GEOHYDROLOGY AND CHEMICAL QUALITY OF GROUND WATER, SAN BERNARDINO NATIONAL WILDLIFE REFUGE, ARIZONA

By STEVE A. LONGSWORTH

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 90—4190

Prepared in cooperation with the
U.S. FISH AND WILDLIFE SERVICE

Tucson, Arizona
February 1991

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

For additional information write to:

District Chief
U.S. Geological Survey
Federal Building, FB-44
300 West Congress Street
Tucson, Arizona 85701-1393

Copies of this report can be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Building 810
Box 25425
Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

For readers who prefer to use International System (SI) units, the conversion factors for terms in this report are listed below:

Multiply inch-pound unit	*By*	*To obtain SI unit*
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
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)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "*Sea Level Datum of 1929*".

GEOHYDROLOGY AND CHEMICAL QUALITY OF GROUND WATER, SAN BERNARDINO NATIONAL WILDLIFE REFUGE, ARIZONA

By

Steve A. Longsworth

ABSTRACT

In 1982, the San Bernardino National Wildlife Refuge was established in San Bernardino Valley to protect unique wetlands habitat for fish and wildlife and an endangered species of fish—the Yaqui topminnow. Black Draw, the main surface-water drainage in the valley, is perennial in a short reach in the refuge near the international boundary with Mexico. Ten wells and at least four springs are connected with the wetlands in the refuge. Wetland restoration was begun in response to habitat damage caused by cattle grazing and land clearing for farming.

Interlayered alluvium and basalt flows compose the principal aquifer system in the valley. Ground water flows from recharge areas near mountain fronts toward the basin center and then southward. Discharges from flowing wells and springs contribute water to the wetlands in the refuge.

Fluctuations in ground-water levels and discharges of flowing wells reflect variations in climatic conditions. Irrigation in the valley is minimal, and ground-water levels have remained stable since the mid-1950's. Discharges from flowing wells were measured during 1983-88. Annual discharge from the flowing wells totals about 400 acre-feet. The effects of ground-water withdrawals in Mexico on well-discharge rates in the refuge are not known, but continued development could affect ground-water conditions.

Ground water in the study area is of acceptable chemical quality for most uses and does not contain concentrations of constituents that exceed State of Arizona water-quality standards. Only small quantities of ground water are withdrawn near the refuge.

INTRODUCTION

The San Bernardino National Wildlife Refuge was established in 1982 to protect a wetlands habitat for wildlife and several species of fish, including an endangered species of fish—the Yaqui topminnow (*Poeciliopsis occidentalis sonoriensis*). The refuge covers about 2,300 acres of the San Bernardino Valley in southeastern Arizona (fig. 1). Marshes, ponds, springs, and flowing wells in the refuge sustain a unique ecosystem in southeastern Arizona. In 1984, the U.S. Geological Survey,

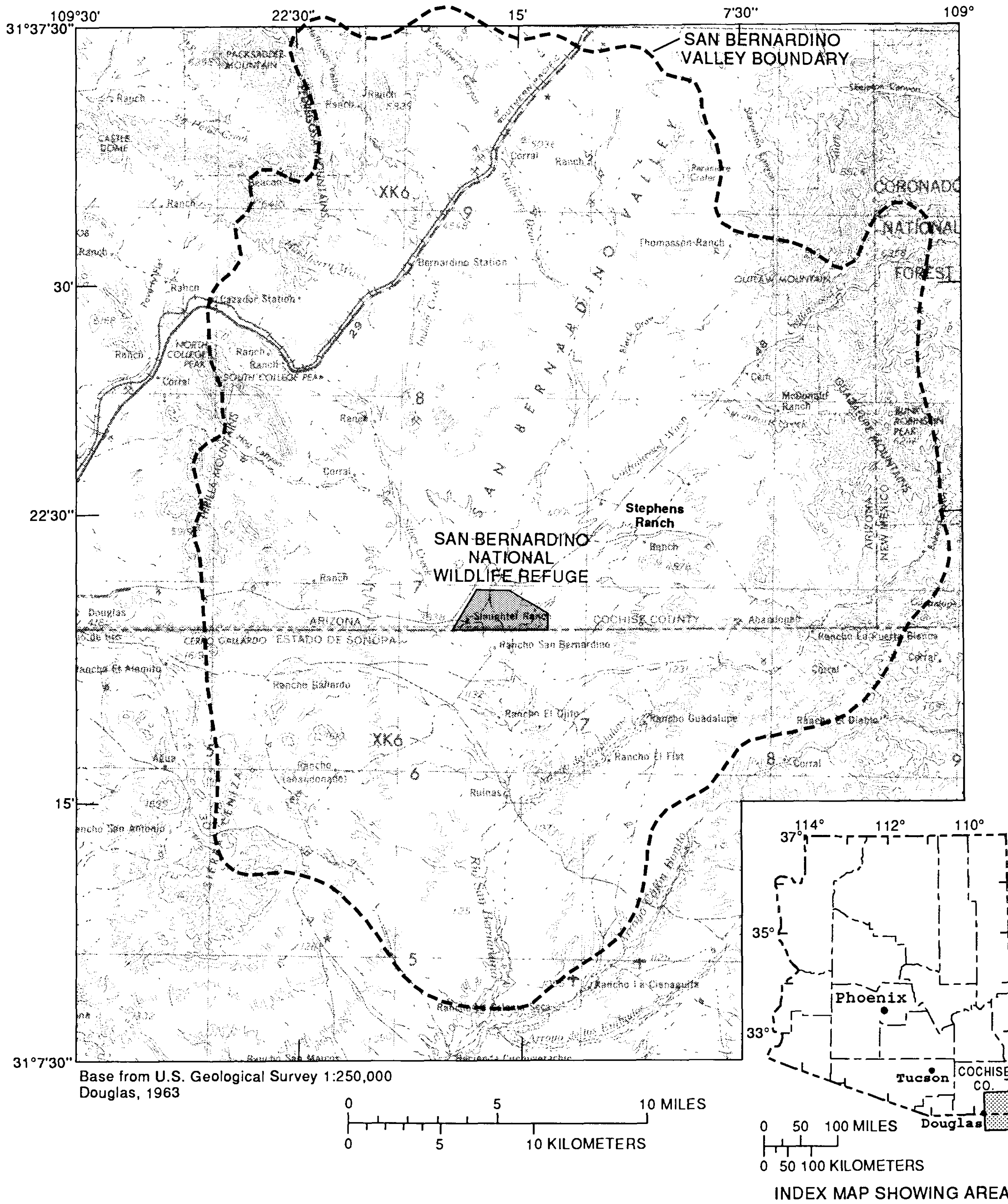


Figure 1.--Location of San Bernardino National Wildlife Refuge and approximate boundary of San Bernardino Valley.

in cooperation with the U.S. Fish and Wildlife Service, began a study to investigate the geohydrologic system in the refuge.

Habitat damage from cattle grazing and land clearing for farming before acquisition of the area by the U.S. Fish and Wildlife Service resulted in a decline in native fish and wildlife (Ben Robertson, Refuge Superintendent, U.S. Fish and Wildlife Service, oral commun., 1987). Restoration of previously drained wetlands using water from flowing wells and springs has promoted growth of vegetation and an increase in wildlife and endangered fish populations. Ground water is used in restoration because surface-water resources are insufficient and the refuge will require a dependable long-term water supply. Although the quantity of ground water pumped in San Bernardino Valley is small, development in the future could cause the head in the aquifer to decrease and the wells in the refuge to cease flowing. Ground-water pumpage for agriculture in Mexico is expected to increase in the future, and the effects of such pumping on ground-water conditions within the refuge are not known.

This report describes the geohydrologic setting and the occurrence, movement, and chemical quality of ground water on the basis of available data. Geohydrologic characteristics of the refuge are controlled by the physiographic and geologic setting of San Bernardino Valley. Geologic, climatic, water-level, and water-quality data collected throughout the valley were analyzed to define the regional geohydrologic system and to interpret conditions within the refuge boundaries. Eleven wells and two named springs are in the refuge (fig. 2). Wells are numbered in accordance with the Bureau of Land Management's system of land subdivision (fig. 3).

PHYSIOGRAPHY

San Bernardino Valley is partly in the United States and partly in Mexico (fig. 1). In Arizona, the valley is bounded by the Pedregosa and Perilla Mountains on the west and the Chiricahua Mountains on the north. The Peloncillo Mountains in southwestern New Mexico form the east boundary. The south end of the valley lies in Mexico; however, this report includes only data from the area north of the international boundary. Ephemeral streams drain the mountains that surround the valley and are tributary to Black Draw. Black Draw, which flows southward into Mexico, is the main surface-water drainage in the San Bernardino Valley.

Altitudes range from about 3,400 ft on the valley floor in the San Bernardino National Wildlife Refuge to about 8,000 ft in the Chiricahua Mountains. The valley floor has an average downward slope, north to south, of about 40 ft/mi. Land in San Bernardino Valley is used primarily for cattle grazing. No extensive farming is done in the valley, but land previously cleared for farming is now covered by grass. Land occupied by the refuge and areas upstream along Black Draw were farmed prior to 1980. Vegetation consists of grasses, desert shrubs, cacti, mesquite, and acacia. Cottonwood and willow trees grow near the wetlands.

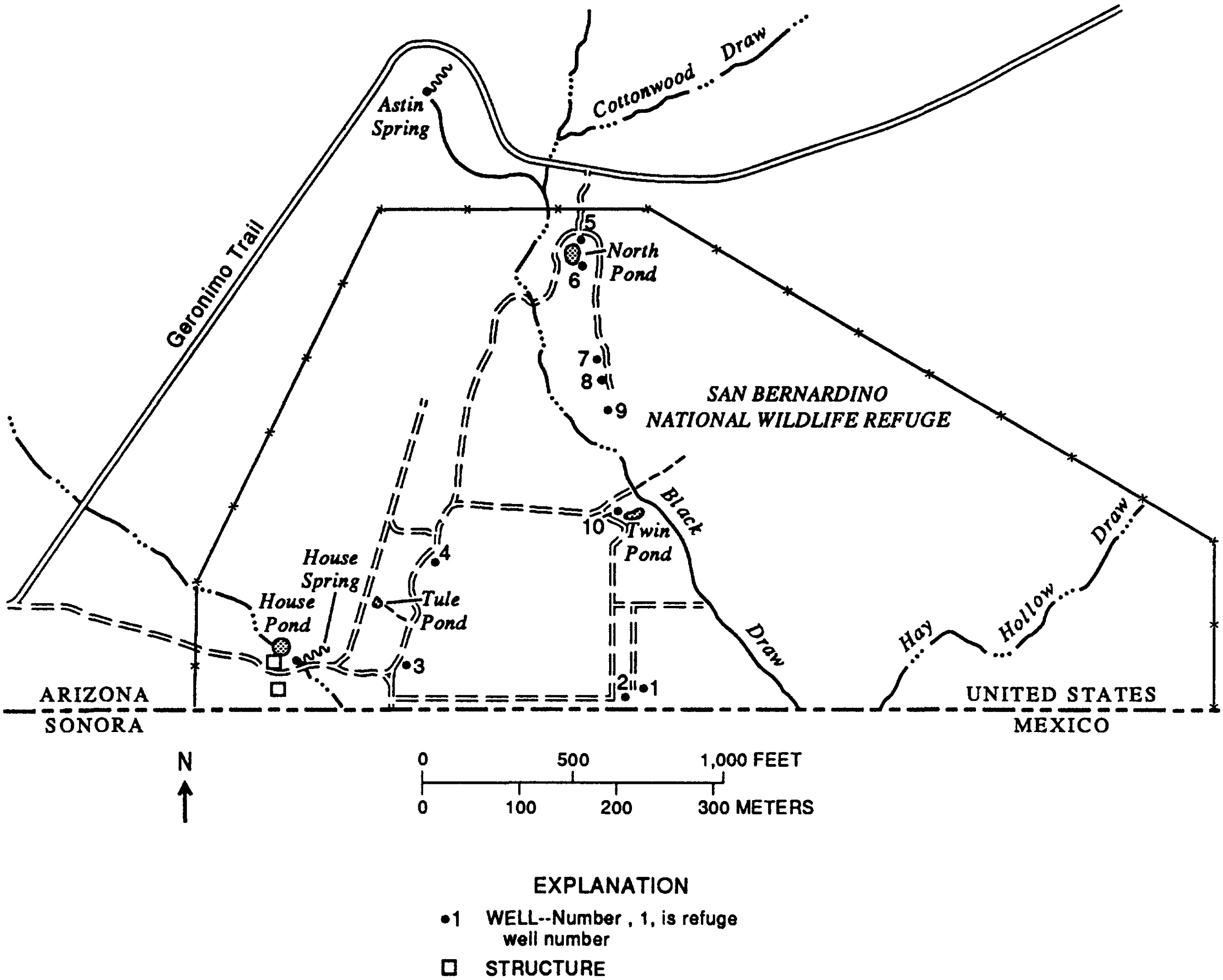
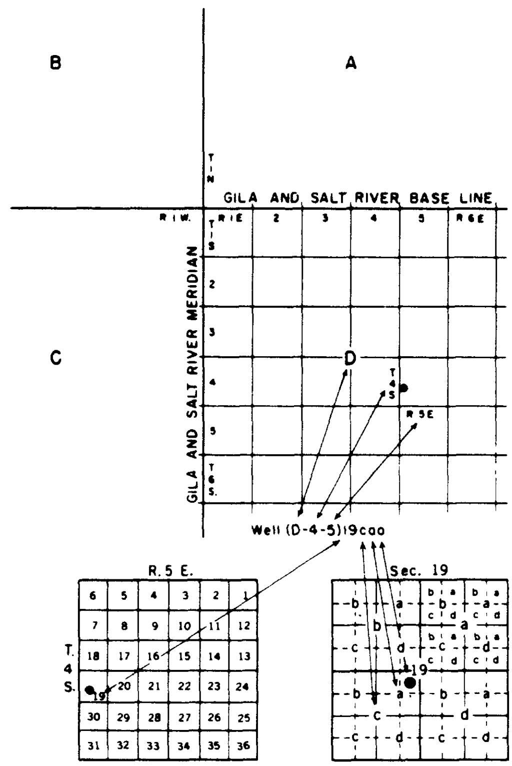


Figure 2.--Well and spring locations.

GEOHYDROLOGY

Geologic Setting

San Bernardino Valley was formed initially during the middle to late Tertiary Period by steep, normal faulting that occurred near the present basin edges (Menges and McFadden, 1981; Pool, 1985). The Chiricahua, Pedregosa, Perilla, and Peloncillo Mountains were formed when rock units were displaced upward along faults relative to basin rock units during the Basin and Range structural disturbance (Scarborough and Pierce, 1978). Sedimentation of the basin was contemporaneous with basin subsidence and resulted from deposition of locally derived sediments and outpouring of basalt. Basin-fill sediments and stream alluvium overlie pre-Basin and Range deposits and bedrock on the valley floor



The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (D-4-5)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 3.--Well-numbering system in Arizona.

(fig. 4). In southern Arizona, basin-fill sediments have been subdivided into a lower and an upper unit on the basis of structural and stratigraphic characteristics (Pool, 1985). Hydrologic characteristics of San Bernardino Valley are influenced by geologic structure, rock type, and climate.

The mountains surrounding the valley are composed of igneous, metamorphic, and sedimentary rocks of Paleozoic to middle Tertiary age (Cooper, 1959). Some pre-existing faulted and folded sedimentary and volcanic rock units were displaced in mountain blocks and basin blocks during basin formation. The consolidated rocks store and transmit small quantities of water through fractures but generally act as barriers to ground-water flow in the basin sediments. Limestone crops out in several places east of the refuge and north of the international boundary (Cooper, 1959), but the subsurface extent is unknown.

Basin-fill sediments consist of unconsolidated to well-consolidated alluvial material of Cenozoic age derived from the rocks of surrounding mountains interlayered with late Tertiary and Quaternary basalt layers (Cooper, 1959; Lynch, 1978). The lower and upper units of the basin-fill sediments generally are coarse grained near the basin boundaries and fine grained near the basin center.

Lower basin fill generally is more fine grained than the upper basin fill and was deposited during the early stages of the Basin and Range structural disturbance when relief was not great and the basin drainage was not established. Sediments in the lower part of the lower basin fill consist of mudstone and siltstone that contain 80 percent or more silt and clay and locally include disseminated gypsum. Sediments in the upper part of the lower basin fill generally are coarser than sediments in the lower part and contain 55 to 80 percent silt and clay, do not contain evaporites, and can have sand and gravel lenses (Pool, 1985).

Upper basin fill generally consists of clay, silt, and sand layers that interfinger with late Tertiary and Quaternary basalt flows and tuff deposits. The upper basin fill was deposited during a period of transition to integrated drainage among basins and generally lies undisturbed over major Basin and Range faults and pediments (Pool, 1985). In San Bernardino Valley, however, several minor faults displace the unit (Morrison and others, 1981). The thickness of the upper basin fill in San Bernardino Valley has not been determined. In many southern Arizona basins, much of the upper basin fill was extensively eroded during and after establishment of regional integrated drainage (Pool, 1985).

Basalt covers a large surface area in the basin (fig. 5). Volcanism occurred during and after basin subsidence, approximately 3 to 0.27 million years ago (Lynch, 1978), and produced interfingering of basalt flows with locally produced detritus. Drillers' logs from several wells in the valley indicate the presence of at least eight basalt flows in the basin-fill sediments (Lynch, 1978). Most basalt flows present on the surface have been highly weathered and relief is slight. Basalt flows abut the Peloncillo Mountains along the east edge of the valley (fig. 5). In the western part of the valley near the Pedregosa Mountains, alluvium has buried the youngest basalt flow.

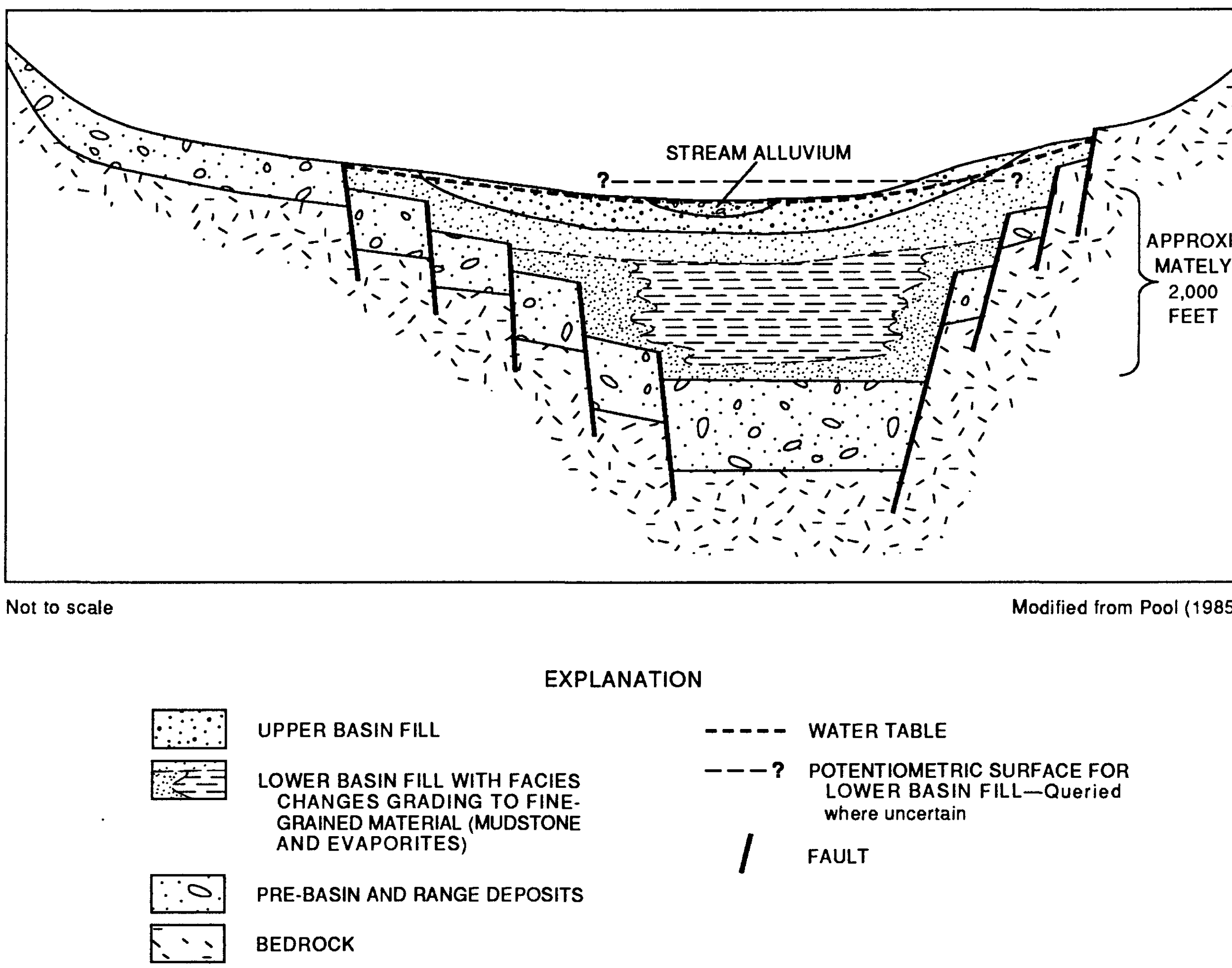


Figure 4.--Generalized basin structure and stratigraphy of alluvial basins in southeastern Arizona.

Stream channels are cut into alluvium that is composed of unconsolidated gravel, sand, silts, and clays. This stream alluvium is less than 100 ft thick and is thickest along Black Draw. The deepest part of San Bernardino Valley is in the northwest near the base of the Chiricahua Mountains where depths to bedrock exceed 800 ft (Oppenheimer and Sumner, 1981).

The basin-fill sediments and basalt flows in the southern part of the valley have been incised by recent streamflow. In the San Bernardino Wildlife Refuge, significant erosion and subsequent terracing of upper basin-fill sediments have occurred as Black Draw and other drainages downcut into surficial rock material. The refuge area

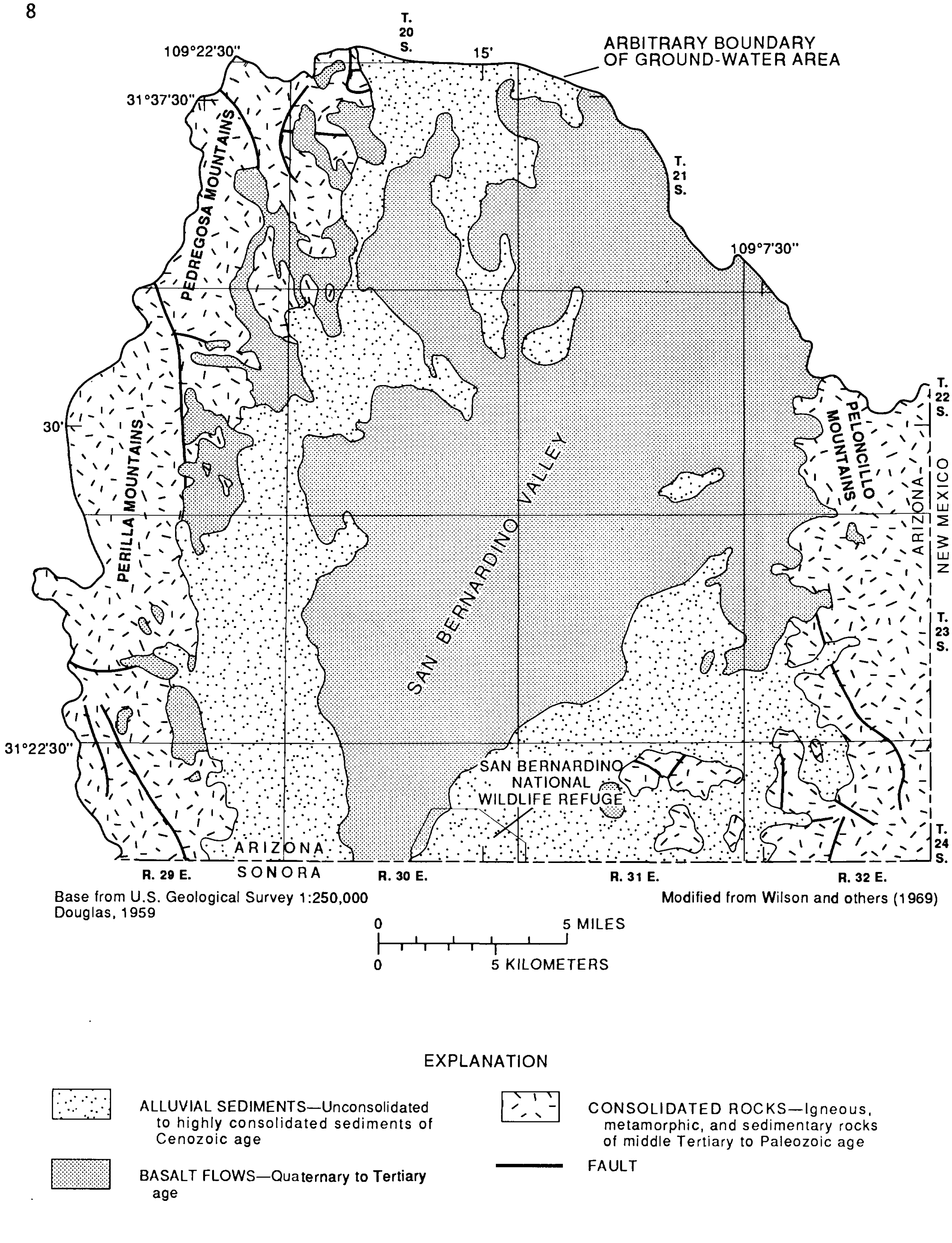


Figure 5.--Generalized distribution of rock types.

encompasses the east margins of basalt flows, upper basin-fill terrace deposits, and stream alluvium (fig. 6). The western part of the refuge lies on a plateau of several late Tertiary and Quaternary basalt flows as mapped by Cooper (1959). The margins of the basalt flows within the refuge boundaries trend north-northeasterly and overlie upper basin-fill sediments. The basin-fill sediments form an intermediate terrace between the basalt plateau and the present (1989) stream channel of Black Draw.

Occurrence and Movement of Ground Water

Basin-fill sediments and stream alluvium are the primary water-bearing units in the San Bernardino Valley aquifer system. Basalt and less permeable sediments restrict ground-water movement and produce confined or semiconfined aquifer conditions in areas where the hydraulic head is sufficiently high. Permeable basin-fill sediments and basalt generally are discontinuous throughout the valley. Interfingering of permeable and relatively impermeable layers has produced many thin, hydraulically interconnected water-bearing zones.

Ground water occurs under confined conditions in the lower part of the lower basin fill in the refuge. Nine of the ten wells near the wetlands flow at land surface. The water level in well 9 generally is at or near land surface. The water-bearing units are confined partly by low-permeability clays of the lower basin fill or overlying dense basalt (fig. 6). Springs exist in several areas in the western part of the refuge where basalt flows terminate or are eroded, exposing permeable sediments of the upper basin fill (fig. 4). More springs probably exist in the dense underbrush in the valley. House spring, (D-24-30)15cdc1, supplies water to the restored ranch house. House Pond, North Pond, and Tule Pond receive recharge from one or more springs. Astin Spring, (D-24-30)11bbc, discharges into Black Draw north of the refuge.

Ground water in San Bernardino Valley is recharged by precipitation falling on the high-altitude parts of the basin. Annual precipitation is about 13 in. on the valley floor near the refuge (Stephens Ranch) at an altitude of 4,000 ft. In the Chiricahua Mountains, the precipitation is almost 18 in. at an altitude of 5,340 ft (Rucker Canyon, approximately 10 mi north of Packsaddle Mountain) and more than 25 in. at an altitude of about 7,000 ft (Sellers and others, 1985). Precipitation that does not evaporate or discharge as plant transpiration infiltrates the soils, percolates through the unsaturated zone, and eventually reaches the water table. Along the base of the Peloncillo Mountains in the eastern part of the valley, extensive alluvial deposits are not present, and recharge to water-bearing units can occur through fractures in and along margins of basalt flows. Surface-water infiltration occurs in the coarse alluvial sediments along mountain fronts and throughout the valley in stream channels.

Data from 57 wells in San Bernardino Valley outside the refuge indicate that withdrawals from 46 wells are used for stock supply, withdrawals from 8 wells are used for domestic supply, and 3 wells are unused (table 1). Several of the wells used for stock supply also are used for domestic supply. No water is withdrawn for irrigation in the

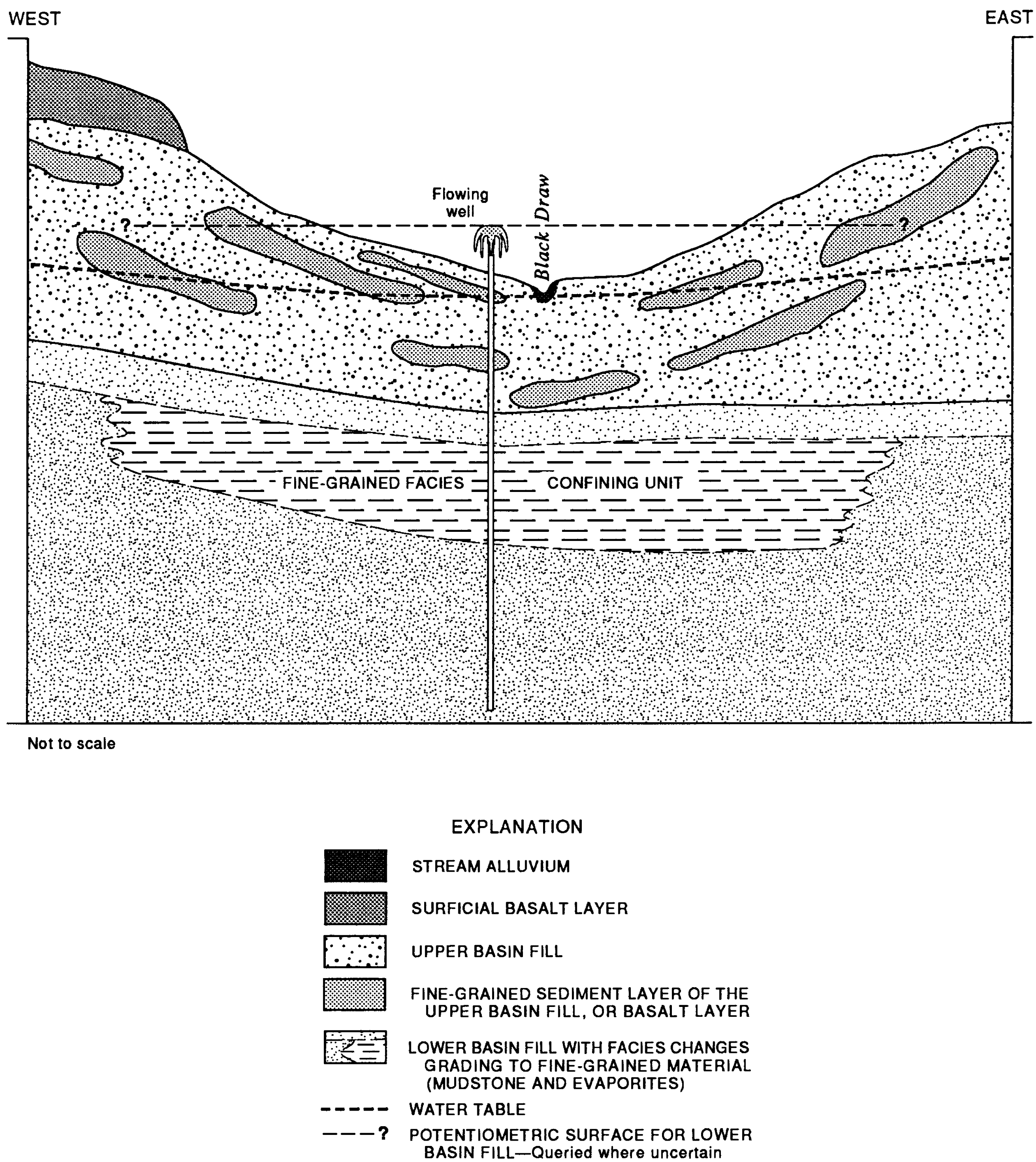


Figure 6.--Generalized relations of lithologic units in the San Bernardino National Wildlife Refuge.

Table 1.--Well and spring information and water levels, July 1985, San Bernardino Valley

[Primary use of site: W, withdrawal; U, unused. Primary use of water: H, domestic supply; S, livestock supply; R, reported; U, unused; Z, refuge well. Dashes indicate no information]

Site identification	Type of site	Latitute, in degrees	Longitude, in degrees	Altitude of land surface, in feet	Primary use of site	Primary use of water	Depth drilled, in feet	Depth of well, in feet	Date water level measured	Water level, in feet
(D-21-29)13dbd	Well	313605	1092028	5,355	W	H	950	950	--------	-----
(D-21-29)24dda	Well	313508	1092015	5,200	W	H	75.0	75.0	--------	-----
(D-21-30)05dcc	Well	313730	1091839	4,960	W	S	200	200	--------	-----
(D-21-30)20add	Well	313527	1091810	4,930	W	S	580	580	--------	-----
(D-21-30)30bba	Well	313448	1092002	5,120	W	S	200	200	--------	-----
(D-21-30)32acb	Well	313348	1091835	4,770	W	S	200	200	--------	-----
(D-21-31)08dbd	Well	313650	1091229	4,675	W	H	620	620	07-10-85	600R
(D-21-31)23ccd	Well	313453	1090953	4,690	W	S	-----	-----	07-10-85	700R
(D-21-31)32bdd	Well	313335	1091234	4,520	W	S	726	726	07-10-85	600R
(D-22-29)02aba	Well	313303	1092134	4,900	W	S	900	900	--------	-----
(D-22-29)23abd	Well	313024	1092133	4,620	W	S	420	420	--------	-----
(D-22-30)09cbb	Well	313151	1091805	4,548	W	S	770	770	--------	-----
(D-22-30)13cbb	Well	313057	1091459	4,450	W	S	800	800	07-09-85	612R
(D-22-30)15add	Well	313101	1091607	4,460	W	S	675	675	07-09-85	640R
(D-22-31)05cdd	Well	313219	1091233	4,455	W	S	567	567	--------	-----
(D-22-31)33dcd	Well	312757	1091119	4,240	W	S	508	508	--------	-----
(D-22-32)06bcc	Well	313040	1090752	4,800	W	S	979	979	--------	-----
(D-22-32)17cca	Well	313112	1090641	5,120	W	S	458	458	--------	-----
(D-22-32)18bcb	Well	313104	1090749	4,655	W	H	865	865	07-10-85	700R
(D-23-30)10dbd	Well	312627	1091620	4,240	W	S	715	715	07-09-85	420R
(D-23-30)18bbd	Well	312600	1091957	4,120	W	S	400	400	--------	-----
(D-23-30)18caa	Well	312544	1091945	4,200	W	H	475	475	--------	-----
(D-23-30)30dbb	Well	312351	1091935	4,020	W	S	300	300	07-10-85	120R
(D-23-30)32ccd	Well	312248	1091859	3,955	W	S	-----	-----	07-09-85	75R
(D-23-30)33aab	Well	312331	1091716	3,962	W	S	250	250	07-09-85	80R
(D-23-30)36bab	Well	312334	1091446	3,900	W	S	308	308	07-09-85	120R
(D-23-31)04cab	Well	312730	1091137	4,215	W	S	675	675	07-10-85	400R
(D-23-31)18dcb1	Well	312528	1091329	4,060	W	S	-----	-----	07-09-85	235R
(D-23-31)18dcb2	Well	312528	1091331	4,060	W	S	328	328	07-09-85	233R
(D-23-31)26abc1	Well	312415	1090922	4,137	W	S	325	325	--------	-----
(D-23-31)26abc2	Well	312415	1090924	4,145	W	S	325	325	07-09-85	305R
(D-23-31)29dca1	Well	312341	1091215	4,000	W	S	300	300	07-09-85	165R
(D-23-31)29dca2	Well	312340	1091216	4,040	W	H	250	250	07-09-85	200R
(D-23-32)06aad1	Well	312747	1090655	4,550	W	S	180	180	07-09-85	55R
(D-23-32(06aad2	Well	312747	1090655	4,550	W	H	134	134.0	07-09-85	40R
(D-23-32)08dcc	Well	312612	1090618	4,560	W	H	180	180	--------	-----
(D-24-29)09cac	Well	312111	1092407	4,350	W	S	-----	-----	--------	-----
(D-24-29)09cbd	Well	312111	1092412	4,365	W	S	-----	-----	07-09-85	58.4
(D-24-29)11cab	Well	312122	1092202	4,150	U	U	-----	-----	07-09-85	31.3
(D-24-29)13cbc	Well	312022	1092115	4,100	W	S	280	280	--------	-----
(D-24-29)16acc	Well	312036	1092347	4,520	W	S	205	205	--------	-----
(D-24-30)04aac	Well	312234	1091716	3,900	W	S	135	135	07-09-85	43R
(D-24-30)07bdb	Well	312133	1091954	4,000	W	S	270	270	--------	-----
(D-24-30)08daa1	Well	312119	1091811	3,870	W	S	160	160	--------	-----
(D-24-30)08daa2	Well	312120	1091811	3,880	U	U	115	115	07-09-85	80R
(D-24-30)11aad1	Well	312139	1091507	3,810	W	S	600	600	07-09-85	12R
(D-24-30)11aad2	Well	312137	1091507	3,810	W	S	900	900	07-09-85	15R
(D-24-30)11aad3	Well	312139	1091506	3,810	W	S	130	130	07-09-85	24R
(D-24-30)11bbc	Spring	312140	1091600	3,800	Not pumped	S	-----	-----	--------	-----
(D-24-30)11cad1	Well	312117	1091540	3,740	W	Z	-----	-----	--------	-----

Table 1.--Well and spring information and water levels, July 1985, San Bernardino Valley--Continued

Site identification	Type of site	Latitute, in degrees	Longitude, in degrees	Altitude of land surface, in feet	Primary use of site	Primary use of water	Depth drilled, in feet	Depth of well, in feet	Date water level measured	Water level, in feet
(D-24-30)11cad2	Well	312014	1091538	3,740	W	Z	-----	-----	--------	-----
(D-24-30)13dba	Well	312028	1091420	3,760	W	S	-----	-----	--------	-----
(D-24-30)14bac	Well	312050	1091542	3,750	W	Z	-----	-----	--------	-----
(D-24-30)14bda	Well	312040	1091540	3,780	U	U	-----	-----	--------	-----
(D-24-30)14bdb	Well	312044	1091541	3,750	W	Z	-----	-----	--------	-----
(D-24-30)14cbd	Well	312026	1091552	3,750	W	Z	583	583	--------	-----
(D-24-30)15cdc1	Spring	312011	1091642	3,780	W	H	-----	-----	--------	-----
(D-24-30)15dad	Well	312022	1091608	3,759	W	Z	-----	-----	--------	-----
(D-24-30)15ddc	Well	312010	1091616	3,759	W	Z	-----	-----	--------	-----
(D-24-30)16ccc	Well	312006	1091806	3,800	W	S	100	100	07-09-85	30.2
(D-24-30)23bab1	Well	312002	1091546	3,760	W	Z	-----	-----	--------	-----
(D-24-30)23bab2	Well	312003	1091546	3,740	W	Z	-----	-----	--------	-----
(D-24-31)03bab	Well	312102	1091050	4,035	W	S	250	250	07-09-85	180R
(D-24-31)05acc	Well	312343	1091224	3,920	W	S	500	500	07-09-85	93.3
(D-24-31)07ccd	Well	312059	1091350	3,820	W	S	140	140	07-09-85	35R
(D-24-31)10ccc	Well	312237	1091051	4,005	W	S	250	250	07-09-85	215R
(D-24-31)12dbb	Well	312124	1090840	4,200	U	U	466	466	--------	-----
(D-24-32)14bda	Well	312042	1090325	4,335	W	S	28.0	28.0	--------	-----
(D-24-32)21aac	Well	311959	1090506	4,260	W	S	30.0	30.0	--------	-----

valley. The wells in the refuge supply water to ponds or are closed off with valves.

Ground water generally flows from mountain-front recharge areas toward the basin center and then southward. The water moves through the hydraulically connected permeable sediments from areas of high hydraulic head to areas of low hydraulic head. Movement of ground water correlates approximately with directions of surface-water flow.

Some water apparently moves along the basalt layers at shallow depth and discharges through springs or small seeps along the intermediate terrace in the refuge and evaporates or is transpired by vegetation. The flow pattern and extent of this system are not known, and additional points of discharge probably exist elsewhere in the valley or in Mexico. The chemical quality of water from House Spring differs from that of water from refuge wells (see section titled "Chemical Quality of Ground Water," and table 4). Ground water discharges through springs and flowing wells into Black Draw. An unknown quantity of ground water also moves as underflow and discharges south of the refuge in Mexico.

Water Levels

Water levels in San Bernardino Valley have remained stable since initial measurements were made in the mid-1950's. Ground-water discharge from the aquifer has remained stable because irrigation withdrawals in the past were small and stock and domestic water requirements have not increased in the valley. The water level in a well represents the hydraulic head in the aquifer and fluctuates in response to changes in ground-water storage. Ground-water recharge is proportional to the amount of precipitation; thus, increases in precipitation result in increased quantities of ground water stored in the aquifer. Flow from springs and flowing wells also increases in response to increases in the hydraulic head in the aquifer.

Long-term water-level measurements made at three wells show small fluctuations. The depth to water at well (D-24-31)05acc, drilled to a depth of 500 ft, was 96 ft in May 1974 and 93 ft in July 1985 (fig. 7). Intermittent water-level measurements were made at wells (D-24-30)16ccc and (D-23-31)29dca1 between 1956 and 1989 (fig. 8). The depth to water at well (D-24-30)16ccc, drilled to a depth of 100 ft, was 30 ft in January 1977 and 30 ft in January 1989. The depth to water at well (D-23-31)29dca1, drilled to a depth of 300 ft, was 165 ft in December 1956 and 166 ft in March 1987.

A study by Wilson (1976) identified ground-water conditions in San Bernardino Valley in 1974-75. Depth to water generally was less than 200 ft in the southern part of the valley and exceeded 600 ft in the northern part. The report included water levels measured during 1974-75, measured prior to 1974-75, and reported by well owners for periods prior to 1974-75.

Water-level measurements were made at refuge wells 3 and 5, and flow was observed from wells 1, 2, 7, and 8 in May 1974 (table 2). The water levels in the wells were affected by pumping from well 10 for irrigation. At well 3, (D-24-30)15ddc, the water level was 2 ft below land surface and at well 5, (D-24-30)11cad1, the water level was 4 ft below land surface. The water level in wells 4, (D-24-30)15dad, and 6, (D-24-30)11cad2, could not be measured in 1974, however, neither was flowing. The water level in well 9 was not measured. Water levels reported by well owners and measured in July 1985 had not changed significantly from water levels measured in 1956 and 1975 (fig. 7). Field inspections made between December 1983 and March 1988 indicate that refuge wells generally flow throughout the year.

Differences in hydraulic head exist between water-bearing units of different depths. Wells (D-24-30)11aad2 and (D-24-30)11aad3 north of the refuge are 900 ft and 130 ft deep, respectively. In June 1974, the depth to water was 24 ft in the deep well and 26 ft in the shallow well. Because the wells are at the same land-surface altitude, the higher water level in the deep well can be attributed to the deep water-bearing units that have a higher hydraulic head than the shallow water-bearing units.

Well Discharges

Measurements of flow from refuge wells began in December 1983 by personnel of the U.S. Fish and Wildlife Service. On the basis of discharge measurements made between 1983 and 1988, average well discharge ranged from 6.2 to 108 gal/min (table 3). Annual discharge from the 10 wells, except for well 2, totals about 400 acre-ft or enough water to

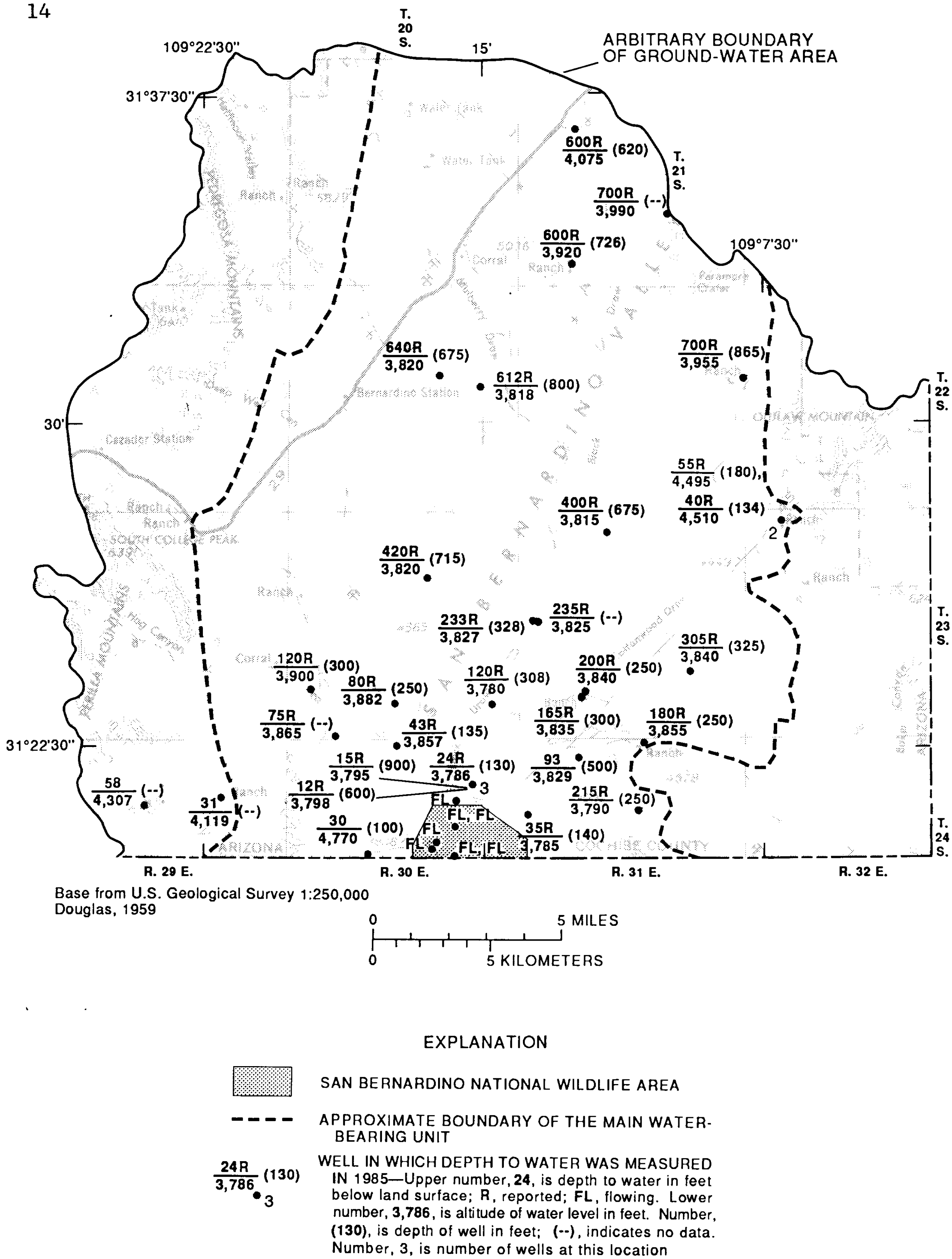


Figure 7.--Water levels in San Bernardino Valley, 1985.

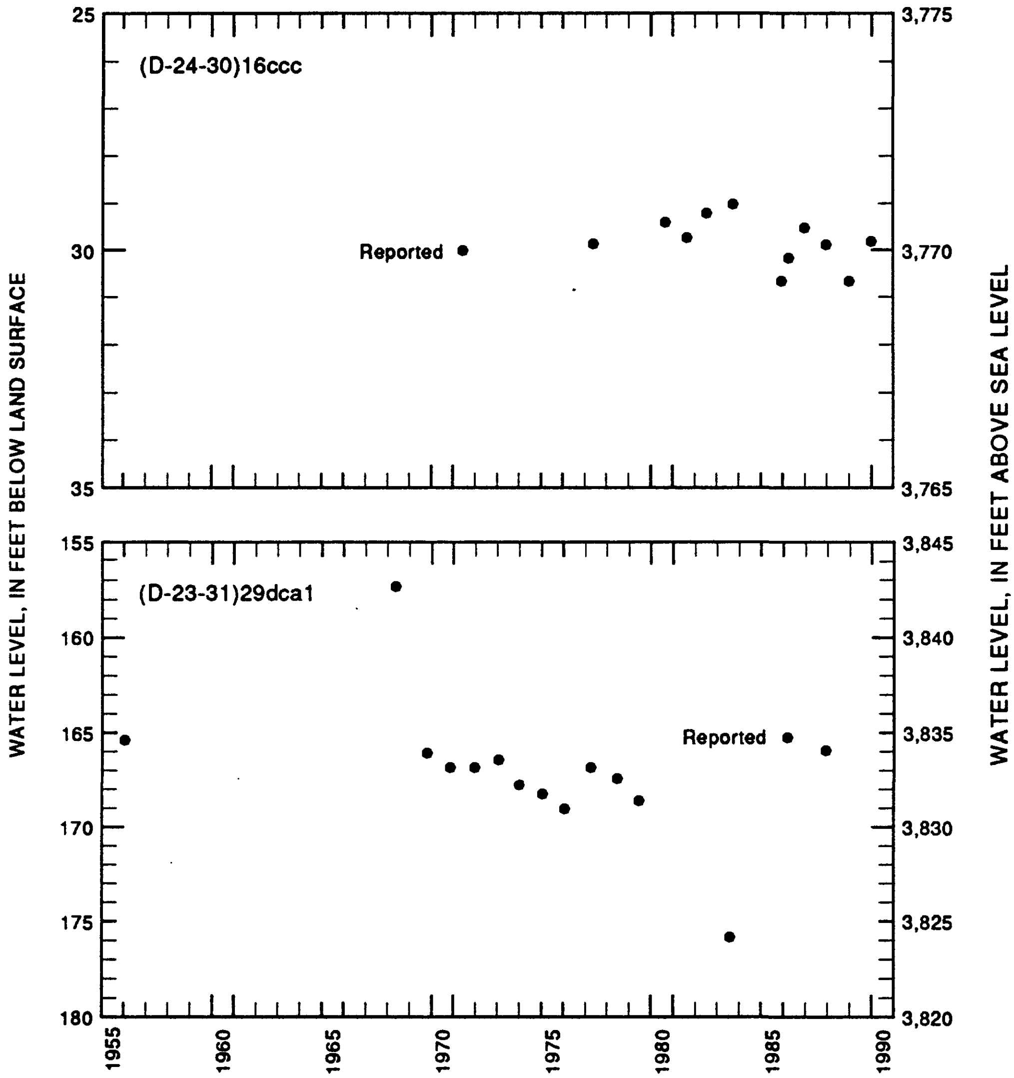


Figure 8.--Water levels for wells (D-24-30)16ccc and (D-23-31)29dcal, 1956-89.

cover the entire refuge with 2 in. of water. Between 1982 and 1987, water was pumped from well 10 intermittently to maintain stable water levels in Twin Pond (Ben Robertson, U.S. Fish and Wildlife Service, oral commun., 1987). Data from observations made between 1983 and 1986 show that pumping from well 10 could have affected flow rates of the other wells, but specific effects were masked by seasonal fluctuations and irregular monitoring patterns. Small withdrawals probably had little effect on flow rates. Discharge rates from the flowing wells have remained virtually unchanged since monitoring began in 1983.

A deep water-bearing unit contributes to ground-water flow from well 10 on the refuge (depth, 583 ft). Although depths of the other refuge wells are unknown, the presence of artesian flows indicate similar depths with connection to the confined lower water-bearing unit.

Table 2.--Measured depth to water and discharge rates for wells in San Bernardino National Wildlife Refuge, 1974-88

[Data for 1983-84 measured by U.S. Fish and Wildlife Service; NM, not measured; R, flow restricted by valve; OFF, well was shut off; FL, flowing; NF, not flowing; P, well was pumping; L, leaking around top of casing; E, estimated]

Well number	Depth to water, in feet below land surface, May 1974	Discharge, in gallons per minute on indicated date																	
		1983	1984						1985		1986					1987		1988	
		Dec. 15	Jan. 17	Feb. 16	Mar. 21	April 18	May 7	May 15	Mar. 2	July 26	Mar. 9	May 24	July 15	Sept. 15	Oct. 29	April 15	Nov. 18	Mar. 10	Mar. 30
1	NM	75.0	100	150	11.5R	OFF	NM	OFF	NM	NM	NM	NM	NM	NM	NM	108	NM	NM	NM
2	FL	OFF	OFF	OFF	OFF	OFF	OFF	OFF	NM	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
3	2	13	14.3	14.3	NF	NF	12	NF	19.0	2.1	11.7	10.6	12.7	12.6	11.6	12.6	NM	NM	NM
4	NF	25	28.6	27.3	8.6	12	NM	15.8	33.0	20.4	26.7	24.8	26.7	NM	27.3	NM	NM	21.1	NM
5	4	4.3	3.9	4.1	12	3.8	NM	3.7	NM	4.2	NM	NM	NM	5.7	NM	7.7	11.1	NM	NM
6	NF	7.3	6.5	6.8	5.8	6.7	NM	6.6	8.9	NM	NM	NM	NM	NM	NM	11.9	11	NM	NM
7	FL	25	20	20	17.7	20	NM	20.8	22.0	19.3	NM	NM	NM	NM	NM	21.6	19	NM	NM
8	FL	42.9	42.8	42.9	37.5	37.5	NM	38.0	41.5	36.0	30.9	29.2	NM	NM	33.2	33.8	28	NM	NM
9	NM	13	15.4	13.6	8.1	5	L	L	L	L	L	L	L	L	L	L	L	L	L
10	P	NF	NF	NF	NF	NF	NM	NF	NF	NF	24.5	23.5	26.7	NM	NM	NM	9	NM	20E

Table 3.--Average measured discharge rates of flowing wells and daily and annual discharge, San Bernardino National Wildlife Refuge, 1983-88

Well number	Well identification	Average discharge rate, in gallons per minute
1	(D-24-30)23bab1	[1]108
2	(D-24-30)23bab2	([2])
3	(D-24-30)15ddc	9.8
4	(D-24-30)15dad	22.9
5	(D-24-30)11cad1	6.2
6	(D-24-30)11cad2	7.9
7	(D-24-30)14bac	20.5
8	(D-24-30)14bdb	36.5
9	(D-24-30)14bda	[3]11.0
10	(D-24-30)14cbd	20.7

	Daily	Annual
Total average discharge available from flowing wells, in gallons.............	350,640	127,983,600

[1]Valve on well 1 remains closed when flow is not being measured.

[2]Valve on well 2 remains closed and flow cannot be measured.

[3]Casing deterioration has prevented the volumetric measuring of discharge from well 9 after April 18, 1984.

Flowmeter testing showed that most of the ground-water flow to well 10 occurs in units where the borehole has been enlarged by solution of the water-bearing sediments. More than half the ground-water flow occurs at a depth of about 488 ft where the borehole diameter exceeds 17 in. In the uncased part above 300 ft, the borehole diameter is about 10 in. Flow to the well also occurs from 310 to 340 ft, 380 to 410 ft, and 494 to 500 ft. The diameter of the borehole is about 12 in. from 310 to 340 ft, 15 in. from 380 to 410 ft, and 11 in. from 494 to 500 ft. No flow was measured below 500 ft. The lateral extent of these zones cannot be determined with present (1989) data. Effects of pumping on water levels and discharge rates in this area have not been defined by thorough aquifer analysis.

CHEMICAL QUALITY OF GROUND WATER

Water-quality data from San Bernardino Valley include analyses of samples from 18 wells and 2 springs collected between 1956 and 1987. Concentrations of constituents shown in table 4 were below Federal maximum contaminant levels for drinking water and State of Arizona maximum

Table 4.--Chemical analysis of well and spring water, San Bernardino Valley

[Dashes indicate no data; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter, <, less than]

Well or spring identification	Station number	Date sampled	Time	Temperature water (°C)	Temperature air (°C)	Specific conductance (µS/cm)	Field pH (standard units)	pH lab (standard units)	Carbon dioxide dissolved (mg/L as CO_2)	Alkalinity wat wh tot fet field (mg/L as $CaCO_3$)
(D-24-30)23bab1	312002109154601	03-02-85	1330	28.0	21.5	425	8.10	8.10	---	---
([1])		09-15-86	----	----	----	---	----	----	---	---
(D-24-30)15ddc	312010109161601	03-02-85	1130	32.5	21.5	431	8.30	8.30	---	---
(D-24-30)15cdc1	312011109164201	03-01-85	1614	19.0	24.0	500	7.70	7.80	---	---
(D-24-30)11cad1[1]	312117109154001	09-15-86	----	----	----	---	----	----	---	---
(D-24-30)11cad2	312014109153801	03-02-85	0850	30.0	18.0	398	8.00	8.20	---	---
(D-24-30)15dad	312022109160801	03-02-85	1100	32.0	18.0	495	8.40	8.50	---	---
(D-24-30)13dba[1]	312028109142001	09-15-86	----	----	----	---	----	----	---	---
(D-24-30)14cbd	312026109155201	05-22-74	----	29.0	----	458	----	----	---	223
		11-17-87	1510	----	----	450	----	8.30	---	---
(D-24-30)14cbd		08-18-86	1630	----	----	---	----	----	---	---
		08-20-86	1445	----	----	---	----	----	---	---
		08-20-86	1845	----	----	---	----	----	---	---
		08-21-86	152	----	----	---	----	----	---	---
([1])		09-15-86	----	----	----	---	----	----	---	---
(D-24-30)14bdb	312044109154101	03-02-85	1000	29.0	18.0	411	7.90	8.10	---	---
(D-24-31)03bab	312102109105001	11-27-56	----	----	----	1,700	7.10	----	143	927
		05-23-74	----	29.0	----	1,320	----	----	---	687
(D-24-31)10ccc	312237109105101	05-23-74	----	25.5	----	1,370	----	----	---	716
(D-23-30)36bab	312334109144601	06-12-74	----	31.0	----	1,410	----	----	---	747
(D-23-31)26abc2	312415109092401	06-06-74	----	28.0	----	390	----	----	---	192
(D-23-31)04cab	312730109113701	06-03-74	----	28.0	----	397	----	----	---	190
(D-23-32)06aad1	312747109065501	06-03-74	----	22.0	----	702	----	----	---	180
(D-22-32)18bcb	313104109074901	01-04-57	----	----	----	381	7.20	----	23	185
(D-21-30)32acb	313348109183501	06-04-74	----	26.5	----	388	----	----	---	144
(D-22-32)17cca	313645109064101	06-12-74	----	26.5	----	373	----	----	---	189
(D-24-30)16ccc	312006109180601	03-15-87	1300	23.0	----	380	7.90	8.60	---	243
(D-23-30)32ccd	312248109185901	03-15-87	1600	25.0	----	304	7.78	8.40	---	185
(D-24-29)09cac	312111109240701	03-15-87	1030	20.0	----	730	7.59	8.30	---	334
(D-24-30)11bbc	312140109160001	03-15-87	1430	22.0	----	345	----	----	---	---

See footnotes at end of table.

Table 4.--Chemical analysis of well and spring water, San Bernardino Valley--Continued

Well or spring identification	Bicarbonate water wh fet field (mg/L as HCO_3)	Carbonate water wh fet field (mg/L as CO_3)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Nitrogen, NO2+NO3 dissolved (mg/L as N)	Phosphate, ortho, dissolved (mg/L as PO_4)	Phosphorous ortho, dissolved (mg/L as P)	Hardness total (mg/L as $CaCO_3$)	Hardness noncarb wh wat tot fld (mg/L as $CaCO_3$)	Calcium dissolved (mg/L as Ca)
(D-24-30)23bab1	-----	----	------	-----	1.20	0.06	0.020	110	0	24
([1])	-----	----	------	-----	-----	----	------	---	---	---
(D-24-30)15ddc	-----	----	------	-----	1.70	0.09	0.030	62	0	11
(D-24-30)15cdc1	-----	----	------	-----	4.10	0.09	0.030	180	0	23
(D-24-30)11cad1[1]	-----	----	------	-----	-----	----	------	---	---	---
(D-24-30)11cad2	-----	----	------	-----	1.20	0.06	0.020	92	0	17
(D-24-30)15dad	-----	----	------	-----	1.40	0.09	0.030	26	0	5
(D-24-30)13dba[1]	-----	----	------	-----	-----	----	------	---	---	---
(D-24-30)14cbd	270	----	------	-----	1.20	0.0	<0.010	92	0	17
	-----	----	------	-----	1.00	---	<0.010	64	0	12
(D-24-30)14cbd	-----	----	------	-----	-----	----	------	---	---	---
	-----	----	------	-----	-----	----	------	---	---	---
	-----	----	------	-----	-----	----	------	---	---	---
	-----	----	------	-----	-----	----	------	---	---	---
([1])	-----	----	------	-----	-----	----	------	---	---	---
(D-24-30)14bdb	-----	----	------	-----	1.10	0.06	0.020	130	0	24
(D-24-31)03bab	1,130	0	------	-----	-----	----	-----	590	0	150
	840	----	------	-----	0.190	0.03	0.010	310	0	50
(D-24-31)10ccc	870	----	------	-----	0.030	0.09	0.030	330	0	58
(D-23-30)36bab	-----	<0.0	10	0.080	0.080	0.06	0.020	260	0	50
(D-23-31)26abc2	230	----	------	-----	2.00	0.09	0.030	150	0	29
(D-23-31)04cab	230	----	<0.010	1.40	1.40	0.06	0.020	110	0	15
(D-23-32)06aad1	220	----	------	-----	7.30	0.06	0.020	290	110	98
(D-22-32)18bcb	220	0	------	-----	-----	----	-----	160	0	23
(D-21-30)32acb	170	----	------	-----	6.90	0.06	0.020	150	8	41
(D-22-32)17cca	230	----	------	-----	0.820	0.03	0.010	140	0	33
(D-24-30)16ccc	300	0	------	-----	1.60	----	0.010	200	0	28
(D-23-30)32ccd	---	---	------	-----	7.80	----	0.010	190	---	38
(D-24-29)09cac	---	---	------	-----	3.20	----	0.010	510	---	110
(D-24-30)11bbc	---	---	------	-----	----	----	-----	---	---	---

See footnotes at end of table.

Table 4.--Chemical analysis of well and spring water, San Bernardino Valley--Continued

Well or spring identification	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Sodium percent	Sodium+ potassium dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)
(D-24-30)23bab1	11	62	3	55	---	2.5	6.4	14	0.40	35
([1])	----	---	----	--	---	----	---	-----	----	--
(D-24-30)15ddc	8.4	78	4	72	---	4.1	6.4	12	0.40	20
(D-24-30)15cdc1	30	46	2	35	---	4.3	15	26	0.40	33
(D-24-30)11cad1[1]	----	---	----	---	---	----	----	-----	----	--
(D-24-30)11cad2	12	67	3	60	---	2.8	7.2	13	0.50	31
(D-24-30)15dad	2.9	110	10	89	---	2.6	7.0	13	0.50	21
(D-24-30)13dba[1]	----	---	----	--	---	----	----	-----	----	--
(D-24-30)14cbd	12	69	3	61	---	4.5	6.9	12	0.40	33
	8.3	83	5	73	---	3.0	10	11	0.50	34
(D-24-30)14cbd	----	---	----	--	---	----	----	-----	----	--
	----	---	----	--	---	----	----	-----	----	--
	----	---	----	--	---	----	----	-----	----	--
	----	---	----	--	---	----	----	-----	----	--
([1])	----	---	----	--	---	----	----	-----	----	--
(D-24-30)14bdb	16	53	2	47	---	2.6	6.5	13	0.40	34
(D-24-31)03bab	51	---	4	43	200	----	22	54	3.6	30
	45	190	5	54	---	32	19	48	1.9	30
(D-24-31)10ccc	45	200	5	54	---	34	20	49	2.5	36
(D-23-30)36bab	32	240	7	64	---	31	19	40	2.7	34
(D-23-31)26abc2	20	28	1	27	---	5.9	5.3	6.4	0.30	50
(D-23-31)04cab	17	41	2	43	---	8.8	5.7	9.9	0.40	35
(D-23-32)06aad1	12	31	0.8	18	---	4.2	23	120	0.20	48
(D-22-32)18bcb	24	---	0.8	25	24	----	8.0	4.5	0.80	51
(D-21-30)32acb	12	20	0.7	22	---	2.8	10	17	0.10	30
(D-22-32)17cca	15	23	0.9	25	---	5.5	6.4	3.5	0.30	55
(D-24-30)16ccc	32	39	1	29	---	7.0	6.6	26	0.40	35
(D-23-30)32ccd	23	17	0.5	16	---	6.2	3.6	11	0.20	32
(D-24-29)09cac	57	50	1.0	18	---	5.6	18	270	0.60	13
(D-24-30)11bbc	----	---	----	--	---	----	----	-----	----	--

See footnotes at end of table.

Table 4.--Chemical analysis of well and spring water, San Bernardino Valley--Continued

Well or spring identification	Arsenic dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Boron, dis-solved (µg/L as B)	Cadmium dis-solved (µg/L as Cd)	Chro-mium, hexa-valent, dis. (µg/L as Cr)	Iron, dis-solved (µg/L as Fe)	Lead, dis-solved (µg/L as Pb)	Manga-nese, dis-solved (µg/L as Mn)	Stron-tium, dis-solved (µg/L as Sr)	Alum-inum, dis-solved (µg/L as Al)
(D-24-30)23bab1	<1	28	40	2	9	6	<1	<1	330	10
([1])	--	--	---	--	--	---	--	---	-----	---
(D-24-30)15ddc	3	18	60	<1	3	7	<1	<1	300	10
(D-24-30)15cdc1	2	32	40	2	<1	8	<1	<1	300	20
(D-24-30)11cad1[1]	--	--	---	--	--	---	--	---	-----	---
(D-24-30)11cad2	<1	22	50	2	7	7	2	<1	200	20
(D-24-30)15dad	3	16	70	1	2	<3	1	2	110	20
(D-24-30)13dba[1]	--	--	---	--	--	---	--	---	-----	---
(D-24-30)14cbd	--	--	60	--	--	<10	--	<10	-----	---
	2	--	60	--	3	<3	<5	<1	-----	<10
(D-24-30)14cbd	--	--	---	--	--	---	--	---	-----	---
	--	--	---	--	--	---	--	---	-----	---
	--	--	---	--	--	---	--	---	-----	---
	--	--	---	--	--	---	--	---	-----	---
([1])	--	--	---	--	--	---	--	---	-----	---
(D-24-30)14bdb	<1	32	40	<1	3	7	<1	<1	310	<10
(D-24-31)03bab	--	--	---	--	--	---	--	---	-----	---
	--	--	190	--	--	<10	--	<10	-----	---
(D-24-31)10ccc	--	--	190	--	--	<10	--	<10	-----	---
(D-23-30)36bab	--	--	200	--	--	<10	--	<10	-----	---
(D-23-31)26abc2	--	--	90	--	--	<10	--	<10	-----	---
(D-23-31)04cab	--	--	60	--	--	<10	--	<10	-----	---
(D-23-32)06aad1	--	--	30	--	--	20	--	<10	-----	---
(D-22-32)18bcb	--	--	---	--	--	---	--	---	-----	---
(D-21-30)32acb	--	--	30	--	--	<10	--	<10	-----	---
(D-22-32)17cca	--	--	30	--	--	<10	--	<10	-----	---
(D-24-30)16ccc	--	--	70	--	--	6	--	1	-----	---
(D-23-30)32ccd	--	--	20	--	--	18	--	2	-----	---
(D-24-29)09cac	2	20	170	1	1	3	5	140	1,800	10
(D-24-30)11bbc	--	--	---	--	--	---	--	---	-----	---

See footnotes at end of table.

Table 4.--Chemical analysis of well and spring water, San Bernardino Valley--Continued

Well or spring identification	Lithium, dis- solved (µg/L as Li)	Sele- nium, dis- solved (µg/L as Se)	Gross beta, dis- solved (pCi/L as Cs-137)	Gross beta, susp. total (pCi/L as Cs-137)	Solids, sum of consti- tuents, dis- solved (mg/L)	Solids, dis- solved (tons per acre-ft)	Nitro- gen, nitrate total (mg/L as NO_3)	Nitro- gen, nitrate dis- solved (mg/L as NO_3)	Nitro- gen, nitrite dis- solved (mg/L as NO_2)	Mercury dis- solved (µg/L as Hg)
(D-24-30)23bab1	47	<1	----	----	-----	----	---	----	---	----
([1])	---	--	5.0	2.2	284	0.39	---	----	---	----
(D-24-30)15ddc	38	1	----	----	271	0.37	---	----	---	----
(D-24-30)15cdc1	18	1	----	----	331	0.45	---	----	---	----
(D-24-30)11cad1[1]	---	--	3.8	<0.4	-----	----	---	----	---	----
(D-24-30)11cad2	60	<1	----	----	275	0.37	---	----	---	----
(D-24-30)15dad	65	<1	----	----	312	0.42	---	----	---	----
(D-24-30)13dba[1]	---	--	31	2.1	-----	----	---	----	---	----
(D-24-30)14cbd	---	--	----	----	294	0.40	---	----	---	----
	---	<1	----	----	300	0.41	---	----	---	<0.1
(D-24-30)14cbd	---	--	4.4	<0.4	-----	----	---	----	---	----
	---	--	6.5	33	-----	----	---	----	---	----
	---	--	5.2	0.7	-----	----	---	----	---	----
	---	--	6.2	0.8	-----	----	---	----	---	----
([1])	---	--	3.4	<1.4	-----	----	---	----	---	----
(D-24-30)14bdb	57	<1	----	----	279	0.38	---	----	---	----
(D-24-31)03bab	---	--	----	----	1,070	1.46	1.4	----	---	----
	---	--	----	----	829	1.13	---	----	---	----
(D-24-31)10ccc	---	--	----	----	874	1.19	---	----	---	----
(D-23-30)36bab	---	--	----	----	897	1.22	---	0.35	0.0	----
(D-23-31)26abc2	---	--	----	----	269	0.37	---	----	---	----
(D-23-31)04cab	---	--	----	----	253	0.34	---	6.2	0.0	----
(D-23-32)06aad1	---	--	----	----	477	0.65	---	----	---	----
(D-22-32)18bcb	---	--	----	----	253	0.34	5.9	----	---	----
(D-21-30)32acb	---	--	----	----	249	0.34	---	----	---	----
(D-22-32)17cca	---	--	----	----	258	0.35	---	----	---	----
(D-24-30)16ccc	---	--	----	----	321	----	---	----	---	----
(D-23-30)32ccd	---	--	----	----	209	----	---	----	---	----
(D-24-29)09cac	130	1	----	----	602	----	---	----	--	----
(D-24-30)11bbc	---	--	----	----	---	----	---	----	--	----

See footnotes at end of table.

Table 4.--Chemical analysis of well and spring water, San Bernardino Valley--Continued

Well or spring identification	Elevation of land surface datum (feet above NGVD)	Depth of well, total (feet)	Depth below land surface (water level, (feet)	Gross alpha, dis-solved (µg/L as U-NAT)	Gross alpha, susp. total (µg/L as U-NAT)	Gross beta, dis-solved (pCi/L as Sr/Yt-90)	Gross beta, susp. total (pCi/L as Sr/Yt-90)	Spe-cific con-duct-ance lab (µS/cm)	Alka-linity lab (mg/L as $CaCO_3$)
(D-24-30)23bab1	3,760	------	------	----	----	---	----	437	205
([1])	3,760	------	------	3.0	1.5	---	----	---	---
(D-24-30)15ddc	3,759	------	------	----	----	---	----	441	204
(D-24-30)15cdc1	3,780	Spring	0.0	----	----	---	----	553	225
(D-24-30)11cad1[1]	3,740	------	------	8.7	<0.5	---	----	---	---
(D-24-30)11cad2	3,740	------	------	----	----	---	----	431	199
(D-24-30)15dad	3,759	------	------	----	----	---	----	503	238
(D-24-30)13dba[1]	3,760	------	------	81	<0.5	---	----	---	---
(D-24-30)14cbd	3,750	583	------	----	----	---	----	---	---
	3,750	583	------	----	----	---	----	463	223
(D-24-30)14cbd	3,750	583	------	5.0	<0.4	3.3	<0.4	---	---
	3,750	583	------	6.0	34	4.9	31	---	---
	3,750	583	------	6.2	<0.4	4.0	0.7	---	---
	3,750	583	------	6.6	<0.4	4.7	0.8	---	---
([1])	3,750	583	------	3.7	<0.6	---	----	---	---
(D-24-30)14bdb	3,750	------	------	----	----	---	----	432	207
(D-24-31)03bab	4,035	250	------	----	----	---	----	---	---
	4,035	250	------	----	----	---	----	---	---
(D-24-31)10ccc	4,005	250	------	----	----	---	----	---	---
(D-23-30)36bab	3,900	308	------	----	----	---	----	---	---
(D-23-31)26abc2	4,145	325	------	----	----	---	----	---	---
(D-23-31)04cab	4,215	[2]450	------	----	----	---	----	---	---
(D-23-32)06aad1	4,550	180	------	----	----	---	----	---	---
(D-22-32)18bcb	4,655	865	808.00	----	----	---	----	---	---
(D-21-30)32acb	4,770	200	------	----	----	---	----	---	---
(D-22-32)17cca	5,120	458	------	----	----	---	----	---	---
(D-24-30)16ccc	3,800	100	------	----	----	---	----	438	198
(D-23-30)32ccd	3,955	------	------	----	----	---	----	334	130
(D-24-29)09cac	4,350	------	------	----	----	---	----	811	126
(D-24-30)11bbc	3,800	------	------	----	----	---	----	---	---

[1]Analysis by Arizona State University, College of Engineering and Applied Sciences.
[2]Well has been deepened to 675 feet since date sampled.

contaminant levels for non-community water systems (Gillen, 1987; U.S. Environmental Protection Agency, 1986). Concentrations in spring-water samples were below State of Arizona maximum allowable limits established for surface-water aquatic and wildlife protected-use basins (Gillen, 1987). State of Arizona standards for surface-water quality, however, have not been established for San Bernardino Valley.

The springs and 17 of the wells sampled are in the southern and eastern part of San Bernardino Valley. Well (D-21-30)32acb is about 14 mi north of the refuge near the west edge of the valley. Springs sampled were Astin Spring, north of the refuge, and House Spring, in the refuge near the restored ranch house. Only water-quality data were collected at well (D-24-30)24dba. The well does not flow and is not used in wetland restoration. Samples were collected from refuge wells 1, 3, 4, 6, 8, and 10. Depths of wells sampled ranged from 100 to 865 ft, and seven wells have unknown depths. Of the 12 wells located outside the refuge, water from 11 wells is used for livestock supply and water from 1 well is used for domestic supply (table 1). Water from House Spring is used for domestic supply and water from the refuge wells is used to maintain wildlife habitats.

Ground-water chemistry generally is controlled by environmental factors such as precipitation, biologic and biochemical processes, lithology of aquifer materials, and surface characteristics of recharge areas. The chemistry could be altered along ground-water flow paths from recharge areas to discharge areas (Hem, 1985). Variability in concentrations of constituents reflect lateral and vertical changes in aquifer lithology.

Water from several wells to the west, east, and north of the refuge exhibit chemistry typically related to calcium carbonate source materials. Calcium concentrations ranged from 50 to 150 mg/L (milligrams per liter), and alkalinity ranged from 334 to 927 mg/L as $CaCO_3$ in water from wells (D-24-29)09cac, (D-24-31)03bab, (D-24-31)10ccc, and (D-23-30)36bab. Magnesium and sodium concentrations ranged from 32 to 57 mg/L and 50 to 240 mg/L, respectively. Hardness values in samples from these wells ranged from 260 to 590 mg/L as $CaCO_3$. Water from the four wells had specific-conductance values that ranged from 730 to 1,700 μS/cm (microsiemens per centimeter) and dissolved-solids concentrations that ranged from 602 to 1,070 mg/L. Total nitrogen concentrations ranged from 0.030 to 3.20 mg/L. Three of the wells are near limestone outcrops in the southeastern part of the valley and possibly could penetrate one or more calcium carbonate type rock layers in the subsurface. One well is west of the refuge and possibly penetrates calcium carbonate type rocks of the Perilla Mountains.

Concentrations of major constituents (Hem, 1985, p. 54) generally were smaller in the remaining 14 wells. These wells generally yield a moderately hard to very hard sodium bicarbonate water. Calcium concentrations ranged from 5.4 to 98 mg/L, and alkalinity ranged from 144 to 243 mg/L as $CaCO_3$. Magnesium and sodium concentrations ranged from 2.9 to 32 mg/L and 20 to 110 mg/L, respectively. Hardness values generally were lower for these 14 wells and ranged from 26 to 290 mg/L. Specific-conductance values ranged from 304 to 702 μS/cm, and dissolved-solids concentrations ranged from 209 to 477 mg/L. Total nitrogen concentrations ranged from 0.0820 to 7.80 mg/L.

The water discharged at House Spring is a very hard, magnesium bicarbonate type that generally contains greater concentrations of major constituents than does water from the refuge wells. The calcium concentration was 23 mg/L, and alkalinity was 225 mg/L as $CaCO_3$. Magnesium and sodium concentrations were 30 mg/L and 46 mg/L, respectively. The hardness value was 180 mg/L as $CaCO_3$, specific conductance was 553 µS/cm, and dissolved-solids concentration was 331 mg/L. Total nitrogen concentration in water from House Spring was 4.1 mg/L. The greater concentrations of nitrogen measured in House Spring and several wells outside the refuge could result from nitrate formed from the solution of nitrogen-bearing caliche deposits (Halpenny and others, 1952), from livestock operations near recharge areas (Hem, 1985), or from a combination of these and other factors.

Analyses of water from the six refuge wells and House Spring for arsenic, chromium, lead, and selenium showed concentrations below State of Arizona maximum allowable limits established for aquatic and wildlife protected use. One sample from well 10 was analyzed for mercury, and samples from wells 1, 3, 4, 6, 8, and House Spring were analyzed for cadmium. Mercury and cadmium concentrations were below the maximum allowable limits.

Eight samples from four refuge wells were analyzed for radionuclides. Dissolved gross beta activities ranged from 3.3 to 31 pCi/L (picocuries per liter). Suspended gross beta activities ranged from 0.7 to 33 pCi/L in five samples and were undetected in three samples. Dissolved gross alpha concentrations ranged from 3.7 to 81 µg/L (micrograms per liter). Suspended gross alpha concentrations were 1.5 and 34 µg/L in two samples and undetected in six samples. Concentrations of radon, uranium, and radium-226 were not determined in water from the four wells, and therefore compliance with Federal and State of Arizona drinking water maximum contaminant levels for gross alpha activity cannot be determined. Gross alpha concentrations were within a typical range for natural water (Hem, 1985). Analyses of samples done by Arizona State University indicated that no manmade radionuclides were present (John W. McKlveen, Director, Radiation Measurements Facility, Arizona State University, College of Engineering and Applied Sciences, written commun., 1986); therefore, radioactivities resulted from naturally occurring materials in the ground-water system.

POTENTIAL FOR LONG-TERM WATER SUPPLY

Ground-water withdrawals in San Bernardino Valley north of the international boundary with Mexico have remained relatively constant because of the absence of large-scale irrigation. Water levels have fluctuated because of changes in precipitation amounts but have remained stable since the mid-1950's. Effects of irrigation pumping in Mexico on ground-water conditions in the refuge are not known. Long-term discharge or water-level measurements have not been made on the refuge wells, and detailed records of pumpage in Mexico are not available.

The response of the ground-water system to pumping stress is dependent on pumping locations and the geometry and characteristics of the aquifer. Thickness, lithology, and permeability of water-bearing units determine ground-water flow rates. Ground-water withdrawals from wells near the international boundary would have the greatest effect on flow from refuge wells. The effect of large withdrawals on flow from refuge wells is determined by the degree of hydraulic connection between the water-bearing units. The deep water-bearing unit or the units that provide water to refuge wells probably are hydraulically connected to shallower units through discontinuities in overlying fine-grained layers. Under present (1989) conditions, ground-water withdrawals in Arizona and in Mexico do not severely affect flow rates at refuge wells.

Additional information is needed to evaluate the ground-water system and determine the potential for long-term supply. Measurements of aquifer characteristics such as transmissivity, hydraulic conductivity, and storage coefficient would allow for more accurate predictions of water-level declines caused by pumping. Data relating to the thickness and lateral extent of alluvial and basalt units, in addition to aquifer characteristics, would provide more detailed information on hydraulic-head relations and ground-water movement. Close monitoring of discharge from refuge wells, ground-water quality, and pumping in nearby areas could identify trends or changes in ground-water conditions. Available data are insufficient to accurately predict aquifer response to increased pumping of ground water.

SUMMARY

The hydrologic system in the San Bernardino National Wildlife Refuge provides an adequate ground-water supply for restoration and maintenance of the unique wetlands habitat for fish and wildlife. Surface-water supplies in the area are sparse and unreliable, and thus habitat restoration and protection depends on the availability of a reliable supply of ground water of acceptable chemical quality.

Results of field investigations pertaining to geology, water quality, aquifer hydraulics, and water use indicate that an adequate supply of good-quality water is available under existing hydrologic conditions. Small quantities of artesian flow are available from nine wells, and small pumps could be used to increase water quantity for short-term demands. The total effects of environmental stresses on the ground-water system, however, cannot be evaluated on the basis of available data. Further studies involving additional data-collection activities, including data on well-discharge rates, ground-water quality, and pumpage in areas near the refuge, could provide information necessary for a more accurate evaluation of the hydrologic system.

SELECTED REFERENCES

Cooper, J.R., 1959, Reconnaissance geologic map of southeastern Cochise County, Arizona: U.S. Geological Survey Mineral Investigations Field Studies Map MF-213, 1 sheet.

Davidson, E.S., 1973, Geohydrology and water resources of the Tucson basin, Arizona: U.S. Geological Survey Water-Supply Paper 1939-E, 81 p.

Drewes, H.D., 1981, Tectonics of southeastern Arizona: U.S. Geological Survey Professional Paper 1144, 96 p.

Gillen, I.M., ed., 1987, Arizona Administrative Code: Phoenix, Office of the Secretary of State, R18-4-221-B, (Supp. 87-3), p. 23-25; R18-11-205-B, no. 5, (Supp. 87-3), p. 9; R18-11, Articles 1-2, (Supp. 87-3).

Halpenny, L.C., and others, 1952, Ground water in the Gila River basin and adjacent areas, Arizona—A summary: U.S. Geological Survey open-file report (unnumbered), 224 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Lynch, D.J., 1978, The San Bernardino volcanic field of southeastern Arizona, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise: New Mexico Geological Society Guidebook 29th Field Conference, p. 261-268.

Menges, C.M., and McFadden, L.D., 1981, Evidence for a latest Miocene to Pliocene transition from basin-range tectonic to post-tectonic landscape evolution in southeastern Arizona: Arizona Geological Society Digest, v. 13, p. 151-160.

Morrison, R.B., Menges, C.M., and Lepley, L.K., 1981, Neotectonic maps of Arizona: Arizona Geological Society Digest, v. 13, p. 179-183.

National Environmental Satellite Data and Information Service, 1983-1987, Climatological data, Arizona: National Oceanic and Atmospheric Administration, National Environmental and Satellite Data and Information Service, v. 87-91, nos. 1-12.

Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range Province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115.

Pool, D.R., 1985, Aquifer geology of alluvial basins of Arizona, *in* Anderson, T.W. and Johnson, A.I., eds., Regional Aquifer Systems of the United States, Southwest Alluvial Basins of Arizona: American Water Resources Association Monograph Series 7, p. 25-36.

Scarborough, R.B., and Peirce, H.W., 1978, Late Cenozoic basins of Arizona, *in* Callender, J.F., Wilt, J.C., and Clemons, R.E., eds., Land of Cochise: New Mexico Geological Society Guidebook 29th Field Conference, p. 253-259.

Sellers, W.D., Hill, R.H., and Sanderson-Rae, Margaret, eds., 1985, Arizona climate—The first hundred years: Tucson, University of Arizona Press, 143 p.

U.S. Environmental Protection Agency, 1986, Maximum contaminant levels (Subpart B of Part 141, National Interim Primary Drinking-Water Regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised as of July 1, 1986, p. 524-528.

Wilson, E.D., Moore, R.T., and Cooper, J.R., 1969, Geologic map of Arizona: Arizona Bureau of Mines map, scale 1:500,000.

Wilson, R.P., 1976, Maps showing ground-water conditions in the San Bernardino Valley area, Cochise County, Arizona—1975: U.S. Geological Survey Water-Resources Investigations Report 76-81, 2 sheets.