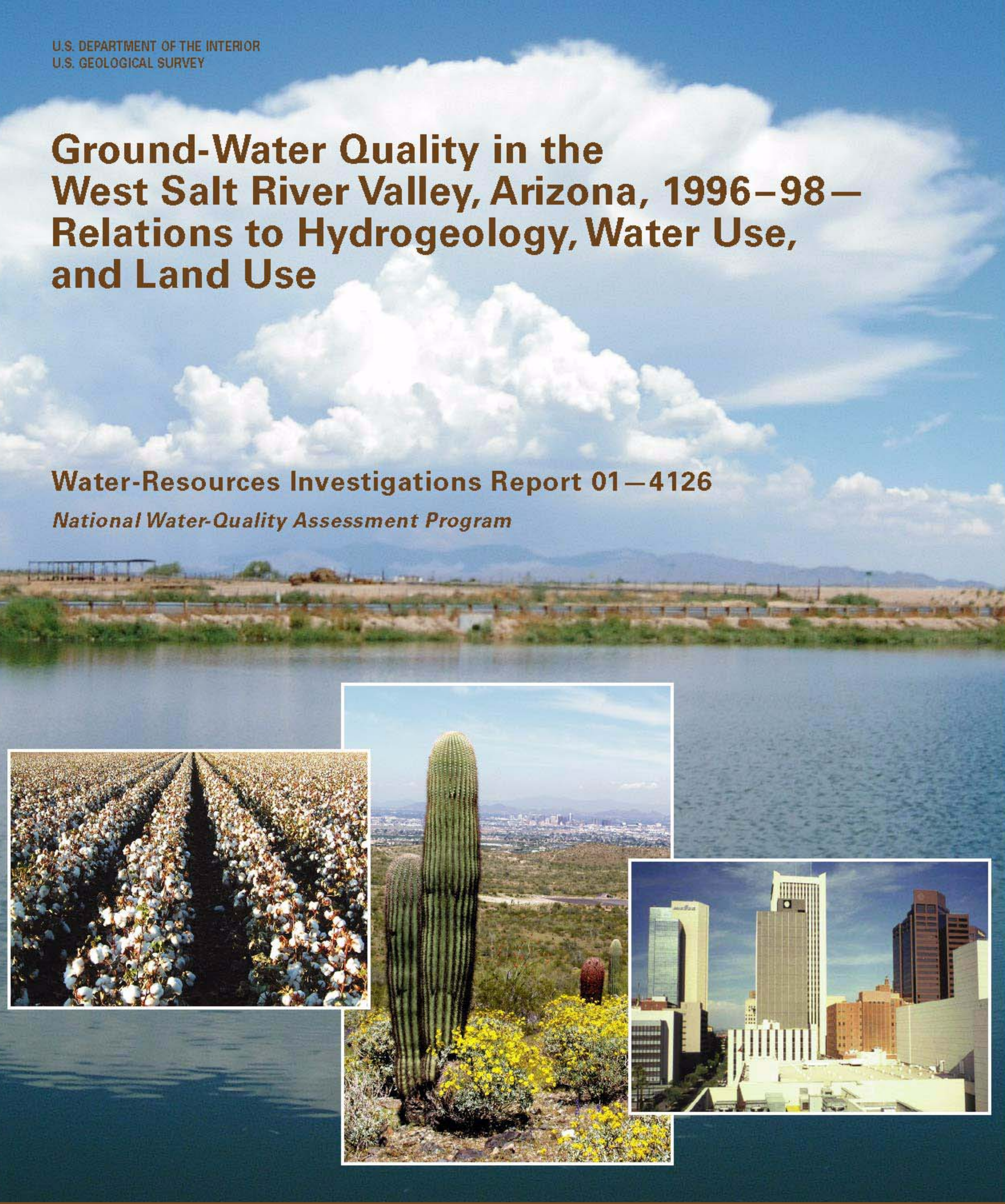
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Ground-Water Quality in the West Salt River Valley, Arizona, 1996–98—Relations to Hydrogeology, Water Use, and Land Use

Water-Resources Investigations Report 01—4126

National Water-Quality Assessment Program



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Ground-Water Quality in the West Salt River Valley, Arizona 1996–98—Relations to Hydrogeology, Water Use, and Land Use

By R.J. Edmonds *and* D.J. Gellenbeck

Water-Resources Investigations Report 01—4126

Prepared in cooperation with
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Tucson, Arizona
2002

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Associate Director for Water

CONTENTS

Page

Abstract 1
Introduction 2
  Purpose and scope 2
  Acknowledgments 2
Description of the study area 2
  Physiography and climate 2
  Geology 4
  Hydrology 6
    Surface water 6
    Ground water 8
  Water use and land use 8
Study design and methods 11
  Subunit-survey design and selection of well locations 11
  Agricultural land-use study design 15
    Selection of well locations 15
    Well construction 17
  Sample collection 18
  Sample analysis 18
  Statistical methods 19
Ground-water quality 20
  Subunit survey 20
    Principal inorganic constituents 20
    Nitrate 23
    Dissolved oxygen 23
    Trace constituents 23
    Pesticides 24
    Volatile organic compounds 24
    Isotopes 29
  Agricultural land-use study 29
    Principal inorganic constituents 31
    Nitrate 33
    Trace constituents 33
    Pesticides 34
    Volatile organic compounds 35
    Isotopes 36
Relation of ground-water quality to hydrogeology, water use, and land use 37
  Classification of wells 37
  Ground-water quality among the well classes 39
    Principal inorganic constituents 39
    Nitrate 42
    Isotopes 42
    Pesticides 46
Summary and conclusions 47
Selected references 49
Quality assurance and quality control 52

FIGURES

Page

1. Map showing location of study area, subunit survey, and agricultural land-use study, West Salt River Valley, Arizona 3
2. Generalized geologic section, West Salt River Valley, Arizona. 5
3. Map showing land-use types and major canals, West Salt River Valley, Arizona 7
4. Graph showing estimated ground-water withdrawals, Salt River Valley, Arizona 9
5. Maps showing urban areas in 1955, 1974–83, and in 1995, West Salt River Valley, Arizona 10
6. Graph showing population of Maricopa County, Arizona, 1940–95 11
7. Map showing wells sampled for agricultural land-use study, West Salt River Valley, Arizona 14
8. Map showing wells sampled and wells selected for subunit survey (10–44) 16
9. Diagram showing general design of a monitoring well in the agricultural land-use study, West Salt River Valley, Arizona 17
10. Photograph showing cleaning of Bennett pump used to sample wells in the agricultural land-use study, West Salt River Valley, Arizona 18
11. Photograph showing measurement of field properties, West Salt River Valley, Arizona. 19
12. Graph showing pesticides in ground water in subunit survey and agricultural land-use study wells, West Salt River Valley, Arizona, 1996–98 25
13. Map showing locations of pesticide detections, subunit survey, West Salt River Valley, Arizona, 1996–97 26
14. Map showing locations of volatile organic compound detections, subunit survey, West Salt River Valley, Arizona, 1996–97 27
15. Graph showing volatile organic compounds in ground water in subunit survey and agricultural land-use study wells, West Salt River Valley, Arizona, 1996–98 28
16. Map showing tritium in ground water from wells in the subunit survey, West Salt River Valley, Arizona, 1996–97 30
17. Graph showing relation between δD and $\delta^{18}O$ in ground water from wells in the subunit survey, West Salt River Valley, Arizona, 1996–97 31
18. Graph showing ratio of deethlatrazine to atrazine in wells, agricultural land-use study, West Salt River Valley, Arizona, August 1997 and February 1998 35
19. Diagram showing construction typical of classified wells, West Salt River Valley, Arizona 37
20. Map showing classification of wells, West Salt River Valley, Arizona 38
21. Graph showing dissolved-solids concentration in ground water by well class, West Salt River, Valley, Arizona 40
22. Graph showing relative composition of ground water by well class, West Salt River Valley, Arizona, 1996–97 41
23. Graph showing nitrate concentration in ground water by well class, West Salt River Valley, Arizona, 1996–97 43
24. Graph showing relation between dD and d18O in ground water by well class, West Salt River Valley, Arizona, 1996–97 44
25. Graph showing relative oxygen-isotope ratios in ground water by well class, West Salt River Valley, Arizona, 1996–97 45
26. Graph showing pesticides in ground water by well class, West Salt River Valley, Arizona, 1996–98 47

TABLES

Page

1. Site identification and classification of wells, West Salt River Valley, Arizona, 1996–98 12
2. Differences that indicate stability in field measurements.. 19
3. Primary and Secondary Maximum Contaminant Levels, human-health advisory limits, and aquifer water-quality standards for selected constituents 21
4. Summary of selected constituents, subunit survey, West Salt River Valley, Arizona, 1996–97 22
5. Summary of selected constituents, agricultural land-use study, West Salt River Valley, Arizona, August 1997 and February 1998 32
6. Median concentrations of selected constituents of the subunit survey and the agricultural land-use study, West Salt River Valley, Arizona, 1996–97 32
7. Median concentrations of selected constituents by well class, West Salt River Valley, Arizona.. 40
8. Detection of pesticides for different well classes, West Salt River Valley, Arizona, 1996–98 46
9. Number and type of quality-control samples collected, West Salt River Valley, Arizona 53
10. Water-quality data for field-blank samples from existing wells, West Salt River Valley, Arizona.. 53
11. Water-quality data for replicate samples from existing wells, West Salt River Valley, Arizona 54
12. Water-quality data for field-blank and equipment-blank samples, agricultural land-use study, West Salt River Valley, Arizona 55
13. Water-quality data for replicate samples, agricultural land-use study, West Salt River Valley, Arizona.. 55
14. Summary of replicate analyses for existing wells, West Salt River Valley, Arizona 57
15. Summary of replicate analyses for agricultural land-use study, West Salt River Valley, Arizona.. 58

CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
gallon (gal)	3.785	liter
acre	4,407	square meter
acre	0.4047	hectare
square mile (mi^2)	259.0	hectare
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
pound (lb)	0.4536	kilogram
picocurie per liter (pCi/L)	0.037	becquerel per liter

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

$$°C = (°F-32)/1.8$$

ABBREVIATED WATER-QUALITY UNITS

Chemical concentrations 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 mass (milligrams) 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). Radioactivity is expressed in picocuries per liter (pCi/L), which it the amount of radio active decay producing 2.2 disintegrations per minute in a unit volume (liter) of water or sediment. 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 turbidity meter 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.

VERTICAL DATUM

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

WELL-NUMBERING SYSTEM, ARIZONA

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. These quadrants are designated counterclockwise by the capital letters, A,B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township; the second, the range; and the third, the section in which the well is situated. The lowercase letters *a*, *b*, *c*, and *d* after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract; the second, the 40-acre tract; and the third, the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (A-01-01)21bcd designated the well as being in the SE1/4SW1/4NW1/4, sec. 21 T. 1 N., R. 2E. Where more than 1 well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Ground-Water Quality in the West Salt River Valley, Arizona, 1996–98—Relations to Hydrogeology, Water Use, and Land Use

By R.J. Edmonds *and* D.J. Gellenbeck

Abstract

The U.S. Geological Survey collected and analyzed ground-water samples in the West Salt River Valley from 64 existing wells selected by a stratified-random procedure. Samples from an areally distributed group of 35 of these wells were used to characterize overall ground-water quality in the basin-fill aquifer. Analytes included the principal inorganic constituents, trace constituents, pesticides, and volatile organic compounds. Additional analytes were tritium, radon, and stable isotopes of hydrogen and oxygen. Analyses of replicate samples and blank samples provided evidence that the analyses of the ground-water samples were adequate for interpretation. The median concentration of dissolved solids in samples from the 35 wells was 560 milligrams per liter, which exceeded the U.S. Environmental Protection Agency Secondary Maximum Contaminant Level for drinking water. Eleven of the 35 samples had a nitrate concentration (as nitrogen) that exceeded the U.S. Environmental Protection Agency Maximum Contaminant Level for drinking water of 10 milligrams per liter. Pesticides were detected in eight samples; concentrations were below the Maximum Contaminant Levels. Deethylatrazine was most commonly detected. The pesticides were detected in samples from wells in agricultural or urban areas that have been irrigated. Concentrations of all trace constituents, except arsenic, were less than the Maximum Contaminant Levels. The concentration of arsenic exceeded the Maximum Contaminant Level of 50 micrograms per liter in two samples.

Nine monitoring wells were constructed in an area near Buckeye to assess the effects of agricultural land use on shallow ground water. The median concentration of dissolved solids was 3,340 milligrams per liter in samples collected from these wells in August 1997. The nitrate concentration (as nitrogen) exceeded the Maximum Contaminant Level (10 milligrams per liter) in samples from eight of the nine monitoring wells in August 1997 and again in February 1998. Analyses of all samples collected from the monitoring wells indicated low concentrations of pesticides and volatile organic compounds. The most frequently detected pesticides were deethylatrazine and atrazine. Trichloromethane (chloroform) and tetrachloroethene (PCE) were the most frequently detected volatile organic compounds in the monitoring wells. Two compounds [dieldrin and 1,1-dichloro-2,2-bis(p-dichlorodiphenyl)ethylene (DDE)], decomposition products of two banned pesticides, aldrin and dichlorodiphenylethylene (DDT), were detected at low concentrations in samples analyzed for the agricultural land-use study. In the West Salt River Valley, a high concentration of the heavier oxygen isotope—oxygen-18—in ground water generally indicates effects of evaporation on recharge water from irrigation.

Wells in undeveloped areas and wells that have openings beneath a confining bed generally yield ground water that is free of the effects of irrigation seepage. Samples from these wells did not contain detectable concentrations of pesticides. The median concentrations of nitrate (as nitrogen) and dissolved solids in samples from wells in undeveloped areas were 1.7 milligrams per liter and 257 milligrams per liter, respectively. The median concentrations of nitrate (as nitrogen) and dissolved solids in samples from wells that yield water from below confining beds were 2.0 and 747 milligrams per liter, respectively.

INTRODUCTION

The West Salt River Valley (**fig. 1**), which includes a major part of the city of Phoenix, is undergoing rapid population growth. As a consequence, land use is shifting from irrigated agricultural to urban development. Ground-water use is higher in the West Salt River Valley than in any of the other basins in southern Arizona. Continuing large changes in water and land use are expected to affect ground-water quality.

The goals of the National Water Quality Assessment program (NAWQA) of the U.S. Geological Survey (USGS) are to (1) describe the current status of and trends in water quality of large, representative portions of the Nation’s water resources and (2) provide a scientific understanding of natural and anthropogenic factors that affect the quality of these resources (Hirsch and others, 1988; Gilliom and others, 1995). In order to accomplish these goals, a nationally consistent database is being created to integrate water-quality information collected at local and regional scales. Sixty study units were selected nationwide to represent most river basins and aquifer systems and to include 60 to 70 percent of the Nation’s usable water supply. One of these study units is the Central Arizona Basins (CAZB), which includes the West Salt River Valley (fig. 1). In 1994, the USGS began ground-water, surface-water, and biological studies in the CAZB study area. The West Salt River Valley is one of three basins in the CAZB that were chosen for a detailed study of ground-water quality and the effects of land use on the quality of shallow ground water. The Upper Santa Cruz Basin and the Sierra Vista Subbasin of the San Pedro basin also were studied.

Purpose and Scope

This report describes ground-water quality in the West Salt River Valley and evaluates the effects of hydrogeologic factors, water use, and land use on ground-water quality by using data collected as a part of the NAWQA program during 1996–98. Ground-water samples were collected from 64 existing wells during 1996 and 1997. Thirty-five of these wells were selected for a subunit survey to provide areally distributed coverage of the study area. Nine wells were constructed during the summer of 1997 to monitor the quality of shallow ground water near Buckeye for an agricultural land-use study. The monitoring wells were sampled in August 1997 and in February 1998 to detect seasonal changes in water quality associated with agricultural-land use.

Acknowledgments

Land owners and home owners in the West Salt River Valley allowed the USGS to sample their wells and drill monitoring wells on their property. The cities of Buckeye, Goodyear, Peoria, and Phoenix allowed the USGS to sample several municipal wells. The Buckeye Water Conservation and Drainage District and the Roosevelt Irrigation District (RID) allowed sampling of multiple wells in each district.

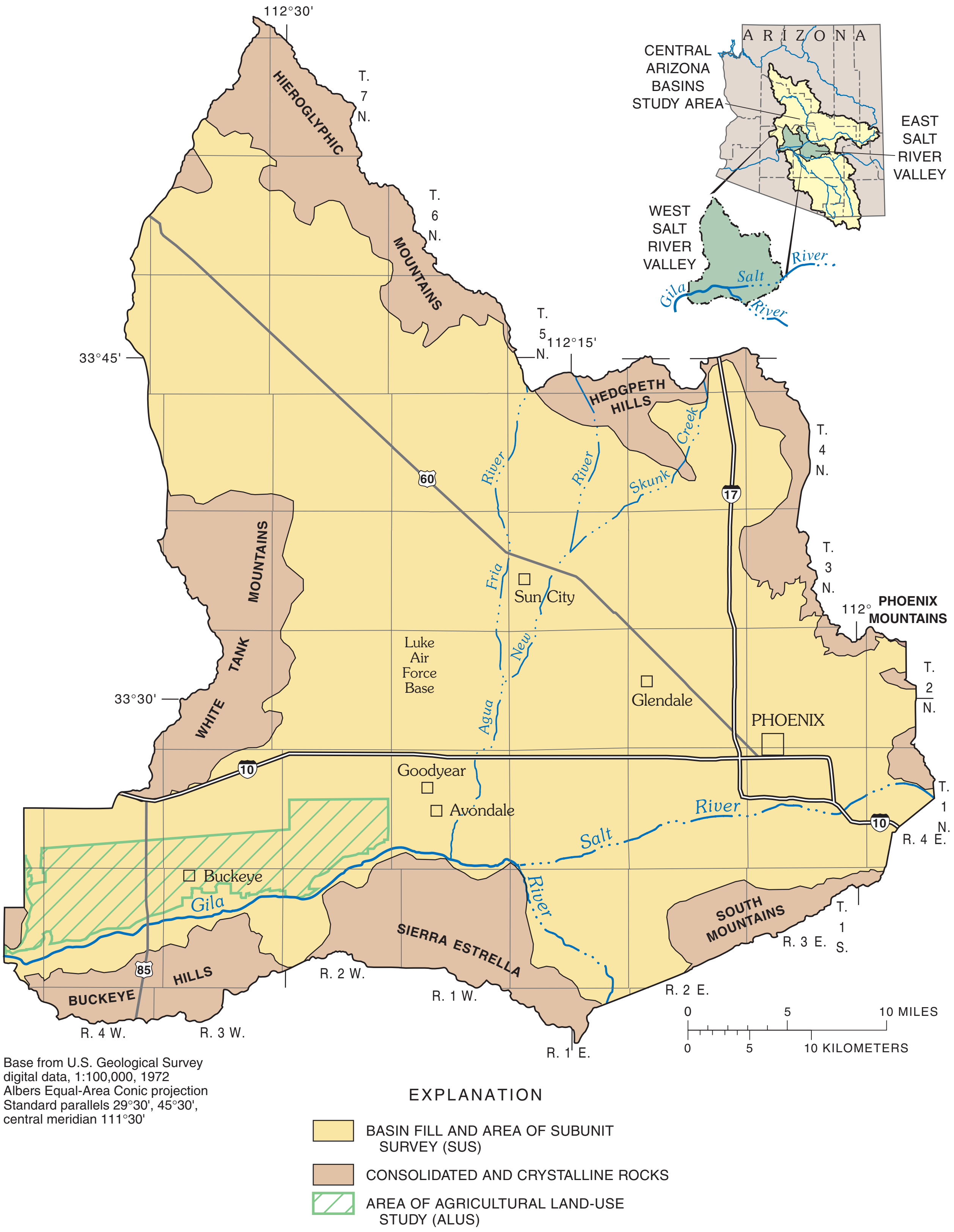
Henry Sanger, Julie Rees, David Peyton, and Alissa Coes (USGS) collected many of the samples and obtained and set up equipment. Dawn McDoniel, Todd Ingersol, Karen Beaulieu, Ray Davis, Christy O’Day, Melissa Butler, and Ann Tillery (USGS) processed pesticide samples and assisted with sample collection. Cory Angeroth, Alissa Coes, and David Peyton (USGS) developed the monitoring wells constructed for the land-use study.

DESCRIPTION OF THE STUDY AREA

The West Salt River Valley is a sediment-filled basin of about 1,330 mi^2 in central Arizona (fig. 1). This area is equivalent to the West Salt River Valley Subbasin of the Phoenix Active Management Area (Arizona Department of Water Resources, 1994). The Salt River Valley comprises the West Salt River Valley and the East Salt River Valley (fig. 1). Most of the city of Phoenix is within the West Salt River Valley. Land use is shifting from agricultural to urban in the entire Salt River Valley as the population increases rapidly in Phoenix and its suburbs.

Physiography and Climate

The West Salt River Valley is an oval structural basin in the Basin and Range Lowlands hydrologic province (Arizona State Land Department, 1963). The valley is drained by the Gila River and its tributaries, which include the Salt and Agua Fria Rivers (fig. 1). The valley is bordered by desert mountain ranges that include the White Tank Mountains on the west; the Hieroglyphic Mountains and the Hedgpeth Hills on the north; the Phoenix Mountains and Camelback Mountain on the east; and the South Mountains, the Sierra Estrella, and the Buckeye Hills on the south. Altitude ranges from about 800 ft above sea level along the Gila River west of Buckeye to about 4,500 ft in the Sierra Estrella.



Base from U.S. Geological Survey digital data, 1:100,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30', 45°30', central meridian 111°30'

EXPLANATION

🟨	BASIN FILL AND AREA OF SUBUNIT SURVEY (SUS)
🟫	CONSOLIDATED AND CRYSTALLINE ROCKS
▨	AREA OF AGRICULTURAL LAND-USE STUDY (ALUS)

Figure 1. Location of study area, subunit survey, and agricultural land-use study, West Salt River Valley, Arizona.

The climate of the valley is arid and is characterized by hot summers, mild winters, and large diurnal temperature variations. Mean monthly max-imum temperature at Buckeye was 68.1°F in January and 109.2°F in July from 1961 through 1990. Mean monthly minimum temperature at Buckeye was 36.4°F in January and 76.0°F in July from 1961 through 1990 (Owenby and Ezell, 1992). Mean annual precipitation was 7.3 in. at Buckeye and 8.5 in. at Phoenix Sky Harbor International Airport for the same period (Owenby and Ezell, 1992). Precipitation varies greatly from year to year, and wet years may have as much as four times the precipitation of dry years (Cordy and others, 1998). The climate is characterized by two rainy periods. Convective storms occur during July and August and are sometimes intense. Frontal storms of lesser intensity occur from December through mid-March (Sellers and Hill, 1974). Evaporation rates are high, and free-water surface evaporation exceeds 5 ft/yr (Farnsworth and others, 1982).

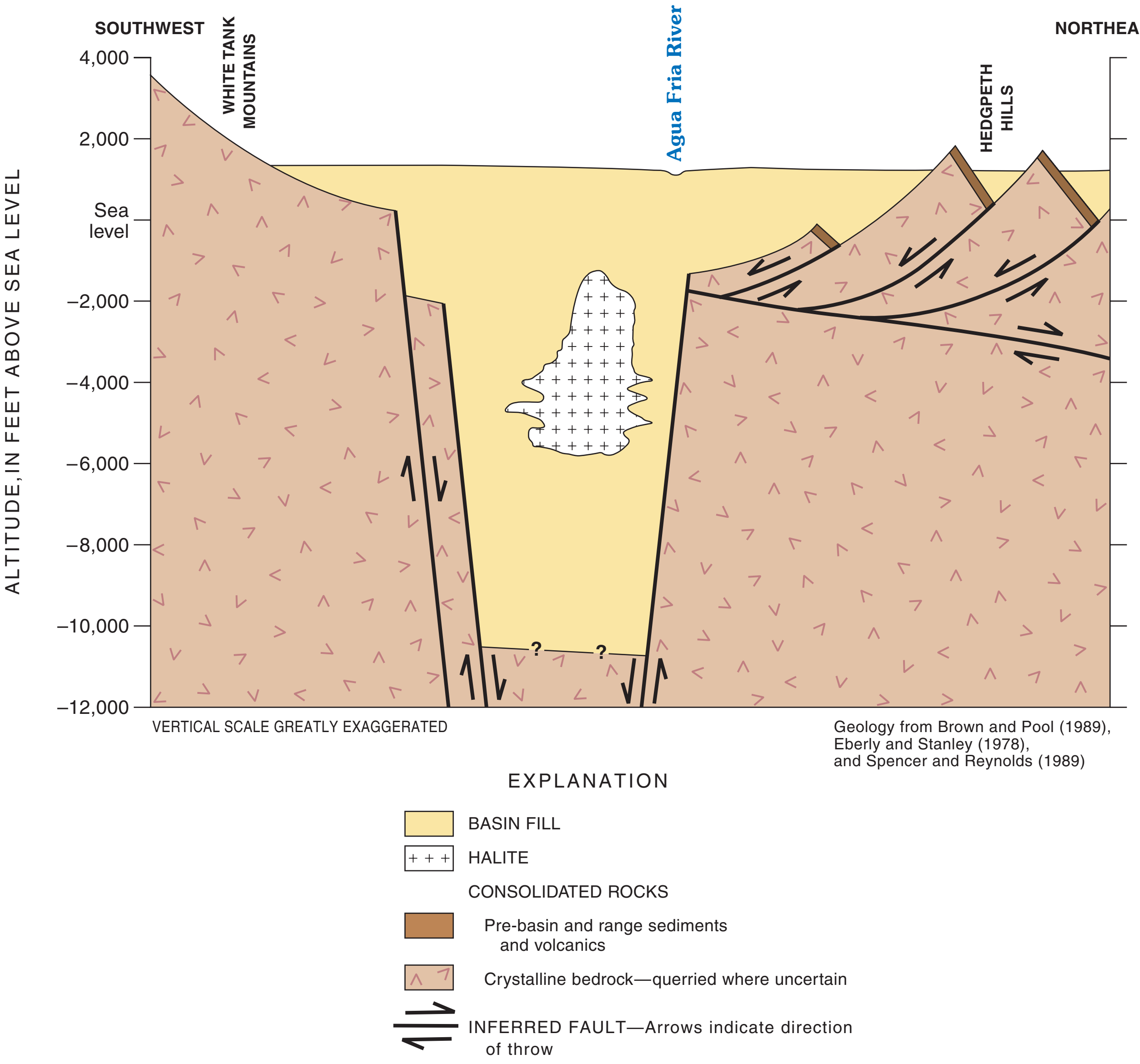
Geology

The West Salt River Valley is one of a series of structural basins along a northwestward-southeastward trend characterized by exposed lower-plate crystalline rocks (Spencer and Reynolds, 1989) and deep basins containing 8,000 to 12,000 ft of basin-fill sediments (Anderson and others, 1992). The basins were formed by high-angle faulting of the Basin and Range disturbance [15 to 5 million years ago (m.y. ago); Menges and Pearthree, 1989] superimposed on the effects of crustal extension and the low-angle detachment faults of the mid-Tertiary disturbance (37 to 15 m.y. ago; Dickinson, 1989; fig. 2, this report). Detachment faulting and later block faulting disrupted pre-existing drainage patterns. Continued subsidence formed closed basins with interior drainage that slowly filled with locally derived sediments and evaporite deposits. When the basins filled with sediment, streams began to flow through the lowest divides into adjacent basins. A slow continuation of this process has resulted in the integrated drainage system of the Gila River and its tributaries (Damon and others, 1984).

The valley is divided into northeastern and southwestern parts by a major linear subsurface structure that is generally along U.S. Route 60 (Brown and Pool, 1989). The northeastern part is dominated by a series of structural blocks tilted to the northeast and trending northwest. Each block is composed of Tertiary volcanic rocks overlying Precambrian crystalline rocks. The thickness of basin fill in the northeastern part generally is less than 2,000 ft. The thickness of basin fill in the southwestern part may exceed 10,000 ft.

The crystalline bedrock forms an impermeable boundary at the basin margin and beneath the basin fill. In the study area, the bedrock is composed principally of a variety of granitic and metamorphic rocks of Precambrian to middle Tertiary age (Brown and Pool, 1989; Reynolds, 1985). Sedimentary and volcanic rocks older than middle Tertiary age are exposed in the Hieroglyphic Mountains, the Hedgpeth Hills, Camelback Mountain, and the Phoenix Mountains (Reynolds, 1988) in the northeastern part of the study area. The principal pre-Basin and Range sedimentary unit is a well-cemented, red conglomerate with clast sizes ranging from clay to boulders that are 15 ft in diameter. This unit may underlie the basin fill in many places in the southeastern part of the basin (Brown and Pool, 1989) and crops out on Camelback Mountain at the eastern margin of the study area (G.E. Cordy, hydrologist, USGS, oral commun., 1999). The unit is not exposed along the mountain fronts in the southwestern part of the basin. In this report, the red unit is considered to be a part of the bedrock of the mountains where it is exposed above the water table and is included with the basin-fill sediments at depth where it is saturated.

The basin fill is composed of alluvial sediments deposited in the structural basin since the mid-Tertiary disturbance particularly during and after the Basin and Range faulting (Brown and Pool, 1989). The basin fill consists of beds of clay, silt, sand, and gravel typical of a continental environment. Beds usually are lenticular and cannot be traced laterally for long distances either in outcrops or in the subsurface. Sediments penetrated in two wells drilled only a few hundred feet apart are quite different in many cases. Sediments tend to be coarse grained near the mountain fronts and fine grained toward the center of the basin. The basin-fill sediments also tend to be coarse grained at the base of the unit where it overlies the crystalline bedrock. Evaporites including anhydrite, gypsum, and especially halite were deposited near the center of the southwestern part of the basin in the lower part of the basin fill (Brown and Pool, 1989). The Luke salt body (Eaton and others, 1972) lies in the center of the southwestern part.



Geology from Brown and Pool (1989), Eberly and Stanley (1978), and Spencer and Reynolds (1989)

Figure 2. Generalized geologic section, West Salt River Valley, Arizona.

The uppermost 400 to 500 ft of basin fill was deposited during and after the transition to through-flowing drainage and typically is coarser than sediments at greater depths. The upper part of the basin fill contains more sand, gravel, and fine-grained material derived from outside the basin; but it also contains extensive beds of silt and clay across the southern part of the study area. Brown and Pool (1989) reported that the upper part of the basin fill (identified as the “middle unit”) in an area west of Goodyear contained more than 80-percent silt and clay. The upper part of the basin fill is coarser grained in the northern part of the study area than in the southern part. Beds of silt and clay are not as widespread in the upper part of the basin fill north of Interstate Highway 10 (I-10; **fig. 1**) as they are south of I-10.

Stream alluvium overlies the basin fill along and beneath the present river channels, principally the Agua Fria River, the Salt River, and the Gila River. The stream alluvium was deposited after the filling of the basins with sediment and consists of flood-plain and channel-fill deposits. The stream alluvium ranges from clay and silt in the flood-plain deposits to sand and gravel in the channel-fill deposits. Gravel of cobble-sized clasts is prominent particularly along the channel of the Salt River. The thickness of stream alluvium ranges from 0 where the Salt River flows over bedrock as it enters the study area to as much as 400 ft near the confluence of the Salt and Gila Rivers (Brown and Pool, 1989).

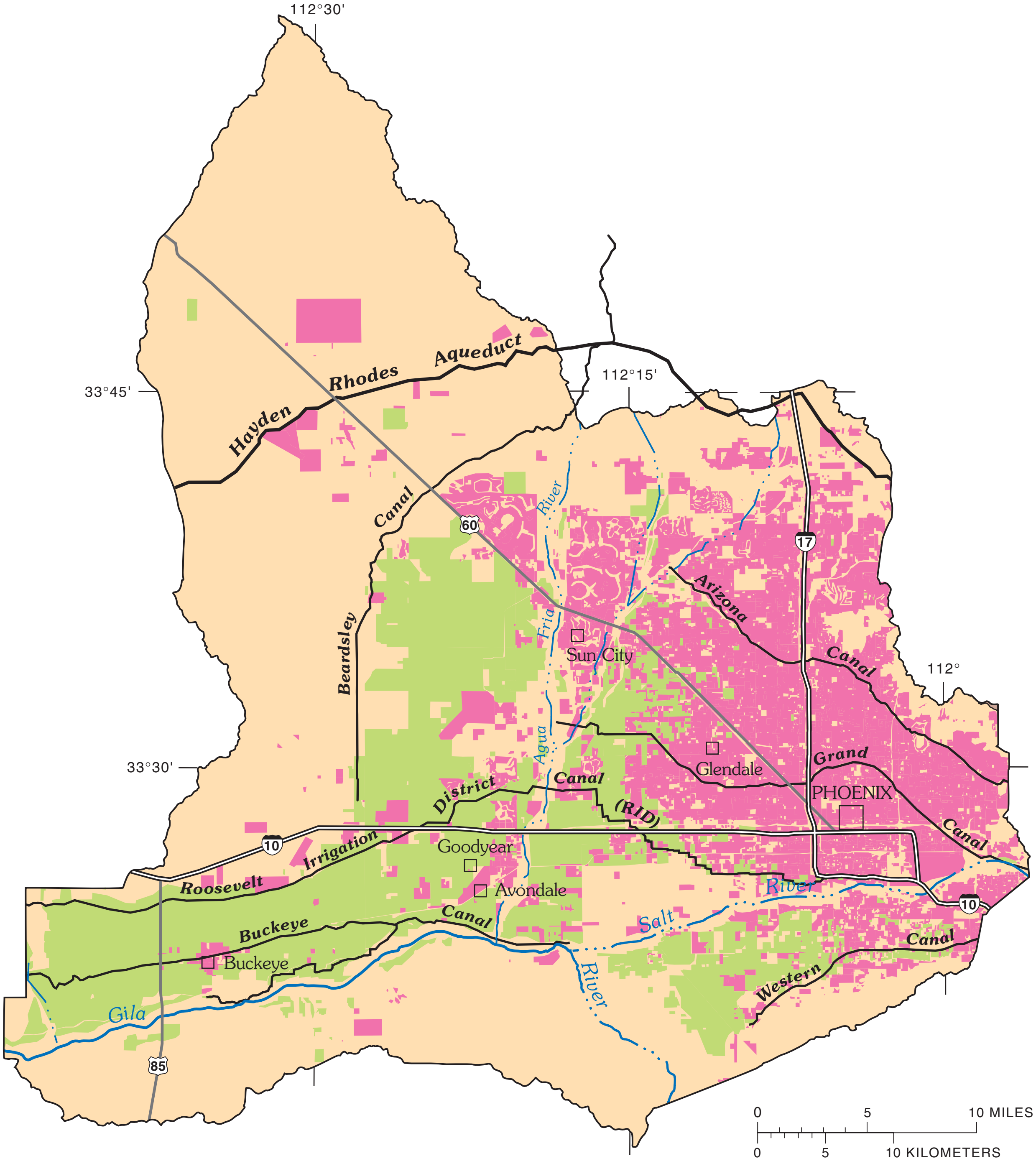
Hydrology

The West Salt River Valley receives an average of less than 10 in./yr of precipitation. Sufficient water to support irrigated agriculture and a growing urban population has been obtained by building reservoirs on the Salt, Verde, and Agua Fria Rivers and by pumping ground water from the alluvial sediments in the basin. The water used does not depend on local precipitation, but comes from snowmelt in the mountains of eastern and central Arizona and from ground water recharged to the aquifer in prehistoric times. Since 1985, additional water has been imported from the Colorado River and either used directly or stored in the basin-fill aquifer. The hydrologic system is managed carefully, and the use of surface water and ground water is regulated strictly.

Surface Water

The streams that drain the mountains bordering the study area are ephemeral. Channels of the mountain streams typically are dry except during periods of precipitation. Flows in the local rivers—the Agua Fria, Salt, and Gila—are almost completely regulated. In years of normal precipitation, all flow is captured and stored behind dams that are upstream from the study area. Downstream from the dams, only occasional flow in local tributaries reaches the riverbeds except at times of high flows during extremely wet years. Flow in the Salt River is stored behind Roosevelt Dam and three other dams downstream. Flow in the Verde River, the largest tributary of the Salt River, is stored behind Horseshoe and Bartlett Dams. The flow of the Gila River is stored in the San Carlos Reservoir behind Coolidge Dam. Flow in the Agua Fria River is stored in Lake Pleasant behind New Waddell Dam.

Water from the reservoirs is distributed in the study area through a system of canals (**fig. 3**). Originally, the canals were designed to provide only surface water for irrigated agriculture, but as the area developed, ground water augmented the supply. Since the early 1960s, treated effluent from metropolitan Phoenix has been delivered through some canals in the study area. As the area has undergone a transition from agricultural to urban land use, the canals have become integrated into urban water-supply systems. Water from the Salt River is diverted upstream from Phoenix and transported into the study area through the Arizona, Grand, and Western Canals that are operated by the Salt River Project (SRP). The RID Canal receives treated effluent from the 23rd Avenue wastewater-treatment plant (WWTP) operated by the city of Phoenix and provides irrigation water for farmland west of the Agua Fria River in the southwestern part of the study area. The Buckeye Canal diverts treated effluent from the 91st Avenue WWTP operated by the city of Phoenix and delivers it to farmland between the RID Canal and the Gila River in the southwestern part of the study area. The lands served by the Buckeye Canal have been irrigated for more than 100 years. Lands served by the RID Canal have been irrigated since the 1920s when the canal was constructed. (Montgomery and Associates, 1988). The Beardsley Canal, operated by the Maricopa Water District, transports water from New Waddell Dam to the west-central part of the study area.



Base from U.S. Geological Survey
digital data, 1:100,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30', 45°30',
central meridian 111°30'

EXPLANATION

LAND USE AND LAND COVER

🟩 Agriculture

🟥 Urban

▨ Undeveloped

Figure 3. Land-use types and major canals, West Salt River Valley, Arizona. Digital data for land-use types from Maricopa Association of Governments (unpublished data, 1999). Digital data for canals from Bureau of Reclamation (unpublished data, 1999).

The water supply from rivers within the basin is augmented by the Central Arizona Project (CAP) which brings water from the Colorado River to central and southern Arizona. Some of this water is available for use in the study area. The cities of Phoenix and Glendale treat CAP water and distribute it through their municipal systems. CAP water also can be delivered to the study area through SRP canals and the Beardsley Canal. CAP water is stored in Lake Pleasant with water from the Agua Fria River.

Ground Water

The sediments of the basin fill and stream alluvium form the most productive and important aquifer in the study area and are referred to as the basin-fill aquifer in this report. Although the basin-fill aquifer in the study area may be more than 11,000 ft thick, most ground water is pumped from the top 1,000 ft (Anderson and others, 1992). Ground water occurs under unconfined and semiconfined conditions in this aquifer. The semiconfined conditions occur locally where lenticular clay and silt beds form a confining layer. Properly constructed wells with perforations open to the basin-fill aquifer can yield as much as several thousand gallons per minute. Where saturated, the upper part of the basin-fill aquifer yields more water than the lower part because the upper part generally is more coarse grained and less cemented than the lower part. Brown and Pool (1989) estimated that the hydraulic conductivity of the upper part ranges from 180 to 1,700 ft/d, and the hydraulic conductivity of the lower part ranges from 3 to 60 ft/d.

Before agricultural development began in the late 1800s, the surface of the water table sloped to the south and southwest, which indicates that ground water moved in that direction (Corkhill and others, 1993). Discharge was primarily to the Gila River at the southwestern edge of the study area and through transpiration by the phreatophytes growing on the flood plains. Ground water also left the valley by underflow to the southwest through the basin-fill aquifer between the Buckeye Hills and the White Tank Mountains (fig. 1). The basin-fill aquifer receives recharge by infiltration of runoff from the mountains along the edge of the basin and by infiltration from the major streams flowing through the basin. Little, if any, recharge results from precipitation falling directly on the valley floor (Anderson and others, 1992).

Development of agricultural and urban lands in the valley provided new sources of recharge and discharge to the basin-fill aquifer. A major new source of ground-water discharge began with the widespread use of high-capacity turbine pumps for irrigation in the 1920s. The application of irrigation water in excess of plant needs provides a major new source of ground-water recharge in some areas that had not been receiving direct recharge previously. Leakage from canals and laterals also provides ground-water recharge on the part of the valley floor that is away from the major streams. Water also is recharged deliberately through the thousands of dry wells installed in urban areas for collecting runoff. Limited natural, areally distributed recharge and the replacement of recharge from natural streamflow with recharge from a managed system of canals, irrigation, and urban distribution has resulted in a ground-water system significantly different from systems in most parts of the United States.

The direction of ground-water flow has changed in response to large-scale ground-water pumping. Before extensive pumping began, ground-water flow was primarily to the southwest. Major cones of depression have developed where ground-water levels have declined more than 300 ft in Deer Valley northwest of Glendale and between Luke Air Force Base and the White Tank Mountains. By the 1960s, ground-water flow in the center of the West Salt River Valley had been redirected primarily toward these cones of depression (Anderson, 1968).

In response to the continuing decline of ground-water levels, the Groundwater Management Code was passed by the Arizona Legislature in 1980 to eliminate severe ground-water overdraft and to provide a means for allocating Arizona’s limited ground-water resources. As a result of the Groundwater Management Code, the Arizona Department of Water Resources (ADWR) and the Phoenix Active Management Area (AMA) were established (Arizona Department of Water Resources, 1998). A principal goal of the Phoenix AMA is to reduce ground-water pumping by 2025 to a quantity that is equal to or less than the quantity being recharged.

Water Use and Land Use

Two major trends in water use and land use have affected ground-water quality in the West Salt River Valley. The first occurred from the 1870s until the

1920s when irrigated agriculture replaced native vegetation. The second is the rapid population increase in metropolitan Phoenix and the accompanying conversion of agricultural and desert land to urban land (Cordy and others, 2001). The quality of ground water may reflect prior land use because of the slow movement of ground water and rapid changes in land use. In addition, the quality of ground water is affected by the type of land use only where enough water is applied to the land to recharge the aquifer.

The construction of dams on the Salt and Verde Rivers hastened the growth of irrigated agriculture by providing a dependable year-round supply of surface water. The principal crops are citrus, cotton, alfalfa, and grains. Irrigation seepage and canal leakage recharged ground water over broad areas away from river channels. The increased use of surface water, however, led to rising ground-water levels and waterlogging by the 1920s (Smith and others, 1982). The Buckeye Water Conservation and Drainage District constructed ditches in the 1920s to help control waterlogging (Errol L. Montgomery and Associates, 1986). Increased pumping of ground water (fig. 4) led to water-level declines in other parts of the study area, particularly in the years after World War II.

Irrigation seepage generally has been recognized as a major factor in the increase of the concentrations of dissolved solids and nitrate in ground water in the West Salt River Valley (Schmidt, 1983). More than half of the water applied during irrigation is used by plants or returned to the atmosphere by evaporation. Almost all the dissolved solids in the applied irrigation water remain in the water unused by the crops thereby increasing the dissolved-solids concentration in the remaining water (Bouwer, 1997). This water seeps into the soil during irrigation and, in many cases, eventually moves down to the water table. The nitrate contained in fertilizers is dissolved in the irrigation water and the portion of the nitrate unused by the plants may be carried down in the irrigation seepage. Long before the introduction of chemical fertilizers (Lee, 1905; Smith and other, 1982), ground-water analyses from the West Salt River Valley indicated that nitrate concentrations exceeded the present-day Maximum Contaminant Level (MCL) of 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1996). Smith and others, (1982) suggested that, in this case, naturally occurring nitrate had been flushed out of the soil by the first application of irrigation water. In some cases, pesticides applied to the crops also are carried down to the water table with the irrigation seepage.

Rapid population growth of metropolitan Phoenix has resulted in continuous conversion of agricultural land to urban land, particularly in the eastern part of the study area (**fig. 5**, this report; Knowles-Yanez and others, 1999). By 1995, about 252 mi^2 of the study area remained in agriculture and about 285 mi^2 was in urban-land use, which is 19.0 percent and 21.5 percent of the study area, respectively. The population in Maricopa County has increased continually since 1945 (**fig. 6**).

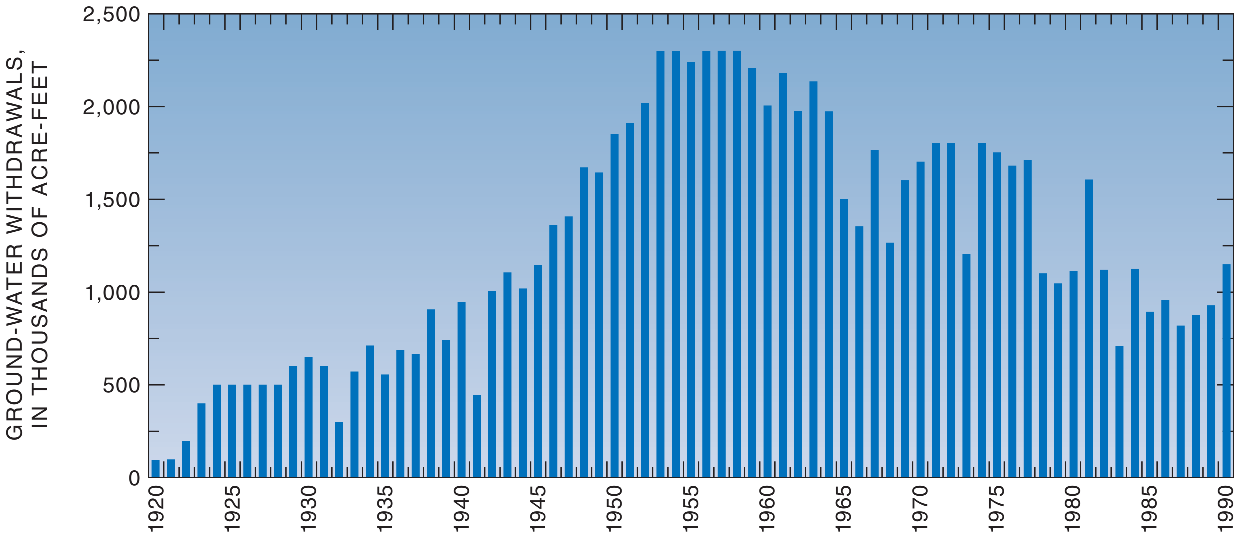


Figure 4. Estimated ground-water withdrawals, Salt River Valley, Arizona. Data from Anning and Duet (1994).

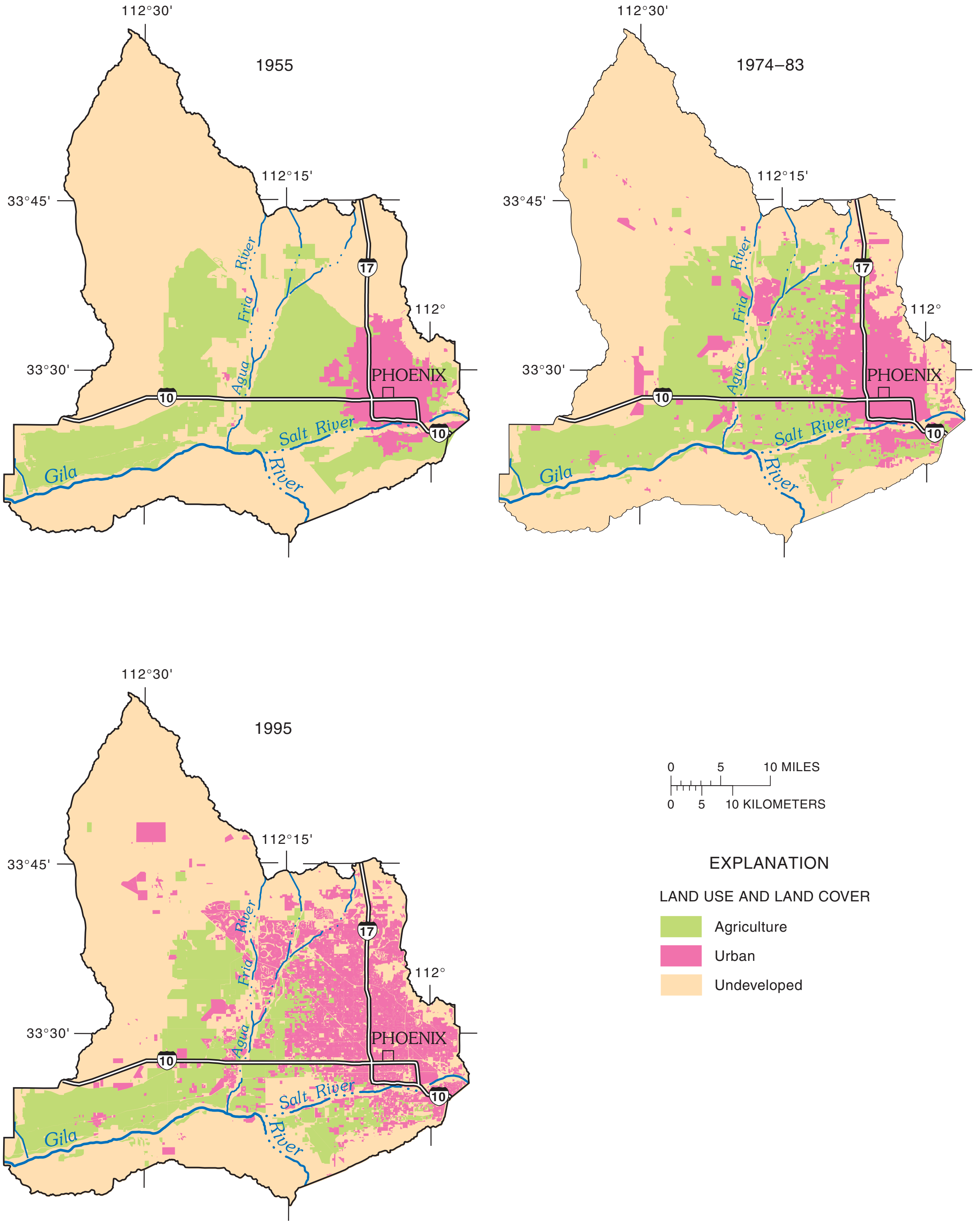


Figure 5. Urban areas in 1955, 1974–83, and in 1995, West Salt River Valley, Arizona. Digital data for 1955 from Knowles-Yánez and others (1999). Digital data fro 1974–83 from Anderson and others (1976). Digital data for 1955 from Maricopa Association of Governments (unpublished data, 1999).

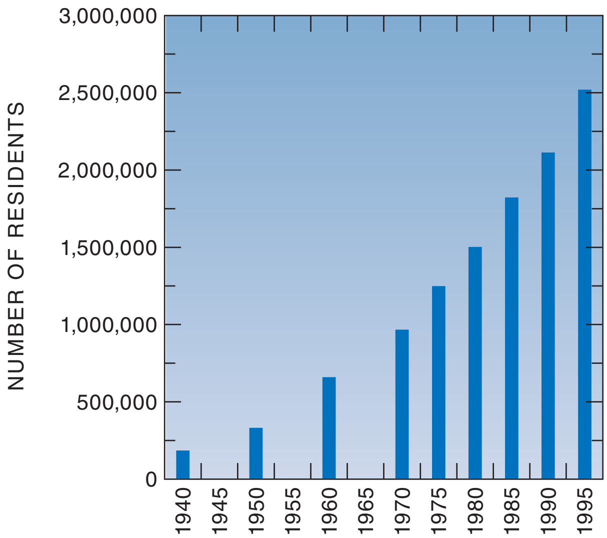


Figure 6. Population of Maricopa County, Arizona, 1940–95.

In the study area, the population was estimated to be about 1,435,000 in 1995 (Hitt, 1994; Arizona Department of Economic Security, 2000). As the urbanization of agricultural land progressed, water used for agriculture has been gradually redirected to urban use. A different group of potential contaminants, volatile organic compounds (VOCs), has been introduced to the water supply by urban development. These contaminants can reach ground water when sufficient water is applied to the land surface. The volume of effluent from WWTPs also has increased as cities have grown, and reclaimed effluent has become a source of irrigation water in the study area.

STUDY DESIGN AND METHODS

Ground-water studies in the West Salt River Valley were designed initially in 1996 to determine (1) the current (1996) ground-water quality in the West Salt River Valley, and (2) the effects of land use on ground-water quality by sampling existing wells in agricultural, urban, and undeveloped areas. The results of the sampling completed in 1996 in agricultural and undeveloped areas indicated that about half of the samples were from ground water that received recharge prior to 1953—therefore, the land use at the time of sampling may not have been the same as the land use at the time of the ground-water recharge.

From these results, it was determined that the second objective of the initial design could not be achieved by sampling existing wells. To account for this, the studies were reconfigured before sampling in 1997 into a subunit survey (SUS) and an agricultural land-use study (ALUS). The SUS included 35 wells and was designed to provide complete geographic coverage of the basin-fill aquifer in the West Salt River Valley. Analyses of samples from 11 of the existing wells sampled in 1996 were combined with analyses from 24 existing wells sampled in 1997 to characterize ground water in the SUS (table 1). A total of 64 existing wells, including 5 wells sampled to characterize deep ground-water resources beneath an agricultural area, were sampled during 1996 and 1997. The ALUS was designed to study the effects of agricultural land use on the quality of ground water by drilling and constructing nine monitoring wells in an area with shallow ground water (fig. 7).

Subunit-Survey Design and Selection of Well Locations

SUSs are designed by the NAWQA Program to provide a broad assessment of the water-quality conditions in those areas where ground water is an important resource (Gilliom and others, 1995). The SUS for the West Salt River Valley consists of a set of 35 areally distributed wells; 24 wells sampled in 1997 combined with 6 wells in agricultural areas and 5 wells in undeveloped areas sampled in 1996. The set of SUS wells includes irrigation wells, domestic wells, municipal wells, and a dewatering well. The wells are of various depths and perforated intervals.

Wells were selected for sampling using a stratified-random design so that individual wells could be selected randomly and still provide complete and uniform coverage of the area. To select wells to be sampled in 1997, agricultural and urban areas in the West Salt River Valley (fig. 3) were divided into 30 equal-area cells using a geographic information system (GIS) program (Scott, 1990). Of the 30 cells, 6 cells in the western part of the study area contained multiple wells that had been sampled in 1996 and did not need to be resampled in 1997. Wells were selected randomly for sampling in each of the 24 cells that did not include wells sampled in 1996.

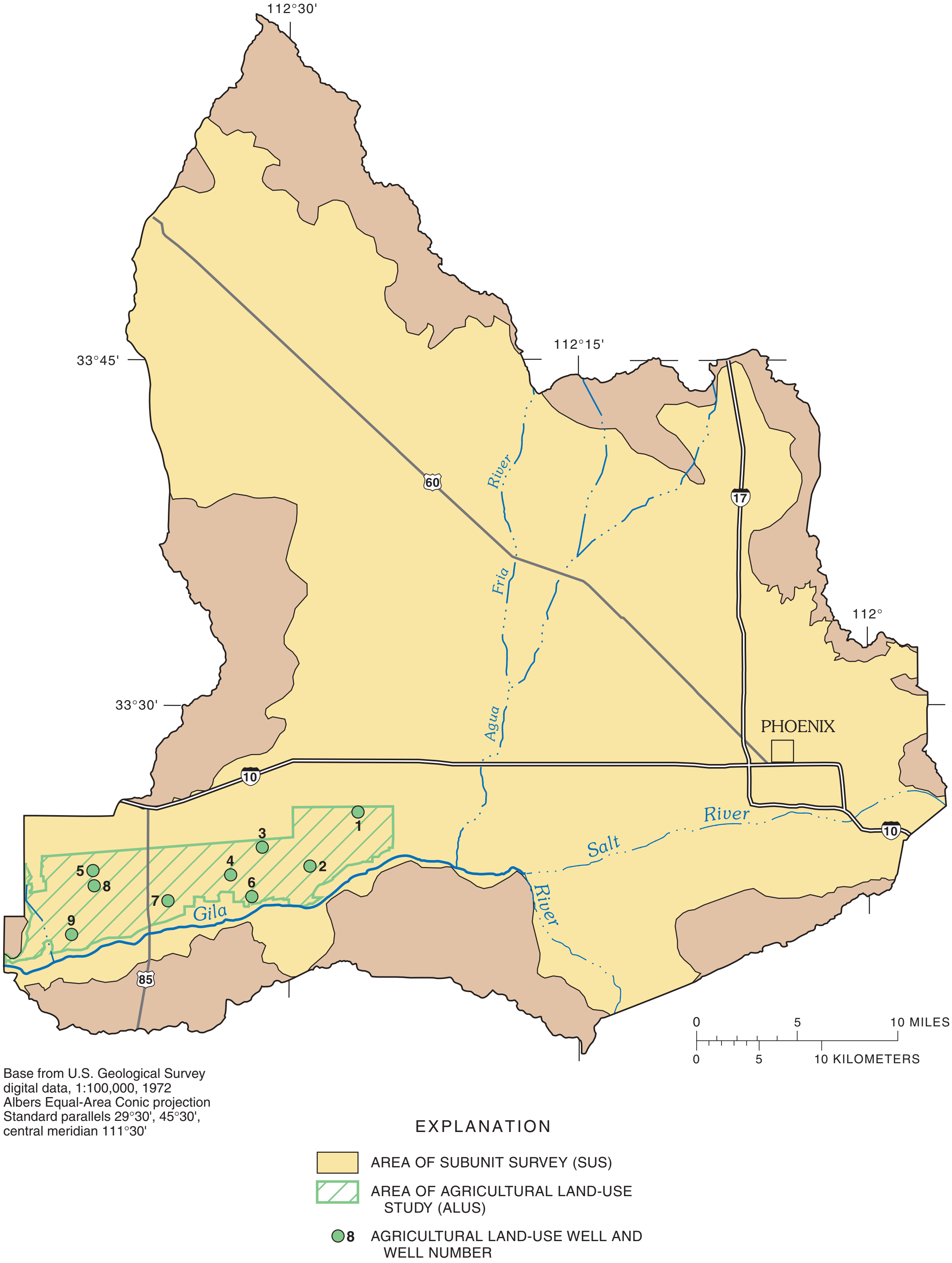
Table 1. Site identification and classification of wells, West Salt River Valley, Arizona, 1996–98

[ALUS, agricultural land-use study; SUS, subunit survey; DP, deep well. Dashes indicate no data]

				Quality-control samples collected for inorganic constituents					
Site number	Local identifier	Study group	Well class	Blank	Replicate	Replicate for trace elements only	Date sampled	Well depth, in feet	Depth of perforation, in feet
1	(B-01-02)14cac	ALUS	E				08–27–97	78.5	68.5–73.5
						X	02–10–98		
2	(B-01-02)32cbb2	ALUS	E				08–19–97	25	20.0–25.0
						X	02–12–98		
3	(B-01-03)25cbb2	ALUS	E	X	X		08–28–97	83	73.0–78.0
							02–05–98		
4	(B-01-03)34cdd	ALUS	E		x		08–20–97	43	33.0–38.0
							02–06–98		
5	(B-01-04)33cad	ALUS	E				08–26–97	68.5	58.5–63.5
				X	X		02–03–98		
6	(C-01-03)02dcc	ALUS	E			X	08–22–97	25	20.0–25.0
				X	X		02–11–98		
7	(C-01-03)07bbd	ALUS	E				08–25–97	22	17.0–22.0
						X	02–12–98		
8	(C-01-04)04caa	ALUS	E			X	08–26–97	61.5	51.5–56.5
							02–18–98		
9	(C-01-04)20baa	ALUS	E	X	X		08–21–97	20	15.0–20.0
							02–04–98		
10	(A-01-01)14bab2	SUS	D				05–08–97	1,445	445–518, 1,133–1,445
11	(A-01-01)22dcc	SUS	D				05–20–97	417	359–417
12	(A-01-01)28bba	SUS	D	X	X		04–10–97	450	400–450
13	(A-01-02)21bcd	SUS	D				06–17–97	520	342–363, 483–520
14	(A-01-02)34ada	SUS	D				03–26–97	635	595–635
15	(A-02-02)36cba	SUS	D			X	05–07–97	780	750–770
16	(A-02-03)13dac2	SUS	B				04–23–97	170	145–165
17	(A-02-04)21ccb	SUS	B				04–21–97	150	110–150
18	(A-03-01)25abb	SUS	D				06–03–97	1,180	525–1,150, 1,170–1,180
19	(A-03-01)34ddd2	SUS	D				06–05–97	1,000	500–985
20	(A-03-02)16aaa	SUS	B	X	X		04–24–97	538	144–538
21	(A-03-02)26dcb	SUS	B				05–21–97	1,400	312–1,400
22	(A-04-01)05acc	SUS	A				06–04–97	390	330–370
23	(A-05-02)35acb2	SUS	A			X	05–22–97	345	285–345
24	(B-01-01)14dbd	SUS	D				06–02–97	378	363–378
25	(B-01-02)09cbd	SUS	C		X		03–08–96	300	240–300
26	(B-01-02)32add	SUS	D				02–06–96	205	---
27	(B-01-03)13acc	SUS	D				03–27–97	600	460–590
28	(B-01-03)30cdc	SUS	D				02–28–96	228	224–228
29	(B-01-03)34bbb	SUS	C				04–25–96	200	145–165
30	(B-02-01)01bbb	SUS	B	X	X		05–06–97	340	300–340

Table 1. Site identification and classification of wells, West Salt River Valley, Arizona, 1996–98—Continued

Site number	Local identifier	Study group	Well class	Quality-control samples collected for inorganic constituents: Blank	Replicate	Replicate for trace elements only	Date sampled	Well depth, in feet	Depth of perforation, in feet
31	(B-02-01)36add	SUS	B				04–22–97	326	322–326
32	(B-02-02)28bca	SUS	A				04–07–97	555	433–553
33	(B-02-02)33ada	SUS	B				04–03–96	364	320–364
34	(B-03-01)02dcc	SUS	B				05–05–97	480	475–480
35	(B-03-01)09ccc	SUS	B				04–09–97	800	640–800
36	(B-03-01)34bbb	SUS	B				05–22–97	1,200	550–1,200
37	(B-04-01)07aaa	SUS	---				04–23–96	610	474–604
38	(B-04-03)04bdb	SUS	A				04–16–96	562	---
39	(B-05-03)15aaa	SUS	A				04–22–96	600	500–600
40	(B-05-03)24ada	SUS	A				04–16–96	---	---
41	(B-06-03)36ddd	SUS	A	X	X		04–17–96	667	---
42	(C-01-02)19ccc	SUS	A				03–27–97	240	50–240
43	(C-01-04)20bab	SUS	C				03–01–96	100	---
44	(D-01-02)10aca	SUS	B				03–25–97	120	60–100
45	(B-01-02)22dba2	DP	D	X	X		06–18–97	555	395–555
46	(B-01-04)33caa	DP	D				09–03–97	760	727–760
47	(C-01-03)05bbd	DP	D	X	X		09–09–97	552	502–552
48	(B-01-02)10aab	---	D				03–27–96	277	272–277
49	(B-01-02)13aba2	---	---				02–13–96	276	---
50	(B-01-02)13dbd	---	---				02–13–96	280	---
51	(B-01-02)20ccc1	---	---				02–12–96	190	---
52	(B-01-02)21bcc	---	---				03–06–96	200	---
53	(B-01-02)24baa	---	---				02–16–96	241	232–241
54	(B-01-02)35bab	---	C				02–27–96	120	---
55	(B-01-03)19ddd	---	---				03–04–96	300	---
56	(B-01-03)23cbb	DP	---				08–05–96	976	---
57	(B-01-03)34cdd2	---	C				02–28–96	55	---
58	(B-01-03)35dad	---	D			X	03–28–96	165	154–165
59	(B-01-04)23dda	---	---				02–29–96	290	---
60	(B-01-04)27aad	---	C				03–29–96	300	155–285
61	(B-01-04)32dbb	---	---	X	X		03–07–96	240	---
62	(B-01-04)33bda	---	C				04–15–96	400	70–400
63	(B-02-02)24baa	---	B	X	X		04–26–96	922	232–910
64	(B-02-02)26aaa	---	B				04–02–96	760	---
65	(C-01-02)06dbb	---	---	X			02–15–96	157	---
66	(C-01-03)07bbb	---	C				02–08–96	160	148–160
67	(C-01-04)01bdd3	---	---				03–28–96	165	---
68	(C-01-04)04cbb2	---	C			X	03–25–96	213	60–205
69	(C-01-04)05caa	DP	C				07–01–96	1,190	147–1,190
70	(C-01-04)06abb	---	---				03–26–96	220	---
71	(C-01-04)07aaa	---	---				03–05–96	210	---
72	(C-01-04)11ccb	---	C				04–18–96	146	---
73	(C-01-04)16bbd	---	D				03–05–96	165	148–165



Base from U.S. Geological Survey
digital data, 1:100,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30', 45°30',
central meridian 111°30'

Figure 7. Wells sampled for agricultural land-use study, West Salt River Valley, Arizona.

Wells equipped with submersible pumps were selected, where available, to eliminate the risk of contamination from turbine-pump lubrication. Wells equipped with submersible pumps and listed in the well-registry file of the ADWR were assigned to the cell in which they were located and listed in random order. Wells then were visited in the order in which they appeared on the list for each cell. The first well in each cell with suitable construction information and for which permission to sample was granted by the owner was selected. A well with a turbine pump was selected for those cells in which a well with a submersible pump was not available. A similar process had been used in 1996 to select wells for sampling in agricultural and undeveloped areas.

To complete the set of 30 areally distributed wells in agricultural and urban areas, 1 previously sampled well was selected from each of the 6 cells containing wells sampled in 1996. A point was located randomly in each of these cells by the GIS program (Scott, 1990). The well closest to the point was selected for inclusion in the set of 35 wells used to represent the SUS. Wells lacking construction information, drillers' logs, or water-level data were excluded from the selection.

Analyses of ground water from the five wells sampled in 1996 in the undeveloped area in the northwestern part of the West Salt River Valley also were included in the set of wells used to represent the SUS. The final result was a set of 35 areally distributed wells (wells 10–44; table 1) that represent the entire SUS (**fig. 8**).

Five existing deep wells that were not randomly selected were sampled to compare the quality of deep ground water with ground water that may have been affected by agricultural or urban land use. Deep wells 56 and 69 (table 1) were sampled in 1996 and have depths of 900 and 1,190 ft, respectively. Deep wells 45, 46, and 47 (table 1) were sampled in 1997 and have depths of 555, 760, and 552 ft, respectively. The deep wells are not included in the set of 35 wells used to represent the SUS.

Agricultural Land-Use Study Design

Land-use studies were designed by NAWQA to assess the occurrence and distribution of water-quality constituents in recently recharged ground water associated with the most dominant land uses and hydrogeologic conditions in a study area (Gilliom and others, 1995). In the CAZB study area, an agricultural area west of metropolitan Phoenix was chosen for an agricultural land-use study (ALUS; **fig. 1**) because the area has been used for agriculture since the 1800s, the depths to ground water are shallower than in other parts of the study area, and ground water in this area may be used in the future to supply drinking water for the growing population.

In 1997, nine monitoring wells were drilled in the ALUS area to assess the quality of shallow ground water beneath agricultural land in the CAZB study unit. All nine monitoring wells were sampled at two different times (August 1997 and February 1998) to determine if there were any seasonal differences in shallow ground-water quality.

Selection of Well Locations

Locations of the monitoring wells were selected in a 60-square-mile area using the GIS program developed by Scott (1990). The ALUS area was divided into 10 equal-area cells. Primary, secondary, and tertiary points were located randomly within each cell by the GIS program. In order to be considered an adequate site for a monitoring well, the following criteria had to be met (Lapham and others, 1995).

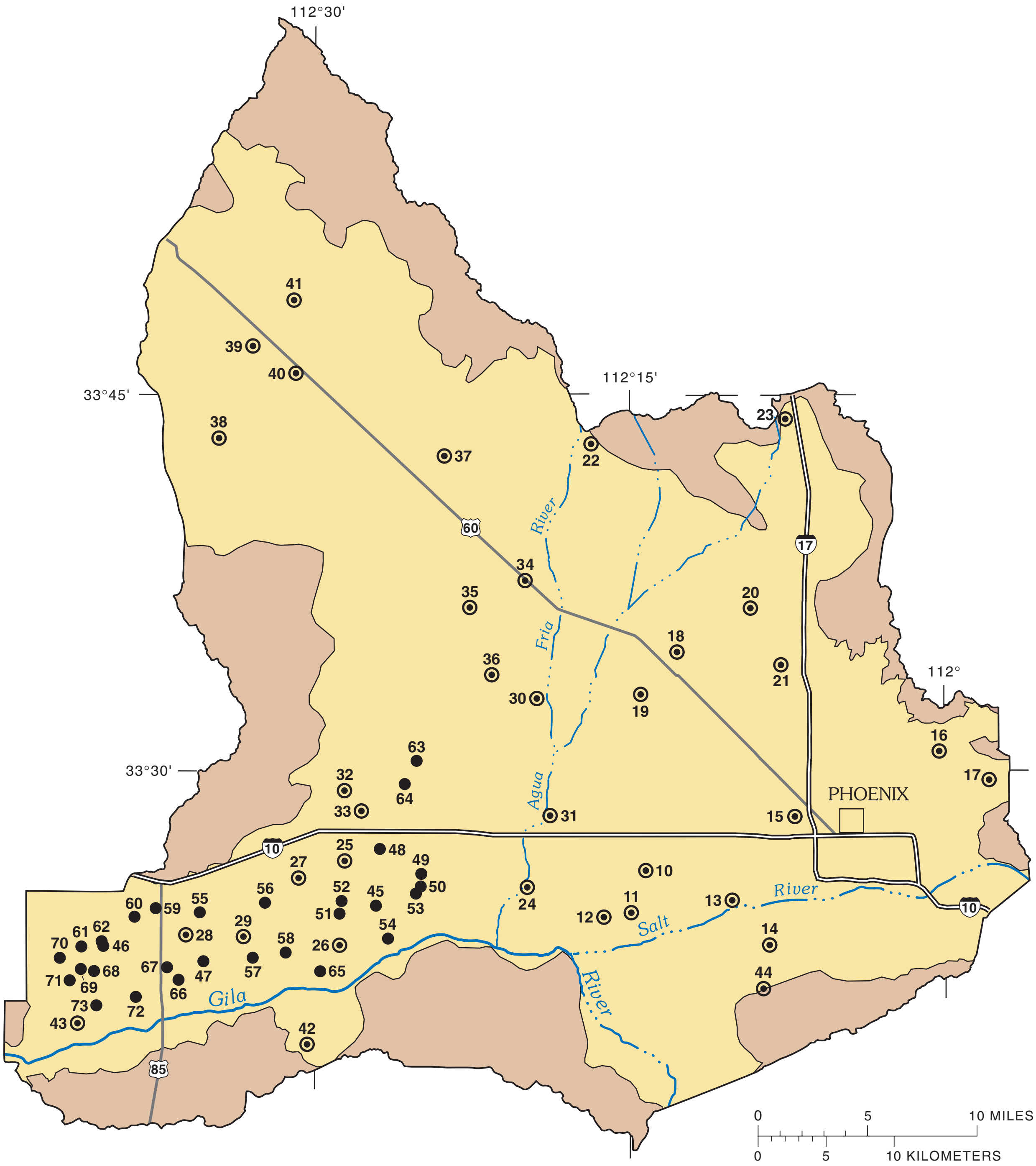
(1.) Land use has been stable for the past decade.

(2.) Wells are sited in recharge areas underlying or immediately downgradient from the agricultural land.

(3.) Wells are away from roads or highways where herbicides are used.

Additionally, land owners' permission was required to install a monitoring well and to do repeated sampling and measurements of water levels for the foreseeable future. NAWQA well-site selection and well-construction methods are discussed by Lapham and others (1995).

Field reconnaissance was done to locate adequate sites within 1 mi of the primary point within each cell. If no adequate site was near the primary point, then the secondary and tertiary points were used in sequence. Ten sites were chosen using this process. Access to the sites was granted by the land owners and approval was obtained from the ADWR to drill and install monitoring wells. The sites were primarily in agricultural fields along a road used to access the fields. Crop rotation is practiced in this area; therefore, fields in which the wells are located may have different crops in successive years. In 1997, the sites were planted with cotton, alfalfa, and hay. Other crops in the area included wheat and sorghum.



Base from U.S. Geological Survey
digital data, 1:100,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30', 45°30',
central meridian 111°30'

EXPLANATION

▨ AREA OF SUBUNIT SURVEY (SUS)

SAMPLED WELL AND WELL NUMBER (See table 1)

40 ⊙ Selected for subunit survey

● 68 Not selected for subunit survey

Figure 8. Wells sampled and wells selected for subunit survey (10–44). West Salt River Valley, Arizona.

Well Construction

In July 1997, drilling at 9 of the 10 sites was completed using a hollow-stem auger drill rig operated by the USGS. The tenth site was unsuitable for drilling because of overhead power lines; therefore, a well was not drilled. Holes with a diameter of 8.75 in. were drilled to depths of about 10 ft below the top of the first occurrence of ground water. The nine holes ranged in depth from 20 to 85 ft below the land surface. Geologic logs of cuttings from the holes were completed during drilling. The auger flights and drill stem were pressure washed with water to prevent cross-contamination between well sites.

Each well was constructed while the drill stem was in the hole to ensure proper placement of the filter pack and annular seals. All monitoring wells were constructed using 2-inch inside-diameter, schedule-40, flush-threaded, polyvinyl chloride (PVC) pipe with PVC slotted screens (fig. 9).

For wells that were more than 25 ft deep, 5 ft of nonslotted casing with a solid end cap was placed in the bottom of the hole followed by 5 ft of slotted casing. Nonslotted casing was used to about 1.5 ft above the land surface, and the well was capped with a solid end cap. For those wells that were less than 25 ft deep, 5 ft of slotted casing with a solid end cap was placed in the bottom of the hole followed by nonslotted casing to about 1.5 ft above the land surface. Construction information about these wells is presented in Tadayon and others (1999, p. 420).

The annular space surrounding the casing was packed in the following manner. Colorado silica sand was placed from the bottom of the hole to about 5 ft above the top of the slotted casing to form a filter pack. A layer of fine-grained sand was placed on top of the filter pack, and bentonite grout was placed from the top of the fine-grained sand to about 5 ft below the land surface. Concrete was poured into the top 5 ft of the annular space to form a surface seal and to secure a 5-foot-long, 6-inch-diameter, protective steel casing with locking cap. In some cases, natural fill also was present in the annular space because of sloughing of unconsolidated materials as the drill stem was being removed from the hole.

Well development was completed within 1 month of drilling and construction. Air surging was used to develop each well. Surging was applied until the water exiting the well appeared clear. At some wells, where surging was not adequate, a Bennett pump also was used to develop the well. Pumping continued until the water exiting the well was clear, and values of pH, temperature, specific conductance, and turbidity stabilized.

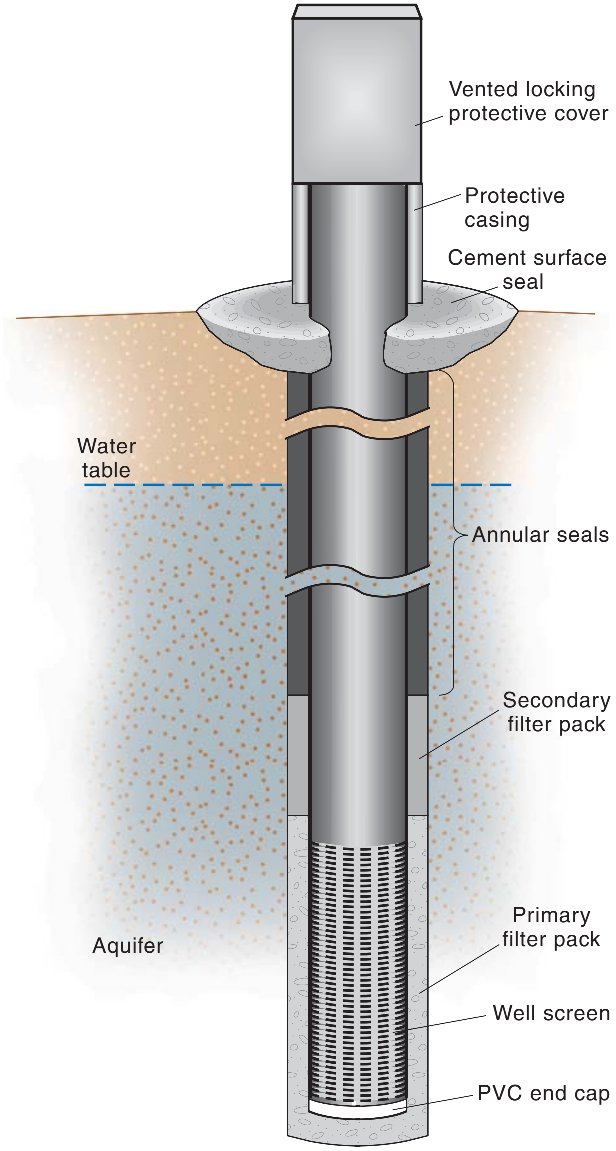


Figure 9. General design of a monitoring well in the agricultural land-use study, West Salt River Valley, Arizona.

Sample Collection

Ground-water samples were collected according to NAWQA ground-water sampling protocols described by Koterba and others (1995). All samples were collected in a vehicle dedicated to water-quality sampling. During sampling, the water had contact only with materials within the well and pump system, teflon tubing, and stainless-steel connections. Samples for the determination of inorganic constituents were collected after they had passed through a 0.45-micrometer in-line cartridge filter. At existing wells, samples were collected before the water entered storage tanks or treatment equipment. At the monitoring wells installed for the ALUS, a Bennett pump was used to collect ground water from the well. Between monitoring wells, the teflon tubing and all equipment used to collect samples were cleaned (fig. 10) according to protocols described by Koterba and others (1995).

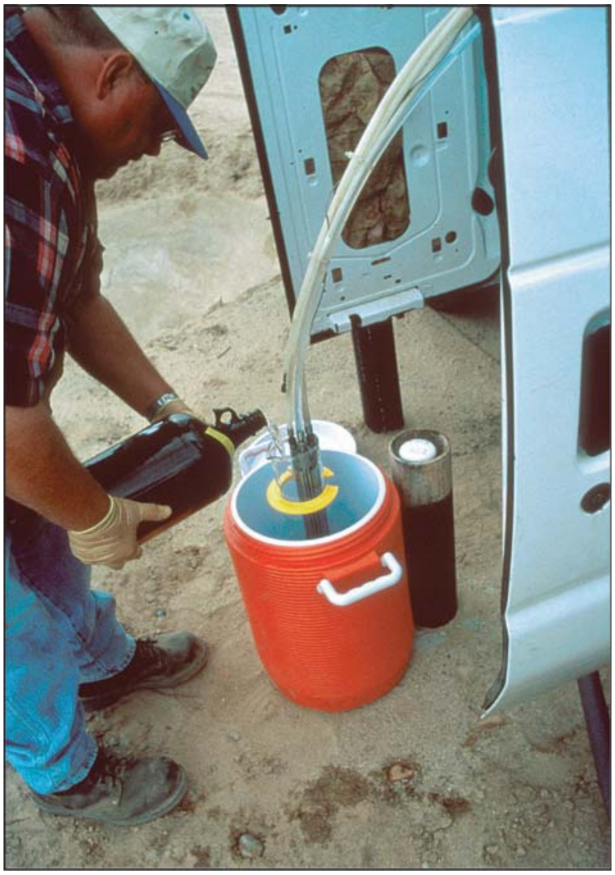


Figure 10. Cleaning of Bennett pump used to sample wells in the agricultural land-use study, West Salt River Valley, Arizona.

All wells were purged of at least three casing volumes of water, before sample collection. Field measurements of pH, temperature, and dissolved oxygen were monitored in a flow-through chamber to prevent contact with the atmosphere (**fig. 11**). In addition, specific conductance and turbidity measurements were monitored outside the flow-through chamber. During the last 25 minutes of purging, measurements were made every 5 minutes. Samples were collected when the difference between successive measurements was equal to or less than values shown in **table 2**. Samples that had turbidity measurements greater than 10 Nephelometric Turbidity Units or 10 Formazin Turbidity Units were not used for trace-constituent data analyses in this report.

Sample Analysis

Laboratory analyses for the principal inorganic constituents were done at the National Water-Quality Laboratory (NWQL) in Denver, Colorado, using methods described in Fishman and Friedman (1989) and Fishman (1993). Analyses of most trace constituents were completed using inductively coupled plasma mass spectrometry (Faires, 1993). Analyses for selenium and arsenic were completed using methods described in Fishman and Friedman (1989). Analyses of nitrogen species by the NWQL measured the concentration of nitrite and the sum of nitrate and nitrite concentrations dissolved in a water sample and are reported as nitrogen. The concentration of nitrite, however, was not large enough to contribute significantly to this sum in any of the samples collected for the SUS or the ALUS. For this reason, the constituent reported as dissolved nitrite plus nitrate from the NWQL is referred to as nitrate in this report.

Analyses of stable isotopes of oxygen and hydrogen were completed by the Isotope Fractionation Project of the USGS in Reston, Virginia. Hydrogen-isotope-ratio analyses were done using a hydrogen-equilibration technique (Coplen and others, 1991). Oxygen-isotope-ratio analyses were done using the carbon-dioxide equilibration technique (Epstein and Mayeda, 1953).

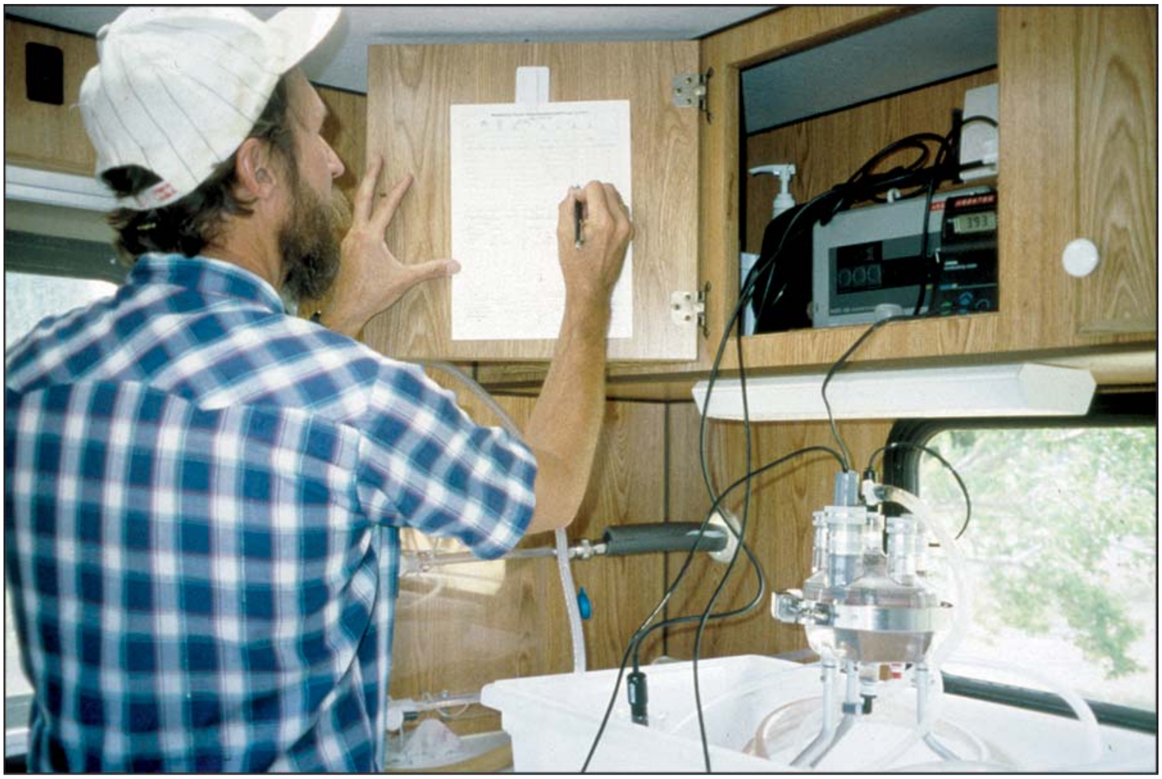


Figure 11. Measurement of field properties, West Salt River Valley, Arizona.

Tritium concentrations were used to identify ground water that had been recharged since atmospheric testing of thermonuclear weapons was begun in 1953. Analyses of tritium concentrations were completed by a USGS laboratory in Menlo Park, California, using the liquid scintillation counting method described by Thatcher and others (1977, p. 79–81). Methods of analysis for pesticides and VOCs were described by Gellenbeck (2002).

Table 2. Differences that indicate stability in field measurements

[Koterba and others (1995). ±, plus or minus; °C, degrees Celsius; mg/L, milligrams per liter]

Property	Allowable difference or value
Temperature	±0.2°C
pH	±.05 standard units
Specific conductance	±5 percent
Dissolved oxygen	±0.3 mg/L
Turbidity	±10 percent

Statistical Methods

A variety of statistical methods were used to evaluate the distribution of constituents in ground water in the study area. Nonparametric measures of the data were used in this report because much of the data are not normally distributed. SYSTAT (SPSS, Inc., 1998) was used to complete most of the statistical analyses mentioned in this report; analyses not done using SYSTAT are identified below.

The determination of Spearman’s rho (Helsel and Hirsch, 1992) was used to evaluate the correlation between values of $\delta^{18}O$ and δD and other constituents. A hypothesis test was used to determine the significance of the correlation. The null hypothesis of no correlation was rejected if the probability of obtaining no correlation by chance was less than 0.05.

Analyses of samples collected for the ALUS in August 1997 were compared with analyses of samples collected in February 1998 to determine if any seasonal changes in ground-water quality existed. The exact form of the Wilcoxon signed-rank test was used to determine whether the median differences between paired observations equaled zero (Helsel and Hirsch, 1992). The null hypothesis of the difference between medians equaling zero was rejected if the probability of obtaining a difference of zero by chance was less than 0.05.

Comparisons between results for samples from different well classes were analyzed using the Kruskal-Wallis test statistic (Helsel and Hirsch, 1992), which is a nonparametric measure of the association between several independent sets of data. This statistic was used to test the hypothesis that concentrations of several constituents in samples from different well classes were the same. The null hypothesis of identical median values for all well classes was rejected if the probability of obtaining identical medians by chance was less than 0.05. If the null hypothesis was rejected, the Tukey method of multiple comparisons on the ranks of the data was used (Helsel and Hirsch, 1992). This test was used to identify differences between well classes. The null hypothesis of identical medians 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.

GROUND-WATER QUALITY

Ground-water quality is discussed separately for the SUS and the ALUS for principal inorganic constituents, nitrate, dissolved oxygen, trace constituents, pesticides, VOCs, and isotopes. Complete analyses of ground-water samples collected are published in Smith and others (1997) and in Tadayon and others (1998, 1999). Analyses of quality-control (QC) samples and a discussion of their significance are in the section entitled “Quality Assurance and Quality Control” at the back of this report.

Some of the constituents measured for this study have standards set by the U.S. Environmental Protection Agency (USEPA; 1996) and the State of Arizona (1996; **table 3**, this report). The MCLs for drinking water are health-based standards that define the maximum concentration of a constituent that is allowed in a public-water system (U.S. Environmental Protection Agency, 1996). State water-quality standards apply to aquifers classified for drinking water use (State of Arizona, 1996). The Secondary Maximum Contaminant Levels (SMCLs) generally are for constituents that can affect the aesthetic qualities of drinking water and are not enforceable (U.S. Environmental Protection Agency, 1996). The human-health advisory levels (HALs) for drinking water are guidance values based on noncancer health effects (U.S. Environmental Protection Agency, 1996).

Subunit Survey

The SUS was designed to provide an overall characterization of ground-water quality in the West Salt River Valley. Although ground-water samples were collected from 64 wells, the discussion of ground-water-quality characteristics of the basin is based on the analyses of samples collected from the areally distributed set of 35 SUS wells. The set of analyses of ground water from these 35 SUS wells is believed to be more suitable for comparison with other subunits sampled by the NAWQA program in the CAZB and in other States. The SUS wells have site numbers 10 through 44 (**table 1**).

Principal Inorganic Constituents

The principal inorganic constituents dissolved in ground water from the study area are calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, nitrate, fluoride, and silica. Nitrate is discussed separately because of its local significance in regard to drinking water. None of the median concentrations of the principal inorganic constituents (**table 4**) were greater than the primary standards (State of Arizona, 1996) or MCLs (U.S. Environmental Protection Agency, 1996; **table 2**, this report). The concentrations of chloride exceeded the SMCL (U.S. Environmental Protection Agency, 1996) of 250 mg/L in 13 of the 35 wells (37 percent). The concentration of sulfate exceeded the SMCL (U.S. Environmental Protection Agency, 1996) in 4 of the 35 wells (11 percent). The fluoride concentration exceeded the MCL of 4.0 mg/L (U.S. Environmental Protection Agency, 1996) in 2 (6 percent) of the 35 wells. Ground water in the northern part of the study area had lower fluoride concentrations overall than ground water in the southern part. The median fluoride concentration in water from wells north of I-10 was 0.53 mg/L compared with 1.70 mg/L in the water from wells to the south.

Table 3. Primary and Secondary Maximum Contaminant Levels, human-health advisory limits, and aquifer water-quality standards for selected constituents

[Concentrations are dissolved and are reported in micrograms per liter unless otherwise noted. HAL, human-health advisory level for drinking water (U.S. Environmental Protection Agency, 1996). Aquifer water-quality standards established by State of Arizona (1996). MCL, Maximum Contaminant Level; mg/L, milligrams per liter. Dashes indicate no data]

	U.S. Environmental Protection Agency			State of Arizona
Property or constituent	Primary MCL	Secondary MCL	HAL	Aquifer water-quality standard
Inorganic properties or constituents				
Arsenic	[1]50	---	---	50
Barium	2,000	---	---	2,000
Chloride (mg/L)	---	250	---	---
Chromium	100	---	---	100
Fluoride (mg/L)	[1]4	[1]2	---	4
Lead	[2]15	---	---	50
Nitrate plus nitrite (mg/L as nitrogen)	10	---	---	10
Selenium	50	---	---	50
Sulfate (mg/L)	---	250	---	---
Total dissolved solids (mg/L)	---	500	---	---
Pesticides				
Atrazine	3	---	---	---
Chlorpyrifos	---	---	20	---
Cyanazine	---	---	[3]1	---
Dinoseb	7	---	---	---
Disulfoton	---	---	.3	---
Diuron	---	---	10	---
Metribuzin	---	---	100	---
Prometon	---	---	[1]100	---
Simazine	4	---	---	4
Terbacil	---	---	90	---
Trifluralin	---	---	5	---
Volatile organic compounds				
Benzene	5	---	---	5
Bromodichloromethane	[3]100	---	---	---
Chloromethane	---	---	3	---
1,1,1-Trichloroethane	200	---	---	200
1,1-Dichloroethene	7	---	---	7
Methyl tert-butyl ether	---	---	[2]20–200	---
Tetrachloroethene	5	---	---	5
Trichloroethene	5	---	---	5
Trichloromethane	[3]100	---	---	---

[1] Under review.
[2] Action level.
[3] Draft.

Table 4. Summary of selected constituents, subunit survey, West Salt River Valley, Arizona, 1996–97

[Concentrations are in milligrams per liter unless otherwise indicated. Aquifer water-quality standards from State of Arizona (1996). <, less than; μg/L, micrograms per liter; per mil, parts per thousand. Dashes indicate that aquifer water-quality standards have not been set]

Property or constituent	Minimum	Percentile					Maximum	Aquifer water-quality standards
		10	25	Median	75	90		
Dissolved solids	212	234	302	560	834	1,560	3,050	---
Calcium	1.6	14	24	35	73	104	320	---
Magnesium	0.048	5.7	10	15	39	62	100	---
Sodium	29	37	61	82	212	346	660	---
Potassium	.79	2.2	2.6	3.0	4.4	5.3	7.8	---
Chloride	17	21	44	140	332	448	1,200	---
Sulfate	15	22	29	61	122	344	465	500
Bicarbonate	51	105	134	148	195	331	720	---
Nitrate (as nitrogen)	.280	.729	.151	2.69	10.6	18.0	37.6	10
Dissolved oxygen	.3	1.5	2.4	4.1	5.8	7.0	8.5	---
Fluoride	.18	.39	.33	.70	1.8	2.9	7.4	4.0
Arsenic (μg/L)	1	2	3	6	14	39	81	50
Barium (μg/L)	8.2	23	37	49	67	160	298	2,000
Chromium (μg/L)	<1	1.7	4.4	10	19	31	44	100
Strontium (μg/L)	44.0	311	459	865	1,270	1,970	7,880	---
Hydrogen isotope ratio (δD, per mil)	-79.7	-71.6	-69.6	-65.8	-64.1	-63.0	-55.9	---
Oxygen isotope ratio (δ^{18}O, per mil)	-10.77	-9.73	-9.58	-9.25	-8.73	-8.33	-8.03	---

The measurement of dissolved-solids concentration in ground water includes all the principal inorganic and trace constituents and has sometimes been referred to as salinity. Dissolved-solids concentrations ranged from 212 mg/L to 3,050 mg/L in samples collected from the SUS wells. The median concentration of dissolved solids was 560 mg/L (table 4), which exceeds the SMCL level of 500 mg/L (**table 3**, this report; U.S. Environmental Protection Agency, 1996). Ground water from wells south of I-10 had a higher dissolved-solids concentration (median = 790 mg/L) than ground water from wells north of I-10 (median = 316 mg/L). Water from wells completed in the shallowest parts of the basin-fill aquifer tended to have a higher dissolved-solids concentration than ground water from other wells. Wells in which the top perforation is less than 350 ft below land surface had a median dissolved-solids concentration of 745 mg/L; those wells in which the top perforation is greater than 350 ft below land surface had a median concentration of 348 mg/L.

Dissolved solids in applied irrigation water are concentrated in shallow ground water and accumulate as salts in the soil. Ground water near the southwestern or downstream end of the study area has a higher dissolved-solids concentration because of the effects of the irrigation process and the way in which water is reused. Dissolved-solids concentrations increase through evapotranspiration when plants are irrigated and the concentration in ground water increases as irrigation seepage reaches the water table. Dissolved-solids concentrations also are higher at the downstream parts of a system of irrigation canals because of reuse of water that has already passed through an irrigation cycle. The concentration of dissolved solids in ground water also can be expected to increase as agricultural irrigation efficiency increases owing to mandated water-conservation measures. Concern has been raised about the accumulation of dissolved solids in local ground water because of the application of irrigation water with high dissolved-solids concentrations imported from outside the area (Cordy and Bouwer, 1999). The Salt and Verde Rivers that historically have been used for irrigation in most of the study area have a mean dissolved-solids concentration of about 400 mg/L. Water in the Agua Fria River which is supplied to irrigated lands in the western part of the study area through the Beardsley Canal (**fig. 3**) had a mean dissolved-solids concentration of 380 mg/L. Dissolved-solids concentration of the CAP water, which is imported to replace pumped ground water, is about 700 mg/L (David Anning, hydrologist, USGS, oral commun., 1999). An increase in the dissolved-solids concentration in applied water could increase the salinity of underlying ground water.

Nitrate

Dissolved nitrate is widespread in the ground water in the study area and comes from a variety of natural and anthropogenic sources. These sources include dairies, chemical-fertilizer use, effluent from WWTPs, rainfall, dust, geologic processes, and legume species of desert vegetation. The total nitrogen load from all sources for the Salt River Valley, which includes the study area, greatly exceeds the quantity leaving in streamflow (D.W. Anning, hydrologist USGS, written commun., 1999). Samples from 11 of the 35 SUS wells (31 percent) exceeded the MCL of 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1996; tables 3 and 4, this report). All SUS wells that yield water exceeding the MCL are in areas that have past and (or) present agricultural or urban irrigation. The maximum concentration of nitrate measured in this study (37.6 mg/L as nitrogen) was from a well in a field that had been fallow for more than 10 years but was surrounded by urban development when sampled in 1997.

Although most high nitrate concentrations probably are the result of the application of chemical fertilizer, high nitrate concentrations were measured in some areas when the areas were first cultivated. Smith and others (1982) suggested that the high nitrate concentrations that were as much as 40 mg/L (as nitrogen) detected in ground water soon after agriculture and irrigation were established were the result of natural nitrate being leached from the soil by the first application of irrigation water. This finding is consistent with the observation of Robertson (1991) that nitrate salts accumulate in the soil where natural nitrate deposition exceeds the rate of removal because precipitation is insufficient to leach soluble nitrate salts from the soil.

Dissolved Oxygen

Ground water in the alluvial aquifer in the West Salt River Valley contains significant concentrations of dissolved oxygen, which is indicative of an environment capable of sustaining high nitrate concentrations. The median concentration of dissolved oxygen measured in water samples from the 35 SUS wells was 4.1 mg/L (**table 4**). Dissolved oxygen and nitrate in ground water often are removed from solution by biological processes that occur when there is sufficient organic matter in the aquifer. Nitrate in the water will be utilized by microorganisms after the oxygen has been consumed (Devinny, 1990). The alluvial basin-fill aquifer, however, lacks organic matter (Robertson, 1991); therefore, dissolved oxygen and nitrate remain in the ground water in the study area.

Trace Constituents

Trace constituents identified in ground water in the SUS wells include several for which MCLs have been established—lead, selenium, cadmium arsenic, chromium, and fluoride. Lead was detected in 7 of the 35 samples (20 percent) and had a maximum concentration of 2.0 μg/L, which is well below the MCL of 50 μg/L. Selenium was detected in 13 of the 35 samples (37 percent) and had a maximum concentration of 16 μg/L, which is below the MCL of 100 μg/L. Cadmium was not detected in any of the samples. Low concentrations of trace constituents may be the result of contamination from the pump or pipes, because most samples collected for the SUS were collected from existing wells with metal pumps, metal casings, and metal-outflow pipes.

Arsenic was detected in all wells sampled for the SUS, and the median concentration was 6 μg/L. Concentrations in samples from two wells exceeded the MCL of 50 μg/L (U.S. Environmental Protection Agency, 1996). Arsenic in the water from 49 percent of the sampled wells, however, exceeded a proposed MCL of 5 μg/L. The source of arsenic in ground water is from arsenic compounds in the basin fill that are presumed to come from hydrothermal sulfide and arsenide deposits in the surrounding mountains (Robertson, 1991).

Robertson (1991) reported concentrations of chromium that exceeded the MCL of 100 μg/L (U.S. Environmental Protection Agency, 1996) in ground-water samples collected from southern and central Arizona. Although chromium was detected in all but 1 of the 35 SUS samples, none of the concentrations exceeded the MCL. The median concentration of chromium found in ground water in the study area was 10 μg/L, and the maximum concentration was 44 μg/L (table 4).

Pesticides

Six pesticide compounds and two degradation products, including herbicides and insecticides, were detected in 8 (23 percent) of the 35 wells used for the SUS (**figs. 12** and **13**). None of the pesticides detected had concentrations greater than standards established by the USEPA (1996) or State of Arizona (1996; **table 3**, this report).

Deethylatrazine, which is a degradation product of atrazine, was detected in 4 of 34 wells. Atrazine, S-ethyl dipropylthiocarbamate (EPTC), simazine, and prometon were detected in 2 of the 35 wells and were the most commonly detected compounds after deethylatrazine. From the distribution of pesticide detections in the 35 SUS wells, it is apparent that pesticides used on the land surface are being detected in ground water in both agricultural and nonagricultural settings in the study area. The concentrations, however, are not above established standards. For example, simazine and prometon were detected in samples collected in both agricultural and urban areas. This occurrence and distribution is the result of characteristics of the pesticide, land-use type, and hydrogeologic conditions.

Atrazine is a selective herbicide that controls broadleaf and grassy weeds in agricultural areas and also is applied as a nonselective herbicide in nonagricultural areas (Extension Toxicology Network, 1996). The compound is highly persistent in soil and is moderately to highly mobile in the subsurface. Detections in ground water of the parent compound and its degradation products, including deethylatrazine, can be expected where atrazine is used, especially in areas with shallow depths to ground water and significant recharge (Extension Toxicology Network, 1996).

EPTC is applied as a selective pre-emergent herbicide for control of grassy weeds, perennial weeds, and some broadleaf weeds in a variety of crops (Extension Toxicology Network, 1996). EPTC has a low persistence in the soil and has a short half-life (less than 1 week), so its detection in ground water is not expected (Extension Toxicology Network, 1996). EPTC was detected in wells 29 and 33; however, these wells are in agricultural areas where samples probably were collected close to the time of application and irrigation.

The likelihood that a pesticide will be detected in ground water is not related directly to the amount applied. Pesticide-use data (Majewski, 1997) for the CAZB study area indicate that 3,017 lbs of atrazine were applied in 1992. Although the amount of EPTC used in the study area was much greater (14,525 lbs; Majewski, 1997) than the amount of atrazine applied, EPTC was not detected more frequently. EPTC is not as persistent in the soil as atrazine and, therefore, is less likely to migrate to the ground water. The occurrence of deethylatrazine in the ground water is a result of the persistence and degradation of atrazine (the parent product).

Simazine and prometon were detected in wells in an urban area (wells 16 and 17). Simazine is applied in agricultural and nonagricultural settings to control broadleaf weeds and annual grasses (Extension Toxicology Network, 1996). Simazine can be mobile in the subsurface, especially in sandy loam soils, and can remain active in the soil for at least 1 year (U.S. Department of Agriculture, accessed August 23, 1999). Prometon is used to control perennial broadleaf and grassy weeds on nonagricultural land, is highly mobile, and can remain active in the soil for at least 1 year (U.S. Department of Agriculture, accessed August 23, 1999).

Volatile Organic Compounds

No ground-water samples collected in the West Salt River Valley contained VOCs in concentrations that exceeded the established standards set by the USEPA (1996) and State of Arizona (1996; table 3, this report). Most VOCs in samples from existing wells were detected at concentrations below the minimum reporting limit and cannot be quantified reliably. Thirty-three detections of 18 different VOCs were identified in samples from 21 (70 percent) of the 30 SUS wells that had VOC data (**figs. 14** and **15**). A detection of a VOC was disregarded if it also was found in a field blank representing the time period of collection. The low-level detections of VOCs in the samples from existing wells might be from materials used in well construction, contamination during sampling, or leakage outside the well casing and may not be representative of ground water in the aquifer.

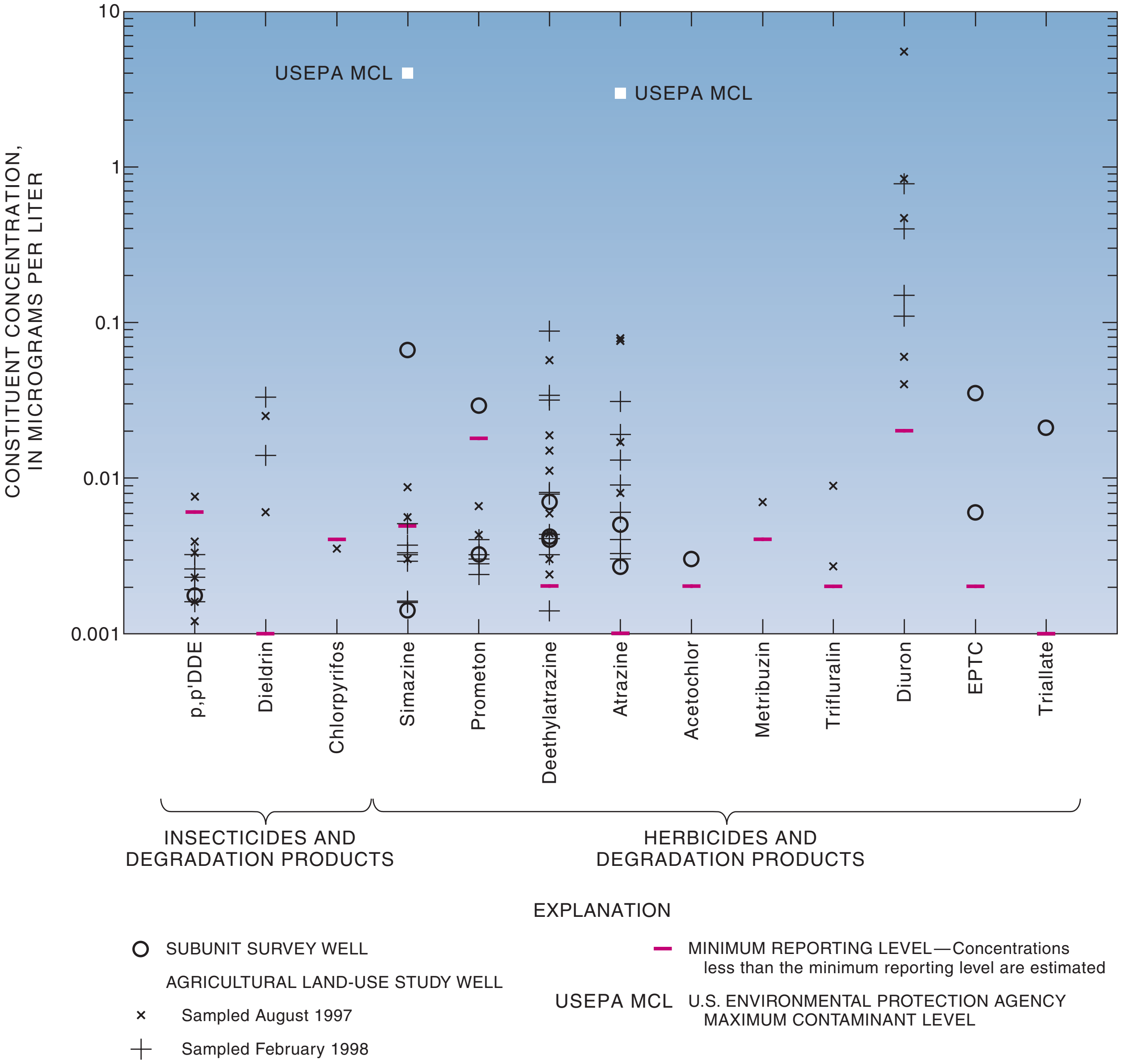


Figure 12. Pesticides in ground water in subunit survey and agricultural land-use study wells, West Salt River Valley, Arizona, 1996–98.

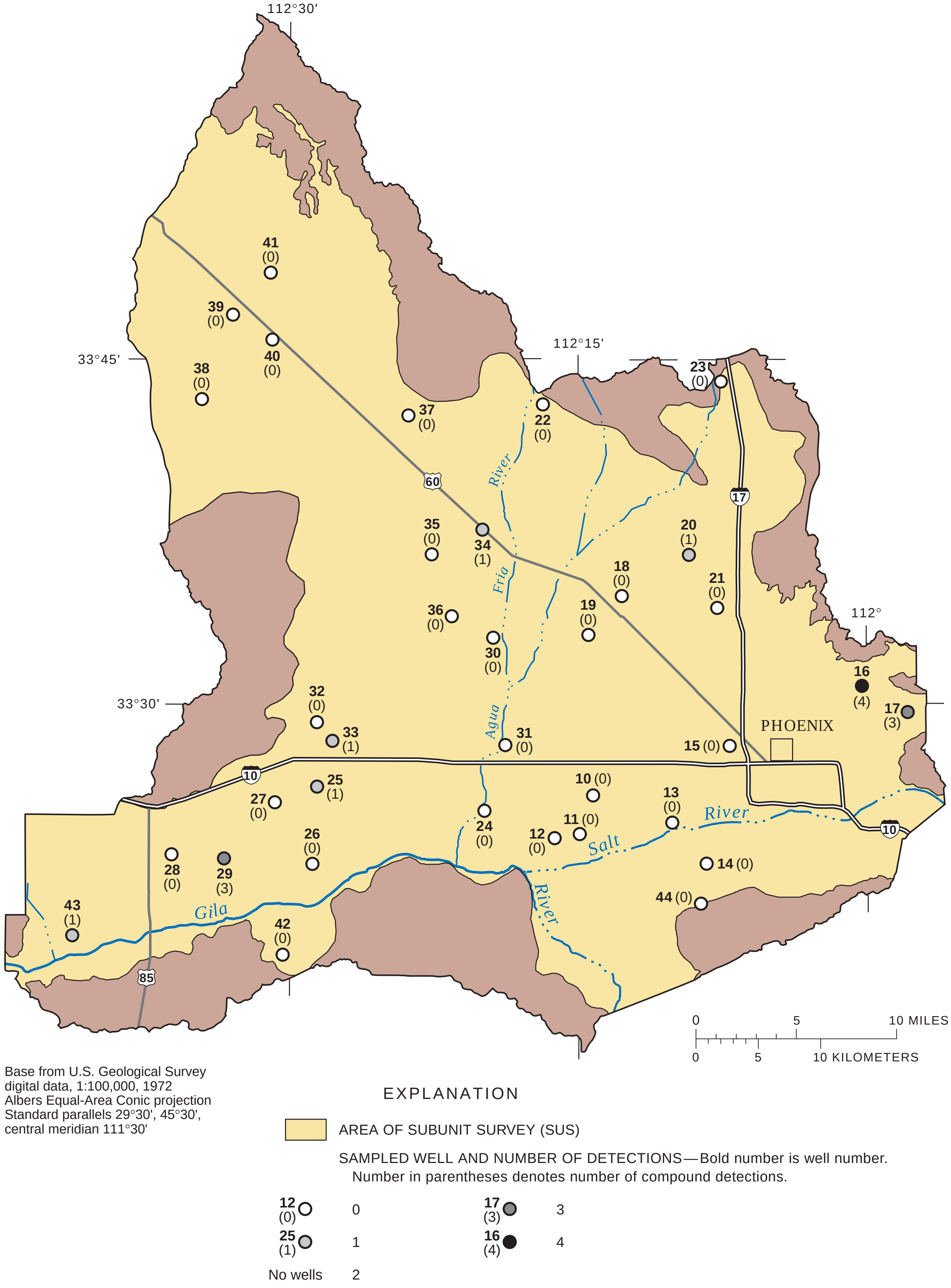
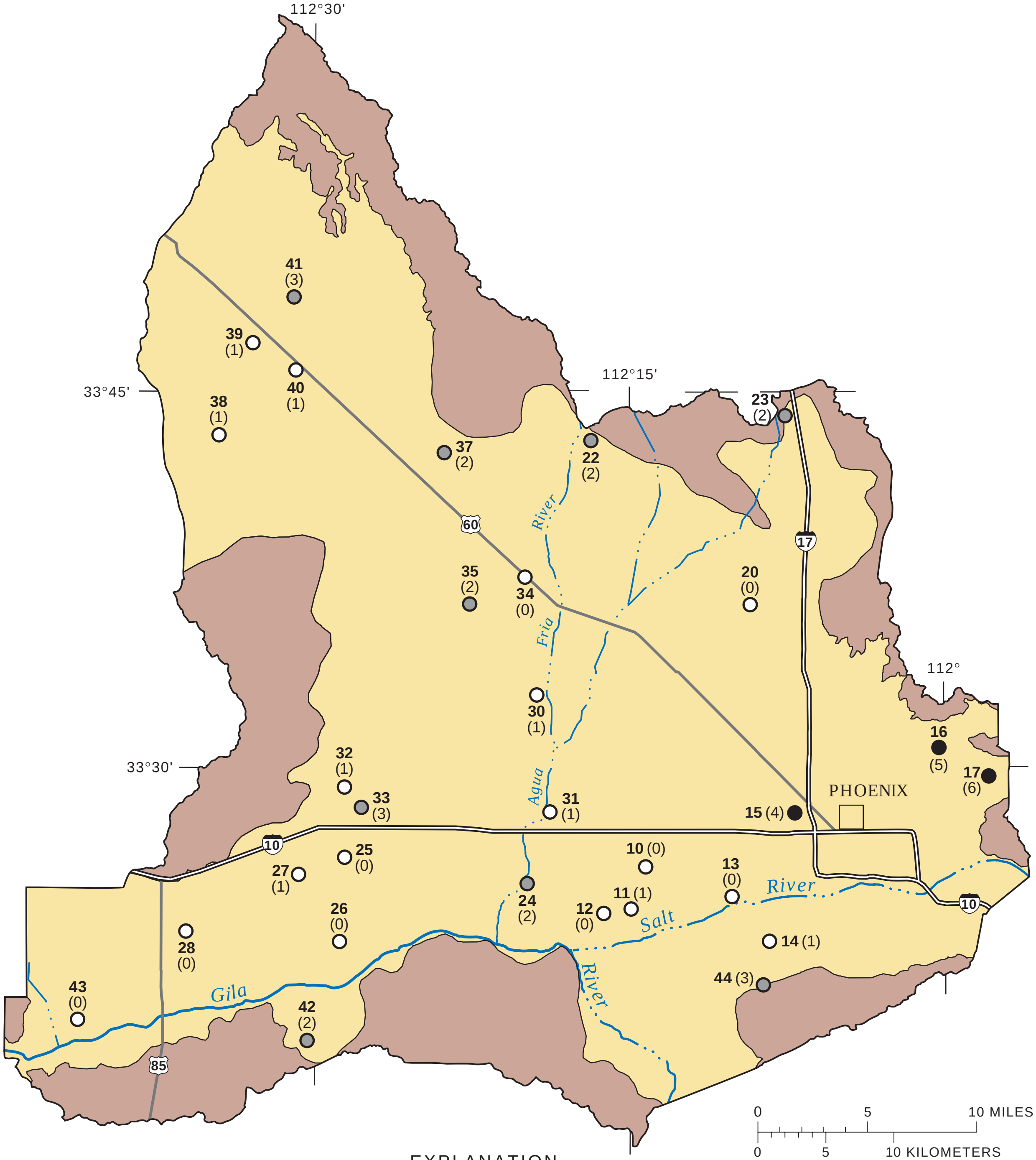


Figure 13. Locations of pesticide detections, subunit survey, West Salt River Valley, Arizona, 1996–97.



Base from U.S. Geological Survey
digital data, 1:100,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30', 45°30',
central meridian 111°30'

EXPLANATION

▨ AREA OF SUBUNIT SURVEY (SUS)

SAMPLED WELL AND NUMBER OF DETECTIONS—Bold number is well number. Number in parentheses denotes number of compound detections.

12 (0) ○	0–1
23 (2) ◍	2–3
17 (6) ●	4–6

Figure 14. Locations of volatile organic compound detections, subunit survey, West Salt River Valley, Arizona, 1996–97.

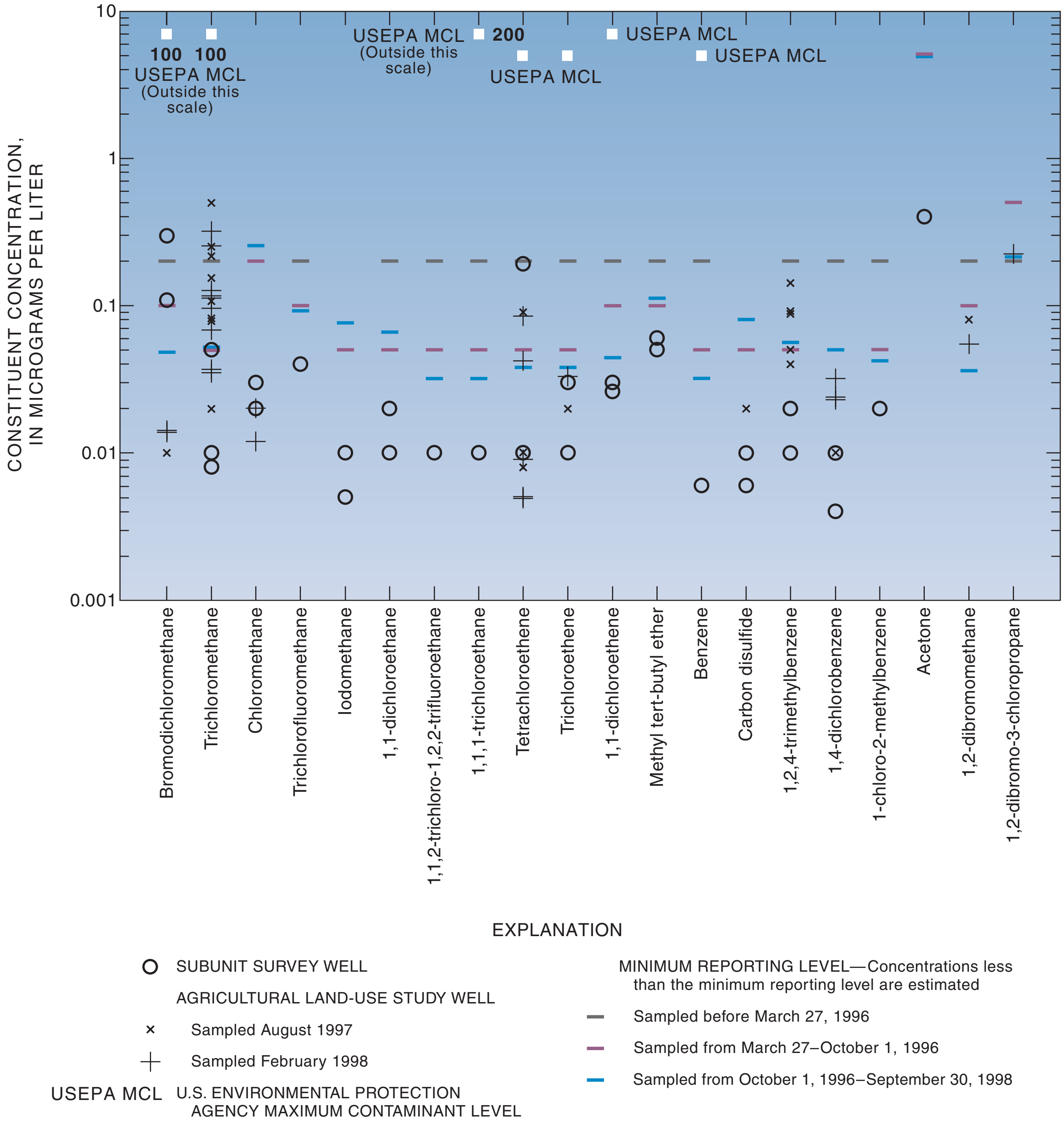


Figure 15. Volatile organic compounds in ground water in subunit survey and agricultural land-use study wells, West Salt River Valley, Arizona, 1996–98.

Because of the low concentrations of most VOCs detected, it is difficult to identify the sources of the VOCs in the samples. Detections of VOCs at such low levels may or may not imply contamination of ground water. Additional sampling of VOCs in properly constructed monitoring wells is needed to verify their presence in the ground water at these low detection levels. A more complete discussion of the interpretation of VOC detections in samples from existing wells and the accompanying QC data is given in Gellenbeck (2002).

Isotopes

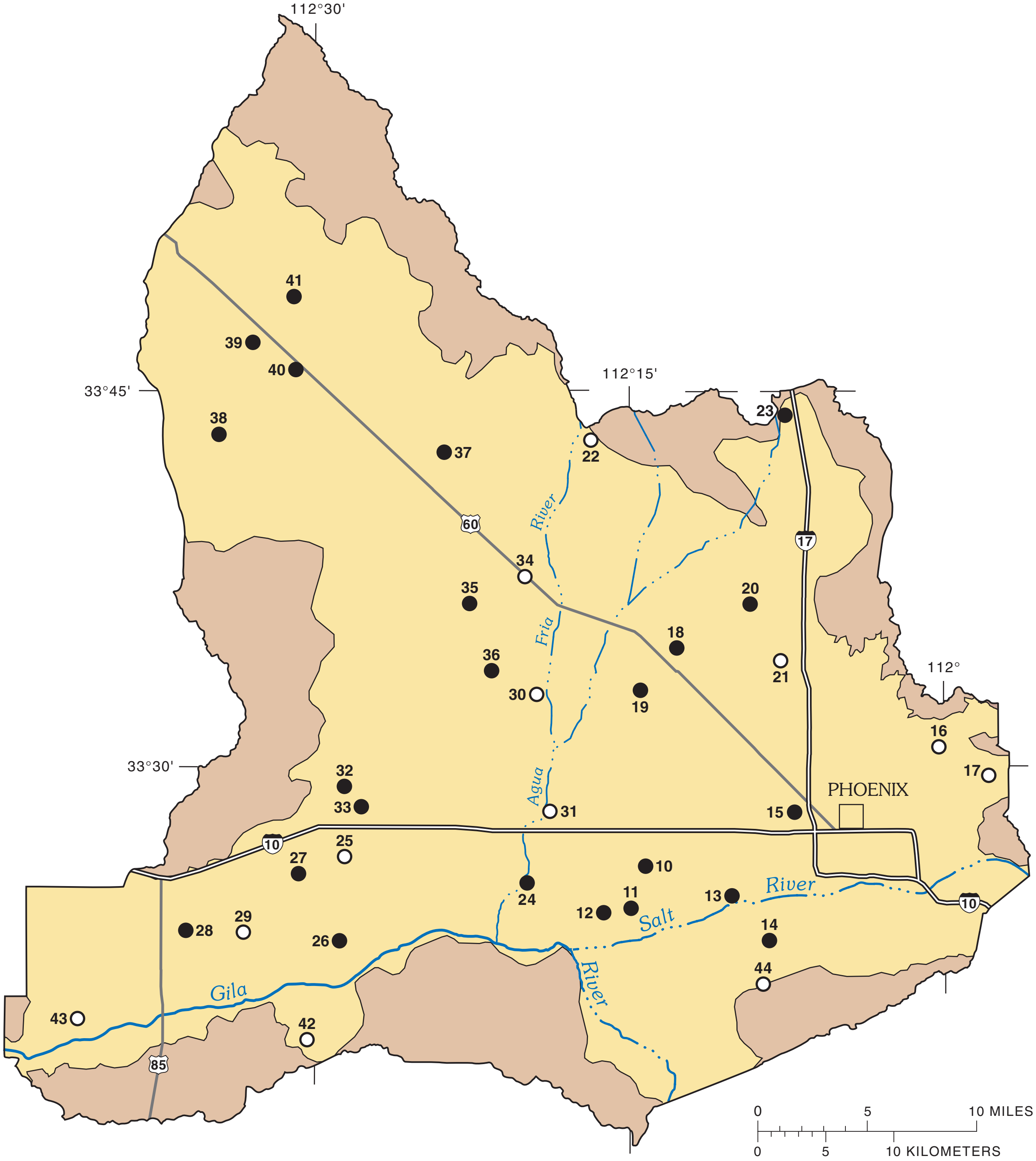
Ground water from 12 of the 35 wells included in the SUS had tritium concentrations greater than 5.7 pCi/L (**fig. 16**). Only those wells with measurable levels of tritium yield water that has been recharged within the last 40 years. The method of analysis for tritium was changed during sampling in 1996 so that the detection limit changed from 5.7 to 2.5 pCi/L. Two samples had tritium concentrations between 2.5 and 5.7 pCi/L. The lack of detectable tritium in water from most of the wells suggests that ground-water recharge occurred prior to 1953 when atmospheric thermonuclear testing began, and because of that, ground-water quality may not be related to subsequent land uses.

Values of $\delta^{18}O$ and δD in ground water from the 35 SUS wells ranged from -10.8 to -8.0 per mil (median = -9.3 per mil) and -79.7 to -55.9 per mil (median = -65.8 per mil), respectively. The data show the effects of evaporation with respect to the global meteoric water line (GMWL; **fig. 17**); the GMWL is the linear relation of $\delta^{18}O$ and δD values for precipitation throughout the world (Craig, 1961). Data for ground water in the SUS can be compared with data from potential sources of ground-water recharge in the study area to help identify the sources of recharge. A principal source of recharge, before and after the construction of storage reservoirs, is infiltration from the Salt and Verde Rivers during the winter and spring when the volume of runoff is greatest. The values of $\delta^{18}O$ and δD in these sources typically are less than -10 and -70 per mil, respectively. These values are more negative than most of the values for ground water in the study area (Smith, and others, 1997; Tadayon and others, 1998). The discrepancy in isotopic composition can be explained by the isotopic fractionation of hydrogen and oxygen during the evapotranspiration of irrigation water applied to crops and landscaping in the study area. The water that remains to recharge the aquifer is enriched in the heavier isotopes and thus has less negative $\delta^{18}O$ and δD values. These processes explain the less negative median $\delta^{18}O$ and δD values (**table 4**) in ground water from most of the SUS wells compared with values for the Salt and Verde Rivers upstream from the reservoirs (Tadayon and others, 1998).

The ranks of values of $\delta^{18}O$ are correlated positively with ranks of nitrate concentrations (rho = 0.765), and the relation is statistically significant ($p < 0.0001$). The ranks of values of $\delta^{18}O$ also are correlated positively with ranks of dissolved-solids concentrations (rho = 0.269); however, the relation is not statistically significant ($p = 0.06$). The concentrations of these constituents tend to increase in ground water because of the application of nitrogen fertilizers and evaporation during irrigation of crops and landscaping. The ranks of the values of δD were found to be correlated positively with ranks of nitrate concentrations (rho = 0.610) and were statistically significant ($p < 0.0001$); however, the correlation of δD with dissolved solids was not statistically significant ($p = 0.064$). The better correlation of $\delta^{18}O$ with nitrate and dissolved solids than of δD with nitrate and dissolved solids is consistent with the findings of Schmidt (1983) that $\delta^{18}O$ was more useful than δD in distinguishing irrigation seepage from canal seepage. These relations indicate that less negative $\delta^{18}O$ values are good indicators that ground water has been affected by irrigation seepage.

Agricultural Land-Use Study

Nine wells were constructed for an ALUS in an agricultural area with shallow ground water (**fig. 7**) to determine the effects of irrigated agriculture on ground water. The wells were sampled before and after the irrigation season to detect changes in the quality of ground water. Samples were collected in August 1997 near the end of the irrigation season and again in February 1998 before the start of the next irrigation season. Water samples in the ALUS were analyzed for the same constituents as water samples in the SUS. Because there were no statistical differences between most constituents analyzed in August 1997 and February 1998 (**table 5**), the samples collected in August 1997 were used for making comparisons with ground-water samples from the SUS wells that were collected in 1996–97 (**table 6**). Statistical significance of the comparison was not calculated because of the difference in the number of wells in the ALUS (9) and the SUS (35) (Dennis Helsel, hydrologist, USGS, written commun., 1999).



Base from U.S. Geological Survey
digital data, 1:100,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30', 45°30',
central meridian 111°30'

EXPLANATION

🟨 AREA OF SUBUNIT SURVEY (SUS)

SAMPLED WELL AND WELL NUMBER

○ 31 Tritium concentration greater than 5.7 picocuries per liter

● 28 Tritium concentration less than or equal to 5.7 picocuries per liter

Figure 16. Tritium in ground water from wells in the subunit survey, West Salt River Valley, Arizona, 1996–97.

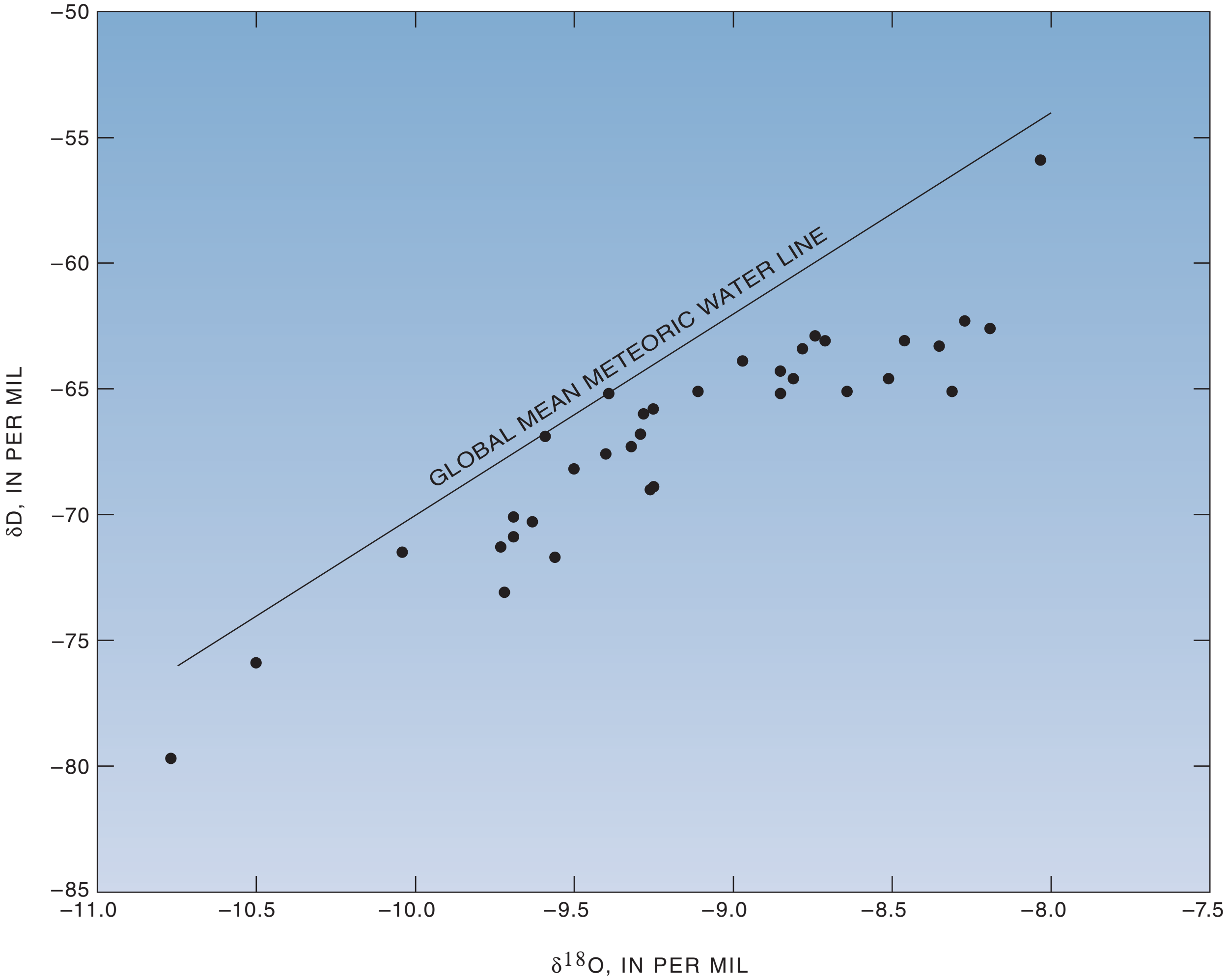


Figure 17. Relation between δD and δ^{18}O in ground water from wells in the subunit survey, West Salt River Valley, Arizona, 1996–97.

Samples collected from the ALUS wells are representative of ground water that has been recently (after 1953) recharged by irrigation seepage. Since the 1960s, significant water-level increases have been reported in the ALUS area, which indicates that recharge from the applied irrigation water has been greater than ground-water withdrawals during this period (E.L. Montgomery and Associates, 1986). Irrigation seepage percolates to the water table and accumulates at the top of the body of ground water. The most recent seepage is expected to be immediately below the water table at the top of the saturated zone.

Principal Inorganic Constituents

In the ALUS, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, nitrate, and fluoride are the principal inorganic constituents dissolved in ground water. Ground-water samples from the ALUS can be characterized as a sodium chloride type. No statistically significant difference in the medians (**table 5**) for any of these constituents was identified between the samples collected in August 1997 and samples collected in February 1998. The median dissolved-solids concentration was 3,350 mg/L in August 1997 and 3,400 mg/L in February 1998 in samples collected for the ALUS.

Concentrations of all these constituents were greater in ground-water samples collected for the ALUS than in ground-water samples collected for the SUS as shown by a comparison of median values (**table 6**). The median sodium concentration of the samples from the ALUS was about nine times that of the samples from the SUS. The median chloride concentration of the samples from the ALUS was about seven times that of the samples from the SUS.

Table 5. Summary of selected constituents, agricultural land-use study, West Salt River Valley, Arizona, August 1997 and February 1998

[Values are in milligrams per liter unless otherwise indicated. <, less than; µg/L, micrograms per liter; per mil, parts per thousand]

Property or constituent	August 1997			February 1998			Change significant at α=0.05
	Minimum	Median	Maximum	Minimum	Median	Maximum	
Dissolved solids	2,170	3,350	5,830	2,350	3,400	4,420	No
Calcium	83	180	670	160	210	470	No
Magnesium	36	101	121	82	100	144	No
Sodium	447	733	912	457	798	950	No
Potassium	2.4	4.8	9.9	3.6	4.8	24	No
Chloride	650	1,000	1,500	810	1,100	1,500	No
Sulfate	410	600	1,900	490	760	1,800	No
Bicarbonate	272	382	593	267	361	588	No
Nitrate (as nitrogen)	4.91	16.9	21.5	6.93	19.6	29.0	Yes
Fluoride	1.2	2.4	5.4	1.2	2.2	3.5	No
Arsenic (µg/L)	<1	10	40	1	11	31	No
Barium (µg/L)	14	36	47	13	35	56	No
Chromium (µg/L)	4.1	8.1	15	7.2	14	16	Yes
Molybdenum(µg/L)	3.6	9.8	55	3.6	10	46	No
Selenium (µg/L)	3	6	24	3	10	17	No
Strontium (µg/L)	2,400	3,820	25,800	2,700	4,100	16,000	No
Hydrogen isotope ratio (δD, per mil)	-69.7	-65.4	-62.2	-68.5	-64.8	-60.8	No
Oxygen isotope ratio (δ^{18}O, per mil)	-8.72	-8.37	-7.90	-8.79	-8.32	-8.00	No

Table 6. Median concentrations of selected constituents of the subunit survey and the agricultural land-use study, West Salt River Valley, Arizona, 1996–97

[Concentrations are in milligrams per liter unless otherwise indicated. µg/L, micrograms per liter; per mil, parts per thousand]

Property or constituent	Subunit survey	Agricultural land-use study
Dissolved solids	560	3,350
Calcium	35	180
Magnesium	15	101
Sodium	82	733
Potassium	3.0	4.8
Chloride	140	1,000
Sulfate	61	600
Bicarbonate	148	382
Nitrate (as nitrogen)	2.69	16.9
Fluoride	.70	2.4
Arsenic (µg/L)	6	10
Barium (µg/L)	49	36
Chromium (µg/L)	10	8.1
Strontium (µg/L)	865	3,820
Hydrogen isotope ratio (δD, per mil)	-65.8	-65.4
Oxygen isotope ratio (δ^{18}O, per mil)	-9.3	-8.37

The median fluoride concentration of the ALUS samples was 1.7 mg/L more than the median for the SUS samples. The median dissolved-solids concentration of samples collected from the ALUS in August 1997 was 3,350 mg/L; however, the median concentration of dissolved solids was only 560 mg/L for samples collected from the SUS (**table 6**). The minimum dissolved-solids concentration measured in samples from the ALUS (2,170 mg/L) was greater than the 90th percentile (1,560 mg/L) for dissolved solids in samples collected from the SUS.

An estimate of overall irrigation efficiency can be made by comparing the concentration of chloride in applied water to the concentration in irrigation seepage. Although concentrations of most of the principal inorganic constituents may change as percolating water interacts with the soil, chloride concentration generally is conservative and not affected by interaction with soil minerals (Drever, 1988). Five of the nine wells constructed for the ALUS are in the area served by the Buckeye Canal. The median concentration of chloride in those five wells was 1,000 mg/L. In the Buckeye Canal, the median concentration of chloride was 500 mg/L (Tadayon and others, 1998, 1999), which indicates an overall irrigation efficiency of about 50 percent for the agricultural lands served by the canal. An estimate of irrigation efficiency for the part of the ALUS served by the RID Canal was not attempted because of a lack of information on the chloride concentration in the applied water. This method can be used where recent irrigation seepage has reached shallow ground water and the chloride concentration in the applied water is known. This method provides a means of checking irrigation efficiencies calculated by other methods.

Nitrate

The concentration of nitrate exceeded the MCL (U.S. Environmental Protection Agency, 1996) of 10 mg/L as nitrogen in samples from seven of the nine wells sampled for the ALUS in August 1997 and February 1998. The median nitrate concentration in samples from the ALUS wells increased from 16.9 mg/L (as nitrogen) in August 1997 to 19.6 mg/L (as nitrogen) in February 1998—a statistically significant difference (**table 5**). Increases in nitrate concentration in shallow ground water from fertilizer appear to lag the application of irrigation water by several months. Most irrigation water is applied in the spring and summer during the peak growing season. The greater nitrate concentration in the winter may be a function of the length of time it takes irrigation seepage to reach the water table.

Nitrate concentrations generally were greater in ground-water samples collected for the ALUS in August 1997 than in samples collected for the SUS. The median nitrate concentration was 16.9 mg/L as nitrogen in the samples collected from the ALUS wells and only 2.7 mg/L as nitrogen in samples collected for the SUS.

Trace Constituents

Most concentrations of the trace constituents did not change significantly from the sampling in August 1997 to the sampling in February 1998. Chromium was the only trace constituent whose median concentrations in samples collected in August 1997 and February 1998 were significantly different. The median concentration of chromium increased by 5.56 μg/L, more than 10 times the variation of 0.5 μg/L in the ALUS replicate samples (see section entitled “Quality Assurance and Quality Control” at the back of the report). The cause of the increase in chromium concentrations is not known.

In contrast to the medians of the principal inorganic constituents, the medians of most of the concentrations of trace constituents in the ALUS samples collected in August 1997 were not greatly different than the medians of the concentrations of trace constituents in the SUS samples (table 6). The median chromium concentration for the ALUS samples collected in August 1997 was 1.9 μg/L less than the SUS samples; however, the median in February 1998 exceeded the SUS median by 3.7 μg/L. Low concentrations of chromium (less than 1 μg/L) detected in blank samples collected with the SUS samples indicated that contamination occurred during sampling or analysis (see section entitled “Quality Assurance and Quality Control” at the back of the report). None of the concentrations of trace constituents in the ALUS samples exceeded the Arizona standards (State of Arizona, 1996) or MCLs (U.S. Environmental Protection Agency, 1996; **table 3**, this report).

Other trace constituents that occurred in higher concentrations in the ALUS samples than in the SUS samples (selenium, molybdenum, and phosphorous) were not detected in many of the SUS samples.

Selenium was detected in only 37 percent of the SUS samples; however, selenium was measured in 100 percent of the ALUS samples and had a median concentration of 6 μg/L in the samples collected in August 1997. Dissolved phosphorous was detected in only 11 percent of the SUS samples but was detected in four of the nine ALUS samples (44 percent) collected in August 1997. Water in the Buckeye Canal could be the source of dissolved phosphorous in the ALUS samples because the samples in which phosphorous was detected were from wells in the area served by the canal.

Pesticides

Analyses of ground-water data from the ALUS wells during August 1997 and February 1998 indicate that pesticides are reaching the shallow ground water beneath the agricultural area near Buckeye. None of the pesticide concentrations exceeded standards set by the USEPA (1996) or State of Arizona (1996; **table 3**, this report). Pesticides were detected in eight of the nine ALUS wells (wells 2–9) in August 1997 and in all nine wells in February 1998. Ten different pesticides were detected during August 1997 and seven different pesticides were detected during February 1998 (**fig. 12**). The larger number of compounds detected during August 1997 may be the result of pesticide-degradation rates. The summer growing and irrigation season ended in August 1997. The likelihood of detecting a large number of compounds in August is increased because most of the compounds have been applied throughout the growing season, and irrigation provided the water required for these compounds to infiltrate to the ground water. In February, most pesticides have not yet been applied and irrigation has not begun. The compounds detected in samples collected in February are those that are more persistent from the previous season and are moderately to strongly adsorbed on the soil particles.

Atrazine and its degradation product, deethylatrazine, were the most commonly detected pesticide compounds analyzed in the ALUS samples. Atrazine was detected at least once in each of the nine wells, and deethylatrazine was detected during August 1997 and February 1998 in eight of the nine ALUS wells (wells 2–9).

Determining the ratio between deethylatrazine and atrazine can provide information about the degradation process of atrazine in the environment. At some time after application, and assuming no further addition of atrazine, a larger amount of deethylatrazine than atrazine is expected to be in the ground water. Ratios of deethylatrazine to atrazine were determined for eight ALUS wells in which the compounds were detected during August 1977 and February 1998 (wells 2–9). Deethylatrazine to atrazine ratios in samples collected from all eight wells in February 1998 were higher than in samples collected in August 1997 (**fig. 18**). These results indicate that atrazine degrades to deethylatrazine in the shallow ground water between irrigation seasons and the degradate persists after application.

Simazine, 1,1-dichloro-2,2-bis(p-dichloro-diphenyl)ethylene (DDE), diuron, and prometon were detected a total of 11, 10, 9, and 7 times, respectively, during both sampling periods. The detection of prometon in the agricultural area of the West Salt River Valley indicates that pesticides used for nonagricultural purposes are reaching the ground water in this area.

Low-level concentrations of DDE were detected at six wells sampled in August 1997 and at four wells sampled in February 1998. All but one of these detections were below the method reporting limit and are reported as estimated values (Tadayon and others, 1999). DDE is a degradation product of dichlorodiphenyltrichloro-ethane (DDT), an insecticide used in agricultural areas from 1944 until its use was banned in Arizona in 1965 (Brew and Baker, 1987). This compound and its degradation products are highly persistent in the soil, have a low solubility in water, and, over long periods of time, may leach into the ground water (Extension Toxicology Network, 1996). Because this compound is highly persistent in the soil and its use ended about 25 years before the ALUS sampling, it is plausible that the source of DDT and its degradation products in ground water is the soil in this part of the West Salt River Valley (Brown, 1993). Detections of DDE in this area were not unexpected because DDT and its degradation products have been identified in urban runoff within metropolitan Phoenix (Lopes and others, 1995) and in fish and other aquatic organisms in the lower Hassayampa River, the Salt River below the 23rd Avenue WWTP, and the Gila River from the confluence with the Salt River to Painted Rock Reservoir (Marsh, 1994).

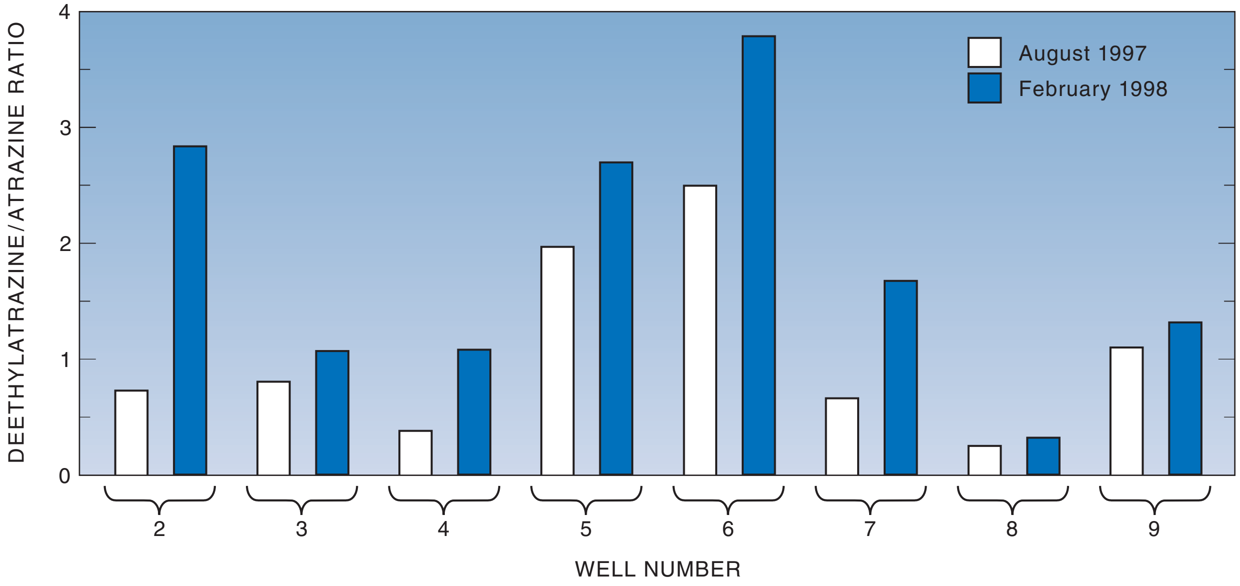


Figure 18. Ratio of deethlatrazine to atrazine in wells, agricultural land-use study, West Salt River Valley, Arizona, August 1997 and February 1998.

Diuron was detected at five wells sampled in August 1997 and at four wells sampled in February 1998. Diuron is a herbicide that controls a wide variety of annual and perennial broadleaf and grassy weeds and is applied in both agricultural and nonagricultural areas (Extension Toxicology Network, 1996). The compound is moderately to highly persistent in soils and has been detected in studies of ground water in other areas (Extension Toxicology Network, 1996). Because diuron has been used to control pests affecting cotton crops in Arizona since 1955 (Brew and Baker, 1987), its detection in the shallow ground water in this area is not unexpected.

Dieldrin was detected at two of the nine wells (wells 5 and 8) sampled in August 1997 and February 1998. Dieldrin is an insecticide and metabolic degradation product of aldrin. Dieldrin was recommended for use on cotton crops beginning around 1955 when cotton was the primary crop in the West Salt River Valley (Brew and Baker, 1987). By 1972, uses of aldrin and dieldrin were banned (U.S. Environmental Protection Agency, 1980) except for subsurface termite control, nonfood agricultural uses, and moth proofing in closed systems in manufacturing processes. By 1987, industry had removed aldrin and dieldrin from the marketplace for all uses (U.S. Environmental Protection Agency, 1995). The persistence of dieldrin is indicated by its detection in these wells 10 years after its use was banned. The detection of dieldrin at only two of the nine ALUS wells indicates that this compound is not widespread in the Buckeye area in the shallow ground water.

Volatile Organic Compounds

At least one VOC was detected in ground-water samples from each of the nine ALUS wells (wells 1–9) collected in August 1997 and February 1998. Eight different VOCs were detected 23 times in samples collected in August 1997, and 8 different VOCs were detected 20 times in samples collected in February 1998 (fig. 15). Detections of VOCs are counted for concentrations greater than the minimum reporting limit (MRL), as well as concentrations below the MRL. For those detections of concentrations below the MRL, the presence of the compound in the sample is assured, but the quantity is not. The development process used on these wells may have introduced some contaminants to the well, but it is difficult to determine which contaminants those might have been or to what extent any contamination affected the results. For this report, sample contamination is determined only by the analyses of field blanks (Gellenbeck, 2002). None of the VOC concentrations exceeded standards set by the USEPA (1996) or ADEQ (State of Arizona, 1996; table 3, this report).

Trichloromethane (also known as chloroform) was the most commonly detected VOC and was detected in every well during both sampling periods. Trichloromethane is a solvent, a common byproduct of chlorinated drinking water, and a byproduct of disinfection. The area of the ALUS is irrigated with treated effluent from the Phoenix WWTPs that process chlorinated city water. This compound also can enter the ground water in recharge of lawn irrigation, leaking water mains, and sewers (Squillace and others, 1999). The existence of trichloromethane in the shallow ground water in this area indicates that the shallow ground water is affected by human activities.

The second most commonly detected VOC in the ALUS wells was PCE, which was detected eight times at five of the wells (wells 1, 2, 3, 5, and 6)—three detections in August 1997 and five detections in February 1998. PCE was detected in samples collected from three of four wells (wells 1, 2, and 6) during both sampling periods, and TCE also was detected at one of these four wells (well 1). An important characteristic of these detections is that all but one of the detections were below the MRL. Four of the five wells at which PCE or TCE was detected (wells 1, 2, 3, and 6) are downgradient from a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site at the Phoenix-Goodyear Airport where the ground water is contaminated with TCE and PCE (Marsh, 1994). Another possible source of all detections of PCE and TCE in the five ALUS wells is the local use of these compounds as solvents.

In August 1997, 1,2,4-trimethylbenzene was detected in ground water samples from five wells. Two detections of this compound in samples collected in February 1998 were considered to be contamination on the basis of analyses of field blanks (Gellenbeck, 2002). The sources of this compound are widespread, and it is difficult to identify a specific source. 1,4-dichlorobenzene was detected in four samples from four different wells—one sample collected in August 1997 and three samples collected in February 1998. Seven additional detections of this compound were considered to be contamination on the basis of analyses of field blanks (Gellenbeck, 2002).

Dichlorobromomethane was detected a total of three times in two ALUS wells (wells 1 and 5). This compound is a byproduct of chlorinated drinking water and commonly is detected where trichloromethane is detected. Because trichloromethane was detected at each of the nine ALUS wells, it is possible that the source of dichlorobromomethane is the same as the source of trichloromethane. Dichlorobromomethane may not have been detected in some ALUS wells because of volatilization.

Carbon disulfide, 1,2-dibromomethane, and dibromochloropropane (DBCP) were each detected once in the ALUS wells. In 1979, DBCP was the first pesticide detected in ground water in Arizona (Daniel and others, 1988). This compound was applied to soils in citrus and cotton fields from the 1950s through the 1980s to control nematodes (Brew and Baker, 1987; Daniel and others, 1988). Although a summary of pesticides in ground water reported detections of DBCP throughout the West Salt River Valley (Daniel and others, 1988), DBCP was detected only once during the NAWQA sampling in 1996–98. Previous studies reported detections of DBCP in areas that are not near the ALUS area. The reason for the lack of detections of DBCP in the sampling completed for NAWQA in the West Salt River Valley is unclear.

Isotopes

All samples collected for the ALUS were analyzed for δ^{18}O, δD, and tritium. The values of δ^{18}O and δD for samples collected in August 1997 were compared with values for samples collected in February 1998 and were not found to be significantly different. Tritium concentrations exceeded 15 pCi/L in all samples collected for the ALUS, which indicates that the ground water collected had fallen as precipitation after atmospheric testing of thermonuclear weapons began in 1953.

Ground water sampled for the ALUS is recharged primarily from irrigation seepage that has been concentrated by evapotranspiration. Water from the ALUS wells was expected to be enriched in ^{18}O and D compared with most of the ground water sampled for the SUS. The median values of δ^{18}O for the samples collected in August 1997 (-8.4 per mil) and the SUS samples (-9.3 per mil) were determined to be significantly different statistically. The difference in δD was only 0.4 per mil between the ALUS samples collected in August 1997 and the SUS samples, and the values of δD were not significantly different statistically. The significant difference in the δ^{18}O values and the lack of significant difference in the δD values illustrates that the oxygen isotopes are a more sensitive indicator of the effects of evaporation during irrigation than the hydrogen isotopes.

RELATION OF GROUND-WATER QUALITY TO HYDROGEOLOGY, WATER USE, AND LAND USE

Ground-water quality and its variation in the study area can be better understood by examining its relation to hydrogeology, water use, and land use. Although samples from the 35 wells included in the SUS provide a reasonably unbiased, areal representation of ground water in the study area, the data set was selected so that comparisons with data from other NAWQA study areas in the United States could be made. Use of a larger subset of the 73 wells (64 SUS and 9 ALUS) sampled in the study area can result in a better interpretation on the basis of the land-use, water-use, and well characteristics. All sampled wells having adequate construction and log information were selected for additional interpretation. These 59 wells were grouped into five classes (A, B, C, D, and E) on the basis of land and water use, well construction, and particular geologic conditions existing within parts of the study area (fig. 19).

Classification of Wells

Class A consists of those wells in undeveloped areas that have no surrounding intensive urban development and have never been irrigated for agriculture. Land use is and has been low-density rural residential or rangeland. Irrigation systems or urban water-distribution systems had not been built near these wells at the time of sampling. Wells in class A are near the margins of the valley, particularly in the northwestern part between the White Tank and the Hieroglyphic Mountains (fig. 20).

Class B consists of wells in irrigated agricultural areas north of the RID Canal or east of the Agua Fria River. Additionally, the logs of wells in class B indicate that the wells yield water from an unconfined part of the aquifer. The logs show either that there are no significant, fine-grained beds penetrated by the well, or that the wells were perforated above any fine-grained confining beds. Municipal and irrigation wells are included in class B. Some class B wells could be affected by canal seepage, and other class B wells could be affected by flow in the Agua Fria or Salt Rivers.

Wells in class C yield ground water from the upper part of the basin-fill aquifer beneath lands that are irrigated with water from the Buckeye or RID Canals.

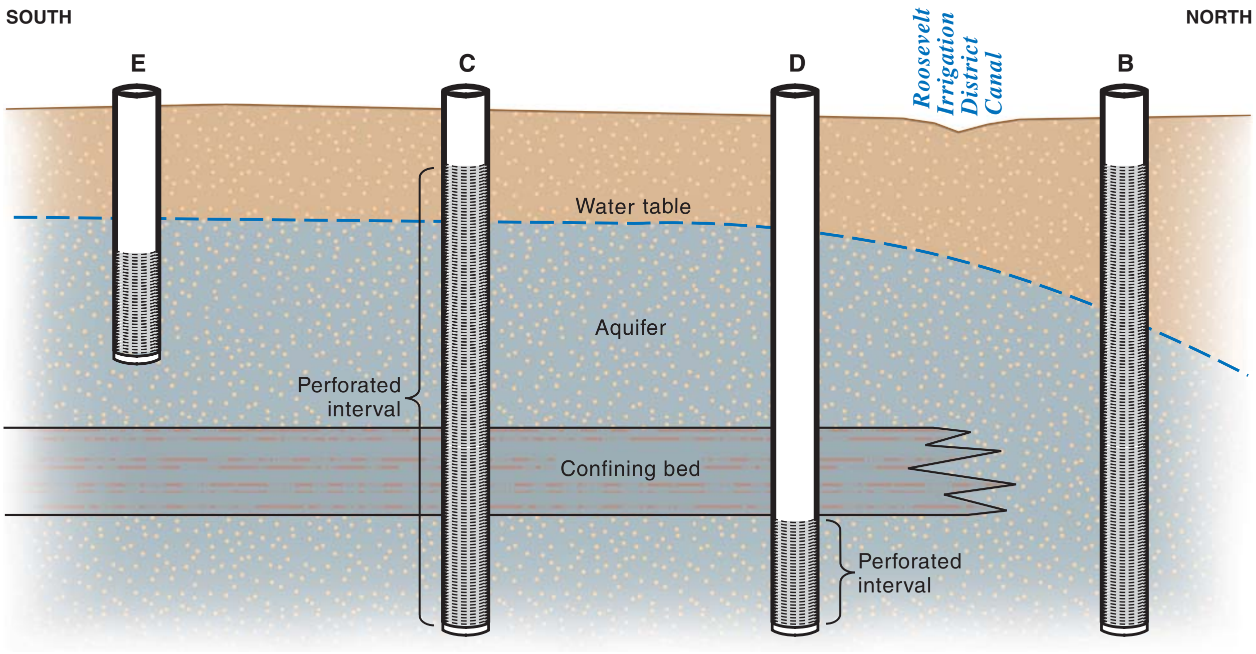
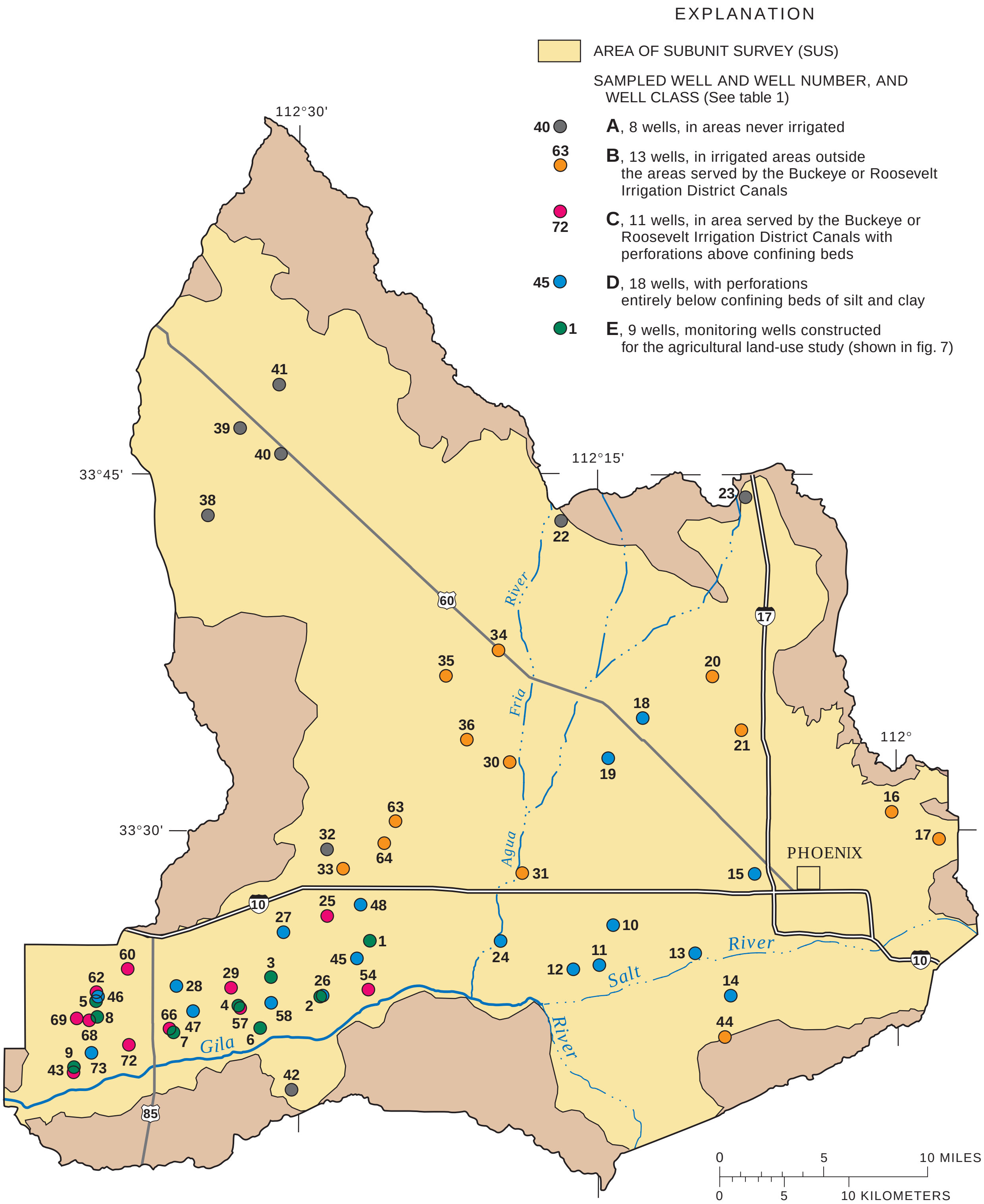


Figure 19. Construction typical of classified wells, West Salt River Valley, Arizona. (Class A not shown.)



Base from U.S. Geological Survey digital data, 1:100,000, 1972
Albers Equal-Area Conic projection
Standard parallels 29°30', 45°30', central meridian 111°30'

Figure 20. Classification of wells, West Salt River Valley, Arizona.

The extensive silt and clay beds in the middle unit described by Brown and Pool (1989) form a barrier to the downward movement of water and serve as a confining bed in this area. Wells were included in this class if they were perforated above the fine-grained unit according to construction records and drillers' logs. Many of the wells of this group are equipped with turbine pumps and are used for irrigation. Wells 43, 57, and 72 were included in class C, even though perforation information was missing, because well depths were shallower than the clay beds found in nearby wells.

Rising ground-water levels require dewatering in the area of class C wells and have been a problem since the 1920s. Although water levels declined somewhat from the 1930s until the early 1960s, they have risen significantly since the 1960s (Errol L. Montgomery and Associates, 1988). The depth to ground water generally is shallow in this area and ranges from less than 10 ft near the Gila River to about 150 ft near the RID Canal. The area served by the Buckeye and RID Canals is supplied by water imported from outside the service areas. The supply is supplemented by wells within each service area including some of the class C wells. Treated effluent and surface water are delivered through the Buckeye Canal. Ground water from the western part of the SRP service area, treated effluent, and some surface water is delivered through the RID Canal. The presence of ground water recharged by irrigation seepage and the shallow water table provided the opportunity to study the effects of irrigated agriculture on ground water by sampling class C wells.

Wells in class D are wells within the area of agricultural or urban irrigation constructed so that shallow ground water cannot enter the well. Perforations in these wells are completely below a bed of clay with unperforated casing extending from land surface to the clay bed. Sediments of the basin-fill aquifer are lenticular and of variable grain size. The wells in class D are concentrated in the southern part of the study area (**fig. 20**) where fine-grained sediments, including silt and clay, are most extensive (Brown and Pool, 1989). Wells were included in class D using the following criteria: (1) presence of a clay bed indicated on drillers' logs, (2) all perforations were below the clay bed as indicated on the ADWR construction records, and (3) tritium was not detected in well samples. Many of the wells in this group are domestic wells equipped with submersible pumps.

Class E consists of the nine wells that were constructed for the ALUS and is considered to be a separate group for comparison because the wells were located specifically in an irrigated area where depths to water were shallow, and the wells were constructed to allow samples to be collected at the water table. Samples from class E wells provided a group of analyses from ground water that is known to be affected directly by irrigated agriculture. Except for pesticides, comparisons of ground-water quality of class E wells with other well classes was based on the samples collected in August 1997. Counts of pesticide detections in class E wells were based on samples collected in August 1997 and February 1998.

Ground-Water Quality Among the Well Classes

The quality of ground water from each of the different well classes is distinct. Ground-water quality is controlled by the source and pathway of recharge water in addition to the mineralogic composition of the aquifer. A comparison of VOC results between classes is not included here because of the difficulty associated with identifying whether VOC detections in the existing wells truly represent ground-water quality.

Principal Inorganic Constituents

Median concentrations of dissolved solids for samples from each well class fall into two groups. The median concentration of dissolved solids for samples from well classes C and E, which are in areas served by the Buckeye and RID Canals, was greater than 3,000 mg/L (**table 7**). The median concentrations for classes A, B, and D were less than 1,000 mg/L (**fig. 21**). The median dissolved-solids concentrations for well classes known not to be affected by irrigation seepage were 257 mg/L (class A) and 747 mg/L (class D).

The well classes display the same distribution for principal inorganic constituents, except bicarbonate, as they do for dissolved solids (table 7). The water from class B wells varied widely from a mixed calcium sodium bicarbonate chloride type water to a calcium chloride type water possibly because of the variations in location and well construction (**fig. 22**).

Table 7. Median concentrations of selected constituents by well class, West Salt River Valley, Arizona

[Values are in milligrams per liter unless otherwise indicated; per mil, parts per thousand]

Property or constituent	Well class A	Well class B	Well class C	Well class D	Well class E
Dissolved solids	257	668	3,050	747	3,350
Calcium	37	55	210	24	181
Magnesium	12	30	79	10	101
Sodium	39	90	660	190	733
Potassium	2.74	3.50	5.40	2.95	4.84
Chloride	21	165	970	300	1,000
Sulfate	23	83	720	68	595
Bicarbonate	190	143	254	109	382
Nitrate (as nitrogen)	1.7	11.4	19.0	2.0	16.9
Hydrogen isotope ratio (δD, per mil)	-66.9	-63.4	-65.1	-70.6	-65.4
Oxygen isotope ratio ($\delta^{18}O$, per mil)	-9.32	-8.74	-8.64	-9.66	-8.37

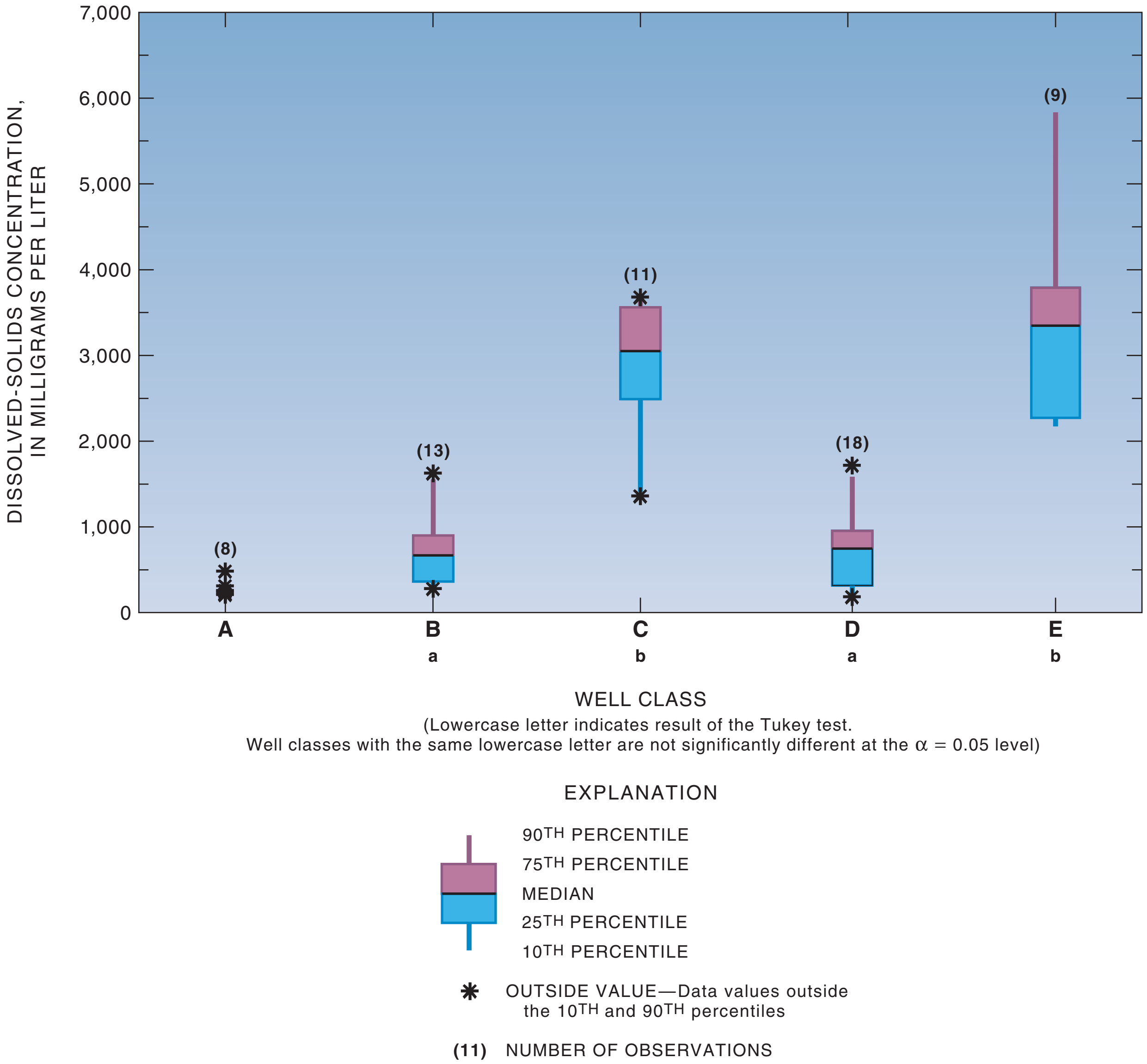
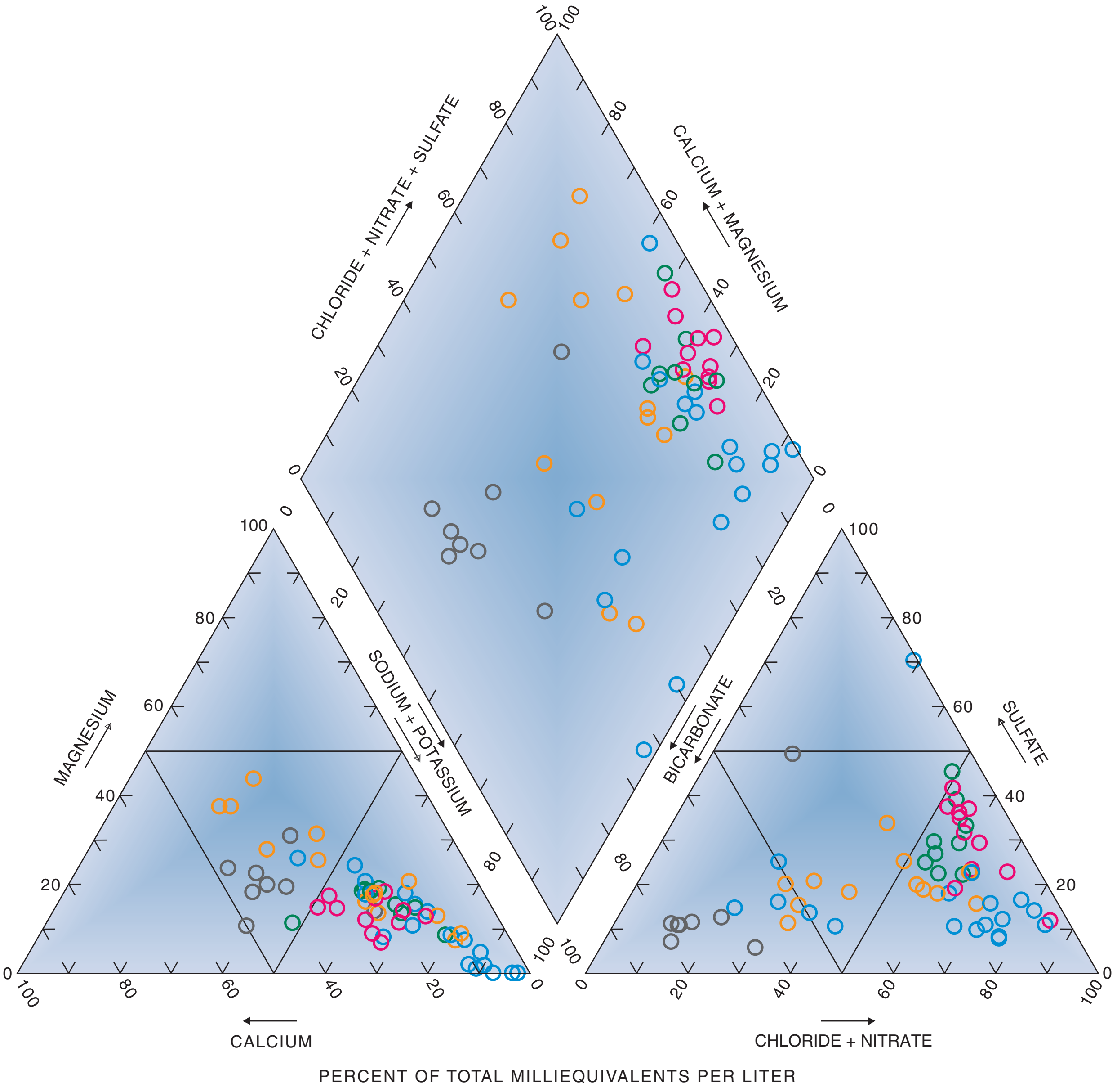


Figure 21. Dissolved-solids concentration in ground water by well class, West Salt River, Valley, Arizona.



EXPLANATION

WELL CLASS (See table 1)

○ **A**, 8 wells, in areas never irrigated

○ **B**, 13 wells, in irrigated areas outside the areas served by the Buckeye or Roosevelt Irrigation District Canals

○ **C**, 11 wells, in area served by the Buckeye or Roosevelt Irrigation District Canals with perforations above confining beds

○ **D**, 18 wells, with perforations entirely below confining beds of silt and clay

○ **E**, 9 wells, monitoring wells constructed for the agricultural land-use study (shown in fig. 7)

Figure 22. Relative composition of ground water by well class, West Salt River Valley, Arizona, 1996–97.

Well classes A and D yield native ground water that has not been affected by irrigation seepage. Water from class A wells probably is from a different source than water from class D wells. Ground water from class A wells is a calcium bicarbonate type and ground water from class D wells is a mixed sodium bicarbonate chloride type (fig. 22). Most samples of ground water from beneath clay beds (class D wells) were collected in the southern part of the West Salt River Valley where flow in the Salt and Gila Rivers could have provided recharge before ground-water development. Ground water in the northern part of the subbasin, including most of the still-undeveloped area, probably was recharged by runoff from the local mountains at the basin margins or by underflow along the northwest margin of the West Salt River Valley. Median concentrations of the principal inorganic constituents in samples from class A wells were lower than median concentrations for any other well class (**table 7**).

Ground water from class C and E wells is a sodium chloride type and has been affected by the recharge of agricultural irrigation seepage. Median concentrations of dissolved solids, calcium, sodium, chloride, and sulfate were much higher in samples from wells in classes C and E than in samples from wells in other classes. The higher concentration of dissolved solids in water from class C and E wells compared with concentrations from class B wells, however, probably is the result of the higher concentration of dissolved solids in the applied irrigation water near the C and E wells. Ground water in the southwestern part (downstream end) of the study area where the class C and E wells are located, has a higher dissolved-solids concentration than ground water in the eastern part (upstream end). The higher concentrations in this area are the result of salts in the irrigation water and the reuse of water as it moves through the West Salt River Valley. The median concentration of dissolved solids in water from the head of the Buckeye Canal (Tadayon and others, 1998 and 1999) was 1,400 mg/L, which is greater than that for the class B wells (668 mg/L).

Class B wells are in areas that have been irrigated for agricultural or urban purposes, and the ground water yielded by these wells could have been affected by irrigation seepage. The water from class B wells varied widely, from a sodium bicarbonate chloride type to a calcium magnesium chloride type, possibly because of the variety of sources of applied irrigation water and the variety in location and well construction. The dissolved-solids concentration of water from class B wells is not significantly different from dissolved-solids concentrations in water from the confined aquifer from the class D wells in spite of the more variable ground water chemistry associated with class B wells.

Nitrate

Nitrate concentrations were distributed somewhat differently among the well classes than dissolved solids (**fig. 23**). The median concentrations of nitrate in samples from class A and D wells were significantly less than the median concentrations for the other well classes. Wells in classes A and D are not affected by recharge from irrigation seepage. The median nitrate concentrations were 1.7 and 2.0 mg/L (as nitrogen), respectively. The median concentration of nitrate for samples from each of the other well classes exceeded the MCL for nitrate in drinking water. Although the median concentrations in samples from class C and E wells were the highest, nitrate concentrations in samples from some individual wells in class B exceeded these medians. Nitrate concentrations ranged from 2 to 38 mg/L (as nitrogen) in class B wells. This wide range of nitrate concentrations in samples from class B wells probably resulted from variation in well depth, well construction, geographic location, and fertilizer use.

Isotopes

The $\delta^{18}O$ and δD values of ground-water samples from each well class in the study area plot to the right of the GMWL (**fig. 24**). Most isotope data from wells in classes A and D tend to plot close to the GMWL and indicate that ground water from these wells, which are outside the irrigated areas or yield water from below a confining clay bed, does not show significant effects of evaporation. Most isotope data from class B, C, and E wells are enriched in ^{18}O and D and tend to plot farther to the right of the GMWL than values for class A and D wells. The enrichment of ^{18}O and D in ground water from class B, C, and E wells indicates that ground water has been affected by the recharge of irrigation seepage that has undergone evaporation.

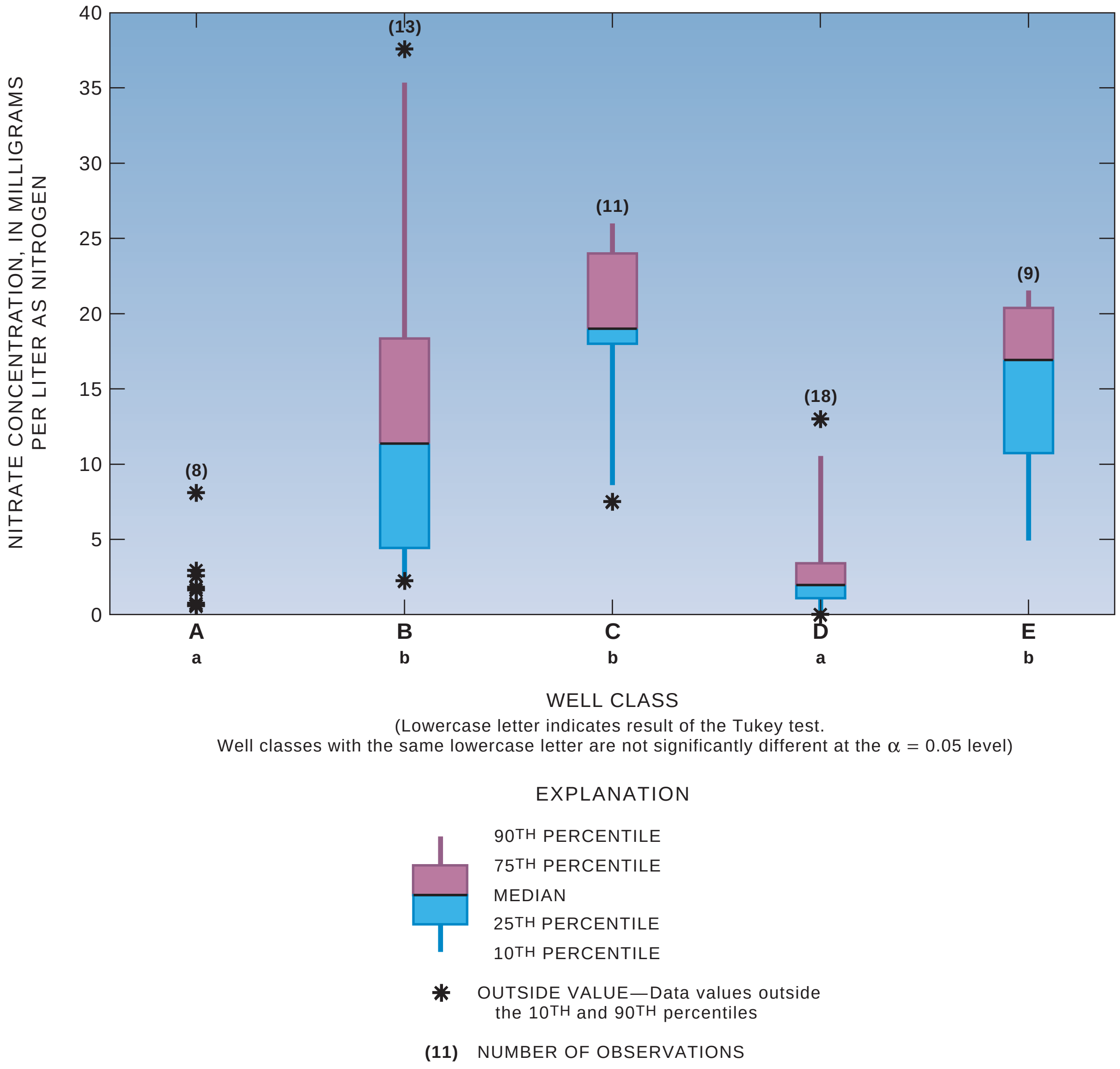


Figure 23. Nitrate concentration in ground water by well class, West Salt River Valley, Arizona, 1996–97.

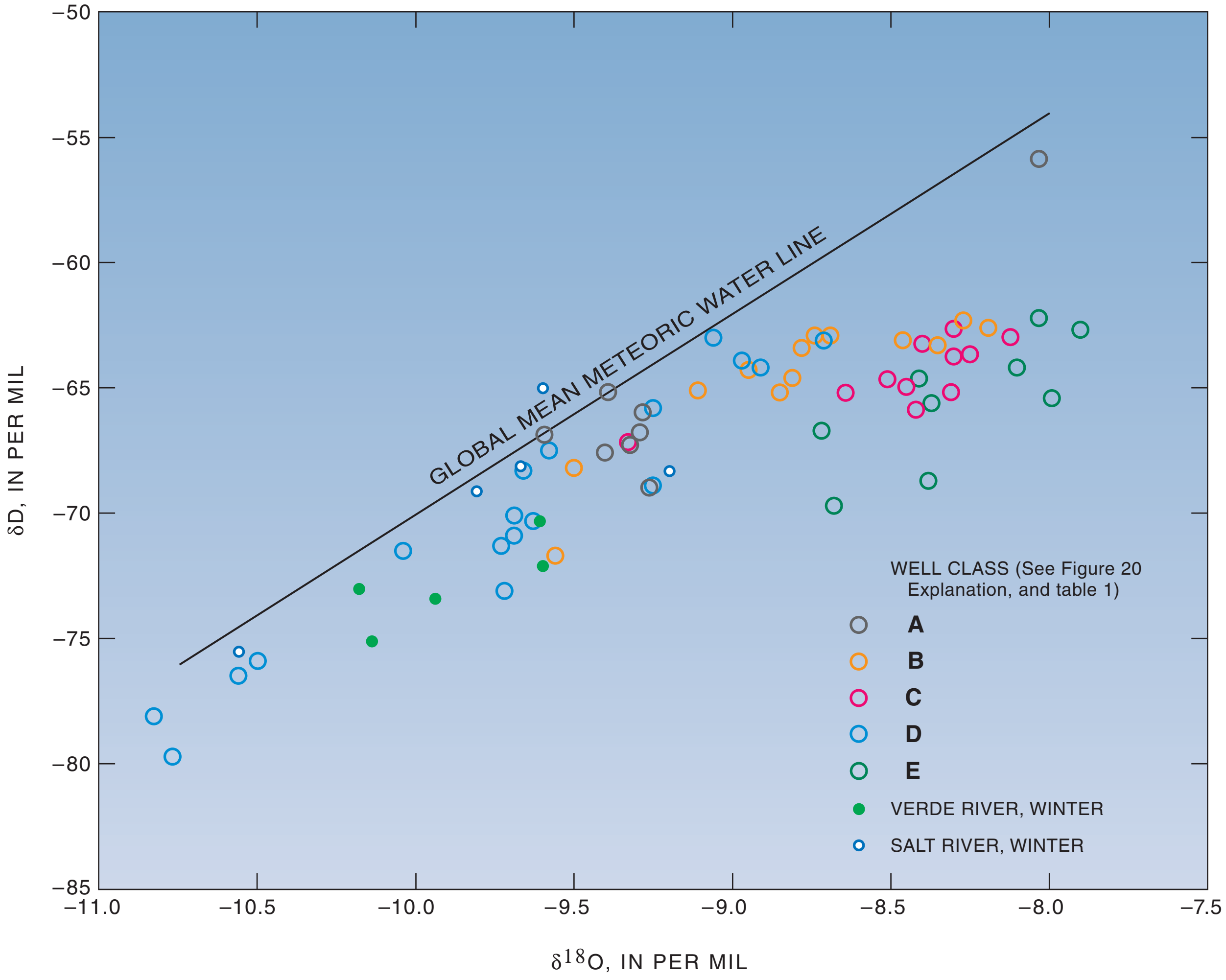


Figure 24. Relation between δD and $\delta^{18}O$ in ground water by well class, West Salt River Valley, Arizona, 1996–97.

Median $\delta^{18}O$ values for samples from class A and D wells are not considered to be significantly different from each other (**fig. 25**), but the range of values is much greater for the wells in class D, which have perforations beneath confining clay beds. The $\delta^{18}O$ values for class A ranged from -9.59 to -9.26 per mil. The $\delta^{18}O$ values of class D ranged from -10.83 to -8.71 per mil. Additionally, points in the plot of δD against $\delta^{18}O$ (fig. 24) are more tightly grouped for ground water from class A wells than for ground water from class D wells. Data for class A wells reflect an isotopically homogenous source of recharge from precipitation over mountains to the north of the study area or from underflow from northwest of the West Salt River Valley. The greater range in isotopic composition of water from class D wells reflects the variability of the isotopic composition of the rivers, which were the probable recharge sources in predevelopment times. The difference in the range of $\delta^{18}O$ values between samples from class A and D wells, however, may be simply the result of the small sample size of class A.

Tukey's multiple-comparison test on the ranks of $\delta^{18}O$ values indicates that the median values of $\delta^{18}O$ in water from class B, C, and E wells cannot be considered to be significantly different statistically (fig. 25). Class B and C wells, however, have greater ranges of $\delta^{18}O$ values than class E wells. The range of $\delta^{18}O$ values for class B and C wells is -9.50 to -8.19 per mil and -9.92 to -8.12 per mil, respectively. The range of $\delta^{18}O$ values for class E wells is -8.72 to -7.90 per mil. The plot of the $\delta^{18}O$ and δD values for class B wells (fig. 24) defines an evaporation trajectory to the right of the GMWL.

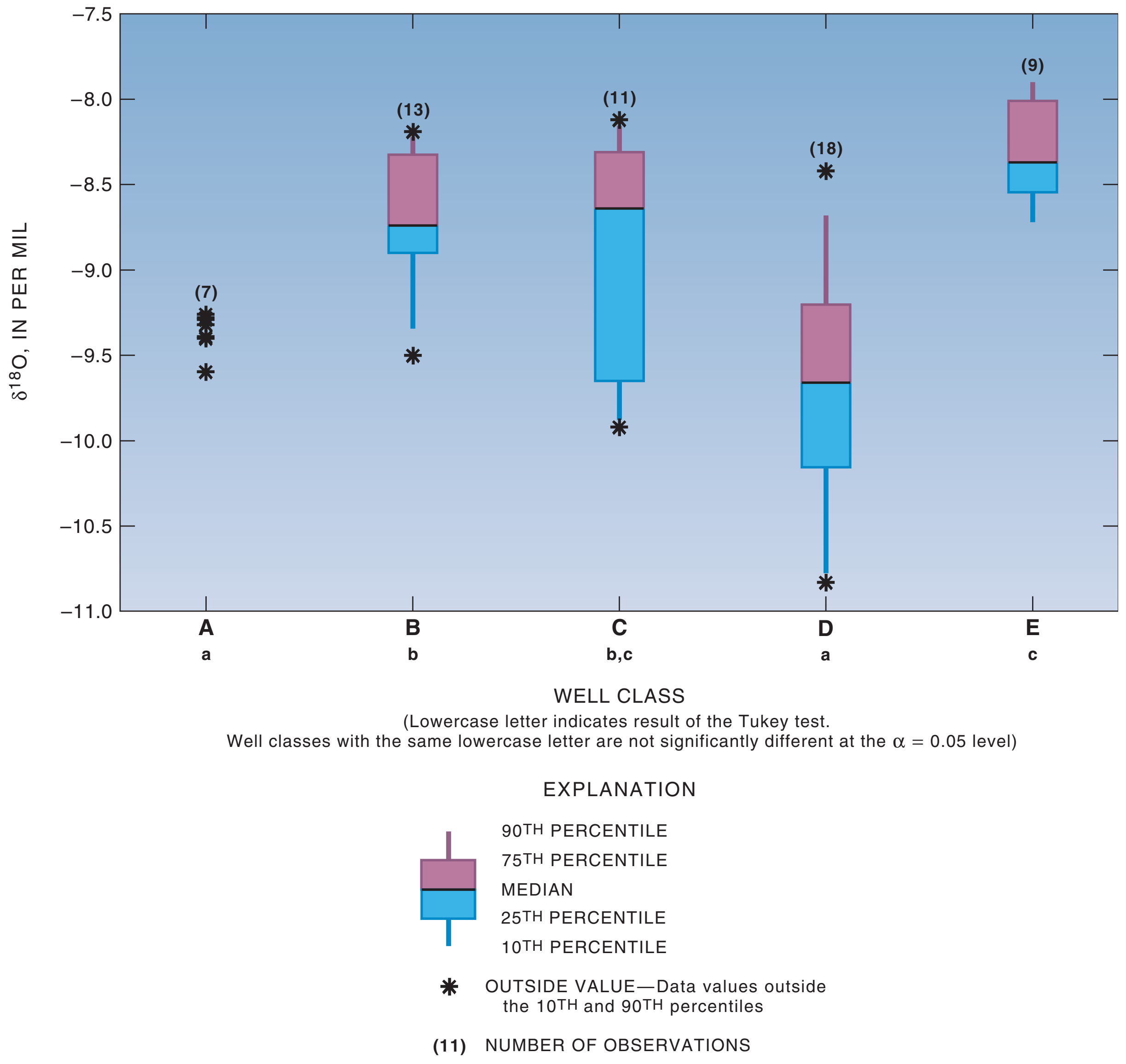


Figure 25. Relative oxygen-isotope ratios in ground water by well class, West Salt River Valley, Arizona, 1996–97.

The linear projection of that trajectory to the GMWL intersects the group of points for the class A wells and could indicate that water from the class B wells is evaporated native ground water that has a source similar to that of water in the class A wells.

Although most recharge to class B and C wells probably is from irrigation seepage, differences in the depths of well-perforation and in well locations may contribute to the variability of $\delta^{18}O$ values. Many wells in class C are perforated over long intervals and may yield some ground water depleted in ^{18}O and D from below the clay beds in addition to shallow ground water. Class B also includes wells that could receive direct recharge from canals, or from the Agua Fria River, that has not been enriched in ^{18}O and D by evaporation. Tritium was detected in 8 of the 13 class B wells, which indicates that at least some of the ground water had originated as precipitation sometime since 1953.

Well 42 was omitted from the statistical calculations because its $\delta^{18}O$ value of -8.03 per mil is an outlier in the data from well class A (fig. 24). The well is south of the Gila River and receives recharge from rainfall on low desert mountains south of the study area where snowmelt is not a significant contributor. The value of $\delta^{18}O$ is believed to reflect the value of the recharge water rather than the effects of evaporation because no irrigated areas are nearby. Data from other wells in class A reflect a source of recharge that is more depleted in the heavy isotopes than recharge for well 42.

The sample collected from well 47 represents an outlier in the water chemistry data from the class D wells (ground water below the clay beds). Well 47 has adequate log information and is constructed so that all pumped water should come from below the clay beds. The dissolved-solids concentration is higher than expected (1,720 mg L), and sodium and chloride are the predominant ions. A low nitrate concentration (2.0 mg/L, as nitrogen) and a low $\delta^{18}O$ (-10.56 per mil) in well 47 rule out the possibility of infiltration of recharge water affected by irrigation seepage. Well 47 lies close to the Gila River and may lie in a zone of high salinity mapped by Kister (1974).

Pesticides

The distribution of pesticide and pesticide-degradation compounds in ground water was similar to the distribution of nitrate concentrations. Pesticides were detected in class B, C, and E wells (**table 8**). The three well classes also had the highest median nitrate concentrations. Samples from these three classes were expected to have detectable concentrations of pesticides because the wells are in areas where pesticides were applied to crops that receive irrigation water, which can recharge the ground water. Pesticide detections in water from class A and D wells were not expected because the wells represent an area that has never been irrigated (class A) and an area where wells were perforated below a clay bed (class D). Pesticide detections in class B, C, and E wells indicate the effect of irrigation on unconfined aquifers.

Of the pesticides detected in wells sampled, 4 were insecticides or degradation products of insecticides, and the remaining 13 compounds were herbicides or degradation products of herbicides (**fig. 26**). In most of the wells in which pesticides were detected, three or more pesticides were detected. Within class C, eight wells (80 percent) had three or more pesticides detected. Within class E, nine wells (100 percent) had three or more pesticides detected. In class B, two wells (wells 16 and 17; 15 percent) had three or more pesticides detected.

The most commonly detected compound in class B, C, and E wells was deethylatrazine, which was detected in ground water from two, nine, and nine wells, respectively. The next most commonly detected compounds were atrazine, simazine, and prometon. Atrazine was detected in one class B well, seven class C wells, and eight class E wells. Simazine was detected in two class B wells, four class C wells, and eight class E wells. Prometon was detected in two wells in class B, three well in class C, and six wells in class E. These findings indicate that these compounds are used widely within the study area and are reaching the ground water where there is sufficient irrigation seepage. Lack of pesticide detections in areas where pesticides have been used possibly is attributed to insufficient irrigation seepage or adsorption of pesticides to soil particles.

Three of the pesticides and degradation compounds detected in class B, C, and E wells are from compounds that have been banned for several years—DDT, dieldrin, and dinoseb. These compounds were detected in ground water from wells in the current (1995) agricultural area (**fig. 3**; wells 2, 4, 5, 6, 7, 8, 9, 60, 62, 64, and 68) and in metropolitan Phoenix (well 17). Ground water in areas that are or were irrigated may be contaminated by pesticides that have been banned from use but persist in the soil and ground water.

Table 8. Detection of pesticides for different well classes, West Salt River Valley, Arizona, 1996–98

Well class	Number of detections	Number of wells where pesticides were detected	Number of compounds detected
A	0	0	0
B	11	6	7
C	35	10	11
D	0	0	0
E	78	9	10

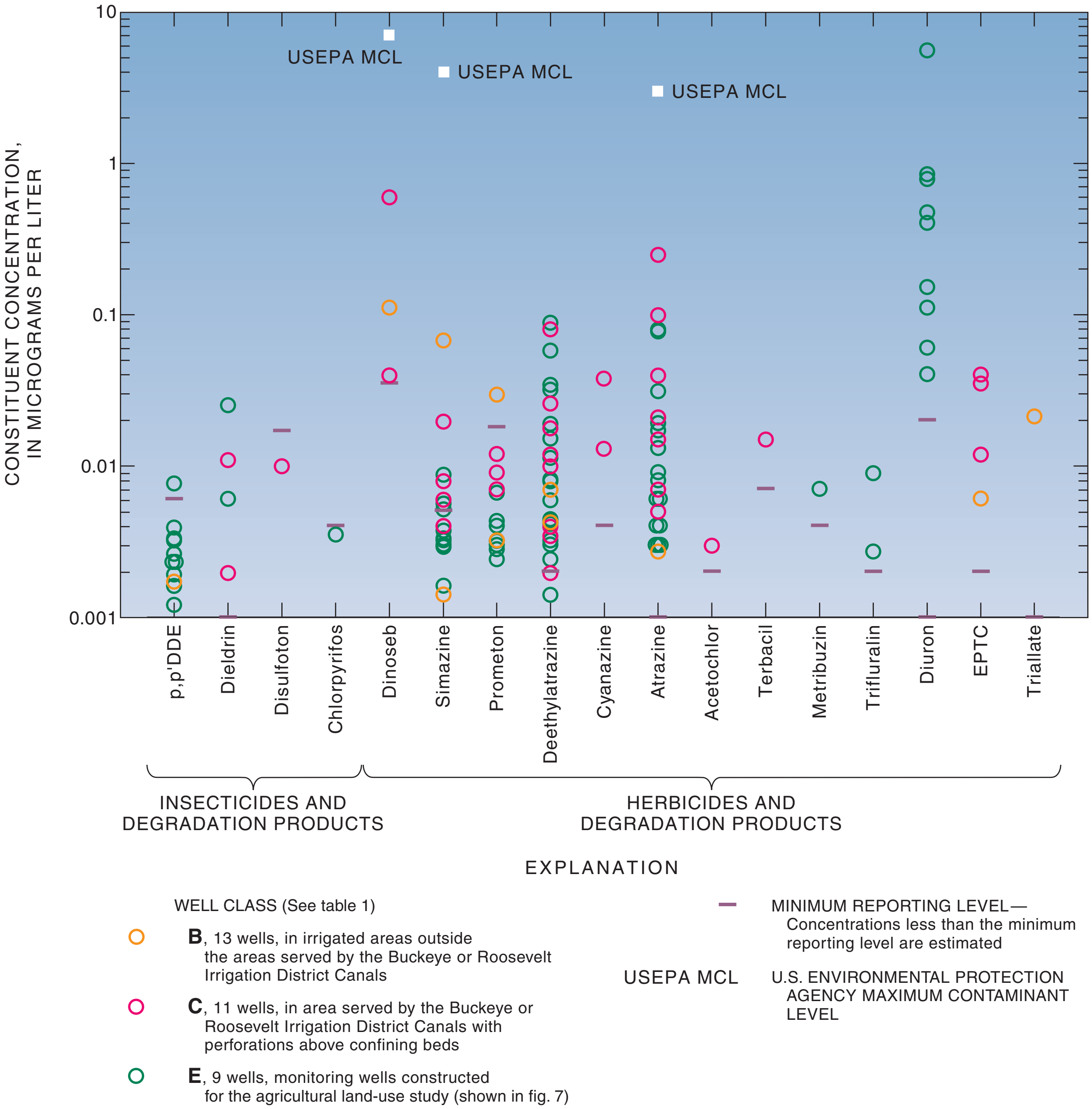


Figure 26. Pesticides in ground water by well class, West Salt River Valley, Arizona, 1996–98.

SUMMARY AND CONCLUSIONS

Ground-water quality in the West Salt River Valley was assessed by the USGS during 1996–98 as a part of the NAWQA program. Samples were collected to characterize the ground-water quality in the valley in the context of water use, land use, and hydrogeologic factors. Samples were collected from 64 existing wells selected by a stratified-random procedure to assess the chemical characteristics of ground water throughout the valley. Nine monitoring wells were constructed and sampled to observe the effects of agricultural land use on ground-water quality.

Water samples were collected using standard NAWQA sampling techniques and protocols. Field measurements of specific conductance, pH, alkalinity, turbidity, dissolved oxygen, and water temperature were made at the time of sampling. Water samples were analyzed in USGS laboratories. Samples were analyzed for major ions, trace constituents, pesticides, VOCs, stable isotopes of hydrogen and oxygen, tritium, and radon. Replicate and blank samples were collected to ensure that the analyses of the ground-water samples were representative of actual water quality.

The West Salt River Valley was subdivided into 35 cells of equal area. One well from each cell was selected randomly and sampled to provide uniform geographic coverage for statistical analysis of the ground-water quality of the SUS. The MCL of 10 mg/L for nitrate was exceeded in 11 of these 35 wells. Wells that yield water that exceeds the MCL for nitrate are in areas that have past and (or) present agricultural or urban irrigation. Fluoride exceeded the MCL of 4 mg/L in 2 of the 35 wells, and exceeded the SMCL of 2 mg/L in 7 wells. Although the water from 2 sampled wells exceeded the MCL of 50 µg/L for arsenic, 17 wells (49 percent) would exceed the proposed drinking-water standard of 5 µg/L. Pesticides were detected in 23 percent of the SUS wells in both agricultural and nonagricultural settings; however, the concentrations did not exceed MCLs of the USEPA or standards of the State of Arizona. The most frequently detected pesticide was deethylatrazine, a degradation product of the herbicide atrazine. VOCs were detected in samples from 21 of the 30 wells sampled for analysis (70 percent); however, most detections were below the MRL and none exceeded established standards. Detections of VOCs at such low levels may or may not imply contamination in the ground water; it is difficult to identify specific sources of the VOCs in these samples at the low concentrations. Tritium was not detected in samples from 57 percent of the wells, which indicates that the water from these wells had fallen as precipitation sometime before 1953 and implies that ground-water quality may not be related to current or recent land use.

Samples collected from the nine wells constructed for the ALUS are representative of ground water that has been recharged by recent irrigation seepage. Samples were collected in August 1997 and again in February 1998 to detect seasonal differences in water quality. The dissolved-solids concentration and the concentrations of principal inorganic constituents were higher in the ALUS wells than in the SUS wells. No significant change in the concentration of dissolved solids was noted between the samples collected in August 1997 and the samples collected in February 1998. The median nitrate concentration in the ALUS wells exceeded the MCL. The median nitrate concentration in the samples collected in February 1998 (19.6 mg/L) was significantly higher than the median nitrate concentration of the samples collected in August 1997 (16.9 mg/L). The increase in nitrate concentration in shallow ground water several months after the irrigation season could be a function of the rate at which irrigation seepage reaches the water table. Median concentrations of trace constituents in the ALUS wells are not greatly different than in the SUS wells, and none of the concentrations exceeded the MCLs. Water from ALUS wells is enriched in ^{18}O compared with water from the SUS wells as a result of recharge of evaporated irrigation seepage.

Pesticides and VOCs were found in shallow ground water in the ALUS area. Pesticides were detected in eight of the nine wells sampled in August 1997 and in all nine wells in February 1998. None of the pesticide concentrations exceeded established standards. Atrazine and deethylatrazine were the most commonly detected pesticides. Low levels of dieldrin and DDE were detected in two and six monitoring wells, respectively. Detections of these two compounds, which have been banned from use, indicates that residual pesticides in the soil can affect ground water. At least one VOC was detected in each of the samples from the ALUS wells although none of the concentrations exceeded established USEPA or State of Arizona standards. Eight different VOCs were detected a total of 23 times in samples collected in August 1997, and 8 different VOCs were detected 20 times in samples collected in February 1998. Trichloromethane (chloroform) was the VOC detected most frequently in samples collected from the ALUS wells.

The wells sampled by NAWQA were grouped into five classes on the basis of well construction, water use, and screened depth relative to a confining bed to evaluate ground-water quality. Statistically significant differences between classes were found in the quality of the sampled ground water. Median nitrate concentrations in ground water from classes of wells that have been affected by irrigation seepage (classes B, C, and E) exceeded the MCL of 10 mg/L (as nitrogen). Median nitrate concentrations at wells in undeveloped areas (class A) and at wells in which the aquifer is protected by a confining bed (class D) were 1.7 and 2.0 mg/L, respectively. The median dissolved-solids concentration for class C and E wells yielding shallow ground water in an area west of the Agua Fria River and south of the RID Canal was much higher than concentrations for the other well classes. Evaporation of recharge water during irrigation probably has caused an enrichment of D and ^{18}O in ground water of well classes B, C, and E. Pesticides were not detected in wells in undeveloped areas (class A) or those wells completed in aquifers protected by confining beds (class D).

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QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance (QA) techniques were applied and quality control (QC) samples were collected according to NAWQA protocols (Koterba and others, 1995) to verify the accuracy of the data produced. The following description gives specific details of QA/QC for inorganic constituents in samples collected as part of the SUS and the ALUS in the West Salt River Valley. Gellenbeck (2002) gives details about the QA and QC samples for organic constituents. An analysis of data from the QC samples is included to document that the data were not significantly biased by contamination during sample collection or analysis (table 9). Results of analyses of samples collected for QC are contained in tables 10, 11, 12, and 13 in this section. Discussion of the QC samples is in two parts—the first part discusses the quality of data for the SUS, and the second part discusses the quality of data for the ALUS. Because differing well types and sampling methods were used for the SUS and the ALUS, QC samples collected for each study can be used to qualify the data for the respective study only.

Table 9. Number and type of quality-control samples collected, West Salt River Valley, Arizona

[Dashes indicate no data]

Constituent	Number and type of sample Field blanks	 Equipment blanks	 Replicates
Existing wells			
Inorganic constituent	9	---	9
Trace constituents	9	---	13
Land-use survey			
Inorganic constituents	[1]4	2	4
Trace constituents	[1]4	2	8

[1] Two samples in August 1997 and two samples in February 1998.

Table 10. Water-quality data for field-blank samples from existing wells, West Salt River Valley, Arizona

[Values are in milligrams per liter unless otherwise indicated. <, less than; μg/L, micrograms per liter. Data are for wells shown in figure 8. Dashes indicate no data]

Property or constituent	Site numbers 12	 20	 30	 41	 45	 47	 61	 63	 65
Dissolved solids	3	4	<1	<1	3	8	2	<1	<1
Calcium	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
Magnesium	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Sodium	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Potassium	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Chloride	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Sulfate	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Nitrate plus nitrite (as nitrogen)	<.05	<.05	<.05	.13	<.05	.065	<.05	<.05	<.05
Ammonia	<.015	<.015	<.015	<.015	<.015	<.015	<.015	<.015	<.015
Phosphorus	<.01	.049	<.01	<.01	<.01	.03	<.01	<.01	<.01
Arsenic (μg/L)	<1	<1	<1	<1	<1	<1	---	<1	<1
Barium (μg/L)	<.2	<.2	<.2	<.2	.27	<.2	<.2	<.2	<.2
Chromium (μg/L)	.29	.83	<.2	.2	.76	.54	.21	.26	<.2
Fluoride	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Molybdenum (μg/L)	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2	<.2
Selenium (μg/L)	<1	<1	<1	<1	<1	<1	---	<1	<1
Strontium (μg/L)	<.1	.18	<.1	<.1	<.1	<.1	<.1	.14	<.1

Table 11. Water-quality data for replicate samples from existing wells, West Salt River Valley, Arizona

[All values in milligrams per liter unless otherwise indicated. <, less than; µg/L, micrograms per liter; pCi/L, picocuries per liter; per mil, parts per thousand. Data are for wells shown in figure 8. Dashes indicate no data]

Property or constituent	Site numbers												
	12	**15**	**20**	**23**	**25**	**30**	**41**	**45**	**47**	**58**	**61**	**63**	**68**
Dissolved solids	705	---	972	---	2,920	280	484	1,570	1,720	---	3,020	494	---
	706	---	1,080	---	2,920	284	486	1,570	1,720	---	2,980	480	---
Calcium	25	---	110	---	170	28	67	31	55	---	430	39	---
	26	---	110	---	170	28	67	31	57	---	420	39	---
Magnesium	12	---	65	---	100	15	17	.16	3.8	---	81	16	---
	12	---	61	---	100	15	17	.16	3.7	---	81	16	---
Sodium	210	---	71	---	640	50	61	460	560	---	340	110	---
	210	---	67	---	640	50	62	460	570	---	350	110	---
Potassium	2.8	---	5.7	---	1.2	2.4	3.0	1.7	4.6	---	1.2	3.1	---
	2.8	---	5.6	---	1.2	2.4	3.0	1.8	4.5	---	1.2	3.1	---
Chloride	310	---	270	---	1,000	56	40	220	830	---	1,000	140	---
	320	---	270	---	1,000	53	40	220	810	---	990	140	---
Sulfate	69	---	140	---	500	35	180	730	150	---	620	67	---
	69	---	140	---	510	35	180	730	160	---	620	67	---
Nitrate plus nitrite (as nitrogen)	1.02	---	37.6	---	18	2.69	1.8	<.05	2.01	---	29	13	---
	.978	---	36.4	---	18	2.69	1.9	.055	1.96	---	29	13	---
Ammonia	<.015	---	<.015	---	<.015	<.015	.02	<.015	<.015	---	.07	<.015	---
	<.015	---	<.015	---	<.015	<.015	<.015	.332	<.015	---	.09	<.015	---
Phosphorus	<.01	---	<.01	---	<.01	<.01	.01	<.01	.014	---	<.01	<.01	---
	<.01	---	<.01	---	<.01	<.01	<.01	<.01	<.01	---	<.01	<.01	---
Arsenic (µg/L)	4	3	4	16	1	7	16	38	48	28	3	13	4
	5	3	4	16	2	6	17	37	46	27	3	12	4
Barium (µg/L)	53	168	47	19	46	49	57	18	67	91	77	99	29
	53	163	47	18	45	48	58	18	68	95	76	101	29
Chromium (µg/L)	24	7.7	18	23	8.0	[1]2.1	[1]1.0	<1	30	28	6.0	22	6.0
	25	8.0	19	23	8.0	[1]2.0	[1]1.0	<1	30	27	6.0	21	4.0
Fluoride	.36	---	.53	---	1.5	.54	.90	7.8	3.1	---	.60	1.0	---
	.31	---	.51	---	1.5	.50	.90	8.0	3.3	---	.60	1.0	---
Molybdenum (µg/L)	6.0	<1	1.2	2.5	41	1.2	10	61	28	6	<2	4	24
	6.9	<1	1.1	2.6	41	1.3	10	62	29	6	<2	4	25
Selenium (µg/L)	<1	3	6	<1	16	<1	2	<1	1	1	11	2	16
	<1	2	7	<1	16	<1	2	<1	1	1	12	1	13
Strontium (µg/L)	860	2,360	1,800	418	---	596	---	771	1,440	---	---	---	---
	856	2,370	1,780	411	---	595	---	732	1,490	---	---	---	---
Tritium (pCi/L)	<2.5	---	<2.5	---	19	8.3	<2.5	<2.5	<2.5	---	<5.7	4.2	---
	<2.5	---	<2.5	---	15	7.4	<2.5	<2.5	<2.5	---	<5.7	4.2	---
Hydrogen isotope ratio (δD, per mil)	-70.9	---	-63.1	---	-65.1	-68.2	-67.3	-78.1	-76.5	---	-62.4	-64.3	---
	-69.5	---	-63.8	---	-66.0	-68.4	-65.6	-79.3	-77.1	---	-62.3	-64.5	---
Oxygen isotope ratio ($\delta^{18}O$, per mil)	-9.69	---	-8.42	---	-8.64	-9.50	-9.32	-10.83	-10.56	---	-8.38	-8.95	---
	-9.66	---	-8.46	---	-8.61	-9.50	-9.30	-10.85	-10.49	---	-8.35	-8.94	---

[1] Sample may have been contaminated during collection.

Table 12. Water-quality data for field-blank and equipment-blank samples, agricultural land-use study, West Salt River Valley, Arizona

[All values in milligrams per liter unless otherwise indicated. <, less than; µg/L, micrograms per liter. Data are for wells shown in figure 7]

Property or constituent	Field blanks				Equipment blanks	
Site Number	9	3	5	6		
Date of Sample	8–21–97	8–28–97	2–3–98	2–11–98	8–18–97	2–2–98
Dissolved solids	18	2	<10	<10	14	<10
Calcium	<.02	.021	.051	<.02	.079	.053
Magnesium	<.01	<.01	.024	<.004	.031	.024
Sodium	<.2	<.2	.174	<.1	.206	.174
Potassium	<.1	<.1	<.1	<.1	.1	<.1
Chloride	<.1	<.1	.238	<.1	<.1	<.1
Sulfate	<.1	<.1	.247	<.1	<.1	<.1
Nitrate plus nitrite (as nitrogen)	.059	.099	.059	.077	.06	<.05
Ammonia	.039	<.015	<.02	<.02	.026	<.02
Phosphorus	<.01	<.01	<.01	<.01	<.01	<.01
Arsenic (µg/L)	<1	<1	<1	<1	<1	<1
Barium (µg/L)	<.2	<.2	<.2	<.2	<.2	<.2
Chromium (µg/L)	1.11	.37	.27	<.2	.52	.37
Fluoride	<.1	<.1	<.1	<.1	<.1	<.1
Molybdenum (µg/L)	<.2	<.2	<.2	<.2	<.5	<.2
Selenium (µg/L)	<1	<1	<1	<1	<1	<1
Strontium (µg/L)	<.1	<.1	.17	<.1	.31	<.1

Table 13. Water-quality data for replicate samples, agricultural land-use study, West Salt River Valley, Arizona

[All values in milligrams per liter unless otherwise indicated. <, less than; µg/L, micrograms per liter; pCi/L, picocuries per liter; per mil, parts per thousand. Data are for wells shown in figure 7. Dashes indicate no data]

Property or constituent	Site numbers and dates of sampling							
	9	6	8	3	5	1	6	7
	8–21–97	8–22–97	8–26–97	8–28–97	2–3–98	2–10–98	2–11–98	2–12–98
Dissolved solids	3,780	---	---	3,800	4,420	---	3,120	---
	3,780	---	---	3,800	4,470	---	3,160	---
Calcium	210	---	---	160	470	---	200	---
	250	---	---	160	470	---	200	---
Magnesium	105	---	---	101	86	---	90	---
	111	---	---	101	86	---	90	---
Sodium	851	---	---	896	788	---	798	---
	888	---	---	894	786	---	788	---
Potassium	5.3	---	---	4.8	4.2	---	9.7	---
	5.5	---	---	4.8	4.2	---	1.8	---
Chloride	1,200	---	---	1,000	800	---	1,100	---
	1,200	---	---	1,000	780	---	1,100	---
Sulfate	830	---	---	1,100	1,800	---	520	---
	830	---	---	1,100	1,800	---	520	---
Nitrate plus nitrite	19.8	---	---	21.0	19.6	---	6.92	---
(as nitrogen)	21.1	---	---	21.8	19.8	---	7.02	---

Table 13. Water-quality data for replicate samples, agricultural land-use study, West Salt River Valley, Arizona—Continued

	Site numbers and dates of sampling							
	9	6	8	3	5	1	6	7
Property or constituent	8–21–97	8–22–97	8–26–97	8–28–97	2–3–98	2–10–98	2–11–98	2–12–98
Ammonia	.031	---	---	<.015	.04	---	<.02	---
	.033	---	---	<.015	.031	---	<.02	---
Phosphorus	0.013	---	---	<.01	<.01	---	.141	---
	0.019	---	---	<.01	<.01	---	.145	---
Arsenic (μg/L)	14	17	20	3	26	2	17	1
	14	16	20	3	25	2	16	1
Barium (μg/L)	30	47	14	23	13	44	48	56
	29	46	14	24	13	45	48	56
Chromium (μg/L)	7.0	8.2	4.6	8.1	9.4	9.3	16	16
	7.5	7.7	4.9	8.6	9.3	10	18	16
Fluoride	2.9	---	---	1.2	3.4	---	3.0	---
	2.9	---	---	1.2	3.6	---	3.0	---
Molybdenum (μg/L)	13	9.8	55	46	46	3.6	9.9	4.5
	14	10	55	46	46	4.0	10	4.4
Selenium (μg/L)	8	3	24	19	14	6	3	8
	9	3	27	20	14	5	3	8
Strontium (μg/L)	4,500	2,400	25,800	3,860	16,000	5,770	2,740	4,430
	4,600	2,410	25,800	3,800	15,900	5,900	2,750	4,350
Tritium (pCi/L)	17.9	---	---	15	20.5	---	22.4	---
	19.2	---	---	15.4	20.5	---	20.8	---
Hydrogen isotope ratio (δD, per mil)	-64.2	---	---	-65.6	-62.6	---	-64.8	---
	-63.1	---	---	-64.6	-60.5	---	-68.3	---
Oxygen isotope ratio (δ^{18}O, per mil)	-8.10	---	---	-8.37	-8.00	---	-8.23	---
	-8.11	---	---	-8.34	-8.04	---	-8.19	---

Statistics calculated using data from ground-water analyses are more affected by the systematic contamination of a majority of the samples than by the random contamination of a few samples. Even systematic contamination of a majority of samples may not significantly affect calculated statistics of a constituent if the concentration caused by contamination is much less than the concentration of that constituent in environmental samples. Blank samples were processed in the field and analyzed to determine the extent of contamination associated with sample collection and analysis. Field-blank samples were processed after collection of the environmental samples was completed and after water that was free of the constituents of interest was passed through the sampling equipment. Systematic contamination for a particular constituent was considered to be present if more than 50 percent of the field-blank samples contained measurable quantities of that constituent. Individual environmental samples were considered to be significantly contaminated if the concentration of a particular constituent was greater than 10 percent of its median concentration in the blank samples.

For the existing wells, the sample population was nine field-blank samples collected during 1996–97 (tables 1 and 9). Seven of the nine samples (sites 12, 20, 41, 45, 47, 61, and 63) had measurable concentrations of chromium that possibly were from steel casings in the wells. The median chromium concentration in the blank samples was 26 μg/L. Environmental concentrations of chromium were considered to be contaminated if the concentrations were less than 2.60 μg/L. Most of the environmental concentrations (median = 11 μg/L), however, were greater than 2.60 μg/L and were not considered to be significantly contaminated.

For the ALUS, the sample population was four field-blank samples collected during 1997–98 (table 9). Two of the four field-blank samples for the ALUS had measurable concentrations of calcium and dissolved solids. Environmental concentrations of calcium and dissolved solids in all ALUS samples were greater than 10 times the median concentration in the blank samples and, therefore, the environmental samples were considered not to be significantly contaminated. Three of the four field-blank samples for the ALUS had measurable concentrations of chromium; environmental concentrations in all ALUS samples were greater than 10 times the median concentration in the blank samples. None of the concentrations in the ALUS environmental samples was considered to be significantly biased by contamination during collection and analysis. All four field-blank samples had measurable concentrations of nitrate, but all the environmental concentrations were greater than 10 times the median of the nitrate concentrations in the blank samples. The ALUS nitrate concentrations were not considered to be significantly biased by contamination.

Replicate samples were obtained by sequentially collecting two environmental samples for analyses of the same constituents from the same site. Data from these samples provide a measure of the variability that results from the combined effects of field and laboratory procedures (tables 11 and 13). Variability in constituent concentrations between each pair of replicate samples is represented in tables 14 and 15 both in terms of absolute concentration units and as a percent difference. The percent difference is the absolute value of the difference between concentrations in the replicate samples divided by the average concentration for the replicate samples multiplied by 100.

Table 14. Summary of replicate analyses for existing wells, West Salt River Valley, Arizona

[All values in milligrams per liter unless otherwise indicated. µg/L, micrograms per liter; pCi/L, picocuries per liter; per mil, parts per thousand. Dashes indicate quantity undefined because of nondetection]

Property or constituent	Replicate analyses for subunit survey						
	Number of samples	Difference, in percent			Difference, in concentration units		
		Minimum	Median	Maximum	Minimum	Median	Maximum
Dissolved solids	9	0	0.4	10	0	2	108
Calcium	9	0	0	3.9	0	0	10
Magnesium	9	0	0	6.4	0	0	4
Sodium	9	0	.5	5.8	0	0	10
Potassium	9	0	0	5.7	0	0	.1
Chloride	9	0	0	5.5	0	0	20
Sulfate	9	0	0	6.4	0	0	10
Nitrate plus nitrite (as nitrogen)	8	0	1.2	5.4	0	.02	1.2
Ammonia	1	---	---	---	.02	.02	.02
Phosphorus	0	---	---	---	---	---	---
Arsenic (µg/L)	13	0	3.6	67	0	1	2
Barium (µg/L)	13	0	1.7	5.5	0	1	5
Chromium (µg/L)	12	0	3.7	40	0	.2	2
Fluoride	9	0	2.1	15	0	.02	.2
Molybdenum (µg/L)	11	0	3.6	14	0	.1	1
Selenium (µg/L)	9	0	8.7	67	0	1	3
Strontium (µg/L)	7	.2	.9	5.3	1	13	52
Tritium (pCi/L)	3	0	11	24	0	.9	4
Hydrogen isotope ratio (δD, per mil)	9	.2	1.1	2.6	.1	.7	1.7
Oxygen isotope ratio ($\delta^{18}O$, per mil)	9	0	.3	.7	0	.03	.07

Table 15. Summary of replicate analyses for agricultural land-use study, West Salt River Valley, Arizona

[All values in milligrams per liter unless otherwise indicated. µg/L, micrograms per liter; pCi/L, picocuries per liter; per mil, parts per thousand]

Property or constituent	Number of samples	Difference, in percent: Minimum	Difference, in percent: Median	Difference, in percent: Maximum	Difference, in concentration units: Minimum	Difference, in concentration units: Median	Difference, in concentration units: Maximum
Dissolved solids	4	0	0.6	1.3	0	20	50
Calcium	4	0	0	17.4	0	0	40
Magnesium	4	0	0	5.6	0	0	6
Sodium	4	.2	.8	4.3	2	6	37
Potassium	4	0	1.9	133.9	0	.1	7.3
Chloride)	4	0	0	2.5	0	0	20
Sulfate	4	0	0	0	0	0	0
Nitrate plus nitrite (as nitrogen)	4	1.0	2.6	6.4	.1	.5	1.3
Ammonia	2	6.3	15.8	25.4	.002	.006	.009
Phosphorus	2	2.8	20.1	37.5	.004	.006	.006
Arsenic (µg/L)	8	0	0	6.1	0	0	1
Barium (µg/L)	8	0	1.1	4.3	0	.5	1
Chromium (µg/L)	8	0	6.3	11.8	0	.5	2
Fluoride	4	0	0	5.7	0	0	.20
Molybdenum (µg/L)	8	0	1.5	10.5	0	.1	1
Selenium (µg/L)	8	0	2.6	18.2	0	0	3
Strontium (µg/L)	8	.1	1.2	2.2	10	74	129
Tritium (pCi/L)	4	0	4.8	7.4	0	.8	1.6
Hydrogen isotope ratio (δD, per mil)	4	1.5	2.6	5.3	1	1.6	3.5
Oxygen isotope ratio (δ^{18}O, per mil)	4	.1	.4	.5	.01	.04	.04

Results for replicate samples collected for the existing wells indicate that the median difference for most of the constituents in replicate samples was less than 5 percent (table 14). Median differences for replicates for selenium and tritium were more than 5 percent. These percentages are equal to absolute differences of 1 µg/L and 0.9 pCi/L for selenium and tritium, respectively. These concentrations are less than one standard deviation from the mean of measurable concentrations for these four constituents in the environmental samples for the SUS. This variation caused by field and laboratory procedures must be considered when variation in the environmental samples is analyzed.

Results for replicate samples collected for the ALUS indicate that the median difference for most constituents was less than 5 percent. Median differences for replicates of ammonia, phosphorus, and chromium were more than 5 percent and were equal to absolute differences of 0.006 µg/L, 0.005 µg/L, and 0.5 µg/L, respectively. These concentrations are less than one standard deviation from the mean of measurable concentrations for these three constituents in environmental samples. The interpretation of any variation between environmental samples must include the possibility that variation is the result of field and laboratory procedures and not environmental factors.

In addition to the QA techniques and QC samples collected, the USGS NWQL maintains an internal program that includes blank, replicate, and spike samples to ensure that the laboratory is analyzing water-quality samples accurately (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, which operates independently of the NWQL, also submits blind samples to the NWQL.