Prepared in cooperation with the Washington County Water Conservancy District

Assessment of Managed Aquifer Recharge at Sand Hollow Reservoir, Washington County, Utah, Updated to Conditions through 2014

Open-File Report 2016–1078

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

Cover photograph: View of Sand Hollow Reservoir looking north towards the town of Hurricane, Utah. Photo by Tom M. Marston, April 2015.

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By Thomas M. Marston and Victor M. Heilweil

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

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Conversion Factors, Datums, and Abbreviated Water-Quality Units

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per foot (ft/ft)	0.3048	meter per meter (m/m)

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

°F=(1.8×°C)+32

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

°C=(°F–32)/1.8

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

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

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).

Total dissolved-gas pressure is reported in millimeters of mercury (mm Hg), where 760 mm Hg equals one atmosphere.

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

Stable isotope (oxygen and deuterium) concentrations are reported as permil, which is equivalent to parts per thousand.

Tritium units (TU) are used to report tritium concentration, where 1 TU equals tritium concentration in picoCuries per liter divided by 3.22.

Chlorofluorocarbon (CFC) concentrations are reported as picomoles per kilogram (pmol/kg).

Sulfur hexafluoride (SF_6) concentrations are reported as femtomoles per kilogram (fmol/kg).

Acronyms and Abbreviations

CFCs	chlorofluorocarbons
Cl/Br	chloride to bromide ratio
DO	dissolved oxygen
DOC	dissolved organic carbon
MAR	managed aquifer recharge
NRCS	Natural Resources Conservation Service
SCAN	Soil Climate Analysis Network
TDG	total dissolved gas
USGS	U.S. Geological Survey
WCWCD	Washington County Water Conservancy District
WD	water district

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Abstract

Sand Hollow Reservoir in Washington County, Utah, was completed in March 2002 and is operated primarily for managed aquifer recharge by the Washington County Water Conservancy District. From 2002 through 2014, diversions of about 216,000 acre-feet from the Virgin River to Sand Hollow Reservoir have allowed the reservoir to remain nearly full since 2006. Groundwater levels in monitoring wells near the reservoir rose through 2006 and have fluctuated more recently because of variations in reservoir stage and nearby pumping from production wells. Between 2004 and 2014, about 29,000 acre-feet of groundwater was withdrawn by these wells for municipal supply. In addition, about 31,000 acre-feet of shallow seepage was captured by French drains adjacent to the North and West Dams and used for municipal supply, irrigation, or returned to the reservoir. From 2002 through 2014, about 127,000 acre-feet of water seeped beneath the reservoir to recharge the underlying Navajo Sandstone aquifer.

Water quality continued to be monitored at various wells in Sand Hollow during 2013–14 to evaluate the timing and location of reservoir recharge as it moved through the aquifer. Changing geochemical conditions at monitoring wells WD 4 and WD 12 indicate rising groundwater levels and mobilization of vadose-zone salts, which could be a precursor to the arrival of reservoir recharge.

Introduction

Sand Hollow Reservoir (fig. 1) in Washington County, Utah, was completed in March 2002 and is operated primarily for managed aquifer recharge (MAR) by the Washington County Water Conservancy District (WCWCD). The reservoir is an off-channel facility that receives water diverted from the Virgin River near the town of Virgin, Utah. Sand Hollow has been the subject of interdisciplinary, cooperative investigations of groundwater hydrology and geochemistry since 1999. Previous Sand Hollow reports document pre-reservoir vadose-zone and groundwater conditions prior to March 2002 (Heilweil and Solomon, 2004; Heilweil and others, 2006; Heilweil and others, 2007; Heilweil and McKinney, 2007; Heilweil and others, 2009b), pond and trench infiltration studies adjacent to the reservoir (Heilweil and others, 2004; Heilweil and Watt, 2011), and post-reservoir groundwater conditions, water budgets, and estimates of groundwater recharge from the reservoir from March 2002 through December 2012 (Heilweil and others, 2005; Heilweil and Susong, 2007; Heilweil and others, 2009a; Heilweil and Marston, 2011; Marston and Heilweil, 2013). These reports also contain monitoring-well and production-well completion information, as well as historical water-quality and precipitation data. The objectives of this report are to present and interpret (1) groundwater levels, reservoir altitude, well withdrawals, drain discharge, meteorological data, reservoir water temperature, and inflows/outflows from March 2002 through December 2014 for estimating monthly amounts of MAR from Sand Hollow Reservoir to the Navajo Sandstone, and (2) groundwater and surface-water chemical data collected prior to the construction of the reservoir through April 2014 for evaluating groundwater flow paths and travel times of this MAR. This study is a cooperative effort by the WCWCD and the U.S. Geological Survey (USGS). Funding for this work was provided by both the USGS and the WCWCD.

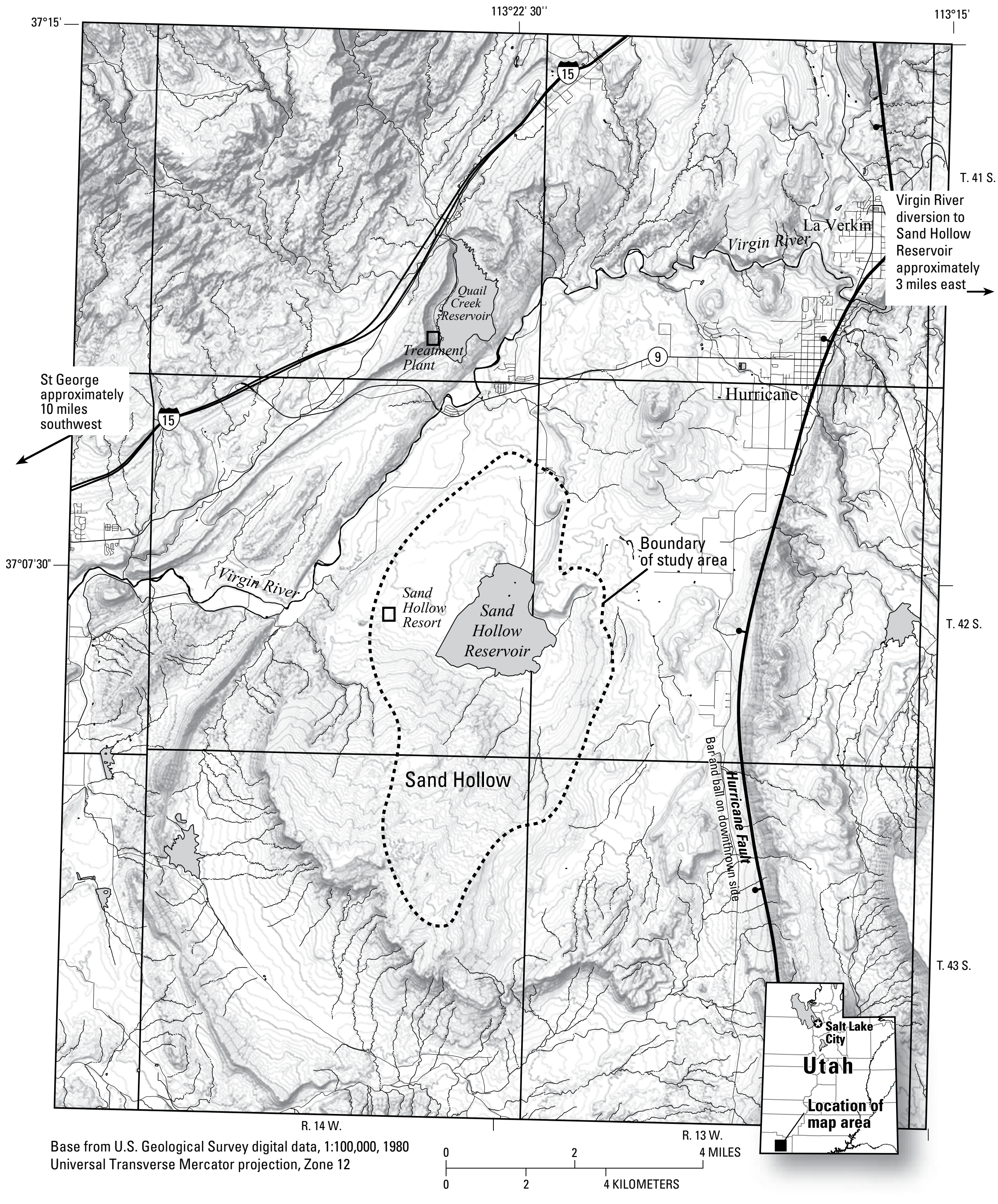


Figure 1. Location of the Sand Hollow study area, Washington County, Utah.

Assessment of Managed Aquifer Recharge from Sand Hollow Reservoir

Many different types of data have been collected to investigate recharge processes, quantify recharge from Sand Hollow Reservoir, and to evaluate hydraulic and geochemical changes in the underlying Navajo Sandstone aquifer (Navajo aquifer). These data include production-well withdrawals near the reservoir, amounts of pumpage from drains capturing shallow groundwater discharge adjacent to the reservoir, reservoir and monitoring-well water levels, inflows and outflows through the pipeline connecting Sand Hollow Reservoir with the Virgin River and Quail Creek Reservoir and treatment plant, meteorological parameters, and reservoir water temperatures (fig. 1).

Data Collection Methods and Results

Data collection methods are described in detail in Heilweil and others (2005) and briefly summarized in the following sections.

Production-Well Withdrawals

The WCWCD has 13 production wells completed in the Navajo Sandstone that are available to capture both preexisting groundwater (natural recharge) in Sand Hollow and recharge from Sand Hollow Reservoir (fig. 2). The WCWCD and other water users have withdrawn natural recharge in Sand Hollow for many years. The WCWCD groundwater withdrawals are recorded monthly from inline magnetic flow meters installed at each well. Since August 2004, monthly withdrawals by the WCWCD have generally exceeded 150 acre-feet (acre-ft), except for several months during the winters of 2004–05, 2005–06, 2008–09, and 2010 (fig. 3). The majority of this pumping was from wells 8 and 9 through late 2012 (fig. 3), both located adjacent to the North Dam. Starting in early 2013, some of the pumping has been shifted to wells 19, 21, and 23 (fig. 3). From 2004 through 2006, there were minimal withdrawals from these wells during the winter. Since 2006, withdrawals have been more constant yearround. Monthly withdrawals from production wells averaged about 250 acre-ft from March 2006 through December 2014. Smaller amounts have been sporadically withdrawn from wells 1, 2, and 17 (fig. 3). Approximately 29,000 acre-ft were pumped from the WCWCD production wells from January 2004 through December 2014 (fig. 3). Through 2014, withdrawals by the WCWCD at Sand Hollow have been permitted by the Utah Division of Water Rights as natural recharge in Sand Hollow. These withdrawals are governed by different water rights than recharge from Sand Hollow Reservoir; withdrawal rights for this artificial recharge have not yet been exercised.

Drain Discharge

Because of the steep gradients associated with the hydraulic connection between the reservoir and the underlying Navajo aquifer, some land-surface areas downgradient of the North and West Dams became saturated following construction of the reservoir. In response, three French drains (North Dam drain, West Dam drain, and West Dam Spring drain) were constructed for capturing this shallow groundwater (fig. 2). Timing of excavation and spatial dimensions for the three drains can be found in Heilweil and Marston (2011).

Amounts of discharge pumped from these drains are measured with a Tigermag totalizing flow meter (Sparling Instruments in El Monte, California). Discharge from the North Dam drain has been pumped relatively consistently since September 2003 (fig. 4); about 8,000 acre-ft were pumped from the North Dam drain between 2003 and 2014. Initially, all of this water was returned to the reservoir, but since 2007, the majority of the water has been used by Sand Hollow Resort (fig. 1) to meet irrigation demands. About 2,100 acre-ft of water were pumped from the West Dam drain back into the reservoir from 2005 through 2014. Beginning in October 2006, pumping of discharge from the West Dam Spring drain was initiated and has largely replaced the need for pumping of the West Dam drain. From 2006 through 2014, about 21,000 acre-ft were pumped from the West Dam Spring drain for municipal use or returned back to Sand Hollow Reservoir. Although drainage to the West Dam Spring drain likely does not vary greatly, pumping from this drain has been intermittent. The intermittent pumping schedule results in high variability in the monthly reported discharge from the West Dam Spring drain (fig. 4).

Groundwater-Level Data and Reservoir Altitude

Groundwater levels measured in an extensive monitoring-well network surrounding Sand Hollow Reservoir were used to document changes in the potentiometric surface associated with recharge from Sand Hollow Reservoir. The WCWCD measures water levels monthly in 20 monitoring wells completed in the Navajo Sandstone (fig. 2; the WD RJ monitoring well was removed in 2013). These wells were constructed with either 1- or 2-inch (in.) diameter PVC casing, with perforations along the bottom 5- to 20-foot (ft) length of the casing. Three locations have nested pairs of water district (WD) monitoring wells: WD 15 and WD 16, WD 17 and WD 18, and WD 19 and WD 20. The vertical distance between well screens for the nested-pair wells are 243 ft, 79 ft, and 227 ft, respectively. Water levels were measured by the WCWCD using electric-tape water-level indicators. Annual independent check measurements are performed by USGS personnel for quality assurance to ensure accurate and repeatable instrument measurements.

Daily reservoir water-level altitude (stage) was recorded from January 2005 through December 2014 by using a pressure transducer installed by the WCWCD in the reservoir

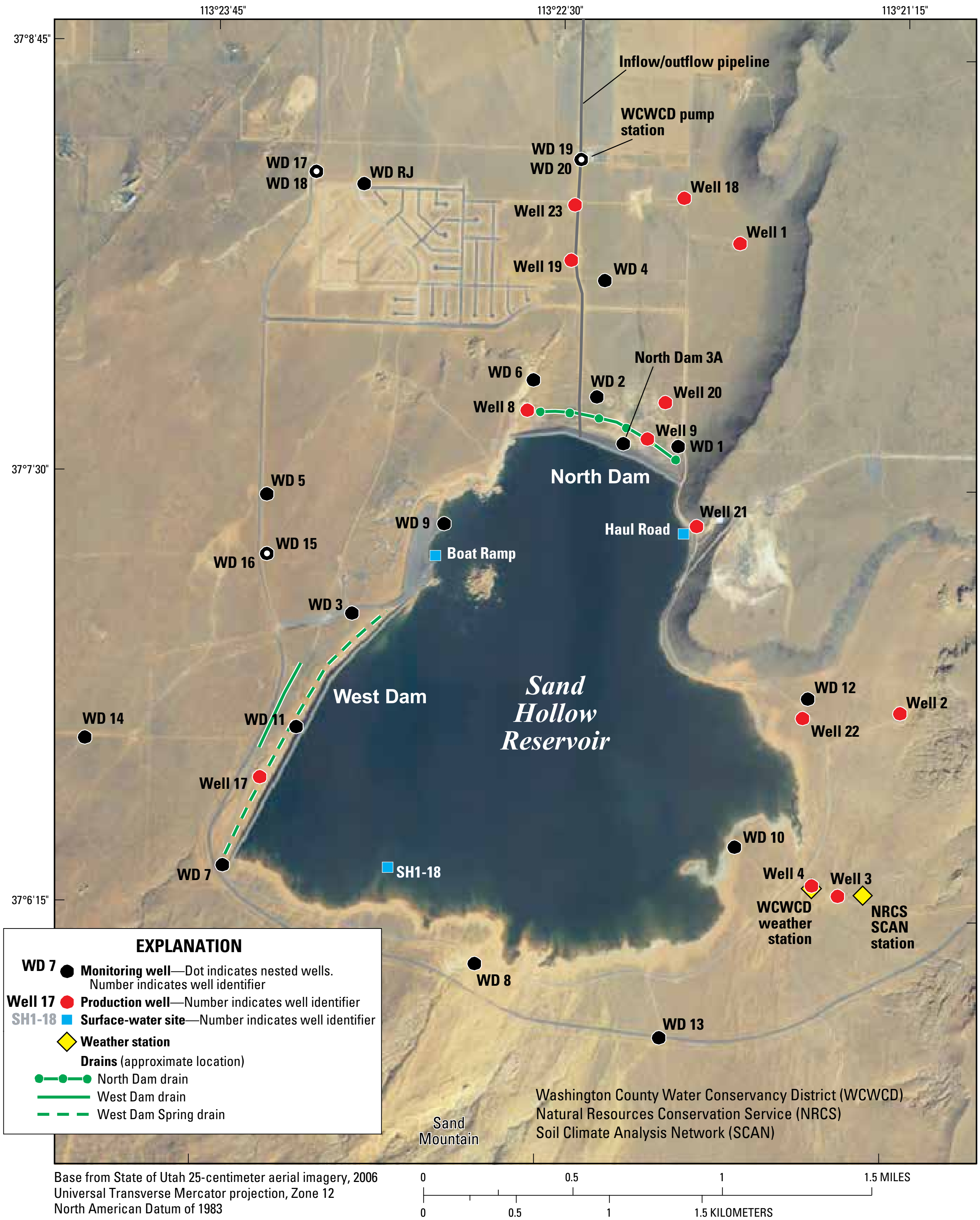


Figure 2. Location of monitoring and production wells, weather stations, drains, and reservoir sampling sites in Sand Hollow, Washington County, Utah.

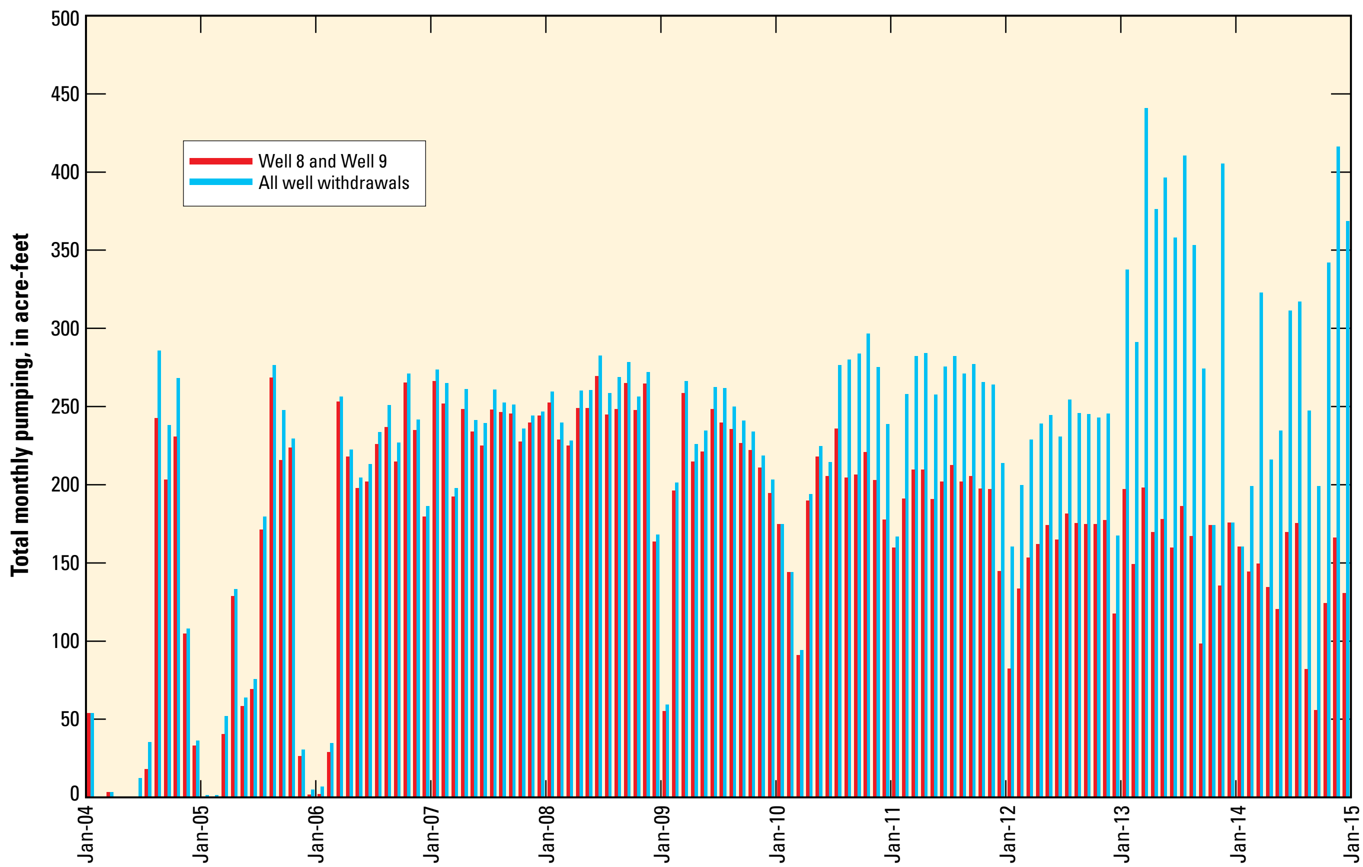


Figure 3. Washington County Water Conservancy District production-well withdrawals in Sand Hollow, Washington County, Utah, 2004–14.

along the North Dam. Because of periods of transducer malfunction from 2005 through 2007, and from August 2011 to December 2011, daily reservoir stage was interpolated on the basis of monthly measurements recorded at the boat ramp by WCWCD and Sand Hollow State Park personnel, and then correlated with trends from the transducer data.

Recently measured (January 2008 through December 2014) and previously reported (Heilweil and others, 2005; Heilweil and Susong, 2007; Heilweil and others, 2009; Heilweil and Marston, 2011; Marston and Heilweil, 2013) groundwater levels and reservoir water-level altitude are shown in figure 5. The reservoir stage rose from about 2,980 ft at the beginning of March 2002 to a maximum of about 3,060 ft in May 2006, when the reservoir was first filled to capacity. The reservoir altitude receded to about 3,040 ft in December 2007 as a result of reduced inflows and evaporative losses, and then fluctuated between about 3,040 and 3,060 ft from 2008 through 2011. From 2012 through 2014, the reservoir altitude dropped to a fluctuating level between 3,030 and 3,050 ft.

On the basis of water-level measurements in the 20 monitoring wells, altitude of the water table (or potentiometric surface) near Sand Hollow Reservoir during December 2014 ranged from 2,889 to 3,040 ft (fig. 6). The reservoir altitude during this same period was about 3,040 ft. The lines on figure 6 represent estimated potentiometric contours in the aquifer, which indicate lines of equal groundwater-level altitude, and the arrows indicate generalized directions of horizontal groundwater movement away from the reservoir. Horizontal hydraulic gradients, calculated by dividing the difference in water-level altitude between two points by the distance separating these locations, indicate the potential horizontal direction of groundwater movement. The steepest horizontal hydraulic gradients are beneath the North and West Dams and generally decline with increasing distance from the reservoir. The steep gradients beneath the dams are the combined result of low-conductivity materials at the core of the dams and pumping in wells and drains at the base of both dams. For example, the horizontal hydraulic gradient between Sand Hollow Reservoir (reservoir altitude of 3,040 ft) and WD 1 (groundwater-level altitude of 2,970 ft) in 2014 was 0.122 foot per foot (ft/ft), whereas the gradient between WD 6 (groundwater-level altitude of 2,958 ft) and WD 19 (2,898 ft) was 0.015 ft/ft. In 2014, the broader regional gradient between WD 9 (3,040-ft altitude) and WD 17 (2,918-ft altitude) was 0.019 ft/ft. In comparison, the hydraulic gradient between these same two wells in 2004 was 0.017 ft/ft (fig. 7 of Heilweil and others, 2005).

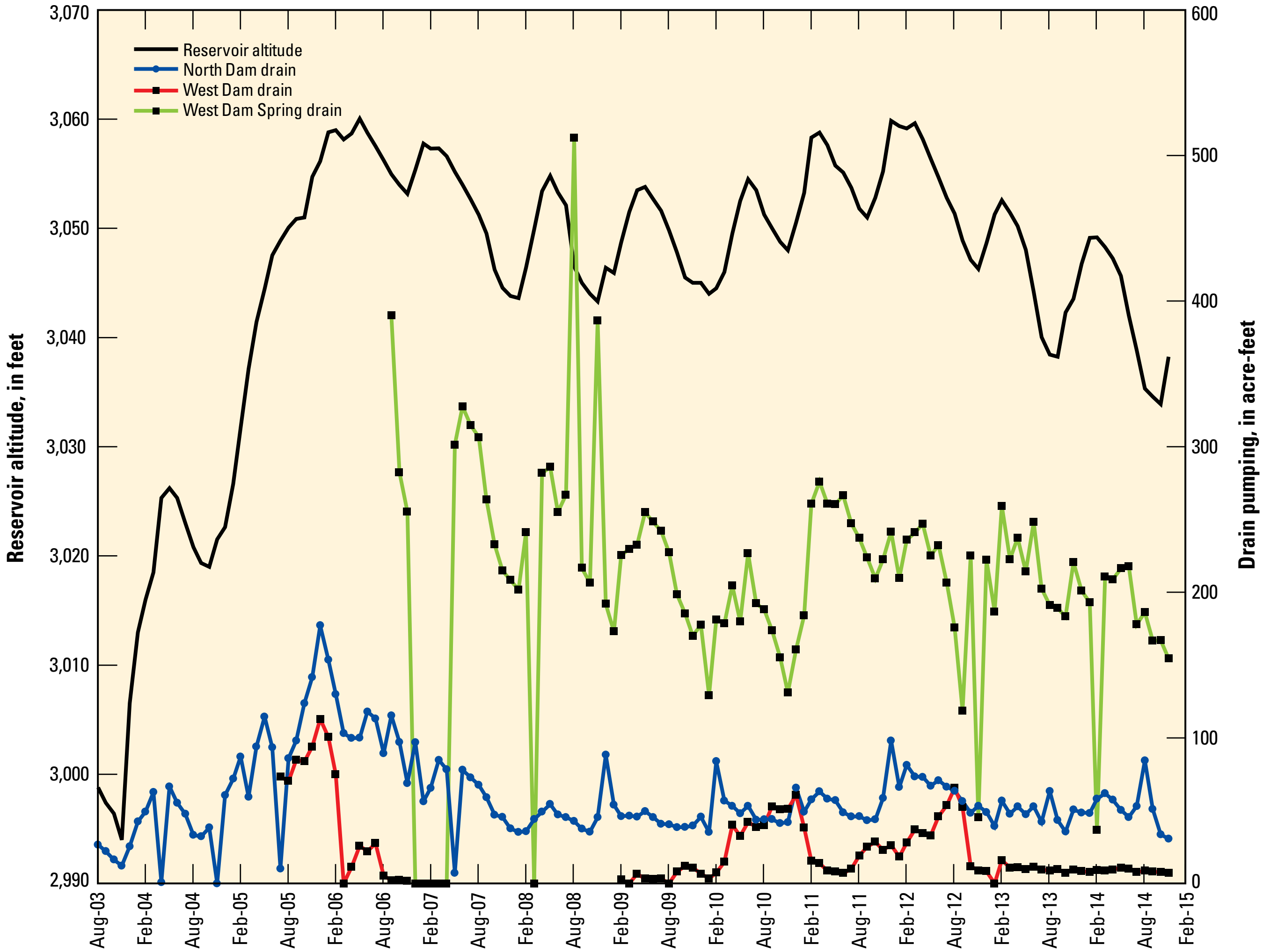


Figure 4. Monthly reported discharge from the North and West Dam drains, and West Dam Spring drain in relation to reservoir altitude, Sand Hollow, Washington County, Utah, 2003–14.

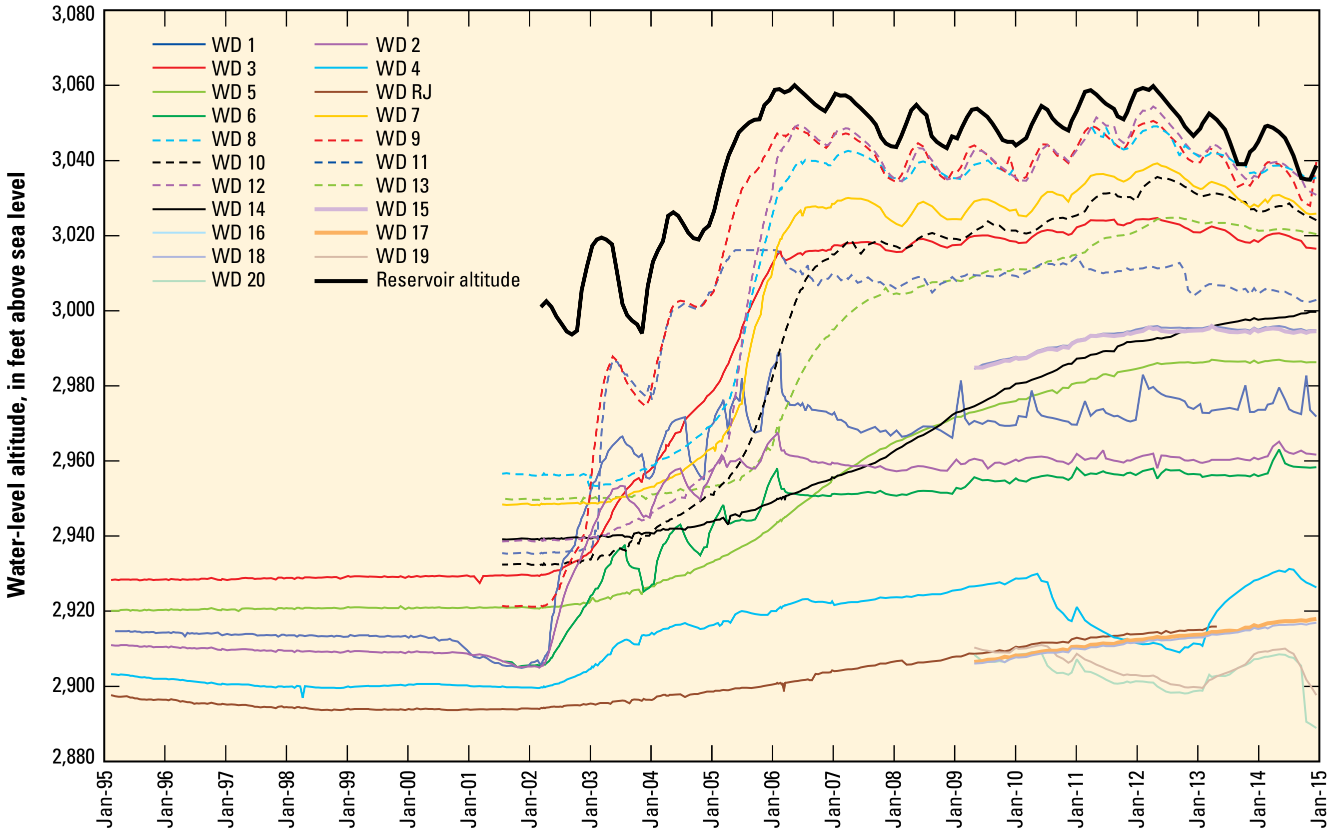
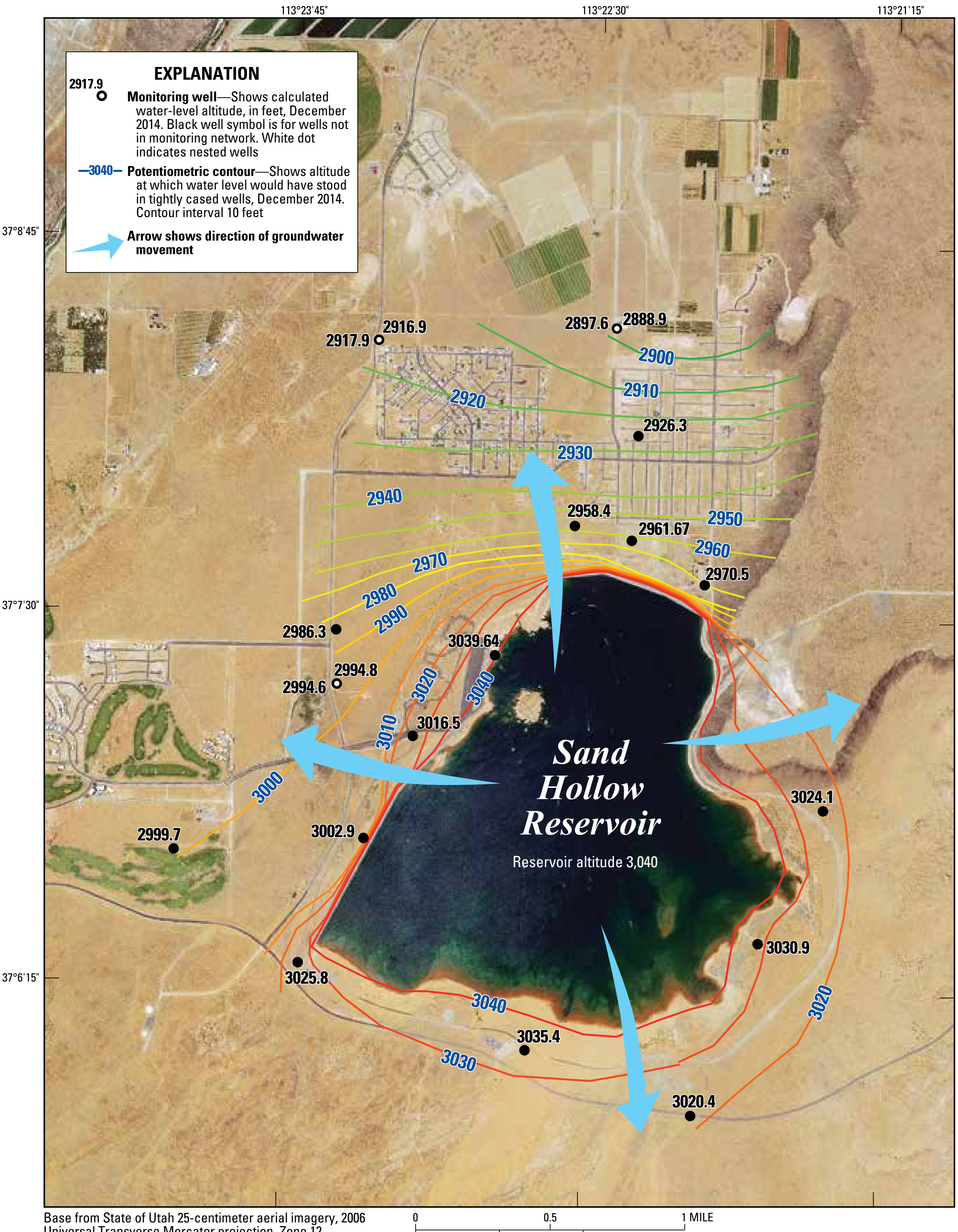


Figure 5. Water-level altitude in monitoring wells and Sand Hollow Reservoir altitude, Sand Hollow, Washington County, Utah, 1995–2014.



Base from State of Utah 25-centimeter aerial imagery, 2006
Universal Transverse Mercator projection, Zone 12
North American Datum of 1983

Figure 6. Potentiometric surface of the Navajo aquifer in December 2014, Sand Hollow, Washington County, Utah.

Surface-Water Inflow to and Outflow from Sand Hollow Reservoir

Surface water is pumped into and flows out of Sand Hollow Reservoir through a 60-in. diameter pipeline that enters through an inlet structure at the North Dam (fig. 2). This pipeline is part of a network of pipelines that connect the Virgin River, Sand Hollow Reservoir, Quail Creek Reservoir, and the Quail Creek Reservoir Water Treatment Facility. The WCWCD has the capability to move water within this network of pipelines by using gravity-induced flow and inline pumping. Sand Hollow Reservoir is currently managed to maximize groundwater recharge and little surface water has been removed from the reservoir. Monthly surface-water inflow to and outflow from Sand Hollow Reservoir is shown in table 1. The "Monthly pump station inflow or outflow" column in this table is the amount of Sand Hollow Reservoir surface water coming in from the Virgin River or going out to Quail Creek Reservoir, the Quail Creek Water Treatment Plant, or other facilities (fig. 1). These data were collected at the WCWCD pump station located about 1 mi north of the North Dam. Five pumps, each with Sparling Tigermag totalizing flow meters, are linked to a computer system that combines and records total daily discharge in gallons. The flow meters have electronic modules on which calibration diagnostics are performed monthly by the WCWCD. Each module is removed annually for factory recalibration.

The "Monthly drain and spring return flow to reservoir" column in table 1 is the portion of discharge to the three drains that is pumped back into Sand Hollow Reservoir. The "Monthly outflow to Sand Hollow Resort" column is the amount of water required by the resort that cannot be met by discharge to the North Dam drain and is fulfilled by outflow of stored water from Sand Hollow Reservoir. Therefore, the "Monthly total inflow or outflow to/from reservoir" column is a sum of the pump station inflow/outflow, the drain and spring return flow, and the outflow to Sand Hollow Resort (table 1).

The "Monthly pump station inflow or outflow" column is unchanged from Heilweil and Marston (2011) and is comparable to the "Total surface-water inflow or outflow" column in table 7 of Heilweil and others (2005) from March 2002 to August 2004, the "Monthly surface-water inflow or outflow" column in table 2 of Heilweil and Susong (2007) from September 2004 to August 2006, and the "Monthly net surface-water inflow/outflow" column in table 2 of Heilweil and others (2009) from September 2006 to December 2007.

As in Heilweil and Marston (2011), both "Monthly drain and spring return flow to reservoir" and "Monthly outflow to Sand Hollow Resort" are included in calculations of total inflow to and outflow from the reservoir. These amounts are added to the "Monthly pump station inflow or outflow" and summed in the "Monthly total inflow or outflow to/from reservoir" column. Monthly total inflow/outflow amounts from March 2002 through December 2014 range from about −5,000 acre-ft to 6,600 acre-ft. Approximately 216,000 acre-ft of total net inflow were pumped into Sand Hollow Reservoir from the Virgin River from 2002 through 2014.

Meteorological Data

Meteorological data have been collected at the WCWCD weather station (fig. 2) in Sand Hollow since January 1998. Beginning in 2010, a Soil Climate Analysis Network (SCAN) Sand Hollow weather station (*http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=2159*) operated by the Natural Resources Conservation Service (NRCS), replaced the collection of data by the WCWCD weather station. The NRCS Sand Hollow SCAN station is located south of the reservoir within Sand Hollow basin near the WCWCD station (fig. 2). Data from both weather stations have been used for evaluating evaporation and precipitation, which are required for calculating monthly recharge from Sand Hollow Reservoir. Parameters measured include air temperature, wind speed, wind direction, precipitation, relative humidity, and incoming solar radiation. Instrumentation includes a temperature and relative humidity probe, a wind direction and speed monitor, a tipping bucket rain gage, and a solar radiometer. Sensors collect data every minute, and average hourly and daily values are computed and stored on a data logger, with the exception of precipitation, which is summed rather than averaged. The solar radiation and temperature data were used for calculating evaporation by using the version of the Jenson-Haise method found in McGuinness and Bordne (1971). The other data were collected to permit calculations of evaporation using other methods.

From January 13, 1998, to December 30, 2014, daily average air temperature ranged from -10 to 37 degrees Celsius (°C). The coldest temperatures during the year were typically in December and January, when minimum air temperatures occasionally were below −10 °C. The warmest temperatures were typically in July, when maximum air temperatures occasionally approached 45 °C. Daily average solar radiation ranged from 34 to 840 calories per square centimeter per day. The minimum daily averages are typically in December and January, and the maximum daily averages are typically in June and July.

Monthly precipitation was recorded at the Sand Hollow weather station continuously from January 1998 through December 2011, except for two periods when malfunctioning instrumentation resulted in data loss: December 26, 2008, to January 3, 2009, and September 28 to November 16, 2009. Precipitation amounts during these two periods were estimated on the basis of data from the nearby St. George Southgate Golf Course weather station (#427516; *http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ut7516*). From January 1998 through December 2014, monthly precipitation ranged from 0 to about 4.3 in. (fig. 7) and averaged about 0.6 in. Average annual precipitation during the 14-year period was 7.4 in.

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Reservoir altitude (feet)	Reservoir storage (acre-feet)	Monthly pump station inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly drain and spring return flow to reservoir (acre-feet)	Monthly outflow (-) to Sand Hollow Resort (acre-feet)	Monthly total inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly reservoir storage change (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)[2]
Mar.–02	3,001	3,090	6,620	0	0	6,620	3,090	260	0.24
Apr.–02	3,003	3,500	3,690	0	0	3,690	410	280	0.46
May–02	3,001	3,090	2,450	0	0	2,450	-410	260	0.68
June–02	2,999	2,480	0	0	0	0	-610	230	0.91
July–02	2,997	2,050	0	0	0	0	-430	210	0.90
Aug.–02	2,995	1,650	0	0	0	0	-400	180	0.81
Sept.–02	2,994	1,300	0	0	0	0	-350	140	0.47
Oct.–02	2,995	1,500	790	0	0	790	200	160	0.26
Nov.–02	3,006	4,220	3,590	0	0	3,590	2,720	320	0.11
Dec.–02	3,012	7,000	3,930	0	0	3,930	2,780	400	0.05
Jan.–03	3,017	9,760	4,580	0	0	4,580	2,760	590	0.09
Feb.–03	3,019	10,670	2,850	0	0	2,850	910	570	0.10
Mar.–03	3,020	10,930	1,930	0	0	1,930	260	580	0.24
Apr.–03	3,019	10,680	540	0	0	540	-250	570	0.37
May–03	3,018	9,930	0	0	0	0	-750	540	0.66
June–03	3,010	6,040	-3,120	0	0	-3,120	-3,890	390	0.89
July–03	3,002	3,200	-2,020	0	0	-2,020	-2,840	240	0.92
Aug.–03	2,999	2,540	0	0	0	0	-660	230	0.75
Sept.–03	2,997	2,100	0	30	0	30	-440	220	0.58
Oct.–03	2,996	1,850	0	20	0	20	-250	170	0.36
Nov.–03	2,994	1,560	0	20	0	20	-290	200	0.09
Dec.–03	3,007	4,700	3,590	10	0	3,600	3,140	330	0.06
Jan.–04	3,013	7,600	3,990	30	0	4,020	2,900	480	0.06
Feb.–04	3,016	8,840	2,320	40	0	2,360	1,240	600	0.08
Mar.–04	3,019	10,400	2,400	50	0	2,450	1,560	630	0.38
Apr.–04	3,025	15,070	5,620	60	0	5,680	4,670	750	0.42
May–04	3,026	15,830	2,050	0	0	2,050	760	780	0.72
June–04	3,025	14,400	0	70	0	70	-1,430	750	0.87
July–04	3,023	13,000	0	60	0	60	-1,400	680	0.94
Aug.–04	3,021	11,670	0	50	0	50	-1,330	680	0.78
Sept.–04	3,019	11,260	[3]600	30	0	630	-410	630	0.53
Oct.–04	3,019	11,040	[3]630	30	0	660	-220	610	0.25
Nov.–04	3,022	12,650	[3]2,300	40	0	2,340	1,610	630	0.10
Dec.–04	3,023	13,390	[3]1,400	0	0	1,400	740	670	0.06
Jan.–05	3,027	16,200	[3]3,500	60	0	3,560	2,810	740	0.07
Feb.–05	3,032	20,280	[3]5,200	70	0	5,270	4,080	780	0.11
Mar.–05	3,037	25,030	6,530	90	0	6,620	4,750	880	0.24
Apr.–05	3,041	29,220	6,180	60	0	6,240	4,190	960	0.39
May–05	3,044	32,370	5,140	90	0	5,230	3,150	1,020	0.70
June–05	3,048	35,750	6,100	110	0	6,210	3,380	1,080	0.75
July–05	3,049	37,280	3,600	90	0	3,690	1,530	1,120	0.97
Aug.–05	3,050	38,670	3,390	80	0	3,470	1,390	1,140	0.75
Sept.–05	3,051	39,580	3,010	160	0	3,170	910	1,160	0.54

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.—Continued

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge (acre-feet)	Monthly groundwater recharge uncertainty, 2σ (percent)	Monthly groundwater recharge uncertainty, 2σ (acre-feet)	Groundwater recharge rate (feet/day)
Mar.–02	60	—	3,470	6.7	232	0.430
Apr.–02	130	—	3,150	5.9	187	0.383
May–02	180	—	2,680	6.6	176	0.330
June–02	210	—	400	12.6	50	0.058
July–02	190	—	240	13.1	31	0.040
Aug.–02	150	—	250	12.7	32	0.044
Sept.–02	70	—	280	11.7	33	0.070
Oct.–02	40	—	550	6.6	36	0.110
Nov.–02	30	—	840	7.2	61	0.090
Dec.–02	20	—	1,130	7.1	80	0.090
Jan.–03	50	—	1,770	7.0	123	0.097
Feb.–03	60	—	1,880	6.4	121	0.118
Mar.–03	140	—	1,530	6.5	99	0.085
Apr.–03	210	—	580	9.4	55	0.034
May–03	360	—	390	13.2	52	0.023
June–03	350	—	420	8.4	35	0.036
July–03	220	—	600	8.4	51	0.081
Aug.–03	170	—	490	12.0	59	0.069
Sept.–03	130	—	340	12.3	42	0.052
Oct.–03	60	—	210	11.9	25	0.040
Nov.–03	20	—	290	10.6	31	0.048
Dec.–03	20	—	440	7.4	32	0.043
Jan.–04	30	—	1,090	7.2	78	0.073
Feb.–04	40	—	1,080	6.9	74	0.064
Mar.–04	240	—	650	7.7	50	0.033
Apr.–04	310	—	700	7.6	53	0.031
May–04	560	—	730	8.6	63	0.030
June–04	650	—	850	13.1	112	0.038
July–04	640	—	820	13.1	108	0.039
Aug.–04	530	—	850	12.8	109	0.040
Sept.–04	330	—	710	10.2	73	0.038
Oct.–04	150	—	730	8.4	61	0.039
Nov.–04	70	—	660	7.3	48	0.035
Dec.–04	40	—	620	7.0	43	0.030
Jan.–05	50	—	700	7.3	51	0.031
Feb.–05	80	130	1,240	7.3	91	0.057
Mar.–05	210	100	1,760	7.4	130	0.065
Apr.–05	370	130	1,810	7.5	136	0.063
May–05	710	40	1,410	7.9	112	0.045
June–05	810	20	2,040	7.8	160	0.063
July–05	1,080	10	1,090	8.8	96	0.031
Aug.–05	850	40	1,270	8.5	108	0.036
Sept.–05	630	20	1,650	8.1	133	0.047

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.—Continued

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Reservoir altitude (feet)	Reservoir storage (acre-feet)	Monthly pump station inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly drain and spring return flow to reservoir (acre-feet)	Monthly outflow (-) to Sand Hollow Resort (acre-feet)	Monthly total inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly reservoir storage change (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)[2]
Oct.–05	[4]3,052	[4]40,960	2,960	180	0	3,140	[4]1,380	[4]1,190	0.28
Nov.–05	3,055	44,310	5,160	210	0	5,370	[4]3,350	1,230	0.11
Dec.–05	3,056	46,120	3,380	240	0	3,620	1,810	1,250	0.05
Jan.–06	3,059	49,590	4,660	290	0	4,950	3,470	1,290	0.08
Feb.–06	3,059	49,840	1,200	250	0	1,450	250	1,320	0.12
Mar.–06	3,058	48,700	60	210	0	270	-1,140	1,310	0.18
Apr.–06	3,059	49,450	2,060	100	0	2,160	750	1,300	0.45
May–06	3,060	51,280	3,650	110	0	3,760	1,830	1,320	0.76
June–06	3,059	49,520	10	130	0	140	-1,760	1,330	0.92
July–06	3,058	47,920	30	140	0	170	-1,600	1,310	0.88
Aug.–06	3,056	46,220	0	140	0	140	-1,700	1,280	0.80
Sept.–06	3,055	44,610	10	90	0	100	-1,610	1,260	0.52
Oct.–06	3,054	43,390	30	120	0	150	-1,220	1,230	0.22
Nov.–06	3,053	42,360	0	100	0	100	-1,030	1,220	0.07
Dec.–06	3,055	45,100	4,430	70	0	4,500	2,740	1,230	0.04
Jan.–07	3,058	48,230	4,190	100	0	4,290	3,130	1,270	0.05
Feb.–07	3,057	47,630	30	60	0	90	-600	1,290	0.13
Mar.–07	3,057	47,660	1,210	70	0	1,280	30	1,290	0.33
Apr.–07	3,057	46,720	50	80	0	130	-940	1,280	0.45
May–07	3,055	44,880	0	0	-110	-110	-1,840	1,220	0.74
June–07	3,054	43,390	0	0	-220	-220	-1,490	1,240	0.93
July–07	3,053	41,740	120	0	-200	-80	-1,650	1,210	0.92
Aug.–07	3,051	40,040	60	0	-210	-150	-1,700	1,180	0.81
Sept.–07	3,050	38,040	[5]-750	0	-210	[6]-910	-2,000	1,160	0.57
Oct.–07	3,046	34,280	[5]-2,660	0	-120	[6]-2,780	-3,760	1,120	0.32
Nov.–07	3,045	32,480	[5]-750	0	-100	[6]-850	-1,800	1,060	0.16
Dec.–07	3,044	31,680	90	10	0	100	-800	1,040	0.05
Jan.–08	3,044	31,470	0	20	0	20	-210	1,030	0.06
Feb.–08	3,046	34,490	3,240	20	0	3,260	3,020	1,050	0.13
Mar.–08	3,050	38,460	4,420	0	-70	4,350	3,970	1,110	0.29
Apr.–08	3,053	42,670	4,950	0	-160	4,790	4,210	1,180	0.45
May–08	3,055	44,410	3,260	0	-120	3,140	1,740	1,230	0.61
June–08	3,053	42,540	0	0	-220	-220	-1,870	1,230	0.93
July–08	3,052	41,080	0	0	-180	-180	-1,460	1,180	0.95
Aug.–08	3,047	34,600	[7]-5,000	0	-180	-5,180	-6,480	1,140	0.82
Sept.–08	3,045	32,960	0	0	-140	-140	-1,640	1,070	0.61
Oct.–08	3,044	31,890	0	0	-70	-70	-1,070	1,050	0.36
Nov.–08	3,043	31,160	0	0	-10	-10	-730	1,040	0.16
Dec.–08	3,046	34,490	4,100	40	0	4,140	3,330	1,050	0.06
Jan.–09	3,046	33,830	0	70	0	70	-660	1,080	0.09
Feb.–09	3,049	37,770	4,630	50	0	4,680	3,940	1,110	0.14
Mar.–09	3,052	41,320	4,800	0	-30	4,770	3,550	1,190	0.30
Apr.–09	3,055	44,030	3,920	0	-70	3,850	2,710	1,220	0.44

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.—Continued

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge (acre-feet)	Monthly groundwater recharge uncertainty, 2σ (percent)	Monthly groundwater recharge uncertainty, 2σ (acre-feet)	Groundwater recharge rate (feet/day)
Oct.–05	[4]330	60	1,490	7.6	113	0.040
Nov.–05	140	40	1,920	7.2	138	0.052
Dec.–05	60	20	1,770	6.9	122	0.046
Jan.–06	100	10	1,390	7.3	101	0.035
Feb.–06	160	30	1,070	7.3	78	0.029
Mar.–06	240	60	1,230	11.4	140	0.030
Apr.–06	580	40	870	8.7	76	0.022
May–06	1,000	0	930	8.7	81	0.023
June–06	1,220	10	690	14.1	97	0.017
July–06	1,160	30	640	14.1	90	0.016
Aug.–06	1,020	0	820	13.8	113	0.021
Sept.–06	650	10	1,070	12.8	137	0.028
Oct.–06	270	30	1,130	11.6	132	0.030
Nov.–06	90	0	1,040	10.8	112	0.028
Dec.–06	60	10	1,710	7.0	120	0.045
Jan.–07	60	10	1,110	7.2	80	0.028
Feb.–07	170	30	550	11.9	65	0.015
Mar.–07	430	0	820	9.0	73	0.021
Apr.–07	580	50	540	13.4	73	0.014
May–07	900	0	830	13.3	110	0.022
June–07	1,150	0	120	14.4	17	0.003
July–07	1,110	110	560	13.5	76	0.015
Aug.–07	960	60	650	13.3	87	0.018
Sept.–07	660	80	510	10.8	55	0.015
Oct.–07	360	0	620	8.6	53	0.018
Nov.–07	170	100	880	9.3	82	0.028
Dec.–07	50	90	940	10.0	94	0.029
Jan.–08	60	50	220	11.9	26	0.007
Feb.–08	140	100	200	7.7	15	0.007
Mar.–08	320	10	70	7.8	5	0.002
Apr.–08	530	0	50	8.0	4	0.001
May–08	750	50	700	8.5	59	0.018
June–08	1,140	10	520	13.8	72	0.014
July–08	1,120	110	270	14.2	38	0.007
Aug.–08	940	10	370	8.7	32	0.010
Sept.–08	650	20	870	12.8	111	0.027
Oct.–08	370	60	690	12.5	86	0.021
Nov.–08	160	80	640	11.6	75	0.021
Dec.–08	60	50	800	7.4	59	0.025
Jan.–09	100	50	680	11.2	76	0.020
Feb.–09	150	60	650	7.5	49	0.021
Mar.–09	360	0	860	7.7	66	0.023
Apr.–09	530	20	630	8.0	50	0.017

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.—Continued

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Reservoir altitude (feet)	Reservoir storage (acre-feet)	Monthly pump station inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly drain and spring return flow to reservoir (acre-feet)	Monthly outflow (-) to Sand Hollow Resort (acre-feet)	Monthly total inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly reservoir storage change (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)[2]
May–09	3,053	42,180	180	10	-170	20	-1,850	1,220	0.78
June–09	3,052	40,600	210	0	-130	80	-1,580	1,190	0.73
July–09	3,050	38,700	220	0	-170	50	-1,900	1,170	0.96
Aug.–09	3,049	36,960	210	0	-150	60	-1,740	1,140	0.80
Sept.–09	3,047	35,380	200	0	-150	50	-1,580	1,110	0.58
Oct.–09	3,046	33,940	200	10	-80	130	-1,440	1,090	0.30
Nov.–09	3,045	32,960	180	10	-20	170	-980	1,070	0.16
Dec.–09	3,044	32,320	200	40	0	240	-640	1,050	0.05
Jan.–10	3,044	31,890	0	50	0	50	-430	1,040	0.07
Feb.–10	3,044	31,470	0	40	0	40	-420	1,040	0.10
Mar.–10	3,047	35,490	5,100	90	-50	5,140	4,020	1,070	0.23
Apr.–10	3,050	38,930	5,280	70	-110	5,240	3,440	1,130	0.36
May–10	3,053	41,810	4,650	90	-160	4,580	2,880	1,180	0.56
June–10	3,054	43,660	3,890	80	-190	3,780	1,850	1,220	0.81
July–10	3,053	42,300	570	100	-240	430	-1,360	1,220	0.91
Aug.–10	3,051	40,240	0	80	-220	-140	-2,060	1,190	0.77
Sept.–10	3,050	38,350	0	80	-210	-130	-1,890	1,160	0.60
Oct.–10	3,049	37,310	0	100	-90	10	-1,040	1,140	0.29
Nov.–10	3,048	36,620	0	90	-40	50	-690	1,120	0.13
Dec.–10	3,051	40,240	4,290	90	-10	4,370	3,620	1,150	0.06
Jan.–11	3,054	43,960	5,650	60	-10	5,700	3,720	1,200	0.09
Feb.–11	3,057	47,750	4,540	40	-30	4,550	3,790	1,260	0.11
Mar.–11	3,059	50,270	3,780	20	-30	3,770	2,520	1,310	0.26
Apr.–11	3,058	49,110	0	10	-140	-130	-1,160	1,310	0.43
May–11	3,057	47,460	0	10	-150	-140	-1,650	1,290	0.59
June–11	3,056	45,680	0	80	-190	-110	-1,780	1,270	0.89
July–11	3,054	43,710	0	10	-200	-190	-1,970	1,240	0.89
Aug.–11	3,053	41,990	0	10	-190	-180	-1,720	1,220	0.93
Sept.–11	3,052	40,600	0	20	-150	-130	-1,390	1,190	0.61
Oct.–11	3,051	39,910	0	30	-70	-40	-690	1,170	0.35
Nov.–11	3,054	43,490	3,980	30	-30	3,980	3,580	1,200	0.15
Dec.–11	3,058	48,010	4,990	20	-10	5,000	4,520	1,260	0.07
Jan.–12	3,060	50,990	3,540	120	-20	3,650	2,980	1,320	0.10
Feb.–12	3,059	50,360	340	80	-20	400	-630	1,330	0.14
Mar.–12	3,059	50,070	1,010	110	-70	1,050	-300	1,320	0.29
Apr.–12	3,060	50,710	1,700	110	-110	1,700	640	1,330	0.49
May–12	3,058	48,740	0	110	-200	-90	-1,980	1,310	0.83
June–12	3,056	46,440	-330	100	-200	-430	-2,300	1,280	0.98
July–12	3,055	44,220	-750	120	-200	-830	-2,220	1,250	0.87
Aug.–12	3,053	41,920	-800	120	-190	-870	-2,310	1,220	0.81
Sept.–12	3,051	40,170	-310	130	-140	-320	-1,750	1,190	0.58
Oct.–12	3,049	37,280	-1,560	110	-100	-1,550	-2,880	1,150	0.38
Nov.–12	3,047	35,280	-1,190	60	-50	-1,180	-2,010	1,110	0.18

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.—Continued

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge (acre-feet)	Monthly groundwater recharge uncertainty, 2σ (percent)	Monthly groundwater recharge uncertainty, 2σ (acre-feet)	Groundwater recharge rate (feet/day)
May–09	950	0	920	12.9	119	0.024
June–09	870	10	800	12.9	103	0.022
July–09	1,120	10	840	13.1	110	0.023
Aug.–09	910	0	890	12.8	114	0.025
Sept.–09	650	0	980	12.3	120	0.029
Oct.–09	320	[8]0	1,320	11.1	147	0.039
Nov.–09	170	[8]0	1,050	10.6	111	0.033
Dec.–09	60	100	920	9.6	88	0.028
Jan.–10	80	150	550	11.2	62	0.017
Feb.–10	110	220	570	11.5	65	0.018
Mar.–10	250	190	1,060	7.6	80	0.032
Apr.–10	400	40	1,440	7.6	109	0.041
May–10	660	10	1,050	8.0	84	0.029
June–10	990	0	940	8.6	81	0.025
July–10	1,100	0	690	12.7	88	0.018
Aug.–10	920	60	1,060	13.0	138	0.029
Sept.–10	690	0	1,070	12.7	136	0.030
Oct.–10	320	280	1,010	12.0	121	0.029
Nov.–10	150	80	670	11.6	78	0.019
Dec.–10	70	410	1,090	7.5	82	0.031
Jan.–11	100	10	1,890	7.1	135	0.051
Feb.–11	140	170	790	7.5	60	0.020
Mar.–11	340	110	1,020	7.7	79	0.025
Apr.–11	560	90	560	13.1	73	0.014
May–11	760	50	800	13.1	105	0.020
June–11	1,130	10	550	13.9	76	0.014
July–11	1,110	10	680	13.6	92	0.018
Aug.–11	1,130	20	430	13.9	60	0.011
Sept.–11	720	50	590	13.3	79	0.016
Oct.–11	420	120	350	13.4	47	0.010
Nov.–11	180	40	260	7.7	20	0.007
Dec.–11	90	50	440	7.5	33	0.011
Jan.–12	130	60	590	7.6	45	0.014
Feb.–12	180	150	1,010	10.1	102	0.024
Mar.–12	380	40	1,000	9.3	93	0.024
Apr.–12	650	60	450	9.4	42	0.011
May–12	1,090	0	800	13.6	109	0.020
June–12	1,260	40	650	12.8	83	0.016
July–12	1,090	200	500	11.7	58	0.013
Aug.–12	990	130	580	11.4	66	0.015
Sept.–12	690	110	850	11.9	101	0.023
Oct.–12	440	60	950	9.3	89	0.027
Nov.–12	200	0	630	8.8	56	0.018

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.—Continued

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Reservoir altitude (feet)	Reservoir storage (acre-feet)	Monthly pump station inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly drain and spring return flow to reservoir (acre-feet)	Monthly outflow (-) to Sand Hollow Resort (acre-feet)	Monthly total inflow or outflow (-) to/from reservoir (acre-feet)[1]	Monthly reservoir storage change (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)[2]
Dec.–12	3,046	34,370	-310	60	-20	-260	-910	1,090	0.07
Jan.–13	3,049	37,020	2,860	280	-10	3,130	2,650	1,100	0.06
Feb.–13	3,051	40,080	3,190	130	-10	3,310	3,060	1,140	0.13
Mar.–13	3,053	41,650	2,070	70	-100	2,040	1,570	1,190	0.34
Apr.–13	3,051	40,260	0	60	-150	-90	-1,390	1,190	0.49
May–13	3,050	38,820	0	60	-150	-90	-1,440	1,160	0.82
June–13	3,048	36,320	-820	60	-190	-950	-2,490	1,140	1.17
July–13	3,044	32,070	-2,940	60	-180	-3,050	-4,250	1,080	1.02
Aug.–13	3,040	27,830	-2,560	50	-150	-2,660	-4,240	1,000	0.89
Sept.–13	3,038	26,280	-540	70	-110	-580	-1,560	950	0.57
Oct.–13	3,038	26,090	1,020	50	-90	980	-190	930	0.36
Nov.–13	3,042	30,120	4,360	40	-50	4,360	4,030	980	0.17
Dec.–13	3,044	31,410	1,910	60	-10	1,970	1,290	1,030	0.06
Jan.–14	3,047	34,870	4,350	60	-20	4,390	3,460	1,070	0.12
Feb.–14	3,049	37,570	3,100	60	-20	3,130	2,700	1,120	0.17
Mar.–14	3,049	37,630	1,070	100	-90	1,090	60	1,140	0.35
Apr.–14	3,048	36,600	0	280	-110	170	-1,030	1,130	0.53
May–14	3,047	35,430	0	280	-160	120	-1,160	1,110	0.79
June–14	3,046	33,660	-400	280	-180	-300	-1,780	1,090	1.12
July–14	3,042	29,820	-2,350	270	-190	-2,270	-3,830	1,040	1.05
Aug.–14	3,039	26,650	-2,230	240	-130	-2,120	-3,170	970	0.83
Sept.–14	3,035	23,400	-2,120	280	-120	-1,960	-3,260	910	0.70
Oct.–14	3,035	22,720	0	230	-90	140	-680	880	0.46
Nov.–14	3,034	22,130	0	210	-40	170	-580	870	0.19
Dec.–14	3,038	26,090	4,290	190	-10	4,470	3,950	900	0.10
Total	—	—	—	—	—	215,750	—	—	—

[1]Negative (-) values indicate flows out of Sand Hollow Reservoir to Quail Creek Water Treatment Plant or to Quail Creek Reservoir.

[2]Monthly evaporation rate from February 2007 through December 2009 was calculated with a correction factor to account for higher solar radiation measurements with new instrument.

[3]Because of problems with monitoring equipment, inflows from September 2004 through February 2005 are estimated based on previous inflow history and changes in reservoir altitude.

[4]Revised value based on refined reservoir altitude estimate for October 2005.

[5]Monthly pump station outflow was increased from amount reported in Heilweil and others (2009a) based on reservoir altitude relations.

[6]Monthly total outflow was increased from amount reported by Washington County Water Conservancy District based on reservoir altitude relations.

[7]Monthly pump station outflow was increased from amount reported in Heilweil and others (2009a) based on reservoir altitude relations.

[8]Sand Hollow rain gauge not functioning; values of 0 based on lack of precipitation from St. George precipitation station #427516.

[9]Monthly total inflow or outflow (-) to/from reservoir (acre-feet).

Table 1. Reservoir data, evaporation, precipitation, and calculated recharge beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.—Continued

[Reservoir altitude and Reservoir storage: value is from the last day of each month; Reservoir surface area: value is an average of the daily values for each month; 2σ, 2 standard deviation; —, no data available]

Month	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge (acre-feet)	Monthly groundwater recharge uncertainty, 2σ (percent)	Monthly groundwater recharge uncertainty, 2σ (acre-feet)	Groundwater recharge rate (feet/day)
Dec.–12	80	100	670	9.4	64	0.020
Jan.–13	70	90	500	7.6	38	0.015
Feb.–13	150	30	130	7.7	10	0.004
Mar.–13	400	40	110	8.5	9	0.003
Apr.–13	580	30	750	12.9	97	0.021
May–13	950	10	420	14.0	58	0.012
June–13	1,330	0	210	12.0	25	0.006
July–13	1,100	150	250	9.6	24	0.007
Aug.–13	890	80	760	9.5	73	0.025
Sept.–13	540	170	600	11.0	66	0.020
Oct.–13	340	20	860	8.9	77	0.030
Nov.–13	170	110	260	7.7	20	0.009
Dec.–13	60	50	660	7.3	48	0.021
Jan.–14	130	10	810	7.4	60	0.025
Feb.–14	190	120	350	7.8	28	0.010
Mar.–14	390	50	690	9.1	63	0.019
Apr.–14	600	50	650	13.6	89	0.019
May–14	880	110	520	14.1	73	0.015
June–14	1,210	0	260	13.0	34	0.008
July–14	1,100	10	480	9.9	47	0.015
Aug.–14	810	180	420	9.5	40	0.014
Sept.–14	640	140	800	9.3	75	0.029
Oct.–14	410	0	410	13.8	56	0.015
Nov.–14	160	20	600	12.1	73	0.022
Dec.–14	90	60	490	7.5	37	0.017
Total	70,140	—	126,510	—	—	—

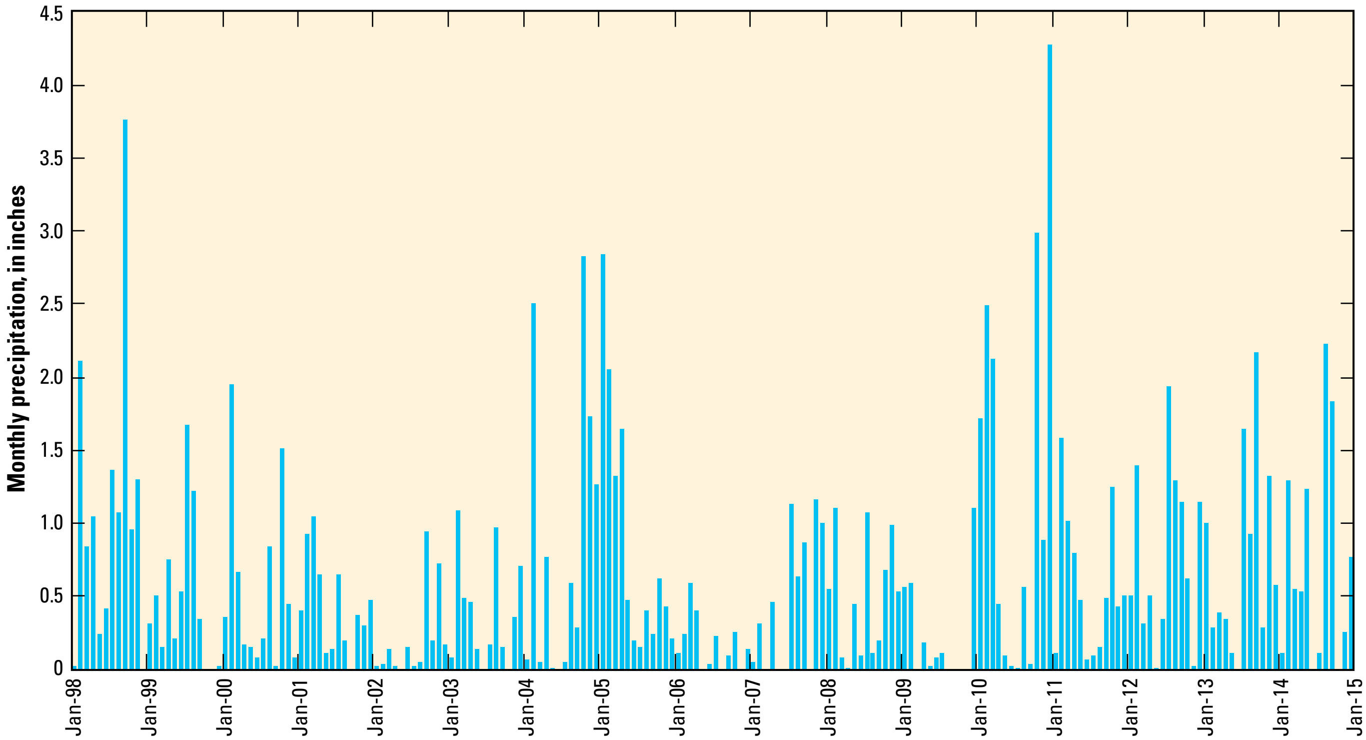


Figure 7. Monthly precipitation at Sand Hollow, Washington County, Utah, 1998–2014.

Estimates of Managed Aquifer Recharge from Sand Hollow Reservoir

Substantial amounts of surface water from Sand Hollow Reservoir infiltrate through the underlying sediments to recharge the Navajo aquifer. This recharge either is captured by production wells for municipal supply, or it moves northward through the aquifer towards the Virgin River. Through 2014, withdrawals from production wells operated by the WCWCD at Sand Hollow have been permitted for the capture of natural recharge in Sand Hollow. These withdrawals are governed by different water rights than those associated with MAR from Sand Hollow Reservoir; withdrawal rights for this artificial recharge have not yet been exercised.

Recharge from Sand Hollow Reservoir is calculated as the residual with the following water-budget equation (modified from Heilweil and others, 2005):

$$R = I_{sw} + I_{dr} - O_{sw} + P \pm \Delta S - E \tag{1}$$

where

- R is recharge,
- I_{sw} is surface-water inflow,
- I_{dr} is drain return flow,
- O_{sw} is surface-water outflow,
- P is the amount of precipitation falling directly on the reservoir,
- ΔS is change in surface-water storage, and
- E is evaporation.

All the variables in equation 1 are in units of acre-feet.

The following equation was developed to evaluate the uncertainty for each monthly recharge estimate:

$$CU = \Sigma[(|C_i| / \Sigma|C_i|) * U_i] \tag{2}$$

where

- CU is the composite uncertainty fraction (2 standard deviation, 2σ),
- $|C_i|$ is the absolute value of each component of the water budget (acre-feet),
- $\Sigma|C_i|$ is the sum of absolute values of all the water-budget components (acre-feet), and
- U_i is the uncertainty fraction (2σ) for each individual water-budget component.

The smallest estimated uncertainty fraction is 0.05 (5 percent) for I_{sw}, I_{dr}, and O_{sw} because these flows are recorded using calibrated inline flow meters. The estimated uncertainty fraction for P is higher, at 0.10 (10 percent), because it is an indirect measurement made on the basis of nearby meteorological station data. Similarly, the estimated uncertainty fraction is also 0.10 (10 percent) for ΔS because changes in surface-water storage are based only on approximate reservoir water-level altitude/volume relations rather than direct measurements. The largest estimated uncertainty fraction is 0.20 (20 percent) for E, which is based on differences between alternative methods for estimating evaporation at Sand Hollow and in other areas (Heilweil and others, 2007; Rosenberry and others, 2007).

The first two reports documenting monthly groundwater recharge beneath Sand Hollow Reservoir through August 2006 (Heilweil and others, 2005; Heilweil and Susong, 2007) did not include precipitation falling directly on the reservoir. Beginning with the third report (Heilweil and others, 2009a), and continuing in this report, an additional term for precipitation falling directly on the reservoir (P) was included in equation 1. The monthly amount of precipitation falling on the reservoir is calculated by multiplying the total monthly precipitation recorded by the Sand Hollow weather station by the average reservoir surface area for that month, based on reservoir water-level altitude to area relations for the reservoir (Washington County Water Conservancy District, written commun., 2006; RBG Engineering, written commun., 2002). The precipitation term in equation 1, however, does not account for precipitation runoff to the reservoir. Because of high evaporation rates and permeable surficial soils, precipitation events seldom produce runoff that reaches the lower part of Sand Hollow (L. Jessop, Washington County Water Conservancy District, oral commun., 2001), where the reservoir is situated.

Monthly water-budget values for Sand Hollow Reservoir are shown in table 1. Values are generally monthly averages or totals, except for reservoir altitude and storage, which are shown for the last day of each month. Values for “Monthly evaporation rate,” “Monthly evaporation,” and “Monthly groundwater recharge” from March 2002 through January 2005 and from January 2008 through December 2011 are monthly averages; during February 2005 through December 2007, however, the values are the sum of daily measurements. Summing of daily evaporation estimates was discontinued after 2007 because comparison of daily and average monthly calculations during 2008 and 2009 showed little difference, and the equation used for calculating evapotranspiration is more appropriate for calculating average evaporation over longer periods (McGuinness and Bordne, 1971).

Changes in Reservoir Storage

Changes in reservoir storage were calculated from daily reservoir water-level altitudes reported by the WCWCD by using altitude to volume relations (RBG Engineering, written commun., 2002). Since inception of the reservoir in 2002, surface-water storage increased to a maximum of about 51,000 acre-ft in May 2006. From the latter half of 2006 through 2007, surface-water storage decreased to about 32,000 acre-ft, and during 2008 through 2010, surface-water storage varied between about 31,000 and 44,000 acre-ft. Following the abnormally wet winter and spring of 2010–11, surface-water storage was kept at a high level during 2011 through mid-2012, varying between 40,000 to 50,000 acre-ft but then declined to as little as 22,000 acre-ft in December 2014 as a result of decreased flows in the Virgin River (table 1).

Reservoir Evaporation

The McGuinness and Bordne (1971) version of the Jensen-Haise method was selected for calculating evaporation from Sand Hollow Reservoir during this study. A detailed comparison to results using other methods for estimating evaporation is given in Heilweil and others (2005). The McGuinness and Bordne (1971) version of the Jensen-Haise method is based on the following relation:

$$PET = \{[((0.01T_a) - 0.37)(Q_s)]0.000673\}2.54 \qquad (3)$$

where

PET is potential evaporation, in centimeters per day,

T_a is air temperature, in degrees Fahrenheit, and

Q_s is solar radiation, in calories per square centimeter per day.

The units for PET can be converted to feet per day by multiplying by 0.0328.

By using air temperature and solar radiation from the nearby SCAN weather station (fig. 2), monthly evaporation rates were calculated with equation 3. These estimated evaporation rates ranged from 0.04 to 1.17 ft per month from March 2002 through December 2014 (table 1). Multiplying the estimated evaporation rates by average reservoir surface area yields monthly evaporation losses that ranged from about 20 to 1,300 acre-ft between March 2002 and December 2014.

Estimates of Total Volume of Managed Aquifer Recharge from Sand Hollow Reservoir

Monthly estimates of precipitation (P), evaporation (E), inflows (I_{sw} and I_{dr}), outflows (O_{sw}), and changes in surface-water storage (ΔS) were used in equation 1 to calculate recharge to the Navajo aquifer beneath Sand Hollow Reservoir. Monthly recharge rates from March 2002 through December 2014 ranged from about 50 to 3,500 acre-ft (fig. 8), with 2 standard deviation (2σ) composite uncertainties ranging from about 6 to 14 percent of the estimate (table 1). Higher composite uncertainties in the summer reflect the larger, weighted importance of evaporation losses, which have the highest uncertainty.

Estimated average monthly recharge rates beneath Sand Hollow Reservoir ranged from about 0.001 to 0.43 foot per day (ft/d) between March 2002 and December 2014 (fig. 9). Although the graph shows large monthly fluctuations, recharge has generally stabilized at an average of about 0.02 ft/d during 2011 through 2014.

Net annual inflow, evaporation, and groundwater recharge from Sand Hollow Reservoir from 2002 through 2014 are

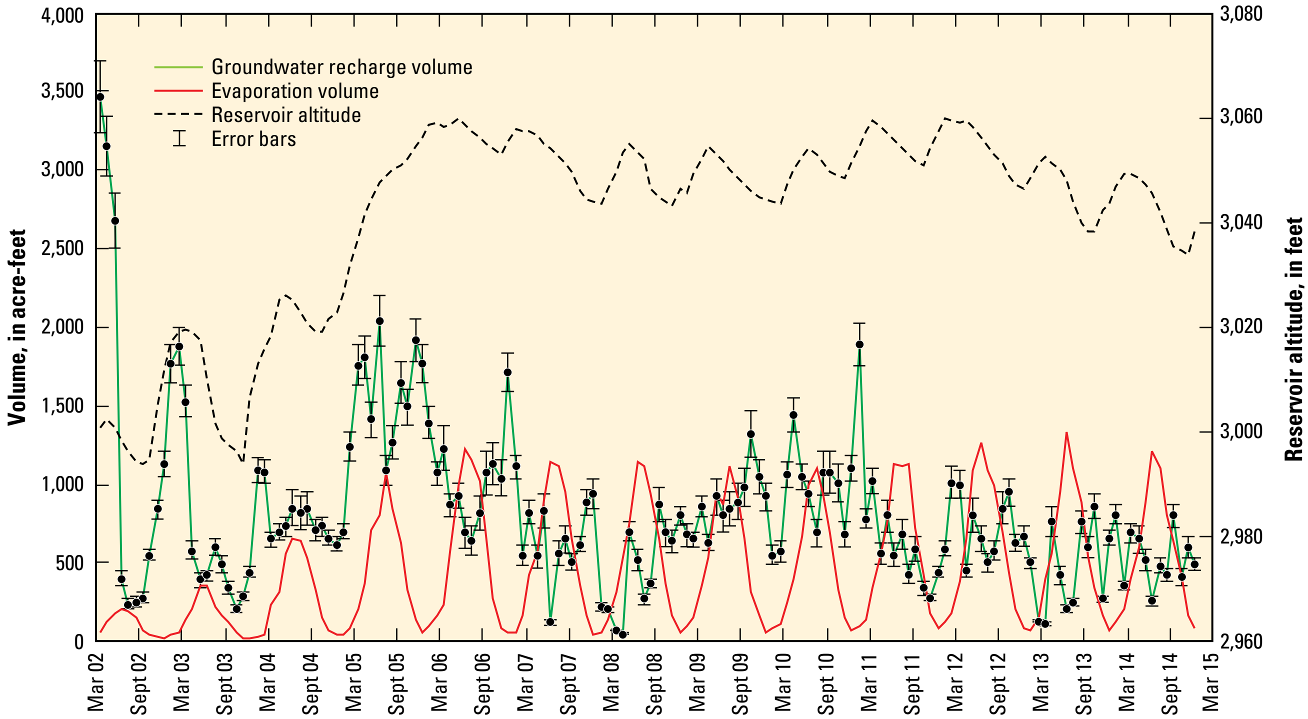


Figure 8. Monthly estimated evaporation, groundwater recharge, and reservoir altitude, Sand Hollow Reservoir, Washington County, Utah, 2002–14.

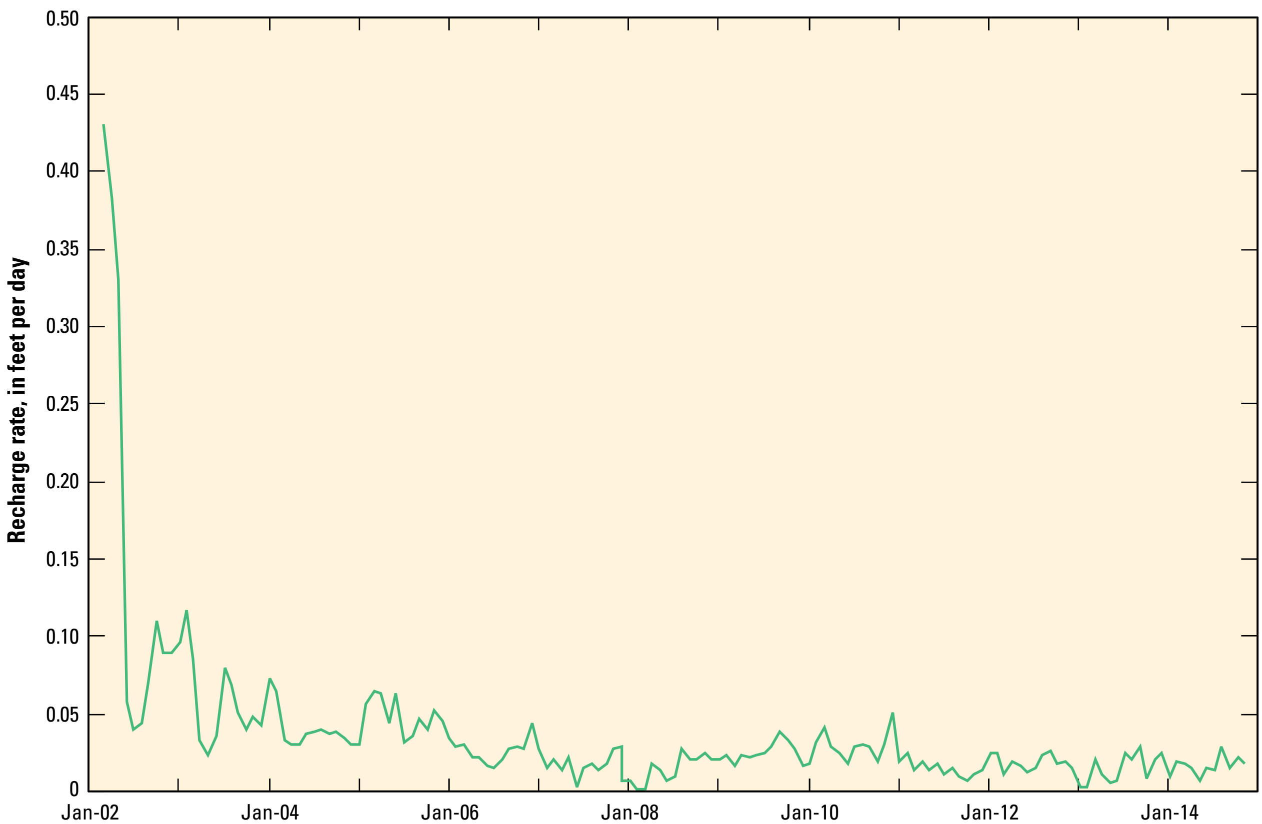


Figure 9. Monthly calculated groundwater recharge rates beneath Sand Hollow Reservoir, Washington County, Utah, 2002–14.

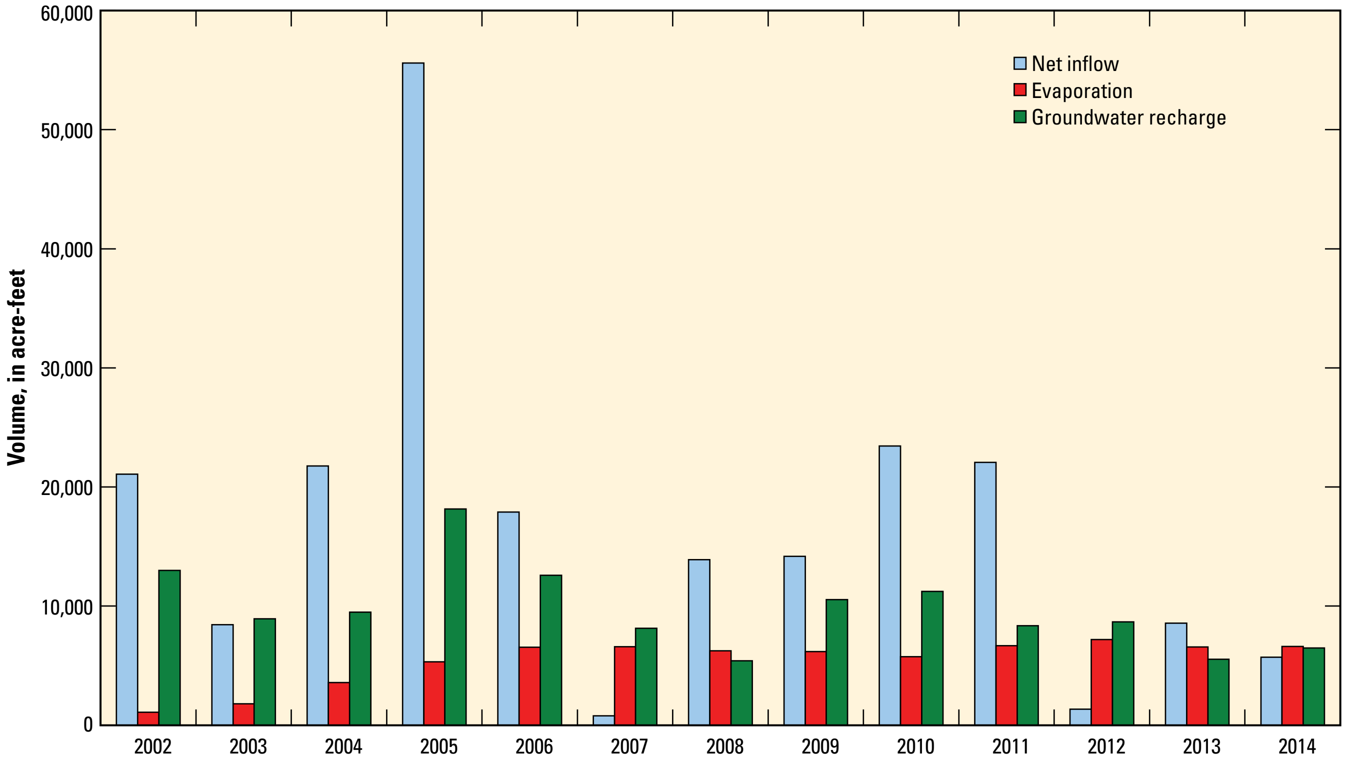


Figure 10. Estimated annual inflow, evaporation, and groundwater recharge, Sand Hollow Reservoir, Washington County, Utah, 2002–14.

shown in figure 10. Total net inflow during this period was about 216,000 acre-ft, with annual inflow during this period ranging from about 800 acre-ft in 2007 to 56,000 acre-ft in 2005. The general increase in reservoir water-level altitude and area from 2002 to 2007 resulted in a steady increase in the volume of annual evaporation from about 1,000 acre-ft in 2002 to about 6,600 acre-ft in 2006, and then leveled off from 2007 through 2014. Total estimated evaporative losses from 2002 through 2014 were about 70,000 acre-ft. Annual recharge ranged from a low of about 5,000 acre-ft in 2008 to a high of about 18,000 acre-ft in 2005. Total estimated recharge from 2002 through 2014 was about 127,000 acre-ft, with a 2 standard deviation (2σ) uncertainty of 11,900 acre-ft.

Groundwater and Surface-Water Quality in Sand Hollow

As MAR from Sand Hollow Reservoir moves into the underlying Navajo aquifer, it has an initial water-quality signature similar to the reservoir water, but this evolves as water moves through the subsurface. Along its flow path, the MAR initially moves from the reservoir through the organic-rich silt layer that has accumulated beneath the reservoir, and then through the pre-reservoir vadose zone (now saturated) where vadose-zone solutes had naturally accumulated and air was trapped prior to and during filling of the reservoir. This results in water quality that is different from native groundwater. As part of the monitoring of MAR from Sand Hollow Reservoir, water-quality samples from the reservoir and surrounding monitoring wells were collected and analyzed for both field water-quality parameters and laboratory chemical, isotopic, and dissolved-gas concentrations.

Field water-quality parameters included water temperature, specific conductance, pH, dissolved oxygen (DO), and total dissolved-gas (TDG) pressure. TDG pressure is the combination of partial pressures of all dissolved gases in the water. Field parameters were measured with a multi-parameter sonde placed within the screened interval at the bottom of each 2-in. monitoring well, and in the reservoir at water depths of approximately 2 ft. The multi-parameter sonde was too large to enter the 1-in. monitoring wells (North Dam 3A, WD 4, WD 5, and WD 12). Consequently, field measurements from these wells were made onsite with a flow-through chamber connected to the discharge line from either a Waterra or peristaltic pump; no TDG pressure measurements were made at these sites. Additional details regarding field parameter methods are given in Heilweil and others (2005) and Heilweil and Susong (2007).

Laboratory water-quality analyses of water from Sand Hollow Reservoir and groundwater from the Navajo aquifer included dissolved major and trace inorganic elements, dissolved organic carbon (DOC), tritium (^3H), and industrial dissolved gases. The major inorganic ions included calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, and nitrate. Trace elements included bromide, iron, manganese, arsenic, nitrite, ammonia, and orthophosphate. Dissolved gases included chlorofluorocarbons (CFC–11, CFC–12, CFC–113) and sulfur hexafluoride (SF_6).

Water samples were collected from 2-in. monitoring wells by using either a Grundfos or Bennett submersible pump; 1-in. wells were sampled with a Waterra hand pump; production wells were sampled utilizing installed turbine pumps. Prior to water sample collection from monitoring wells, water was purged from each well until field parameters stabilized and a minimum of three casing volumes were removed. After purging each well, water was pumped into sample bottles and filtered as necessary. Since 2009, a set of replicate samples has been collected annually at one randomly selected site and separately analyzed for all constituents for quality assurance. Samples for major cations and trace elements were filtered through 0.45-micron disposable filters and collected in clean polyethylene bottles according to procedures described by Wilde and Radtke (1998); samples for major anion analysis were preserved with 7.7-normal nitric acid. Tritium samples were collected in 500-milliliter (ml) polyethylene bottles with polyseal caps and no head space. CFC and SF_6 samples were collected in 250-ml and 1-liter (L) glass bottles, respectively, according to procedures described on the USGS Reston Groundwater Dating Laboratory website at *http://water.usgs.gov/lab/*.

Inorganic and organic chemical analyses (major ions, trace elements, DOC) were analyzed by the U.S. Geological Survey at the National Water Quality Laboratory in Denver, Colorado. CFCs and SF_6 (through 2012) were analyzed by the U.S. Geological Survey Chlorofluorocarbon Laboratory in Reston, Virginia. Tritium and SF_6 (2013–2014) were analyzed at the University of Utah Dissolved Gas Service Center.

Water-Quality Results

Detailed water-quality data and interpretations at Sand Hollow, including trends through 2012, have been previously published (Heilweil and others, 2005; Heilweil and Susong, 2007; Heilweil and others, 2009a; Heilweil and Marston, 2011; Marston and Heilweil, 2013). Tables 2 and 3 provide this previous data, along with additional data collected during 2013 and 2014. The following discussion describes recent changes or the continuation of longer trends in water quality. Perhaps most significant are changes at wells WD 4 and WD 12, located 2,600 and 1,000 ft from the reservoir, respectively. Although the low chloride to bromide (Cl/Br) ratios indicate that reservoir water has not yet arrived at these sites, increases in other constituents indicate a flush of naturally accumulating vadose-zone salts ahead of reservoir recharge. At WD 4, specific conductance and dissolved-solids concentrations increased from 2011 through 2014 to values similar to those in the reservoir water. Although environmental tracers (tritium, CFCs, and SF_6) have also increased, their concentrations are still lower than those in the reservoir water. At WD 12, specific conductance and dissolved-solids concentrations increased from 2011 through 2014 to higher values than those in the reservoir, indicating mobilization of naturally accumulating vadose-zone salts; however, Cl/Br ratios and environmental tracer concentrations (tritium, CFCs, and SF_6) were still lower than those in the reservoir water.

At well WD 6, located 1,000 ft from the reservoir, the increase in the Cl/Br ratio from 2002 through 2014 towards ratios in the reservoir water indicates the arrival of recharge from the reservoir; specific conductance, dissolved-solids concentrations and concentrations of some environmental tracers (tritium, CFC-12, CFC-113) are also about the same as those in the reservoir and have remained relatively stable from 2012 through 2014. Other industrial gases (CFC-11, SF_6) and DOC concentrations are substantially lower than reservoir concentrations, but this may indicate other processes such as microbial degradation and gas exchange with trapped air bubbles in the aquifer matrix. Although still elevated, the decrease in DO in water from WD 6 from 2009 through 2014 may indicate the dissolution of some of this trapped air.

Although well WD 8 has had a slight increase in the Cl/Br ratio from 2002 through 2014, it is still much lower than the ratio in the reservoir water. Although located only 500 ft from the reservoir, this well is downgradient of an area of high natural recharge on Sand Mountain and may lie along a groundwater boundary between the two recharge mounds. The relatively high concentrations of modern environmental tracers may be caused by natural recharge. The recently observed concentration of DO, 26 mg/L, indicates a rapid rise in water level and entrapment of air bubbles.

At wells WD 9 and WD 11, 55 and 160 ft away from the reservoir, respectively, the various field parameters, along with the results of chemical analyses and environmental tracers (with the exception of CFC-11 and CFC-113, which were possibly reduced by microbial degradation) indicate that reservoir recharge arrived several years prior to 2014. Recent declines in DO in the well may be due to a combination of dissolution of trapped air bubbles and chemical reduction as recharge infiltrates through carbon-rich sediment at the bottom of the reservoir.

At well WD 15, located 2,400 ft from the reservoir (fig. 2), specific conductance and dissolved-solids concentrations increased from 2010 through 2014, yet Cl/Br ratios and tritium concentrations remained much lower than those in the reservoir water. This may indicate vadose-zone salt mobilization, likely from rising water levels rather than a salt flush prior to the arrival of reservoir water. Elevated TDG pressure and DO similarly indicate air entrapment associated with rising water levels. WD 16, located at the same site but screened at a deeper interval, does not show an increase in salinity and has even lower Cl/Br ratios and tritium concentrations, supporting the interpretation of rising water levels rather than salt flushing prior to the arrival of reservoir recharge. Wells farther from the reservoir that were sampled in 2013 or 2014 (WD 5 located 2,800 ft away and wells WD 17 and WD 18 located 5,900 ft away) show that reservoir recharge has not yet reached these locations.

Arsenic concentrations have generally decreased at locations where reservoir recharge has already arrived or where there has been a water-table rise and flushing of vadose-zone salts, typically a precursor to the arrival of recharge. This decline may be attributable to an increase in oxidizing conditions, which facilitate the adsorption of arsenic on iron oxides within the aquifer matrix, in contrast to reducing conditions, which would mobilize arsenic. Wells WD 4, WD 6, WD 8, and WD 12 all show this trend of decreasing arsenic concentration with increasing DO.

Table 2. Field water-quality parameters, total dissolved-gas pressure, dissolved organic carbon, tritium, chlorofluorocarbons, and sulfur hexafluoride in groundwater and surface water from Sand Hollow, Washington County, Utah.

[Analyzing agency: Dissolved organic carbon at U.S. Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado; Tritium at University of Utah Dissolved Gas Laboratory in Salt Lake City, Utah; CFC-11, CFC-12, CFC-113, and SF_6 at USGS Chlorofluorocarbon (CFC) Laboratory in Reston, Virginia. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; mm Hg, millimeters of mercury; TU, tritium units; pmol/kg, picomoles per kilogram; fmol/kg, femtomoles per kilogram; —, no data available; E, estimated; >, greater than; <, less than]

Site name	Date sampled	Water temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Total dissolved-gas pressure (mm Hg)	Dissolved organic carbon (mg/L)	Tritium (TU)	Tritium precision (TU)	CFC-11 (pmol/kg)	CFC-12 (pmol/kg)	CFC-113 (pmol/kg)	SF_6 (fmol/kg)
Groundwater													
North Dam 3A	10/8/02	15.9	4,430	8.0	5.0	—	—	2.71	0.14	—	—	—	—
	12/18/02	14.7	2,830	8.0	10.8	—	—	—	—	—	—	—	—
	6/10/03	21.5	1,330	7.8	—	—	—	—	—	—	—	—	—
	10/9/03	—	1,230	7.8	—	—	—	—	—	—	—	—	—
	1/8/04	16.0	1,220	8.2	—	—	—	—	—	—	—	—	—
	9/21/04	18.4	980	7.7	11.0	—	—	—	—	—	—	—	—
	10/29/04	15.9	910	7.9	11.1	—	—	—	—	—	—	—	—
	2/10/05	15.3	960	7.7	13.5	—	—	—	—	—	—	—	—
	4/5/05	16.5	960	7.8	12.6	—	—	—	—	—	—	—	—
	1/19/06	—	840	8.0	—	—	—	—	—	—	—	—	—
	2/15/07	15.2	840	7.9	7.5	—	—	2.53	0.31	—	—	—	—
	3/14/08	14.8	820	7.7	4.0	—	—	3.45	0.44	—	—	—	—
	4/30/09	—	850	7.2	—	—	—	3.03	0.11	—	—	—	—
	3/16/10	22.8	860	7.6	1.3	—	1.91	3.05	0.12	0.54	2.0	0.10	—
	3/10/11	20.3	830	7.4	0.8	—	1.93	2.87	0.12	0.60	1.93	0.09	—
	2/6/12	11.3	820	7.8	—	—	2.00	3.46	0.41	—	—	—	—
	4/15/13	25.7	870	—	2	—	2.09	3.10	0.10	0.54	2.01	0.09	1.85
	4/29/14	23.6	912	8.0	0	—	2.02	3.04	0.15	—	—	—	—

Table 2. Field water-quality parameters, total dissolved-gas pressure, dissolved organic carbon, tritium, chlorofluorocarbons, and sulfur hexafluoride in groundwater and surface water from Sand Hollow, Washington County, Utah.—Continued

[Analyzing agency: Dissolved organic carbon at U.S. Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado; Tritium at University of Utah Dissolved Gas Laboratory in Salt Lake City, Utah; CFC-11, CFC-12, CFC-113, and SF_6 at USGS Chlorofluorocarbon (CFC) Laboratory in Reston, Virginia. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; mm Hg, millimeters of mercury; TU, tritium units; pmol/kg, picomoles per kilogram; fmol/kg, femtomoles per kilogram; —, no data available; E, estimated; >, greater than; <, less than]

Site name	Date sampled	Water temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Total dissolved-gas pressure (mm Hg)	Dissolved organic carbon (mg/L)	Tritium (TU)	Tritium precision (TU)	CFC-11 (pmol/kg)	CFC-12 (pmol/kg)	CFC-113 (pmol/kg)	SF_6 (fmol/kg)
WD 4	4/2/99	21.0	360	8.2	—	—	—	0.22	0.10	—	—	—	—
	12/18/02	18.7	350	7.7	8.1	—	—	—	—	—	—	—	—
	1/19/06	—	350	8.0	—	—	—	—	—	—	—	—	—
	2/15/07	19.0	340	7.9	8.7	—	—	—	—	—	—	—	—
	3/13/08	22.6	350	7.8	7.8	—	—	0.25	0.10	—	—	—	—
	10/23/08	21.2	360	8.0	—	—	—	0.13	0.10	0.62	0.61	0.09	0.44
	4/28/09	—	350	7.8	—	—	—	0.15	0.07	0.54	0.52	0.07	0.45
	11/24/09	18.7	340	7.8	9.5	—	0.43	0.09	0.03	0.42	0.54	0.07	—
	3/15/10	19.7	360	7.7	9.5	—	E0.37	0.06	0.03	0.62	0.60	0.09	—
	3/10/11	19.7	360	7.4	10.5	—	0.40	0.12	0.03	1.04	0.79	0.13	0.73
	2/8/12	19.5	550	7.3	8.9	—	2.25	0.00	0.15	1.26	1.07	0.30	1.19
	4/15/13	19.9	696	—	22.5	—	0.89	0.51	0.03	1.47	1.34	0.17	1.34
	4/29/14	20.5	796	7.7	10.9	—	1.16	0.38	0.03	1.43	1.24	0.18	1.28
WD 5	4/3/99	15.0	540	8.3	—	—	—	0.19	0.03	—	—	—	—
	12/17/02	17.6	530	7.8	6.6	—	—	—	—	—	—	—	—
	1/18/06	—	530	7.9	—	—	—	—	—	—	—	—	—
	2/15/07	18.3	530	7.8	8.3	—	—	—	—	—	—	—	—
	3/13/08	20.0	540	7.8	7.0	—	—	0.05	0.10	—	—	—	—
	10/23/08	21.0	540	8.2	—	—	—	0.07	0.10	0.12	0.08	0.01	0.13
	4/30/09	—	520	7.5	—	—	—	0.02	0.06	—	—	—	—
	11/24/09	16.9	510	8.5	7.2	—	0.45	0.09	0.05	0.20	0.07	0.02	—
	3/15/10	21.0	540	7.7	8.1	—	E0.44	0.09	0.10	0.19	0.10	0.03	—
	3/10/11	19.5	510	7.4	8.0	—	0.72	0.00	0.03	0.12	0.07	0.03	0.10
	4/16/13	19.8	502	7.6	9.1	—	0.89	0.51	0.03	1.47	1.34	0.17	1.34
	4/30/14	20.1	522	7.4	—	—	1.16	0.38	0.03	1.43	1.24	0.18	1.28
WD RJ	4/2/99	18.0	560	8.2	—	—	—	0.02	0.05	—	—	—	—
	12/17/02	18.2	530	7.7	6.4	—	—	—	—	—	—	—	—
	1/18/06	—	550	7.7	—	—	—	—	—	—	—	—	—
	2/15/07	19.0	530	7.7	8.1	—	—	—	—	—	—	—	—
	3/12/08	19.3	540	7.3	6.8	—	—	0.03	0.10	—	—	—	—
	4/28/09	—	550	7.5	—	—	—	0.04	0.02	—	—	—	—
	3/15/10	19.6	560	7.6	8.0	—	0.84	0.06	0.03	0.25	0.13	0.07	—
	3/9/11	19.6	540	7.3	7.5	—	—	0.00	0.03	0.34	0.15	0.06	—
WD 6	5/15/01	—	130	7.6	—	—	—	4.77	0.24	—	—	—	—
	8/28/01	19.7	190	7.7	6.1	710	—	6.88	0.34	—	—	—	—
	9/9/02	19.4	290	7.7	—	850	—	—	—	—	—	—	—
	12/17/02	19.0	400	7.6	9.3	920	—	—	—	—	—	—	—
	3/19/03	19.2	424	7.5	10.9	1,150	—	—	—	—	—	—	—
	5/7/03	19.3	450	7.5	—	1,220	—	—	—	—	—	—	—
	6/9/03	19.6	390	7.8	14.0	1,260	—	—	—	—	—	—	—
	8/4/03	19.3	350	7.5	11.9	1,280	—	—	—	—	—	—	—
	10/6/03	19.6	400	7.6	12.0	1,160	—	—	—	—	—	—	—
	5/3/04	19.4	700	7.4	15.2	1,360	—	—	—	—	—	—	—
	9/20/04	19.6	820	7.7	15.0	1,270	—	—	—	—	—	—	—
	10/28/04	19.0	810	7.6	13.5	1,240	—	—	—	—	—	—	—
	2/9/05	19.2	450	7.9	14.6	1,460	—	—	—	—	—	—	—
	4/5/05	19.2	460	7.6	15.5	1,490	—	—	—	—	—	—	—
	1/19/06	18.9	680	7.6	17.7	[1]1,700	—	—	—	—	—	—	—
	2/15/07	19.1	1,110	7.6	17.2	[1]1,600	—	—	—	—	—	—	—

Table 2. Field water-quality parameters, total dissolved-gas pressure, dissolved organic carbon, tritium, chlorofluorocarbons, and sulfur hexafluoride in groundwater and surface water from Sand Hollow, Washington County, Utah.—Continued

[Analyzing agency: Dissolved organic carbon at U.S. Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado; Tritium at University of Utah Dissolved Gas Laboratory in Salt Lake City, Utah; CFC-11, CFC-12, CFC-113, and SF_6 at USGS Chlorofluorocarbon (CFC) Laboratory in Reston, Virginia. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; mm Hg, millimeters of mercury; TU, tritium units; pmol/kg, picomoles per kilogram; fmol/kg, femtomoles per kilogram; —, no data available; E, estimated; >, greater than; <, less than]

Site name	Date sampled	Water temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Total dissolved-gas pressure (mm Hg)	Dissolved organic carbon (mg/L)	Tritium (TU)	Tritium precision (TU)	CFC-11 (pmol/kg)	CFC-12 (pmol/kg)	CFC-113 (pmol/kg)	SF_6 (fmol/kg)
WD 6	3/13/08	19.2	1,300	7.5	14.4	[1]1,590	—	2.11	0.14	—	—	—	—
	4/29/08	19.3	1,290	7.7	17.1	[1]1,590	—	—	—	—	—	—	—
	6/3/08	19.4	1,330	7.6	16.5	[1]1,590	—	—	—	—	—	—	—
	10/24/08	19.0	1,190	—	16.3	[1]1,540	—	2.55	0.13	2.8	1.3	0.15	0.72
	4/30/09	19.2	1,050	7.7	22.0	[1]1,810	—	2.66	0.14	3.2	1.5	0.16	0.73
	11/23/09	18.9	970	7.9	15.3	[1]1,650	1.71	2.93	0.23	1.7	1.8	0.17	—
	3/15/10	19.2	920	7.5	14.4	1,200	1.68	3.15	0.15	1.7	1.6	0.19	—
	3/9/11	19.1	900	7.5	11.2	[2]1,410	1.56	1.54	0.10	2.64	1.73	0.20	0.65
(replicate)	3/9/11	19.1	900	7.5	11.2	[2]1,410	1.59	2.83	0.13	2.64	1.73	0.20	0.72
	2/7/12	19.1	810	7.3	15.6	[1]1,700	1.70	2.88	0.31	2.23	1.67	0.18	0.87
	4/16/13	18.9	810	7.0	11.8	[1]1,600	1.18	2.52	0.14	2.1	1.9	0.19	0.71
	4/29/14	19.0	810	7.3	10.1	[1]1,550	0.92	2.85	0.11	2.0	1.9	0.19	0.87
WD 8	5/21/01	—	300	7.7	—	—	—	4.13	0.38	—	—	—	—
	9/12/01	18.7	305	7.7	9.6	890	—	2.98	0.15	—	—	—	—
	9/9/02	18.9	305	7.9	—	840	—	3.89	0.19	—	—	—	—
	3/20/03	18.7	335	7.6	7.8	910	—	—	—	—	—	—	—
	5/8/03	18.6	340	7.5	4.6	880	—	—	—	—	—	—	—
	10/16/03	—	360	7.4	—	—	—	—	—	—	—	—	—
	2/7/12	18.5	250	7.1	20.8	[2]2,300	0.75	3.36	0.33	1.93	1.71	0.16	—
	4/16/13	18.5	350	7.1	21.1	[1]>2,290	0.52	3.14	0.16	2.02	1.69	0.16	0.42
	4/30/14	18.7	380	7.8	25.9	[1]1,620	0.64	3.07	0.15	2.00	1.80	0.18	0.21
WD 9	5/23/01	19.5	300	7.7	8.0	800	—	0.00	0.01	—	—	—	—
	9/14/01	19.4	280	7.4	—	790	—	0.20	0.15	—	—	—	—
	9/11/02	19.5	350	7.9	—	980	—	—	—	—	—	—	—
	5/7/03	19.7	320	7.8	—	[1]>2,250	—	—	—	—	—	—	—
	6/9/03	19.5	350	7.7	24.4	[1]>2,250	—	—	—	—	—	—	—
	8/5/03	19.7	720	7.5	19.3	[1]1,800	—	—	—	—	—	—	—
	10/7/03	19.6	740	7.5	17.9	[1]1,600	—	—	—	—	—	—	—
	1/6/04	19.4	630	7.7	16.7	[1]1,700	—	—	—	—	—	—	—
	5/3/04	19.4	530	7.4	25.7	[1]>2,250	—	—	—	—	—	—	—
	9/20/04	18.5	750	7.8	22.6	[1]>2,250	—	—	—	—	—	—	—
	10/28/04	18.5	760	7.6	20.7	[1]2,210	—	—	—	—	—	—	—
	2/9/05	18.4	880	7.7	20.2	[1]>2,250	—	—	—	—	—	—	—
	4/5/05	18.5	820	7.4	23.2	[1]>2,250	—	—	—	—	—	—	—
	1/18/06	18.0	1,230	7.9	15.0	[1]1,900	—	—	—	—	—	—	—
	2/14/07	17.3	790	7.4	4.6	[1]1,600	—	—	—	—	—	—	—
	3/11/08	17.0	820	7.3	1.5	1,080	—	2.61	0.22	—	—	—	—
	4/27/09	16.6	830	7.4	1.8	840	—	2.99	0.12	1.2	2.2	0.19	2.15
	3/15/10	16.4	840	7.3	1.7	920	1.23	3.20	0.14	0.8	2.2	0.21	—
(replicate)	3/15/10	16.4	840	7.3	1.7	920	1.17	2.90	0.12	0.8	2.2	0.18	—
	3/8/11	16.1	900	7.3	0.5	900	1.36	3.34	0.16	1.33	2.10	0.17	—
	2/7/12	16.3	830	7.1	0.4	720	1.77	3.56	0.28	0.76	1.85	0.13	—
	4/15/13	16.1	860	7.3	0.6	790	1.30	3.23	0.15	0.91	2.01	0.14	2.64
	4/28/14	16.1	880	7.0	0.16	1,010	1.29	2.78	0.11	0.52	1.78	0.08	3.59
WD 11	6/14/01	18.5	420	7.8	8.1	860	—	—	—	—	—	—	—
	9/14/01	18.5	450	7.7	8.6	900	—	0.53	0.08	0.53	0.24	—	—
	9/12/02	18.5	465	7.6	—	873	—	—	—	—	—	—	—
	12/16/02	18.2	455	7.6	8.1	890	—	—	—	—	—	—	—
	5/7/03	18.4	620	7.7	—	[1]1,770	—	—	—	—	—	—	—

Table 2. Field water-quality parameters, total dissolved-gas pressure, dissolved organic carbon, tritium, chlorofluorocarbons, and sulfur hexafluoride in groundwater and surface water from Sand Hollow, Washington County, Utah.—Continued

[Analyzing agency: Dissolved organic carbon at U.S. Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado; Tritium at University of Utah Dissolved Gas Laboratory in Salt Lake City, Utah; CFC-11, CFC-12, CFC-113, and SF_6 at USGS Chlorofluorocarbon (CFC) Laboratory in Reston, Virginia. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; mm Hg, millimeters of mercury; TU, tritium units; pmol/kg, picomoles per kilogram; fmol/kg, femtomoles per kilogram; —, no data available; E, estimated; >, greater than; <, less than]

Site name	Date sampled	Water temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Total dissolved-gas pressure (mm Hg)	Dissolved organic carbon (mg/L)	Tritium (TU)	Tritium precision (TU)	CFC-11 (pmol/kg)	CFC-12 (pmol/kg)	CFC-113 (pmol/kg)	SF_6 (fmol/kg)
WD 11	6/9/03	18.4	650	7.9	22.5	[1]1,600	—	—	—	—	—	—	—
	8/5/03	18.6	700	7.8	12.4	[1]1,520	—	—	—	—	—	—	—
	10/7/03	18.5	800	7.8	19.4	[1]1,700	—	—	—	—	—	—	—
	5/3/04	18.4	680	7.7	21.5	[1]1,900	—	—	—	—	—	—	—
	9/20/04	18.0	920	8.2	23.5	[1]>2,250	—	—	—	—	—	—	—
	10/28/04	18.0	990	7.9	22.8	[1]2,080	—	—	—	—	—	—	—
	2/9/05	18.0	960	8.1	22.1	[1]2,200	—	—	—	—	—	—	—
	4/5/05	17.8	930	7.9	25.2	[1]>2,250	—	—	—	—	—	—	—
	1/18/06	17.6	980	7.9	23.0	[1]>2,250	—	—	—	—	—	—	—
	2/14/07	17.1	820	7.6	19.0	[1]>2,250	—	—	—	—	—	—	—
	3/11/08	17.0	840	7.6	14.9	[1]>2,250	—	2.30	0.14	—	—	—	—
	4/30/08	17.0	840	7.7	17.4	[1]>2,250	—	—	—	—	—	—	—
	6/2/08	17.1	850	7.7	18.9	[1]>2,250	—	—	—	—	—	—	—
	10/22/08	16.7	840	8.0	15.9	[1]>2,250	—	2.36	0.11	—	—	—	—
	4/30/09	15.9	840	7.7	19.4	[1]2,160	—	3.06	0.14	2.0	3.0	0.34	3.5
	11/23/09	16.3	840	7.9	13.2	[1]2,160	1.46	2.75	0.12	0.8	3.0	0.30	—
	3/15/10	16.2	840	7.7	10.3	[2]1,700	1.35	2.81	0.13	0.8	2.9	0.30	—
	3/8/11	16.0	890	7.7	9.9	[2]1,940	1.45	2.76	0.14	1.24	2.76	0.24	—
	2/7/12	15.4	800	7.4	9.5	[2]1,850	1.57	2.52	0.21	0.76	2.60	0.18	—
	4/15/13	16.1	830	6.7	11.4	[1]2,160	1.32	2.66	0.09	0.63	2.31	0.11	1.85
(replicate)	4/15/13	16.1	830	6.7	11.4	[1]2,160	1.50	2.63	0.13	0.59	2.27	0.11	—
	4/28/14	16.2	820	7.3	3.1	[1]>1,570	2.43	2.59	0.12	0.51	2.14	0.10	3.88
WD 12	4/30/99	—	330	—	—	—	—	0.53	0.38	—	—	—	—
	9/12/02	—	335	7.9	—	—	—	0.02	0.06	—	—	—	—
	12/16/02	—	330	7.8	7.0	—	—	—	—	—	—	—	—
	3/9/11	19.9	1,670	7.1	13.4	—	2.17	0.96	0.06	2.34	2.20	0.25	0.68
	2/8/12	19.3	2,100	7.2	9.2	—	3.81	1.01	0.13	2.27	2.04	0.28	1.10
	4/16/13	19.0	2,390	7.3	17.8	—	2.93	1.49	0.10	2.58	2.26	0.28	0.77
	4/28/14	20.5	2,380	7.4	—	—	3.23	1.69	0.07	2.62	2.04	0.28	0.70
WD 15	10/25/08	18.8	720	—	14.2	1,300	—	—	—	—	—	—	—
	4/28/09	18.9	710	8.0	17.6	1,490	—	0.77	0.04	2.3	1.9	0.23	1.4
	11/23/09	18.8	730	8.3	14.5	1,410	2.47	0.68	0.05	1.0	1.9	0.22	—
	3/16/10	19.1	730	7.9	11.5	1,320	2.49	0.72	0.05	1.2	2.1	0.25	—
	3/8/11	19.1	820	8.0	12.5	1,400	2.50	0.55	0.06	2.56	2.27	0.28	1.56
	2/7/12	19.1	820	8.0	18.8	[2]1,450	3.15	0.15	0.13	2.36	2.14	0.27	1.48
	4/17/13	18.9	900	—	17.8	[1]1,780	2.44	0.60	0.02	2.24	2.21	0.26	1.23
	4/29/14	18.8	970	7.7	11.7	[1]1,560	2.75	0.63	0.03	2.16	2.23	0.27	1.18
(replicate)	4/29/14	18.8	970	7.7	11.7	[1]1,560	2.72	0.50	0.04	2.14	2.20	0.27	1.25
WD 16	10/25/08	18.7	470	8.0	7.7	780	—	—	—	—	—	—	—
	4/27/09	18.7	440	7.7	8.7	970	—	0.02	0.02	0.28	0.13	0.04	0.43
	11/24/09	18.7	450	7.7	7.1	760	<0.66	0.03	0.04	0.12	0.01	0.01	—
	3/16/10	18.7	440	7.6	5.1	770	<0.66	0.03	0.02	0.13	0.04	0.01	—
	3/8/11	18.5	480	7.7	4.1	770	<0.15	0.04	0.03	0.07	0.01	0.02	0.2
	4/17/13	18.7	430	—	8.1	830	<0.23	0.05	0.02	0.11	0.05	0.01	1.16
	4/29/14	18.7	450	7.4	3.7	1,060	<0.23	-0.05	-0.15	0.20	0.15	0.01	0.27
WD 17	10/24/08	19.5	615	—	8.4	1,000	—	—	—	—	—	—	—
	4/16/13	19.4	545	7.6	11.0	1,030	0.54	0.05	0.01	0.79	0.76	0.09	2.29

Table 2. Field water-quality parameters, total dissolved-gas pressure, dissolved organic carbon, tritium, chlorofluorocarbons, and sulfur hexafluoride in groundwater and surface water from Sand Hollow, Washington County, Utah.—Continued

[Analyzing agency: Dissolved organic carbon at U.S. Geological Survey (USGS) National Water Quality Laboratory in Denver, Colorado; Tritium at University of Utah Dissolved Gas Laboratory in Salt Lake City, Utah; CFC-11, CFC-12, CFC-113, and SF_6 at USGS Chlorofluorocarbon (CFC) Laboratory in Reston, Virginia. °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; mm Hg, millimeters of mercury; TU, tritium units; pmol/kg, picomoles per kilogram; fmol/kg, femtomoles per kilogram; —, no data available; E, estimated; >, greater than; <, less than]

Site name	Date sampled	Water temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Total dissolved-gas pressure (mm Hg)	Dissolved organic carbon (mg/L)	Tritium (TU)	Tritium precision (TU)	CFC-11 (pmol/kg)	CFC-12 (pmol/kg)	CFC-113 (pmol/kg)	SF_6 (fmol/kg)
WD 18	4/28/09	19.7	500	7.4	7.5	870	—	0.04	0.02	0.21	0.16	0.03	1.46
	3/16/10	19.3	470	7.4	4.9	740	E0.48	0.14	0.02	0.16	0.07	0.01	—
	3/9/11	19.2	480	7.3	7.8	750	0.70	0.03	0.03	0.08	0.02	0.02	—
WD 19	10/23/08	18.9	1,070	—	9.2	910	—	—	—	—	—	—	—
	3/10/11	19.1	2,030	7.5	9.8	920	4.61	2.70	0.10	3.25	2.03	0.31	—
	2/7/12	18.6	1,900	7.5	6.8	820	4.87	2.99	0.30	3.17	1.82	0.30	1.55
(replicate)	2/7/12	18.6	1,900	7.5	6.8	820	5.65	2.84	0.29	3.21	1.85	0.29	1.54
WD 20	10/23/08	19.1	340	—	7.9	740	—	—	—	—	—	—	—
	4/29/09	19.7	330	7.5	6.7	760	—	0.06	0.01	0.10	0.02	0.01	0.01
(replicate)	4/29/09	19.7	330	7.5	6.7	760	—	0.06	0.01	0.12	0.02	0.01	0.06
	3/17/10	19.4	340	7.4	7.2	720	<0.66	0.03	0.04	0.11	0.04	0.01	—
	3/10/11	18.9	330	7.3	7.2	710	0.23	0.01	0.04	0.15	0.07	0.02	—
Sand Hollow Reservoir water													
Boat ramp	5/5/04	17.3	710	8.2	8.5	680	—	—	—	—	—	—	—
	9/22/04	18.9	770	8.5	7.2	—	—	—	—	—	—	—	—
	2/10/05	8.3	860	8.4	11.3	—	—	—	—	—	—	—	—
	1/18/06	6.9	820	8.5	11.9	—	—	—	—	—	—	—	—
	2/14/07	5.1	760	8.1	11.6	—	—	—	—	—	—	—	—
	3/13/08	9.6	820	8.4	10.1	—	—	—	—	—	—	—	—
	10/21/08	18.3	820	8.7	8.9	700	—	3.59	0.18	2.3	1.5	0.22	1.49
	4/29/09	16.1	790	8.4	7.0	—	—	4.61	0.20	3.1	2.0	0.32	1.94
	8/10/09	25.0	800	8.6	—	—	2.85	—	—	—	—	—	—
	11/24/09	11.3	800	8.5	9.5	—	2.95	3.29	0.14	2.1	2.6	0.30	—
Boat ramp	3/1610	9.8	820	8.0	9.4	—	2.88	3.64	0.15	3.0	3.3	0.47	—
	3/9/11	8.6	830	8.1	10.7	710	2.73	3.79	0.14	5.31	3.14	0.52	2.86
	2/8/12	6.1	820	8.2	9.2	700	2.70	3.23	0.30	5.37	2.98	0.52	2.91
	4/17/13	13.2	870	7.8	8.6	670	2.84	3.23	0.11	3.89	2.42	0.33	2.02
	4/29/14	15.2	850	9.0	10.5	690	2.64	2.61	0.10	3.36	2.18	0.31	2.00
SH1-18	10/23/08	18.0	820	8.7	9.1	690	—	4.60	0.34	2.5	1.6	0.23	1.16
	4/29/09	14.3	800	8.6	9.6	—	—	2.55	0.22	3.4	2.1	0.26	1.98
	8/10/09	25.3	800	8.7	9.1	—	5.67	—	—	—	—	—	—
	3/16/10	9.6	820	8.0	9.6	—	2.87	3.68	0.13	3.0	3.2	0.44	—
	3/9/11	8.1	820	8.2	10.7	700	2.66	3.52	0.13	5.47	3.19	0.50	—
	2/8/12	5.9	800	8.0	10.7	670	2.76	3.49	0.53	5.45	3.05	0.52	—
	4/18/13	12.5	880	8.0	8.7	680	2.55	3.26	0.12	3.92	2.43	0.31	2.39
	4/30/14	14.1	840	8.2	—	700	2.78	2.98	0.16	—	—	—	—

[1]Total dissolved-gas pressures greater than 1,500 mm Hg exceed the linear calibration of the multi-parameter sonde.

[2]Total dissolved-gas pressure determined with advanced diffusion sampler.

[3]WD RJ monitoring well removed in 2013.

Table 3. Field measurements and major ions, selected trace elements, and nutrient concentrations in groundwater and surface water from selected sites in Sand Hollow, Washington County, Utah.

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; Cl/Br, chloride to bromide ratio; µg/L, micrograms per liter; <, less than; E, estimated; —, no data available; ft, feet]

Site Name	Date	Temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Dissolved-solids concentration (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Alkalinity as $CaCO_3$ (mg/L)	Sulfate (mg/L as SO_4)
Groundwater												
North Dam 3A	10/8/02	15.9	4,430	8.0	5.0	3,020	150	160	590	2.0	148	1,020
	12/18/02	14.7	2,830	8.0	10.8	1,890	110	110	340	3.6	155	584
	3/16/10	22.8	864	7.6	1.3	554	65.8	38.0	51.2	3.0	177	187
	3/10/11	20.3	834	7.4	0.82	538	68.0	36.7	59.0	3.40	170	181
	2/6/12	11.3	820	7.8	—	523	64.8	35.9	58.0	3.36	180	174
	4/15/13	25.7	870	—	1.60	571	68.6	39.4	63.7	3.67	181	201
	4/29/14	23.6	912	8.0	0.32	572	68.8	39.1	64.0	3.67	183	193
WD 4	12/18/02	18.7	350	7.7	8.1	205	29	17	16	2.1	125	18.1
	11/24/09	18.7	338	7.8	9.5	197	28.7	16.6	15.1	2.1	121	20.6
	3/15/10	19.7	362	7.7	9.5	217	27.3	16.2	13.3	2.1	129	19.7
	3/10/11	19.7	361	7.4	10.5	208	31.2	18.3	15.2	2.2	125	21.8
([1])	2/8/12	19.5	549	7.3	8.9	325	44.8	26.6	29.5	2.6	134	68.4
	4/15/13	19.9	696	—	22.5	421	50.8	30.8	46.5	2.91	140	103
	4/29/14	20.5	796	7.7	10.9	486	56.3	33.2	54.3	2.94	138	119
WD 5	12/17/02	17.6	530	7.8	6.6	311	45	22	29	1.8	138	46.8
	11/24/09	16.9	512	8.5	7.2	298	43.1	21.4	27.2	1.8	136	46.4
	3/15/10	21.0	543	7.7	8.1	313	43.3	22.2	24.9	2.0	136	45.8
	3/10/11	19.5	510	7.4	8.0	298	45.7	22.1	26.9	2.0	141	43.8
	4/16/13	19.8	502	7.6	9.1	298	43.7	22.9	27.2	1.92	139	47.6
	4/30/14	20.1	522	7.4	—	319	44.5	22.8	29.8	1.92	136	49.7
WD 6	9/9/02	19.4	290	7.7	—	167	37	3.4	12	1.6	93	24
	4/30/09	19.2	1,040	7.7	22.0	660	98.5	9.0	113	1.6	169	220
	11/23/09	18.9	968	7.9	15.3	629	93.6	8.7	101	1.5	161	210
	3/15/10	19.2	923	7.5	14.4	618	94.1	8.6	86.3	1.5	166	211
	3/9/11	19.1	896	7.5	11.2	577	106	11.5	73.4	1.49	157	208
(replicate)	3/9/11	19.1	896	7.5	11.2	590	106	11.5	72.5	1.47	153	208
	2/7/12	19.1	807	7.3	15.6	542	103	11.5	58.7	1.63	152	200
	4/16/13	18.9	814	7.0	11.8	513	100	12.9	56.9	1.72	144	200
	4/29/14	19.0	814	7.3	10.1	516	99	12.7	55.9	1.91	122	186
WD RJ	12/17/02	18.2	530	7.7	6.4	309	47	22	27	2.3	137	46
	3/15/10	19.6	560	7.6	8.0	338	46.6	22.6	25.1	2.3	139	47.9
	3/9/11	19.6	539	7.3	7.5	324	48.9	23.1	28	2.4	143	47.3
WD 7	9/10/01	18.8	380	7.8	9.8	—	37	12	25	1.9	137	28
WD 8	9/9/02	18.9	305	7.9	—	173	37	10	8.9	2.3	116	15
	2/7/12	18.5	251	7.1	20.8	179	47.1	4.0	6.6	1.6	95	25.9
	4/16/13	18.5	353	7.1	21.1	247	58.6	4.6	11.9	1.7	103	47.2
	4/30/14	18.7	379	7.8	25.9	236	58.1	4.8	13.5	1.8	102	50.9
WD 9	9/11/02	19.5	335	7.9	—	189	36	7	22	1.6	120	18
	4/27/09	16.6	832	7.4	1.8	549	78.2	30.9	53.7	3.4	157	200
	3/15/10	16.4	842	7.3	1.7	543	71.8	31.0	52.2	3.3	157	200
(replicate)	3/15/10	16.4	842	7.3	1.7	545	67.4	28.8	51.0	3.2	155	198
	3/8/11	16.1	902	7.3	0.5	531	73.8	33.9	60.9	3.58	161	188
	2/7/12	16.3	826	7.1	0.4	533	66.4	34.2	56.6	3.45	162	185
	4/15/13	16.1	855	7.3	0.60	545	67.0	38.4	62.1	3.73	167	207
	4/28/14	16.1	877	7.0	0.16	570	67.7	38.5	63.4	3.72	151	191

Table 3. Field measurements and major ions, selected trace elements, and nutrient concentrations in groundwater and surface water from selected sites in Sand Hollow, Washington County, Utah.—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; Cl/Br, chloride to bromide ratio; µg/L, micrograms per liter; <, less than; E, estimated; —, no data available; ft, feet]

Site Name	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Cl/Br	Silica (mg/L as SiO_2)	Iron (µg/L as Fe)	Manganese (µg/L as Mn)	Arsenic (µg/L as As)	Nitrogen (nitrite + nitrate) (mg/L as N)	Nitrogen, nitrite (mg/L as N)	Nitrogen, ammonia (mg/L as N)	Phosphorus (orthophosphate) (mg/L as P)
Groundwater												
North Dam 3A	744	0.90	41.2	18	13.0	<30	<5	90.1	17.8	<0.008	0.03	0.030
	476	0.79	2.44	195	14.0	<30	<5	63.9	14.3	<0.008	<0.04	0.030
	55.2	0.43	0.06	882	15.7	<6	3.19	35.2	<0.04	E0.001	E0.01	0.035
	58.3	0.45	0.06	936	15.5	<3.2	3.48	35.2	0.03	<0.001	0.07	0.033
	55.4	0.39	0.07	778	16.3	12.6	17.3	34.0	0.07	<0.001	0.21	0.037
	60.4	0.34	0.08	715	15.0	4.2	26.1	35.6	0.04	<0.001	0.31	0.038
	60	0.37	0.06	938	15.0	<4	21.2	34.5	0.04	<0.001	0.38	0.038
WD 4	18.8	0.23	0.08	235	14	<10	<2	13.2	2.35	<0.008	<0.04	0.02
	17.2	0.23	0.10	179	14.3	E3.8	<0.2	14.7	2.29	<0.002	<0.02	0.03
	17.9	0.25	0.10	184	15.7	<6	<0.2	14.4	2.29	<0.002	<0.02	0.03
	20.2	0.25	0.14	150	15.3	<3.2	0.19	13.7	2.25	<0.001	<0.01	0.03
([1])	54.5	0.20	0.42	128	15.7	4.5	0.37	11.9	2.21	<0.001	<0.01	0.02
	72.9	0.19	0.54	135	14.5	7.2	0.75	12.2	2.16	<0.001	<0.01	0.025
	93.6	0.21	0.63	149	14.5	<4.0	0.26	11.8	2.22	<0.001	<0.01	0.022
WD 5	44.8	0.29	0.16	280	13	<10	E1	9.1	4.18	<0.008	<0.04	E0.01
	37.9	0.27	0.23	168	13.4	<6	<0.2	9.6	4.61	<0.002	<0.02	0.02
	39.2	0.28	0.24	164	15	<6	<0.2	9.0	4.60	<0.002	<0.02	0.01
	38.2	0.31	0.21	179	14.3	<3.2	0.19	9.3	4.60	<0.001	<0.01	0.01
	40.3	0.24	0.22	187	13.6	4.8	0.41	9.2	4.73	<0.001	<0.01	0.012
	42.8	0.26	0.23	189	13.7	<4.0	<0.02	9.4	4.73	<0.001	<0.01	0.010
WD 6	15.0	E0.08	0.16	94	13.3	<10	E2	2.0	E1.6	<0.008	<0.04	0.020
	92.5	0.32	0.31	295	13.2	<4	0.23	3.3	1.20	<0.002	<0.02	0.011
	80.3	0.30	0.28	286	12.2	<6	<0.2	3.3	1.06	<0.002	<0.02	0.012
	77.9	0.32	0.24	322	13.4	20.8	0.32	3.0	0.97	<0.002	<0.02	0.013
	63.5	0.30	0.14	457	13.5	6.3	0.40	2.8	0.71	<0.001	<0.01	0.010
(replicate)	63.3	0.32	0.14	455	13.6	6.1	0.31	2.8	0.70	0.001	<0.01	0.009
	54.8	0.22	0.08	684	13.9	17.6	0.75	2.3	0.47	<0.001	0.02	0.011
	57.2	0.18	0.07	840	12.9	20.3	0.88	2.3	0.34	<0.001	<0.01	0.009
	53.8	0.18	0.06	928	12.7	10.5	0.50	2.1	0.32	<0.001	<0.01	0.012
WD RJ	47.8	0.51	0.20	239	14	<10	<2	7.9	3.28	<0.008	<0.04	0.01
	47.2	0.51	0.27	176	15.3	<6	<0.2	8.3	3.28	<0.002	E0.01	0.02
	47.4	0.54	0.24	196	14.5	<3.2	0.18	8.5	3.34	<0.001	<0.01	0.01
WD 7	18.0	0.3	0.13	139	14	<10	<3	6.0	3.80	<0.008	<0.04	0.02
WD 8	10.1	0.1	0.07	144	14	<10	<2	6.0	3.90	<0.008	<0.04	0.02
	13.6	0.1	0.08	173	13.8	7.4	0.99	11.5	3.33	<0.001	<0.01	0.02
	19.4	0.07	0.12	169	13.4	11.7	2.25	10.6	3.52	<0.001	<0.01	0.014
	20.5	0.07	0.10	199	13.5	9.3	2.07	10.0	3.60	<0.001	<0.01	0.015
WD 9	21.4	0.5	0.06	357	15	9	15	12.0	0.48	<0.008	<0.04	0.01
	53.4	0.27	0.06	900	12.2	5	3.72	5.8	0.09	<0.002	<0.02	0.013
	56.6	0.24	0.05	1,040	12.1	13.6	0.68	6.1	0.09	<0.002	<0.02	0.014
(replicate)	56.3	0.27	0.05	1,083	11.9	13.5	0.57	6.1	0.09	<0.002	<0.02	0.013
	58.7	0.28	0.04	1,310	11.6	6.7	0.47	6.1	0.05	0.002	<0.01	0.011
	55.6	0.27	0.06	927	11.3	26.3	2.53	5.9	0.06	<0.001	0.01	0.010
	62.1	0.24	0.08	764	10.6	22.4	2.06	5.9	0.04	<0.001	0.01	0.011
	60.7	0.25	0.06	1,029	10.7	16.6	2.64	5.9	<0.04	0.001	0.02	0.013

Table 3. Field measurements and major ions, selected trace elements, and nutrient concentrations in groundwater and surface water from selected sites in Sand Hollow, Washington County, Utah.—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; Cl/Br, chloride to bromide ratio; µg/L, micrograms per liter; <, less than; E, estimated; —, no data available; ft, feet]

Site Name	Date	Temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Dissolved-solids concentration (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Alkalinity as $CaCO_3$ (mg/L)	Sulfate (mg/L as SO_4)
WD 11	5/3/04	18.4	677	7.7	21.5	440	69.0	31.6	68.1	1.7	187	89.7
	4/30/09	15.9	843	7.7	19.4	557	79.2	38.6	49.6	2.4	186	187
	11/23/09	16.3	835	7.9	13.2	553	74.0	35.7	49.4	2.2	171	191
	3/15/10	16.2	837	7.7	10.3	552	67.2	34.3	45.6	2.2	178	190
	3/8/11	16.0	891	7.7	9.9	533	75.2	36.6	51.2	2.15	186	179
	2/7/12	15.4	798	7.4	9.5	529	74.6	34.5	51.6	2.05	193	169
	4/15/13	16.1	832	6.7	11.4	519	71.5	34.3	53.9	2.14	194	166
(replicate)	4/15/13	16.1	832	6.7	11.4	527	73.9	34.5	55	2.08	194	167
	4/28/14	16.2	818	7.3	3.1	520	75.1	32.7	55.3	1.98	154	162
WD 12	9/12/02	—	335	7.9	—	202	37	13	9.0	1.6	115	19
([1])	3/9/11	19.9	1,670	7.1	13.4	1,150	132	57.3	150	3.0	116	440
([1])	2/8/12	19.3	2,100	7.2	9.2	1,510	173	75.0	188	3.5	124	665
	4/16/13	19.0	2,390	7.3	17.8	1,730	192	83.7	237	3.62	131	802
	4/28/14	20.5	2,380	7.4	—	1,750	178	77.1	249	3.59	115	783
WD 13	8/30/01	19.9	275	8.1	—	—	24	16	8.4	1.5	109	12
WD 14	12/18/02	19.3	385	7.7	8.3	220	36	20	10	2.4	122	29
[1]WD 15	4/28/09	18.9	707	8.0	17.6	414	41.0	35.9	48.0	2.1	191	71.4
([1])	11/23/09	18.8	729	8.3	14.5	436	43.3	33.6	57.5	2.1	184	80.4
([1])	3/16/10	19.1	734	7.9	11.5	458	42.0	33.8	51.6	2.1	188	84.7
([1])	3/8/11	19.1	816	8.0	12.5	469	45.9	39.3	60.6	2.1	182	91.3
([1])	2/7/12	19.1	821	8.0	18.8	473	42.2	38.2	67.8	2.1	169	102
	4/17/13	18.9	895	—	17.8	531	50.2	36.7	82.1	2.3	170	122
	4/29/14	18.8	969	7.7	11.7	583	52.4	38.0	88.4	2.3	169	132
(replicate)	4/29/14	18.8	969	7.7	11.7	560	52.2	38.0	88.5	2.34	167	128
WD 16	4/27/09	18.7	444	7.7	8.7	255	44.1	23.0	13.2	1.9	136	33.6
	11/24/09	18.7	449	7.7	7.1	260	42.3	21.9	13.7	1.7	129	33.8
	3/16/10	18.7	441	7.6	5.1	262	41.7	22.4	12.3	1.8	135	33.0
	3/8/11	18.5	478	7.7	4.1	241	45.4	23.0	13.6	1.9	135	32.0
	4/17/13	18.7	432	—	8.1	269	43.1	22.7	13.4	1.76	137	34.4
	4/29/14	18.7	446	7.4	3.7	253	42.5	22.2	14.1	1.81	132	34.3
WD 17	4/16/13	19.4	545	7.6	11.0	332	51.3	20.5	34.0	2.0	141	56.1
WD 18	4/28/09	19.7	500	7.4	7.5	280	45.2	19.5	24.5	1.9	143	40.4
	3/16/10	19.3	467	7.4	4.9	296	43.7	19.2	21.3	1.8	155	37.9
	3/9/11	19.2	476	7.3	7.8	293	46.0	19.2	23.8	1.7	138	38.0
[1]WD 19	3/10/11	19.1	2,030	7.5	9.8	1,120	120	41.6	216	2.8	210	282
([1,2])	2/7/12	18.6	1,900	7.5	6.8	1,150	123	43.1	181	2.9	246	349
WD 20	4/29/09	19.7	331	7.5	6.7	188	30.2	17.4	11.7	2.1	120	20.8
	3/17/10	19.4	344	7.4	7.2	214	28.0	16.1	10.5	1.9	120	19.6
	3/10/11	18.9	332	7.3	7.2	181	31.5	17.7	12.1	2.0	116	18.9
Well 1 at 890 ft	5/6/03	—	350	7.8	—	216	31	21	7.4	2.9	130	19
Well 2 at 400 ft	10/10/02	—	365	8.0	—	208	30	21	9.0	2.1	129	20
Well 2 at 615 ft	10/10/02	—	365	8.1	—	190	30	21	6.5	2.5	131	16
Well 2 at 750 ft	10/10/02	—	370	8.1	—	196	30	22	6.8	2.7	134	18
Well 4	8/29/01	20.1	480	8.0	—	—	36	19	38	2.0	128	58
	9/11/02	19.1	495	8.1	—	297	36	19	35	2.0	124	56
Well 8 at 245 ft	10/8/02	19.0	550	7.5	—	323	49	20	35	2.1	141	70

Table 3. Field measurements and major ions, selected trace elements, and nutrient concentrations in groundwater and surface water from selected sites in Sand Hollow, Washington County, Utah.—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; Cl/Br, chloride to bromide ratio; µg/L, micrograms per liter; <, less than; E, estimated; —, no data available; ft, feet]

Site Name	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Cl/Br	Silica (mg/L as SiO_2)	Iron (µg/L as Fe)	Manganese (µg/L as Mn)	Arsenic (µg/L as As)	Nitrogen (nitrite + nitrate) (mg/L as N)	Nitrogen, nitrite (mg/L as N)	Nitrogen, ammonia (mg/L as N)	Phosphorus (orthophos-phate) (mg/L as P)
WD 11	49.8	0.40	0.25	199	14.5	<6	<0.8	15.3	3.06	<0.008	<0.04	0.020
	49.6	0.35	0.07	687	14.0	<4	<0.2	9.6	0.99	<0.002	<0.02	0.014
	49.8	0.31	0.07	711	13.1	<6	<0.2	10.3	0.67	<0.002	<0.02	0.013
	51.8	0.32	0.07	781	14.3	18.6	0.26	10.0	0.70	<0.002	<0.02	0.016
	53.6	0.31	0.07	811	14.7	4.4	0.26	9.6	0.48	0.001	<0.01	0.012
	53.3	0.26	0.07	733	15.3	11.4	0.34	9.2	0.48	<0.001	<0.01	0.012
	58.1	0.19	0.08	720	14.9	14.5	0.27	8.9	0.51	<0.001	<0.01	0.012
(replicate)	58.2	0.19	0.09	658	16.2	17.9	0.86	8.8	0.52	<0.001	<0.01	0.011
	57.8	0.23	0.07	838	15.2	6.11	0.34	9.0	0.56	<0.001	<0.01	0.014
WD 12	20.0	0.2	0.08	250	15	<10	1	10.0	2.10	<0.008	<0.04	0.02
([1])	196	0.10	1.16	169	17.0	<3.2	0.35	8.2	1.89	<0.001	<0.01	0.009
([1])	264	0.12	1.54	171	17.1	14.5	<0.32	7.3	1.92	<0.001	0.01	0.008
	290	0.09	1.69	172	16.8	<8	<0.32	6.9	1.66	<0.001	<0.01	0.008
	265	0.14	1.46	182	16.9	<8	<0.4	7.2	1.43	<0.001	<0.01	0.007
WD 13	12.1	E0.1	0.05	258	12	<10	2	6.3	2.00	<0.006	<0.04	0.02
WD 14	28.3	0.25	0.11	257	13	<10	<2	15.6	2.18	<0.008	<0.04	0.02
[1]WD 15	57.0	0.41	0.33	174	15	<4	0.7	28.3	3.32	E0.001	<0.02	0.02
([1])	63.5	0.41	0.36	178	14	<6	0.1	28.9	3.46	<0.002	<0.02	0.02
([1])	68.8	0.42	0.36	189	15	<6	<0.2	27.5	3.54	<0.002	<0.02	0.02
([1])	77.0	0.40	0.43	180	14.5	<3.2	<0.16	27.6	3.78	<0.001	<0.01	0.02
([1])	88.2	0.37	0.50	176	14.1	<3.2	2.08	26.7	4.32	<0.001	0.02	0.02
	108	0.31	0.56	193	14.0	6.6	0.65	24.7	3.85	<0.001	<0.01	0.025
	117	0.34	0.58	203	13.7	<4	0.23	24.9	3.80	<0.001	<0.01	0.021
(replicate)	114	0.34	0.58	196	13.7	<4	<0.2	25.0	3.82	<0.001	<0.01	0.020
WD 16	29.1	0.25	0.17	170	14	<4	<0.2	6.2	4.48	E0.001	<0.02	0.01
	28.7	0.21	0.18	158	13	<6	<0.2	6.1	4.50	<0.002	<0.02	0.01
	29.9	0.22	0.18	169	13.8	<6	0.79	5.9	4.44	<0.002	<0.02	0.01
	29.4	0.28	0.18	166	13.6	<3.2	<0.16	6.0	4.43	<0.001	<0.01	0.01
	30.8	0.19	0.19	164	12.9	<4	0.39	6.0	4.60	<0.001	<0.01	0.006
	31	0.21	0.19	165	12.7	<4	<0.2	6.1	4.57	<0.001	<0.01	0.005
WD 17	55.2	0.34	0.30	187	15.0	20.8	0.57	12.8	3.06	<0.001	<0.01	0.015
WD 18	36.1	0.37	0.21	171	16	16	1	10.6	3.15	0.002	<0.02	0.01
	34.1	0.33	0.22	154	15.8	<6	<0.2	10.0	3.14	<0.002	<0.02	0.02
	35.1	0.36	0.22	163	15.3	<3.2	<0.16	10.2	3.12	<0.001	<0.01	0.01
[1]WD 19	252	0.37	1.17	215	17.1	<3.2	<0.16	9.9	8.75	<0.001	<0.01	0.02
([1,2])	192	0.34	0.89	216	17.5	5.2	0.16	9.3	9.38	<0.001	<0.01	0.03
WD 20	16.4	0.28	0.09	178	14	53	1	7.7	2.41	E0.001	<0.02	0.02
	17.2	0.24	0.09	185	14.2	<6	0.53	8.0	2.40	<0.002	<0.02	0.02
	16.9	0.22	0.09	197	14.3	<3.2	<0.16	7.6	2.37	<0.001	<0.01	0.02
Well 1 at 890 ft	16.9	1.08	—	—	11	11	19	9.1	3.37	0.008	0.03	0.01
Well 2 at 400 ft	17.8	0.2	—	—	11	10	12	2.6	3.41	0.008	0.10	0.02
Well 2 at 615 ft	13.2	0.23	—	—	11	27	6	4.6	3.73	0.004	<0.04	0.02
Well 2 at 750 ft	14.3	0.23	0.10	143	12	19	3	5.9	3.84	<0.008	0.03	0.02
Well 4	44.4	E0.1	0.20	218	13	<10	<3	7.1	1.50	<0.006	<0.04	0.02
	42.0	0.2	0.17	247	13	<10	<2	8.0	2.10	<0.008	<0.04	0.02
Well 8 at 245 ft	38.7	0.29	0.15	258	14	<10	5	16.6	1.72	0.03	0.18	0.01

Table 3. Field measurements and major ions, selected trace elements, and nutrient concentrations in groundwater and surface water from selected sites in Sand Hollow, Washington County, Utah.—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; Cl/Br, chloride to bromide ratio; µg/L, micrograms per liter; <, less than; E, estimated; —, no data available; ft, feet]

Site Name	Date	Temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Dissolved-solids concentration (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Alkalinity as $CaCO_3$ (mg/L)	Sulfate (mg/L as SO_4)
Well 9	8/30/01	20.7	285	7.9	—	179	27	16	7.0	1.9	115	13
	9/11/02	19.5	740	8.2	—	458	53	28	52	2.3	124	126
	3/10/11	15.3	777	7.6	3.8	535	60.2	36.1	54.2	3.32	151	175
Sand Hollow Reservoir water												
Haul road	9/10/02	24.2	1,000	8.8	—	669	63	43	71	5.3	92	300
Boat ramp	5/5/04	17.3	710	8.2	8.5	442	63	26	45	3.3	161	122
	4/29/09	16.1	790	8.4	7.0	503	54.3	37.4	53.7	4.0	147	189
	11/24/09	11.3	797	8.5	9.5	502	40.9	39.8	62.9	4.3	108	212
	3/16/10	9.8	817	8.0	9.4	534	43.5	38.4	57.6	4.6	120	211
	3/9/11	8.6	827	8.1	10.7	534	60.2	39.2	62.2	4.5	142	212
	2/6/12	6.1	821	8.2	9.2	534	53.6	39.8	61.3	4.3	138	213
	4/17/13	13.2	874	7.8	8.6	562	56.5	42.7	66.0	4.89	149	223
	4/29/14	15.2	846	9.0	10.5	535	52.0	40.8	66.2	4.66	134	207
SH 1-18	4/29/09	14.3	800	8.6	9.6	502	56.1	37.2	53.6	4.2	146	190
	8/10/09	25.3	800	8.7	9.1	501	42.6	38.3	60.5	4.3	110	—
	3/16/10	9.6	819	8.0	9.6	525	45.9	40.8	58.6	4.7	124	211
	3/9/11	8.1	820	8.2	10.7	528	60.1	39.6	61.2	4.43	140	210
	2/8/12	5.9	801	8.0	10.7	526	54.2	39.5	59.6	4.28	140	214
	4/18/13	12.5	883	8.0	8.7	553	58.1	43.1	67.1	4.73	148	223
	4/30/14	14.1	835	8.2	—	531	51.7	40.6	65.8	4.38	136	200

[1] High or increasing dissolved-solids concentrations but low Cl/Br ratios indicate groundwater is affected by flushing of naturally occurring solutes in vadose zone prior to reservoir construction.

[2] Replicate sample not reported because submersible pump was re-installed for sample collection and dissolved-solids concentration differed by more than 10 percent.

Table 3. Field measurements and major ions, selected trace elements, and nutrient concentrations in groundwater and surface water from selected sites in Sand Hollow, Washington County, Utah.—Continued

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; Cl/Br, chloride to bromide ratio; µg/L, micrograms per liter; <, less than; E, estimated; —, no data available; ft, feet]

Site Name	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Cl/Br	Silica (mg/L as SiO_2)	Iron (µg/L as Fe)	Manganese (µg/L as Mn)	Arsenic (µg/L as As)	Nitrogen (nitrite + nitrate) (mg/L as N)	Nitrogen, nitrite (mg/L as N)	Nitrogen, ammonia (mg/L as N)	Phosphorus (orthophosphate) (mg/L as P)
Well 9	13.0	0.20	0.07	186	13	<10	<3	12.4	2.40	<0.006	<0.04	0.02
	72.2	0.20	0.28	258	14.2	250	6.0	17.0	2.20	<0.008	<0.04	0.020
	53.8	0.33	0.08	706	11.7	13.5	2.61	13.8	0.56	<0.001	<0.01	0.009
Sand Hollow Reservoir water												
Haul road	76.0	0.30	0.02	3,800	4.9	<10	<2	2.0	0.04	<0.008	<0.04	0.02
Boat ramp	50.0	0.21	0.01	5,000	7.3	<6	1.3	1.1	—	—	—	—
	54.9	0.31	0.04	1,227	2.9	<4	0.3	1.4	0.04	0.002	<0.02	0.008
	60.4	0.28	0.05	1,313	1.5	<6	0.2	1.6	<0.04	<0.002	<0.02	0.008
	61.7	0.30	0.04	1,374	1.4	6.3	1.7	1.3	E0.03	<0.002	0.02	<0.008
	57.0	0.30	0.04	1,390	4.0	<3.2	2.0	1.13	0.10	0.004	0.03	<0.004
	58.3	0.27	0.05	1,108	4.2	<3.2	0.86	1.01	0.12	0.001	0.01	<0.004
	65.8	0.25	0.08	875	2.9	5.2	1.22	<0.04	0.09	0.007	0.04	<0.004
	65.3	0.27	0.05	1,280	1.2	<4	0.74	1.3	0.04	0.002	<0.01	<0.004
SH 1-18	54.6	0.27	0.04	1,318	3.0	<4	0.4	1.4	0.04	0.003	0.13	0.008
	—	0.24	—	—	1.3	3	0.3	1.6	<0.04	<0.002	<0.02	0.008
	61.6	0.30	0.04	1,417	1.2	6.2	1.8	1.4	E0.02	<0.002	0.02	<0.008
	57.2	0.30	0.04	1,546	3.9	<3.2	2.10	1.12	0.10	0.005	0.02	<0.004
	56.5	0.27	0.05	1,060	4.1	<3.2	1.31	1.04	0.09	0.001	0.02	<0.004
	65.3	0.25	0.07	898	2.8	2.1	0.82	1.2	0.09	0.007	0.03	<0.004
	63.2	0.26	0.05	1,170	1.1	<4	0.45	1.2	0.04	0.001	<0.01	<0.004

Summary

Since its inception in 2002, diversions to Sand Hollow Reservoir from the nearby Virgin River generally have resulted in rising reservoir stage, ranging from about 3,000 feet in 2002 to a maximum of about 3,060 feet in 2006, which then fluctuated between about 3,040 and 3,060 feet from 2008 through 2014. Similarly, groundwater levels in monitoring wells closest to the reservoir generally rose between 2002 and 2006, and then fluctuated with reservoir altitude and pumpage rate from nearby production wells. Water levels in monitoring wells farther from the reservoir were still rising through 2014.

About 29,000 acre-feet (acre-ft) of groundwater were withdrawn between 2004 and 2014 from production wells located near Sand Hollow Reservoir. French drains, installed to capture shallow seepage near the reservoir, were also pumped as they filled with water. About 8,000 acre-ft of groundwater were pumped from the North Dam drain between 2003 and 2014. This water initially was returned to the reservoir, but since 2007, has been used by Sand Hollow Resort for irrigation. About 2,100 acre-ft of water were pumped from the West Dam drain back into the reservoir from 2005 through 2014. In 2006, the West Dam Spring drain was constructed and has largely replaced the function of the West Dam drain. About 21,000 acre-ft were pumped from this drain from 2006 through 2014 into the Washington County Water Conservancy District's municipal supply system.

Total annual surface-water inflow to Sand Hollow Reservoir ranged from about 56,000 acre-ft in 2005 to 800 acre-ft in 2007. Total inflow from 2002 through 2014 was about 216,000 acre-ft. The general increase in reservoir water-level altitude and surface area from 2002 to 2007 resulted in a steady increase in the volume of annual evaporation from about 1,000 to about 6,600 acre-ft through 2006, which then leveled off from 2007 through 2014. Total estimated cumulative evaporative loss from 2002 through 2014 was about 70,000 acre-ft. During this same period, annual reservoir recharge to the underlying Navajo Sandstone aquifer fluctuated between about 5,000 and 18,000 acre-ft. Total calculated reservoir recharge from 2002 through 2014 was about 127,000 acre-ft with a 2 standard deviation uncertainty of 11,900 acre-ft. From 2002 through 2014, calculated monthly recharge volumes ranged from 50 to almost 3,500 acre-ft, and average daily recharge rates (calculated for each month) ranged from 0.001 to 0.43 feet.

Annual water-quality sampling, including field parameters, chemistry, and environmental tracers (tritium, chlorofluorocarbons, sulfur hexafluoride) was continued during 2013 and 2014. The most significant changes occurred at monitoring wells WD 4 (2,600 feet from the reservoir) and WD 12 (1,000 feet away), where increases in salinity (specific conductance) and dissolved oxygen (and environmental tracer concentrations at WD 4) indicate rising groundwater levels and mobilization of vadose-zone salts, likely a precursor to the arrival of reservoir recharge. At wells WD 9 (55 feet away) and WD 11 (160 feet away), field parameters, and water-quality and environmental tracer data indicate that reservoir recharge arrived several years prior to 2014. At well WD 6 (1,000 feet away), salinity, chloride to bromide ratios, and environmental tracer data all indicate the recent arrival of reservoir recharge. Although well WD 8 is located only 500 feet from the reservoir, it is downgradient of an area of high natural recharge on Sand Mountain and may lie along a groundwater boundary between the two recharge mounds; relatively high concentrations of modern environmental tracers may be caused by natural recharge. At WD 15 and WD 16 (nested wells located 2,400 feet from the reservoir), water-quality and environmental tracer data indicate a rising water table, but no arrival yet of reservoir recharge.

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