

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

# Ground-Water Quality in the Sierra Vista Subbasin, Arizona, 1996–97

Water-Resources Investigations Report 99—4056

*NATIONAL WATER-QUALITY ASSESSMENT PROGRAM*

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By ALISSA L. COES, D.J. GELLENBECK, and DOUGLAS C. TOWNE

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National Water-Quality Assessment Program

Cover photograph: San Pedro River looking south across the Tombstone Hills, autumn 1988.  
(Photograph by Marty Cordano, Bureau of Land Management, San Pedro Office.)

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## FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resources agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for a specific contamination problem; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) program. In 1991, the USGS began full implementation of the program. The NAWQA program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch  
Chief Hydrologist

# CONTENTS

	Page
Abstract .....	1
Introduction.....	1
Purpose and scope .....	3
Physical setting.....	3
Land use and population.....	4
Geohydrologic setting.....	4
Aquifer characteristics.....	6
Recharge and movement of ground water.....	8
Methods of investigation.....	8
Selection of historical data (1950–65).....	9
Selection of sample locations.....	9
Field methods.....	10
U.S. Geological Survey field methods.....	12
Arizona Department of Environmental Quality field methods.....	12
Laboratory methods.....	13
Quality assurance.....	13
U.S. Geological Survey quality-assurance plan and quality-control data.....	13
Arizona Department of Environmental Quality quality-assurance plan and quality-control data.....	17
Combined quality-control data.....	19
Statistical methods.....	22
Ground-water quality.....	23
Present conditions (1996–97).....	23
Physical and general mineral characteristics.....	24
General mineral constituents.....	26
Nutrient constituents.....	29
Trace constituents.....	29
Comparison of historical (1950–65) conditions and present (1996–97) conditions.....	36
Summary and conclusions.....	37
References cited.....	38
Basic data.....	41

## FIGURES

1.-3. Maps showing:	
1. Location of the Sierra Vista subbasin, Arizona.....	2
2. Generalized land-use types and well locations in the Sierra Vista subbasin, Arizona.....	5
3. Generalized surficial geology and well locations in the Sierra Vista subbasin, Arizona.....	7
4. Graph showing ground-water quality samples available in the U.S. Geological Survey National Water Information System, Sierra Vista subbasin, Arizona, 1920–95.....	10
5. Map showing wells used for the historical data analysis, Sierra Vista subbasin, Arizona, 1950–65.....	11

FIGURES—CONTINUED

Page

6. Map showing wells where quality-control samples were collected, Sierra Vista subbasin, Arizona, 1996–97 .....	15
7. Trilinear diagram showing relative composition of ground-water samples, Sierra Vista subbasin, Arizona, 1996–97 .....	20
8. Map showing wells where U.S. Environmental Protection Agency primary or secondary maximum contaminant levels or State of Arizona aquifer water-quality standards were exceeded, Sierra Vista subbasin, Arizona, 1996–97 .....	25
9. Graphs showing temperature, pH, and calcium concentrations as functions of well depth, Sierra Vista subbasin, Arizona, 1996–97 .....	27
10. Boxplots showing concentrations of sodium, potassium, nitrite plus nitrate, fluoride, and chloride relative to well location and aquifer type, Sierra Vista subbasin, Arizona, 1996–97 .....	30
11-13. Graphs showing:	
11. Concentrations of total dissolved solids, calcium, and magnesium as functions of sulfate concentrations, Sierra Vista subbasin, Arizona, 1996–97 .....	32
12. Concentrations of magnesium and chloride as functions of nitrite plus nitrate concentrations, Sierra Vista subbasin, Arizona, 1996–97 .....	33
13. pH and concentrations of sodium and potassium as functions of fluoride concentrations, Sierra Vista subbasin, Arizona, 1996–97 .....	35

TABLES

1. Ground-water analyses by the U.S. Geological Survey and the Arizona Department of Environmental Quality, Sierra Vista subbasin, Arizona, 1996–97 .....	9
2. Allowable differences that indicate stability in U.S. Geological Survey field measurements .....	12
3. Laboratory methods used by the U.S. Geological Survey National Water-Quality Laboratory and the Arizona Department of Health Services Laboratory for analyses of ground water, Sierra Vista subbasin, Arizona .....	14
4. Summary results of the analyses of replicate samples collected by the U.S. Geological Survey and the Arizona Department of Environmental Quality, Sierra Vista subbasin, Arizona, 1996–97 .....	16
5. Results of the analyses of standard reference samples for mineral characteristics and constituents—Standard Reference Sample M-134 .....	18
6. Results of the analyses of standard reference samples for nutrient constituents—Standard Reference Sample N-52 .....	18
7. Results of the analyses of standard reference samples for trace constituents—Standard Reference Sample T-129 .....	18
8. Summary results of the analyses of split samples collected by the U.S. Geological Survey and the Arizona Department of Environmental Quality, Sierra Vista subbasin, Arizona, 1996–97 .....	21
9. U.S. Environmental Protection Agency primary and secondary maximum contaminant levels and State of Arizona aquifer water-quality standards (drinking water protected use) for selected constituents .....	24
10. Summary statistics for ground-water quality data, Sierra Vista subbasin, Arizona, 1996–97 .....	26
11. Calcite, dolomite, and gypsum saturation indices for selected ground-water samples, Sierra Vista subbasin, Arizona, 1996–97 .....	29
12. Fluorite saturation indices for selected ground-water samples, Sierra Vista subbasin, Arizona, 1996–97 .....	34
13. Summary statistics for historical ground-water quality data, Sierra Vista subbasin, Arizona, 1950–65 .....	36

TABLES—CONTINUED

Page

14. Water-quality data for field-blank and replicate samples, Sierra Vista subbasin, Arizona, 1996–97 .....	43
15. Water-quality data for split samples, Sierra Vista subbasin, Arizona, 1996–97 .....	45
16. Water-quality data for ground water, Sierra Vista subbasin, Arizona, 1996–97 .....	46
17. Site information and well-construction data for sample locations, Sierra Vista subbasin, Arizona, 1996–97 .....	50

CONVERSION FACTORS

Multiply	By	To obtain
	micrometer (μm)	3.937 x 10 <sup>-5</sup> inch
	centimeter (cm)	0.3937 inch
	meter (m)	3.281 foot
	kilometer (km)	0.6214 mile
	square kilometer (km <sup>2</sup> )	0.3861 square mile
	milliliter (mL)	2.642 x 10 <sup>-4</sup> gallon
	liter (L)	0.2642 gallon
	cubic hectometer per year (hm <sup>3</sup> /yr)	811.03 acre-foot per year
	liter per second (L/s)	15.85 gallon per minute
	liter per second per meter [(L/s)/m]	4.831 gallon per minute per foot
	meter per kilometer (m/km)	5.280 foot per mile
	meter squared per day (m <sup>2</sup> /d)	10.76 foot squared per day

In this report, temperatures are given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the following equation:

$$^{\circ}\text{F} = 1.8(^{\circ}\text{C}) + 32$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm). Microsiemens per centimeter at 25 degrees Celsius is a unit expressing the conductance (microsiemens) of a body of unit length and unit cross section (centimeter) at a specified temperature (25°C). Turbidity is given either in Nephelometric Turbidity Units (NTU) or Formazin Turbidity Units (FTU). A Nephelometric Turbidity Unit is a unit expressing the amount of light scattered at 90 degrees when the turbidimeter is calibrated with formazin. A Formazin Turbidity Unit is a unit expressing the amount of light scattered at a specific wavelength when the spectrophotometer is calibrated with formazin; a wavelength of 450 nanometers was used for this study.

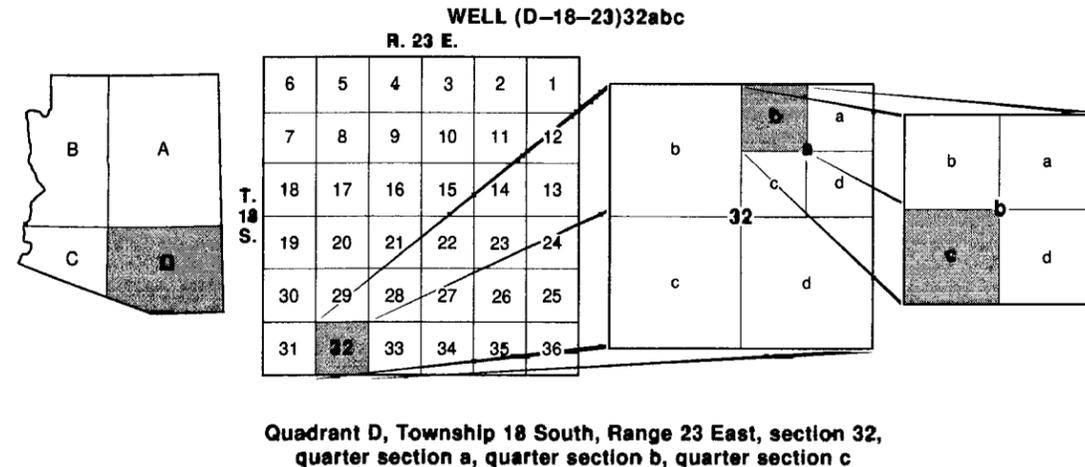
VERTICAL DATUM

*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 “Sea Level Datum of 1929.”

## ABBREVIATIONS

ADEQ	Arizona Department of Environmental Quality	NAWQA	National Water-Quality Assessment Program
ADHS	Arizona Department of Health Services	NWIS	National Water Information System
BQS	Branch of Quality Systems	NWQL	National Water-Quality Laboratory
CAZB	Central Arizona Basins	QAPP	Quality Assurance Project Plan
MCL	Maximum Contaminant Level	USEPA	U.S. Environmental Protection Agency
MPV	Most Probable Value	USGS	U.S. Geological Survey
MRL	Minimum Reporting Level		

## WELL-NUMBERING AND NAMING SYSTEM



The well numbers used by the U.S. 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 and are designated by capital letters A, B, C, and D in a counterclockwise direction beginning in the northeast quarter. 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. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes. In the example shown, well number (D-18-23)32abc designates the well as being in the NE<sup>1</sup>/<sub>4</sub>, NW<sup>1</sup>/<sub>4</sub>, SW<sup>1</sup>/<sub>4</sub>, section 32, Township 18 South, and Range 23 East.

# Ground-Water Quality in the Sierra Vista Subbasin, Arizona, 1996-97

By Alissa L. Coes, D.J. Gellenbeck, and Douglas C. Towne<sup>1</sup>

## Abstract

Thirty-nine ground-water samples were collected and analyzed in 1996-97 by the U.S. Geological Survey and the Arizona Department of Environmental Quality to assess ground-water quality in the Sierra Vista subbasin in southern Arizona. The U.S. Environmental Protection Agency primary maximum contaminant level and the State of Arizona aquifer water-quality standard for fluoride and the U.S. Environmental Protection Agency secondary maximum contaminant levels for fluoride, iron, manganese, pH, sulfate, and total dissolved solids were exceeded in samples collected for this study. On the basis of statistical tests, significant variations were identified between ground-water quality and well location, well depth, and aquifer type. Significant differences were not identified between ground-water quality data and geology, land use, or ground-water quality data collected during 1950-65. Temperature and pH values increased and calcium concentrations decreased with increased well depth. Sodium, potassium, and fluoride concentrations in samples from the northern part of the subbasin were higher than concentrations in samples from the southern part of the subbasin. Sodium and chloride concentrations in samples from bedrock areas were higher than concentrations in samples from unconfined parts of the basin-fill aquifer; sodium and fluoride concentrations in samples from confined parts of the basin-fill aquifer in the St. David-Pomerene area were higher than concentrations in samples from unconfined parts of the basin-fill aquifer. Geochemical reactions in the basin-fill deposits are responsible for the concentrations of constituents that exceeded U.S. Environmental Protection Agency primary and secondary maximum contaminant levels and State of Arizona aquifer water-quality standards and the statistically significant variations of ground-water quality data in relation to well location and aquifer type.

Quality-control samples collected and analyzed by the U.S. Geological Survey and the Arizona Department of Environmental Quality generally verified that combining the ground-water quality data collected by the two agencies for regional assessment was acceptable. Statistically significant differences, however, were identified between quality-control samples collected and analyzed by the two agencies for alkalinity, specific conductance, magnesium, and potassium concentrations. Consideration of this variability was taken into account when analyzing the data from this study.

## INTRODUCTION

The Sierra Vista subbasin (fig. 1) historically has been minimally affected by urban

development, but the population is expected to increase substantially during the next several decades. Ground water is the primary source for municipal, domestic, livestock, and irrigation needs in the subbasin. A projected 30-percent increase in the population between 1990 and 2010 (Arizona Department of Water Resources, 1993) in the Upper

<sup>1</sup>Arizona Department of Environmental Quality, Phoenix, Arizona.

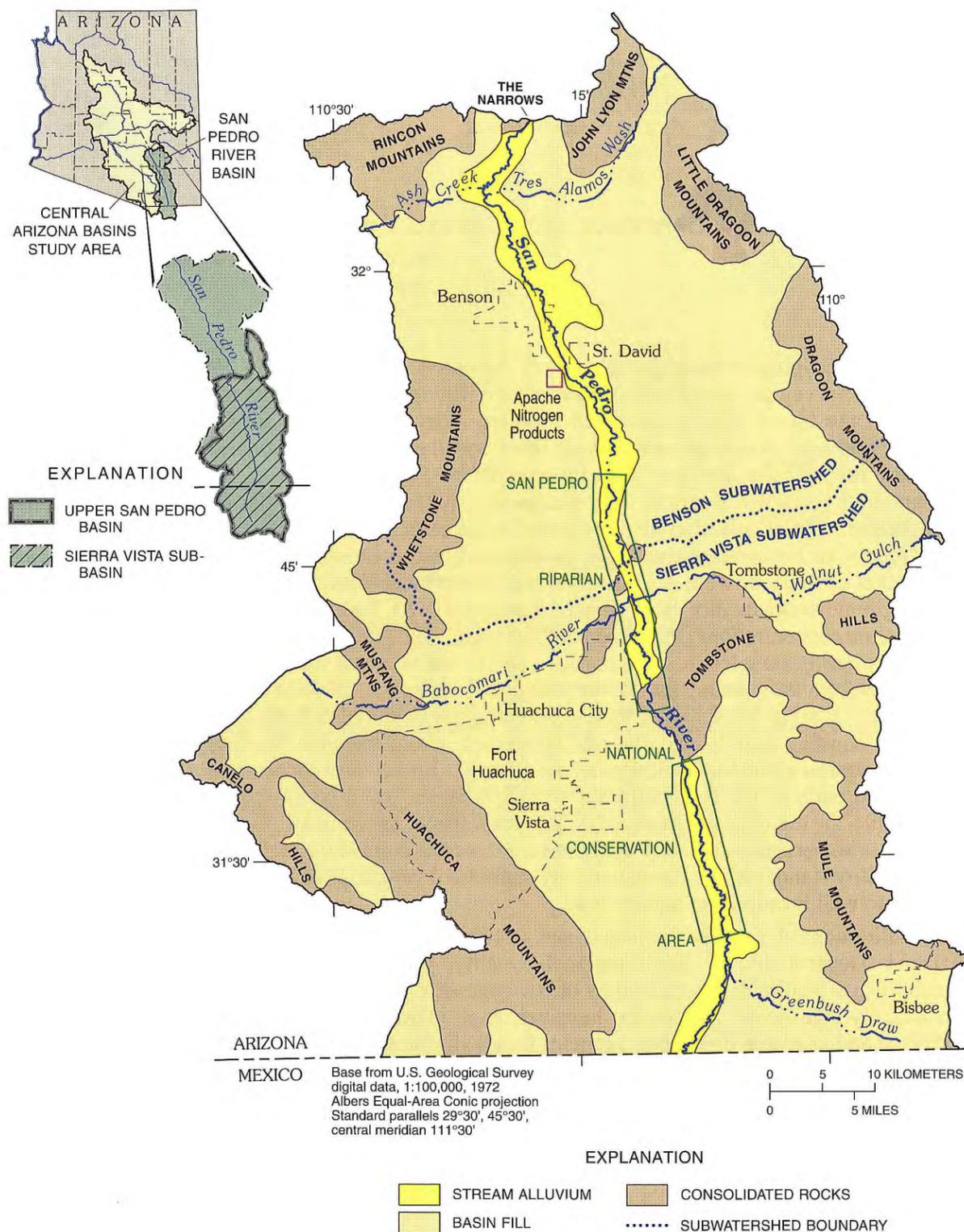


Figure 1. Location of the Sierra Vista subbasin, Arizona.

San Pedro Basin, which contains the Sierra Vista subbasin, would cause an increase in ground-water use, and increased development in the subbasin may potentially affect ground-water quality. The U.S. Geological Survey (USGS) and the Arizona Department of Environmental Quality (ADEQ) designed a cooperative study to characterize the current (1996-97) ground-water quality conditions in the Sierra Vista subbasin to provide a baseline against which the future effects of population growth will be compared.

Collection of ground-water samples in the Sierra Vista subbasin by the USGS was part of the National Water-Quality Assessment (NAWQA) Program in the Central Arizona Basins (CAZB) study area (fig. 1). The CAZB study area is one of 60 study units selected for the NAWQA program. Long-term goals of the program include providing a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources, defining long-term trends in water quality, and understanding the natural and human factors that affect water quality (Gilliom and others, 1995). In 1994, the USGS began ground-water, surface-water, and biological studies in the CAZB study area. Ground-water studies within the CAZB study area generally are focused on basins in which water quality has been, or has the potential to be, substantially affected by human activities. The Sierra Vista subbasin was chosen for study because it has been affected only minimally by human activities when compared with other basins in the CAZB study area, and there is potential for a change in ground-water quality in the future.

Sampling by the ADEQ was completed as a part of the Ambient Groundwater Monitoring Program, which is based on the legislative mandate in the Arizona Revised Statutes §49-225 (Arizona Department of Environmental Quality, 1995) that authorizes the "ongoing monitoring of the waters of the state, including...aquifers." Objectives of this mandate include determining the presence of pollutants and compliance with applicable water-quality standards, evaluating the effectiveness of best management practices and the effects of pollutants on public health and the environment, and identifying water-quality trends. Basinwide-random sampling is used in the Ambient Groundwater Monitoring Program to determine regional ground-water quality; while targeted

higher-density sampling is done to determine potential effects of specific land uses on ground-water quality.

### Purpose and Scope

This report presents results from a ground-water quality assessment of the Sierra Vista subbasin that was done by the USGS and the ADEQ in 1996-97. Analyses of physical and general mineral characteristics, general mineral constituents, nutrient constituents, and trace constituents from 39 wells were used in the assessment. This report presents: (1) present (1996-97) ground-water quality conditions; (2) the effects of well location, well depth, aquifer type, geology, and land use on ground-water quality; and (3) a comparison of historical (1950-65) ground-water quality data with data collected during this study to determine changes in ground-water quality over time.

This study provided a unique opportunity to combine ground-water quality sampling efforts of the USGS and the ADEQ. The cooperative effort increased the quantity of data available for the study and tested the validity of combining ground-water quality data from the two agencies. Descriptions of field and analytical methods used by the two agencies are included in this report and data compatibility was tested and verified.

### Physical Setting

The Sierra Vista subbasin is in the southern part of the San Pedro River Basin in southeastern Arizona (fig. 1) and encompasses approximately 6,480 km<sup>2</sup>. Approximately 1,810 km<sup>2</sup> of the subbasin lies south of the international boundary in Mexico (Arizona Department of Water Resources, 1991) and was not included in this study. The subbasin consists of a broad alluvial valley that slopes northward at an average gradient of 2.3 to 2.8 m/km (Freethey, 1982). Elevations of the valley floor vary from about 1,000 to 1,300 m above sea level.

The Sierra Vista subbasin is bounded on the west by the Canelo Hills and the Huachuca, Mustang, Whetstone, and Rincon Mountains, on

the east by the Mule, Dragoon, Little Dragoon, and John Lyon Mountains and the Tombstone Hills, and on the north by "the Narrows," a bedrock constriction (fig. 1). The southern boundary of the study area is the international boundary between Arizona and Mexico. A subwatershed boundary separates the Sierra Vista subwatershed from the Benson subwatershed within the Sierra Vista subbasin (Arizona Department of Water Resources, 1991; fig. 1).

The San Pedro River flows northward through the Sierra Vista subbasin (fig. 1). The river is intermittent, but perennial reaches exist within the San Pedro Riparian National Conservation Area (fig. 1). Major tributaries of the San Pedro River within the study area are, from south to north—Greenbush Draw, the Babocomari River, Walnut Gulch, Ash Creek, and Tres Alamos Wash (fig. 1). The tributaries are ephemeral and flow only in direct response to rainfall or snowmelt, except for the Babocomari River, which is perennial near its confluence with the San Pedro River.

The Sierra Vista subbasin has an arid to semiarid climate. Owing to the high elevation of the basin, summer temperatures rarely reach 38°C (Arizona Department of Water Resources, 1991). In 1996, the average temperature at Tombstone was 18.8°C and the total precipitation was 27 cm (U.S. Department of Commerce, 1996). Total annual precipitation can be as much as 76 cm in the Huachuca Mountains (Arizona Department of Water Resources, 1991). Generally, 50 to 60 percent of the basin's annual precipitation occurs during the summer monsoon season (usually July through September), and 21 to 35 percent occurs in the winter months (usually January through March; Arizona Department of Water Resources, 1991).

### Land Use and Population

The major land-use type (approximately 83 percent) in the Sierra Vista subbasin is rangeland (U.S. Geological Survey, 1986; fig. 2). Other land-use types are forest, 12.6 percent; urban, 1.8 percent; agricultural, 1.5 percent; and transitional (quarries, bare rock, gravel pits, sandy areas), 0.9 percent. The remaining land-use type (0.2 percent) is wetlands (U.S. Geological Survey, 1986).

Fort Huachuca Military Reservation, the U.S. Army electronic proving ground, covers 295 km<sup>2</sup> in the Sierra Vista subbasin (Bill Lopez, Media and Community Relations Officer, Public Affairs Office, U.S. Army Intelligence Center, Fort Huachuca, oral commun., 1998) and is northeast of the Huachuca Mountains (fig. 2). Heavy industry in the subbasin includes Apache Nitrogen Products—a large manufacturing plant for mining explosives and nitrogen fertilizers—located southwest of St. David (fig. 1). Apache Nitrogen Products was listed on the Federal Superfund National Priorities List in 1990 by the U.S. Environmental Protection Agency (Arizona Department of Environmental Quality, 1998). The primary ground-water contaminant at the site is nitrate, and the primary soil contaminants are metals, nitrate, 2,4-dinitrotoluene, and 2,6-dinitrotoluene (Arizona Department of Environmental Quality, 1998). The San Pedro Riparian National Conservation Area (fig. 1)—a Federal reserve that encompasses parts of the San Pedro River—was established in 1988 by the U.S. Congress in an effort to protect riparian habitat along the San Pedro River from potential damage owing to increasing water use in the surrounding area (Arizona Department of Water Resources, 1991).

Approximately 98 percent of the Sierra Vista subbasin contains less than 50 people per square kilometer (Hitt, 1994). Sierra Vista, the largest city in the subbasin had a population of 36,855 in 1994 (Arizona Department of Economic Security, 1994). The population of Sierra Vista includes about 10,000 people residing at Fort Huachuca (Bill Lopez, Media and Community Relations Officer, Public Affairs Office, U.S. Army Intelligence Center, Fort Huachuca, oral commun., 1998). By the year 2010, the population of Sierra Vista is expected to be about 43,000 (Arizona Department of Water Resources, 1993). Populations of other cities in the subbasin in 1994 were: 6,500 in Bisbee, 4,035 in Benson, 1,915 in Huachuca City, and 1,300 in Tombstone (Arizona Department of Economic Security, 1994).

### GEOHYDROLOGIC SETTING

The mountains surrounding the Sierra Vista subbasin consist of igneous, metamorphic, and

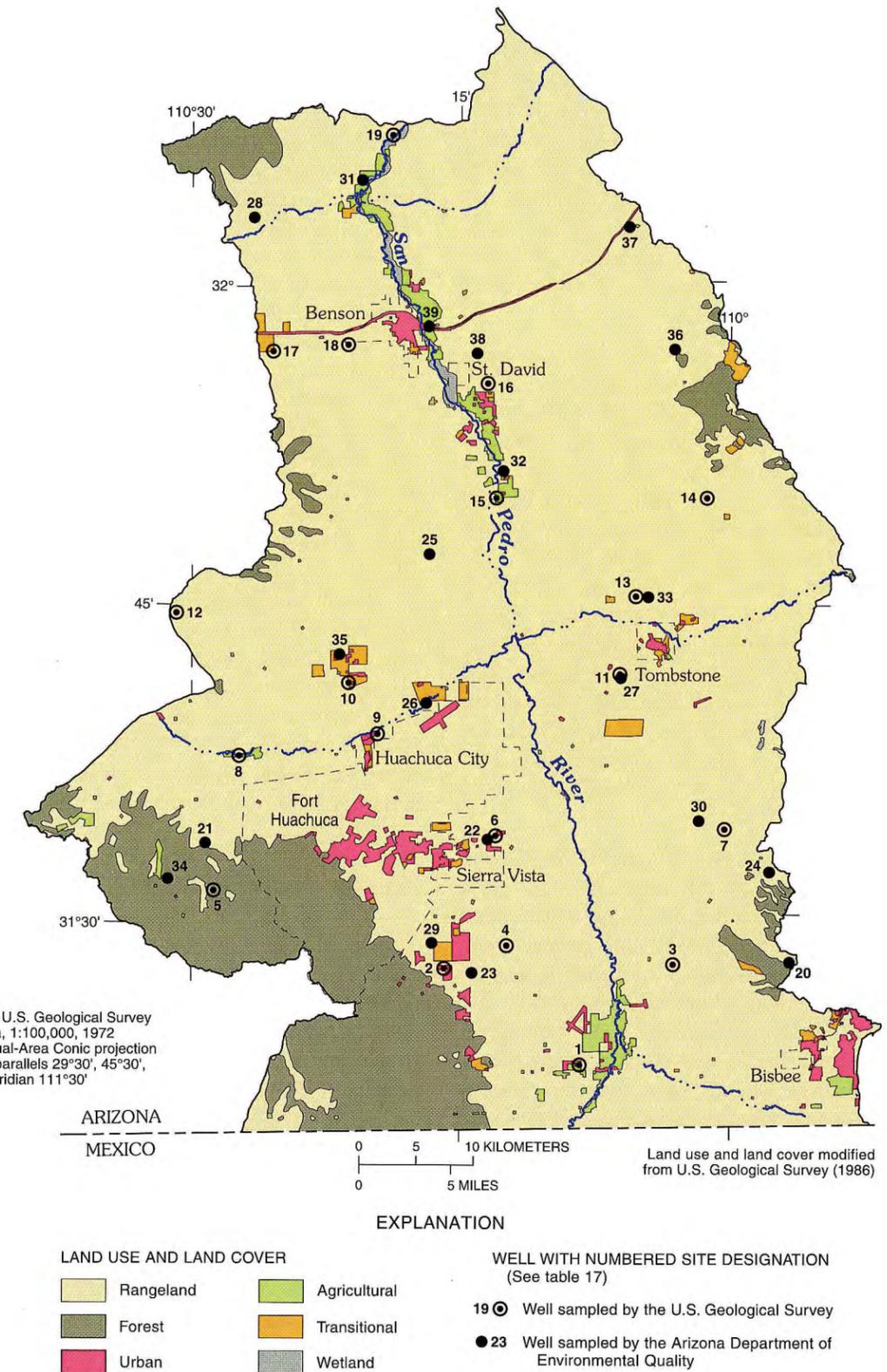


Figure 2. Generalized land-use types and well locations in the Sierra Vista subbasin, Arizona.

consolidated sedimentary rocks (Roeske and Werrell, 1973; fig. 3). The mountains on the west side of the subbasin consist of granite, andesite, rhyolite, schist, shale, limestone, gypsum, and sandstone (Graybeal, 1962; Hayes and Raup, 1968); the mountains on the east side of the subbasin consist of granite, andesite, latite, basalt, rhyolite, quartzite, schist, limestone, dolomite, and sandstone (Gilluly, 1956). The igneous, metamorphic, and consolidated sedimentary rocks are primarily impermeable; secondary fractures store water.

A consolidated to semiconsolidated conglomerate, the Pantano Formation (Brennan, 1962), overlies the basal bedrock in the subbasin and is the oldest of the basin sediments. The Pantano Formation consists of gravelly sandstone to conglomerate interbedded with mudstone and siltstone and is strongly tilted and offset by faulting (Roeske and Werrell, 1973). In the Sierra Vista-Fort Huachuca area, the formation is several thousand meters thick (Brown and others, 1966). Within the Sierra Vista subbasin, the Pantano Formation crops out along the northern and northeastern slopes of the Huachuca Mountains. Primary permeabilities of the Pantano Formation are low because of secondary cementation; ground water primarily occurs in fractures (Brown and others, 1966).

Basin-fill deposits (fig. 3) overlie the Pantano Formation. The basin-fill deposits have been divided into lower and upper units on the basis of compositional, textural, and depositional differences. The lower unit of the basin fill consists of partially cemented interbedded gravel and sandstone (Roeske and Werrell, 1973). The gravel beds are poorly sorted and contain a mixture of boulders, cobbles, pebbles, sand, and silt consisting mainly of quartz, granite, limestone, and quartzite (Brown and others, 1966). The sandstone beds are fine grained to very coarse grained and include quartz, feldspar, mica, and interstitial clay (Brown and others, 1966). Along the edges of the subbasin, the gravel and sandstone beds are coarse grained and a few meters thick; toward the center of the subbasin, the gravel and sandstone beds are finer grained and reach thicknesses of more than 300 m (Roeske and Werrell, 1973). Permeability of the lower unit of the basin fill varies from low to high

because of variability in sediment size, sorting, and cementation (Brown and others, 1966).

The upper unit of the basin fill consists of poorly cemented gravel, sand, silt, and clay (Brown and others, 1966). Brown and others (1966) describe three principal facies of the upper unit on the basis of grain size and mode of deposition—sand and silt deposited as alluvial fans along mountain fronts that have very high permeabilities, a silt and clay facies along the San Pedro River that has a low permeability, and a sand and silt facies that has an intermediate permeability located between the mountain fronts and the San Pedro River. The thickness of the upper unit in the area between the international boundary and Benson ranges from about 200 m along the mountain fronts to a few meters at the center of the subbasin along the San Pedro River (Brown and others, 1966). Erosion has removed most of the upper unit north of Benson (Roeske and Werrell, 1973).

Recent stream alluvium lies along most of the San Pedro River in the Sierra Vista subbasin (fig. 3). Stream alluvium deposits are very permeable and are composed of lenticular beds and unstratified deposits of gravel, sand, and silt (Roeske and Werrell, 1973). Along the San Pedro River, the stream alluvium generally is from a few meters to 30 m thick (Roeske and Werrell, 1973).

### Aquifer Characteristics

The stream alluvium forms a long, narrow, shallow aquifer along the San Pedro River, which is referred to as the flood-plain aquifer. The flood-plain aquifer provides most of the perennial streamflow in the San Pedro River and is the principal ground-water system involved in surface-water/ground-water interactions (Arizona Department of Water Resources, 1991). Depth to water in the flood-plain aquifer typically is less than 10 m (Arizona Department of Water Resources, 1991). Water levels in this aquifer are a major influence on river discharges and show seasonal trends reflecting cycles of surface-water runoff, evaporation, and transpiration (Arizona Department of Water Resources, 1991).

Roeske and Werrell (1973) reported a specific-capacity range of 2.07 to 22.7 L/s/m and an

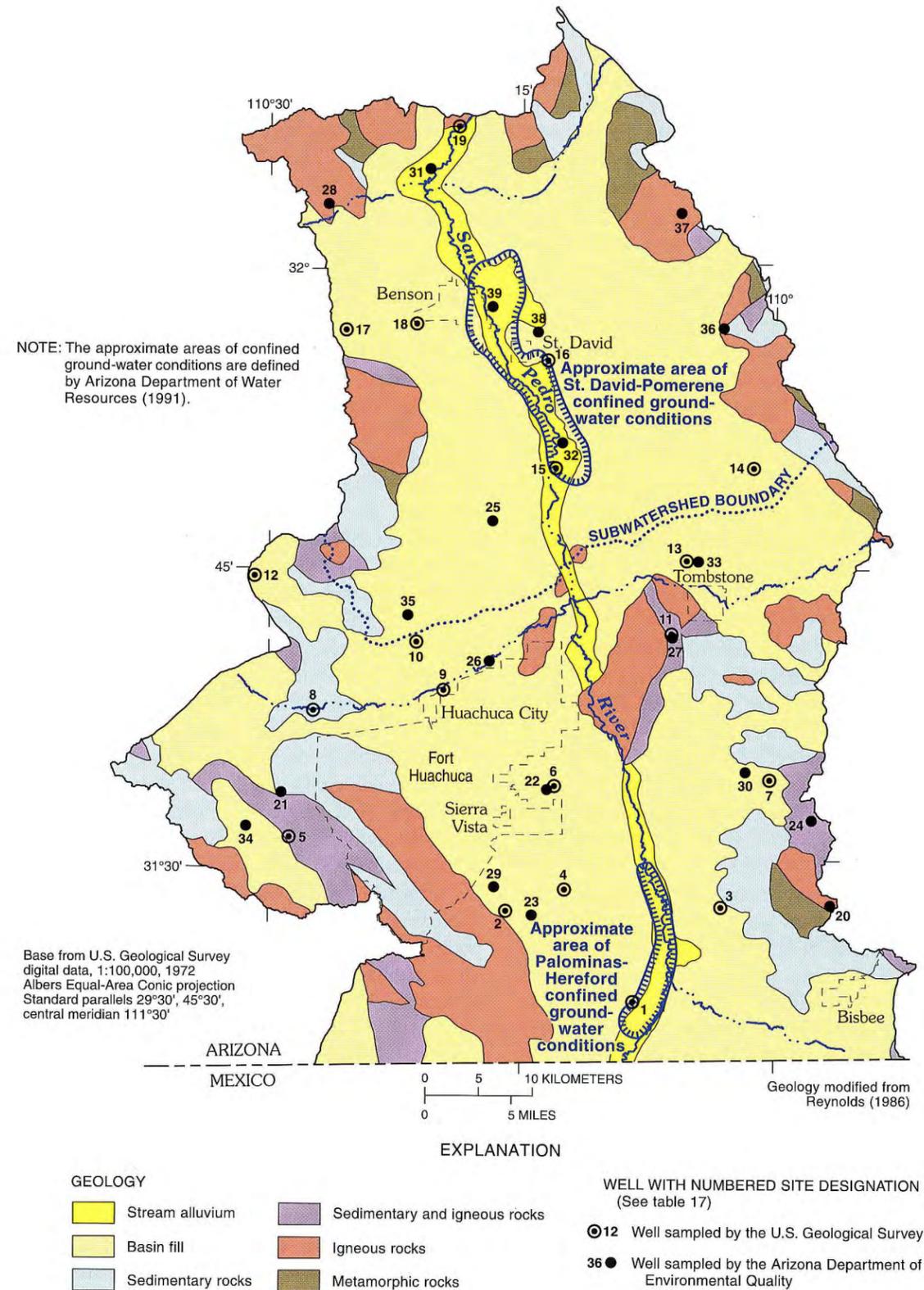


Figure 3. Generalized surficial geology and well locations in the Sierra Vista subbasin, Arizona.

average of 8.28 L/s/m for the flood-plain aquifer. Specific-yield estimates range from 0.04 to 0.23 (Freethy, 1982).

The upper and lower units of the basin-fill deposits are the major water-yielding units in the Sierra Vista subbasin and constitute the basin-fill aquifer. The basin-fill aquifer primarily is unconfined, but confined conditions occur in the Palominas-Hereford area and in the St. David-Pomerene area (fig. 3). In the Palominas-Hereford area, ground water is under pressure at depths of about 60 m below the land surface; in the southern part of the St. David-Pomerene area, ground water generally is under pressure at depths greater than 60 m below the land surface; and in the northern part of the St. David-Pomerene area, ground water generally is under pressure at depths of 150 to 300 m below the land surface (Roeske and Werrell, 1973). Depth to water in the unconfined areas of the basin-fill aquifer ranges from less than 10 m to greater than 150 m (Arizona Department of Water Resources, 1991).

Roeske and Werrell (1973) reported a specific-capacity range of 0.207 to 8.28 L/s/m and an average of 2.69 L/s/m for the basin-fill aquifer. Specific-yield estimates range from 0.02 to 0.15 for the unconfined parts of the basin-fill aquifer (Harshbarger and Associates, 1974); storage coefficients average  $1 \times 10^{-5}$  for the confined parts of the basin-fill aquifer (Freethy, 1982). Transmissivity estimates for the basin-fill aquifer range from 46.45 to 1,393.5 m<sup>2</sup>/d (Harshbarger and Associates, 1974).

The rocks of the mountains surrounding the Sierra Vista subbasin store water where they are jointed, fractured, or faulted. Springs are present in most of the mountain ranges where these features intersect the land surface. Wells finished in these bedrock areas usually have low yields.

### Recharge and Movement of Ground Water

Recharge to the basin-fill aquifer primarily occurs from infiltration of precipitation along the mountain fronts at an estimated rate of 32 hm<sup>3</sup>/yr (Arizona Department of Water Resources, 1991). A small quantity of streamflow also infiltrates sediments in tributary channels. As a result of high

evaporation and low precipitation, direct infiltration through the basin floor is considered negligible (Freethy, 1982). Underflow to the subbasin occurs east of the San Pedro River in the flood-plain and the basin-fill aquifers across the international boundary at an estimated rate of 3.7 hm<sup>3</sup>/yr (Arizona Department of Water Resources, 1991).

From the mountain-front recharge areas, ground water in the basin-fill aquifer flows roughly perpendicular to the San Pedro River. Along the basin axis, a component of ground-water flow in the basin-fill aquifer discharges to the flood-plain aquifer, however, the predominant direction of flow is northward, following the gradient of the river channel. Ground water in the flood-plain aquifer also flows northward, parallel to the river, and is discharged to the San Pedro River at varying rates throughout the year, depending on ground-water gradients in the flood-plain aquifer (Arizona Department of Water Resources, 1991). Where the San Pedro River crosses the Tombstone Hills, volcanic deposits restrict ground-water flow and force ground water to the surface of the river channel. As a result, little underflow occurs across the subwatershed divide between the Sierra Vista and Benson subwatersheds (Arizona Department of Water Resources, 1991).

Exceptions to the regional ground-water flow pattern exist locally near the Sierra Vista-Fort Huachuca area. Extensive pumping from the basin-fill aquifer in this area has resulted in a cone of depression that is expanding in size (Arizona Department of Water Resources, 1991). In 1990, approximately 34.5 hm<sup>3</sup>/yr of ground water was pumped from the basin-fill aquifer in the Sierra Vista subbasin, (Arizona Department of Water Resources, 1991).

### METHODS OF INVESTIGATION

Ground-water samples were collected in the Sierra Vista subbasin by the USGS and the ADEQ and analyzed for physical and general mineral characteristics, general mineral constituents, nutrient constituents, and trace constituents (table 1) to characterize ground-water quality. In addition to the analyses listed in table 1, the USGS analyzed ground-water samples for dissolved

**Table 1.** Ground-water analyses by the U.S. Geological Survey and the Arizona Department of Environmental Quality, Sierra Vista subbasin, Arizona, 1996–97

Physical characteristics	General mineral characteristics	General mineral constituents	Nutrient constituents	Trace constituents
Temperature	Alkalinity	Calcium	Nitrite plus nitrate	Aluminum
pH	Total dissolved solids	Magnesium	Ammonia	Antimony
	Specific conductance	Sodium	Phosphorus	Arsenic
		Potassium		Barium
		Chloride		Beryllium
		Sulfate		Cadmium
				Chromium
				Copper
				Fluoride
				Iron
				Lead
				Manganese
				Selenium
				Silver
				Zinc

oxygen (field), turbidity (field), hardness, silica, orthophosphorus, bromide, cobalt, molybdenum, nickel, uranium, isotopes of oxygen and hydrogen, radon, dissolved organic carbon, pesticides, and volatile organic compounds (Tadayon and others, 1998); the ADEQ analyzed ground-water samples for turbidity, phenol alkalinity, hardness, total kjeldahl nitrogen, boron, mercury, and thallium. The sampling efforts of the USGS and the ADEQ were combined to increase the quantity of data available for the joint study. Similar quality-assurance procedures were used by the USGS and the ADEQ. Individual and joint quality-control samples were collected to ensure that the data could be combined and analyzed as one data set. Statistical methods were used to analyze variability of ground-water characteristics and constituents relative to well location, well depth, aquifer type, geology, and land use, and to compare the data set to historical data.

### Selection of Historical Data (1950–65)

Historical ground-water quality data available in the USGS water-quality data base—the National Water Information System (NWIS)—for the Sierra Vista subbasin were compared with ground-water quality data collected during 1996–97 to identify changes in water quality over time. To identify a suitable set of historical data for comparison with the data collected for this study, the number of ground-water quality samples available in the

NWIS was compared to the year the samples were collected (fig. 4). Data from samples collected during 1950–65 were chosen for comparison with the data collected for this study because this data set represented a large number of samples collected over a large area (fig. 5) during a continual time period (fig. 4). In the Sierra Vista subbasin, 195 samples were collected at 73 wells during 1950–65. If data were available from a well that was sampled more than one time, the median value for a constituent was used in the data analysis. Data for the same constituents collected during 1996–97 were compiled from historical analyses in the NWIS. Data were not available in the NWIS for alkalinity, the nutrient constituents, or the trace constituents, with the exception of fluoride.

### Selection of Sample Locations

The USGS and the ADEQ each planned to sample 20 wells in the Sierra Vista subbasin to characterize the ground-water quality. Wells were chosen using a statistically based stratified-random approach. Computer software (Scott, 1990) was used to divide the subbasin into 20 equal-area polygons, referred to as cells. Within each cell, primary, secondary, and tertiary points were randomly assigned by the computer software. Different sets of random points within each cell were used by the USGS and the ADEQ.

Wells within about a 1.6-kilometer radius of each primary point were identified from a data base

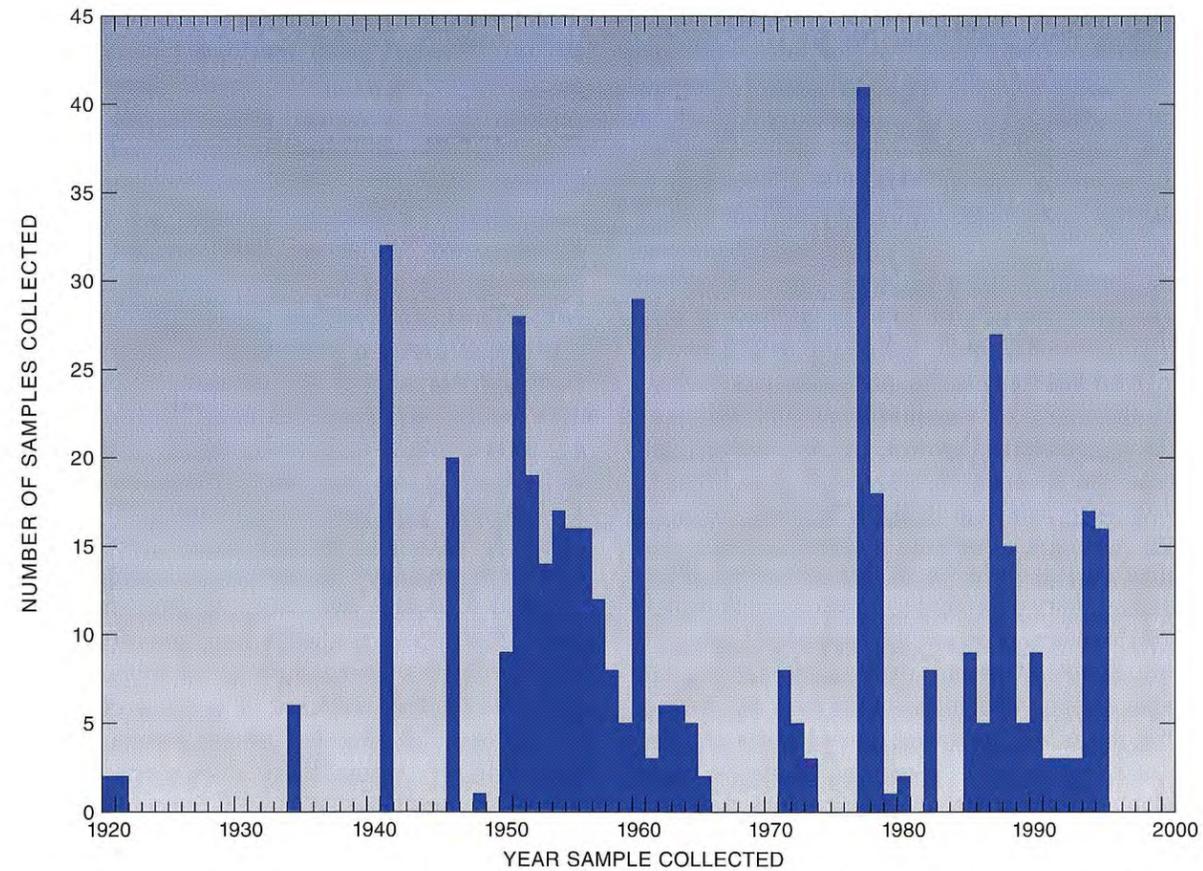


Figure 4. Ground-water quality samples available in the U.S. Geological Survey National Water Information System, Sierra Vista subbasin, Arizona, 1920–95.

of wells registered with the Arizona Department of Water Resources. These wells were then randomly ordered. The wells were visited sequentially to determine if they were suitable for sampling. If none of the wells within a 1.6-kilometer radius of the primary point were adequate, wells around the secondary point were identified, randomly ordered, and visited. If none of the wells within a 1.6-kilometer radius of the secondary point were adequate, wells around the tertiary point were identified, randomly ordered, and visited. A well was suitable for sampling if it had a submersible pump, a sampling point between the pump and storage tanks, and a measuring point to determine depth to water; if construction information (depth, perforated interval, casing diameter, and driller's log) was available; and if the well owner gave permission to sample. Water from the wells selected was being used for public, domestic, and livestock supply. Wells open to the basin-fill

aquifer were targeted for this study. In some areas, it was difficult to locate wells open to the basin-fill aquifer; therefore, some wells open to bedrock water-bearing units were sampled.

The USGS sampled one well in each of 19 cells; no suitable well was found in the twentieth cell located in the northeast corner of the basin. The ADEQ sampled one well in each of the 20 cells (figs. 2 and 3).

### Field Methods

The USGS followed NAWQA ground-water sampling protocols and procedures (Koterba and others, 1995) and the ADEQ followed the "Quality Assurance Project Plan" (QAPP; Arizona Department of Environmental Quality, 1991) and the "Field Manual for Water Quality Sampling" (Arizona Water Resources Research Center, 1995).

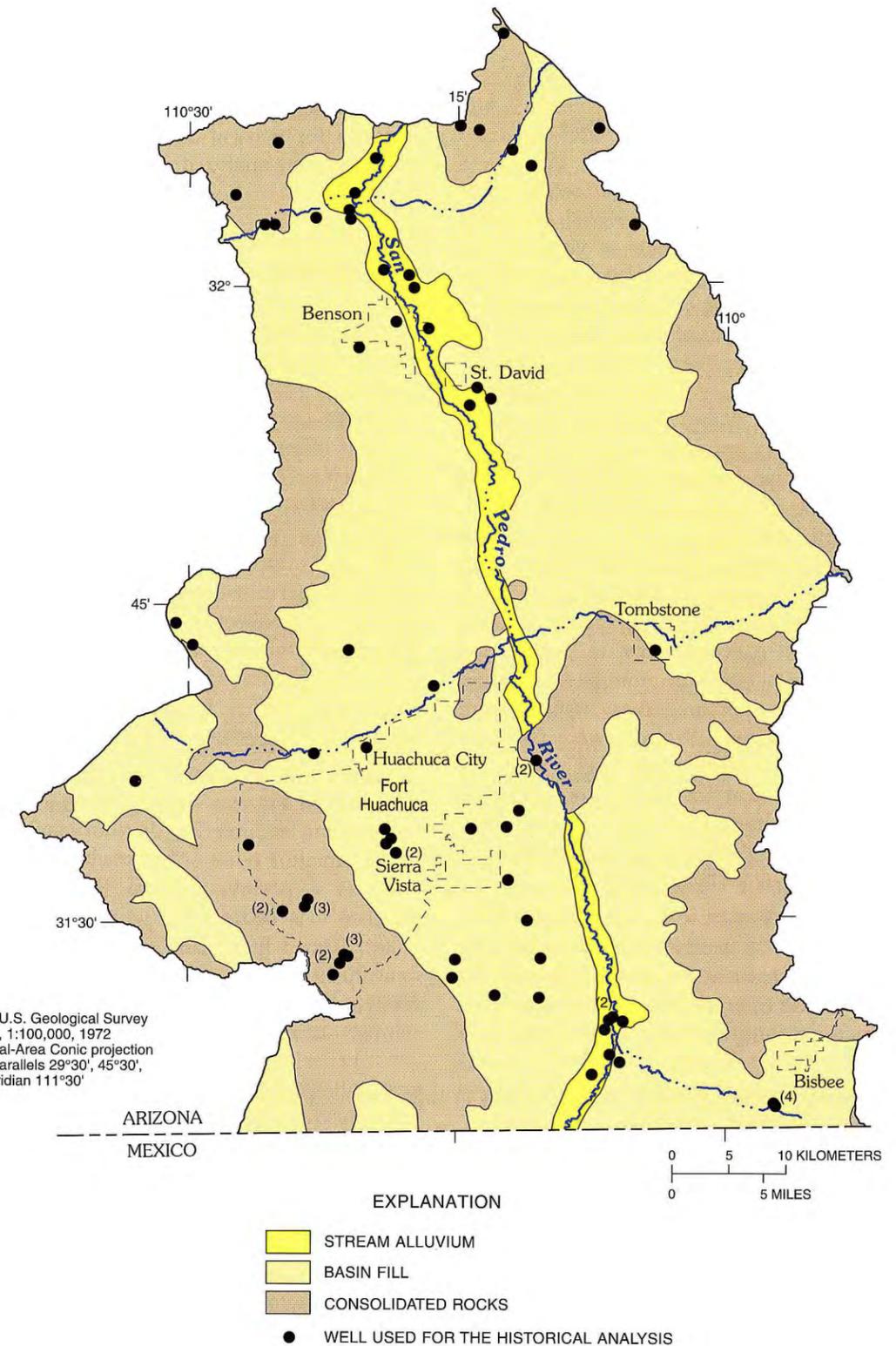


Figure 5. Wells used for the historical data analysis, Sierra Vista subbasin, Arizona, 1950–65.

The USGS and the ADEQ both measured depth to water in the well casing before samples were collected.

### U.S. Geological Survey Field Methods

The USGS used equipment and procedures that were designed to minimize potential bias and variability. A vehicle dedicated to water-quality sampling was used as a field laboratory. Wells were pumped before sample collection to purge at least three casing volumes of water. Samples were collected before water entered storage tanks or treatment equipment at each site. Samples contacted materials within the well and pump system, teflon tubing, and stainless-steel connectors during the collection process. During the purging of water, temperature, pH, specific conductance, turbidity, and dissolved-oxygen concentrations were measured using individual meters (table 16 in the "Basic Data" section). A flow-through chamber was used for measurements of temperature, pH, and dissolved-oxygen concentrations to isolate the samples from contact with the atmosphere. During the last 25 minutes of purging, measurements were made every 5 minutes. Samples were collected after field measurements stabilized (table 2). Trace-constituent samples were not collected if the measured turbidity was greater than 10 Nephelometric Turbidity Units (NTU) or 10 Formazin Turbidity Units (FTU).

Chambers were used to isolate samples from potential atmospheric contamination as the samples were being collected and preserved. Samples for the determination of some mineral characteristics and mineral, nutrient, and trace constituents were

collected after they had passed through a 0.45-micrometer in-line cartridge filter. One milliliter of nitric acid (70 percent) was used to preserve 250-milliliter samples analyzed for trace constituents and some mineral constituents. Samples for nutrient analyses were kept chilled until they were analyzed at the laboratory.

### Arizona Department of Environmental Quality Field Methods

The ADEQ used equipment and procedures that were designed to minimize potential bias and variability. Wells were pumped before sample collection to purge at least one to three casing volumes of water. Samples were collected before water entered storage tanks or treatment equipment. During well purging, temperature, pH, and specific conductance were measured using a Hydrolab (table 16 in the "Basic Data" section). Approximately 5 to 10 measurements were made before the samples were collected; at most wells, this equated to one measurement every 5 minutes. Temperature, pH, and specific conductance were considered stable when values from repeated measurements were within 10 percent of one another.

A 0.45-micrometer in-line cartridge filter was used to filter samples for trace-constituent analysis by attaching the filter directly to an adaptor attached to the sampling point or by attaching the cartridge filter to a positive-pressure filtering apparatus attached to a bottle filled with unfiltered sample water. The 1-liter samples collected for trace-constituent analysis were preserved with 5 mL of concentrated nitric acid (70 percent). The 1-liter nutrient samples were preserved with 2 mL of

**Table 2.** Allowable differences that indicate stability in U.S. Geological Survey field measurements (Koterba and others, 1995)

[°C, degrees Celsius;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25°C; mg/L, milligrams per liter; NTU, Nephelometric Turbidity Units; FTU, Formazin Turbidity Units]

Characteristic	Allowable difference or value
pH	$\pm 0.05$ units
Temperature	$\pm 0.2^\circ\text{C}$
Specific conductance (SC)	$\pm 5$ percent for SC $\leq 100$ $\mu\text{S}/\text{cm}$ $\pm 3$ percent for SC $> 100$ $\mu\text{S}/\text{cm}$
Dissolved oxygen	$\pm 0.3$ mg/L
Turbidity (TU)	$\pm 10$ percent for TU $< 100$ NTU/FTU

concentrated sulfuric acid (95.5 percent). Samples for mineral, nutrient, and trace-constituent analysis were kept chilled until they were analyzed at the laboratory. Chain of custody procedures were followed during handling of the samples.

### Laboratory Methods

Alkalinity, total dissolved solids, mineral, nutrient, and trace constituents were analyzed by the USGS National Water-Quality Laboratory (NWQL) for samples collected by the USGS, and by the Arizona Department of Health Services Laboratory (ADHS) for samples collected by the ADEQ. Laboratory alkalinities are reported because field alkalinities were not determined by both agencies. Laboratory alkalinities and field alkalinities were within 15 percent of one another for the USGS data. Several different methods were used at the laboratories to determine concentrations of constituents (table 3). The different methods used in the laboratories resulted in different minimum reporting levels (MRL's), which is of particular importance because some concentrations were below one MRL and above the other. Consequently, data interpretations were difficult and are discussed in the "Quality Assurance" section.

### Quality Assurance

The USGS and the ADEQ followed quality-assurance procedures to minimize the potential for bias and variability of the environmental data during sample collection and analysis. The USGS and the ADEQ collected joint quality-control samples to ensure that environmental data could be combined and analyzed as one data set. Design of the USGS quality-assurance plan and quality-control sample collection was based on requirements described by Koterba and others (1995). Design of the ADEQ quality-assurance plan and quality-control sample collection was based on recommendations included in the QAPP (Arizona Department of Environmental Quality, 1991).

### U.S. Geological Survey Quality-Assurance Plan and Quality-Control Data

The USGS collected three field-blank samples and three replicate samples for mineral characteristics and mineral-, nutrient-, and trace-constituent analyses at 3 of the 19 wells sampled (fig. 6; table 14 in the "Basic Data" section). Quality control of water-level measurements was achieved by repeating measurements until the measurements were within 0.03 m of one another.

Field-blank samples were collected subsequent to collection of the environmental samples, and subsequent to the cleaning of the sampling equipment, by passing water free of the constituents of interest through the sampling equipment. These samples were analyzed to determine bias in the data from contamination of environmental samples during sample collection and analysis for most of the constituents. Measurable concentrations of calcium (site 13), potassium (site 16), and ammonia (site 13) each occurred only once in the data for the blank samples; therefore, contamination of the environmental samples was not considered significant. One nutrient constituent and four trace constituents were present in measurable concentrations in more than one of the field-blank samples—nitrite plus nitrate (sites 13 and 16), aluminum (sites 8, 13, and 16), chromium (sites 8 and 16), copper (sites 8 and 16), and zinc (sites 8 and 16). These constituents were considered to be affected by systematic contamination (D.J. Gellenbeck, U.S. Geological Survey, written commun., 1998). Only a small number of nitrite plus nitrate environmental samples were affected and analyses of nitrite plus nitrate data was completed. Aluminum, chromium, copper, and zinc were not used to interpret the analyses from the environmental samples collected for this study.

Replicate samples were obtained by sequentially collecting two environmental samples for the same constituents from the same site. Data from these samples provide a measure of the variability that resulted from the combined effects of field and laboratory procedures (table 4). Variability in constituent concentrations between each pair of replicate samples is represented in table 4 as the percent difference, which is the absolute difference between concentrations in the replicate samples divided by the average

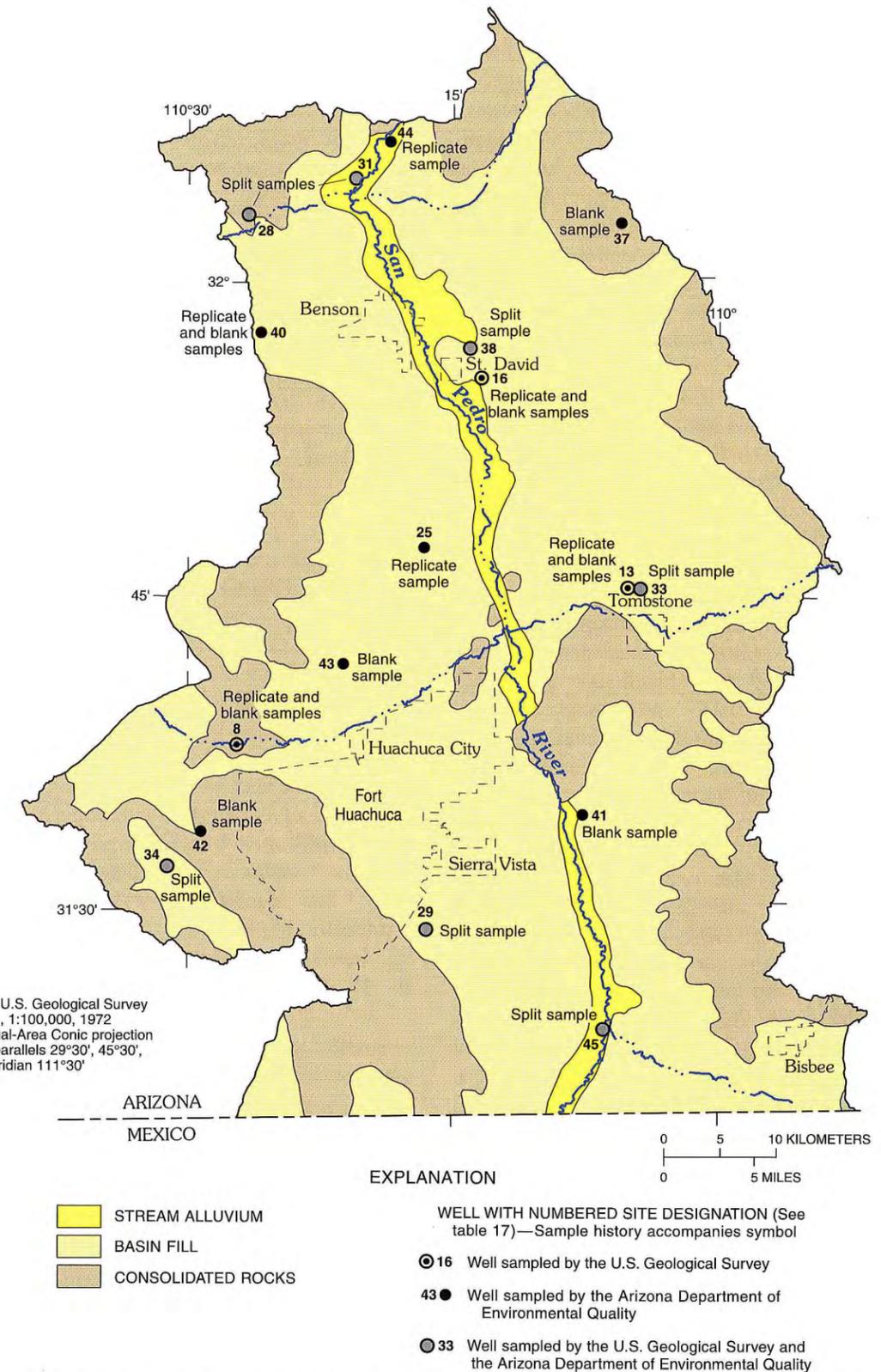
**Table 3.** Laboratory methods used by the U.S. Geological Survey National Water-Quality Laboratory and the Arizona Department of Health Services Laboratory for analyses of ground water, Sierra Vista subbasin, Arizona

[NWQL, National Water-Quality Laboratory; ADHS, Arizona Department of Health Services Laboratory; ICP, inductively coupled plasma; AES, atomic emission spectroscopy; AA, atomic absorption; MS, mass spectroscopy; constituents are dissolved and are reported in milligrams per liter unless otherwise noted; µg/L, micrograms per liter]

Constituent or compound	NWQL method	NWQL minimum reporting level	ADHS method	ADHS minimum reporting level
<b>General mineral characteristics</b>				
Alkalinity	Electrometric titration	1	Electrometric titration	2
Total dissolved solids	Gravimetric	1	Gravimetric	10
<b>Mineral constituents</b>				
Calcium	ICP	.02	ICP-AES	1
Magnesium	ICP	.01	ICP-AES	1
Sodium	ICP	.2	ICP-AES	5
Potassium	Flame AA	.1	Flame AA	.5
Chloride	Ion chromatography	.1	Potentiometric titration	1
Sulfate	Ion chromatography	.1	Colorimetric	10
<b>Nutrient constituents</b>				
Nitrite plus nitrate	Colorimetric	.05	Colorimetric	.1
Ammonia	Colorimetric	.015	Colorimetric	.1
Phosphorus	Colorimetric	.01	Colorimetric	.1
<b>Trace constituents</b>				
Aluminum (µg/L)	ICP-MS	1	ICP-AES	500
Antimony (µg/L)	ICP-MS	1	Graphite furnace AA	5
Arsenic (µg/L)	Hydride generation	1	Graphite furnace AA	10
Barium (µg/L)	ICP-MS	1	ICP-AES	100
Beryllium (µg/L)	ICP-MS	1	Graphite furnace AA	.5
Cadmium (µg/L)	ICP-MS	1	Graphite furnace AA	1
Chromium (µg/L)	ICP-MS	1	Graphite furnace AA	10
Copper (µg/L)	ICP-MS	1	Graphite furnace AA	10
Fluoride	Ion selective electrode	.1	Ion selective electrode	.2
Iron (µg/L)	ICP	3	ICP-AES	100
Lead (µg/L)	ICP-MS	1	Graphite furnace AA	5
Manganese (µg/L)	ICP-MS	1	ICP-AES	50
Selenium (µg/L)	Hydride generation	1	Graphite furnace AA	5
Silver (µg/L)	ICP-MS	1	Graphite furnace AA	1
Zinc (µg/L)	ICP-MS	1	ICP-AES	50

concentration for the replicate samples multiplied by 100, and in terms of absolute concentration units. Only those values greater than the MRL were used in this analysis. The results indicate that the maximum difference for concentrations in most of the constituents and compounds in replicate samples were within 5 percent of the concentration in the environmental samples. Replicate results for

sodium, potassium, aluminum, arsenic, iron, and zinc varied by more than 5 percent. Because aluminum and zinc concentrations have been identified as affected by systematic contamination and iron concentrations are believed to be affected by the steel casing present at many of the wells sampled, the differences between the results from the replicate samples and the results from the



**Figure 6.** Wells where quality-control samples were collected, Sierra Vista subbasin, Arizona, 1996–97.

**Table 4.** Summary results of the analyses of replicate samples collected by the U.S. Geological Survey and the Arizona Department of Environmental Quality, Sierra Vista subbasin, Arizona, 1996–97

[N, number of replicate samples; constituents are dissolved and are reported in milligrams per liter unless otherwise noted; µg/L, micrograms per liter; --, no data]

Characteristic or constituent	USGS replicate samples						ADEQ replicate samples							
	N	Difference, in percent		Difference, in concentration units			N	Difference, in percent		Difference, in concentration units				
		Mini-mum	Maxi-mum	Me-dian	Mini-mum	Maxi-mum		Me-dian	Mini-mum	Maxi-mum	Me-dian	Mini-mum	Maxi-mum	Me-dian
<b>General mineral characteristics</b>														
Alkalinity.....	3	0	0.8	0	0	1	0	3	0.6	4.4	0.8	1	10	2
Total dissolved solids....	3	0	2.1	.5	0	6	1	3	.1	.5	.5	5	12	6
<b>Mineral constituents</b>														
Calcium.....	3	0	1.3	0	0	1	0	3	0	2	.8	0	1	.3
Magnesium .....	3	0	1.8	1	0	.1	.1	3	.3	.9	.8	0	.2	.1
Sodium .....	3	0	7.4	0	0	1	0	3	.3	1.7	.6	.1	2	.1
Potassium.....	3	0	8.7	5.1	0	.2	.1	3	.3	.9	.8	.1	.2	.1
Chloride.....	3	0	0	0	0	0	0	3	0	1.9	0	0	.5	0
Sulfate.....	3	0	4.1	0	0	.1	0	3	1.8	8.5	2.8	.9	24	7
<b>Nutrient constituents</b>														
Nitrite plus nitrate....	3	3.5	4.2	4.1	0	.2	0	2	.3	.4	.4	.01	.01	.01
Ammonia .....	1	0	0	--	0	0	--	0	--	--	--	--	--	--
Phosphorus .....	0	--	--	--	--	--	--	0	--	--	--	--	--	--
<b>Trace constituents</b>														
Aluminum (µg/L)....	3	0	29	0	0	1	0	0	--	--	--	--	--	--
Antimony (µg/L)....	0	--	--	--	--	--	--	0	--	--	--	--	--	--
Arsenic (µg/L).....	2	0	20	10	0	2	1	0	--	--	--	--	--	--
Barium (µg/L).....	3	1	3.8	1.5	1	3	1	1	0	0	0	0	0	0
Beryllium (µg/L)....	0	--	--	--	--	--	--	0	--	--	--	--	--	--
Cadmium (µg/L).....	0	--	--	--	--	--	--	0	--	--	--	--	--	--
Chromium (µg/L)....	2	0	0	0	0	0	0	0	--	--	--	--	--	--
Copper (µg/L).....	2	0	0	0	0	0	0	0	--	--	--	--	--	--
Fluoride.....	3	0	0	0	0	0	0	3	0	20	2.2	0	.1	.02
Iron (µg/L).....	1	40	40	--	2	2	--	1	0	0	--	0	0	--
Lead (µg/L).....	1	0	0	--	0	0	--	1	0	0	--	0	0	--
Manganese (µg/L) ...	1	0	0	--	0	0	--	0	--	--	--	--	--	--
Selenium (µg/L).....	0	--	--	--	--	--	--	0	--	--	--	--	--	--
Silver (µg/L).....	0	--	--	--	--	--	--	0	--	--	--	--	--	--
Zinc (µg/L).....	3	3.1	91	3.4	1	5	1	0	--	--	--	--	--	--

environmental samples for these constituents were not considered significant. The maximum difference in the replicate samples for sodium, potassium, and arsenic are 1 mg/L, 0.2 mg/L, and 2 µg/L, respectively; all of these values are within one standard deviation of the mean for these constituents in the environmental samples collected by the USGS.

The USGS NWQL maintains an internal program that includes blank, replicate, and spike samples to ensure that the laboratory is accurately analyzing water-quality samples (Pritt and Raese, 1995). The Quality Assurance Unit of the NWQL routinely submits blind reference and blank samples to the NWQL. The USGS Branch of Quality Systems (BQS), which operates independently of the NWQL, also submits blind samples to the NWQL.

**Arizona Department of Environmental Quality Quality-Assurance Plan and Quality-Control Data**

The ADEQ collected 1 field-blank sample and 1 replicate sample for mineral characteristics and mineral-, nutrient-, and trace-constituent analyses at 2 of the 20 wells sampled for this study; 4 field-blank samples and 2 replicate samples were collected at 6 additional wells chosen by the ADEQ for other studies (fig. 6; table 14 in the "Basic Data" section). Additionally, 2 standard reference samples for mineral-, nutrient-, and trace-constituent analyses, 1 travel blank for mineral and trace-constituent analyses, and 1 spiked sample for nitrite plus nitrate, were also included as quality-control samples.

Field-blank samples for mineral characteristics and mineral- and nutrient-constituent analyses were collected by directly pouring water free of the constituent of interest into the sample bottles. Field-blank samples for trace-constituent analyses were collected by placing water free of the constituent of interest into the same bottle used to transfer the unfiltered environmental sample, and then filtering the water using a positive-pressure filtering apparatus fitted with a 0.45-micrometer in-line cartridge filter. The bottle used to transfer water to the filtering apparatus was cleaned according to the QAPP recommendations (Arizona

Department of Environmental Quality, 1991). Of the 5 field-blank samples, 1 sample had measurable concentrations of potassium and antimony (site 40). Because only one of the field-blank samples was affected, the effects of sampling equipment and procedures on the environmental samples were not considered significant. Two field-blank samples had measurable concentrations of total dissolved solids (sites 40 and 42) that were within one standard deviation of the mean of total dissolved-solids values in the ADEQ data set. The concentrations also were not considered significant relative to the environmental data.

Replicate samples were obtained by sequentially collecting two environmental samples for mineral characteristics and mineral, nutrient, and trace constituents (table 4). Replicate results for sulfate and fluoride varied by more than 5 percent. The corresponding maximum differences in concentration for sulfate and fluoride, were 24 and 0.11 mg/L, respectively. These differences were within one standard deviation of the mean value for these constituents in the ADEQ data and were not considered significant. Replicate results for thirteen constituents were below the MRL for the ADHS laboratory.

Two standard-reference samples for mineral characteristics and constituents, nutrient constituents, and trace constituents were received from the USGS BQS and transferred to sample bottles supplied by the ADHS laboratory. Replicates of the standard-reference samples were submitted to the ADHS laboratory for analyses (tables 5, 6, and 7). Data from these samples provide a measure of the bias of the ADHS laboratory compared with other laboratories, including the NWQL, that participate in the interlaboratory-evaluation program that the USGS BQS designs and operates (Farrar and Long, 1997). If the results for one of the replicate samples from the ADHS laboratory were within 1.5 times the F-pseudostigma value of the most probable value (MPV) determined by the BQS for the standard-reference samples, the results were considered acceptable for this study. The F-pseudostigma value is equivalent to the standard deviation of traditional statistics when the data have a Gaussian distribution (Long and Farrar, 1994). The fluoride analyses from the ADHS laboratory and the NWQL were considered unacceptable for

**Table 5. Results of the analyses of standard reference samples for mineral characteristics and constituents—Standard Reference Sample M-134 (Long and Farrar, 1995)**

[Most Probable Value, F-pseudostandard, and National Water-Quality Laboratory analyses from Long and Farrar (1995). ADHS, Arizona Department of Health Services Laboratory; NWQL, National Water-Quality Laboratory; constituents are dissolved and are reported in milligrams per liter unless otherwise noted;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; --, constituent was not determined]

	pH (stand- ard units)	Alkalin- ity as $\text{CaCO}_3$	Specific conduc- tance ( $\mu\text{S}/\text{cm}$ )	Cal- cium	Mag- ne- sium	Sodium	Po- tas- sium	Chlo- ride	Sulfate	Fluo- ride
Most Probable Value	7.7	63	615	44	9.8	61	2.4	65	78	0.56
F-pseudostandard	.17	1.6	18	2.4	.41	2.4	.22	2.1	2.4	.03
ADHS sample 1	--	64	597	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	63	<sup>2</sup> 91	<sup>2,3</sup> 61
ADHS sample 2	--	64	594	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	64	79	<sup>2,3</sup> 73
NWQL sample	7.5	65	606	46	9.7	60	2.4	65	75	<sup>2</sup> 62

<sup>1</sup>Analyses completed as part of trace-constituent sample in table 7.

<sup>2</sup>Values are greater than 1.5 times the F-pseudostandard.

<sup>3</sup>Trace constituent analyzed as part of mineral-constituent sample

**Table 6. Results of the analyses of standard reference samples for nutrient constituents—Standard Reference Sample N-52 (Farrar and Long, 1997)**

[Most Probable Value, F-pseudostandard, and National Water-Quality Laboratory analyses from Farrar and Long (1997). ADHS, Arizona Department of Health Services Laboratory; NWQL, National Water-Quality Laboratory; constituents are dissolved and are reported in milligrams per liter]

	Nitrite plus nitrate	Ammonia	Phosphorus
Most Probable Value	1.7	1.33	1.6
F-pseudostandard	.10	.090	.06
ADHS sample 1	1.8	1.12	<sup>1</sup> 1.4
ADHS sample 2	<sup>1</sup> 1.9	1.29	1.5
NWQL sample	1.7	1.36	1.6

<sup>1</sup>Values are greater than 1.5 times the F-pseudostandard.

**Table 7. Results of the analyses of standard reference samples for trace constituents—Standard Reference Sample T-129 (Long and Farrar, 1994)**

[Most Probable Value, F-pseudostandard, and values for National Water-Quality Laboratory analyses from Long and Farrar (1994). ADHS, Arizona Department of Health Services Laboratory; NWQL, National Water Quality Laboratory; constituents are dissolved and are reported in micrograms per liter unless otherwise noted; mg/L, milligrams per liter; <, less than]

	Aluminum	Antimony	Arsenic	Barium	Beryl- lium	Cad- mium	Chro- mium	Copper	Iron	Lead
Most Probable Value	50	0.6	0.6	34	0.1	0.3	0.7	2.7	10	1.0
F-pseudostandard	12	.9	1.1	2	.1	.2	1.4	1.4	8.2	1.4
ADHS sample 1	<500	<5	<10	<100	<.5	<1	<10	<10	<100	<5
ADHS sample 2	<500	<5	<10	<100	<.5	<1	<10	<10	<100	<5
NWQL sample	46	.2	<1	33	<.5	.3	.6	2.7	5.1	.03

	Manganese	Selenium	Silver	Zinc	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)
Most Probable Value	25	1.6	0.4	72	21	5.8	36	3.0
F-pseudostandard	2.2	1.6	1.4	4.8	1	.3	1.5	.2
ADHS sample 1	<50	<5	<1	<sup>1</sup> 80	21	<sup>1</sup> 6.6	37	3.2
ADHS sample 2	<50	<5	<1	<sup>1</sup> 80	21	<sup>1</sup> 6.5	37	3.3
NWQL sample	24	<1	.1	68	21	5.9	35	2.9

<sup>1</sup>Values are greater than 1.5 times the F-pseudostandard.

this study (table 5). Magnesium and zinc analyses from the ADHS laboratory were also considered unacceptable (table 7). The high bias associated with these constituents was considered in the interpretation of these data. Trace constituent concentrations generally were below the MRL established by the ADHS laboratory. These results correspond with the MPV determined by the BQS for these constituents and are not sufficient to characterize any bias associated with these analyses from the ADHS laboratory.

A travel-blank sample was collected by placing bottles of water free of the constituent of interest into an ice chest used to store and chill the environmental samples during transport to the ADHS laboratory. The bottles were filled before the field sampling and were not opened during field sampling. This sample was submitted to the ADHS laboratory for analyses of mineral and trace constituents. Concentrations of all constituents analyzed in the travel blank were less than the MRL's for the ADHS laboratory.

The spiked sample for nitrate was received from the ADHS laboratory, placed in an ice chest used to store and chill the environmental samples during transport, and then submitted to the ADHS laboratory for analyses. The results from this spiked sample show that recovery of nitrate was within 4 percent of the expected value (10 mg/L).

#### Combined Quality-Control Data

The USGS and the ADEQ simultaneously collected environmental samples (one sample collected by each agency) as split samples for analysis of physical and general mineral characteristics and mineral, nutrient, and trace constituents at seven sites (fig. 6; table 15 in the "Basic Data" section). Data from these samples provide a measure of the variability between the USGS and the ADEQ field and laboratory procedures. Wells selected for collection of split samples were spatially distributed and included various ground-water types in the study area (fig. 7). The split samples were collected at 6 of the ADEQ's 20 wells sampled for this study (sites 28, 29, 31, 33, 34, and 38). An additional split sample was collected at a well chosen by the ADEQ for a study that included targeted higher-density

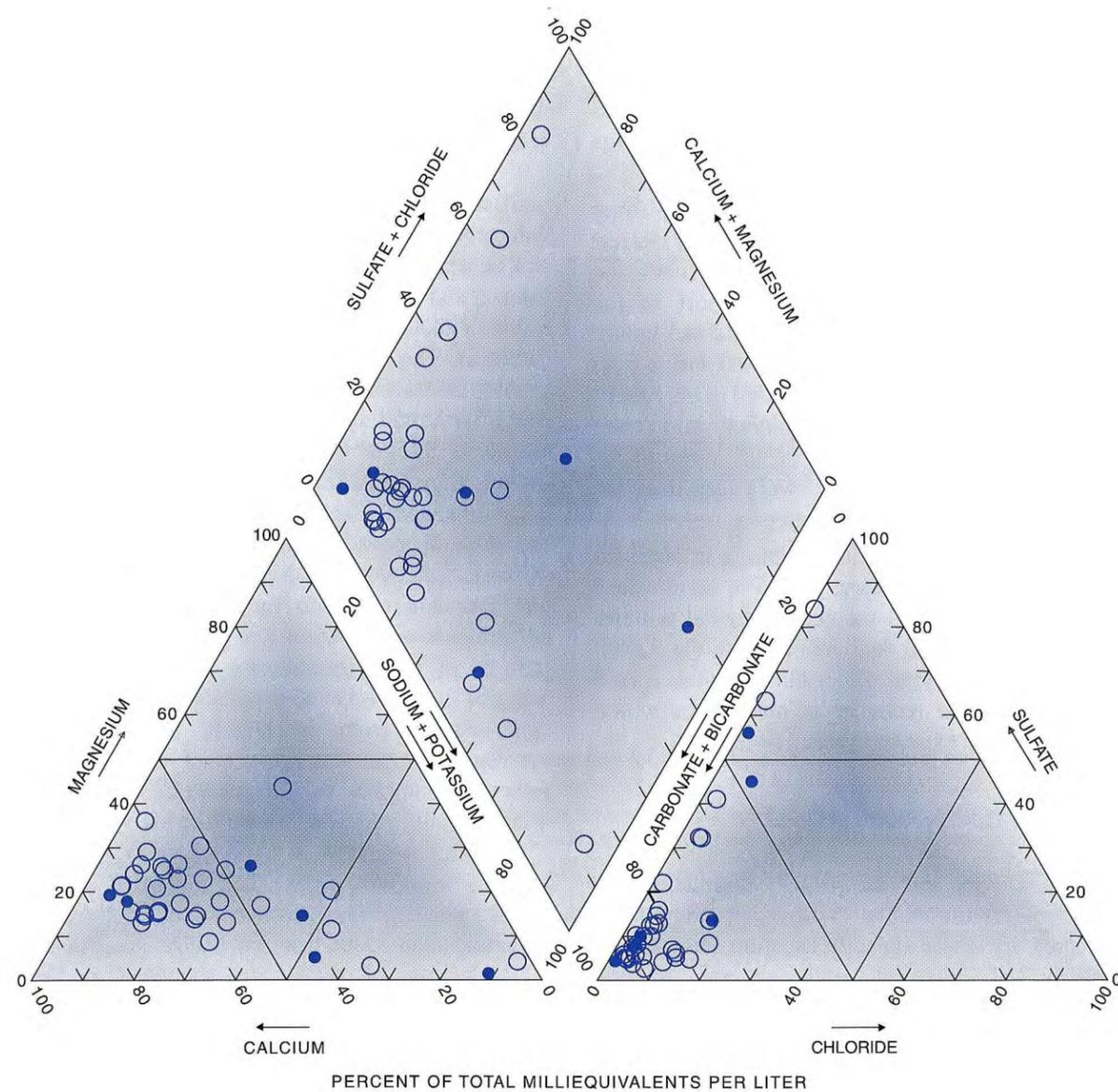
sampling (site 45). The NAWQA ground-water sampling protocols and procedures were followed by both the USGS and the ADEQ for the split samples.

Analytical results from the split samples were evaluated using the exact form of the sign test (Helsel and Hirsch, 1992) to determine if there were any significant differences between the analytical data collected by the USGS and the analytical data collected by the ADEQ at a significance level of 0.05. The exact form of the sign test generally verified that combining the ground-water quality data collected by the USGS and the ADEQ was acceptable. Among the physical and general mineral characteristics, significant differences were found in alkalinity and specific-conductance values (table 8). The alkalinity concentrations measured by the ADEQ were lower than those measured by the USGS, and the specific-conductance values measured by the USGS were lower than those measured by the ADEQ.

Application of the exact form of the sign test to the mineral constituents resulted in significant differences between the data collected by the USGS and the data collected by the ADEQ for two constituents—magnesium and potassium. Concentrations of these constituents in the seven split samples from the ADEQ were higher than those in split samples from the USGS. This high bias corresponds with the results of the standard-reference samples for magnesium, which also indicated high values relative to the MPV (table 7). Values for potassium for the standard reference samples were also higher than the MPV and the NWQL result (table 7), but less than 1.5 times the F-pseudostandard value from the MPV.

Detection of differences between nutrient constituents in split samples collected by the USGS and the ADEQ was limited to nitrite plus nitrate because there were no measurable concentrations of ammonia and phosphorus in the split samples. This result corresponds with concentrations of these two constituents in the environmental samples that generally were at or below the MRL's (table 16 in the "Basic Data" section). Split samples collected by the USGS and the ADEQ showed no significant differences in nitrite plus nitrate values.

Concentrations of several trace constituents—aluminum, arsenic, barium, chromium, iron, and zinc—in some split samples were below the MRL



**EXPLANATION**

○ ENVIRONMENTAL SAMPLES—U.S. Geological Survey and Arizona Department of Environmental Quality

● SPLIT SAMPLES—U.S. Geological Survey and Arizona Department of Environmental Quality

Figure 7. Relative composition of ground-water samples, Sierra Vista subbasin, Arizona, 1996-97.

Table 8. Summary results of the analyses of split samples collected by the U.S. Geological Survey and the Arizona Department of Environmental Quality, Sierra Vista subbasin, Arizona, 1996-97

[N, number of split samples; constituents are dissolved and are reported in milligrams per liter unless otherwise noted; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; --, no data available; µg/L, micrograms per liter; ADEQ, Arizona Department of Environmental Quality; USGS, U.S. Geological Survey; ADEQ < USGS, ADEQ values are significantly lower than USGS values; ADEQ > USGS, ADEQ values are significantly higher than USGS values]

Characteristic or constituent	N	Absolute difference, in percent			Absolute difference, in concentration units			ADEQ and USGS data significantly different (α=0.05)
		Minimum	Maximum	Median	Minimum	Maximum	Median	
<b>Physical characteristics</b>								
Temperature (°C) .....	7	0.1	11	2.4	0.04	2.1	0.5	No
pH (standard units) .....	7	1.1	4.4	2.1	.1	.4	.2	No
<b>General mineral characteristics</b>								
Alkalinity .....	7	.8	5.1	3.6	1	10	4	Yes (ADEQ < USGS)
Total dissolved solids .....	7	1.1	9.8	3.3	3	16	12	No
Specific conductance (µS/cm) .....	7	1.1	8.3	3.6	5	36	9	Yes (ADEQ > USGS)
<b>Mineral constituents</b>								
Calcium .....	7	2.8	17	4.2	.4	4.8	2.3	No
Magnesium .....	7	0	70	6.7	0	.7	.6	Yes (ADEQ > USGS)
Sodium .....	6	1.8	11	2.3	.2	12	.7	No
Potassium .....	7	10	35	11	.1	.4	.2	Yes (ADEQ > USGS)
Chloride .....	7	3.2	15	6.3	.1	1.2	.4	No
Sulfate .....	7	.7	78	5.4	.3	5.6	1.3	No
<b>Nutrient constituents</b>								
Nitrite plus nitrate .....	7	6.1	20	13	.03	.61	.06	No
Ammonia .....	0	--	--	--	--	--	--	--
Phosphorus .....	0	--	--	--	--	--	--	--
<b>Trace constituents</b>								
Aluminum (µg/L) .....	0	--	--	--	--	--	--	--
Antimony (µg/L) .....	0	--	--	--	--	--	--	--
Arsenic (µg/L) .....	2	8	9.5	8.8	1	3	2	--
Barium (µg/L) .....	3	.8	7.1	3.3	2	33	7	--
Beryllium (µg/L) .....	0	--	--	--	--	--	--	--
Cadmium (µg/L) .....	0	--	--	--	--	--	--	--
Chromium (µg/L) .....	0	--	--	--	--	--	--	--
Copper (µg/L) .....	0	--	--	--	--	--	--	--
Fluoride .....	7	3.1	19	6.9	.01	.2	.03	No
Iron (µg/L) .....	0	--	--	--	--	--	--	--
Lead (µg/L) .....	0	--	--	--	--	--	--	--
Manganese (µg/L) .....	0	--	--	--	--	--	--	--
Selenium (µg/L) .....	0	--	--	--	--	--	--	--
Silver (µg/L) .....	0	--	--	--	--	--	--	--
Zinc (µg/L) .....	2	15	22	19	10	14	12	--

for the ADHS laboratory but were measurable by the NWQL. Measurable concentrations from only one of the laboratories were not sufficient to test the statistical significance of differences between the USGS and the ADEQ data. Concentrations of eight of the trace constituents—antimony, beryllium, cadmium, copper, lead, manganese, selenium, and silver—in the split samples were below the MRL's for both the ADHS laboratory and the NWQL. Because these results correspond with the environmental data for four of these constituents—antimony, beryllium, cadmium, and silver (table 16 in the "Basic Data" section)—a comparison of the analytical data was not considered necessary. Five of these constituents—chromium, copper, lead, manganese, and selenium—were detected in less than half of the environmental samples, and concentrations generally were at or near the MRL (table 16 in the "Basic Data" section). Most of these detections were in samples collected by the USGS owing to the generally lower detection limits for the trace constituents. Because there were few detections of these constituents, comparisons of data from the split samples were not considered necessary. Concentrations of only one trace constituent—fluoride—were measurable in all seven split samples. Differences in the fluoride data between the USGS and the ADEQ were not significant on the basis of results from the exact form of the sign test.

### Statistical Methods

A variety of methods were used to complete statistical analyses for the ground-water quality data collected by the USGS and the ADEQ during 1996–97. Constituent data that included data below one or more MRL's and for which less than 80 percent of the concentrations were below the MRL's were tested for log-transformed normality using the Kolmogorov-Smirnov one-sample test (SSPS Inc., 1997). Values representing concentrations that exceed no more than 10, 25, 50, 75, and 90 percent of the constituent concentrations were calculated using the maximum likelihood estimation method (Cohen, 1959) for normal log-transformed data, or the probability regression method (Cohen, 1959) for nonnormal log-

transformed data. If more than 80 percent of the data reported for a constituent were below the MRL's, no calculations were completed.

The Statistical Analysis System (SAS; SAS Institute Inc., 1990) 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 concentrations of different constituents and between concentrations of constituents and well depth. 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. For those sets of constituent data that included values less than or equal to either of the agencies' MRL for that constituent, concentrations reported below the highest MRL were changed to a single value that was less than the highest MRL. Kendall's tau-b test statistic is not valid for data sets with a large percentage of concentrations (greater than 20 percent) below the MRL (Helsel and Hirsch, 1992). For sulfate and barium, more than 20 percent of the data collected by both the USGS and the ADEQ were below the highest MRL's, but less than 20 percent of the USGS data were below the USGS MRL's. Consequently, Kendall's tau-b test statistic was calculated for sulfate and barium using data collected only by the USGS.

Statit (Statware, Inc., 1990) 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 hypothesis that concentrations of constituents in water from wells that represent different locations, aquifer types, geology, and land-use types within the study area were the same. The null hypothesis of identical median values for all data sets within each of the four tests was rejected if the probability of obtaining identical medians by chance was less than 0.05. If the null hypothesis was rejected for any of the four tests conducted, Statit was used to apply the Tukey method of multiple comparisons on the ranks of the data (Helsel and Hirsch, 1992). This test identified significant differences between constituent concentrations when compared to each possibility within each of four tests. The null hypothesis of identical median values for two possibilities in each test was rejected if the probability of obtaining identical medians by

chance was less than or equal to 0.05. For those sets of constituent data that included values less than or equal to either of the agencies' MRL for that constituent, concentrations reported below the highest MRL were changed to a single value that was less than the highest MRL. The Kruskal-Wallis test statistic and the Tukey method are not valid for data sets with a large percentage of concentrations (greater than 50 percent) below the MRL (Helsel and Hirsch, 1992). For barium and arsenic, more than 50 percent of the data collected by both the USGS and the ADEQ were below the highest MRL's, but less than 50 percent of the USGS data were below the USGS MRL's. Consequently, the Kruskal-Wallis test statistic and the Tukey method were calculated for barium and arsenic using data collected only by the USGS.

For the historical data, Statit (Statware, Inc., 1990) was used to compute the Wilcoxon rank-sum statistic—a nonparametric measure of the association between two independent sets of data. This statistic was used to test the null hypothesis that concentrations of constituents collected from 1950–65 were the same as concentrations of constituents collected for this study during 1996–97. The null hypothesis of identical median values for both data sets was rejected if the probability of obtaining identical medians by chance was less than 0.05.

### GROUND-WATER QUALITY

Ground-water quality in the Sierra Vista subbasin was examined by determining present ground-water quality conditions (1996–97); by determining variations in ground-water quality that relate to differences in well location, well depth, aquifer type, geology, and land use (table 17 in the "Basic Data" section); and by comparing present ground-water quality conditions to historical ground-water quality conditions (1950–65). Differences in present ground-water quality conditions that relate to well location were defined by dividing the study area into four quadrants (southwest, southeast, northwest, and northeast) on the basis of two physical delineations: the subwatershed divide that divides the subbasin into northern and southern parts, and the San Pedro River that divides the subbasin into eastern and

western parts (fig. 1). Well depth was defined by well drillers' logs. Aquifer types (flood plain, unconfined basin fill, confined basin fill in the Hereford-Palominas area, confined basin fill in the St. David-Pomerene area, and bedrock water-bearing units; fig. 3) were identified by well drillers' logs and water levels. Geology (alluvium, basin fill, sedimentary, igneous, and metamorphic; fig. 3) was defined by well drillers' logs and open-interval depths. Land use (rangeland, forest, urban, agricultural, transitional, and wetland; fig. 2) was defined using digital information (U.S. Geological Survey, 1986). Changes in water quality through time were examined by comparing constituent concentrations in the historical data to constituent concentrations in data collected for this study.

### Present Conditions (1996–97)

Comparison of the ground-water quality data (table 16 in the "Basic Data" section) with drinking-water regulations and aquifer water-quality standards indicate that ground water in the Sierra Vista subbasin generally is suitable for domestic, irrigation, stock, industrial, and municipal uses. The U.S. Environmental Protection Agency (USEPA) primary maximum contaminant levels (MCL's) for drinking water are health-based standards that define the maximum concentration of a constituent that is allowed in a public-water system; the State of Arizona aquifer water-quality standards apply to aquifers classified for drinking-water use (table 9). The USEPA secondary MCL is an unenforceable guideline that defines the maximum concentration of a characteristic or constituent that can be present without unpleasant taste, color, odor, or other aesthetic effects on drinking water. Of the 39 samples collected in the Sierra Vista subbasin as part of the recent study, 1 sample exceeded the USEPA primary MCL and State of Arizona aquifer water-quality standards for fluoride (site 39; fig. 8), 7 samples exceeded the USEPA secondary MCL for fluoride (sites 14, 16, 31, 32, 37, 38, and 39), 1 sample exceeded the USEPA secondary MCL for iron (site 37), 1 sample exceeded the USEPA secondary MCL for manganese (site 37), 2 samples were outside the USEPA secondary MCL range for pH (sites 28 and

**Table 9.** U.S. Environmental Protection Agency primary and secondary maximum contaminant levels and State of Arizona aquifer water-quality standards (drinking water protected use) for selected constituents

[Constituents are dissolved and are reported in micrograms per liter unless otherwise noted; MCL, Maximum Contaminant Level; mg/L, milligrams per liter; --, no standard]

Constituent	U.S. Environmental Protection Agency <sup>1</sup>		State of Arizona <sup>2</sup>
	Primary MCL	Secondary MCL	Aquifer water-quality standard
Aluminum.....	--	50–200	--
Antimony.....	6	--	6
Arsenic.....	<sup>3</sup> 50	--	50
Barium.....	2,000	--	2,000
Beryllium.....	4	--	4
Cadmium.....	5	--	5
Chloride (mg/L).....	--	250	--
Chromium.....	100	--	100
Copper.....	--	1,000	--
Fluoride (mg/L).....	<sup>3</sup> 4	<sup>3</sup> 2	4
Iron.....	--	300	--
Lead.....	--	--	50
Manganese.....	--	50	--
Nitrite plus nitrate (mg/L).....	10	--	10
pH (standard units).....	--	6.5–8.5	--
Selenium.....	50	--	50
Silver.....	--	100	--
Sulfate (mg/L).....	--	250	--
Total dissolved solids (mg/L).....	--	500	--
Zinc.....	--	5,000	--

<sup>1</sup>U.S. Environmental Protection Agency (1996).

<sup>2</sup>State of Arizona (1996).

<sup>3</sup>Under review.

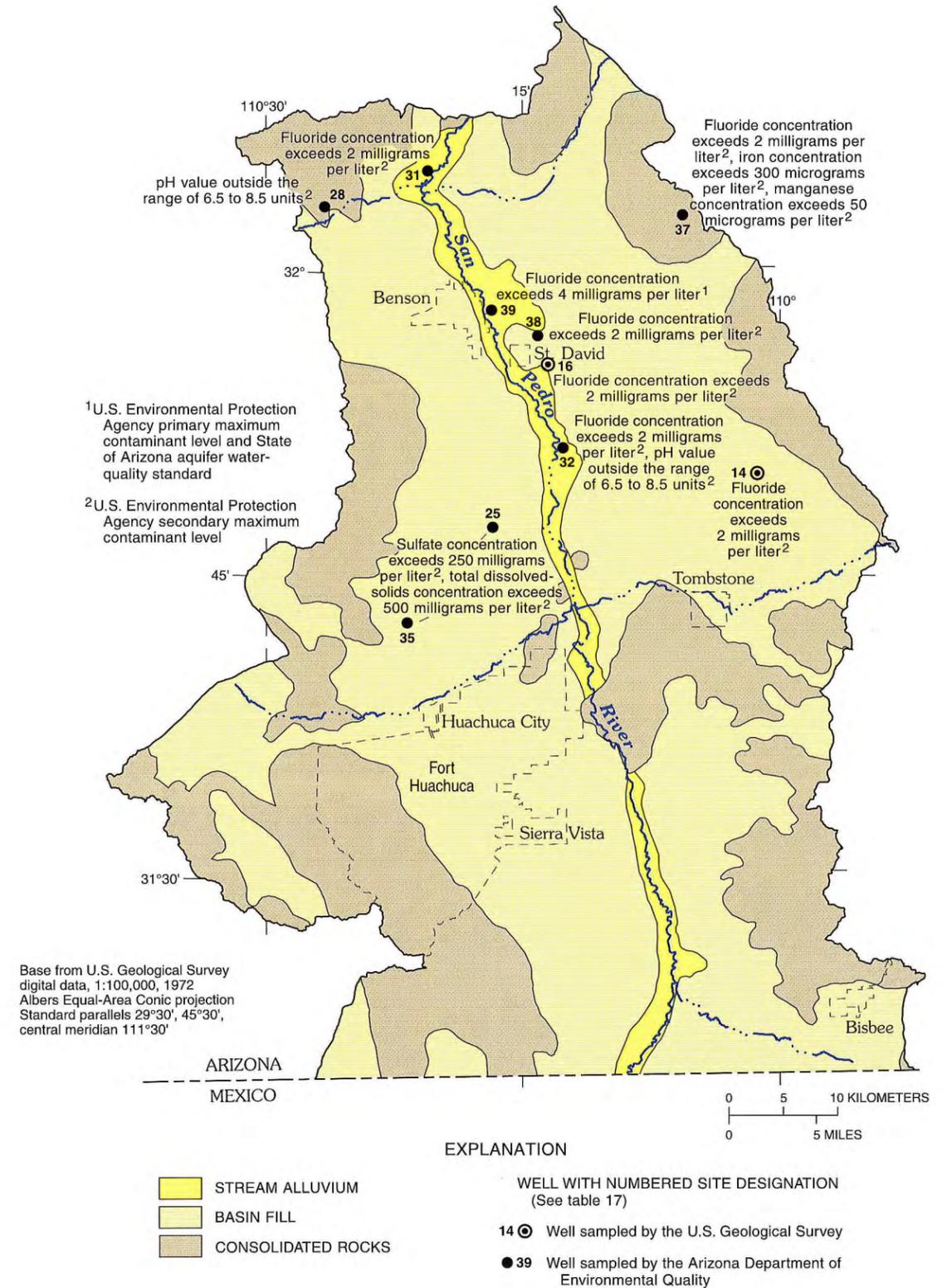
32), 2 samples exceeded the USEPA secondary MCL for sulfate (sites 25 and 35), and 2 samples exceeded the USEPA secondary MCL for total dissolved solids (sites 25 and 35).

**Physical and General Mineral Characteristics**

Ground-water samples collected in the Sierra Vista subbasin varied slightly in temperature, pH, alkalinity, specific conductance, and total dissolved solids (table 10). Alkalinity concentrations for the samples were similar to alkalinity concentrations

typically found in natural waters and can be attributed entirely to dissolved bicarbonate and carbonate because of the neutral pH values (Hem, 1985). The pH values and total dissolved-solids concentrations that exceeded the USEPA secondary MCL's can be attributed to natural geochemical reactions and will be discussed later in the report in relation to fluoride and sulfate concentrations, respectively.

Significant correlations between temperature and well depth and pH and well depth were identified with Kendall's tau-b test statistic; both



**Figure 8.** Wells where U.S. Environmental Protection Agency primary or secondary maximum contaminant levels or State of Arizona aquifer water-quality standards were exceeded, Sierra Vista subbasin, Arizona, 1996–97.

**Table 10.** Summary statistics for ground-water quality data, Sierra Vista subbasin, Arizona, 1996–97

[MRL, Minimum Reporting Level; constituents are dissolved and are reported in milligrams per liter unless otherwise noted; N/A, not available; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; µg/L, micrograms per liter; >, greater than]

	Number of samples	Highest MRL	Lowest MRL	10th percentile	25th percentile	50th percentile (median)	75th percentile	90th percentile
<b>Physical characteristics</b>								
Temperature (°C).....	38	N/A	N/A	19	21	22	25	27
pH (standard units).....	39	0.1	N/A	7.2	7.3	7.4	7.6	7.9
<b>General mineral characteristics</b>								
Alkalinity.....	39	2	1	114	153	179	217	245
Specific conductance (µS/cm).....	38	1	N/A	268	378	457	524	737
Total dissolved solids.....	39	10	1	174	222	262	316	419
<b>General mineral constituents</b>								
Calcium <sup>1</sup> .....	39	1	.02	18	38	56	73	114
Magnesium <sup>1</sup> .....	38	1	.01	3.8	7.5	11	14	21
Sodium <sup>1</sup> .....	39	5	.2	9.8	13	17	30	50
Potassium.....	39	.5	.1	.7	1.3	2.0	2.6	3.1
Chloride.....	39	1	.1	3.1	4.3	7.0	12	22
Sulfate <sup>1</sup> .....	39	10	.1	2.7	6.5	17	37	120
<b>Nutrient constituents</b>								
Nitrite plus nitrate <sup>1</sup> .....	38	.1	.05	<sup>2</sup> .02	.47	.78	1.40	3.9
Nitrogen ammonia <sup>3</sup> .....	38	.1	.015	<sup>2</sup> .001	<sup>2</sup> .003	<sup>2</sup> .014	4.030	4.053
Phosphorus.....	38	.1	.01	> 80 percent data reported below both MRL's				
<b>Trace constituents</b>								
Antimony (µg/L).....	39	5	1	100 percent data reported below both MRL's				
Arsenic (µg/L) <sup>1</sup> .....	39	10	1	<sup>2</sup> .19	<sup>2</sup> .48	41.3	43.5	48.5
Barium (µg/L) <sup>3</sup> .....	39	100	1	<sup>4</sup> 26	<sup>4</sup> 36	499	240	450
Beryllium (µg/L).....	39	1	.5	100 percent data reported below both MRL's				
Cadmium (µg/L).....	39	1	N/A	100 percent data reported below both MRL's				
Fluoride <sup>3</sup> .....	39	.2	.1	.2	.2	.5	1.0	2.7
Iron (µg/L).....	39	100	3	> 80 percent data reported below both MRL's				
Lead (µg/L).....	39	5	1	> 80 percent data reported below both MRL's				
Manganese (µg/L).....	39	50	1	> 80 percent data reported below both MRL's				
Selenium (µg/L).....	39	5	1	> 80 percent data reported below both MRL's				
Silver (µg/L).....	39	1	N/A	100 percent data reported below both MRL's				

<sup>1</sup>Summary statistics calculated using maximum likelihood estimation method (Cohen, 1959).

<sup>2</sup>Values are extrapolated below the two detection limits.

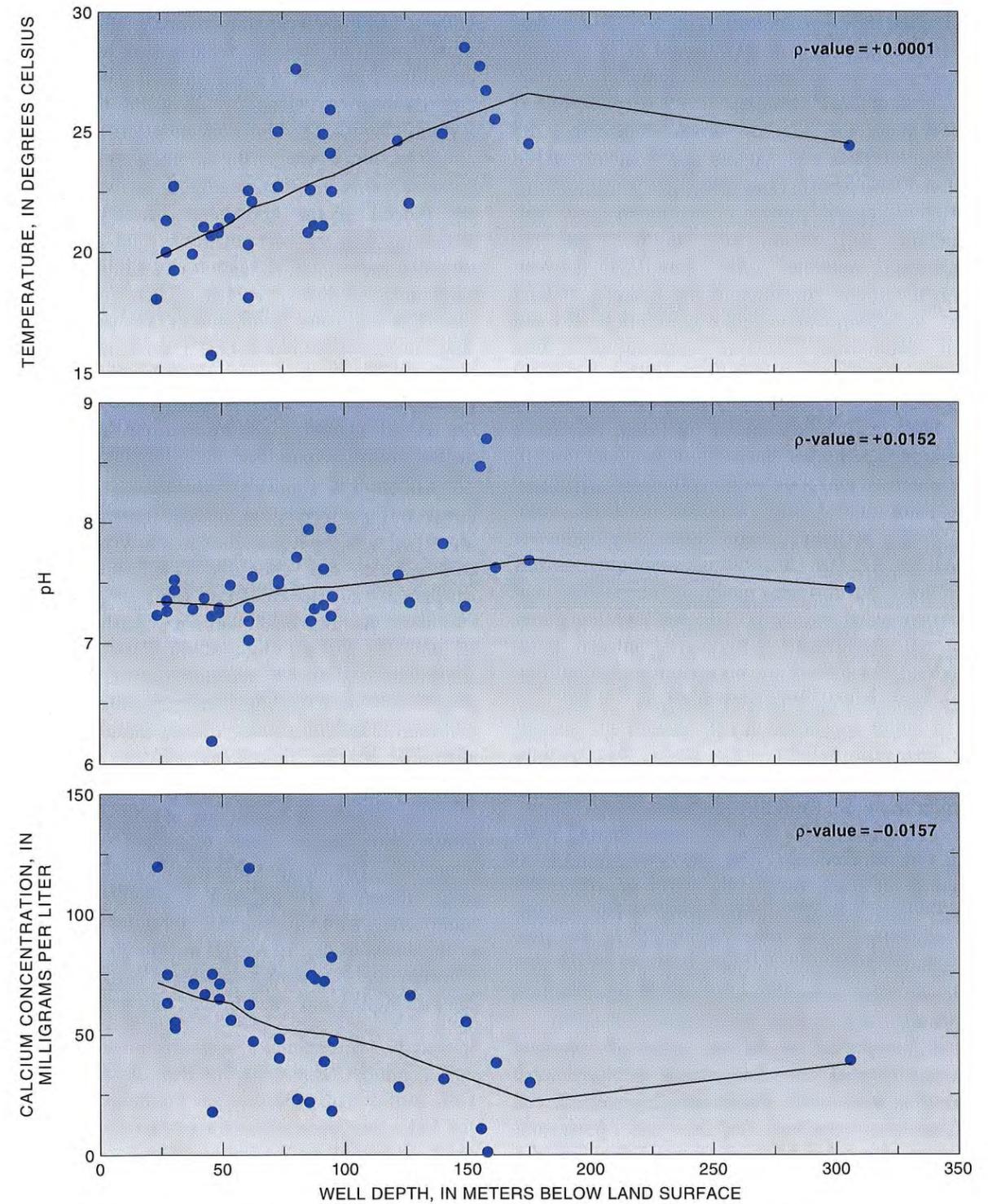
<sup>3</sup>Summary statistics calculated using probability regression method (Cohen, 1959).

<sup>4</sup>Values are extrapolated between the two detection limits.

increased with increased well depth (fig. 9). No significant relations between any of the physical and general mineral characteristics and well location, aquifer type, geology, or land use were identified with the Kruskal-Wallis test statistic.

**General Mineral Constituents**

On the basis of the cations and anions that contribute more than 50 percent of the ions in solution, ground water in the Sierra Vista subbasin



NOTE: p-value, the probability that observed differences are due to chance rather than the factor tested, are for Kendall's tau-b test statistic; only p-values significant at  $\alpha = 0.05$  are graphed.

**EXPLANATION**

— LOCALLY WEIGHTED SCATTERPLOT SMOOTHING (LOWESS)

**Figure 9.** Temperature, pH, and calcium concentrations as functions of well depth, Sierra Vista subbasin, Arizona, 1996–97.

is a calcium bicarbonate type (fig. 7). Potassium and chloride were detected in all 39 samples, calcium and sodium were detected in 38 samples, magnesium was detected in 37 samples, and sulfate was detected in 31 samples.

Within the Sierra Vista subbasin, the Kruskal-Wallis test statistic and Kendall's tau-b test statistic identified several significant relations between general mineral constituents and well location, well depth, and aquifer type; no significant relations were identified between general mineral constituents and geology or land use. A significant negative correlation between well depth and calcium concentrations was identified with the Kendall's tau-b test statistic (fig. 9).

Sodium concentrations in the northeast quadrant were higher than sodium concentrations in the southeast and southwest quadrants, and sodium concentrations in the northwest quadrant were higher than sodium concentrations in the southwest quadrant (fig. 10). In addition, potassium concentrations in the northeast quadrant were higher than potassium concentrations in the southwest quadrant (fig. 10). Significant differences between these quadrants for sodium and potassium were identified with the Kruskal-Wallis test statistic.

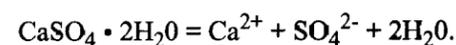
Sodium concentrations in unconfined parts of the basin-fill aquifer were lower than sodium concentrations in confined parts of the basin-fill aquifer in the St. David-Pomerene area and sodium concentrations in the bedrock water-bearing units (fig. 10). In addition, chloride concentrations in unconfined parts of the basin-fill aquifer were lower than chloride concentrations in the bedrock water-bearing units (fig. 10). Significant differences between these aquifer types for sodium and chloride were identified with the Kruskal-Wallis test statistic.

Although no significant relations between general mineral constituents and geology were identified with the Kruskal-Wallis test statistic, the differences between sodium and potassium concentrations in the northeast quadrant of the basin and concentrations in the southern half of the basin, and the differences between sodium and chloride concentrations in the bedrock water-bearing units and concentrations in unconfined parts of the basin-fill aquifer are most likely directly related to the varied mineralogy of the mountains

surrounding the Sierra Vista subbasin. Samples collected from wells open to bedrock water-bearing units contain higher concentrations of sodium and chloride because of the presence of sodium- and chloride-bearing volcanic rocks in these units (Gilluly, 1956). The high concentrations of sodium and potassium in the northeast quadrant relative to concentrations in other quadrants in the subbasin are related to the abundance of sodium- and potassium-bearing volcanic rocks and associated intrusive rocks of the Dragoon and Little Dragoon Mountains (Gilluly, 1956). This relation is discussed in greater detail later in the discussion of fluoride concentrations in the "Trace Constituents" section. The high levels of potassium in the northeast quadrant also may be related to the bias of the ADHS laboratory toward high potassium concentrations relative to the USGS laboratory.

Although a significant difference in sulfate concentrations in relation to well location was not identified with the Kruskal-Wallis test statistic, the two samples that exceeded USEPA secondary MCL's for sulfate are from wells close to one another in the northwest quadrant of the basin (sites 25 and 35; fig. 8). Both of these samples also exceeded the USEPA secondary MCL for total dissolved solids. The high concentrations of sulfate and total dissolved solids in these samples can be attributed to the mineralogy of the mountains adjacent to these wells.

The Whetstone Mountains, which are located directly upgradient from the two wells that contained high concentrations of sulfate, contain large deposits of gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) interbedded with siltstone and dolomite that range in thickness from 120 to 260 m (Graybeal, 1962). Gypsum dissolves readily in contact with water and releases sulfate and calcium ions into solution:



Calculated saturation indices for samples from the south end of the Whetstone Mountains indicate that ground water in this area is strongly undersaturated with respect to gypsum and undersaturated but close to saturation with respect to calcite ( $\text{CaCO}_3$ ) and dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ) (table 11). The concurrent reactions of gypsum dissolution from deposits in the Whetstone

**Table 11.** Calcite, dolomite, and gypsum saturation indices for selected ground-water samples, Sierra Vista subbasin, Arizona, 1996-97

[A positive number indicates a precipitation potential; a negative number indicates a dissolution potential]

Site number	Saturation index <sup>1</sup>		
	Calcite ( $\text{CaCO}_3$ )	Dolomite ( $\text{CaMg}(\text{CO}_3)_2$ )	Gypsum ( $\text{CaSO}_4$ )
25	0.07	-0.09	-1.06
35	-.15	-.42	-.59

<sup>1</sup>Calculated using WATEQFP (Plummer and others, 1991).

Mountains and dolomite and calcite dissolution from basin-fill deposits could create the locally high concentrations of total dissolved solids. The significant positive correlation of sulfate with total dissolved solids, calcium, and magnesium (fig. 11) supports the occurrence of these reactions.

#### Nutrient Constituents

Ground-water samples collected in the Sierra Vista subbasin varied slightly in concentrations of nitrite plus nitrate, ammonia, and phosphorus (table 10). Nitrite plus nitrate was detected in 36 samples, ammonia was detected in 11 samples, and phosphorus was detected in 2 samples. A significant positive correlation between nitrite plus nitrate and magnesium concentrations and between nitrite plus nitrate and chloride concentrations was identified with the Kendall's tau-b test statistic (fig. 12). Nitrite plus nitrate and chloride have several common sources, both are used in agriculture and both can be contributed to ground water by animal waste and by septic systems (Hem, 1985).

Because the data set contained a large number (greater than 50 percent) of ammonia and phosphorus concentrations below the MRL, only nitrite plus nitrate was examined for statistical trends. Nitrite plus nitrate concentrations in the northeast quadrant were lower than nitrite plus nitrate concentrations in the southeast quadrant (fig. 10). A significant difference between these quadrants for nitrite plus nitrate was identified with the Kruskal-Wallis test statistic. Both quadrants have minimal agricultural activity; agricultural practices probably are not causing the increases in nitrite plus nitrate values in one quadrant relative to another. At present, adequate data are not available

to attribute the higher nitrite plus nitrate concentrations in the southeast quadrant to a particular source. No significant relations were identified between nitrite plus nitrate and well depth, aquifer type, geology, or land use.

#### Trace Constituents

Most of the samples collected in the Sierra Vista subbasin did not contain detectable concentrations of trace constituents. Fluoride was detected in 37 samples, barium was detected in 28 samples, arsenic was detected in 14 samples, iron was detected in 8 samples, manganese was detected in 6 samples, lead was detected in 5 samples, and selenium was detected in 1 sample. The trace constituents—antimony, beryllium, cadmium, and silver—were not detected by either agency.

One ground-water sample exceeded USEPA secondary MCL's for iron and manganese (site 37; fig. 8). This sample was collected from an unused well with a steel casing; the iron and manganese concentrations may not be indicative of actual ground-water conditions.

Because fluoride and barium were the only trace constituents present in a large number (greater than 80 percent) of samples at concentrations above the MRL, only fluoride and barium were examined for statistical trends with well depth using the Kendall's tau-b test statistic. Only fluoride, barium, and arsenic data had greater than 50 percent of the concentrations above the MRL; fluoride, barium, and arsenic were examined for statistical differences related to well location, aquifer type, geology, and land use using the Kruskal-Wallis test statistic. Significant differences of fluoride in

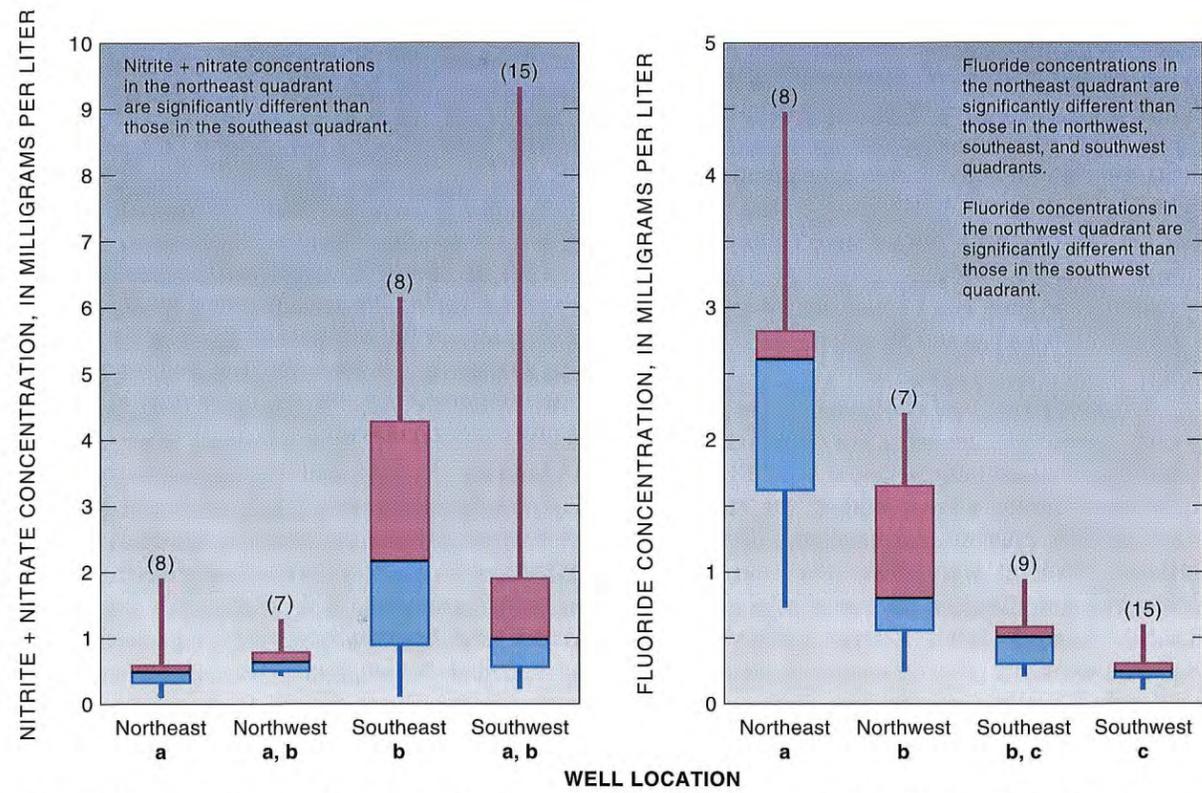
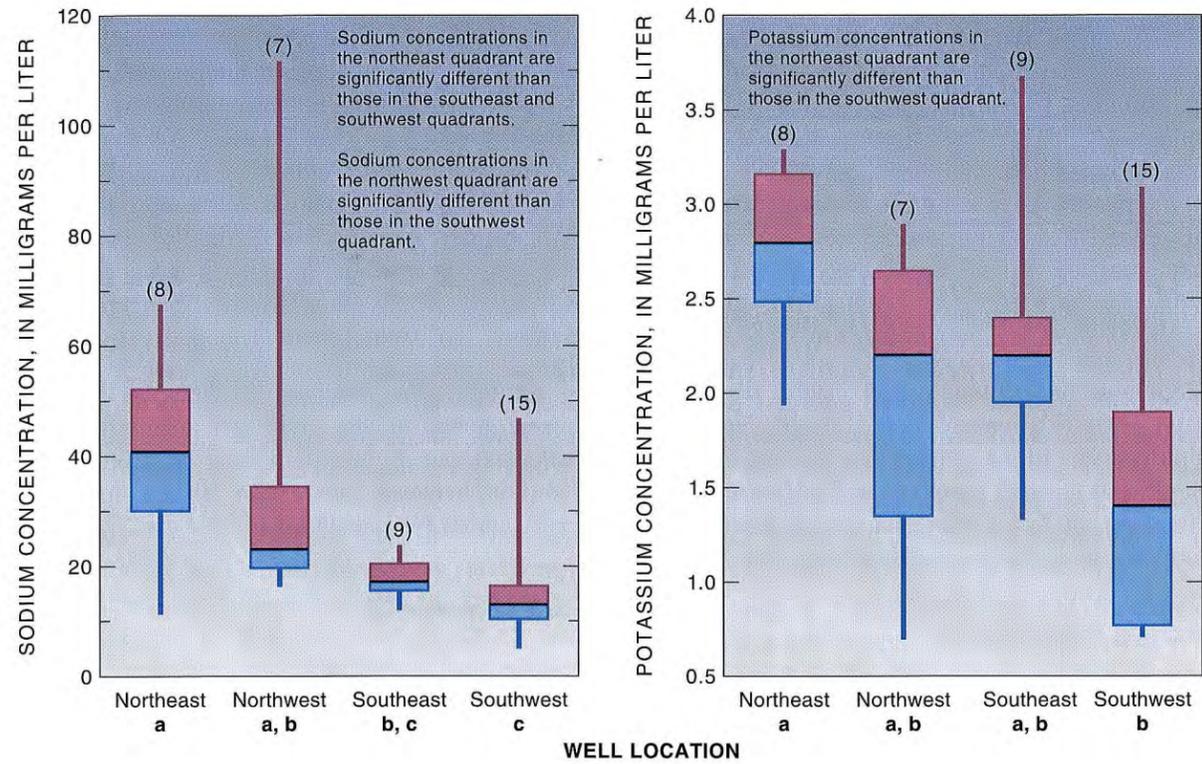
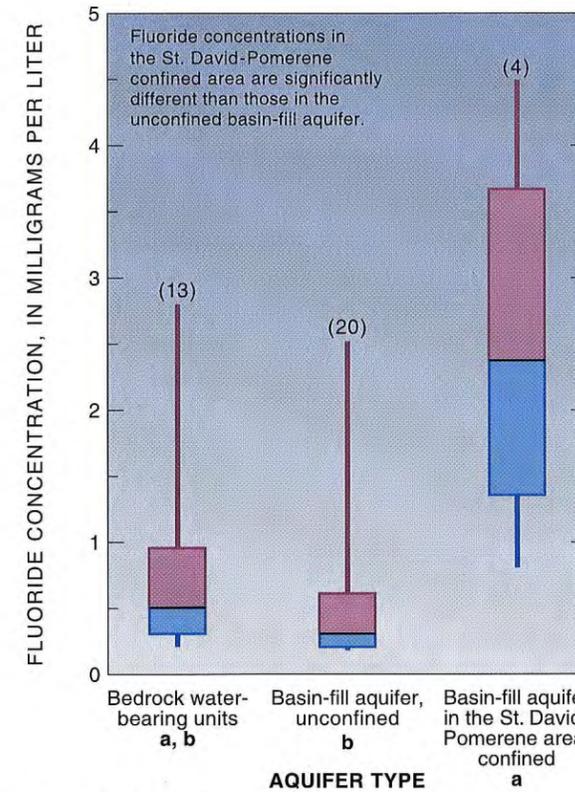
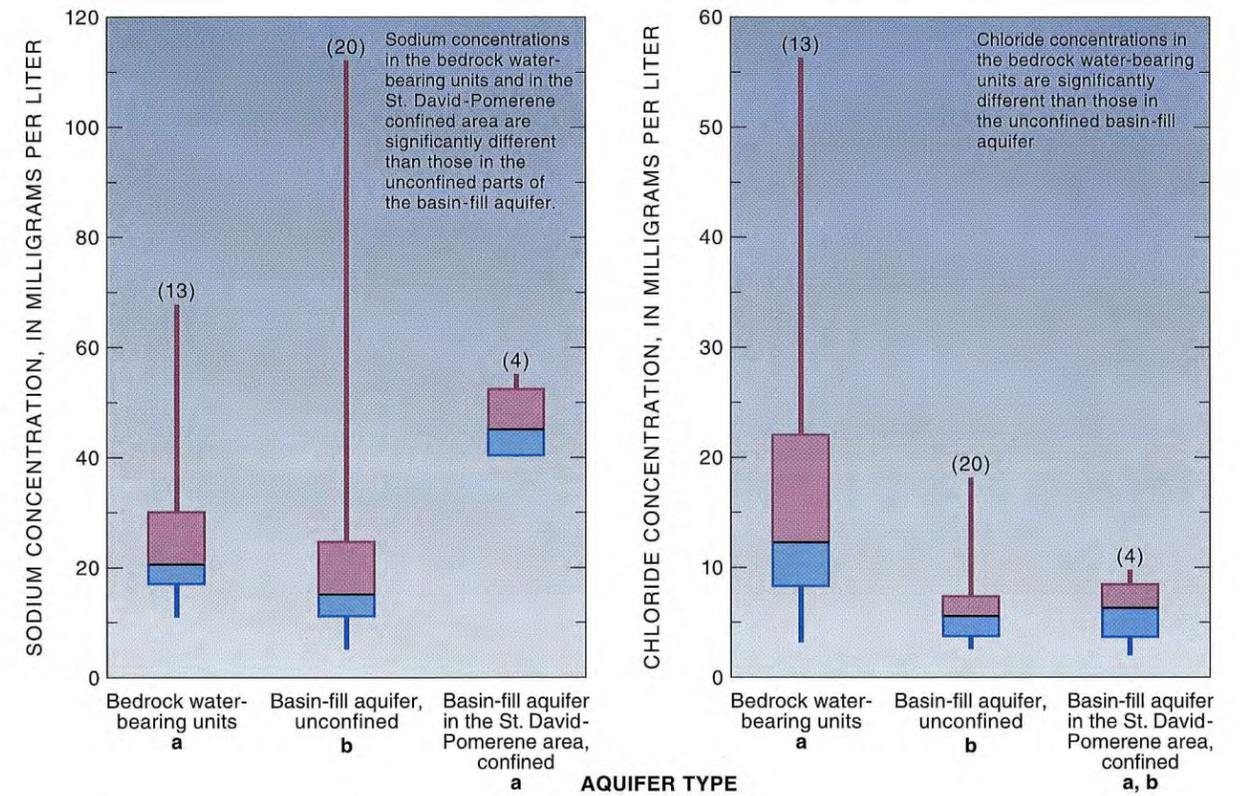


Figure 10. Concentrations of sodium, potassium, nitrite plus nitrate, fluoride, and chloride relative to well location and aquifer type, Sierra Vista subbasin, Arizona, 1996–97.



**EXPLANATION**

(4) NUMBER OF OBSERVATIONS

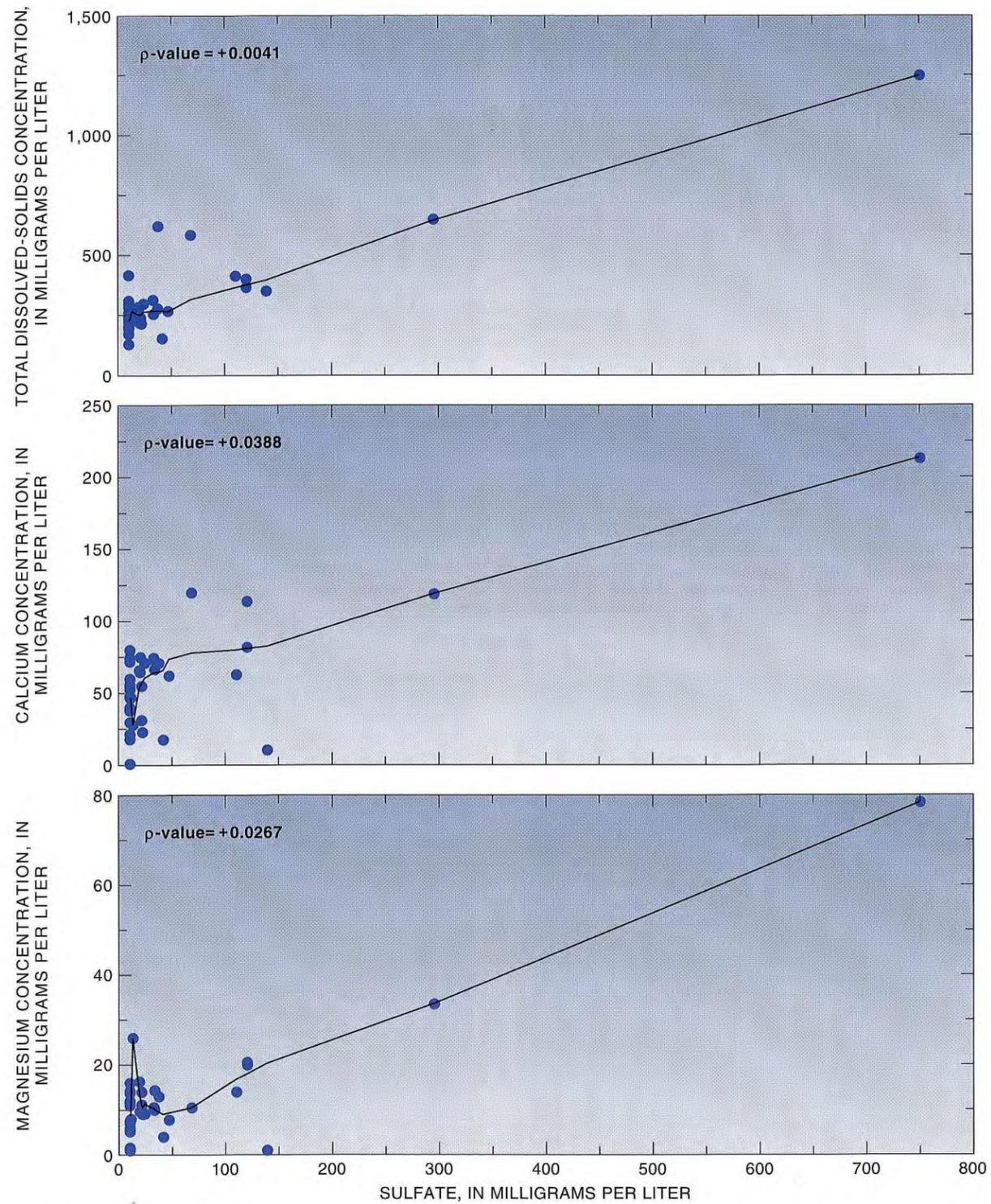
PERCENTILE—Percentage of analyses equal to or less than the indicated values

MAXIMUM VALUE  
75TH PERCENTILE  
MEDIAN  
25TH PERCENTILE  
MINIMUM VALUE

Box represents range of actual data

**a** LETTER INDICATES RESULT OF THE TUKEY TEST—Well locations and aquifer types with the same letters are not significantly different at the  $\alpha = 0.05$  test level

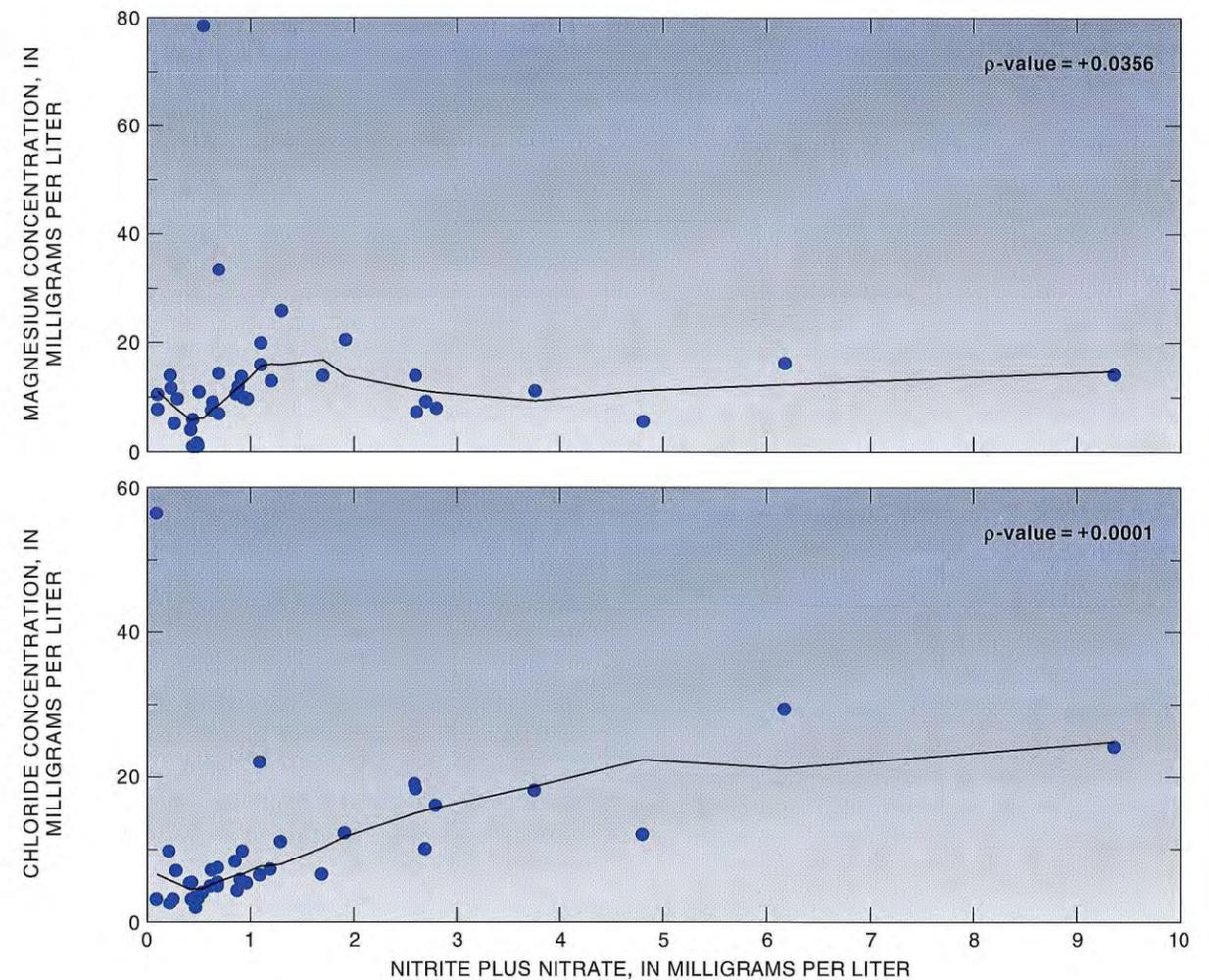
Figure 10. Continued.



NOTE:  $p$ -value, the probability that observed differences are due to chance rather than the factor tested, are for Kendall's tau-b test statistic; only  $p$ -values significant at  $\alpha = 0.05$  are graphed.

EXPLANATION  
 ——— LOCALLY WEIGHTED SCATTERPLOT SMOOTHING (LOWESS)

Figure 11. Concentrations of total dissolved solids, calcium, and magnesium as functions of sulfate concentrations, Sierra Vista subbasin, Arizona, 1996–97.



NOTE:  $p$ -value, the probability that observed differences are due to chance rather than the factor tested, are for Kendall's tau-b test statistic; only  $p$ -values significant at  $\alpha = 0.05$  are graphed.

EXPLANATION  
 ——— LOCALLY WEIGHTED SCATTERPLOT SMOOTHING (LOWESS)

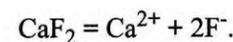
Figure 12. Concentrations of magnesium and chloride as functions of nitrite plus nitrate concentrations, Sierra Vista subbasin, Arizona, 1996–97.

relation to well location and aquifer type were identified with the Kruskal-Wallis test statistic.

Fluoride concentrations in the northeast quadrant were higher than fluoride concentrations in the northwest, southeast, and southwest quadrants; fluoride concentrations in the northwest quadrant were higher than fluoride concentrations in the southwest quadrant (fig. 10). In addition, fluoride concentrations in confined parts of the basin-fill aquifer in the St. David-Pomerene area were higher than fluoride concentrations in unconfined parts of the basin-fill aquifer (fig. 10). Significant differences in fluoride concentrations

between these quadrants and between these aquifer types were identified with the Kruskal-Wallis test statistic. Seven samples in the northern quadrants exceeded the USEPA secondary MCL for fluoride (fig. 8). Both the USGS and the ADEQ analyses exhibited a bias toward high concentrations of fluoride; however, because no significant difference existed between concentrations analyzed by the NWQL and the ADHS laboratory, the significant differences in data from different well locations and aquifer types were not related to laboratory bias.

Although no significant relations between fluoride and geology were identified with the Kruskal-Wallis test statistic, the high fluoride values in the northern quadrants and in confined parts of the basin-fill aquifer in the St. David-Pomerene area probably are directly related to the geology of the surrounding Dagoon, Little Dagoon, and Whetstone Mountains. The Dagoon and Little Dagoon Mountains, which are both directly upgradient from the wells containing high concentrations of fluoride, contain fluoride-bearing minerals in the Pinal Schist units (Gilluly, 1956; Cooper and Silver, 1964). The Pinal Schist and associated intrusive rocks contain traces of muscovite, hornblende, biotite, and tourmaline (Gilluly, 1956; Cooper and Silver, 1964), which may contain fluoride that has replaced part of the hydroxide. The Pinal Schist and associated intrusive rock additionally contain apatite ( $\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})$ ) (Gilluly, 1956; Cooper and Silver, 1964), which may also contain fluoride. Cooper and Silver (1964) reported the presence of fluorite ( $\text{CaF}_2$ ) in quartz veins in the Little Dagoon Mountains. Fluorite dissolves readily in contact with water, releasing fluoride and calcium ions into solution:



Fluorite also is present in schist in the Whetstone Mountains where the mineral was mined from 1946-67 (Keith, 1973). On the basis of the mineralogy of the Dagoon, Little Dagoon, and Whetstone Mountains, it is likely that the basin-fill deposits downgradient from these mountain ranges contain fluoride-bearing minerals.

Fluoride concentrations in ground water in the northern quadrants may be partially controlled by fluorite equilibrium. Ground water from one well in the Little Dagoon Mountains and from one well located downgradient near St. David were near equilibrium with respect to fluorite (sites 37 and 39; table 12). The calculated saturation indices suggest that in some areas fluorite equilibrium is controlling fluoride concentrations. Other wells with elevated fluoride values, however, are strongly undersaturated with respect to fluorite (sites 14, 16, 31, 32, and 38; table 12), and therefore, fluorite equilibrium

**Table 12.** Fluorite saturation indices for selected ground-water samples, Sierra Vista subbasin, Arizona, 1996-97

[A positive number indicates a precipitation potential; a negative number indicates a dissolution potential]

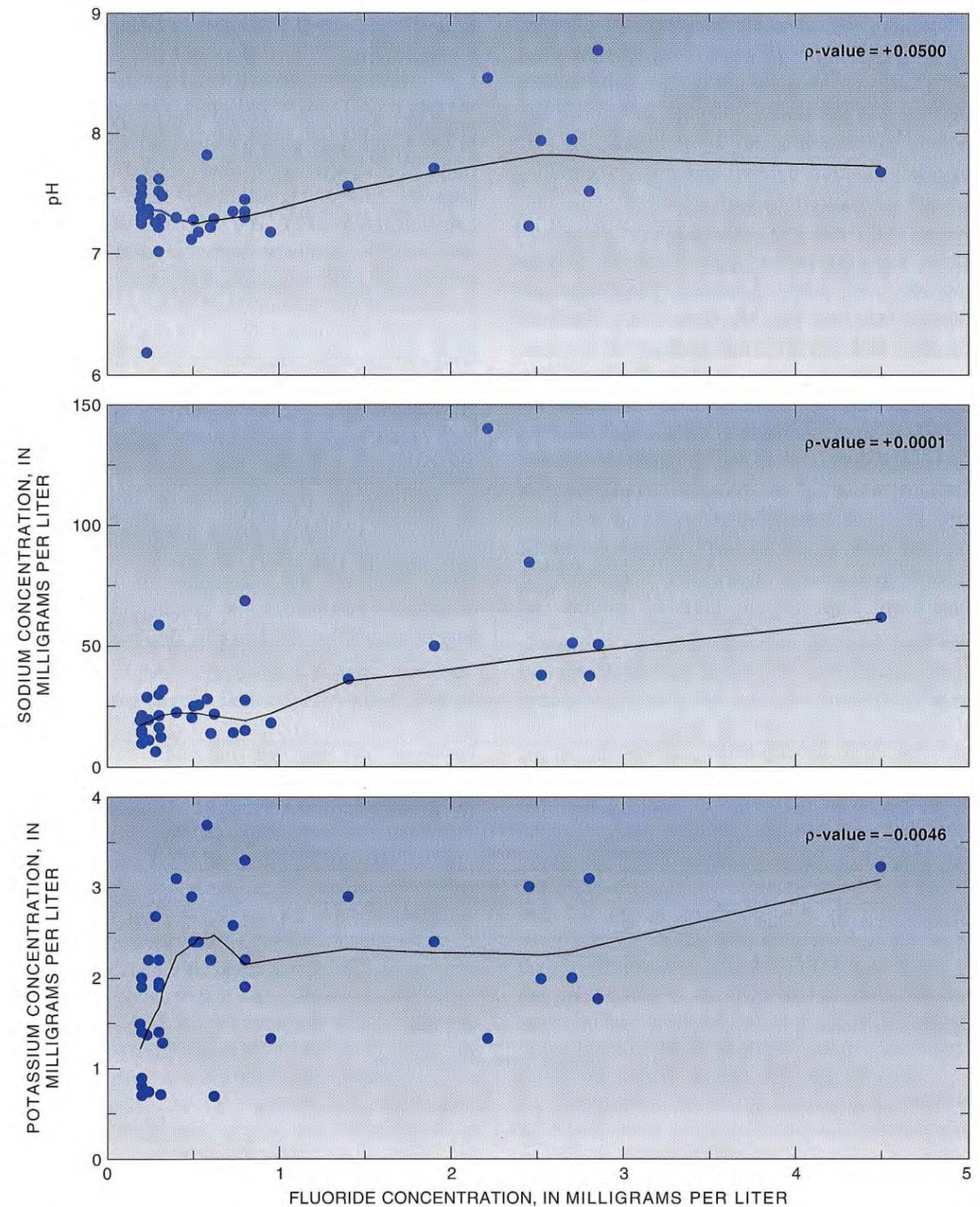
Site number	Saturation index <sup>1</sup>
	Fluorite ( $\text{CaF}_2$ )
14	-0.20
16	-.62
31	-1.06
32	-2.14
37	.02
38	-.56
39	-.01

<sup>1</sup>Calculated using WATEQFP (Plummer and others, 1991).

alone cannot be controlling the fluoride concentrations.

The strong correlation of fluoride to pH (fig. 13) suggests that pH-dependent exchange also may be partially controlling fluoride concentrations in the St. David-Pomerene area. During the weathering of fluoride-bearing minerals near mountain fronts, fluoride may exchange for hydroxyl ions on clay surfaces. As the pH of the ground water increases downgradient as a result of silicate-hydrolysis reactions, the additional hydroxyl ions in solution may exchange for the fluoride ions held on the clay surfaces, therefore, increasing the fluoride concentration in solution. A significant correlation between fluoride and calcium was not identified with the Kendall's tau-b test statistic. The lack of a significant correlation of fluoride to calcium and the low saturation indices for the majority of wells in the St. David-Pomerene area supports the theory that pH-dependent exchange is partially controlling fluoride concentrations in this area.

Robertson (1984) suggested that sorption-desorption reactions also may partially control fluoride concentrations in alluvial basins of Arizona. Analysis of leachate from basin-fill sediments in laboratory experiments showed that the concentrations of fluoride in the leachate generally were an order of magnitude or more greater than concentrations in ground water. This leachable fluoride is available for dissolution to the aqueous phase.



NOTE:  $\rho$ -value, the probability that observed differences are due to chance rather than the factor tested, are for Kendall's tau-b test statistic; only  $\rho$ -values significant at  $\alpha = 0.05$  are graphed.

EXPLANATION

— LOCALLY WEIGHTED SCATTERPLOT SMOOTHING (LOWESS)

**Figure 13.** pH and concentrations of sodium and potassium as functions of fluoride concentrations, Sierra Vista subbasin, Arizona, 1996-97.

The significant correlation between fluoride and sodium and between fluoride and potassium (fig. 13), the similar relations of fluoride, sodium, and potassium concentrations to well location (fig. 10), and the similar relations of fluoride and sodium concentrations to aquifer type (fig. 10) suggest a relation between processes controlling fluoride concentrations and processes controlling sodium and potassium concentrations. The Pinal Schist and associated intrusive rocks of the Dagoon and Little Dagoon Mountains are common sources for all three ions. Basin-fill deposits and clays downgradient from these mountain ranges may contain sodium- and potassium-bearing minerals in addition to fluoride-bearing minerals, accounting for the similar differences in concentrations between well locations; however, the processes controlling the different concentrations of fluoride and sodium in confined parts of the basin-fill aquifer in the St. David-Pomerene area relative to concentrations in unconfined parts of the basin-fill aquifer are unclear.

### Comparison of Historical (1950–65) Conditions and Present (1996–97) Conditions

The historical ground-water quality data (1950–65) include physical characteristics, general mineral characteristics, and concentrations of general mineral constituents and one trace constituent (table 13). The Wilcoxon rank-sum test was used to compare historical data with data collected in 1996–97 as part of this study to identify variations in the ground-water quality of the Sierra Vista subbasin through time. The only constituent with significantly different median values for the two sets of data was total dissolved solids; however, after removing an outlier value from the historical data (3,680 mg/L), the two total dissolved-solids medians were no longer significantly different.

In 1960, the population of the city of Sierra Vista was 3,121 (U.S. Bureau of the Census, 1961), approximately one tenth of the 1994 population. From 1960–94, the population of Bisbee has decreased by 34 percent, the population of Benson has increased by 62 percent, the population of

Huachuca City has increased by 44 percent, and the population of Tombstone has remained the same (U.S. Bureau of the Census, 1961). The lack of significant differences between the historical USGS data and the data collected by the USGS and the ADEQ for this study indicates that, on the basis of sample data, as the overall population of the basin has increased, ground-water quality has not changed significantly from 1950–65 to 1996–97.

### SUMMARY AND CONCLUSIONS

Ground-water quality in the Sierra Vista subbasin was assessed in 1996–97 by the USGS and the ADEQ. This study included combining ground-water quality data collected by the two agencies in order to: (1) characterize present (1996–97) conditions; (2) analyze the effect of well location, well depth, aquifer type, geology, and land use on ground-water quality; and (3) compare historical (1950–65) and current (1996–97) ground-water quality data to determine changes in water quality through time.

The USGS and the ADEQ followed similar quality-assurance procedures and collected individual and combined quality-control data to ensure the validity of combining the ground-water quality data collected by the two agencies. Analyses of field-blank samples collected by the USGS indicated systematic contamination by nitrite plus nitrate, aluminum, chromium, copper, and zinc; the trace constituents were omitted from the data analysis. Analyses of standard reference samples by the NWQL and the ADHS laboratory indicated a bias toward high concentrations of magnesium and zinc from the ADHS laboratory, and a bias toward high concentrations of fluoride from both laboratories. Analyses of split samples collected by both agencies at the same times and locations generally verified that combining the ground-water quality data was acceptable. Analyses identified significant differences in alkalinity, specific conductance, magnesium, and potassium between the USGS and the ADEQ data. Consideration of the laboratories' bias and sampling variability was taken into account when analyzing the data from 1996–97.

Thirty-nine ground-water quality samples were collected in the Sierra Vista subbasin by the USGS

and the ADEQ for this study. Comparison of the ground-water quality data with USEPA primary and secondary MCL's and State of Arizona aquifer water-quality standards indicated that ground water in the Sierra Vista subbasin generally is suitable for domestic, irrigation, stock, industrial, and municipal uses. Of the 39 samples, 1 sample exceeded the USEPA primary MCL and State of Arizona aquifer water-quality standard for fluoride (4 mg/L), 7 samples exceeded the USEPA secondary MCL for fluoride (2 mg/L), 1 sample exceeded the USEPA secondary MCL for iron (300 µg/L), 1 sample exceeded the USEPA secondary MCL for manganese (50 µg/L), 2 samples were outside the USEPA secondary MCL range for pH (6.5–8.5), 2 samples exceeded the USEPA secondary MCL for sulfate (250 mg/L), and 2 samples exceeded the USEPA secondary MCL for total dissolved solids (500 mg/L).

On the basis of statistical tests, significant variations were identified between ground-water quality data collected for this study and well depth, well location, and aquifer type. Temperature and pH values increased and concentrations of calcium decreased with increased well depth. Concentrations of sodium, potassium, and fluoride in the northern quadrants of the study area were higher than concentrations in the southern quadrants. Nitrite plus nitrate concentrations in the southeast quadrant were higher than concentrations in the northeast quadrant. Concentrations of sodium and chloride in the bedrock water-bearing units were higher than concentrations in unconfined parts of the basin-fill aquifer. Concentrations of sodium and fluoride in confined parts of the basin-fill aquifer in the St. David-Pomerene area were higher than concentrations in unconfined parts of the basin-fill aquifer. On the basis of statistical tests, no significant differences were identified between ground-water quality data and geology, land use, or water-quality data collected during 1950–65.

The mineralogy of the mountains surrounding the Sierra Vista subbasin accounts for many of the variations observed between ground-water quality and well location and aquifer type. Samples collected from wells open to bedrock units contained higher concentrations of sodium and chloride than wells open to unconfined parts of the basin-fill aquifer because of the abundance of sodium- and chloride-bearing volcanic rocks in the

**Table 13.** Summary statistics for historical ground-water quality data, Sierra Vista subbasin, Arizona, 1950–65

[Constituents are dissolved and are reported in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, no data]

	Number of samples	10th percentile	25th percentile	50th percentile (median)	75th percentile	90th percentile
<b>Physical characteristics</b>						
pH (standard units) .....	38	7	7.2	7.4	7.7	7.8
<b>General mineral characteristics</b>						
Specific conductance (µS/cm) .....	69	308	346	412	574	1,130
Total dissolved solids .....	36	215	241	289	422	1,330
<b>General mineral constituents</b>						
Calcium .....	41	23	42	54	78	200
Magnesium .....	42	3.6	7	11	18	37
Sodium .....	9	2.8	2.9	16	28	97
Potassium .....	1	--	--	2.2	--	--
Chloride .....	73	3.4	4.7	6.4	13	25
Sulfate .....	43	5.3	8	14	50	790
<b>Trace constituents</b>						
Fluoride .....	38	.1	.2	.4	1.2	2.6

bedrock units in which the wells are perforated. Samples collected from wells in the northern quadrants of the study area contained high concentrations of sodium, potassium, and fluoride because minerals in the Pinal Schist and associated intrusive rocks of the Dragoon and Little Dragoon Mountains, which are the likely source of local basin-fill deposits, contain fluoride, sodium, and potassium. Controls of the high concentrations of fluoride in the northern quadrants could include fluorite equilibrium, pH-dependent exchange on clay minerals, and sorption-desorption reactions. The high concentrations of sulfate in ground-water samples from the northwest quadrant probably are from large deposits of gypsum in the Whetstone Mountains, which are directly upgradient from the sample locations. Controls of the high concentrations of sulfate and total dissolved solids for these samples could include gypsum, calcite, and dolomite dissolution.

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**BASIC DATA**

**Tables 14-17**

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**Table 14.** Water-quality data for field-blank and replicate samples, Sierra Vista subbasin, Arizona, 1996–97

[USGS, U.S. Geological Survey; ADEQ, Arizona Department of Environmental Quality; site numbers correspond with sites on figures 2, 3, and 6; constituents are dissolved and are reported in milligrams per liter unless otherwise noted; °C, degrees Celsius; μS/cm, microsiemens per centimeter at 25°C; μg/L, micrograms per liter; --, no data available; <, less than; V, samples may have been contaminated during collection, actual value is less than or equal to value shown]

Characteristic or constituent	Blanks								Replicates					
	USGS sites			ADEQ sites					USGS sites			ADEQ sites		
	8	13	16	37	40	41	42	43	8	13	16	25	40	44
<b>Physical characteristics</b>														
Temperature (°C).....	--	--	--	--	--	--	--	--	<sup>1</sup> 15.7	<sup>1</sup> 25.5	<sup>1</sup> 24.1	<sup>1</sup> 22.5	<sup>1</sup> 25.6	<sup>1</sup> 20
pH (standard units).....	--	--	--	--	--	--	--	--	<sup>1</sup> 7.2	<sup>1</sup> 7.6	<sup>1</sup> 7.9	<sup>1</sup> 7.3	<sup>1</sup> 7.8	<sup>1</sup> 7.4
<b>General mineral characteristics</b>														
Alkalinity.....	1.3	1.3	--	<2	<2	<2	<2	<2	236 236	128 128	129 130	171 170	243 241	222 232
Total dissolved solids.....	<1	<1	<1	<10	16	<10	17	<10	286 280	210 209	173 173	641 653	324 318	879 884
Specific conductance (μS/cm).....	2	1	1	<sup>2</sup> 2	<sup>2</sup> 2	<sup>2</sup> 1	<sup>2</sup> 2	<sup>2</sup> 10	<sup>1</sup> 507	<sup>1</sup> 333	<sup>1</sup> 269	<sup>1</sup> 817	<sup>1</sup> 503	<sup>1</sup> 1,238
<b>Mineral constituents</b>														
Calcium.....	<.02	.02	<.02	<1	<1	<1	<1	<1	75 76	38 38	18 18	119 118	15 16	119 119
Magnesium.....	<.01	<.01	<.01	<1	<1	<1	<1	<1	9.7 9.8	5.6 5.5	1.1 1.1	34 34	11 11	26 26
Sodium.....	<.2	<.2	<.2	<5	<5	<5	<5	<5	13 14	17 17	41 41	17 18	90 90	120 120
Potassium.....	<.1	<.1	.2	<.5	<.5	<.5	<.5	<.5	1.9 2	2.2 2.4	2 2	.7 .7	2.5 2.6	2.9 2.9
Chloride.....	<.1	<.1	<.1	<1	<1	<1	<1	<1	7 7	12 12	3.3 3.3	4.9 4.9	5.8 5.8	26 26
Sulfate.....	<.1	<.1	<.1	<10	<10	<10	<10	<10	20 20	6.7 6.7	2.4 2.5	300 270	32 33	400 390
<b>Nutrient constituents</b>														
Nitrite plus nitrate.....	<.05	.07	.07	<.10	<.10	<.10	<.10	<.10	V.29 V.28	4.8 5	V.49 V.47	.69 .7	<.10 <.10	.86 .85
Ammonia.....	<.015	.020	<.015	<.10	<.10	<.10	<.10	<.10	<.015 <.015	.020 .020	<.015 <.015	<.10 <.10	<.10 <.10	<.10 <.10
Phosphorus.....	<.01	<.01	<.01	<.1	<.1	<.1	<.1	<.1	<.01 <.01	<.01 <.01	<.01 <.01	<.1 <.1	<.1 <.1	<.1 <.1

**Table 14.** Water-quality data for field-blank and replicate samples, Sierra Vista subbasin, Arizona, 1996–97—Continued

Characteristic or constituent	Blanks									Replicates					
	USGS sites			ADEQ sites			USGS sites			ADEQ sites					
	8	13	16	37	40	41	42	43	8	13	16	25	40	44	
<b>Trace constituents</b>															
Aluminum (µg/L).....	V2.9	V3	V2.8	<500	<500	<500	<500	<500	V3	V3	V4	<500	<500	<500	
									V3	V3	V3	<500	<500	<500	
Antimony (µg/L).....	<1	<1	<1	<5	11	<5	<5	<5	<1	<1	<1	<5	<5	<5	
									<1	<1	<1	<5	<5	<5	
Arsenic (µg/L).....	<1	<1	<1	<10	<10	<10	<10	<10	1	11	1	<10	<10	<10	
									1	9	<1	<10	<10	<10	
Barium (µg/L).....	<1	<1	<1	<100	<100	<100	<100	<100	198	27	99	<100	110	<100	
									195	26	100	<100	110	<100	
Beryllium (µg/L).....	<1	<1	<1	<.5	<.5	<.5	<.5	<.5	<1	<1	<1	<.5	<.5	<.5	
									<1	<1	<1	<.5	<.5	<.5	
Cadmium (µg/L).....	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
									<1	<1	<1	<1	<1	<1	
Chromium (µg/L).....	.3	<1	.3	<10	<10	<10	<10	<10	3	<1	3	<10	<10	<10	
									3	<1	3	<10	<10	<10	
Copper (µg/L).....	.3	<1	.2	<10	<10	<10	<10	<10	1	4	<1	<10	<10	<10	
									1	4	<1	<10	<10	<10	
Fluoride.....	<1	<1	<1	<.2	<.2	<.2	<.2	<.2	.3	.3	2.7	.6	1.7	.9	
									.3	.3	2.7	.5	1.7	.9	
Iron (µg/L).....	<3	<3	<3	<100	<100	<100	<100	<100	<3	<3	6	<100	430	<100	
									<3	<3	4	<100	430	<100	
Lead (µg/L).....	<1	<1	<1	<5	<5	<5	<5	<5	<1	2	<1	<5	<5	10	
									<1	2	<1	<5	<5	10	
Manganese (µg/L).....	<1	<1	<1	<50	<50	<50	<50	<50	<1	<1	<1	<50	<50	<50	
									<1	<1	<1	<50	<50	<50	
Selenium (µg/L).....	<1	<1	<1	<5	<5	<5	<5	<5	<1	<1	<1	<5	<5	<5	
									<1	<1	<1	<5	<5	<5	
Silver (µg/L).....	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	
									<1	<1	<1	<1	<1	<1	
Zinc (µg/L).....	V.92	<1	V3	<50	<50	<50	<50	<50	33	V3	29	<50	<50	<50	
									32	V8	30	<50	<50	<50	

<sup>1</sup>Only one value is available.  
<sup>2</sup>Value was determined in laboratory.

**Table 15.** Water-quality data for split samples, Sierra Vista subbasin, Arizona, 1996–97

[ADEQ, Arizona Department of Environmental Quality; USGS, U.S. Geological Survey; site numbers correspond with sites on figures 2, 3, and 6; constituents are dissolved and are reported in milligrams per liter unless otherwise noted; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; µg/L, micrograms per liter; <, less than; V, sample may have been contaminated during collection, actual value is less than or equal to value shown]

Characteristic or constituent	Site numbers where split samples were collected													
	28		29		31		33		34		38		45	
	ADEQ	USGS	ADEQ	USGS	ADEQ	USGS	ADEQ	USGS	ADEQ	USGS	ADEQ	USGS	ADEQ	USGS
<b>Physical characteristics</b>														
Temperature (°C).....	20.7	19.7	21	21.2	27.7	27.7	24.9	25	20	19.5	20.8	21.7	20.8	18.7
pH (standard units).....	6.2	6.3	7.3	7.5	8.5	8.3	7.8	7.7	7.3	7.1	7.9	8.3	7.3	7.4
<b>General mineral characteristics</b>														
Alkalinity.....	45	47	178	183	109	113	114	120	225	235	116	117	218	222
Total dissolved solids.....	155	171	222	237	353	365	224	219	262	259	174	160	342	336
Specific conductance (µS/cm).....	211	206	412	406	594	558	390	359	486	451	242	251	541	535
<b>Mineral constituents</b>														
Calcium.....	18	15	65	60	11	11	31	30	75	70	22	21	64	66
Magnesium.....	4	3.3	9.7	9	<1	.48	11.2	11	11.7	11	1.6	1.6	9.2	8.6
Sodium.....	23	20	9.8	10	110	100	23	23	<5	3.8	30	31	39	38
Potassium.....	1.4	1.2	.7	.5	1.3	1.2	3.7	3.3	2.7	2.4	2	1.8	2	1.8
Chloride.....	5.3	5.8	5.3	5.5	3.1	3.2	18	17	2.5	2.9	3.4	3.6	8.7	9.9
Sulfate.....	41	40	20	20	140	140	21	20	<10	4.6	<10	4.4	40	35
<b>Nutrient constituents</b>														
Nitrite plus nitrate.....	.42	V.48	.97	1.1	.44	V.38	3.8	4	.23	V.28	.48	V.51	4.3	4.9
Ammonia.....	<1	<.015	<1	<.015	<1	<.015	<1	<.015	<1	<.015	<1	<.015	<1	<.015
Phosphorus.....	<1	.28	<1	<.01	<1	<.01	<1	<.01	<1	.02	<1	<.01	<1	<.01
<b>Trace constituents</b>														
Aluminum (µg/L).....	<500	V3	<500	V3	<500	V6	<500	V3	<500	V3	<500	V4	<500	V3
Antimony (µg/L).....	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1
Arsenic (µg/L).....	<10	<1	<10	<1	33	30	13	12	<10	2	<10	2	<10	2
Barium (µg/L).....	<100	24	<100	46	<100	19	<100	22	450	483	210	217	240	242
Beryllium (µg/L).....	<.5	<1	<.5	<1	<.5	<1	<.5	<1	<.5	<1	<.5	<1	<.5	<1
Cadmium (µg/L).....	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chromium (µg/L).....	<10	V1	<10	<1	<10	9	<10	V2	<10	4	<10	3	<10	4
Copper (µg/L).....	<10	<1	<10	<1	<10	V1	<10	<1	<10	V2	<10	<1	<10	<1
Fluoride.....	.2	.2	.3	.3	2.2	2.4	.6	.6	.3	.3	2.5	2.6	.3	.4
Iron (µg/L).....	<100	19	<100	11	<100	34	<100	<3	<100	<3	<100	<3	<100	<3
Lead (µg/L).....	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1
Manganese (µg/L).....	<50	16	<50	<1	<50	<1	<50	<1	<50	<1	<50	<1	<50	<1
Selenium (µg/L).....	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1	<5	<1
Silver (µg/L).....	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Zinc (µg/L).....	70	56	70	60	<50	V10	<50	V11	<50	V1	<50	V5	<50	V16

**Table 16.** Water-quality data for ground water, Sierra Vista subbasin, Arizona, 1996–97

[Site numbers correspond with sites on figures 2, 3, 6, and 8; constituents are dissolved; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter as 25°C; NTU, Nephelometric Turbidity Units; FTU, Formazin Turbidity Units; µg/L, micrograms per liter; --, no data; <, less than; V, sample may have been contaminated during collection, actual value is less than or equal to value shown]

Site number	Site identification number	Date	Temperature, field (°C)	pH, field (standard units)	Alkalinity, laboratory (mg/L as CaCO <sub>3</sub> )	Total dissolved solids, residue at 180°C (mg/L)	Specific conductance, field (µS/cm)	Oxygen, field (mg/L)	Turbidity, field (NTU)	Turbidity, field (FTU)
1	(D-23-22)31dda	06/24/96	22.1	7.5	153	250	393	5.7	--	2
2	(D-23-20)01acc2	07/24/96	19.9	7.3	190	280	479	7.6	--	44
3	(D-23-23)06bcc2	06/26/96	28.5	7.3	193	242	439	3.8	--	2
4	(D-22-21)33aaa	07/10/96	22.5	7.4	161	196	321	6.1	--	0
5	(D-22-18)13bbd	08/13/96	20.3	7.0	356	419	723	3.2	2	1
6	(D-21-21)33bda	08/15/96	25.0	7.5	168	201	336	6.1	0	0
7	(D-21-23)33aaa	10/23/96	21.1	7.3	253	312	519	5.5	.6	--
8	(D-21-19)06cc unsvr	06/25/96	15.7	7.2	236	286	507	3.8	--	0
9	(D-20-20)32dcb2	07/25/96	20.8	7.3	215	300	498	6.1	--	0
10	(D-20-20)18ccc	07/23/96	25.9	7.2	181	403	605	4.2	--	0
11	(D-20-22)16ddb	10/22/96	21.1	7.3	230	316	500	2.3	.2	--
12	(D-19-18)33aaa2	06/27/96	19.6	7.3	215	298	498	5.6	--	0
13	(D-19-22)27acc	08/14/96	25.5	7.6	128	210	333	7.5	2	--
14	(D-18-23)32abc	10/29/96	22.7	7.5	199	250	397	6.3	.2	--
15	(D-18-21)33bbb	08/28/96	21.3	7.3	228	416	633	1.2	0	0
16	(D-17-21)29dca	09/17/96	24.1	7.9	129	173	269	.4	8	5
17	(D-17-19)17ddd2	08/12/96	24.6	7.6	217	267	469	1.8	1	0
18	(D-17-20)18bbb	09/18/96	24.4	7.4	193	227	383	5	.3	0
19	(D-15-20)21bda	08/26/96	27.6	7.7	150	217	364	4.9	7	5
20	(D-23-24)06bda	06/03/96	18.1	7.2	167	269	442	--	--	--
21	(D-21-18)35dbb	07/22/96	21.4	7.5	171	286	516	--	--	--
22	(D-21-21)33bbc	07/22/96	24.9	7.6	158	200	338	--	--	--
23	(D-23-21)05ccb	07/24/96	21.1	7.4	191	257	478	--	--	--
24	(D-24-23)13	07/24/96	22.7	7.5	164	254	428	--	--	--
25	(D-19-20)14baa	08/07/96	22.5	7.3	171	651	858	--	--	--
26	(D-20-20)26bab	08/08/96	19.2	7.4	191	239	418	--	--	--
27	(D-20-22)16dbb	08/08/96	22.6	7.2	226	316	518	--	--	--
28	(D-16-19)07dda	08/27/96	20.7	6.2	45	155	230	--	--	--
29	(D-22-20)35aaa	08/27/96	21.0	7.3	178	222	445	--	--	--
30	(D-21-23)29acc	08/28/96	22.0	7.3	172	287	552	--	--	--
31	(D-15-20)31ccb	10/01/96	27.7	8.5	109	353	564	--	--	--
32	(D-18-21)21caa	10/01/96	26.7	8.7	89	131	210	--	--	--
33	(D-19-22)27dad	10/02/96	24.9	7.8	114	224	390	--	--	--
34	(D-22-18)09dba	10/02/96	20.0	7.3	225	262	539	--	--	--
35	(D-20-19)12cdd	11/12/96	24.1	7.1	142	1,250	1,490	--	--	--
36	(D-17-22)24aab	12/16/96	--	7.4	245	368	--	--	--	--
37	(D-16-22)15acc	12/18/96	18.0	7.2	270	287	1,030	--	--	--
38	(D-17-21)20bbd	12/19/96	20.8	7.9	116	174	261	--	--	--
39	(D-17-20)11cac	01/22/97	24.5	7.7	179	242	390	--	--	--

**Table 16.** Ground-water quality data, Sierra Vista subbasin, Arizona, 1996–97—Continued

Site number	Site identification number	Date	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO <sub>4</sub> )	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> (mg/L as N)	Nitrogen, ammonia (mg/L as N)	Phosphorus (mg/L as P)
1	(D-23-22)31dda	06/24/96	47	8	17	1.4	16	11	2.8	<0.015	<.01
2	(D-23-20)01acc2	07/24/96	71	13	7.7	.7	7.2	37	1.2	.050	<.01
3	(D-23-23)06bcc2	06/26/96	55	14	12	1.9	6.5	21	1.7	<.015	<.01
4	(D-22-21)33aaa	07/10/96	47	5.2	11	.7	3.1	3.1	V.26	.020	<.01
5	(D-22-18)13bbd	08/13/96	80	16	47	1.4	22	8.7	1.1	.020	<.01
6	(D-21-21)33bda	08/15/96	40	11	12	.8	3.2	6.4	V.5	.020	<.01
7	(D-21-23)33aaa	10/23/96	72	14	17	2	9.9	8.8	--	--	--
8	(D-21-19)06cc unsvr	06/25/96	75	9.7	13	1.9	7	20	V.29	<.015	<.01
9	(D-20-20)32dcb2	07/25/96	71	9.2	16	1.9	10	24	2.7	.050	<.01
10	(D-20-20)18ccc	07/23/96	82	20	11	2.2	6.4	120	1.1	.050	<.01
11	(D-20-22)16ddb	10/22/96	73	10	20	2.4	9.7	33	.93	.020	<.01
12	(D-19-18)33aaa2	06/27/96	60	14	18	3.1	19	9.7	2.6	<.015	<.01
13	(D-19-22)27acc	08/14/96	38	5.6	17	2.2	12	6.7	4.8	.020	<.01
14	(D-18-23)32abc	10/29/96	48	7	30	3.1	5.4	5.2	V.69	.020	<.01
15	(D-18-21)33bbb	08/28/96	63	14	55	3.3	9.7	110	V.22	<.015	.01
16	(D-17-21)29dca	09/17/96	18	1.1	41	2	3.3	2.4	V.49	<.015	<.01
17	(D-17-19)17ddd2	08/12/96	28	26	29	2.9	11	13	1.3	.030	<.01
18	(D-17-20)18bbb	09/18/96	39	12	22	2.2	4.3	4.1	.88	<.015	<.01
19	(D-15-20)21bda	08/26/96	23	9.1	40	2.4	7.1	22	V.63	<.015	<.01
20	(D-23-24)06bda	06/03/96	62	7.8	15	1.3	3.1	47	<.10	<.100	<.10
21	(D-21-18)35dbb	07/22/96	56	14	25	1.3	24	<10	9.4	<.100	<.10
22	(D-21-21)33bbc	07/22/96	39	14	15	.9	5.8	<10	.91	<.100	<.10
23	(D-23-21)05ccb	07/24/96	67	14	8.8	.7	7.4	33	.69	<.100	<.10
24	(D-24-23)13	07/24/96	53	7.3	24	2	18	<10	2.6	<.100	<.10
25	(D-19-20)14baa	08/07/96	120	34	17	.7	4.9	300	.69	<.100	<.10
26	(D-20-20)26bab	08/08/96	55	7.6	15	1.5	4.9	<10	.62	<.100	<.10
27	(D-20-22)16dbb	08/08/96	75	11	21	2.4	8.3	32	.86	<.100	<.10
28	(D-16-19)07dda	08/27/96	18	4	23	1.4	5.3	41	.42	<.100	<.10
29	(D-22-20)35aaa	08/27/96	65	9.7	9.8	.7	5.3	20	.97	<.100	<.10
30	(D-21-23)29acc	08/28/96	66	16	16	2.2	29	19	6.2	<.100	<.10
31	(D-15-20)31ccb	10/01/96	11	<1	110	1.3	3.1	140	.44	<.100	<.10
32	(D-18-21)21caa	10/01/96	<1	<1	41	1.8	1.9	<10	.48	<.100	<.10
33	(D-19-22)27dad	10/02/96	31	11	23	3.7	18	21	3.8	<.100	<.10
34	(D-22-18)09dba	10/02/96	75	12	<5	2.7	2.5	<10	.23	<.100	<.10
35	(D-20-19)12cdd	11/12/96	210	78	16	2.9	4	750	.54	<.100	<.10
36	(D-17-22)24aab	12/16/96	110	21	11	2.6	12	120	1.9	<.100	<.10
37	(D-16-22)15acc	12/18/96	120	11	68	3	56	68	<.10	1.9	.82
38	(D-17-21)20bbd	12/19/96	22	1.6	30	2	3.4	<10	.48	<.100	<.10
39	(D-17-20)11cac	01/22/97	30	5.9	50	3.2	5.4	<10	.44	<.100	<.10

Table 16. Ground-water quality data, Sierra Vista subbasin, Arizona, 1996-97—Continued

Site number	Site identification number	Date	Aluminum (µg/L as Al)	Antimony (µg/L as Sb)	Arsenic (µg/L as As)	Barium (µg/L as Ba)	Beryllium (µg/L as Be)	Cadmium (µg/L as Cd)	Chromium (µg/L as Cr)	Copper (µg/L as Cu)
1	(D-23-22)31dda	06/24/96	V3	<1	3	464	<1	<1	3	V1
2	(D-23-20)01acc2	07/24/96	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )
3	(D-23-23)06bcc2	06/26/96	V3	<1	1	39	<1	<1	V2	4
4	(D-22-21)33aaa	07/10/96	V4	<1	<1	29	<1	<1	V2	<1
5	(D-22-18)13bbd	08/13/96	V3	<1	<1	465	<1	<1	4	V2
6	(D-21-21)33bda	08/15/96	V3	<1	<1	66	<1	<1	3	<1
7	(D-21-23)33aaa	10/23/96	V3	<1	<1	517	<1	<1	4	<1
8	(D-21-19)06cc unsvr	06/25/96	V3	<1	1	198	<1	<1	3	V1
9	(D-20-20)32dcb2	07/25/96	V3	<1	<1	216	<1	<1	3	V1
10	(D-20-20)18ccc	07/23/96	V3	<1	3	36	<1	<1	3	V1
11	(D-20-22)16ddb	10/22/96	V3	<1	<1	149	<1	<1	3	V2
12	(D-19-18)33aaa2	06/27/96	V4	<1	1	353	<1	<1	3	<1
13	(D-19-22)27acc	08/14/96	V3	<1	11	27	<1	<1	<1	4
14	(D-18-23)32abc	10/29/96	V4	<1	1	15	<1	<1	V2	V2
15	(D-18-21)33bbb	08/28/96	V3	<1	7	135	<1	<1	V2	<1
16	(D-17-21)29dca	09/17/96	V4	<1	1	99	<1	<1	3	<1
17	(D-17-19)17ddd2	08/12/96	V3	<1	<1	26	<1	<1	V2	<1
18	(D-17-20)18bbb	09/18/96	V3	<1	3	223	<1	<1	V2	<1
19	(D-15-20)21bda	08/26/96	V4	<1	4	33	<1	<1	3	<1
20	(D-23-24)06bda	06/03/96	<500	<5	<10	<100	<5	<1	<10	<10
21	(D-21-18)35dbb	07/22/96	<500	<5	<10	290	<5	<1	<10	<10
22	(D-21-21)33bbc	07/22/96	<500	<5	<10	140	<5	<1	<10	<10
23	(D-23-21)05ccb	07/24/96	<500	<5	<10	<100	<5	<1	<10	<10
24	(D-24-23)13	07/24/96	<500	<5	<10	320	<5	<1	<10	<10
25	(D-19-20)14baa	08/07/96	<500	<5	<10	<100	<5	<1	<10	<10
26	(D-20-20)26bab	08/08/96	<500	<5	<10	240	<5	<1	<10	<10
27	(D-20-22)16dbb	08/08/96	<500	<5	<10	140	<5	<1	<10	<10
28	(D-16-19)07dda	08/27/96	<500	<5	<10	<100	<5	<1	<10	<10
29	(D-22-20)35aaa	08/27/96	<500	<5	<10	<100	<5	<1	<10	<10
30	(D-21-23)29acc	08/28/96	<500	<5	<10	390	<5	<1	<10	<10
31	(D-15-20)31ccb	10/01/96	<500	<5	33	<100	<5	<1	<10	<10
32	(D-18-21)21caa	10/01/96	<500	<5	<10	<100	<5	<1	<10	<10
33	(D-19-22)27dad	10/02/96	<500	<5	13	<100	<5	<1	<10	<10
34	(D-22-18)09dba	10/02/96	<500	<5	<10	450	<5	<1	<10	<10
35	(D-20-19)12cdd	11/12/96	<500	<5	<10	<100	<5	<1	<10	<10
36	(D-17-22)24aab	12/16/96	<500	<5	<10	<100	<5	<1	<10	<10
37	(D-16-22)15acc	12/18/96	<500	<5	<10	180	<5	<1	<10	<10
38	(D-17-21)20bbd	12/19/96	<500	<5	<10	210	<5	<1	<10	<10
39	(D-17-20)11cac	01/22/97	<500	<5	26	350	<5	<1	<10	<10

Table 16. Ground-water quality data, Sierra Vista subbasin, Arizona, 1996-97—Continued

Site number	Site identification number	Date	Fluoride (mg/L as F)	Iron (µg/L as Fe)	Lead (µg/L as Pb)	Manganese (µg/L as Mn)	Selenium (µg/L as Se)	Silver (µg/L as Ag)	Zinc (µg/L as Zn)
1	(D-23-22)31dda	06/24/96	0.2	<3	<1	<1	<1	<1	39
2	(D-23-20)01acc2	07/24/96	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )	( <sup>1</sup> )
3	(D-23-23)06bcc2	06/26/96	.8	6	<1	<1	<1	<1	188
4	(D-22-21)33aaa	07/10/96	.1	<3	1	<1	<1	<1	V2
5	(D-22-18)13bbd	08/13/96	.3	10	<1	2	<1	<1	106
6	(D-21-21)33bda	08/15/96	.1	<3	<1	<1	<1	<1	V13
7	(D-21-23)33aaa	10/23/96	.2	<3	<1	<1	<1	<1	146
8	(D-21-19)06cc unsvr	06/25/96	.3	<3	<1	<1	<1	<1	33
9	(D-20-20)32dcb2	07/25/96	.2	<3	<1	<1	<1	<1	31
10	(D-20-20)18ccc	07/23/96	.6	<3	1	<1	<1	<1	137
11	(D-20-22)16ddb	10/22/96	.5	<3	1	<1	2	<1	53
12	(D-19-18)33aaa2	06/27/96	.4	<3	<1	<1	<1	<1	27
13	(D-19-22)27acc	08/14/96	.3	<3	2	<1	<1	<1	V3
14	(D-18-23)32abc	10/29/96	2.8	<3	<1	<1	<1	<1	351
15	(D-18-21)33bbb	08/28/96	.8	<3	<1	<1	<1	<1	20
16	(D-17-21)29dca	09/17/96	2.7	6	<1	3	<1	<1	29
17	(D-17-19)17ddd2	08/12/96	1.4	9	<1	2	<1	<1	95
18	(D-17-20)18bbb	09/18/96	.8	5	2	<1	<1	<1	V6
19	(D-15-20)21bda	08/26/96	1.9	10	<1	<2	<1	<1	36
20	(D-23-24)06bda	06/03/96	1	<100	<5	390	<5	<1	<50
21	(D-21-18)35dbb	07/22/96	.3	<100	<5	<50	<5	<1	<50
22	(D-21-21)33bbc	07/22/96	<.2	<100	<5	<50	<5	<1	<50
23	(D-23-21)05ccb	07/24/96	.2	<100	<5	<50	<5	<1	120
24	(D-24-23)13	07/24/96	.3	<100	<5	<50	<5	<1	<50
25	(D-19-20)14baa	08/07/96	.6	<100	<5	<50	<5	<1	<50
26	(D-20-20)26bab	08/08/96	.2	<100	<5	<50	<5	<1	<50
27	(D-20-22)16dbb	08/08/96	.5	<100	<5	<50	<5	<1	<50
28	(D-16-19)07dda	08/27/96	.2	<100	<5	<50	<5	<1	70
29	(D-22-20)35aaa	08/27/96	.3	<100	<5	<50	<5	<1	70
30	(D-21-23)29acc	08/28/96	.2	<100	<5	<50	<5	<1	500
31	(D-15-20)31ccb	10/01/96	2.2	<100	<5	<50	<5	<1	<50
32	(D-18-21)21caa	10/01/96	2.9	<100	<5	<50	<5	<1	<50
33	(D-19-22)27dad	10/02/96	.6	120	<5	<50	<5	<1	<50
34	(D-22-18)09dba	10/02/96	.3	<100	<5	<50	<5	<1	<50
35	(D-20-19)12cdd	11/12/96	.5	<100	<5	<50	<5	<1	<50
36	(D-17-22)24aab	12/16/96	.7	<100	<5	<50	<5	<1	<50
37	(D-16-22)15acc	12/18/96	2.5	1,200	<5	1,400	<5	<1	<50
38	(D-17-21)20bbd	12/19/96	2.5	<100	<5	<50	<5	<1	<50
39	(D-17-20)11cac	01/22/97	4.5	<100	<5	<50	<5	<1	<50

<sup>1</sup>Turbidity greater than 10 FTU, trace constituents were not analyzed.

**Table 17.** Site information and well-construction data for sample locations, Sierra Vista subbasin, Arizona, 1996–97

[Site numbers correspond with sites on figures 2, 3, 6, and 8. Collecting agency: USGS, U.S. Geological Survey; ADEQ, Arizona Department of Environmental Quality. Well location: SW, southwest; SE, southeast; NW, northwest; NE, northeast. Land use: A, agriculture; R, rangeland; F, forest; U, urban; T, transitional. Geology: BF, basin fill; Sd, sedimentary rocks; Ig, igneous rocks. Aquifer type: BF, unconfined basin fill; B, bedrock; HPC, confined basin fill in the Hereford-Palominas area; SPC, confined basin fill in the St. David-Pomerene area. --, no data; only quality-control samples were collected at wells 40, 41, 42, 43, 44, and 45]

Site number	Site identification number	Collecting agency	Well location (quadrant)	Land use	Geology	Aquifer type	Depth of well (meters below land surface)	Open interval (meters below land surface)	Date of water level	Water level (meters below land surface)
1	(D-23-22)31dda	USGS	SW	A	BF	HPC	62.5	24.4–32.0	06/24/96	22.5
2	(D-23-20)01acc2	USGS	SW	R	BF	BF	38.1	15.8–38.1	07/24/96	10.0
3	(D-23-23)06bcc2	USGS	SE	R	BF	BF	149.4	136.6–149.4	06/26/96	114.4
4	(D-22-21)33aaa	USGS	SW	R	BF	BF	95.1	82.9–95.1	07/10/96	72.3
5	(D-22-18)13bbd	USGS	SW	F	Ig	B	61.0	--	08/13/96	21.7
6	(D-21-21)33bda	USGS	SW	R	BF	BF	73.1	61.0–73.1	08/15/96	46.4
7	(D-21-23)33aaa	USGS	SE	R	Sd	B	91.4	78.6–91.4	10/23/96	61.6
8	(D-21-19)06cc unsurv <sup>1,2</sup>	USGS	SW	R	BF	BF	45.7	--	06/25/96	9.2
9	(D-20-20)32dcb2	USGS	SW	R	BF	BF	48.8	27.4–48.8	07/25/96	28.4
10	(D-20-20)18ccc	USGS	SW	U	BF	BF	94.5	76.2–94.5	07/23/96	75.5
11	(D-20-22)16ddb	USGS	SE	R	Ig	B	87.9	52.1–86.3	10/22/96	63.2
12	(D-19-18)33aaa <sup>2</sup>	USGS	SW	R	Sd, Ig	B	140.2	36.6–76.2	06/27/96	37.8
13	(D-19-22)27acc <sup>1,2</sup>	USGS	SE	R	BF	BF	161.5	146.3–161.5	08/14/96	107.3
14	(D-18-23)32abc	USGS	NE	R	Ig	B	73.2	54.9–76.2	10/29/96	32.1
15	(D-18-21)33bbb	USGS	NE	A	BF	SPC	27.4	15.2–27.4	08/28/96	12.3
16	(D-17-21)29dca <sup>1,2</sup>	USGS	NE	R	Ig	B	94.5	81.7–94.5	09/17/96	17.5
17	(D-17-19)17ddd2	USGS	NW	T	BF	BF	121.9	109.7–121.9	08/12/96	97.6
18	(D-17-20)18bbb	USGS	NW	R	BF, Ig	BF, B	305.7	167.6–304.8	09/18/96	140.7
19	(D-15-20)21bda	USGS	NW	R	BF	SPC	80.5	74.1–80.5	08/26/96	16.1
20	(D-23-24)06bda	ADEQ	SE	R	Ig	B	61.0	--	06/03/96	13.4
21	(D-21-18)35dbb	ADEQ	SW	U	Ig	B	53.3	30.5–53.3	07/22/96	11.9
22	(D-21-21)33bbc	ADEQ	SW	U	BF	BF	91.4	85.3–91.4	07/22/96	57.9
23	(D-23-21)05ccb	ADEQ	SW	R	BF	BF	42.7	30.5–42.7	07/24/96	22.6
24	(D-24-23)13	ADEQ	SE	R	Ig	B	30.5	16.8–29.0	07/24/96	21.9
25	(D-19-20)14baa <sup>1</sup>	ADEQ	NW	R	BF	BF	61.0	42.7–61.0	08/07/96	36.6
26	(D-20-20)26bab	ADEQ	SW	T	BF	BF	30.5	24.4–30.5	08/08/96	6.6
27	(D-20-22)16dbb	ADEQ	SE	R	Ig	B	86.3	52.1–86.0	08/08/96	59.1
28	(D-16-19)07dda <sup>3</sup>	ADEQ	NW	R	BF	BF	45.7	42.7–45.7	08/27/96	18.3
29	(D-22-20)35aaa <sup>3</sup>	ADEQ	SW	R	BF	BF	48.8	42.7–48.8	08/27/96	35.4
30	(D-21-23)29acc	ADEQ	SE	R	Ig	B	126.5	114.3–126.5	08/28/96	117.3
31	(D-15-20)31ccb <sup>3</sup>	ADEQ	NW	A	BF	BF	155.5	142.6–155.4	10/01/96	125.0
32	(D-18-21)21caa <sup>4</sup>	ADEQ	NE	A	BF	SPC	157.9	146.3–157.9	10/01/96	Flowing
33	(D-19-22)27dad <sup>3</sup>	ADEQ	SE	R	BF	BF	140.2	121.9–140.2	10/02/96	67.1
34	(D-22-18)09dba <sup>3</sup>	ADEQ	SW	F	BF	BF	27.4	21.3–27.4	10/02/96	7.2
35	(D-20-19)12cdd	ADEQ	NW	R	BF	BF	--	--	11/12/96	76.2
36	(D-17-22)24aab	ADEQ	NE	R	Sd	B	--	--	12/16/96	--
37	(D-16-22)15acc <sup>2</sup>	ADEQ	NE	A	Ig	B	23.5	--	12/18/96	11.1
38	(D-17-21)20bbd <sup>3</sup>	ADEQ	NE	R	BF	BF	85.3	67.1–85.3	12/19/96	56.4
39	(D-17-20)11cac <sup>4</sup>	ADEQ	NE	U	BF	SPC	175.3	--	01/22/97	Flowing
40	(D-17-19)17abc <sup>1,2</sup>	ADEQ	--	--	--	--	139.0	--	06/26/96	65.2
41	(D-21-23)29cbb <sup>2</sup>	ADEQ	--	--	--	--	189.0	140.2–189.0	08/09/96	98.7
42	(D-21-18)35dbc <sup>2</sup>	ADEQ	--	--	--	--	67.1	--	08/26/96	2.7
43	(D-20-19)13ada <sup>2</sup>	ADEQ	--	--	--	--	100.6	--	01/24/97	75.6
44	(D-15-20)21dbc <sup>1</sup>	ADEQ	--	--	--	--	36.6	--	01/23/97	22.3
45	(D-23-22)28 <sup>3</sup>	ADEQ	--	--	--	--	35.7	--	11/13/96	8.7

<sup>1</sup>A replicate sample was collected at this well.

<sup>2</sup>A blank sample was collected at this well.

<sup>3</sup>A split sample was collected at this well.

<sup>4</sup>This is an artesian well.

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Water-Resources Investigations Report 99–4056