed/pages/ecoregions/wy_eco.htm*.

Childress, C.J.O., Foreman, 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.

Coplen, T.B., Wildman, J.D., and Chen, Julie, 1991, Improvements in the gaseous hydrogen-water equilibration technique for hydrogen isotope ratio analysis: Analytical Chemistry, v. 63, p. 910–912.

Corsi, S.R., Hall, D.W., and Geis, S.W., 2001, Aircraft and runway deicers at General Mitchell International Airport, Milwaukee, Wisconsin, USA, 2. Toxicity of aircraft and runway deicers: Environmental Toxicology and Chemistry, v. 20, no. 7, p. 1483–1490.

Corsi, S.R., Geis, S.W., Loyo-Rosales, J.E., Rice, C.P., Sheesley, R.J., Failey, G.G., and Cancilla, D.A., 2006a, Characterization of aircraft deicer and anti-icer components and toxicity in airport snowbanks and snowmelt runoff: Environmental Science and Technology, v. 40, no. 10, p. 3195–3202.

Corsi, S.R., Geis, S.W., Loyo-Rosales, J.E., Rice, C.P., 2006b, Aquatic toxicity of nine aircraft deicer and anti-icer formulations and relative toxicity of additive package ingredients alkylphenol ethoxylates and 4,5-methyl-1H-benzotriazoles: Environmental Science and Technology, v. 40, no. 23, p. 7409–7415.

Craig, Harmon, 1961, Isotopic variations in meteoric waters: Science, v. 133, p. 1702–1703.

Drever, J.I., 1997, The geochemistry of natural waters—Surface and groundwater environments (3d ed.): Upper Saddle River, N.J., Prentice-Hall, 437 p.

Eddy-Miller, C.A., Wheeler, J.D., and Essaid, H.I., 2009, Characterization of interactions between surface water and near-stream groundwater along Fish Creek, Teton County, Wyoming, by using heat as a tracer: U.S. Geological Survey Scientific Investigations Report 2009–5160, 53 p.

Epstein, Samuel, and Mayeda, T.K., 1953, Variation of O-18 content of water from natural sources: Geochimica et Cosmochimica Acta, v. 4, p. 213–224.

Fetter, C.W., 1988, Applied hydrogeology (2d ed.): Columbus, Ohio, Merrill Publishing Company, 592 p.

Fetter, C.W., 1993, Contaminant hydrogeology: New York, New York, Macmillan Publishing Company, 458 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Fishman, M.J., and Friedman, L.C., 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.

HACH, 1996, DR/2000 Spectrophotometer Procedures Manual, 1996 (ed. 11), accessed October 14, 2009, at *http://www.hach.com/fmmimghach?/CODE%3A44487900O-Z176%7C1*.

Hamerlinck, J.D., and Arneson, C.S., 1998, Assessing ground water vulnerability to pesticides, *in* Hamerlinck, J.D., and Arneson, C.S., eds., Wyoming ground water vulnerability assessment handbook, v. 2: Laramie, Wyoming, University of Wyoming, Spatial Data and Visualization Center publication SDVC 98–01–2.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 81 p.

Hem, J.D., 1985, Study and interpretation of chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

In-Situ, Incorporated, 2007, Level Troll® operators manual, p. 75, accessed February 26, 2010, at *http://www.in-situ.com/force_download.php?file=351*.

Jackson Hole Airport, 2009, Airport history, accessed October 7, 2009, at *http://www.jacksonholeairport.com/admin_history.htm*.

Jurgens, B.C., McMahon, P.B., Chapelle, F.H., and Eberts, S.M., 2009, An Excel® workbook for identifying redox processes in ground water: U.S. Geological Survey Open-File Report 2009–1004, 8 p. (Also available at *http://pubs.usgs.gov/of/2009/1004/*.)

Klecka, G.M., Carpenter, C.L., and Landenberger, B.D., 1993, Biodegradation of aircraft deicing fluids in soil at low temperatures: Ecotoxicology and Environmental Safety, v. 25, no. 3, p. 280–295.

Lapham, W.W., Wilde, F.D., and Koterba, M.T., 1995, Ground-water data collection protocols and procedures for the National Water-Quality Assessment Program—Selection, installation, and documentation of wells and collection of related data: U.S. Geological Survey Open-File Report 95–398, 69 p.

Lohman, S.W., and others, 1972, Definitions of selected ground-water terms—Revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

Love, J.D., and Reed, J.C., Jr., 1971, Creation of the Teton landscape, the geologic story of Grand Teton National Park: Moose, Wyo., Grand Teton Natural History Association, 120 p., accessed December 10, 2009, at *http://www.nps.gov/history/history/online_books/grte/grte_geology/contents.htm*.

Love, J.D., and Christiansen, A.C., 1985, Geologic map of Wyoming: U.S. Geological Survey Geologic Map, scale 1:500,000, 3 sheets.

Love, J.D., Reed, J.C., Jr., and Christiansen, A.C., 1992, Geologic map of Grand Teton National Park: U.S. Geological Survey Miscellaneous Investigations Series Map I-2031, scale 1:62,500.

Love, J.D., Reed, J.C., JR., and Pierce, K.L., 2003, A geological chronicle of Jackson Hole and the Teton Range: Moose, Wyo., Grand Teton Natural History Association, in cooperation with the U.S. National Park Service, 132 p.

McMahon, P.B., and Chapelle, F.H., 2008, Redox processes and water quality of selected principal aquifer systems: Ground Water, v. 46, no. 2, p. 259–271.

Mueller, D.K., and Helsel, D.R., 1996, Nutrients in the nation’s waters—Too much of a good thing?: U.S. Geological Survey Circular 1136, 24 p.

Mueller, D.K., Martin, J.D., and Lopes, T.J., 1997, Quality-control design for surface-water sampling in the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 97–223, 17 p.

Munch, J.W., 1995, Measurement of purgeable organic compounds in water by capillary column gas chromatography/mass spectrometry, EPA Method 524.2 (Revision 4.1): U.S. Environmental Protection Agency, 48 p.

Nelson Engineering, 1992, Teton County westbank groundwater study: Jackson, Wyo., Nelson Engineering Report, 61 p.

Nolan, B.T., Campbell, D.L., and Senterfit, R.M., 1998, Depth of the base of the Jackson aquifer, based on geophysical exploration, southern Jackson Hole, Wyoming, USA: Hydrogeology Journal, v. 6, p. 374–382.

Nolan, B.T., and Miller, K.A., 1995, Water resources of Teton County, Wyoming exclusive of Yellowstone National Park: U.S. Geological Survey Water-Resources Investigations Report 95–4204, 76 p.

Pierce, K.L., and Good, J.D., 1992, Field guide to the Quaternary geology of Jackson Hole, Wyoming: U.S. Geological Survey Open-File Report 92–504, 49 p.

Piper, A.M., 1944, A graphic procedure in the geochemical interpretation of water analyses: American Geophysical Union Transactions, v. 25, p. 914–923.

Timme, P.J., 1995, National Water Quality Laboratory 1995 Services Catalog: U.S. Geological Survey Open-File Report 95–352, 52 p.

U.S. Environmental Protection Agency, 1996a, Test methods for evaluating solid waste, physical/chemical methods, SW-846, 3d ed., update IV; Method 8015B Nonhalogenated organics using GC/FID, Rev. 2: Washington D.C., U.S. Environmental Protection Agency, [variously paged].

U.S. Environmental Protection Agency, 1996b, Test methods for evaluating solid waste, physical/chemical methods, SW-846, 3rd ed., update IV; Method 8021B Aromatic and halogenated volatiles by gas chromatography using photoionization and/or electrolytic conductivity detectors, Rev. 2: Washington D.C., U.S. Environmental Protection Agency, [variously paged].

U.S. Environmental Protection Agency, 2009a, Technology transfer network; air toxics web site, accessed November 2, 2009, at *http://www.epa.gov/ttn/atw/hlthef/methylen.html.*

U.S. Environmental Protection Agency, 2009b, 2009 Edition of the drinking water standards and health advisories: Washington D.C., U.S. Environmental Protection Agency, Office of Water, EPA 822–R–09–11, October 2009, 12 p., accessed July 1, 2010, at *http://www.epa.gov/waterscience/criteria/drinking/dwstandards.pdf*.

U.S. Environmental Protection Agency, 2010, Integrated Risk Information System (IRIS) database: Washington D.C., U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, accessed July 1, 2010, at *http://www.epa.gov/iris/*.

U.S. Geological Survey, 1997-2010, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9, available at *http://pubs.water.usgs.gov/twri9A*.

U.S. Geological Survey, 2004, Codes used in water-quality processing system (Appendix A of 4 appendixes), table 17: U.S. Geological Survey National Water Information System, accessed June 2, 2010, at *http://nwis.usgs.gov/nwisdocs4_3/qw/QW-AppxA.pdf*.

U.S. Geological Survey, 2005, Estimated use of water in the United States county-level data for 2005, accessed November 18, 2009, at *http://water.usgs.gov/watuse/data/2005/index.html*.

U.S. Geological Survey, accessed December 9, 2009, online at *http://toxics.usgs.gov/definitions/methanogenesis.html.*

Western Regional Climate Center, 2009, COOP data/record of climatological observations, U.S., data for station no. 486428, Moose, Wyo., accessed October 22, 2009, at *http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wy6428*.

Supplemental Information

Table 11. Analytical results for chemical oxygen demand, major ions, trace elements, nutrients, dissolved organic carbon, and stable isotopes in groundwater samples from wells at Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the laboratory reporting level; --, not analyzed; N, nitrogen; P, phosphorus; E, estimated concentration; µg/L, micrograms per liter; **Bold** value indicates constituent exceeded a U.S. Environmental Protection Agency drinking-water standard]

USGS site-identification number	Well identifier	Date	Time	Chemical oxygen demand, high level, total (mg/L)	Dissolved solids (mg/L)	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)	Potassium, dissolved (mg/L)	Sodium, dissolved (mg/L)	Alkalinity, field, dissolved, as $CaCO_3$ (mg/L)	Bicarbonate, field, dissolved (mg/L)
Environmental samples											
433615110440001	JH–1	10/15/2008	1630	<10	149	34.3	7.21	2.02	7.27	113	138
		03/03/2009	1345	<10	151	33.4	7.36	2.00	7.89	109	133
		05/05/2009	1700	<10	154	34.6	7.21	1.96	7.42	113	137
		06/16/2009	1530	<10	167	34.8	7.28	1.97	7.05	120	146
433551110443501	JH–2	10/17/2008	1100	<10	182	48.8	8.81	2.07	7.08	150	183
		03/05/2009	1020	<10	174	42.5	8.09	1.94	7.71	136	166
		05/07/2009	1030	<10	202	52.5	10.0	2.13	7.96	168	205
		06/18/2009	0940	<10	254	62.4	11.8	2.2	7.17	200	244
433603110443501	JH–3	10/16/2008	1330	<10	242	62.5	11.2	1.96	7.43	200	244
		03/04/2009	1200	<10	214	46.9	8.82	1.89	7.28	160	194
		05/06/2009	1230	<10	215	54.5	9.31	1.81	7.11	176	214
		06/17/2009	1630	<10	255	62.8	11.4	2.07	7.67	210	256
433603110443502	JH–3D	10/16/2008	1630	<10	196	51.7	9.66	1.96	7.36	169	207
		03/04/2009	1500	<10	188	40.4	8.16	1.85	7.12	141	172
		05/06/2009	1600	<10	187	45.3	8.28	1.77	6.81	147	180
		06/17/2009	1345	<10	208	50.0	9.09	1.93	7.18	169	206
433613110443501	JH–4	10/16/2008	1000	<10	142	34.7	6.75	1.88	6.14	110	134
		03/04/2009	0950	--	--	--	--	--	--	--	--
		05/06/2009	1030	<10	153	34.4	6.63	1.79	5.88	110	134
		06/17/2009	0945	<10	153	35.7	6.99	1.83	5.86	117	143
433607110440901	Hangar 1	10/17/2008	1630	<10	140	33.8	7.28	2.07	7.31	113	138
		03/03/2009	1030	<10	155	32.5	7.32	1.96	7.42	110	134
		05/05/2009	1030	<10	155	34.3	7.24	1.99	7.21	110	134
		06/16/2009	1010	<10	161	33.2	7.34	2.01	7.03	113	138
433556110441601	Hangar 5	10/17/2008	1400	<10	151	37.9	8.13	2.27	8.00	123	150
		03/05/2009	1300	<10	159	33.9	7.97	2.22	7.87	123	150
		05/05/2009	1345	<10	177	41.0	8.61	2.22	7.74	122	148
		06/16/2009	1250	<10	189	40.9	8.68	2.29	8.73	131	160
433553110443601	Irrigation ditch	06/18/2009	1050	--	--	--	--	--	--	--	--
Quality-control samples											
433551110443501	[1]JH–2	10/17/2008	0930	<10	10	0.02	0.01	0.06	0.12	--	--
433603110443501	[2]JH–3	05/06/2009	1235	<10	232	57.3	9.53	1.87	7.13	176	214

Table 11. Analytical results for chemical oxygen demand, major ions, trace elements, nutrients, dissolved organic carbon, and stable isotopes in groundwater samples from wells at Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; **Bold** value indicates constituent exceeded a U.S. Environmental Protection Agency drinking-water standard]

Well identifier	Date	Hardness, total, as $CaCO_3$	Bromide, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved as SiO_2 (mg/L)	Sulfate, dissolved (mg/L)	Ammonia, dissolved, as N (mg/L)	Nitrate plus nitrite, dissolved, as N (mg/L)	Nitrite, dissolved, as N (mg/L)	Orthophosphate, dissolved, as P (mg/L)
Environmental samples											
JH–1	10/15/2008	120	E0.01	3.78	0.43	18.4	10.7	<0.02	0.18	<0.002	0.019
	03/03/2009	110	E.01	3.90	.45	18.7	11.4	<.02	.24	<.002	.019
	05/05/2009	120	.02	3.91	.42	19.1	10.7	<.02	.22	<.002	.021
	06/16/2009	120	<.02	3.54	.44	18.5	9.87	<.02	.23	<.002	.02
JH–2	10/17/2008	160	E.01	4.03	.41	17.5	12.4	<.02	.26	<.002	.018
	03/05/2009	140	E.01	3.80	.48	18.2	11.7	<.02	.22	<.002	.019
	05/07/2009	170	E.01	3.84	.39	19.1	11.0	<.02	.40	<.002	.021
	06/18/2009	200	E.02	4.61	.35	18.2	11.9	<.02	1.27	<.002	.017
JH–3	10/16/2008	200	.02	5.93	.33	21.9	4.27	<.02	<.04	<.002	.014
	03/04/2009	150	.02	4.04	.40	21.6	8.45	.388	<.04	<.002	.067
	05/06/2009	170	.03	4.31	.35	21.8	7.38	.044	<.04	<.002	.013
	06/17/2009	200	.02	5.31	.41	21.2	1.65	E.012	<.04	<.002	.011
JH–3D	10/16/2008	170	E.02	4.73	.35	21.0	6.58	<.02	<.04	<.002	.016
	03/04/2009	130	<.02	3.91	.41	20.5	9.51	.012	<.04	<.002	.014
	05/06/2009	150	E.01	4.24	.37	20.8	7.88	<.02	<.04	<.002	.012
	06/17/2009	160	E.02	4.77	.39	20.2	3.78	<.02	<.04	<.002	.012
JH–4	10/16/2008	110	E.01	3.06	.36	18.0	8.03	<.02	.39	<.002	.017
	03/04/2009	--	--	--	--	--	--	--	--	--	--
	05/06/2009	110	E.02	3.77	.33	18.3	8.16	<.02	.59	<.002	.019
	06/17/2009	120	E.01	3.40	.34	18.3	7.75	<.02	.38	<.002	.018
Hangar 1	10/17/2008	110	E.01	3.63	.42	18.6	11.5	<.02	.16	<.002	.02
	03/03/2009	110	E.01	3.80	.45	18.0	11.9	<.02	.22	<.002	.02
	05/05/2009	120	E.02	4.16	.42	19.5	11.5	<.02	.22	<.002	.02
	06/16/2009	110	E.01	4.00	.45	18.7	11.3	<.02	.21	<.002	.02
Hangar 5	10/17/2008	130	E.02	3.86	.44	18.7	12.7	<.02	.25	<.002	.037
	03/05/2009	120	E.01	4.07	.45	18.8	13.0	<.02	.25	<.002	.033
	05/05/2009	140	E.02	11.20	.42	19.8	12.4	<.02	.52	<.002	.032
	06/16/2009	140	.02	8.37	.42	18.9	12.6	<.02	.97	<.002	.034
Irrigation ditch	06/18/2009	--	--	--	--	--	--	--	--	--	--
Quality-control samples											
[1]JH–2	10/17/2008	--	<0.02	0.12	0.08	0.02	0.18	<0.02	<0.04	<0.002	<0.008
[2]JH–3	05/06/2009	180	E.01	4.37	.36	21.41	7.35	.037	E.02	<.002	.014

Table 11. Analytical results for chemical oxygen demand, major ions, trace elements, nutrients, dissolved organic carbon, and stable isotopes in groundwater samples from wells at Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; µg/L, micrograms per liter; $CaCO_3$, calcium carbonate; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; **Bold** value indicates constituent exceeded a U.S. Environmental Protection Agency drinking-water standard]

Well identifier	Date	Phosphorus, total, as P (mg/L)	Total nitrogen (nitrate + nitrite + ammonia + organic-N), unfiltered (mg/L)	Iron, dissolved (mg/L)	Manganese, dissolved (mg/L)	Organic carbon, dissolved (mg/L)	$\delta^{2}H$ (per mil)	$\delta^{16}O$ (per mil)	Sulfide (sum of H_2S, HS^-, and S^{2-}), total, field (mg/L)	Ferrous iron, total, field, (mg/L)	Dissolved oxygen, low level, dissolved, field (µg/L)
Environmental samples											
JH–1	10/15/2008	0.014	0.18	4	0.5	E0.3	--	--	--	--	--
	03/03/2009	.015	.25	E3	.5	E.3	--	--	--	--	--
	05/05/2009	.015	.19	<4	.3	E.3	--	--	--	--	--
	06/16/2009	.015	.25	<4	<.2	E.3	–133	–17.42	--	--	--
JH–2	10/17/2008	.014	.26	E3	.9	E.3	--	--	--	--	--
	03/05/2009	.014	.21	<4	.9	E.3	--	--	--	--	--
	05/07/2009	.014	.42	<4	.4	.4	--	--	--	--	--
	06/18/2009	.015	1.32	E2	.4	.6	–132	–17.38	--	--	--
JH–3	10/16/2008	.013	<.1	**563**	**1,740**	.6	--	--	--	--	--
	03/04/2009	.076	.59	**373**	**1,500**	3.1	--	--	--	--	--
	05/06/2009	.017	E.08	196	**1,460**	.5	--	--	0.001	0.22	167
	06/17/2009	.016	<.1	**428**	**1,590**	1	–133	–17.45	.034	.04	173
JH–3D	10/16/2008	E.011	<.1	**346**	**1,210**	.5	--	--	--	--	--
	03/04/2009	.010	<.1	236	**994**	E.3	--	--	--	--	--
	05/06/2009	.011	<.1	196	**947**	E.3	--	--	.005	.20	120
	06/17/2009	.011	<.1	257	**964**	.4	–134	–17.49	.007	.27	192
JH–4	10/16/2008	.013	.39	E3	.3	E.3	--	--	--	--	--
	03/04/2009	--	--	--	--	--	--	--	--	--	--
	05/06/2009	.016	.59	E3	.3	E.3	--	--	--	--	--
	06/17/2009	.014	.38	8	.3	E.3	–133	–17.42	--	--	--
Hangar 1	10/17/2008	.014	.17	<4	.2	E.3	--	--	--	--	--
	03/03/2009	.014	.23	27	.4	E.3	--	--	--	--	--
	05/05/2009	.015	.22	<4	.3	E.3	--	--	--	--	--
	06/16/2009	.016	.22	<4	<.2	E.3	–133	–17.48	--	--	--
Hangar 5	10/17/2008	.033	.22	<4	<.2	E.4	--	--	--	--	--
	03/05/2009	.030	.26	<4	<.2	E.4	--	--	--	--	--
	05/05/2009	.029	.51	<4	.2	E.3	--	--	--	--	--
	06/16/2009	.030	.98	E2	<.2	E.4	–133	–17.5	--	--	--
Irrigation ditch	06/18/2009	--	--	--	--	--	–135	–18.11	--	--	--
Quality-control samples											
[1]JH–2	10/17/2008	<0.012	<0.1	<4	<0.2	<0.4	--	--	--	--	--
[2]JH–3	05/06/2009	.014	.12	218	1,454	.5	--	--	--	--	--

[1] Field blank.

[2] Replicate sample.

Table 12. Analytical results for volatile organic compounds and gasoline-range organics in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, estimated concentration. **Bold** value indicates that compound was detected, but was attributed to sample contamination]

USGS site-identification number	Well identifier	Date	Time (24 hour)	1,1-Dichloro-ethane (µg/L)	1,1-Dichloro-ethene (µg/L)	1,1-Dichloro-propene (µg/L)	1,1,1-Trichloro-ethane (µg/L)	1,1,1,2-Tetra-chloroethane (µg/L)	1,1,2-Trichloro-ethane (µg/L)	1,1,2,2-Tetra-chloro-ethane (µg/L)	1,2-Dibromo-3-chloropropane (µg/L)
Environmental samples											
433615110440001	JH–1	10/15/2008	1630	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
		03/03/2009	1345	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		05/05/2009	1700	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		06/17/2009	1530	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
433551110443501	JH–2	10/17/2008	1100	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		03/05/2009	1020	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		05/07/2009	1030	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		06/17/2009	0940	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
433603110443501	JH–3	10/16/2008	1330	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		03/04/2009	1200	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		05/06/2009	1230	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		06/17/2009	1630	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
433603110443502	JH–3D	10/16/2008	1630	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		03/04/2009	1500	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		05/06/2009	1600	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		06/17/2009	1345	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
433613110443501	JH–4	10/16/2008	1000	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		05/06/2009	1030	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		06/17/2009	0945	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
433607110440901	Hangar 1	10/17/2008	1630	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		03/03/2009	1030	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		05/06/2009	1235	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		06/17/2009	1010	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
433556110441601	Hangar 5	10/17/2008	1400	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		03/05/2009	1300	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		05/05/2009	1345	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
		06/17/2009	1250	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
Quality-control samples											
433551110443501	JH–2	[1]10/17/2008	0930	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
		[2]05/07/2009	1032	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
433603110443501	JH–3	[3]05/06/2009	1235	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50

Table 12. Analytical results for volatile organic compounds and gasoline-range organics in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, estimated concentration. **Bold** value indicates that compound was detected, but was attributed to sample contamination]

Well identifier	Date	1,2-Dibromo-ethane (µg/L)	1,2-Dichloro-benzene (µg/L)	1,2-Dichloro-ethane (µg/L)	1,2-Dichloro-propane (µg/L)	1,2,3-Trichloro-benzene (µg/L)	1,2,3-Trichloro propane (µg/L)	1,2,4-Trichloro-benzene (mg/L)	1,2,4-Trimethyl-benzene (µg/L)	1,3-Dichloro-benzene (µg/L)	1,3-Dichloro-propane (µg/L)	1,3,5-Trimethyl-benzene (µg/L)
Environmental samples												
JH–1	10/15/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–2	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/07/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–3	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–3D	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–4	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
Hangar 1	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
Hangar 5	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
Quality-control samples												
JH–2	[1]10/17/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
	[2]05/07/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–3	[3]05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50

Table 12. Analytical results for volatile organic compounds and gasoline-range organics in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, estimated concentration. **Bold** value indicates that compound was detected, but was attributed to sample contamination]

Well identifier	Date	1,4-Dichloro-benzene (µg/L)	2-Chloro-toluene (µg/L)	2,2-Dichloro-propane (µg/L)	4-Chloro-toluene (µg/L)	4-Iso-propyl-toluene (µg/L)	Benzene (µg/L)	Bromo-benzene (µg/L)	Bromo-chloro-methane (µg/L)	Bromo-dichloro-methane (µg/L)	Bromo-form (µg/L)	Bromo-methane (µg/L)
						Environmental samples						
JH–1	10/15/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.0
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
JH–2	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	05/07/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
JH–3	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
JH–3D	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
JH–4	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
Hangar 1	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
Hangar 5	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
						Quality-control samples						
JH–2	[1]10/17/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.0
	[2]05/07/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0
JH–3	[3]05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<1.0

Table 12. Analytical results for volatile organic compounds and gasoline-range organics in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, estimated concentration. **Bold** value indicates that compound was detected, but was attributed to sample contamination]

Well identifier	Date	Carbon tetra-chloride (µg/L)	Chloro-benzene (µg/L)	Chloro-ethane (µg/L)	Chloro form (µg/L)	Chloro-methane (µg/L)	*cis*-1,2-Dichloro-ethene (µg/L)	*cis*-1,3-Dichloro-propene (µg/L)	Dibromo-chloro-methane (µg/L)	Dibromo-methane (µg/L)	Dichloro-difluoro-methane (µg/L)	Ethyl-benzene (µg/L)
						Environmental samples						
JH–1	10/15/2008	<0.50	<0.50	<1.0	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
	03/03/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/05/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–2	10/17/2008	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/05/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/07/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–3	10/16/2008	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/04/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–3D	10/16/2008	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/04/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–4	10/16/2008	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
Hangar 1	10/17/2008	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/03/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
Hangar 5	10/17/2008	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	03/05/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	05/05/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
						Quality-control samples						
JH–2	[1]10/17/2008	<0.50	<0.50	<1.0	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
	[2]05/07/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50
JH–3	[3]05/06/2009	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50

Table 12. Analytical results for volatile organic compounds and gasoline-range organics in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, estimated concentration. **Bold** value indicates that compound was detected, but was attributed to sample contamination]

Well identifier	Date	Hexachloro-butadiene (µg/L)	Isopropyl-benzene (µg/L)	Methylene chloride (µg/L)	Methyl *tert*-butyl ether (µg/L)	*m*-Xylene and *p*-xylene (µg/L)	Naph-thalene (µg/L)	*n*-Butyl-benzene (µg/L)	*n*-Propyl-benzene (µg/L)	*o*-Xylene (µg/L)	*sec*-Butyl-benzene (µg/L)	Styrene (µg/L)
						Environmental samples						
JH–1	10/15/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<1.0	<0.50	<0.50	<0.50	<0.50	<0.50
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
JH–2	10/17/2008	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	05/07/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
JH–3	10/16/2008	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	**E.31**	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
JH–3D	10/16/2008	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
JH–4	10/16/2008	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
Hangar 1	10/17/2008	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
Hangar 5	10/17/2008	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
						Quality-control samples						
JH–2	[1]10/17/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<1.0	<0.50	<0.50	<0.50	<0.50	<0.50
	[2]05/07/2009	<.50	<.50	**E.61**	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50
JH–3	[3]05/06/2009	<.50	<.50	<.50	<.50	<.50	<1.0	<.50	<.50	<.50	<.50	<.50

Table 12. Analytical results for volatile organic compounds and gasoline-range organics in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, estimated concentration. **Bold** value indicates that compound was detected, but was attributed to sample contamination]

Well identifier	Date	*tert*-Butyl-benzene (µg/L)	*tert*-Butyl ethyl ether (µg/L)	Tetrachloro-ethene (µg/L)	Toluene (µg/L)	*trans*-1,2-Dichloroethene (µg/L)	*trans*-1,3-Dichloropropene (µg/L)	Trichloro-ethene (µg/L)	Trichloro-fluoromethane (µg/L)	Vinyl chloride (µg/L)	Xylene, total (µg/L)	Gasoline-range organics (µg/L)
Environmental samples												
JH–1	10/15/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<10
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
JH–2	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	05/07/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
JH–3	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
JH–3D	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	03/04/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
JH–4	10/16/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
Hangar 1	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	03/03/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
Hangar 5	10/17/2008	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	03/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	05/05/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
	06/17/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10
Quality-control samples												
JH–2	[1]10/17/2008	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<10
	[2]05/07/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	--
JH–3	[3]05/06/2009	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<10

[1] Field blank.

[2] Trip blank.

[3] Replicate sample.

Table 13. Analytical results for glycols and diesel-range organics in groundwater samples from wells at Jackson Hole Airport, Jackson, Wyoming, October 2008–June 2009.

[Detections are in **bold type and underlined**. USGS, U.S. Geological Survey; mg/L, milligrams per liter; DRO, diesel-range organics; C10–C32 and C10–C36, ranges of carbon compounds included in the analysis; <, less than symbol indicates chemical was not detected, and the value following the less than symbol is the laboratory reporting level; E, estimated concentration]

USGS site-identification number	Well identifier	Date	Time (24 hour)	Diethylene glycol (mg/L)	Diethylene glycol, monobutyl ether (mg/L)	Ethylene glycol (mg/L)	Propylene glycol (mg/L)	Triethylene glycol (mg/L)	DRO C10–C32 (mg/L)	DRO C10–C36 (mg/L)
Environmental samples										
433615110440001	JH–1	10/15/2008	1630	<25	<10	<25	<25	<25	<0.25	<0.25
		03/03/2009	1345	<25	<10	<25	<25	<25	<.25	<.25
		05/05/2009	1700	<25	<10	<25	<25	<25	**E.033**	**E.035**
		06/16/2009	1530	<25	<10	<25	<25	<25	<.25	<.25
433551110443501	JH–2	10/17/2008	1100	<25	<10	<25	<25	<25	<.25	<.25
		03/05/2009	1020	<25	<10	<25	<25	<25	<.25	<.25
		05/07/2009	1030	<25	<10	<25	<25	<25	**E.083**	**E.10**
		06/18/2009	0940	<25	<10	<25	<25	<25	<.25	<.25
433603110443501	JH–3	10/16/2008	1330	<25	<10	<25	<25	<25	<.25	<.25
		03/04/2009	1200	<25	<10	<25	<25	<25	<.25	<.25
		05/06/2009	1230	<25	<10	<25	<25	<25	<.25	<.25
		06/17/2009	1630	<25	<10	<25	<25	<25	<.25	<.25
433603110443502	JH–3D	10/16/2008	1630	<25	<10	<25	<25	<25	<.25	<.25
		03/05/2009	1500	<25	<10	<25	<25	<25	<.25	<.25
		05/06/2009	1600	<25	<10	<25	<25	<25	<.25	<.25
		06/17/2009	1345	<25	<10	<25	<25	<25	<.25	<.25
433613110443501	JH–4	10/16/2008	1000	<25	<10	<25	<25	<25	<.25	<.25
		05/06/2009	1030	<25	<10	<25	<25	<25	**E.099**	**E.12**
		06/17/2009	0945	<25	<10	<25	<25	<25	<.25	<.25
433607110440901	Hangar 1	10/17/2008	1630	<25	<10	<25	<25	<25	<.25	<.25
		03/03/2009	1030	<25	<10	<25	<25	<25	<.25	**E.034**
		05/05/2009	1030	<25	<10	<25	<25	<25	<.25	<.25
		06/18/2009	1050	<25	<10	<25	<25	<25	<.25	<.25
433556110441601	Hangar 5	10/17/2008	1400	<25	<10	<25	<25	<25	<.25	<.25
		03/05/2009	1300	<25	<10	<25	<25	<25	<.25	<.25
		05/05/2009	1345	<25	<10	<25	<25	<25	<.25	<.25
		06/16/2009	1010	<25	<10	<25	<25	<25	<.25	<.25
Quality-control samples										
433551110443501	JH–2	[1]10/17/2008	0930	<25	<10	<25	<25	<25	<.25	<.25
433603110443501	JH–3	[2]05/06/2009	1235	<25	<10	<25	<25	<25	<.25	<.25

[1] Field blank.

[2] Replicate.

Table 14. Replicate data for major ions, nutrients, dissolved organic carbon, and trace elements in the groundwater sample from well JH–3, Jackson Hole Airport, Jackson, Wyoming, May 2009.

Physical property or constituent	Environmental sample	Replicate sample	Calculated relative percent difference
Major ions and related characteristics, in milligrams per liter			
Total dissolved solids	215	232	7.61
Calcium	54.5	57.3	5.01
Magnesium	9.31	9.53	2.34
Potassium	1.81	1.87	3.26
Sodium	7.11	7.13	.28
Hardness, total, as $CaCO_3$	170	180	5.71
Bromide	.03	.01	100
Chloride	4.31	4.37	1.38
Fluoride	.35	.36	2.82
Silica	21.8	21.41	1.81
Sulfate	7.38	7.35	.41
Nutrients and dissolved organic carbon, in milligrams per liter			
Ammonia, as nitrogen	0.044	0.037	17.28
Orthophosphate, as phosphorus	.013	.014	7.41
Phosphorus, total, as phosphorus	.017	.014	19.35
Total nitrogen (nitrate + nitrite + ammonia + organic-nitrogen), unfiltered	.08	.12	40.00
Dissolved organic carbon	.5	.5	.00
Trace elements, in micrograms per liter			
Iron	196	218	10.63
Manganese	1,460	1,454	.41

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