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Ground-Water Quality in Alluvial Basins that have Minimal Urban Development, South-Central Arizona

Water-Resources Investigations Report 99—4005

National Water-Quality Assessment Program

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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National Water-Quality Assessment Program

Tucson, Arizona
1999

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CONVERSION FACTORS

Multiply	By	To obtain
feet (ft)	0.3048	meter
mile (mi)	1.609	kilometers
square mile (mi^2)	2.590	square kilometer

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration in water is given in milligrams per liter (mg/L). Milligrams per liter is a unit expressing the solute mass (milligrams) per unit volume (liter) of water. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

VERTICAL DATUM

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

Ground-Water Quality in Alluvial Basins that have Minimal Urban Development, South-Central Arizona

By D.J. Gellenbeck *and* Alissa L. Coes

Abstract

Ground-water quality data (1917–96) from 772 wells in 16 alluvial basins that have minimal urban development were used to determine the effect of nonurban factors on ground-water quality in south-central Arizona. Characterization of the spatial variability of ground-water quality within and among alluvial basins that have minimal urban development will provide a baseline to which water-quality problems associated with urbanization can be compared. Four water-type categories—calcium carbonate, calcium mixed anion, sodium carbonate, and sodium chloride—were used to classify the 13 alluvial basins for which adequate data were available. Ground-water quality was compared to U.S. Environmental Protection Agency maximum contaminant levels for drinking water, depth of well, and depth to top of perforated interval for five alluvial basins that represented the four water-type categories. Exceedances of maximum contaminant levels for fluoride and nitrate occurred in three and four basins, respectively, of the five selected basins. Specific-conductance values for ground water in the five selected basins tend to increase in a northwesterly direction toward the central part of Arizona as the extent of evaporite deposits increases. The results of this study, which are part of the U.S. Geological Survey's National Water-Quality Assessment Program, can be used to determine the effects of urban land-use activities on ground-water quality in similar hydrogeologic conditions and may be the best indicator available for nonurban ground-water quality in the region.

INTRODUCTION

Ground-water quality in alluvial basins is a concern in south-central Arizona because ground water is the primary source of water for public supply, household, industrial, stock, and agricultural uses. Ground-water quality is naturally determined by the mineralogy of soils and aquifer materials through which the water moves and the length of time the water has been in contact with the soils and aquifer materials. Urban and agricultural land-use activities can alter the ground-water quality by introducing contaminants.

The U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program provides an opportunity to assess the ground-water quality in south-central Arizona. The objectives of the NAWQA program are to describe current water-quality conditions and trends in rivers, streams, and ground water and to understand the natural and human factors that affect the conditions and trends in water quality throughout the Nation (Hirsch and others, 1988). The Central Arizona Basins (CAZB) study area (fig. 1), which includes 34,700 mi^2, was one of 60 study areas across the United States that was selected to help meet these objectives. One objective of the ground-water program in the CAZB study area is to characterize the effects of urban development on ground-water quality. Data from ground-water samples collected for NAWQA in urbanized areas of the CAZB will be used to describe current water-quality conditions.

The effects of urban development on ground-water quality have been identified in other NAWQA study areas throughout the United States (Land and others, 1998; Wall and others, 1998; Bevans and others, 1998; Berndt and others, 1998;

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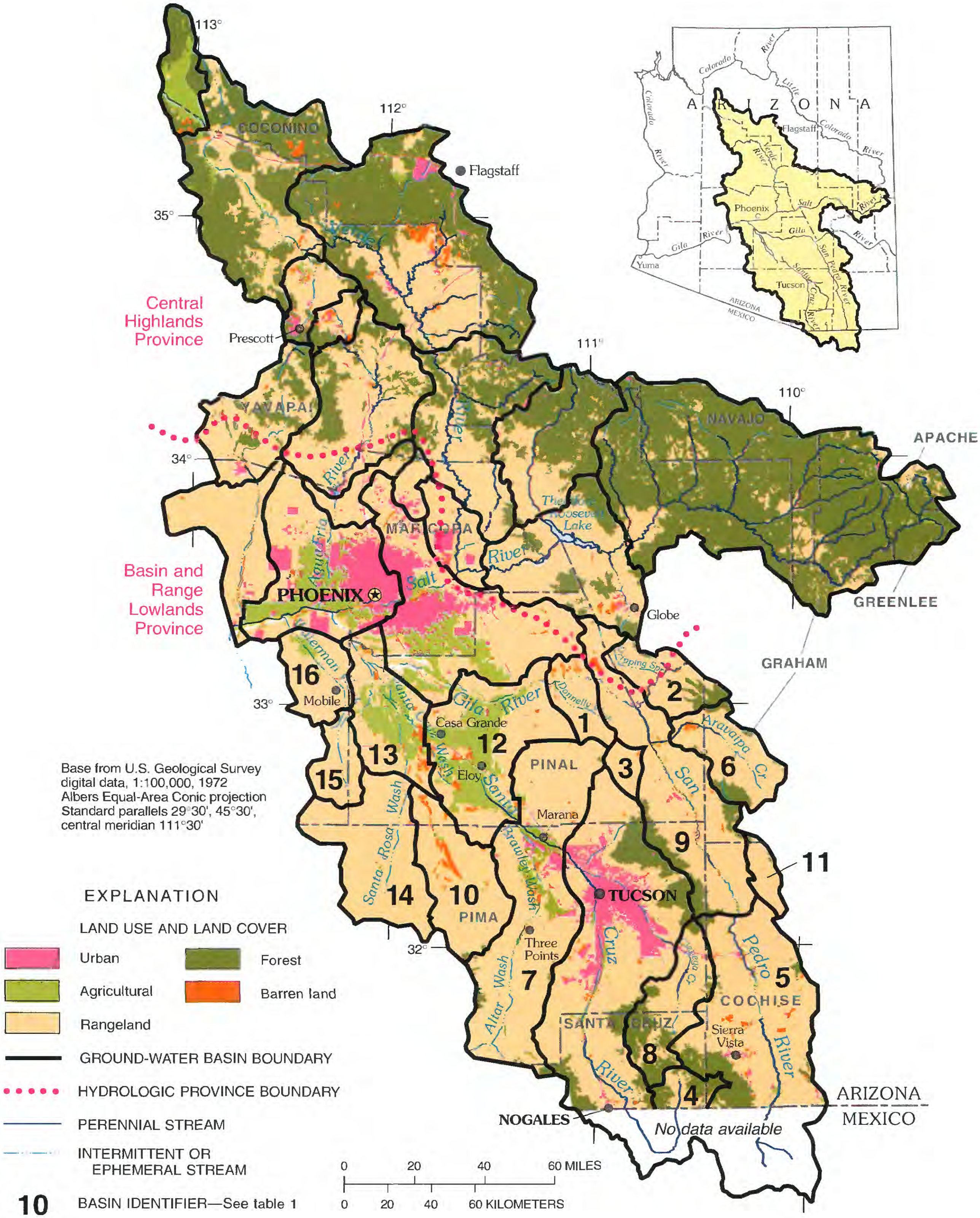


Figure 1. Land use and land cover of the ground-water basins in the Central Arizona Basins study area (digital data modified from U.S. Geological Survey, 1974–86; urban digital data for 1990 from Maricopa Association of Governments, Pima County, and the University of Arizona).

Fenelon, 1998; Dennehy and others, 1998). These studies generally have identified urban effects on ground-water quality as detections of pesticides and (or) volatile organic compounds (VOC's). Concentrations of nitrate above background levels or above the U.S Environmental Protection Agency's (USEPA) maximum contaminant level (MCL) for drinking water also have been identified as urban effects on ground-water quality. In some studies (Bevans and others, 1998; Wall and others, 1998; Land and others, 1998; Fenelon, 1998; Dennehy and others, 1998), high dissolved-solids concentrations or specific-conductance values have been identified in ground water beneath urban areas. Naturally occurring dissolved solids from geologic sources and concentration by evapotranspiration have been identified as causes of these higher values.

In order to determine how ground-water quality is affected by urban development, the effects of nonurban factors on ground-water quality must be understood. Characterization of ground-water quality in areas that have minimal urban development will provide a baseline for comparison to ground-water quality in areas that have similar hydrogeologic conditions but substantial urban development. In the CAZB, the greatest urban development is occurring in the Basin and Range Lowlands Province (fig. 1). Data used in this report were collected for other U.S. Geological Survey (USGS) studies of ground-water quality in the Basin and Range Lowlands Province and include calcium, magnesium, sodium, chloride, sulfate, bicarbonate, nitrate plus nitrite, potassium, and fluoride concentrations and specific-conductance values in basins that have minimal urban development. Data to describe the occurrence of VOC's and pesticides were not available.

The objectives of this study are (1) to characterize the spatial variability of ground-water quality within and among alluvial basins that have minimal urban development in the Basin and Range Lowlands Province of the CAZB and (2) to provide ground-water quality information for these basins that can be used for comparison to ground-water quality in basins that have similar hydrogeologic conditions but greater urban development.

Ground-water quality data for inorganic constituents were used to categorize the ground-water quality of 16 alluvial basins on the basis of the general chemical composition of the ground water. Additional evaluation of the ground-water quality for five individual basins—Sierra Vista, Avra Valley, Santa Rosa, Eloy, and Rainbow Valley—identified characteristics of each individual basin as well as characteristics of regional trends.

Description of the Study Area

The Basin and Range Lowlands Province of the CAZB study area includes approximately 19,000 mi^2 of south-central Arizona (fig. 1). Information about the geologic evolution of alluvial basins in the study area and information about population and land use are included to generally describe some of the factors that may affect ground-water quality. A more detailed description of the environmental setting of the CAZB study area is included in Cordy and others (1998).

Geologic Setting

Alluvial basins in south-central Arizona are the result of the Basin and Range Disturbance, which began about 15 to 12 million years ago (Damon and others, 1984) and to a lesser degree, continues to the present in some areas (Shafiqullah and others, 1980). Normal faulting during this period resulted in uplifted and downdropped blocks that form the mountains and valleys, respectively. Generally, the mountains are the physical boundaries of the alluvial basins in the study area and the valleys are filled with sediments, referred to here as basin-fill deposits.

The Basin and Range Disturbance created internally drained basins into which sediments derived from the surrounding uplifted mountains were deposited. As the basins filled with sediment, streams were able to flow over the lowest divides into adjoining basins that were lower in elevation, creating an integrated drainage pattern (Damon and others, 1984; fig. 2). Basin-fill deposits may be as much as 12,000 ft thick (Cordy and others, 1998). The thickest basin-fill deposits are in basins along a structurally low area referred to as the "Gila Low" by Peirce (1974; fig. 3).

1. were the "effects" merely "detections"?
2. Aren't these the objectives of this report? If not, what are?

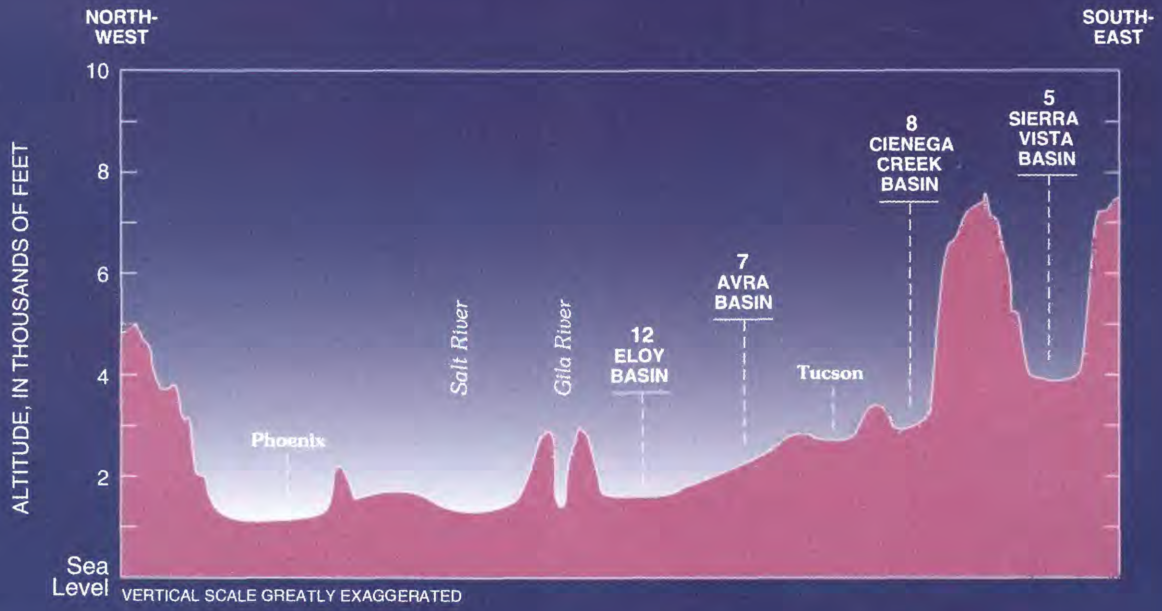


Figure 2. Structural positions of some Arizona basins. See figure 3 and table 1 (modified from Scarborough and Peirce, 1978).

Anderson and others (1992) generally characterized the basin-fill deposits as weakly to highly consolidated gravel, sand, silt, and clay that range in age from late Tertiary to Quaternary. These deposits are the major water-yielding deposits and are coarse grained near the mountain fronts to fine grained in the centers of the basins. Evaporite and mudstone deposits are found within the lower part of the basin-fill deposits. Stream alluvium overlies the basin-fill deposits and occurs along the surface-water drainages in most of the alluvial basins.

Population and Land Use

The two largest urban areas in the study area are Phoenix and Tucson (fig. 1). In 1994, about 26 percent of the population of the State of Arizona resided in Phoenix and about 11 percent resided in Tucson (U.S. Department of Economic Security, 1994). Continued population growth and urbanization in these areas is predicted (Arizona Department of Water Resources, 1993).

Basins with small urban centers (less than 40,000 people) and land-use types that are primarily rangeland (table 1) were selected for the characterization of ground-water quality in areas of minimal urban development. The percentages of land-use types in each basin were determined from spatial data sets by computing the area for each land-use type relative to the total area of the basin (fig. 1; table 1). The spatial data were originally from satellite imagery collected in the mid-1970's. Urban areas near the cities of Phoenix and Tucson were updated to reflect spatial data collected in 1990. A detailed description of the compilation of the spatial data is available in Cordy and others (1998).

DESCRIPTION OF DATA AND STATISTICAL METHODS OF DATA ANALYSIS

Data Selection

Ground-water quality data used in this study were retrieved from the USGS National Water Information System (NWIS) data base for 16 basins within the Basin and Range Lowlands Province that have minimal urban development (fig. 1). This data retrieval included 1,175 individual samples that contained data for calcium, magnesium, sodium, chloride, sulfate, and bicarbonate. These data were from 772 wells sampled between 1917–96 (table 1). Data for three of the 16 basins—Donelly, Dripping

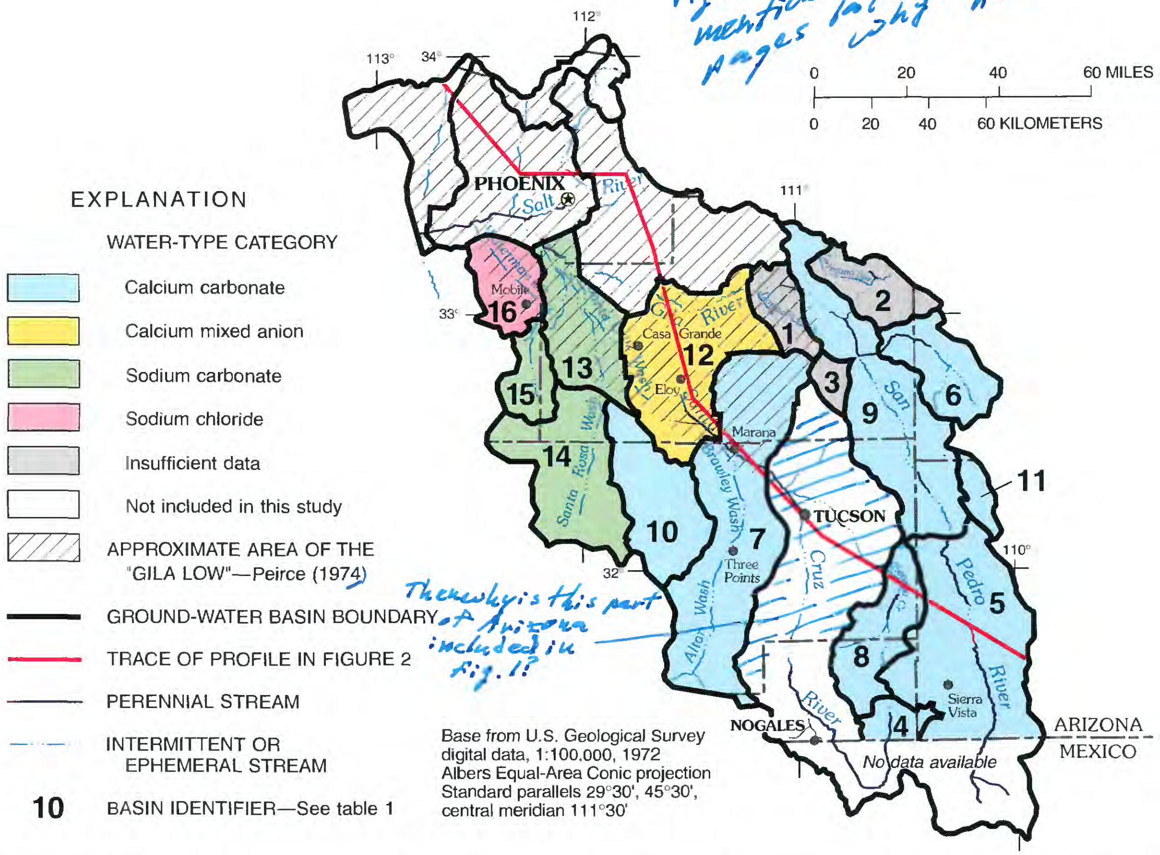


Figure 3. Water-type categories of the ground-water basins and the approximate area of the "Gila Low" in the Basin and Range Lowlands Province of the Central Arizona Basins study area.

Springs, and Camp Grant—were not evaluated because less than 10 sample analyses were available for each of the basins. Specific-conductance data are used as a general characteristic of the inorganic composition of the ground water.

To categorize the water types of the 13 remaining basins, calculations were completed to determine if one cation and (or) one anion contributed 50 percent or more of the cations or anions to solution, respectively, on a milliequivalent basis. If more than 50 percent of the samples for each basin had the same predominant cation or anion, the ground-water type was defined as those ions; if no cation or anion was predominant in more than 50 percent of the samples, the cation or anion was defined as mixed.

Five of the remaining 13 basins were chosen to represent each of the water-type categories. Because there were a large number of basins that were categorized as calcium carbonate, two basins were chosen from that category. For each of these five basins, samples collected at individual wells were selected for additional evaluation if the following conditions were satisfied:

- Data for total depth of well from which the sample was collected were available in NWIS.
- Data for depth of top and bottom of perforated interval of the well from which the sample was collected were available in NWIS.
- The calculated ionic balance of the sample available in NWIS was ±5 percent.

Evaluations of ground-water quality data for each of the five basins were completed using one sample analysis per well. Analyses for samples collected before 1970 were not used because of possible analytical differences compared to more recent methods. If multiple sample analyses were available for a well, the analysis closest to the median year of the data set for the basin was included. Other data available for evaluation included concentrations of nitrate plus nitrite, potassium, and fluoride.

Table 1. Ground-water quality and land-use data for basins in the Basin and Range Lowlands Province of the Central Arizona Basins study area, 1917–96

[Basin number corresponds to number used in figures 1 and 2]

Basin number	Basin name	Number of available samples	Number of wells	Time period	Land-use type and percentage	
			Basins that have less than 10 samples			
1	Donnelly	2	2	1973–85	Rangeland, 97 Urban, <1 Barren land, 2	
2	Dripping Springs	1	1	1985	Rangeland, 85 Urban, <1 Barren land, <1	Forest, 14 Agricultural, <1
3	Camp Grant	7	7	1951–90	Rangeland, 98 Urban, <1 Barren land, <1	Forest, 2 Agricultural, <1
			Calcium carbonate			
4	San Rafael	15	7	1941–95	Rangeland, 41 Agricultural, <1 Barren land, <1	Forest, 58 Urban, <1
5	Sierra Vista[1]	196	124	1920–96	Rangeland, 83 Urban, 2 Barren land, <1	Forest, 13 Agricultural, 1 Other, <1
6	Aravaipa	18	11	1946–95	Rangeland, 84 Urban, <1 Barren land, 1	Forest, 14 Agricultural, <1
7	Avra Valley[1]	253	176	1917–95	Rangeland, 87 Urban, 3 Barren land, 1	Forest, 2 Agricultural, 6 Other, <1
8	Cienega Creek	38	29	1941–95	Rangeland, 65 Urban, <1 Barren land, <1	Forest, 33 Agricultural, <1
9	Mammoth	94	71	1921–95	Rangeland, 85 Urban, <1 Barren land, 1	Forest, 11 Agricultural, <1 Other, <1
10	Aguirre	32	28	1917–81	Rangeland, 95 Urban, <1 Barren land, 4	Forest, 1 Agricultural, <1
11	Allen Flat	15	7	1921–95	Rangeland, 94 Urban, <1 Agricultural, <1	Forest, 6
			Calcium mixed anion			
12	Eloy[1]	252	166	1941–95	Rangeland, 62 Agricultural, 33 Barren land, 3	Urban, 1 Other, <1
			Sodium carbonate			
13	Maricopa-Stanfield	125	62	1941–95	Rangeland, 61 Agricultural, 31 Other, <1	Urban, 2 Barren land, 4
14	Santa Rosa[1]	60	42	1941–81	Rangeland, 99 Agricultural, <1 Barren land, <1	Urban, <1
15	Vekol	20	14	1955–83	Rangeland, 99 Urban, <1	Other, <1
			Sodium chloride			
16	Rainbow Valley[1]	47	25	1949–95	Rangeland, 92 Agricultural, 7	Urban, <1 Other, <1

[1]Basin chosen for additional statistical evaluations.

Statistical Methods of Data Analysis

A variety of statistical methods were used to determine the amount of association between inorganic constituents and other parameters. The Statistical Analysis System (SAS, SAS Institute, Inc., 1989) was used to calculate Kendall's tau-b test statistic (Helsel and Hirsch, 1992)—a nonparametric measure of the association between two variables—for correlations between specific-conductance values and total depth of well, and specific-conductance values and depth to top of the perforated interval. The null hypothesis of no association between variables was rejected if the probability of obtaining the correlation by chance was less than or equal to 0.05.

SAS was used to calculate the Kruskal-Wallis test statistic (Helsel and Hirsch, 1992)—a nonparametric measure of the association between several independent sets of data. This statistic was used to test the hypotheses that (1) specific-conductance values for all basins in a group were the same and (2) calcium and sodium concentrations were the same for wells in the Santa Rosa Basin that were completed in different geologic units. The null hypothesis of identical median values for all data sets was rejected if the probability of obtaining identical medians by chance was less than 0.05. The computer program Statit (Statware, Inc., 1992) was used to apply the Tukey method of multiple comparisons (Helsel and Hirsch, 1992) to the ranks of specific-conductance data to determine if the data for one basin were significantly different when compared with data for other basins in the group. An overall probability less than or equal to 0.05 for the Tukey test was considered statistically significant.

GROUND-WATER QUALITY IN ALLUVIAL BASINS THAT HAVE MINIMAL URBAN DEVELOPMENT

Ground-water types were defined for 13 of the 16 alluvial basins in the study area. Five of the 13 basins—Sierra Vista, Avra Valley, Santa Rosa, Eloy, and Rainbow Valley—were chosen for additional evaluations. Evaluations included comparisons of water-quality data to the aquifer materials and to USEPA drinking-water regulations, and statistical evaluations of the relation between specific-conductance values and well depth, and specific-conductance values and depth to top of well-casing perforations.

Categorization of Basins by Ground-Water Type

Cations and anions that contributed more than 50 percent of ions to solution on a milliequivalent basis were identified for samples from 13 of the 16 basins (table 1). The predominant cation and (or) anion that contributed more than 50 percent of the ions to solution in more than 50 percent of the samples for the basin were used to define four water-type categories—calcium carbonate ($CaCO_3$), calcium mixed anion (Ca mixed anion), sodium carbonate ($NaCO_3$), and sodium chloride (NaCl) (table 2). Evaluation of the spatial distribution of the water-type categories indicated that basins with the same water types generally are located in the same geographical area (fig. 3; table 2). This categorization generally is the same as that in previous investigations of this area (Thompson and others, 1984).

To further characterize each of the four water-type categories, at least one basin from each category was selected for additional evaluations. The basins selected were Sierra Vista, Avra Valley, Eloy, Santa Rosa, and Rainbow Valley. In general, the basins chosen in each category were either the only basin in the category or the basins that had the largest number of sample analyses available. Although Maricopa-Stanfield had a larger number of analyses than Santa Rosa, Santa Rosa was chosen because of the smaller extent of agricultural land use relative to Maricopa-Stanfield. Two basins—Sierra Vista and Avra Valley—were chosen to characterize the calcium carbonate water-type category because of the large number of basins in that category. Water-quality analyses available in each of these five basins were compared to the conditions described in the "Data Selection" section of this report to determine if the analyses contained acceptable data for additional evaluation. The data selection process reduced the number of available analyses for evaluation in each of the five selected basins (table 2).

Table 2. Characteristics of ground-water quality data used for detailed evaluations

[Basin number corresponds to number used in figures 1 and 2; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; ft, feet; number in parentheses is median value]

Basin number	Basin name	Time period	Number of analyses evaluated	Water-type category	Specific conductance (µS/cm) Range	Fluoride (mg/L as F) Range	Nitrate plus nitrite (mg/L as N) Range	Well depth (ft below land surface) Range
5	Sierra Vista	1971–96	23	Calcium carbonate	241–4,400 (360)	0.1–2.2 (0.3)	0.05–3.0 (0.75)	100–855 (500)
7	Avra Valley	1971–86	43	Calcium carbonate	300–1,270 (415)	0.1–8.7 (0.5)	0.67–25 (1.9)	135–1,510 (580)
12	Eloy	1976–92	18	Calcium mixed anion	379–3,300 (794)	0.3–3.5 (0.6)	[1]0.88–38 (6.9)	102–1,300 (666)
14	Santa Rosa	1976–80	14	Sodium carbonate	497–1,250 (695)	0.1–2.2 (0.85)	[2]1.30–3.70 (2.50)	36–692 (236.5)
16	Rainbow Valley	1972–86	16	Sodium chloride	860–3,600 (1,707)	0.6–6.8 (4.45)	1.2–28 (6.95)	434–1,150 (842.5)

[1]Fifteen analyses available.
[2]Two analyses available.

Hydrogeology and Ground-Water Quality of Selected Basins

Sierra Vista Basin

The Sierra Vista Basin (also referred to as the Sierra Vista subbasin) has an area of 2,500 mi^2 of which 699 mi^2 are in Mexico. The basin is 97 mi long and has an average width of 30 mi (Arizona Department of Water Resources, 1991). The western boundary of the basin is formed by the Huachuca, Mustang, Whetstone, and Rincon Mountains (fig. 4). The Mule, Dragoon, and Little Dragoon Mountains and the Tombstone Hills form the eastern boundary. A bedrock constriction referred to as "the Narrows" forms the northern boundary, and the border between the United States and Mexico is the southern boundary of the study area.

The highest point in the basin—about 9,400 ft above sea level—is in the Huachuca Mountains. The elevation of the valley floor ranges from about 3,300 to about 4,300 ft above sea level. The major surface-water drainage, the San Pedro River, flows northward through the basin; however, flow is perennial only in some sections of the river. Land use in the basin is 83 percent rangeland, 13 percent forest, 2 percent urban, 1 percent agricultural, and less than 1 percent barren land (fig. 1; table 1). The cities of Sierra Vista, Bisbee, Benson, Huachuca City, and Tombstone are in this basin (fig. 4).

Hydrogeology

The mountains that surround the Sierra Vista Basin consist of metamorphic, igneous, and consolidated sedimentary rocks that range from Precambrian to Tertiary in age (fig. 4; Roeske and Werrell, 1973). The mountains on the west side of the basin mainly consist of sedimentary, granitic, and volcanic rocks. The mountains on the east side of the basin mainly consist of consolidated sedimentary, volcanic, metamorphic, and granitic rocks (Roeske and Werrell, 1973).

Sediments in the basin range from Tertiary to Quaternary in age and were derived from the local mountains (Brown and others, 1966) and are further categorized on the basis of lithology. The oldest sediments are part of the Pantano Formation that consist of gravelly sandstone to conglomerate interbedded with mudstone and siltstone (Roeske and Werrell, 1973); near Sierra Vista, these sediments range in thickness from 490 to 1,180 ft (Putman and others, 1988). Basin-fill deposits that overlie the Pantano Formation range in thickness from a few feet to more than 1,640 ft and include partially cemented interbedded gravel and sandstone overlain by poorly cemented gravel,

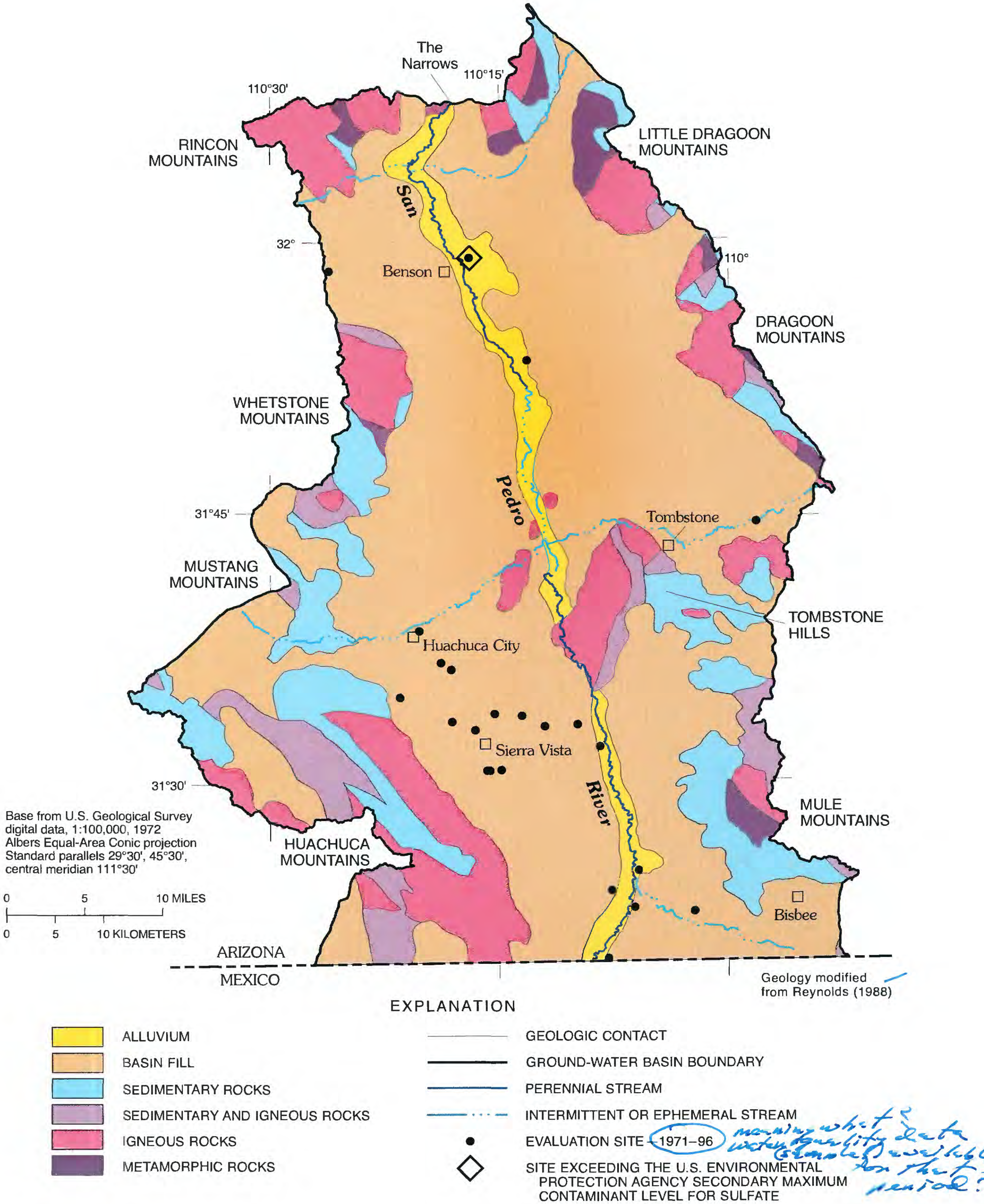


Figure 4. Location of evaluation sites and generalized surficial geology of the Sierra Vista Basin (basin 5 on figure 1).

sand, silt, and clay (Roeske and Werrell, 1973; Brown and others, 1966). Stream alluvium along the San Pedro River and parts of its tributaries ranges in thickness from 40 to 100 ft (Roeske and Werrell, 1973) and consists of unconsolidated deposits of gravel, sand, silt, and clay.

Ground water is recharged along the mountain fronts and flows toward the San Pedro River. Ground-water recharge occurs in all the mountains throughout the study area. Along the basin axis, ground-water flow is northward, parallel to the gradient of the river. A cone of depression caused by pumping in the Sierra Vista area has locally altered the direction of ground-water flow (Arizona Department of Water Resources, 1991).

Ground-Water Quality

The ground-water quality data used for the evaluation of the Sierra Vista Basin included 23 samples collected from 1971–96 (fig. 4; table 2). Ground water in this basin is classified as calcium carbonate (fig. 5). Flowpath modeling of ground water in the basin-fill deposits in the southern part of the basin identified a change in the ground-water chemistry from calcium carbonate to sodium carbonate along a flowpath from the Huachuca Mountains to the San Pedro River (Coes, 1997). This change in water chemistry is attributed to calcite precipitation, dolomite dissolution, and cation exchange.

One of the 23 samples exceeded the USEPA secondary MCL for sulfate (SO_4) of 250 mg/L (U.S. Environmental Protection Agency, 1996; fig. 4). The SO_4 concentration in this sample, 2,000 mg/L, is much higher than other SO_4 concentrations in this data set (median = 8 mg/L). The specific-conductance value for this sample, 4,400 μS/cm, is the highest in the data set (median = 360 μS/cm). This sample is from a well that is completed in a shallow part of the stream alluvium (well depth = 123 ft) near the San Pedro River; whereas, other wells in the data set are completed at greater depths (median = 500 ft). Specific-conductance values for the 23 samples range from 241 to 4,400 μS/cm and have no significant trend with well depth or depth to top of well-casing perforations.

Avra Valley Basin

The Avra Valley Basin includes approximately 1,400 mi^2; the basin is 70 mi long and the valley floor ranges in width from 8 to 15 mi. The southern boundary, which lies 3 mi north of the international border with Mexico, is formed by the Pozo Verde, San Luis, Oro Blanco, and Los Guijas Mountains (fig. 6). The eastern boundary is formed by the Cerro Colorado, Sierrita, Tucson, and Tortolita Mountains. The northern and northwestern boundaries are ground-water divides between the Avra Valley and Eloy Basins (fig. 1; table 1). The Silver Bell, Waterman, Roskruge, Coyote, Quinlan, and Baboquivari Mountains form the western boundary. The highest point in the basin is in the Sierrita Mountains at about 5,900 ft above sea level. The elevation of the valley floor ranges from about 1,900 to about 3,600 ft above sea level.

The Avra Valley Basin is the combination of the Altar and Avra Valleys. The boundary between these two valleys is located near Three Points. The major surface-water feature trends northward through the basin and is named Altar Wash in the southern part of the basin and Brawley Wash in the northern part. Brawley Wash flows into Los Robles Wash, which eventually flows into the Santa Cruz River. The Santa Cruz River flows from east to west through the northern part of the basin. Flow in these washes and the Santa Cruz River is ephemeral, which is normally the result of heavy rainfall.

More than 87 percent of the land area in the Avra Valley Basin is rangeland; approximately 6 percent is agricultural, 3 percent is urban, and the remaining 3 percent is a combination of forest and barren land (fig. 1; table 1). The city of Marana is in the northern part of the basin, and the town of Three Points is in the southern part of the basin. Part of the San Xavier District and other parts of the Tohono O'odham Indian Reservation are in the central part of the basin along the western and eastern boundaries, respectively.

Hydrogeology

The mountains that surround the Avra Valley Basin include igneous, sedimentary, and metamorphic rocks that range from Precambrian to Tertiary in age (fig. 6). Volcanic rocks are exposed in the mountains along the western boundary in the

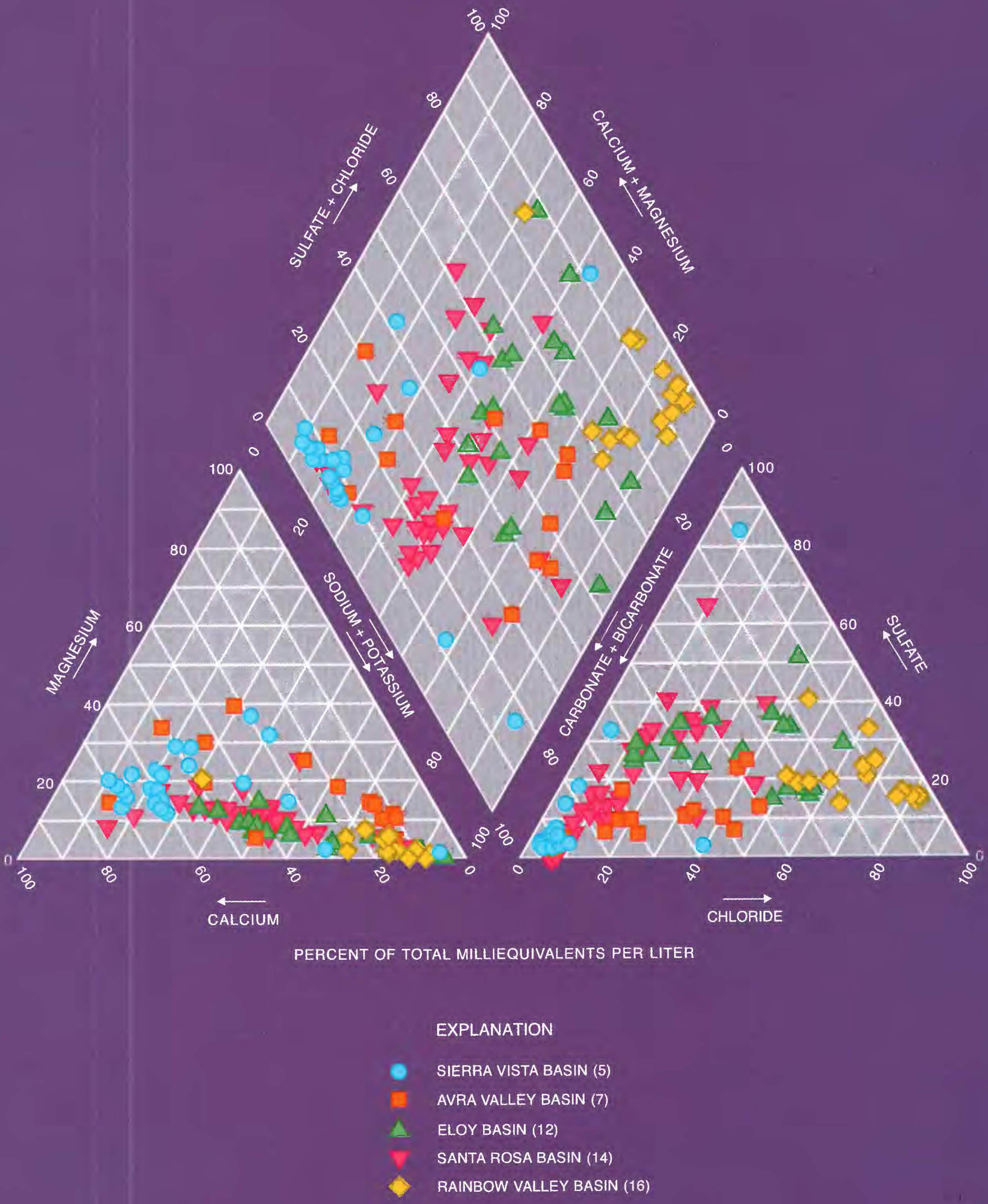


Figure 5. Relative compositions of ground water from the Sierra Vista, Avra Valley, Eloy, Santa Rosa, and Rainbow Valley Basins, south-central Arizona. (See figure 1 for locations of the basins by number.)

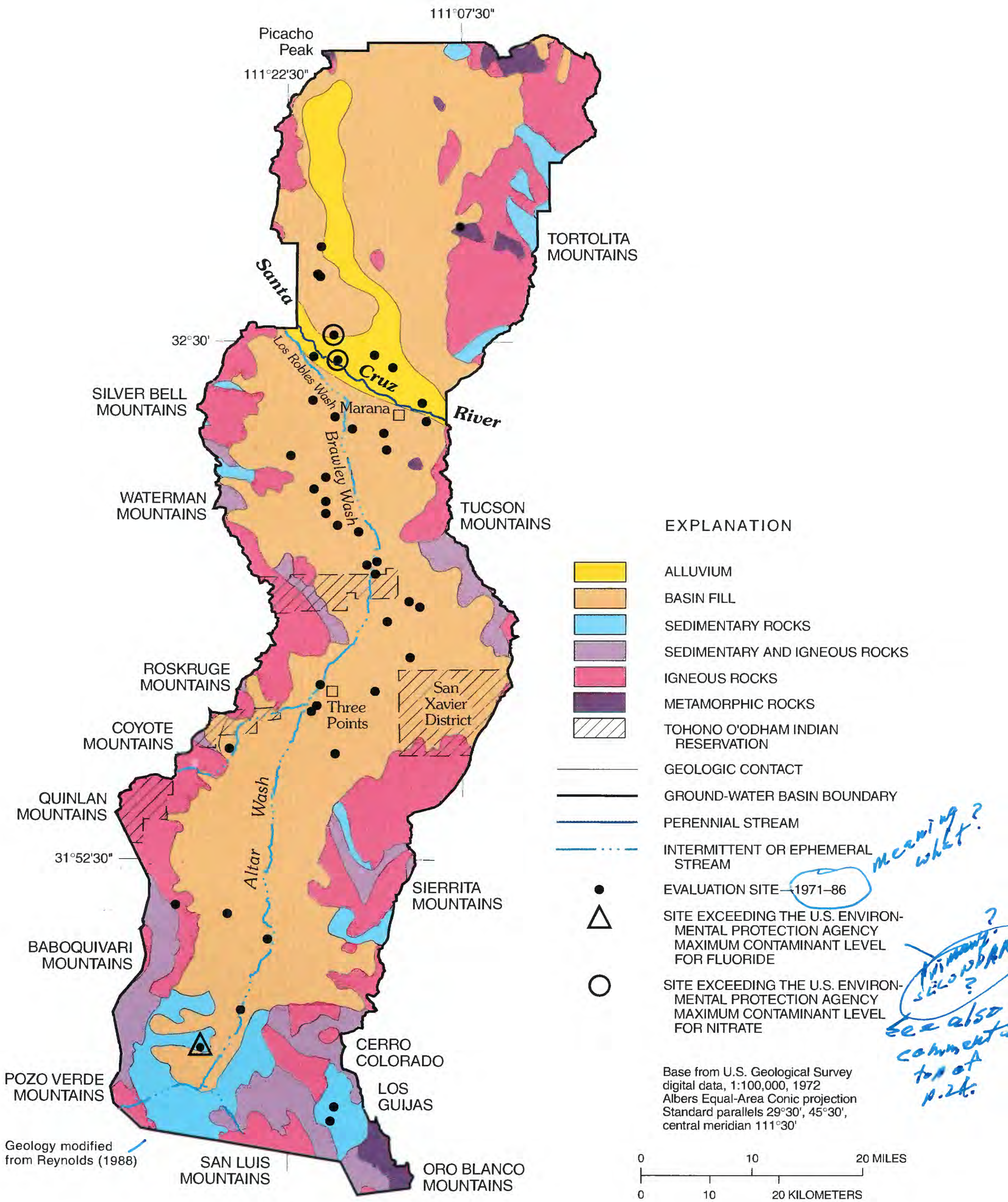


Figure 6. Location of evaluation sites and generalized surficial geology of the Avra Valley Basin (basin 7 on figure 1).

Silver Bell, Waterman, Roskruge, and Baboquivari Mountains and along the eastern and southern boundaries in the Tortolita, Tucson, Sierrita, Cerro Colorado, and San Luis Mountains. Intrusive igneous rocks, primarily granite, are found mainly in the Tortolita, Sierrita, and Quinlan Mountains. Sedimentary rocks are exposed in the Pozo Verde and Oro Blanco Mountains along the southern boundary. Sedimentary rocks with local volcanic rocks are found in the Tucson, Sierrita, Los Guijas, San Luis, Baboquivari, Roskruge, and Waterman Mountains. Metamorphic rocks are found in the Oro Blanco and Tortolita Mountains.

According to Hanson and others (1990), the basin-fill deposits are more than 9,000 ft thick in the northern part of the basin and are divided into two hydrogeologic units—upper alluvium and lower alluvium. The upper alluvium is gravel, sand, and clayey silt, and is 100 to 1,000 ft thick. The lower alluvium is more consolidated and in the north-central part of the basin consists of fine-grained evaporite deposits of gypsiferous and anhydritic clayey silt and mudstone.

Ground-water flow before the beginning of agricultural activities generally was from south to north through the basin (White and others, 1966). Increasing depths to ground water through time in the northern part of the basin reflect the effects of ground-water withdrawals that occurred until 1985 (White and others, 1966; Cuff and Anderson, 1987). In the northern part of the basin, perched ground water was believed to have developed from ground-water withdrawals during this same period (Cuff and Anderson, 1987). Pumpage from Avra Valley was significantly reduced during 1975 to 1984 as the result of the purchase and retirement of agricultural land by the city of Tucson, which is in the adjoining ground-water basin to the east of Avra Valley (Cuff and Anderson, 1987). Depths to ground water seem to have decreased or remained steady since 1985 (City of Tucson, 1997). Ground-water flow in the northern part of the Avra Valley Basin near Three Points is toward the northeast; along the general alignment of Brawley Wash, ground-water flow is toward the north to northwest (City of Tucson, 1997).

Ground-water withdrawals in the southern part of the basin have not been as great as in the northern part; consequently, depths to ground water in the southern area have not been affected by pumping (White and others, 1966). Ground water flows from south to north through this part of the basin and is recharged from infiltration of precipitation that falls in the surrounding mountains.

Ground-Water Quality

The ground-water quality data used for this analysis included 43 samples collected between 1971–86 (fig. 6; table 2). Ground water in this basin has been classified as calcium carbonate (fig. 3). One sample from southern Avra Valley contained fluoride at a concentration higher than the USEPA MCL of 4 mg/L (U.S. Environmental Protection Agency, 1996; fig. 6). The sample was collected in an area previously identified by Robertson and Garrett (1988) as having fluoride concentrations lower than the USEPA MCL—1 to 2 mg/L. The occurrence of fluoride in ground water in southern Arizona is controlled by the availability of fluoride in rocks, mineral equilibrium reactions, and exchange or sorption-desorption reactions on clay minerals (Robertson and Garrett, 1988). Two samples had nitrate (NO_3) concentrations greater than or equal to the USEPA MCL of 10 mg/L as nitrogen (fig. 6). These samples are from an area where similar NO_3 concentrations were found in ground water along the Santa Cruz River (Osterkamp and Laney, 1974). Possible sources of NO_3 in this area include sewage effluent discharged to the Santa Cruz River and used for irrigation, irrigation return flows, septic tanks, feedlots, dairies, and sanitary landfills (Martin, 1980). Nitrate concentrations increased in this area between 1944 and 1977 and were attributed to the application of sewage effluent that was used for irrigation until 1970 (Martin, 1980). Many of the wells used in this evaluation are within agricultural areas; therefore, the high nitrate concentrations could be related to this land-use type.

Specific-conductance values for ground water in the Avra Valley Basin range from 300 to 1,270 µS/cm (median = 415 µS/cm) and generally are less than 1,000 µS/cm. The sample with the highest specific-conductance value is from a well in the northern part of the basin where basin-fill evaporite deposits have been identified (Hanson and others, 1990) and concentrations of dissolved solids tend to be greater than 1,000 µS/cm (Kister, 1974). This area also had some of the most intensive agricultural activity in the basin in conjunction with the largest increases in depth to ground water (Cuff and Anderson, 1987). Specific-conductance values had no significant trend with well depth or depth to top of well-casing perforations.

Eloy Basin

The Eloy Basin includes approximately 1,260 mi^2; the basin is 45 mi long and the valley floor ranges in width from 10 to 35 mi. The southern boundary is formed by the Silver Bell Mountains (fig. 7). The eastern boundary is formed by Picacho Peak, the Picacho Mountains, and an unnamed range that contains Middle Mountain and Allen's Peak. The northern boundary is formed by an unnamed range on the northeast that contains Mineral Mountain and on the northwest by the Santan and Sacaton Mountains. The basin-fill sediments along the western boundary are continuous with those of the Maricopa-Stanfield Basin (fig. 1; table 1). The Casa Grande Mountains are in the basin near the western boundary, and the Silver Reef and Sawtooth Mountains form part of the western boundary. The highest point in the basin is in the Picacho Mountains at approximately 4,500 ft above sea level. The elevation of the valley floor ranges from about 1,300 to about 1,800 ft above sea level.

The major surface-water drainages are the Santa Cruz and Gila Rivers. The Santa Cruz River enters the basin between Picacho Peak and the Silver Bell Mountains; however, it seldom flows northwestward through the basin, except during extended periods of heavy rainfall. The channel becomes indistinct within the basin and becomes more defined where it exits the basin between the Casa Grande and Silver Reef Mountains. The Gila River flows across the northern part of the basin from east to west; the Ashurst-Hayden diversion dam at the northeast end of the basin diverts most of the water from the Gila River for irrigation use.

More than 60 percent of the area in this basin is rangeland, 1 percent is urban, 33 percent is agricultural, and the remaining 3 percent is barren land (fig. 1; table 1). The town of Florence and the cities of Casa Grande, Coolidge, and Eloy are located in this basin. Parts of the Tohono O'odam and Gila River Indian Reservations are along the southwestern and northern boundaries, respectively.

Hydrogeology

The mountains that surround the Eloy Basin include igneous, sedimentary, and metamorphic rocks that range from Precambrian to Tertiary in age (fig. 7). Volcanic rocks are exposed in the mountains along the southern boundary at Picacho Peak and in the Silver Bell, Sawtooth, and Silver Reef Mountains. The mountains along the eastern boundary primarily consist of granitic and sedimentary rocks and include some metamorphic rocks. The mountains along the northwestern boundary primarily consist of granitic rocks and include some metamorphic and volcanic rocks. The rocks in the Casa Grande Mountains are metamorphic.

The basin-fill deposits are several thousand feet thick (Thomsen and Baldys, 1985). Hammett (1992) divided the basin-fill deposits into two hydrogeologic units—upper basin fill and lower basin fill. The upper basin fill is moderately consolidated to unconsolidated gravel, sand, silt, and clay. The center of the basin contains the most fine-grained sediments. The lower basin fill is more consolidated and consists of finer-grained deposits of sand, silt, and clay than the upper basin fill. Evaporite deposits that include gypsum and salt (Kister and Hardt, 1966) and gypsiferous mudstone also are found in this unit.

Before the beginning of agricultural activities, ground-water flow generally was northwestward through the basin (Thomsen and Baldys, 1985). Hammett (1992) described two ground-water flow regimes that correspond with the hydrogeologic units and several areas of perched ground water. Ground-water flow in the upper and lower basin fill is toward depressions in the ground-water table that have resulted from excessive pumping over several decades. Ground-water flow in the upper basin fill is affected by a depression in the ground-water table approximately halfway between the Picacho and Casa Grande Mountains. Ground water in the lower basin fill flows toward the water-table depressions to the south, east, and northeast of the Casa Grande Mountains. In the northern part of the basin,

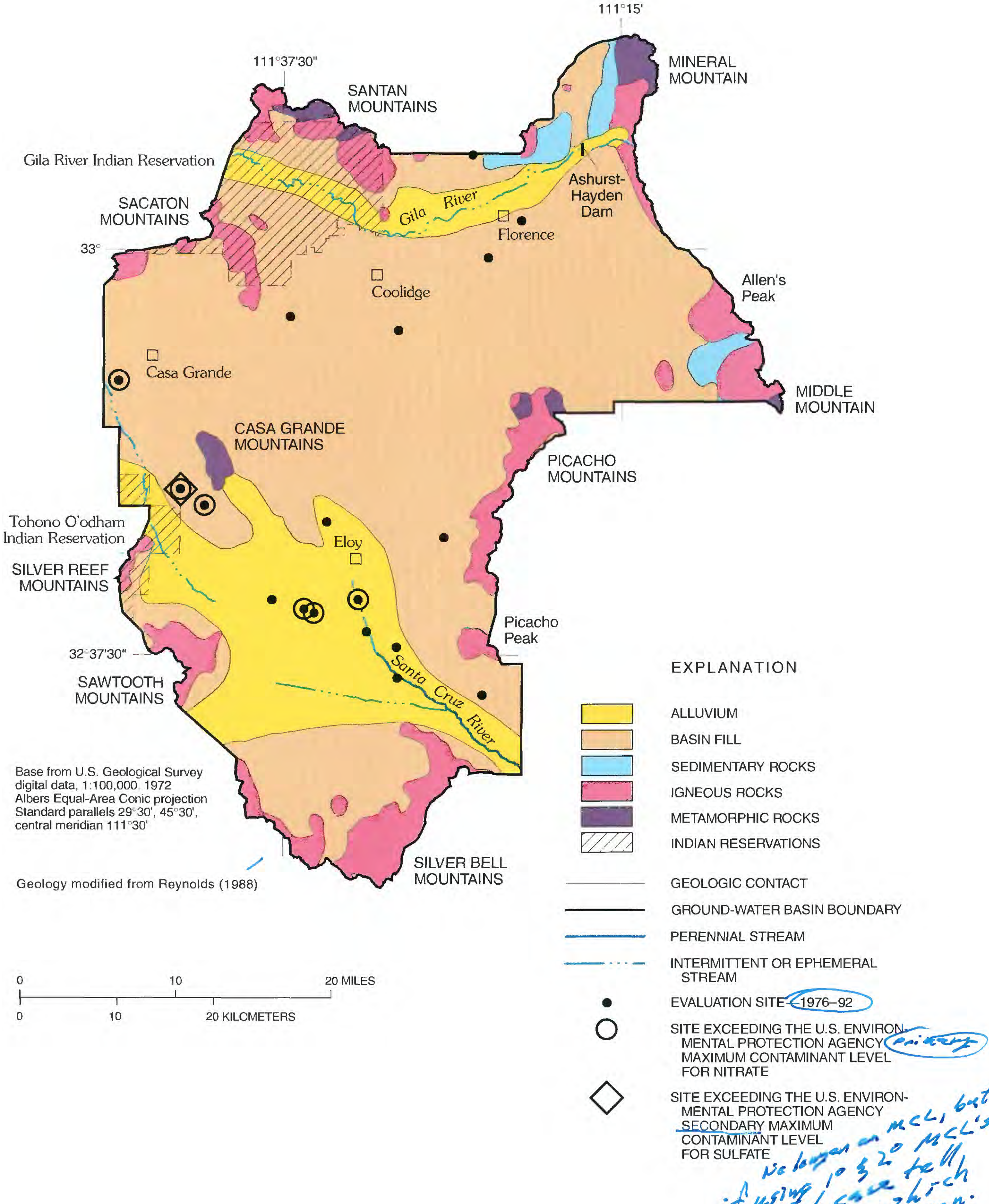


Figure 7. Location of evaluation sites and generalized surficial geology of the Eloy Basin (basin 12 on figure 1).

ground-water flow in the lower basin fill is toward the Gila River. Inflow to the lower basin fill occurs between Picacho Peak and the Silver Bell Mountains and between the Sawtooth Mountains and the west side of the Silver Bell Mountains. Perched ground-water areas include an area north and south of the Casa Grande Mountains that extends into the Maricopa-Stanfield Basin to the west (fig. 2) and an area 5 mi west of the Picacho Mountains that extends from near the southern end of the mountains to the Santan Mountains in the north.

Ground-Water Quality

Ground-water quality data used for this analysis included 18 samples collected between 1976–92 (fig. 7; table 2). Ground water in this basin has been classified as calcium mixed anion (fig. 5). Six samples had NO_3 concentrations greater than or equal to the USEPA MCL of 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1996; fig. 7). Sources of NO_3 have not been identified in this basin, but possible sources of nitrogen include a geologic origin, fertilizers, legume species of desert plants, and atmospheric sources (Robertson, 1991). One sample contained sulfate at a concentration higher than the USEPA secondary MCL of 250 mg/L (U.S. Environmental Protection Agency, 1996; fig. 7).

Specific-conductance values in the ground water from the Eloy Basin vary from 379 to 3,300 μS/cm (median = 794 μS/cm). Higher specific-conductance values (>2,000 μS/cm) have been identified in localized areas that correspond with depressions in the ground-water table—north of the Casa Grande Mountains both in the basin fill and in the perched ground water (Kister and Hardt, 1966; Thomsen and Baldys, 1985; Hammett, 1992). Specific-conductance values greater than 1,000 μS/cm were identified near the cities of Coolidge and Eloy (Hammett, 1992).

Changes in ground-water quality over time have been studied by Kister and Hardt (1966) and Thomsen and Baldys (1985). No change in quality was identified between 1940–60 (Kister and Hardt, 1966), but a change was recognized by Thomsen and Baldys in 1985. Pre-1953 analyses indicated that the water was a mixed cation chloride type, post-1979 analyses showed that the water was a mixed ion type (major ions—Na, Ca, Cl, SO_4). The change was variable throughout the basin as different ions were found to be increasing and decreasing in different parts of the basin. This change in water type was attributed to a lowering of the water table that caused deeper, poorer quality water to be pumped and possibly to a change in sampling techniques and methods of laboratory analyses (Thomsen and Baldys, 1985).

Kister and Hardt (1966) identified a change in specific-conductance values with depth owing to the proportion of ground water from the basin-fill evaporite deposits. As the proportion of ground water from the basin-fill evaporites increased, the specific-conductance values increased. As the ground-water table is lowered, a larger proportion of ground water will be drawn from the basin-fill evaporite deposits; thus, increasing the specific-conductance values in the water withdrawn from wells. The analyses used in this study (1976–92) showed a significant relation between specific-conductance values and total well depth but no significant relation between specific-conductance values and depth to top of well-casing perforations.

Several studies of the ground water in this basin have identified fluoride concentrations greater than the USEPA MCL of 4 mg/L (U.S. Environmental Protection Agency, 1996) in local areas. North of the Casa Grande Mountains in the lower basin fill and in the perched ground water in this same area, fluoride concentrations from 2–10 mg/L have been identified (Kister and Hardt, 1966; Robertson and Garrett, 1988; Thomsen and Baldys, 1985; Hammett, 1992). These areas correspond with areas that have higher specific-conductance values than other areas of the basin. Similar fluoride concentrations have been found in localized areas near the cities of Coolidge and Eloy where specific-conductance values also are high relative to values in surrounding areas (Kister and Hardt, 1966; Thomsen and Baldys, 1985; Robertson and Garrett, 1988; Hammett, 1992). Kister and Hardt (1966) associated higher fluoride concentrations in ground water to wells that penetrate bedrock in the basin. Robertson and Garrett (1988) attributed the higher fluoride concentrations to equilibrium reactions with the mineral fluorite (CaF_2), which dissolves readily when in contact with water. Smaller concentrations of calcium in the ground water can result in the dissolution of fluorite, which increases the concentration of fluoride in the ground water—these conditions exist in the Eloy Basin (Kister and Hardt, 1966; Robertson and Garrett, 1988). Ion exchange and sorption-desorption reactions are additional controls on fluoride concentrations (Robertson and Garrett, 1988; Hammett, 1992).

Santa Rosa Basin

The Santa Rosa Basin has an area of more than 850 mi^2; the basin is 39 mi long and ranges from 15 to 30 mi wide. The western boundary of the basin is formed by the Sand Tank, Cimarron, Vekol, Castle, and Sheridan Mountains (fig. 8). The Tat Momoli, Slate, and Santa Rosa Mountains form the eastern boundary. The Table Top Mountains and Viava Hills form the northern boundary. The southern boundary includes the Sil Nakya Hills and the Brownwell, Sierra Blanca, Quijotoa, South Comobabi, and North Comobabi Mountains. A ground-water divide in the southern part of the basin is the southern boundary (Heindl and others, 1962). The highest point in the basin is in the North Comobabi Mountains and is more than 4,700 ft above sea level. The elevation of the valley floor ranges from about 1,400 to about 2,000 ft above sea level.

The major surface-water drainage is the ephemeral Santa Rosa Wash that flows northward through the basin. Rangeland is the major land-use type (99 percent) in this basin (fig. 1; table 1). Most of the basin is within the Tohono O'odham Indian Reservation.

Hydrogeology

The mountains that surround the Santa Rosa Basin consist of metamorphic, igneous, and consolidated sedimentary rocks that range from Precambrian to Tertiary in age (fig. 8; Heindl and others, 1962). The mountains on the western boundary of the basin mainly consist of volcanic rocks in the Sand Tank, Cimarron, and Castle Mountains; and also include some sedimentary and granitic rocks. The mountains along the northwestern boundary of the basin include limestone and metamorphic rocks. The mountains on the southwestern boundary of the basin mainly consist of sedimentary, volcanic, and granitic rocks. The mountains along the southeastern, eastern, and northeastern boundaries of the basin mainly consist of sedimentary and granitic rocks and include some volcanic rocks; metamorphic rocks also are found in the mountains along the northeastern boundary. The mountains along the northern boundary include volcanic and sedimentary rocks.

The basin-fill deposits are more than 2,000 ft thick (Hollett and Garrett, 1984) and consist of unconsolidated to moderately consolidated gravel, sand, silt, and clay and some evaporites (Hollett and Garrett, 1984). Ground water is recharged along the mountain fronts and flows toward Santa Rosa Wash. Along the basin axis, ground water flows to the north-northeast parallel to the wash.

Ground-Water Quality

The ground-water quality data used for the Santa Rosa Basin included 14 samples collected between 1976–80 (fig. 8; table 2). Ground water in this basin is classified as sodium carbonate (fig. 5). Calcium is the predominant cation in water from wells completed in the bedrock formations (7 wells) and sodium is the predominant cation in water from wells completed in the basin-fill deposits (7 wells). Concentrations of sodium and calcium in water from wells completed in the bedrock formations are significantly different from concentrations in water from wells completed in basin-fill deposits on the basis of a Kruskal-Wallis statistical test (fig. 9). Hollett and Garrett (1984) identified similar results and attributed the difference to cation-exchange processes along the ground-water flowpath from the mountains to the basin axis.

Fluoride concentrations above the USEPA MCL of 4 mg/L (U.S. Environmental Protection Agency, 1996) have been documented by Hollett and Garrett (1984) and Robertson and Garrett (1988) in the northernmost part of the basin. The highest fluoride concentration of the 14 samples used in this study was 2.2 mg/L. Robertson (1984) identified the sources of fluoride in alluvial basins as fluorite, apatite, mica, and amphiboles. The concentration of fluoride in ground water could be controlled by sorption or exchange reactions or the state of saturation of minerals that contain fluoride

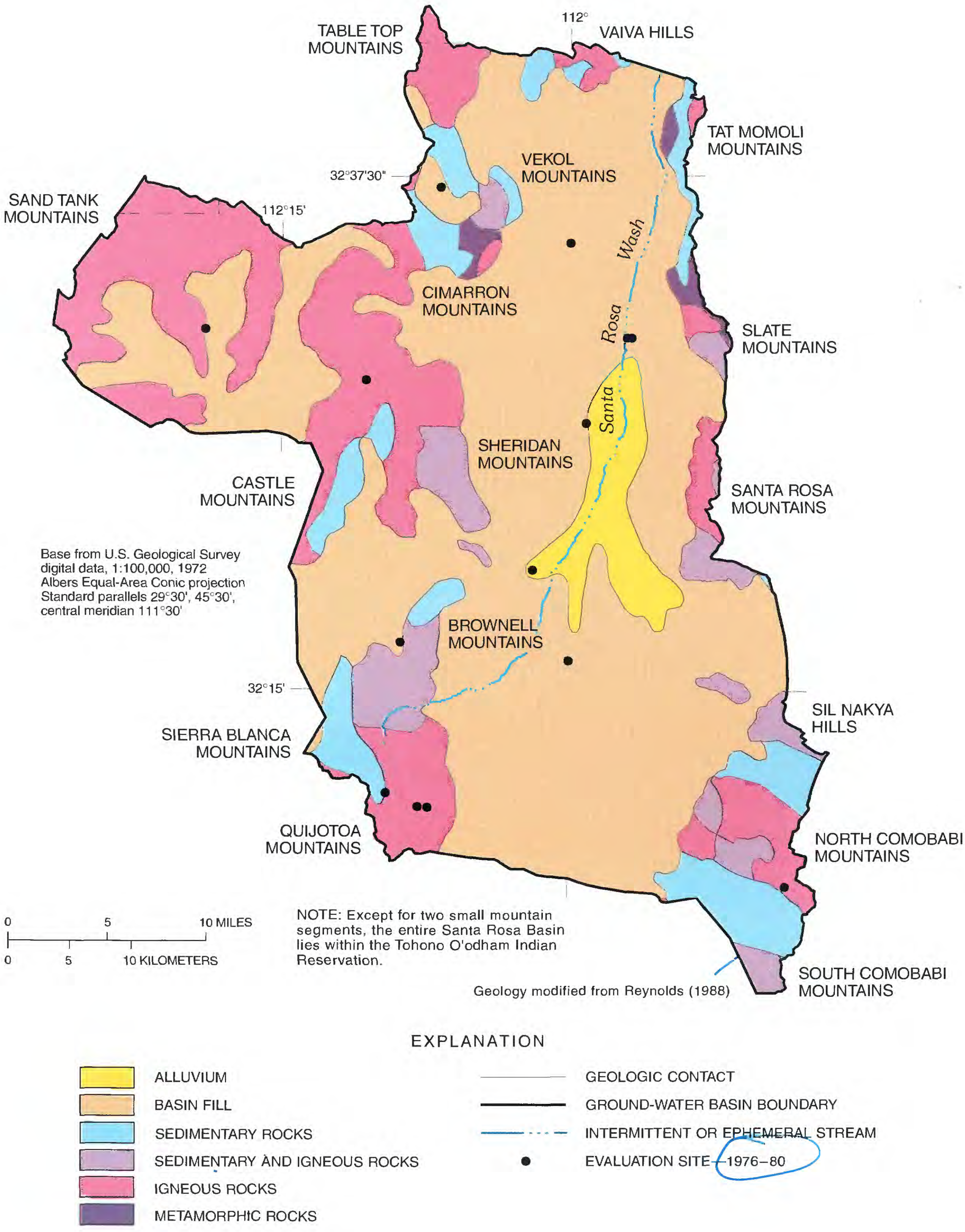
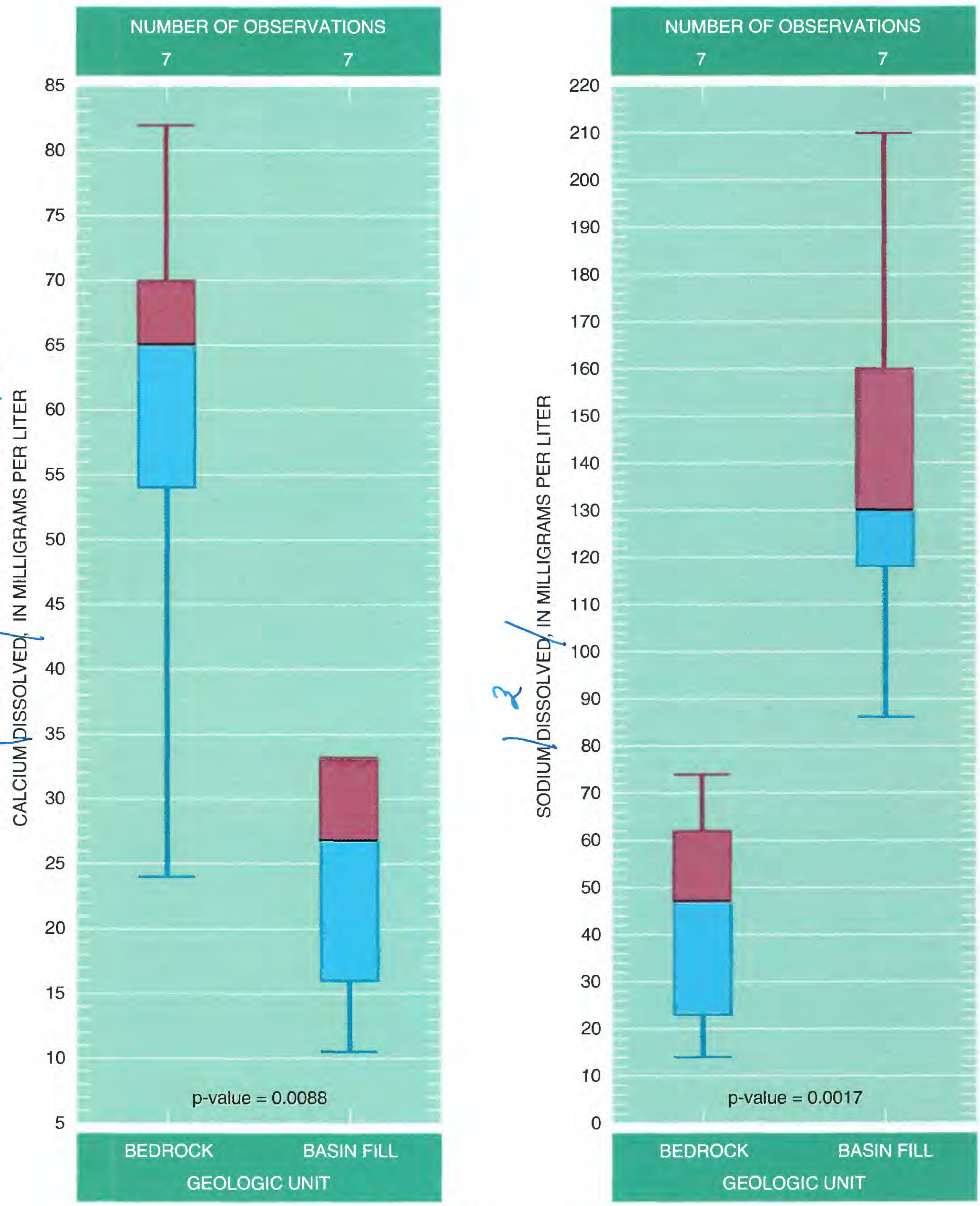


Figure 8. Location of evaluation sites and generalized surficial geology of the Santa Rosa Basin (basin 14 on figure 1).



NOTE: p-value, the probability that observed differences are due to chance rather than the factor tested, is for the Kruskal-Wallis test statistic.

Figure 9. Concentrations of dissolved sodium and calcium in ground water from bedrock and basin-fill deposits, Santa Rosa Basin (basin 14 on figure 1).

in the basin-fill deposits (Robertson, 1984). Hollett and Garrett (1984) reported arsenic concentrations greater than the USEPA MCL of 0.05 mg/L (U.S. Environmental Protection Agency, 1996) in the central part of the basin and attributed the concentrations to the thick sequences of clay in the basin-fill deposits.

Specific-conductance values range from 497 to 1,250 μS/cm (median = 695 μS/cm) for this data set. This range of specific-conductance values can be attributed to locally occurring basin-fill evaporite deposits. The specific-conductance values do not show a significant trend with well depth. The relation of specific-conductance values to depth to the top of the well-casing perforations could not be evaluated because of insufficient data.

Rainbow Valley Basin

The Rainbow Valley Basin has an area of approximately 400 mi^2, and the valley floor is approximately 8 mi wide and 25 mi long (White, 1963). The basin is bounded on the east and northeast by the Sierra Estrella, on the northwest by the Buckeye Hills, on the west and south by the Maricopa Mountains, and on the southeast by the Palo Verde Mountains (fig. 10). A geologic saddle, formed by granitic rocks and covered by alluvial deposits of various thicknesses, separates the Rainbow Valley Basin from the ground-water basin to the west (White, 1963). The highest point in the basin—more than 4,500 ft above sea level—is in the Sierra Estrella. The elevation of the valley floor ranges from about 1,000 to about 1,400 ft above sea level.

Waterman Wash, the main surface-water feature, is ephemeral and extends northwestward through the basin and exits between the Buckeye Hills and Sierra Estrella. Rangeland is the major land-use type (92 percent), urban land use accounts for less than 1 percent of the basin area, and agricultural activities are limited to a small area of the basin (7 percent; fig. 1; table 1).

Hydrogeology

The mountains that surround the Rainbow Valley Basin consist of igneous and metamorphic rocks of Precambrian age (fig. 10). Granitic and some metasedimentary rocks are exposed in the Sierra Estrella; granitic and metasedimentary rocks are exposed in the Maricopa Mountains; granitic and metamorphic rocks are exposed in the Buckeye Hills; and granitic rocks are exposed in the Palo Verde Mountains.

The basin-fill deposits are derived from erosion of the local mountains and are more than 1,500 ft thick (Denis, 1968). According to White (1963), sediments more than 600–800 ft below land surface may have been deposited before the Basin and Range Disturbance. From 600–200 ft below land surface, the sediments are poorly consolidated and contain some clay. From about 200 ft to land surface, fine-grained sediments including abundant clay are present.

Before development of the agricultural area in the northern part of the basin, ground-water flow was from the mountain fronts to the basin axis and then northward through the basin. After development of the agricultural area, ground-water flow was shifted toward the pumping center in the agricultural area (Denis, 1968; fig. 1).

Ground-Water Quality

Ground-water quality data used for the Rainbow Valley Basin included 16 samples collected from 1972–86 (table 2). Ground water in this basin is classified as sodium chloride (fig. 5). Of the 16 samples used in the analysis, 10 had fluoride concentrations higher than the USEPA MCL of 4 mg/L (U.S. Environmental Protection Agency, 1996; fig. 10). High concentrations of fluoride in this area also were identified by White (1963), Denis (1968), and Robertson and Garrett (1988). Robertson (1984) identified the sources of fluoride in alluvial basins in Arizona as fluorite, apatite, mica, and amphiboles. For this basin, Robertson (1984) suggested that the solubility of fluorite controls the fluoride concentrations in ground water because the saturation of fluorite approaches equilibrium. Four of the 16 samples had concentrations of NO_3 greater than the USEPA MCL of 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1996; fig. 10). Nitrogen in this basin possibly is from natural or geologic sources and (or) from agricultural activities. For one sample that had a NO_3 concentration of 15.4 mg/L

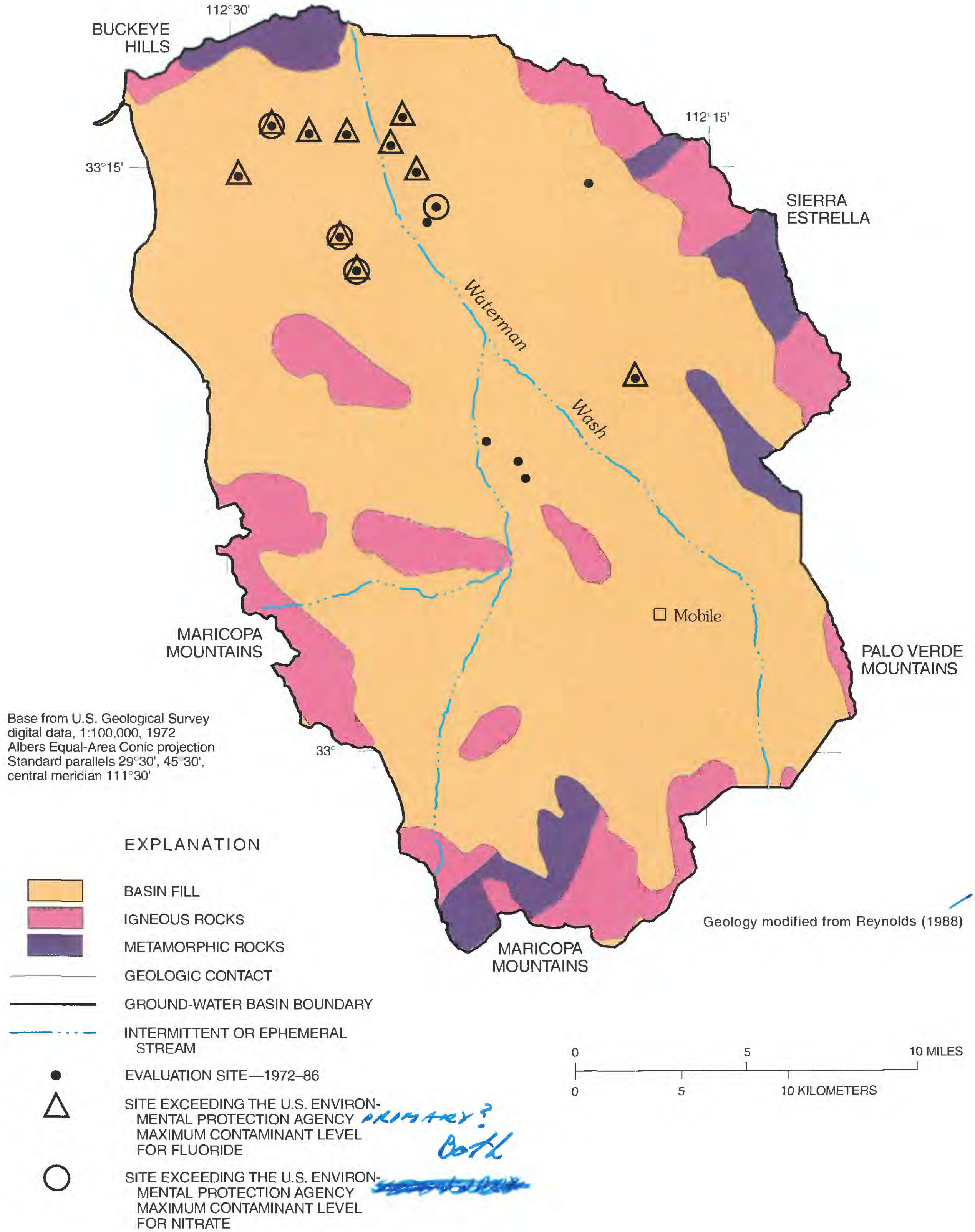


Figure 10. Location of evaluation sites and generalized surficial geology of the Rainbow Valley Basin (basin 16 on figure 1).

as N and was collected from an undeveloped ground-water basin along the western boundary of the Rainbow Valley Basin, Robertson (1991) attributed the nitrogen to natural sources.

Specific-conductance values for this data set (1972–86) range from 860 to 3,600 µS/cm (median = 1,707 µS/cm). Four specific-conductance values from samples collected when agricultural activities began in this basin (1949–52) ranged from 500–3,000 µS/cm (H.N. Wolcott, hydrologist, U.S. Geological Survey, written commun., 1953). Additionally, there is no significant statistical difference between specific-conductance values presented in White (1963) and Denis (1968) and the data set used in these analyses, which indicates that specific-conductance values for ground water in this basin have not changed for two decades. White (1963) hypothesized that the agricultural activities in this basin would cause deterioration of the ground-water quality; however, these effects have not been observed. The high specific-conductance values in this basin could be caused by fine-grained deposits instead of by agricultural activities. Fine-grained deposits that include clay occur from 600 ft below the land surface to the land surface. Slower ground-water movement through these deposits could increase the time available for water-rock interactions and result in high specific-conductance values. Specific-conductance values and well depth or depth to top of well-casing perforations have no significant statistical relation.

Comparison of Ground-Water Quality Among Selected Basins

In addition to the differences that exist among the relative percentages of ions present in ground water from the five selected basins (fig. 5), there are differences in the specific-conductance values for ground water from these same areas. The distribution of specific-conductance values for the five selected basins indicates a general increase of specific-conductance values in a northwestward direction toward the central part of Arizona (fig. 11). The Rainbow Valley Basin had the highest median value for specific conductance (1,707 µS/cm) of the five selected basins; Eloy and Santa Rosa Basins had similar median values (794 and 695 µS/cm, respectively); Avra Valley and Sierra Vista Basins had the lowest median values (415 and 360 µS/cm, respectively). A Kruskal-Wallis statistical test on the specific-conductance values of the five basins indicates that the values are not significantly the same for all five basins; consequently, values for at least one basin are different from values for the other basins. Tukey's multiple comparison test on the ranks of the specific-conductance values indicates that the values for ground water from the Rainbow Valley Basin are different from values for the other four selected basins (pairwise comparison probabilities: Avra = 0.000, Eloy = 0.004, Santa Rosa = 0.012, Sierra Vista = 0.000); Eloy and Santa Rosa are not significantly different from each other (pairwise comparison probability = 1.000); and Avra Valley and Sierra Vista are not significantly different from each other (pairwise comparison probability = 0.180).

The differences in water quality in a northwestward direction could be attributed to the formation of the basins. Parts of three of the selected basins—Rainbow Valley, Eloy and Avra Valley—are within the "Gila Low" (fig. 3; Peirce, 1974), a subprovince within the Basin and Range Lowland Province that is characterized by the presence of massive basin-fill evaporite deposits (Scarborough and Peirce, 1978). The elevation of the tops of basin-fill deposits in this subprovince increase toward the north, east, and south, similar to the modern surface-drainage network (fig. 2). Peirce (1984) suggested that this topography indicates that in the late Cenozoic era, this area was a regionally closed system consisting of interconnected basins. Runoff from the north, east, and south was collected in this region and delivered massive amounts of dissolved minerals that were deposited by evaporation. This process led to the description of the "Gila Low" area as the "south-central Arizona sump."

The evaporite deposits in the basins associated with the "Gila Low" provide the source for dissolved minerals and the increase in specific-conductance values in ground water. Basin-fill evaporite deposits have been documented in the Avra Valley, Eloy, and Santa Rosa Basins. The northern part of the Rainbow Valley Basin is considered to be within the boundary of the "Gila Low" (fig. 3; Peirce, 1974), although basin-fill evaporite deposits have not been identified in the basin. The Rainbow Valley Basin had the highest

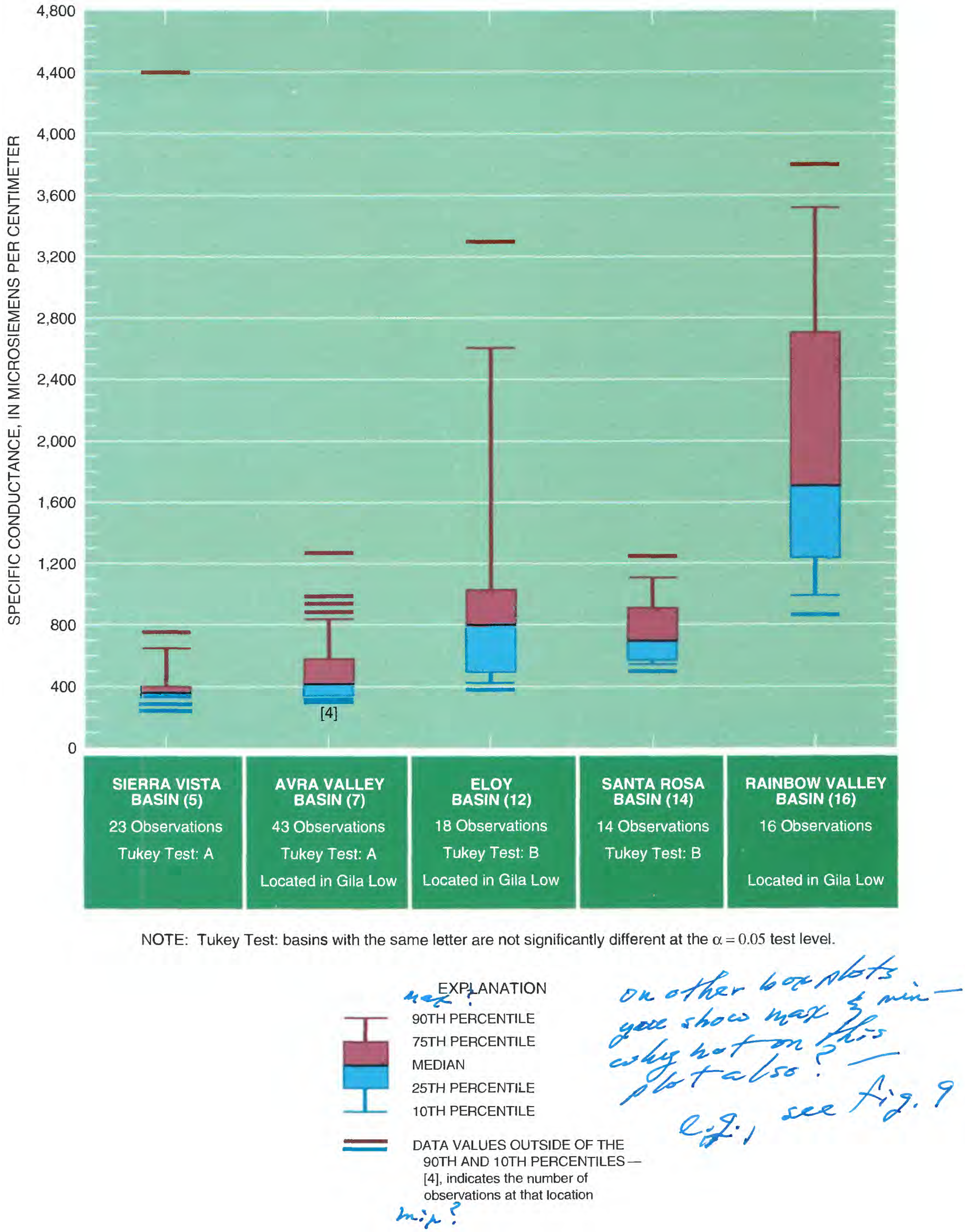


Figure 11. Specific-conductance values in ground water from the Sierra Vista, Avra Valley, Eloy, Santa Rosa, and Rainbow Valley Basins, south-central Arizona. (See figure 1 for locations of the basins by number.)

median specific-conductance value of the five basins (fig. 11), which could be attributed to the slow movement of ground water through fine-grained deposits that allow more time for water-rock interactions. These interactions could result in higher specific-conductance values; however, the composition of the basin-fill deposits and the chemical reactions with water are not well known owing to a lack of data. Additional study of the basin-fill material in the Rainbow Valley Basin may reveal the presence of evaporites.

In the Avra Valley Basin, basin-fill evaporite deposits are in the northern part of the basin (Hanson and others, 1990), which corresponds with the location of the higher specific-conductance values in ground water and with the approximate southern boundary of the "Gila Low" (fig. 3; Peirce, 1974). Higher specific-conductance values in ground water from the Eloy Basin, which is almost entirely in the "Gila Low," were attributed to the basin-fill evaporite deposits that were contributing larger relative percentages of the ground water being pumped (Kister and Hardt, 1966). The Santa Rosa Basin is just south of the approximate boundary of the "Gila Low" and contains evaporite deposits. The Sierra Vista Basin is far outside of the "Gila Low" and does not contain evaporite deposits.

Results from the comparison of ground-water quality among basins that have minimal urban development indicate that basins that exist within the "Gila Low" are likely to have higher specific-conductance values in the ground water. These results can be used when determining the extent to which urban land-use activities and (or) aquifer materials have affected the specific-conductance values of the ground water.

SUMMARY AND CONCLUSIONS

Ground-water quality in alluvial basins of south-central Arizona that have minimal urban development was characterized using data for 772 wells and 1,175 individual samples from 16 basins. This study was part of the NAWQA program in the Central Arizona Basins and encompassed 19,000 mi^2 in the Basin and Range Lowlands Province of the CAZB study area. The objectives of this study were to determine the spatial variability of ground-water quality within and among alluvial basins that have minimal urban development and to provide information that can be used for comparison with data collected in basins with similar hydrologic conditions but more urban development. From the water-quality data reviewed for this study, four water-type categories—calcium carbonate, calcium mixed anion, sodium carbonate, and sodium chloride were identified from those basins that had data for at least 10 samples (13 of 16 basins). To further characterize each of the water-type categories, at least one basin was selected from each category for detailed evaluations—Sierra Vista, Avra Valley, Eloy, Santa Rosa, and Rainbow Valley Basins. The water-quality analysis used for detailed evaluations were selected on the basis of available construction information for the well sampled and the ionic balance of the sample. Additional analyses included comparisons of water-quality data to the aquifer materials and to USEPA drinking-water regulations, and analyses of the relation between specific-conductance values and well depth, and specific-conductance values and depth to top of well-casing perforations.

Ground water from the Sierra Vista and Avra Valley Basins were categorized as calcium carbonate. Samples of ground water from the Sierra Vista Basin had the lowest median specific-conductance value, 360 µS/cm, and one exceedance of the USEPA secondary MCL of 250 mg/L for sulfate. The Avra Valley Basin had the next highest median specific-conductance value, 415 µS/cm, and exceedances in localized areas of USEPA MCL's for fluoride (4 mg/L) and nitrate (10 mg/L as N). Higher specific-conductance values in the northern part of the Avra Valley Basin were attributed to evaporite deposits. Ground water from the Eloy Basin was categorized as calcium mixed anion and had a median specific-conductance value of 794 µS/cm; higher values (>2,000 µS/cm) for this basin were attributed to evaporite deposits in the basin fill. One sample used in the evaluation for the Eloy Basin exceeded the USEPA secondary MCL for sulfate; six samples exceeded the USEPA MCL for nitrate. Other studies (Kister and Hardt, 1966; Robertson and Garrett, 1988; Thomsen and Baldys, 1985; Hammett, 1992) have reported fluoride concentrations that exceeded the USEPA MCL in the Eloy Basin. Ground water from the Santa Rosa Basin was categorized as sodium carbonate and had a median specific-conductance value of 695 μS/cm. Other studies (Hollett and Garrett, 1984; Robertson and Garrett, 1988) have reported fluoride and arsenic concentrations that exceeded USEPA MCL's. Basin-fill evaporite deposits contribute to the relatively higher median specific-conductance values in this basin. Ground water from Rainbow Valley Basin was categorized as sodium chloride and had the highest median specific-conductance value, 1,707 μS/cm, of the five selected basins. Ten of the 16 samples used in this evaluation had fluoride concentrations greater than the USEPA MCL. Four of the 16 samples had nitrate concentrations greater than the USEPA MCL.

The sources of fluoride in the ground water in the selected basins are minerals in the basin-fill deposits, including fluorite (CaF_2), ion exchange, and sorption-desorption reactions (Robertson and Garrett, 1988). Nitrogen sources include a geologic origin, as well as anthropogenic inputs that include fertilizers and sewage effluent used for irrigation (Martin, 1980; Robertson, 1991).

In general, the specific-conductance data used for the selected basins were not significantly correlated with well depth or depth to the top of well-casing perforations. A relation of increasing specific-conductance values with increasing well depth was found to exist in the data used for the Eloy Basin, possibly owing to the relative proportion of ground-water contribution from the basin-fill evaporite deposits.

When specific-conductance values were compared among the five selected basins, values were shown to increase in a northwestward direction toward the central part of Arizona. Statistical comparisons of specific-conductance values indicated that ground water in the Rainbow Valley Basin was significantly different from ground water in the other four basins. Alternately, specific-conductance values for the Eloy and Santa Rosa Basins were not found to be significantly different from each other, and values for the Avra Valley and Sierra Vista Basins were not found to be significantly different from each other. The increase in specific-conductance values toward the northwest could be attributed to the basin-fill evaporite deposits located in three of the basins within the "Gila Low" (Pierce, 1984). The Eloy Basin and northern parts of the Avra Valley and Rainbow Valley Basins are within the boundary of the "Gila Low." Basin-fill evaporite deposits have been documented in the Eloy and Avra Valley Basins, but have not been identified in the Rainbow Valley Basin, which is also within the "Gila Low." Additional information on the basin-fill materials in the Rainbow Valley Basin may reveal the presence of evaporites.

The results from this study provide a framework upon which effects from water-quality problems associated with urbanization can be evaluated. Ground-water quality data for basins with significant urban development within the Basin and Range Lowlands Province of the CAZB study area can be compared with these results to differentiate between effects on water quality from urban development and effects from other factors.

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