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Central Columbia Plateau (Circular 1144)
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Connecticut, Housatonic and Thames River Basins (Circular 1155)
Eastern Iowa Basins (Circular 1210)
Georgia-Florida Coastal Plain (Circular 1151)
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Western Lake Michigan Drainages (Circular 1156)
White River Basin (Circular 1150)
Willamette Basin (Circular 1161)

National Assessments

The Quality of Our Nation's Waters—Nutrients and Pesticides (Circular 1225)

Front cover: Sabino Creek in Sabino Canyon near Tucson. The water is colored brown by natural tannin from plant material in the stream. *(Photograph by Gail E. Cordy.)*
Back cover: Left, view of Tucson from "A" Mountain*;* right, view of west side of the Whetstone Mountains, southeast of Tucson. *(Photographs by Alissa L. Coes.)*

Water Quality in the Central Arizona Basins, Arizona, 1995–98

By Gail E. Cordy, D.J. Gellenbeck, Joseph B. Gebler, David W. Anning, Alissa L. Coes, R.J. Edmonds, Julie A. H. Rees, *and* H.W. Sanger

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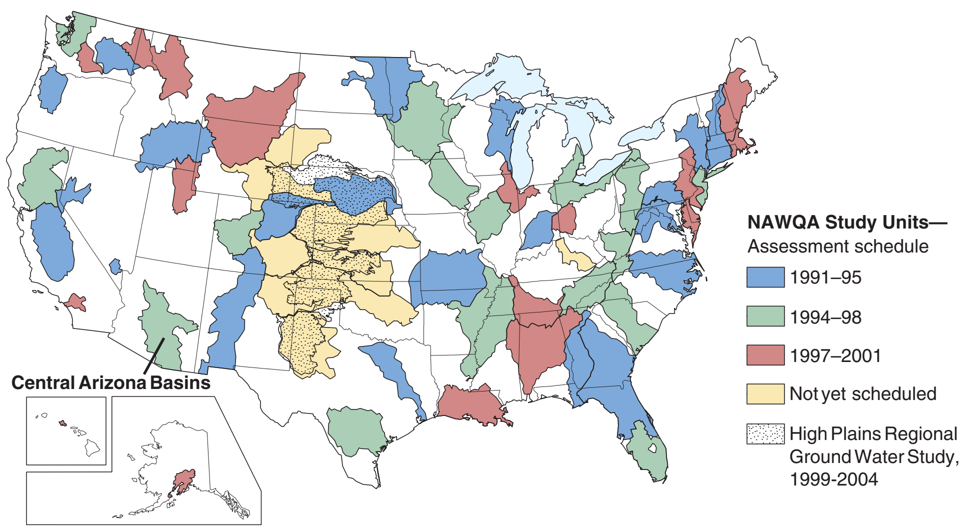
CONTENTS

THIS REPORT summarizes major findings about water quality in the Central Arizona Basins Study Unit that emerged from an assessment conducted between 1995 and 1998 by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Water quality is discussed in terms of local and regional issues and compared to conditions found in the 36 NAWQA study areas, called Study Units, assessed to date. Findings are also explained in the context of selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms. The NAWQA Program was not intended to assess the quality of the Nation's drinking water, such as by monitoring water from household taps. Rather, the assessments focus on the quality of the resource itself, thereby complementing many ongoing Federal, State, and local drinking-water-monitoring programs. The comparisons made in this report to drinking-water standards and guidelines are only in the context of the available untreated resource. Finally, this report includes information about the status of aquatic communities and the condition of in-stream habitats as elements of a complete water-quality assessment.

Many topics covered in this report reflect the concerns of officials of State and Federal agencies, water-resource managers, and members of stakeholder groups who provided advice and input during the Central Arizona Basins assessment. Basin residents who wish to know more about water quality in the areas where they live will find this report informative as well.



THE NAWQA PROGRAM seeks to improve scientific and public understanding of water quality in the Nation's major river basins and ground-water systems. Better understanding facilitates effective resource management, accurate identification of water-quality priorities, and successful development of strategies that protect and restore water quality. Guided by a nationally consistent study design and shaped by ongoing communication with local, State, and Federal agencies, NAWQA assessments support the investigation of local issues and trends while providing a firm foundation for understanding water quality at regional and national scales. The ability to integrate local and national scales of data collection and analysis is a unique feature of the USGS NAWQA Program.

The Central Arizona Basins Study Unit is one of 51 water-quality assessments initiated since 1991, when the U.S. Congress appropriated funds for the USGS to begin the NAWQA Program. As indicated on the map, 36 assessments have been completed, and 15 more assessments will conclude in 2001. Collectively, these assessments cover about one-half of the land area of the United States and include water resources that are available to more than 60 percent of the U.S. population.

The Central Arizona Basins (CAZB) Study Unit of the National Water-Quality Assessment (NAWQA) Program covers 34,700 square miles in the Central Highlands and Basin and Range Lowlands hydrologic provinces. Phoenix was America's fastest growing city during the 1990s, and a population of about 3.8 million people is concentrated around the cities of Phoenix and Tucson. The climate is arid to semiarid, and dams on major perennial streams in the Central Highlands collect water for use in the Phoenix area. More than 50 percent of the water used in the Study Unit is ground water, which is often the sole source available. More than 70 percent of the water is used for agriculture, which accounts for 5 percent of the land use.

Stream and River Highlights

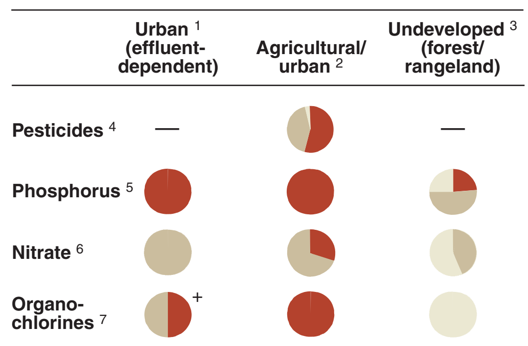
Most of the perennial streams in the Central Arizona Basins (CAZB) Study Unit drain relatively undeveloped basins in the Central Highlands that are covered by forests and (or) rangeland. The water quality of these forest/rangeland streams is primarily determined by natural factors, such as chemical weathering of rocks and soils. About 24 percent of samples from forest/rangeland streams had concentrations of phosphorus that exceeded the U.S. Environmental Protection Agency's (USEPA) desired goal for prevention of nuisance plant growth (eutrophication), whereas nitrate concentrations were typically less than the background levels for streams nationally. More than 75 percent of samples from the Salt River (above reservoirs) exceeded the USEPA drinking-water guideline for dissolved solids; however, rainfall and snowmelt runoff helped dilute these concentrations in reservoirs and in streamflow leaving the reservoirs.

In the Basin and Range Lowlands, streams typically flow only when it rains (ephemeral streams). Consequently, a small fraction of the nutrients and dissolved solids applied to the land surface by human, animal, and natural sources is transported to streams. The remaining dissolved solids and nutrients are accumulating in basins and can degrade ground-water quality.

Urban streams with perennial flow are sustained by the discharge of treated wastewater (effluent-dependent). Agricultural/urban streams are a combination of wastewater and irrigation return flows. All samples from both the effluent-dependent urban and agricultural/urban streams exceeded the USEPA's desired phosphorus goal for prevention of nuisance plant growth, and dissolved-oxygen concentrations were minimal for fish survival. Organochlorine compounds in streambed sediment and fish tissue from urban and agricultural/urban streams exceeded guidelines for protection of aquatic health and fish-eating wildlife.

- Effluent-dependent urban streams are valuable water resources; however, the water quality is poor.
- Organochlorine insecticides from past agricultural use persist in streams, streambed sediment, and fish tissue and are a concern because they exceed guidelines for protection of aquatic life and fish-eating wildlife.
- Insecticide concentrations in water from streams affected by agricultural and urban land uses were among the highest in the Nation.

Selected Indicators of Stream-Water Quality



Percentage of samples with concentrations **equal to or greater than** a health-related national guideline for drinking water, aquatic life, or water-contact recreation; or above a national goal for preventing excess algal growth

Percentage of samples with concentrations **less than** a health-related national guideline for drinking water, aquatic life, or water-contact recreation; or below a national goal for preventing excess algal growth

Percentage of samples with **no detection**

— Not assessed

1 91st Avenue Wastewater Treatment Plant, Santa Cruz River at Cortaro, Santa Cruz River at Tubac, Santa Cruz River near Nogales International Wastewater Treatment Plant (bed sediment only).
2 Buckeye Canal near Avondale (surface water only), Hassayampa River near Arlington (surface water only), Buckeye Canal near Hassayampa (bed sediment only).
3 San Pedro River at Charleston, Gila River at Kelvin, Salt River near Roosevelt, Verde River above West Clear Creek, Verde River below Tangle Creek, West Clear Creek.
4 Insecticides, herbicides, and pesticide metabolites, sampled in water.
5 Total phosphorus, sampled in water.
6 Nitrate (as nitrogen), sampled in water.
7 Organochlorine compounds including DDT and PCBs, sampled in bed sediment.
+ Although the 91st Avenue Wastewater Treatment Plant outfall is classified as urban, past agricultural land use in the area is the source of most organochlorine compounds at this site.

Trends in stream water quality

Water quality of forest/rangeland streams generally is improving over time. From 1950-90, dissolved-solids concentrations decreased in outflow from reservoirs as a result of dilution from increased precipitation and physical and chemical processes in reservoirs. A decrease in nutrient concentrations in forest/rangeland streams in the early 1980s to 1999 could be attributed to decreased contributions from natural sources, better land-use management practices upstream, or increased nitrogen use by aquatic life.

Major Influences on Streams and Rivers

- Natural factors such as chemical weathering of rocks and soil
- Precipitation
- Reservoirs
- Runoff from agricultural and urban lands
- Discharge of treated wastewater to streams

Ground-Water Highlights

Most of the ground water used in the CAZB Study Unit is pumped from basin-fill aquifers in the Basin and Range Lowlands. Water from major aquifers (basinwide) in the West Salt River Valley (WSRV), the Upper Santa Cruz Basin (USCB), and the Sierra Vista subbasin (SVS) generally meets existing USEPA standards and guidelines for drinking water with some exceptions. Nitrate and dissolved-solids concentrations in some samples from the WSRV and USCB exceeded USEPA drinking-water standards and guidelines. Shallow ground water from an agricultural area in the WSRV exceeded drinking-water standards and guidelines for nitrate and dissolved solids in more than 75 percent of samples. More than 90 percent of ground-water samples from the three basins exceeded the USEPA's proposed drinking-water standard for radon. A small percentage of samples exceeded drinking-water standards for arsenic, fluoride, and molybdenum. Samples from urban and agricultural areas contained low concentrations of numerous chemicals (pesticides and volatile organic compounds) that can be linked to household, industrial, and agricultural uses.

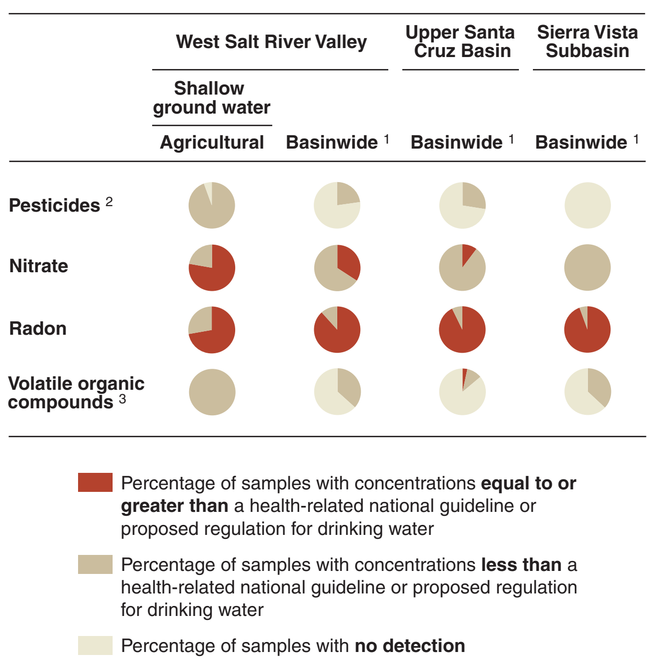
- Most of the deep wells yield old ground water that generally has not been affected by land uses in the last 50 years.
- Use of fertilizers and treated wastewater on agricultural and urban lands and the evaporation of irrigation water have resulted in the accumulation of nitrate and dissolved solids in shallow ground water.
- Adoption of draft or proposed USEPA drinking-water regulations for arsenic, radon, and uranium—constituents that occur naturally in the study area—will require most water suppliers and municipalities to treat their water to remove these constituents or find alternative supplies.
- Pesticides detected in ground-water basins with substantial agricultural and (or) urban development did not exceed USEPA drinking-water standards and guidelines.

Though trends in ground-water quality over time were not determined for the CAZB Study Unit, the data indicate possible future changes. As urban land use spreads with the growing population in the area, ground-water quality is likely to deteriorate, as indicated by detections of pesticides and volatile organic compounds in urban areas. Nitrate and dissolved solids accumulating in shallow ground water in the WSRV have the potential to degrade the quality of deeper drinking-water supplies.

Major Influences on Ground Water

- Geohydrology
- Dissolution of evaporites and other minerals
- Irrigation of agricultural and urban lands
- Agricultural and urban fertilizer and pesticide use

Selected Indicators of Ground-Water Quality



[1] Most wells sampled as part of basinwide surveys were existing domestic (household) wells.
[2] Insecticides, herbicides, and pesticide metabolites, sampled in water.
[3] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in water.

The Central Arizona Basins (CAZB) Study Unit encompasses a 34,700-square-mile area in central and southern Arizona and northern Mexico (fig. 1). The Study Unit includes large parts of two hydrologic provinces—the Central Highlands in the north and the Basin and Range Lowlands in the south (U.S. Geological Survey, 1969). Climate, hydrology, geology, land use, and water use are distinctly different in these two provinces.

The Central Highlands (fig. 1) have minimal development and are generally representative of natural conditions. Mountainous terrain with shallow, narrow intermountain basins predominates in the Central Highlands (Cordy and others, 1998). Forests and rangeland cover most of the province. The largest population is in the town of Prescott—35,785 (Arizona Department of Economic Security, rev. July 7, 2000), and small rural towns dot the region. Agricultural development is minimal except in the northernmost tip of the CAZB.

Most of the perennial streams in the Study Unit are in the Central Highlands (fig. 2). These streams derive their flow from mean annual precipitation of more than 25 inches in the mountains and from rainfall and snowmelt along the Mogollon Rim, which forms the northeastern border of the CAZB Study Unit.

Major streams having their headwaters in the Central Highlands include the Salt, Verde, and Agua Fria Rivers (fig. 2). These rivers flow year around (perennial) in their upper reaches but are captured for water supply for metropolitan Phoenix, power generation, and flood control before they reach the Basin and Range Lowlands.

Though streams provide most of the water for agricultural use in the Central Highlands, ground water is the main source for municipal and industrial supply (fig. 3). Much of the ground water is pumped from sedimentary deposits of limited

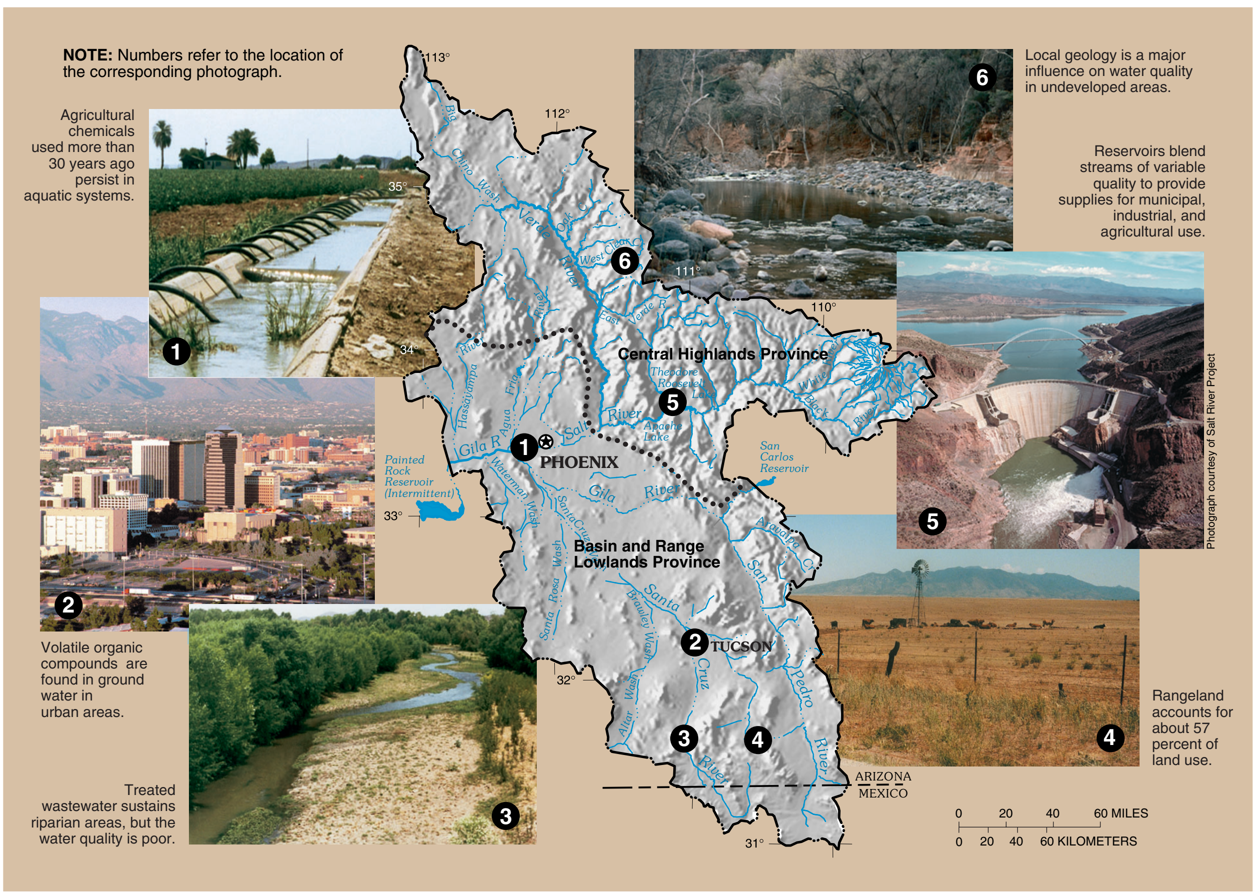


Figure 1. The Central Highlands hydrologic province is mountainous compared to the large, elongate alluvial basins of the Basin and Range Lowlands. Reservoirs capture the perennial streams of the Central Highlands to provide water supplies for the Basin and Range Lowlands.

Figure 2. Perennial streams in the Central Highlands, Colorado River water from the Central Arizona Project Canal, ground water, and treated sewage effluent fulfill water demands in the Basin and Range Lowlands.

extent in the valleys. As a result, some of the fastest-growing towns are being forced to seek alternative water supplies (Arizona Department of Water Resources, 1994). Natural factors such as dissolution of minerals in rocks and basin sediments are major influences on ground-water quality in the Central Highlands (Owen-Joyce and Bell, 1983; Marsh, 2000); however, activities such as mining have affected water quality locally (Brown and Favor, 1996).

The Basin and Range Lowlands (fig. 1) are characterized by a lack of perennial streams, the largest water demands, and reliance on ground water. Deep, broad alluvial basins separated by mountain ranges of small areal extent characterize this hydrologic province. The basins are filled with thick deposits of gravel, sand, silt, and clay and include interbedded evaporite deposits and volcanic rocks in places (Anderson and others, 1992). These basin-fill sediments can be 2,000 feet to as much as 12,000 feet thick and constitute the major aquifers that are often referred to as "basin-fill aquifers." The basin-fill aquifers contain large reserves of ground water that were recharged when Arizona's climate was much wetter than at present, possibly thousands of years ago.

Ephemeral streams are characteristic of the Basin and Range Lowlands (fig. 2). Very little natural streamflow is generated because the average annual rainfall is less than 10 to 15 inches except at the highest elevations. With the exception of some small, higher elevation streams and sections of the San Pedro River, most perennial streams in the Basin and Range Lowlands are effluent-dependent; that is, their flow is sustained all year by treated wastewater (fig. 2). Effluent-dependent streams have beneficial uses. They support riparian and aquatic communities where those communities would not otherwise exist. By recharging effluent, cities can accrue "credits" toward pumping of ground water from other locations in a basin (Arizona Department of Water Resources, 1994).

Rangeland is the predominant land use in the Basin and Range Lowlands. The two largest urban areas—Phoenix and Tucson—account for about 5 percent of the land use and include 75 percent of Arizona's 4.9 million people (Arizona Department of Economic Security, rev. July 7, 2000). Agricultural development, which is mostly west and south of Phoenix, is about 5 percent of the land use (Cordy and others, 1998). Cropland is the primary agricultural land use, and cotton is the main crop.

Water use in the Basin and Range Lowlands represents 96 percent of all water use in the CAZB Study Unit (Cordy and others, 1998). Agriculture is the largest water user (73 percent in 1990; fig. 3). Because of the general lack of surface-water resources in the Basin and Range Lowlands, ground-water is relied upon heavily to meet agricultural and municipal demands (fig. 3). In areas with substantial agricultural and (or) urban development, ground water has been and continues to be used more quickly than it can be replenished naturally. Ground-water levels have declined several hundred feet in areas with the heaviest pumping, and land subsidence has resulted in a loss in aquifer storage capacity (Arizona Department of Water Resources, 1994). To mitigate some of the problems caused by overpumping of ground water, Colorado River water is delivered to central Arizona by the Central Arizona Project (CAP) canal (fig. 2). CAP water is used for aquifer recharge and municipal and agricultural purposes.

The study design focused on the effects of land use on water quality. Water, sediment, and biological samples were collected from streams in urban, agricultural, forest, and rangeland areas of the CAZB Study Unit to assess the overall quality of streams as well as the effects of specific land-use practices on stream-water quality (U.S. Geological Survey, 1999). At most sites, water samples were collected monthly from late 1995 through early 1998, and at some stream sites additional samples were collected during storms to assess the effects of stormwater runoff on water quality. Two stream sites were sampled twice monthly for 1 year to determine the occurrence and distribution of pesticides. A single round of sampling for contaminants in streambed sediment and fish tissue was completed in 1995–96 (See “Study Unit Design,” p. 26).

Ground water was sampled from wells in three alluvial basins in the Basin and Range Lowlands—the West Salt River Valley, the Upper Santa Cruz Basin, and the Sierra Vista subbasin. Existing wells were sampled in the three basins to assess overall water quality as well

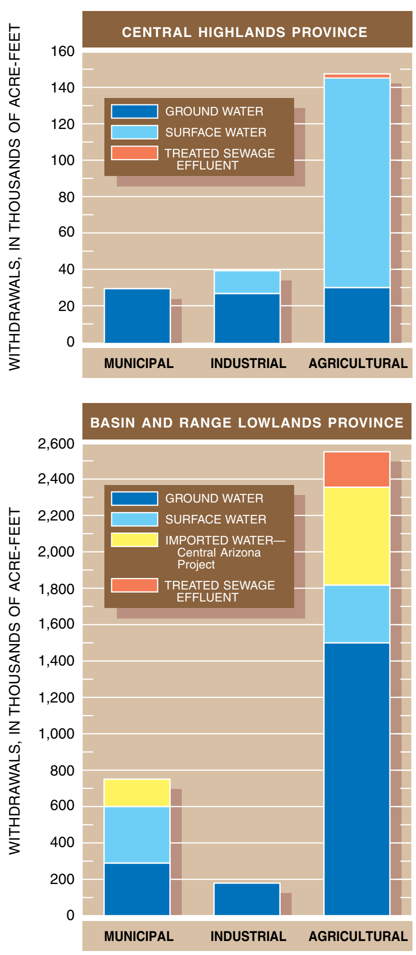
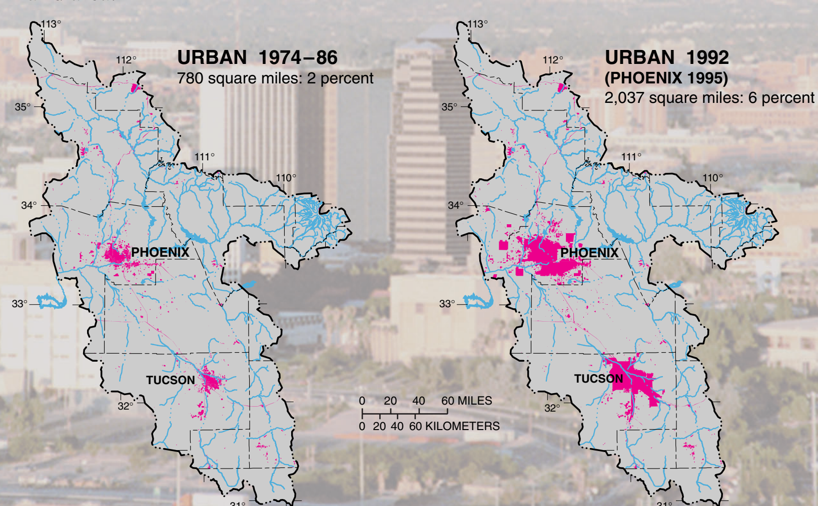


Figure 3. Water-use data for 1990 show the many sources of water used to meet demands in the CAZB Study Unit.

Rapid population growth in central Arizona results in changes in land use.

As in many areas of the Southwestern United States, the population of Arizona is rapidly increasing. The population of the State increased from 2,716,546 in 1980 to 3,665,339 in 1990, an increase of 35 percent. Projections for 2000 indicate an additional 26 percent increase, to 4,924,350 (Arizona Department of Economic Security, rev. July 7, 2000). Much of this population increase has occurred in Tucson and metropolitan Phoenix (Maricopa County). As more and more people relocate to Arizona, desert and agricultural areas are being replaced by urban development. In addition to altering land use, this growth puts increasing demands on the limited water resources of this arid to semiarid area.



Urban land use increased substantially from 1974–86 to the early 1990s in the Phoenix and Tucson metropolitan areas.

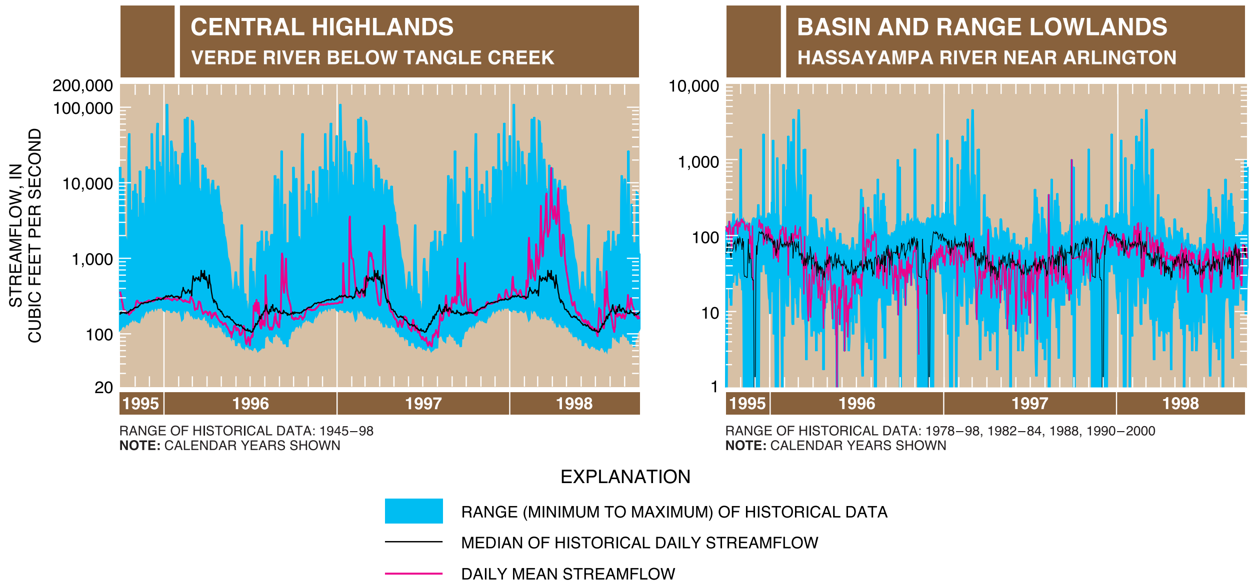


Figure 4. Streamflow in the Central Highlands increased each year from 1996–98 as indicated by the Verde River below Tangle Creek. In the Basin and Range Lowlands, streamflow is difficult to characterize because it is controlled by dams and (or) wastewater-treatment plants. For the Hassayampa River near Arlington, a Basin and Range Lowlands stream, summer streamflow in 1996 and 1997 was greater than the median historical daily value.

as the effects of human activities on water quality. In the West Salt River Valley, shallow monitoring wells were installed and sampled to determine the effects of irrigated agriculture on shallow ground-water quality. Existing ground-water-quality data were used to assess overall water quality in alluvial basins of the Basin and Range Lowlands that were not sampled.

This report is organized into sections on stream-water quality and ground-water quality. In each section, natural water quality, that is water that has been minimally affected by agricultural or urban development, is discussed followed by a discussion of the effects of human activities on water quality. This organization is designed to assist the reader in understanding the changes in natural water quality that result from human activities.

Understanding climatic and hydrologic conditions during the sampling period, 1995–98, is useful in interpreting the CAZB study results. The climate of the Study Unit is characterized by variability from place to place and also by large differences in precipitation from one year to the next. Precipitation can be three times greater in wet years than in dry years (Cordy and others, 1998).

In Central Highlands streams, represented by the Verde River below Tangle Creek (fig. 4), daily mean streamflow was successively higher from 1996 through 1998. Streamflow in 1998 generally was greater than the median of historical daily streamflow, and streamflow in 1996 was less than the median of historical daily streamflow (fig. 4).

Streamflow in the Basin and Range Lowlands is difficult to characterize because it is controlled by dams and (or) wastewater-treatment plants. The Hassayampa River near Arlington is an example of a Basin and Range Lowlands stream that is a combination of effluent and irrigation return flows most of the time, supplemented by flows from storm runoff (fig. 4). Streamflow at the site typically was less than the median historical daily streamflow during 1996 and 1997; however, summer streamflow in those years was greater than the median historical daily streamflow because of increased summer thundershowers. Streamflow during 1998 was about the same as the median of historical daily streamflow.

When streamflow exceeds baseflow as a result of rainfall or snowmelt runoff, dissolved-solids concentrations decrease in streams and reservoirs because of dilution. Nutrient concentrations increase with increased streamflow because precipitation and runoff carry more nutrients to streams.