

Prepared in cooperation with the Jackson Hole Airport Board

Hydrogeology and Water Quality in the Snake River Alluvial Aquifer at Jackson Hole Airport, Jackson, Wyoming, Water Years 2011 and 2012

Scientific Investigations Report 2013–5184

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By Peter R. Wright

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Scientific Investigations Report 2013–5184

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

U.S. Department of the Interior

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U.S. Geological Survey

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U.S. Geological Survey, Reston, Virginia: 2013

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Suggested citation:

Wright, P.R., 2013, Hydrogeology and water quality in the Snake River alluvial aquifer at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012: U.S. Geological Survey Scientific Investigations Report 2013–5184, 56 p., <http://dx.doi.org/10.3133/sir20135184>.

Acknowledgments

The author gratefully acknowledges the Teton Conservation District which maintains continuous groundwater level recorders at the Jackson Hole Airport and provided near real-time groundwater-level data for this study. The author gratefully acknowledges the assistance of Dan Leemon, Teton Conservation District, and the maintenance staff at the Jackson Hole Airport.

Steve Corsi and James Landmeyer, U.S. Geological Survey, are acknowledged for their technical reviews of report drafts. Janet Carter, U.S. Geological Survey, is thanked for report specialist review of this report. Scott Edmiston, Jerrod Wheeler, and Michael Sweat, U.S. Geological Survey, are thanked for their assistance collecting all of the data that made production of this report possible.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m ²)

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

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C}) + 32$$

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$$

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).

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).

Water year is the 12-month period, October 1 through September 30, and is designated by the calendar year in which it ends.

Abbreviations and Acronyms

<	less than
±	plus or minus
4-MeBT	4-methyl-1 <i>H</i> -benzotriazole
5-MeBT	5-methyl-1 <i>H</i> -benzotriazole
ADAF	aircraft deicing/anti-icing fluid
CaCO ₃	calcium carbonate
CH ₄	methane
COD	chemical oxygen demand
DOC	dissolved organic carbon
DRO	diesel-range organic
E	estimated value
e-tape	electronic tape
Fe ²⁺	ferrous iron
GRO	gasoline-range organic
H ₂ S	dihydrogen sulfide (aqueous)
HS ⁻	hydrogen sulfide
IRL	interim reporting level
JHA	Jackson Hole Airport
LOD	limit of detection (Wisconsin State Laboratory of Hygiene)
LRL	laboratory reporting level
MCL	Maximum Contaminant Level (U.S. Environmental Protection Agency)
MDL	method detection limit
Mn ²⁺	manganese
MRL	minimum reporting level
NO ₃ ⁻	nitrate
NWIS	National Water Information System (U.S. Geological Survey)
NWQL	National Water Quality Laboratory (U.S. Geological Survey)
O ₂	oxygen
PVC	polyvinyl chloride
redox	reduction and oxidation
RPD	relative percent difference
S ²⁻	sulfide
SMCL	Secondary Maximum Contaminant Level (U.S. Environmental Protection Agency)
SO ₄ ²⁻	sulfate
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound
WSLH	Wisconsin State Laboratory of Hygiene

Hydrogeology and Water Quality in the Snake River Alluvial Aquifer at Jackson Hole Airport, Jackson, Wyoming, Water Years 2011 and 2012

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, during water years 2011 and 2012 as part of a followup to a previous baseline study during September 2008 through June 2009. Hydrogeologic conditions were characterized using data collected from 19 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 groundwater samples collected from 10 wells during water years 2011 and 2012 are presented and summarized.

The water table at Jackson Hole Airport was lowest in early spring and reached its peak in July or August, with an increase of 12.5 to 15.5 feet between April and July 2011. Groundwater flow was predominantly horizontal but generally had the hydraulic potential for downward flow. Groundwater flow within the Snake River alluvial aquifer at the airport was from the northeast to the west-southwest, with horizontal velocities estimated to be about 25 to 68 feet per day. This range of velocities slightly is broader than the range determined in the previous study and likely is due to variability in the local climate. The travel time from the farthest upgradient well to the farthest downgradient well was approximately 52 to 142 days. This estimate only describes the average movement of groundwater, and some solutes may move at a different rate than groundwater through the aquifer.

The quality of the water in the alluvial aquifer generally was considered good. Water from the alluvial aquifer was fresh, hard to very hard, and dominated by calcium carbonate. No constituents were detected at concentrations exceeding U.S. Environmental Protection Agency maximum contaminant levels or health advisories; however, reduction and oxidation (redox) measurements indicate oxygen-poor water in many of the wells. Gasoline-range organics, three volatile organic compounds, and triazoles were detected in some groundwater

samples. The quality of groundwater in the alluvial aquifer generally was suitable for domestic and other uses; however, dissolved iron and manganese were detected in samples from many of the monitor wells at concentrations exceeding U.S. Environmental Protection Agency secondary maximum contaminant levels. Iron and manganese likely are both natural components of the geologic materials in the area and may have become mobilized in the aquifer because of redox processes. Additionally, measurements of dissolved-oxygen concentrations and analyses of major ions and nutrients indicate reducing conditions exist at 7 of the 10 wells sampled.

Measurements of dissolved-oxygen concentrations (less than 0.1 to 9 milligrams per liter) indicated some variability in the oxygen content of the aquifer. Dissolved-oxygen concentrations in samples from 3 of the 10 wells indicated oxic conditions in the aquifer, whereas low dissolved-oxygen concentrations (less than 1 milligram per liter) in samples from 7 wells indicated anoxic conditions. Nutrients were present in low concentrations in all samples collected. Nitrate plus nitrite was detected in samples from 6 of the 10 monitored wells, whereas dissolved ammonia was detected in small concentrations in 8 of the 10 monitored wells. Dissolved organic carbon concentrations generally were low. At least one dissolved organic carbon concentration was quantified by the laboratory in samples from all 10 wells; one of the concentrations was an order of magnitude higher than other detected dissolved organic carbon concentrations, and slightly exceeded the estimated range for natural groundwater.

Samples were collected for analyses of dissolved gases, and field analyses of ferrous iron, hydrogen sulfide, and low-level dissolved oxygen were completed 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 indicated the presence of methane gas in samples from several wells. Redox processes in the alluvial aquifer were identified using a model designed to use a multiple-lines-of-evidence approach to distinguish reduction processes. Results of redox analyses indicate iron reduction was the dominant redox process; however, the model indicated manganese reduction and methanogenesis also were taking place in the aquifer.

Each set of samples collected during this study included analysis of at least two, but often many anthropogenic compounds. During the previous 2008–09 study at Jackson Hole Airport, diesel-range organics were measured in small (estimated) concentrations in several samples. Samples collected from all 10 wells sampled during the 2011–12 study were analyzed for diesel-range organics, and there were no detections; however, several other anthropogenic compounds were detected in groundwater samples during water years 2011–12 that were not detected during the previous 2008–09 study. Gasoline-range organics, benzene, ethylbenzene, and total xylene were each detected (but reported as estimated concentrations) in at least one groundwater sample. These compounds were not detected during the previous study or consistently during this study. Several possible reasons these compounds were not detected consistently include (1) these compounds are present in the aquifer at concentrations near the analytical method detection limit and are difficult to detect, (2) these compounds were not from a persistent source during this study, and (3) these compounds were detected because of contamination introduced during sampling or analysis. During water years 2011–2012, groundwater samples were analyzed for triazoles, specifically benzotriazole, 4-methyl-1*H*-benzotriazole, and 5-methyl-1*H*-benzotriazole. Triazoles are anthropogenic compounds often used as an additive in deicing and anti-icing fluids as a corrosion inhibitor, and can be detected at lower laboratory reporting levels than glycols, which previously had not been detected. Two of the three triazoles measured, 4-methyl-1*H*-benzotriazole and 5-methyl-1*H*-benzotriazole, were detected at low concentrations in groundwater at 7 of the 10 wells sampled. The detection of triazole compounds in groundwater downgradient from airport operations makes it unlikely there is a natural cause for the high rates of reduction present in many airport monitor wells. It is more likely that aircraft deicers, anti-icers, or pavement deicers have seeped into the groundwater system and caused the reducing conditions.

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 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. The JHA is located in an area of high vulnerability to groundwater contamination which is due to a high water table, coarse soils,

and high rates of hydraulic conductivity (Hamerlinck and Arneson, 1998).

Of particular interest is whether or not 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 and Norway have documented components of aircraft deicing/anti-icing fluid (ADAF) in airport snowbanks (Corsi and others, 2006a), surface-water runoff (Corsi and others, 2001), and shallow groundwater (Breedveld and others, 2002, 2003; Cancilla and others, 1998, 2003a). Decreased dissolved-oxygen conditions were determined to be associated with ADAFs (Cancilla and others, 1998; Corsi and others, 2001; Corsi and others, 2006a, 2006b). These studies have determined that glycols, the primary ingredient in ADAFs, have 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. During 2008 and 2009, the USGS completed a baseline study to characterize the hydrogeology and groundwater quality of the Snake River alluvial aquifer in upgradient and downgradient parts of the aquifer underlying the JHA (Wright, 2010). In that study, Wright (2010) reported the detection of chemical conditions indicative of the presence of organic compounds, such as ADAFs or their breakdown products, in groundwater downgradient from historical deicing application areas. A zone of highly reduced groundwater was observed downgradient from the deicing areas, but the reason why dissolved oxygen was depleted and methane was detected could not be determined.

To achieve a better understanding of such groundwater-quality issues and changes in flow conditions at the JHA, the USGS, in cooperation with the Jackson Hole Airport Board, conducted a followup study of groundwater conditions at the airport during water years 2011–12; a water year is the 12-month period from October 1 through September 30, and is designated by the calendar year in which it ends. The objective of this followup study was to further characterize the hydrogeology and groundwater quality of the Snake River aquifer in upgradient and downgradient parts of the aquifer underlying the airport and facilities.

Purpose and Scope

The purpose of this report is to describe the hydrogeology and water quality within the alluvial aquifer underlying the JHA during water years 2011 and 2012. Water-quality samples were collected during four time periods (June, July, and November 2011 and April 2012), each representing different hydrogeologic conditions and different airport-use periods. Hydrogeologic characteristics, including the direction of groundwater flow, hydraulic gradients, estimated groundwater-flow rates, and water-quality conditions for major-ion chemistry, nutrients, trace elements, volatile organic compounds (VOCs), gasoline-range organics (GROs), diesel-range

organics (DROs), and triazoles, upgradient and downgradient from airport activities and facilities, are described. Reduction and oxidation processes (redox) are characterized. Conclusions drawn from study results are described. Much of the hydrogeologic and water-quality data presented in Wright (2010) will be referenced in this report.

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; in 2008, 3,904 flights carried more than 600,000 passengers (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 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 large water-table aquifer throughout the eastern part of Grand Teton National Park and the Jackson Hole area (Nolan and Miller, 1995; Nolan and others, 1998). The aquifer informally is 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) 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. Recharge of the alluvial aquifer generally is by infiltration of precipitation, streamflow leakage, and irrigation water, and migration of deep groundwater near fault zones (Nolan and Miller, 1995). Groundwater in the Snake River alluvial aquifer generally follows the topography, moving from high altitudes toward the Snake River and to the 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; Wright, 2010).

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 climate station in Moose, Wyoming, 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 from 1958–2012 (Western Regional Climate Center, 2012). Mean monthly precipitation data, also collected at the climate station in Moose, Wyo., ranged from 1.15 inches (in.) in July to 2.62 in. during January with an annual average of 21.33 in. for the period 1958–2012 (Western Regional Climate Center, 2012). Much of the precipitation in the Jackson Hole area is snowfall. On average, snow falls 10 months of the year with an average snowfall of 172.2 in. at Moose, Wyo. (Western Regional Climate Center, 2012). Leading up to the study (2010 and early 2011), precipitation generally was well above average, whereas precipitation was near average during June 2011–April 2012.

Study Design

Water-quality sampling and water-level monitoring were conducted at 10 monitor wells: 5 existing monitor wells installed for the baseline study (Wright, 2010), and 5 new monitor wells installed to help expand knowledge of local hydrogeologic and water-quality characteristics (fig. 2). In addition to the 10 monitor wells, 9 existing production wells were selected for water-level monitoring. The hydrogeology of the Snake River alluvial aquifer underlying the JHA was characterized using water levels collected from these 19 wells during water years 2011 and 2012. The water quality of the Snake River alluvial aquifer was determined from water-quality samples collected at the 10 monitoring wells (fig. 2, appendix 1).

Eight of the 10 monitor wells sampled during this study are screened near the water table, and two monitoring wells (JH-1.5D and JH-3D) are completed in the deeper part of the aquifer (appendix 1). As part of the baseline study, five wells had been installed along the direction of groundwater flow based on published potentiometric-surface contour maps (Kumar and Associates, written commun., 1993; Nolan and Miller, 1995; Wright, 2010). To summarize these existing wells, well JH-1 is north and east of current (2013) airport operations (upgradient), just east of the Teton Interagency Helitack Crew operations center (fig. 2). Three wells (JH-2, JH-3, and JH-4) are along the south and west airport boundary and represent downgradient conditions of current and planned airport operations, and a deep well (JH-3D) is adjacent to well JH-3 along the south and west airport boundary (fig. 2).

Initially, four additional wells were installed for this followup study. Two wells were installed lateral [JH-2.5 (south) and JH-3.5 (north)] to wells JH-3 and JH-3D (well cluster 3), and a water table/deep well pair [wells JH-1.5 and JH-1.5D (wells cluster 1.5)] was installed upgradient from well cluster 3 (fig. 2). During this followup study, it was determined the new shallow wells did not extend deep enough into the aquifer to contain water throughout the year. During October 2011 one new, deeper, water-table well (JH-1.5R) was installed near wells JH-1.5 and JH-1.5D.

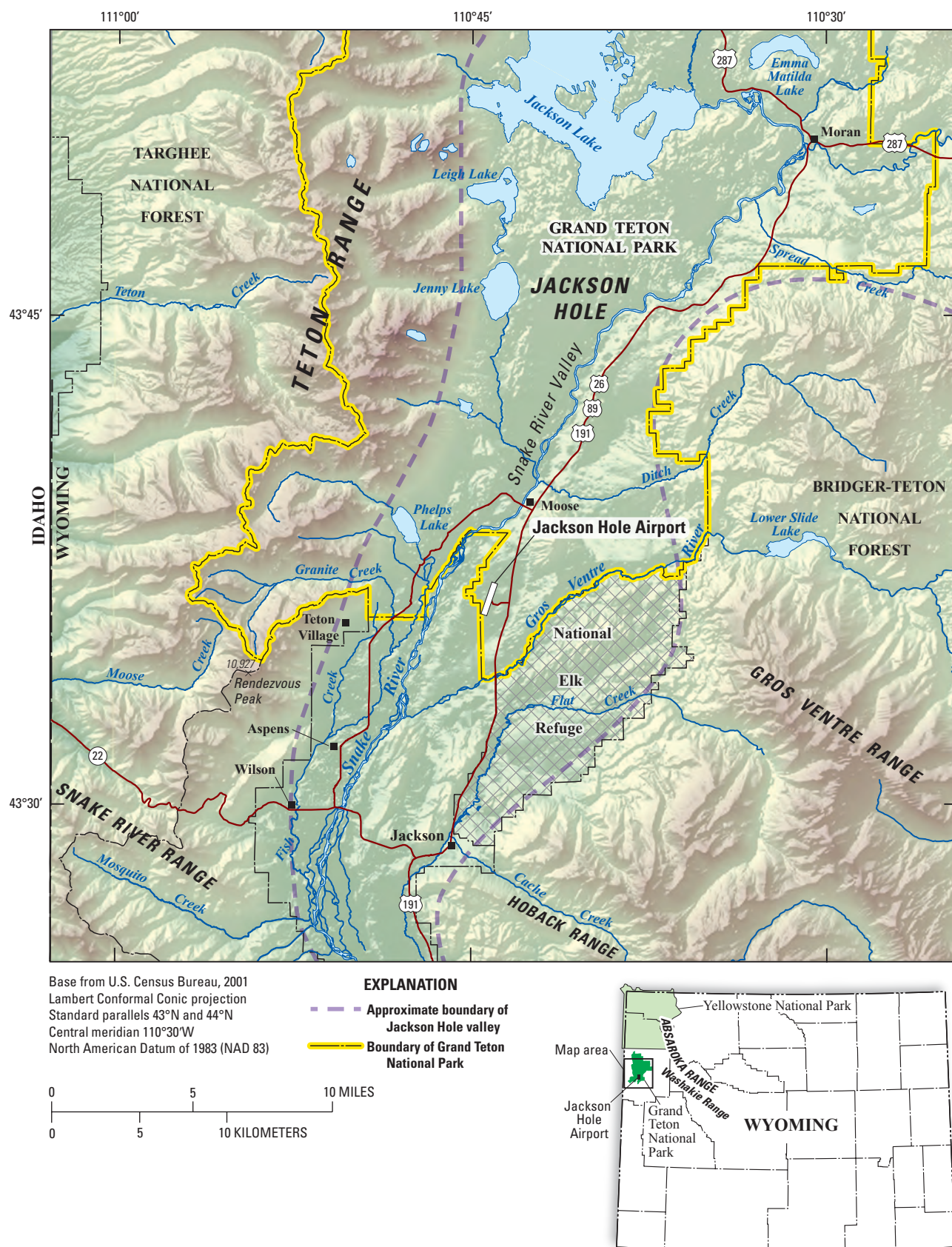


Figure 1. Location of Jackson Hole Airport in the Jackson Hole valley, Wyoming.

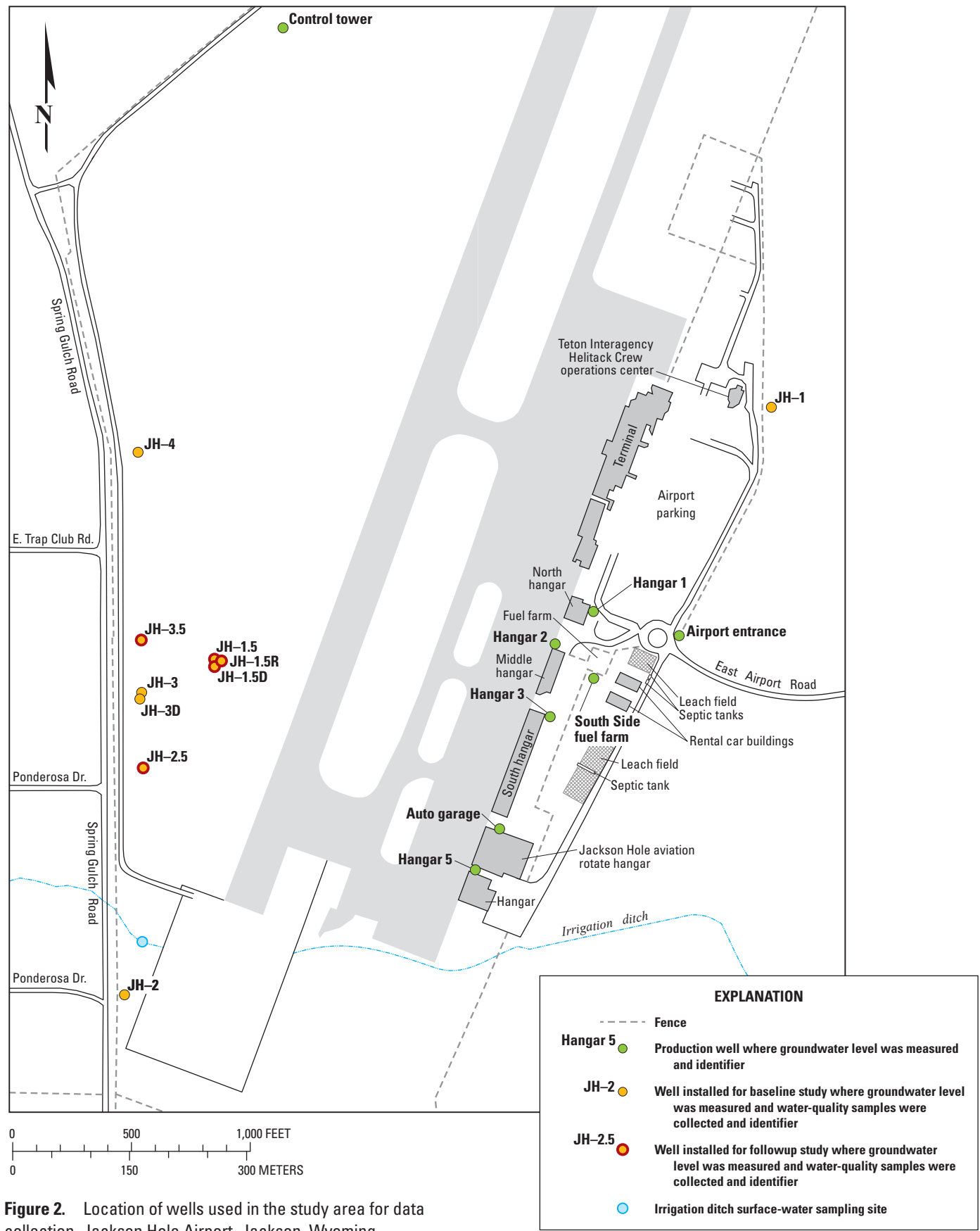


Figure 2. Location of wells used in the study area for data collection, Jackson Hole Airport, Jackson, Wyoming.

Groundwater samples were collected four times from each of the monitor wells with two exceptions. First, wells JH-1.5 and JH-1.5R were each only sampled twice. Since well JH-1.5R was installed very close to well JH-1.5, was screened across the same aquifer (extending several feet deeper) and was a direct replacement for well JH-1.5, the hydrogeologic and water-quality data collected from these two wells have been combined, and treated as one well for data analysis in this report. Second, during the April 2012 sampling event, not enough water was in well JH-3.5 to collect a sample because of a low water table. One surface-water quality sample was collected in June 2011 from the irrigation ditch that flows across the southern end of the airport (fig. 2). Water-quality results described in this report are for samples collected between June 2011 and April 2012; however, where appropriate, data collected during the baseline study (2008–09) described in Wright (2010) are used for comparison.

Laboratory analyses varied by well and sampling date and are listed in table 1. Groundwater samples were collected from existing and new wells to further describe basic groundwater geochemistry, including major inorganics [major ions, dissolved solids, silica, and the trace elements manganese and iron], nutrients (nitrite, nitrate, ammonia, total nitrogen, total phosphorus, and orthophosphate), chemical oxygen demand (COD), and dissolved organic carbon (DOC). Water-quality results for the baseline study (Wright, 2010) did not indicate the presence of VOCs or GRO compounds at wells JH-1, JH-2, JH-3, JH-3D, or JH-4; therefore, samples from these wells were not reanalyzed for these constituents. However, samples from newly drilled wells (JH-1.5, JH-1.5R, JH-1.5D, JH-2.5, and JH-3.5) were analyzed for these constituents to define baseline conditions in these new areas and for comparison to results for these same constituents as presented in Wright (2010) (table 1). DROs were reanalyzed as part of the followup study to confirm or refute the presence of DROs as previously reported (Wright, 2010).

Because glycol compounds were not detected during the baseline study (Wright, 2010), samples were not analyzed for glycols. Instead, samples were analyzed for triazoles, specifically benzotriazole, 4-methyl-1*H*-benzotriazole (4-MeBT) and 5-methyl-1*H*-benzotriazole (5-MeBT). Triazoles are a class of chemicals historically used in ADAFs as corrosion inhibitors and have been shown to increase the toxicity of ADAF to aquatic organisms (Pillard, 1995; Cancilla and others, 1997; and Cornell and others, 2000). These compounds can be detected at laboratory reporting levels two orders of magnitude lower than glycols, and were used in this investigation to determine if deicing compounds are a source of organic carbon associated with the zone of reduced groundwater described in Wright (2010). Additional water-quality data (ferrous iron, dissolved oxygen, and sulfide analyzed in the field during sample collection) were collected from wells with low [less than (<) 1 milligram per liter (mg/L)] dissolved-oxygen concentrations to better understand the redox processes at these wells.

Methods of Data Collection and Analysis

Methods used for monitor well construction, water-level measurement, analysis of hydrogeologic data, and collection and analysis of groundwater, surface-water, and quality-control samples are described herein. Technical guidelines applicable to this study are documented in the USGS “National Field Manual for the Collection of Water-Quality Data” (U.S. Geological Survey, variously dated) and “Groundwater Technical Procedures of the U.S. Geological Survey” (Cunningham and Schalk, 2011). To record data in the USGS National Water Information System (NWIS), each site must be established with at least a minimum set of data (Cunningham and Schalk, 2011). This minimum dataset includes well construction information, documentation of well location, established measuring point and land surface datums, and field measurements of well depth and water level. The techniques used to accomplish the site inventories are included throughout the “Methods of Data Collection and Analysis” section of the report.

Well Construction and Ancillary Information

Many wells have been installed to monitor the hydrogeology and quality of groundwater underlying the JHA. Monitoring wells installed for this study were drilled using a dual rotary drill rig. Well construction and related ancillary information for wells used during this study are presented in appendix 1. Four new monitor wells were installed during the summer of 2010 as part of this followup study. Well JH-1.5D was modified after initial installation with no screen to include a 10-ft screened interval, and a fifth well, JH-1.5R, was installed in October 2011 nearby at a depth approximately 10 ft deeper than well JH-1.5 to ensure there would be water in the shallow (water table) well at this location throughout the year. 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 10 or 20 ft long (appendix 1) and set at depths about 10 to 15 ft below and 5 ft above the water-table surface. This allowed the wells to “straddle” the water table, allowing for measurement of 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. A deep well (JH-1.5D) was drilled to about 95 ft of depth and installed adjacent to well JH-1.5. Well JH-1.5D initially was installed in the same manner as well JH-3D; well JH-3D is not perforated or screened and therefore acts as a piezometer; however, as described above, this well was modified to include a PVC well screen. The driller installed a 2-in. diameter, flush-jointed PVC casing with 10 ft of well screen and removed the 6-in. steel casing. Before sampling, all of the new and updated monitoring wells were

Table 1. Laboratory analyses for groundwater samples collected from wells and for surface-water sample collected from irrigation ditch at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[USGS, U.S. Geological Survey; --, not analyzed; X, analyzed; N, sample was planned but not collected; COD, chemical oxygen demand; DOC, dissolved organic carbon; VOC, volatile organic compound; GRO, gasoline range organic; DRO, diesel range organic]

Constituent	Wells sampled at the Jackson Hole Airport																	
	JH-1			JH-1.5			JH-1.5R			JH-1.5D			JH-2			JH-2.5		
	June 2011	July 2011	Nov. 2011	Apr. 2012	June 2011	July 2011	Nov. 2011	Apr. 2012	June 2011	July 2011	Nov. 2011	Apr. 2012	June 2011	July 2011	Nov. 2011	Apr. 2012	June 2011	July 2011
USGS National Water Quality Laboratory																		
COD	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Major ions	X	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nutrients	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DOC	--	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Iron and manganese	--	X	--	--	--	--	X	--	--	--	--	X	--	--	X	--	--	--
TestAmerica Laboratories																		
VOCs	--	--	--	X	X	X	X	X	X	X	X	X	--	--	--	--	X	--
GROs	--	--	--	X	X	X	X	X	X	X	X	X	--	--	--	--	X	--
DROs	X	X	--	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wisconsin State Laboratory of Hygiene																		
Triazoles	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
USGS Reston Chlorofluorocarbon Laboratory																		
Dissolved gases	X	--	--	X	--	--	--	X	--	--	--	X	--	--	--	X	--	--

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 by the USGS or a survey contractor for each of the monitoring wells. Well locations were determined by the USGS using a global positioning system that reported latitude and longitude using the North American Datum of 1983 (NAD 83) with horizontal accuracy of less than plus or minus (\pm) 49 ft (15 m) (Garmin, 2004). Altitudes for all of the monitoring wells installed for this study were determined using conventional surveying methods.

Water-Level Measurement

Discrete water levels were measured during each site visit to the airport (appendix 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. A detailed description of the methods used to measure water levels by use of e-tape or steel tape are documented in Cunningham and Schalk (2011). Replicate measurements were made during each visit to ensure the water level measured was the correct water level. Water levels were measured to one-hundredth of a foot.

During February 2009, continuous water-level recorders were installed in monitoring wells JH-1, JH-2, JH-3, and JH-4. These instruments were installed by and continue to be maintained by the Teton Conservation District. 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 and during each site visit (appendix 2) to verify proper reading of the instrument. The Teton Conservation District provided continuous and discrete water-level measurements to the USGS for use in this study. Continuous water-level data collected through water year 2012 were checked by USGS personnel, entered into the USGS NWIS database, and 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, hydraulic gradient and groundwater velocity were calculated using methods described in Heath (1983) and presented in Wright (2010). Each set of calculations for direction of groundwater flow and hydraulic gradient required

water-level data from three wells to perform a three-point calculation (Heath, 1983), located in a triangular arrangement. Data necessary for these calculations included water-level altitude (appendix 2) and the linear distance between wells (approximated from a USGS 7.5-minute, 1:24,000-scale topographic map). 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. A groundwater velocity was estimated using a hydraulic conductivity of 2,900 and 1,200 feet per day (Nelson Engineering, 1992), a porosity of 30 percent, and the average hydraulic gradient calculated for each water-level measurement event using the methods described in Heath (1983) and presented in Wright (2010).

Groundwater and Surface-Water Sampling and Analysis

Groundwater samples were collected during four time periods, each event representing different hydrogeologic conditions and airport-use periods. Sampling methods are briefly described herein. Samples were analyzed for many different constituents—some of these constituents were analyzed in the field, whereas other constituents were analyzed in a laboratory. Analytical laboratories, a brief description of the constituents each laboratory analyzed, and a description of laboratory reporting levels, are included in this section of the report.

Groundwater samples were collected and processed in a mobile water-quality laboratory in accordance with standard USGS methods described in the USGS field manual (U.S. Geological Survey, variously dated). 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, and temperature stabilized. These physical properties (table 2) were measured in the field as part of sample collection using methods described in the USGS field manual (U.S. Geological Survey, variously dated). Alkalinity was determined using incremental titration of a filtered water sample with sulfuric acid as described in the USGS field manual (U.S. Geological Survey, variously dated). Samples collected for analyses of major ions, selected nutrients, selected trace elements, and dissolved organic carbon were filtered by passing sample water through a pre-conditioned 0.45-micrometer, nominal-pore-size, disposable capsule filter. In this report, constituents in filtered water samples are referred to as dissolved. Constituents in unfiltered water samples are referred to as total.

One surface-water quality sample was collected from the irrigation ditch that flows across the southern end of the airport (fig. 2) and analyzed for selected constituents as listed in table 1. This surface-water sample was collected and processed in accordance with standard USGS methods

Table 2. Physical properties, inorganic constituents, and other constituents analyzed in groundwater and surface-water samples in the field or at the U.S. Geological Survey National Water Quality Laboratory for samples collected at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[--, not applicable; MRL, minimum reporting level; LTMDL, long-term method detection level; MDL, method detection level; IRL, interim reporting level; LRL, laboratory reporting level]

Physical property or inorganic constituent	Unit of measure	Sampling 2011–12	
		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 ¹	nephelometric turbidity ratio units	--	--
Major ions and related water-quality characteristics			
Dissolved solids, residue on evaporation at 180 degrees Celsius	milligrams per liter	20	MRL
Calcium, dissolved	milligrams per liter	0.044	LTMDL
Magnesium, dissolved	milligrams per liter	0.022	LTMDL
Potassium, dissolved	milligrams per liter	0.06	LTMDL
Sodium, dissolved	milligrams per liter	0.12	LTMDL
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	0.02	MDL
Chloride, dissolved	milligrams per liter	0.12	LTMDL
Fluoride, dissolved	milligrams per liter	0.08	LTMDL
Silica, dissolved	milligrams per liter	0.036	LTMDL
Sulfate, dissolved	milligrams per liter	0.18	LTMDL
Nutrients			
Ammonia, dissolved	milligrams per liter as nitrogen	0.02	LTMDL
Nitrate plus nitrite, dissolved	milligrams per liter as nitrogen	0.08	MDL
Nitrite, dissolved	milligrams per liter as nitrogen	0.002	IRL
Orthophosphate, dissolved	milligrams per liter as phosphorus	0.008	LRL
Phosphorus, total	milligrams per liter	0.008	LRL
Nitrogen, total	milligrams per liter	0.1	LRL
Trace elements ¹			
Iron, dissolved	micrograms per liter	8.0	LTMDL
Manganese, dissolved	micrograms per liter	0.32	LTMDL
Other analyses			
Chemical oxygen demand	milligrams per liter	10	MRL
Organic carbon, dissolved	milligrams per liter	0.46	LTMDL

¹Analyzed in groundwater samples only.

described in the USGS field manual (U.S. Geological Survey, variously dated). To minimize sample disturbance, VOC sample containers were filled directly from the irrigation ditch. Remaining sample containers were filled from a churn splitter containing a representative surface-water sample collected from the irrigation ditch using a DH-81 isokinetic sampler and the equal-width-increment sampling technique (U.S. Geological Survey, variously dated). Processing of the surface-water sample was similar to groundwater samples. The ditch sample was analyzed for all the same constituents as groundwater samples, except for dissolved gases.

The USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, analyzed water samples for major ions, COD, DOC, nutrients, and trace elements of iron and manganese. Major ions and trace elements (table 2) were analyzed using ion-exchange chromatography or inductively coupled plasma-atomic-emission spectroscopy (Fishman and Friedman, 1989; Fishman, 1993). Nutrients and COD were analyzed using colorimetry (Fishman, 1993). DOC was analyzed using ultraviolet light-promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993).

TestAmerica Laboratories, Inc., in Denver, Colo., was contracted to analyze water samples for VOCs, GRO, and DRO (table 3) using U.S. Environmental Protection Agency (USEPA) methods. VOCs were analyzed using USEPA method 524.2 (Munch, 1995), GROs were analyzed using USEPA SW846 method 8021/8015B (U.S. Environmental Protection Agency, 1996a, 1996b), and DROs were analyzed using USEPA SW846 method 8015B (U.S. Environmental Protection Agency, 1996a) in the C_{10} – C_{36} ranges (table 3).

The Wisconsin State Laboratory of Hygiene (WSLH) was contracted to analyze water samples for benzotriazole, 4-MeBT and 5-MeBT, generally referred to as triazoles in this report. Groundwater samples collected from each well for all sampling events during water years 2011 and 2012 were analyzed for triazoles. The one surface-water sample collected from the irrigation ditch in June 2011 also was analyzed for triazoles. The WSLH has developed a high performance/liquid chromatography/triple quadruple mass spectrometry method to determine the triazole compounds in water (Wisconsin State Laboratory of Hygiene, 2007). The method is considered experimental because it has not received standard approval by the USEPA or other method approving entities.

The USGS Reston Chlorofluorocarbon Laboratory in Reston, Virginia, analyzed nine groundwater samples for dissolved gases (argon, carbon dioxide, methane, nitrogen, and oxygen) using gas chromatography (Busenberg and others, 2001). Dissolved gas samples were all analyzed in duplicate. For the purpose of this study, the mean and standard deviation have been reported to represent duplicate dissolved gas concentrations.

Low-concentration range dissolved oxygen, sulfide, and ferrous iron were analyzed in the field laboratory using a HACH® DR 2800 spectrophotometer (HACH, 2007). Methods of analyses included HACH® method 8316, which is the indigo carmine method using AccuVac ampoules for

low-range dissolved oxygen; HACH® method 8146, which is the 1,10-phenanthroline method using AccuVac ampoules for ferrous iron; and HACH® method 8131, which is a methylene blue method for sulfide (HACH, 2007).

Each of the laboratories described previously reported analytical results in accordance with their protocols. This paragraph generally describes how data included in this report are reported. The less than symbol (<) indicates that the chemical was not detected. For data reported by the NWQL, the USGS Reston Chlorofluorocarbon Laboratory, and TestAmerica Laboratories, the value following the less than (<) symbol is the laboratory reporting level (LRL), interim reporting level (IRL), or the minimum reporting level (MRL) 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 (table 2), is a temporary reporting level used for new or custom schedules when long-term method detection level data are unavailable and a LRL has not yet been established (U.S. Geological Survey, 2004). The MRL, as defined by the NWQL, is the smallest measured concentration of a substance that can be measured reliably by using a given analytical method (Timme, 1995). For triazole data reported by the WSLH, the value following the less than (<) symbol is the limit of detection (LOD) or detection limit, defined as the lowest concentration level that can be determined to be statistically different from a blank sample with 99-percent confidence (Wisconsin Department of Natural Resources, 1996). The LOD approximately is equal to the method detection limit (MDL) for those analyses for which the MDL can be calculated. Some water-quality results, especially those for organic compounds in this study, are qualified with an “E” or are reported as a less than (<) value. The “E” remark code indicates the value is estimated and less than the LRL, but equal to or greater than the laboratory method detection limit. Values commonly are estimated when the value is greater than the MDL but less than the LRL. Generally, concentrations that are less than the LRL have more uncertainty in their quantification than concentrations larger than LRLs. The WSLH data also have been reported with an “E” remark code. In this case, the “E” remark code indicates the value is estimated and less than the limit of quantitation, but equal to or greater than the LOD. The limit of quantitation is the level above which quantitative results may be obtained with a specified degree of confidence. The limit of quantitation is defined mathematically as equal to 10 times the standard deviation of a series of replicate results used to determine the LOD (Wisconsin Department of Natural Resources, 1996).

Concentrations of the redox-sensitive species of ferrous iron (Fe^{2+}), sulfide [sum of dihydrogen sulfide (aqueous H_2S), hydrogen sulfide (HS^-), and sulfide (S^{2-})], and dissolved oxygen (O_2), along with nitrate (NO_3^-), manganese (Mn^{2+}), sulfate (SO_4^{2-}), and methane (CH_4), were used to assess the biological redox status 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 (Jurgens and others, 2009). If a redox assignment was not determined for a sample, it likely is due to missing data for one or more of the redox-sensitive species. A detailed description of the redox classification framework is presented in McMahon and Chapelle (2008) and Chapelle and others (2009); spreadsheet instructions and details of redox assignments are presented in Jurgens and others (2009). A brief description of redox assignments follows. When all five redox-sensitive species are entered, the general redox category (oxic, suboxic, anoxic, or mixed) is determined from the redox process. For samples that have sulfide measurements in addition to the five redox-sensitive species, Fe^{3+} and SO_4^{2-} reduction is differentiated in the redox processes column using the calculated iron/sulfide ratio. For samples missing one or more of the redox-sensitive species other than O_2 , samples are reported as " $\text{O}_2 \geq 0.5 \text{ mg/L}$ " for dissolved-oxygen concentrations greater than or equal to 0.5 mg/L or as " $\text{O}_2 < 0.5 \text{ mg/L}$ " for dissolved-oxygen concentrations less than 0.5 mg/L.

Quality-Control Sample Collection and Data Analysis

In addition to collection of environmental groundwater and surface-water samples, quality-control samples including field-equipment blanks, trip blanks, and replicates were collected. Analytical results from quality-control samples collected in the field and prepared in the laboratories were used to assess the quality of the data reported for environmental samples. Data from quality-control samples collected during this study were evaluated to estimate the bias and variability that may have resulted from sample collection, processing, and analysis.

Bias was estimated using two types of blank samples submitted to analytical laboratories for analysis: field-equipment blanks and trip blanks. Four field-equipment blanks were 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 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. Trip blanks for this study were VOC vials of laboratory blank water, filled and sealed by TestAmerica Laboratories. These trip blanks accompanied environmental sample vials to verify that VOC contamination did not take place during storage, sampling, or shipment to or from TestAmerica. Three trip blanks were analyzed for this study: one trip blank for each round of sampling that included collection of VOC samples. A quantified result in any blank sample was considered evidence that contamination could have affected groundwater sample results. Analytical results for groundwater samples and associated replicate samples were compared to the maximum quantified concentration in any blank collected during the same sampling event. In accordance with USEPA guidance (U.S. Environmental Protection Agency, 1989, p. 5–17), a reported concentration in an environmental sample that is less than five times the concentration in a related blank sample should be qualified. Constituents that have been qualified according to USEPA guidance are identified by a footnote in the water-quality data tables presented in this report. For data analysis purposes, these values are considered to be nondetections. All qualifications were based on quantified results in field-equipment blank or trip blank samples.

Field-equipment and trip blank sample results for inorganic and organic constituents are presented in appendix 3. Overall, six compounds (ammonia as nitrogen, phosphorus, manganese, DOC, benzene, and methylene chloride) were detected in blank samples resulting in qualification of groundwater sample results. All of these compounds were detected in blank samples at concentrations slightly above reporting levels, indicating field and laboratory contamination was minimal.

Potential variability was estimated using replicate groundwater samples. Replicate groundwater samples were collected immediately after the environmental groundwater sample, and were analyzed for the same constituents as the environmental sample to provide a measure of variability which might be due to the effects of field and laboratory procedures. Several replicate samples were collected during 2011 and 2012. One replicate sample was collected and analyzed for a full suite of constituents and two additional replicate samples were collected and analyzed for triazoles. Additionally, samples for all of the dissolved gases (argon, carbon dioxide, methane, nitrogen, and oxygen) were collected and analyzed in replicate. Variability for each analyte is estimated as the relative percent difference (RPD) between constituent concentrations measured in the primary environmental sample and the replicate environmental sample. The RPD was calculated using equation 1.

$$RPD = \text{absolute value} \left(\frac{\text{concentration}_{\text{environmental sample}} - \text{concentration}_{\text{replicate sample}}}{\frac{(\text{concentration}_{\text{environmental sample}} + \text{concentration}_{\text{replicate sample}})}{2}} \right) \times 100 \quad (1)$$

Table 3. Volatile organic compounds, gasoline-range organics, and diesel-range organics analyzed in groundwater and surface-water samples at TestAmerica Laboratories, Inc., laboratory reporting levels, and related U.S. Environmental Protection Agency drinking-water standards and health advisories.

[Compounds detected during study are shown in **bold** type. USEPA, U.S. Environmental Protection Agency; --, not applicable; DRO, diesel-range organics; C₆–C₁₀ and C₁₀–C₃₆, ranges of carbon compounds included in the analysis; µg/L, micrograms per liter]

Compound	Common name/synonym	Chemical Abstracts Service (CAS) registry number ¹	Laboratory reporting level	USEPA drinking-water 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	0.50	² 7
1,1-Dichloropropene	--	563-58-6	0.50	--
1,1,1-Trichloroethane	Methylchloroform	71-55-6	0.50	² 200
1,1,1,2-Tetrachloroethane	--	630-20-6	0.50	³ 100
1,1,2-Trichloroethane	Vinyl trichloride	79-00-5	0.50	² 5
1,1,2,2-Tetrachloroethane	--	79-34-5	0.50	³ 40
1,2-Dibromo-3-chloropropane	DBCP, Nemagon	96-12-8	0.50	² 0.2
1,2-Dibromoethane	Ethylene dibromide (EDB)	106-93-4	0.50	² 0.05
1,2-Dichlorobenzene	<i>o</i> -Dichlorobenzene	95-50-1	0.50	² 600
1,2-Dichloroethane	Ethylene dichloride	106-06-2	0.50	² 5
1,2-Dichloropropane	Propylene dichloride	78-87-5	0.50	² 5
1,2,3-Trichlorobenzene	--	87-61-6	0.50	--
1,2,3-Trichloropropane	Allyl trichloride	96-18-4	0.50	⁴ 4
1,2,4-Trichlorobenzene	--	120-82-1	0.50	² 70
1,2,4-Trimethylbenzene	Pseudocumene	95-63-6	0.50	--
1,3-Dichlorobenzene	<i>m</i> -Dichlorobenzene	541-73-1	0.50	⁵ 600
1,3-Dichloropropane	Trimethylene dichloride	142-28-9	0.50	--
1,3,5-Trimethylbenzene	Mesitylene	108-67-8	0.50	⁶ 10,000
1,4-Dichlorobenzene	<i>p</i> -Dichlorobenzene	106-46-7	0.50	² 75
2-Chlorotoluene	1-chloro-2-methylbenzene	95-49-8	0.50	⁵ 100
2,2-Dichloropropane	--	594-20-7	0.50	--
4-Chlorotoluene	1-chloro-4-methylbenzene	106-43-4	0.50	⁵ 100
4-Isopropyltoluene	4-Cymene	99-87-6	0.50	--
Benzene	Pyobenzol	75-43-2	0.50	² 5
Bromobenzene	Phenyl bromide	108-86-1	0.50	⁵ 60
Bromochloromethane	Methylene chlorobromide	74-97-5	0.50	⁵ 90
Bromodichloromethane	Dichlorobromomethane	75-27-4	0.50	^{2,7} 80
Bromoform	Tribromomethane	75-25-2	0.50	^{2,7} 80
Bromomethane	Methyl bromide	74-83-9	1.0	⁵ 10
Carbon tetrachloride	Tetrachloromethane	56-23-5	0.50	² 5
Chlorobenzene	Monochlorobenzene	108-90-7	0.50	² 100
Chloroethane	Ethyl chloride	75-00-3	1.0	--
Chloroform	Carbon trichloride	67-66-3	0.50	^{2,7} 80
Chloromethane	methyl chloride	74-87-3	0.50	^{4,9} 0,000
<i>cis</i> -1,2-Dichloroethene	(<i>Z</i>)-1,2-Dichloroethene	156-59-2	0.50	² 70
<i>cis</i> -1,3-Dichloropropene	(<i>Z</i>)- <i>cis</i> -1,3-Dichloropropene	542-75-6	0.50	³ 40
Dibromochloromethane	Chlorodibromomethane	124-48-1	0.50	^{2,7} 80

Table 3. Volatile organic compounds, gasoline-range organics, and diesel-range organics analyzed in groundwater and surface-water samples at TestAmerica Laboratories, Inc., laboratory reporting levels, and related U.S. Environmental Protection Agency drinking-water standards and health advisories.—Continued

[Compounds detected during study are shown in **bold** type. USEPA, U.S. Environmental Protection Agency; --, not applicable; DRO, diesel-range organics; C₆–C₁₀ and C₁₀–C₃₆, ranges of carbon compounds included in the analysis; µg/L, micrograms per liter]

Compound	Common name/synonym	Chemical Abstracts Service (CAS) registry number ¹	Laboratory reporting level	USEPA drinking-water standard or health advisory
Dibromomethane	Methylene dibromide	74-95-3	0.50	--
Dichlorodifluoromethane	CFC-12, Freon 12	75-71-8	0.50	⁵ 1,000
Ethylbenzene	Phenylethane	100-41-4	0.50	² 700
Hexachlorobutadiene	Perchlorobutadiene	87-68-3	0.50	⁵ 90
Isopropylbenzene	(1-methylethyl)benzene	98-82-8	0.50	⁸ 4,000
Methylene chloride	Dichloromethane	75-09-2	0.50	² 5
Methyl <i>tert</i> -butyl ether ⁹	MTBE	1634-04-4	0.50	¹⁰ 20–40
Naphthalene ¹¹	Naphthene	91-20-3	1.0	⁵ 100
<i>n</i> -Butylbenzene	1-Phenylbutane	104-51-8	0.50	--
<i>n</i> -Propylbenzene	Isocumene	103-65-1	0.50	--
<i>o</i> -Xylene	1,2-Dimethylbenzene	95-47-6	0.50	^{2,12} 10,000
<i>sec</i> -Butylbenzene	(1-Methylpropyl)benzene	135-98-8	0.50	--
Styrene	Ethenylbenzene	100-42-5	0.50	² 100
<i>tert</i> -Butylbenzene	(1,1-Dimethylethyl)benzene	98-06-6	0.50	--
<i>tert</i> -Butyl ethyl ether ⁹	Ethyl <i>tert</i> -butyl ether (ETBE)	637-92-3	0.50	--
Tetrachloroethene	Perchloroethene (PCE), tetrachloroethylene	127-18-4	0.50	² 5
Toluene	Methylbenzene	108-88-3	0.50	² 1,000
<i>trans</i> -1,2-Dichloroethene	(E)-1,2-Dichloroethene	156-60-5	0.50	² 100
<i>trans</i> -1,3-Dichloropropene	(E)-1,3-Dichloropropene	10061-02-6	0.50	--
Trichloroethene	TCE, trichloroethylene	79-01-6	0.50	² 5
Trichlorofluoromethane	CFC-11, Freon 11	75-69-4	0.50	⁵ 2,000
Vinyl chloride	Chloroethene	75-01-4	0.50	² 2
Xylene, total	Dimethylbenzene	1330-20-7	0.50	^{2,12} 10,000
Gasoline-range organics				
Gasoline-range organics (C ₆ –C ₁₀)	GRO	--	25	--
Diesel-range organics				
DRO, C ₁₀ –C ₃₆	--	--	0.49–0.55	--

¹This 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 ServicesSM.

²U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2012).

³U.S. Environmental Protection Agency Risk-Specific Dose at 10⁻⁴ Cancer Risk (RSD4) (U.S. Environmental Protection Agency, 2012).

⁴U.S. Environmental Protection Agency Reference Dose (RfD), daily oral exposure (U.S. Environmental Protection Agency, 2012).

⁵U.S. Environmental Protection Agency Life-time Health Advisory Level (U.S. Environmental Protection Agency, 2012).

⁶U.S. Environmental Protection Agency, One-day Health Advisory Level, 10-kilogram child (U.S. Environmental Protection Agency, 2012).

⁷The total for all trihalomethanes cannot exceed 80 µg/L (U.S. Environmental Protection Agency, 2012).

⁸U.S. Environmental Protection Agency Drinking Water Equivalent Level (DWEL, lifetime exposure (U.S. Environmental Protection Agency, 2012).

⁹This compound was analyzed as part of volatile organic compounds analysis but actually is an ether used as a fuel oxygenate.

¹⁰The U.S. Environmental Protection Agency Drinking-Water Advisory ranges from 20 to 40 µg/L (U.S. Environmental Protection Agency, 2012).

¹¹Naphthalene was analyzed as part of the volatile organic compounds analysis but actually is a semivolatile compound.

¹²The total for all xylenes combined cannot exceed 10,000 µg/L (U.S. Environmental Protection Agency, 2012).

RPDs were calculated only for constituents with detections, which for this study included only inorganic constituents, triazoles and dissolved gases. RPDs were not calculated for 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. For this study, RPD values greater than 20 percent were considered indicative that analytical results might be affected by high variability. The RPDs for dissolved gases were all 10 percent or less and are not presented in this report. The RPD results for inorganic constituents and triazoles are presented in table 4. Overall, three constituents (nitrate plus nitrite, iron, and 5-MeBT) were qualified because of high variability. These compounds have been identified with a footnote in the water-quality tables where analytical results are presented. Concentrations of bromide, nitrate plus nitrite as nitrogen, and nitrate as nitrogen in environmental and replicate samples were small, causing small concentration differences to result in large RPDs. Although the variability of iron concentrations was high, the magnitude of measured iron concentrations was still substantial.

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, 1989). The percent difference between the sum of concentrations of cations and anions in milliequivalents per liter was calculated using equation 2:

$$\text{Percent difference} = \left(\frac{\text{sum of dissolved cations} - \text{sum of dissolved anions}}{\text{sum of dissolved cations} + \text{sum of dissolved anions}} \right) \times 100 \quad (2)$$

Ionic charge balances were calculated for groundwater samples and the surface-water sample for which major ion data were available. The ionic charge balances ranged from -1.48 to 6.53 percent. An ionic charge balance within plus or minus 5 percent is considered acceptable (Clesceri and others, 1998). One ionic charge balance exceeded 5 percent (well JH-1.5R during April 2012 at 6.53 percent).

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 (fig. 1). The geology around the study area is complex with strata ranging from Precambrian basement rocks to Quaternary unconsolidated surficial deposits (fig. 3).

Table 4. Replicate data for major ions, nutrients, dissolved organic carbon, trace elements, and triazoles in groundwater samples from wells at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[RPD, relative percent difference; --, not applicable; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the laboratory reporting level]

Physical property of constituent	Well name and sample date								
	JH-1.5D, April 5, 2012			JH-2.5, November 3, 2011			JH-3.5, June 9, 2011		
	Environ-mental	Replicate		Environ-mental	Replicate		Environ-mental	Replicate	
	Value	Value	RPD	Value	Value	RPD	Value	Value	RPD
Major ions and related characteristics (in filtered water), in milligrams per liter									
Total dissolved solids	--	--	--	--	--	--	189	177	6.56
Hardness, total	--	--	--	--	--	--	157	156	0.64
Calcium	--	--	--	--	--	--	47.6	47.4	0.42
Magnesium	--	--	--	--	--	--	9.29	9.24	0.54
Potassium	--	--	--	--	--	--	2.09	2.09	0.00
Sodium	--	--	--	--	--	--	7.16	7.15	0.14
Alkalinity as calcium carbonate	--	--	--	--	--	--	162	160	1.24
Bicarbonate	--	--	--	--	--	--	197	195	1.02
Bromide	--	--	--	--	--	--	0.018	0.016	11.76
Carbon dioxide	--	--	--	--	--	--	6.6	6.5	1.53
Chloride	--	--	--	--	--	--	3.73	3.72	0.27
Fluoride	--	--	--	--	--	--	0.39	0.39	0.00
Silica, as silicon dioxide	--	--	--	--	--	--	17.4	17.2	1.16
Sulfate	--	--	--	--	--	--	8.14	8.14	0.00
Nutrients and dissolved organic carbon, in milligrams per liter									
Nitrate plus nitrite	--	--	--	--	--	--	0.04	0.03	28.57
Nitrate	--	--	--	--	--	--	0.134	0.121	10.20
Nitrate, as nitrogen	--	--	--	--	--	--	0.03	0.027	10.53
Nitrite (in filtered water)	--	--	--	--	--	--	0.019	0.018	5.41
Nitrite (in filtered water), as nitrogen	--	--	--	--	--	--	0.006	0.006	0.00
Orthophosphate	--	--	--	--	--	--	0.043	0.044	2.30
Orthophosphate, as phosphorus	--	--	--	--	--	--	0.014	0.014	0.00
Phosphorus, total, as phosphorus	--	--	--	--	--	--	¹ 0.011	¹ 0.009	0.02
Dissolved organic carbon	--	--	--	--	--	--	0.53	0.56	5.50
Trace elements and triazoles compounds, in micrograms per liter									
Iron, water (in filtered water)	--	--	--	--	--	--	7.1	15.2	72.65
Manganese (in filtered water)	--	--	--	--	--	--	21.3	22.4	5.03
4-Methyl-1H-benzotriazole (in unfiltered water)	8.1	8.2	1.23	7.8	7.9	1.27	<0.35	<0.35	--
5-Methyl-1H-benzotriazole (in unfiltered water)	0.4	0.54	29.79	0.72	0.57	23.26	<0.25	<0.25	--

¹Quantified concentration in the environmental sample is less than five times the maximum concentration in a blank sample.

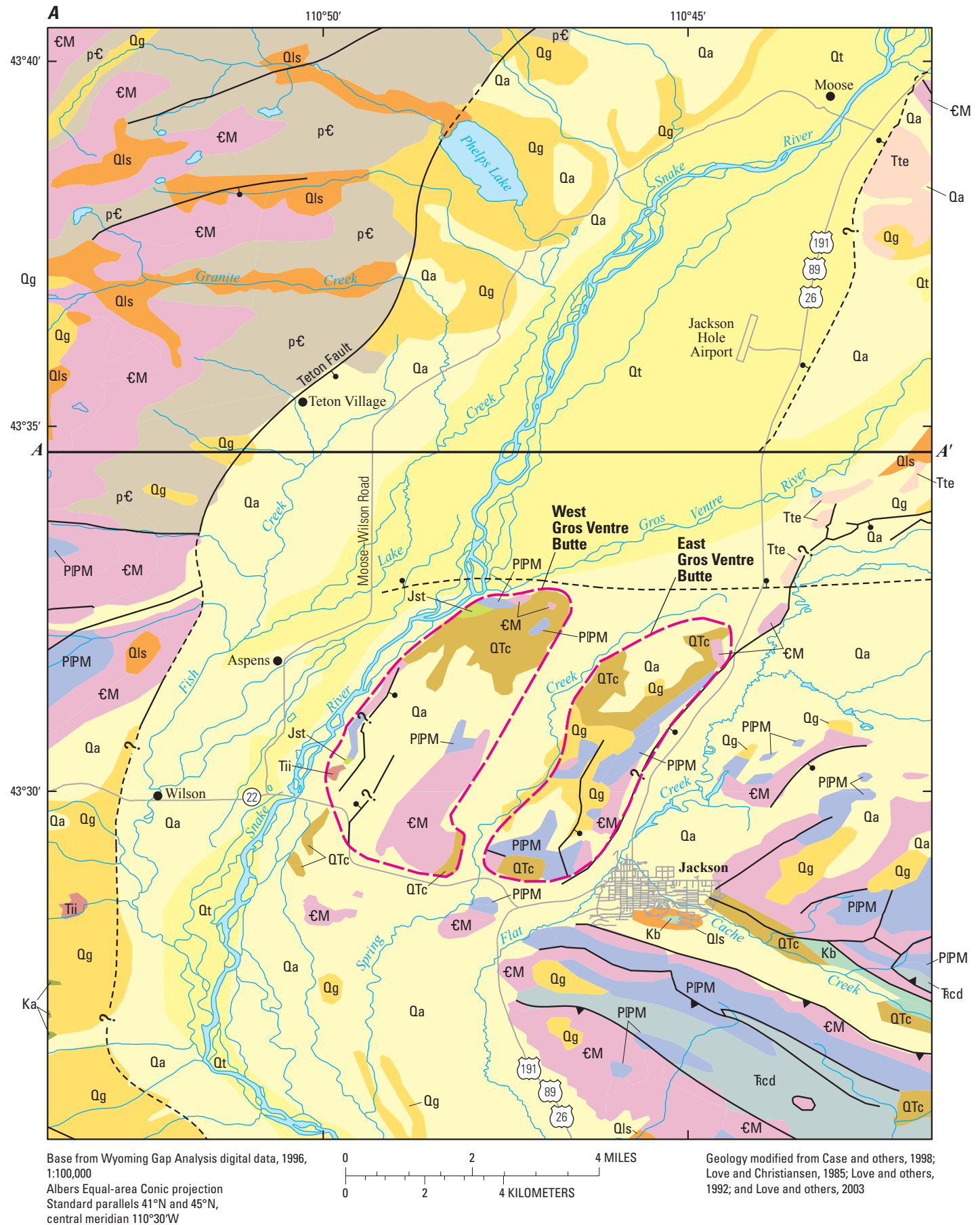


Figure 3. A, Generalized geology and B, geologic section in the vicinity of the Jackson Hole Airport, Jackson, Wyoming (modified from Wright, 2010).

B

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

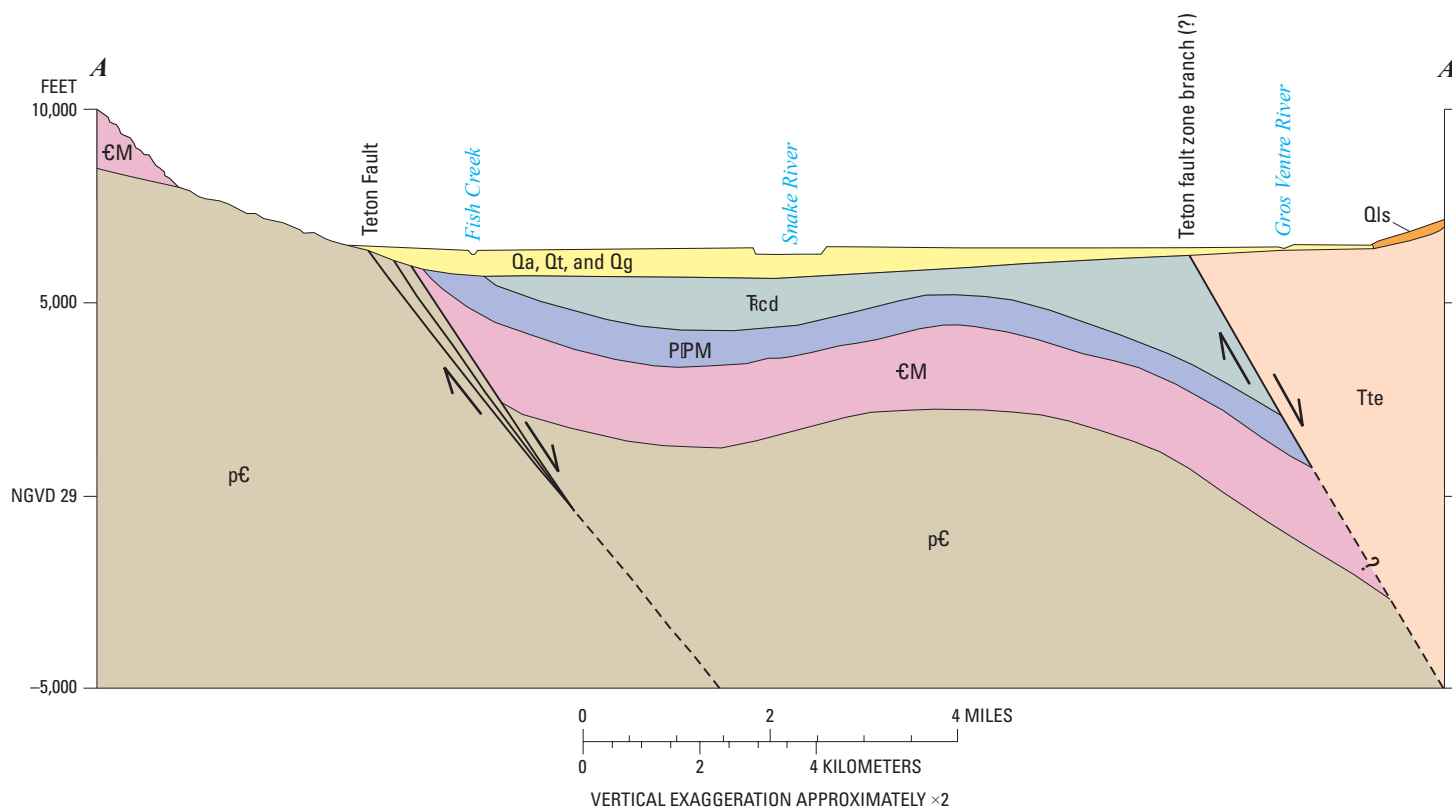
Mesozoic and Paleozoic rocks

Kb	Bacon Ridge Sandstone
Ka	Aspen Shale
Jst	Stump Formation
Tcd	Chugwater and Dinwoody Formations
PIPM	Phosphoria Formation, Wells Formation, Tensleep Sandstone, and Amsden Formation
€M	Flathead Sandstone, Gros Ventre Formation, Gallatin Limestone, Bighorn Dolomite, Darby Formation, and Madison Limestone

Precambrian rocks

p€	Granitic and basaltic rocks, granite gneiss, metasedimentary and metavolcanic rocks, metamorphosed mafic and ultramafic rocks
----	---

- ? Fault—Dashed where concealed 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 3. A, Generalized geology and B, geologic section in the vicinity of the Jackson Hole Airport, Jackson, Wyoming (modified from Wright, 2010).—Continued

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. 3) (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 throughout the baseline and followup studies are presented in figure 4 for wells JH-1, JH-2, JH-3 and JH-4. Discrete water levels for all monitoring wells also are presented in figure 4. For the baseline study, Wright (2010) documented that the water-level surface of the Snake River alluvial aquifer varied seasonally, reflecting a pattern affected by precipitation-driven recharge (primarily snowmelt) during April–June and irrigation-induced recharge during June–October, with minimal aquifer recharge during November–March. The hydrographs displayed in figure 4 indicate that water levels in the Snake River alluvial aquifer continued to vary seasonally during the followup study, reflecting the precipitation-driven recharge pattern described above. Although the actual high and low points of the water table vary from year to year, the water table was at its lowest level in late March to early April, at the beginning of spring, and at its highest level in July to August at the end of the peak of snowmelt. The water level increased about 12.5 to 15.5 ft between April and July 2011 and about 8 to 10 ft between April and July 2012 (fig. 4). Well JH-1 consistently had the highest water-level altitudes, and well JH-2 had the lowest water-level altitudes (appendix 2, fig. 4). 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 ft.

Water-table contours were drawn (figs. 5A–B) using both discrete water-level measurements and contours determined using multiple three-point calculations to assist with “fitting” of contours. A water-table contour map was constructed for two water-level measurement events: low water table in April 2012 (fig. 5A) and high water table in July 2012 (fig. 5B). The direction of groundwater flow generally is to the west-southwest, assuming groundwater flow is perpendicular to water-table contours. The direction of groundwater flow has not changed substantially since 2009 (Wright, 2010). Seasonal variations in the direction of groundwater flow appear to be minimal. Horizontal hydraulic gradients were calculated for several combinations of monitoring wells for the period of May 2011 to July 2012 and are presented in table 5. Horizontal hydraulic gradients ranged from 0.0062 foot per foot (ft/ft) to 0.0072 ft/ft, with an average of 0.0068 ft/ft (table 5), which is slightly higher than the average of 0.0066 ft/ft determined during the baseline study (Wright, 2010). The 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.

Monitor wells JH-1.5(JH-1.5R) and JH-1.5D composing well cluster 1.5 and wells JH-3 and JH-3D composing well cluster 3 were located adjacent to each other and completed at different depths in part to evaluate the hydraulic potential (differences in hydraulic head or groundwater level) for vertical groundwater flow at the location. The vertical gradient in the Snake River alluvial aquifer at both well clusters was small. Calculations of the vertical hydraulic gradient at well cluster 1.5 varied throughout the period of record, ranging from -0.011 ft/ft in May 2011 to 0.021 ft/ft in August of 2011 when the gradient changed from negative to positive. An increasing water-level altitude with depth (appendix 2) indicates a hydraulic potential for upward groundwater flow, whereas a decreasing water-level altitude with depth (appendix 2) indicates a hydraulic potential for downward groundwater flow. It is not clear why there was a change in the vertical gradient at well cluster 1.5. Calculations of the vertical hydraulic gradient at well cluster 3 indicated this gradient varied throughout the year, ranging from a low of 0.0004 ft/ft in June 2011 to a high of 0.009 ft/ft in April 2012, with an average of 0.005 ft/ft. The vertical gradient at well cluster 3 consistently indicates a hydraulic potential for downward groundwater flow in the Snake River alluvial aquifer at this location, consistent with previous results (Wright, 2010). The ratio of the average horizontal hydraulic gradient to the average vertical hydraulic gradient at well cluster 3 is 1.36. Meaning that for every 1.36 ft that water moves horizontally, water also is 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 6) and an estimated porosity as described previously in the “Methods of Data Collection and Analysis” section. Groundwater velocity was estimated as high as 68 foot/day (ft/d) using average hydraulic gradients calculated for July and November 2011 and April 2012, and the hydraulic conductivity for Teton Village; the groundwater velocity was estimated to be as low as 25 ft/d using the average hydraulic gradient calculated for May 2011 and the hydraulic conductivity for the Aspens (table 6). The range of hydraulic gradients determined during 2011 and 2012 is slightly broader than the hydraulic gradients for the period of 2008 and 2009 (Wright, 2010). The change in horizontal hydraulic conductivity values between the 2008–09 and 2011–12 studies could be due to variations in the local climate. Using an estimated linear distance of 3,540 ft from well JH-1 to well JH-2, it would take approximately 52 to 142 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 6) are estimates and could vary at different locations at the JHA. Although lithologic data for monitoring wells JH-1 through JH-4, coupled with a fairly narrow range of hydraulic

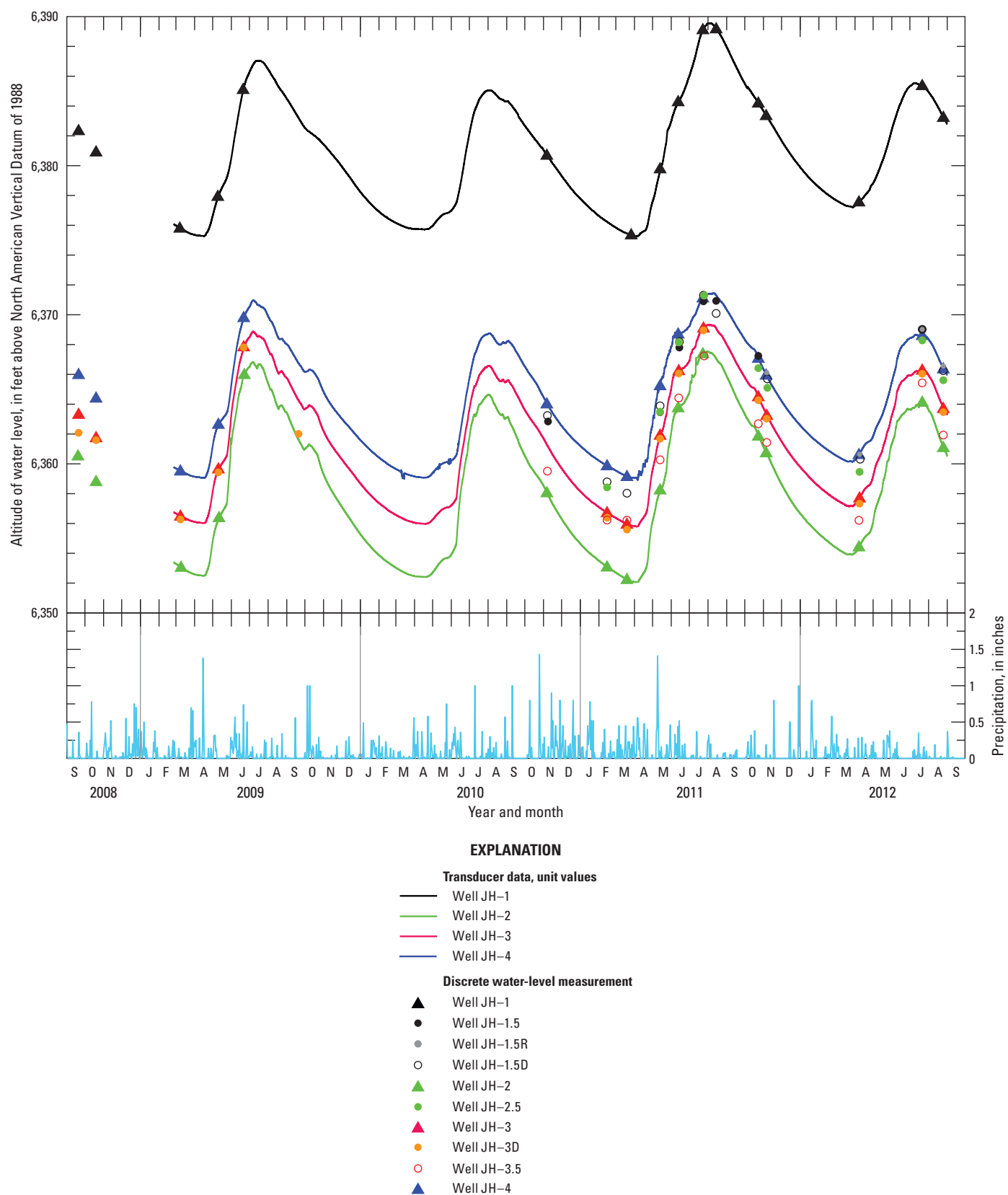


Figure 4. Water levels for selected wells sampled at the Jackson Hole Airport, Jackson, Wyoming with precipitation data collected at Moose, Wyoming, station 486428 (High Plains Regional Climate Center, 2013), water years 2008–12.

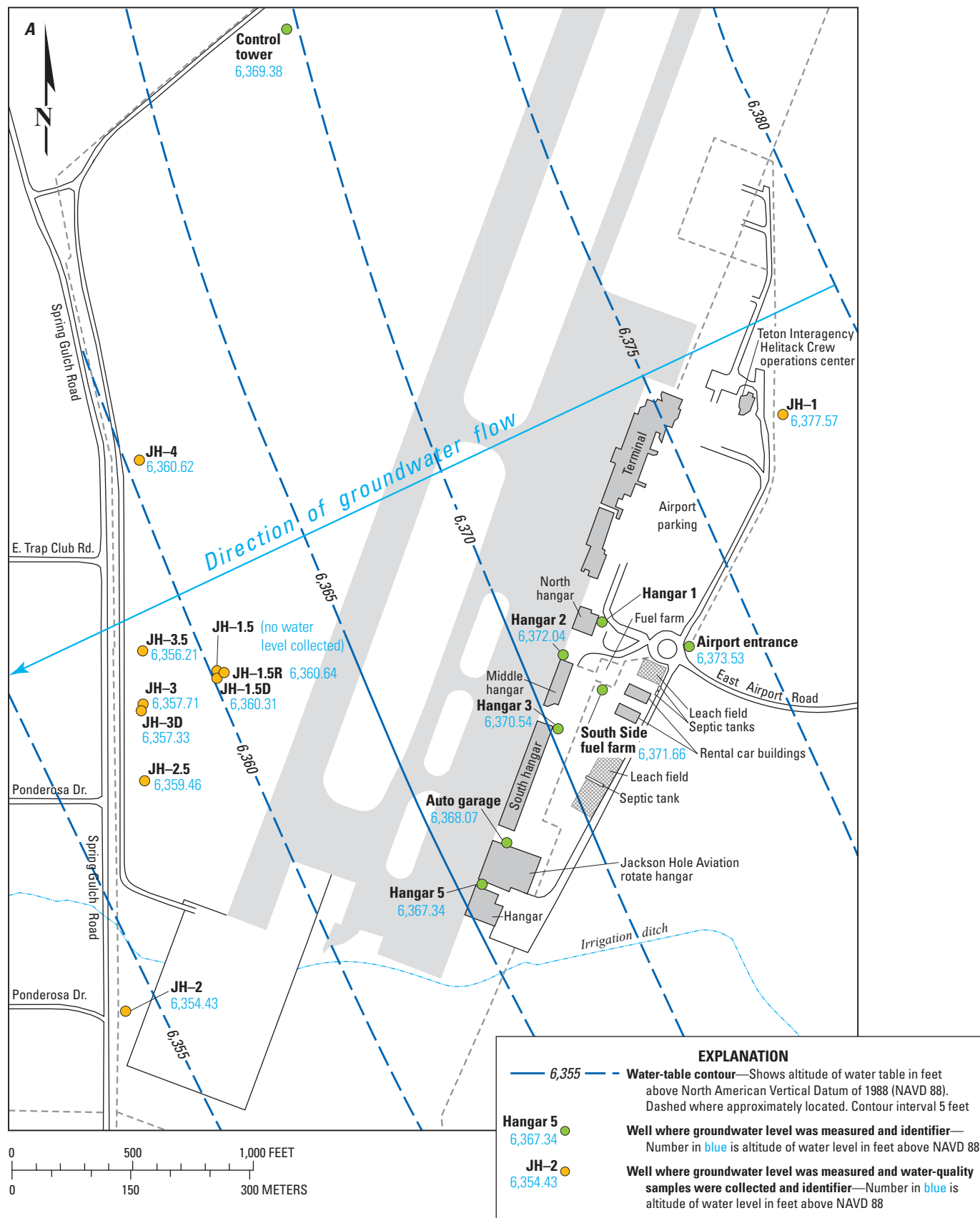


Figure 5. Water-table contours and estimated direction of groundwater flow in *A*, low water table in April 2012; and *B*, high water table in July 2012, Jackson Hole Airport, Jackson, Wyoming.

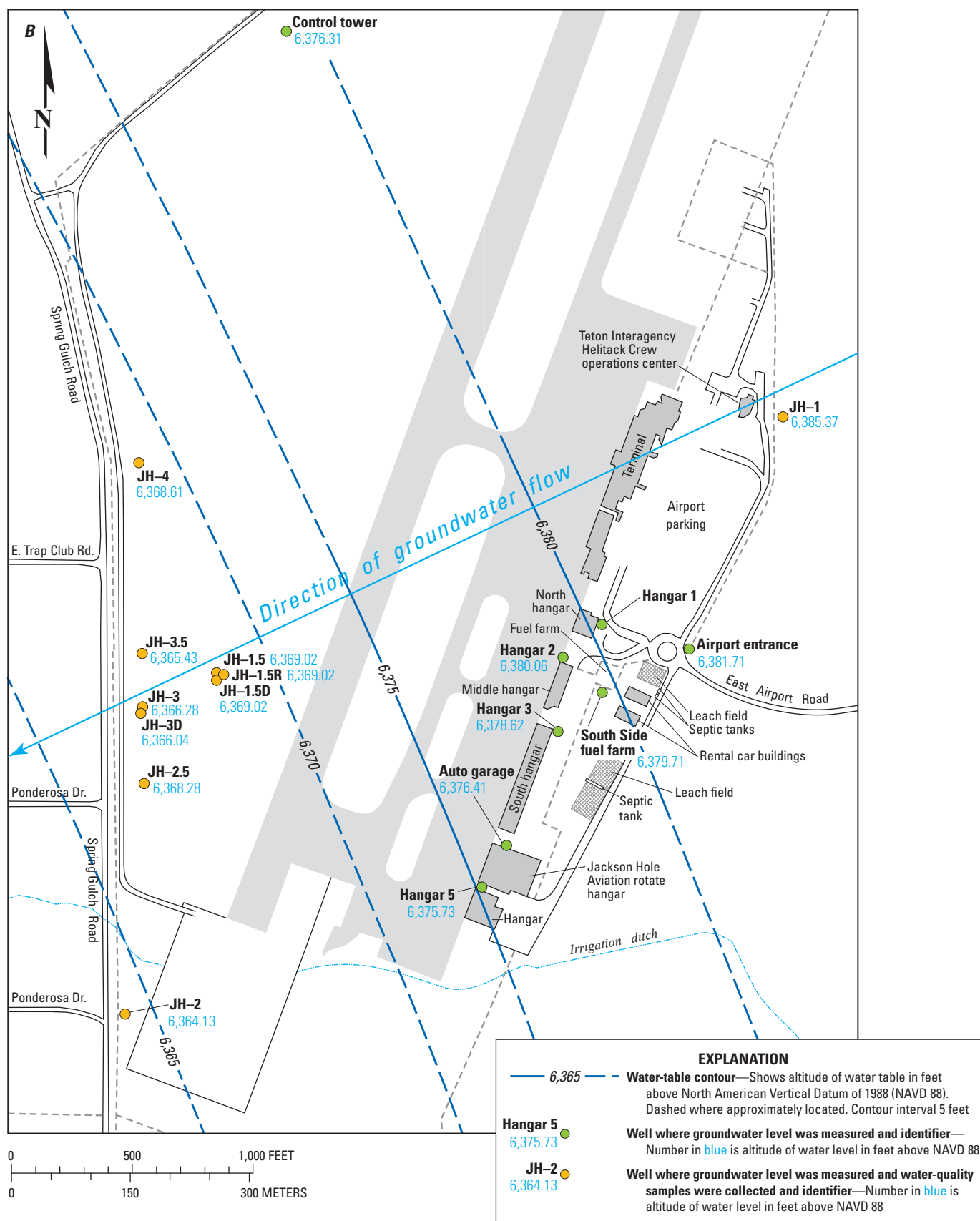


Figure 5. Water-table contours and estimated direction of groundwater flow in A, low water table in April 2012; and B, high water table in July 2012, Jackson Hole Airport, Jackson, Wyoming.—Continued

gradients for these wells, indicate the Snake River alluvial aquifer at the airport is relatively homogeneous, horizontal hydraulic conductivity differs from point to point and along a flow path because lithology typically is 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 5 *A–B* (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 6) only describe movement of groundwater in the Snake River alluvial aquifer and are not applicable to solute movement. Solute movement through saturated media, such as an aquifer, is affected 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 different than groundwater flow through the aquifer.

Table 5. Horizontal hydraulic gradients calculated for selected water-level measurement events at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

Wells used in three-point calculation to determine hydraulic gradient	Horizontal hydraulic gradient (foot per foot)					
	May 2011	July 2011	November 2011	April 2012	July 2012	Average
JH-1, JH-2, JH-4	0.0062	0.0069	0.0070	0.0069	0.0066	0.0067
JH-1, JH-3, JH-4	0.0064	0.0070	0.0069	0.0071	0.0067	0.0068
JH-1, JH-2, JH-3	0.0063	0.0072	0.0071	0.0070	0.0068	0.0069
Average by month	0.0063	0.0070	0.0070	0.0070	0.0067	0.0068

Table 6. Results of groundwater-velocity calculations using hydraulic conductivity values of the Snake River alluvial aquifer at Teton Village and the Aspens.

[K, hydraulic conductivity; ft/d, feet per day; dh, change in head; dl, change in 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)				
May 2011	2,900	0.0063	0.3	61
July 2011	2,900	0.0070	0.3	68
November 2011	2,900	0.0070	0.3	68
April 2012	2,900	0.0070	0.3	68
July 2012	2,900	0.0067	0.3	65
Average 2011–2012	2,900	0.0068	0.3	66
Hydraulic conductivity at the Aspens (Nelson Engineering, 1992)				
May 2011	1,200	0.0063	0.3	25
July 2011	1,200	0.0070	0.3	28
November 2011	1,200	0.0070	0.3	28
April 2012	1,200	0.0070	0.3	28
July 2012	1,200	0.0067	0.3	27
Average 2011–2012	1,200	0.0068	0.3	27

Water Quality

Constituent concentrations in samples collected for the followup study are compared to the USEPA drinking-water standards and health advisories for drinking water (U.S. Environmental Protection Agency, 2012) listed in tables 3 and 7. Although none of the wells sampled for this study are used to supply drinking water, USEPA drinking-water standards and health advisories provide a basis for assessing the groundwater quality at the JHA. No constituents were detected at concentrations exceeding the USEPA Maximum Contaminant Levels (MCLs) or health advisories; however, concentrations for some constituents exceeded USEPA Secondary Maximum Contaminant Levels (SMCLs). The SMCLs are non-enforceable standards for constituents that may cause cosmetic effects (discoloration of teeth or skin) or aesthetic effects (undesirable taste, odor, or color) in drinking water (U.S. Environmental Protection Agency, 2012). Redox measurements indicate oxygen-poor conditions in many of the wells. Many anthropogenic constituents were included in sample analyses, and six of these constituents, including one GRO, three VOCs, and two triazole compounds, were detected (many at qualified concentrations) in groundwater samples.

Results from analyses of groundwater samples collected during this study are summarized in tables 3 and 7, and are presented in detail in appendixes 4, 5, 6, 7, and 8. Results from analyses of the surface-water sample collected from the irrigation ditch are presented in appendixes 4, 5, 7, and 8. No VOCs, DROs, GROs, or triazoles were detected in the surface-water sample; thus, only the groundwater-quality findings at the JHA for water years 2011 and 2012 are described further in this section.

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, 1989). 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 appendix 4. The properties that best describe the groundwater composition in the Snake River alluvial aquifer are described further in this section of the report.

Groundwater was neutral to alkaline (pH values ranged from 7.0 to 8.0) with concentrations of alkalinity as calcium carbonate (CaCO_3) ranging from 112 to 328 mg/L. Groundwater at the airport was fresh (dissolved solids concentration less than 1,000 mg/L; Heath, 1983), with dissolved solids concentrations ranging from 150 to 382 mg/L (appendix 5). Specific-conductance values were low, ranging from 247 to 622 microsiemens per centimeter at 25 degrees Celsius

($\mu\text{S}/\text{cm}$) (table 7, appendix 4). These values were similar to the range of values for dissolved solids (91 to 538 mg/L) and specific conductance (112 to 863 $\mu\text{S}/\text{cm}$) reported by Nolan and Miller (1995) for water from wells producing from Quaternary alluvium, colluvium, and gravel, and pediment, fan, and glacial deposits in Teton County, Wyoming. Calculated hardness concentrations ranged from 120 to 310 mg/L (as CaCO_3), making water at the airport generally moderately hard (61 to 120 mg/L as CaCO_3) to very hard (121 to 180 mg/L as CaCO_3) (Hem, 1989).

The major ion composition of groundwater in the study area largely results 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 plus carbonate (based on field titration), 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. 6). The sample compositions presented in figure 6 are differentiated by the study (baseline or followup) for which they were collected. 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). There was little to no difference between the ion composition of samples collected for the baseline study and followup study. As reported in Wright (2010), 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. 6).

Redox Conditions

The chemical quality of groundwater commonly is affected by redox processes (Chapelle and others, 2009). During the 2008–09 baseline study, Wright (2010) reported that most groundwater measured at the JHA was oxidic (oxygenated), whereas groundwater from two wells (JH–3 and JH–3D) was reduced (oxygen-poor). Reduction reactions generally are sequential and happen 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; McMahon and Chapelle, 2008). 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 the previously described wells.

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 <0.1 to

Table 7. Summary of physical properties and inorganic groundwater-quality data collected from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; NTRU, nephelometric turbidity ratio units; CaCO_3 , calcium carbonate; HCO_3^- , bicarbonate; SiO_2 , silica; N, nitrogen; n, below the lower reporting level and above the long term method detection level; b, value extrapolated at low end; <, less than; USEPA, U.S. Environmental Protection Agency; --, not applicable; SMCL, Secondary Maximum Contaminant Level; DWA, Drinking Water Advisory; MCL, Maximum Contaminant Level; HAL, Health Advisory Level]

Constituent or physical characteristic	Number of detections/number of samples	Minimum value or concentration	Median value or concentration	Maximum value or concentration	USEPA drinking-water standards ^{1,2} or health advisories ^{3,4,5,6}	Number of USEPA drinking-water standard or health advisory exceedances
Physical properties						
Dissolved oxygen, mg/L	34/35	<0.1	2.7	9	--	--
pH, unfiltered field, standard units	35/35	7	7.5	8	² 6.5–8.5 (SMCL)	0
Specific conductance, field, $\mu\text{S}/\text{cm}$	35/35	247	359	622	--	--
Temperature, water, $^{\circ}\text{C}$	35/35	7	9.9	16.1	--	--
Turbidity, NTRU	33/35	0.1	1.24	5	² 5.0 (SMCL)	--
Major ions and related water-quality characteristics, in milligrams per liter unless otherwise noted, dissolved (sample filtered through a 0.45-micrometer filter)						
Dissolved solids	25/25	150	230	382	² 500 (SMCL)	0
Hardness, total, as CaCO_3 , calculated	25/25	120	186	310	--	--
Calcium	25/25	35.2	57.3	96	--	--
Magnesium	25/25	7.41	10.50	17.10	--	--
Potassium	25/25	1.79	2.04	2.61	--	--
Sodium	25/25	6.43	7.63	8.35	⁴ 20 (DWA), ⁵ 30–60 (DWA)	0
Alkalinity, field, as CaCO_3	35/35	112	178.9	328	--	--
Bicarbonate, as HCO_3^-	35/35	130	217.6	400	--	--
Chloride	25/25	3.19	5.48	13.10	² 250 (SMCL)	0
Fluoride	25/25	0.32	0.39	0.48	³ 4 (MCL), ² 2 (SMCL)	0
Silica as SiO_2	25/25	17.4	20.1	23.7	--	--
Sulfate	25/25	0.16	6.54	11.6	² 250 (SMCL), ⁴ 500 (DWA)	0
Nutrients, in milligrams per liter, dissolved (sample filtered through 0.45-micrometer filter)						
Ammonia as nitrogen	10/22	n0.011	0.05	0.294	⁶ 30 (HAL)	0
Nitrate plus nitrite as nitrogen	9/22	bn0.02	0.32	1.35	³ 10 (MCL)	0
Nitrite as nitrogen	5/22	bn0.002	0.01	0.007	³ 1 (MCL)	0
Total nitrogen (nitrate plus nitrite plus ammonia plus organic-N), unfiltered	7/22	0.14	0.56	1.47	--	--
Orthophosphate as phosphorus	22/22	n0.006	0.02	0.055	--	--
Phosphorus, as phosphorus	22/22	n0.006	0.02	0.111	--	--

Table 7. Summary of physical properties and inorganic groundwater-quality data collected from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $^{\circ}\text{C}$, degrees Celsius; NTRU, nephelometric turbidity ratio units; CaCO_3 , calcium carbonate; HCO_3^- , bicarbonate; SiO_2 , silica; N, nitrogen; n, below the lower reporting level and above the long term method detection level; b, value extrapolated at low end; <, less than; USEPA, U.S. Environmental Protection Agency; --, not applicable; SMCL, Secondary Maximum Contaminant Level; DWA, Drinking Water Advisory; MCL, Maximum Contaminant Level; HAL, Health Advisory Level]

Constituent or physical characteristic	Number of detections/number of samples	Minimum value or concentration	Median value or concentration	Maximum value or concentration	USEPA drinking-water standards ^{1,2} or health advisories ^{3,4,5,6}	Number of USEPA drinking-water standard or health advisory exceedances
Trace elements, in micrograms per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)						
Bromide (mg/L)	24/25	bn0.012	0.02	0.041	--	--
Iron	26/35	n3.4	368	1,050	² 300 (SMCL)	13
Manganese	27/35	n0.18	887.5	3,040	² 50 (SMCL)	21
Other analyses (dissolved organic carbon sample filtered through 0.45-micrometer filter)						
Chemical oxygen demand	0/20	<10	<10	<10	--	--
Dissolved organic carbon	20/20	bn0.36	1	4.12	--	--

¹Median values were determined using detections and nondetections.

²U.S. Environmental Protection Agency Secondary Maximum Contaminant Level (SMCL) (U.S. Environmental Protection Agency, 2012).

³U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2012).

⁴The U.S. Environmental Protection Agency Drinking-Water Advisory Health-based Value (U.S. Environmental Protection Agency, 2012).

⁵The U.S. Environmental Protection Agency Drinking-Water Advisory Taste Threshold (U.S. Environmental Protection Agency, 2012).

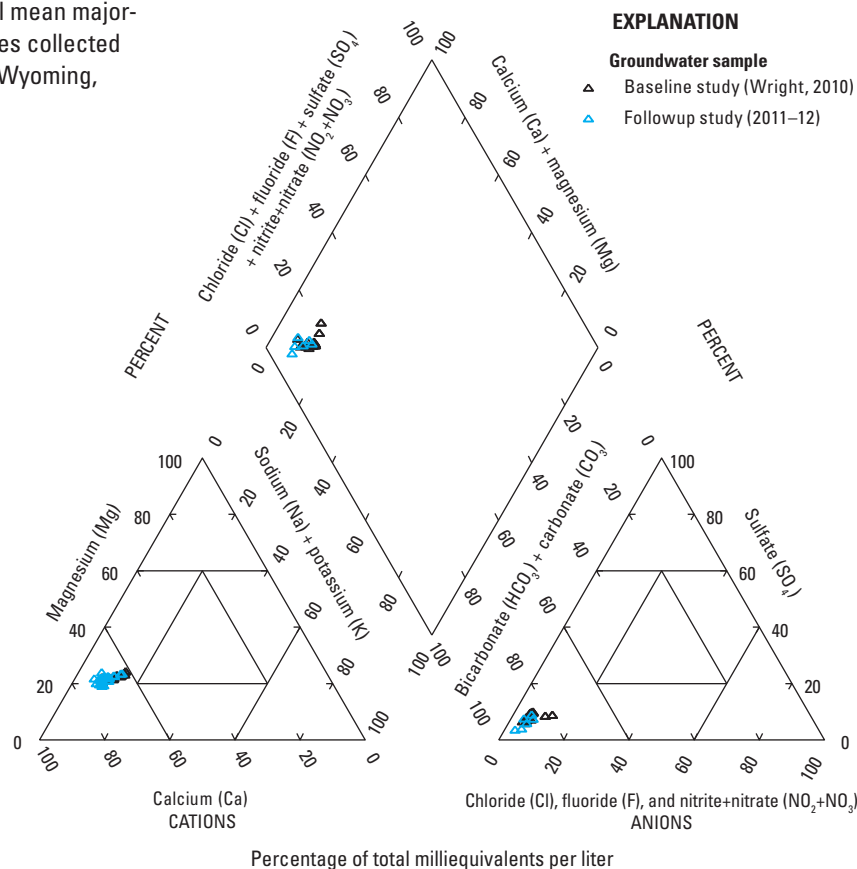
⁶U.S. Environmental Protection Agency Lifetime Health Advisory (HAL) (U.S. Environmental Protection Agency, 2012).

9.0 mg/L (table 7, appendix 4). The dissolved-oxygen measurement of 9.0 mg/L, that was collected at well JH-1 on June 8, 2011, is considered questionable because this measurement was about 1 mg/L higher than all of the other measurements collected from this well (including those from the baseline study reported in Wright, 2010). This dissolved-oxygen measurement was not used to compute any statistics; however, this measurement is presented in appendix 4 because it shows that the groundwater at well JH-1 during June 2011 was oxygenated. Median dissolved-oxygen ranges are presented for each monitor well (data for wells JH-1.5 and JH-1.5R have been combined and presented as if they are from one well) in figure 7 based on data collected for followup study (water years 2011 and 2012). This map shows the distribution of dissolved-oxygen concentrations across the JHA. 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 7 of the 10 monitor wells sampled (fig. 7). 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 a high of 6.9 mg/L in May 2009 (Wright, 2010) to a low of 3.3 mg/L in November 2011. In addition to field measurements, dissolved-oxygen concentrations also

were measured in water from wells with dissolved-oxygen concentrations less than 1 mg/L using spectrophotometry (appendix 5). This low-level method consistently reported slightly lower concentrations of dissolved oxygen than the field meter.

Nutrients were detected at low concentrations in all 35 groundwater (appendix 5) samples, and all concentrations were less than applicable USEPA MCLs and health advisories (table 7); however, 5 ammonia and 14 phosphorus concentrations were measured at concentrations less than five times the maximum quantified concentration measured in blank samples. In accordance with USEPA guidance (U.S. Environmental Protection Agency, 1989, p. 5–17), these concentrations were qualified and were footnoted in appendix 5. Total nitrogen was detected in all of the samples except those from wells JH-1.5, JH-1.5R, JH-1.5D, JH-3D, and JH-3.5. Dissolved nitrate plus nitrite as nitrogen (referred to as nitrate in this report) was detected in samples from all wells except wells JH-1.5R, JH-1.5D, JH-3, and JH-3D, indicating nitrate was the primary nitrogen species in the alluvial aquifer. Ammonia as nitrogen was detected in at least one sample from each of the wells (including qualified concentrations) except well JH-2. Nitrate can be reduced by bacteria to nitrous oxide, ammonia, and nitrogen gas (Hem, 1989) when exposed to anaerobic conditions; therefore, the presence of

Figure 6. Trilinear diagram showing proportional mean major-ion composition, by study, for groundwater samples collected from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2008–12.



ammonia instead of nitrate is another indicator of reducing conditions at and in the vicinity of wells JH–3 and JH–3D. One sample collected from well JH–2 during June 2011 had higher concentrations of nitrate (1.35 mg/L) and total nitrogen (1.47 mg/L) than were detected in samples from other airport wells. These higher concentrations could be a result of this well being directly downgradient from the septic leach field at the airport (fig. 5B), as was reported by Wright (2010) for similar high nitrate concentrations measured in the same well. These higher observed nitrate concentrations are only 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 effects (Mueller and Helsel, 1996). Total phosphorus and dissolved orthophosphate (as phosphorus) were detected in water from all 10 wells (table 7; appendix 5). The median value for total phosphorus (0.02 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 could be expected in groundwater in the absence of human effects.

The dissolved trace elements of iron and manganese were detected in at least one sample from all 10 wells and in 27 of the 35 samples collected during water years 2011 and 2012 (appendix 5). Three manganese concentrations were measured at less than five times the maximum concentration measured in blank samples and have been footnoted in appendix 5. The distribution of median dissolved iron and dissolved-manganese concentration ranges across the JHA is shown in figure 7. Concentrations of dissolved iron and manganese were less than or near the LRLs (3.2 and 0.16 $\mu\text{g/L}$, respectively) in samples from three wells (fig. 7). Samples from the remaining seven wells had high concentrations of dissolved iron and manganese (fig. 7); these high concentrations measured in groundwater are an additional indicator of reducing conditions (McMahon and Chapelle, 2008).

Dissolved iron concentrations exceeded the USEPA SMCL of 300 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 2012) in 1 of 2 samples from well JH–1.5, in all 4 samples from well JH–1.5D, in 3 of 4 samples from well JH–3, in all 4 samples from well JH–3D, and in 1 of 3 samples from well JH–3.5 (fig. 7; table 7; appendix 5). There is some uncertainty in the reproducibility of iron concentrations because of high RPDs (table 4); however, iron concentrations adjusted for variability would still exceed the SMCL.

Dissolved manganese concentrations exceeded the SMCL of 50 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 2012)

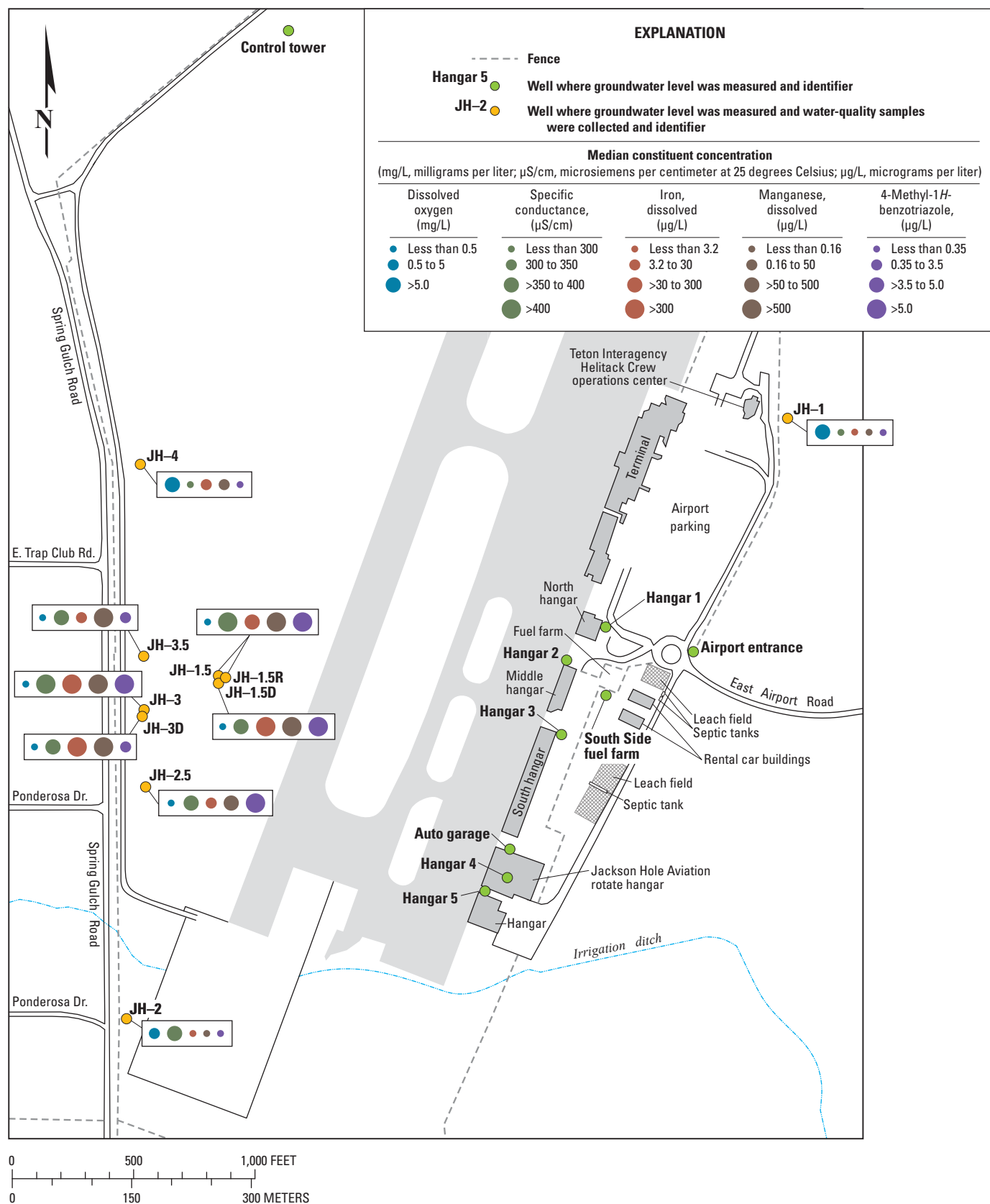


Figure 7. Distribution ranges of median concentrations of selected constituents measured in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

in several samples from wells JH-2.5 and JH-3.5, and in all samples collected from wells JH-1.5, JH-1.5R, JH-1.5D, JH-3, and JH-3D (fig. 7; table 7; appendix 5). None of the wells sampled for this study are used to supply drinking water.

Samples for analyses of dissolved gases (argon, carbon dioxide, methane, nitrogen, and oxygen) were collected from all nine existing monitoring wells during June 2011. Dissolved gas measurements are useful for the determination of geochemical reactions along a flow path. Some dissolved gases can allow for the determination of recharge areas and the seasonal period that the sample entered the aquifer; others are helpful when identifying biochemical reactions such as methanogenesis and denitrification.

For the purpose of this study, the dissolved gas data provided an additional confirmation of reducing conditions at many of the wells. The concentrations of dissolved oxygen detected in the dissolved gas samples were used to confirm low field readings and often were lower (appendix 6) than those measured using the field meter (appendix 4). Additionally, methane gas (appendix 6) was detected in samples from wells with reducing conditions such as well JH-1.5 and not in oxygenated wells such as JH-2 (appendix 6). Methane gas is produced by methanogenic microorganisms under anaerobic conditions (U.S. Geological Survey, 2009). These methanogenic conditions generally are present after all the other possible “reduction reactants” have been consumed and indicate extremely reducing conditions.

Ferrous iron (Fe^{2+}), hydrogen sulfide (H_2S) measured as sulfide (S^{2-}), and a more accurate quantification of low-level dissolved oxygen were analyzed in the field at wells with measured dissolved-oxygen concentrations less than 1 mg/L. These analyses are presented in table 8 along with the redox classification assigned to each sample by the automated spreadsheet program presented in Jurgens and others (2009). Manganese reduction was the dominant process taking place (table 8) at well JH-1.5 during June of 2011 and well JH-2.5 during June and July 2011. Samples from wells JH-1.5R, JH-1.5D, JH-3, and JH-3D had iron-to-sulfide ratios greater than 10 (table 8), indicating that iron reduction was the dominant redox process at that time (Chapelle and others 2009). Methanogenesis was identified as a dominant process twice during the study, once at well JH-1.5 during June 2011 and once at well JH-3 during July 2011. High dissolved methane concentrations were measured in samples from both wells JH-1.5 and JH-3 (appendix 6) during June 2011, indicating methanogenesis had taken place in the aquifer in the vicinity of these wells. Dissolved methane gas also was detected in samples from wells JH-1.5D, JH-2.5, JH-3D, and JH-3.5 (appendix 6), indicating methanogenesis also has taken place in the vicinity of these wells.

Concentrations of DOC, a potential carbon source for heterotrophic bacteria, generally were low in samples from all 10 wells, ranging from an estimated 0.36 to 4.12 mg/L (table 7; appendix 5). DOC was detected in at least one sample from each well during the study (appendix 5) and in a field-equipment blank collected during July 2011 (appendix 3).

Three DOC concentrations were qualified with a footnote in appendix 5 owing to being measured at less than five times the maximum concentration measured in a blank sample. The highest concentrations of DOC were measured in samples collected in July 2011 from wells JH-1.5 and JH-1.5D, and in samples collected on July 20, 2011, and April 4, 2012, from well JH-3 (appendix 5); these high DOC concentrations are consistent with the determination of reducing conditions in those wells. The DOC concentrations in samples collected during 2011 and 2012, from all 10 wells, were within the estimated range of 0 to about 3 mg/L considered natural in groundwater (Drever, 1997, fig. 6–1), with the exception of the maximum concentration of 4.12 mg/L at well JH-1.5, which was only slightly greater. Chemical oxygen demand (COD) was not detected in samples at concentrations greater than the MRL of 10 mg/L (appendix 5).

Anthropogenic Compounds

As a commercial airport, the JHA uses many different anthropogenic compounds as part of daily operations. Wright (2010) reported only DRO were detected in measurable quantities during the baseline water-quality study. Only samples from the new monitor wells were analyzed for VOCs and GROs, whereas samples from all wells were analyzed for DROs during the followup study during water years 2011–12. Data for VOCs, GROs, and DROs for the followup study are presented in appendix 7.

Samples for analyses of VOCs and GROs were collected from the five new monitoring wells during June and July 2011 and April 2012. Concentrations of GROs were less than the LRLs used for this study in all except one sample collected from well JH-1.5 on July 20, 2011, which had an estimated concentration of 11 micrograms per liter ($\mu\text{g/L}$) (appendix 7). Three of the 63 VOCs included in the analyses (benzene, ethylbenzene, and total xylene) were detected at small (estimated) concentrations in at least one environmental sample. Benzene was detected in the sample from well JH-1.5D collected during April 2012, ethylbenzene was detected in the sample from well JH-2.5 collected during June 2011, and xylene was detected in the samples from well JH-2.5 collected during June and July 2011. Because the quantified benzene concentration from well JH-1.5D is less than five times the concentration measured in the trip blank, the value from the environmental sample has been qualified (appendix 7). None of the compounds described in this paragraph were detected during the previous baseline study, or consistently during this followup study. Several possible reasons these compounds were not consistently detected include (1) these compounds are present in the aquifer at concentrations near the analytical MDL and are difficult to detect, (2) these compounds were not from a persistent source during this study, and (3) these compounds were detected because of contamination introduced during sampling or analysis.

Table 8. Assignment of redox categories and processes for groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[mg/L, milligrams per liter; NO₃⁻, nitrate; --, not applicable; Mn²⁺, manganous manganese; µg/L, micrograms per liter; Fe²⁺, ferrous iron; SO₄²⁻, sulfate; H₂S, dihydrogen sulfide; HS⁻, hydrogen sulfide; S²⁻, sulfide; General redox category: O₂ ≥ 0.5 mg/L, dissolved oxygen greater than or equal to 0.5 mg/L; O₂ < 0.5 mg/L, dissolved oxygen less than 0.5 mg/L; Redox process: O₂, oxygen reduction; Mn(IV), manganese reduction; CH₄gen, methanogenesis; Fe(III), iron reduction; SO₄, sulfate reduction; NO₃, nitrate reduction]

Sample date	Sample time	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 ₂ S, HS ⁻ , S ²⁻) (mg/L)	General redox category	Redox process	Fe ²⁺ /sulfide ratio
Well JH-1										
06/08/2011	1200	¹ 9	--	0.16	3.2	9.75	--	O ₂ ≥ 0.5 mg/L	Unknown	--
07/19/2011	1030	--	--	0.16	3.4	--	--	O ₂ ≥ 0.5 mg/L	Unknown	--
11/01/2011	1100	8.2	--	0.16	3.2	--	--	O ₂ ≥ 0.5 mg/L	Unknown	--
04/03/2012	1030	7.7	0.286	0.16	3.2	10.80	--	Oxic	O ₂	--
Well JH-1.5										
06/10/2011	1030	0.1	0.023	967	23.9	1.99	0.002	Anoxic	Mn(IV)	--
07/20/2011	1800	0.2	0.2	3,040	843	0.24	0.0075	Anoxic	CH ₄ gen	--
Well JH-1.5R										
11/02/2011	1730	0.3	--	1,640	230	--	0	O ₂ < 0.5 mg/L	Unknown	--
04/04/2012	1820	0.1	0.04	1,120	153	9.43	0.002	Anoxic	Fe(III)	76.50
Well JH-1.5D										
06/10/2011	1150	0.2	0.02	907	470	5.64	0.005	Anoxic	Fe(III)	94.00
07/20/2011	1930	0.1	0.02	1,130	1,050	1.01	0.0545	Anoxic	Fe(III)	19.27
11/03/2011	1300	0.1	--	1,450	931	7.95	0.003	O ₂ < 0.5 mg/L	Unknown	--
04/05/2012	1020	0.1	0.04	1,160	617	9.58	0.007	Anoxic	Fe(III)	88.14
Well JH-2										
06/08/2011	1710	4.3	1.34	0.16	3.2	8.05	0	Oxic	O ₂	--
07/19/2011	1530	4.7	0.764	0.16	3.2	11.20	0.08	Oxic	O ₂	--
11/01/2011	1510	3.3	--	0.16	3.2	--	--	O ₂ ≥ 0.5 mg/L	Unknown	--
04/03/2012	1530	4.1	0.197	0.32	3.2	11.60	--	Oxic	O ₂	--
Well JH-2.5										
06/09/2011	1500	0.2	0.037	108	3.2	6.59	0.005	Anoxic	Mn(IV)	--
07/21/2011	1100	0.3	0.018	61.7	7.2	4.53	0.005	Anoxic	Mn(IV)	--
11/03/2011	1430	0.1	--	135	5.7	--	0.005	O ₂ < 0.5 mg/L	Unknown	--
04/04/2012	0950	1.0	0.04	8.92	47.1	11.00	0.005	Oxic	O ₂	--
Well JH-3										
06/09/2011	1830	0.1	0.02	1,690	584	3.52	0.006	Anoxic	Fe(III)	97.33
07/20/2011	1100	0.2	0.013	1,730	735	0.16	0.024	Anoxic	CH ₄ gen	--
11/02/2011	1350	0.1	--	1,530	515	--	0.005	O ₂ < 0.5 mg/L	Unknown	--
04/04/2012	1250	0.1	0.04	1,090	254	9.5	0.009	Anoxic	Fe(III)	28.22
Well JH-3D										
06/09/2011	2030	0.1	0.02	1,030	592	5.43	0.008	Anoxic	Fe(III)	74.00
07/20/2011	1300	0.1	0.02	1,060	572	1.87	0.02	Anoxic	Fe(III)	28.60
11/02/2011	1510	0.2	--	898	648	--	0.012	O ₂ < 0.5 mg/L	Unknown	--
04/04/2012	1450	0.1	0.04	769	493	8.92	0.023	Anoxic	Fe(III)	21.43
Well JH-3.5										
06/09/2011	1000	0.3	0.03	21.3	7.1	8.14	0.005	Suboxic	Suboxic	--
07/21/2011	1430	0.2	--	806	8.1	0.43	0.005	O ₂ < 0.5 mg/L	Unknown	--
11/02/2011	1110	0.1	--	1,610	760	--	0.011	O ₂ < 0.5 mg/L	Unknown	--
Well JH-4										
06/08/2011	1500	8.2	--	0.21	3.2	7.71	--	O ₂ ≥ 0.5 mg/L	Unknown	--
07/19/2011	1300	8.0	--	0.26	10.9	--	--	O ₂ ≥ 0.5 mg/L	Unknown	--
11/01/2011	1330	8.0	--	0.16	3.7	--	--	O ₂ ≥ 0.5 mg/L	Unknown	--
04/03/2012	1300	7.5	0.168	0.18	4.2	8.48	--	Oxic	O ₂	--

¹Dissolved-oxygen concentration measured by laboratory was an average of 7.1 mg/L. This field measurement is questionable and only presented in this table to show sample was oxic. This value was not used in analysis.

Small concentrations of DROs in the C₁₀–C₃₆ and C₁₀–C₃₂ ranges were detected in several samples collected during the baseline study (Wright, 2010) from wells JH–1, JH–2, and JH–4. The source of the low-level DRO concentrations in samples from the wells, including well JH–1, which is upgradient from all airport operations, is not known. During the followup study, samples collected from all monitor wells during June and July 2011 and April 2012 were analyzed for DROs. The DROs were not detected during this followup study (appendix 7).

Triazoles were detected in 7 of the 10 wells sampled (appendix 8). Only two of the three triazoles measured, 4-MeBT and 5-MeBT, were detected. Measurable

concentrations of 4-MeBT ranged from an estimated 0.37 to 9.8 µg/L with most detections an order of magnitude greater than the LRL. The measurable concentrations of 5-MeBT were all estimated and ranged from 0.26 to 0.77 µg/L. The triazole 4-MeBT was detected consistently in greater concentrations than 5-MeBT (appendix 8). This pattern in the data is consistent with other triazole research, which determined 5-MeBT is more biodegradable, whereas 4-MeBT is more recalcitrant (Cornell, 2002; Weiss and Reemtsma, 2005). The highest concentrations of 4-MeBT and 5-MeBT were in samples from wells JH–1.5D and JH–1.5R, respectively, during November 2011. Triazoles were detected only in monitor wells with reducing conditions.

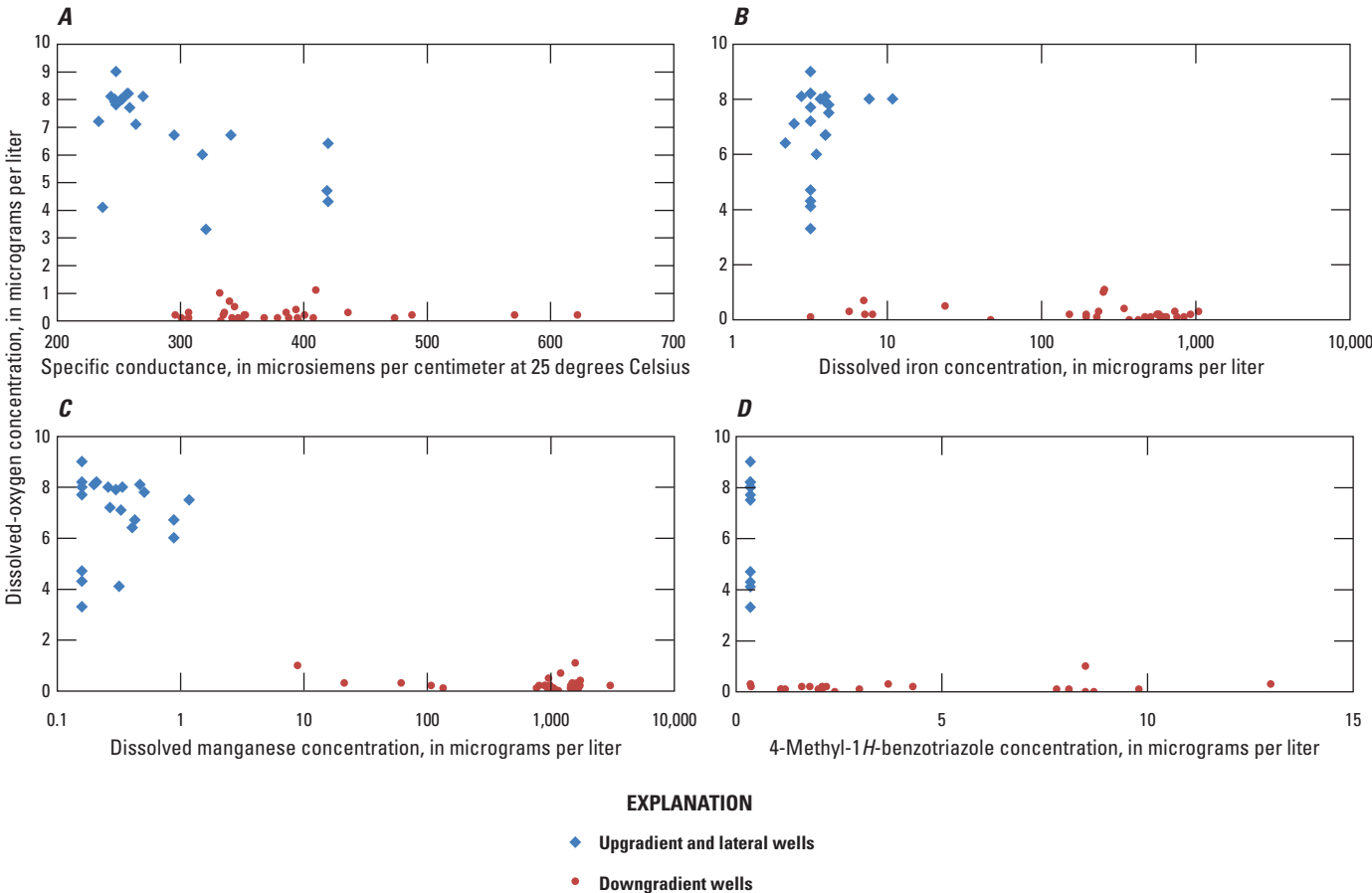


Figure 8. Bivariate graphs showing the relations between concentrations of dissolved oxygen and as compared to selected properties value or constituents measured in groundwater-quality samples collected from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012. A, specific conductance; B, dissolved iron; C, dissolved manganese; and manganese; D, 4-methyl-1H-benzotriazole.

Implications for Reduced Groundwater Conditions

During the baseline study at the JHA, Wright (2010) reported that a zone of highly reduced groundwater had been observed downgradient from airport operations. The chemical conditions in the groundwater were indicative of the presence of organic compounds such as those present in fuels, ADAFs, or their breakdown products; however, none of the organic compounds were detected at substantial concentrations in the groundwater, and the source of reducing conditions was not determined. The addition of several new monitor wells and water-quality analyses for this followup study have provided a better understanding of the groundwater conditions at the JHA.

Groundwater from all of the new monitor wells (JH-1.5, JH-1.5R, JH-1.5D, JH-2.5, and JH-3.5) installed for the followup study had water-quality characteristics similar to characteristics in groundwater from wells JH-3 and JH-3D. A series of graphs (fig. 8) show the relations between concentrations of dissolved oxygen as compared to *A*, specific conductance; *B* dissolved iron; *C* dissolved manganese; and *D*, 4-MeBT. Wells that are upgradient from and lateral to airport deicing operations (blue symbols) are wells JH-1, JH-2, and JH-4; wells that are downgradient from airport deicing operations (red symbols) are wells JH-1.5, JH-1.5R, JH-1.5D, JH-2.5, JH-3, JH-3D, and JH-3.5. The graphs in figure 8*A*, *B*, and *C* show that samples of groundwater with low concentrations of dissolved oxygen (reduced conditions) had higher values of specific conductance and higher concentrations of dissolved iron and dissolved manganese, respectively. Additionally, these graphs show that the values of specific conductance and concentrations of dissolved iron and dissolved manganese detected in upgradient and lateral wells are distinctly different from the values and concentrations of these constituents detected in the wells downgradient from airport operations. The compound 4-MeBT was only detected in measurable concentrations in downgradient monitor wells (fig. 8*D*) with low dissolved-oxygen concentrations. Although well JH-2 has been included in analyses as a well lateral to the reduced groundwater zone, it should be noted the average dissolved-oxygen concentration measured at well JH-2 dropped from 6.7 mg/L during the period 2008–09 (Wright, 2010) to 4.1 mg/L during the period 2011–12.

When compared to USEPA water-quality standards and health advisories (U.S. Environmental Protection Agency, 2012), the water quality in the Snake River alluvial aquifer at the airport generally is high quality and considered to be suitable for domestic and other uses without treatment. However, water-quality results for some constituents (figs. 7 and 8) in samples from wells downgradient from the airport terminal (fig. 5*A*) commonly were different than water-quality results for wells upgradient from and lateral to the groundwater flow path. Reducing conditions present in an otherwise oxic aquifer system indicate an upgradient or a natural, in place, source of

organic carbon or oxidizable minerals (Appelo and Postma, 2005; Drever, 1997; Hem, 1989). The source of organic carbon causing reduced groundwater conditions downgradient from airport operations could not be directly determined; however, the detection of triazoles in groundwater directly downgradient from airport operations (fig. 7) is important because these compounds are not naturally occurring and often are additives in human made products used at the airport, including ADAFs. The detection of triazoles associated with ADAFs in samples from wells downgradient from airport operations makes a natural cause for the reduced conditions unlikely. It is more likely that ADAFs or pavement deicers have seeped into the groundwater system. Although triazole concentrations detected at the airport are not of toxicological significance (Cancilla and others 1998, 2003b; Corsi and others, 2006a), it should be noted that Cancilla and others (1997) identified triazoles as the additives in formulated ADAF mixtures that are toxic to microorganisms.

Summary

Groundwater levels were measured in and groundwater-quality samples were collected from wells completed in the Snake River alluvial aquifer at the Jackson Hole Airport in northwestern Wyoming during water years 2011 and 2012 for a followup study to a previous baseline study conducted during 2008–09. This followup study was conducted by the U.S. Geological Survey, in cooperation with the Jackson Hole Airport Board, to further characterize the hydrogeology and groundwater quality of the Snake River aquifer in upgradient and downgradient parts of the aquifer underlying the airport. Five new wells were installed upgradient from and laterally to selected monitoring wells installed for the baseline study. Groundwater-level measurements were collected from 19 wells and groundwater-quality analyses from a subset of 10 of these wells. Data, including groundwater levels, field measurements of physical properties of water, major ions, nutrients, volatile organic compounds (VOCs), gasoline-range organics (GROs), diesel-range organics (DROs), triazoles, dissolved gases, and miscellaneous field and laboratory analytical results, are presented 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 and oxidation (redox) condition is characterized for selected well locations.

Water levels collected throughout the followup study indicate the water table was lowest in the early spring and reached its peak in July or August, with an increase of 12.5 to 15.5 feet between April and July of 2011. 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 with an average hydraulic gradient of 0.0068 foot/foot, which slightly is higher than the average of 0.0066 foot per foot determined during the baseline study. Generally, the vertical hydraulic gradient was small, averaging 0.005 foot per foot. 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. The horizontal groundwater velocity in the alluvial aquifer was estimated to be 25 to 68 feet per day. The travel time from the farthest upgradient well to the farthest downgradient well was approximately 52 to 142 days. This estimate of groundwater velocity only describes the movement of water through the aquifer because solutes may move at a different rate.

Generally, water in the Snake River alluvial aquifer was determined to be of good quality. No constituents were detected at concentrations exceeding U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Levels or health advisories; however, redox measurements indicate oxygen-poor water in many of the wells. Gasoline-range organics, three volatile organic compounds, and triazoles were detected in some groundwater samples. 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 at concentrations exceeding USEPA Secondary Maximum Contaminant Levels in some samples.

Specific-conductance values ranged from 247 to 622 microsiemens per centimeter at 25 degrees Celsius, and pH values were neutral to alkaline. Dissolved solids and major-ion data indicated the groundwater sampled at the airport is considered hard to very hard, fresh, calcium bicarbonate water. Dissolved-oxygen concentrations ranged from less than 0.1 to 9.0 milligrams per liter indicating some variability in the oxygen content of the aquifer underlying the airport. Although oxic aquifer conditions were indicated for three of the wells, dissolved-oxygen concentrations indicated reducing conditions at the seven remaining wells.

Nutrients were detected at low concentrations in all samples collected. Nitrate is the primary dissolved-nitrogen species in the aquifer. In samples in which nitrate was not detected, ammonia was detected. 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 greater than the estimated range for natural groundwater and had a concentration a magnitude higher than other dissolved organic carbon concentrations measured in this followup study. Chemical oxygen demand was not detected in any samples.

Dissolved gas samples were collected and hydrogen sulfide, low-level dissolved oxygen, and ferrous iron were analyzed in the field to better understand the redox conditions of the alluvial aquifer. These additional analyses confirmed the low concentrations of dissolved oxygen and indicated the presence of low concentrations of methane gas in samples from several wells. The biological redox status of low dissolved

oxygen in groundwater in the Snake River alluvial aquifer was identified using a spreadsheet model designed to use a multiple-line-of-evidence approach to distinguish the source of reduction. Results indicate iron reduction is the dominant redox process; however, the model indicated manganese reduction and methanogenesis also are active redox processes at the JHA.

Samples from all of the wells included in the followup study were analyzed for anthropogenic compounds; only samples collected from the five new wells were analyzed for VOCs and GROs, whereas samples from all of the wells were analyzed for DROs and triazoles. GROs, benzene, ethylbenzene, and total xylene each were detected (but reported as estimated concentrations) in at least one groundwater sample. These compounds were not detected during the previous study or consistently during this study. Several possible reasons these compounds were not detected consistently include (1) these compounds are present in the aquifer at concentrations near the analytical method detection limit and are difficult to detect, (2) these compounds were not from a persistent source during this study, and (3) these compounds were detected because of contamination introduced during sampling or analysis.

DROs were detected during the baseline study but were not detected in any samples during the followup study. Two of the three triazoles (4-methyl-1*H*-benzotriazole and 5-methyl-1*H*-benzotriazole) were detected at low concentrations in 7 of the 10 wells sampled.

In general, low dissolved-oxygen concentrations and reducing conditions present at many airport monitoring wells are not uncommon in groundwater; however, dissolved-oxygen concentrations in water from other wells sampled at the Jackson Hole Airport were 3.3 milligrams per liter or higher, indicating the Snake River alluvial aquifer naturally is oxic in the vicinity of the airport. Reducing conditions in an otherwise oxic aquifer system are indicative of an upgradient or in place source of organic carbon. The detection of triazoles in groundwater downgradient from airport operations makes it unlikely there is a natural cause for the high rates of reduction present in many airport monitor wells. It is more likely that aircraft deicers, anti-icers, or pavement deicers have seeped into the groundwater system.

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Appendixes

Appendix 1. Well construction and related ancillary information for wells used for data collection at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[USGS, U.S. Geological Survey; SS, south side; NAD 83, North American Datum of 1983; °, degrees; ', minutes; ", seconds; ft, feet; bls, below land surface; MP, measuring point; --, not able to measure or find listed; -XX, a negative MP indicates a measurement above land surface; NAVD 88, North American Vertical Datum of 1988; PVC, polyvinyl chloride; na, value is not available]

USGS site identification number	Well identifier	Latitude (NAD 83)	Longitude (NAD 83)	Well depth, ft, bls	Depth to top of screen ft, bls	Depth to bottom of screen ft, bls	Height of MP ft	Elevation of MP, ft above NAVD 88	Description of MP
Water-quality and water levels									
433615110440001	JH-1	43°36'14.55"	110°44'02.31"	60.36	30	50	0.55	6,421.91	Top of PVC casing.
433604110443401	JH-1.5	43°36'04.2"	110°44'03.5"	55	45	55	-1.26	6,415.52	Top of PVC casing.
433604110443403	JH-1.5R	43°36'04.25"	110°44'33.58"	64	44	64	-0.48	6,415.88	Top of PVC casing.
433604110443402	JH-1.5D	43°36'04.2"	110°44'33.5"	94.45	85	95	-0.40	6,416.05	Top of PVC casing.
433551110443501	JH-2	43°35'50.69"	110°44'37.54"	59.45	30	55	0.32	6,406.27	Top of PVC casing.
433600110443701	JH-2.5	43°35'59.8"	110°44'37.5"	55.0	45	55	0.25	6,412.72	Top of PVC casing.
433603110443501	JH-3	43°36'02.92"	110°44'37.31"	60.23	40	60	0.28	6,411.94	Top of PVC casing.
433603110443502	JH-3D	43°06'02.65"	110°44'37.45"	102.58	--	--	-1.97	6,413.96	Top of steel casing.
433605110443801	JH-3.5	43°36'04.97"	110°44'37.57"	55.0	45	55	0.31	6,410.51	Top of PVC casing.
433613110443501	JH-4	43°36'12.48"	110°44'37.70"	58.87	40	55	0.32	6,417.74	Top of PVC casing.
Water levels only									
433556110441601	Hangar 5	43°35'55.94"	110°44'18.76"	92	na	na	0.25	6,409.61	Top of steel casing.
433630110442701	Control tower	43°06'29.45"	110°44'30.02"	100	na	na	-1.07	6,428.62	Top of well cap.
433604110441001	SS gas tanks	43°36'03.36"	110°44'12.81"	55.70	na	na	0.12	6,416.51	Top of well cap.
433606110440501	Airport entrance	43°36'05.64"	110°44'07.94"	81	na	na	-1.17	6,418.34	Top of well cap.
433605110441201	Hangar 2	43°36'04.93"	110°44'14.51"	89	na	na	-1.26	6,418.09	Top of well cap.
433602110441201	Hangar 3	43°36'02.01"	110°44'14.50"	--	na	na	-1.02	6,415.11	Top of well cap.
433558110441501	Auto garage	43°05'57.57"	110°44'17.43"	--	na	na	0.26	6,412.31	Top of steel casing.
433607110440901	Hangar 1	43°36'06.4"	110°44'11.94"	65	na	na	-1.24	6,419.75	Top of steel casing.

Appendix 2. Water-level data and related ancillary information for measurements collected from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[SS, south side; BLS, below land surface; e-tape, calibrated electric tape; NAVD 88, North American Vertical Datum of 1988; --, not applicable]

Well identifier (fig. 2)	Date	Time (24 hour)	Water level (feet BLS)	Water level method	Water-level altitude, (feet above NAVD 88)
JH-1	11/2/2010	0900	41.76	e-tape	6,380.70
	3/22/2011	1130	47.1	e-tape	6,375.36
	5/9/2011	1800	42.67	e-tape	6,379.79
	6/8/2011	0940	38.17	e-tape	6,384.29
	7/19/2011	0847	33.34	e-tape	6,389.12
	8/10/2011	1600	33.28	e-tape	6,389.18
	11/1/2011	0920	39.1	e-tape	6,383.36
	4/3/2012	0855	44.89	e-tape	6,377.57
	7/17/2012	0930	37.09	e-tape	6,385.37
JH-1.5	8/21/2012	1500	39.22	e-tape	6,383.24
	11/3/2010	0934	51.42	e-tape	6,362.84
	2/10/2011	1255	Dry	e-tape	--
	3/15/2011	1430	Dry	e-tape	--
	5/9/2011	1540	50.8	e-tape	6,363.46
	6/10/2011	0818	46.46	e-tape	6,367.80
	7/20/2011	1600	43.36	e-tape	6,370.90
	8/10/2011	1310	43.33	e-tape	6,370.93
	10/19/2011	1625	47.02	e-tape	6,370.24
JH-1.5R	7/17/2012	1122	45.24	e-tape	6,369.02
	11/2/2011	1625	49.28	e-tape	6,366.12
	4/4/2012	1720	54.76	e-tape	6,360.64
	7/17/2012	1120	46.38	e-tape	6,369.02
JH-1.5D	8/21/2012	1611	48.84	e-tape	6,366.56
	11/3/2010	1520	52.01	e-tape	6,363.24
	2/10/2011	1300	56.46	e-tape	6,358.79
	3/15/2011	1500	57.22	e-tape	6,358.03
	5/9/2011	1615	51.36	e-tape	6,363.89
	6/10/2011	0820	47.06	e-tape	6,368.19
	7/20/2011	1602	43.94	e-tape	6,371.31
	8/10/2011	1158	45.16	steel tape	6,370.09
	11/3/2011	0915	49.55	e-tape	6,365.70
	4/5/2012	0835	54.94	e-tape	6,360.31
	7/17/2012	1125	46.23	e-tape	6,369.02
	8/21/2012	1608	49	e-tape	6,366.25
JH-2	11/2/2010	1600	48.53	e-tape	6,358.06
	2/10/2011	1330	53.51	e-tape	6,353.08
	3/15/2011	1700	54.35	e-tape	6,352.24
	5/9/2011	1720	48.34	e-tape	6,358.25
	6/8/2011	1610	42.83	e-tape	6,363.76
	7/19/2011	1417	39.21	e-tape	6,367.38
	10/19/2011	1808	44.73	e-tape	6,361.86
	11/1/2011	1442	45.85	e-tape	6,360.74
	4/3/2012	1415	52.16	e-tape	6,354.43
	7/17/2012	1013	42.46	e-tape	6,364.13
	8/21/2012	1621	45.5	e-tape	6,361.09

Appendix 2. Water-level data and related ancillary information for measurements collected from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[SS, south side; BLS, below land surface; e-tape, calibrated electric tape; NAVD 88, North American Vertical Datum of 1988; --, not applicable]

Well identifier (fig. 2)	Date	Time (24 hour)	Water level (feet BLS)	Water level method	Water-level altitude, (feet above NAVD 88)
JH-2.5	2/10/2011	1310	54.55	e-tape	6,358.42
	3/15/2011	1630	Dry	e-tape	--
	5/9/2011	1705	49.49	e-tape	6,363.48
	6/9/2011	1358	44.82	e-tape	6,368.15
	7/21/2011	0917	41.68	e-tape	6,731.29
	10/19/2011	0910	46.55	e-tape	6,366.42
	11/3/2011	1334	47.87	e-tape	6,365.10
	4/4/2012	0830	53.51	e-tape	6,359.46
	7/17/2012	1105	44.69	e-tape	6,368.28
	8/21/2012	1616	47.36	e-tape	6,365.61
JH-3	2/10/2011	1240	55.5	e-tape	6,356.72
	3/15/2012	1330	56.27	e-tape	6,355.95
	5/9/2011	1435	50.3	e-tape	6,361.92
	6/9/2011	1652	45.97	e-tape	6,366.25
	7/20/2011	0825	43.11	e-tape	6,369.11
	10/19/2011	0858	47.72	e-tape	6,364.50
	11/2/2011	1238	48.97	e-tape	6,363.25
	4/4/2012	1132	54.51	e-tape	6,357.71
	7/17/2012	1131	45.94	e-tape	6,366.28
JH-3D	8/21/2012	1559	48.51	e-tape	6,363.71
	2/10/2011	1250	55.6	e-tape	6,356.39
	3/15/2011	1340	56.4	e-tape	6,355.59
	5/9/2011	1500	50.31	e-tape	6,361.68
	6/9/2011	1658	45.93	e-tape	6,366.06
	7/20/2011	0828	43.04	e-tape	6,368.95
	10/19/2011	0902	47.72	e-tape	6,364.27
	11/2/2011	1220	48.96	e-tape	6,363.03
	4/4/2012	1135	54.66	e-tape	6,357.33
JH-3.5	7/17/2012	1136	45.95	e-tape	6,366.04
	8/21/2012	1603	48.52	e-tape	6,363.47
	11/3/2010	0820	50.31	e-tape	6,360.51
	2/10/2011	1230	54.59	e-tape	6,356.23
	3/15/2011	1245	54.6	e-tape	6,356.22
	5/9/2011	1415	50.55	e-tape	6,360.27
	6/9/2011	0830	46.4	e-tape	6,364.42
	7/21/2011	1242	43.58	e-tape	6,367.24
	10/19/2011	0918	48.13	e-tape	6,362.69
	11/2/2011	0938	49.39	e-tape	6,361.43
	4/3/2012	1615	54.61	e-tape	6,356.21
	7/17/2012	1140	45.39	e-tape	6,365.43
	8/21/2012	1554	48.89	e-tape	6,361.93

Appendix 2. Water-level data and related ancillary information for measurements collected from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[SS, south side; BLS, below land surface; e-tape, calibrated electric tape; NAVD 88, North American Vertical Datum of 1988; --, not applicable]

Well identifier (fig. 2)	Date	Time (24 hour)	Water level (feet BLS)	Water level method	Water-level altitude, (feet above NAVD 88)
JH-4	11/2/2010	1320	54.04	e-tape	6,364.02
	2/10/2011	1220	58.19	e-tape	6,359.87
	3/15/2011	1145	58.91	e-tape	6,359.15
	5/9/2011	1330	52.82	e-tape	6,365.24
	6/8/2011	1403	49.35	e-tape	6,368.71
	7/19/2011	1155	46.93	e-tape	6,371.13
	10/19/2011	1155	50.98	e-tape	6,367.08
	11/1/2011	1240	52.11	e-tape	6,365.95
	4/3/2012	1144	57.44	e-tape	6,360.62
	7/17/2012	1145	49.45	e-tape	6,368.61
	8/21/2012	1539	51.69	e-tape	6,366.37
Hangar 1	11/1/2011	1210	40.2	steel tape	6,376.35
	4/3/2012	1830	46.03	steel tape	6,370.48
	8/21/2012	1452	41.1	steel tape	6,375.41
Hangar 5	11/1/2011	1630	36.59	e-tape	6,373.27
	4/3/2012	1725	42.52	e-tape	6,367.34
	7/18/2012	1445	34.13	e-tape	6,375.73
	8/21/2012	1635	36.59	e-tape	6,373.27
Control Tower	7/19/2011	1720	48.9	steel tape	6,378.66
	11/1/2011	1604	53.38	steel tape	6,374.17
	4/3/2012	1655	58.17	steel tape	6,369.38
	7/17/2012	1155	51.24	e-tape	6,376.31
	8/21/2012	1501	52.95	steel tape	6,374.60
SS fuel farm	11/1/2011	1710	39.12	e-tape	6,377.51
	4/3/2012	1756	44.97	e-tape	6,371.66
	7/18/2012	1520	36.92	e-tape	6,379.71
	8/21/2012	1655	38.37	e-tape	6,378.26
Airport Entrance	11/1/2011	1200	37.63	steel tape	6,379.54
	4/3/2012	1835	43.62	steel tape	6,373.55
	7/18/2012	0730	35.46	e-tape	6,381.71
	8/21/2012	1445	37.76	steel tape	6,379.41
Hangar 2	11/1/2011	1720	39	steel tape	6,377.83
	4/3/2012	1812	44.79	steel tape	6,372.04
	7/18/2012	1530	36.77	e-tape	6,380.06
	8/21/2012	1701	40.04	steel tape	6,376.79
Hangar 3	11/1/2011	1652	37.73	steel tape	6,376.36
	4/3/2012	1747	43.55	steel tape	6,370.54
	7/18/2012	1511	35.47	e-tape	6,378.62
	8/21/2012	1646	37.74	steel tape	6,376.35
Auto Garage	11/1/2011	1645	38.66	e-tape	6,373.91
	4/3/2012	1738	44.5	e-tape	6,368.07
	7/18/2012	1505	36.16	e-tape	6,376.41
	8/21/2012	1641	38.69	e-tape	6,373.88

Appendix 3. Inorganic and organic constituents in blank samples collected for followup study at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[mg/L, milligrams per liter; --, not applicable; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the laboratory reporting level; **Bold** value indicates constituent was detected above reporting level; µg/L, micrograms per liter; E, estimated concentration]

Physical property or constituent	Units	Trip blanks			Field equipment blanks			
		JH-1.5	JH-1	JH-1.5R	JH-2.5	JH-2.5	JH-3	JH-1.5R
		06/10/2011	07/19/2011	04/04/2012	06/09/2011	07/21/2011	07/20/2011	04/04/2012
Styrene	µg/L	<0.280	<0.280	<0.280	<0.280	<0.280	--	<0.280
<i>tert</i> -Butyl ethyl ether	µg/L	<0.26	<0.26	<0.26	<0.26	<0.26	--	--
<i>tert</i> -Butylbenzene	µg/L	<0.140	<0.140	<0.140	<0.140	<0.140	--	<0.140
Tetrachloroethene	µg/L	<0.30	<0.30	<0.30	<0.30	<0.30	--	<0.30
Tetrachloromethane	µg/L	<0.22	<0.22	<0.22	<0.22	<0.22	--	<0.22
Toluene	µg/L	<0.23	<0.17	<0.17	<0.17	<0.17	--	<0.23
<i>trans</i> -1,2-Dichloroethene	µg/L	<0.24	<0.24	<0.24	<0.24	<0.24	--	<0.24
Tribromomethane	µg/L	<0.390	<0.390	<0.390	<0.390	<0.390	--	<0.390
Trichloroethene	µg/L	<0.37	<0.37	<0.37	<0.37	<0.37	--	<0.37
Trichlorofluoromethane	µg/L	<0.230	<0.230	<0.230	<0.230	<0.230	--	<0.230
Trichloromethane	µg/L	<0.29	<0.29	<0.29	<0.29	<0.29	--	<0.29
Trihalomethanes	µg/L	<1.6	<1.6	<1.6	<1.6	<1.6	--	<1.6
Vinyl chloride	µg/L	<0.33	<0.33	<0.33	<0.33	<0.33	--	--
Xylene (all isomers)	µg/L	<0.27	<0.19	<0.19	<0.19	<0.19	--	--
Diesel range organics (DRO), gasoline range organics (GRO), and triazoles compounds								
Diesel range organic compounds (C ₁₀ -C ₃₆)	mg/L	--	--	--	<0.057	<0.059	--	<0.510
Gasoline range organic compounds	µg/L	--	<10	<10	<10	<10	--	<25
4-Methyl-1 <i>H</i> -benzotriazole	µg/L	--	--	--	<0.35	<0.35	--	<0.35
5-Methyl-1 <i>H</i> -benzotriazole	µg/L	--	--	--	<0.25	<0.25	--	<0.25

Appendix 4. Physical properties measured in groundwater samples from wells and a surface-water sample from irrigation ditch at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

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

USGS site- identification number	Well or site identifier	Date	Sample time (24 hour)	Air temperature (°C)	Dissolved oxygen (mg/L)	pH, field (standard units)	Specific conduc- tance, field (µS/cm)	Water temperature (°C)	Turbidity (NTRU)
433615110440001	JH-1	06/08/2011	1200	--	¹ 9.0	8.0	248	9.5	0.3
		07/19/2011	1030	25.0	--	7.9	260	9.8	0.7
		11/01/2011	1100	-1.0	8.2	8.0	257	7.0	0.5
		04/03/2012	1030	5.0	7.7	7.9	259	7.4	0.1
433604110443401	JH-1.5	06/11/2011	1030	--	0.1	7.2	474	11.0	2.5
		07/20/2011	1800	23.0	0.2	7.0	622	16.1	5.0
433604110443403	JH-1.5R	11/02/2011	1730	4.5	0.3	7.2	386	7.8	0.4
		04/04/2012	1820	12	<0.1	7.2	350	8.3	0.3
433604110443403	JH-1.5D	06/10/2011	1150	--	0.2	7.3	352	9.9	3.0
		07/20/2011	1930	23.0	<0.1	7.4	396	9.2	1.5
		11/03/2011	1300	6.5	0.1	7.3	368	9.6	4.0
		04/05/2012	1020	5.5	<0.1	7.3	333	8.4	0.2
43355110443501	JH-2	06/08/2011	1710	--	4.3	7.4	420	11.0	--
		07/19/2011	1530	26.0	4.7	7.3	419	12.0	1.2
		11/01/2011	1510	1.5	3.3	7.6	321	7.5	0.6
		04/03/2012	1530	13.5	4.1	7.5	321	8.6	0.2
433600110443701	JH-2.5	06/09/2011	1500	--	0.2	7.5	401	10.8	0.4
		07/21/2011	1100	22.0	0.3	7.3	436	10.7	1.3
		11/03/2011	1430	8.5	0.1	7.5	347	10.4	0.3
		04/04/2012	0950	10.0	1.0	7.3	332	7.9	0.5
433603110443501	JH-3	06/09/2011	1830	--	0.1	7.3	408	9.7	0.1
		07/20/2011	1100	23.0	0.2	7.1	488	15.5	1.0
		11/02/2011	1350	3.5	0.1	7.2	395	7.7	0.3
		04/04/2012	1250	16	<0.1	7.2	348	8.8	0.7
433603110443502	JH-3D	06/09/2011	2030	--	0.1	7.3	342	9.0	0.9
		07/20/2011	1300	23.0	0.1	7.3	379	15.7	0.8
		11/02/2011	1510	4.5	0.2	7.4	335	10.5	5.0
		04/04/2012	1450	16	0.1	7.5	307	9.03	0.7
433605110443801	JH-3.5	06/09/2011	1000	--	0.3	7.7	307	9.4	2.0
		07/20/2011	1430	25.0	0.2	7.3	571	11.3	2.5
		11/02/2011	1110	2.5	0.1	7.2	388	7.7	0.5
433613110443501	JH-4	06/08/2011	1500	--	8.2	8.0	253	10.8	0.6
		07/19/2011	1300	28.0	8.0	7.9	258	11.4	0.7
		11/01/2011	1330	4.5	8.0	8.0	247	8.2	0.3
		04/03/2012	1300	11.0	7.5	7.8	252	7.9	0.5
433553110443601	Irrigation ditch	06/08/2011	1840	--	9.0	8.4	266	10.5	--

¹Dissolved-oxygen concentration measured by laboratory was an average of 7.1 mg/L. This field measurement is presented in this table but was not used in analysis.

Appendix 5. Analytical results for chemical oxygen demand, major ions, trace elements, nutrients, dissolved organic carbon, and stable isotopes in groundwater samples from wells and a surface-water sample from irrigation ditch at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; --, not analyzed; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the laboratory reporting level; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; H₂S, dihydrogen sulfide; HS⁻, hydrogen sulfide; S₂⁻, sulfide; **Bold** value indicates constituent exceeded a U.S. Environmental Protection Agency Secondary Maximum Contaminant Level]

USGS site-identification number	Well or site identifier	Date	Time (24 hour)	Chemical oxygen demand, high level, total (mg/L)	Dissolved solids (mg/L)	Hardness, total, as CaCO ₃ (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)	Bromide, dissolved (mg/L)	Chloride, dissolved (mg/L)
433615110440001	JH-1	06/08/2011	1200	--	156	120	35.2	7.83	1.93	7.71	120	146	0.013	3.47
	JH-1	07/19/2011	1030	--	--	--	--	--	--	--	126	154	--	--
	JH-1	11/01/2011	1100	--	--	--	--	--	--	--	121	147	--	--
	JH-1	04/03/2012	1030	<10	158	122	36.0	7.92	2.01	7.53	114	138	0.021	3.90
433604110443401	JH-1.5	06/10/2011	1030	<10	267	254	79.9	13.1	2.25	8.22	263	321	0.025	5.28
	JH-1.5	07/20/2011	1800	<10	382	310	96.0	17.1	2.28	8.06	328	400	0.041	13.1
433604110443403	JH-1.5R	11/02/2011	1730	--	--	--	--	--	--	--	206	251	--	--
	JH-1.5R	04/04/2012	1820	<10	245	173	54.8	8.72	1.88	7.50	153	186	0.022	4.16
433604110443403	JH-1.5D	06/10/2011	1150	<10	224	171	52.9	9.54	2.02	8.20	178	217	0.016	4.88
	JH-1.5D	07/20/2011	1930	<10	247	187	57.2	10.8	2.08	7.98	198	242	0.023	8.41
	JH-1.5D	11/03/2011	1300	--	230	187	59.2	9.63	1.93	7.18	187	228	0.020	5.62
	JH-1.5D	04/05/2012	1020	<10	211	163	51.6	8.40	1.79	7.12	153	186	0.019	3.87
433551110443501	JH-2	06/08/2011	1710	--	258	223	67.8	13.1	2.32	8.35	215	262	0.017	4.67
	JH-2	07/19/2011	1530	--	256	208	63.7	11.9	2.11	7.13	188	230	<0.010	6.18
	JH-2	11/01/2011	1510	--	--	--	--	--	--	--	159	193	--	--
	JH-2	04/03/2012	1530	<10	212	159	49.0	8.91	1.94	7.91	151	183	0.019	3.66
433600110443701	JH-2.5	06/09/2011	1500	<10	229	205	63.9	11.0	2.10	8.24	204	249	0.018	4.61
	JH-2.5	07/21/2011	1100	<10	256	213	66.2	11.7	2.15	7.79	218	266	0.032	9.98
	JH-2.5	11/03/2011	1430	--	--	--	--	--	--	--	177	215	--	--
	JH-2.5	04/04/2012	0950	<10	257	162	51.3	8.29	1.94	7.39	155	189	0.018	3.77
433603110443501	JH-3	06/09/2011	1830	<10	240	213	65.6	11.8	2.01	8.14	222	270	0.015	4.82
	JH-3	07/20/2011	1100	<10	292	245	75.7	13.7	2.24	8.17	248	302	0.029	9.33
	JH-3	11/02/2011	1350	--	--	--	--	--	--	--	207	252	--	--
	JH-3	04/04/2012	1250	<10	210	167	52.6	8.71	1.85	7.03	161	196	0.023	3.89
433603110443502	JH-3D	06/09/2011	2030	<10	203	170	51.5	10.0	1.95	7.78	176	214	0.018	4.53
	JH-3D	07/20/2011	1300	<10	218	180	54.5	10.8	2.08	7.95	195	237	0.012	6.56
	JH-3D	11/02/2011	1510	--	--	--	--	--	--	--	164	199	--	--
	JH-3D	04/04/2012	1450	<10	178	145	44.1	8.40	1.82	6.92	135	164	0.020	4.34
433605110443801	JH-3.5	06/09/2011	1000	<10	189	157	47.6	9.29	2.09	7.16	162	197	0.018	3.73
	JH-3.5	07/21/2011	1430	<10	330	273	81.5	16.8	2.61	8.33	294	358	0.033	6.07
	JH-3.5	11/02/2011	1110	--	--	--	--	--	--	--	210	256	--	--
433613110443501	JH-4	06/08/2011	1500	--	160	125	37.5	7.70	1.85	6.47	122	149	0.013	3.19
	JH-4	07/19/2011	1300	--	--	--	--	--	--	--	118	143	--	--
	JH-4	11/01/2011	1330	--	--	--	--	--	--	--	120	145	--	--
	JH-4	04/03/2012	1300	<10	150	121	36.2	7.41	1.86	6.43	112	130	0.024	5.01
433553110443601	Irrigation ditch	06/08/2011	1840	20	169	123	35.8	8.09	1.33	10.5	105	126	<0.010	0.84
Quality-control samples														
433605110443801	³ JH-3.5	06/09/2011	1001	<10	177	156	47.4	9.24	2.09	7.15	160	195	0.016	3.72

¹Quantified concentration in the environmental sample is less than five times the maximum concentration in a blank sample.

²Relative percent difference (RPD) between the groundwater sample and replicate sample is greater than 20 percent.

³Replicate.

Appendix 5. Analytical results for chemical oxygen demand, major ions, trace elements, nutrients, dissolved organic carbon, and stable isotopes in groundwater samples from wells and a surface-water sample from irrigation ditch at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; --, not analyzed; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the laboratory reporting level; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; H₂S, dihydrogen sulfide; HS⁻, hydrogen sulfide; S₂⁻, sulfide; **Bold** value indicates constituent exceeded a U.S. Environmental Protection Agency Secondary Maximum Contaminant Level]

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)	Phosphorus, total as P (mg/L)	Total nitrogen (nitrate plus nitrite plus ammonia plus organic-N), unfiltered (mg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)	Organic carbon, dissolved (mg/L)	Sulfide (sum of H ₂ S, HS ⁻ , and S ₂ ⁻), total, field (mg/L)	Ferrous iron, total, field (µg/L)	Dissolved oxygen, low level, dissolved, field (µg/L)
0.43	18.6	9.75	--	--	--	--	--	--	<3.2	<0.16	--	--	--	--
--	--	--	--	--	--	--	--	--	² 3.4	<0.16	--	--	--	--
--	--	--	--	--	--	--	--	--	<3.2	<0.16	--	--	--	--
0.46	19.8	10.8	¹ 0.011	² 0.286	<0.001	0.019	0.016	0.24	<3.2	<0.16	0.49	--	--	--
0.34	19.8	1.99	0.017	² 0.02	<0.001	0.014	¹ 0.007	<0.05	² 23.9	967	0.69	<0.0050	<0.02	224
0.33	23.7	.24	<0.010	<0.02	<0.001	0.020	¹ 0.021	<0.05	2843	3,040	4.12	0.0075	0.89	153
--	--	--	--	--	--	--	--	--	² 230	1,640	--	<0.0050	0.026	171
0.45	20.9	9.43	¹ 0.039	<0.040	<0.001	0.008	0.009	<0.05	² 153	1,120	0.51	<5.0	0.195	164
0.39	19.2	5.64	<0.010	<0.02	<0.001	0.014	¹ 0.011	<0.05	2470	907	0.53	0.0050	0.53	76
0.41	20.5	1.01	<0.010	<0.02	<0.001	0.013	¹ 0.017	<0.05	² 1,050	1,130	1.82	0.0545	1.05	294
0.41	22.7	7.95	--	--	--	--	--	--	2931	1,450	--	<0.0050	1	213
0.47	21.0	9.58	¹ 0.022	<0.040	<0.001	0.009	0.015	<0.05	2617	1,160	0.45	0.0070	0.69	355
0.33	19.3	8.05	<0.010	² 1.35	0.002	0.020	¹ 0.013	1.47	<3.2	<0.16	--	--	--	--
0.33	18.9	11.2	<0.010	² 0.76	<0.001	0.021	¹ 0.011	0.78	<3.2	<0.16	--	--	--	--
--	--	--	--	--	--	--	--	--	<3.2	<0.16	--	--	--	--
0.48	19.8	11.6	<0.010	² 0.197	<0.001	0.017	0.014	0.15	<3.2	¹ 0.32	0.42	--	--	--
0.38	19.1	6.59	<0.010	² 0.04	0.006	0.014	¹ 0.006	<0.05	<3.2	108	0.64	<0.0050	<0.02	192
0.37	19.8	4.53	<0.010	² 0.02	0.004	0.015	¹ 0.006	<0.05	² 7.2	61.7	10.8	<0.0050	0.075	246
--	--	--	--	--	--	--	--	--	² 5.7	135	--	<0.0050	<0.02	240
0.46	19.4	11.1	0.079	<0.040	<0.001	0.027	0.039	0.21	² 47.1	8.92	0.83	<0.0050	0.06	0.06
0.35	21.2	3.52	<0.010	<0.02	<0.001	0.014	¹ 0.013	<0.05	2584	1,690	0.68	0.0055	0.6	142
0.35	22.4	0.16	0.014	<0.02	0.007	0.015	¹ 0.014	<0.05	2735	1,730	1.31	0.0240	0.78	237
--	--	--	--	--	--	--	--	--	2515	1,530	--	<0.0050	0.55	248
0.46	20.2	9.50	0.294	<0.040	<0.001	0.055	0.111	0.92	2254	1,090	2.90	0.0090	0.28	162
0.39	20.1	5.43	<0.010	<0.02	<0.001	0.012	¹ 0.012	<0.05	2592	1,030	0.72	0.0085	0.62	193
0.38	21.0	1.87	0.012	<0.02	<0.001	0.015	¹ 0.012	<0.05	2572	1,060	10.71	0.0205	0.565	193
--	--	--	--	--	--	--	--	--	2648	898	--	0.0120	0.76	237
0.42	19.4	8.92	¹ 0.028	<0.040	<0.001	0.006	0.012	<0.05	2493	769	0.56	0.0230	0.6	513
0.39	17.4	8.14	<0.010	² 0.04	0.006	0.014	¹ 0.011	<0.05	² 7.1	21.3	0.53	<0.0050	<0.02	227
0.32	21.1	0.43	<0.010	<0.02	<0.001	0.015	¹ 0.007	<0.05	² 8.1	806	¹ 0.97	<0.0050	0.02	173
--	--	--	--	--	--	--	--	--	² 760	1,610	--	0.0110	0.785	138
0.34	18.3	7.71	--	--	--	--	--	--	<3.2	0.21	--	--	--	--
--	--	--	--	--	--	--	--	--	² 10.9	¹ 0.26	--	--	--	--
--	--	--	--	--	--	--	--	--	23.7	<0.16	--	--	--	--
0.38	18.9	8.48	¹ 0.011	² 0.168	<0.001	0.017	0.014	0.14	24.2	¹ 0.18	0.36	--	--	--
0.13	6.58	33.9	<0.010	<0.02	0.001	0.013	0.124	0.40	² 38.2	4.61	6.43	--	--	--
Quality-control samples														
0.39	17.2	8.14	<0.010	2.03	0.006	0.014	¹ 0.009	<0.05	15.2	22.4	0.56	--	--	--

Appendix 6. Analyses for dissolved gases in groundwater samples from wells at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.
[USGS, U.S. Geological Survey]

USGS site-identification number	Well identifier	Sample date	Sample time (24 hour)	Water tempera- ture, field (degrees Celsius)	Dissolved gas concentration, in milligrams per liter							
					Argon (Ar)		Carbon dioxide (CO ₂)		Methane (CH ₄)		Nitrogen (N ₂)	
					Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
433615110436001	JH-1	6/8/2011	1200	9.4	0.6738	0.0267	3.6538	0.2023	0.0000	0.0000	19.1720	1.4406
433604110443401	JH-1.5	6/10/2011	1030	11	0.5630	0.0048	33.9014	0.5036	11.9555	0.2846	14.2260	0.1934
433604110443402	JH-1.5D	6/10/2011	1150	9.9	0.5928	0.0015	10.6211	0.1179	5.8280	0.0396	15.7265	0.0584
433551110443501	JH-2	6/8/2011	1710	11	0.7336	0.0040	19.9980	0.1163	0.0000	0.0000	20.9006	0.1609
433600110443701	JH-2.5	6/9/2011	1500	9.3	0.6808	0.0027	16.3661	0.0619	2.0054	0.0120	19.8330	0.0048
433603110443501	JH-3	6/9/2011	1830	9.7	0.5868	0.0040	20.7174	0.0346	9.6526	0.1694	15.3105	0.2210
433603110443502	JH-3D	6/9/2011	2030	9	0.5976	0.0015	9.9704	0.2915	6.4712	0.0425	15.8017	0.0316
433605110443801	JH-3.5	6/9/2011	1000	9.3	0.6866	0.0015	6.5377	0.0686	0.3651	0.0002	20.3519	0.0487
433605110443801	JH-3.5 ¹	6/9/2011	1001	9.3	0.6868	0.0009	6.5348	0.0426	0.3636	0.0120	20.3770	0.0521
433613110443501	JH-4	6/8/2011	1500	10.8	0.6522	0.0011	3.9602	0.1124	0.0000	0.0000	18.3121	0.0078

¹Replicate sample.

Appendix 7. Analytical results for volatile organic compounds, gasoline-range organics, and diesel-range organics in groundwater samples from wells and a surface-water sample from irrigation ditch at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; $\mu\text{g/L}$, micrograms per liter; --, not analyzed; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, value is less than the reporting level, but equal to or greater than the method detection limit; **Bold** value indicates that compound was detected, but was attributed to sample contamination; DRO, diesel-range organics; $\text{C}_{10}\text{-C}_{60}$, range of carbon compounds included in the analysis]

[illegible]

Appendix 7. Analytical results for volatile organic compounds, gasoline-range organics, and diesel-range organics in groundwater samples from wells and a surface-water sample from irrigation ditch at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; -, not analyzed; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, value is less than the reporting level, but equal to or greater than the method detection limit; **Bold** value indicates that compound was detected, but was attributed to sample contamination; DRO, diesel-range organics; C₁₀-C₃₀, range of carbon compounds included in the analysis]

[illegible]

Appendix 7. Analytical results for volatile organic compounds, gasoline-range organics, and diesel-range organics in groundwater samples from wells and a surface-water sample from irrigation ditch at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; $\mu\text{g/L}$, micrograms per liter; --, not analyzed; <, less than symbol indicates compound was not detected less than symbol indicates the value following the less than symbol is the laboratory reporting level; E, value is less than the reporting level, but equal to or greater than the method detection limit; **Bold** value indicates that compound was detected, but was attributed to sample contamination; DRO, diesel-range organics; $\text{C}_{10}\text{-C}_{30}$, range of carbon compounds included in the analysis]

[illegible]

Appendix 7. Analytical results for volatile organic compounds, gasoline-range organics, and diesel-range organics in groundwater samples from wells and a surface-water sample from irrigation ditch at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; --, not analyzed; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, value is less than the reporting level, but equal to or greater than the method detection limit; **Bold** value indicates that compound was detected, but was attributed to sample contamination; DRO, diesel-range organics; C₁₀-C₄₀, range of carbon compounds included in the analysis]

USGS site-identification number	Well or site identifier	Date	Time (24 hour)	Benzene (µg/L)	Bromo- benzene (µg/L)	Bromo- chloro- methane (µg/L)	Bromo- dichloro- methane (µg/L)	Chloro- benzene (µg/L)	Chloro- ethane (µg/L)	Chloro- methane (µg/L)	cis-1,2- Dichloro- ethene (µg/L)	Dibromo- chloro- methane (µg/L)
Groundwater-quality data												
433615110440001	JH-1	06/08/2011	1200	--	--	--	--	--	--	--	--	--
	JH-1	07/19/2011	1030	--	--	--	--	--	--	--	--	--
	JH-1	04/03/2012	1030	--	--	--	--	--	--	--	--	--
433604110443401	JH-1.5	06/10/2011	1030	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
	JH-1.5	07/20/2011	1800	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
433604110443403	JH-1.5R	04/04/2012	1820	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
433604110443403	JH-1.5D	06/10/2011	1150	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
	JH-1.5D	07/20/2011	1930	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
	JH-1.5D	04/05/2012	1020	E0.09	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
433551110443501	JH-2	06/08/2011	1710	--	--	--	--	--	--	--	--	--
	JH-2	07/19/2011	1530	--	--	--	--	--	--	--	--	--
	JH-2	04/03/2012	1530	--	--	--	--	--	--	--	--	--
433600110443701	JH-2.5	06/09/2011	1500	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
	JH-2.5	07/21/2011	1100	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
	JH-2.5	04/04/2012	0950	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
433603110443501	JH-3	06/09/2011	1830	--	--	--	--	--	--	--	--	--
	JH-3	07/20/2011	1100	--	--	--	--	--	--	--	--	--
	JH-3	04/04/2012	1250	--	--	--	--	--	--	--	--	--
433603110443502	JH-3D	06/09/2011	2030	--	--	--	--	--	--	--	--	--
	JH-3D	07/20/2011	1300	--	--	--	--	--	--	--	--	--
	JH-3D	04/04/2012	1450	--	--	--	--	--	--	--	--	--
433605110443801	JH-3.5	06/09/2011	1000	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
	JH-3.5	07/21/2011	1430	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
433613110443501	JH-4	06/08/2011	1500	--	--	--	--	--	--	--	--	--
	JH-4	07/19/2011	1300	--	--	--	--	--	--	--	--	--
	JH-4	04/03/2012	1300	--	--	--	--	--	--	--	--	--
433553110443601	Irrigation ditch	06/08/2011	1840	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50
Quality-control data												
433605110443801	² JH-3.5	06/09/2011	1001	<0.50	<0.50	<0.50	<1.0	<0.50	<1.0	<0.50	<0.50	<0.50

Appendix 7. Analytical results for volatile organic compounds, gasoline-range organics, and diesel-range organics in groundwater samples from wells and a surface-water sample from irrigation ditch at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; --, not analyzed; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, value is less than the reporting level, but equal to or greater than the method detection limit; **Bold** value indicates that compound was detected, but was attributed to sample contamination; DRO, diesel-range organics; C₁₀-C₃₆, range of carbon compounds included in the analysis]

USGS site-identification number	Well or site identifier	Date	Time (24 hour)	Dibromo-methane (µg/L)	Dichloro-difluoro-methane (µg/L)	DRO C ₁₀ -C ₃₆ (mg/L)	Ethyl-benzene (µg/L)	Gasoline-range organics (µg/L)	Hexachloro-butadiene (µg/L)	Isopropyl-benzene (µg/L)	Methylene chloride (µg/L)	Methyl tert-butyl ether (µg/L)
Groundwater-quality data												
433615110440001	JH-1	06/08/2011	1200	--	--	<0.50	--	--	--	--	--	--
	JH-1	07/19/2011	1030	--	--	<0.51	--	--	--	--	--	--
	JH-1	04/03/2012	1030	--	--	<0.50	--	--	--	--	--	--
433604110443401	JH-1.5	06/10/2011	1030	<0.50	<0.50	<0.52	<0.50	<25	<0.50	<0.50	<0.50	<0.50
	JH-1.5	07/20/2011	1800	<0.50	<0.50	<0.55	<0.50	E11	<0.50	<0.50	<0.50	<0.50
433604110443403	JH-1.5R	04/04/2012	1820	<0.50	<0.50	<0.52	<0.50	<25	<0.50	<0.50	<0.50	<0.50
433604110443403	JH-1.5D	06/10/2011	1150	<0.50	<0.50	<0.53	<0.50	<25	<0.50	<0.50	<0.50	<0.50
	JH-1.5D	07/20/2011	1930	<0.50	<0.50	<0.54	<0.50	<25	<0.50	<0.50	<0.50	<0.50
	JH-1.5D	04/05/2012	1020	<0.50	<0.50	<0.54	<0.50	<25	<0.50	<0.50	<0.50	<0.50
433551110443501	JH-2	06/08/2011	1710	--	--	<0.51	--	--	--	--	--	--
	JH-2	07/19/2011	1530	--	--	<0.51	--	--	--	--	--	--
	JH-2	04/03/2012	1530	--	--	<0.53	--	--	--	--	--	--
433600110443701	JH-2.5	06/09/2011	1500	<0.50	<0.50	<0.53	E0.11	<25	<0.50	<0.50	<0.50	<0.50
	JH-2.5	07/21/2011	1100	<0.50	<0.50	<0.52	<0.50	<25	<0.50	<0.50	<0.50	<0.50
	JH-2.5	04/04/2012	0950	<0.50	<0.50	<0.52	<0.50	<25	<0.50	<0.50	<0.50	<0.50
433603110443501	JH-3	06/09/2011	1830	--	--	<0.51	--	--	--	--	--	--
	JH-3	07/20/2011	1100	--	--	<0.52	--	--	--	--	--	--
	JH-3	04/04/2012	1250	--	--	<0.49	--	--	--	--	--	--
433603110443502	JH-3D	06/09/2011	2030	--	--	<0.52	--	--	--	--	--	--
	JH-3D	07/20/2011	1300	--	--	<0.52	--	--	--	--	--	--
	JH-3D	04/04/2012	1450	--	--	<0.52	--	--	--	--	--	--
433605110443801	JH-3.5	06/09/2011	1000	<0.50	<0.50	<0.53	<0.50	<25	<0.50	<0.50	<0.50	<0.50
	JH-3.5	07/21/2011	1430	<0.50	<0.50	<0.50	<0.50	<25	<0.50	<0.50	<0.50	<0.50
433613110443501	JH-4	06/08/2011	1500	--	--	<0.52	--	--	--	--	--	--
	JH-4	07/19/2011	1300	--	--	<0.53	--	--	--	--	--	--
	JH-4	04/03/2012	1300	--	--	<0.50	--	--	--	--	--	--
433553110443601	Irrigation ditch	06/08/2011	1840	<0.50	<0.50	<0.50	<0.50	<25	<0.50	<0.50	<0.50	<0.50
Quality-control data												
433605110443801	² JH-3.5	06/09/2011	1001	<0.50	<0.50	<0.53	<0.50	<25	<0.50	<0.50	<0.50	<0.50

Appendix 7. Analytical results for volatile organic compounds, gasoline-range organics, and diesel-range organics in groundwater samples from wells and a surface-water sample from irrigation ditch at the Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.—Continued

[All samples for analysis of volatile organic compounds were unfiltered. USGS, U.S. Geological Survey; µg/L, micrograms per liter; --, not analyzed; <, less than symbol indicates compound was not detected and the value following the less than symbol is the laboratory reporting level; E, value is less than the reporting level, but equal to or greater than the method detection limit; **Bold** value indicates that compound was detected, but was attributed to sample contamination; DRO, diesel-range organics; C₁₀-C₃₆, range of carbon compounds included in the analysis]

USGS site-identification number	Well or site identifier	Date	Time (24 hour)	Tetra- chloro- ethene (µg/L)	Carbon tetra- chloride (µg/L)	Toluene (µg/L)	trans-1,2- Dichloro- ethene (µg/L)	Bromoform (µg/L)	Trichloro- ethene (µg/L)	Trichloro fluoro methane (µg/L)	Chloro- form (µg/L)	Trihalo- methanes (µg/L)	Vinyl chloride (µg/L)	Xylene, total (µg/L)
Groundwater-quality data														
433615110440001	JH-1	06/08/2011	1200	--	--	--	--	--	--	--	--	--	--	--
	JH-1	07/19/2011	1030	--	--	--	--	--	--	--	--	--	--	--
	JH-1	04/03/2012	1030	--	--	--	--	--	--	--	--	--	--	--
433604110443401	JH-1.5	06/10/2011	1030	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
	JH-1.5	07/20/2011	1800	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
433604110443403	JH-1.5R	04/04/2012	1820	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
433604110443403	JH-1.5D	06/10/2011	1150	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
	JH-1.5D	07/20/2011	1930	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
	JH-1.5D	04/05/2012	1020	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
433551110443501	JH-2	06/08/2011	1710	--	--	--	--	--	--	--	--	--	--	--
	JH-2	07/19/2011	1530	--	--	--	--	--	--	--	--	--	--	--
	JH-2	04/03/2012	1530	--	--	--	--	--	--	--	--	--	--	--
433600110443701	JH-2.5	06/09/2011	1500	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	E0.26
	JH-2.5	07/21/2011	1100	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	E0.20
	JH-2.5	04/04/2012	0950	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
433603110443501	JH-3	06/09/2011	1830	--	--	--	--	--	--	--	--	--	--	--
	JH-3	07/20/2011	1100	--	--	--	--	--	--	--	--	--	--	--
	JH-3	04/04/2012	1250	--	--	--	--	--	--	--	--	--	--	--
433603110443502	JH-3D	06/09/2011	2030	--	--	--	--	--	--	--	--	--	--	--
	JH-3D	07/20/2011	1300	--	--	--	--	--	--	--	--	--	--	--
	JH-3D	04/04/2012	1450	--	--	--	--	--	--	--	--	--	--	--
433605110443801	JH-3.5	06/09/2011	1000	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
	JH-3.5	07/21/2011	1430	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
433613110443501	JH-4	06/08/2011	1500	--	--	--	--	--	--	--	--	--	--	--
	JH-4	07/19/2011	1300	--	--	--	--	--	--	--	--	--	--	--
	JH-4	04/03/2012	1300	--	--	--	--	--	--	--	--	--	--	--
433553110443601	Irrigation ditch	06/08/2011	1840	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50
Quality-control data														
433605110443801	² JH-3.5	06/09/2011	1001	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<1.6	<0.50	<0.50

¹Quantified concentration in the environmental sample is less than five times the maximum concentration in a blank sample.

²Replicate sample.

Appendix 8. Analytical results for triazoles in groundwater samples from wells and a surface-water sample from irrigation ditch at Jackson Hole Airport, Jackson, Wyoming, water years 2011 and 2012.

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; <, less than symbol indicates the chemical was not detected and the value following the less than symbol is the limit of detection; E, estimated concentration; **Bold** value indicates constituent was detected above the limit of quantitation; --, not applicable]

USGS site-identification number	Well or site identifier	Date	Time	Benzotriazole (µg/L)	4-Methyl-1- <i>H</i> - Benzotriazole (µg/L)	5-Methyl-1- <i>H</i> - Benzotriazole (µg/L)
433615110440001	JH-1	06/08/2011	1200	<0.25	<0.35	<0.25
		07/19/2011	1030	<0.25	<0.35	<0.25
		11/01/2011	1100	<0.25	<0.35	<0.25
		04/03/2012	1030	<0.25	<0.35	<0.25
433604110443401	JH-1.5	06/10/2011	1030	<0.25	2.1	² E0.33
		07/20/2011	1800	<0.25	1.6	² E0.27
433604110443403	JH-1.5R	11/02/2011	1730	<0.25	13	² E0.68
		04/04/2012	1820	<0.25	8.5	² E0.33
433604110443402	JH-1.5D	06/10/2011	1150	<0.25	2.2	² E0.33
		07/20/2011	1930	<0.25	2.4	² E0.33
		11/03/2011	1300	<0.25	9.8	² E0.77
		04/05/2012	1020	<0.25	8.1	² E0.40
433551110443501	JH-2	06/08/2011	1710	<0.25	<0.35	<0.25
		07/19/2011	1530	<0.25	<0.35	<0.25
		11/01/2011	1510	<0.25	<0.35	<0.25
		04/03/2012	1530	<0.25	<0.35	<0.25
433600110443701	JH-2.5	06/09/2011	1500	<0.25	4.3	² E0.43
		07/21/2011	1100	<0.25	3.7	² E0.32
		11/03/2011	1430	<0.25	7.8	² E0.72
		04/04/2012	0950	<0.25	8.5	² E0.26
433603110443501	JH-3	06/09/2011	1830	<0.25	2.0	² E0.39
		07/20/2011	1100	<0.25	1.8	² E0.41
		11/02/2011	1350	<0.25	8.1	² E0.61
		04/04/2012	1250	<0.25	8.7	² E0.52
433603110443502	JH-3D	06/09/2011	2030	<0.25	1.1	² E0.28
		07/20/2011	1300	<0.25	1.1	² E0.26
		11/02/2011	1510	<0.25	2.1	² E0.27
		04/04/2012	1450	<0.25	3.0	² E0.31
433605110443801	JH-3.5	06/09/2011	1000	<0.25	<0.35	<0.25
		07/21/2011	1430	<0.25	E0.37	<0.25
		11/02/2011	1110	<0.25	1.2	² E0.28
		April 2012	--	No sample	No sample	No sample
433613110443501	JH-4	06/08/2011	1500	<0.25	<0.35	<0.25
		07/19/2011	1300	<0.25	<0.35	<0.25
		11/01/2011	1330	<0.25	<0.35	<0.25
		04/03/12	1300	<0.25	<0.35	<0.25
433553110443601	Irrigation ditch	06/08/2011	1840	<0.25	<0.35	<0.25
Quality assurance samples						
433600110443501	¹ JH-2.5	06/09/2011	1300	<0.25	<0.35	<0.25
433605110443801	² JH-3.5	06/09/2011	1001	<0.25	<0.35	<0.25
433600110443501	¹ JH-2.5	07/21/2011	0900	<0.25	<0.35	<0.25
433605110443801	² JH-3.5	07/21/2011	1431	<0.25	<0.35	<0.25
433600110443501	² JH-2.5	11/03/2011	1431	<0.25	7.9	² E0.57
433604110443403	¹ JH-1.5R	04/04/2012	1630	<0.25	<0.35	<0.25
433604110443402	² JH-1.5D	04/05/2012	1021	<0.25	8.2	² E0.54

¹Field blank.

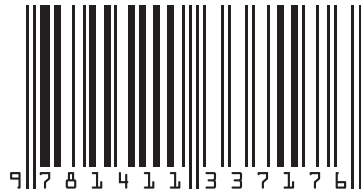
²Replicate sample.

Publishing support provided by:
Rolla and Denver Publishing Service Centers

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<http://wy.water.usgs.gov/>

ISBN 978-1-4113-3717-6



ISSN 2328-031X (print)

ISSN 2328-0328 (online)

<http://dx.doi.org/10.3133/sir20135184>