Prepared in cooperation with the Uintah Water Conservancy District and the Bureau of Reclamation

Groundwater and Surface-Water Resources near Red Fleet Reservoir, Uintah County, Utah

Scientific Investigations Report 2019–5101

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

Cover: View of Red Fleet Reservoir looking northeast near well DH-109; photograph taken by Mike Hess, U.S. Geological Survey, August 2016.

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square inch (in^2)	6.452	square centimeter (cm^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)

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

$$°F = (1.8 \times °C) + 32.$$

Datums

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).

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

Supplemental Information

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

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

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

Stable isotope concentration is reported as per mil, which is equivalent to parts per thousand.

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

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

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

Abbreviations

^3H	tritium
^3He	helium-3
$^3He_{trit}$	tritiogenic helium-3
^4He	helium-4
$^4He_{terr}$	terrigenic helium-4
AVWTP	Ashley Valley Water Treatment Plant
CE	closed-system equilibration
CFC-11	trichlorofluoromethane
CFC-113	1,1,2-trichloro-1,2,2-trifluoroethane
CFC-12	dichlorodifluoromethane
CFC	chlorofluorocarbon
DM	dispersion model
EPA	Environmental Protection Agency
He	helium
He_{terr}	terrigenic helium
Kr	krypton
LPM	lumped parameter modeling
ml	milliliter
NGT	noble-gas recharge temperature
NRCS	Natural Resources Conservation Service
PET	potential evaporation
RFSP	Red Fleet State Park
SCAN	Soil Climate Analysis Network
SF_6	sulfur hexafluoride
TDG	total dissolved gas
BOR	Bureau of Reclamation
USGS	U.S. Geological Survey
UWCD	Uintah Water Conservancy District
Xe	xenon
σ	standard deviation
χ^2	chi-squared statistic

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By Thomas M. Marston, John E. Solder, and Katherine K. Jones

Abstract

Red Fleet Reservoir in Uintah County, Utah, is an approximately 26,000 acre-foot (acre-ft) on-channel reservoir in the Big Brush Creek drainage on the south slope of the Uinta Mountains. It is operated primarily for irrigation needs while providing a supplemental drinking-water supply to the Vernal, Utah area. Red Fleet Reservoir, which was operated by the Bureau of Reclamation and the Uintah Water Conservancy District through 2015, began storing water in May 1980. The reservoir is on southward dipping Mesozoic lithologies ranging from Jurassic to Cretaceous in age. The Nugget and Frontier Sandstone aquifers are the targeted units in this investigation, which is to characterize groundwater conditions that exist in each sandstone aquifer and how they interact with Red Fleet Reservoir. Groundwater levels were measured in six wells and one spring in the Nugget Sandstone and the Frontier Sandstone aquifers. Water levels in the Nugget Sandstone aquifer were 35–70 feet above the maximum stage of Red Fleet Reservoir on the west and east banks. Water levels in the Frontier Sandstone aquifer were 15–30 feet below the observed stage of Red Fleet Reservoir on the west bank during the study period.

A water budget was calculated for Red Fleet Reservoir between May 1980 and December 2015. During this period, 1,050,000 acre-ft of water from Big Brush Creek discharged into the reservoir, while 993,000 acre-ft of water was released downstream of Red Fleet Dam. Total evaporation from May 1980 through December 2015 was about 52,000 acre-ft, while total precipitation over the same period was about 12,000 acre-ft. From May 1980 through December 2015, the total pumped volume of water from the Tyzack Pump Station, at the base of Red Fleet Dam, was about 42,000 acre-ft. Total groundwater discharge to Red Fleet Reservoir from 1980 through 2015 was about 40,000 acre-ft.

Water was sampled from four wells and from the inflow arm of Red Fleet Reservoir, and analyzed for major-ion chemistry, selected trace metals, nutrients, and environmental tracers. Water sampled from the Nugget Sandstone aquifer yielded good-quality water with dissolved-solids concentrations of less than 200 milligrams per liter, and no trace elements above the Environmental Protection Agency drinking-water standards. Water sampled from the Frontier Sandstone aquifer yielded poor-quality water with dissolved-solids concentrations of about 2,150 milligrams per liter and arsenic approaching the drinking-water standard of 10 milligrams per liter. Dissolved noble gases used to identify recharge elevations and temperatures for groundwater indicate that water in the Nugget Sandstone aquifer likely recharged at a high altitude and low temperature, and not locally because of interaction with Red Fleet Reservoir. The Frontier Sandstone aquifer is likely recharged at low elevation and at temperatures similar to those observed at Red Fleet Reservoir.

Introduction

Red Fleet Reservoir (fig. 1) in Uintah County, Utah, was completed in May 1980 and is operated primarily as an impoundment for irrigation water for the downstream community of Jensen, Utah as well as for Vernal, Utah. Red Fleet Reservoir can store up to approximately 26,000 acre-feet (acre-ft) of water at full stage. It also supplies water to the Ashley Valley Water Treatment Plant (AVWTP) in Vernal during spring runoff when Ashley Spring, the treatment plant's primary water source, has elevated turbidity. The reservoir is an on-channel impoundment of Big Brush Creek and has not been previously investigated with respect to the reservoir's interaction with the surrounding groundwater systems. The geology of the region was studied in the 1960s by the Bureau of Reclamation (BOR) to investigate the feasibility of future dam sites for Red Fleet Reservoir (Thompson, 1969). Extensive characterization of local geology around the reservoir site was attained by field mapping as well as multiple drilled test holes. The Uintah Water Conservancy District (UWCD) and the BOR are interested in evaluating the groundwater resources surrounding the reservoir as well as the surface-water/groundwater interactions that occur in Red Fleet Reservoir to better understand how the resources could be managed in the future if groundwater withdrawals were initiated.

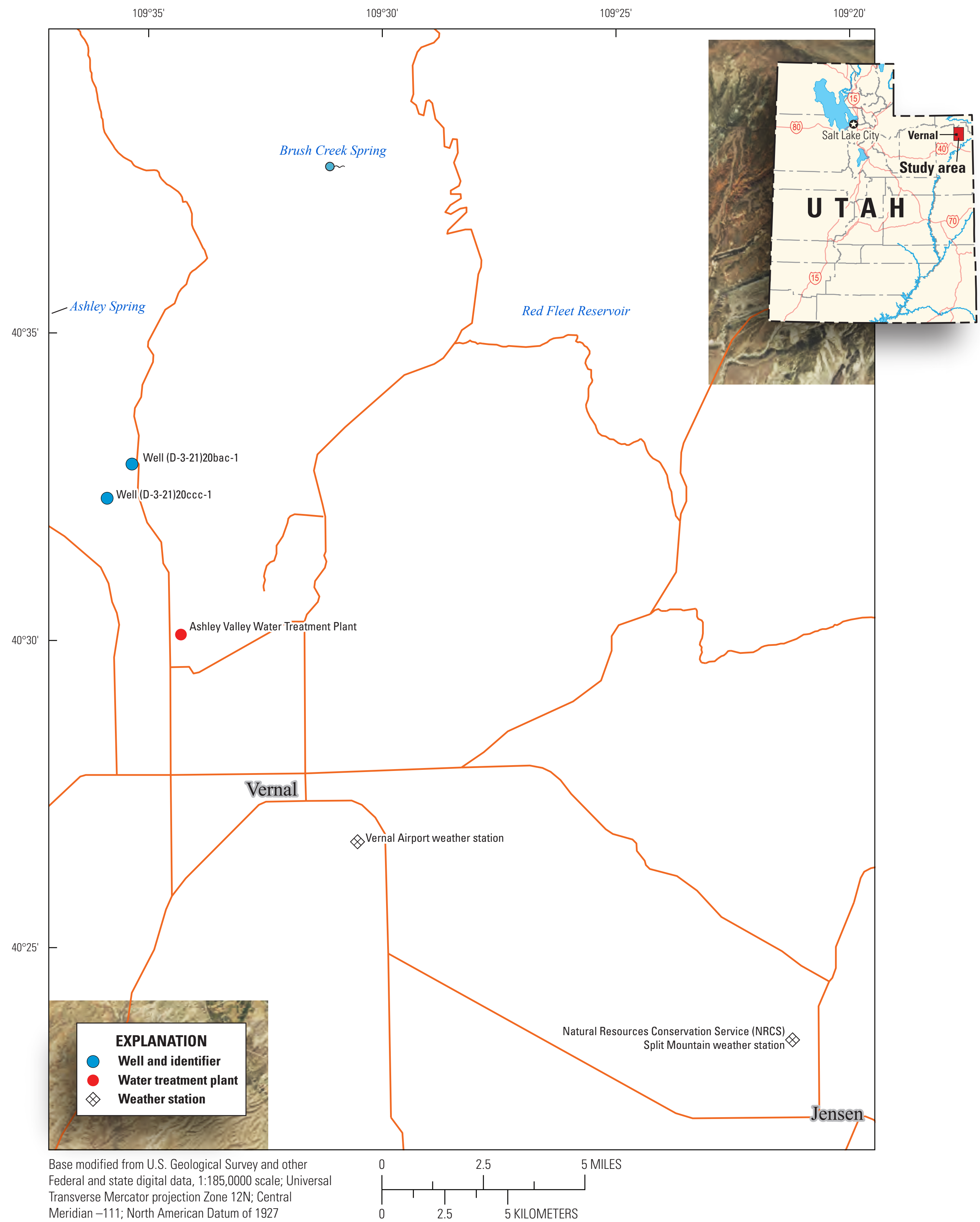


Figure 1. Location of the Red Fleet Reservoir study area, Uintah County, Utah.

The objectives of this report are to present and interpret (1) groundwater levels, reservoir altitude, meteorological data, and inflows/outflows to and from Red Fleet Reservoir from May 1980 through December 2015 for the purpose of estimating groundwater recharge/discharge to and from surrounding aquifer units; (2) aquifer properties of the Nugget Sandstone near Red Fleet Reservoir from a two-well aquifer test; and (3) groundwater and surface-water chemical data to evaluate the origin of groundwater in aquifer units adjacent to Red Fleet Reservoir. This study is a cooperative effort by the UWCD, the BOR, and the U.S. Geological Survey (USGS).

Hydrogeology

Red Fleet Reservoir is on southward dipping Mesozoic lithologies ranging in age from Jurassic to Cretaceous. The geologic units dip southward at approximately 20–30 degrees. Formations crop out from north to south and include the Jurassic Nugget Sandstone, Carmel Formation, Entrada Sandstone, Curtis Formation, Morrison Formation, Cretaceous Dakota Sandstone, Mowry Shale, Frontier Sandstone, and Mancos Shale (Thompson, 1969). The Nugget Sandstone aquifer is utilized regionally for drinking water near Vernal, Utah. East/west jointing observed in the Frontier Sandstone may result in enhanced secondary permeability in relation to groundwater/surface-water interaction with Red Fleet Reservoir. Geologic units other than the Nugget Sandstone and Frontier Sandstone generally are characterized by fine-grained lithologies such as siltstones and shales and likely act as low-permeability barriers to groundwater flow.

Assessment of Groundwater Interaction with Red Fleet Reservoir

To estimate groundwater interactions between Red Fleet Reservoir and the underlying sandstone aquifers, an annual surface-water budget for the reservoir was developed. The calculation of the reservoir water budget included reservoir inflows and outflows, changes in reservoir storage, evapotranspiration, and precipitation, with calculated residual values representing groundwater interactions with the reservoir. The reservoir water budget covers the length of time that Red Fleet Reservoir has been in operation (May 1980 through December 2015).

Data Collection Methods and Results

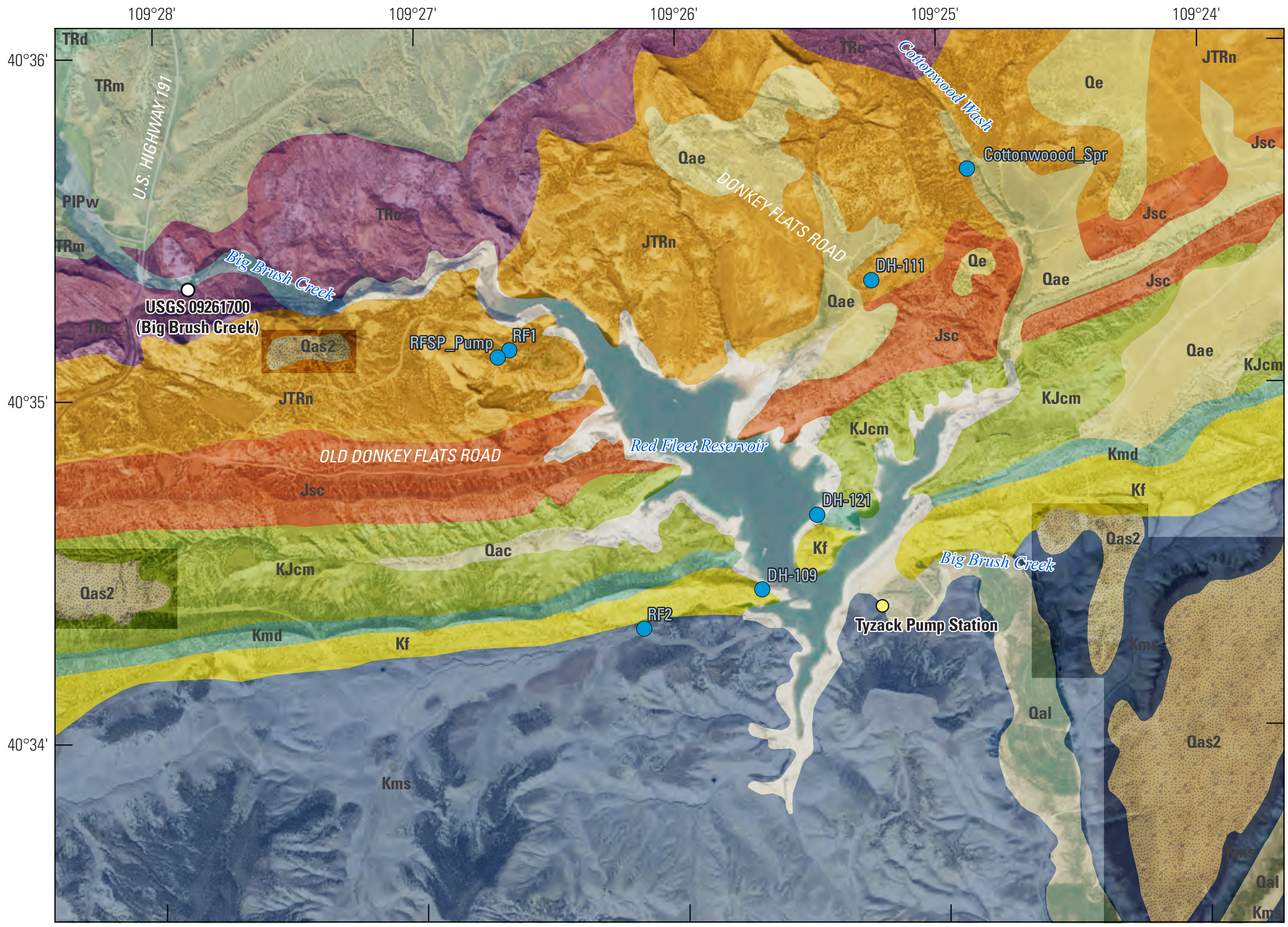
Many types of data have been collected as part of routine operations associated with Red Fleet Reservoir. These data include stream inflow from Big Brush Creek, stream outflow from dam releases and spillway discharge, reservoir and monitoring-well water levels, meteorological parameters, and pumpage from the Tyzack Pump Station to the nearby AVWTP and irrigation distribution systems (figs. 1 and 2).

Surface-Water Inflow to and Outflow from Red Fleet Reservoir

Big Brush Creek is the only perennial source of surface-water inflow to Red Fleet Reservoir. Big Brush Creek is predominantly supplied by Brush Creek Spring, which is about 4 miles (mi) upstream of the U.S. Highway 191 bridge over Big Brush Creek (fig. 1). The spring is the primary discharge point for karst features that are developed in Paleozoic carbonate lithologies on the south slope of the Uinta Mountains. Other small ephemeral streams that drain into the reservoir, Cottonwood Wash being the largest, only contribute small amounts of discharge during spring runoff in above average precipitation years and during intense monsoonal precipitation events. The USGS has operated a streamgage on Big Brush Creek since 1939; from 1939 to 1979 the gage (USGS 09262000, now inundated by Red Fleet Reservoir) was located along the historic Donkey Flats Road where it crossed Big Brush Creek. As a result of the implementation of Red Fleet Reservoir, the streamgaging site for Big Brush Creek was moved upstream near U.S. Highway 191 where it crosses Big Brush Creek in order to avoid inundation. This USGS site (09261700) has been operated continuously since 1979.

From 1980 through 2015, Big Brush Creek discharged an average of 29,200 acre-feet per year (acre-ft/yr) of water to Red Fleet Reservoir. Maximum and minimum annual discharge from Big Brush Creek to Red Fleet Reservoir from 1980 through 2015 was 49,000 and 12,200 acre-ft, respectively, with the minimum year in 2002 and the maximum year in 1998 (fig. 3).

Streamflow discharge from Red Fleet Reservoir is controlled by gates and jet valves at the base of Red Fleet Dam as well as a spillway on the east abutment. The discharge works have been operated continuously by the BOR or the UWCD since the reservoir first started filling in May 1980. A record of daily discharge has been maintained in the form of a written log book from which the data for this study were obtained (John Hunting, Uintah Water Conservancy District, written commun., 2016). Water from the reservoir has only discharged over the spillway for a short period during above-average spring runoff conditions in June 1984 and was not quantified in the water budget. For all other periods during the operational record of the dam, discharge is well quantified through the logged record of discharge gate and valve settings.



Base modified from U.S. Geological Survey and other Federal and state digital data, various scales; Universal Transverse Mercator projection Zone 12N; Central Meridian –111; North American Datum of 1927

0 0.5 1 MILE

0 0.5 1 KILOMETER

EXPLANATION

- Kms — Mancos Shale
- Kf — Frontier Sandstone
- Kmd — Mowry Shale and Dakota Sandstone
- KJcm — Cedar Mountain and Morrison Formations
- Jsc — Stump Formation, Entrada Sandstone, and Carmel Formation
- JTRn — Nugget Sandstone
- TRc — Chinle Formation
- USGS 09261700 (Big Brush Creek) — USGS streamgage and identifier
- RF2 — USGS well and identifier
- Tyzack Pump Station — Pump station and identifier

Figure 2. Geology and location of wells, streamgage, and pump station near Red Fleet Reservoir, Utah.

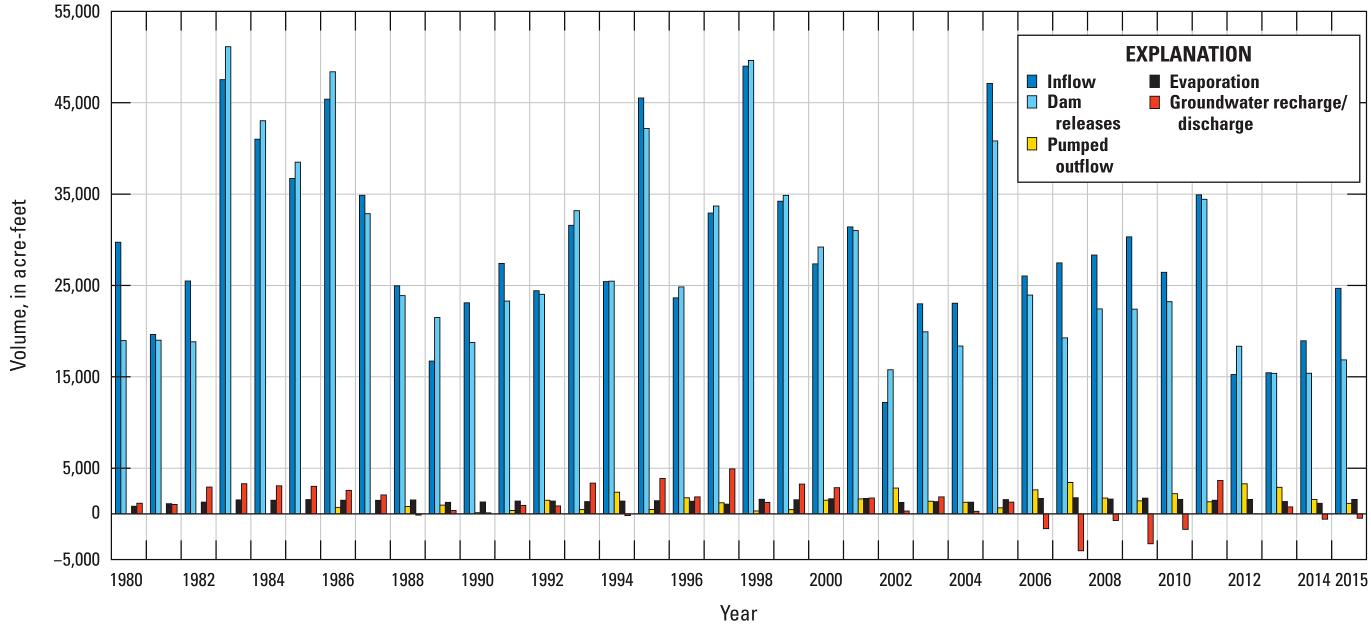


Figure 3. Annual inflows and outflows to and from Red Fleet Reservoir, near Vernal, Utah, 1980–2015.

Pumped Outflow from Red Fleet Reservoir

The Tyzack Pump Station is at the base of Red Fleet Dam and is operated by the UWCD (fig. 1). Pumping from the station first occurred during the early summer of 1986 to provide water to the AVWTP (Brad Grammar, Ashley Valley Water Treatment Plant, written commun., 2016). Pumping to provide water to the AVWTP occurred every early summer from 1988 to 2015. The average annual pumped volume of water from the Tyzack Pump Station during years when pumping occurred was about 1,400 acre-ft. The total volume of water pumped from the Tyzack Pump Station from 1980 through 2015 was about 42,500 acre-ft (table 1). Beginning in 1994, a diversion was built into the pipeline that connects the Tyzack Pump Station and AVWTP. The UWCD utilized this pipeline to supply irrigation water to users in Ashley Valley. This diversion was used in the summers of 1994, 1996, 1997, and every summer between 2000 and 2015. During the years when the irrigation diversion was used, the annual volume of water diverted from the pipeline for irrigation ranged from 58 to 1,078 acre-ft.

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/ discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/ discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/ discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
Empty stage	5,494.2					0									
May-80	5,561.6	9,830	2,959	0	0	8,237	57	20	–1,403	149	0.38	0.14	8,237.24	10.04	140.78
June-80	5,576.6	11,080	5,899	0	0	12,700	191	0	528	321	0.59	0.00	4,462.29	10.09	53.28
July-80	5,574.05	2,690	3,491	0	0	11,866	236	16	–187	333	0.71	0.05	–833.80	10.35	19.37
August-80	5,569.95	2,020	3,113	0	0	10,587	171	24	39	313	0.55	0.08	–1,279.08	10.30	4.01
September-80	5,569.4	1,240	1,494	0	0	10,421	106	22	–172	302	0.35	0.07	–166.11	10.42	17.97
October-80	5,567.7	1,090	1,034	0	0	9,926	50	13	513	303	0.17	0.04	–494.51	10.24	52.53
November-80	5,571.4	918	345	0	0	11,031	13	17	–527	307	0.04	0.06	1,104.63	10.13	53.39
December-80	5,571.98	863	632	0	0	11,211	8	0	43	314	0.03	0.00	180.12	10.05	4.29
January-81	5,572.55	710	535	0	0	11,389	5	3	–6	315	0.02	0.01	178.45	10.05	0.59
February-81	5,573.78	639	227	0	0	11,779	13	4	13	320	0.04	0.01	389.98	10.13	1.35
March-81	5,575.81	718	184	0	0	12,438	40	43	–122	330	0.12	0.13	658.73	10.50	12.84
April-81	5,579.45	2,310	1,163	0	0	13,669	96	27	–153	343	0.28	0.08	1,230.58	10.25	15.66
May-81	5,580.6	4,380	4,165	0	0	14,071	135	44	–279	358	0.38	0.12	402.58	10.20	28.47
June-81	5,579.4	3,370	3,807	0	0	13,651	223	2	–237	359	0.62	0.01	–419.93	10.29	24.42
July-81	5,574.69	2,350	3,571	0	0	12,072	241	16	133	342	0.70	0.05	–1,579.03	10.33	13.77
August-81	5,570.3	1,550	2,792	0	0	10,693	177	19	–20	314	0.56	0.06	–1,379.13	10.33	2.08
September-81	5,568.2	1,070	1,734	0	0	10,062	114	24	–124	300	0.38	0.08	–630.60	10.39	12.88
October-81	5,570.3	914	593	0	0	10,693	46	109	–247	299	0.15	0.36	630.60	10.68	26.35
November-81	5,572.7	863	119	0	0	11,436	16	8	–7	312	0.05	0.03	743.41	10.13	0.75
December-81	5,574.6	750	123	0	0	12,043	5	11	27	323	0.01	0.03	606.58	10.10	2.68
January-82	5,577.1	700	97	0	0	12,867	0	12	–209	334	0.00	0.04	823.63	10.08	21.02
February-82	5,579.2	604	0	0	0	13,582	12	5	–118	341	0.04	0.02	715.27	10.13	11.97
March-82	5,581.2	666	0	0	0	14,284	39	40	–35	351	0.11	0.11	701.96	10.54	3.71
April-82	5,583.84	1,050	359	0	0	15,243	69	7	–330	370	0.19	0.02	958.93	10.31	34.00
May-82	5,595.94	8,090	3,980	0	0	20,157	151	33	–922	384	0.39	0.09	4,914.45	10.11	93.18
June-82	5,596.03	3,430	3,612	0	0	20,188	248	8	–453	447	0.55	0.02	31.11	10.35	46.89
July-82	5,593.76	3,070	4,117	0	0	19,202	297	26	–332	440	0.68	0.06	–986.39	10.38	34.49

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
August-82	5,590.58	1,940	3,281	0	0	17,871	251	22	–239	423	0.59	0.05	–1,330.88	10.40	24.86
September-82	5,590.94	1,600	1,494	0	0	18,019	144	93	–93	414	0.35	0.23	147.71	10.68	9.93
October-82	5,595.53	1,860	192	0	0	19,968	61	65	–278	442	0.14	0.15	1,949.66	10.31	28.69
November-82	5,597.15	1,270	486	0	0	20,686	13	35	89	451	0.03	0.08	717.90	10.19	9.07
December-82	5,597.25	1,210	1,214	0	0	20,731	3	37	–14	454	0.01	0.08	44.83	10.16	1.46
January-83	5,597.4	1,070	1,202	0	0	20,799	2	21	–181	455	0.00	0.05	67.36	10.10	18.23
February-83	5,597.47	859	502	0	0	20,830	11	36	350	457	0.02	0.08	31.48	10.33	36.16
March-83	5,600.72	1,050	419	0	0	22,324	61	29	–896	472	0.13	0.06	1,494.36	10.29	92.21
April-83	5,597.83	1,130	2,627	0	0	20,992	78	51	–192	457	0.17	0.11	–1,332.00	10.25	19.64
May-83	5,602.43	6,850	4,990	0	0	23,137	160	52	–392	460	0.35	0.11	2,144.29	10.15	39.81
June-83	5,608.02	18,680	16,652	0	0	25,920	283	39	–998	520	0.54	0.08	2,783.37	10.08	100.67
July-83	5,606.75	7,780	8,567	0	0	25,270	343	30	–450	521	0.66	0.06	–649.77	10.21	46.00
August-83	5,605.03	3,150	4,271	0	0	24,407	306	29	–535	511	0.60	0.06	–863.60	10.39	55.54
September-83	5,600.55	1,760	3,865	0	0	22,245	182	33	–92	487	0.37	0.07	–2,162.06	10.27	9.42
October-83	5,596.4	2,070	3,612	0	0	20,352	82	32	300	462	0.18	0.07	–1,892.58	10.15	30.40
November-83	5,596.65	1,570	1,965	0	0	20,463	19	57	–469	449	0.04	0.13	111.06	10.21	47.82
December-83	5,594.1	1,560	2,460	0	0	19,348	0	42	257	443	0.00	0.09	–1,115.34	10.08	25.94
January-84	5,591.7	1,380	2,460	0	0	18,333	0	11	–54	428	0.00	0.03	–1,014.66	10.02	5.39
February-84	5,591.3	1,150	1,320	0	0	18,167	0	8	4	419	0.00	0.02	–165.84	10.03	0.37
March-84	5,591.14	1,160	1,355	0	0	18,101	29	12	–146	418	0.07	0.03	–66.08	10.16	14.84
April-84	5,591.35	1,730	1,696	0	0	18,188	80	25	–108	418	0.19	0.06	86.76	10.29	11.13
May-84	5,605.78	11,150	4,953	0	0	24,781	197	15	–579	448	0.44	0.03	6,592.99	10.09	58.39
June-84	5,608.1	11,620	11,388	0	0	25,961	289	66	–1,171	528	0.55	0.12	1,180.39	10.14	118.79
July-84	5,605.32	3,460	5,621	0	0	24,551	361	51	–1,061	519	0.70	0.10	–1,410.36	10.38	110.06
August-84	5,602.07	2,790	4,545	0	0	22,964	284	16	–435	495	0.57	0.03	–1,586.80	10.32	44.95
September-84	5,598.73	1,770	3,410	0	0	21,402	167	42	–202	476	0.35	0.09	–1,562.42	10.30	20.82
October-84	5,595.3	1,940	3,083	0	0	19,868	66	39	364	449	0.15	0.09	–1,533.94	10.16	36.99
November-84	5,594.2	1,520	2,380	0	0	19,391	16	25	–374	442	0.04	0.06	–477.04	10.09	37.77

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
December-84	5,593.9	1,340	821	0	0	19,262	1	43	691	435	0.00	0.10	–128.86	10.19	70.42
January-85	5,596	1,160	325	0	0	20,175	0	13	–65	445	0.00	0.03	913.21	10.05	6.57
February-85	5,596.4	974	1,055	0	0	20,352	1	7	–252	449	0.00	0.02	176.92	10.03	25.29
March-85	5,596.4	1,120	1,168	0	0	20,352	35	31	–52	449	0.08	0.07	0.00	10.28	5.36
April-85	5,602.4	5,290	2,530	0	0	23,122	126	15	–121	474	0.26	0.03	2,770.23	10.13	12.22
May-85	5,607.94	12,870	11,243	0	0	25,879	223	35	–1,318	517	0.43	0.07	2,756.54	10.10	133.01
June-85	5,607	3,920	4,692	0	0	25,397	315	41	–565	522	0.60	0.08	–481.45	10.38	58.64
July-85	5,605.5	3,060	3,775	0	0	24,641	357	47	–269	507	0.70	0.09	–756.57	10.51	28.23
August-85	5,602.1	2,390	4,109	0	0	22,979	275	2	–329	498	0.55	0.00	–1,662.28	10.33	34.02
September-85	5,599.05	1,860	3,343	0	0	21,548	143	74	–122	474	0.30	0.16	–1,430.04	10.32	12.60
October-85	5,593.4	1,660	3,997	0	0	19,048	68	37	132	450	0.15	0.08	–2,500.14	10.13	13.40
November-85	5,593.18	1,270	1,398	0	0	18,955	15	37	–13	430	0.03	0.09	–93.51	10.18	1.28
December-85	5,593.95	1,130	856	0	0	19,283	1	15	–40	430	0.00	0.04	328.53	10.07	4.03
January-86	5,595.86	1,130	307	0	0	20,113	0	7	–1	440	0.00	0.02	830.07	10.03	0.14
February-86	5,597.9	1,050	278	0	0	21,024	24	14	–149	453	0.05	0.03	910.63	10.17	15.17
March-86	5,598	1,500	1,302	0	0	21,069	76	42	118	461	0.17	0.09	45.28	10.40	12.32
April-86	5,595.19	4,820	6,183	0	0	19,820	98	83	–129	449	0.22	0.18	–1,249.56	10.15	13.05
May-86	5,604.05	12,850	8,792	287	0	23,923	169	47	–453	468	0.36	0.10	4,103.22	10.08	45.71
June-86	5,607.81	11,120	10,006	334	0	25,812	312	20	–1,400	520	0.60	0.04	1,888.89	10.14	142.01
July-86	5,605.22	3,120	4,552	0	0	24,501	317	43	–396	510	0.62	0.08	–1,310.74	10.38	41.12
August-86	5,600.7	2,410	4,422	17	0	22,315	268	49	–61	490	0.55	0.10	–2,186.16	10.34	6.28
September-86	5,596.22	1,940	3,746	76	0	20,272	138	74	96	459	0.30	0.16	–2,042.69	10.26	9.89
October-86	5,594.4	2,350	3,074	0	0	19,477	67	61	65	443	0.15	0.14	–795.34	10.20	6.59
November-86	5,592.47	1,740	2,680	0	0	18,655	18	3	–133	434	0.04	0.01	–822.00	10.04	13.35
December-86	5,588.67	1,360	3,043	0	0	17,100	3	5	–126	414	0.01	0.01	–1,555.12	10.01	12.63
January-87	5,589.09	1,290	989	0	0	17,266	2	13	147	404	0.00	0.03	165.93	10.06	14.75
February-87	5,589.82	1,190	833	0	0	17,560	12	27	78	409	0.03	0.07	294.13	10.17	7.97
March-87	5,590.5	1,280	922	0	0	17,837	36	36	81	413	0.09	0.09	276.90	10.28	8.37

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
April-87	5,597.45	4,230	1,286	0	0	20,821	104	2	–141	427	0.24	0.01	2,984.22	10.12	14.32
May-87	5,606.81	12,180	8,401	0	0	25,301	204	63	–842	507	0.40	0.12	4,479.71	10.11	85.10
June-87	5,606.19	4,610	5,352	0	0	24,987	305	11	–722	519	0.59	0.02	–313.70	10.30	74.35
July-87	5,603.23	2,860	4,481	0	0	23,523	316	84	–390	498	0.63	0.17	–1,464.10	10.43	40.66
August-87	5,600.42	2,100	3,742	0	0	22,184	247	67	–483	489	0.51	0.14	–1,339.20	10.42	50.33
September-87	5,596.31	1,630	3,570	0	0	20,312	157	5	–221	462	0.34	0.01	–1,871.59	10.22	22.61
October-87	5,595	1,250	1,743	0	0	19,737	80	56	58	441	0.18	0.13	–575.16	10.37	6.01
November-87	5,595.35	1,230	893	0	0	19,890	19	45	211	441	0.04	0.10	152.67	10.27	21.63
December-87	5,595.88	1,020	648	0	0	20,122	3	21	157	444	0.01	0.05	232.57	10.12	15.86
January-88	5,596.44	946	615	0	0	20,370	0	13	97	447	0.00	0.03	247.56	10.07	9.77
February-88	5,596.88	831	575	0	0	20,566	3	3	60	451	0.01	0.01	195.83	10.04	5.99
March-88	5,597.33	986	615	0	0	20,767	49	8	129	453	0.11	0.02	201.48	10.31	13.26
April-88	5,601.28	3,020	931	0	0	22,588	127	62	201	464	0.27	0.13	1,821.32	10.32	20.78
May-88	5,608.08	8,140	4,946	0	0	25,951	209	36	–342	509	0.41	0.07	3,362.59	10.15	34.74
June-88	5,604.95	3,260	5,023	0	0	24,367	312	18	–474	516	0.61	0.04	–1,584.04	10.32	48.90
July-88	5,599.95	2,300	4,676	49	0	21,965	332	7	–348	486	0.68	0.01	–2,402.46	10.35	36.01
August-88	5,593.47	1,780	3,856	425	0	19,078	244	10	151	451	0.54	0.02	–2,886.37	10.28	15.54
September-88	5,590.98	1,060	1,530	218	0	18,035	138	29	246	422	0.33	0.07	–1,042.88	10.42	25.57
October-88	5,590.85	904	505	109	0	17,982	84	0	259	416	0.20	0.00	–53.46	10.51	27.26
November-88	5,591.69	807	369	0	0	18,329	18	5	78	418	0.04	0.01	347.15	10.15	7.95
December-88	5,593.15	926	246	0	0	18,942	1	8	74	425	0.00	0.02	613.14	10.05	7.46
January-89	5,594.6	910	246	0	0	19,563	0	9	51	434	0.00	0.02	621.32	10.05	5.17
February-89	5,595.82	752	222	0	0	20,096	3	4	–1	442	0.01	0.01	532.41	10.05	0.15
March-89	5,597.31	976	246	0	0	20,758	65	8	10	450	0.15	0.02	662.29	10.37	1.06
April-89	5,599.92	3,290	2,416	0	0	21,951	123	2	–439	462	0.27	0.01	1,192.45	10.18	44.68
May-89	5,596.53	3,120	4,900	0	0	20,410	187	10	–417	460	0.41	0.02	–1,540.81	10.20	42.53
June-89	5,591.06	1,590	3,662	120	0	18,068	236	45	–41	435	0.54	0.10	–2,341.54	10.35	4.26
July-89	5,582.85	1,590	4,091	414	0	14,877	273	3	6	390	0.70	0.01	–3,191.43	10.29	0.65

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
August-89	5,576.19	1,250	3,051	294	0	12,563	187	21	53	355	0.53	0.06	–2,313.38	10.29	5.42
September-89	5,573.27	936	1,528	127	0	11,617	112	18	133	325	0.35	0.05	–946.71	10.35	13.78
October-89	5,573.13	831	717	0	0	11,572	59	11	111	320	0.18	0.04	–44.41	10.42	11.62
November-89	5,574.36	740	238	0	0	11,965	15	11	104	323	0.05	0.03	393.20	10.18	10.60
December-89	5,575.91	738	171	0	0	12,471	1	2	63	330	0.00	0.01	505.41	10.02	6.31
January-90	5,578.04	742	41	0	0	13,184	3	3	–12	340	0.01	0.01	713.21	10.04	1.20
February-90	5,580.11	621	0	0	0	13,899	3	18	–79	351	0.01	0.05	714.64	10.15	8.02
March-90	5,582.32	740	0	0	0	14,686	48	7	–88	363	0.13	0.02	787.37	10.35	9.14
April-90	5,588.44	3,430	980	0	0	17,007	104	38	63	382	0.27	0.10	2,320.48	10.21	6.41
May-90	5,594.11	6,170	4,011	0	0	19,355	162	12	–340	417	0.39	0.03	2,348.74	10.14	34.43
June-90	5,596.19	3,930	2,953	0	0	20,259	266	80	–113	448	0.59	0.18	903.72	10.42	11.76
July-90	5,589.44	1,840	4,348	0	0	17,408	284	5	64	425	0.67	0.01	–2,850.79	10.31	6.55
August-90	5,583.39	1,850	3,848	0	0	15,077	212	2	124	390	0.54	0.01	–2,331.58	10.26	12.76
September-90	5,581.99	1,440	1,468	129	0	14,567	144	29	237	370	0.39	0.08	–509.78	10.47	24.83
October-90	5,581.94	940	875	0	0	14,549	59	59	83	366	0.16	0.16	–18.01	10.60	8.82
November-90	5,583.61	736	129	0	0	15,158	14	12	–4	370	0.04	0.03	608.87	10.17	0.39
December-90	5,585.27	661	99	0	0	15,778	0	14	–45	380	0.00	0.04	620.41	10.10	4.58
January-91	5,586.67	632	123	0	0	16,313	0	3	–23	389	0.00	0.01	535.33	10.03	2.31
February-91	5,587.93	631	111	0	0	16,805	10	3	22	396	0.03	0.01	491.50	10.11	2.17
March-91	5,589.72	684	44	0	0	17,519	37	23	–88	405	0.09	0.06	714.43	10.40	9.16
April-91	5,591.9	1,090	103	0	0	18,416	78	46	59	415	0.19	0.11	896.50	10.56	6.22
May-91	5,603.78	8,070	2,977	105	0	23,791	169	14	–542	448	0.38	0.03	5,374.89	10.11	54.83
June-91	5,606.58	6,900	5,504	264	0	25,184	295	23	–533	517	0.57	0.05	1,393.27	10.22	54.48
July-91	5,600.91	2,240	4,667	0	0	22,414	325	8	26	491	0.66	0.02	–2,770.33	10.33	2.72
August-91	5,597.62	2,380	3,691	0	0	20,898	245	32	–8	469	0.52	0.07	–1,516.17	10.35	0.83
September-91	5,596.37	1,930	2,471	0	0	20,339	148	35	–95	450	0.33	0.08	–558.84	10.36	9.88
October-91	5,593.79	1,090	2,108	0	0	19,215	81	25	50	441	0.18	0.06	–1,123.94	10.24	5.13
November-91	5,594.16	962	678	0	0	19,374	13	10	121	435	0.03	0.02	158.76	10.13	12.28

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
December-91	5,593.95	801	815	0	0	19,283	1	9	85	435	0.00	0.02	–90.21	10.06	8.54
January-92	5,593.89	760	720	0	0	19,258	0	9	74	434	0.00	0.02	–25.73	10.06	7.47
February-92	5,594.29	610	468	0	0	19,430	15	16	–29	435	0.03	0.04	171.90	10.24	2.93
March-92	5,594.48	793	706	0	0	19,512	55	24	–26	437	0.13	0.05	81.99	10.47	2.73
April-92	5,601.81	4,740	1,521	0	0	22,840	128	6	–232	453	0.28	0.01	3,328.55	10.14	23.56
May-92	5,608.06	8,670	5,937	251	0	25,941	211	58	–771	514	0.41	0.11	3,100.61	10.15	78.22
June-92	5,603.92	2,140	3,663	348	0	23,859	265	26	–29	512	0.52	0.05	–2,081.38	10.34	2.96
July-92	5,600.69	1,930	2,922	328	0	22,310	267	68	30	482	0.55	0.14	–1,549.00	10.47	3.15
August-92	5,594.37	1,580	3,878	358	0	19,464	231	28	–12	455	0.51	0.06	–2,846.27	10.29	1.27
September-92	5,590.61	976	2,154	204	0	17,883	145	22	76	426	0.34	0.05	–1,580.66	10.33	7.81
October-92	5,588.89	831	1,353	0	0	17,188	73	34	135	407	0.18	0.08	–695.75	10.36	14.00
November-92	5,589.43	758	422	0	0	17,402	11	21	130	405	0.03	0.05	214.75	10.22	13.33
December-92	5,590.86	630	286	0	0	17,985	0	24	–214	411	0.00	0.06	582.19	10.16	21.72
January-93	5,591.77	619	375	0	0	18,362	1	27	–107	419	0.00	0.06	377.67	10.20	10.94
February-93	5,592.61	588	319	0	0	18,714	1	34	–50	423	0.00	0.08	351.64	10.27	5.14
March-93	5,594.62	735	40	0	0	19,572	38	68	–133	431	0.09	0.16	858.21	10.61	14.07
April-93	5,594.45	1,750	1,745	14	0	19,499	81	30	13	440	0.18	0.07	–73.51	10.30	1.37
May-93	5,602.62	11,210	7,696	236	0	23,228	197	40	–608	456	0.43	0.09	3,729.50	10.10	61.39
June-93	5,606.49	8,120	8,602	220	0	25,139	269	33	–2,849	510	0.53	0.07	1,910.47	10.16	289.37
July-93	5,600.13	1,900	4,614	0	0	22,048	303	11	84	491	0.62	0.02	–3,090.21	10.32	8.67
August-93	5,597.46	2,280	3,606	0	0	20,826	240	39	–304	467	0.51	0.08	–1,222.79	10.38	31.58
September-93	5,592.74	1,350	3,158	0	0	18,769	150	18	117	440	0.34	0.04	–2,056.88	10.25	12.00
October-93	5,590.5	1,280	2,073	0	0	17,838	51	89	176	419	0.12	0.21	–930.28	10.32	18.16
November-93	5,591.36	930	438	0	0	18,192	8	14	144	417	0.02	0.03	353.72	10.13	14.55
December-93	5,591.72	821	518	0	0	18,341	1	0	153	420	0.00	0.00	149.34	10.01	15.27
January-94	5,592.73	803	266	0	0	18,764	6	0	109	424	0.01	0.00	423.01	10.04	10.93
February-94	5,593.94	682	222	0	0	19,279	8	34	–29	430	0.02	0.08	514.63	10.29	3.02
March-94	5,595.44	869	143	0	0	19,929	57	10	29	439	0.13	0.02	649.97	10.39	2.99

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
April-94	5,600.28	3,840	1,379	80	0	22,118	107	17	103	452	0.24	0.04	2,189.26	10.16	10.47
May-94	5,607.11	8,740	5,290	276	0	25,453	218	32	–347	498	0.44	0.06	3,335.11	10.14	35.24
June-94	5,601.55	2,350	4,861	350	0	22,716	315	9	–431	504	0.62	0.02	–2,737.01	10.30	44.38
July-94	5,591.27	1,760	5,171	419	52	18,155	299	1	382	447	0.67	0.00	–4,561.54	10.29	39.29
August-94	5,581.37	1,800	4,439	336	642	14,341	218	23	2	391	0.56	0.06	–3,813.54	10.78	0.18
September-94	5,573.8	962	2,420	222	0	11,786	120	23	779	341	0.35	0.07	–2,555.71	10.23	79.66
October-94	5,576.87	1,480	674	0	0	12,790	44	106	–137	329	0.13	0.32	1,004.00	10.45	14.27
November-94	5,579.81	1,170	298	0	0	13,794	8	33	–106	349	0.02	0.10	1,004.20	10.16	10.82
December-94	5,582.14	964	307	0	0	14,621	2	8	–164	362	0.01	0.02	827.19	10.05	16.48
January-95	5,584.26	895	307	0	0	15,399	5	14	–181	373	0.01	0.04	777.85	10.09	18.27
February-95	5,586.28	817	278	0	0	16,163	26	30	–221	384	0.07	0.08	764.38	10.29	22.71
March-95	5,588.88	1,220	307	0	0	17,182	44	8	–141	397	0.11	0.02	1,018.53	10.20	14.43
April-95	5,593.63	2,850	1,115	83	0	19,149	78	39	–354	420	0.19	0.09	1,966.86	10.19	36.05
May-95	5,603.25	10,090	5,970	127	0	23,533	131	107	–415	459	0.29	0.23	4,384.03	10.11	41.97
June-95	5,608.21	17,040	14,652	242	0	26,018	260	51	–548	516	0.50	0.10	2,485.50	10.09	55.31
July-95	5,605.72	5,530	7,918	36	0	24,751	328	38	–1,447	518	0.63	0.07	–1,267.29	10.24	148.16
August-95	5,599.97	2,200	5,236	0	0	21,974	296	29	–526	490	0.60	0.06	–2,777.05	10.31	54.17
September-95	5,596.02	1,610	3,253	0	0	20,184	167	24	4	454	0.37	0.05	–1,789.87	10.28	0.43
October-95	5,596.68	1,410	996	0	0	20,476	72	6	56	449	0.16	0.01	292.51	10.28	5.78
November-95	5,596.28	930	1,174	0	0	20,299	26	3	–89	449	0.06	0.01	–177.59	10.13	8.99
December-95	5,596.16	927	984	0	0	20,246	9	2	–10	448	0.02	0.01	–53.09	10.05	1.00
January-96	5,597.14	845	504	0	0	20,682	3	27	–71	449	0.01	0.06	436.10	10.16	7.26
February-96	5,598.2	847	288	0	0	21,160	14	19	87	456	0.03	0.04	478.21	10.20	8.87
March-96	5,599.29	956	307	0	0	21,659	47	19	121	463	0.10	0.04	498.85	10.36	12.57
April-96	5,600.51	1,930	1,099	15	0	22,226	90	17	176	471	0.19	0.04	566.94	10.29	18.10
May-96	5,605.24	6,450	4,655	279	0	24,511	151	52	–868	485	0.31	0.11	2,285.23	10.15	88.10
June-96	5,606.07	4,720	4,403	361	0	24,927	272	29	–703	517	0.53	0.06	415.49	10.30	72.38
July-96	5,600.98	2,390	4,681	317	0	22,447	353	63	–419	493	0.72	0.13	–2,479.87	10.40	43.56

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
August-96	5,593.57	1,730	4,794	106	116	19,121	263	1	–223	454	0.58	0.00	–3,325.95	10.37	23.10
September-96	5,588.89	1,050	2,267	224	340	17,188	109	35	78	413	0.26	0.09	–1,933.17	10.81	8.42
October-96	5,589.59	974	629	0	0	17,467	63	34	37	407	0.15	0.08	279.27	10.49	3.92
November-96	5,590.37	845	595	0	0	17,784	13	25	–55	411	0.03	0.06	316.77	10.22	5.60
December-96	5,591.16	906	615	0	0	18,109	3	18	–20	415	0.01	0.04	325.79	10.11	1.99
January-97	5,592.1	841	615	0	0	18,500	1	46	–120	421	0.00	0.11	390.44	10.25	12.32
February-97	5,592.79	774	555	0	0	18,790	1	25	–48	425	0.00	0.06	289.87	10.16	4.86
March-97	5,593.23	1,090	1,531	0	0	18,976	46	2	–672	432	0.11	0.00	186.30	10.17	68.28
April-97	5,590.89	1,960	3,011	42	0	17,998	56	42	–129	420	0.13	0.10	–977.81	10.16	13.09
May-97	5,600.43	10,820	8,467	324	0	22,188	135	22	–2,274	437	0.31	0.05	4,190.18	10.07	228.90
June-97	5,603.6	5,940	4,701	358	0	23,703	237	40	–831	498	0.48	0.08	1,514.51	10.22	84.85
July-97	5,596.27	2,340	5,415	217	90	20,294	227	13	–187	468	0.48	0.03	–3,408.50	10.28	19.19
August-97	5,593.69	2,000	3,239	172	10	19,172	174	89	–384	442	0.39	0.20	–1,122.41	10.40	39.96
September-97	5,592.85	2,090	2,636	0	0	18,815	111	101	–199	423	0.26	0.24	–356.95	10.40	20.70
October-97	5,596.49	2,050	337	0	0	20,392	65	25	96	439	0.15	0.06	1,576.90	10.22	9.77
November-97	5,597.45	1,700	1,369	0	0	20,821	13	9	–102	455	0.03	0.02	429.05	10.06	10.24
December-97	5,596.55	1,320	1,815	0	0	20,419	1	25	–68	452	0.00	0.06	–402.39	10.07	6.87
January-98	5,596.63	1,120	1,230	0	0	20,454	6	13	–138	450	0.01	0.03	35.57	10.08	13.96
February-98	5,596.55	946	1,111	0	0	20,419	14	44	–99	450	0.03	0.10	–35.57	10.27	10.18
March-98	5,596.84	968	1,230	0	0	20,548	51	29	–413	450	0.11	0.06	129.13	10.33	42.65
April-98	5,597.79	2,300	1,974	47	0	20,974	107	5	–249	453	0.24	0.01	426.55	10.23	25.51
May-98	5,608.28	18,200	11,712	270	0	26,054	203	4	939	496	0.41	0.01	5,080.04	10.06	94.46
June-98	5,608.12	13,840	13,932	0	0	25,972	270	54	–225	524	0.52	0.10	–82.70	10.12	22.80
July-98	5,605.21	3,550	5,576	0	0	24,496	370	76	–844	516	0.72	0.15	–1,475.48	10.40	87.80
August-98	5,600.77	2,660	4,931	0	0	22,348	287	41	–369	492	0.58	0.08	–2,148.29	10.33	38.13
September-98	5,595.74	1,750	3,808	0	0	20,061	186	17	60	457	0.41	0.04	–2,287.25	10.25	6.16
October-98	5,594.54	1,330	1,825	0	0	19,537	78	63	13	439	0.18	0.14	–523.18	10.37	1.33
November-98	5,594.81	1,170	1,071	0	0	19,654	22	30	–10	439	0.05	0.07	116.97	10.22	1.02

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
December-98	5,594.47	1,170	1,230	0	0	19,507	4	9	92	438	0.01	0.02	–147.22	10.05	9.30
January-99	5,595.17	1,030	635	0	0	19,811	4	29	117	438	0.01	0.07	303.86	10.16	11.88
February-99	5,596.48	781	278	0	0	20,388	18	21	–70	446	0.04	0.05	576.48	10.23	7.17
March-99	5,597.81	930	307	0	0	20,983	74	0	–47	453	0.16	0.00	595.81	10.39	4.86
April-99	5,598.62	1,570	1,309	34	0	21,351	86	68	–160	461	0.19	0.15	368.10	10.45	16.73
May-99	5,603.43	9,260	7,220	226	0	23,620	179	61	–573	470	0.38	0.13	2,268.68	10.12	57.96
June-99	5,607.73	10,350	8,975	206	0	25,771	281	13	–1,250	519	0.54	0.02	2,150.64	10.13	126.69
July-99	5,603.66	2,510	4,947	0	0	23,732	336	29	–706	506	0.67	0.06	–2,038.56	10.37	73.21
August-99	5,600.02	2,480	4,403	0	0	21,997	271	84	–376	482	0.56	0.17	–1,735.13	10.40	39.04
September-99	5,598.97	1,930	2,430	0	0	21,512	163	43	–135	470	0.35	0.09	–485.34	10.41	14.07
October-99	5,597.18	1,340	2,043	0	0	20,700	98	2	13	458	0.21	0.01	–811.94	10.23	1.38
November-99	5,596.82	1,070	1,190	0	0	20,539	33	4	11	453	0.07	0.01	–160.96	10.15	1.16
December-99	5,596.67	972	1,123	0	0	20,472	2	4	–82	451	0.01	0.01	–66.84	10.03	8.26
January-00	5,596.51	879	1,097	0	0	20,401	11	18	–140	450	0.03	0.04	–71.14	10.14	14.24
February-00	5,596.53	783	978	0	0	20,410	19	37	–185	449	0.04	0.08	8.88	10.31	19.08
March-00	5,596.22	807	1,045	0	0	20,272	59	21	–138	449	0.13	0.05	–137.44	10.39	14.35
April-00	5,598.05	3,370	2,529	66	0	21,092	145	22	–167	448	0.32	0.05	819.69	10.24	17.14
May-00	5,608.24	11,820	6,893	283	0	26,034	251	20	–528	506	0.50	0.04	4,941.66	10.11	53.37
June-00	5,604.8	2,720	4,572	205	0	24,293	317	8	–624	515	0.61	0.02	–1,741.04	10.34	64.56
July-00	5,601.34	2,170	3,898	0	0	22,617	356	11	–397	492	0.72	0.02	–1,675.80	10.45	41.50
August-00	5,593.21	1,140	4,443	0	452	18,968	273	19	–360	455	0.60	0.04	–3,649.26	10.74	38.65
September-00	5,588.4	839	2,483	0	496	16,993	146	56	–256	411	0.36	0.14	–1,975.05	11.16	28.53
October-00	5,589.49	1,020	666	0	0	17,427	67	56	–91	404	0.16	0.14	434.04	10.55	9.62
November-00	5,591.06	954	298	0	0	18,067	7	11	20	413	0.02	0.03	640.45	10.10	2.06
December-00	5,592.37	857	307	0	0	18,613	2	2	4	421	0.00	0.00	545.99	10.02	0.36
January-01	5,593.56	809	307	0	0	19,117	1	16	13	428	0.00	0.04	503.55	10.11	1.36
February-01	5,594.6	670	278	0	0	19,563	15	25	–45	435	0.04	0.06	446.89	10.28	4.66
March-01	5,595.61	762	307	0	0	20,004	73	17	–42	441	0.17	0.04	440.13	10.56	4.42

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/ discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/ discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/ discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
April-01	5,598.95	3,190	803	60	0	21,503	120	46	753	453	0.27	0.10	1,499.01	10.29	77.48
May-01	5,608.26	14,640	10,602	279	0	26,044	228	9	–1,001	506	0.45	0.02	4,541.45	10.08	100.87
June-01	5,608.02	3,700	5,135	78	72	25,920	338	18	–1,781	521	0.65	0.03	–123.96	10.45	186.15
July-01	5,600.73	2,120	4,403	0	256	22,329	349	40	743	490	0.71	0.08	–3,590.96	10.60	78.75
August-01	5,599.97	1,720	4,197	0	350	21,974	270	38	–2,704	455	0.59	0.08	–355.28	10.95	296.01
September-01	5,588.65	1,010	3,302	0	540	17,092	176	4	1,877	421	0.42	0.01	–4,881.93	10.73	201.37
October-01	5,586.95	962	1,309	0	0	16,422	83	29	269	393	0.21	0.07	–669.97	10.36	27.85
November-01	5,588.53	908	179	0	0	17,042	27	9	91	398	0.07	0.02	620.41	10.20	9.25
December-01	5,590.13	918	184	0	0	17,686	0	1	91	407	0.00	0.00	643.46	10.00	9.08
January-02	5,591.52	861	184	0	0	18,258	1	0	103	416	0.00	0.00	572.58	10.01	10.32
February-02	5,592.68	724	167	0	0	18,743	7	0	66	423	0.02	0.00	484.99	10.05	6.61
March-02	5,594.06	783	184	0	0	19,331	51	20	–19	431	0.12	0.05	587.22	10.44	2.01
April-02	5,593.97	1,440	1,402	85	0	19,292	135	0	–144	437	0.31	0.00	–38.64	10.44	15.01
May-02	5,589.99	2,330	3,735	259	240	17,631	204	0	–446	426	0.48	0.00	–1,661.32	10.53	46.97
June-02	5,582.3	1,440	3,178	263	827	14,679	266	0	–142	390	0.68	0.00	–2,951.76	11.22	15.95
July-02	5,575.19	887	2,698	0	430	12,235	265	12	–50	345	0.77	0.03	–2,444.13	11.05	5.54
August-02	5,566.74	739	2,793	0	447	9,634	180	0	–81	308	0.59	0.00	–2,600.28	10.93	8.84
September-02	5,565.15	776	700	0	274	9,199	93	53	198	281	0.33	0.19	–435.79	11.80	23.33
October-02	5,565.23	797	492	0	0	9,221	46	21	257	281	0.16	0.07	22.35	10.48	26.97
November-02	5,567.16	712	119	0	0	9,769	10	22	57	286	0.03	0.08	548.38	10.23	5.85
December-02	5,569.53	704	123	0	0	10,468	0	7	–110	297	0.00	0.03	698.15	10.05	11.03
January-03	5,571.62	682	123	0	0	11,106	1	12	–69	307	0.00	0.04	638.80	10.09	6.95
February-03	5,573.37	583	111	0	0	11,648	7	25	–52	317	0.02	0.08	542.14	10.25	5.33
March-03	5,575.28	660	123	0	0	12,264	46	22	–103	327	0.14	0.07	615.65	10.46	10.78
April-03	5,578.79	2,540	1,021	72	0	13,441	88	5	187	338	0.26	0.01	1,176.42	10.19	19.01
May-03	5,591.77	8,480	3,289	210	28	18,362	160	61	–66	374	0.43	0.16	4,921.10	10.15	6.72
June-03	5,593.62	3,300	3,414	145	0	19,142	241	38	–1,242	431	0.56	0.09	780.50	10.35	128.60
July-03	5,588.86	2,390	3,993	0	368	17,176	329	0	–333	419	0.78	0.00	–1,966.49	10.77	35.87

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
August-03	5,581.33	1,260	3,535	0	434	14,330	239	10	–92	384	0.62	0.03	–2,845.42	10.82	9.99
September-03	5,576.53	821	2,291	0	127	12,676	135	7	–71	352	0.38	0.02	–1,653.98	10.53	7.43
October-03	5,573.11	730	1,783	0	0	11,566	83	5	–21	327	0.25	0.02	–1,110.28	10.24	2.16
November-03	5,574.98	734	119	0	0	12,166	11	24	28	326	0.03	0.07	600.35	10.24	2.84
December-03	5,577.22	809	123	0	0	12,907	2	37	–19	336	0.01	0.11	740.62	10.23	1.95
January-04	5,579.04	730	123	0	0	13,527	0	4	–9	346	0.00	0.01	619.71	10.03	0.87
February-04	5,580.66	639	115	0	0	14,092	7	20	–29	355	0.02	0.06	565.66	10.20	3.01
March-04	5,582.87	928	123	0	0	14,886	79	1	–67	365	0.22	0.00	793.79	10.41	6.96
April-04	5,588.91	3,320	835	0	0	17,194	103	35	108	387	0.27	0.09	2,307.66	10.21	11.06
May-04	5,594.58	5,770	3,741	236	0	19,559	190	9	–754	429	0.44	0.02	2,365.43	10.16	76.62
June-04	5,590.69	1,880	3,227	62	44	17,916	239	43	–6	429	0.56	0.10	–1,643.03	10.46	0.62
July-04	5,587.08	2,010	2,878	93	184	16,474	266	8	39	404	0.66	0.02	–1,442.47	10.66	4.21
August-04	5,579.8	1,490	3,416	0	417	13,790	202	6	144	375	0.54	0.02	–2,683.35	10.76	15.53
September-04	5,574.96	1,040	2,124	0	235	12,160	119	49	241	341	0.35	0.14	–1,630.53	10.78	25.96
October-04	5,575.2	1,670	1,543	0	0	12,238	54	113	108	324	0.17	0.35	78.19	10.48	11.28
November-04	5,581.67	2,180	119	0	0	14,452	14	42	–125	350	0.04	0.12	2,213.86	10.12	12.61
December-04	5,584.97	1,400	123	0	0	15,665	5	8	67	375	0.01	0.02	1,213.04	10.05	6.69
January-05	5,587.89	1,160	123	0	0	16,789	6	66	–27	392	0.01	0.17	1,124.35	10.29	2.80
February-05	5,587.29	1,010	1,269	0	0	16,554	16	19	–21	398	0.04	0.05	–235.06	10.13	2.17
March-05	5,586.86	1,310	1,537	0	0	16,387	51	45	–66	394	0.13	0.11	–167.17	10.31	6.77
April-05	5,589.9	5,330	4,106	74	0	17,592	99	39	–115	395	0.25	0.10	1,205.32	10.13	11.67
May-05	5,604.07	17,120	10,284	253	0	23,999	191	58	43	440	0.43	0.13	6,406.86	10.07	4.28
June-05	5,608.06	10,760	9,749	222	0	25,941	259	37	–1,374	521	0.50	0.07	1,941.49	10.13	139.20
July-05	5,605.42	2,890	4,005	29	0	24,601	364	3	–164	515	0.71	0.01	–1,339.84	10.42	17.13
August-05	5,603.61	2,660	3,140	21	58	23,708	275	28	87	499	0.55	0.06	–893.04	10.51	9.15
September-05	5,600.62	1,410	2,606	0	0	22,277	177	59	116	483	0.37	0.12	–1,430.37	10.41	12.10
October-05	5,599.22	1,330	1,837	0	0	21,627	89	51	105	470	0.19	0.11	–650.76	10.35	10.92
November-05	5,598.88	1,190	1,212	0	0	21,470	26	14	122	465	0.06	0.03	–156.23	10.16	12.43

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
December-05	5,598.82	936	952	0	0	21,443	6	6	11	464	0.01	0.01	–27.50	10.06	1.15
January-06	5,599.77	875	476	0	0	21,881	6	27	–18	466	0.01	0.06	437.96	10.18	1.82
February-06	5,601.2	833	139	0	0	22,551	15	0	9	474	0.03	0.00	669.67	10.09	0.91
March-06	5,603.05	958	154	0	0	23,436	55	89	–47	484	0.11	0.18	885.11	10.67	5.01
April-06	5,602.33	4,290	4,363	68	0	23,089	140	27	94	490	0.29	0.06	–347.00	10.18	9.53
May-06	5,606.41	9,020	5,881	371	0	25,098	246	6	519	500	0.49	0.01	2,009.39	10.14	52.62
June-06	5,602.86	2,610	3,499	84	243	23,344	364	34	208	505	0.72	0.07	–1,754.27	10.75	22.38
July-06	5,596.88	2,130	3,796	14	696	20,566	353	5	54	470	0.75	0.01	–2,778.19	11.08	5.96
August-06	5,589.42	1,250	2,850	10	963	17,400	257	19	354	429	0.60	0.05	–3,165.42	11.46	40.57
September-06	5,587.46	1,050	1,317	0	180	16,621	145	64	252	399	0.36	0.16	–779.64	11.10	27.94
October-06	5,586.87	1,070	1,192	0	0	16,391	71	105	141	393	0.18	0.27	–229.68	10.66	15.05
November-06	5,589.01	1,000	137	0	0	17,234	26	13	7	400	0.07	0.03	842.85	10.19	0.67
December-06	5,590.91	952	141	0	0	18,005	2	12	48	411	0.01	0.03	771.40	10.08	4.87
January-07	5,592.57	823	141	0	0	18,697	0	11	1	421	0.00	0.03	691.88	10.07	0.08
February-07	5,594.09	688	128	0	0	19,343	17	13	–90	431	0.04	0.03	646.44	10.20	9.16
March-07	5,596.46	1,290	141	0	0	20,379	81	7	40	441	0.18	0.02	1,035.20	10.35	4.11
April-07	5,600.28	4,990	1,759	130	0	22,118	127	27	1,261	463	0.27	0.06	1,739.64	10.18	128.34
May-07	5,607.89	9,010	3,588	289	0	25,853	235	45	1,209	508	0.46	0.09	3,734.76	10.17	122.89
June-07	5,604.45	3,480	3,777	149	544	24,120	361	5	387	517	0.70	0.01	–1,733.37	10.91	42.22
July-07	5,598.42	2,200	3,390	13	1,078	21,260	377	8	210	480	0.79	0.02	–2,859.50	11.47	24.06
August-07	5,591.78	1,130	2,876	9	460	18,366	292	9	396	441	0.66	0.02	–2,893.80	10.99	43.50
September-07	5,585.97	1,010	2,037	17	748	16,045	170	15	374	402	0.42	0.04	–2,321.39	11.48	42.94
October-07	5,585.32	1,170	1,125	0	0	15,797	76	4	221	385	0.20	0.01	–247.91	10.30	22.80
November-07	5,587.11	958	149	0	0	16,484	30	0	92	390	0.08	0.00	686.99	10.16	9.38
December-07	5,588.89	718	154	0	0	17,186	0	75	–62	400	0.00	0.19	701.69	10.46	6.53
January-08	5,590.57	708	154	0	0	17,865	0	16	–110	410	0.00	0.04	679.72	10.10	11.10
February-08	5,592.41	672	144	0	0	18,630	2	29	–209	420	0.01	0.07	764.29	10.20	21.31
March-08	5,594.3	768	154	0	0	19,434	36	33	–194	431	0.08	0.08	804.08	10.39	20.11

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
April-08	5,595.76	1,260	481	40	0	20,069	91	15	27	441	0.21	0.03	635.58	10.42	2.86
May-08	5,605.48	10,250	4,731	304	0	24,631	195	0	459	474	0.41	0.00	4,561.38	10.10	46.34
June-08	5,607.77	7,340	5,891	222	0	25,791	334	62	–206	520	0.64	0.12	1,160.52	10.26	21.11
July-08	5,603.14	2,310	3,771	22	379	23,479	380	6	76	505	0.75	0.01	–2,312.04	10.83	8.26
August-08	5,596.25	1,450	3,507	24	639	20,286	301	69	242	471	0.64	0.15	–3,193.70	11.10	26.90
September-08	5,592.93	851	1,781	24	70	18,849	159	38	291	438	0.36	0.09	–1,436.68	10.61	30.90
October-08	5,590.88	1,010	1,517	0	0	17,994	86	25	287	420	0.20	0.06	–854.77	10.32	29.58
November-08	5,592.48	875	149	0	0	18,659	29	21	53	421	0.07	0.05	665.04	10.29	5.47
December-08	5,594.16	837	154	0	0	19,374	5	38	2	430	0.01	0.09	714.39	10.24	0.22
January-09	5,595.97	970	154	0	0	20,162	2	40	66	441	0.00	0.09	788.33	10.21	6.70
February-09	5,597.55	815	139	0	0	20,866	12	7	–34	451	0.03	0.02	704.15	10.11	3.39
March-09	5,598.94	833	154	0	0	21,498	62	9	–5	460	0.13	0.02	631.93	10.42	0.56
April-09	5,598.9	1,390	1,202	42	0	21,480	113	41	93	465	0.24	0.09	–18.35	10.55	9.83
May-09	5,607.97	9,260	4,413	275	0	25,894	238	22	–58	497	0.48	0.05	4,414.65	10.14	5.90
June-09	5,608.12	7,060	4,344	139	0	25,972	312	60	2,248	524	0.60	0.11	77.38	10.31	231.73
July-09	5,606.15	4,380	4,552	68	101	24,967	376	6	294	519	0.72	0.01	–1,004.77	10.46	30.77
August-09	5,601.43	2,350	3,529	0	643	22,659	298	21	210	496	0.60	0.04	–2,307.42	11.05	23.19
September-09	5,598.36	1,040	1,930	38	116	21,233	206	43	220	468	0.44	0.09	–1,426.60	10.76	23.66
October-09	5,597	758	1,142	0	0	20,619	74	24	179	455	0.16	0.05	–613.64	10.37	18.57
November-09	5,597.7	738	417	0	0	20,934	28	14	–7	455	0.06	0.03	314.45	10.28	0.75
December-09	5,598.3	728	430	0	0	21,206	1	42	67	459	0.00	0.09	271.88	10.29	6.94
January-10	5,598.95	728	430	0	0	21,503	1	22	22	463	0.00	0.05	297.00	10.15	2.19
February-10	5,599.28	609	389	0	0	21,654	0	6	74	465	0.00	0.01	151.77	10.05	7.47
March-10	5,599.68	571	430	0	0	21,839	47	20	–71	468	0.10	0.04	184.85	10.54	7.46
April-10	5,601.66	1,870	716	44	0	22,769	116	55	119	472	0.25	0.12	929.49	10.46	12.46
May-10	5,607.64	7,960	4,120	265	0	25,725	174	25	471	499	0.35	0.05	2,955.87	10.13	47.66
June-10	5,607.12	7,270	6,799	295	0	25,459	320	67	188	522	0.61	0.13	–266.03	10.26	19.33
July-10	5,603.22	2,590	3,695	57	227	23,518	351	36	236	503	0.70	0.07	–1,940.43	10.69	25.27

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
August-10	5,596.46	1,490	3,441	36	617	20,379	271	30	294	471	0.58	0.06	–3,139.42	11.02	32.36
September-10	5,590.86	916	2,154	41	625	17,986	188	12	312	431	0.44	0.03	–2,392.75	11.30	35.26
October-10	5,590.77	889	745	0	0	17,949	84	56	154	413	0.20	0.14	–36.96	10.77	16.55
November-10	5,592.35	762	149	0	0	18,605	23	29	–36	420	0.05	0.07	655.63	10.32	3.76
December-10	5,594.21	783	154	0	0	19,395	5	97	–69	430	0.01	0.23	790.50	10.56	7.31
January-11	5,595.74	681	154	0	0	20,061	0	0	–138	441	0.00	0.00	665.56	10.00	13.83
February-11	5,596.91	559	139	0	0	20,579	1	22	–78	448	0.00	0.05	518.37	10.19	7.93
March-11	5,596.08	736	1,220	0	0	20,210	41	16	–140	451	0.09	0.04	–368.58	10.24	14.38
April-11	5,594.8	1,450	1,864	85	0	19,650	83	42	19	443	0.19	0.09	–560.34	10.31	1.99
May-11	5,601.72	8,470	6,672	291	0	22,797	139	95	–1,685	456	0.31	0.21	3,147.13	10.12	170.56
June-11	5,607.96	11,640	9,808	381	0	25,889	273	20	–1,895	510	0.54	0.04	3,091.90	10.12	191.66
July-11	5,607.19	4,020	4,721	174	0	25,494	327	110	–697	522	0.63	0.21	–394.89	10.45	72.83
August-11	5,602.82	2,590	3,874	0	394	23,324	325	23	190	505	0.64	0.05	–2,169.74	10.79	20.51
September-11	5,599.21	1,460	2,664	0	0	21,622	202	4	300	476	0.43	0.01	–1,702.41	10.34	31.04
October-11	5,598.2	1,270	1,476	0	0	21,160	83	68	242	461	0.18	0.15	–461.99	10.45	25.28
November-11	5,598.21	1,060	918	0	0	21,165	17	24	144	460	0.04	0.05	4.54	10.20	14.67
December-11	5,598.16	986	922	0	0	21,142	1	8	93	460	0.00	0.02	–22.71	10.05	9.31
January-12	5,599.44	823	253	0	0	21,728	3	14	–5	463	0.01	0.03	586.23	10.10	0.48
February-12	5,600.78	720	144	0	0	22,353	12	26	–34	472	0.03	0.06	624.44	10.25	3.50
March-12	5,602.44	926	154	0	0	23,141	88	0	–105	481	0.18	0.00	788.90	10.45	10.93
April-12	5,605.69	3,920	2,001	237	38	24,736	149	19	–80	497	0.30	0.04	1,594.35	10.26	8.22
May-12	5,603.24	2,630	3,324	464	13	23,528	240	3	–201	503	0.48	0.01	–1,208.04	10.32	20.70
June-12	5,598.3	1,990	3,199	210	765	21,206	333	0	–194	478	0.70	0.00	–2,322.24	11.24	21.84
July-12	5,589.52	825	3,503	39	644	17,440	293	26	137	434	0.68	0.06	–3,765.06	11.06	15.13
August-12	5,579.05	710	3,211	0	882	13,530	225	17	319	377	0.60	0.04	–3,910.41	11.25	35.91
September-12	5,573.44	676	2,099	0	0	11,671	136	59	360	336	0.40	0.18	–1,859.35	10.40	37.49
October-12	5,574.88	651	159	0	0	12,134	65	27	–9	325	0.20	0.08	463.05	10.68	0.97
November-12	5,576.79	706	148	0	0	12,763	25	5	–91	334	0.07	0.01	629.10	10.20	9.33

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
December-12	5,578.62	670	154	0	0	13,382	5	22	–86	344	0.01	0.06	619.27	10.18	8.74
January-13	5,580.42	661	154	0	0	14,008	0	29	–90	353	0.00	0.08	625.48	10.20	9.18
February-13	5,581.56	458	139	0	0	14,412	0	8	–78	361	0.00	0.02	404.79	10.07	7.87
March-13	5,582.91	586	154	0	0	14,901	47	20	–83	368	0.13	0.05	488.27	10.51	8.70
April-13	5,583.59	780	512	108	0	15,150	83	38	–134	375	0.22	0.10	249.67	10.69	14.30
May-13	5,589.93	5,480	3,205	357	0	17,605	210	25	–721	391	0.54	0.07	2,454.14	10.20	73.52
June-13	5,584.78	1,870	3,249	359	0	15,593	327	0	–54	399	0.82	0.00	–2,011.08	10.42	5.60
July-13	5,576.92	1,870	3,406	45	773	12,806	305	25	153	359	0.85	0.07	–2,787.08	11.20	17.12
August-13	5,565.09	720	2,959	45	881	9,161	200	14	294	307	0.65	0.04	–3,645.70	11.29	33.16
September-13	5,562.32	629	883	204	138	8,428	110	64	91	268	0.41	0.24	–733.13	11.13	10.15
October-13	5,563.64	762	478	0	0	8,783	50	33	–88	268	0.18	0.12	355.03	10.49	9.21
November-13	5,566.29	805	119	0	0	9,520	14	9	–56	280	0.05	0.03	737.44	10.13	5.71
December-13	5,568.83	823	123	0	0	10,258	0	41	2	293	0.00	0.14	738.48	10.24	0.24
January-14	5,570.83	686	123	0	0	10,862	0	13	–28	304	0.00	0.04	603.83	10.09	2.87
February-14	5,572.63	617	111	0	0	11,414	17	4	–59	313	0.06	0.01	552.11	10.17	6.00
March-14	5,574.57	702	149	0	0	12,033	53	25	–94	323	0.16	0.08	618.91	10.50	9.86
April-14	5,576.36	1,710	1,034	6	0	12,620	97	19	5	332	0.29	0.06	586.44	10.34	0.52
May-14	5,579.86	4,530	3,001	283	0	13,811	169	3	–112	346	0.49	0.01	1,191.53	10.19	11.37
June-14	5,573.43	2,430	3,364	329	235	11,668	240	1	406	341	0.71	0.00	–2,143.72	10.54	42.83
July-14	5,561.31	1,520	3,481	218	441	8,112	240	15	710	290	0.83	0.05	–3,555.18	10.74	76.24
August-14	5,555.97	1,300	2,146	68	0	6,830	146	74	297	239	0.61	0.31	–1,282.73	10.44	31.01
September-14	5,559.74	1,610	837	0	0	7,757	108	59	–204	246	0.44	0.24	926.99	10.47	21.33
October-14	5,563.88	1,850	885	0	0	8,848	64	1	–189	269	0.24	0.01	1,091.32	10.17	19.21
November-14	5,567.45	1,050	103	0	0	9,853	15	10	–64	285	0.05	0.04	1,005.38	10.12	6.46
December-14	5,570.37	936	154	0	0	10,729	5	13	–86	300	0.02	0.04	875.66	10.09	8.64
January-15	5,572.77	807	154	0	0	11,458	4	8	–72	313	0.01	0.03	729.49	10.07	7.30
February-15	5,574.62	680	139	0	0	12,049	23	0	–73	324	0.07	0.00	590.99	10.16	7.39
March-15	5,576.82	839	154	0	0	12,773	66	44	–60	334	0.20	0.13	723.43	10.60	6.40

Table 1. Reservoir data, evaporation, and calculated recharge and discharge from Red Fleet Reservoir, Utah, 1980–2015.—Continued

[AVWTP, Ashley Valley Water Treatment Plant; σ, sigma (standard deviation); —, no data]

Month/year	Reservoir altitude (feet)	Monthly Big Brush Creek inflow (acre-feet)	Monthly Red Fleet Dam outflow (acre-feet)	Monthly pumped outflows (acre-feet)		Reservoir storage (acre-feet)	Monthly evaporation (acre-feet)	Monthly precipitation (acre-feet)	Monthly groundwater recharge/ discharge (–) (acre-feet)	Reservoir surface area (acres)	Monthly evaporation rate (feet)	Monthly precipitation rate (feet)	Monthly reservoir storage change (acre-feet)	Monthly groundwater recharge/ discharge uncertainty, 2σ (percent)	Monthly groundwater recharge/ discharge uncertainty, 2σ (acre-feet)
				AVWTP	Irrigation										
April-15	5,576.27	1,510	1,688	0	0	12,590	98	9	–84	337	0.29	0.03	–183.01	10.31	8.66
May-15	5,591.77	7,630	1,521	203	0	18,362	142	105	97	367	0.39	0.29	5,771.73	10.16	9.87
June-15	5,598.77	6,330	2,945	239	0	21,420	358	12	–259	461	0.78	0.03	3,058.43	10.29	26.61
July-15	5,594.48	2,190	3,150	296	150	19,512	317	26	212	448	0.71	0.06	–1,908.53	10.61	22.48
August-15	5,587.57	1,530	3,511	166	81	16,665	275	15	359	417	0.66	0.04	–2,846.40	10.44	37.44
September-15	5,583.12	795	2,200	22	0	14,978	179	46	128	385	0.47	0.12	–1,687.59	10.46	13.41
October-15	5,581.68	903	1,088	0	0	14,455	94	22	266	366	0.26	0.06	–522.09	10.44	27.74
November-15	5,583.47	823	149	0	0	15,106	21	29	32	370	0.06	0.08	650.69	10.30	3.28
December-15	5,585.06	654	154	0	0	15,699	0	19	–74	379	0.00	0.05	592.70	10.13	7.47
Total	—	1,050,000	993,000	21,200	21,300	—	51,700	11,500	–39,900	—	—	—	—	—	—

Meteorological Data

Meteorological data utilized in this study have been collected at the Vernal Airport weather station (fig. 1) in Vernal, Utah, since the filling of Red Fleet Reservoir in 1980. The Vernal Airport weather station is approximately 10 mi southwest of the reservoir at an elevation of 5,270 feet (ft) above sea level. Beginning in 2010, data from a Soil Climate Analysis Network (SCAN) Split Mountain weather station operated by the Natural Resources Conservation Service (NRCS) also were utilized. The NRCS SCAN Split Mountain weather station is approximately 13 mi south of the reservoir (fig. 1) at an elevation of 4,844 ft above sea level. Data from both weather stations have been used for evaluating evaporation and precipitation, which are required for calculating monthly groundwater recharge/discharge from Red Fleet Reservoir. Parameters measured include air temperature, wind speed, precipitation, relative humidity, and incoming solar radiation. The solar-radiation and temperature data were used for calculating evaporation using the McGuinness and Bordne (1972) version of the Jensen-Haise method.

From May 1, 1980, to December 31, 2015, daily average air temperature ranged from –29 to 28 degrees Celsius (°C) at the Vernal Airport. The coldest temperatures during the year typically were in December and January, when minimum air temperatures occasionally were below –35 °C. The warmest temperatures were typically in July, when maximum air temperatures occasionally approached 40 °C. Daily average solar radiation ranged from 39 to 790 calories per square centimeter per day (cm^2/d). The minimum daily averages are typically in December and January, and the maximum daily averages are typically in June and July. Temperature and solar-radiation data from the NRCS SCAN Split Mountain weather station from January 27, 2010, to December 31, 2015, were used for comparison to investigate spatial meteorological variability; during this period the average daily air temperature ranged from –25 to 28 °C. Daily solar radiation ranged from 31 to 860 calories per cm^2/d. Cross-plotted average daily temperature data for the two sites between January 27, 2010, and December 31, 2015, yielded a correlation coefficient of 0.97. Cross-plotting the average daily solar-radiation data for the two sites for the same period yielded a correlation coefficient of 0.92. On average, daily solar-radiation values recorded at Split Mountain were about 50 calories per cm^2/d greater than at Vernal Airport. This is likely the result of numerous types of variability associated with solar-radiation measurements including individual sensor performance, latitudinal variation, and sensor orientation (level and free from shadow).

Monthly precipitation totals recorded at the Vernal Airport weather station from May 1980 through December 2015 were used to estimate precipitation at Red Fleet Reservoir; the monthly precipitation ranged from 0 to about 0.37 ft (4.4 inches [in.]; table 1) and averaged about 0.07 ft (0.8 in.). Average annual precipitation during the 36-year period from 1980 through 2015 was 9.3 in. (fig. 4). The years when annual precipitation was greater than 1 standard deviation (1σ) or 11.4 in. were 1981, 1983, 1986, 1997, 2010, and 2013, which is indicative of wetter than normal conditions near Red Fleet Reservoir. The years when annual precipitation was less than 1σ or 7.1 in. were 1988, 1989, 1991, 2001, 2002, 2007, and 2012, which is indicative of drier than normal conditions near Red Fleet Reservoir.

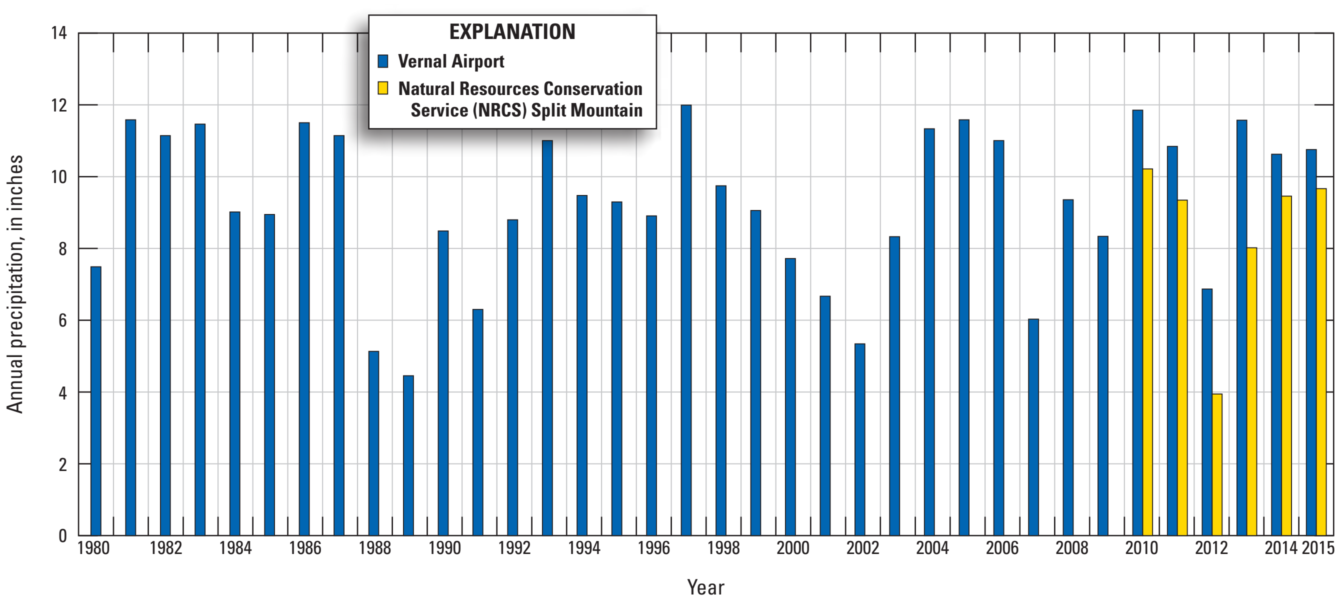


Figure 4. Annual precipitation at Vernal Airport and Natural Resources Conservation Service Split Mountain weather stations, Utah, 1980–2015.

Water-Level Data

Water levels in four wells were recorded with Onset® Hobo water level data loggers from mid-August 2016 through September 2017 (fig. 5). The Red Fleet Reservoir stage recorded by UWCD is plotted on figure 5 with reference to water-level altitudes observed in nearby wells. A separate data logger was installed 10 ft below land surface and about 40 ft above the average water level inside monitoring well RF1 to record barometric pressure at the site for the same period (fig. 2). Barometric pressure data from this logger were used to make water-level corrections because of barometric fluctuations over the period of record. Regular electric-tape measurements were taken at each of the four wells to facilitate corrections to water levels recorded by the loggers.

The Red Fleet Reservoir stage observed between August 2016 and September 2017 fluctuated between about 5,585 ft to about 5,605 ft with low stage during the late summer, and with the reservoir slowly filling through the winter and reaching high stage in the late spring/early summer following spring runoff. Water levels observed in well DH-109 follow the same trend as the altitude of the stage in Red Fleet Reservoir (fig. 5). Well DH-109 is on the west side of the reservoir near the eastern tip of a peninsula formed by the Frontier Sandstone that extends about 1,100 ft into the reservoir and was drilled by the BOR during the geologic investigations for the Red Fleet Dam site in the 1960s; DH-109 was drilled to a depth of 201 ft below land surface and is open to the Frontier Sandstone and the Morrison Formation (Thompson, 1969). The water level observed in DH-109 was consistently about 3 ft lower than the reservoir stage, indicating that the reservoir was likely recharging the Frontier Sandstone during the period of record.

Well RF2 is on the west side of the reservoir near the south end about 1,200 ft west of the nearest shore; RF2 was drilled and cased in September 2016 to a depth of 265 ft below land surface. The bottom 20 ft of RF2 is screened in the upper part of the Frontier Sandstone. Water levels in RF2 were about 15–30 ft lower than the stage observed in Red Fleet Reservoir, which indicates a downward groundwater-flow gradient in the Frontier Sandstone aquifer west of the reservoir during the period of record. Water levels in well RF2 remained relatively stable throughout the period of record with a slight increase from 5,578 ft in August 2016 to 5,580 ft in September 2017.

Well RF1 is on the west side of the reservoir near the inflow arm about 800 ft west of the state park boat ramp and about 550 ft from the nearest shore to the north. Water levels observed in well RF1 remained relatively stable throughout the period of record with a slight increase in water level from 5,639 ft in August 2016 to 5,640 ft in September 2017. Well RF1 was drilled and cased in September 2016 to a depth of 100 ft below land surface; the bottom 20 ft of RF1 is screened in the Nugget Sandstone aquifer. The water levels in RF1 were about 35–50 ft higher than the stage observed in Red Fleet Reservoir, indicating that the Nugget Sandstone aquifer was discharging water to Red Fleet Reservoir during the observed period of record.

Water levels observed in well DH-111 were about 70–85 ft higher than the stage observed in Red Fleet Reservoir over the same period. Well DH-111 is on the east side of the reservoir near Donkey Flats Road and was drilled by the BOR during the geologic investigations for the Red Fleet Dam site in the 1960s (fig. 2); DH-111 was drilled to a depth of 95 ft below land surface and is open to the Nugget Sandstone aquifer (Thompson, 1969). The water levels observed in DH-111 were relatively stable with the exception of a water-level increase in February 2017. This increase in water level coincided with significant ponding from a mid-elevation snowmelt around the well at that time. Given the shallow depth to water (approximately 32 ft below land surface), the increase in water level was likely the result of local recharge.

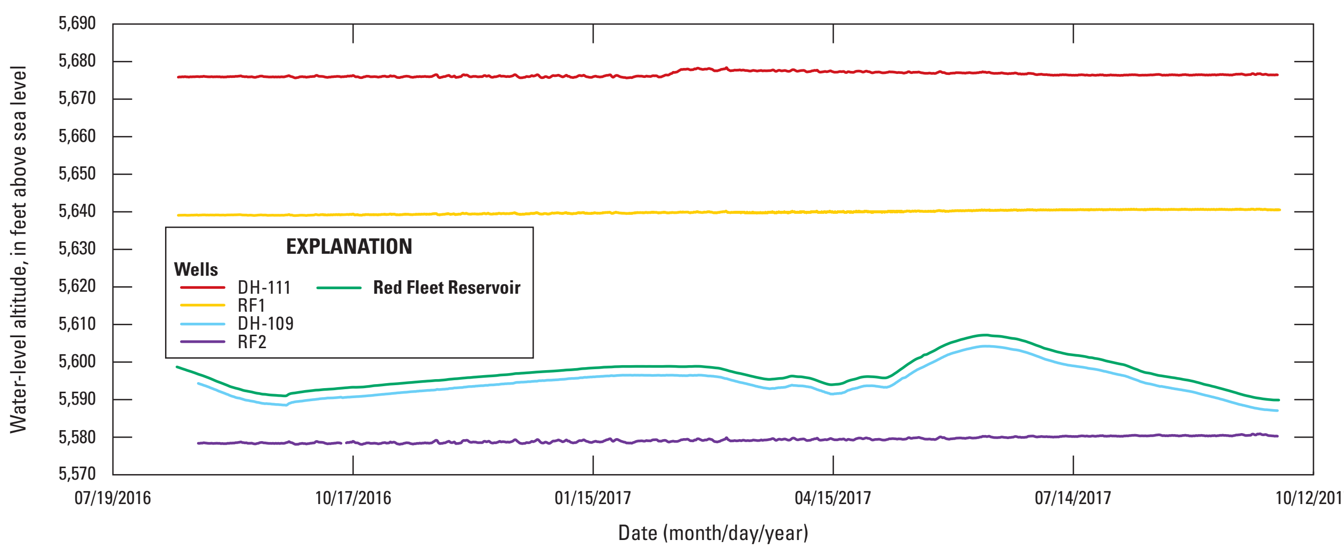


Figure 5. Water-level altitude in selected wells and Red Fleet Reservoir stage, Uintah County, Utah, 2016–17.

Well DH-121, which was drilled by the BOR during the geologic investigations for the Red Fleet Dam site in the 1960s, is on the eastern peninsula that separates the Cottonwood Wash arm of Red Fleet Reservoir from the main body and wash (fig. 2). This well was drilled to a depth of 130 ft below land surface and in September 2016, the water level was 49 ft below land surface. The well is open to the Morrison Formation and Dakota Sandstone. Given the similar geographic conditions at DH-121, it is likely that the hydrologic responses in the well are similar to those observed in DH-109. Well DH-121 was not instrumented with a water-level recorder because of the difficulty of access.

Cottonwood Spring, located approximately 0.25 mi northwest of the Donkey Flats Road crossing of Cottonwood Wash, is a small spring that discharges in the channel of Cottonwood Wash. The spring discharges at an elevation of 5,726 ft above sea level and is near the geologic contact of the Nugget Sandstone and the Carmel Formation.

Groundwater Movement

Based on water-level measurements in six wells and one spring, altitudes of the potentiometric surface in September 2017 near Red Fleet Reservoir in the Nugget and Frontier Sandstones ranged from 5,578.13 to 5,726.00 ft. The reservoir altitude during this same period was about 5,590 ft. The lines on figure 6 show the estimated potentiometric contours (lines of equal groundwater-level altitude) for the Nugget and Frontier Sandstone aquifers. Groundwater-flow gradients observed in September 2017 in the Nugget Sandstone aquifer indicate that groundwater was discharging to Red Fleet Reservoir from the aquifer from the east and west banks of the reservoir. An upward vertical groundwater gradient also was observed in the Nugget Sandstone aquifer as the altitude of the water level in the Red Fleet State Park well, which has an open bottom at a depth of 510 ft below land surface, was 5,645.76 ft compared to 5,640.45 ft in well RF1; well RF1 is 270 ft away and is screened to a depth of 99 ft below land surface (fig. 6).

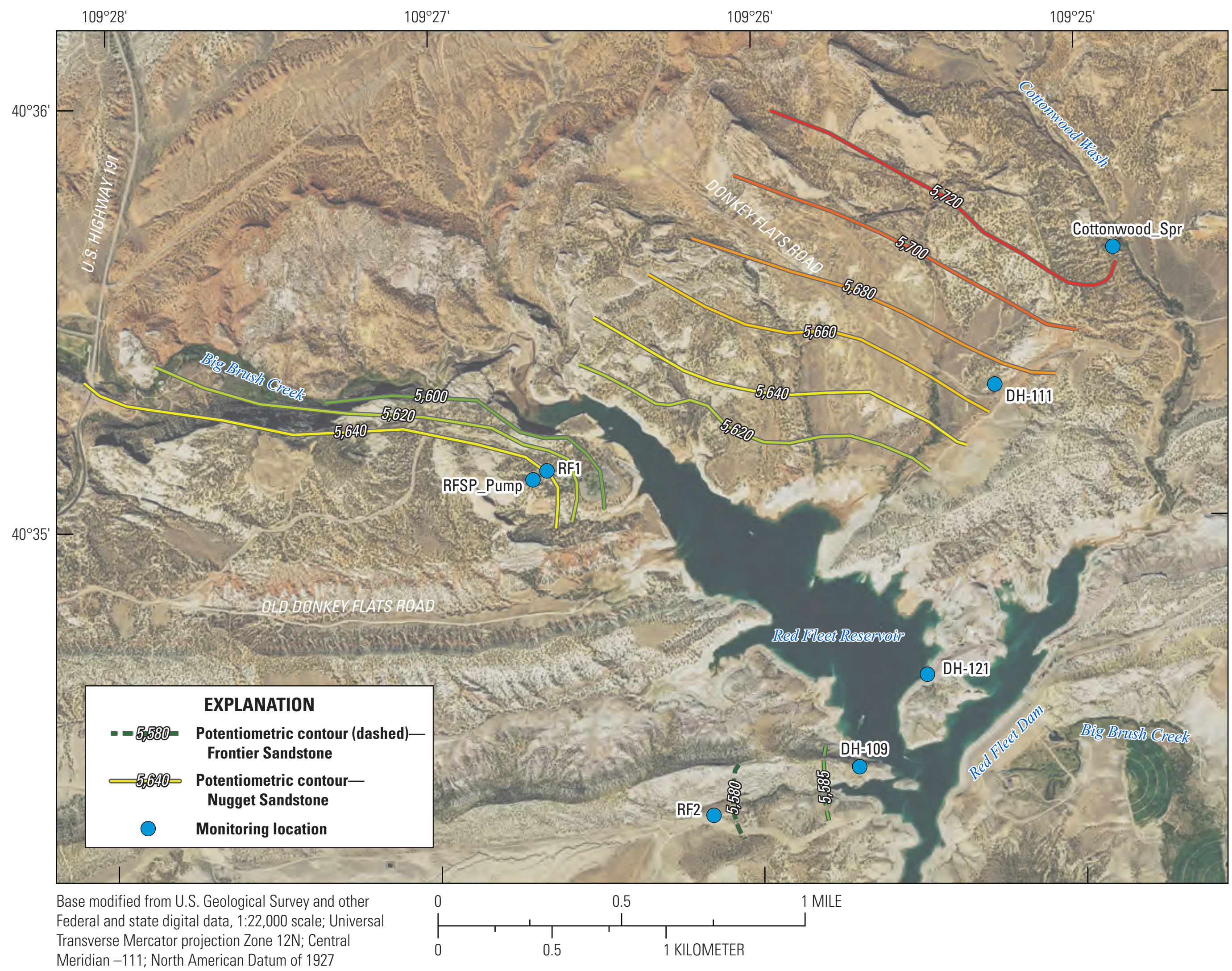


Figure 6. Potentiometric contours of the Nugget and Frontier Sandstone aquifers in September 2017, Red Fleet Reservoir, Utah.

Groundwater-flow gradients observed in September 2017 in the Frontier Sandstone aquifer indicate that the reservoir was recharging the aquifer on the west bank near Red Fleet Dam. The difference in groundwater altitude in well RF2 and the stage of Red Fleet Reservoir in September 2017 indicates a shallow gradient between the reservoir and the aquifer (fig. 6).

Estimates of Groundwater Recharge and Discharge from Red Fleet Reservoir

Recharge from and discharge to Red Fleet Reservoir is calculated as the residual with the following water-budget equation (modified from Heilweil and others, 2005):

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

where

- R is recharge (acre-ft),
- I_{sw} is surface-water inflow (acre-ft),
- O_{sw} is surface-water outflow (acre-ft),
- O_{pump} is pumped outflow (acre-ft),
- P is the amount of precipitation falling directly on the reservoir (acre-ft),
- ΔS is the change in surface-water storage (acre-ft), and
- E is evaporation (acre-ft).

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

$$CU = \sum\left[\left(|C_i| / \sum|C_i|\right) * U_i\right] \qquad (2)$$

where

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

The estimated uncertainty fraction is 0.10 (10 percent) for I_{sw}, O_{sw}, and O_{pump} because these flows are recorded using USGS streamgaging methods, engineered control devices, and calibrated inline flow meters. The estimated uncertainty fraction is 0.10 (10 percent) for ΔS because changes in surface-water storage are based only on approximate reservoir water-level altitude/volume relations rather than direct measurements. The estimated uncertainty fraction for P is 0.20 (20 percent) because it is an indirect measurement taken on the basis of nearby meteorology station data approximately 10 mi from the study area. The estimated uncertainty fraction is 0.20 (20 percent) for E, which is based on differences between alternative methods for estimating evaporation at Red Fleet Reservoir and other areas (Heilweil and Susong, 2007; Rosenberry and others, 2007).

The monthly amount of precipitation falling on the reservoir is calculated by multiplying the total monthly precipitation recorded by the Vernal Airport weather station by the average reservoir surface area for that month (based on reservoir water-level altitude to area relations for the reservoir; John Hunting, Uintah Water Conservancy District, written commun., 2016). The precipitation term in equation 1, however, does not account for precipitation runoff to the reservoir. Summer monsoon precipitation events occasionally produce runoff that reaches Red Fleet Reservoir, primarily through the Cottonwood Wash drainage. The volume of runoff produced by these events is negligible in comparison to the total reservoir water budget.

Monthly water-budget values for Red Fleet Reservoir are shown in table 1. Values are monthly totals, except for reservoir altitude and storage, which are shown for the last day of each month.

Changes in Reservoir Storage

Changes in reservoir storage were calculated from daily reservoir water-level altitudes reported by the BOR using altitude to volume relations (John Hunting, Uintah Water Conservancy District, written commun., 2016). Since Red Fleet Reservoir began filling in May 1980, surface-water storage increased to a maximum of about 26,000 acre-ft in June 1983. Between 1983 and 2015 surface-water storage in the reservoir seasonally fluctuated from about 15,000 to 26,000 acre-ft during average to above-average annual precipitation years, but dropped to about 7,000 acre-ft during periods of below-average annual precipitation (table 1).

Reservoir Evaporation

The McGuinness and Bordne (1972) version of the Jensen-Haise method was selected for calculating evaporation from Red Fleet Reservoir and is based on the relation:

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

where

- PET is potential evaporation, in centimeters per day,
- T_a is air temperature, in degrees Fahrenheit, and
- Q_s is solar radiation, in calories per square centimeter per day.

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

Monthly evaporation rates were calculated with equation 3 using air temperature and solar radiation from the nearby weather stations (fig. 1). These estimated evaporation rates ranged from 0.00 to 0.85 foot per month from May 1980 through December 2015 (table 1). Multiplying the estimated evaporation rates by the average reservoir surface area yields monthly evaporation losses that ranged from about 0 to 380 acre-ft between May 1980 and December 2015.

Estimates of Groundwater Recharge and Discharge at Red Fleet Reservoir

Monthly estimates of precipitation (*P*), evaporation (*E*), inflow (I_{sw}), outflows (O_{sw} and O_{pump}), and changes in surface-water storage (ΔS) were used in equation 1 to calculate recharge and discharge to and from the Nugget and Frontier Sandstone aquifers beneath Red Fleet Reservoir. Monthly recharge (plus, +) and discharge (minus, –) from May 1980 through December 2015 ranged from about –2,800 to 2,200 acre-ft (fig. 7), with 2σ composite uncertainties ranging from about 10 to 12 percent of the estimate (table 1). Higher composite uncertainties in the summer reflect the larger, weighted importance of evaporation losses, which have the highest uncertainty.

Annual inflow, dam releases, pumped outflow, evaporation, and groundwater recharge/discharge to and from Red Fleet Reservoir from 1980 through 2015 are shown on figure 3. During this period, total inflow was about 1,050,000 acre-ft, with annual inflow ranging from about 12,000 acre-ft in 2002 to 49,000 acre-ft in 1998. From 1980 through 2015, total dam releases were about 993,000 acre-ft, with annual dam releases ranging from about 15,000 acre-ft in 2013 to about 51,000 acre-ft in 1983. Total pumped outflow from 1980 through 2015 was about 42,000 acre-ft, with annual pumped outflow ranging from 0 acre-ft before 1986 to about 3,400 acre-ft in 2007. Total evaporation from 1980 through 2015 was about 52,000 acre-ft, with annual evaporation ranging from about 830 acre-ft in 1980 to about 1,770 acre-ft in 2007. Annual groundwater recharge was greatest in 2007 at about 4,000 acre-ft following a period from early 2001 through early 2005 when the reservoir volume was substantially decreased. Annual groundwater discharge was greatest in 1997 at about 4,900 acre-ft, and total groundwater recharge/discharge to Red Fleet Reservoir from 1980 through 2015 was about 40,000 acre-ft, with a 2σ uncertainty of 11,000 acre-ft (fig. 7; table 1).

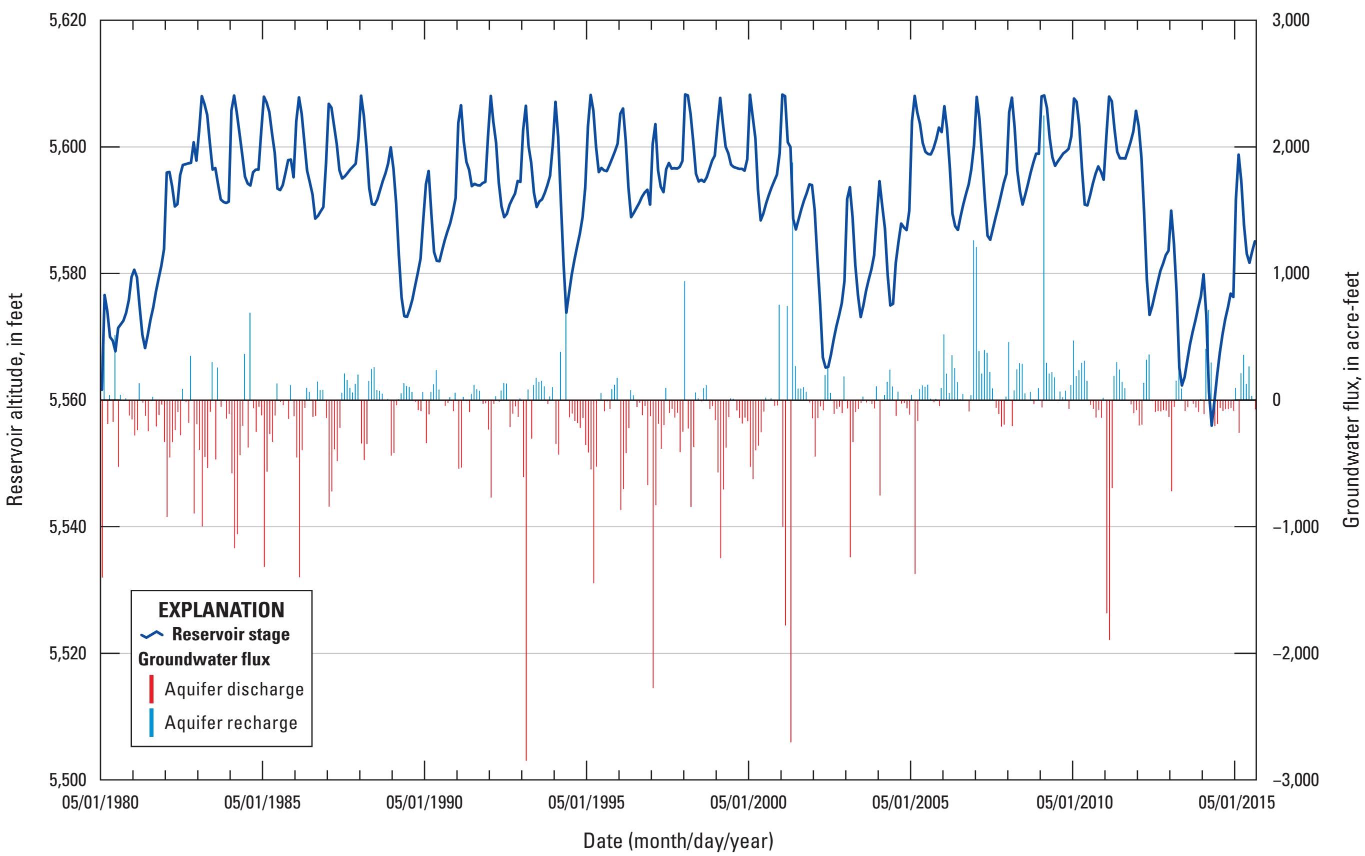


Figure 7. Reservoir stage and calculated groundwater recharge/discharge at Red Fleet Reservoir, Utah, 1980–2015.

Big Brush Creek Seepage Assessment Upstream of Red Fleet Reservoir

A seepage study was completed on November 17, 2017, on Big Brush Creek under baseflow conditions to quantify groundwater gains or losses between the Big Brush Creek streamgage (USGS 09261700) and the inflow to Red Fleet Reservoir (fig. 8). Big Brush Creek is fed primarily by Brush Creek Spring approximately 4 mi upstream of the USGS streamgage. The reservoir inflow site, about 1 mi downstream, was chosen to be as close as possible to Red Fleet Reservoir without compromising measurement quality because of slack water. There are no known surface-water inflows, turnouts, or return points throughout the reach.

Two discharge measurements were taken at the downstream inflow site and one at the upstream gaged site. The measured value at the upstream site was supported by a value computed from the stage-discharge rating model in use at the USGS streamgage. The model was previously developed by calibrating stage to periodic streamflow measurements. Discharge measurements were taken with a SonTek FlowTracker2 handheld Acoustic Doppler Velocimeter using standard USGS methods (Turnipseed and Sauer, 2010). Percent statistical uncertainty values calculated by the FlowTracker2 ADV software are used by the USGS as standard practice for estimating discharge error because of channel conditions and measurement instrumentation. For the full methodology of this calculation see the section “Discharge Uncertainty Calculations Using a SonTek FlowTracker” in SonTek (2009). Mean discharge measured at each location and uncertainty values are shown on figure 9.

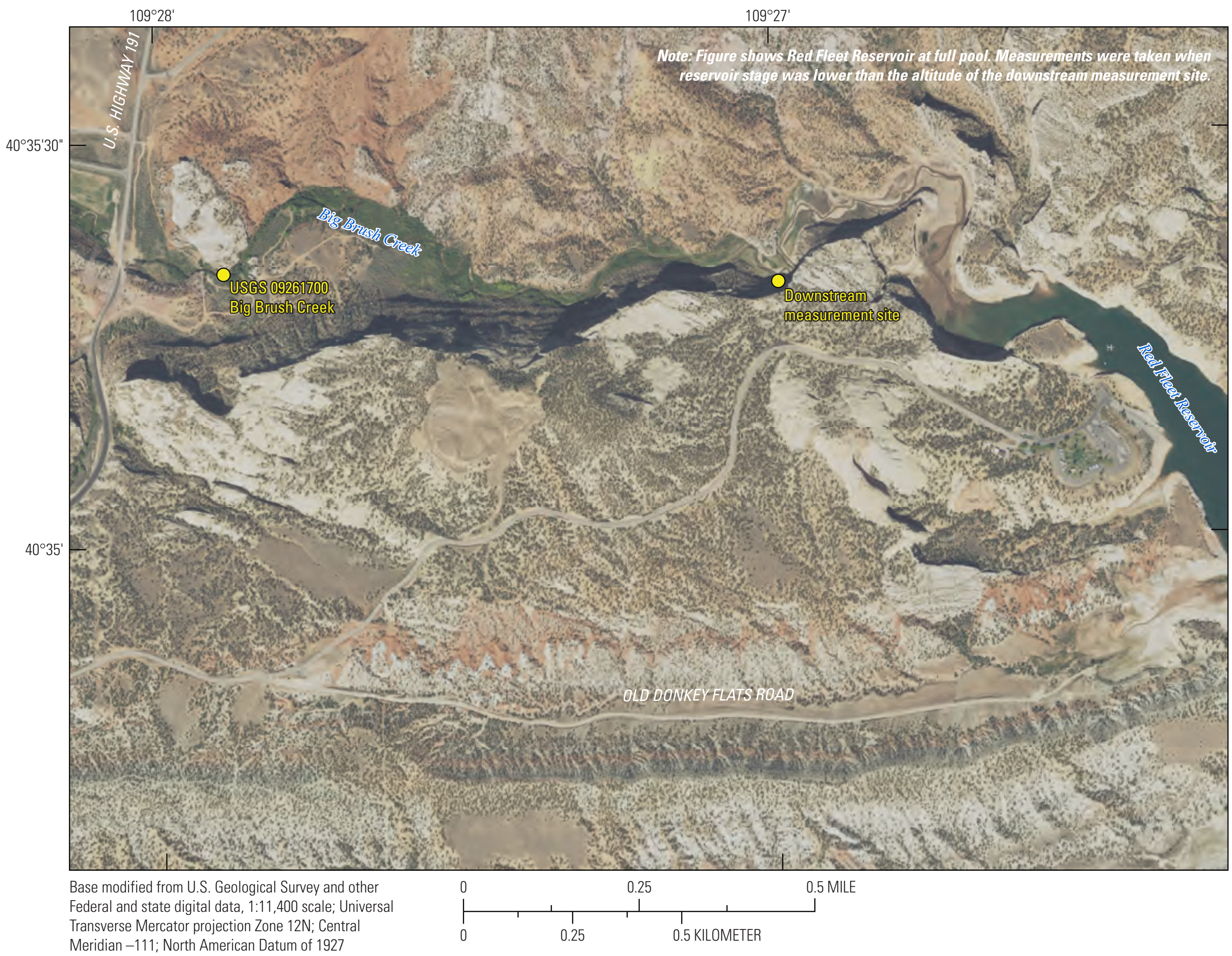


Figure 8. Locations of seepage measurements taken on November 17, 2017, on Big Brush Creek upstream of Red Fleet Reservoir, Utah.

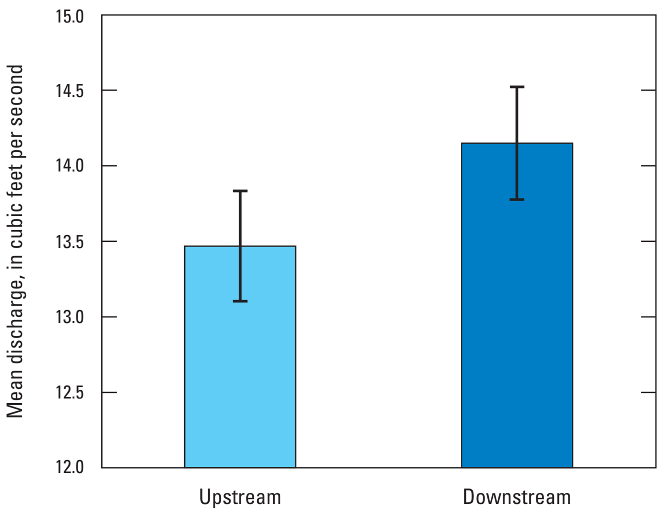


Figure 9. Measured discharge and uncertainty at two stations on Big Brush Creek upstream of Red Fleet Reservoir, Utah.

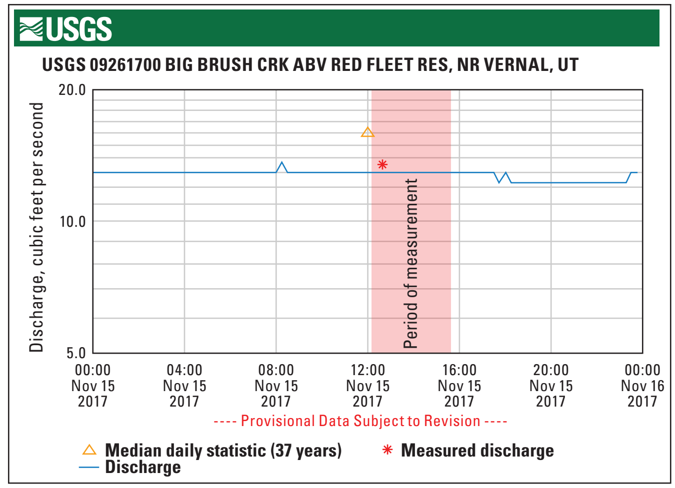


Figure 10. Recorded discharge at the U.S. Geological Survey Big Brush Creek streamgage 09261700 during the November 17, 2017, seepage assessment above Red Fleet Reservoir, Utah.

The measurements spanned a period of relatively steady flow conditions based on the continuous water-stage record obtained from the streamgage (fig. 10). The increase or decrease between measurement sites represents the net seepage interchange between groundwater and surface water. The measurements show an increase in discharge between the upstream and downstream sites of about 0.68 cubic foot per second (ft^3/s) or 4.8 percent of the gage streamflow (fig. 10). Calculated seepage over the reach is subject to inherent measurement uncertainty, but is supported by trends in sampled radon concentration observed throughout the stream reach. The increase in flow observed under baseflow conditions indicates a considerable annual groundwater discharge from the Nugget Sandstone aquifer to the stream reach.

Evaluation of Aquifer Properties in the Nugget Sandstone Aquifer near Red Fleet Reservoir

Regionally, the Nugget Sandstone aquifer is utilized as a good-quality groundwater source for domestic use. To better understand how groundwater flows through the Nugget Sandstone aquifer near Red Fleet Reservoir, a constant-discharge test was completed on the Red Fleet State Park drinking-water supply well (RFSP). This test was used to evaluate aquifer properties in the Nugget Sandstone aquifer near Red Fleet Reservoir to compare to published values in the region. The RFSP well was pumped at an average rate of 11 gallons per minute (gal/min) from March 9, 2017, to March 17, 2017, as part of an 8-day constant-discharge test. Water-level data were collected at the pumping well (RFSP) and at monitoring well RF1 for the duration of the test and during a 30-day recovery period so that transmissivity and storage coefficient values of the Nugget Sandstone aquifer could be estimated (fig. 11).

Pumping well RFSP is an 8.375-inch-diameter well completed in an 8.375-inch-diameter borehole. The drillers log reports that the well only penetrates the Nugget Sandstone aquifer to a total depth of 510 ft below land surface. The well is not screened or perforated and is only open to the aquifer at the base of the well casing. The aquifer is assumed to be unconfined. The static water level before pumping began was 73.05 ft below land surface.

Observation well RF1 is a 2-inch-diameter well completed in a 6-inch-diameter borehole; it was drilled to a depth of 99 ft below land surface and only penetrates the Nugget Sandstone aquifer. The well is screened in the Nugget Sandstone aquifer from 79 to 99 ft below land surface and is 270 ft northeast of the RFSP pumping well. The static water level before pumping began was 53.48 ft below land surface.

Aquifer Test Description and Analysis

The aquifer test commenced when well RFSP began pumping at 10:35 a.m. on March 9, 2017, and continued for 8 days until 10:35 a.m., March 17, 2017. Discharge from the pumped well ranged from 16.5 to 10.4 gal/min during the test (fig. 12). Discharge water was routed away from the test site through a 2-inch discharge line to a drainage approximately 700 ft to the southeast (fig. 11). Once pumping had ceased, water levels were allowed to recover for 30 days. During the test and recovery period, water levels in wells RF1 and RFSP were monitored at 5-minute intervals.

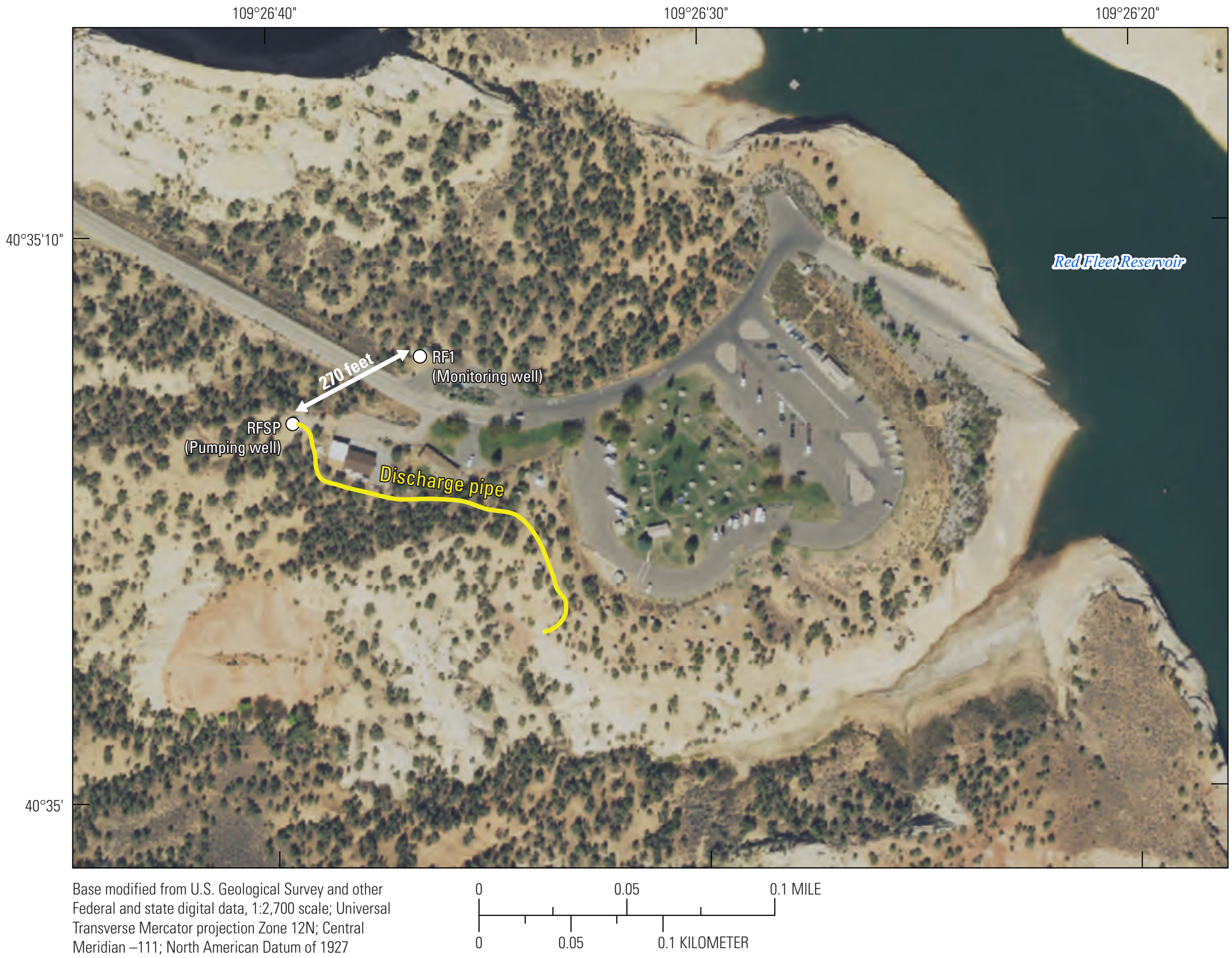


Figure 11. Locations of wells and discharge pipe used during the March 2017 Nugget Sandstone aquifer test at Red Fleet Reservoir, Utah. The Red Fleet State Park well is identified as a "pumping well" and RF1 is identified as a "monitoring well."

An Excel spreadsheet program (SeriesSEE) was used to analyze the data (Halford and others, 2012). A water-level model was constructed to simulate water-level fluctuations observed in well RF1 using data from barometric pressure, a nearby reference well (RF2) that was unaffected by pumping, and a superimposed Theis solution. A series of moving average transforms were applied to the barometric pressure and reference-well data to analyze water-level fluctuations with variable frequencies (fig. 13).

The sum of the transformed data and the superimposed Theis solution created the simulated water level observed on figure 12. The resulting superimposed Theis solution from this water-level model yielded a simulated transmissivity of 660 square feet per day (ft^2/d) with a storage coefficient of 0.13 for the Nugget Sandstone aquifer near the RFSP well. The transmissivity and storage coefficient values fall within the range of known values for the Nugget Sandstone in the region.

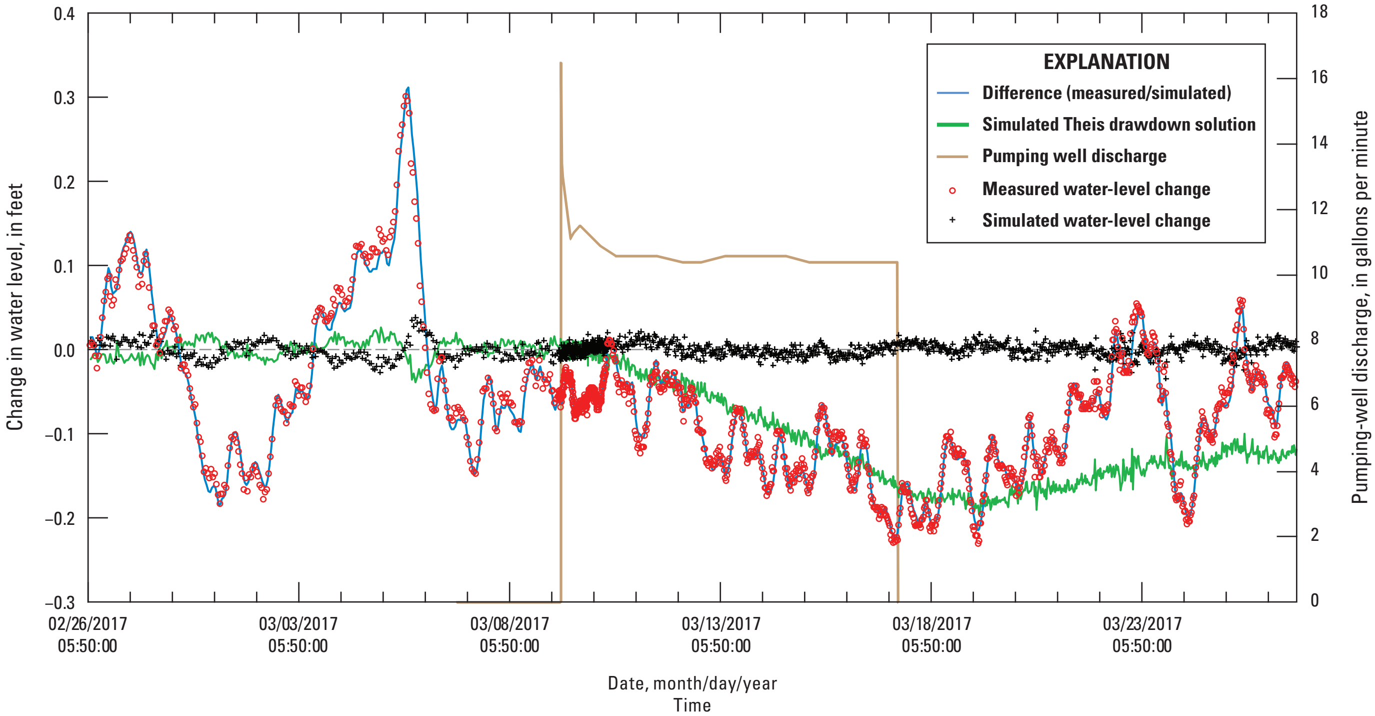


Figure 12. Measured change in water level from observation well RF1 near Red Fleet Reservoir resulting from pumping at the Red Fleet State Park well, and simulated change in water level from a Theis aquifer-response solution, March 2017, Red Fleet Reservoir, Utah.

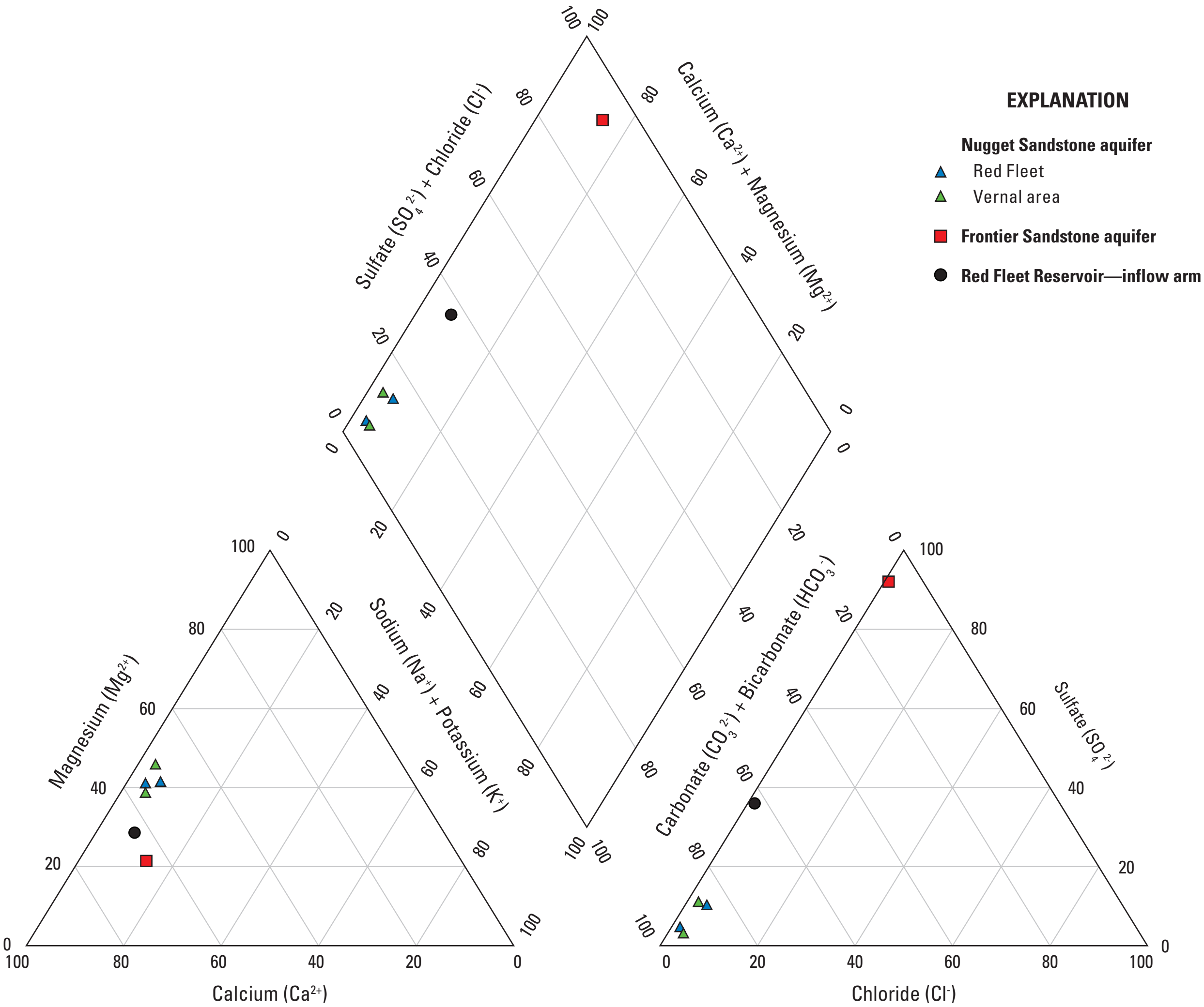


Figure 13. Relative major-ion concentrations for selected wells near Red Fleet Reservoir, Utah.

Evaluation of Groundwater Geochemical Characteristics in the Nugget and Frontier Sandstones

Water samples were collected from four sites near and in Red Fleet Reservoir, including two monitoring wells, a culinary well, and surface water from the reservoir. The water samples were analyzed for major ions, nutrients, and selected trace metals to characterize general chemistry and patterns of water quality for a limited area near and in Red Fleet Reservoir. Water samples also were analyzed for several environmental tracers including the radioactive isotope of hydrogen (tritium, ^{3}H), dissolved noble gases, chlorofluorocarbons, and sulfur hexafluoride. These environmental tracers were used to investigate potential groundwater recharge areas and groundwater ages to provide an understanding of the groundwater interaction that occurs at Red Fleet Reservoir.

Field parameters were measured to provide an on-site characterization of surface-water and groundwater quality. Field water-quality parameters included water temperature, specific conductance, pH, dissolved oxygen, and total dissolved-gas (TDG) pressure. Total dissolved-gas pressure is the combination of the partial pressures of all the dissolved gas in water.

Data Collection Methods

Field parameters were measured with a multi-parameter sonde placed in the screened interval at the bottom of each 2-inch monitoring well, and in the reservoir at water depths of approximately 3 ft. The multi-parameter sonde was too large to enter the 1-inch access port on the Red Fleet State Park drinking-water well. Consequently, field measurements from this well were made on-site with a flow-through chamber connected to a discharge spigot near the well head before the drinking water holding tank.

Laboratory water-quality analyses of surface water from Red Fleet Reservoir and groundwater from the Nugget and Frontier Sandstone aquifers included major and trace dissolved inorganic and organic constituents, ^{3}H, and noble and industrial dissolved gases. The major inorganic ions included calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and nitrate. Trace ions and nutrients included fluoride, bromide, iron, manganese, arsenic, nitrite, ammonia, and orthophosphate. Dissolved organic constituents included dissolved organic carbon. Dissolved gases included chlorofluorocarbons (trichlorofluoromethane, CFC-11; dichlorodifluoromethane, CFC-12; and 1,1,2-trichloro-1,2,2-trifluoroethane, CFC-113), sulfur hexafluoride (SF_6), and noble gases (helium, He; neon, Ne; argon, Ar; krypton, Kr; and xenon, Xe).

Water-chemistry samples were collected from 2-inch monitoring wells using a Grundfos RediFlo-2 or Geotech SS Geosub sample pump, and production wells were sampled utilizing installed submersible pumps. Before the water-chemistry sample collection from monitoring wells, water was purged from each well until a minimum of three casing volumes were removed and field parameters had stabilized. After purging each well, water was pumped into samples bottles and filtered as necessary.

Samples for major ions and trace ions were filtered with 0.45-micron disposable filters and collected in clean polyethylene bottles according to procedures described by Wilde and Radtke (1998); samples for cation analysis were preserved with 7.7-normal nitric acid. Tritium samples were collected in 500-milliliter (ml) polyethylene bottles with polyseal caps without head space. The CFC and SF_6 samples were collected in 250-ml and 1-liter (L) glass bottles, respectively, according to procedures described at the USGS Reston Groundwater Dating Laboratory (https://water.usgs.gov/lab/). Noble gases were collected with diffusion sampler methods described by Sheldon (2002) and Gardner and Solomon (2009), and with copper-tube methods described by Stute and Schlosser (2000).

Inorganic and organic chemical analyses (major ions, trace ions, and dissolved organic carbon) were analyzed by the USGS at the National Water Quality Laboratory in Denver, Colorado. The CFCs and SF_6 were analyzed by the USGS at the Chlorofluorocarbon Laboratory in Reston, Virginia. Tritium and noble gases were analyzed by the University of Utah Dissolved Gas Laboratory using quadrupole and sector-field mass spectrometers; tritium concentrations were determined using the in-growth method (Clarke and others, 1976).

Data Interpretation Methods

Noble Gases

Dissolved heavy noble-gas samples (neon-20, ^{20}Ne; argon-40, ^{40}Ar; krypton-84 ^{84}Kr; and xenon-129, ^{129}Xe) were used to determine noble-gas recharge temperatures (NGTs, assumed to equal the temperature of groundwater recharge as it crosses the water table) as an indicator of recharge source (mountain versus reservoir) and groundwater movement. Noble gases dissolved in groundwater primarily are of atmospheric origin, with concentrations being a function of gas solubility (with the possible addition of excess air from dissolution of trapped bubbles) at the temperature, pressure, and salinity conditions when recharge crosses the water table. Variation in the solubility of individual noble gases is such that measured concentrations of multiple noble gases can be used to fit unique models of recharge conditions. Because noble gases are geochemically inert, groundwater NGTs are preserved along the length of a groundwater flow path.

A complete review of noble gases as groundwater tracers is found in Stute and Schlosser (2000).

For this study, the noble-gas concentrations were interpreted using the closed-system equilibration (CE) model (Aeschbach-Hertig and others, 2000; Kipfer and others, 2002). In addition to recharge temperature, the CE model also calculates excess air as the dimensionless ratio of the total volume of trapped (moist) air at the pressure and temperature of the free atmosphere to the volume of water (A) and a fractionation factor (F) accounting for partial dissolution of trapped air bubbles. For samples collected in areas of high topographic gradient, the recharge altitude (a proxy for barometric pressure) is an unknown parameter. Because recharge temperature (T_r) and recharge altitude are correlated, a range of NGTs (assumed to equal T_r) was calculated for each sample with the most likely NGT determined by the intersection of calculated NGT with the temperature lapse rate, a method described by Manning and Solomon (2003) and Manning (2011). The range of possible NGTs was based on the minimum recharge altitude, typically that of the sample site and the maximum possible recharge altitude, which was estimated to be 10,000 ft for all samples based on the elevation of high-altitude plateaus and lakes in the Uinta Mountains where recharge is most likely to occur. Temperature lapse rate and change in temperature as a function of altitude were determined at points along south to north transects starting at the study area and based on 30-year mean annual air temperature (PRISM Climate Group, 2012) and the National Elevation Dataset (U.S. Geological Survey, 2017). A water-table lapse rate was estimated based on general observations of a +3 °C difference between air and water-table temperatures (Manning and Solomon, 2003). The recharge parameters (NGT, A, and F) were evaluated across the range of recharge altitudes with a standard Newton inversion technique to minimize the error-weighted misfit (χ^2) between measured and modeled dissolved-gas concentrations (Aeschbach-Hertig and others, 2000; Manning and Solomon, 2003). An χ^2 probability threshold of 3.84, based on four measured gases and three recharge parameters (P greater than 0.05), was used to define good model fits for NGT, A, and F. Because of noble-gas measurement precision, uncertainty in NGTs is generally 0.5–1.5 °C (Manning and Solomon, 2003; Manning, 2009; Masbruch and others, 2012).

Tritium and Helium Isotopes

Tritium and helium isotopes were used in this study to evaluate the age of groundwater and reservoir samples. Tritium is a radioactive isotope of hydrogen with a half-life of 12.32 years (Lucas and Unterweger, 2000) that decays to tritiogenic helium-3 ($^3He_{trit}$). Tritium is present in water as part of the water molecule, whereas its decay product ($^3He_{trit}$) is a component of the total helium budget dissolved in water. During the 1950s and 1960s, large amounts of ^3H were released into the atmosphere and introduced into the hydrologic cycle by above-ground thermonuclear weapons testing. As a result, ^3H concentrations in precipitation in the northern hemisphere during 1963–64 peaked at three orders of magnitude above natural concentrations (Michel, 1989).

Concentrations of ^3H and $^3He_{trit}$ can be used to determine the apparent age of groundwater that is less than about 60 years old. These ages are referred to as "apparent" as the calculation assumes plug flow along a single flow path (for example, piston flow) and can differ from the true mean age of the sample if it contains a mixture of water of different ages. Mixtures of modern (post-mid-1950s recharge) and pre-modern (pre-mid-1950s recharge) water typically have apparent $^3H/^3He_{trit}$ ages that represent the age of the young fraction of the sample because dilution with pre-modern water will leave the ratio of ^3H to $^3He_{trit}$ virtually unchanged. Further details of this groundwater dating method are presented in Solomon and Cook (2000).

Although ^3H in modern precipitation was not measured during this study, recharge after 2012 is assumed to contain 6–11 tritium units (TU) as indicated by empirical relationships derived from measured ^3H across a range of latitude and longitude (Michel, 1989). In a sample of pre-modern groundwater, ^3H would have decayed from background "prebomb" concentrations of about 8 TU to less than 0.3 TU, which is approaching the analytical detection limit. Samples collected during this study having concentrations of 0.4 TU or less and accounting for a typical analytical uncertainty of 0.1 TU, were interpreted to contain no modern water. Apparent $^3H/^3He_{trit}$ ages were computed for samples that had concentrations of more than 0.4 TU.

In addition to ^3He derived from ^3H decay, groundwater also accumulates dissolved helium because it is produced from the radioactive decay of naturally occurring uranium- and thorium-series elements in aquifer solids (crustal He) and from the upward advection and (or) diffusion of primordial helium from the mantle (mantle He). Crustal- and mantle-sourced He are collectively referred to as "terrigenic He" (He_{terr}; Solomon, 2000). Crustal- and mantle-sourced He are distinguishable by their relative abundance of ^3He and ^4He (helium-4) isotopes, and because He_{terr} concentrations generally increase with increasing residence time. Dissolved terrigenic helium-4 ($^4He_{terr}$) concentrations have been used as a semiquantitative tool for dating groundwater with ages from 1,000 to more than 1,000,000 years (Mazor and Bosch, 1992; Solomon, 2000). No attempts were made to accurately date groundwater in this study using $^4He_{terr}$ because crustal He_{terr} production rates are highly variable and substantial additional data would have been required to constrain these rates within the study area. Even without precise knowledge of local ^4He production rates, ^4He concentrations in excess of atmospheric solubility are useful as qualitative measures of groundwater age.

Lumped Parameter Modeling

Categorical Tritium Age

Measured tritium values can be used to categorically define the age of groundwater by correcting the estimated annual tritium concentration of local precipitation for the radioactive decay of tritium, which has a half-life of 12.32 years (Lucas and Unterweger, 2000). For this study, the categories were defined as pre-modern (pre-1953 recharge) with measured ^3H concentrations less than 0.4 TU, modern (post-1953 recharge) with ^3H concentrations of greater than 3.5 TU, and a mixture of pre-modern and modern water with ^3H concentrations between these two values. The categorical age is useful in assigning a generalized age and in identification of outlier tracers because ^3H is the least susceptible to contamination or other in situ alterations.

Groundwater Age

An estimated mean age and age distribution, describing the relative contribution of various flow paths, were determined for each sample using a modified version of TracerLPM (Jurgens and others, 2012; Bryant Jurgens, U.S. Geological Survey, written commun., 2013) and a local hydrogeologic conceptualization. The lumped parameter modeling (LPM) approach assumes steady-state groundwater flow and conservative tracer behavior (with the exception of radioactive decay). The selected conceptual age distribution for a given sample is mathematically convoluted with the measured atmospheric tracer concentrations (input functions) to calculate tracer concentrations for any given mean age. The mean age and age-distribution parameters are optimized to match the measured and simulated tracer concentrations. Selection of the most suitable LPM is based on multiple lines of evidence including conceptual hydrogeology, tracer concentrations, and LPM results, and is an iterative process. Geologic cross sections and lithologic well logs were used to develop a conceptual model of the hydrogeology. The conceptual hydrogeology provides context and physical constraints on the selection of a suitable distribution (see "Jurgens and others, 2012" for conceptual flow-path diagrams). For this study, the dispersion model (DM) with a small dispersion parameter of 0.001 (inverse of the Peclet number; Jurgens and others, 2012) was used in lieu of the piston-flow model, which does not account for hydrodynamic dispersion along flow paths in real groundwater-flow systems. Use of a DM brings the conceptualized flow system represented by the LPM more in line with known physical processes. Measured tracer concentrations are used to select tracers for LPM modeling and refine age-distribution selection. Tracer cross-plots are a graphical representation of the convolution of two tracer input functions for a given age distribution and are used to check consistency between tracer pairs and identify anomalous tracer concentrations which could indicate tracer contamination or biodegradation. Relative merit of the optimized mean age and age distribution are assessed by the number of fitted tracers, the sum of chi-squared statistic (χ^2), tracer cross-plots, objective judgment regarding distribution model parameters, and tracer selection based on the conceptual hydrogeology and other nearby samples.

Water-Quality Results

Major Ions, Nutrients, and Trace Metals

Water-quality results from the Nugget and the Frontier Sandstones indicated two distinct chemical water types. The Nugget Sandstone aquifer near Red Fleet Reservoir can be characterized as calcium-magnesium-bicarbonate water with dissolved-solids concentrations that ranged from 135 to 240 milligrams per liter (mg/L; fig. 13; table 2). Concentrations of trace metals sampled including arsenic, selenium, and uranium, were all low with ranges of 0.05–0.07 micrograms per liter (µg/L) for arsenic, 0.46–2.11 µg/L for selenium, and 0.71–8.35 µg/L for uranium. All of the concentrations for trace metals and nutrients in Nugget Sandstone wells sampled near Red Fleet Reservoir were below the Environmental Protection Agency (EPA) maximum contaminant levels. Overall water quality of the wells sampled in the Nugget Sandstone indicates that the aquifer is a good source of drinking water. Geochemical results for two wells west of the study area (fig. 1), but within the Vernal, Utah, region are included in figure 13 and table 2 for comparison to known Nugget Sandstone aquifer geochemistry outside the influence of a nearby reservoir. Water from Vernal area wells screened in the Nugget Sandstone was very similar to water sampled from wells near Red Fleet Reservoir, indicating that the reservoir has limited interaction with the Nugget Sandstone aquifer.

A sample from well RF2 was used to characterize and evaluate water quality in the Frontier Sandstone aquifer near Red Fleet Reservoir (fig. 13; table 2). This sample was characterized as a calcium-magnesium-sulfate water with a dissolved-solids concentration of 2,150 mg/L. The trace metals sampled included arsenic at 9.42 µg/L, selenium at 15.2 µg/L, and uranium at 1.33 µg/L; all were below EPA maximum contaminant levels. The nitrate and nitrite concentrations were well below EPA maximum contaminant levels for drinking water of 10 and 1 mg/L, respectively. The elevated selenium concentration in well RF2 was likely derived from the overlying Mancos Shale, a known reservoir of selenium in the region. Overall water quality in well RF2, which represents the upper part of the Frontier Sandstone aquifer, was poor because of the high dissolved-solids concentration.

Table 2. Field measurements and major ions, selected trace elements, and nutrient concentrations in groundwater and surface water from selected sites near Red Fleet Reservoir, Utah.

[Sample sites are plotted on figure 2. **Abbreviations**: USGS, U.S. Geological Survey; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; Cl:Br, chloride-to-bromide ratio; µg/L, micrograms per liter; RF1 and RF2 are wells; RFSP, Red Fleet State Park; —, no data available; <, less than]

Site name	USGS site identifier	Date	Temperature (°C)	Specific conductance (µS/cm)	pH (standard units)	Dissolved oxygen (mg/L)	Total dissolved solids (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 $CaCO_3$)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)
RF1	403508109263901	10/13/2016	10.9	302	8.1	9.1	168	35.1	16.7	4.26	1.67	142	12.9	4.66
RFSP	403506109264201	10/13/2016	11.0	228	8.3	8.9	135	28.8	12.8	1.79	1.13	120	4.34	1.58
(D-3-21)20bac-1	403254109352401	10/24/2014	10.9	247	8.0	—	139	31.3	12.7	2.79	0.92	127	3.12	2.81
(D-3-21)20ccc-1	403215109354501	9/17/2013	11.4	466	7.8	—	240	56.0	30.2	3.35	2.63	248	24.4	4.26
RF2	403418109260901	10/12/2016	11.0	2,810	6.9	0.0	2,150	391	76.9	95.7	5.39	120	1,240	14.3
Red Fleet Reservoir inflow arm	403451109260001	10/13/2016	15.0	270	8.2	7.2	172	38.1	10.2	4.91	1.09	96.4	43.8	1.64

Site name	USGS site identifier	Date	Fluoride (mg/L as F)	Bromide (mg/L as Br)	Cl:Br	Silica (mg/L as SiO_2)	Arsenic (µg/L as As)	Iron (µg/L as Fe)	Manganese (µg/L as Mn)	Selenium (µg/L as Se)	Uranium (µg/L as U)	Nitrogen (nitrite + nitrate) (mg/L as N)	Nitrogen, nitrite (mg/L as N)	Nitrogen, ammonia (mg/L as N)	Phosphorous (orthophosphate) (mg/L as P)
RF1	403508109263901	10/13/2016	0.17	0.048	97.1	9.83	0.07	13.1	0.47	2.11	1.14	0.94	<0.001	<0.01	<0.004
RFSP	403506109264201	10/13/2016	0.11	0.015	105.3	8.85	0.05	<5	<0.20	1.05	0.71	0.50	<0.001	<0.01	<0.004
(D-3-21)20bac-1	403254109352401	10/24/2014	0.14	—	—	10.1	<0.10	<4	<0.20	0.46	1.58	0.83	—	<0.01	<0.004
(D-3-21)20ccc-1	403215109354501	9/17/2013	0.19	—	—	7.41	0.20	235	9.95	0.69	8.35	<0.01	—	—	<0.004
RF2	403418109260901	10/12/2016	0.58	0.113	126.5	40.1	9.42	10,000	321	15.2	1.33	<0.04	<0.001	0.31	0.021
RedFleet Reservoir inflow arm	403451109260001	10/13/2016	0.10	0.010	164.0	5.69	0.97	9.6	1.07	0.51	1.03	<0.04	0.002	<0.01	<0.004

Red Fleet Reservoir water sampled from the inflow arm was characterized as a calcium-sulfate-bicarbonate water with a dissolved-solids concentration of 172 mg/L (fig. 13; table 2). The reservoir water did have higher concentrations of sulfate than surrounding Nugget Sandstone aquifer water, which was likely the result of dissolution of sulfate-bearing minerals upstream of Red Fleet Reservoir in the Big Brush Creek drainage. The trace metals sampled included arsenic at 0.97 µg/L, selenium at 0.51 µg/L, and uranium at 1.03 µg/L; all were below EPA maximum contaminant levels. The nitrate and nitrite concentrations were well below EPA maximum contaminant levels for drinking water of 10 and 1 mg/L, respectively.

Environmental Tracer Results

Noble-Gas Analysis

Noble-gas samples were collected at three groundwater wells with measured concentrations of Ne, Ar, Kr, and Xe being well explained by the CE model (χ^2 fits less than 0.5 for all samples) that indicated low amounts of excess air that was moderately fractionated (table 3; fig. 1). A full range of possible NGTs were calculated for each site (fig. 14), with most likely NGTs determined by the intersection of water table and air lapse rates with the modeled NGT lapse rate. Air-temperature lapse rates were used for two sites (RF1 and RFSP) because calculated NGTs did not intersect estimated water-table temperatures. This indicates that the geothermal gradient does not have a strong effect on water-table temperature in the recharge zone for these two sites, possibly as a result of relatively rapid recharge (see “Manning and Solomon, 2003” for further discussion of the relation between mean annual air temperature and recharge temperature). The cool NGTs of 0 and 2.36 °C for RFSP and RF1, respectively, and corresponding recharge elevations (table 3; fig. 14), indicate that high-elevation snowmelt is the primary recharge source. The warmer NGT of 7.51 °C at RF2 indicates a larger proportion of low-elevation recharge, with warmer recharge temperatures, was being captured at the well. As shown by hydraulic gradients, groundwater chemistry, and estimated ages, the warmer low-elevation recharge was not likely to be recharge from the reservoir, but rather lower elevation mountain recharge.

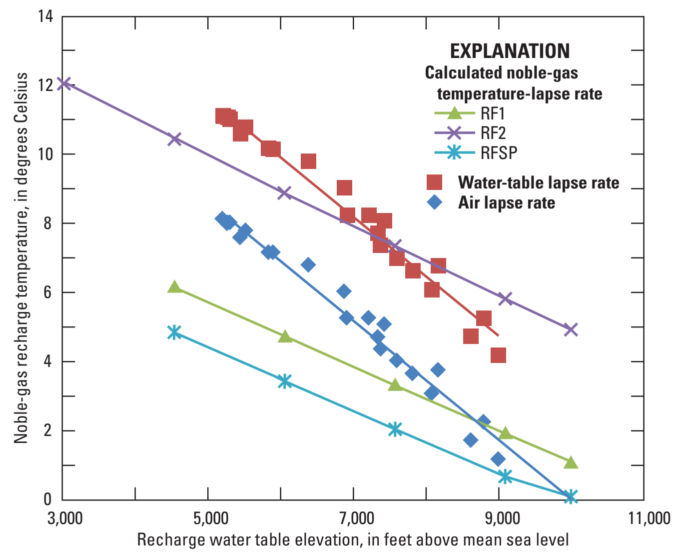


Figure 14. Modeled noble-gas recharge temperature and elevation for groundwater sampled near Red Fleet Reservoir, Utah.

Table 3. Noble-gas model results from samples collected at Red Fleet Reservoir, Utah.

[R/Ra, ratio of helium-3 to helium-4 (He-4) measured in the sample to the atmosphere (Atmo,); ccSTP/g, cubic centimeters at standard temperature and pressure per gram of water; °C, degrees Celsius; atm, atmospheres; F, fractionation factor; ΔNe, percent (%) difference between measured and modeled neon concentration; χ2, chi-squared model fit; RFSP, Red Fleet State Park; —, no data available; Ne, neon; Ar, argon; Kr, krypton; Xe, xenon; RF1 and RF2 are wells]

Site	Elevation (feet)	R/Ra (unitless)	He-4 (ccSTP/g)	NGT (°C)	Excess air (ccSTP/g)	Atmo. pressure (atm)	F (unitless)	ΔNe (%)	χ^2	Gases modeled
RFSP	3,300	1.01	4.60156E–08	0	0.02	—	0.66	0.0004	0.48	Ne, Ar, Kr, Xe
RF1	2,850	1.02	5.82296E–06	2.36	0.03	0.71	0.59	–0.0004	0.17	Ne, Ar, Kr, Xe
RF2	2,450	0.79	8.36451E–06	7.51	0.06	0.74	0.51	0.0012	0.36	Ne, Ar, Kr, Xe

Age Tracers and Mean Age

Measured ^3H ranged from 0.2 to 7.9 TU with corresponding categorical ^3H ages that varied from modern to pre-modern, and calculated $^3He_{trit}$ values that ranged from 0 to 3 TU (table 4). Tracer cross-plots show $^3He_{trit}$ values were lower than expected, based on known atmospheric tracer histories, even for a mixture of modern and pre-modern water (fig. 15). Lower than expected $^3He_{trit}$ was possibly a result of error in the helium balance as indicated by calculated values of initial ^3H (sum of ^3H and $^3He_{trit}$). Initial ^3H should be equal to or greater than the background ^3H of 8 TU from cosmogenic production. Initial ^3H less than 8 TU is one indication that $^3He_{trit}$ is not entirely reliable and should be cautiously interpreted. Measured CFC concentrations were internally inconsistent with disagreement between the CFCs (CFC-11, -12, -113) and historical record of measured atmospheric concentrations, indicating contamination or degradation, making age determinations based on CFCs unreliable; thus, CFC concentrations are not reported here.

Estimated mean ages, calculated based on ^3H only and the selected age distributions, ranged from 25 to 73 years (table 4). The exponential mixing model was most appropriate for the reservoir because it represents mixing of the full range of flow-path ages. Samples from wells were best represented by a DM, approximating a piston-flow model, as determined by the hydrogeology, well characteristics, and LPM results. A larger component of pre-modern water could have been present in the samples, but was not captured by the estimated mean ages. Helium-4 was the only pre-modern tracer collected, which was difficult to interpret quantitatively, limiting the ability to identify additional pre-modern water. Apparent ^3H/He age was only defined for two samples (RF1 and RFSP) with respective ages of about 25 and 45 years. The apparent ^3H/He age represented the minimum possible age of the young component (modern fraction of a mixture) of the sample as underestimation of $^3He_{trit}$ resulted in an underestimation of the “true” ^3H/He age. Estimated mean ages were considered more reliable in comparison to ^3H/He ages because there was evidence of error in $^3He_{trit}$ calculations.

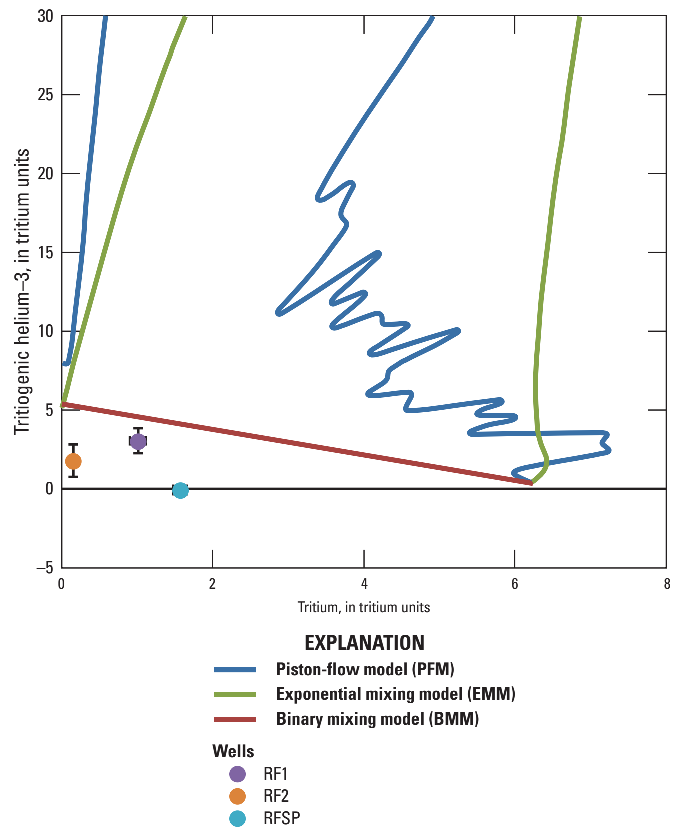


Figure 15. Age-tracer cross-plot of groundwater near Red Fleet Reservoir, Utah.

Table 4. Age-tracer concentrations and estimated mean age and age distribution of groundwater near Red Fleet Reservoir, Utah.

[ID, identification; ^3H, tritium; TU, tritium units; $^3He_{trit}$, tritiogenic helium-3; ^3H age, tritium age; Est, estimated; dist, distribution; RF Res, Red Fleet Reservoir; ±, plus or minus; —, no data available; EMM, exponential mixing model; RF1 and RF2 are wells; DM, dispersion model; RFSP, Red Fleet State Park]

Station ID	Sample name	Sample date	^3H (TU)	$^3He_{trit}$ (TU)	$^3H/^3He_{trit}$ age (years)	^3H age	Est. mean age (years)	Age dist.
403451109260001	RF Res	11/14/2016	7.9 ± 0.35	—	—	Modern	25 ± 5.8	EMM
403418109260901	RF1	11/13/2016	1 ± 0.1	3.03 ± 0.8	24.7	Mixture	67 ± 0.2	DM
403508109263901	RF2	11/12/2016	1.6 ± 0.09	–0.05 ± 0.01	—	Mixture	66 ± 0.1	DM
403506109264201	RFSP	10/13/2016	0.2 ± 0.03	1.78 ± 1.02	45	Pre-modern	73 ± 1.8	DM

Discussion

Multiple sources of evidence indicate that groundwater in the Nugget Sandstone aquifer is not significantly recharged by Red Fleet Reservoir. Modeling results with dissolved noble gases in sampled groundwater indicate that the source of groundwater recharge occurs at much lower temperatures more common to high-altitude mountainous regions observed north of the reservoir in the Uinta Mountains. A comparison of major-ion chemistry in sampled Nugget Sandstone aquifer wells near the reservoir and wells several miles from the reservoir indicates similar characteristics in the aquifer regionally that differ from the chemistry observed in Red Fleet Reservoir (table 2). Water levels observed in the Nugget Sandstone near the reservoir also indicate that there is a strong flow gradient from the aquifer to the reservoir with observed water levels in nearby wells ranging from about 35 to 70 ft higher than the maximum reservoir stage (fig. 5). Groundwater chemistry and groundwater-flow gradients indicate that there is limited evidence of groundwater recharging the Nugget Sandstone aquifer immediately surrounding the reservoir, and groundwater discharge from the Nugget Sandstone to the reservoir is the dominant exchange. Conversely, groundwater altitudes in the Frontier Sandstone were 15 to 30 ft lower than the reservoir, indicating that reservoir water is recharging the Frontier Sandstone aquifer.

Trends observed in groundwater discharge volumes calculated in the Red Fleet Reservoir water budget indicate that periods of greatest groundwater discharge occur synonymously during late spring/early summer snowmelt runoff and peaks at similar periods to peakflows observed in the Big Brush Creek discharge record (fig. 7). Results from the seepage study done during baseflow conditions in November 2017 indicate that the reach of Big Brush Creek between the USGS streamgage and the top of Red Fleet Reservoir is a gaining reach. It is likely that some of the groundwater discharge calculated in the Red Fleet Reservoir water budget occurs as seepage to Big Brush Creek before it enters the reservoir.

Summary

The objectives of this study were to present and interpret (1) groundwater levels, reservoir altitude, meteorological data, and inflows/outflows to and from Red Fleet Reservoir from May 1980 through December 2015 in order to estimate monthly groundwater recharge/discharge to and from surrounding aquifers; (2) aquifer properties for the Nugget Sandstone near Red Fleet Reservoir from a two-well aquifer test; and (3) groundwater and surface-water chemical data to evaluate the origin of water in aquifers adjacent to Red Fleet Reservoir.

From 1980 through 2015, Big Brush Creek discharged water at an average of 29,200 acre-feet per year to Red Fleet Reservoir with a total discharge of about 1,050,000 acre-feet (acre-ft). Maximum and minimum annual discharge from Big Brush Creek to Red Fleet Reservoir from 1980 through 2015 was 49,000 and 12,200 acre-ft, respectively, with the minimum in 2002 and the maximum in 1998. Streamflow discharge from Red Fleet Reservoir is controlled by gates and jet valves at the base of Red Fleet Dam as well as a spillway on the east abutment. Total dam releases from 1980 through 2015 were about 993,000 acre-ft, with annual dam releases during this period ranging from about 15,000 acre-ft in 2013 to about 51,000 acre-ft in 1983. Total evaporation from 1980 through 2015 was about 52,000 acre-ft, with annual evaporation during this period ranging from about 830 acre-ft in 1980 to about 1,770 acre-ft in 2007. The average annual pumped volume of water from the Tyzack Pump Station at the base of Red Fleet Dam during years when pumping occurred was about 1,400 acre-ft. The total volume of water pumped from the Tyzack Pump Station from 1980 through 2015 was about 42,500 acre-ft. Total groundwater discharge to Red Fleet Reservoir from 1980 through 2015 was about 40,000 acre-ft.

Based on water-level measurements at six wells and one spring, altitudes of the groundwater in September 2017 near Red Fleet Reservoir in the Nugget and Frontier Sandstones ranged from 5,578 to 5,726 feet (ft). The reservoir altitude during this same period was about 5,590 ft. Groundwater-flow gradients observed in September 2017 in the Nugget Sandstone aquifer indicated that groundwater was discharging to Red Fleet Reservoir from the east and west banks of the reservoir. The water levels in the Frontier Sandstone aquifer observed at well RF2 were about 15–30 ft lower than the stage observed in Red Fleet Reservoir, which indicates a downward groundwater-flow gradient in the Frontier Sandstone west of the reservoir from August 2016 through September 2017.

An aquifer test in the Nugget Sandstone aquifer was completed utilizing the Red Fleet State Park well. This well was pumped at an average rate of 11 gallons per minute from March 9, 2017, to March 17, 2017, as part of an 8-day constant-discharge test. Water-level data were collected at the pumping well and at observation well RF1 for the duration of the test and during a 30-day recovery period so that transmissivity and storage coefficient values of the Nugget Sandstone aquifer could be estimated. Aquifer properties determined by a numerical model for the Nugget Sandstone aquifer near the pumping well yielded a transmissivity of 660 square feet per day with a storage coefficient of 0.13.

Water samples were collected from four sites near and in Red Fleet Reservoir: two monitoring wells, a culinary well, and surface water from the reservoir. The water samples were analyzed for major ions, nutrients, and selected trace metals to characterize general chemistry and patterns of water quality for a limited area near and in Red Fleet Reservoir.

Water samples also were analyzed for several environmental tracers including the radioactive isotope of hydrogen (tritium, ^3H), dissolved noble gases, chlorofluorocarbons, and sulfur hexafluoride. The Nugget Sandstone aquifer near Red Fleet Reservoir can be characterized as calcium-magnesium-bicarbonate water with dissolved-solids concentrations that range from 135 to 169 milligrams per liter. The Frontier Sandstone aquifer near Red Fleet Reservoir can be characterized as calcium-magnesium-sulfate water with a dissolved-solids concentration of 2,150 mg/L. Apparent ^3H/He (helium) age was only defined for two samples (wells RF1 and RFSP) with respective ages of about 25 and 45 years. The apparent ^3H/He age represents the minimum possible age of the young component (modern fraction of a mixture) of the sample as underestimation of tritiogenic helium-3 resulted in an underestimation of the "true" ^3H/He age. Recharge temperatures calculated from dissolved noble gases sampled at two wells in the Nugget Sandstone aquifer indicate that high-elevation snowmelt is the primary recharge source. The warmer recharge temperature calculated from noble-gas samples from the Frontier Sandstone aquifer from well RF2 indicates a larger proportion of low-elevation recharge, which is consistent with the idea that the Frontier Sandstone aquifer is recharged by the Red Fleet Reservoir.

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For more information concerning the research in this report, contact the
Director, Utah Water Science Center
U.S. Geological Survey
2329 West Orton Circle
Salt Lake City, Utah 84119-2047
801-908-5000
https://ut.water.usgs.gov

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