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Pre-and Post-Reservoir Ground-Water Conditions and Assessment of Artificial Recharge at Sand Hollow, Washington County, Utah, 1995-2005

Scientific Investigations Report 2005-5185

Prepared in cooperation with the
Washington County Water Conservancy District,
Bureau of Reclamation, and the
University of Utah Department of Geology and Geophysics

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

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By V.M. Heilweil, D.D. Susong, P.M. Gardner, and D.E. Watt

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Salt Lake City, Utah
2005

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, DATUMS, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (k^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.59	square kilometer (k^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
cubic inch (in^3)	16	milliliter (ml)
	Flow rate	
inch per day (in/d)	2.54	centimeters per day (cm/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per foot (ft/ft)	1	meter per meter (m/m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/k)
	Weight	
ton	1,016.05	kilogram (k)
	Dynamic viscosity	
pounds per foot-second (lb/ft-sec)	1,488	centipoise

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

$$°F = (1.8 \times °C) + 32.$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88); horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

Chemical concentration and water temperature are reported only in International System (SI) units. Chemical concentration in water is reported either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Chemical concentration in rock is reported as parts per million (ppm). Atmospheric deposition of solutes is reported as milligrams per square inch (mg/in^2) and milligrams per square centimeter (mg/cm^2). The chlorofluorocarbon concentration in water is reported in picomoles per kilogram (pmole/kg). These units express the solute weight per unit volume (liter) or unit mass (kilogram) of water. A liter of water is assumed to weigh 1 kilogram. The numerical value in milligrams per liter is about the same as for concentrations in parts per million. One thousand micrograms per liter is equivalent to 1 milligram per liter, one million picomoles per kilogram is equivalent to 1 mole per liter, and one million parts per trillion is equivalent to 1 part per million. A mole of substance is its atomic or formula weight in grams. Concentration in moles per liter can be determined from milligrams per liter by dividing by the atomic or formula weight of the constituent, in milligrams. Stable isotope concentration is reported as per mil, which is equivalent to parts per thousand.

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

Pre- and Post-Reservoir Ground-Water Conditions and Assessment of Artificial Recharge at Sand Hollow, Washington County, Utah, 1995-2005

By Victor M. Heilweil, David D. Susong, Philip M. Gardner, and Dennis E. Watt

ABSTRACT

Sand Hollow, Utah, is the site of a surface-water reservoir completed in March 2002, which is being operated by the Washington County Water Conservancy District. The reservoir is an off-channel facility receiving water from the Virgin River, diverted near the town of Virgin, Utah. It is being operated conjunctively, providing both surface-water storage and artificial recharge to the underlying Navajo aquifer. The U.S. Geological Survey and the Bureau of Reclamation conducted a study to document baseline ground-water conditions at Sand Hollow prior to the operation of the reservoir and to evaluate changes in ground-water conditions caused by the reservoir.

Pre-reservoir age dating using tritium/helium, chlorofluorocarbons, and carbon-14 shows that shallow ground water in the Navajo Sandstone in some high-infilration areas of Sand Hollow entered the aquifer from 2 to 25 years before sample collection. Ground water in low-infiltration areas and deeper within the aquifer may have entered the aquifer more than 8,000 years ago. Ground-water levels in the immediate vicinity of Sand Hollow Reservoir have risen by as much as 80 feet since initial filling began in March 2002. In 2005, ground water was moving laterally away from the reservoir in all directions, whereas the pre-reservoir direction of ground-water flow was predominantly toward the north.

Tracers, or attributes, of artificial recharge include higher specific conductance, higher dissolved-solids concentrations, higher chloride-to-bromide ratios, more-depleted stable isotopes (δ^2H and δ^{18}O), and higher total-dissolved gas pressures. These tracers have been detected at observation and production wells close to the reservoir. About 15,000 tons of naturally occurring salts that previously accumulated in the vadose zone beneath the reservoir are being flushed into the aquifer. Except for the shallowest parts of the aquifer, this is generally not affecting water quality, largely because of the large saturated thickness of the Navajo aquifer. Since the initial filling of Sand Hollow Reservoir, arsenic concentrations have risen to exceed U.S. Environmental Protection Agency standards in some shallow observation wells. These increases in arsenic concentration are likely caused by increasing pH associated with artificial recharge beneath the reservoir, rather than flushing of previously accumulated salts in the vadose zone. There has been no trend of increasing arsenic concentration in deeper production wells.

Estimated evaporation rates for Sand Hollow Reservoir, calculated by the Jensen-Haise method with data from the Sand Hollow weather station, range from about 55 to 61 inches per year and result in a total evaporative loss of about 6,000 acre-feet of water from March 2002 to September 2004. Rates of artificial recharge of ground water beneath Sand Hollow Reservoir have ranged from about 0.02 to 0.44 feet per day, with an average rate excluding the initial 3-month wetting period of about 0.06 feet per day. A total of about 28,000 acre-feet of recharge to the underlying Navajo aquifer occurred from March 2002 to September 2004.

INTRODUCTION

Ground water in fractured bedrock aquifers is increasingly being used to meet the demands of rapidly growing communities in the arid southwestern United States. The Navajo Sandstone is a regionally important bedrock aquifer. It is part of the Dakota-Glen Canyon aquifer system, consisting of permeable sedimentary formations ranging in age from Lower Jurassic to Upper Cretaceous, and is the principal source of ground water in the Colorado Plateau region (Robson and Banta, 1995). This aquifer system covers an area of more than 75,000 mi^2 in Utah, Arizona, Colorado, and New Mexico. Many municipalities in this region, including most cities and towns in Washington County, Utah, derive the majority of their municipal water from the Navajo aquifer.

Washington County is in the northeastern corner of the Mojave Desert and is therefore the warmest, driest, and lowest-altitude part of Utah. Average annual precipitation at St. George, Utah, is about 8 in. per year (Western Region Climate Center, 2004). However, a recent 5-year drought has reduced this annual rainfall to about 5 in. during 1999-2003. Meanwhile, the population of Washington County has nearly doubled from 48,000 in 1990 to 90,000 in 2000 (U.S. Census Bureau, 1992, 2003) and is expected to increase to nearly 230,000 by 2020 (Boyle Engineering and Alpha Engineering, Washington County Water Conservancy District Purpose and Need Study, 84 p., written commun., 1995). The combination of low rainfall and rapid growth is driving the need to actively develop water resources, including ground water from the Navajo aquifer. To better manage this resource, Sand Hollow Reservoir was constructed in 2002 to provide both surface-water storage and artificial recharge to the underlying Navajo aquifer (fig. 1). This will use the storage within the previously unsaturated part of the Navajo Sandstone. The source of water for the reservoir is the Virgin River. Because of the large range of flow in the Virgin River caused by variable spring snowmelt runoff and monsoonal precipitation, the number of years required to fill Sand Hollow Reservoir is unknown. The maximum acreage and storage volume of the surface-water reservoir, when full, will be 1,300 acres and 50,000 acre-ft, respectively.

The numbering system used in Utah for hydrologic-data sites is illustrated in figure 2. This system locates sites in the study area by township, range, and section. Corresponding map numbers for each of the sites are shown in figure 3 and are included for reference in all of the tables within the report.

Purpose and Scope

This report documents (1) baseline water-level and water-quality conditions in the Navajo aquifer of Sand Hollow prior to the construction of Sand Hollow Reservoir; (2) water-level and water-quality changes within the aquifer during the initial 3 years of operation of the reservoir; and (3) estimates of reservoir evaporation and ground-water recharge beneath Sand Hollow Reservoir. This is a cooperative study including the Washington County Water Conservancy District (WCWCD), the U.S. Geological Survey (USGS), the Bureau of Reclamation (BOR), and the University of Utah Department of Geology and Geophysics. Supporting data presented in this report include well completion and water-level information, meteorology data, reservoir water-temperature profiles, and physical properties and chemical constituents for ground water and surface water. Chemical constituents include major and trace ions, nutrients, dissolved-gas concentrations, and stable and radioactive isotopes of hydrogen, oxygen, and carbon. Some of these chemical constituents collected prior to the completion of the surface-water reservoir are used for determining ages and residence times of ground water prior to artificial recharge.

Previous Studies

Geologic and previous hydrologic data for Sand Hollow are presented in Cordova (1978), Hurlow (1998), Wilkowske and others (1998), and Heilweil and others (2000). Vadose-zone physical and pore-water chemical properties of the Navajo Sandstone and the calculation of natural recharge rates by using environmental tracers is presented in Heilweil and others (in press). Vadose-zone solute accumulations in trenches and implications for the spatial variability of natural recharge at Sand Hollow are discussed in Heilweil and Solomon (2004). A field-scale infiltration pond artificial recharge experiment conducted prior to the construction of Sand Hollow Reservoir is described in Heilweil and others (2004). Additional hydrogeologic data are available in Heilweil (2003).

Acknowledgments

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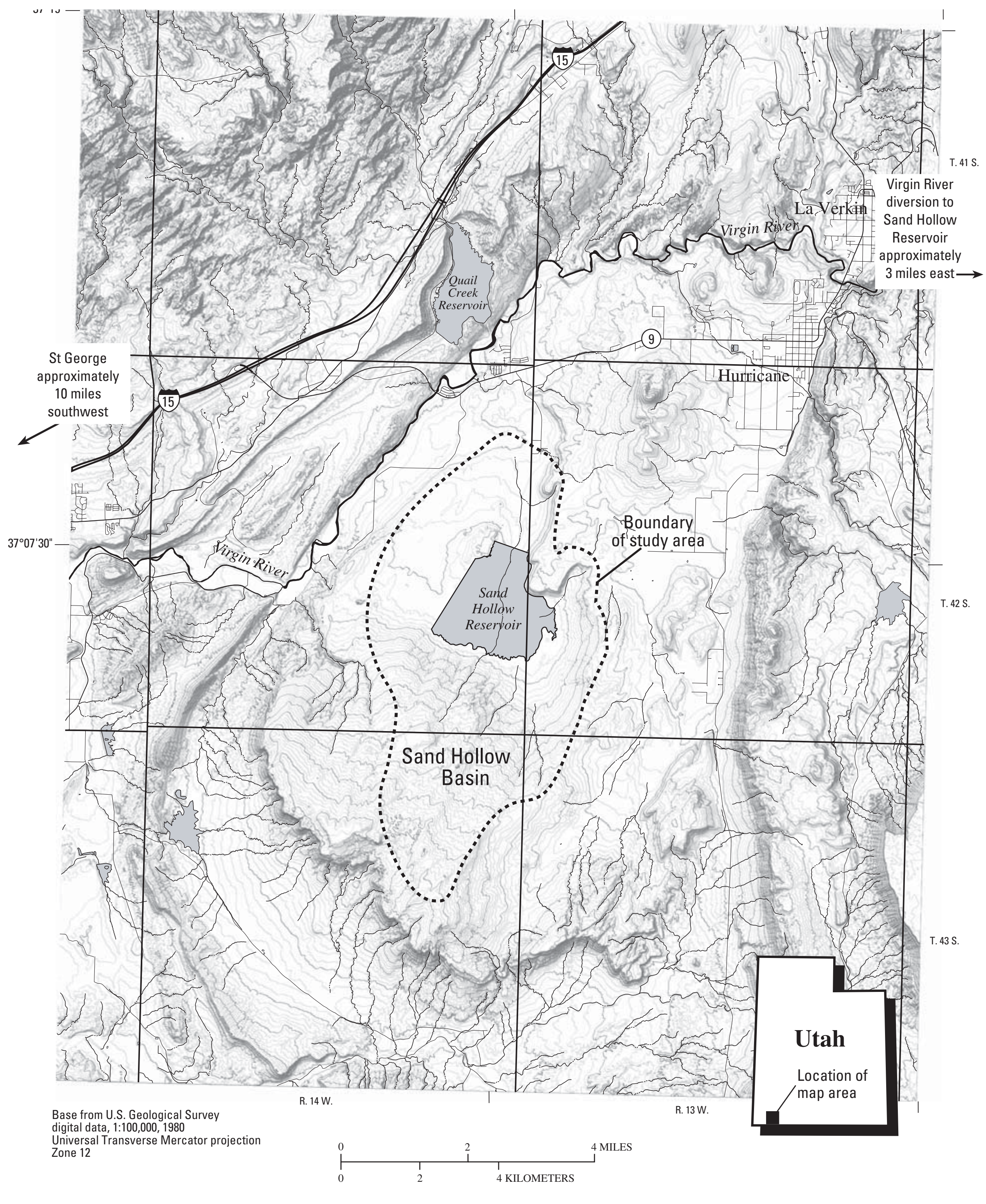
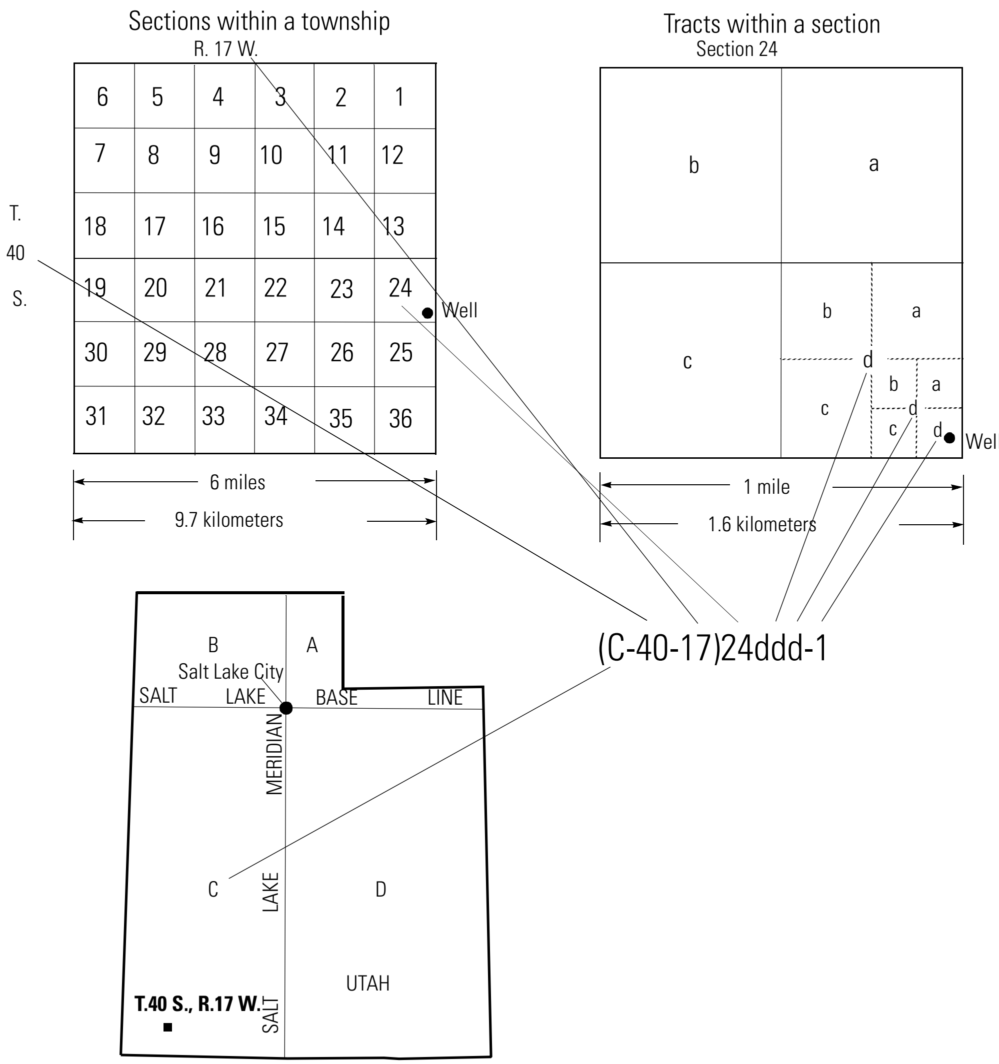


Figure 1. Location of Sand Hollow study area, Washington County, Utah.

The system of numbering wells and springs in Utah is based on the cadastral land-survey system of the U.S. Government. The number, in addition to designating the well or spring, describes its position in the land net. The land-survey system divides the State into four quadrants separated by the Salt Lake Base Line and the Salt Lake Meridian. These quadrants are designated by the uppercase letters A, B, C, and D, indicating the northeast, northwest, southwest, and southeast quadrants, respectively. Numbers designating the township and range, in that order, follow the quadrant letter, and all three are enclosed in parentheses. The number after the parentheses indicates the section and is followed by three letters indicating the quarter section, the quarter-quarter section, and the quarter-quarter-quarter section—generally 10 acres for a regular section[1]. The lowercase letters a, b, c, and d indicate, respectively, the northeast, northwest, southwest, and southeast quarters of each subdivision. The number after the letters is the serial number of the well or spring within the 10-acre tract. When the serial number is not preceded by a letter, the number designates a well. When the serial number is preceded by an "S," the number designates a spring. A number having all three quarter designations but no serial number indicates a miscellaneous data site other than a well or spring, such as a location for a surface-water measurement site or tunnel portal. Thus, (C-40-17)24ddd-1 designates the first well constructed or visited in the southeast 1/4 of the southeast 1/4 of the southeast 1/4 of section 24, T. 40 S., R. 17 W.



[1]Although the basic land unit, the section, is theoretically 1 square mile, many sections are irregular in size and shape. Such sections are subdivided into 10-acre tracts, generally beginning at the southeast corner, and the surplus or shortage is taken up in the tracts along the north and west sides of the section.

Figure 2. Numbering system used for hydrologic-data sites in Utah.

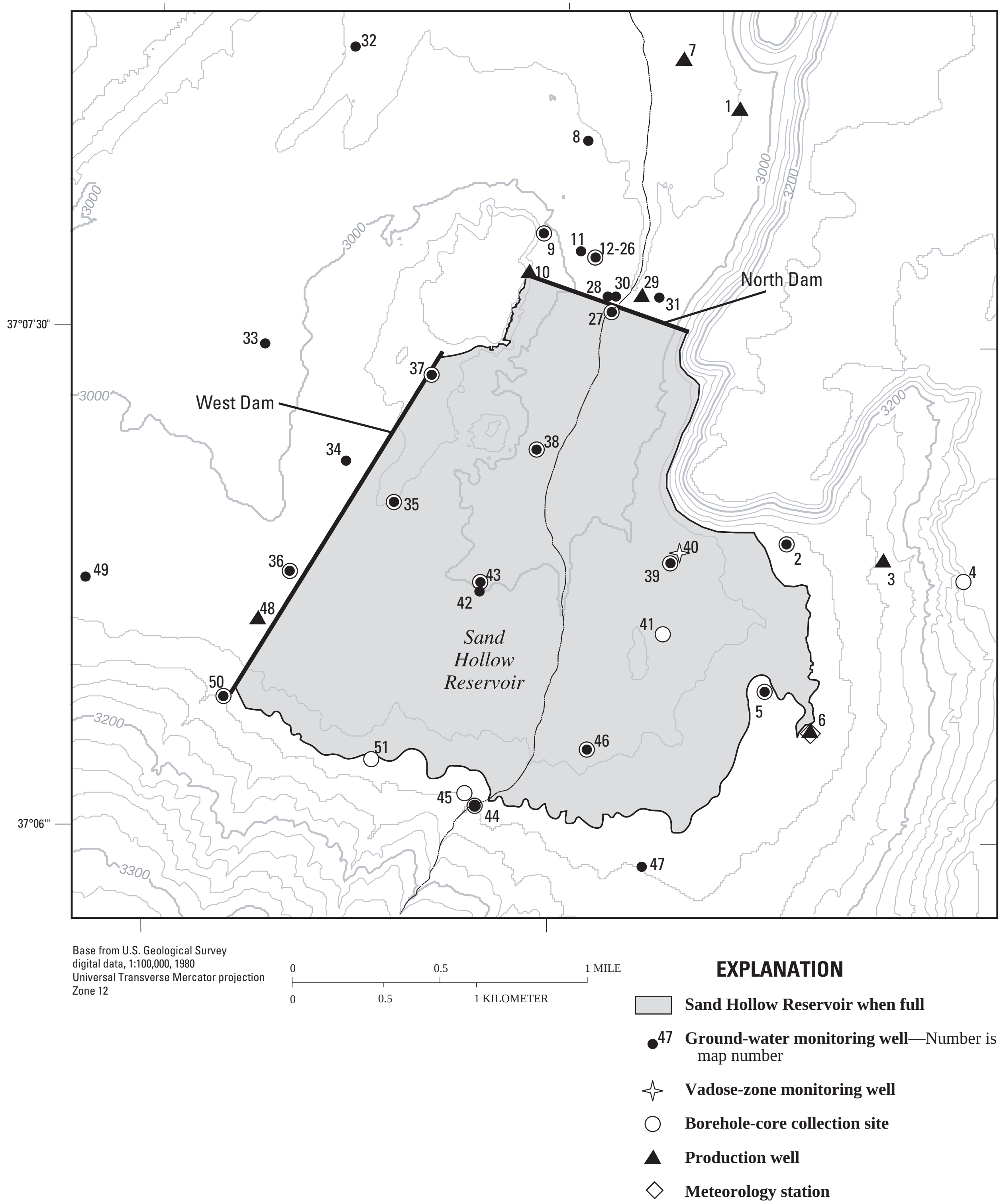


Figure 3. Location of wells, borehole-core collection sites, and weather station in Sand Hollow, Utah.

the University of Utah Stable Isotope Ratio Facility for Environmental Research (SIRFER) Laboratory for his assistance in the analysis of stable isotope samples. Within the USGS, the authors thank John Izbicki of the Water Resources Discipline (WRD) San Diego, California, office for providing the atmospheric deposition sampler and anion analyses, and personnel from the WRD Cedar City, Utah, office for installing monitoring-well instrumentation.

Hydrogeologic Setting

Sand Hollow is a 20-mi^2 basin located in the southeastern part of Washington County, Utah, about 10 mi northeast of St. George (fig. 1). It is part of the Virgin River drainage basin of the Lower Colorado River Basin. Washington County is in the lowest-altitude part of Utah; the altitudes within Sand Hollow Basin range from about 3,000 to 4,200 ft.

Sand Hollow is underlain primarily by Navajo Sandstone that is either exposed at the surface or covered by a veneer of soil or surface-flood basalts (Hurlow, 1998). Although the total stratigraphic thickness of the Navajo Sandstone in this region is more than 2,000 ft, much of this has been eroded off within the study area, resulting in a sandstone thickness ranging from a few hundred to more than 1,200 ft thick. The Navajo Sandstone is characterized as fine-grained quartzose sandstone loosely cemented with calcite (Cordova, 1978). Predominant cross-bedding features reflect its eolian depositional environment (Hurlow, 1998). Because the Navajo Sandstone at Sand Hollow is only loosely cemented and well sorted, it has a relatively high porosity and permeability. Laboratory porosity and saturated hydraulic conductivity, as determined from core samples within the study area, ranged from 20 to 27 percent and 0.03 to 1.38 ft/d, respectively (Heilweil and others, 2004). Depth to the water table prior to the completion of the reservoir ranged from about 50 to 150 ft below land surface in the central and northern parts of the basin (table 1), providing a substantial volume of vadose zone available for conversion to ground-water storage. These properties make the Navajo Sandstone of Sand Hollow a good target for aquifer storage and recovery.

Methods

Water-Level Data

Water levels were measured with both steel and electric tapes in 44 observation wells in Sand Hollow Basin from 1995 through 2004 (tables 1 and 2). Six wells have been measured monthly by the WCWCD since 1995 and eight additional wells were added to the monthly monitoring network in August 2001, prior to the inception of the reservoir in March 2002. Wells measured monthly by the WCWCD have had sporadic check measurements performed by USGS personnel for quality assurance.

Ground-Water Samples

Ground-water samples were collected from open 4-in.-diameter boreholes, 1- and 2-in.-diameter polyvinyl chloride (PVC) piezometers, and production wells for chemical analysis. Water samples from the open 4-inch-diameter boreholes and the 2-in.-diameter piezometers were collected by using an air-operated submersible piston pump. Water samples were collected from the 1-in.-diameter piezometers by using Waterra valves with 5/8-in.-diameter polyethelene tubing. A minimum of three casing volumes (or until specific conductance stabilized) was purged from all of the boreholes and wells prior to sample collection. Samples were collected in clean polyethelene bottles and filtered with 0.45-micron disposable filters. Samples for metals analysis were preserved with 7.7-normal nitric acid.

Dissolved-gas samples were collected as water samples in copper tubes and as gas samples with in-situ diffusion samplers. The copper-tube collection method for dissolved gases is described by Stute and Schlosser (2001). The diffusion sampler-method is described by Sheldon (2002). The diffusion sampler consists of a small copper chamber (about 0.05 in^3) with gas-permeable membranes. Samplers were installed at the depth of the perforated zone in each well and allowed to equilibrate with the water for 24 hours. These samples were quickly removed and cold-welded by using a pinch-off tool.

Surface-Water Samples

Surface-water samples were collected from the Virgin River, Sand Hollow Reservoir, and the main ephemeral wash near the WD 8 observation well (map number 44 in fig. 3, table 1) for chemical analysis. Samples were filtered with 0.45-micron disposable membrane filters attached to a peristaltic pump. Samples for metals analysis were preserved with 7.7-normal nitric acid.

Chemical Analyses

Ground-water, surface-water, and precipitation samples collected during this study were analyzed for (1) major and minor cations and anions, (2) selected trace elements, (3) stable isotopic ratios of carbon, oxygen, and hydrogen, (4) carbon-14 (^{14}C) and tritium, and (5) dissolved gases including chlorofluorocarbons, nitrogen, argon, krypton, neon, and helium. All major and minor cations and anions, as well as trace elements, were collected by using USGS procedures described by Wilde and others (1998). These were analyzed by the USGS National Water-Quality Laboratory in Denver, Colorado, the USGS in San Diego, California, and the Los Alamos National Laboratory in Los Alamos, New Mexico. Water samples for ^{14}C and stable-carbon isotopes were collected according to procedures described by Coplen and others (1996) and analyzed by the University of Waterloo in Waterloo, Ontario. Water samples for the stable isotopes of hydrogen and oxygen were collected according to procedures described by Coplen and others (1996) and analyzed on a Finnigan Delta S isotope ratio mass spectrometer at the University of Utah SIRFER Laboratory. Tritium samples were analyzed for helium-3 with the tritium in-growth method (Clarke and others, 1976). Helium-3 and other dissolved-gas concentrations were analyzed by using both quadrapole and MAP mass spectrometers at the University of Utah Dissolved Gas Service Center. The mass-spectrometer analysis provides the relative mole fractions of dissolved gases. The dissolved-gas concentration of the water sample is then calculated based on Henry's law relations by using field measurements of total dissolved-gas pressure and water temperature.

Four vadose-zone pore-air samples were collected from ports at a 45-ft depth in the Slope 1B borehole (map number 40 in fig. 3, table 1) and at a 96.7-ft depth in the Slope 2 borehole (map number 2 in fig. 3, table 1) for analysis of stable carbon-13 ($\delta^{13}C$). Samples were collected from 3/8-in.-diameter copper tubes with 0.3-ft-length mesh screens installed in these boreholes and backfilled with silica sand adjacent to the ports and bentonite clay elsewhere to minimize vertical contamination. After removing the equivalent of three casing volumes of pore air from the copper tubing with a peristaltic pump, gas samples were collected and sealed in evacuated mylar balloons. The pore-air samples were analyzed by Geochron Laboratories in Cambridge, Massachusetts, and the data were used for correcting ground-water ^{14}C ages.

Meteorology and Precipitation Data

Meteorology data were collected at a weather station (map number 6, fig. 3) in Sand Hollow from January 13, 1998, through September 20, 2004. Parameters measured were temperature, wind speed, wind direction, precipitation, relative humidity, and solar radiation. Instruments used were a Vaisala Temperature and RH probe, RM Young Wind Monitor, Weathertronics tipping bucket rain gage, and a Matrix MK 1-G Sol-A-Meter with a spectral response from 0.35 to 1.15 microns. Sensors collected data every minute, with average hourly values, except for cumulative values of precipitation, stored on a data logger. The anemometer at the Sand Hollow weather station began to under-measure wind speeds in 2002, probably as the result of bearing failure. To correct for this, average daily and monthly wind speeds for 1999-2001 and 2002-04 were compared. The winds speeds in the later period were adjusted by adding the instrument threshold of 1.5 ft per second to the average hourly wind speeds.

Atmospheric-deposition samples for individual storms were collected for chemical analyses by using a 0.5-ft-diameter brass funnel draining into a 250-milliliter high-density polyethylene bottle. Composite atmospheric-deposition samples also were collected at multiple-month intervals for water-quality analyses. The sampler consisted of a 3-in.-diameter straight-sided Buchner funnel at a height of about 3 ft above ground supported by a stake and connected with copper tubing to a 1-liter plastic sample bottle buried about 1 ft below ground. A thin (0.5-in.) layer of mineral oil in the bottle was used to minimize evaporation of water (Friedman and others, 1992). To sample both wet fall and dust deposition between rainfall events, the funnels for both the individual storms and the multiple-month composite samples were not rinsed. Rather, only particulate matter, such as insect debris and bird droppings, was removed during routine maintenance.

Temperature of Reservoir Water

Continuous water temperature measurements were made in Sand Hollow Reservoir for both turbulent transfer evaporation calculations and for evaluating effects of changing viscosity on seepage rates beneath the reservoir. A string of five thermisters was installed in the deepest part of Sand Hollow Reservoir, about 300 ft from the North dam. The thermisters were attached to a floating buoy at depths of 0.3, 3, 10, 16, and 33 ft or bottom of the reservoir, if shallower. The thermisters are reported to have an accuracy of less than 0.5ºC over the temperature range of 0 to 35 ºC. Temperature data were collected from January 30, 2003, through September 21, 2004. However, because of instrument malfunctions, data are missing for the thermisters from May 6 to August 4, 2003. Data also are missing for the thermister at the 3.3-ft depth from August 4 to October 9, 2003, and the thermisters at the 0.3-ft and 3.3-ft depths from May 4 through September 21, 2004.

Evaporation and Artificial Recharge

To calculate artificial recharge to the Navajo aquifer underlying Sand Hollow Reservoir, the following water-budget equation was used:

$$R = I_{sw} - O_{sw} \pm S - E \qquad (1)$$

where

R is recharge,
I_{sw} is surface-water inflow,
O_{sw} is surface-water outflow,
S is change in surface-water storage, and
E is evaporation.

Surface-water inflow and outflow to Sand Hollow Reservoir, along with reservoir-stage measurements, were recorded monthly by the WCWCD. Changes in surface-water storage were calculated from reservoir-stage measurements and stage-volume relations for the reservoir (Washington County Water Conservancy District, written commun., 2004).

Evaporation from Sand Hollow Reservoir was determined by using multiple methods to develop more confidence in evaporation estimates and to assess simple and cost-effective methods for estimating evaporation. Evaporation from a reservoir surface is a function of climatic conditions, water temperature, and the reservoir-surface area. There are numerous methods for measuring and estimating evaporation from a reservoir that vary in complexity from simple temperature index calculations to complete measurement of the energy balance and fluxes (Warnaka and Pochop, 1988; Winter and others, 1995). For this study, the Jensen-Haise and turbulent-transfer methods were calculated by using climate date from the Sand Hollow weather station. These results are compared to long-term average pan evaporation measurements and Penman evaporation calculations for St. George, Utah (Western Regional Climate Center, 2004).

Pan Evaporation

Pan evaporation was measured in St. George, Utah, from 1869 to 1993 with a standard class A pan (Western Region Climate Center, 2004). Pan evaporation for winter months (December – February) was not measured because of freezing temperatures. Pan-evaporation data from long-term records at nearby Boulder City, Nevada, and Wahweap, Utah, were collected year round, and indicate that 7 to 10 percent of annual evaporation occurs in the winter months. Pan-evaporation data must be corrected to account for the thermal effects of the pan and ground on the evaporation rate. Typically a coefficient of 0.6-0.8 is used to make this correction.

Penman Evaporation

The general Penman equation (Winter and others, 1995) is a simplified energy budget approach that requires temperature, relative humidity, wind speed, net solar radiation, and soil or water temperature data. Penman evaporation was calculated by the Western Regional Climate Center (2004) with climate data from St. George, Utah.

Jensen-Haise Evaporation

Air-temperature and solar-radiation data from the Sand Hollow weather station were used with the Jensen-Haise equation to calculate evaporation. In detailed comparisons with other methods, the Jensen-Haise method has been shown to be reasonably accurate (Winter and others, 1995). There are several forms of the Jensen-Haise equation. For this study, the version described by McGuinness and Bordne (1971) is used:

$$PET = \{[((0.014Ta) - 0.37)(Qs)]0.000673\}2.54 \qquad (2)$$

where

PET is potential evaporation in centimeters,

Ta is air temperature, in degrees Fahrenheit, and

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

Daily and monthly evaporation was calculated with the Jensen-Haise method. Because the method was developed for periods longer than 5 days (Winter and others, 1995), daily evaporation calculated with this method was used only for preliminary comparison with the turbulent-transfer method. Final analysis of the differences between the two methods was done on a monthly basis.

Turbulent-Transfer Evaporation

The turbulent-transfer method calculations for this study use Brutsaert's formulation of the Businger-Dyer model (Brutsaert, 1982). Evaporation was calculated with the program "trbxfr" in the Image Processing Workbench (IPW) software package, version 2 (U.S. Department of Agriculture, 1999). The turbulent-transfer method calculates the flux of water vapor above a surface and requires measurements or estimates of temperature and vapor pressure calculated from two heights (both below and above the water surface; vapor pressure above the water surface is calculated from air temperature and relative humidity), wind speed, and surface-roughness length. This method generally works well in arid climates where there are large vapor-pressure gradients.

Evaporation was calculated with the turbulent-transfer method for the period February 1, 2003, through April 30, 2004, when water temperatures were measured hourly at five depths within Sand Hollow Reservoir. Calculations were done at average hourly and daily intervals and compiled into monthly estimates of evaporation. Water-temperature data near the surface was missing because of instrument failure during two time periods (May 4-August 4, 2003; May 4-September 21, 2004). Daily average water-surface temperature, Tw_{ave}, was estimated for these missing periods by using a linear regression of water temperature with daily average air temperature in ºC, Ta_{ave}, which yielded equations:

$$Tw_{ave} = 6.587 + 0.0477*Ta_{ave} \quad (R^2 = 0.95, p < 0.001). \tag{3}$$

Missing hourly water temperatures were estimated by applying a sine function to average daily water temperature. Air temperature, relative humidity and wind speed were measured at the weather station on the southeastern edge of the reservoir (map number 6, fig. 3).

Viscosity Corrections for Recharge Rates

Calculations of intrinsic permeability can be used to remove the temperature-dependent viscosity effects on recharge rates:

$$\kappa = K\frac{\eta}{\rho g} \tag{4}$$

where

κ is intrinsic permeability,

K is hydraulic conductivity (Darcy velocity),

η is dynamic viscosity,

ρ is the density of water,

and g is the acceleration of gravity.

The dynamic viscosity of water at 20ºC is 1.0 centipoise (6.7 x 10^{-4} lb/ft-sec). However, the dynamic viscosity of water varies by more than a factor of 5, from 1.8 centipoise at 0ºC to 0.28 centipoise at 100ºC. Temperature data from thermisters at a depth of about 33 ft in the reservoir were used to calculate dynamic viscosities. The density of water does not vary substantially within the normal range of surface-water temperatures and the acceleration of gravity is not temperature-dependent. Viscosity values can, therefore, be used in the following equation to calculate viscosity-corrected hydraulic conductivity values:

$$K_c = K\frac{\eta}{\eta_{20}} \tag{5}$$

where

K_c is the viscosity-corrected hydraulic conductivity in ft/d,

K is the actual hydraulic conductivity in ft/d (assuming a unit vertical hydraulic gradient),

η is the calculated viscosity of water, and

η_{20} is the viscosity of water at 20ºC.

PRE- AND POST- RESERVOIR GROUND-WATER CONDITIONS

To evaluate the effects of artificial recharge on ground water in Sand Hollow, pre- and post-reservoir ground-water levels and chemistry data were collected and analyzed. Prior to the initial filling of the reservoir in March 2002, a water-level inventory was conducted at 26 ground-water sites by the USGS. In addition, water-level measurements have been measured monthly by the WCWCD at 6 wells since 1995 and at 14 sites since 2001.

Field water-quality parameters have been monitored and geochemical samples have been collected and analyzed at 34 ground-water sites both prior to and since the inception of the reservoir in order to asses pre-reservoir water quality, ground-water age and residence time, and to evaluate water-quality changes associated with artificial recharge. In addition, the chemistry of precipitation and surface water, including the Virgin River and Sand Hollow Reservoir, has been monitored to evaluate the geochemical evolution of this ground water and effects of vadose-zone salt flushing on ground water.

Water Levels

Prior to the filling of Sand Hollow Reservoir in March 2002, water-level fluctuations generally were less than 10 ft (table 2; fig. 4), except at the WD 1 (map number 31 in fig. 3, table 1) and WD 2 (map number 11 in fig. 3, table 1) observation wells, which showed decreased water levels caused by ground-water withdrawals from nearby Well 9 (map number 29 in fig. 3, table 1) during 2000 and 2001. The altitude of the potentiometric surface of the Navajo aquifer in Sand Hollow prior to the reservoir is shown in figure 5. Water levels were higher in the southern part of the basin and lower in the northern part of the basin.The average pre-reservoir hydraulic gradient was about 0.006 ft/ft (30 ft/mi). Ground water generally moved to the north, where it discharged as base flow to the Virgin River (Herbert, 1995). This indicates that the primary source of recharge to the Navajo aquifer prior to the reservoir was local infiltration of precipitation within Sand Hollow. The predominant south-to-north direction of ground-water flow rules out the possibility of lateral ground-water inflow to Sand Hollow from the higher-elevation Pine Valley mountains to the north or the Hurricane Cliffs to the east.

Since the reservoir began to fill in March 2002, ground-water levels have generally increased in Sand Hollow, as a result of infiltration and ground-water mounding of this artificial recharge (figs. 6 and 7). The post-reservoir hydraulic gradient is as much as 0.03 ft/ft, about five times as steep as the pre-reservoir gradient. The largest water-level rises of 30 to more than 80 ft between March 2002 and January 2005 occurred in observation wells WD 1, 2, 6, 9, and 11 (map numbers 31, 11, 9, 37, and 36, respectively, in fig. 3, table 2), all located within 800 ft of the shoreline during the highest stage of the reservoir since inception through January 2005 (3,027 ft on May 11, 2004; fig. 7). These same five wells all show water-level declines from summer 2003 through winter 2003-04, corresponding to the decreased stage of the reservoir (fig. 6).

Observation wells WD 4, 5, 7, 8, 10, and 12 (map numbers 8, 33, 50, 44, 5, and 2, respectively, in fig. 3, table 1) are located farther (1,600 to 3,000 ft) from the shoreline during the high stage of 3,027 ft on May 11, 2004 (fig. 7). These wells all show some water-level rise associated with recharge beneath the reservoir. The water levels in these wells, however, respond slower to this recharge and do not show the decline from summer 2003 through winter 2003-04 observed in the closer set of observation wells corresponding to the decrease in reservoir stage (fig. 4).

Observation wells WD 13 and WD RJ (map numbers 47 and 32, respectively, in fig. 3, table 1), are located at distances farther (3,700 and 5,200 ft, respectively) from the shoreline during the high stage of 3,027 ft on May 11, 2004 (fig. 7). Water levels in both wells rose slightly between March 2002 and summer 2004 (about 2.3 and 2.1 ft at WD 13 and WD RJ, respectively). However, these water-level changes are within the longer-term fluctuations recorded at WD RJ since 1995 (fig. 4). Therefore, it is assumed that the mounding associated with artificial recharge beneath the reservoir did not reach these longer distances by summer 2004.

As shown in the map view of the ground-water mounding during July/August 2004, more than 2 years after filling of the reservoir began and prior to large-scale pumping of the production wells, the mounding is largest directly beneath the reservoir (fig. 7). The potentiometric contours indicate that ground water is moving laterally away from the reservoir in all directions, with the steepest gradient to the north toward the Virgin River.

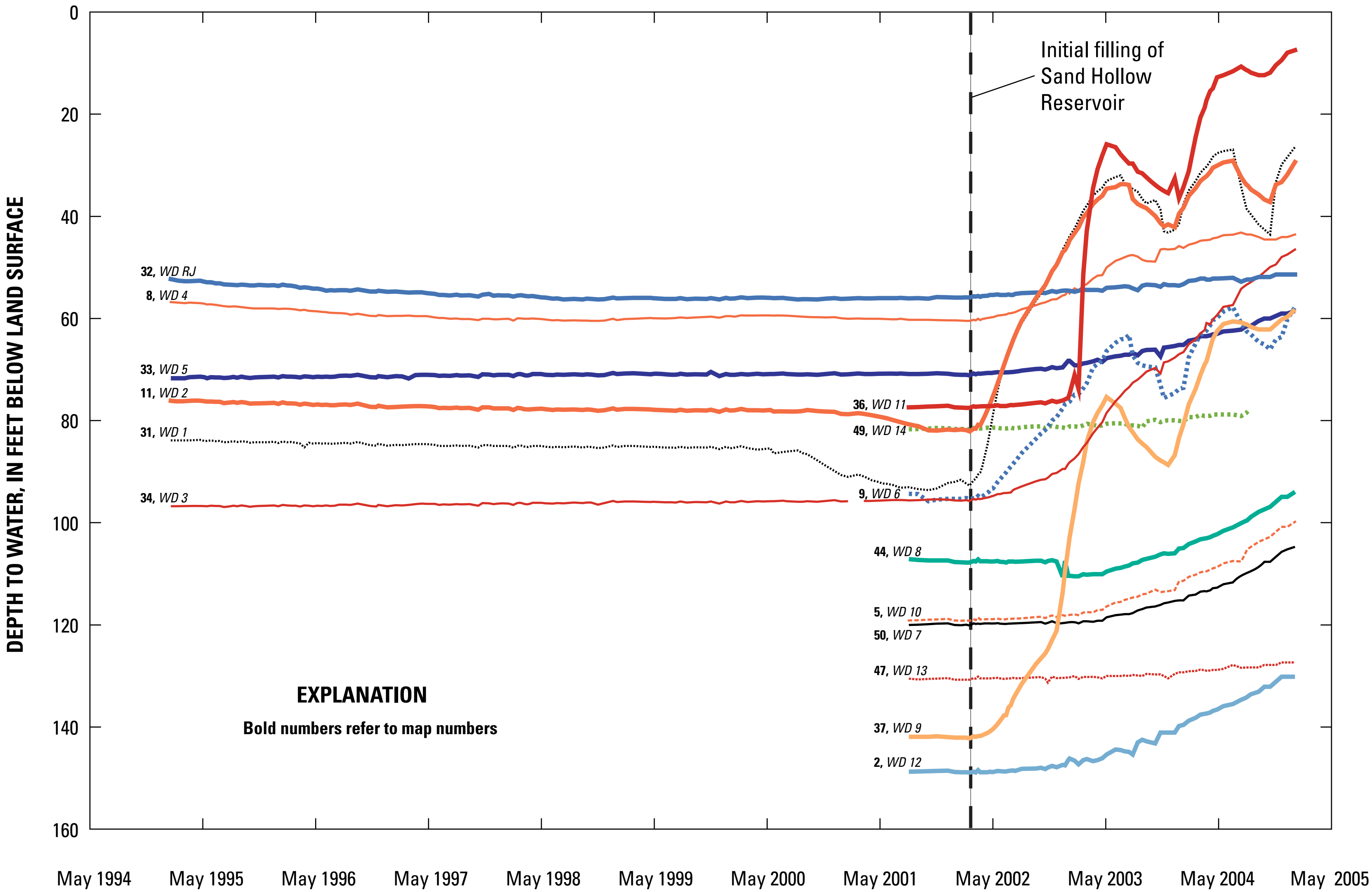


Figure 4. Water level in selected wells in Sand Hollow, Utah, 1995-2005.

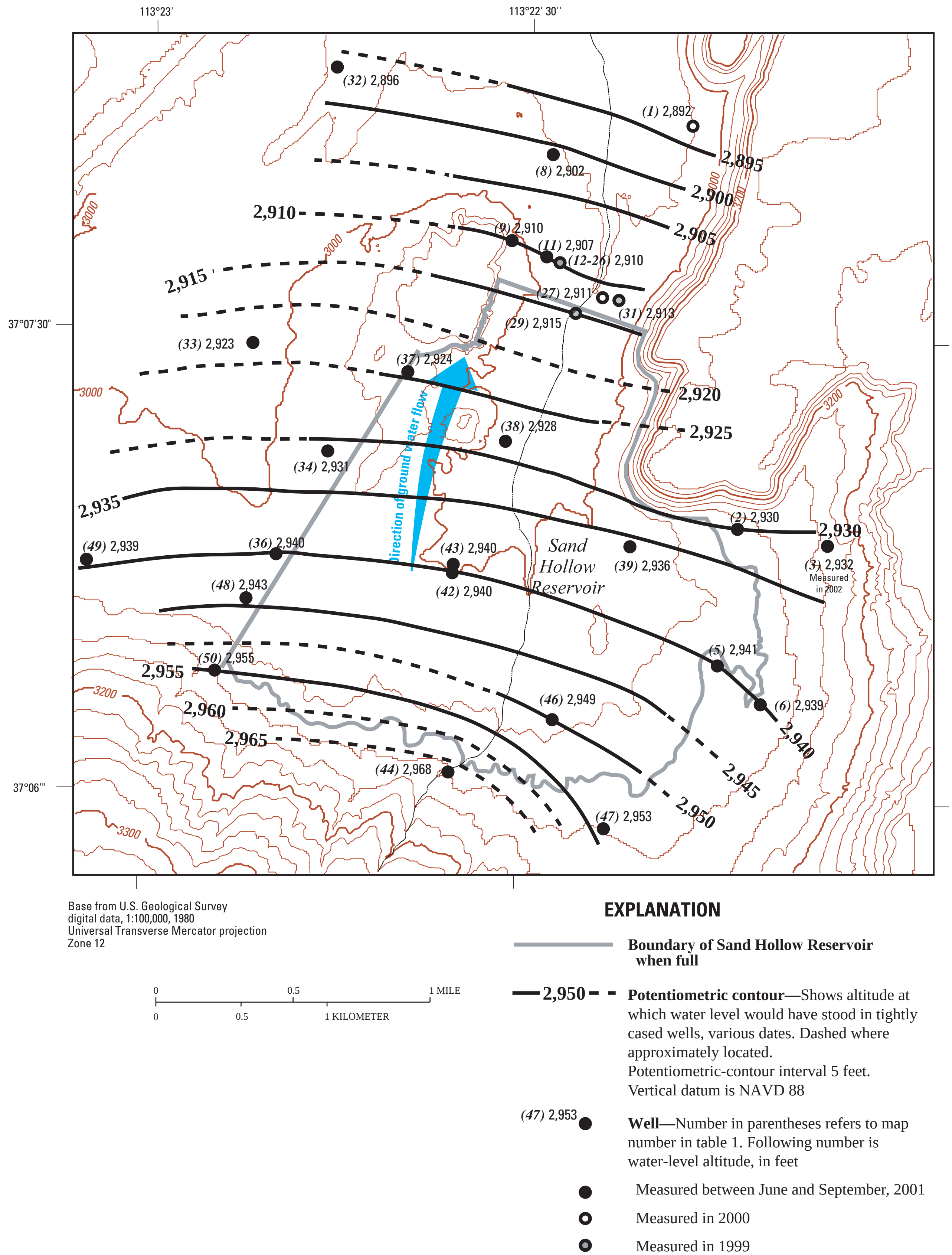


Figure 5. Potentiometric surface of the Navajo aquifer prior to completion of the reservoir, Sand Hollow, Utah.

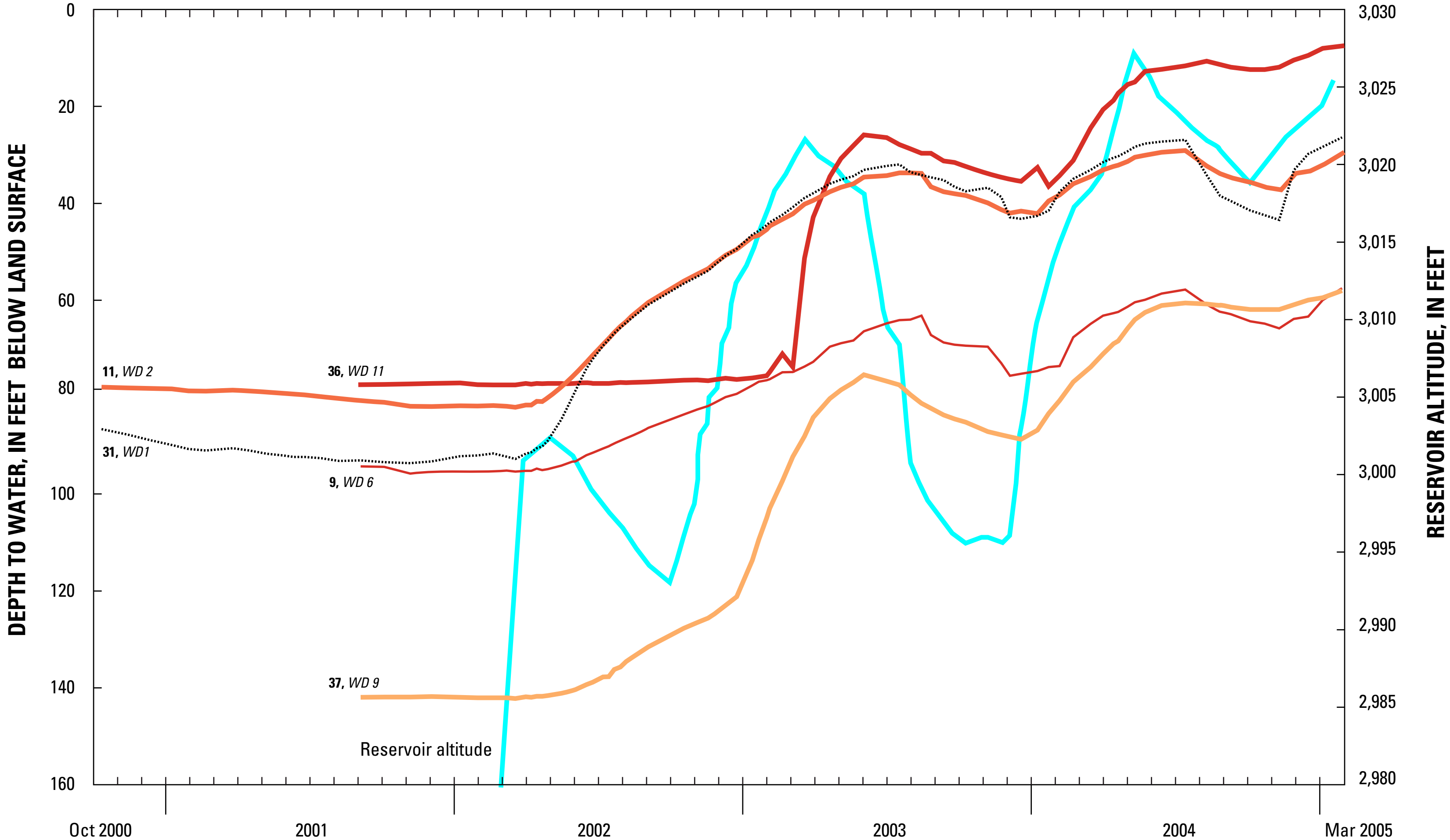


Figure 6. Relation between water level in selected wells and reservoir altitude, Sand Hollow, Utah, 2000-05.

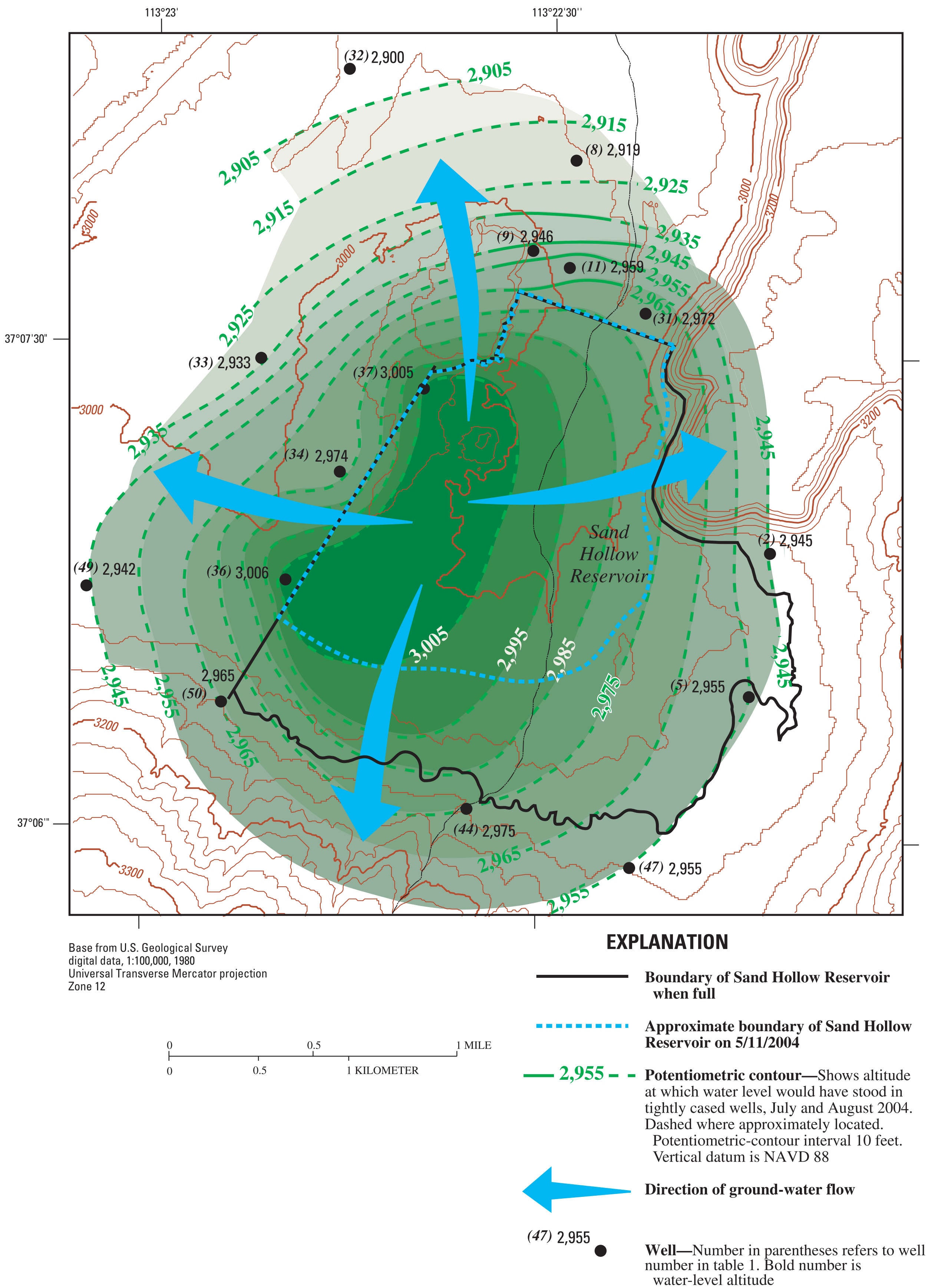


Figure 7. Potentiometric surface of the Navajo aquifer in 2004, after completion of the reservoir and prior to pumping of production wells, Sand Hollow, Utah.

Precipitation

From January 1998 through September 2004, the maximum daily and monthly precipitation measured at the weather station at Sand Hollow occurred during September 1998 and was 1.3 and 3.7 in., respectively. Total annual precipitation at Sand Hollow from 1998 through 2004 averaged 6.7 in., ranging from 2.5 to 13.2 in. (fig. 8). Total annual precipitation for St. George from 1998 through 2004 was similar to that for Sand Hollow, averaging 7.2 in. and ranging from 1.5 to 14.0 in. This period was slightly drier than the longer-term average annual precipitation at St. George of 8.1 inches from 1893 through 2004 (Western Regional Climate Center, 2004). Total monthly precipitation at Sand Hollow is shown in figure 9.

The precipitation-weighted mean concentration of atmospheric chloride (Cl) deposition at the Sand Hollow weather station (altitude 3,070 ft) is 0.8 (+/- 0.3) mg/L, based on eight 6-month atmospheric-deposition samples collected from June 1999 through September 2004 at the weather station (map number 6 in fig. 3), which ranged from 0.5 to 1.2 mg/L (Heilweil and others, in press, table 1). Three other 6-month periods were excluded because of high sulfate concentrations, which indicate possible contamination from bird droppings, decaying insect debris, or dust associated with nearby construction. The range in 6-month composite Cl deposition values is similar to the range in Cl concentrations in samples collected during 13 individual storms from October 2000 to July 2001, which ranged from 0.3 to 2.9 mg/L. Bromide (Br) concentration of five multiple-month atmospheric-deposition samples collected from June 1999 through September 2002 ranged from 0.007 to 0.05 mg/L. This is similar to the Br concentrations measured during the 13 individual storms, which ranged from 0.007 to 0.03 mg/L. Chloride-to-bromide ratios in 10 precipitation samples ranged from 37 to 287, with an average value of 120. Uncorrected sulfate concentration of five multiple-month atmospheric-deposition samples collected from June 1999 through September 2002 ranged from 3.0 to 4.0 mg/L. The sulfate concentration of atmospheric deposition samples collected during the 13 individual storms ranged from 0.7 to 8.4 mg/L (Heilweil and others, in press, table 1).

The range of values and the relation between the stable isotopes of hydrogen (δ^2H) and oxygen (δ^{18}O) in precipitation are shown in figure 10. The δ^2H values of six 6-month precipitation samples collected from June 1999 through May 2003 ranged from -97.6 to -1.0 permil. The δ^2H values of precipitation from 30 individual storms from October 2000 through November 2002 ranged from -126.4 to +4.2 permil. The median δ^2H value for all precipitation samples collected during the study was -81.0 permil.

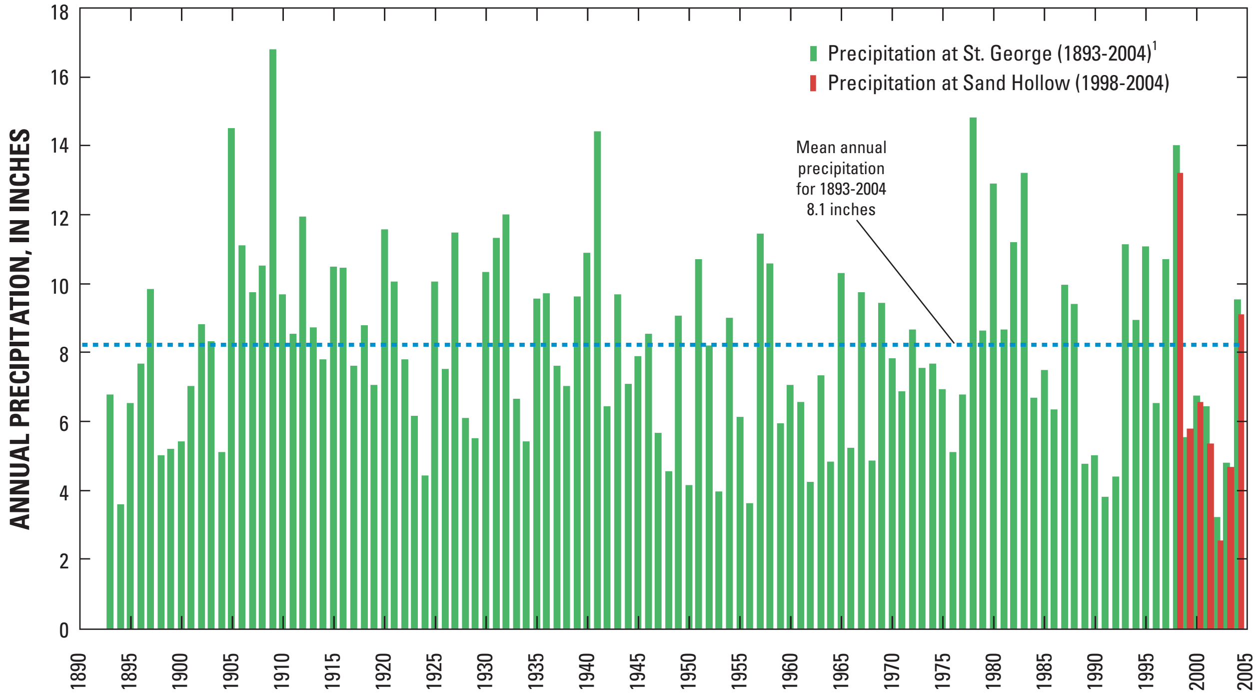
δ^{18}O values in six multiple-month precipitation samples collected during June 1999 through May 2003 ranged from -13.0 to +2.8 permil. The δ^{18}O values of precipitation from 34 individual storms from October 2000 through November 2002 ranged from -15.5 to +3.3 permil. The median δ^{18}O value for all precipitation samples collected during the study was -10.8 permil. Although winter precipitation generally had lighter (more negative) stable isotopic ratios than summer precipitation, there was a very large variation in values over relatively short time periods. For example, samples collected during October 2000 show a range in δ^2H from –16.9 to -122.1 permil.

A local meteoric water line (LMWL) was constructed by linear curve-fitting to the stable-isotope ratios of 36 precipitation samples collected at Sand Hollow during 1999-2002 (fig. 10). The equation for this LMWL is

$$\delta^2 H = 7.61 \delta O - 0.03 . \tag{6}$$

This LMWL has a shallower slope and a smaller y-intercept than the global meteoric water line, which has a slope of 8 and a y-intercept of 10 (Craig, 1961). Because of evaporation of falling precipitation in this arid climate, the slope and intercept of the LMWL is similar to other published precipitation-isotope data from other arid locations in the southwestern United States (Welch and Preissler, 1986).

Tritium concentrations in precipitation samples collected during three individual storms ranged from 9.1 to 21.0 TU. These values are consistent with the range of reported values for other recently collected precipitation samples from other sites in the southwestern United States (International Atomic Energy Agency, 2002).



[1] Western Region Climate Center (2004).

Figure 8. Annual precipitation from 1893-2004 at St. George, Utah, and from 1998-2004 at Sand Hollow, Utah.

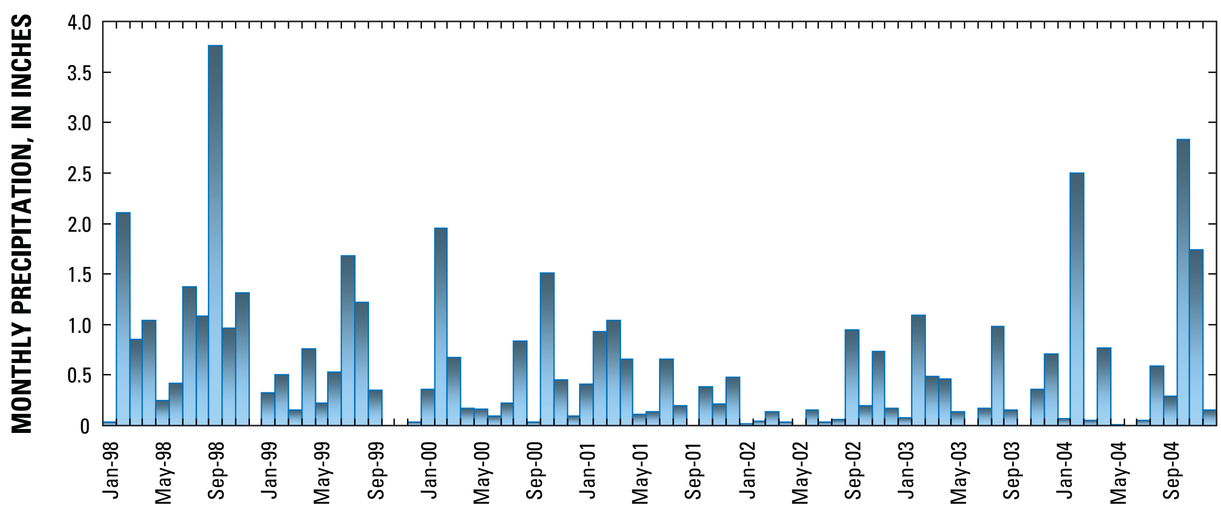


Figure 9. Monthly precipitation at Sand Hollow, Utah, 1998-2004.

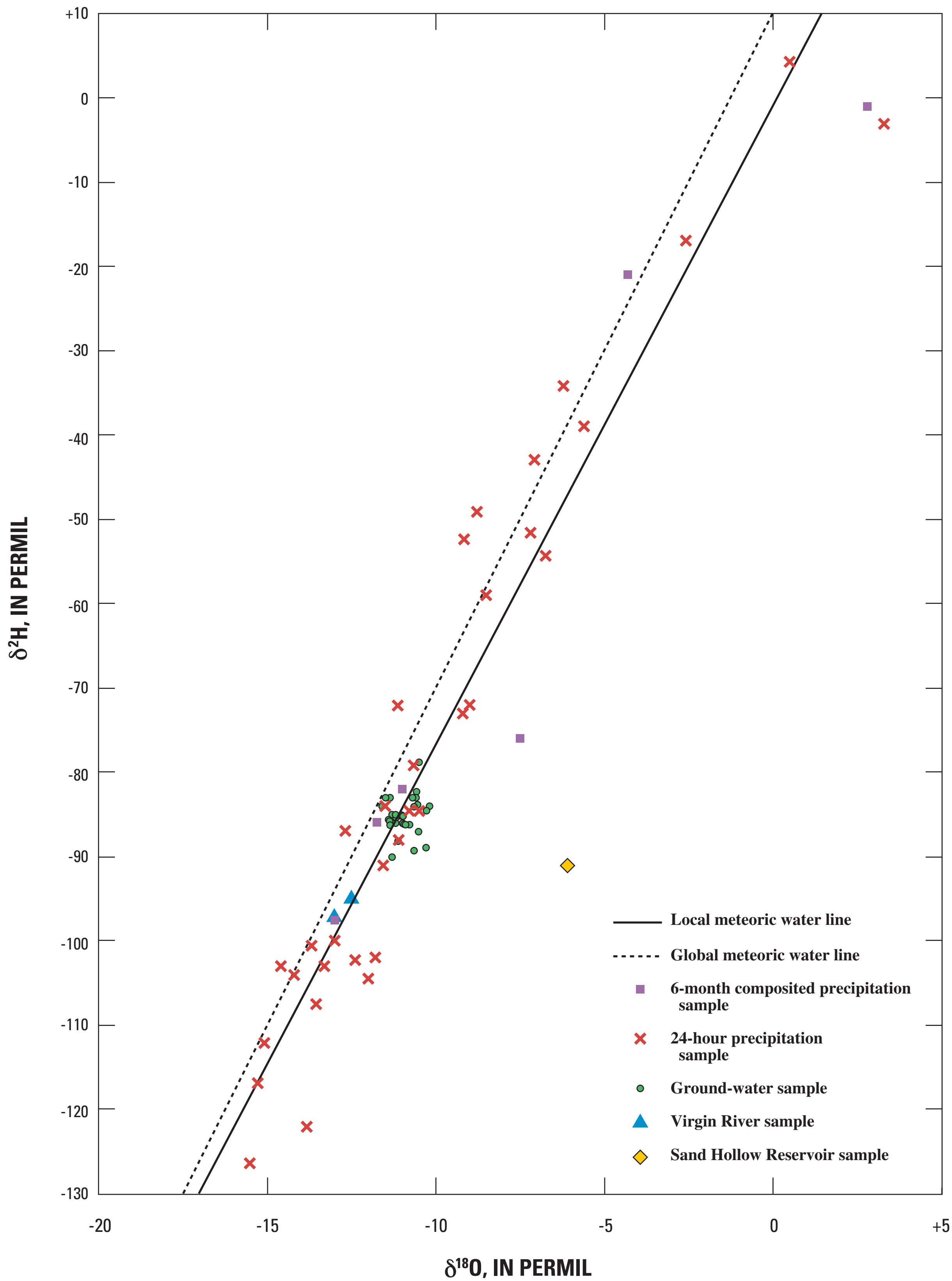


Figure 10. Relation between δ^2H and δ^{18}O values in precipitation, ground-, and surface-water samples in and near Sand Hollow, Utah.

Pre-Reservoir Ground-Water Quality

Prior to filling of the reservoir, the specific conductance of ground water at Sand Hollow ranged from 130 µS/cm at WD 6 (map number 9 in fig. 3, table 1) to 620 µS/cm at the Basin 1 borehole site (map number 38 in fig. 3, table 1), but generally was less than 500 µS/cm. Corresponding dissolved-solids concentrations ranged from 88 to 370 mg/L (table 3). Natural ground water at Sand Hollow is generally a calcium-magnesium-bicarbonate-type water (fig. 11). Measured natural concentrations of nutrients including nitrate, ammonia, and phosphorus are generally less than current U.S. Environmental Protection Agency (EPA) drinking-water standards.

The pre-reservoir Cl concentration of ground water in Sand Hollow ranged from 6.5 to 64 mg/L (table 3). The mean Cl concentration from 31 ground-water sites in Sand Hollow is 22.5 ±12.5 mg/L. It is assumed that all of the Cl in the unsaturated zone and the underlying aquifer is of atmospheric origin because the Navajo is a clean, well-sorted, eolian sandstone containing no evaporite or other salt deposits. However, because of the upward advective movement into the Navajo Sandstone of Cl-rich brines from underlying formations documented at other study sites (Kimball, 1992; Naftz and others, 1997; Heilweil and others, 2000), Cl-to-Br (Cl:Br) ratios were examined to evaluate potential Cl contributions from geologic sources. Such geologic sources of Cl typically have Cl:Br ratios exceeding 1,000 and the ratios increase with increasing Cl concentration (Davis and others, 1998). However, no such trend is evident in ground water from Sand Hollow (fig. 12). Pre-reservoir Br concentrations ranged from 0.01 to 0.27 mg/L, resulting in Cl:Br ratios that were between 85 and 415 (table 3). Furthermore, vadose-zone pore water Cl:Br ratios generally increase from land surface to the water table (Heilweil and others, in press), consistent with a doubling in the mean Cl:Br ratio from 120 for atmospheric-deposition samples to 230 for ground-water samples. This indicates that some unsaturated-zone process, such as preferential uptake of Br by plant roots, influences ground-water Cl:Br ratios rather than a geologic source of Cl. Pre-reservoir sulfate concentrations in ground water ranged from 7.4 to 66 mg/L. Pre-reservoir nitrate concentrations in ground water ranged from 0.29 to 3.8 mg/L.

Water temperatures in wells at Sand Hollow ranged from 17.6 to 21.0ºC, slightly warmer than the average annual air temperature of 17ºC. Although this may be partially due to the geothermal gradient, which causes an increase in temperature with depth of about 0.6 to 0.9ºC per 100 ft (Press and Siever, 1978), it also may be caused by the proximity of recent volcanic activity associated with Volcano Mountain just 2 mi northeast of the study area. The Utah Geological Survey designated much of Sand Hollow as the Southeast Basin of the St. George geothermal basin, a low-temperature geothermal basin (Budding and Sommer, 1986).

Water from five wells had natural arsenic concentrations of from 12 to 55 µg/L, exceeding the EPA drinking-water standard of 10 µg/L. Three possible sources of this elevated arsenic at Sand Hollow Basin may be the concentration by evapotranspiration of arsenic in atmospheric deposition (Scudlark and Church, 1988), the upwelling of mineralized geothermal waters (Welch and others, 2000), or the mobilization of arsenic adsorbed on the surface of hematite and magnetite nodules present within the Navajo Sandstone as a result of changes in pH or redox conditions. Chemical analyses of these iron oxide nodules from the Navajo Sandstone in south-central Utah showed whole-rock arsenic concentrations as high as 470 ppm (Beitler and others, 2005).

Ratios of stable isotopes in ground water at 37 sites in Sand Hollow range from -79 to -94 permil for δ^2H and -9.7 to -11.9 permil for $\delta^{18}O$ (table 4; fig. 10). Although these values are within a much narrower range than the precipitation samples, the mean ground-water values of -86 permil for δ^2H and -11.1 permil for $\delta^{18}O$ are similar to the mean precipitation values. This supports the earlier interpretation, based on the pre-reservoir ground-water potentiometric surface, showing infiltration of local precipitation as the primary source of recharge to the aquifer. The ground-water stable-isotope ratios are generally less negative and have less variation than earlier reported stable-isotope values for the Navajo aquifer in other parts of Washington County, which ranged from -90 to -110 permil for δ^2H and from -11.9 to -14.7 permil for $\delta^{18}O$ (Heilweil and others, 2000). This indicates that natural recharge to the Navajo aquifer at Sand Hollow likely comes from a lower-altitude, localized source of precipitation within the study area, rather than precipitation in the higher-altitude Pine Valley Mountains about 12 mi north of Sand Hollow.

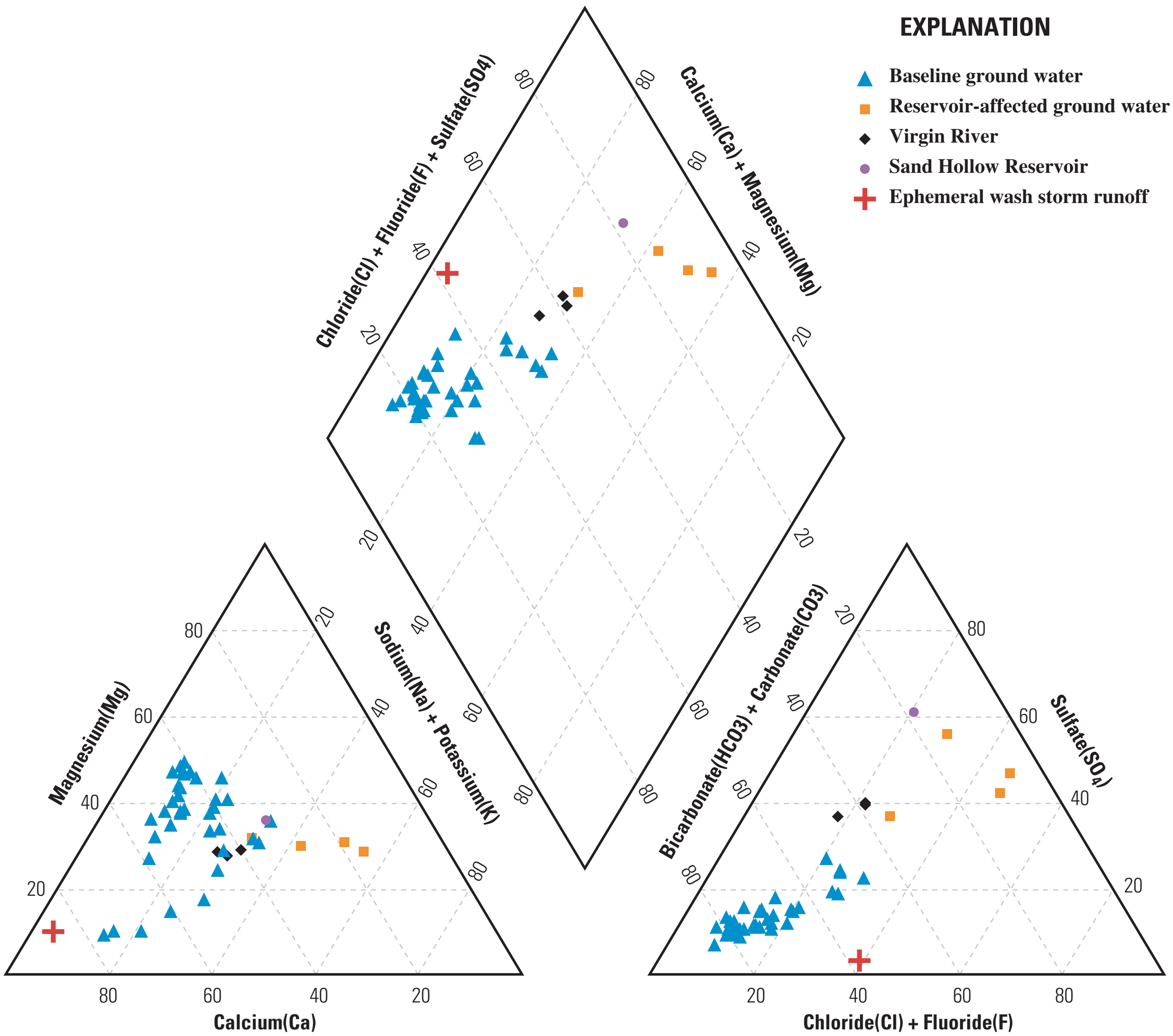


Figure 11. Major-ion chemistry of surface water, ground water, and ephemeral wash storm runoff in and near Sand Hollow, Utah.

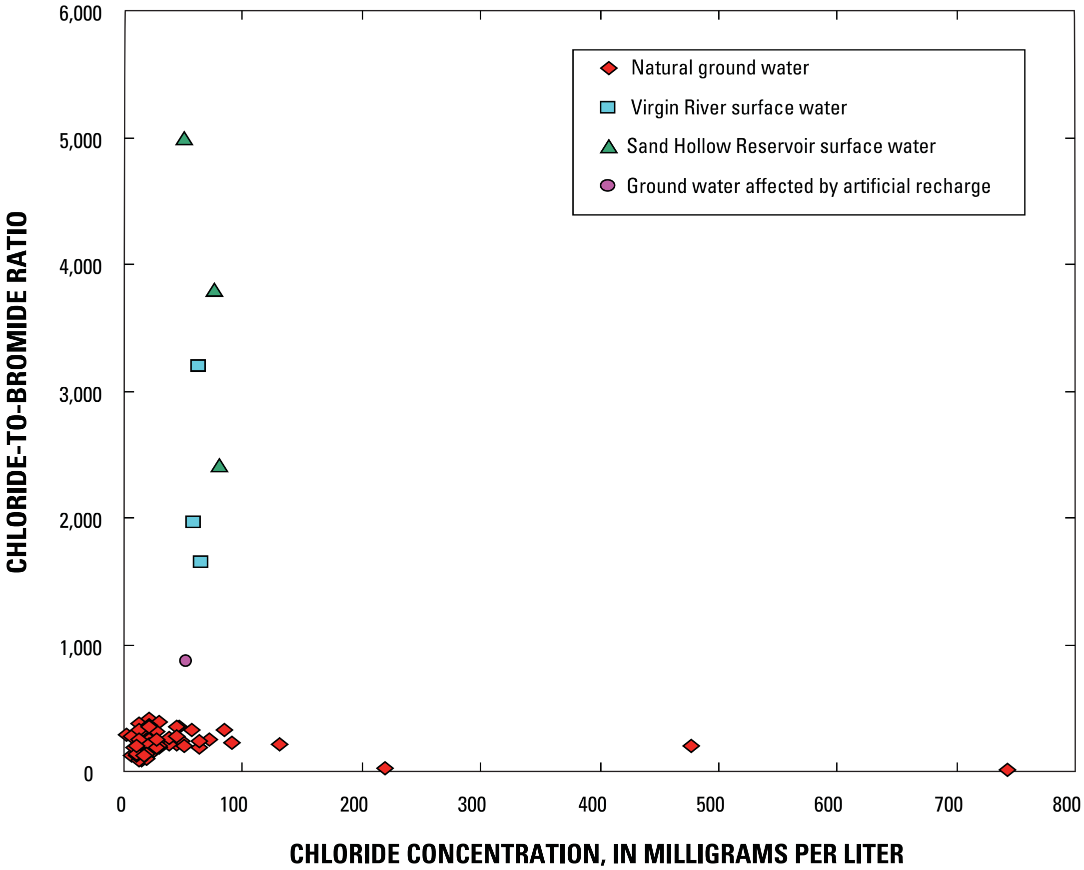


Figure 12. Relation between chloride-to-bromide ratio and chloride concentration for ground water and surface water in and near Sand Hollow, Utah.

Apparent Age of Pre-Reservoir Ground Water

Radioactive carbon-14 (^{14}C) in ground water was collected in Sand Hollow at 22 sites prior to inception of the reservoir. Concentrations of ^{14}C ranged from 14.7 to 105.3 percent modern carbon (pmc) (table 4). The radioactive half-life of carbon-14 is 5,730 years (Kalin, 2000). The stable-isotopic ratio of carbon ($\delta^{13}C$) in ground water ranged from -6.5 to -8.5 permil. Vadose-zone pore air carbon dioxide $\delta^{13}C$ values ranged from 15.1 to 20.9 permil. The Pearson and Hanshaw (1970) method was used with the $\delta^{13}C$ values of both the ground water and the vadose-zone pore-air carbon dioxide to calculate corrected ^{14}C ages ranging from modern to 8,500 years (table 5). This indicates that some of the ground water in Sand Hollow originated as precipitation many thousands of years ago, whereas other parts of the aquifer contain much younger water. Except for the Sky Ranch #2 well (map number 6 in fig. 3, table 1), ground-water with modern apparent ^{14}C ages was generally located in wells with perforation depths less than 100 ft below the water table. Ground water from wells perforated deeper than 100 ft below the water table had apparent ^{14}C ages ranging from 500 to 8,500 years.

Ground-water samples at 37 sites in Sand Hollow for analysis of radioactive tritium (^{3}H) were collected prior to the initial filling of the surface-water reservoir. Concentrations ranged from 0 to 6.9 TU (table 4). The lowest ^{3}H concentrations indicate water that originated as precipitation more than 50 years ago, prior to above-ground nuclear testing. The highest ^{3}H concentrations were measured in various shallow wells and indicate that some shallow parts of the aquifer have received natural recharge during the past few decades.

In conjunction with ^{3}H data, dissolved helium (^{3}He) concentrations and helium isotopic ratios were analyzed for various ground-water sites within Sand

Hollow for estimating $^3H/^3He$ recharge year (table 5). The youngest waters were found in shallow wells screened just below the water table in high-recharge parts of Sand Hollow. $^3H/^3He$ concentrations indicate that recharge to the Navajo aquifer occurred as recently as two years proir to sampling at WD 6 (map number 9 in fig. 3, table 1). Other sites with recent recharge include WD 8 (map number 44) with recharge occurring around 1997 (water crossing the water table about 5 years before the sampling date) and at Hole O (map number 43) with recharge occurring round 1975 (water crossing the water table about 25 years before the sampling date). $^3H/^3He$ concentrations at all the other sites indicate that recharge occurred prior to the 1950s.

Chlorofluorocarbons (CFCs) were analyzed from samples at 13 sites as a potential ground-water age-dating tool prior to the initial filling of the surface-water reservoir. Concentrations of chlorofluorocarbon-11 (CFC-11) and chlorofluorocarbon-12 (CFC-12) in ground water ranged from 0.1 to 2.8 and from 0.1 to 2.4 pmol/kg, respectively (table 4). The higher concentrations approach values of water in equilibrium with the modern atmosphere. These CFC concentrations correspond to apparent CFC-11 recharge years of 1963 to 1983 and apparent CFC-12 recharge years of 1963 to 1997 (table 5). However, these relatively young ages may sometimes indicate the rapid transport of chlorofluorocarbons through pore air in unsaturated fractured rock (Thorstenson and others, 1998), rather than indicating recent recharge. ^3H is part of the water molecule, whereas CFCs are atmospheric gases dissolved in water that may not accurately represent the infiltration and recharge of precipitation. This may explain the poor correlation between CFC-12 and ^3H-derived ages. Eleven of 13 the sites had ground water with modern (post-1950s) apparent CFC ages, yet pre-1950s apparent $^3H/^3He$ ages.

Virgin River and Sand Hollow Reservoir Surface-Water Quality

Surface-water-quality sampling, including both field parameters and chemical analyses, was conducted at both the Virgin River near Virgin, Utah (about 12 mi northeast of Sand Hollow), and at Sand Hollow Reservoir. Although the two groups of samples are generally similar, there are some geochemical differences, likely caused by some combination of the following factors: (1) surface water was also brought to Sand Hollow from Quail Creek Reservoir, particularly during 2002 and the early part of 2003, when Quail Creek Reservoir was emptied for dam repairs; (2) runoff of natural precipitation into Sand Hollow Reservoir, including the flushing of surface sediments containing salts accumulating from dust and evaporation of precipitation; and (3) evaporative concentration, as is expected for a surface-water body in a warm, arid region.

Three water samples collected from the Virgin River at Virgin, Utah, had an average specific conductance value of 840 µS/cm (table 3). These samples were collected from August through November of 2001 and may not represent the full range of seasonal or multi-year variability. The average of seven specific conductance measurements of Sand Hollow Reservoir surface water between 2002 and 2004 is only slightly higher (870). Similarly, average sulfate and Cl concentrations of reservoir water (210 mg/L and 69 mg/L, respectively) are slightly higher than average Virgin River values (160 mg/L and 63 mg/L, respectively). Nitrogen concentrations of Virgin River surface-water samples generally were very low (0.35 to 0.45 mg/L) and were even lower ($<$ 0.2 mg/L) in the reservoir, possibly caused by nutrient uptake by biota.

Although the Cl concentrations of both the Virgin River and Sand Hollow Reservoir surface-water samples were similar to higher Cl values in pre-reservoir ground water at some locations in Sand Hollow, surface-water Br concentrations were very low (about 0.03 mg/L), resulting in Cl:Br ratios of 1,650 to 5,000 (fig. 12, table 3). These ratios are much higher than pre-reservoir Sand Hollow ground-water samples, which ranged from 85 to 864 (table 3, fig. 12). Therefore, the Cl:Br ratio is a potential tracer of artificial recharge to the Navajo aquifer beneath Sand Hollow Reservoir.

The ^3H concentration of one Virgin River and one Sand Hollow Reservoir water sample was 1.6 and 2.5 tritium units, respectively (table 4). The δ^2H isotopic ratios of two Virgin River water samples ranged from -95 to -97 permil, similar to one reservoir sample having -91 permil (table 4). However, the $\delta^{18}O$ isotopic ratio of the reservoir sample (-6.2 permil) was more positive than the Virgin River samples (-12.5 to -13.0 permil), showing evaporative enrichment (table 4; fig. 10). Because the source of precipitation for the Virgin River is primarily from the higher-altitude Kolob Plateau, these δ^2H and $\delta^{18}O$ values are more negative than ground-water samples from Sand Hollow, which averaged -86 and -11.6 permil, respectively. Therefore, δ^2H and $\delta^{18}O$ are potential tracers for evaluating both artificial recharge and the extent of reservoir evaporation.

Flushing of Naturally Accumulated Vadose-Zone Salts

A previous investigation (Heilweil and Solomon, in press) determined large amounts of naturally accumulated salts to be present in vadose-zone pore waters of Sand Hollow. Naturally occurring pore-water Cl concentrations from vadose-zone boreholes within Sand Hollow were as much as 30,000 mg/L. Vadose-zone Cl accumulations measured at 13 borehole sites drilled in and around the reservoir prior to filling ranged from 25 to 1,500 mg/in^2 for a 1-in. by 1-in. column of rock from land surface to the water table (4 to 230 mg/cm^2 for a 1-cm by 1-cm column). A geometric mean value of 180 mg/in^2 (28 mg/cm^2) was calculated for the area beneath the reservoir. Based on an average ratio of Cl to dissolved-solids concentration in ground water in Sand Hollow (table 3) of about 0.1, it is estimated that the average total salt accumulation in the vadose zone beneath Sand Hollow reservoir prior to filling was about 1,800 mg/in^2. Multiplying this salt concentration by the 1,300-acre area of the reservoir when full (a surface altitude of 3,067 ft), it is estimated that that about 15,000 tons of salts were in the vadose zone of Sand Hollow prior to the filling of Sand Hollow Reservoir.

A shallow observation well in the Navajo aquifer along the North Dam, which was unsaturated prior to completion of Sand Hollow Reservoir, shows the flushing of these naturally accumulated vadose-zone salts. The dissolved-solids concentration of water from North Dam 3A well (map number 28 in fig. 3, table 1; screened 15 to 25 ft below land surface) exceeded 3,000 mg/L soon after filling of the reservoir in 2002 and decreased to about 700 mg/L by 2004 (table 3). Similarly, elevated nitrate concentrations (as much as 18 mg/L) also were measured at this site. Increases in nitrate (as much as 4.6 mg/L) also have been measured at shallow observation well WD 11 (map number 36 in fig. 3, table 1). These are similar to earlier findings of salt flushing at a shallow observation well beneath a small-scale infiltration pond (map number 12 in fig. 3, table 1) during a 10-month experiment conducted from 2000 to 2001 (Heilweil and others, 2004). Although these shallow water-table concentrations exceed drinking-water standards, ground-water concentrations in nearby production wells are much lower, likely caused by dilution of these flushed salts with deeper ground water. For example, if the estimated 15,000 tons of vadose-zone salts beneath Sand Hollow reservoir is diluted with ground water in the upper 500 ft of the aquifer in the northern half of the basin (10 mi^2), the increase in dissolved solids, besides any increase from the higher-dissolved-solids Virgin River source water, would only be about 20 mg/L.

Effects of Artificial Recharge on Ground-Water Quality

Ground-water field water-quality measurements and geochemical sampling and analysis were conducted between 1999 and 2005 in Sand Hollow. This information can be used to evaluate the effects of artificial recharge on ground-water quality.

Field Parameters

Field measurements in observation and production wells closest to Sand Hollow reservoir indicate the arrival of artificial recharge to the Navajo aquifer during the first 2 years of operation. In particular, specific-conductance values and total dissolved-gas pressures have risen substantially at the shallow observation wells nearest the reservoir. Specific-conductance values at these wells all approached the average reservoir conductance of about 800 μS/cm. Values increased from 130 to more than 800 μS/cm at WD 6 (map number 9) and from 280 to 815 μS/cm at WD 9 (map number 37). These increases are shown in figure 13 and table 3. The increase in specific-conductance values up to about 1,000 μS/cm at WD 11 (map number 36) during late 2004 and 2005 was likely caused, in part, by vadose-zone salt flushing The decrease in specific-conductance values at WD 6 during 2005 was likely a result of pumping of nearby production wells, which may have caused a reversal in hydraulic gradient and brought pre-reservoir ground-water back toward the observation well.

In-situ total dissolved-gas pressure in ground water near the reservoir showed large increases since the filling of the reservoir, caused by a combination of dissolution of entrapped air bubbles (excess air) and increased hydrostatic head associated with the rapidly rising water table. A previous investigation determined that about 10 percent of the porosity beneath the infiltration pond (map number 12 in fig. 3, table 1) was filled with trapped air rather than water under otherwise saturated conditions (Heilweil and others, 2004). The larger hydrostatic-head change associated with the reservoir, as compared with

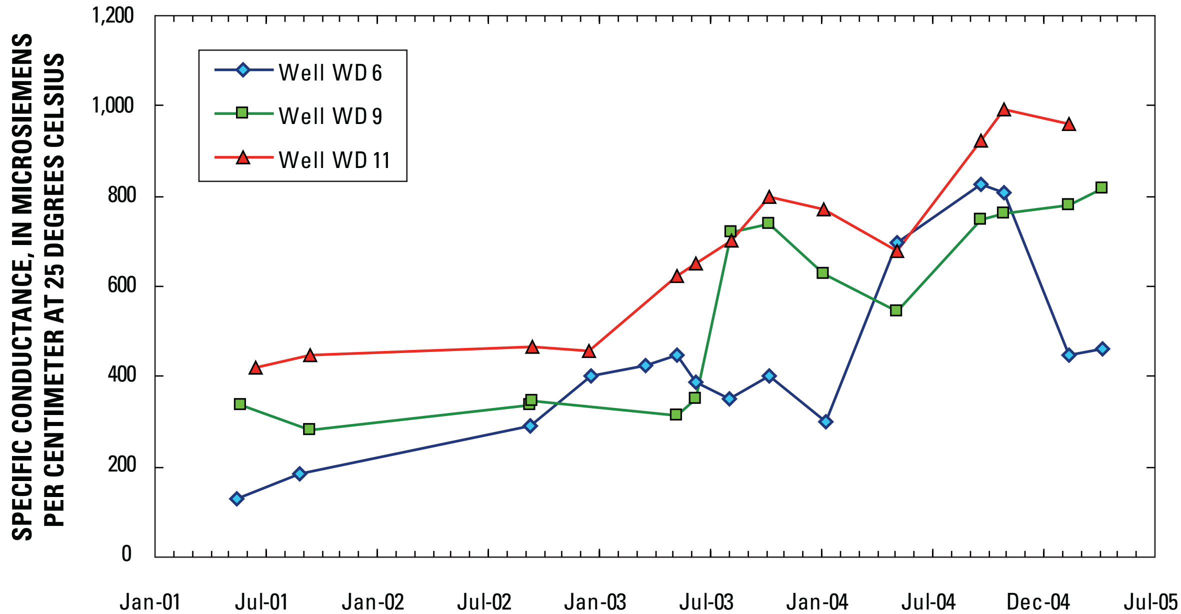


Figure 13. Specific conductance at shallow observation wells near Sand Hollow Reservoir, Utah, 2001-05.

the infiltration pond, has resulted in even more air entrapment and very high total dissolved-gas pressures. Pressure has risen from 0.9 to 1.8 atmospheres (atm) at WD 6, and from about 1 to more than 3 atm at WD 9 and WD 11 (fig. 14). This indicates that gas clogging associated with trapped air is substantially reducing the permeability of the sandstone in the vicinity of the reservoir. Previous calculations indicate that it can take years for such trapped air to re-dissolve (Heilweil and Solomon, 2004). A study of dissolved-gas concentrations near the reservoir (Solomon and Heilweil, 2004) showed that as much as 20 percent of the porosity beneath and adjacent to the reservoir may be filled with trapped air, as much as twice that of the previous infiltration pond experiment. Based on laboratory unsaturated hydraulic-conductivity measurements, a 20-percent reduction in saturation may reduce hydraulic conductivity by more than an order of magnitude (from about 0.6 ft/d to about 0.03 ft/d; Heilweil and Solomon, 2004, fig. 5).

Geochemical Parameters

Similar to specific conductance, dissolved-solids concentrations have risen substantially at the shallow observation wells nearest the reservoir: from 88 to 445 mg/L at WD6, from 190 to 445 mg/L at WD 9, and from 230 to 480 mg/L at WD 11 (table 3). Similar increases in the major cations and anions also have been measured. Calcium, magnesium, sodium, sulfate, and chloride concentrations all have increased at these wells since filling of the reservoir began during March 2002. Interestingly, potassium concentrations have declined even though Virgin River and reservoir water samples have higher potassium concentrations than native ground water in the Navajo aquifer at Sand Hollow. This indicates that a geochemical sodium/potassium exchange reaction may be occurring between the native ground water and the artificially recharged reservoir water.

Although the geochemistry of shallow ground-water samples from the Navajo aquifer in the vicinity of the reservoir after the initial filling is similar to both Virgin River and Sand Hollow Reservoir surface-water samples, they show a more pronounced sodium chloride signature (fig. 11), likely caused by the flushing of vadose-zone salts. The flushing of these naturally accumulating vadose-zone salts with low Cl:Br ratios (Heilweil and others, in press) may also explain why Cl:Br ratios in observation wells remain well below the large ratios of as much as 5,000 measured in reservoir water.

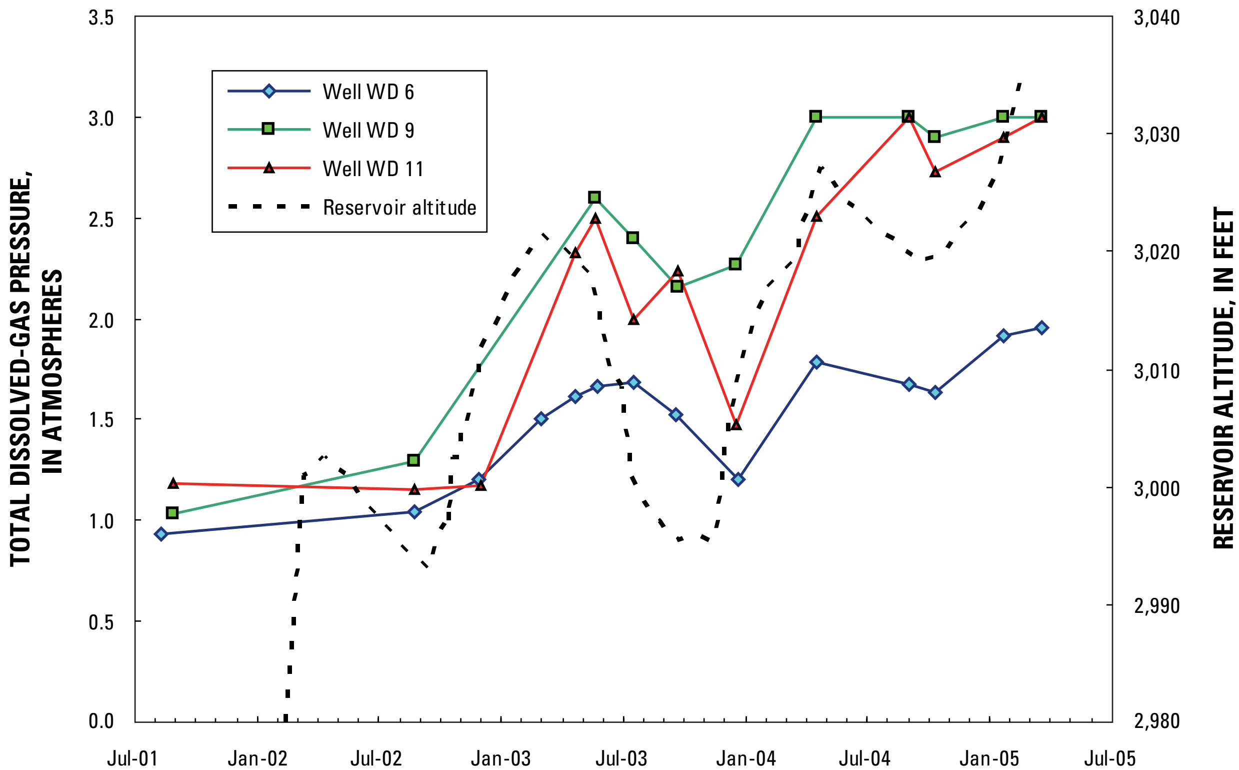


Figure 14. Relation between total dissolved-gas pressure in ground water and reservoir altitude, Sand Hollow, Utah, 2001-05.

In general, the arsenic concentration of ground water has risen in some but not all areas of the aquifer affected by artificial recharge. Arsenic in the shallowest part of the Navajo aquifer (North Dam 3A; map number 28 in fig. 3, table 1) was monitored from September 2002 through April 2005. This well is screened from 15 to 25 ft below land surface and was dry prior to filling of the reservoir. Concentrations of arsenic shortly after the reservoir filled were as much as 90 µg/L initially, but gradually decreased to a range of from 42 to 48 µg/L (fig. 15, table 3). Unlike concentrations of other chemical constituents at this site, which initially showed vadose-zone salt flushing yet decreased to surface-water ranges, the arsenic concentration has remained well above EPA standards for drinking water. This is similar to shallow ground-water monitoring during an earlier (2000-01) infiltration experiment at the nearby Infiltration Pond site (map number 12 in fig. 3, table 1), which also showed elevated arsenic concentrations persisting much longer than dissolved-solids or nitrate concentrations. This indicates a different process than salt flushing, such as the mobilization of arsenic adsorbed on the surface of hematite and magnetite nodules as a result of changes in pH conditions. The pH of the infiltrating reservoir water is generally more than 8.0, higher than the native ground-water within the Navajo aquifer in Sand Hollow. The persistence of high arsenic concentrations at the North Dam 3A well may indicate the slow release of arsenic adsorbed to these iron and magnetite oxides. The continued high arsenic concentrations do not appear to be related to fluctuations in water levels (fig. 15).

Shallow observation wells WD 6, WD 9, and WD 11, perforated just beneath the pre-reservoir water table, had smaller increases in arsenic after the reservoir filling began. At well WD 6 (map number 9 in fig. 3, tables 1 and 3), the arsenic concentration increased from 2.0 µg/L on September 9, 2002, to 2.8 µg/L on May 3, 2004. At well WD 9 (map number 37), the arsenic concentration increased from 9.4 µg/L on May 23, 2001, to 13.3 µg/L on May 3, 2004, but then decreased to 7.3 µg/L on April 9, 2005. At well WD 11 (map number 36), the arsenic concentration increased from 7.3 µg/L on December 16, 2002, to 17.0 µg/L on February 9, 2005. Arsenic concentrations at both WD 9 and WD 11 have decreased slightly since 2004.

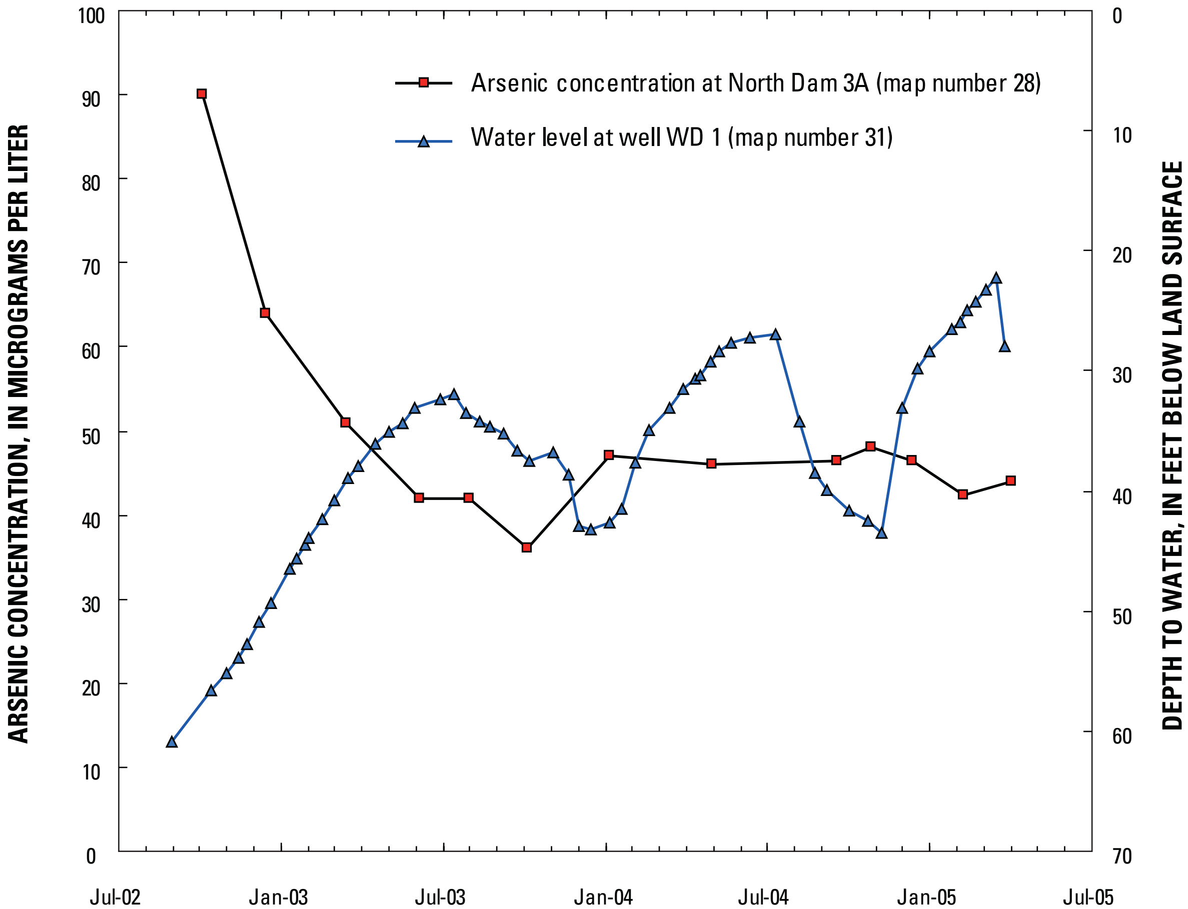


Figure 15. Relation between dissolved arsenic concentration in the North Dam 3A well and water level in the nearby WD 1 well, Sand Hollow, Utah, 2002-05.

Deeper production wells located just north of the reservoir and screened to hundreds of feet below the water table do not show the same increase in ground-water arsenic concentrations since the initial filling of the reservoir. At well 8 (map number 10 in fig. 3, tables 1 and 3), arsenic concentrations decreased from 16.6 µg/L on October 8, 2002, to 8.1 µg/L on September 21, 2004. At well 9 (map number 29), arsenic concentrations oscillated between 12 and 17 µg/L between August 30, 2001, to April 8, 2005.

ASSESSMENT OF ARTIFICIAL RECHARGE

To estimate artificial recharge beneath Sand Hollow Reservoir, evaporation rates were first calculated and compared by using five different methods (uncorrected pan, corrected pan, Penman, Jensen-Haise, and turbulent transfer) to select the most appropriate method. These evaporation rates, multiplied by the surface area of the reservoir, were then used for calculating the total monthly amount of evaporation from Sand Hollow Reservoir. Evaporation (E), along with total monthly inflows (I_{sw}), outflows (O_{sw}), and changes in surface water storage (S), were used in equation (1) to calculate monthly estimated ground-water recharge beneath Sand Hollow Reservoir.

Comparison of Evaporation Rates

Average monthly and corrected average pan evaporation for 1869-1993 is listed in table 6. Uncorrected average monthly rates range from 2.68 in. in November to 13.17 in. in July. Corrected monthly pan evaporation, calculated using a correction factor of 80 percent, ranges from 2.14 in. in November to 10.53 in. in

July. Pan evaporation rates are not calculated for the winter months (December through February) because of problems associated with freezing.

Monthly and annual Penman evaporation calculations for St. George from 1999 through 2004 are listed in table 6. Monthly values generally range from about 3 in. in December and January to about 8 in. in July and August. Months with at least 1 day of missing data are noted with a footnote in table 6. Some months were missing all the climate data for that month so calculations could not be made. Years 1999 and 2003 had complete data sets and annual evaporation of 72.9 and 67.6 in. respectively.

Daily Jensen-Haise evaporation was calculated from meteorology data collected at the Sand Hollow weather station from January 13, 1998, to September 20, 2004 (fig. 16). Daily evaporation rates generally varied from 0 to almost 0.5 in/day, reflecting seasonal fluctuations in daily temperature and solar radiation. Monthly evaporation estimates calculated with the Jensen-Haise equation also reflect this seasonality, generally varying from less than 1 in. during December and January to more than 10 in. during June and July. Annual estimates range from 55.3 in. 1999 to 61.2 in. in 2003 (table 6).

Daily evaporation was calculated with the turbulent-transfer method from January 2003 through April 2004 from reservoir water temperatures (fig. 17). Evaporation rates varied from 0.0 to 0.97 in/day (fig. 18). This is a much wider range than daily evaporation calculated with the Jensen-Haise method (0.0 to 0.45 in/day; fig. 16). The turbulent-transfer method more accurately represents high evaporation conditions on windy days or when there are high vapor-pressure gradients between the reservoir and the atmosphere. Monthly evaporation calculated using the transfer method ranged from 1.1 to 8.7 in (table 6).

Monthly and annual evaporation estimates for all the methods are listed in table 6. Monthly evaporation calculated with the turbulent-transfer method also has a different seasonal distribution than the Jensen-Haise monthly evaporation. Turbulent-transfer method calculations during peak evaporation months (summer) are less than calculations made using the Jensen-Haise method, yet larger during the fall. Average monthly pan evaporation for 1869-1993 multiplied by a 0.8 coefficient is generally similar to evaporation calculated with the Jensen-Haise equation.

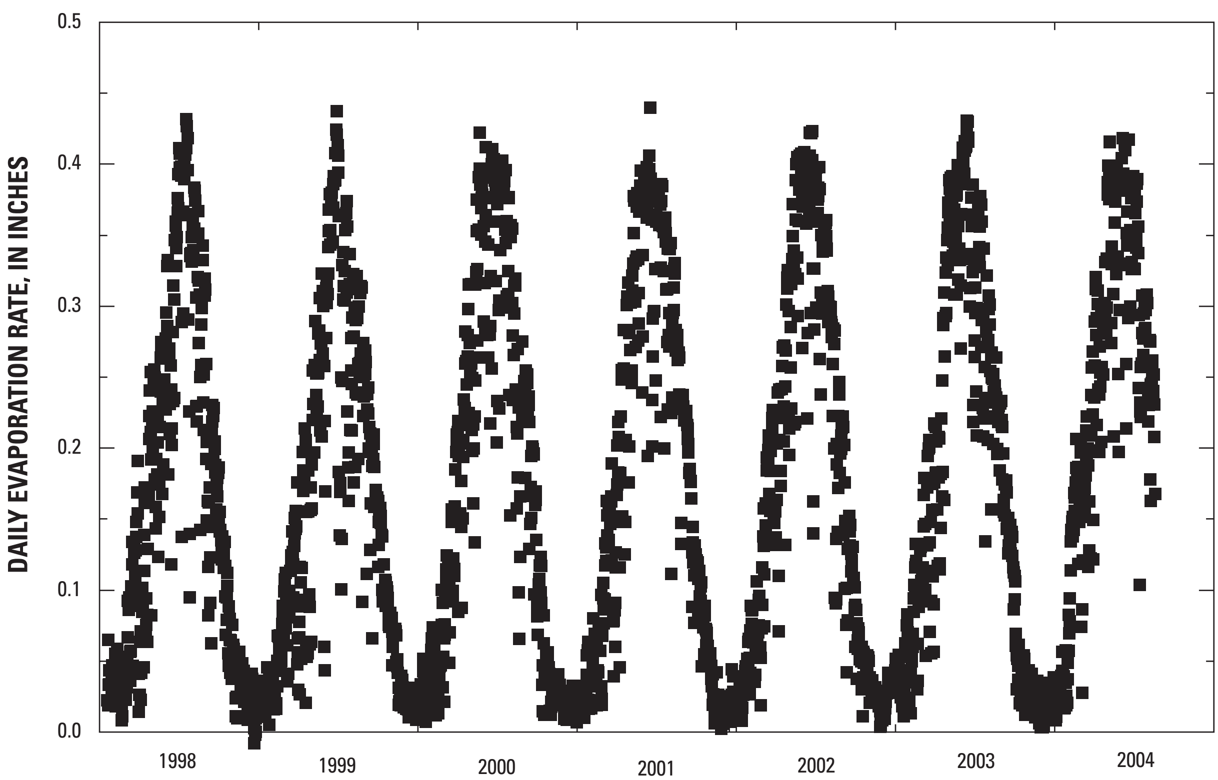


Figure 16. Daily evaporation rate calculated with the Jensen-Haise method for Sand Hollow Reservoir, Utah, 1998-2004.

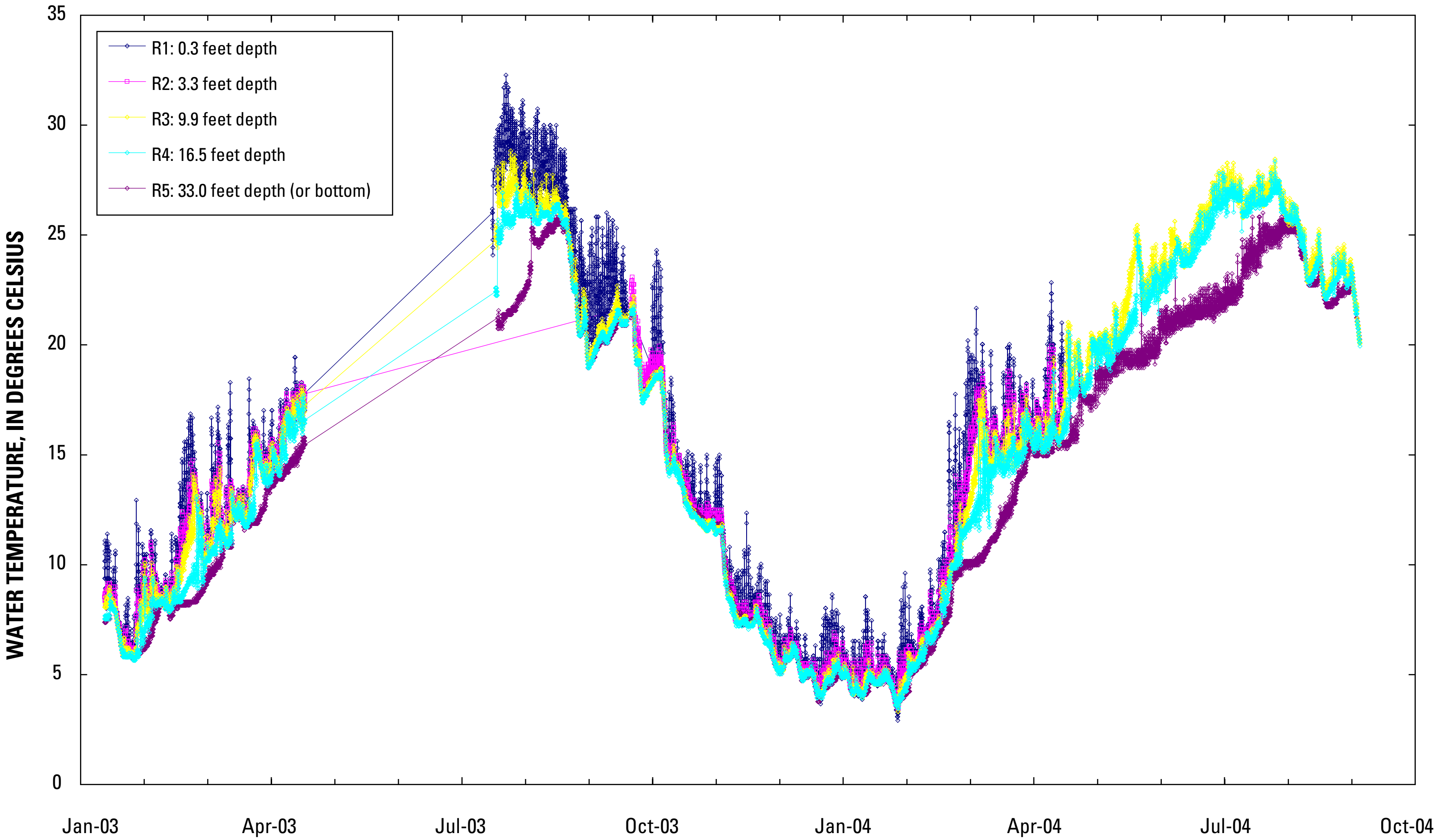


Figure 17. Average hourly water temperature at various depths in Sand Hollow Reservoir, Utah, 2003-04.

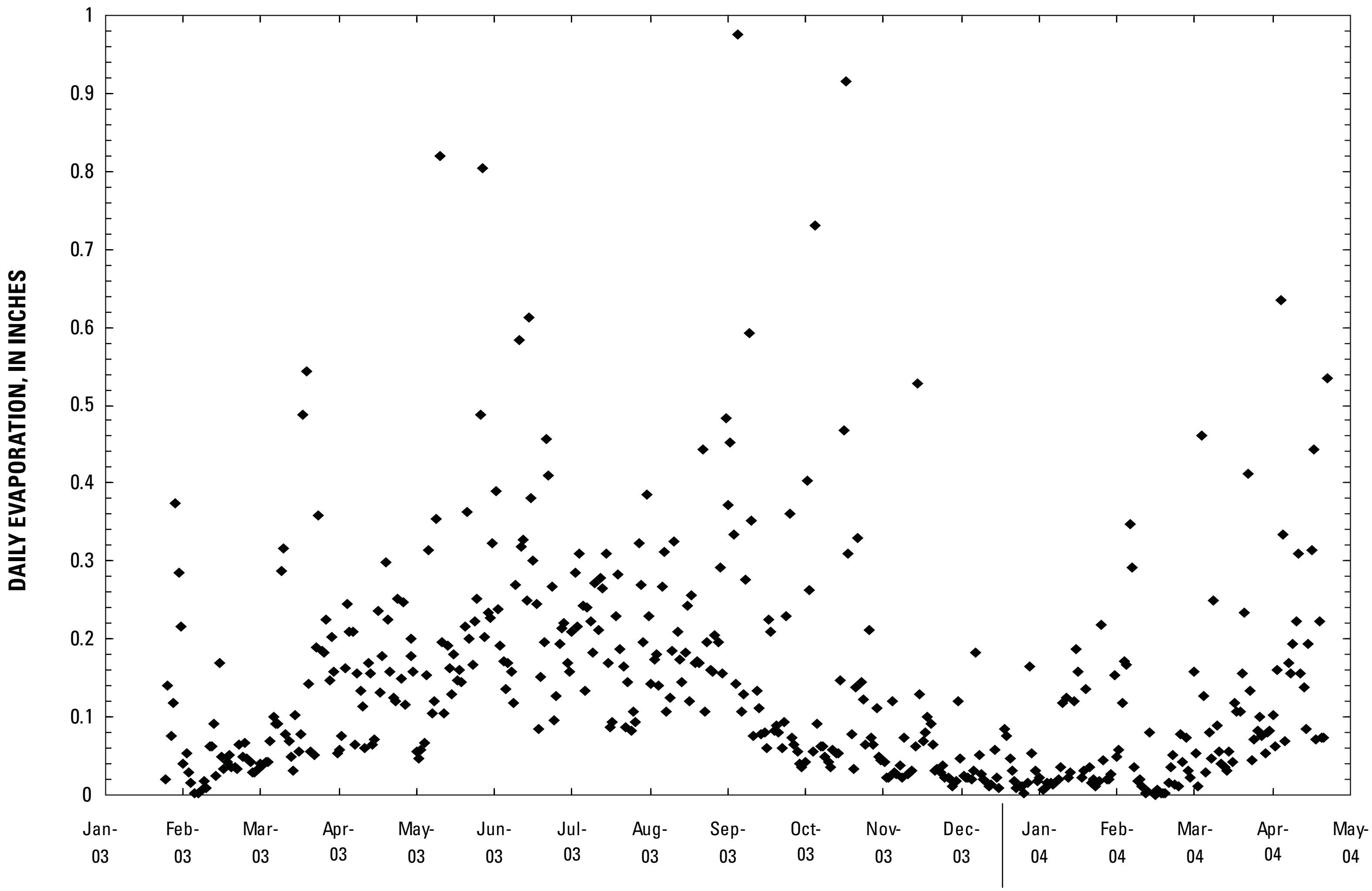


Figure 18. Daily evaporation calculated with the turbulent-transfer method for Sand Hollow Reservoir, Utah, 2003-04.

A comparison of annual evaporation estimates are shown in figure 19. Assuming that about 8 percent of annual evaporation occurs during the winter months (December through February), the 9-month corrected average annual pan-evaporation rate can be extrapolated to an estimated annual average evaporation rate of about 65 in. per year. Annual Jensen-Haise evaporation ranged from 55.3 to 61.2 in. with an average of 59.8 in. for 1999-2003. A detailed evaporation study made using the energy-budget method was done from rafts in Lake Mead, and about 72-84 in. of annual evaporation was measured (Guy DeMeo, U.S. Geological Survey, oral commun., 2004). Lake Mead is at a lower altitude and has a warmer climate than Sand Hollow and thus would be expected to have more evaporation. By estimating evaporation for the missing month of January 2003 as 1.5 in., the annual 2003 turbulent-transfer method evaporation is 54.8 in. This is 10 percent less than the annual evaporation calculated with the Jensen-Haise method for 2003. The difference could be the result of the roughness length used in the turbulent-transfer calculation.

Annual Penman evaporation for St. George, Utah, for 1999 and 2003 (72.87 and 67.59 in., respectively) is greater than evaporation estimates from the long-term average (1869-1993) corrected pan evaporation (65 in., with estimates of the winter months), the 1999-2003 average annual Jensen-Haise evaporation (59.8 in.), and the 2003 annual turbulent-transfer egmvaporation (54.8 in.). These annual Penman evaporation estimates are almost equal to evaporation measured at Lake Mead with energy-budget methods, which indicates that it is probably overestimating evaporation (Guy DeMeo, U.S. Geological Survey, oral commun., 2004). The overestimation of evaporation at Sand Hollow Reservoir made using the Penman equation with St. George data is possibly because the climate is slightly different between the two sites. To use the Penman method at Sand Hollow Reservoir, a net radiometer and soil-temperature and heat-flux sensors would need to be added to the Sand Hollow weather station.

Regarding the applicability of the other methods for estimating evaporation from Sand Hollow Reservoir, the turbulent-transfer method estimates evaporation over daily to weekly time periods more accurately than the other methods, but requires more climate variables (including reservoir water temperatures) and is dependent upon the selection of an appropriate roughness coefficient. The corrected St. George pan evaporation rates are considered accurate for Sand Hollow, but have not been calculated since 1993 and do not include winter

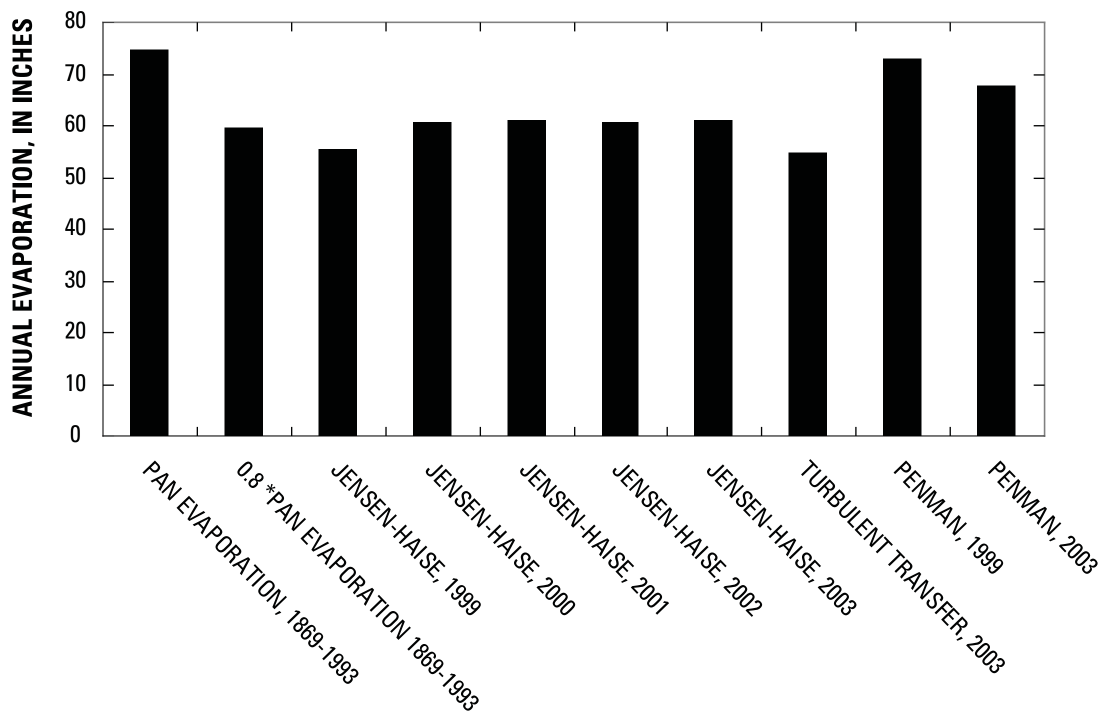


Figure 19. Comparison of average annual estimated evaporation rates for Sand Hollow Reservoir, Utah.

measurements. Therefore, the Jensen-Haise method is considered the most cost-effective and suitable for estimating evaporative losses from Sand Hollow Reservoir.

The total estimated amount of evaporation from Sand Hollow Reservoir from March 2002 to September 2004 is 5,850 acre-ft (table 6). This is based on evaporation rates estimated using the Jensen-Haise method, as well as reservoir-surface altitudes and stage-surface-area relations for the reservoir (Washington County Water Conservancy District, written commun., 2004). Since the initial filling of the reservoir, monthly evaporation amounts ranged from about 20 acre-ft during November 2003 to 650 acre-ft during June 2004, depending both on the reservoir surface area and the evaporation rate.

Artificial Recharge Estimates

Since the initial filling of Sand Hollow Reservoir in March 2002 until September 2004, its altitude has varied from 2,993 to 3,027 ft (fig. 20), with an estimated surface area ranging from 140 to 780 acres (Washington County Water Conservancy District, written commun., 2004). Monthly estimated recharge was calculated by using equation 2. On the basis of reported surface-water inflows, outflows, and changes in reservoir storage (Washington County Water Conservancy District, written commun., 2004), monthly recharge ranged from about 3,500 acre-ft during March 2002 down to about 190 acre-ft during October 2003 (table 7, fig. 20). On the basis of total net surface-water inflows into the reservoir of about 46,000 acre-ft from March 2002 through August 2004, evaporative losses of about 6,000 acre-ft, and the approximately 12,000 acre-ft of surface-water in the reservoir as of August 30, 2004, the total estimated artificial recharge to the underlying Navajo aquifer during this 30-month period is estimated to be about 28,000 acre-ft.

Artificial recharge rates beneath Sand Hollow reservoir decreased from 0.44 ft/d during the first month down to about 0.03 ft/d during the latter part of 2003. The anomalously large amounts of recharge during the first 3 months were caused by the filling of the previously dry vadose zone. Excluding the initial 3-month wetting-up of the vadose zone, the average recharge rate and hydraulic conductivity was about 0.06 ft/d.

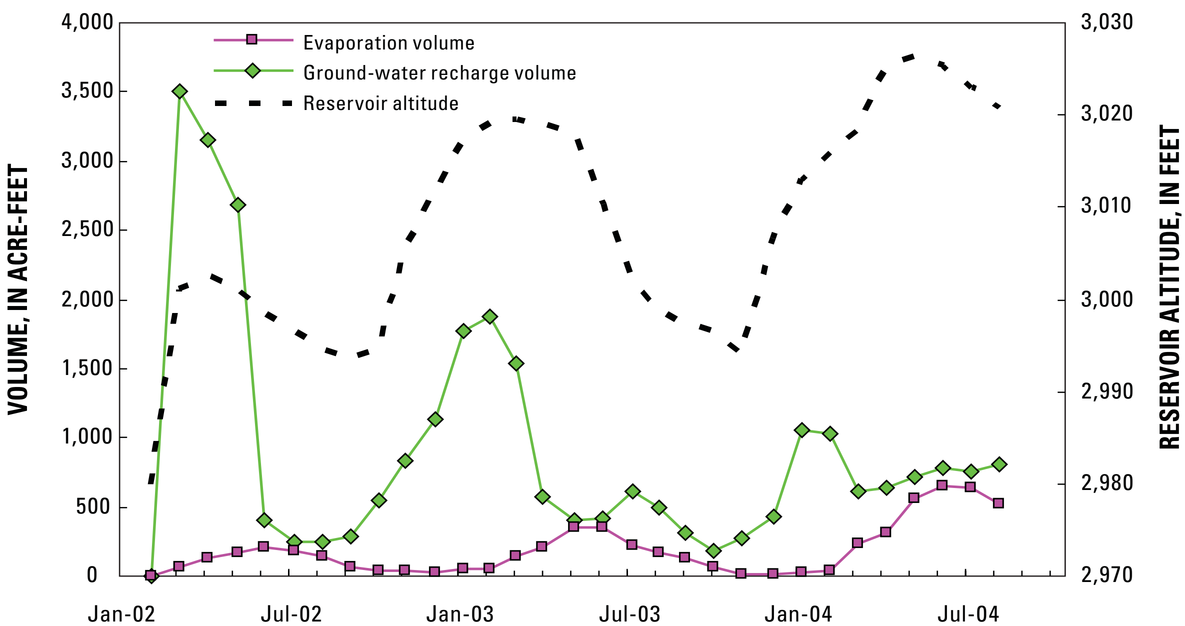


Figure 20. Monthly estimated evaporation, ground-water recharge, and reservoir altitude, Sand Hollow Reservoir, Utah, 2002-04.

For the measured range in water temperature of 5.0 to 24.0ºC at a depth of about 33 ft in Sand Hollow Reservoir, dynamic viscosities range from 0.92 to 1.52 centipoise (6.22×10^{-4} to 1.02×10^{-3} lb/ft-sec). In equation 4, these dynamic viscosity values indicate that actual recharge rates and hydraulic conductivity values beneath the reservoir were as much as 8 percent lower during the summer months and as much as 36 percent higher during the winter months than if the reservoir water temperature remained constant at 20.0ºC. Average monthly viscosity-corrected hydraulic conductivity ranges from 0.02 to 0.57 ft/d were calculated by using equations 4 and 5 (table 7, fig. 21). These are at the low end of the range of laboratory core saturated hydraulic-conductivity values reported by Heilweil and others (2004), which generally represent matrix (rather than fracture) permeability.

Monthly total recharge quantities (fig. 20) and viscosity-corrected hydraulic-conductivity values (fig. 21) generally mimic reservoir altitudes because a higher reservoir stage results in both larger wetted areas and larger vertical hydraulic gradients. However, viscosity-corrected hydraulic conductivity dropped off in the spring of all three years (2002-04) when the reservoir altitude was still high. Similarly, despite the higher reservoir stage each consecutive year, the peak monthly total recharge was almost 50 percent lower in each of the three consecutive years (fig. 20). Possible causes for these seasonal and longer-term decreases are siltation, biofilm formation, or gas clogging along the bottom of the reservoir. A yearly silt layer may form as suspended sediments in the new water brought into the reservoir each winter and spring settle out on the floor of the reservoir. These low-permeability fine-grained sediments would likely reduce vertical hydraulic conductivity and artificial recharge. Seasonal biofilm development has been observed beneath the reservoir, corresponding to increases in reservoir water temperature. This may also reduce infiltration into the material beneath the reservoir. Finally, trapped gas bubbles in the sediments directly beneath the reservoir may expand seasonally with warmer spring and summer water temperatures, causing increased gas-clogging and permeability reduction.

Excluding the very large initial recharge rates during the wetting-up period, the average recharge rate of 0.08 ft/d beneath Sand Hollow Reservoir during the first year of operation is less than one-half of the recharge rate of 0.18 ft/d reported during the 10-month infiltration

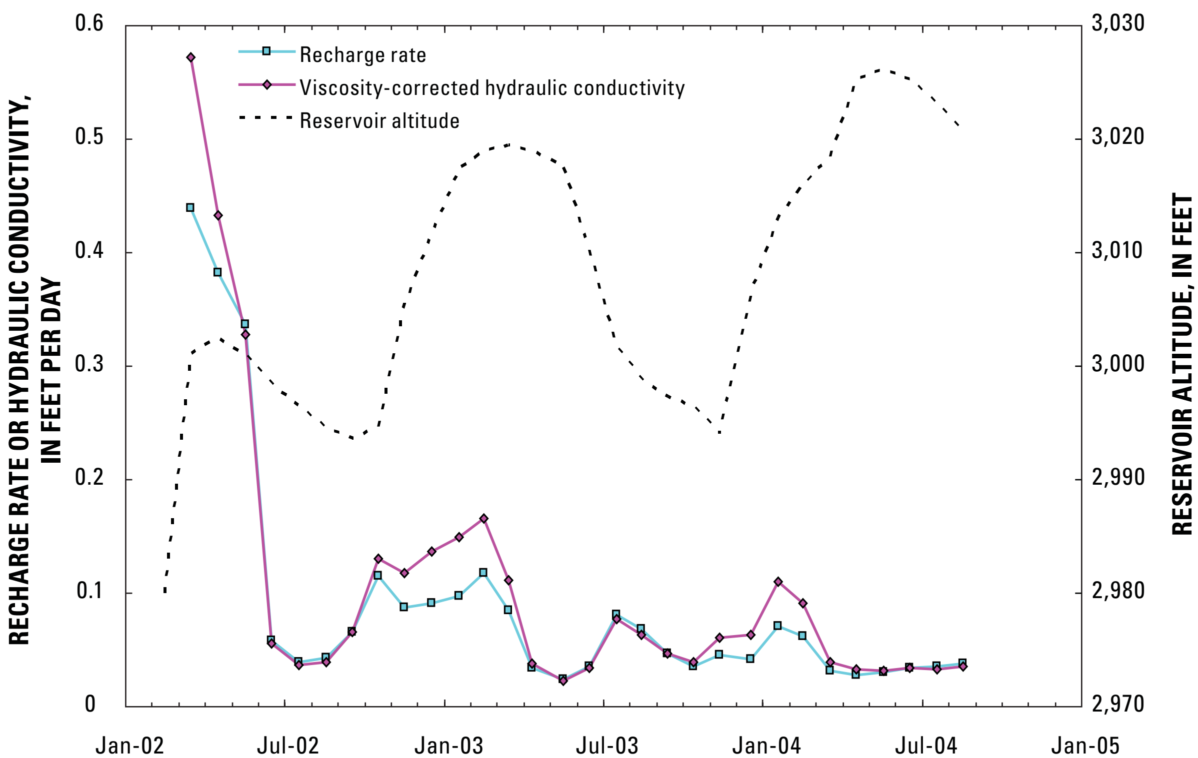


Figure 21. Monthly artificial recharge rate, viscosity-corrected hydraulic conductivity, and reservoir altitude, Sand Hollow Reservoir, Utah, 2002-04.

pond experiment (Heilweil and others, 2004) located at the IFP 1 site (map number 12 in fig. 3, table 1). These lower recharge rates may be caused by (1) lower hydraulic gradients after the ground-water table connected with the surface-water reservoir, (2) finer-grained surficial soils beneath the lower part of the reservoir, compared to the IFP 1 site (Heilweil and Solomon, in press, fig. 2), (3) more biofilm development beneath the larger reservoir because of higher nutrient concentrations in the surface-water sources compared to the ground water used for the infiltration pond experiment, (4) the deposition of more silt along the bottom of the reservoir, which is filled with Virgin River water containing higher suspended sediments than the ground water used during the infiltration pond experiment, or (5) larger amounts of trapped air beneath the reservoir, causing more gas-clogging and permeability reduction.

SUMMARY

Sand Hollow Reservoir was constructed in 2002 to provide both surface-water storage and artificial recharge to the underlying Navajo aquifer in Washington County, Utah. The U.S. Geological Survey conducted a study in cooperation with the Washington County Water Conservancy District, Bureau of Reclamation, and the University of Utah Department of Geology and Geophysics to document baseline ground-water conditions at Sand Hollow prior to the operation of the surface-water reservoir to evaluate changes in ground-water conditions caused by the reservoir.

Prior to the filling of Sand Hollow Reservoir in March 2002, water-level fluctuations at observation wells generally were less than 10 ft except in the immediate vicinity of production wells. The pre-reservoir direction of ground-water flow was predominantly north toward where it discharges into the Virgin River. Since March 2002, water levels in the immediate vicinity of Sand Hollow Reservoir have risen by as much as 80 ft and ground water is currently moving away from the reservoir in all directions.

Before the reservoir was constructed, age dating of ground water in Sand Hollow basin by using $^3H/^3He$, chlorofluorocarbons, and ^{14}C indicated that shallow ground water in Sand Hollow had entered the aquifer recently at some locations. Water deeper within the aquifer may be as old as 8,500 years. The dissolved-solids concentration of pre-reservoir ground water within Sand Hollow was less than 400 mg/L. Measured natural concentrations of nutrients including nitrate, ammonia, and phosphorus were generally less than current EPA drinking-water standards. Water from seven wells had pre-reservoir arsenic concentrations exceeding the EPA standard of 10 μg/L, with values ranging between 12 and 55 μg/L. Ratios of stable isotopes in pre-reservoir ground water had mean ground-water values of -86 permil for δ^2H and -11.1 permil for $\delta^{18}O$, which is similar to mean precipitation values and indicates that local precipitation is the primary source of natural recharge to the aquifer.

Tracers of artificial recharge include specific conductance, Cl:Br ratios, and total dissolved-gas pressures. Specific-conductance values of ground water have risen at observation wells close to the reservoir, approaching reservoir values, which average about 800 μS/cm. Cl:Br ratios of ground water have increased in some wells near the reservoir but remain well below the values (as high as 5,000) measured in reservoir water, possibly buffered by the flushing of previously accumulated vadose-zone salts with relatively low Cl:Br ratios. The flushing of these naturally occurring vadose-zone salts, however, is not generally affecting water quality within the aquifer, likely because of its large saturated thickness. In-situ total dissolved-gas pressure in ground water near the reservoir showed large increases since the filling of the reservoir, caused by the combination of dissolution of entrapped air bubbles (excess air) and increased hydrostatic head associated with the rapidly rising water table. Total dissolved-gas pressure has risen from about 1 to at least 3 atmospheres in shallow observation wells adjacent to the reservoir. This indicates that gas clogging associated with trapped air may be reducing the permeability of the sandstone in the vicinity of the reservoir.

Arsenic concentrations have risen in water at three shallow observation wells within Sand Hollow, but no trends are apparent yet in arsenic concentrations in ground water from deeper within the aquifer. In addition to the wells containing water with high natural arsenic concentrations (prior to the reservoir filling), 10 other wells have water with post-reservoir arsenic concentrations exceeding the EPA standard, with values ranging from 10 to 90 μg/L. On the basis of the persistence of high arsenic concentrations at the North Dam 3A observation well, increased arsenic concentration is likely caused by changes in pH associated with the reservoir, rather than flushing of vadose-zone salts or from recharging reservoir water (with arsenic concentrations generally less than 3 μg/L).

To estimate artificial recharge beneath Sand Hollow Reservoir, a water-budget approach was used. Components of the water budget include surface-water inflows and outflows to and from the reservoir, evaporation, and changes in surface-water storage. Evaporation from the surface of Sand Hollow Reservoir was estimated with a variety of techniques, including physical measurements (pan-evaporation data from nearby St. George, Utah), estimates based on meteorological data (Penman and Jensen-Haise methods), and estimates based on reservoir water-temperature measurements (turbulent-transfer method). Using meteorological data from the weather station at Sand Hollow, the Jensen-Haise method provides the best combination of cost and accuracy. Estimated evaporation rates using this method range from 55 to 61 in. per year, resulting in a total estimated evaporative loss of about 6,000 acre-ft of water from March 2002 to September 2004 from Sand Hollow Reservoir. Based on total net surface-water inflows to the reservoir of about 46,000 acre-ft during this period and the 12,000 acre-ft of surface-water in the reservoir as of August 30, 2002, the total estimated artificial recharge to the underlying Navajo aquifer during this 30-month period is estimated to be about 28,000 acre-ft. Rates of artificial recharge have ranged from about 0.02 to 0.44 ft/day, with an average rate (excluding the initial 3-month wetting period) of about 0.06 ft/d. This is about one-third of the expected rates based on a previous 10-month long infiltration pond experiment. Possible causes for this are lower hydraulic gradients once the ground-water table connected with the surface-water reservoir, lower-permeability surficial soils, siltation and/or bioclogging, or gas clogging caused by trapped air. The general decline in recharge rates during the 3-year period since initial filling is a typical pattern observed at most artificial recharge facilities.

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Table 1. Records of selected wells and boreholes in Sand Hollow, Utah

[**Map number:** Refer to figure 3; **Primary use of site:** W, withdrawal; O, observation. **Depth of well:** A, abandoned. **Casing finish:** F, sand with perforations; S, screen; X, open hole. **Water level:** Measured by the U.S. Geological Survey except where noted; L, reported in drillers' logs; E, estimated; **Other data available:** W, water-level measurements in table 2; C, general chemical analyses in table 3; I, chemical analyses of isotopes, chlorofluorocarbons, and/or tritium in table 4. All wells are within the Navajo Sandstone; —, no data available]

Map number	Well location	Well name	Latitude (degree/minute/second)	Longitude (degree/minute/second)	Altitude of land surface (feet)	Year drilled	Primary use of site
1a	(C-42-13)18bcb-2	Wayne Wilson (original)	370812	1132148	2,960	1959	W
1b	(C-42-13)18bcb-2	Well 1 (Wayne Wilson redrilled)	370812	1132148	2,960	2002	W
2	(C-42-13)19cdb-1	WD 12 (Slope 2)	370654	1132135	3,079	1999	O
3	(C-42-13)19dcb-1	Well 2 (east side of reservoir)	370651	1132117	3,145	2002	W
4	(C-42-13)19ddd-1	Ridge 1	370647	1132054	3,380	1999	O
5	(C-42-13)30bcd-1	WD 10 (Island)	370628	1132141	3,060	2001	O
6	(C-42-13)30bdc-1	Well 4 (Sky Ranch 2)	370622	1132133	3,070	1994	W
7	(C-42-14)13aad-1	Dale Wilson	370821	1132201	2,940	1985	W
8	(C-42-14)13acd-2	WD 4	370806	1132222	2,962	1995	O
9	(C-42-14)13cda-1	WD 6 (Slickrock)	370753	1132231	3,004	2001	O
10	(C-42-14)13cdd-1	Well 8 (west side North Dam)	370742	1132236	3,050	2001	W
11	(C-42-14)13dca-1	WD 2	370746	1132223	2,988	1995	O
12	(C-42-14)13dca-2	IFP 1	370745	1132220	2,976	1999	O
13	(C-42-14)13dca-11	IFP 1 (Port 1)	370745	1132220	2,976	1999	O
14	(C-42-14)13dca-12	IFP 1 (Port 2)	370745	1132220	2,976	1999	O
15	(C-42-14)13dca-13	IFP 1 (Port 3)	370745	1132220	2,976	1999	O
16	(C-42-14)13dca-14	IFP 1 (Port 4)	370745	1132220	2,976	1999	O
17	(C-42-14)13dca-15	IFP 1 (Port 5)	370745	1132220	2,976	1999	O
18	(C-42-14)13dca-17	IFP 5 Shallow	370745	1132220	2,977	2000	O
19	(C-42-14)13dca-18	IFP 5 Medium	370745	1132220	2,977	2000	O
20	(C-42-14)13dca-19	IFP 5 Deep	370745	1132220	2,977	2000	O
21	(C-42-14)13dca-20	IFP 6 Shallow	370745	1132220	2,977	2000	O
22	(C-42-14)13dca-21	IFP 6 Medium	370745	1132220	2,977	2000	O
23	(C-42-14)13dca-22	IFP 6 Deep	370745	1132220	2,977	2000	O
24	(C-42-14)13dca-23	IFP 7 Shallow	370745	1132220	2,980	2000	O
25	(C-42-14)13dca-24	IFP 7 Deep	370745	1132220	2,980	2000	O
26	(C-42-14)13dca-29	[1]IFP 2	370745	1132221	2,977	1999	O
27	(C-42-14)13dcd-1	Wash 1	370737	1132220	2,972	1999	O
28	(C-42-14)13dcd-2	North Dam 3A	370738	1132217	2,970	2001	O
29	(C-42-14)13ddc-1	Well 9 (east side of North Dam)	370738	1132209	2,970	2000	W
30	(C-42-14)13ddc-2	North Dam Drain	370738	1132215	2,970	2001	W
31	(C-42-14)13ddd-1	WD 1	370738	1132205	2,998	1995	O
32	(C-42-14)14aad-1	WD RJ	370822	1132315	2,952	1995	O

Table 1. Records of selected wells and boreholes in Sand Hollow, Utah—Continued

Map number	Depth of well (feet)	Casing: Diameter (inches)	Casing: Bottom (feet)	Casing: Finish (feet)	Water level: Below land surface (feet)	Water level: Date measured	Depth of openings below water table (feet)	Other data available
1a	194	14	17	X 17-194	67.63	01/04/2000	0 to 126	C,I
1b	1,000	24	1,000	S 120-340	—	—	52 to 272	C, I
				S 380-500	—	—	312 to 432	—
				S 540-660	—	—	472 to 592	—
				S 700-820	—	—	632 to 752	—
				S 860-1,000	—	—	792 to 932	C, I
2	164.6	.75	155.5	F 150.3-155.3	148.78	09/04/2001	1.5 to 6.5	W, I
3	900	16	900	S 135-295	212.29	10/07/2002	0 to 81	C, I
				S 335-415	—	—	123 to 194	C, I
				S 455-535	—	—	243 to 323	C, I
				S 575-655	—	—	363 to 443	C, I
				S 695-855	—	—	483 to 643	C, I
4	89 A	—	—	—	Dry	05/04/1999	—	—
5	133.8	2	122	F 116.8-121.9	119.13	09/04/2001	0 to 2.7	C, I
6	590	12	52	X 52-590	130.68	07/17/2001	0 to 459	C, I
7	200	8	20	X 20-200	59.40	02/17/1996	0 to 141	I
8	90	1	90	F 80-90	60.25	09/04/2001	20 to 30	W, C, I
9	96	2	96	F 90.8-95.8	94.32	09/04/2001	0 to 5	W, C, I
10	624	16	624	S 144-504	[2]91.52	10/06/2002	52 to 412	C, I
				S 544-624	—	—	452 to 532	C, I
11	104	1	104	F 94-104	80.70	09/04/2001	13 to 23	W, I
12	103.5	—	—	X 0-103.5	64.13	09/28/1999	0 to 39	C, I
13	103.5	.5	93.1	F 92.5-93.0	64.14	11/28/1999	28.5 to 29.0	I
14	103.5	.5	88.6	F 88.0-88.5	64.12	11/28/1999	24.0 to 24.5	—
15	103.5	.5	82.1	F 81.5-82.0	64.09	11/28/1999	17.5 to 18.0	—
16	103.5	.5	75.6	F 75.0-75.5	64.02	11/28/1999	11.0 to 11.5	I
17	103.5	.5	69.1	F 68.5-69.0	64.00	11/28/1999	4.5 to 5.0	I
18	101	.75	71.2	F 66.0-71.0	65.35	07/18/2000	.7 to 5.7	I
19	101	.75	81.2	F 76.0-81.0	65.27	07/18/2000	10.7 to 15.7	I
20	101	.75	91.2	F 86.0-91.0	—	—	20.7 to 25.7	I
21	103	.75	72.2	F 67.0-72.0	64.79	09/14/2000	2.2 to 7.2	—
22	103	.75	82.2	F 77.0-82.0	64.68	09/08/2000	12.2 to 17.2	—
23	103	.75	92.2	F 87.0-92.0	—	—	22.2 to 27.2	—
24	79	.75	69.2	F 64.0-69.0	67.80	07/19/2000	0 to 1.2	C
25	79	.75	77.2	F 72.0-77.0	66.99	06/08/2000	4.2 to 9.2	—
26	66 A	—	—	—	—	—	0 to 2	C, I
27	68 A	—	—	—	56.02	05/26/1999	0 to 12	C, I
28	26	1	25.7	F 15-25	[2]7.74	10/08/2002	7.3 to 17.3	C, I
29	1,210	24	1,210	S 104-1140	69 L	06/30/2000	35 to 1,071	C, I
30	15	48	15	—	—	—		C, I
31	110	1	110	F 100-110	93.05	09/04/2001	7 to 17	W, C, I
32	205	1	205	F 195-205	56.06	09/04/2001	139 to 149	W, C, I

Table 1. Records of selected wells and boreholes in Sand Hollow, Utah—Continued

Map number	Well location	Well name	Latitude (deg/min/sec)	Longitude (deg/min/sec)	Altitude of land surface (feet)	Year drilled	Primary use of site
33	(C-42-14)23abc-1	WD 5	370728	1132334	2,994	1995	O
34	(C-42-14)23daa-1	WD 3	370707	1132315	3,027	1995	O
35	(C-42-14)23dda-1	Hole N	370700	1132304	3,018	2001	O
36	(C-42-14)23ddc-1	WD 11 (West Dam)	370647	1132327	3,017	2001	O
37	(C-42-14)24bcd-1	WD 9 (Boat Ramp)	370723	1132256	3,066	2001	O
38	(C-42-14)24caa-1	Basin 1	370710	1132232	2,979	1999	O
39	(C-42-14)24ddd-1	Slope 1a	370650	1132201	3,029	1999	O
40	(C-42-14)24ddd-2	Slope 1b	370650	1132201	3,030	1999	O
41	(C-42-14)25aac-1	Hole Q	370636	1132201	3,036	2001	O
42	(C-42-14)25abb-1	Terracor 3	370645	1132244	3,006	1970	O
43	(C-42-14)25abb-2	Hole O	370645	1132244	3,006	2001	O
44	(C-42-14)25cdb-1	WD 8 (Sand Dune)	370607	1132247	3,075	2001	O
45	(C-42-14)25cdb-2	Hole S[1]	370607	1132247	3,082	2002	O
46	(C-42-14)25dba-1	Basin 2	370616	1132219	3,042	1999	O
47	(C-42-14)25ddd-1	WD 13 (Corral)	370555	1132206	3,083	—	O
48	(C-42-14)26abb-1	Well 17 (West Dam)	370638	1132334	3,027	2000	W
49	(C-42-14)26bbb-1	WD 14 (Terracor 2)	370645	1132413	3,021	1970	O
50	(C-42-14)26bdd-1	WD 7 (south end of West Dam)	370626	1132342	3,075	2001	O
51	(C-42-14)26dad-1	Hole K	370612	1132306	3,070	2001	O

[1]Drilled at a 45 degree angle.
[2]Water level affected by reservoir seepage.

Table 1. Records of selected wells and boreholes in Sand Hollow, Utah—Continued

Map number	Depth of well (feet)	Casing			Water level		Depth of openings below water table (feet)	Other data available
		Diameter (inches)	Bottom (feet)	Finish (feet)	Below land surface (feet)	Date measured		
33	160	1	160	F 150-160	70.90	09/04/2001	79 to 89	W, C, I
34	164	1	164	F 144-164	95.64	09/04/2001	48 to 68	W, C, I
35	88.6 A	—	—	—	80 E	—	0 to 9	C, I
36	112	2	98.5	F 93.5-98.5	77.42	09/04/2001	16 to 21	W, C, I
37	155	2	155	F 149.8-154.8	141.95	09/04/2001	8 to 13	W, C, I
38	111 A	2	92.5	F 87.3-92.3	51.20	06/15/2001	36 to 41	C, I
39	143.6	2	130	F 124.8-129.8	92.66	09/12/2001	32 to 37	C, I
40	98.8	8	8.5	X 8.5-98.8	94	05/19/1999	0 to 5	—
41	50 A	—	—	—	Dry	05/26/2001	—	—
42	720 A	12	4	X 4-720	67.16	09/04/2001	0 to 653	C, I
43	73 A	2	72	F 66.8-71.8	66.35	09/04/2001	.5 to 5.5	C, I
44	130	2	118.7	F 113.5-118.5	107.12	09/04/2001	6.4 to 11.4	W, C, I
45	114	—	—	—	—	—	—	—
46	143.6 A	2	118	F 112.8-117.8	92.80	07/16/2001	20 to 25	C, I
47	250 E	—	—	—	130.54	09/04/2001	0 to 120 E	W, C, I
48	608	16	608	S 140-580	84.18	09/04/2001	56 to 496	C, I
49	645	8	5	X 5-645	81.72	09/04/2001	0 to 563	W, C, I
50	139.6	2	130	F 124.8 -129.8	120.03	09/04/2001	4.8 to 9.8	W, C, I
51	28.6 A	—	—	—	Dry	05/17/2001	—	—

Table 2. Water levels in selected wells in Sand Hollow, Utah

[**Well location:** See figure 2 for an explanation of the numbering system used for hydrologic-data sites in Utah. See table 1 for well information; see figure 3 for map location; **Water Level**: In feet below land surface. All water levels reported from Washington County Water ConservancyDistrict]

Well location, well name, and map number	Date	Water level
(C-42-13)19cdb-1	09/04/2001	148.78
(WD 12, Map # 2)	10/04/2001	148.73
	11/06/2001	148.65
	12/03/2001	148.60
	01/08/2002	148.54
	01/30/2002	148.82
	02/19/2002	148.85
	03/08/2002	148.87
	03/19/2002	148.92
	04/01/2002	148.75
	04/08/2002	148.94
	04/15/2002	148.45
	04/22/2002	148.88
	04/29/2002	148.85
	05/16/2002	148.85
	05/23/2002	148.77
	05/30/2002	148.79
	06/03/2002	148.80
	06/17/2002	148.60
	06/25/2002	148.65
	07/08/2002	148.70
	07/15/2002	148.70
	07/22/2002	148.60
	07/30/2002	148.55
	08/06/2002	148.50
	08/13/2002	148.60
	09/03/2002	148.20
	10/18/2002	148.13
	11/04/2002	147.99
	11/18/2002	148.23
	11/26/2002	147.93
	12/10/2002	147.65
	12/24/2002	147.88
	01/13/2003	147.40
	01/21/2003	147.50
	01/31/2003	146.50
	02/04/2003	146.20
	02/20/2003	146.60
	03/05/2003	147.30
	03/20/2003	146.50
	03/31/2003	146.30
	04/21/2003	146.70
	05/05/2003	146.50
	05/21/2003	146.10
(C-42-13)19cdb-1—Continued	06/03/2003	145.40
	07/02/2003	144.40
	07/18/2003	144.50
	08/01/2003	144.80
	08/15/2003	144.90
	08/27/2003	145.40
	09/12/2003	143.00
	09/26/2003	142.50
	10/10/2003	142.80
	11/07/2003	143.20
	11/24/2003	141.10
	12/05/2003	141.10
	12/19/2003	141.10
	01/09/2004	141.10
	01/23/2004	139.80
	02/06/2004	139.60
	02/23/2004	138.75
	03/16/2004	138.20
	04/01/2004	137.60
	04/14/2004	137.40
	04/20/2004	137.35
	05/02/2004	137.15
	05/11/2004	136.85
	05/24/2004	136.60
	06/14/2004	135.90
	07/14/2004	135.50
	08/10/2004	134.70
	08/27/2004	134.25
	09/10/2004	133.80
	10/04/2004	133.00
	10/25/2004	132.20
	11/10/2004	132.00
	12/02/2004	131.20
	12/20/2004	130.25
	01/03/2005	130.00
	01/28/2005	130.20
(C-42-13)30bcd-1	09/04/2001	119.13
(WD 10, Map # 5)	10/04/2001	119.10
	11/06/2001	119.00
	12/03/2001	118.92
	01/08/2002	118.85
	01/30/2002	119.16
	02/19/2002	119.18
	03/08/2002	119.15

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-13)30bcd-1—Continued	03/19/2002	119.22
	04/01/2002	118.87
	04/08/2002	119.07
	04/15/2002	118.53
	04/22/2002	118.95
	04/29/2002	118.93
	05/16/2002	118.91
	05/23/2002	118.90
	05/30/2002	118.87
	06/03/2002	118.87
	06/17/2002	118.80
	06/25/2002	118.87
	07/08/2002	118.95
	07/15/2002	118.90
	07/22/2002	118.80
	07/30/2002	118.85
	08/06/2002	118.80
	08/13/2002	118.80
	09/03/2002	118.71
	10/18/2002	118.49
	11/04/2002	118.40
	11/18/2002	118.66
	11/26/2002	118.44
	12/10/2002	118.15
	12/24/2002	118.45
	01/13/2003	118.10
	01/21/2003	118.20
	01/31/2003	118.10
	02/04/2003	118.05
	02/20/2003	117.95
	03/05/2003	118.10
	03/20/2003	117.60
	03/31/2003	117.50
	04/21/2003	117.60
	05/05/2003	117.10
	05/21/2003	117.10
	06/03/2003	116.40
	07/02/2003	115.60
	07/18/2003	115.50
	08/01/2003	115.10
	08/15/2003	114.90
	08/27/2003	114.65
	09/12/2003	114.50
	09/26/2003	114.00
	10/10/2003	113.90
	11/07/2003	113.10
	11/24/2003	113.60

Well location, well name, and map number	Date	Water level
(C-42-13)30bcd-1—Continued	12/05/2003	113.50
	12/19/2003	113.40
	01/09/2004	113.20
	01/23/2004	111.50
	02/06/2004	111.40
	02/23/2004	110.60
	03/16/2004	110.20
	04/01/2004	109.70
	04/14/2004	109.50
	04/20/2004	109.50
	05/02/2004	109.20
	05/11/2004	108.95
	05/24/2004	108.70
	06/14/2004	107.95
	07/14/2004	107.50
	08/10/2004	107.60
	08/27/2004	105.40
	09/10/2004	104.80
	10/04/2004	103.90
	10/25/2004	103.05
	11/10/2004	102.70
	12/02/2004	101.80
	12/20/2004	100.90
	01/03/2005	100.60
	01/28/2005	99.80
(C-42-14)13acd-2 (WD 4, Map # 8)	03/03/1995	56.80
	03/27/1995	56.90
	04/17/1995	57.00
	05/01/1995	56.90
	06/05/1995	57.00
	06/19/1995	57.10
	06/27/1995	57.25
	07/10/1995	57.20
	07/25/1995	57.38
	08/07/1995	57.45
	08/21/1995	57.59
	09/05/1995	57.70
	09/20/1995	57.62
	10/02/1995	57.75
	10/16/1995	57.76
	10/30/1995	57.88
	11/13/1995	58.01
	11/27/1995	58.02
	12/11/1995	58.04
	01/09/1996	58.02
	01/29/1996	58.04
	02/12/1996	58.16

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
C-42-14)13acd-2—Continued	02/26/1996	58.09
	03/11/1996	58.11
	03/25/1996	58.16
	04/08/1996	58.27
	04/22/1996	58.40
	05/06/1996	58.33
	05/20/1996	58.50
	06/03/1996	58.58
	06/17/1996	58.62
	07/01/1996	58.71
	07/15/1996	58.75
	07/29/1996	58.85
	08/12/1996	58.91
	08/26/1996	58.97
	09/16/1996	59.04
	10/01/1996	59.27
	10/25/1996	59.08
	12/04/1996	59.50
	12/23/1996	59.57
	12/30/1996	59.35
	01/28/1997	59.53
	02/24/1997	59.49
	03/17/1997	59.50
	04/07/1997	59.45
	04/28/1997	59.55
	05/19/1997	59.54
	06/04/1997	59.57
	06/30/1997	59.80
	07/14/1997	59.93
	07/28/1997	59.92
	08/18/1997	60.04
	09/08/1997	60.02
	09/22/1997	60.13
	10/20/1997	60.11
	11/17/1997	60.33
	12/01/1997	60.09
	12/22/1997	60.05
	01/05/1998	60.19
	01/20/1998	60.15
	02/02/1998	60.11
	02/23/1998	60.06
	03/10/1998	60.43
	03/24/1998	59.94
	04/06/1998	60.02
	04/13/1998	60.04
	04/27/1998	60.08
	05/11/1998	59.99
(C-42-14)13acd-2—Continued	06/08/1998	60.11
	06/22/1998	60.21
	07/15/1998	60.38
	07/30/1998	60.34
	08/18/1998	60.44
	09/21/1998	60.40
	10/19/1998	60.45
	11/02/1998	60.42
	11/16/1998	60.46
	12/08/1998	60.47
	12/28/1998	60.43
	01/25/1999	60.07
	02/07/1999	60.31
	03/05/1999	60.10
	04/02/1999	60.04
	05/28/1999	59.92
	06/01/1999	59.98
	07/12/1999	59.99
	08/02/1999	59.97
	08/16/1999	59.91
	08/30/1999	59.81
	09/20/1999	59.89
	10/18/1999	59.78
	11/23/1999	59.68
	12/06//1999	59.63
	01/03/2000	59.86
	01/24/2000	59.55
	02/07/2000	59.53
	02/22/2000	59.64
	03/13/2000	59.39
	04/03/2000	59.44
	05/04/2000	59.39
	05/22/2000	59.43
	06/15/2000	59.38
	06/26/2000	59.44
	07/26/2000	59.39
	08/07/2000	59.52
	09/12/2000	59.59
	09/27/2000	59.64
	10/11/2000	59.71
	11/13/2000	59.76
	12/11/2000	59.78
	01/08/2001	59.76
	01/29/2001	59.98
	02/20/2001	60.05
	03/26/2001	60.00
	04/16/2001	60.06

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)13acd-2—Continued	05/08/2001	60.08
	05/29/2001	60.07
	06/11/2001	60.12
	06/25/2001	60.13
	07/16/2001	60.17
	07/30/2001	60.17
	08/08/2001	60.08
	09/04/2001	60.25
	10/04/2001	60.28
	11/06/2001	60.29
	12/03/2001	60.33
	01/08/2002	60.35
	01/30/2002	60.38
	02/19/2002	60.45
	03/08/2002	60.49
	03/19/2002	60.50
	04/01/2002	60.26
	04/08/2002	60.37
	04/15/2002	60.06
	04/22/2002	60.31
	04/29/2002	60.11
	05/16/2002	59.91
	05/23/2002	59.85
	05/30/2002	59.77
	06/03/2002	59.75
	06/17/2002	59.45
	06/25/2002	59.40
	07/08/2002	59.30
	07/15/2002	59.25
	07/22/2002	59.05
	07/30/2002	58.97
	08/06/2002	58.85
	08/13/2002	58.75
	09/03/2002	58.20
	10/18/2002	57.42
	11/04/2002	57.07
	11/18/2002	56.88
	11/26/2002	56.66
	12/10/2002	56.28
	12/24/2002	56.21
	01/13/2003	55.50
	01/21/2003	55.40
	01/31/2003	54.60
	02/04/2003	55.10
	02/20/2003	54.10
	03/05/2003	54.50
(C-42-14)13acd-2—Continued	03/20/2003	53.60
	03/31/2003	53.30
	04/21/2003	52.20
	05/05/2003	51.60
	05/21/2003	51.50
	06/03/2003	50.00
	07/02/2003	48.70
	07/18/2003	48.35
	08/01/2003	48.00
	08/15/2003	47.70
	08/27/2003	47.60
	09/12/2003	47.90
	09/26/2003	48.50
	10/10/2003	48.80
	11/07/2003	48.90
	11/24/2003	46.50
	12/05/2003	46.40
	12/19/2003	46.50
	01/09/2004	46.40
	01/23/2004	45.80
	02/06/2004	46.20
	02/23/2004	45.55
	03/16/2004	45.20
	04/01/2004	44.80
	04/14/2004	44.70
	04/20/2004	44.70
	05/02/2004	44.60
	05/11/2004	44.30
	05/24/2004	44.15
	06/14/2004	43.70
	07/14/2004	43.60
	08/10/2004	43.20
	08/27/2004	43.54
	09/10/2004	43.75
	10/04/2004	44.10
	10/25/2004	44.40
	11/10/2004	44.75
	12/02/2004	44.65
	12/20/2004	44.20
	01/03/2005	43.90
	01/28/2005	43.70
(C-42-14)13cda-1 (WD 6, Map # 9)	09/04/2001	94.32
	10/04/2001	94.42
	11/06/2001	95.78
	12/03/2001	95.48
	01/08/2002	95.31

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
C-42-14)13cda-1—Continued	01/30/2002	95.35
	02/19/2002	95.35
	03/08/2002	95.18
	03/19/2002	95.40
	04/01/2002	95.21
	04/08/2002	95.20
	04/15/2002	94.78
	04/22/2002	95.09
	04/29/2002	94.84
	05/16/2002	94.15
	05/23/2002	93.75
	05/30/2002	93.30
	06/03/2002	93.25
	06/17/2002	92.00
	06/25/2002	91.50
	07/08/2002	90.60
	07/15/2002	90.15
	07/22/2002	89.55
	07/30/2002	89.00
	08/06/2002	88.50
	08/13/2002	88.00
	09/03/2002	86.36
	10/18/2002	83.61
	11/04/2002	82.55
	11/18/2002	81.86
	11/26/2002	81.20
	12/10/2002	79.98
	12/24/2002	79.31
	01/13/2003	77.60
	01/21/2003	76.80
	01/31/2003	76.50
	02/04/2003	76.30
	02/20/2003	74.90
	03/05/2003	74.80
	03/20/2003	73.70
	03/31/2003	72.70
	04/21/2003	69.60
	05/05/2003	68.90
	05/21/2003	68.30
	06/03/2003	66.40
	07/02/2003	64.80
	07/18/2003	64.10
	08/01/2003	64.00
	08/15/2003	63.20
	08/27/2003	67.19
	09/12/2003	68.70
(C-42-14)13cda-1—Continued	09/26/2003	69.20
	10/10/2003	69.40
	11/07/2003	69.60
	11/24/2003	73.00
	12/05/2003	75.60
	12/19/2003	75.20
	01/09/2004	74.60
	01/23/2004	73.80
	02/06/2004	73.60
	02/23/2004	67.64
	03/16/2004	64.90
	04/01/2004	63.20
	04/14/2004	62.70
	04/20/2004	62.40
	05/02/2004	61.35
	05/11/2004	60.40
	05/24/2004	59.90
	06/14/2004	58.65
	07/14/2004	57.80
	08/10/2004	60.90
	08/27/2004	62.45
	09/10/2004	63.30
	10/04/2004	64.55
	10/25/2004	65.25
	11/10/2004	66.00
	12/02/2004	63.90
	12/20/2004	63.75
	01/03/2005	60.15
	01/28/2005	57.55
(C-42-14)13dca-1 (WD 2, Map # 11)	03/03/1995	76.10
	03/27/1995	76.20
	04/17/1995	76.20
	05/01/1995	76.10
	06/05/1995	76.10
	06/19/1995	76.20
	06/27/1995	76.27
	07/10/1995	76.25
	07/25/1995	76.32
	08/07/1995	76.32
	08/21/1995	76.56
	09/05/1995	76.50
	09/20/1995	76.37
	10/02/1995	76.51
	10/16/1995	76.36
	10/30/1995	76.48
	11/13/1995	76.69

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)13dca-1—Continued	11/27/1995	76.62
	12/11/1995	76.62
	01/09/1996	76.60
	01/29/1996	76.54
	02/12/1996	76.74
	02/26/1996	76.45
	03/11/1996	76.61
	03/25/1996	76.64
	04/08/1996	76.71
	04/22/1996	76.90
	05/06/1996	76.68
	05/20/1996	76.77
	06/03/1996	76.93
	06/17/1996	76.85
	07/01/1996	76.96
	07/15/1996	76.91
	07/29/1996	77.02
	08/12/1996	76.99
	08/26/1996	76.89
	09/16/1996	76.86
	10/01/1996	76.96
	10/25/1996	76.71
	12/04/1996	77.30
	12/23/1996	77.37
	12/30/1996	77.12
	01/28/1997	77.43
	02/24/1997	77.31
	03/17/1997	77.33
	04/07/1997	77.22
	04/28/1997	77.19
	05/19/1997	77.20
	06/04/1997	77.22
	06/30/1997	77.34
	07/14/1997	77.56
	07/28/1997	77.50
	08/18/1997	77.58
	09/08/1997	77.48
	09/22/1997	77.59
	10/20/1997	77.52
	11/17/1997	77.90
	12/01/1997	77.42
	12/22/1997	77.43
	01/05/1998	77.62
	01/20/1998	77.60
	02/02/1998	77.63
	02/23/1998	77.62
	03/10/1998	77.95
(C-42-14)13dca-1—Continued	03/24/1998	77.52
	04/06/1998	77.60
	04/13/1998	77.75
	04/27/1998	77.84
	05/11/1998	77.78
	06/08/1998	77.65
	06/22/1998	77.79
	07/15/1998	77.91
	07/30/1998	77.81
	08/18/1998	77.89
	09/21/1998	77.81
	10/19/1998	77.94
	11/02/1998	77.83
	11/16/1998	77.88
	12/08/1998	78.11
	12/28/1998	78.00
	01/25/1999	77.62
	02/07/1999	77.89
	03/05/1999	77.71
	04/02/1999	77.71
	05/28/1999	77.84
	06/01/1999	77.89
	07/12/1999	78.00
	08/02/1999	78.02
	08/16/1999	78.10
	08/30/1999	77.88
	09/20/1999	78.07
	10/18/1999	77.98
	11/23/1999	78.04
	12/06/1999	77.87
	01/03/2000	78.27
	01/24/2000	77.83
	02/07/2000	78.03
	02/22/2000	77.99
	03/13/2000	77.74
	04/03/2000	77.99
	05/04/2000	77.96
	05/22/2000	78.01
	06/15/2000	77.95
	06/26/2000	78.24
	07/26/2000	78.17
	08/07/2000	78.25
	09/12/2000	78.18
	09/27/2000	78.12
	10/11/2000	77.95
	11/13/2000	78.12
	12/11/2000	78.22

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)13dca-1—Continued	01/08/2001	78.30
	01/29/2001	78.71
	02/20/2001	78.77
	03/26/2001	78.55
	04/16/2001	78.75
	05/08/2001	78.91
	05/29/2001	79.21
	06/11/2001	79.39
	06/25/2001	79.55
	07/16/2001	79.91
	07/30/2001	80.16
	08/08/2001	80.33
	09/04/2001	80.70
	10/04/2001	81.08
	11/06/2001	81.92
	12/03/2001	81.95
	01/08/2002	81.78
	01/30/2002	81.84
	02/19/2002	81.74
	03/08/2002	81.88
	03/19/2002	82.12
	04/01/2002	81.63
	04/08/2002	81.62
	04/15/2002	80.85
	04/22/2002	80.93
	04/29/2002	80.12
	05/16/2002	77.90
	05/23/2002	76.85
	05/30/2002	75.82
	06/03/2002	75.16
	06/17/2002	72.75
	06/25/2002	71.35
	07/08/2002	69.15
	07/15/2002	67.90
	07/22/2002	66.65
	07/30/2002	65.40
	08/06/2002	64.40
	08/13/2002	63.30
	09/03/2002	60.48
	10/18/2002	56.06
	11/04/2002	54.62
	11/18/2002	53.48
	11/26/2002	52.43
	12/10/2002	50.72
	12/24/2002	49.49
	01/13/2003	47.00
	01/21/2003	46.60
(C-42-14)13dca-1—Continued	01/31/2003	45.40
	02/04/2003	44.70
	02/20/2003	43.30
	03/05/2003	42.20
	03/20/2003	40.20
	03/31/2003	39.40
	04/21/2003	37.60
	05/05/2003	36.70
	05/21/2003	36.00
	06/03/2003	34.60
	07/02/2003	34.30
	07/18/2003	33.70
	08/01/2003	33.70
	08/15/2003	33.85
	08/27/2003	36.61
	09/12/2003	37.60
	09/26/2003	38.05
	10/10/2003	38.40
	11/07/2003	39.90
	11/24/2003	41.30
	12/05/2003	42.00
	12/19/2003	41.60
	01/09/2004	42.15
	01/23/2004	39.50
	02/06/2004	38.30
	02/23/2004	36.00
	03/16/2004	34.50
	04/01/2004	33.10
	04/14/2004	32.40
	04/20/2004	32.15
	05/02/2004	31.35
	05/11/2004	30.50
	05/24/2004	30.10
	06/14/2004	29.45
	07/14/2004	29.10
	08/10/2004	32.30
	08/27/2004	33.90
	09/10/2004	34.75
	10/04/2004	35.95
	10/25/2004	36.70
	11/10/2004	37.35
	12/02/2004	33.95
	12/20/2004	33.10
	01/03/2005	31.80
	01/28/2005	29.25

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)13ddd-1	03/03/1995	83.90
(WD 1, Map # 31)	03/27/1995	83.90
	04/17/1995	83.90
	05/01/1995	83.90
	06/05/1995	83.80
	06/19/1995	84.00
	06/27/1995	84.00
	07/10/1995	83.90
	07/25/1995	84.02
	08/07/1995	84.00
	08/21/1995	84.25
	09/05/1995	84.18
	09/20/1995	84.05
	10/02/1995	84.17
	10/16/1995	84.07
	10/30/1995	84.11
	11/13/1995	84.35
	11/27/1995	84.27
	12/11/1995	84.26
	01/09/1996	84.23
	01/29/1996	84.15
	02/12/1996	84.39
	02/26/1996	84.09
	03/11/1996	84.25
	03/25/1996	84.20
	04/08/1996	84.33
	04/22/1996	84.48
	05/06/1996	85.25
	05/20/1996	84.33
	06/03/1996	84.52
	06/17/1996	84.40
	07/01/1996	84.52
	07/15/1996	84.45
	07/29/1996	84.58
	08/12/1996	84.52
	08/26/1996	84.44
	09/16/1996	84.35
	10/01/1996	84.50
	10/25/1996	84.21
	12/04/1996	84.79
	12/23/1996	84.94
	12/30/1996	84.58
	01/28/1997	84.90
	02/24/1997	84.77
	03/17/1997	84.79
	04/07/1997	84.70
	04/28/1997	84.61
(C-42-14)13ddd-1—Continued	05/19/1997	84.61
	06/04/1997	84.61
	06/30/1997	84.76
	07/14/1997	84.99
	07/28/1997	84.97
	08/18/1997	84.97
	09/08/1997	84.87
	09/22/1997	84.97
	10/20/1997	84.91
	11/17/1997	85.30
	12/01/1997	84.80
	12/22/1997	84.80
	01/05/1998	84.99
	01/20/1998	84.95
	02/02/1998	84.96
	02/23/1998	84.96
	03/10/1998	85.33
	03/24/1998	84.92
	04/06/1998	84.93
	04/13/1998	85.05
	04/27/1998	85.16
	05/11/1998	84.98
	06/08/1998	84.96
	06/22/1998	85.12
	07/15/1998	85.24
	07/30/1998	85.14
	08/18/1998	85.23
	09/21/1998	85.09
	10/19/1998	85.30
	11/02/1998	85.12
	11/16/1998	85.20
	12/08/1998	85.40
	12/28/1998	85.30
	01/25/1999	84.87
	02/07/1999	85.17
	03/05/1999	84.97
	04/02/1999	84.96
	05/28/1999	85.18
	06/01/1999	85.13
	07/12/1999	85.28
	08/02/1999	85.28
	08/16/1999	85.34
	08/30/1999	85.13
	09/20/1999	85.32
	10/18/1999	85.24
	11/23/1999	85.28
	12/06/1999	85.13

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)13ddd-1—Continued	01/03/2000	85.59
	01/24/2000	85.12
	02/07/2000	85.45
	02/22/2000	85.28
	03/13/2000	85.00
	04/03/2000	85.38
	05/04/2000	85.68
	05/22/2000	85.57
	06/15/2000	85.44
	06/26/2000	86.41
	07/26/2000	86.18
	08/07/2000	86.08
	09/12/2000	85.86
	09/27/2000	86.36
	10/11/2000	86.60
	11/13/2000	87.75
	12/11/2000	88.87
	01/08/2001	89.87
	01/29/2001	90.69
	02/20/2001	91.04
	03/26/2001	90.58
	04/16/2001	91.01
	05/08/2001	91.68
	05/29/2001	92.02
	06/11/2001	92.34
	06/25/2001	92.37
	07/16/2001	92.62
	07/30/2001	92.95
	08/08/2001	93.17
	09/04/2001	93.05
	10/04/2001	93.43
	11/06/2001	93.62
	12/03/2001	93.29
	01/08/2002	92.20
	01/30/2002	92.03
	02/19/2002	91.61
	03/08/2002	92.32
	03/19/2002	92.74
	04/01/2002	91.68
	04/08/2002	91.40
	04/15/2002	90.54
	04/22/2002	90.22
	04/29/2002	88.97
	05/16/2002	84.62
	05/23/2002	82.36
	05/30/2002	80.07
(C-42-14)13ddd-1—Continued	06/03/2002	78.66
	06/17/2002	74.10
	06/25/2002	72.10
	07/08/2002	69.40
	07/15/2002	68.10
	07/22/2002	66.85
	07/30/2002	65.65
	08/06/2002	64.65
	08/13/2002	63.70
	09/03/2002	60.93
	10/18/2002	56.59
	11/04/2002	55.16
	11/18/2002	53.90
	11/26/2002	52.74
	12/10/2002	50.84
	12/24/2002	49.38
	01/13/2003	46.50
	01/21/2003	45.65
	01/31/2003	44.50
	02/04/2003	43.90
	02/20/2003	42.40
	03/05/2003	40.80
	03/20/2003	38.90
	03/31/2003	37.90
	04/21/2003	36.00
	05/05/2003	35.10
	05/21/2003	34.40
	06/03/2003	33.10
	07/02/2003	32.30
	07/18/2003	32.00
	08/01/2003	33.56
	08/15/2003	34.20
	08/27/2003	34.62
	09/12/2003	35.20
	09/26/2003	36.60
	10/10/2003	37.50
	11/07/2003	36.80
	11/24/2003	38.70
	12/05/2003	42.90
	12/19/2003	43.20
	01/09/2004	42.60
	01/23/2004	41.50
	02/06/2004	37.60
	02/23/2004	34.94
	03/16/2004	33.10
	04/01/2004	31.50

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)13ddd-1—Continued	04/14/2004	30.60
	04/20/2004	30.30
	05/02/2004	29.25
	05/11/2004	28.35
	05/24/2004	27.65
	06/14/2004	27.25
	07/14/2004	26.90
	08/10/2004	34.20
	08/27/2004	38.50
	09/10/2004	39.85
	10/04/2004	41.60
	10/25/2004	42.55
	11/10/2004	43.55
	12/02/2004	33.10
	12/20/2004	29.75
	01/03/2005	28.40
	01/28/2005	26.50
(C-42-14)14aad-1 (WD RJ, Map # 32)	03/03/1995	52.30
	03/27/1995	52.60
	04/17/1995	52.70
	05/01/1995	52.70
	06/05/1995	52.60
	06/19/1995	52.80
	06/27/1995	52.94
	07/10/1995	52.91
	07/25/1995	53.11
	08/07/1995	53.11
	08/21/1995	53.34
	09/05/1995	53.40
	09/20/1995	53.45
	10/02/1995	53.48
	10/16/1995	53.41
	10/30/1995	53.46
	11/13/1995	53.55
	11/27/1995	53.52
	12/11/1995	53.45
	01/09/1996	53.52
	01/29/1996	53.48
	02/12/1996	53.65
	02/26/1996	53.37
	03/11/1996	53.52
	03/25/1996	53.58
	04/08/1996	53.75
	04/22/1996	54.00
	05/06/1996	53.89
	05/20/1996	54.01
(C-42-14)14aad-1—Continued	06/03/1996	54.18
	06/17/1996	54.16
	07/01/1996	54.31
	07/15/1996	54.60
	07/29/1996	54.48
	08/12/1996	54.55
	08/26/1996	54.47
	09/16/1996	54.47
	10/01/1996	54.60
	10/25/1996	54.33
	12/04/1996	54.74
	12/23/1996	54.74
	12/30/1996	54.60
	01/28/1997	54.80
	02/24/1997	54.73
	03/17/1997	54.82
	04/07/1997	54.95
	04/28/1997	54.91
	05/19/1997	54.91
	06/04/1997	55.04
	06/30/1997	55.20
	07/14/1997	55.42
	07/28/1997	55.42
	08/18/1997	55.53
	09/08/1997	55.36
	09/22/1997	55.49
	10/20/1997	55.45
	11/17/1997	55.73
	12/01/1997	55.36
	12/22/1997	55.21
	01/05/1998	55.57
	01/20/1998	55.48
	02/02/1998	55.50
	02/23/1998	55.50
	03/10/1998	55.74
	03/24/1998	55.49
	04/06/1998	55.47
	04/13/1998	55.58
	04/27/1998	55.66
	05/11/1998	55.62
	06/08/1998	55.88
	06/22/1998	55.94
	07/15/1998	56.14
	07/30/1998	56.10
	08/18/1998	56.29
	09/21/1998	56.16

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)14aad-1—Continued	10/19/1998	56.30
	11/02/1998	56.13
	11/16/1998	56.18
	12/08/1998	56.28
	12/28/1998	56.22
	01/25/1999	55.91
	02/07/1999	56.10
	03/05/1999	56.00
	04/02/1999	55.99
	05/28/1999	55.99
	06/01/1999	56.05
	07/12/1999	56.17
	08/02/1999	56.16
	08/16/1999	56.20
	08/30/1999	56.04
	09/20/1999	56.21
	10/18/1999	56.13
	11/23/1999	56.16
	12/06/1999	56.05
	01/03/2000	56.29
	01/24/2000	55.98
	02/07/2000	56.15
	02/22/2000	56.08
	03/13/2000	55.86
	04/03/2000	56.01
	05/04/2000	55.91
	05/22/2000	55.94
	06/15/2000	55.95
	06/26/2000	56.02
	07/26/2000	55.95
	08/07/2000	56.08
	09/12/2000	56.26
	09/27/2000	56.25
	10/11/2000	56.23
	11/13/2000	56.28
	12/11/2000	56.14
	01/08/2001	56.03
	01/29/2001	56.16
	02/20/2001	56.15
	03/26/2001	56.02
	04/16/2001	56.06
	05/08/2001	56.10
	05/29/2001	56.02
	06/11/2001	56.01
	06/25/2001	56.01
	07/16/2001	56.03
	07/30/2001	56.02
(C-42-14)14aad-1—Continued	08/08/2001	55.99
	09/04/2001	56.06
	10/04/2001	56.03
	11/06/2001	56.13
	12/03/2001	55.84
	01/08/2002	55.86
	01/30/2002	55.90
	02/19/2002	55.90
	03/08/2002	55.87
	03/19/2002	55.94
	04/01/2002	55.66
	04/08/2002	55.72
	04/15/2002	55.60
	04/22/2002	55.76
	04/29/2002	55.63
	05/16/2002	55.55
	05/23/2002	55.43
	05/30/2002	55.40
	06/03/2002	55.39
	06/17/2002	55.30
	06/25/2002	55.40
	07/08/2002	55.40
	07/15/2002	55.40
	07/22/2002	55.30
	07/30/2002	55.40
	08/06/2002	55.40
	08/13/2002	55.20
	09/03/2002	55.05
	10/18/2002	54.96
	11/04/2002	54.92
	11/18/2002	55.02
	11/26/2002	54.90
	12/10/2002	54.65
	12/24/2002	54.84
	01/13/2003	54.60
	01/21/2003	54.55
	01/31/2003	54.60
	02/04/2003	54.60
	02/20/2003	54.80
	03/05/2003	54.60
	03/20/2003	54.35
	03/31/2003	54.40
	04/21/2003	54.40
	05/05/2003	54.40
	05/21/2003	54.60
	06/03/2003	54.00
	07/02/2003	53.90

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)14aad-1—Continued	07/18/2003	53.80
	08/01/2003	53.70
	08/15/2003	53.80
	08/27/2003	54.10
	09/12/2003	54.45
	09/26/2003	53.60
	10/10/2003	53.40
	11/07/2003	53.50
	11/24/2003	53.80
	12/05/2003	53.30
	12/19/2003	53.50
	01/09/2004	53.50
	01/23/2004	53.60
	02/06/2004	53.30
	02/23/2004	52.67
	03/16/2004	52.50
	04/01/2004	52.20
	04/14/2004	52.20
	04/20/2004	52.40
	05/02/2004	52.40
	05/11/2004	52.20
	05/24/2004	52.20
	06/14/2004	52.15
	07/14/2004	52.05
	08/10/2004	52.80
	08/27/2004	52.40
	09/10/2004	52.15
	10/04/2004	52.00
	10/25/2004	51.95
	12/20/2004	51.30
	01/03/2005	51.30
	01/28/2005	51.30
(C-42-14)23abc-1 (WD 5, Map # 33)	03/03/1995	71.70
	03/27/1995	71.70
	04/17/1995	71.70
	05/01/1995	71.50
	06/05/1995	71.40
	06/19/1995	71.50
	06/27/1995	71.70
	07/10/1995	71.51
	07/25/1995	71.55
	08/07/1995	71.54
	08/21/1995	71.68
	09/05/1995	71.62
	09/20/1995	71.46
	10/02/1995	71.60
(C-42-14)23abc-1—Continued	10/16/1995	71.41
	10/30/1995	71.54
	11/13/1995	71.66
	11/27/1995	71.58
	12/11/1995	71.50
	01/09/1996	71.48
	01/29/1996	71.42
	02/12/1996	71.56
	02/26/1996	71.31
	03/11/1996	71.41
	03/25/1996	71.43
	04/08/1996	71.45
	04/22/1996	71.58
	05/06/1996	71.36
	05/20/1996	71.42
	06/03/1996	71.51
	06/17/1996	71.40
	07/01/1996	71.46
	07/15/1996	71.40
	07/29/1996	71.46
	08/12/1996	71.41
	08/26/1996	71.26
	09/16/1996	71.22
	10/01/1996	71.27
	10/25/1996	71.02
	12/04/1996	71.49
	12/23/1996	71.55
	12/30/1996	71.28
	01/28/1997	71.52
	02/24/1997	71.32
	03/17/1997	71.37
	04/07/1997	71.76
	04/28/1997	71.10
	05/19/1997	71.05
	06/04/1997	71.06
	06/30/1997	71.11
	07/14/1997	71.27
	07/28/1997	71.21
	08/18/1997	71.23
	09/08/1997	71.11
	09/22/1997	71.20
	10/20/1997	71.12
	11/17/1997	71.45
	12/01/1997	70.96
	12/22/1997	70.99
	01/05/1998	71.13
	01/20/1998	71.02

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)23abc-1—Continued	02/02/1998	71.06
	02/23/1998	71.03
	03/10/1998	71.30
	03/24/1998	70.93
	04/06/1998	70.95
	04/13/1998	71.08
	04/27/1998	71.17
	05/11/1998	70.90
	06/08/1998	70.91
	06/22/1998	71.02
	07/15/1998	71.08
	07/30/1998	71.00
	08/18/1998	71.04
	09/21/1998	70.96
	10/19/1998	71.02
	11/02/1998	70.93
	11/16/1998	70.97
	12/08/1998	71.15
	12/28/1998	71.07
	01/25/1999	70.69
	02/07/1999	70.88
	03/05/1999	70.77
	04/02/1999	70.75
	05/28/1999	70.92
	06/01/1999	70.91
	07/12/1999	70.94
	08/02/1999	70.99
	08/16/1999	71.03
	08/30/1999	70.83
	09/20/1999	71.01
	10/18/1999	70.96
	11/23/1999	71.00
	12/06/1999	70.46
	01/03/2000	71.28
	01/24/2000	70.88
	02/07/2000	71.03
	02/22/2000	71.04
	03/13/2000	70.87
	04/03/2000	71.01
	05/04/2000	70.85
	05/22/2000	70.92
	06/15/2000	70.87
	06/26/2000	70.91
	07/26/2000	70.80
	08/07/2000	70.90
	09/12/2000	71.01
	09/27/2000	71.01

Well location, well name, and map number	Date	Water level
(C-42-14)23abc-1—Continued	10/11/2000	70.93
	11/13/2000	71.02
	12/11/2000	70.91
	01/08/2001	70.75
	01/29/2001	70.99
	02/20/2001	70.96
	03/26/2001	70.80
	04/16/2001	70.90
	05/08/2001	70.91
	05/29/2001	70.86
	06/11/2001	70.84
	06/25/2001	70.79
	07/16/2001	70.82
	07/30/2001	70.81
	08/08/2001	70.76
	09/04/2001	70.90
	10/04/2001	70.88
	11/06/2001	70.81
	12/03/2001	70.71
	01/08/2002	70.85
	01/30/2002	70.98
	02/19/2002	71.03
	03/08/2002	71.05
	03/19/2002	71.13
	04/01/2002	70.76
	04/08/2002	70.93
	04/15/2002	70.78
	04/22/2002	70.85
	04/29/2002	70.80
	05/16/2002	70.70
	05/23/2002	70.68
	05/30/2002	70.66
	06/03/2002	70.64
	06/17/2002	70.55
	06/25/2002	70.60
	07/08/2002	70.60
	07/15/2002	70.60
	07/22/2002	70.50
	07/30/2002	70.45
	08/06/2002	70.55
	08/13/2002	70.40
	09/03/2002	70.20
	10/18/2002	69.92
	11/04/2002	69.87
	11/18/2002	70.02
	11/26/2002	69.86
	12/10/2002	69.52

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)23abc-1—Continued	12/24/2002	69.73
	01/13/2003	69.60
	01/21/2003	69.00
	01/31/2003	68.30
	02/04/2003	68.30
	02/20/2003	69.20
	03/05/2003	69.20
	03/20/2003	68.80
	03/31/2003	68.70
	04/21/2003	68.40
	05/05/2003	68.10
	05/21/2003	68.50
	06/03/2003	67.80
	07/02/2003	67.40
	07/18/2003	67.30
	08/01/2003	67.10
	08/15/2003	67.10
	08/27/2003	66.80
	09/12/2003	67.20
	09/26/2003	66.40
	10/10/2003	66.20
	11/07/2003	66.10
	11/24/2003	67.40
	12/05/2003	65.70
	12/19/2003	65.60
	01/09/2004	65.40
	01/23/2004	65.20
	02/06/2004	65.20
	02/23/2004	64.35
	03/16/2004	64.10
	04/01/2004	63.50
	04/14/2004	63.50
	04/20/2004	63.50
	05/02/2004	63.35
	05/11/2004	63.10
	05/24/2004	63.00
	06/14/2004	62.55
	07/14/2004	62.40
	08/10/2004	62.20
	08/27/2004	61.50
	09/10/2004	61.70
	10/04/2004	60.80
	10/25/2004	60.40
	11/10/2004	60.20
	12/02/2004	59.85
	12/20/2004	59.25
	01/03/2005	59.05
	01/28/2005	58.60
(C-42-14)23daa-1 (WD 3, Map # 34)	03/03/1995	96.80
	03/27/1995	96.70
	04/17/1995	96.80
	05/01/1995	96.70
	06/05/1995	96.70
	06/19/1995	96.70
	06/27/1995	96.76
	07/10/1995	96.69
	07/25/1995	96.72
	08/07/1995	96.72
	08/21/1995	96.91
	09/05/1995	96.82
	09/20/1995	96.65
	10/02/1995	96.77
	10/16/1995	96.61
	10/30/1995	96.70
	11/13/1995	96.86
	11/27/1995	96.79
	12/11/1995	96.73
	01/09/1996	96.68
	01/29/1996	96.63
	02/12/1996	96.80
	02/26/1996	96.53
	03/11/1996	96.63
	03/25/1996	96.69
	04/08/1996	96.67
	04/22/1996	96.83
	05/06/1996	96.62
	05/20/1996	96.67
	06/03/1996	96.76
	06/17/1996	96.66
	07/01/1996	96.71
	07/15/1996	96.64
	07/29/1996	96.71
	08/12/1996	96.65
	08/26/1996	96.49
	09/16/1996	96.47
	10/01/1996	96.51
	10/25/1996	96.24
	12/04/1996	96.73
	12/23/1996	96.82
	12/30/1996	96.54
	01/28/1997	96.80
	02/24/1997	96.58
	03/17/1997	96.61
	04/07/1997	96.53
	04/28/1997	96.35

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)23daa-1—Continued	05/19/1997	96.28
	06/04/1997	96.30
	06/30/1997	96.33
	07/14/1997	96.52
	07/28/1997	96.44
	08/18/1997	96.48
	09/08/1997	96.35
	09/22/1997	96.43
	10/20/1997	96.35
	11/17/1997	96.67
	12/01/1997	96.17
	12/22/1997	96.20
	01/05/1998	96.36
	01/20/1998	96.25
	02/02/1998	96.22
	02/23/1998	96.24
	03/10/1998	96.53
	03/24/1998	96.18
	04/06/1998	96.16
	04/13/1998	96.30
	04/27/1998	96.36
	05/11/1998	96.08
	06/08/1998	96.10
	06/22/1998	96.21
	07/15/1998	96.26
	07/30/1998	96.15
	08/18/1998	96.20
	09/21/1998	96.05
	10/19/1998	96.13
	11/02/1998	96.04
	11/16/1998	96.05
	12/08/1998	96.47
	12/28/1998	96.18
	01/25/1999	95.75
	02/07/1999	95.96
	03/05/1999	95.85
	04/02/1999	95.82
	05/28/1999	95.97
	06/01/1999	95.92
	07/12/1999	95.98
	08/02/1999	96.01
	08/16/1999	96.04
	08/30/1999	95.84
	09/20/1999	96.03
	10/18/1999	95.94
	11/23/1999	96.00
	12/06/1999	95.82
(C-42-14)23daa-1—Continued	01/03/2000	96.27
	01/24/2000	95.83
	02/07/2000	96.00
	02/22/2000	95.98
	03/13/2000	95.74
	04/03/2000	95.95
	05/04/2000	95.77
	05/22/2000	95.84
	06/15/2000	95.77
	06/26/2000	95.81
	07/26/2000	95.67
	08/07/2000	95.77
	09/12/2000	95.90
	09/27/2000	95.89
	10/11/2000	95.81
	11/13/2000	95.90
	12/11/2000	95.74
	01/08/2001	95.58
	01/29/2001	95.86
	02/20/2001	95.79
	03/06/2001	95.63
	04/16/2001	95.73
	05/08/2001	95.73
	05/29/2001	95.70
	06/11/2001	95.66
	06/25/2001	95.61
	07/16/2001	95.60
	07/30/2001	95.58
	08/08/2001	95.52
	09/04/2001	95.64
	10/04/2001	95.61
	11/06/2001	95.49
	12/03/2001	95.41
	01/08/2002	95.48
	01/30/2002	95.64
	02/19/2002	95.67
	03/08/2002	95.58
	03/19/2002	95.76
	04/01/2002	95.35
	04/08/2002	95.48
	04/15/2002	95.35
	04/22/2002	95.39
	04/29/2002	95.30
	05/16/2002	95.06
	05/23/2002	94.96
	05/30/2002	94.82
	06/03/2002	94.75

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)23daa-1—Continued	06/17/2002	94.40
	06/25/2002	94.40
	07/08/2002	94.20
	07/15/2002	94.20
	07/22/2002	94.12
	07/30/2002	94.07
	08/06/2002	93.60
	08/13/2002	93.40
	09/03/2002	92.90
	10/18/2002	91.93
	11/04/2002	91.60
	11/18/2002	91.48
	11/26/2002	91.17
	12/10/2002	90.47
	12/24/2002	90.27
	01/13/2003	89.50
	01/21/2003	89.45
	01/31/2003	88.50
	02/04/2003	88.20
	02/20/2003	87.40
	03/05/2003	86.60
	03/20/2003	85.20
	03/31/2003	84.40
	04/21/2003	82.50
	05/05/2003	81.40
	05/21/2003	80.30
	06/03/2003	78.50
	07/02/2003	76.20
	07/18/2003	75.20
	08/01/2003	74.20
	08/15/2003	73.50
	08/27/2003	72.60
	09/12/2003	71.95
	09/26/2003	71.20
	10/10/2003	70.40
	11/07/2003	69.70
	11/24/2003	70.80
	12/05/2003	68.60
	12/19/2003	68.40
	01/09/2004	67.70
	01/23/2004	67.00
	02/06/2004	66.60
	02/23/2004	65.02
	03/16/2004	64.10
	04/01/2004	62.90
	04/14/2004	62.30
	04/20/2004	60.90
(C-42-14)23daa-1—Continued	05/02/2004	61.15
	05/11/2004	60.20
	05/24/2004	59.35
	06/14/2004	57.75
	07/14/2004	57.35
	08/10/2004	54.20
	08/27/2004	53.40
	09/10/2004	52.70
	10/04/2004	51.65
	10/25/2004	50.70
	11/10/2004	50.15
	12/02/2004	49.20
	12/20/2004	47.90
	01/03/2005	47.45
	01/28/2005	46.30
(C-42-14)23ddc-1 (WD 11, Map # 36)	09/04/2001	77.42
	10/04/2001	77.37
	11/06/2001	77.27
	12/03/2001	77.18
	01/08/2002	77.10
	01/30/2002	77.42
	02/19/2002	77.48
	03/08/2002	77.51
	03/19/2002	77.50
	04/01/2002	77.20
	04/08/2002	77.32
	04/15/2002	77.20
	04/22/2002	77.24
	04/29/2002	77.18
	05/16/2002	77.17
	05/23/2002	77.21
	05/30/2002	77.16
	06/03/2002	77.17
	06/17/2002	77.02
	06/25/2002	77.17
	07/08/2002	77.17
	07/15/2002	77.17
	07/22/2002	77.07
	07/30/2002	76.97
	08/06/2002	77.02
	08/13/2002	76.97
	09/03/2002	76.85
	10/18/2002	76.53
	11/04/2002	76.45
	11/18/2002	76.64
	11/26/2002	76.43

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)23ddc-1—Continued	12/10/2002	76.13
	12/24/2002	76.36
	01/13/2003	76.07
	01/21/2003	75.87
	01/31/2003	75.57
	02/04/2003	74.82
	02/20/2003	71.07
	03/05/2003	73.78
	03/20/2003	51.37
	03/31/2003	42.91
	04/21/2003	34.47
	05/05/2003	30.77
	05/21/2003	28.07
	06/03/2003	25.87
	07/02/2003	26.47
	07/18/2003	27.87
	08/01/2003	28.77
	08/15/2003	29.67
	08/27/2003	29.67
	09/12/2003	31.27
	09/26/2003	31.57
	10/10/2003	32.37
	11/07/2003	33.87
	11/24/2003	34.57
	12/05/2003	35.07
	12/19/2003	35.47
	01/09/2004	32.57
	01/23/2004	36.47
	02/06/2004	34.27
	02/23/2004	31.17
	03/16/2004	24.47
	04/01/2004	20.67
	04/14/2004	18.77
	04/20/2004	17.27
	05/02/2004	15.47
	05/11/2004	14.97
	05/24/2004	12.77
	06/14/2004	12.37
	07/14/2004	11.62
	08/10/2004	10.67
	08/27/2004	11.37
	09/10/2004	11.67
	10/04/2004	12.12
	10/25/2004	12.32
	11/10/2004	11.77
	12/02/2004	10.47
	12/20/2004	9.17
(C-42-14)23ddc-1—Continued	01/03/2005	7.92
	01/28/2005	7.57
(C-42-14)24bcd-1 (WD 9, Map # 37)	09/04/2001	141.95
	10/04/2001	141.93
	11/06/2001	141.91
	12/03/2001	141.83
	01/08/2002	141.98
	01/30/2002	142.07
	02/19/2002	142.08
	03/08/2002	142.08
	03/19/2002	142.22
	04/01/2002	141.85
	04/08/2002	141.94
	04/15/2002	141.76
	04/22/2002	141.78
	04/29/2002	141.62
	05/16/2002	141.13
	05/23/2002	140.89
	05/30/2002	140.58
	06/03/2002	140.35
	06/17/2002	139.35
	06/25/2002	138.85
	07/08/2002	137.75
	07/15/2002	137.70
	07/22/2002	136.20
	07/30/2002	135.70
	08/06/2002	134.60
	08/13/2002	133.80
	09/03/2002	131.56
	10/18/2002	127.73
	11/04/2002	126.54
	11/18/2002	125.61
	11/26/2002	124.76
	12/10/2002	122.99
	12/24/2002	121.19
	01/13/2003	113.65
	01/21/2003	109.40
	01/31/2003	104.90
	02/04/2003	102.95
	02/20/2003	97.30
	03/05/2003	92.30
	03/20/2003	88.10
	03/31/2003	84.20
	04/21/2003	80.30
	05/05/2003	78.50
	05/21/2003	77.00

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)24bcd-1—Continued	06/03/2003	75.40
	07/02/2003	76.70
	07/18/2003	77.50
	08/01/2003	79.50
	08/15/2003	81.30
	08/27/2003	82.30
	09/12/2003	83.70
	09/26/2003	84.50
	10/10/2003	85.20
	11/07/2003	87.10
	11/24/2003	87.80
	12/05/2003	88.20
	12/19/2003	88.70
	01/09/2004	86.80
	01/23/2004	83.40
	02/06/2004	80.70
	02/23/2004	76.85
	03/16/2004	73.80
	04/01/2004	71.10
	04/14/2004	69.00
	04/20/2004	68.40
	05/02/2004	65.80
	05/11/2004	64.00
	05/24/2004	62.50
	06/14/2004	61.10
	07/14/2004	60.60
	08/10/2004	60.80
	08/27/2004	61.15
	09/10/2004	61.45
	10/04/2004	62.00
	10/25/2004	62.30
	11/10/2004	62.30
	12/02/2004	61.35
	12/20/2004	60.05
	01/03/2005	59.70
	01/28/2005	58.15
(C-42-14)25cdb-1 (WD 8, Map # 44)	09/04/2001	107.12
	10/04/2001	107.30
	11/06/2001	107.41
	12/03/2001	107.38
	01/08/2002	107.37
	01/30/2002	107.71
	02/19/2002	107.74
	03/08/2002	107.79
	03/19/2002	107.80
	04/01/2002	107.48
(C-42-14)25cdb-1—Continued	04/08/2002	107.61
	04/15/2002	107.16
	04/22/2002	107.55
	04/29/2002	107.54
	05/16/2002	107.56
	05/23/2002	107.58
	05/30/2002	107.61
	06/03/2002	107.58
	06/17/2002	107.48
	06/25/2002	107.63
	07/08/2002	107.68
	07/15/2002	107.78
	07/22/2002	107.58
	07/30/2002	107.61
	08/06/2002	107.58
	08/13/2002	107.66
	09/03/2002	107.59
	10/18/2002	107.44
	11/04/2002	107.43
	11/18/2002	107.73
	11/26/2002	107.52
	12/10/2002	107.32
	12/24/2002	107.60
	01/13/2003	110.58
	01/21/2003	107.48
	01/31/2003	110.38
	02/04/2003	110.38
	02/20/2003	110.48
	03/05/2003	110.48
	03/20/2003	110.08
	03/31/2003	110.18
	04/21/2003	110.08
	05/05/2003	110.08
	05/21/2003	110.08
	06/03/2003	109.58
	07/02/2003	108.98
	07/18/2003	108.83
	08/01/2003	108.58
	08/15/2003	108.38
	08/27/2003	107.98
	09/12/2003	107.78
	09/26/2003	107.28
	10/10/2003	107.08
	11/07/2003	106.68
	11/24/2003	106.18
	12/05/2003	105.98
	12/19/2003	106.08

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)25cdb-1—Continued	01/09/2004	105.98
	01/23/2004	105.08
	02/06/2004	104.98
	02/23/2004	104.18
	03/16/2004	103.68
	04/01/2004	103.23
	04/14/2004	103.08
	04/20/2004	103.03
	05/02/2004	102.83
	05/11/2004	102.58
	05/24/2004	102.28
	06/14/2004	101.58
	07/14/2004	100.93
	08/10/2004	100.08
	08/27/2004	99.58
	09/10/2004	99.03
	10/04/2004	98.08
	10/25/2004	97.38
	11/10/2004	96.93
	12/02/2004	96.13
	12/20/2004	95.03
	01/03/2005	94.68
	01/28/2005	94.18
(C-42-14)25ddd-1 (WD 13, Map # 47)	09/04/2001	130.54
	10/04/2001	130.68
	11/06/2001	130.58
	12/03/2001	130.52
	01/08/2002	130.45
	01/30/2002	130.73
	02/19/2002	130.73
	03/08/2002	130.72
	03/19/2002	130.72
	04/01/2002	130.45
	04/08/2002	130.54
	04/15/2002	130.11
	04/22/2002	130.51
	04/29/2002	130.48
	05/16/2002	130.48
	05/23/2002	130.48
	05/30/2002	130.48
	06/03/2002	130.45
	06/17/2002	130.40
	06/25/2002	130.48
	07/08/2002	130.60
	07/15/2002	130.55
	07/22/2002	130.50
(C-42-14)25ddd-1—Continued	07/30/2002	130.50
	08/06/2002	130.40
	08/13/2002	130.50
	09/03/2002	130.41
	10/18/2002	130.26
	11/04/2002	130.24
	11/18/2002	130.52
	11/26/2002	131.33
	12/10/2002	130.13
	12/24/2002	130.42
	01/13/2003	130.40
	01/21/2003	130.40
	01/31/2003	130.30
	02/04/2003	130.30
	02/20/2003	130.00
	03/05/2003	130.60
	03/20/2003	130.20
	03/31/2003	130.25
	04/21/2003	130.20
	05/05/2003	130.30
	05/21/2003	130.50
	06/03/2003	130.00
	07/02/2003	130.00
	07/18/2003	130.00
	08/01/2003	129.90
	08/15/2003	130.00
	08/27/2003	129.80
	09/12/2003	129.90
	09/26/2003	130.00
	10/10/2003	129.60
	11/07/2003	129.70
	11/24/2003	129.70
	12/05/2003	130.00
	12/19/2003	130.50
	01/09/2004	129.60
	01/23/2004	129.30
	02/06/2004	129.30
	02/23/2004	129.10
	03/16/2004	129.05
	04/01/2004	128.80
	04/14/2004	128.90
	04/20/2004	129.00
	05/02/2004	128.95
	05/11/2004	128.85
	05/24/2004	128.85
	06/14/2004	128.60
	07/14/2004	127.85

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)25ddd-1—Continued	08/10/2004	128.40
	08/27/2004	128.35
	09/10/2004	128.25
	10/04/2004	128.00
	10/25/2004	127.80
	11/10/2004	127.85
	12/02/2004	127.65
	12/20/2004	127.15
	01/03/2005	127.35
	01/28/2005	127.20
(C-42-14)26bbb-1 (WD 14, Map # 49)	09/04/2001	81.72
	10/04/2001	81.68
	11/06/2001	81.56
	12/03/2001	81.46
	01/08/2002	81.50
	01/30/2002	81.65
	02/19/2002	81.65
	03/08/2002	81.59
	03/19/2002	81.78
	04/01/2002	81.43
	04/08/2002	81.53
	04/15/2002	81.42
	04/22/2002	81.53
	04/29/2002	81.50
	05/16/2002	81.40
	05/23/2002	81.47
	05/30/2002	81.46
	06/03/2002	81.40
	06/17/2002	81.38
	06/25/2002	81.50
	07/08/2002	81.53
	07/15/2002	81.53
	07/22/2002	81.48
	07/30/2002	81.33
	08/06/2002	81.50
	08/13/2002	81.53
	09/03/2002	81.27
	10/18/2002	81.12
	11/04/2002	81.15
	11/18/2002	81.48
	11/26/2002	81.25
	12/10/2002	81.03
	12/24/2002	81.25
	01/13/2003	81.33
	01/21/2003	81.43
	01/31/2003	81.33

Well location, well name, and map number	Date	Water level
(C-42-14)26bbb-1—Continued	02/04/2003	81.13
	02/20/2003	81.13
	03/05/2003	81.23
	03/20/2003	80.93
	03/31/2003	80.63
	04/21/2003	80.83
	05/05/2003	81.08
	05/21/2003	80.93
	06/03/2003	80.63
	07/02/2003	80.53
	07/18/2003	80.58
	08/01/2003	80.58
	08/15/2003	81.03
	08/27/2003	80.93
	09/12/2003	81.03
	09/26/2003	81.33
	10/10/2003	80.13
	11/07/2003	79.83
	11/24/2003	80.33
	12/05/2003	80.03
	12/19/2003	79.93
	01/09/2004	79.93
	01/23/2004	80.03
	02/06/2004	80.13
	02/23/2004	79.33
	03/16/2004	79.33
	04/01/2004	78.88
	04/14/2004	79.13
	04/20/2004	79.13
	05/02/2004	79.08
	05/11/2004	78.83
	05/24/2004	78.83
	06/14/2004	78.83
	07/14/2004	78.83
	08/10/2004	79.13
	08/27/2004	78.48
	09/10/2004	78.43
	10/04/2004	78.33
	10/25/2004	78.08
	11/10/2004	77.93
	12/02/2004	77.68
	12/20/2004	77.08
	01/03/2005	77.08
	01/28/2005	76.83

Table 2. Water levels in selected wells in Sand Hollow, Utah—Continued

Well location, well name, and map number	Date	Water level
(C-42-14)26bdd-1	09/04/2001	120.03
(WD 7, Map # 50)	10/04/2001	119.98
	11/06/2001	119.87
	12/03/2001	119.75
	01/08/2002	119.71
	01/30/2002	120.05
	02/19/2002	120.06
	03/08/2002	119.97
	03/19/2002	120.12
	04/01/2002	119.71
	04/08/2002	119.84
	04/15/2002	119.77
	04/22/2002	119.82
	04/29/2002	119.78
	05/16/2002	119.72
	05/23/2002	119.74
	05/30/2002	119.75
	06/03/2002	119.72
	06/17/2002	119.65
	06/25/2002	119.78
	07/08/2002	119.80
	07/15/2002	119.80
	07/22/2002	119.75
	07/30/2002	119.70
	08/06/2002	119.70
	08/13/2002	119.70
	09/03/2002	119.64
	10/18/2002	119.50
	11/04/2002	119.47
	11/18/2002	119.77
	11/26/2002	119.62
	12/10/2002	119.32
	12/24/2002	119.66
	01/13/2003	119.70
	01/21/2003	119.55
	01/31/2003	119.50
	02/04/2003	119.50
	02/20/2003	119.50
	03/05/2003	119.70
	03/20/2003	119.30
	03/31/2003	119.30
	04/21/2003	119.40
	05/05/2003	119.20
	05/21/2003	119.20
	06/03/2003	118.50
	07/02/2003	118.10
	07/18/2003	118.00

Well location, well name, and map number	Date	Water level
(C-42-14)26bdd-1—Continued	08/01/2003	117.90
	08/15/2003	117.90
	08/27/2003	117.70
	09/12/2003	117.20
	09/26/2003	116.90
	10/10/2003	116.60
	11/07/2003	116.40
	11/24/2003	116.10
	12/05/2003	115.80
	12/19/2003	115.60
	01/09/2004	115.30
	01/23/2004	115.20
	02/06/2004	115.20
	02/23/2004	114.30
	03/16/2004	114.05
	04/01/2004	113.50
	04/14/2004	113.40
	04/20/2004	113.45
	05/02/2004	113.25
	05/11/2004	112.85
	05/24/2004	112.70
	06/14/2004	112.05
	07/14/2004	111.70
	08/10/2004	110.40
	08/27/2004	109.90
	09/10/2004	109.40
	10/04/2004	108.60
	10/25/2004	107.80
	11/10/2004	107.50
	12/02/2004	106.70
	12/20/2004	105.60
	01/03/2005	105.35
	01/28/2005	104.70

Table 3. Selected physical properties and major and minor chemical constituents in ground- and surface-water samples collected from selected sites in Sand Hollow and the Virgin River near Virgin, Utah

[**Map number:** Refer to figure 3 and table 1; **Specific conductance:** µS/cm, microsiemens per centimeter at 25 degrees Celsius. Analyzing agency for all samples (except where noted): U.S. Geological Survey National Water-Quality Laboratory in Denver, Colorado; mg/L, milligrams per liter; µg/L, micrograms per liter; —, no data available; <, less than; E, estimated]

Map number	Well name	Date sampled	Specific conductance (µS/cm)	pH (standard units)	Solids, residue at 180°C (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)
1a	Wayne Wilson (original)	10/25/2000	350	8.1	—	35	16	8.3	1.8	110
1b	Well 1	03/18/2003	325	7.2	198	32	19	8.3	1.7	129
	Well 1 (sampled at 200 feet)	05/06/2003	320	8.0	182	29	19	5.5	1.9	151
	Well 1 (sampled at 890 feet)	05/06/2003	350	7.8	216	31	21	7.4	2.9	130
	Well 1 (redrilled)	08/06/2003	440	7.6	269	—	—	—	—	123
		09/21/2004	335	7.8	184	—	—	—	—	134
2	WD 12	[1]04/30/1999	330	8.2	—	—	—	—	—	100
		09/12/2002	335	7.9	202	37	13	9.0	1.6	115
3	Well 2 (sampled at 245 feet)	10/09/2002	360	7.9	196	31	21	8.2	2.2	128
3	Well 2 (sampled at 400 feet)	10/10/2002	365	8.0	208	30	21	9.0	2.1	129
3	Well 2 (sampled at 615 feet)	10/10/2002	365	8.1	190	30	21	6.5	2.5	131
3	Well 2 (sampled at 750 feet)	10/10/2002	370	8.1	196	30	22	6.8	2.7	134
3	Well 2	09/21/2004	375	7.8	208	—	—	—	—	126
5	WD 10	[1]06/12/2001	375	7.8	202	33	22	16	12	114
		09/13/2001	365	7.8	—	—	—	—	—	125
		05/07/2003	350	7.8	—	—	—	—	—	117
		10/13/2003	350	7.7	—	—	—	—	—	116
6	Well 4	08/29/2001	480	8.0	—	36	19	38	2.0	128
		09/11/2002	495	8.1	297	36	19	35	2.0	124
		10/16/2003	475	7.9	—	—	—	—	—	120
7	Dale Wilson	04/28/1999	450	—	—	—	—	—	—	—
8	WD 4	04/02/1999	355	8.2	—	—	—	—	—	124
		12/18/2002	350	7.7	205	29	17	16	2.1	125
9	WD 6	05/15/2001	130	7.6	88	35	2.9	2.2	11	45
		08/28/2001	185	7.7	—	—	—	—	—	70
		09/09/2002	290	7.7	167	37	3.4	12	1.6	93
		12/17/2002	400	7.6	—	—	—	—	—	—
		03/19/2003	425	7.5	251	—	—	—	—	128
		05/07/2003	450	7.5	276	—	—	—	—	128
		06/09/2003	390	7.8	—	—	—	—	—	122
		08/04/2003	350	7.5	234	—	—	—	—	113
		10/06/2003	400	7.6	239	—	—	—	—	121
		01/08/2004	300	7.7	172	—	—	—	—	86
		05/03/2004	700	7.4	446	85	6	60	1.4	139
		02/09/2005	445	7.9	269	—	—	—	—	115
		04/05/2005	460	7.6	—	—	—	—	—	118
10	Well 8	10/08/2002	550	7.5	323	49	20	35	2.1	141
		10/09/2003	430	7.6	242	—	—	—	—	128
		09/21/2004	530	7.7	312	—	—	—	—	134
11	WD 2	04/02/1999	440	8.3	—	—	—	—	—	125
12	IFP 1	[1]04/20/1999	360	—	—	—	—	—	—	—
24	IFP 7 Shallow	10/25/2000	370	8.0	—	31	17	16	3.0	127
26	IFP 2	04/21/1999	390	—	—	—	—	—	—	—
27	Wash 1	04/20/1999	415	8.2	—	—	—	—	—	129
28	North Dam 3A	10/08/2002	4,430	8.0	3,020	150	160	590	2.0	148
		12/18/2002	2,830	8.0	1,890	110	110	340	3.6	155
		03/19/2003	1,200	7.9	750	—	—	—	—	147
		06/10/2003	1,330	7.8	842	—	—	—	—	144

Table 3. Selected physical properties and major and minor chemical constituents in ground- and surface-water samples collected from selected sites in Sand Hollow and the Virgin River near Virgin, Utah—Continued

Map number	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Chloride: Bromide ratio	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, ortho-phosphate (mg/L as P)
1a	21	19	0.3	0.19	100	14	<10	3.2	10.9	2.6	0.05	<0.04	<0.02
1b	20	10	0.2	—	—	13	<10	<2	9.4	<.008	<.02	3.02	<.04
	13	11	0.4	—	—	12	E6	12	3.7	<.008	<.02	2.89	E .03
	19	17	1.1	—	—	11	11	19	9.1	<.008	E .01	3.37	E .03
	—	—	—	—	—	—	—	—	4.4	2.79	E .007	.06	<.02
	—	—	—	—	—	—	—	—	9.3	—	—	—	—
2	[2] 23	[2] 22	—	[2] .05	[2] 415	—	—	—	—	—	—	—	—
	19	20	.2	.08	250	15	<10	E 1	10.0	2.1	<.008	<.04	<.02
3	19.7	17.3	.2	.10	173	12	E 7	11	4.2	3.15	<.008	<.04	<.02
3	19.7	17.8	.2	—	—	11	10	12	2.6	3.41	.008	.10	<.02
3	16.2	13.2	.2	—	—	11	27	6	4.6	3.73	E .004	<.04	<.02
3	18.0	14.3	.2	.10	143	12	19	E 3	5.9	3.84	<.008	E .03	<.02
3	—	—	—	—	—	—	—	—	6.0	—	—	—	—
5	25	25	.3	.08	313	31	—	—	—	1.6	.007	<.04	<.02
	[2] 26	[2] 26	—	[2] .16	[2] 164	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—
6	58	44	E .1	.20	218	13	<10	<3	7.1	1.5	<.006	<.04	<.02
	56	42	.2	.17	247	13	<10	<2	8.0	E 2.1	<.008	<.04	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
7	[2] 42	[2] 39	—	[2] .18	[2] 214	—	—	—	—	—	—	—	—
8	[2] 20	[2] 18	—	[2] .06	[2] 306	—	—	—	—	—	—	—	—
	18.1	18.8	.2	.08	235	14	<10	<2	13.2	2.35	<.008	<.04	.02
9	7.4	2.9	.2	.01	290	41	—	—	—	.5	.0	<.04	<.02
	[2] 12	[2] 7	—	[2] .02	[2] 277	—	—	—	—	—	—	—	—
	24	15	E .08	.16	94	13	<10	E 2	2.0	E 1.6	<.008	<.04	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	2.4	1.67	<.008	<.04	E .009
	—	—	—	—	—	—	—	—	2.7	1.46	.02	.09	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	2.5	1.45	<.008	<.04	<.02
	—	30	—	.16	188	—	—	—	2.8	—	—	—	—
	—	—	—	—	—	—	—	—	2.7	—	—	—	—
	93	90	.2	.41	220	14	<6.4	E .05	2.8	—	—	—	—
	—	35.4	—	—	—	—	—	—	3.8	—	—	—	—
	—	—	—	—	—	—	—	—	3.6	—	—	—	—
10	70	39	.3	.15	258	14	<10	5	16.6	1.72	.03	.18	E .01
	—	28	—	.14	206	—	—	—	7.4	—	—	—	—
	—	—	—	—	—	—	—	—	8.1	—	—	—	—
11	[2] 33	[2] 30	—	[2] .08	[2] 384	—	—	—	—	—	—	—	—
12	[2] 22	[2] 20	—	[2] .08	[2] 255	—	—	—	—	—	—	—	—
24	22	20	.4	.19	105	15	<10	<3	33.3	2.3	<.008	<.04	<.02
26	[2] 22	[2] 21	—	[2] .09	[2] 251	—	—	—	—	—	—	—	—
27	[2] 28	[2] 28	—	[2] .09	[2] 309	—	—	—	—	—	—	—	—
28	1,020	744	.9	41.2	18	13	<30	<5	90.1	17.8	<.008	E .03	.03
	584	476	.8	2.44	195	14	<30	<5	63.9	14.3	<.008	<.04	.03
	—	—	—	—	—	—	—	—	51.0	3.66	<.008	<.04	.03
	—	—	—	—	—	—	—	—	41.9	7.20	<.008	<.04	.02

Table 3. Selected physical properties and major and minor chemical constituents in ground- and surface-water samples collected from selected sites in Sand Hollow and the Virgin River near Virgin, Utah—Continued

Map number	Well name	Date sampled	Specific conductance (µS/cm)	pH (standard units)	Solids, residue at 180°C (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)
28	North Dam 3A—Continued	08/04/2003	1,130	7.8	677	—	—	—	—	143
		10/09/2003	1,230	7.8	723	—	—	—	—	146
		01/08/2004	1,220	8.2	779	—	—	—	—	153
		05/03/2004	1,300	7.7	828	—	—	—	—	156
		09/21/2004	980	7.7	610	63.3	37.1	83.1	3.3	167
		10/29/2004	905	7.9	—	—	—	—	—	—
		12/14/2004	960	8.0	—	—	—	—	—	—
		02/10/2005	960	7.7	614	—	—	—	—	170
		04/05/2005	960	7.8	—	—	—	—	—	176
29	Well 9	08/30/2001	285	7.9	—	27	16	7.0	1.9	115
		09/11/2002	740	8.2	458	53	28	52	2.3	124
		10/09/2003	920	7.6	585	—	—	—	—	147
		09/21/2004	665	7.7	403	—	—	—	—	—
		04/08/2005	785	7.7	457	—	—	—	—	—
30	North Dam Drain	09/11/2002	2,090	8.0	1,450	120	78	210	4.2	148
		12/18/2002	1,530	8.1	1,070	—	—	—	—	147
		03/19/2003	1,400	8.0	923	—	—	—	—	168
		05/08/2003	1,250	8.0	810	—	—	—	—	—
		06/10/2003	430	8.1	829	—	—	—	—	169
		08/06/2003	920	8.1	659	—	—	—	—	173
		01/08/2004	980	8.3	624	—	—	—	—	155
		05/03/2004	1,050	7.9	637	—	—	—	—	170
31	WD 1	04/02/1999	290	8.2	—	—	—	—	—	106
		09/10/2002	290	7.9	153	27	14	7.0	1.6	111
		05/08/2003	280	8.3	159	—	—	—	—	—
32	WD RJ	04/02/1999	560	8.2	—	—	—	—	—	137
		12/17/2002	530	7.7	309	47	22	27	2.3	137
33	WD 5	[1]04/03/1999	540	8.3	—	—	—	—	—	135
		12/17/2002	530	7.8	311	45	22	29	1.8	138
34	WD 3	12/19/2000	465	—	—	—	—	—	—	—
35	Hole N	05/25/2001	310	7.8	—	34	14	4.4	4.7	125
36	WD 11	[1]06/14/2001	420	7.8	232	44	21	13.2	3.9	149
		12/16/2002	455	7.6	—	—	—	—	—	165
		06/09/2003	650	7.9	386	—	—	—	—	192
		08/05/2003	700	7.8	482	—	—	—	—	218
		10/07/2003	800	7.8	460	—	—	—	—	209
		01/06/2004	770	7.8	450	—	—	—	—	213
		05/03/2004	680	7.7	440	67	32	68	1.7	187
		09/20/2004	920	8.2	—	—	—	—	—	
		02/09/2005	960	8.1	667	—	—	—	—	179
37	WD 9	[1]05/23/2001	335	7.7	—	46	6.7	19	4.1	106
		09/14/2001	280	7.4	—	—	—	—	—	124
		09/11/2002	335	7.9	189	36	7.3	22	1.6	120
		05/07/2003	315	7.8	—	—	—	—	—	100
		06/09/2003	350	7.7	230	—	—	—	—	108
		08/05/2003	720	7.5	377	—	—	—	—	—
		10/07/2003	740	7.5	445	—	—	—	—	150
		01/06/2004	630	7.7	405	—	—	—	—	140
		05/03/2004	545	7.4	240	—	—	—	—	109
		09/20/2004	750	7.8	480	—	—	—	—	165
		02/09/2005	780	7.6	50.3	—	—	—	—	171
		04/09/2005	815	7.7	—	—	—	—	—	173

Table 3. Selected physical properties and major and minor chemical constituents in ground- and surface-water samples collected from selected sites in Sand Hollow and the Virgin River near Virgin, Utah—Continued

Map number	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Chloride: Bromide ratio	Silica (mg/L as SiO_2)	Iron (µg/L as Fe)	Manga-nese (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)	Phos-phorus, ortho-phosphate (mg/L as P)
28	—	—	—	—	—	—	—	—	42.1	6.42	<0.008	<0.04	E 0.02
	—	130	—	0.62	209	—	—	—	[6]36.4	—	—	—	—
	—	—	—	—	—	—	—	—	46.7	—	—	—	—
	—	—	—	—	—	—	—	—	45.7	—	—	—	—
	207	73.7	0.6	.11	664	14	<6.4	<0.8	46.4	—	—	—	—
	—	—	—	—	—	—	—	—	48.0	—	—	—	—
	—	—	—	—	—	—	—	—	46.5	—	—	—	—
	—	74.0	—	—	—	—	—	—	42.4	—	—	—	—
	—	—	—	—	—	—	—	—	43.9	—	—	—	—
29	13	13	.2	.07	186	13	<10	<3	12.4	2.4	<.006	<.04	<.02
	126	72	.2	.28	258	14	250	6	17.0	E 2.2	<.008	<.04	<.02
	—	85	—	.26	331	—	—	—	12.8	—	—	—	—
	—	—	—	—	—	—	—	—	14.5	—	—	—	—
	—	—	—	—	—	—	—	—	16.7	—	—	—	—
30	560	220	1.4	10	22	24	<10	<2	31.0	E 12	E .004	<.04	E .02
	—	—	—	—	—	—	—	—	40.3	2.95	<.008	<.04	.03
	—	—	—	—	—	—	—	—	27.9	1.88	<.008	.012	.016
	—	—	—	—	—	—	—	—	26.0	1.65	.02	<.04	E .02
	—	—	—	—	—	—	—	—	23.8	1.41	<.008	<.04	E .02
	—	—	—	—	—	—	—	—	25.1	.76	<.008	<.04	E .009
	—	—	—	—	—	—	—	—	28.0	—	—	—	—
	—	—	—	—	—	—	—	—	19.3	—	—	—	—
31	[2]13	[2]12	—	[2].04	[2]323	—	—	—	—	—	—	—	—
	13	11	.2	.06	182	14	<10	<2	14.4	E 2.2	<.008	<.04	<.02
	—	—	—	—	—	—	—	—	15.2	2.04	.02	<.04	<.02
32	[2]53	[2]46	—	[2].13	[2]348	—	—	—	—	—	—	—	—
	46.1	47.8	.5	.20	239	14	<10	<2	7.9	3.28	<.008	<.04	E .01
33	[2]47	[2]44	—	[2].13	[2]348	—	—	—	—	—	—	—	—
	46.8	44.8	.3	.16	280	13	<10	E 1	9.1	4.18	<.008	<.04	E .01
34	35	[2]28	—	[2].15	[2]188	—	—	—	—	—	—	—	—
35	16	6.5	.7	.05	130	18	13	6	18.1	.67	.01	E .03	E .02
36	31	14	.5	.10	140	17	—	—	—	1.7	.007	<.04	<.02
	—	—	—	—	—	—	—	—	7.3				
	—	—	—	—	—	—	—	—	15.4	4.59	<.008	<.04	E .01
	—	—	—	—	—	—	—	—	16.0	3.02	<.008	E .02	E .01
	—	64	—	.33	194	—	—	—	16.2	—	—	—	—
	—	—	—	—	—	—	—	—	17.1	—	—	—	—
	90	50	.4	.25	199	15	<6.4	<.8	15.3	3.06	<.008	<.04	.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	17.0	—	—	—	—
37	18	22	.5	.06	367	22	—	—	9.4	.29	.008	<.04	<.02
	[2]15	[2]18	—	[2].12	[2]154	—	—	—	—	—	—	—	—
	18	21	.5	.06	350	15	E 9	15	12.0	E .48	<.008	<.04	E .01
	—	—	—	—	—	—	—	—					
	—	—	—	—	—	—	—	—	11.8	.909	<.008	<.04	E .01
	—	—	—	—	—	—	—	—	9.8	.757	<.008	<.04	E .01
	—	53	—	.06	883	—	—	—	5.8	—	—	—	—
	—	—	—	—	—	—	—	—	8.6	—	—	—	—
	—	—	—	—	—	—	—	—	13.3	—	—	—	—
	—	—	—	.04	—	—	—	—	6.2	—	—	—	—
	—	56	—	—	—	—	—	—	6.8	—	—	—	—
	—	—	—	—	—	—	—	—	7.3	—	—	—	—

Table 3. Selected physical properties and major and minor chemical constituents in ground- and surface-water samples collected from selected sites in Sand Hollow and the Virgin River near Virgin, Utah—Continued

Map number	Well name	Date sampled	Specific conductance (μS/cm)	pH (standard units)	Solids, residue at 180°C (mg/L)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Alkalinity (mg/L as $CaCO_3$)
38	Basin 1	[1]07/22/1999	—	—	—	—	—	—	—	—
		09/10/2001	620	7.6	—	36	25	43	2.4	141
39	Slope 1a	[1]04/28/1999	270	8.1	—	—	—	—	—	94
		09/12/2001	240	7.9	—	26	13	8.3	1.7	109
		09/09/2002	270	8.0	150	26	13	8.6	1.8	107
		03/20/2003	265	7.8	—	—	—	—	—	—
42	Terracor 3	04/23/1999	320	8.3	—	—	—	—	—	124
		09/11/2001	335	7.9	—	33	21	19	1.6	136
43	Hole O	[1]06/11/2001	465	7.6	—	39	31	18	11	160
		09/11/2001	425	8.0	—	—	—	—	—	192
44	WD 8	[1]05/21/2001	300	7.7	168	74	5.5	8.7	12	102
		09/12/2001	305	7.7	—	—	—	—	—	115
		09/09/2002	305	7.9	173	37	10	8.9	2.3	116
		05/08/2003	340	7.5	—	—	—	—	—	145
		10/16/2003	355	7.4	—	—	—	—	—	127
46	Basin 2	[1]07/21/1999	295	8.1	—	—	—	—	—	—
		08/27/2001	290	7.8	—	30	13	8.5	2.4	115
47	WD 13	08/30/2001	275	8.1	—	24	16	8.4	1.5	109
		10/16/2003	225	8.2	—	—	—	—	—	86
48	Well 17	05/18/2000	410	8.1	—	—	—	—	—	117
49	WD 14	12/18/2002	385	7.7	220	36	20	10	2.4	122
50	WD 7	09/10/2001	380	7.8	—	37	12	25	1.9	137
		05/07/2003	390	7.9	—	—	—	—	—	137
		10/08/2003	395	7.8	230	—	—	—	—	130
[3]VR	Virgin River	08/29/2001	850	8.4	—	74	29	55	4.4	159
		10/03/2001	820	8.2	—	67	29	58	3.8	161
		11/27/2001	850	8.1	—	78	30	51	4.0	206
[4]RES	Reservoir	09/10/2002	1,000	8.8	669	63	43	71	5.3	92
		03/20/2003	830	8.2	525	—	—	—	—	171
		06/10/2003	850	8.2		—	—	—	—	164
		08/06/2003	930	7.6	568	—	—	—	—	156
		10/07/2003	910	8.4	569	—	—	—	—	127
		01/08/2004	870	8.4	523	—	—	—	—	176
		05/05/2004	710	8.2	442	63	26	45	3.3	161
		09/22/2004	765	8.5	—	—	—	—	—	139
		02/10/2005	855	8.4	546	—	—	—	—	159
[5]EW	Ephemeral Wash	11/09/2002	85	8.0	49	14	1	0	1.3	42

[1] Sample collected in open hole prior to well installation.
[2] Analyzed by Los Alamos National Laboratory in Los Alamos, New Mexico.
[3] Surface water measured or sampled at Virgin River near Virgin, Utah.
[4] Surface water measured or sampled in Sand Hollow Reservoir, Utah.
[5] Surface water measured or sampled in ephemeral wash at map number 44.
[6] Analyzed by the USGS Research Laboratory, Boulder, Colorado.

Table 3. Selected physical properties and major and minor chemical constituents in ground- and surface-water samples collected from selected sites in Sand Hollow and the Virgin River near Virgin, Utah—Continued

Map number	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Chloride: Bromide ratio	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, ortho-phosphate (mg/L as P)
38	[2]65	[2]58	—	[2]0.18	[2]331	—	—	—	—	—	—	—	—
	66	64	.3	[2].27	237	13	<10	<3	23.0	2.5	<.006	<.04	.03
39	[2]15	[2]12	—	[2].03	[2]379	—	—	—	—	—	—	—	—
	15	13	E .1	.05	277	14	<10	<3	9.3	E 1.7	<.006	<.04	<.02
	14	10	.1	.05	200	14	<10	E .9	10.2	E 1.7	<.008	<.04	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
42	[2]3	[2]27	—	[2].15	[2]183	—	—	—	—	—	—	—	—
	31	29	.3	.14	203	13	<10	E 2	12.8	2.7	<.006	<.04	E .02
43	33	21	.7	.1	210	44	—	—	54.6	1.5	.007	E .024	E .02
	[2]32	[2]12	—	[2].14	[2]85	—	—	—	—	—	—	—	—
44	16	9.2	E 0.1	.05	184	33	—	—	—	2.8	E .005	<.04	<.02
	[2]15	[2]11	—	[2].09	[2]121	—	—	—	—	—	—	—	—
	15	10	.1	.07	143	14	<10	<2	6.0	E 3.9	<.008	<.04	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—
46	[2]14	[2]12	—	[2].05	[2]246	—	—	—	—	—	—	—	—
	13	9.9	E .1	.05	198	14	<10	20	6.3	2.9	<.006	<.04	<.02
47	12	12	E .1	.05	258	12	<10	E 2	6.3	2.0	<.006	<.04	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
48	[2]30	[2]28	—	[2].15	[2]185	—	—	—	—	—	—	—	—
49	29	28	.3	.11	257	13	<10	<2	15.6	2.18	<.008	<.04	<.02
50	28	[2]18	.3	[2].12	[2]139	14	<10	<3	6.0	3.8	<.006	<.04	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	18	—	.14	129	—	—	—	6.8	—	—	—	—
[3]VR	160	64	.2	.02	3,200	11	<10	3	1.1	.38	E .003	<.04	<.02
	160	66	.2	.04	1,650	8.8	<10	9	.9	.35	E .006	E .02	<.02
	160	59	.2	.03	1,967	11	34	14	.6	.45	<.008	<.04	<.02
[4]RES	300	76	.3	.02	3,800	5	<10	<2	2.0	E .04	<.008	<.04	<.02
	—	—	—	—	—	—	—	—	.9	.184	<.008	E .03	<.02
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	2.0	<.06	<.008	<.04	<.02
	—	80	—	.03	2,667	—	—	—	2.3	—	—	—	—
	—	—	—	—	—	—	—	—	1.2	—	—	—	—
	122	50	.2	.01	5,000	7	<6.4	1.3	1.1	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	56	—	—	—	—	—	—	1.5	—	—	—	—
[5]EW	23	20	<.2	<.01	—	2	E 8	5	.8	.39	.05	.08	.10

Table 4. Isotopic and chlorofluorocarbon concentrations of ground- and surface-water samples collected in and near Sand Hollow, Utah

[**Map number**: Refer to figure 3; **Stable isotopes:** δ^2H: Hydrogen-2/hydrogen-1 stable isotope ratio, in permil; $\delta^{18}O$: Oxygen-18/oxygen-16 stable isotope ratio, in permil; $\delta^{13}C$: Carbon-13/carbon-12 stable isotope ratio, in permil; ^{14}C: Carbon-14 concentration in pmc, percent modern carbon; ^3H: tritium concentration and precision in TU, tritium units where one tritium unit = one atom of ^3H in 10^{18} atom of ^1H; pmol/kg, picomoles per kilogram; —, no data available]

Map number	Well name	Date sampled	Stable isotopes δ^2H (permil)	$\delta^{18}O$ (permil)	$\delta^{13}C$ (permil)
1a	Wayne Wilson (original)	01/04/2000	-83	-11.5	—
1b	Wayne Wilson (redrilled) at 200 feet	05/06/2003	-93	-12.2	-7.4
	Wayne Wilson (redrilled) at 890 feet	05/06/2003	-93	-12.1	-6.6
2	WD 12 (Slope 2)	[1]04/30/1999	-85	-11.3	—
		[1,2]04/30/1999	-83	-11.0	—
		[1,2]04/30/1999	-86	—	—
		09/12/2002	-85	-10.8	-7.7
3	Well 2 (east side) at 245 feet	10/09/2002	-89	-11.7	-7.3
	Well 2 (east side) at 400 feet	10/10/2002	-89	-11.5	-7.1
	Well 2 (east side) at 500 feet	10/10/2002	-92	-11.7	—
	Well 2 (east side) at 615 feet	10/10/2002	-92	-11.8	-7.6
	Well 2 (east side) at 750 feet	10/10/2002	-94	-11.9	-7.0
5	WD 10 (Island)	[1]06/12/2001	-85	-11.0	—
		[1,2]06/12/2001	-84	-11.1	—
		09/13/2001	-85	-11.2	-7.2
6	Well 4 (Sky Ranch 2)	03/30/1999	-84	-11.6	—
		08/29/2001	-85	-11.1	—
		02/14/2002	—	—	—
		09/11/2002	-86	-11.0	-7.0
7	Dale Wilson	04/28/1999	-84	-10.2	—
		[2]04/28/1999	-83	—	—
8	WD 4	04/02/1999	-86	-11.0	—
		12/18/2002	-85	-10.8	-6.3
9	WD 6 (Slickrock)	05/15/2001	-82	-10.7	—
		08/28/2001	-79	-10.5	—
		09/09/2002	-82	-10.4	—
10	Well 8 (west side North Dam)	10/08/2002	-82	-10.8	—
11	WD 2	04/02/1999	-90	-11.3	—
12	IFP 1	[1]04/20/1999	-86	-11.0	—
		[1,2]04/20/1999	-82	-11.1	—
		[1,2]04/20/1999	-84	—	—
13	IFP 1 (Port 1)	05/18/2000	—	—	—
16	IFP 1 (Port 4)	05/18/2000	—	—	—
17	IFP 1 (Port 5)	05/17/2000	—	—	—
18	IFP 5 Shallow	05/17/2000	-87	-10.5	—
		[2]05/17/2000	-84	-10.7	—
		[2]05/17/2000	-85	-10.7	—
19	IFP 5 Medium	05/17/2000	-85	-11.0	—
20	IFP 5 Deep	05/17/2000	-86	-11.0	—
26	IFP 2	04/21/1999	-84	-11.6	—
		[2]04/21/1999	-85	—	—
27	Wash 1	04/20/1999	-86	-11.2	—
		[2]04/20/1999	-85	—	—
28	North Dam 3A[3]	10/08/2002	-83	-10.4	—

Table 4. Isotopic and chlorofluorocarbon concentrations of ground- and surface-water samples collected in and near Sand Hollow, Utah—Continued

Map number	^{14}C		^{3}H		Chlorofluorocarbons	
	Concentration (pmc)	Precision, +/- (pmc)	Concentration (TU)	Precision, +/- (TU)	Average CFC-11 (pmol/kg)	Average CFC-12 (pmol/kg)
1a	—	—	0.03	0.05	—	—
1b	17.9	.20	.34	.02	—	—
	16.7	.19	.40	.02	—	—
2	—	—	.53	.38	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
	61.3	.34	.02	.06	—	—
3	22.6	.27	.33	.02	—	—
	23.1	.28	.55	.22	—	—
	—	—	—	—	—	—
	15.1	.22	.02	.02	—	—
	14.7	.30	.22	.06	—	—
5	—	—	.45	.25	—	—
	—	—	—	—	—	—
	62.7	.46	.73	.35	2.51	1.62
6	—	—	.52	.36	—	—
	—	—	.26	.21	—	—
	—	—	—	—	.38	.24
	57.4	.33	—	—	—	—
7	—	—	.40	.26	—	—
	—	—	—	—	—	—
8	—	—	.22	.10	—	—
	70.7	.51	—	—	—	—
9	—	—	4.77	.24	—	—
	—	—	6.88	.34	—	—
	—	—	—	—	—	—
10	—	—	—	—	—	—
11	—	—	.38	.45	—	—
12	—	—	.00	.66	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
13	—	—	.12	.05	—	—
16	—	—	.03	.03	—	—
17	—	—	.00	.01	—	—
18	—	—	.08	.08	—	—
	—	—	—	—	—	—
	—	—	—	—	—	—
19	—	—	.18	.14	—	—
20	—	—	.08	.05	—	—
26	—	—	—	—	—	—
	—	—	—	—	—	—
27	—	—	.27	.10	—	—
	—	—	—	—	—	—
28	—	—	—	—	—	—

Table 4. Isotopic and chlorofluorocarbon concentrations of ground- and surface-water samples collected in and near Sand Hollow, Utah—Continued

Map number	Well name	Date sampled	Stable isotopes		
			δ^2H (permil)	$\delta^{18}O$ (permil)	$\delta^{13}C$ (permil)
29	Well 9 (east side of North Dam)	08/30/2001	-86	-11.4	-7.2
		09/11/2002	-87	-10.6	—
30	North Dam Drain[3]	10/08/2002	-80	-9.6	—
31	WD 1	04/02/1999	-83	-10.6	—
		[2]04/02/1999	-84	—	—
		09/10/2002	-85	-10.9	-7.4
32	WD RJ	04/02/1999	-83	-10.7	—
		12/17/2002	-84	-10.3	-5.8
33	WD 5	04/03/1999	-85	-11.2	—
		12/17/2002	-85	-10.6	-6.7
34	WD 3	12/19/2000	-89	-10.6	—
35	Hole N	05/25/2001	-82	-10.6	—
36	WD 11 (West Dam)	[1]06/14/2001	-85	-9.7	—
		09/14/2001	-86	-10.8	-8.0
		12/16/2002	—	—	-8.0
37	WD 9 (Boat Ramp)	[1]05/23/2001	-88	-11.5	—
		09/14/2001	-86	-11.4	-8.0
		09/11/2002	-89	-11.5	—
38	Basin 1	[1]07/22/1999	-88	-10.9	—
		09/10/2001	-84	-10.7	-6.5
39	Slope 1a	104/28/1999	-85	—	—
		07/20/1999	-85	-11.1	—
		[2]07/20/1999	-87	-11.1	—
		09/12/2001	-83	-11.4	-7.3
		09/09/2002	-86	-11.4	—
42	Terracor 3	04/23/1999	-82	-10.9	—
		[2]04/23/1999	-82	—	—
		09/11/2001	-85	-11.0	—
43	Hole O	[1]06/11/2001	-84	-10.1	—
		09/11/2001	-85	-10.3	-9.5
44	WD 8 (Sand Dune)	[1]05/21/2001	-81	-10.6	—
		[1,2]05/21/2001	-81	-10.6	—
		09/12/2001	-86	-10.9	-8.5
		09/09/2002	-85	-10.9	—
46	Basin 2	[1]05/05/1999	-87	—	—
		07/21/1999	-86	-11.6	—
		[2]07/21/1999	-86	-11.7	—
		08/27/2001	-88	-11.1	-6.9
47	WD 13 (Corral)	01/05/2000	-86	-11.6	—
		08/30/2001	-86	-11.4	—
		09/14/2001	—	—	—
48	Well 17 (West Dam)	05/18/2000	-87	-11.2	—
49	WD 14 (Terracor 2)	12/18/2002	-88	-11.4	—
50	WD 7 (south end of West Dam)	09/10/2001	-85	-10.6	-7.7
VR[4]	Virgin River	08/29/2001	-95	-12.5	—
		10/03/2001	-97	-13.0	—
RES	Sand Hollow Reservoir	09/10/2002	-91	-6.2	—
EW	Ephemeral Wash at Map Number 44	11/09/2002	-48	-6.6	—

[1] Collected prior to well installation.
[2] Replicate sample.
[3] Affected by reservoir seepage.
[4] Not shown in figure 3.

Table 4. Isotopic and chlorofluorocarbon concentrations of ground- and surface-water samples collected in and near Sand Hollow, Utah—Continued

Map number	^{14}C Concentration (pmc)	^{14}C Precision, +/- (pmc)	^{3}H Concentration (TU)	^{3}H Precision, +/- (TU)	Chlorofluorocarbons Average CFC-11 (pmol/kg)	Chlorofluorocarbons Average CFC-12 (pmol/kg)
29	39.4	.32	0.10	0.04	.34	.15
	—	—	—	—	—	—
30	—	—	—	—	—	—
31	—	—	.37	.50	—	—
	—	—	—	—	—	—
	61.1	.36	—	—	—	—
32	—	—	.02	.05	—	—
	56.9	.42	—	—	—	—
33	—	—	.19	.06	—	—
	57.8	.44	—	—	—	—
34	—	—	.28	.20	—	—
35	—	—	4.27	.21	—	—
36	—	—	1.19	.77	—	—
	91.9	.61	.53	.08	.53	.24
	86.9	.58	—	—	—	—
37	—	—	.00	.01	—	—
	70.3	.50	.20	.15	2.34	2.12
	—	—	—	—	—	—
38	—	—	.07	.21	—	—
	74.3	.45	.18	.21	.29	.16
39	—	—	—	—	—	—
	—	—	.39	.18	—	—
	—	—	—	—	—	—
	66.5	.47	.44	.36	.57	.19
	—	—	.07	.06	—	—
42	—	—	.53	.09	—	—
	—	—	—	—	—	—
	—	—	.28	.08	.45	contaminated
43	—	—	1.03	.07	—	—
	105.3	.57	1.09	.20	2.20	1.56
44	—	—	4.13	.38	—	—
	—	—	—	—	—	—
	66.8	.44	2.98	.15	.52	.37
	—	—	3.89	.19	—	—
46	—	—	—	—	—	—
	—	—	.23	.35	—	—
	—	—	—	—	—	—
	73.2	.51	.18	.06	.55	.25
47	—	—	.43	.36	—	—
	—	—	.29	.15	—	—
	—	—	—	—	.26	.18
48	—	—	—	—	—	—
49	—	—	.32	.04	—	—
50	66.4	.44	.21	.09	1.39	.46
VR[4]	—	—	1.56	.09	—	—
	—	—	—	—	—	—
RES	—	—	2.47	.12	—	—
EW	—	—	2.28	.11	—	—

Table 5. Age and apparent recharge year of ground water in Sand Hollow, Utah

[**Map number**: Refer to figure 3;—, no data available; E, estimated]

Map number	Well name	Date sampled	Depth of openings below water table (feet)	Apparent tritium/helium recharge year	Chlorofluorocarbons		^{14}Carbon	
					Apparent CFC-11 recharge year	Apparent CFC-12 recharge year	Percent modern carbon (pmc)	Apparent C-14 age (years)
1b	Wayne Wilson at 200 feet	05/06/2003	52-272	pre-1950s	—	—	18	7,000
	Wayne Wilson at 890 feet	05/06/2003	792-932	pre-1950s	—	—	17	7,000
2	WD 12 (Slope 2)	09/12/2002	1.5-6.5	—	—	—	61	modern
3	Well 2 (east side) at 245 feet	10/08/2002	0-81	pre-1950s	—	—	23	5,000
	Well 2 (east side) at 400 feet	10/10/2002	123-194	pre-1950s	—	—	23	5,000
	Well 2 (east side) at 615 feet	10/10/2002	363-443	pre-1950s	—	—	15	8,500
	Well 2 (east side) at 750 feet	10/10/2002	483-643	pre-1950s	—	—	15	8,000
5	WD 10 (Island)	09/13/2001	0-2.7	—	1983	1992	63	modern
		09/12/2002		pre-1950s	—	—	—	—
6	Well 4 (Sky Ranch 2)	10/03/2001	0-459	—	—	—	—	—
		02/14/2002		pre-1950s	1966	1965	—	—
		09/11/2002		—	—	—	57	modern
		12/17/2002		pre-1950s	—	—	—	—
8	WD 4	12/18/2002	20-30	pre-1950s	—	—	71	modern
9	WD 6 (Slickrock)	08/28/2001	0-5	1998	—	—	—	—
		09/12/2002		2000	—	—	—	—
29	Well 9 (east side of North Dam)	08/30/2001	35-1,071	pre-1950s	1964	1963	39	500
31	WD 1	09/10/2002	7-17	—	—	—	61	modern
		12/18/2002		pre-1950s	—	—	—	—
32	WD RJ	12/17/2002	139-149	pre-1950s	—	—	57	modern
33	WD 5	12/17/2002	79-89	pre-1950s	—	—	58	modern
36	WD 11 (West Dam)	09/14/2001	16-21	—	1967	1966	92	modern
		09/12/2002		pre-1950s	—	—	—	—
		12/16/2002		—	—	—	87	modern
37	WD 9 (Boat Ramp)	09/14/2001	8-13	pre-1950s	1982	1997	70	modern
		09/12/2002		pre-1950s	—	—	—	—
38	Basin 1	09/10/2001	36-41	pre-1950s	1964	1963	74	modern
39	Slope 1a	09/12/2001	32-37	—	1968	1964	67	modern
		09/11/2002		pre-1950s	—	—	—	—
42	Terracor 3	09/11/2001	0-653	pre-1950s	1966	—	—	—
43	Hole O	09/11/2001	.5-5.5	1975	1979	1988	105	modern
44	WD 8 (Sand Dune)	09/12/2001	6.4-11.4	—	1968	1969	67	modern
		09/10/2002		1997	—	—	—	—
46	Basin 2	08/27/2001	20-25	pre-1950s	1968	1967	73	modern
47	WD 13 (Corral Well)	09/14/2001	0-120 E	pre-1950s	1963	1963	—	—
		09/12/2002		pre-1950s	—	—	—	—
49	WD 14 (Terracor 2)	12/18/2002	0-563	pre-1950s	—	—	—	—
50	WD 7 (south end of West Dam)	09/10/2001	4.8-9.8	pre-1950s	1974	1971	66	modern
		09/12/2002		pre-1950s	—	—	—	—

Table 6. Average monthly and annual pan evaporation rates from St. George, Utah, and calculated evaporation rates with Jensen-Haise and turbulent-transfer methods using climate data collected at Sand Hollow, Utah, and calculated Penman evaporation rates using St. George climate data

[—, no data available; E, estimated from 2004 data]

Method for estimating evaporation	Monthly evaporation (inches)												Total annual evaporation (inches)
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
Average Monthly Pan Evaporation, 1869-1993	—	—	4.57	7.36	10.08	12.22	13.17	11.55	8.22	4.83	2.68	—	74.68
Corrected (80 percent) Average Monthly Pan Evaporation, 1869-1993	—	—	3.66	5.88	8.06	9.78	10.53	9.24	6.57	3.86	2.14	—	59.7
Jensen-Haise, 1999	.9	1.4	3.3	3.2	7.4	9.7	9.0	8.2	6.1	3.8	1.6	.7	55.3
Jensen-Haise, 2000	.8	1.2	2.9	5.8	8.8	10.4	11.1	8.3	6.5	3.1	1.0	.7	60.6
Jensen-Haise, 2001	.7	1.2	3.1	4.7	8.7	10.6	10.6	9.2	6.7	3.7	1.5	.5	61.2
Jensen-Haise, 2002	.7	1.5	2.9	5.5	8.1	10.9	10.8	9.7	5.6	3.1	1.3	.6	60.7
Jensen-Haise, 2003	1.1	1.2	2.9	4.4	7.9	10.7	11.0	9.0	6.9	4.3	1.1	.7	61.2
Jensen-Haise, 2004	.7	0.9	4.5	5.0	8.6	10.4	11.3	9.3	4.8	—	—	—	—
Turbulent transfer, 2003	E 1.5	2.0	3.3	4.9	5.8	8.7	6.5	6.2	6.9	5.5	2.4	1.1	54.8
Turbulent transfer, 2004	1.5	1.9	3.2	5.3	—	—	—	—	—	—	—	—	—
Penman, St George, 1999	3.90	3.97	5.82	5.16	6.87	7.38	7.57	8.26	7.62	7.26	5.28	3.78	72.87
Penman, St George, 2000	—	4.03	5.38	6.88	7.6	7.72	8.45	8.04	[1]6.66	[1]5.09	[1]3.29	3.75	[1]66.89
Penman, St George, 2001	3.46	3.57	[1]5.17	5.83	7.78	—	[1]2.24	[1]7.78	[1]7.45	[1]5.78	[1]4.12	[1]2.74	[1]55.92
Penman, St George, 2002	3.25	3.98	5.1	6.01	—	7.72	8.15	8.24	6.94	5.51	4.02	3.11	[1]62.03
Penman, St George, 2003	4.09	3.25	4.88	5.12	6.71	7.22	8.27	7.57	7.32	6.44	3.5	3.22	67.57
Penman, St George, 2004	—	3.05	5.89	5.42	6.68	7.28	7.67	[1]7.67	—	—	—	—	—

[1]Data missing for at least one day.

Table 7. Reservoir data and estimated evaporation and ground-water recharge at Sand Hollow, Utah, 2002-04

Month	Reservoir altitude (feet)	Total surface-water inflow (+) or outflow (-) (acre-feet)	Reservoir storage (acre-feet)	Reservoir storage change (acre-feet)	Reservoir surface area (acres)	[1]Estimated evaporation rate (inches per month)	Estimated evaporation loss (acre-feet)	Estimated recharge rate (acre-feet)	Estimated recharge rate (foot per day)	[2]Viscosity-corrected hydraulic conductivity (foot per day)
March 2002	3,001.0	6,620	3,090	3,060	260	2.9	60	3,500	0.44	0.57
April 2002	3,002.5	3,690	3,500	410	280	5.5	130	3,160	.38	.43
May 2002	3,001.0	2,450	3,090	-410	260	8.1	170	2,680	.34	.33
June 2002	2,998.5	0	2,480	-610	230	10.9	210	400	.06	.06
July 2002	2,996.5	0	2,050	-440	210	10.8	190	250	.04	.04
August 2002	2,994.5	0	1,650	-390	180	9.7	150	240	.04	.04
September 2002	2,993.7	0	1,300	-350	140	5.6	70	290	.07	.07
October 2002	2,994.7	790	1,500	200	160	3.1	40	550	.12	.13
November 2002	3,005.5	3,590	4,220	2,720	320	1.3	30	830	.09	.12
December 2002	3,011.7	3,930	7,000	2,780	400	0.6	20	1,130	.09	.14
January 2003	3,017.3	4,580	9,760	2,760	590	1.1	50	1,770	.10	.15
February 2003	3,019.0	2,850	10,670	920	570	1.2	60	1,870	.12	.17
March 2003	3,019.5	1,930	10,930	250	580	2.9	140	1,540	.09	.11
April 2003	3,019.0	540	10,680	-250	570	4.4	210	580	.03	.04
May 2003	3,017.6	0	9,930	-750	540	7.9	350	400	.02	.02
June 2003	3,010.3	-3,120	6,040	-3,880	390	10.7	350	420	.04	.03
July 2003	3,001.8	-2,020	3,200	-2,840	240	11.0	220	610	.08	.08
August 2003	2,998.8	0	2,540	-660	230	9.0	170	490	.07	.06
September 2003	2,997.4	0	2,100	-440	220	6.9	130	310	.05	.05
October 2003	2,996.4	0	1,850	-250	170	4.3	60	190	.04	.04
November 2003	2,994.0	0	1,560	-290	200	1.1	20	270	.04	.06
December 2003	3,006.5	3,590	4,700	3,140	330	.7	20	430	.04	.06
January 2004	3,013.0	3,990	7,600	2,900	480	.7	30	1,060	.07	.11
February 2004	3,016.0	2,320	8,840	1,240	600	.9	50	1,030	.06	.09
March 2004	3,018.5	2,400	10,400	1,560	630	4.5	240	610	.03	.04
April 2004	3,025.3	5,620	15,070	4,670	750	5.0	310	640	.03	.03
May 2004	3,026.2	2,050	15,830	770	780	8.6	560	720	.03	.03
June 2004	3,025.3	0	14,400	-1,430	750	10.4	650	780	.03	.03
July 2004	3,023.0	0	13,000	-1,400	680	11.3	640	760	.04	.03
August 2004	3,020.8	0	11,670	-1,330	680	9.3	520	810	.04	.04
Total or Average	—	[3]45,800	—	—	—	[4]5.5	[3]5,850	[3]28,320	[5].06	[5].07

[1]Calculated using the Jensen-Haise method.
[2]Assuming a unit hydraulic gradient.
[3]Total.
[4]Average.
[5]Average, excluding initial 3 months.

V.M. Heilweil—Pre- and Post-Reservoir Ground-Water Conditions and Assessment of Artificial Recharge at Sand Hollow, Washington County, Utah, 1995-2005