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Compilation of Hydrologic Data for White Sands Pupfish Habitat and Nonhabitat Areas, Northern Tularosa Basin, White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008

Data Series 810

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

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SALLY JEWELL, Secretary

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

U.S. Geological Survey, Reston, Virginia: 2014

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Suggested citation:
Naus, C.A., Myers, R.G., Saleh, D.K., and Myers, N.C., 2014, Compilation of hydrologic data for White Sands pupfish habitat and nonhabitat areas, northern Tularosa Basin, White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008: U.S. Geological Survey Data Series 810, 35 p., *http://dx.doi.org/10.3133/ds810.*

ISSN 2327-638X (online)

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Conversion Factors, Datums, and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
	Area	
square kilometer (km^2)	247.1	acre
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

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

°F=(1.8×°C)+32

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

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

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

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

Compilation of Hydrologic Data for White Sands Pupfish Habitat and Nonhabitat Areas, Northern Tularosa Basin, White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008

By C.A. Naus, R.G. Myers, D.K. Saleh, and N.C. Myers

Abstract

The White Sands pupfish (*Cyprinodon tularosa*), listed as threatened by the State of New Mexico and as a Federal species of concern, is endemic to the Tularosa Basin, New Mexico. Because water quality can affect pupfish and the environmental conditions of their habitat, a comprehensive compilation of hydrologic data for pupfish habitat and nonhabitat areas in the northern Tularosa Basin was undertaken by the U.S. Geological Survey in cooperation with White Sands Missile Range.

The four locations within the Tularosa Basin that are known pupfish habitat areas are the Salt Creek, Malpais Spring and Malpais Salt Marsh, Main Mound Spring, and Lost River habitat areas. Streamflow data from the Salt Creek near Tularosa streamflow-gaging station indicated that the average annual mean streamflow and average annual total streamflow for water years 1995–2008 were 1.35 cubic feet per second (ft^3/s) and 983 acre-feet, respectively. Periods of no flow were observed in water years 2002 through 2006. Dissolved-solids concentrations in Salt Creek samples collected from 1911 through 2007 ranged from 2,290 to 66,700 milligrams per liter (mg/L).

The average annual mean streamflow and average annual total streamflow at the Malpais Spring near Oscura streamflow-gaging station for water years 2003–8 were 6.81 ft^3/s and 584 acre-feet, respectively. Dissolved-solids concentrations for 16 Malpais Spring samples ranged from 3,882 to 5,500 mg/L. Isotopic data for a Malpais Spring near Oscura water sample collected in 1982 indicated that the water was more than 27,900 years old.

Streamflow from Main Mound Spring was estimated at 0.007 ft^3/s in 1955 and 1957 and ranged from 0.02 to 0.07 ft^3/s from 1996 to 2001. Dissolved-solids concentrations in samples collected between 1955 and 2007 ranged from an estimated 3,760 to 4,240 mg/L in the upper pond and 4,840 to 5,120 mg/L in the lower pond. Isotopic data for a Main Mound Spring water sample collected in 1982 indicated that the water was about 19,600 years old.

Dissolved-solids concentrations of Lost River samples collected from 1984 to 1999 ranged from 8,930 to 118,000 (estimated) mg/L.

Dissolved-solids concentrations in samples from nonhabitat area sites ranged from 1,740 to 54,200 (estimated) mg/L. In general, water collected from pupfish nonhabitat area sites tends to have larger proportions of calcium, magnesium, and sulfate than water from pupfish habitat area sites. Water from springs associated with mounds in pupfish nonhabitat areas was of a similar type (calcium-sulfate) to water associated with mounds in pupfish habitat areas. Alkali Spring had a sodium-chloride water type, but the proportions of sodium-chloride and magnesium-sulfate are unique as compared to samples from other sites.

Introduction

The White Sands pupfish (*Cyprinodon tularosa*) is the only endemic fish species of the Tularosa Basin in south-central New Mexico (fig. 1). The species is listed as threatened by the State of New Mexico (19 NMAC 33.1) and as a Federal species of concern (50CFR 17:64481-64485) (Pittenger and Springer, 1999). A cooperative agreement among White Sands Missile Range, Holloman Air Force Base, New Mexico Department of Game and Fish, U.S. Fish and Wildlife Service, and White Sands National Monument was signed in 1994 (Pittenger and Springer, 1996) to establish an interagency team to develop and implement conservation measures for the White Sands pupfish (Pittenger and Springer, 1999). Because water quality can affect pupfish and the environmental conditions of their habitat, a comprehensive compilation of hydrologic data for pupfish habitat and nonhabitat areas in the northern Tularosa Basin was undertaken by the U.S. Geological Survey (USGS) in cooperation with White Sands Missile Range.

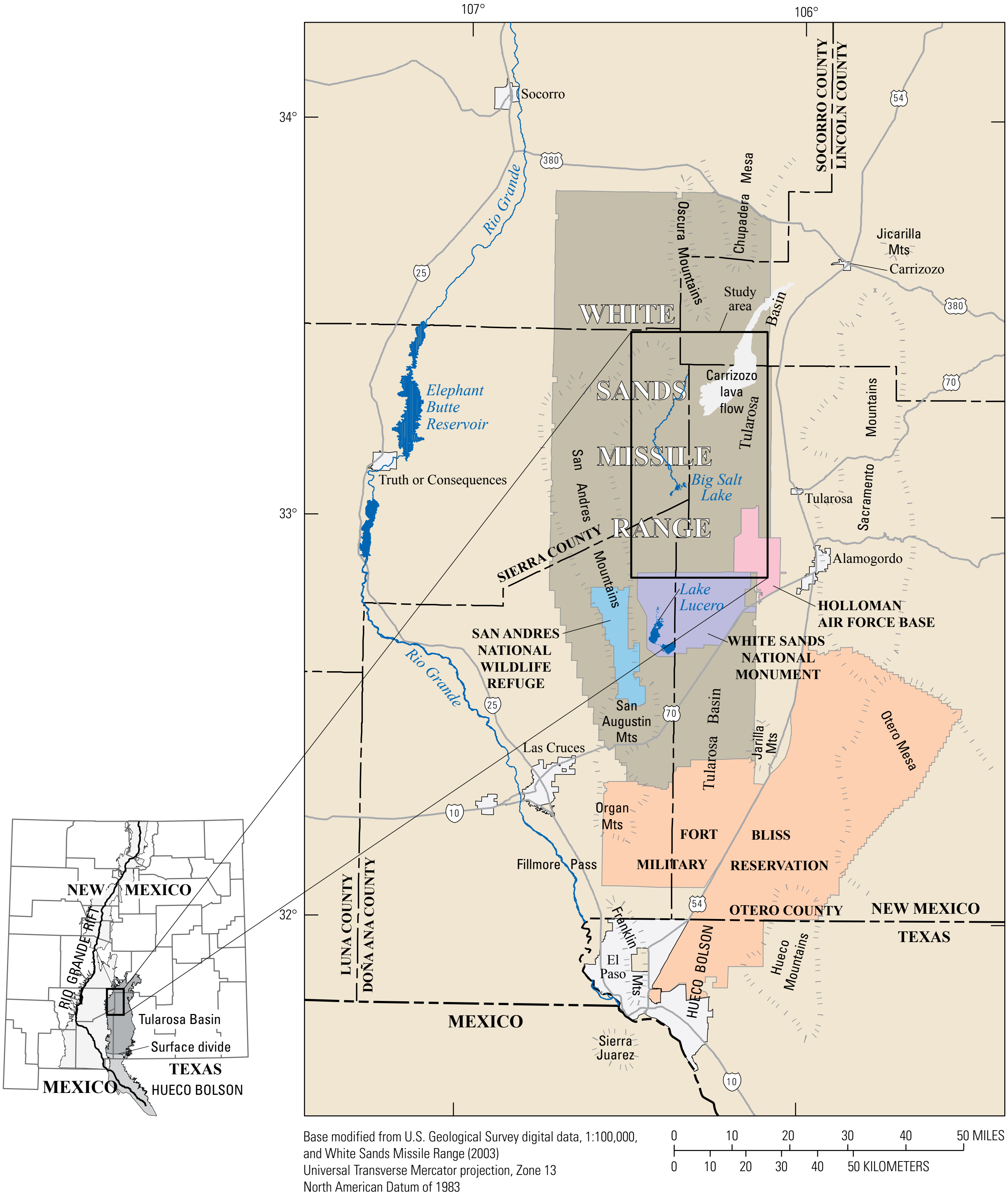

Figure 1. Location of study area in White Sands Missile Range and Holloman Air Force Base, New Mexico.

Purpose and Scope

This report presents a compilation of hydrologic data for springs, streams, and ponds of White Sands pupfish habitat and nonhabitat areas on White Sands Missile Range and Holloman Air Force Base in the northern Tularosa Basin. Data compiled include daily and instantaneous streamflow, suspended-sediment concentrations, streamflow and water-quality data collected during a seepage (gain-loss) study, and physical and chemical water-quality data. Data were collected by the USGS and the Department of Fishery and Wildlife Sciences at New Mexico State University between 1911 and 2008 and compiled from the USGS National Water Information System database (U.S. Geological Survey, 2013), other published (Meinzer and Hare, 1915; Weir, 1965) and unpublished USGS data (data on file with the U.S. Geological Survey, New Mexico Water Science Center, Albuquerque, New Mexico), and a New Mexico State University report (Turner, 1987).

Documentation of water-quality and streamflow conditions in White Sands pupfish habitat areas in the northern Tularosa Basin in White Sands Missile Range will aid in the evaluation of current and future management and research activities, the assessment of cumulative effects of military activities, and adherence to National Environmental Policy Act documentation with regard to White Sands pupfish habitat conservation.

Site-Numbering Systems

Three systems of identifying site locations are used in this report: one based on the Public Land Survey (PLS) system of subdivision of sectionized land, one based on the grid system of latitude and longitude, and one based on the order of sites along streams. Unless otherwise noted, site locations are presented as they appear in data sources. In some instances, it was not possible to locate the site for which data are presented in this report, and so no location information is given herein. Sites are shown on maps in this report only if latitude and longitude were available or if sites were depicted on maps with identifiable landmarks in the source publication.

Location numbers for sites identified according to the PLS system of subdivision of sectionized land (PLS location number in table 1) consist of four segments separated by periods and define the location of the site to the nearest 10-acre tract of land, when possible. The four segments denote, from left to right, the township south (S.) of the New Mexico base line, the range east (E.) of the New Mexico principal meridian, the section, and the particular 10-acre tract within the section. The fourth segment of the number, which consists of three digits, denotes from left to right the 160-, 40-, and 10-acre tracts within the section in which the site is located. To delineate the fourth segment of the number, the section is divided into four quarters, numbered 1, 2, 3, and 4, in the normal reading order (from left to right from top to bottom), for the northwest, northeast, southwest, and southeast quarters. The first digit of the fourth segment of the location number denotes the 160-acre quarter section. Then, the 160-acre quarter section is divided into four quarters numbered in the same manner, and the second digit in the fourth segment of the location number denotes the 40-acre tract. Finally, the 40-acre tract is divided into four quarters, and the third digit in the fourth segment of the location number denotes the 10-acre tract. For example, site 14S.08E.35.144 is located in the southeast quarter of the southeast quarter of the northwest quarter of section 35, Range 08 East, Township 14 South (fig. 2). If more than one site has the same location number, then the letter “a” is appended to the fourth segment of the location number of the second site, the letter “b” is appended to the location number of the third site, and so on. Where sections are irregularly shaped, the site is located by superimposing a regular square section grid on the irregular section with the southeastern corners and eastern section lines of the grid and irregular section matching. The site is then numbered by its location in the superimposed square grid.

Location numbers for sites identified according to the grid system of latitude and longitude (USGS location number in table 1) consist of three parts: a latitude value, a longitude value, and a two-digit sequence number. The latitude and longitude values (denoted in degrees [°], minutes [′], and seconds [″]) are based on an initial determination of site location rounded to the nearest second. The third part of the USGS location number is a two-digit sequence number that is used to uniquely identify sites that have the same latitude and longitude. The first site generally is assigned a sequence number of “01,” the second site with the same latitude and longitude is assigned a sequence number of “02,” and so on. This type of USGS location number consists of 15 digits. For example, the site for which the PLS location number was described above (14S.08E.35.144) is located at latitude 33° 03′ 23″ North and longitude 106° 09′ 38″ West and has a USGS location number of 330323106093801. Once a USGS location number is established it is never changed even if the latitude and longitude of the site is refined or corrected through subsequent measurements. Even though the 15-digit USGS location number is based on latitude and longitude it should never be used as a substitute for the actual latitude and longitude of a site.

The downstream-order system is used to assign USGS location numbers to some surface-water sites (usually streamflow-gaging stations) in river basins. Numbers are assigned, from lowest to highest (upstream to downstream), along the primary (main) stream in a river basin. Downstream order numbers for tributaries also are assigned location numbers in downstream order, but the sites on tributaries are numbered such that their values fall between those of sites on the main stream that are upstream and downstream of the tributary. Sites numbered according to this system have location numbers that consist of eight digits: the first two digits identify the major river basin (for example, “08” designates the Rio Grande Basin), and the six subsequent digits designate the downstream order of the sites.

Table 1. Site names and descriptions, identification numbers, locations, and land-surface altitudes of water-sampling sites on White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008.

[Location information as published in source database or publication unless otherwise indicated. ---, no data; AFB, Air Force Base; HAFB, Holloman Air Force Base; mi, mile; NE, northeast; NM, New Mexico; NMSU, New Mexico State University; NW, northwest; NWIS, National Water Information System; PLS, Public Land Survey; USGS, U.S. Geological Survey; WSMR, White Sands Missile Range]

Site name as shown on maps and (or) tables in this report (site names in bold are shown on figures)	Site name or description in source database or publication (if different from that used in this report)	USGS location number	PLS location number	Latitude (north)	Longitude (west)	Land-surface altitude (feet)	Source
Alkali Flat 1[a]	Water immediately below surface of Alkali Flat	---	12S.06E.12.3	---	---	4,125	Meinzer and Hare (1915).
Alkali Flat 2[a]	Water immediately below surface of Alkali Flat	---	12S.06E.14.2	---	---	4,125	Meinzer and Hare (1915).
Alkali Spring	Alkali Spring on WSMR	330534106294610	---	33° 05′ 34″	106° 29′ 46″	3,940	USGS NWIS.
Barrel Spring-North Pond	Pond north of Barrel Spring near Tularosa, NM	330323106093810	14S.08E.35.144[b]	33° 03′ 23″	106° 09′ 38″	---	USGS NWIS.
Barrel Spring-South Pond	14S.08E.35.144 Barrel Spring-South Pond	330323106093601	14S.08E.35.144[b]	33° 03′ 23″	106° 09′ 36″	4,118	USGS NWIS.
Big Salt Lake	Big Salt Lake near Tularosa, NM	330444106220310	14S.06E.23.342[b]	33° 04′ 44″	106° 22′ 03″	---	USGS NWIS.
Brazel Lake	Brazel Lake at WSMR Road 6 near Tularosa, NM	330450106110910	14S.08E.21.424[b]	33° 04′ 50″	106° 11′ 09″	---	USGS NWIS.
Dead Oryx Mound Spring	Dead Oryx Mound Spring near Oscura, NM	332501106171201	10S.06E.26.242[b]	33° 25′ 01″	106° 17′ 12″	---	USGS NWIS.
Double Mound Springs-Lower Pond[a]	---	---	---	---	---	---	Turner (1987).
Double Mound Springs-Upper Pond[a]	Upper Pond at Double Mound Spring	---	---	---	---	---	Turner (1987).
Guilez Spring	---	330328106091401	14S.08E.35.223	33° 03′ 31″	106° 09′ 13″	4,135	USGS NWIS.
Lost River (Turner)	Lost River-just upstream from culverts under WSMR Range Road 9	---	16S.08E.28.322[c]	---	---	---	Turner (1987).
Lost River 1[a]	Lost River-first pool containing pupfish downstream from the dirt road that crosses Malone Draw	---	---	---	---	---	Turner (1987).
Lost River 2[a]	Lost River-flowing water at the head of an eroded channel less than about 0.3 mi down the drainage	---	---	---	---	---	Turner (1987).
Lost River 3[a]	Lost River-upstream from WSMR Range Road 9 and upstream from where a power line crosses Lost River	---	---	---	---	---	Turner (1987).
Lost River 4[a]	Lost River-just below the west end of the north culvert under WSMR Range Road 9	---	---	---	---	---	Turner (1987).
Lost River 5[a]	Lost River-shallow, fishless reach about 0.9 mi downstream from WSMR Range Road 9	---	---	---	---	---	Turner (1987).

Table 1. Site names and descriptions, identification numbers, locations, and land-surface altitudes of water-sampling sites on White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008.—Continued

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Site name as shown on maps and (or) tables in this report (site names in bold are shown on figures)	Site name or description in source database or publication (if different from that used in this report)	USGS location number	PLS location number	Latitude (north)	Longitude (west)	Land-surface altitude (feet)	Source
Lost River 6[a]	Lost River-ponded area near HAFB Building 1176	---	---	---	---	---	Turner (1987).
Lost River 7[a]	Lost River-just upstream from the boundary between Holloman AFB and White Sands National Monument	---	---	---	---	---	Turner (1987).
Lost River 8[a]	Lost River-most western pool on White Sands National Monument	---	---	---	---	---	Turner (1987).
Lost River on Holloman AFB	Lost River on Holloman Air Force Base, NM	325251106095310	---	32° 52′ 51″	106° 09′ 55″	4,047	USGS NWIS.
Main Mound Spring-Lower Pond	Lower Mound Spring Pond near Oscura, NM	332528106170710	10S.06E.23.442[b]	33° 25′ 28″	106° 17′ 07″	---	USGS NWIS.
Main Mound Spring-Upper Pond	Mound Spring (Upper Pond) near Oscura, NM	332535106170501	10S.06E.24.313[b]	33° 25′ 35″	106° 17′ 05″	---	USGS NWIS.
Malpais Salt Marsh	Malpais Marsh near Oscura, NM	331657106185010	12S.07E.08.434[b]	33° 16′ 57″	106° 18′ 50″	---	USGS NWIS.
Malpais Salt Marsh Lower Lake	Salt Marsh Lower Lake, Site 8 on WSMR, NM	331622106191110	---	33° 16′ 22″	106° 19′ 11″	---	USGS NWIS.
Malpais Spring near Oscura[d]	Malpais Spring near Oscura, NM	08480594	12S.07E.08.424[b]	33° 17′ 15″	106° 18′ 33″	4,150	USGS NWIS.
Malpais Spring (Meinzer and Hare)[a]	---	---	12S.07E.9.3	---	---	4,160	Meinzer and Hare (1915).
Malpais Spring (Turner)[a]	---	---	---	---	---	---	Turner (1987).
Malpais Spring (Wier)[a]	---	---	12S.07E.08.422	---	---	---	Weir (1965).
Malpais Spring Pond	Manmade pond that is located approximately 2 mi south of the springhead near Road 316	---	12S.07E.21.332[c]	---	---	---	Turner (1987).
Malpais Spring-at springhead[a]	---	---	---	---	---	---	Turner (1987).
Malpais Spring-edge of marsh[a]	---	---	---	---	---	---	Turner (1987).
Malpais Spring-middle of marsh[a]	Middle of the marsh that received the outflow from the spring	---	---	---	---	---	Turner (1987).
Malpais Spring-upper end[a]	Near the upper end of the study site on Malpais Spring	---	---	---	---	---	Turner (1987).
Mound Spring (Turner)[a]	---	---	---	---	---	---	Turner (1987).
Mound Spring 25[a]	---	---	10S.06E.26	---	---	4,350	Meinzer and Hare (1915).

Table 1. Site names and descriptions, identification numbers, locations, and land-surface altitudes of water-sampling sites on White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008.—Continued

[Location information as published in source database or publication unless otherwise indicated. ---, no data; AFB, Air Force Base; HAFB, Holloman Air Force Base; mi, mile; NE, northeast; NM, New Mexico; NMSU, New Mexico State University; NW, northwest; NWIS, National Water Information System; PLS, Public Land Survey; USGS, U.S. Geological Survey; WSMR, White Sands Missile Range]

Site name as shown on maps and (or) tables in this report (site names in bold are shown on figures)	Site name or description in source database or publication (if different from that used in this report)	USGS location number	PLS location number	Latitude (north)	Longitude (west)	Land-surface altitude (feet)	Source
Mound Spring 7[a]	---	---	10S.06E.23	---	---	4,350	Meinzer and Hare (1915).
Mound Spring, NW of Double Mound Springs[a]	Single Mound Spring located northwest of the Double Mound Springs	---	---	---	---	---	Turner (1987).
NMSU lower study site	---	---	12S.06E.31.322[c]	---	---	---	Turner (1987).
NMSU upper study site	---	---	11S.06E.24.322[c]	---	---	---	Turner (1987).
North Mound Spring	North Mound Spring near Oscura, NM	332606106172001	10S.06E.23.221[b]	33° 26′ 06″	106° 17′ 20″	---	USGS NWIS.
Salt Creek 1[a]	Salt Creek-sample taken at road crossing in NE 1/4 Sec. 15, T. 12 S., R.6 E.	---	12S.06E.15.2	---	---	---	Meinzer and Hare (1915).
Salt Creek 2[a]	Salt Creek-sample taken at road crossing in NE 1/4 Sec. 19, T. 13 S., R.6 E.	---	13S.06E.19.2	---	---	---	Meinzer and Hare (1915).
Salt Creek 3 at Range Road 6	Salt Creek 3 at Range Road 6 on WSMR, NM	330716106234510	14S.06E.04.441[b]	33° 07′ 16″	106° 23′ 45″	---	USGS NWIS.
Salt Creek 4 at Range Road 7	Salt Creek 4 at Range Road 7 on WSMR, NM	332057106211310	11S.06E.24.144[b]	33° 20′ 57″	106° 21′ 13″	---	USGS NWIS.
Salt Creek above Big Salt Lake at mile 1.2	Salt Creek above Big Salt Lake at mile 1.2 on WSMR, NM	330608106225710	14S.06E.15.213[b]	33° 06′ 08″	106° 22′ 57″	3,960	USGS NWIS.
Salt Creek at Big Salt Lake	Salt Creek at Big Salt Lake on WSMR, NM	330512106222510	14S.06E.23.113[b]	33° 05′ 12″	106° 22′ 25″	3,950	USGS NWIS.
Salt Creek at Road 6[a]	---	---	---	---	---	---	Turner (1987).
Salt Creek at stream mile 5.8	Salt Creek at stream mile 5.8 on WSMR, NM	330847106243810	13S.06E.32.224[b]	33° 08′ 47″	106° 24′ 38″	3,990	USGS NWIS.
Salt Creek at stream mile 6.4	Salt Creek at stream mile 6.4 on WSMR, NM	330944106253510	13S.06E.29.111[b]	33° 09′ 44″	106° 25′ 35″	4,000	USGS NWIS.
Salt Creek at stream mile 8.4	Salt Creek at stream mile 8.4 on WSMR, NM	331042106260710	13S.06E.18.433[b]	33° 10′ 42″	106° 26′ 07″	4,050	USGS NWIS.
Salt Creek at stream mile 12.5	Salt Creek at stream mile 12.5 on WSMR, NM	331346106264410	12S.06E.31.234[b]	33° 13′ 46″	106° 26′ 14″	4,040	USGS NWIS.
Salt Creek at stream mile 14.5	Salt Creek at stream mile 14.5 on WSMR, NM	331454106250110	12S.06E.29.223[b]	33° 14′ 54″	106° 25′ 01″	4,050	USGS NWIS.
Salt Creek at stream mile 18.1	Salt Creek at stream mile 18.1 on WSMR, NM	331722106231910	12S.06E.10.144[b]	33° 17′ 22″	106° 23′ 19″	4,050	USGS NWIS.
Salt Creek at stream mile 21.1	Salt Creek at stream mile 21.1 on WSMR, NM	331845106220210	11S.06E.35.434[b]	33° 18′ 45″	106° 22′ 02″	4,100	USGS NWIS.

Table 1. Site names and descriptions, identification numbers, locations, and land-surface altitudes of water-sampling sites on White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008.—Continued

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Site name as shown on maps and (or) tables in this report (site names in bold are shown on figures)	Site name or description in source database or publication (if different from that used in this report)	USGS location number	PLS location number	Latitude (north)	Longitude (west)	Land-surface altitude (feet)	Source
Salt Creek at Wit Road Bridge[a]	---	---	---	---	---	---	Turner (1987).
Salt Creek below Salt Spring	Salt Creek below Salt Spring on WSMR, NM	332139106210210	11S.06E.13.414[b]	33° 21′ 39″	106° 21′ 02″	4,175	USGS NWIS.
Salt Creek near Tularosa	Salt Creek near Tularosa, NM (formerly named Salt Creek at Range Road 316)	08480595	12S.06E.16.244[b]	33° 16′ 32″	106° 23′ 50″	---	USGS NWIS.
Salt Creek near NW-50	Salt Creek near NW-50 on WSMR, NM	331158106265710	13S.05E.12.422[b]	33° 11′ 58″	106° 26′ 57″	---	USGS NWIS.
Salt Creek-Road 6 bridge[a]	---	---	---	---	---	---	Turner (1987).
Salt Creek-Wit Road[a]	---	---	---	---	---	---	Turner (1987).
Salt Creek-Road 6[a]	---	---	---	---	---	---	Turner (1987).
Salt Creek-top of drainage	---	---	11S.06E.13.234[c]	---	---	---	Turner (1987).
Salt Creek-waterfall	---	---	12S.06E.03.422[c]	---	---	---	Turner (1987).
South Mound Spring	South Mound Spring near Oscura, NM	332420106173901	10S.06E.35.122[b]	33° 24′ 20″	106° 17′ 39″	---	USGS NWIS.
Tularosa Creek	Tularosa Creek at WSMR Road 9, near Tularosa, NM	330508106085910	14S.08E.24.133[b]	33° 05′ 08″	106° 08′ 59″	---	USGS NWIS.
West Mound Spring	West Mound Spring near Oscura, NM	332508106173401	10S.06E.26.213[b]	33° 25′ 08″	106° 17′ 34″	---	USGS NWIS.

[a]Not shown on maps because of insufficient location information.

[b]Derived from location plotted by using latitude and longitude published in NWIS.

[c]Derived from location approximated by using maps in source publication.

[d]Previously USGS site number 331715106183301.

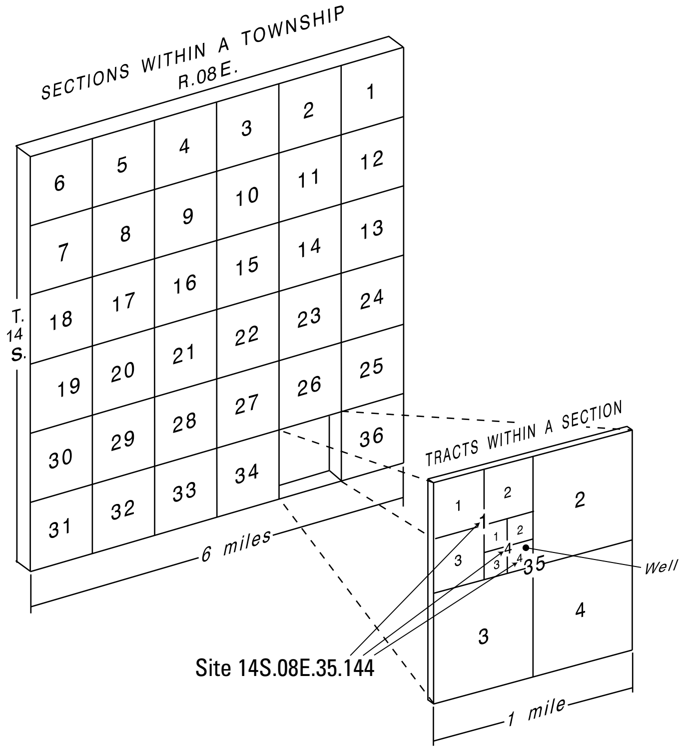

Figure 2. Diagram showing system for identifying site locations according to the Public Land Survey (PLS) system of subdivision of sectionized land in New Mexico.

Acknowledgments

The authors wish to acknowledge White Sands Missile Range personnel for their support of the long-term data-collection efforts that provided the basic data included in this report. We also wish to acknowledge the field data collection efforts of the many USGS and non-USGS personnel who labored in sometimes inclement conditions to obtain the field data.

The White Sands Missile Range Operational Security review of this report was completed on June 22, 2012, and the information contained in this report has been approved for public release by White Sands Missile Range.

Description of Study Area

The study area (fig. 1) is located in the northern part of the Tularosa Basin on the White Sands Missile Range and Holloman Air Force Base, in Doña Ana, Lincoln, Otero, and Sierra Counties, New Mexico. Surface water and springs in the study area are located in alluvium of Quaternary and Tertiary age on the floor of the Tularosa Basin (Hawley, 1983, 1993).

The Tularosa Basin is contained within a large structural basin in the Mexican Highland section of the Basin and Range physiographic province (Fenneman and Johnson, 1946). The combined thickness of Tertiary- and Quaternary-age bolson-fill sedimentary deposits in the basin is as great as 10,000 feet (ft) (Risser, 1988; Orr and Risser, 1992). The present basin-and-range configuration of the Tularosa Basin developed in response to late Tertiary crustal extension associated with the Rio Grande rift.

The Tularosa Basin is a closed surface-water drainage system, separated from the Hueco Bolson (a through-flowing basin) by a subtle high that forms a surface divide near the New Mexico-Texas State line (fig. 1 inset map; Basabilvazo and others, 1994). Much of the surface-water runoff from the mountains bordering the Tularosa Basin infiltrates before reaching the basin floor (Naus, 2002), but surface-water flow during summer thunderstorms may reach depressions and playas on the basin floor, forming ephemeral lakes that eventually evaporate and develop into alkali flats (Basabilvazo and others, 1994).

During the last glacial-pluvial time toward the end of the Pleistocene Epoch, a large ephemeral lake now called Lake Otero was present in Tularosa Basin. Lucas and Hawley (2002) indicated that Lake Otero might have covered about 810 square miles. A large stream, the ancestral Salt Creek, which drained the northern portion of the basin, formed the main tributary to Lake Otero (Weir, 1965; Hawley, 1993). Dating of organic sediment associated with Lake Otero indicates that the lake persisted in the Tularosa Basin until about 10,000 years ago, when a change of climate to more arid conditions resulted in the recession and drying of Lake Otero (Pittenger and Springer, 1999). Lake Lucero (fig. 1) is a small remnant of Lake Otero (White Sands National Monument, n.d.). Pittenger and Springer (1999) postulated that White Sands pupfish inhabited Lake Otero and its tributaries such as the ancestral Salt Creek.

Four locations within the Tularosa Basin are known pupfish habitat areas: Salt Creek, Malpais Spring and Malpais Salt Marsh, Main Mound Spring, and Lost River (figs. 3, 4, and 5). The pupfish habitat areas are on property under the jurisdiction of the Department of Defense. The Salt Creek, Malpais Spring and Malpais Salt Marsh, and Main Mound Spring habitat areas are within the boundaries of White Sands Missile Range, and Lost River flows through Holloman Air Force Base. Photographs of springs, streams, and ponds in pupfish habitat and nonhabitat areas are included in appendix 1.

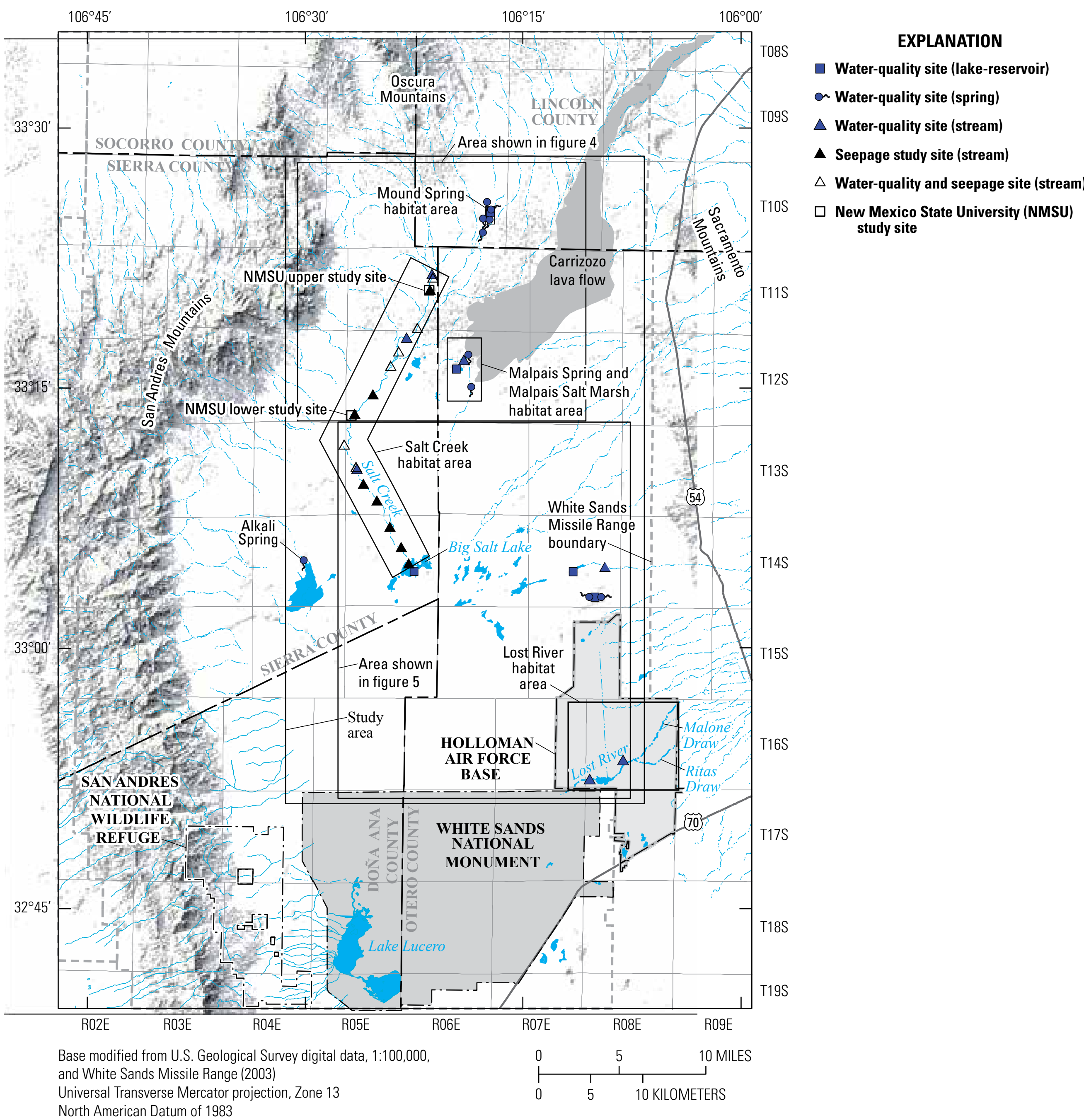

Figure 3. Locations of White Sands pupfish (*Cyprinodon tularosa*) habitat areas and sites in and near pupfish habitat areas, White Sands Missile Range and Holloman Air Force Base, New Mexico.

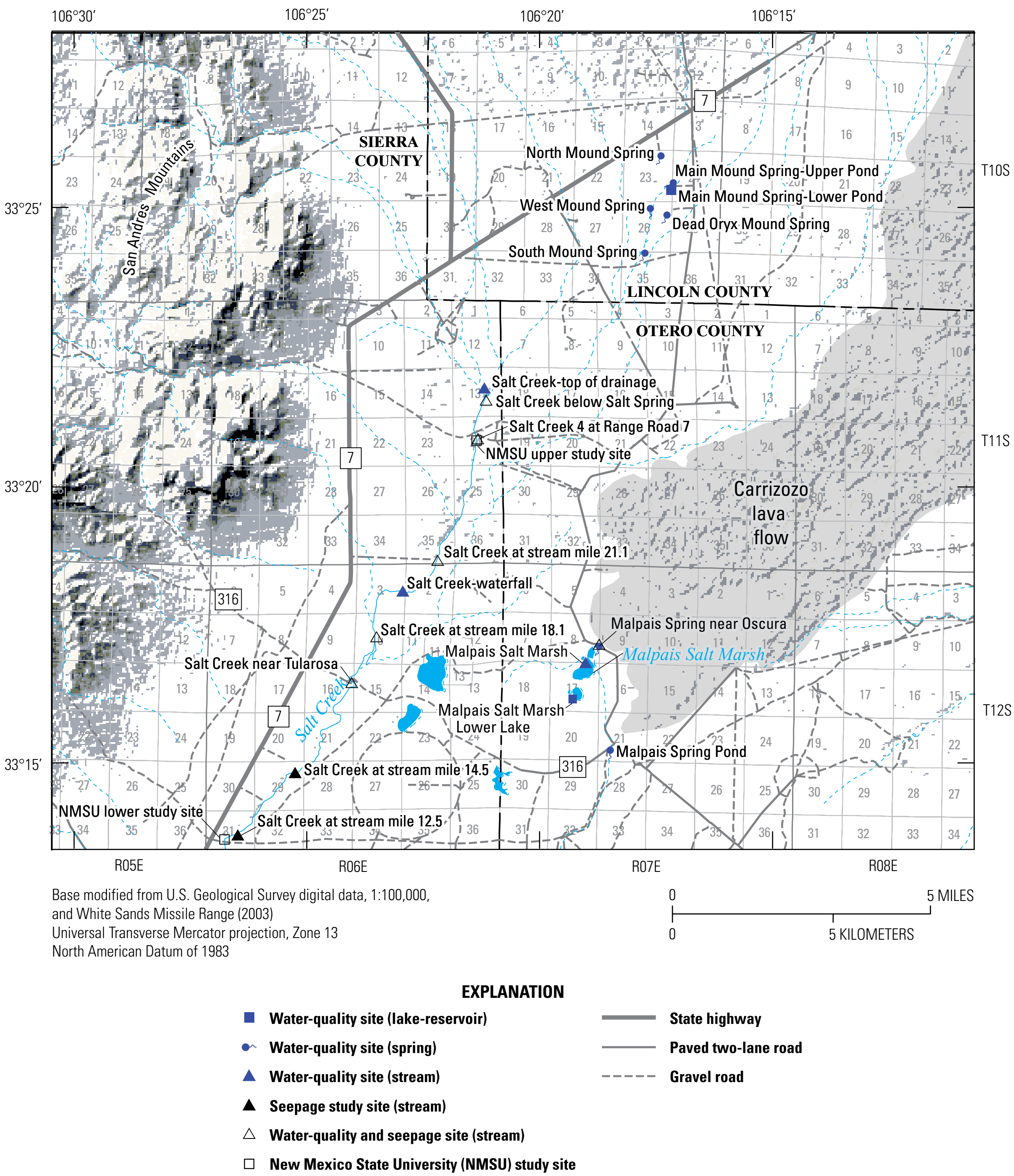

Figure 4. Locations of sites in the White Sands pupfish (*Cyprinodon tularosa*) Malpais Spring and Malpais Salt Marsh, Main Mound Spring, and northern Salt Creek habitat areas and surrounding areas, White Sands Missile Range and Holloman Air Force Base, New Mexico.

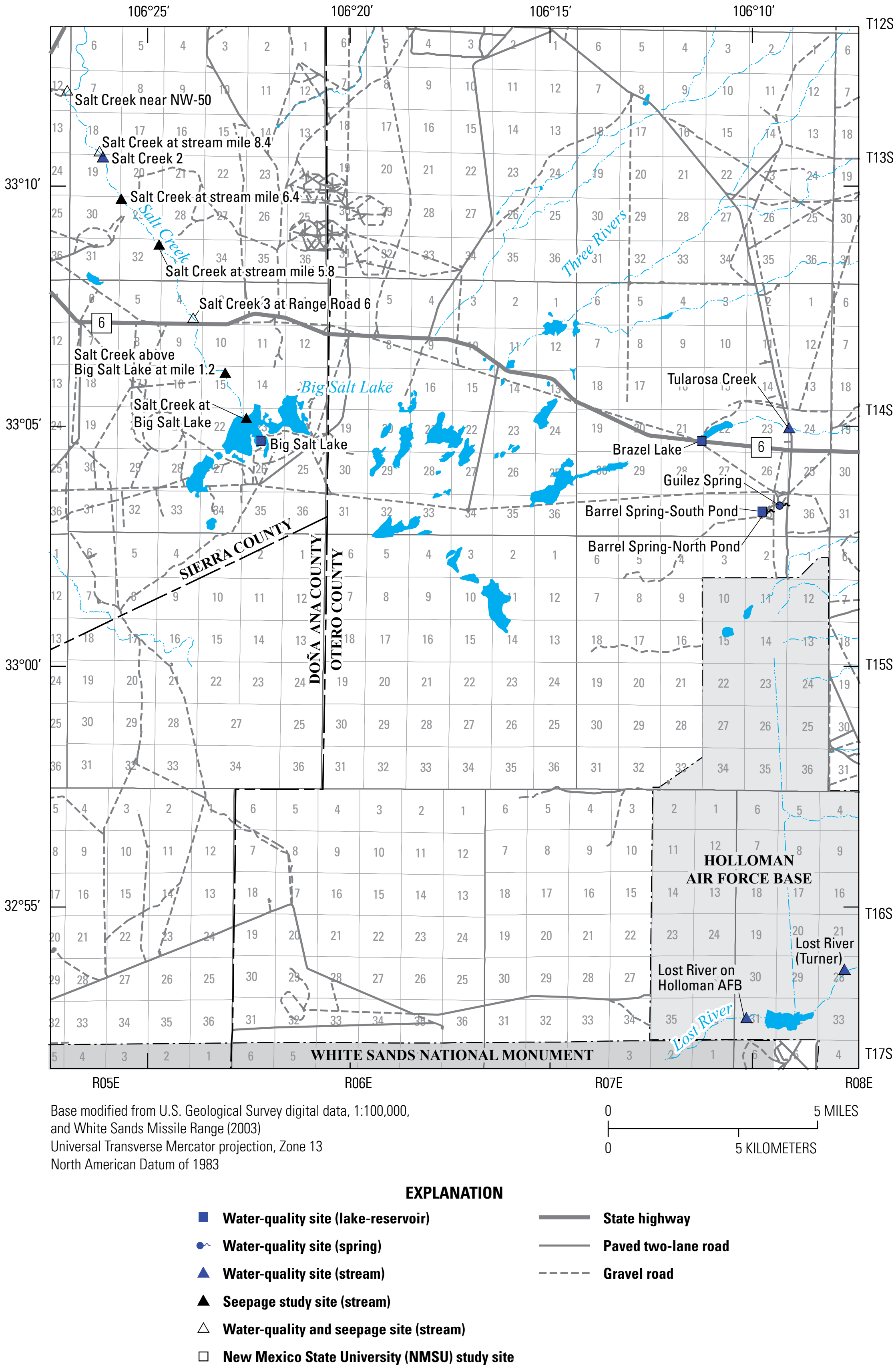

Figure 5. Locations of sites in the White Sands pupfish (*Cyprinodon tularosa*) southern Salt Creek and Lost River habitat areas and surrounding areas, White Sands Missile Range and Holloman Air Force Base, New Mexico.

Salt Creek is a perennial stream in the northern Tularosa Basin (fig. 3) and is one of two endemic habitat areas of the White Sands pupfish. The lower reach of the stream, which drains into Big Salt Lake (fig. 5), is intermittent and ephemeral. The Salt Creek drainage basin includes parts of the northern San Andres and Oscura Mountains (fig. 1) that are west of the Quaternary Carrizozo lava flow (figs. 1, 3, and 4), a 5,000-year-old olivine basalt (Salyards, 1991; Dunbar, 1999). Much of the ancestral Salt Creek stream channel in the northern Tularosa Basin was buried by the Carrizozo lava flow (Hawley, 1983). Lava occupying the ancestral Salt Creek stream channel probably blocked tributary outlets to the ancestral channel and caused shallow depressions to form at the tributary terminuses along the margins of the lava flow (Meinzer and Hare, 1915). Surface-water runoff from the Sacramento Mountains now drains to playas east of the lava flow, and surface-water runoff from the Oscura and San Andres Mountains drains to playas or Salt Creek on the west side of Tularosa Basin. Much of the runoff from the Oscura Mountains is diverted southwestward by the western edge of the lava flow and flows to Salt Creek by way of a major intermittent and ephemeral stream channel. Salt Creek is now the major perennial stream of the Tularosa Basin floor.

The Malpais Spring and Malpais Salt Marsh habitat area, located at the southwestern edge of the Carrizozo lava flow (fig. 3), is the other endemic habitat area of the White Sands pupfish. As noted by Pittenger and Springer (1999), reports of fish in the Malpais Spring area were published as early as 1900 (Herrick) and 1913 (Ligon). The first White Sands pupfish specimens were collected in July 1927 during the University of Michigan-Walker-Harris expedition to New Mexico (Bradley and others, 1927) and currently reside in the University of Michigan Museum of Zoology (Cody Thompson and Douglas Nelson, University of Michigan Museum of Zoology, written commun., 2013). Groundwater discharges from several springs and seeps that issue from the base of the terminus of the Carrizozo lava flow in the Malpais Spring area. The accumulated groundwater discharges form a stream that flows to wetlands, identified as the Malpais Salt Marsh (fig. 4), which encompassed approximately 1,188 acres in 1997 (Lichvar and Sprecher, 1997) and have a salt marsh ecosystem. Dominant species of marsh vegetation in the area include saltgrass (*Distichlis spicata*), iodinebush (*Allenrolfea occidentalis*), and spikerush (*Eleocharis palustris*). Some areas of the wetland are seasonally inundated by water. At one time, the water from the spring area was diverted to a ditch for stock water and, later, military use.

The aquifer that discharges at Malpais Spring was described by Meinzer and Hare (1915) as consisting of basalt of the Carrizozo lava flow. Weir (1965) also recognized the basalt as an aquifer and was the first to suggest that stream sediment buried beneath the basalt was an additional source of water. The Main Mound Spring habitat area (fig. 3), which includes an upper pond and a lower pond, is part of a group of springs associated with mounds between Salt Creek and the Carrizozo lava flow. The mounds were formed by deposition of windborne sediments in and around vegetation supported by water from the springs. The mounds are typically low, flat, symmetrical domes that can be as large as 600 ft in diameter and 15–20 ft high (Meinzer and Hare, 1915). Mound composition can include silt, plant matter that has been partially converted to peat, and gypsum precipitated from springwater and deposited by wind. When Meinzer and Hare (1915) mapped 29 mounds in Township 10 South, Range 7 East (fig. 4), there were more inactive than active (water-bearing) mounds.

The Lost River (figs. 3 and 5) originates in the Sacramento Mountains (fig. 1) and extends onto White Sands National Monument (figs. 3 and 5). Many sections of the stream channel on Holloman Air Force Base and White Sands National Monument are ephemeral and (or) intermittent.

White Sands Pupfish Habitat

The White Sands pupfish (*Cyprinodon tularosa*) was first described as a distinct species by Miller and Echelle (1975). Other papers of interest are Suminski (1977), Jester and Suminski (1982), and Turner (1987). Pittenger and Springer (1999) determined through a record, literature, and oral history search that White Sands pupfish were endemic to the Salt Creek and Malpais Spring habitat areas and that White Sands pupfish were introduced to Lost River in 1970 and Main Mound Spring between 1967 and 1973. Stockwell and others (1998) confirmed the genetic relations of the Main Mound Spring and Lost River pupfish populations to pupfish in Salt Creek. Stockwell and others (1998) also established genetic evidence of two evolutionarily significant units.

Water-quality characteristics of the White Sands pupfish habitats can affect pupfish and the environmental conditions of their habitats. Results from genetic studies by Stockwell and others (1998) illustrated the ability of White Sands pupfish to survive in water-quality conditions that may change rapidly because of precipitation and runoff events. Water-quality characteristics also are important in regard to the body morphology of White Sands pupfish and populations of fish parasites and aquatic snails that can be associated with fish parasites (Collyer, 2003; Harstad, 2003).

Hydrologic Data

Hydrologic data were compiled for 67 sites (table 1) located in the northern Tularosa Basin on White Sands Missile Range and Holloman Air Force Base. Compiled data (app. 2) include streamflow measurements (tables 2–1 and 2–2), selected field water-quality characteristics including suspended-sediment concentrations (table 2–2), measurements from a seepage (gain-loss) study (table 2–3) at Salt Creek, and other physical and chemical water-quality characteristics of surface water and springs in the Quaternary and Tertiary alluvial fill. In addition to the general chemistry and trace elements (tables 2–4 and 2–5), some samples were analyzed for nutrients and anthropogenic constituents such as perchlorate, pesticides, herbicides, organic compounds, and others (tables 2–6, 2–7, and 2–8). The data also include isotopic values in water samples collected by the USGS at Malpais Spring and Main Mound Spring in 1982 as part of a regional hydrochronological study (Cruz, 1983) and from Alkali Spring, Malpais Spring, Main Mound Spring, and Salt Creek in 2006 (table 2–9). Data sources include the USGS National Water Information System database (U.S. Geological Survey, 2013), other published (Meinzer and Hare, 1915; Weir, 1965) and unpublished USGS data (data on file with the U.S. Geological Survey, New Mexico Water Science Center, Albuquerque, New Mexico), and a New Mexico State University report (Turner, 1987). Unless otherwise indicated, dissolved concentrations were determined from analyses of filtered samples. Some constituent concentrations were determined from unfiltered samples, and in these cases, total concentrations are reported and denoted with a capital letter T in parentheses after the constituent abbreviations (app. 2). For example, cadmium (Cd) concentrations may be reported as dissolved concentrations, Cd, or as total concentrations, Cd (T).

This section of the report summarizes streamflow and water-quality characteristics and constituents of water samples collected at sites located in White Sands pupfish habitat areas, as well as at sites in pupfish nonhabitat areas. Throughout the section, dissolved-solids concentrations are presented as the sum of constituents (unless otherwise noted) because results of determination by residue on evaporation are not available for all samples. Discussions of minor and trace elements refer to dissolved concentrations unless otherwise specified. Stiff and piper diagrams (figs. 6–11) illustrate the major-ion chemistry of water samples with ion charge imbalances less than ±10 percent (106 samples from 28 sites). Ion charge imbalances (C.I.) were calculated by using the following equation:

$$\text{C.I. (percent)} = \left(\frac{\text{sum cations} - \text{sum anions}}{\text{sum cations} + \text{sum anions}}\right) \times 100, \quad (1)$$

where

sum cations is the sum of the cations, in milliequivalents per liter, and

sum anions is the sum of the anions, in milliequivalents per liter.

Quality Assurance and Quality Control

To ensure that measurements made in the laboratory also represent the actual environmental concentrations of constituents, the USGS follows prescribed procedures for onsite measurements and for collecting, treating, and shipping water-quality samples (U.S. Geological Survey, variously dated; Wood, 1976). Quality-assurance and quality-control procedures also have been prescribed for streamflow measurements (Benson and Dalrymple, 1967; Matthai, 1967; Bodhaine, 1968; Rantz and others, 1982). Data generated from quality-control samples are used to evaluate the quality of the sampling and processing techniques, as well as to evaluate the data from the environmental samples. Quality-control data for water samples are identified and stored so that they can be related to corresponding environmental samples. The various types of quality-control samples typically collected include blank samples, reference samples, replicate samples, and spike samples (U.S. Geological Survey, variously dated). The USGS National Water Information System database includes information about types of quality-assurance and quality-control procedures associated with water-quality samples, when available.

Very little quality-assurance and quality-control information is available for data compiled for this study from USGS reports published prior to 1970 (Meinzer and Hare, 1915; Weir, 1965) and from non-USGS reports. Turner (1987) cited Orth (1983) for methods used in the New Mexico State University study for streamflow measurements. In that study, water-quality samples collected by the New Mexico State University Department of Fishery and Wildlife Sciences were analyzed by the Soil and Water Testing Laboratory at New Mexico State University (Turner, 1987).

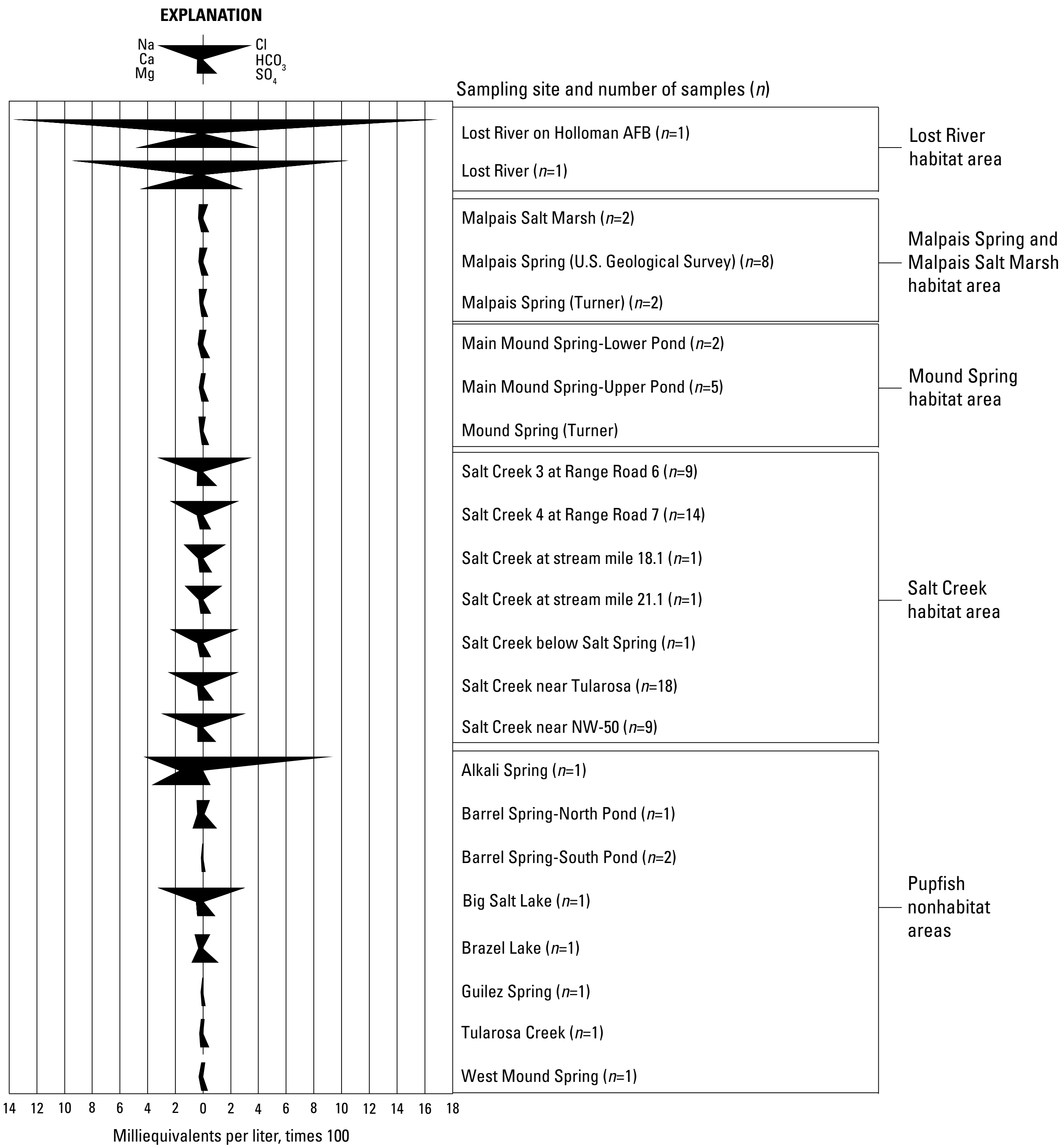

Figure 6. Stiff diagrams showing major-ion chemistry (averaged for sites with more than one sample) of water samples collected from sites in White Sands pupfish (*Cyprinodon tularosa*) habitat and nonhabitat areas, 1983–2007, White Sands Missile Range and Holloman Air Force Base, New Mexico.

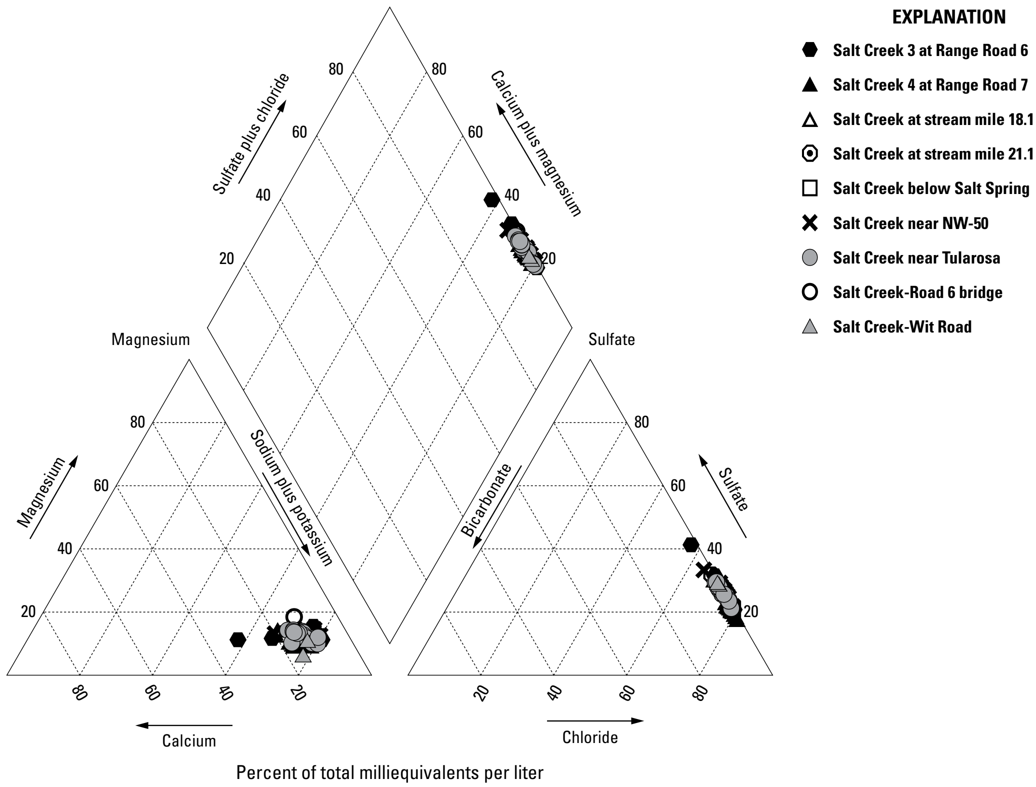

Figure 7. Piper diagram showing major-ion chemistry of water samples collected from sites in the White Sands pupfish (*Cyprinodon tularosa*) Salt Creek habitat area, 1983–2007, White Sands Missile Range and Holloman Air Force Base, New Mexico.

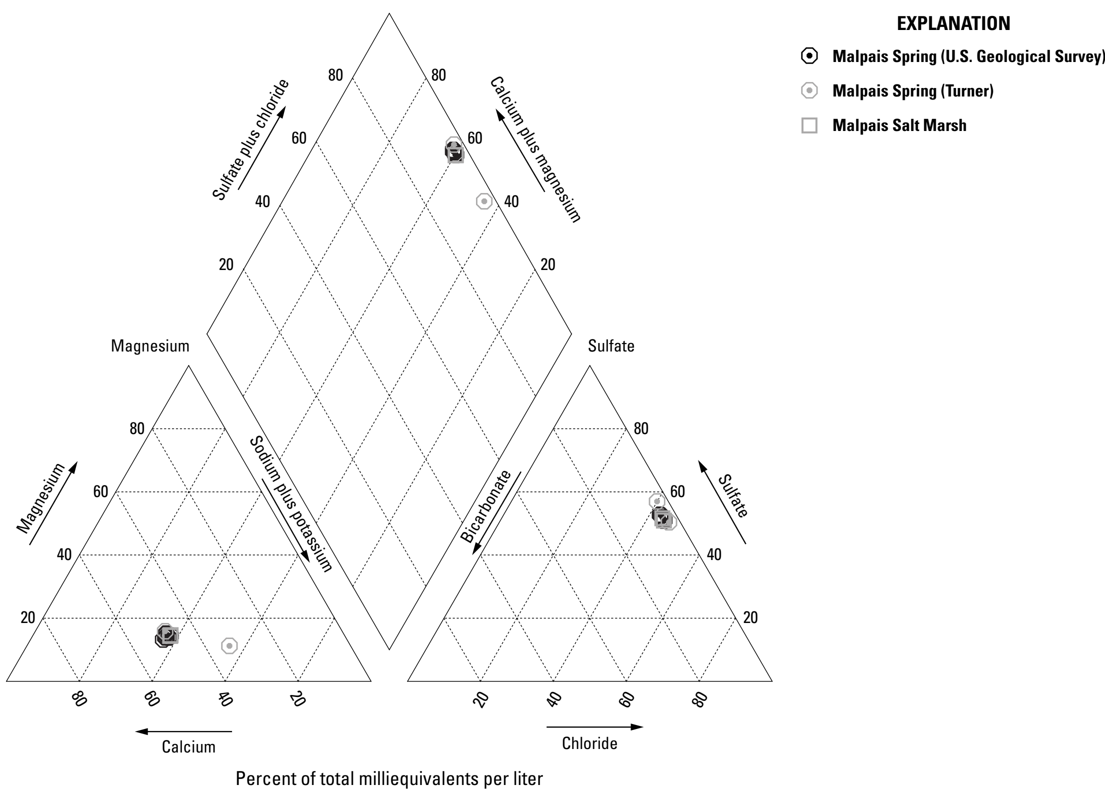

Figure 8. Piper diagram showing major-ion chemistry of water samples collected from sites in the White Sands pupfish (*Cyprinodon tularosa*) Malpais Spring and Malpais Salt Marsh habitat area, 1982–2007, White Sands Missile Range and Holloman Air Force Base, New Mexico.

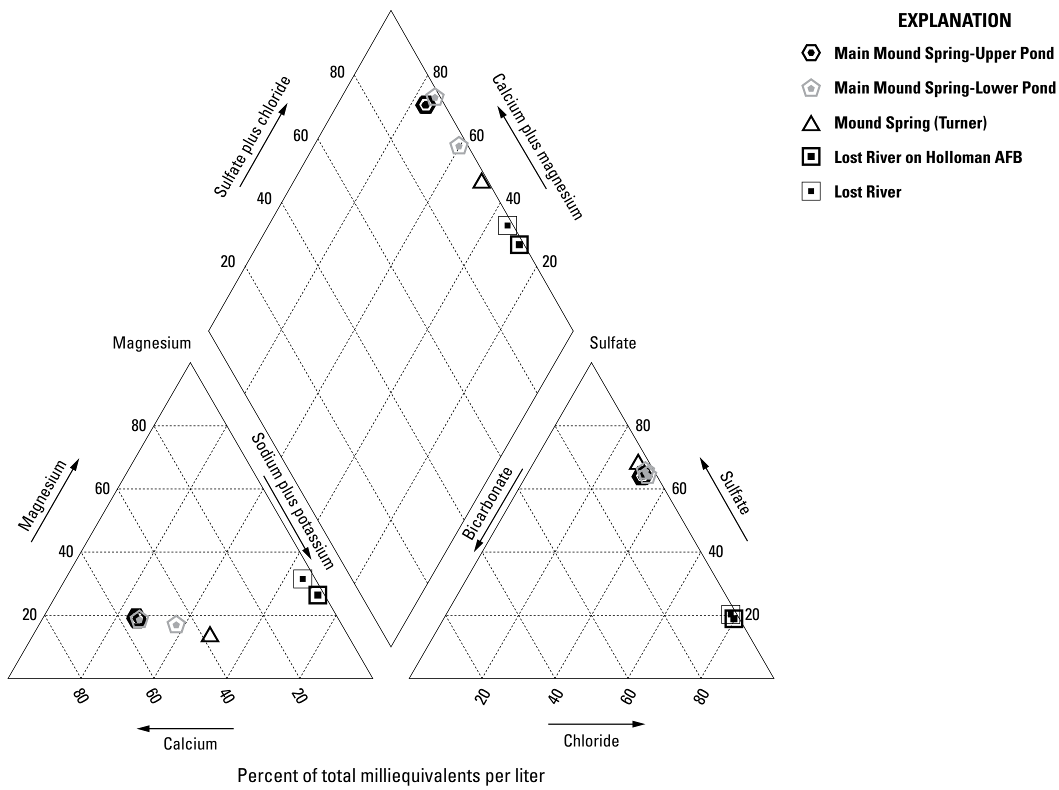

Figure 9. Piper diagram showing major-ion chemistry of water samples collected from sites in the White Sands pupfish (*Cyprinodon tularosa*) Main Mound Spring and Lost River habitat areas, 1982–2006, White Sands Missile Range and Holloman Air Force Base, New Mexico.

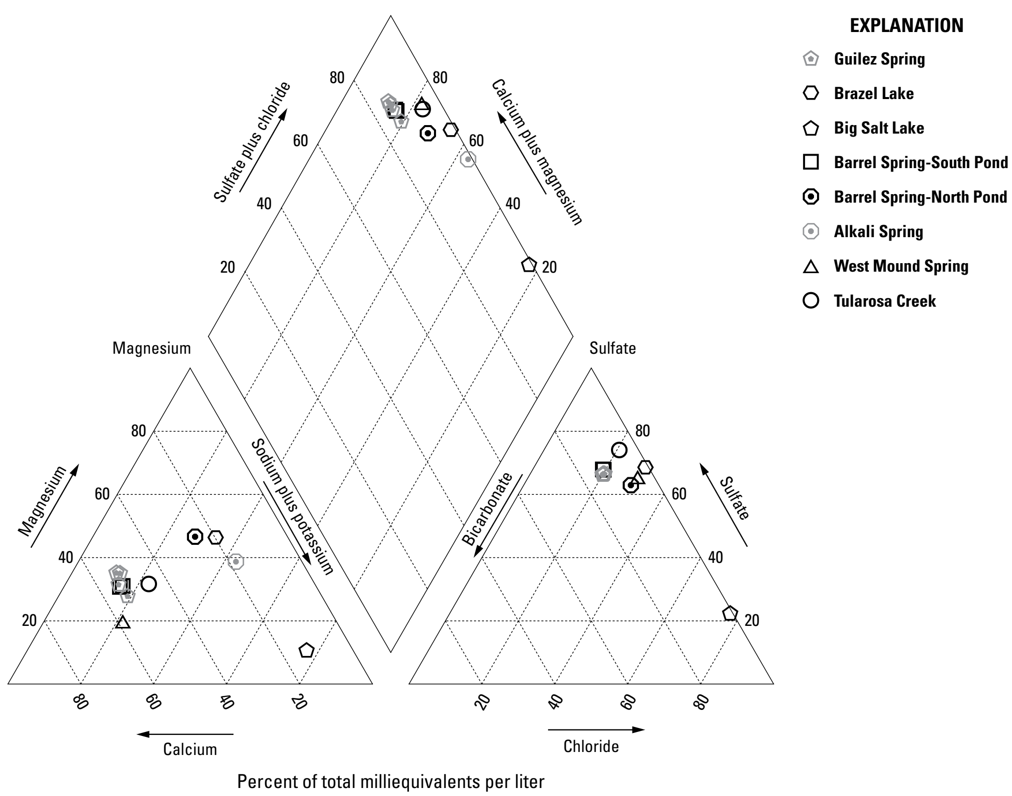

Figure 10. Piper diagram showing major-ion chemistry of water samples collected from sites in White Sands pupfish (*Cyprinodon tularosa*) nonhabitat areas, 1954–2006, White Sands Missile Range and Holloman Air Force Base, New Mexico.

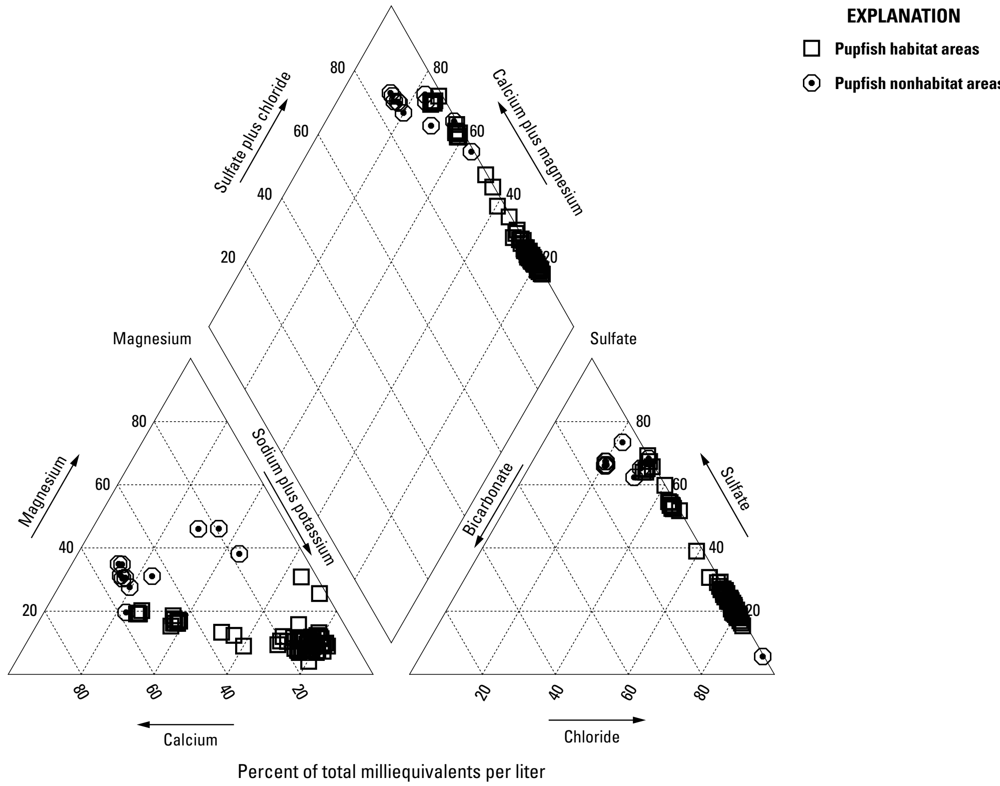

Figure 11. Piper diagram showing major-ion chemistry of water samples collected from White Sands pupfish (*Cyprinodon tularosa*) habitat and nonhabitat areas, 1954–2007, White Sands Missile Range and Holloman Air Force Base, New Mexico.

Salt Creek

As part of the hydrologic monitoring program for pupfish habitats in White Sands Missile Range, streamflow measurements and water samples were collected at seven sites on Salt Creek from 1995 through 2008. USGS streamflow-gaging station 08480595 (Salt Creek near Tularosa [formerly named "Salt Creek at Range Road 316"]; fig. 4), funded by the U.S. Army, White Sands Missile Range, is part of the USGS National Streamflow Information Program, a program designed to ensure the availability of critical information needed to protect and manage rivers in the United States (Hirsch and Norris, 2001). Streamflow data for the Salt Creek near Tularosa gaging station were collected by using both discrete (instantaneous) measurements and a continuous stage-recording device through which either instantaneous or daily mean streamflow may be computed for any time, or any period of time, during the period of record (figs. 12, 13, and 14; tables 2–1 and 2–2). At the six other streamflow-measurement sites on Salt Creek, streamflow data (table 2–2) were obtained through instantaneous measurements without using a continuous stage-recording device. Methods of data collection and computation are described in Byrd and others (2003).

The average annual mean streamflow and average annual total streamflow at the Salt Creek near Tularosa gaging station for water years 1995–2008 were 1.35 cubic feet per second (ft^3/s) and 983 acre-feet, respectively (table 2–1). The maximum instantaneous streamflow (376 ft^3/s) for the period occurred on May 7, 2007. Periods of no flow at the gaging station were observed in water years 2002 through 2006, but small pools of water allowed the White Sands pupfish to maintain their population.

From 1995 to 2008, the USGS periodically collected water-quality data, including field measurements and water samples for chemical analysis, in conjunction with instantaneous streamflow measurements. Beginning in 1998, samples were collected for determination of suspended-sediment concentrations (table 2–2). At the Salt Creek near Tularosa gaging station, suspended-sediment concentrations ranged from 4 to 1,570 milligrams per liter (mg/L) from 1999 through 2008 (table 2–2). Suspended-sediment concentrations in water collected from the other six Salt Creek sites during the same time period ranged from 17 mg/L at the Salt Creek near NW-50 site to 3,430 mg/L at the Salt Creek 4 at Range Road 7 site (table 2–2).

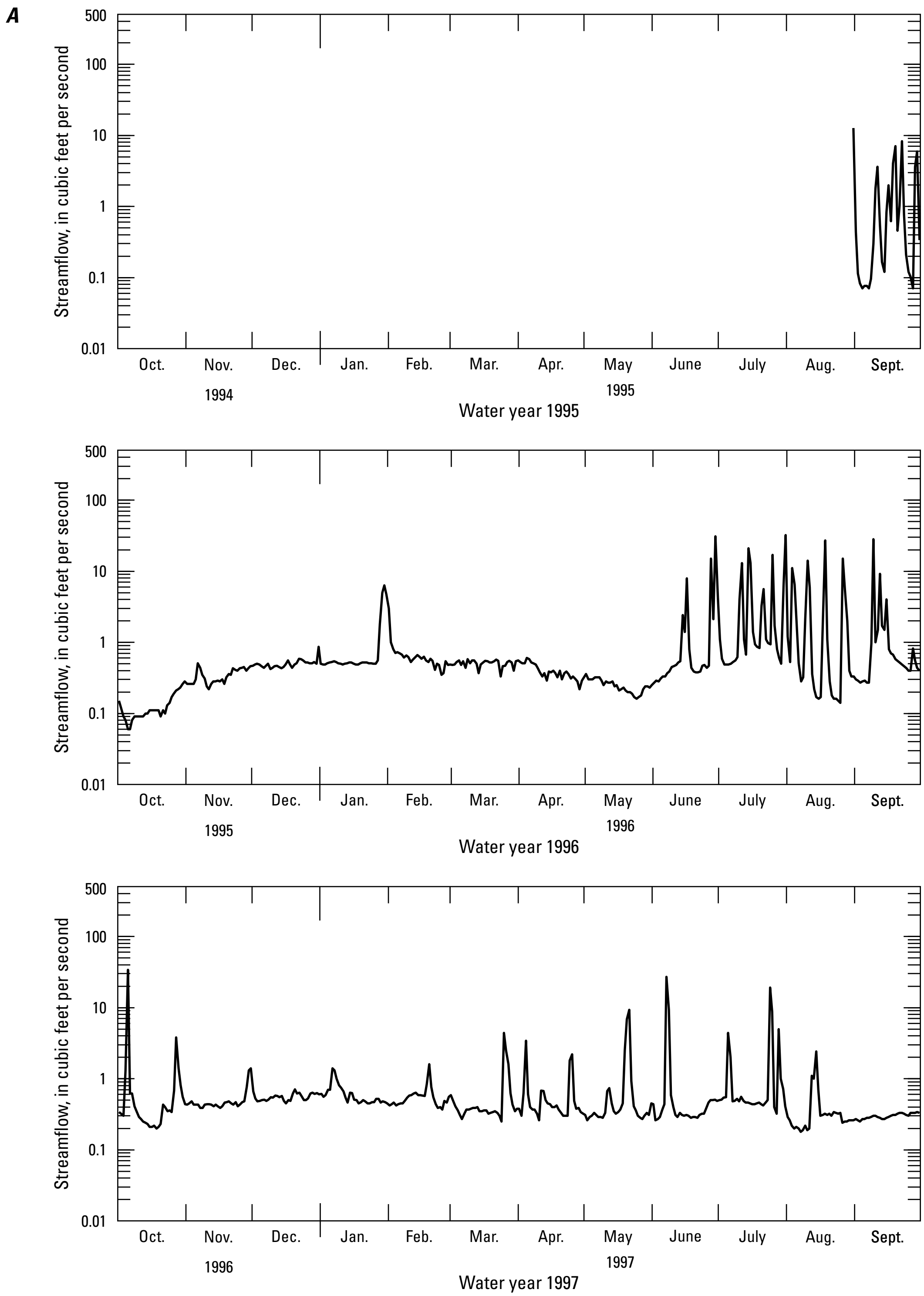

Figure 12. Daily mean streamflow at U.S. Geological Survey streamflow-gaging station Salt Creek near Tularosa, New Mexico (08480595), for water years 1995–2008 (see fig. 4 for location of station). *A*, 1995–1997. *B*, 1998–2000. *C*, 2001–3. *D*, 2004–6. *E*, 2007–8.

B

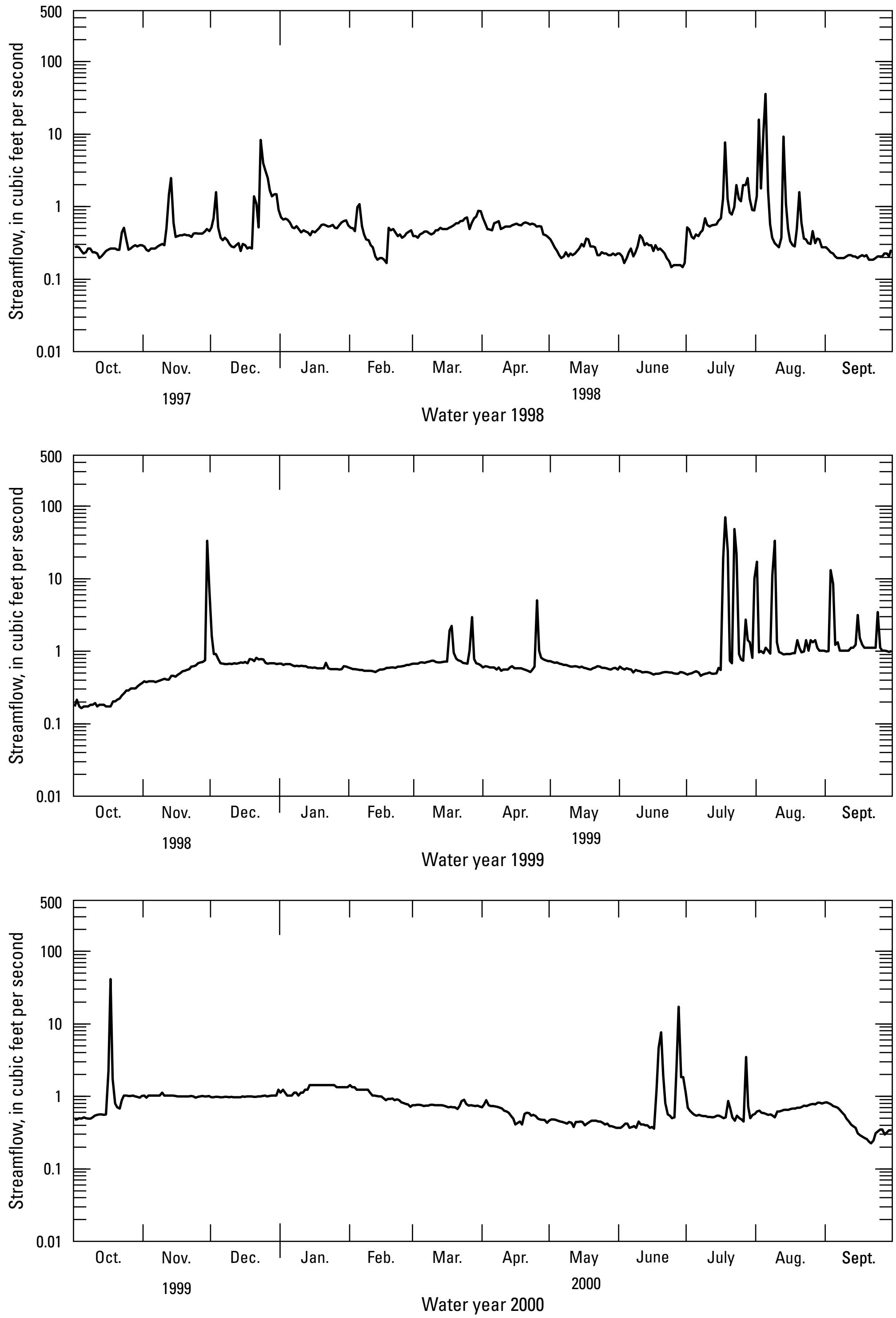

Figure 12. Daily mean streamflow at U.S. Geological Survey streamflow-gaging station Salt Creek near Tularosa, New Mexico (08480595), for water years 1995–2008 (see fig. 4 for location of station). *A*, 1995–1997. *B*, 1998–2000. *C*, 2001–3. *D*, 2004–6. *E*, 2007–8. —Continued

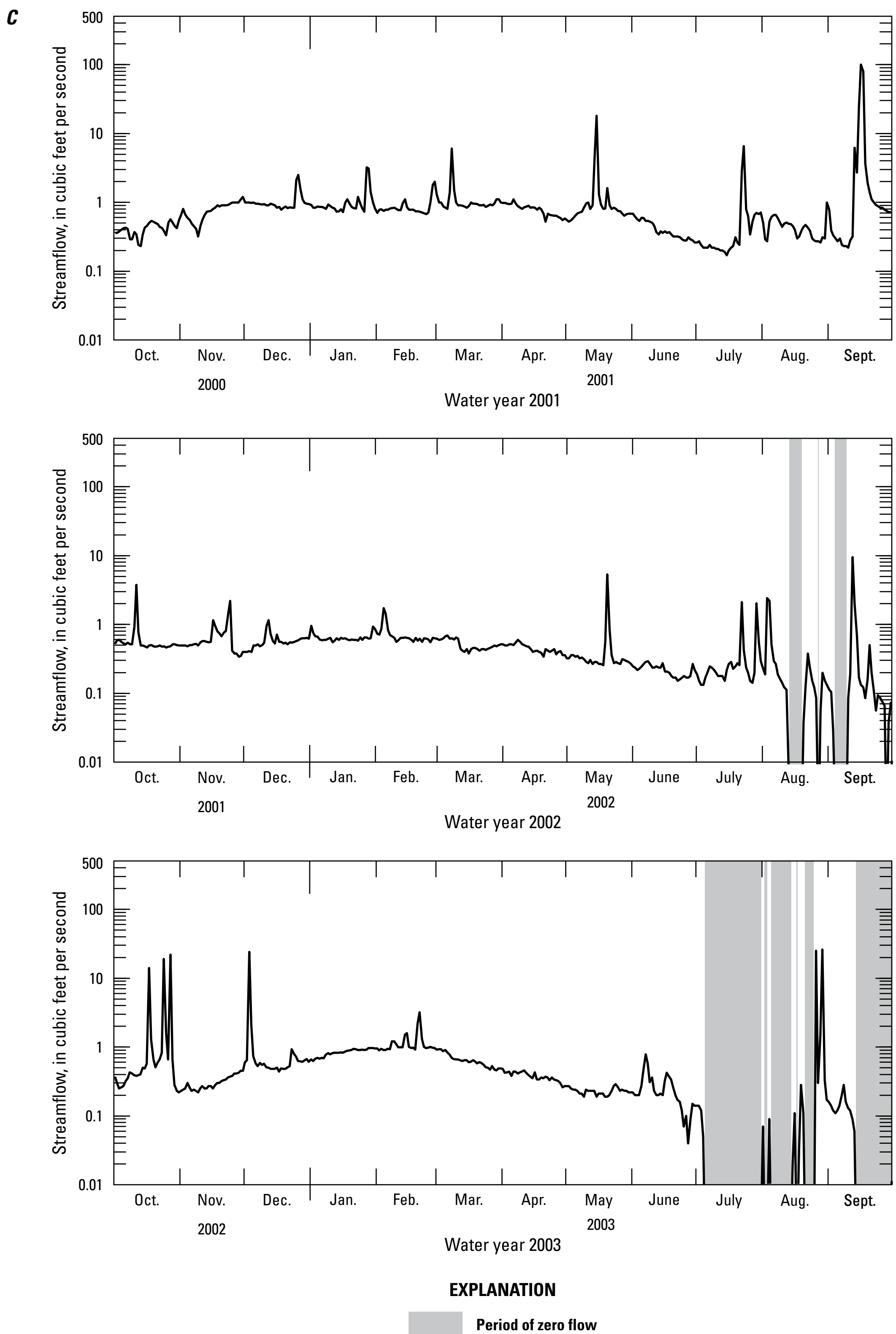

Figure 12. Daily mean streamflow at U.S. Geological Survey streamflow-gaging station Salt Creek near Tularosa, New Mexico (08480595), for water years 1995–2008 (see fig. 4 for location of station). *A*, 1995–1997. *B*, 1998–2000. *C*, 2001–3. *D*, 2004–6. *E*, 2007–8. —Continued

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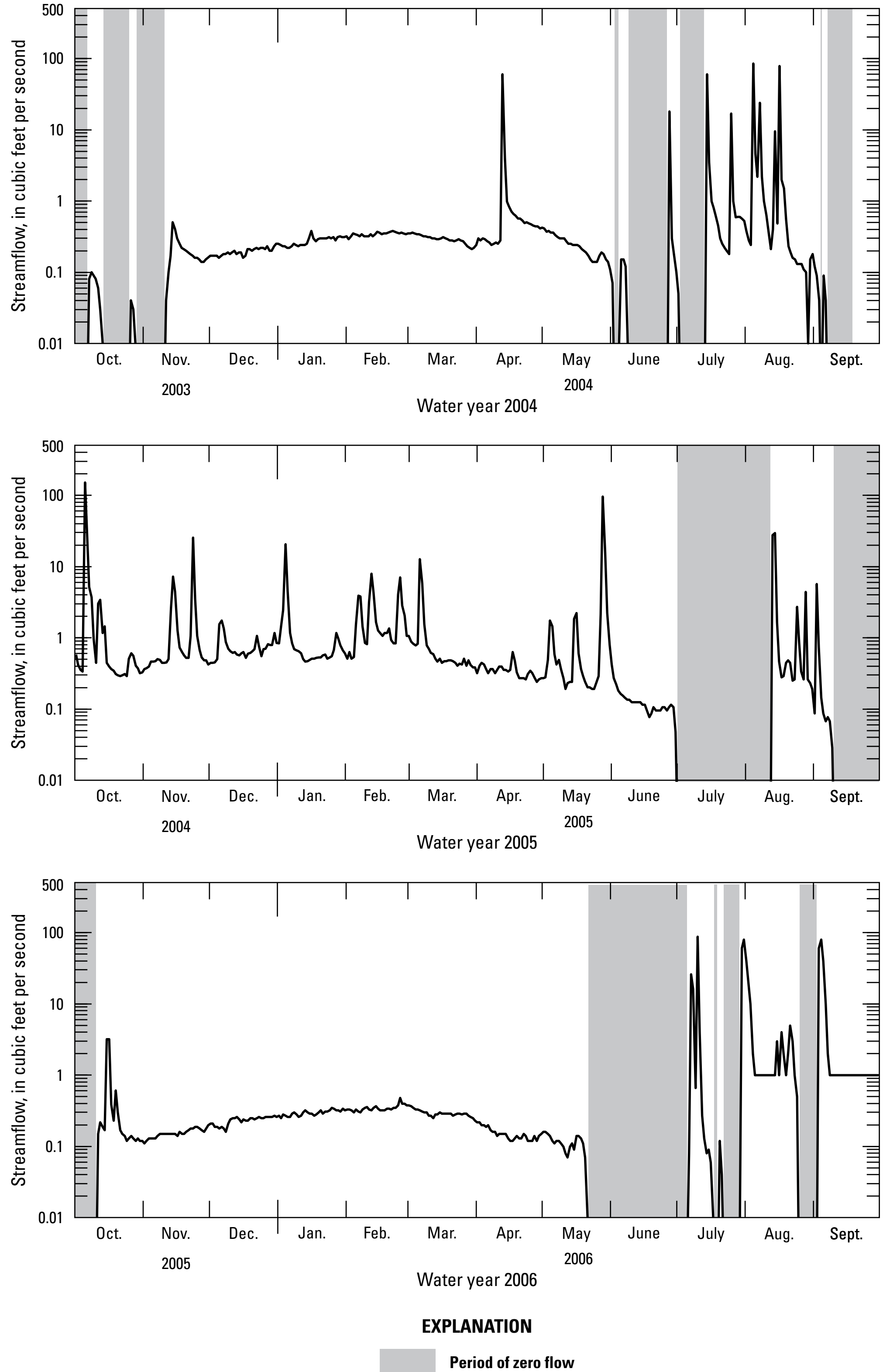

Figure 12. Daily mean streamflow at U.S. Geological Survey streamflow-gaging station Salt Creek near Tularosa, New Mexico (08480595), for water years 1995–2008 (see fig. 4 for location of station). *A*, 1995–1997. *B*, 1998–2000. *C*, 2001–3. *D*, 2004–6. *E*, 2007–8.—Continued

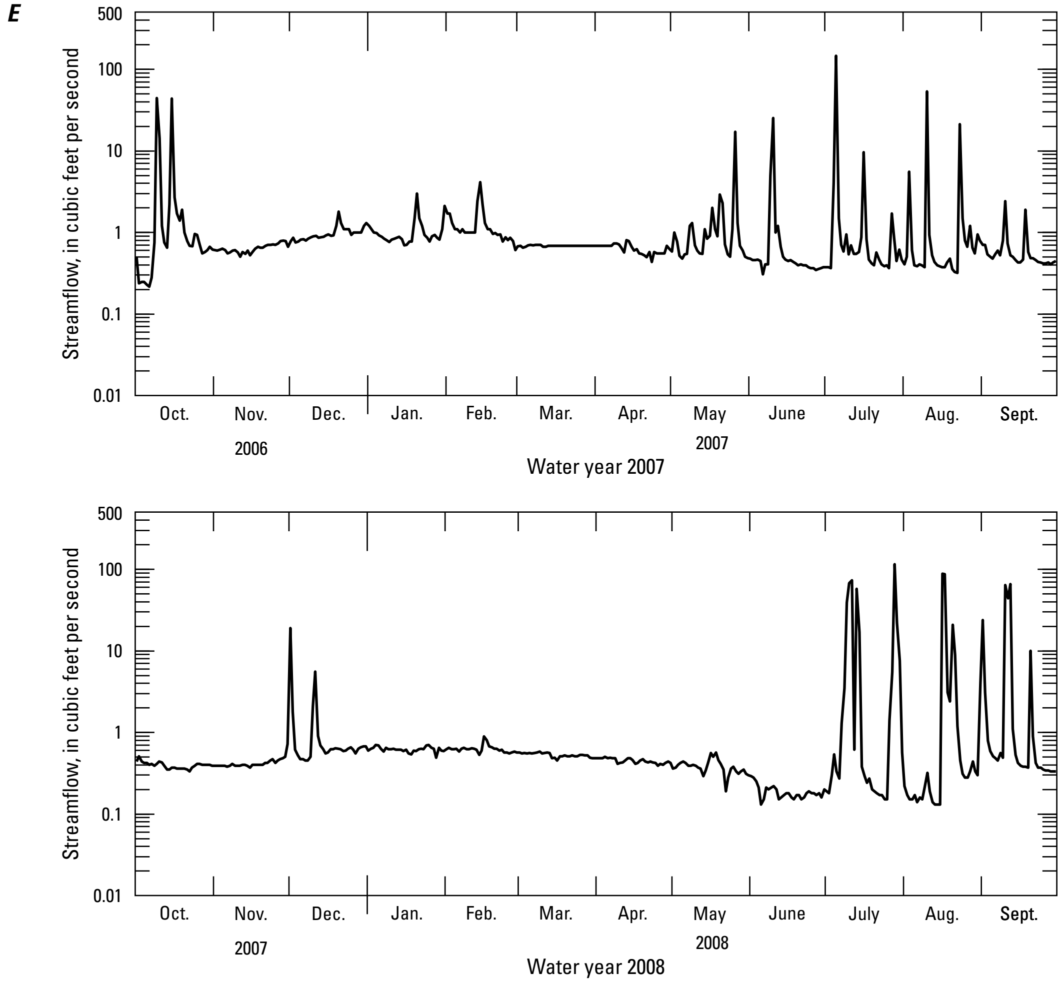

Figure 12. Daily mean streamflow at U.S. Geological Survey streamflow-gaging station Salt Creek near Tularosa, New Mexico (08480595), for water years 1995–2008 (see fig. 4 for location of station). *A*, 1995–1997. *B*, 1998–2000. *C*, 2001–3. *D*, 2004–6. *E*, 2007–8. —Continued

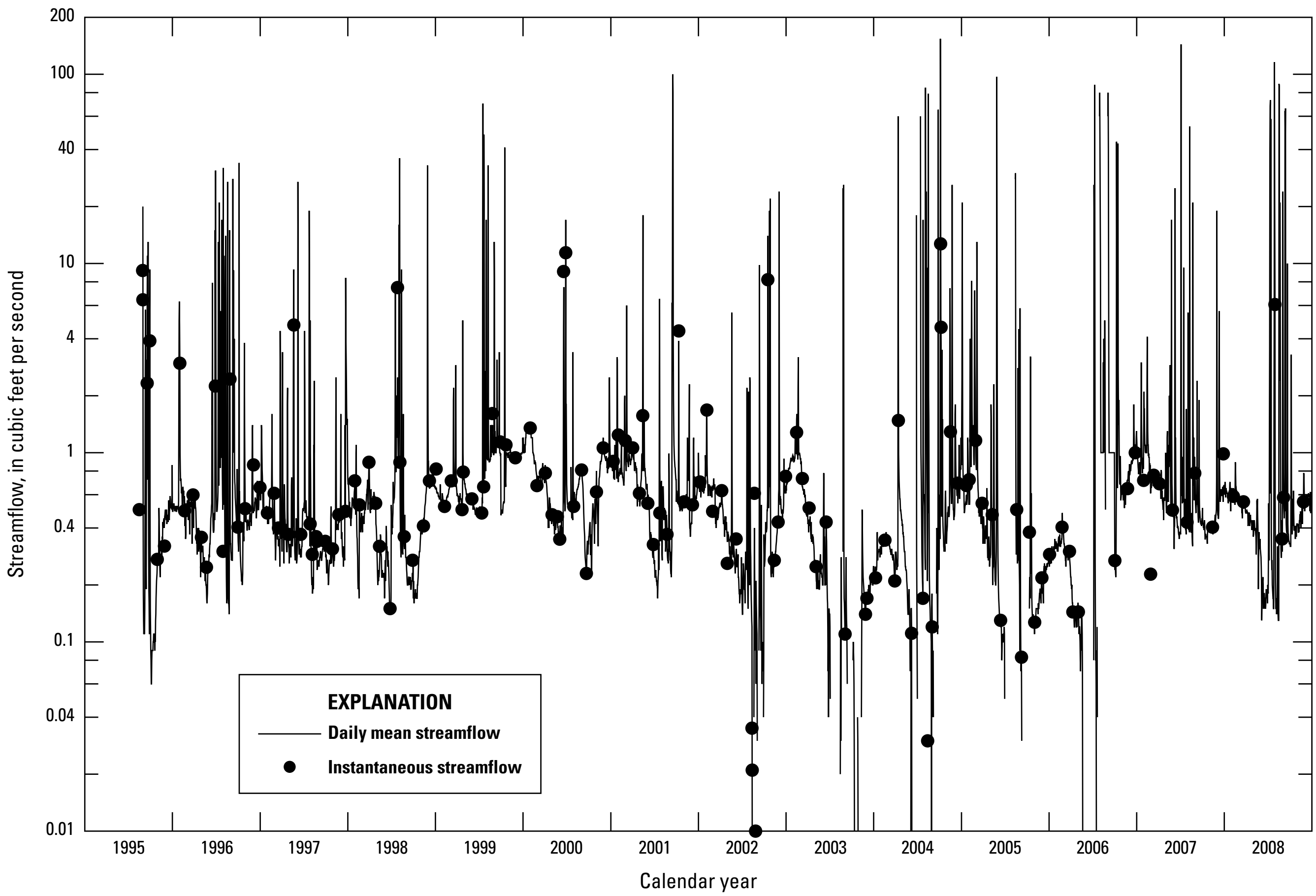

Figure 13. Daily mean and instantaneous streamflow at U.S. Geological Survey streamflow-gaging station Salt Creek near Tularosa, New Mexico (08480595), calendar years 1995–2008 (see fig. 4 for location of station).

The magnitude of the dissolved-solids concentrations in Salt Creek varies throughout the length of the stream channel. Dissolved-solids concentrations and other chemical and physical characteristics of the water also can vary temporally because of precipitation, surface-water runoff, and changes in bank storage of groundwater. In samples collected from Salt Creek from 1911 through 2007, dissolved-solids concentrations ranged from 2,290 to 66,700 mg/L (solids, sum of constituents in table 2–4). Salt Creek base flow generally is saline (defined for this report as 10,000–100,000 mg/L dissolved solids), but during low and high flow, the dissolved-solids concentrations can vary from brackish (defined for this report as 1,000–10,000 mg/L dissolved solids) to saline.

A seepage (gain-loss) study was conducted on August 12–13, 2002, along the 24.5-mile reach from the Salt Creek below Salt Spring site (fig. 4) to the mouth of the creek at Big Salt Lake (fig. 5). Stream miles are referenced upstream from the mouth of the creek, which is designated as stream mile 0. Streamflow measurements (fig. 15; table 2–3) indicate a net seepage loss of 0.07 ft^3/s from the Salt Creek below Salt Spring site at stream mile 24.5 to the Salt Creek near Tularosa gaging station at stream mile 17.6. Ponded, no-flow conditions at stream mile 14.5 were noted, and dry conditions were observed from stream mile 12.5 to the mouth of Salt Creek at stream mile 0. No tributary inflow or outflow (diversions) was observed during the study. Channel gain or loss values incorporate seepage to or from the unlined channel, evaporation from the water surface, and evapotranspiration by vegetation along the channel banks. Individual streamflow measurements, made by using a 3-inch Parshall flume, were rated excellent (error of 5 percent or less) throughout the stream reach (Byrd and others, 2003). The overall investigation was rated fair (error of 15 percent or less) on the basis of unsteady streamflow conditions (Byrd and others, 2003). During the seepage investigation, dissolved-solids concentrations of samples collected from five sites (between stream mile 24.5 and stream mile 17.6) ranged from 12,700 to 38,100 mg/L (fig. 15; table 2–3).

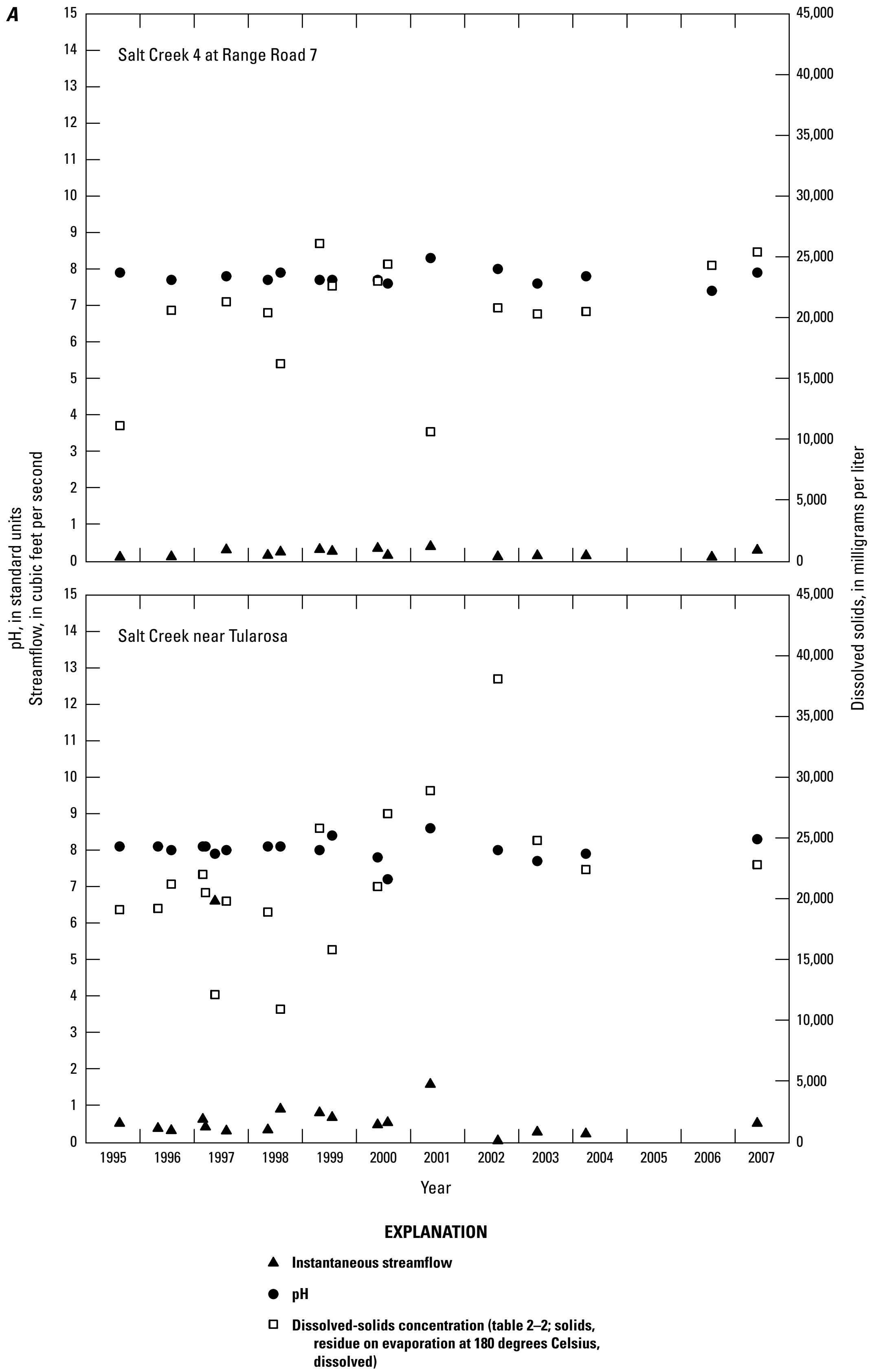

Figure 14. Instantaneous streamflow, dissolved-solids concentration, and pH at Salt Creek surface-water sites (see fig. 4 for locations of sites). *A*, Salt Creek 4 at Range Road 7 and Salt Creek near Tularosa. *B*, Salt Creek near NW-50 and Salt Creek 3 at Range Road 6.

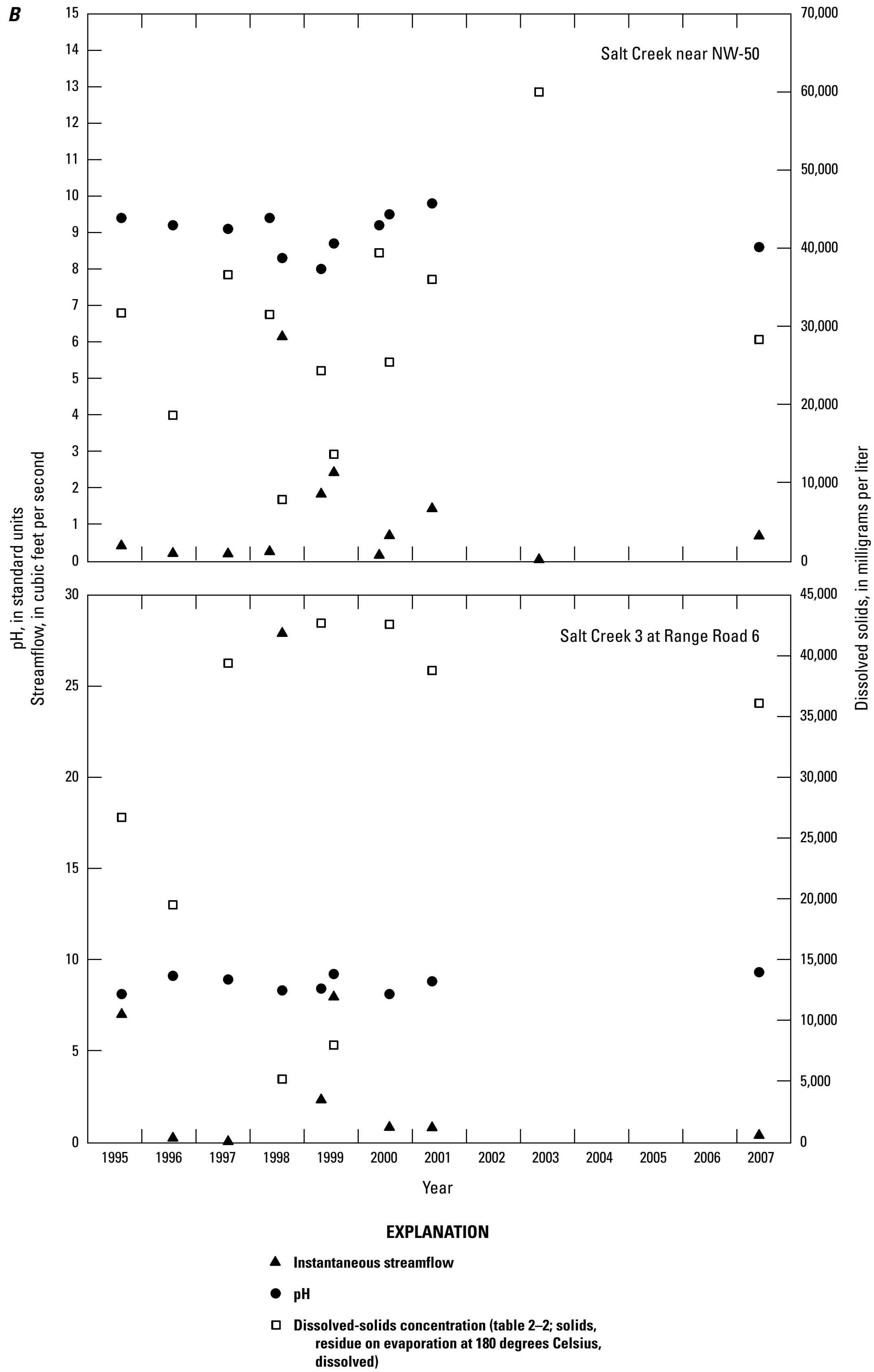

Figure 14. Instantaneous streamflow, dissolved-solids concentration, and pH at Salt Creek surface-water sites (see fig. 4 for locations of sites). *A*, Salt Creek 4 at Range Road 7 and Salt Creek near Tularosa. *B*, Salt Creek near NW-50 and Salt Creek 3 at Range Road 6. —Continued

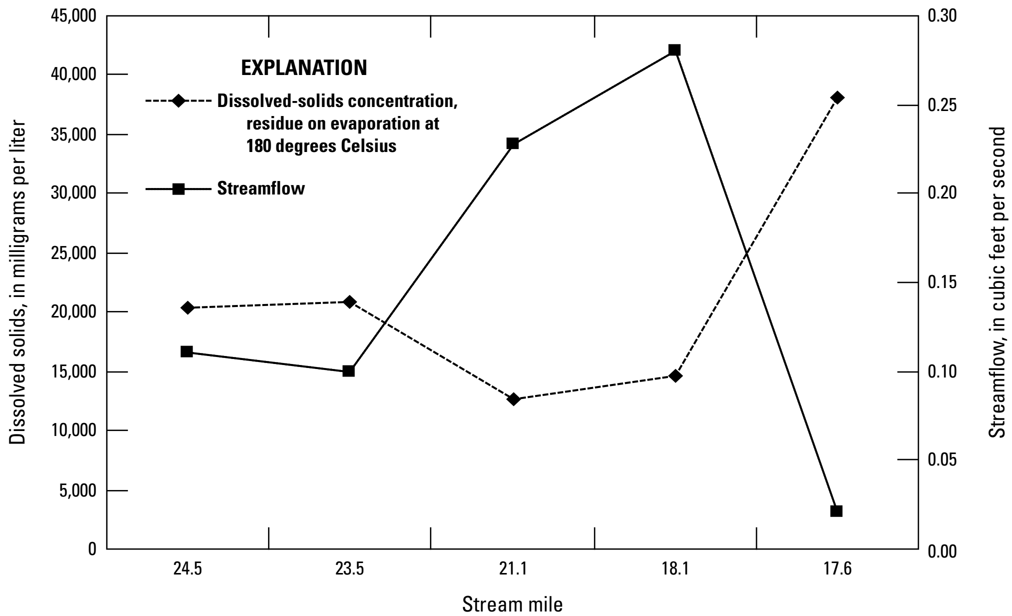

Figure 15. Dissolved-solids concentrations and streamflow during a seepage (gain-loss) study along a 24.5-mile reach of Salt Creek, New Mexico, August 12–13, 2002.

Most Salt Creek samples were sodium-chloride-sulfate type water (figs. 6 and 7); a few samples were sodium-chloride or sodium-calcium-chloride-sulfate type water. Concentrations of sodium and chloride exceeded those of seawater (10,500 and 19,000 mg/L, respectively) in some samples (table 2–4). Concentrations of trace elements (table 2–5), when detected, generally were higher in Salt Creek samples than in most samples from other areas. Dissolved chromium was detected only once in Salt Creek samples at 1.6 micrograms per liter (µg/L) in a sample from the Salt Creek near Tularosa gaging station. Salt Creek dissolved selenium concentrations (ranging from 1 to 10 µg/L) and dissolved strontium concentrations (ranging from 7,110 to 44,500 µg/L) were similar to selenium and strontium concentrations in samples from other sites.

Nitrate (as N) concentrations in Salt Creek samples generally were less than 0.70 mg/L (table 2–6), but in two Salt Creek samples nitrate (as N) concentrations were 1.98 and 1.29 mg/L. In these two samples nitrite (as N) concentrations (0.332 and 0.310 mg/L) were higher than in all other samples except one from Big Salt Lake (0.500 mg/L). Total phosphorus (as P) concentrations were generally similar in Salt Creek samples to concentrations in samples from other locations (generally not more than 0.05 mg/L), but three samples from Salt Creek had concentrations of 0.102, 0.14, and 1.17 mg/L.

In samples collected between 1995 and 2001, total bromide concentrations in Salt Creek samples were highly variable, ranging from 0.55 to 84.8 mg/L (table 2–7). The Salt Creek near NW-50 sample collected in May 2003 had the highest dissolved bromide concentration (6.62 mg/L) of any sample. Triethyl phosphate was not detected in any samples collected in the study area. One sample collected in 2000 from Salt Creek 4 at Range Road 7 had a perchlorate concentration of 16 µg/L; however, this was the only sample collected with detectable perchlorate. In subsequent samples, perchlorate was not detected. The herbicide 2,4-D was detected in 2 of 38 Salt Creek samples collected between 1995 and 2001 (table 2–8). Concentrations in these samples were 0.020 and 0.030 µg/L, less than the maximum contaminant level for drinking water of 70 µg/L set by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, no date).

Malpais Spring and Malpais Salt Marsh

The Malpais Spring near Oscura streamflow-gaging station (08480594) (fig. 4), funded by the U.S. Army, White Sands Missile Range, was installed in July 2003 on the main channel that flows from Malpais Spring to the Malpais Salt Marsh wetlands. Streamflow data for the Malpais Spring near Oscura gaging station were obtained by using both discrete (instantaneous) measurements and a continuous stage-recording device through which either instantaneous or daily mean streamflow may be computed for any time, or any period of time, during the period of record (figs. 16 and 17; tables 2–1 and 2–2).

The average annual mean streamflow and average annual total streamflow at the Malpais Spring near Oscura gaging station for water years 2003–8 were 6.81 ft^3/s and 584 acre-feet, respectively (table 2–1). The maximum instantaneous streamflow of 4.3 ft^3/s for the period occurred on both January 9, 2004, and August 19, 2006.

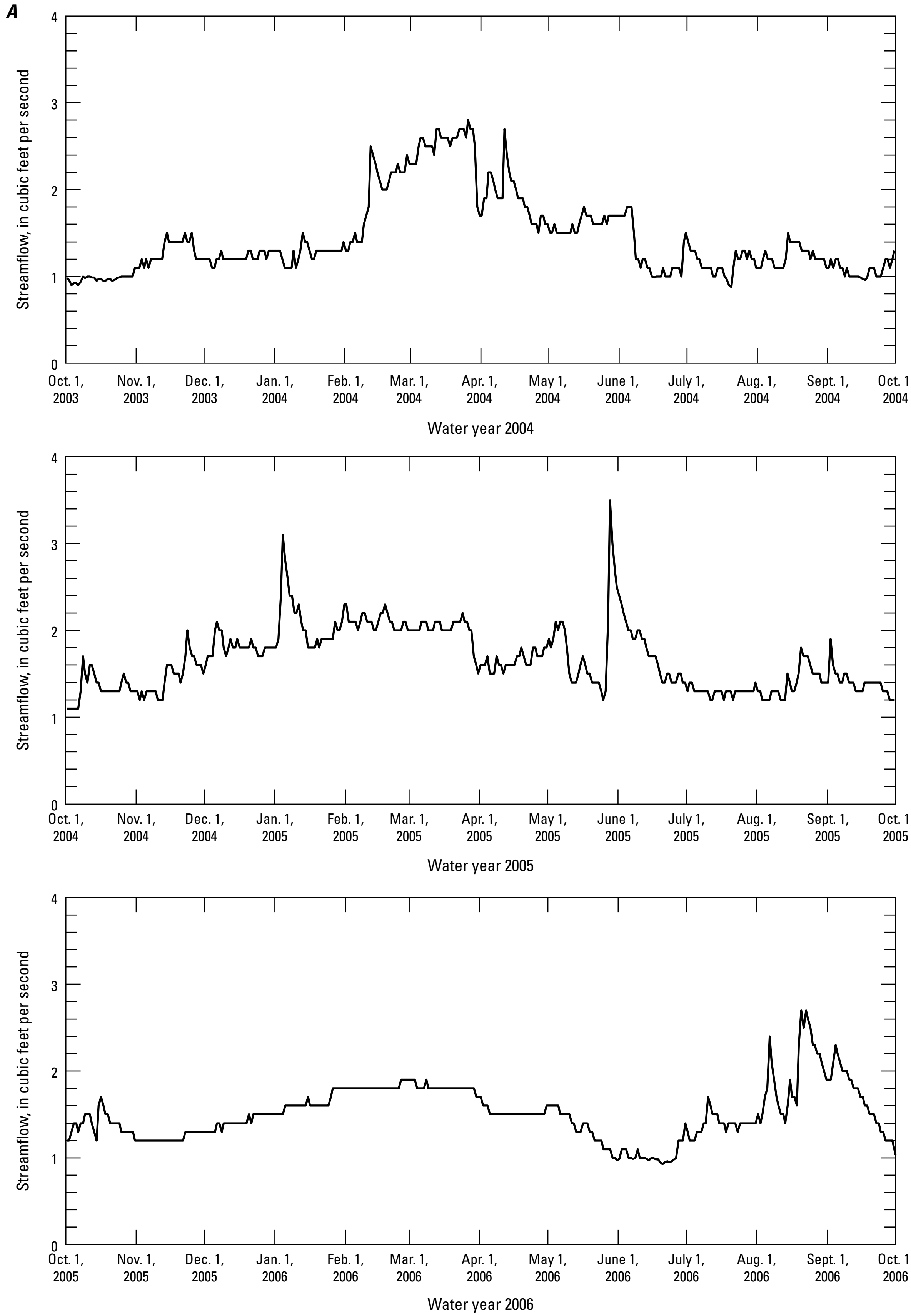

Figure 16. Daily mean streamflow at U.S. Geological Survey streamflow-gaging station Malpais Spring near Oscura, New Mexico (08480594), for water years 2004–8 (see fig. 4 for location of station). *A*, 2004–6. *B*, 2007–8.

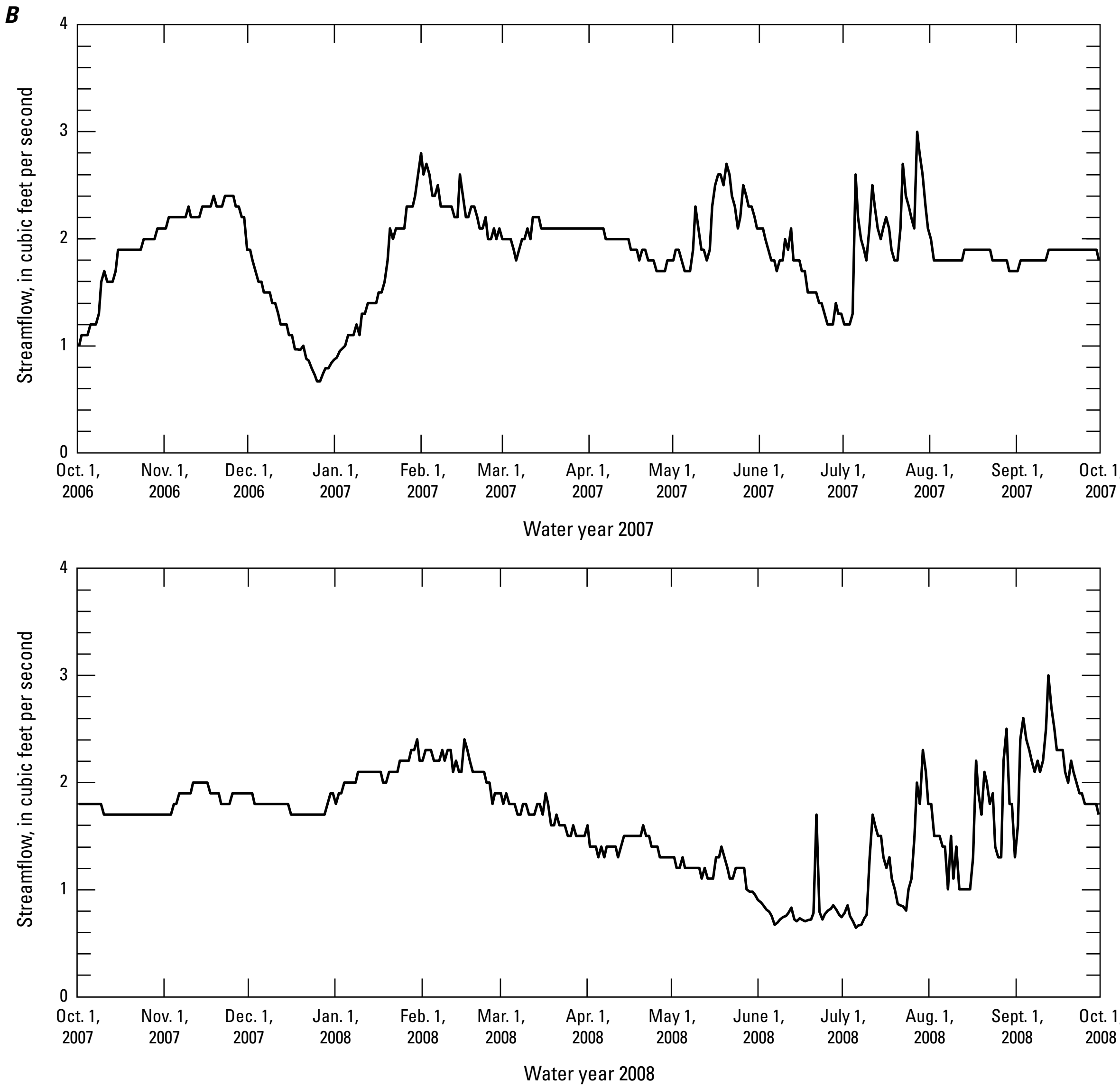

Figure 16. Daily mean streamflow at U.S. Geological Survey streamflow-gaging station Malpais Spring near Oscura, New Mexico (08480594), for water years 2004–8 (see fig. 4 for location of station). *A*, 2004–6. *B*, 2007–8.—Continued

Meinzer and Hare (1915) estimated the flow of Malpais Spring to be about 4.46 ft^3/s in 1911, and Weir (1965) estimated the flow to be about 3.34 ft^3/s in 1955 (table 2–2). Flow rates measured near the upper end of the stream channel in 1984 were 1.3 (March 3, 1984), 1.1 (June 2, 1984), and 1.1 (August 12, 1984) ft^3/s (Malpais Spring-Upper End in table 2–2). From 1996 to 2008, instantaneous flow measurements in the channel near Malpais Spring made by the USGS ranged from 0.74 (December 26, 2006) to 2.6 ft^3/s (March 29, 2004) (table 2–2).

For the 16 Malpais Spring samples (Malpais Spring near Oscura, Malpais Spring [Meinzer and Hare], Malpais Spring [Turner], and Malpais Spring [Weir]) that have dissolved-solids concentrations (solids, sum of constituents, dissolved in table 2–4), the dissolved-solids concentrations ranged from 3,882 to 5,500 mg/L. Excluding the lowest (3,882 mg/L) and highest (5,500 mg/L) concentrations, dissolved-solids concentrations fell within a relatively narrow range of 4,360 (estimated) to 4,800 mg/L (solids, sum of constituents, dissolved in table 2–4). Dissolved-solids concentrations in water samples from Malpais Salt Marsh generally were higher than were concentrations in the Malpais Spring samples, particularly at the lower end of the marsh (Malpais Salt Marsh Lower Lake in table 2–4) where one concentration was an estimated 12,600 mg/L. The two highest dissolved-solids (residue on evaporation) concentrations (8,780 and 7,080 mg/L) in water from any pupfish habitat area springs were measured in samples from Malpais Spring Pond, a manmade

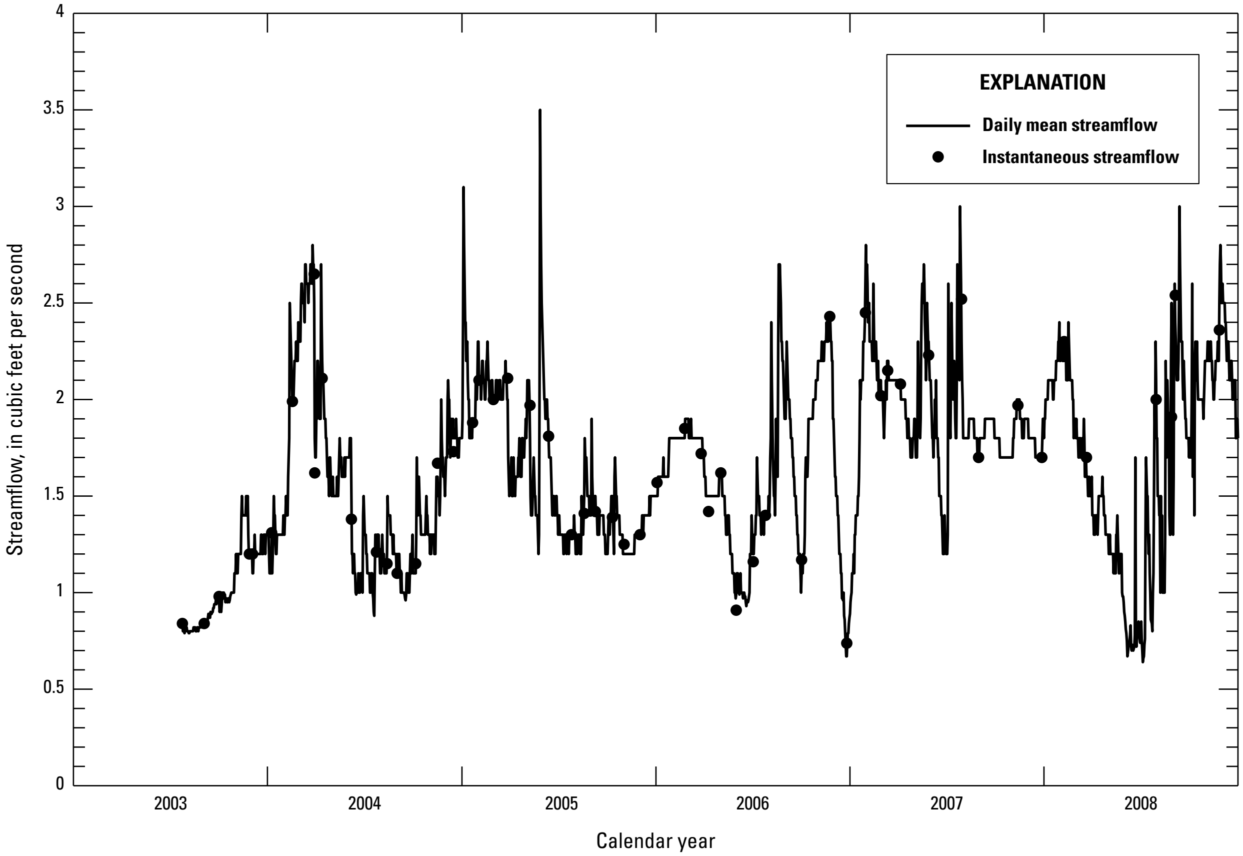

Figure 17. Daily mean and instantaneous streamflow at U.S. Geological Survey streamflow-gaging station Malpais Spring near Oscura, New Mexico (08480594), calendar years 2003–8 (see fig. 4 for location of station)

pond about 2 miles south of the Malpais Spring springhead (fig. 4), and from Malpais Spring-Edge of Marsh, respectively (table 2–4).

The water type of samples from the Malpais Spring and Malpais Salt Marsh habitat area has been consistently calcium-sulfate (fig. 8; table 2), with the exception of one sample collected in 1983 for which the water type was sodium-sulfate (table 2). Although some of the later detection limits were higher than were concentrations of chromium, copper, iron, lead, manganese, and zinc in the 1982 Malpais Spring near Oscura sample (table 2–5), some of the 1982 values appear to be anomalously high as compared with concentrations in the other 12 Malpais Spring samples (with analytical results) from Malpais Spring near Oscura collected from 1996 through 2007. In samples collected from the Malpais Spring and Malpais Salt Marsh habitat area from 1996 through 2007, concentrations of most trace elements, when detected, were similar to or lower than concentrations at most other sites (table 2–5). Exceptions include chromium, which was detected in 10 (including four estimated values) samples at concentrations of 2.0–14.5 (estimated) µg/L, and selenium, which was detected in 13 samples (one estimated value) at concentrations of 1–7 µg/L in samples from Malpais Spring near Oscura and Malpais Salt Marsh (table 2–5).

In samples collected from Malpais Spring near Oscura and Malpais Spring (Weir) nitrate (as N) and nitrate plus nitrite (as N) concentrations generally were higher than concentrations in samples from other sites (table 2–6). Orthophosphate (as P) concentrations generally were similar in Malpais Spring near Oscura samples and samples from other sites, but the highest concentration (0.24 mg/L) at any site was detected in a sample collected from Malpais Spring near Oscura on May 15, 2001 (table 2–6). Total bromide concentrations (table 2–7) measured in two Malpais Spring near Oscura samples (collected in 2000 and 2001) were 0.57 and 8.5 mg/L, respectively. Herbicides and pesticides included in this data compilation were not detected (table 2–8).

Carbon 14 isotopic data for a Malpais Spring near Oscura water sample collected by the USGS in 1982 indicated that the water was greater than 27,900 years old (Cruz, 1983; table 2–9). Before recharging the aquifer, the carbon 14 composition of water can be affected by carbon dioxide gas and dissolution of carbonate minerals in the unsaturated zone (Anderholm and Heywood, 2003). For groundwater samples from the Hueco Bolson (fig. 1) south of Tularosa Basin, Anderholm and Heywood (2003) assumed that at the time the water in their samples recharged the aquifer the carbon 14 composition of that water was 100 percent modern. A

Table 2. Water types of samples collected from sites on White Sands Missile Range and Holloman Air Force Base, New Mexico, 1911–2008.

[Pupfish nonhabitat areas shaded grey. AFB, Air Force Base]

Site name from table 1 and data source for multiple sites with same name (site locations shown in figs. 4 and 5)	Number of samples with sufficient data to determine water type	Pupfish habitat area (habitat areas shown on fig. 3)
Calcium-sulfate water type		
Barrel Spring-South Pond	2	Nonhabitat.
Dead Oryx Mound Spring	1	Nonhabitat.
Guilez Spring	1	Nonhabitat.
Main Mound Spring-Lower Pond	3	Mound Spring.
Main Mound Spring (unknown if from Upper or Lower Pond)	1	Mound Spring.
Main Mound Spring-Upper Pond	8	Mound Spring.
Malpais Salt Marsh	4	Malpais Spring and Malpais Salt Marsh.
Malpais Spring near Oscura	12	Malpais Spring and Malpais Salt Marsh.
Malpais Spring (Meinzer and Hare)	1	Malpais Spring and Malpais Salt Marsh.
Malpais Spring (Turner)[a]	1	Malpais Spring and Malpais Salt Marsh.
North Mound Spring	1	Nonhabitat.
South Mound Spring	1	Nonhabitat.
Tularosa Creek	1	Nonhabitat.
West Mound Spring	2	Nonhabitat.
Magnesium-sulfate water type		
Barrel Spring-North Pond	1	Nonhabitat.
Brazel Lake	1	Nonhabitat.
Sodium-chloride water type		
Alkali Spring	1	Nonhabitat.
Big Salt Lake	1	Nonhabitat.
Lost River on Holloman AFB	1	Lost River.
Lost River	1	Lost River.
Salt Creek 3 at Range Road 6	9	Salt Creek.
Salt Creek 4 at Range Road 7	15	Salt Creek.
Salt Creek at stream mile 18.1	1	Salt Creek.
Salt Creek at stream mile 21.1	1	Salt Creek.
Salt Creek below Salt Spring	1	Salt Creek.
Salt Creek near Tularosa	18	Salt Creek.
Salt Creek near NW-50	11	Salt Creek.
Salt Creek-Road 6 Bridge	1	Salt Creek.
Salt Creek-Wit Road	2	Salt Creek.
Sodium-sulfate water type		
Malpais Spring (Turner)[b]	1	Malpais Spring and Malpais Salt Marsh.
Mound Spring (Turner)	1	Mound Spring.

[a]Sample collected on June 8, 1986.

[b]Sample collected on December 3, 1983.

smaller percentage of modern carbon would cause calculated apparent age to be less. Although Cruz (1983) does not discuss assumptions used to estimate the carbon 14 apparent age for the Malpais Spring near Oscura sample, the apparent age is similar to the high end of the range of groundwater ages (12,100–25,500 years) estimated by Anderholm and Heywood (2003).

Main Mound Spring

At the Main Mound Spring-Upper Pond in 1955 and 1957, streamflow was estimated to be about 0.007 ft^3/s (table 2–2). From 1996 to 2001 measured streamflow ranged from 0.02 to 0.07 ft^3/s (table 2–2). Dissolved-solids concentrations of samples collected by the USGS annually between 1955 and 2007 ranged from 3,760 (estimated) to 4,240 (estimated) mg/L in the Main Mound Spring-Upper Pond and from 4,840 to 5,120 (estimated) mg/L in the Main Mound Spring-Lower Pond (solids, sum of constituents, dissolved in table 2–4).

Water from the Main Mound Spring-Upper Pond and Main Mound Spring-Lower Pond has consistently been a calcium-sulfate type (figs. 6 and 9; table 2). Concentrations of chromium, copper, iron, lead, manganese, and zinc in a sample collected from Main Mound Spring (unknown if from upper or lower pond) in 1982 appear to be anomalously high compared to concentrations in other samples collected from that site (table 2–5). In all other Main Mound Spring-Upper Pond and Main Mound Spring-Lower Pond samples, concentrations of most trace elements, when detected, were similar to or lower than concentrations at other sites. Nutrient concentrations (table 2–6) observed in Main Mound Spring upper and lower pond samples were generally lower than those for Malpais Spring near Oscura samples. No pesticides or herbicides (table 2–8) were detected in Main Mound Spring-Upper Pond or Main Mound Spring-Lower Pond samples. In Main Mound Spring-Upper Pond, total bromide concentrations were 0.60 and 5.3 mg/L in 2000 and 2001, respectively (table 2–7).

Carbon 14 isotopic data for a Main Mound Spring water sample (unknown if from upper or lower pond) collected by the USGS in 1982 indicated that the water was about 19,600 years old (Cruz, 1983; table 2–9). Although Cruz (1983) does not discuss assumptions used to estimate the carbon 14 apparent age for the Main Mound Spring sample, the apparent age within the range of ages (12,100–25,500 years) estimated by Anderholm and Heywood (2003) for groundwater samples collected from wells in the Hueco Bolson (fig. 1) south of Tularosa Basin. A sample collected in 2006 from Main Mound Spring-Upper Pond had a carbon 14 (percent modern carbon) value of 8.58 percent (table 2–9). This value is similar to that of the Main Mound Spring (unknown if from upper or lower pond) (8.80 percent; table 2–9), so the age apparent ages of the two samples would be about the same.

Lost River

The hydrologic characteristics of Lost River are the least studied of the four pupfish habitat areas. Lost River water usually ranges from brackish to briny (briny is defined in this report as greater than 100,000 mg/L dissolved solids). Dissolved-solids concentrations of Lost River (Lost River on Holloman AFB, Lost River, and Lost River 1–8) samples collected from 1984 to 1999 ranged from 8,930 to 118,000 (estimated) mg/L (solids, sum of constituents, dissolved, table 2–4). The water type of samples collected in 1984 and 1999 was sodium-chloride (figs. 6 and 9; table 2). Data are available for only three trace elements analyzed in one sample (Lost River on Holloman AFB); of these, the concentration of dissolved bromide (6.55 mg/L on March 17, 1999; table 2–5) was the second highest of any sample documented in this study. Little nutrient data are available for Lost River, and there are no total bromide, triethyl phosphate, perchlorate, pesticide, or herbicide data.

Sites Located in Pupfish Nonhabitat Areas

Sites located in pupfish nonhabitat areas for which streamflow and (or) water-quality data are available include Alkali Spring (fig. 3), springs near the Main Mound Spring habitat area (Dead Oryx Mound Spring, North Mound Spring, South Mound Spring, and West Mound Spring) (fig. 4), Big Salt Lake (fig. 5), and several sites near the northern boundary of Holloman Air Force Base (Tularosa Creek, Brazel Lake, Guilez Spring, Barrel Spring-North Pond, and Barrel Spring-South Pond) (fig. 5). Data also are available for a few sites for which exact locations are uncertain (table 1) and thus are not shown on any maps (Alkali Flat 1 and 2, Double Mound Springs-Lower and Upper Ponds, Mound Springs 7 and 25, and Mound Spring, NW of Double Mound Springs).

Flow data are available for some of these sites. The flow of Alkali Spring was measured at 0.13 ft^3/s on November 15, 2006 (table 2–2). The flow of Guilez Spring ranged from 0.07 to 0.13 ft^3/s in 1957 (table 2–2). Measured flow rates for South Mound Spring and Tularosa Creek were 0.02 and 0.06 ft^3/s in 1996 and 1997, respectively (table 2–2). Streamflows at the Mound Spring 7 and 25 sites were estimated to be 0.011 and 0.004 ft^3/s, respectively (table 2–2).

In samples from springs located in pupfish nonhabitat areas, dissolved-solids concentrations (solids, sum of constituents, dissolved in table 2–4) ranged from 1,740 mg/L in Barrel Spring-South Pond to 54,200 (estimated) mg/L in Alkali Spring. Dissolved-solids concentrations in samples collected from Dead Oryx Mound Spring, North Mound Spring, South Mound Spring, and West Mound Spring ranged from 3,650 to 4,460 mg/L and were consistently higher than in samples from Barrel Spring-South Pond and Guilez Spring, which ranged from 1,740 to 1,790 mg/L. The highest dissolved-solids concentrations in samples from pupfish nonhabitat areas were 54,200 (estimated) mg/L (Alkali Spring), 24,200 mg/L (Big Salt Lake), 12,600 (estimated) mg/L (Malpais Salt Marsh Lower Lake), 10,600 mg/L (Brazel Lake), and 10,000 mg/L (Barrel Spring-North Pond). A dissolved-solids concentration of 3,940 mg/L was measured in a sample from Tularosa Creek.

Water types of samples collected from sites in pupfish nonhabitat areas are calcium-sulfate, magnesium-sulfate, and sodium-chloride (figs. 6 and 10; table 2). In general, water collected from pupfish nonhabitat area sites tends to have larger proportions of calcium, magnesium, and sulfate than water from pupfish habitat area sites (fig. 11).Water from springs associated with mounds in pupfish nonhabitat areas (Dead Oryx Mound Spring, North Mound Spring, South Mound Spring, and West Mound Spring) was of a similar type (calcium-sulfate) to water associated with mounds in pupfish habitat areas (Main Mound Spring and Malpais Spring and Malpais Salt Marsh) (table 2). Big Salt Lake and Salt Creek water samples were all of similar type (sodium-chloride; figs. 6 and 10; table 2), Barrel Spring-North Pond and Brazel Lake water samples were of a similar type (magnesium-sulfate; figs. 6 and 10; table 2;), and Guilez Spring and Barrel Spring-South Pond water samples were of a similar type (calcium-sulfate; figs. 6 and 10; table 2). Alkali Spring had a sodium-chloride water type (table 2), but the proportions of sodium-chloride and magnesium-sulfate are unique as compared to samples from other sites (figs. 6 and 10).

Concentrations of trace elements, when detected, were higher in samples from Alkali Spring, Barrel Spring-North Pond, Big Salt Lake, and Brazel Lake than in samples from other sites except Salt Creek (table 2–5). Otherwise, concentrations of trace elements in samples collected from sites in pupfish nonhabitat areas were generally in the same range as concentrations in other samples. An exception is one sample from South Mound Spring in which the dissolved iron concentration (120 μg/L) was high relative to concentrations detected in other samples.

In the one sample collected from Big Salt Lake in 1998, the ammonia (as N) concentration (2.72 mg/L) was about one order of magnitude higher than in all other samples for which ammonia concentrations were determined (table 2–6). The nitrite (as N) concentration was higher in this sample (0.5 mg/L) than in any other sample presented in this report. In two of the three Barrel Spring samples, the nitrate (as N) concentrations (1.19 and 1.28 mg/L) were higher than in samples from all other locations except selected samples from Guilez Spring, Malpais Spring, Salt Creek, and Malpais Salt Marsh Lower Lake (table 2–6). West Mound Spring was another site for which the orthophosphate (as P) concentration (0.04 mg/L in one sample) exceeded the range for other sites (generally equal to or less than 0.02 mg/L). Total bromide and perchlorate data (table 2–7) are not available for pupfish nonhabitat area sites, and triethyl phosphate was not detected in any samples submitted for analysis. The pesticides and herbicides included in this report (table 2–8) were not detected in samples from pupfish nonhabitat area springs.

Summary

The White Sands pupfish (*Cyprinodon tularosa*), listed as threatened by the State of New Mexico and as a Federal species of concern, is endemic to the Tularosa Basin, New Mexico. Because water quality can affect pupfish and the environmental conditions of their habitat, a comprehensive compilation of hydrologic data for pupfish habitat and nonhabitat areas in the northern Tularosa Basin was undertaken by the U.S. Geological Survey in cooperation with White Sands Missile Range.

The four locations within the Tularosa Basin that are known pupfish habitat areas are the Salt Creek, Malpais Spring and Malpais Salt Marsh, and Main Mound Spring habitat areas on White Sands Missile Range and the Lost River habitat area on Holloman Air Force Base. Results of genetic studies illustrate the ability of the White Sands pupfish to survive in rapidly changing water-quality conditions.

Streamflow data from the Salt Creek near Tularosa streamflow-gaging station indicate that the average annual mean streamflow and average annual total streamflow for water years 1995–2008 were 1.35 cubic feet per second (ft^3/s) and 983 acre-feet, respectively. The maximum instantaneous streamflow of 376 ft^3/s occurred on May 7, 2007, whereas periods of no flow were observed at the gaging station in water years 2002 through 2006. Suspended-sediment concentrations in samples from Salt Creek at the Salt Creek near Tularosa gaging station ranged from 4 to 1,570 milligrams per liter (mg/L) from 1999 through 2008. Suspended-sediment concentrations ranged from 17 to 3,430 mg/L at other Salt Creek sites.

Dissolved-solids concentrations in Salt Creek samples collected from 1911 through 2007 ranged from 2,290 to 66,700 mg/L. Concentrations of trace elements generally were higher in most Salt Creek samples than in most samples from other areas. Nitrate (as N) concentrations in Salt Creek samples generally were less than 0.70 mg/L but were 1.98 and 1.29 mg/L in two samples. Perchlorate was detected at 16 micrograms per liter (μg/L) in one sample collected in 2000 from the Salt Creek 4 at Range Road 7 site; this was the only sample collected with a detectable perchlorate.

The Malpais Spring near Oscura streamflow-gaging station was installed in July 2003 on the main channel that flows from Malpais Spring to the salt marsh wetlands. For water years 2003–8, the average annual mean streamflow and average annual total streamflow at the Malpais Spring near Oscura gaging station were 6.81 ft^3/s and 584 acre-feet, respectively. A maximum instantaneous streamflow of 4.3 ft^3/s occurred on both January 9, 2004, and August 19, 2006.

Dissolved-solids concentrations for 16 Malpais Spring samples ranged from 3,882 to 5,500 mg/L. Dissolved-solids concentrations in water from Malpais Salt Marsh generally were higher than concentrations in water from Malpais Spring. The water type of samples from the Malpais Spring and Malpais Salt Marsh habitat area has been consistently calcium-sulfate except for one sample for which the water type was sodium-sulfate. Concentrations of chromium, copper, iron, lead, manganese, and zinc appear to be anomalously high in a 1982 Malpais Spring sample. In samples collected from the Malpais Spring and Malpais Salt Marsh habitat area from 1996 to 2007, concentrations of most trace elements, when detected, were similar to or lower than concentrations at most other sites. The nitrate (as N) and nitrate plus nitrite (as N) concentrations generally were higher than concentrations in samples from other sites. Isotopic data for a Malpais Spring near Oscura water sample collected in 1982 indicated that the water was more than 27,900 years old, which is similar to the high end of the range of ages estimated for groundwater samples from the Hueco Bolson.

Streamflow from Main Mound Spring was estimated at 0.007 ft^3/s in 1955 and 1957. From 1996 to 2001 measured streamflow ranged from 0.02 to 0.07 ft^3/s. Dissolved-solids concentrations in samples collected between 1955 and 2007 ranged from an estimated 3,760 to 4,240 mg/L in the upper pond and 4,840 to 5,120 mg/L in the lower pond. Water from the upper and lower ponds has consistently been a calcium-sulfate type. Isotopic data for a Main Mound Spring water sample collected in 1982 indicated that the water was about 19,600 years old and is within the range of ages estimated for groundwater samples from the Hueco Bolson.

Dissolved-solids concentrations of Lost River samples collected from 1984 to 1999 ranged from 8,930 to 118,000 (estimated) mg/L. The water type of samples collected in 1984 and 1999 was sodium-chloride. The concentration of dissolved bromide (6.55 mg/L) was the second highest of any sample documented in this study.

Sites located in pupfish nonhabitat areas include Alkali Spring, Dead Oryx Mound Spring, North Mound Spring, South Mound Spring, West Mound Spring, Big Salt Lake, Tularosa Creek, Brazel Lake, Guilez Spring, Barrel Spring-North Pond, and Barrel Spring-South Pond. Other sites for which the exact locations are uncertain include Alkali Flat 1 and 2, Double Mound Springs-Lower and Upper Ponds, Mound Springs 7 and 25, and Mound Spring, NW of Double Mound Springs.

Dissolved-solids concentrations in samples from pupfish nonhabitat area sites ranged from 1,740 mg/L to 54,200 (estimated) mg/L. Water types of samples from pupfish nonhabitat area sites are calcium-sulfate, magnesium-sulfate, and sodium-chloride. In general, water collected from pupfish nonhabitat area sites tends to have larger proportions of calcium, magnesium, and sulfate than water from pupfish habitat area sites. Water from springs associated with mounds in pupfish nonhabitat areas was of a similar type (calcium-sulfate) to water associated with mounds in pupfish habitat areas. Alkali Spring had a sodium-chloride water type, but the proportions of sodium-chloride and magnesium-sulfate are unique as compared to samples from other sites. Concentrations of trace elements, when detected, were higher in samples from Alkali Spring, Barrel Spring-North Pond, Big Salt Lake, and Brazel Lake than in samples from other sites except Salt Creek. In one sample collected from Big Salt Lake in 1998, the ammonia (as N) concentration was about one order of magnitude higher than in all other samples.

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Publishing support provided by
Lafayette and Rolla Publishing Service Centers

Naus and others—**Compilation of Hydrologic Data for White Sands Pupfish Habitat and Nonhabitat Areas, Northern Tularosa Basin**—DS 810

ISSN 2327-638X (online)
http://dx.doi.org/10.3133/ds810