Section 7.—Conceptual Understanding and Groundwater Quality of the Basin-Fill Aquifer in the West Salt River Valley, Arizona

By David W. Anning

in

Conceptual Understanding and Groundwater Quality of Selected Basin-Fill Aquifers in the Southwestern United States

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Contents

Figures

Tables

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Basin Overview

The West Salt River Valley (fig. 1) in central Arizona has an arid climate and significant water-resources development that support agricultural and urban activities. The basin-fill aquifer is an important resource as it provides about one-third to half of the water supply for the valley, the amount varying annually in part due to the availability of surface-water supplies, imported water, and treated wastewater effluent (Arizona Department of Water Resources, 1999). Groundwater development to support the population and their economic and cultural activities over the past century has caused substantial changes in the basin-fill aquifer, including about a 7-fold increase in recharge and an 8-fold increase in discharge. These and other changes to the aquifer have resulted in an increase in the intrinsic susceptibility of the aquifer to contamination. The effects of both natural and human-related factors on groundwater quality in the valley are discussed in this section.

The West Salt River Valley is a 1,438 mi^2 hydrogeologic area defined by McKinney and Anning (2009) that is approximately coincident with the West Salt River Valley groundwater basin defined by the Arizona Department of Water Resources, except that it encompasses an additional 108 mi^2 of land in areas near the Sierra Estrella, White Tank Mountains, and Hedgpeth Hills. The altitude of the valley floor ranges from about 2,500 ft in the northwestern part of the valley to about 800 ft along the Gila River west of Buckeye. The mountains comprise a smaller portion of the basin than the valley floor, and rise to about 4,500 ft in the Sierra Estrella. The valley is an open basin that is drained by the Gila River and its tributaries, which include the Salt River and Agua Fria River (fig. 1).

The climate of the West Salt River Valley is characterized by hot summers, mild winters, and large diurnal temperature cycles, and is among the warmest and most arid of the basins investigated in this study. Average precipitation for the basin for 1971–2000 was about 9 in/yr, making it the second driest basin of those in the study (McKinney and Anning, 2009). For the period 1961–90, the mean monthly maximum temperature at Buckeye was 68.1°F in January and 109.2°F in July (Owenby and Ezell, 1992).

A large part of the West Salt River Valley has been developed for agricultural, residential, commercial, and industrial uses. Population of the valley for 2005 is estimated to be about 1.97 million people (McKinney and Anning, 2009), most of whom live in the Phoenix metropolitan area. The remainder of the population lives in surrounding farming communities and new communities that have replaced farmland. Land use within the alluvial basin, excluding the surrounding mountainous areas, consists of about 22 percent agricultural and 34 percent urban use (fig. 1; McKinney and Anning, 2009). Most of the present-day urban land was previously agricultural land. Important agricultural crops in the valley include cotton, alfalfa, wheat, and vegetables.

Water demands for municipal and agricultural purposes in the West Salt River Valley are met using a variety of water sources. These include groundwater from the basin-fill aquifer; surface water from the Agua Fria, Gila, Salt, and Verde Rivers, most of which is stored in reservoirs outside the valley; water from the Colorado River imported through the Central Arizona Project (Hayden Rhodes Aqueduct in fig. 1); and recycled water from municipal wastewater-treatment plants. Development of these sources, which has significantly altered the hydrologic system of the valley, is discussed further in the following parts of this section.

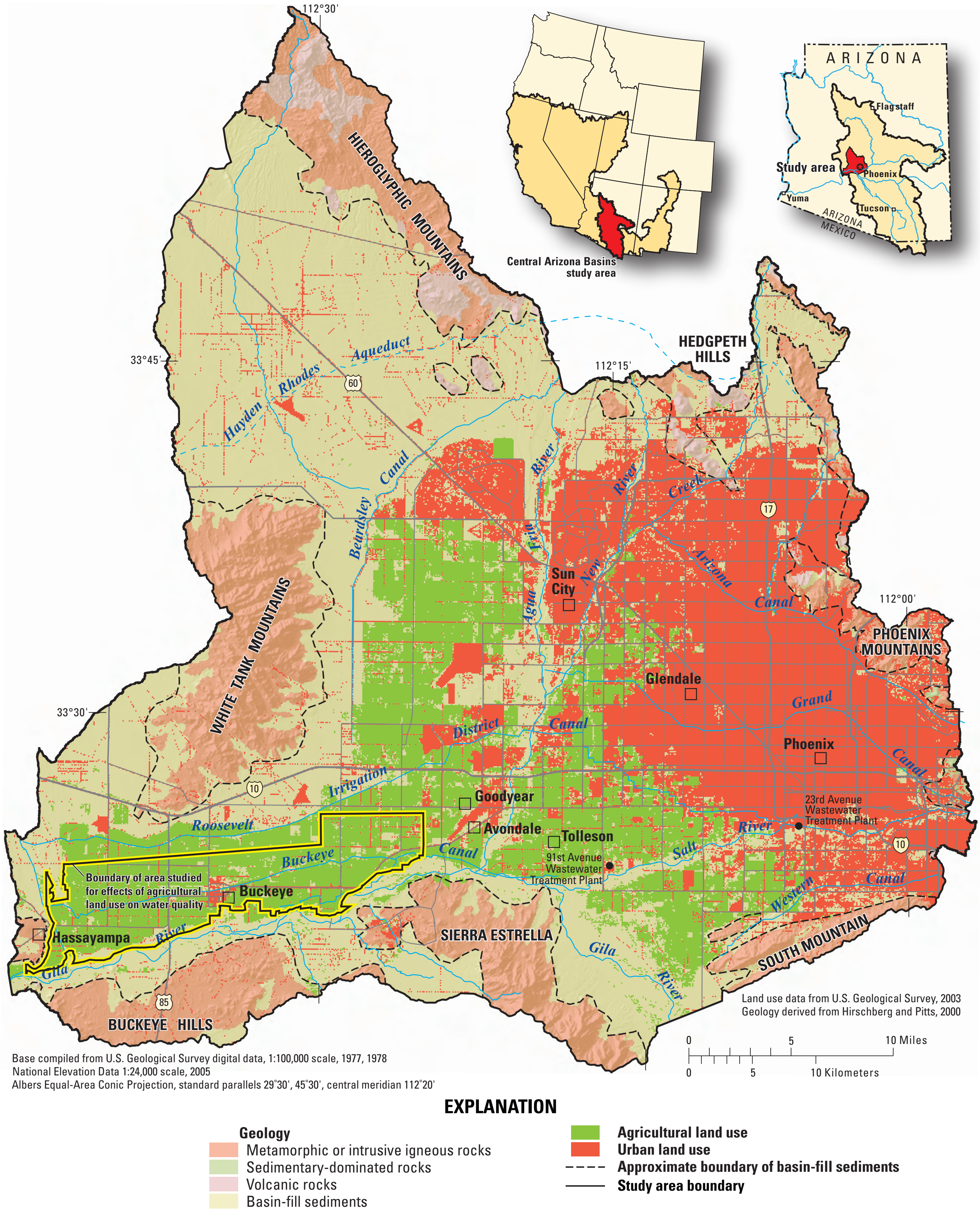


Figure 1. Physiography, land use, and generalized geology of the West Salt River Valley, Arizona.

Water Development History

The Salt River Valley, which contains both the East Salt River Valley and the West Salt River Valley, was originally inhabited by Hohokam Indians from about 300 to 1450 AD. The Hohokam are believed to have been peaceful farmers who built a canal system that traversed about 500 mi and may have supported about 50,000 people (Salt River Project, 2006). The canals laid dormant over the next about 400 years until the 1860s, when pioneers settled in the area and established farming communities. These farmers developed their canals generally using the same routes laid out by the Hohokam canals, and for the most part these canals are still used today (Turney, 1929; Salt River Project, 2006). Fruits and vegetables were grown to support mining communities and the U.S. Cavalry elsewhere in central Arizona. By about 1885, approximately 60,000 acres were irrigated under the Arizona Canal System (Davis, 1897). The population in Phoenix and surrounding rural communities grew to about 16,000 by 1900 (Sargent, 1988).

Water-resources development in the early part of the 20th century allowed for expansion of agricultural lands. Construction of large reservoirs on the Agua Fria, Salt, and Verde Rivers outside the Salt River Valley between 1903 and 1946 provided the capacity to store up to 2.18 million acre-ft of surface water (table 2 in Cordy and others, 1998). Water stored from winter storm runoff in the mountains was later released and diverted into canals (Arizona, Grand, and Western Canals, fig. 1) during the spring and summer months for delivery to agricultural lands in the Salt River Valley.

The early part of the 20th century was also an important period of growth in groundwater development in the Salt River Valley. Groundwater was used when and where surface water was unavailable. Prior to 1920, groundwater withdrawals were less than about 60,000 acre-ft/yr (Anning and Duet, 1994). Significant groundwater withdrawals, however, began with the onset of widespread use of high-capacity turbine pumps in the 1920s (Edmonds and Gellenbeck, 2002). Withdrawals for the entire Salt River Valley (both the East and West parts) steadily increased from about 95,000 acre-ft/yr in 1920 to about 2.3 million acre-ft/yr in the 1950s, after which withdrawal rates began to decline. Withdrawals in 1990 were about 1.1 million acre-ft for the entire valley (Anning and Duet, 1994).

In the later part of the 20th century, the consequences of pumping groundwater at such large rates as those in the 1950s were recognized, and solutions were pursued. For most of the West Salt River Valley, the withdrawals caused water-level declines of more than 50 ft, and in some areas declines were more than 300 ft (Anderson and others, 1992). The lower water levels have resulted in increased pumping costs, and in addition, water depletion has led to aquifer compaction and land subsidence. In an area east of the White Tank Mountains and north of the Interstate-10 freeway, the land surface had subsided as much as 18 ft by 1995 and resulted in a flow reversal in part of the Dysart Drain, a flood drainage canal (Schumann, 1995).

Several water management actions were taken to reduce pumping and its associated problems such as groundwater storage depletion, land subsidence, and increased pumping costs. These include importing surface water, artificial recharge, and use of treated wastewater effluent for irrigation. In 1980, the Groundwater Management Code was passed by the Arizona Legislature to eliminate severe groundwater overdraft and to provide a means for allocating Arizona's limited groundwater resources. This legislation established the Arizona Department of Water Resources and the Phoenix Active Management Area, and contained regulations that encouraged use of Central Arizona Project (CAP) water to reduce groundwater overdraft. The CAP is a series of aqueducts that provide a means to import Colorado River water to central Arizona. CAP deliveries to the West Salt River Valley began in 1985, and by 2005 deliveries were about 222,000 acre-ft/yr (Central Arizona Project, 2006a).

In 1993, the legislature created the Central Arizona Groundwater Replenishment District, the purpose of which is to provide a legal and physical framework for replacing groundwater mined in the Active Management areas, including the West Salt River Valley. In 2005, deliveries to the Agua Fria and Hieroglyphic Mountains recharge facilities were about 52,000 acre-ft (Central Arizona Project, 2006b). Stormwater is also deliberately recharged through thousands of dry wells that are installed in urban areas to enhance infiltration of runoff collected in detention basins.

As the population in the Phoenix metropolitan area grew, so did its "production" of wastewater effluent, which became a valued resource. Most of the effluent from Phoenix and surrounding communities is treated at the 23rd Avenue wastewater treatment plant (WWTP) and at the 91st Avenue WWTP. The Roosevelt Irrigation District Canal (fig. 1) receives effluent from the 23rd Avenue WWTP and this water is applied to crops. Treated municipal wastewater from the 91st Avenue WWTP is released to the Salt River, which flows into the Gila River and is then diverted into the Buckeye Canal (fig. 1) for irrigation of crops. Flow at the head of the Buckeye Canal was 137,500 acre-ft in water year 2000 (Tadayon and others, 2001). Water in the Buckeye Canal, despite its treated-wastewater origin, is often less saline than groundwater from wells in the western part of the valley.

Hydrogeology

The West Salt River Valley is one of several structural basins formed by high-angle faulting of the Basin and Range disturbance (5 to 15 million years ago; Menges and Pearthree, 1989) superimposed on the effects of crustal extension and low-angle detachment faulting of the mid-Tertiary disturbance (15 to 37 million years ago; Dickinson, 1989). Subsidence of the structural basins formed closed drainages that slowly filled with locally derived sediments and evaporite deposits. After subsidence slowed and the basins filled with sediment, streams began to flow through the lowest divides into adjacent basins, and ultimately this process resulted in the integrated drainage system of the Gila River and its tributaries (Damon and others, 1984).

Mountains surrounding the valley are composed primarily of granitic and metamorphic rocks, and secondarily of sedimentary and volcanic rocks (fig. 1; Hirschberg and Pitts, 2000). The mountains generally form barriers to groundwater flow because of the low hydraulic conductivity values of these rocks. A major linear subsurface structure, probably a fault in the crystalline rocks, is aligned with Highway 60 and divides the valley into northeastern and southwestern areas (Brown and Pool, 1989). The northeastern area is characterized by a series of structural blocks tilted to the northeast and trending northwest that are overlain by basin-fill deposits, which are generally less than 2,000 ft thick (fig. 2). Within the southwestern area, the deposits are generally less than 2,000 ft thick in the western part, but increase in thickness to the east to greater than 10,000 ft.

The basin-fill deposits are divided into upper, middle, and lower units (Brown and Pool, 1989). The lower unit was deposited when the basin was closed and subsiding and it consists of playa, alluvial-fan, fluvial, and evaporite deposits. The sediments in the lower unit are generally fine grained, with coarse-grained facies at the basin margins and at depth, and the unit is further divided into upper and lower parts. The thickness of the lower part exceeds 10,000 ft in the center of the basin, whereas the thickness of the upper part is generally less than 1,000 ft. The lower part of the lower unit tends to be more consolidated and the clast type and stratigraphy is more homogeneous than the upper part. Estimated hydraulic conductivity values range from 6 to 14 ft/d for the lower part, and from 3 to 25 ft/d for the upper part (Brown and Pool, 1989). Evaporites were deposited near the center of the southwestern part of the basin in the lower part of the basin fill (Brown and Pool, 1989). Evaporites in the lower part of the lower unit are generally massive and consist of anhydrite, gypsum, and halite, whereas evaporite units in the upper part consist only of gypsum that is interbedded or finely disseminated within the clastic sediments. The Luke Salt Body, the major evaporite deposit in the basin, has a pronounced local effect on the salinity of the groundwater and an indirect effect on the transmissivity of the basin fill (Eaton and others, 1972). Both the upper and lower parts of the lower unit are fully saturated in most of the basin.

The middle unit was deposited when the basin was open and drained by the Agua Fria, Salt, and Gila Rivers (Brown and Pool, 1989). This unit is as much as 800 ft thick near the center of the basin, and includes playa, alluvial-fan, and fluvial deposits of silt, clay, siltstone, and silty sand and gravel. The areal extent of fine-grained sediments increases with depth, and their occurrence is less common in the middle unit than the lower unit. Some lenses or zones in the middle unit with more than 80 percent silt and clay, however, are present in areas near Goodyear and Glendale (Brown and Pool, 1989) and form a confining bed that retards vertical movement of groundwater (Edmonds and Gellenbeck, 2002). Hydraulic conductivity values in the middle unit range from 4 to 60 ft/d. Overdraft of groundwater has significantly dewatered the middle unit in much of the valley, and has completely dewatered it in a large area east of the White Tank Mountains (Brown and Pool, 1989).

The upper unit was deposited primarily by the Agua Fria, Salt, and Gila Rivers, as well as by local tributaries. The unit comprises channel, floodplain, and alluvial-fan deposits consisting largely of gravel, sand, and silt. The thickness of the upper unit ranges from 200 ft or less near the basin margins to about 400 ft near the confluence of the Salt and Gila Rivers. Hydraulic conductivity values in the upper unit are much higher than those of the lower and middle unit, and range from 180 to 1,700 ft/d (Brown and Pool, 1989). Overdraft of groundwater has dewatered most of the upper unit over large parts of the valley (Brown and Pool, 1989).

Conceptual Understanding of the Groundwater Flow System

The groundwater system was under steady-state conditions prior to the beginning of water development by settlers in the 1860s (Corkhill and others, 1993). Long term recharge and discharge of the basin-fill aquifer were in balance with each other and equal to about 68,000 acre-ft/yr (fig. 3; table 1). Most of the recharge was from streamflow infiltration and from subsurface inflow through basin-fill aquifers of adjacent basins (table 1). Most of the discharge took place through evapotranspiration of shallow groundwater and by subsurface outflow northwest of the Buckeye Hills (table 1). Groundwater movement prior to water development is presumed to have been primarily horizontal, and on the basis of early water-level maps, the flow was toward and along the Salt and Gila Rivers (fig. 4*A*; Corkhill and others, 1993; Lee, 1905).

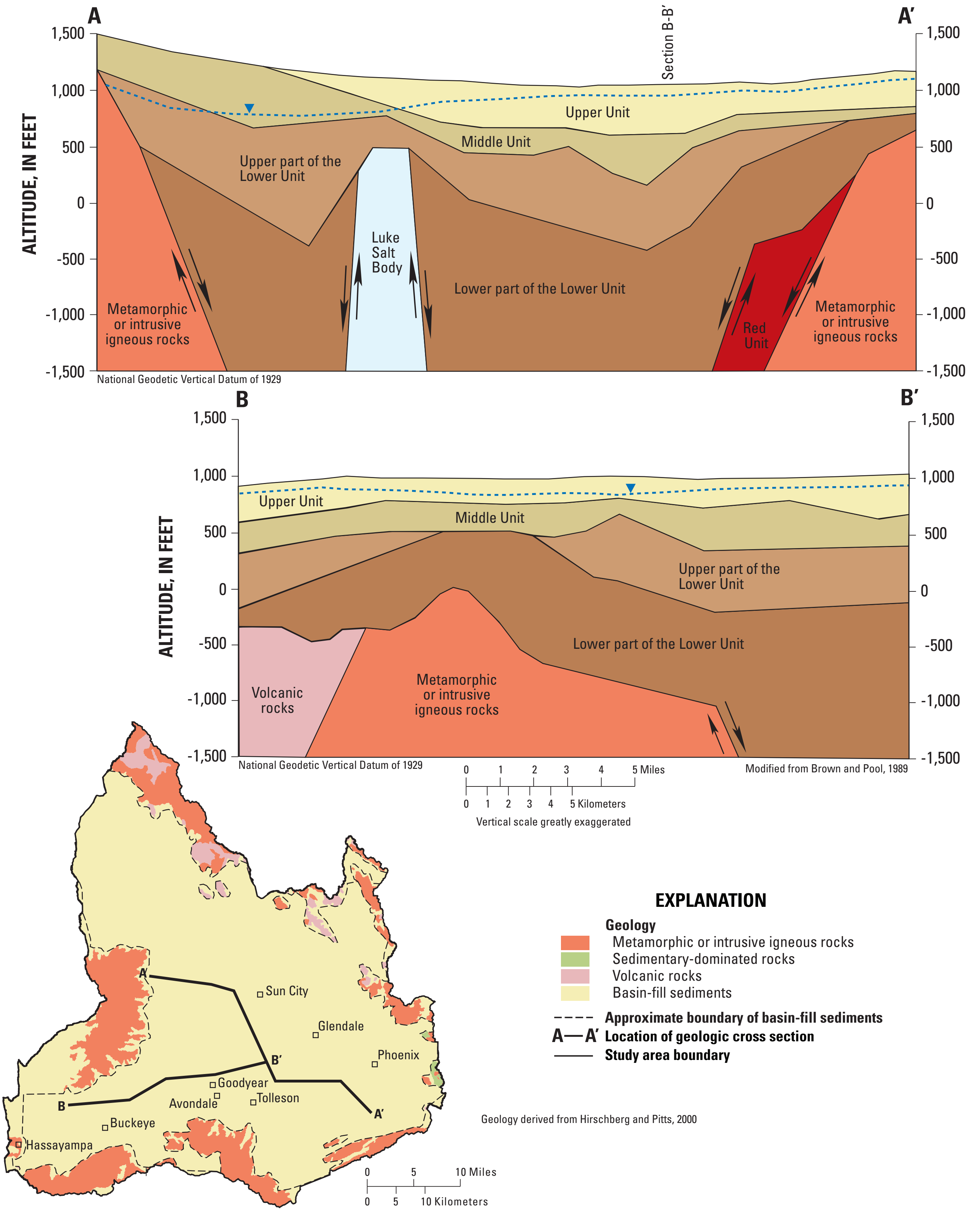


Figure 2. Generalized geologic cross sections of the West Salt River Valley, Arizona.

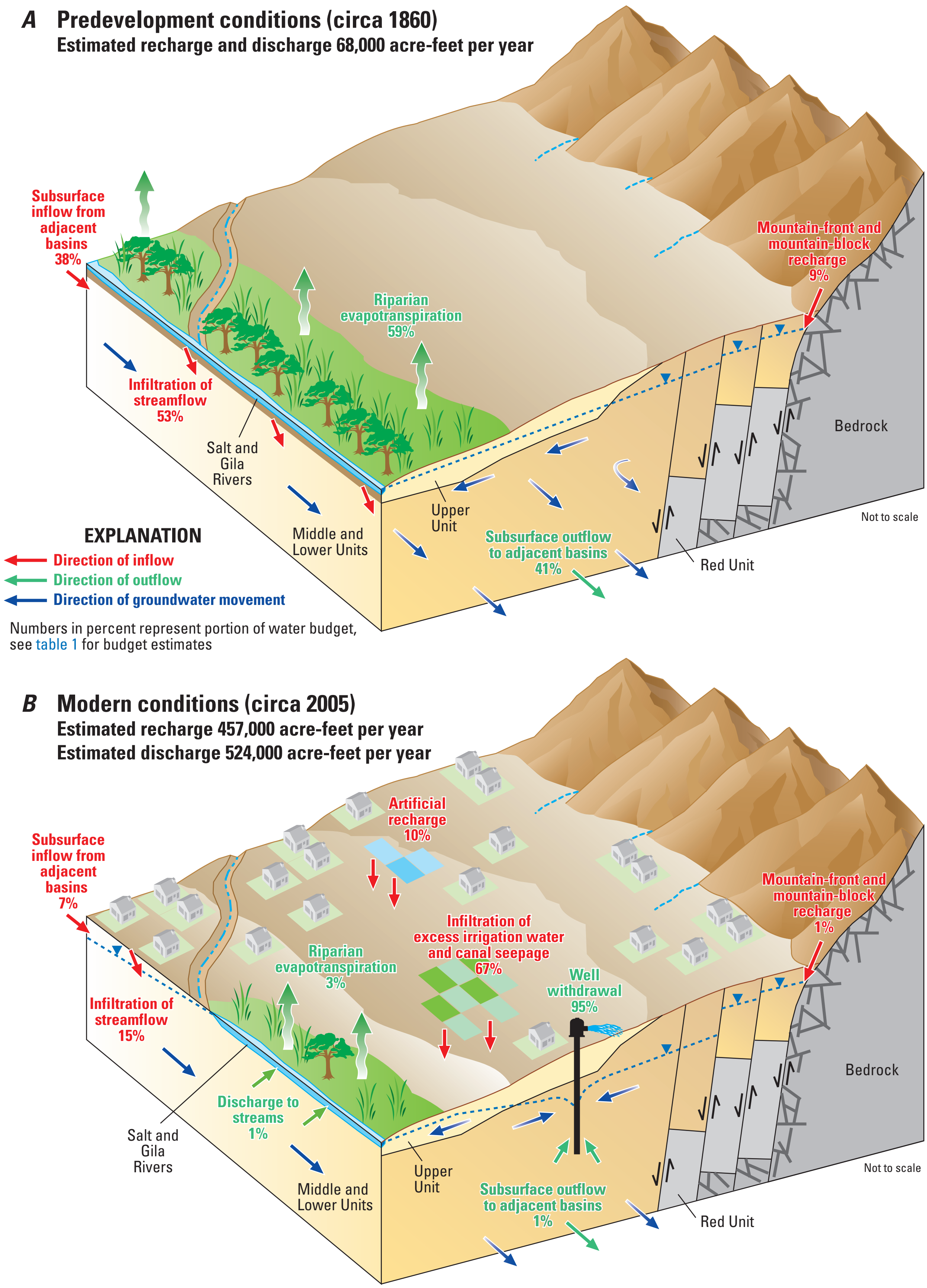


Figure 3. Generalized diagrams for the West Salt River Valley, Arizona, showing components of the groundwater system under (*A*) predevelopment and (*B*) modern conditions.

Table 1. Estimated groundwater budget for the basin-fill aquifer in the West Salt River Valley, Arizona, under predevelopment and modern conditions.

[All values are in acre-feet per year and are rounded to the nearest thousand. Estimates of groundwater recharge and discharge under predevelopment and modern conditions were derived from the footnoted sources. The budgets are intended only to provide a basis for comparison of the overall magnitudes of recharge and discharge between predevelopment and modern conditions, and do not represent a rigorous analysis of individual recharge and discharge components. Percentages for each water budget component are shown in figure 3]

Budget component	Predevelopment conditions, before 1860	Modern conditions, 2005	Change from predevelopment to modern conditions
Estimated recharge			
Subsurface inflow from adjacent basins[1]	26,000	30,000	4,000
Mountain-block and mountain-front recharge[2]	6,000	6,000	0
Infiltration of precipitation on basin[1]	0	0	0
Infiltration of streamflow[1]	36,000	68,000	32,000
Infiltration of excess irrigation water and canal seepage[1]	0	308,000	308,000
Artificial recharge[1]	0	45,000	45,000
Total recharge	68,000	457,000	389,000
Estimated discharge			
Subsurface outflow to adjacent basins[1]	28,000	7,000	-21,000
Evapotranspiration[1]	40,000	15,000	-25,000
Discharge to streams[1]	0	5,000	5,000
Discharge to springs and drains[1]	0	0	0
Well withdrawals[1]	0	497,000	497,000
Total discharge	68,000	524,000	456,000
Estimated change in storage (recharge - discharge)	0	-67,000	-67,000

[1]Predevelopment conditions from Freethey and Anderson (1986), and modern conditions from Corkhill and others (2004).

[2]Predevelopment and modern conditions from Freethey and Anderson (1986).

The groundwater flow system has been substantially altered by water development related stresses such as withdrawals from regional pumping centers and recharge supplied by canal seepage and irrigation losses on croplands and turf (table 1; fig. 4*B*; Corkhill and others, 1993; Corkhill and others 2004). Estimated recharge for the modern (2005) water budget is 457,000 acre-ft/yr, which is nearly seven times the estimated recharge under predevelopment conditions. Most of this increase is due to recharge from excess irrigation water (table 1). Estimated discharge for the modern water budget is 524,000 acre-ft/yr, which is nearly eight times the discharge under predevelopment conditions. Nearly all of this increase is due to withdrawals through wells (table 1). Annual change in storage is assumed to be zero under predevelopment conditions but an estimated 67,000 acre-ft/yr are lost under modern conditions. Use of surface water and imported water from the Central Arizona Project for municipal and agricultural purposes reduces the need for groundwater withdrawals (aquifer discharge) and provides a significant portion of the irrigation losses that recharge the aquifer, both of which help mitigate storage losses.

Groundwater withdrawals in the valley through 1988 depleted storage by about 23 million acre-ft and have resulted in large water-level declines in most areas (fig. 4*C*; Corkhill and others, 1993). Whereas under predevelopment conditions groundwater flow was predominantly horizontal, pumping has created cones of depression within which the flow is vertically downward. In some areas, the direction of groundwater flow has changed and is now toward large depressions in the water table caused by regional pumping centers, such as the one north of the Arizona Canal and the one west of Sun City (fig. 4*B*; Corkhill and others, 1993). Depth to groundwater under modern conditions varies from less than 100 ft in the southern part of the basin, along the Salt and Gila Rivers, to greater than 400 ft west of Sun City (fig. 4*D*).

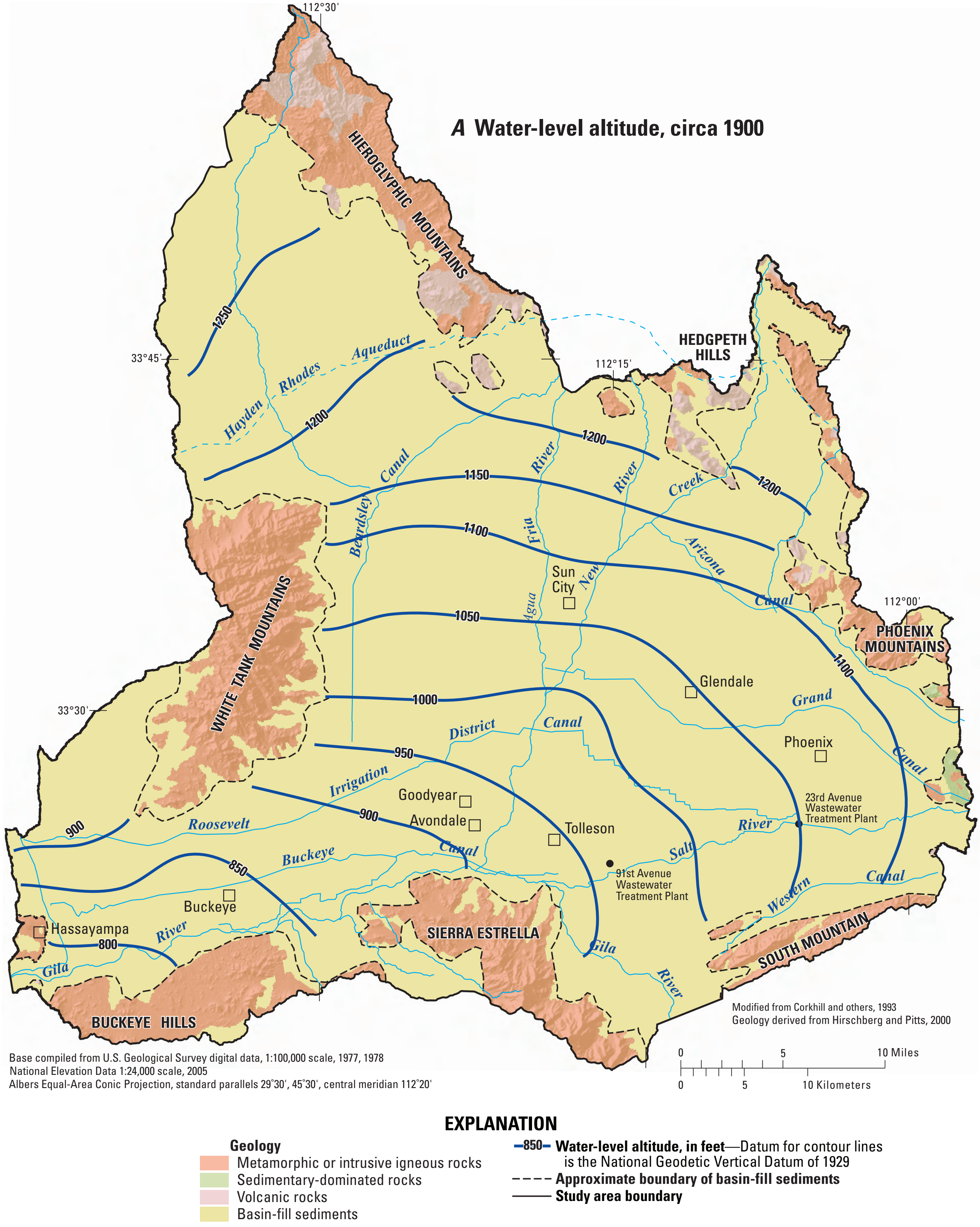
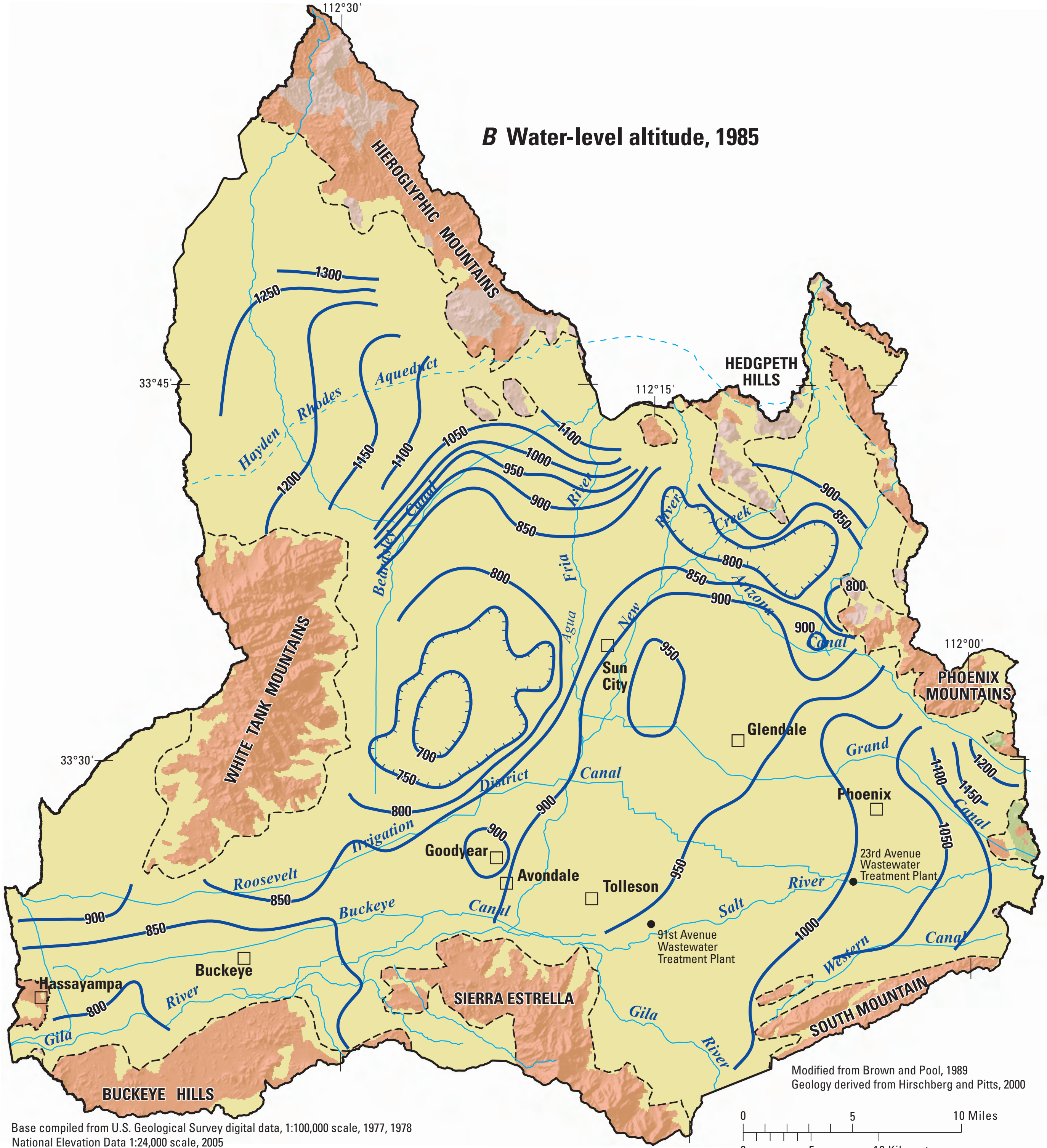


Figure 4. Water levels in the basin-fill aquifer of the West Salt River Valley, Arizona. (*A*) Water-level altitude, circa 1900. (*B*) Water-level altitude, 1985. (*C*) Water-level change for 1900–1980. (*D*) Depth to water, 1983.

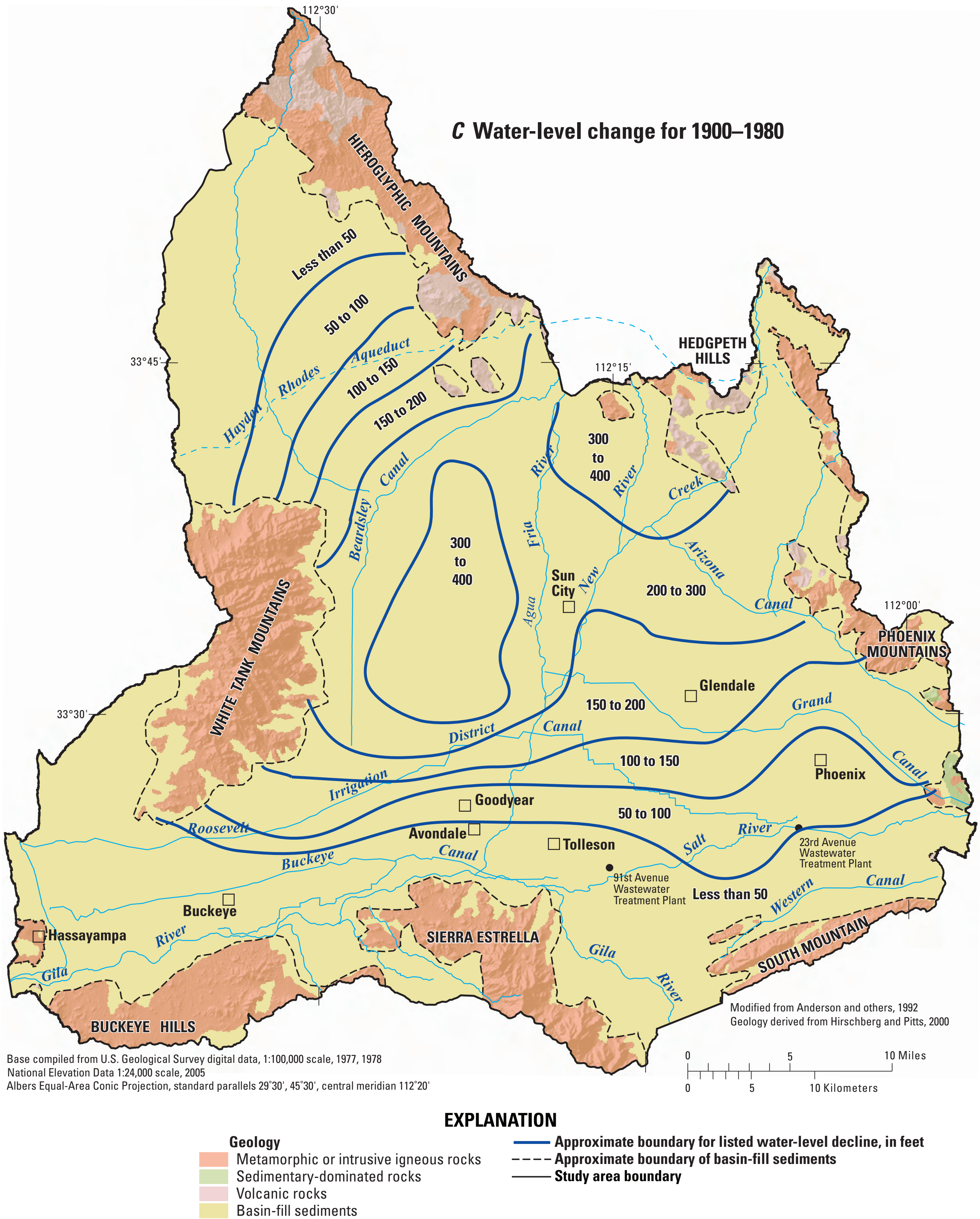


EXPLANATION

Geology
- Metamorphic or intrusive igneous rocks
- Sedimentary-dominated rocks
- Volcanic rocks
- Basin-fill sediments

- 950 **Water-level altitude, in feet**—Datum for contour lines is the National Geodetic Vertical Datum of 1929
- **Approximate boundary of basin-fill sediments**
- **Study area boundary**

Figure 4. Water levels in the basin-fill aquifer of the West Salt River Valley, Arizona. (*A*) Water-level altitude, circa 1900. (*B*) Water-level altitude, 1985. (*C*) Water-level change for 1900–1980. (*D*) Depth to water, 1983—Continued.



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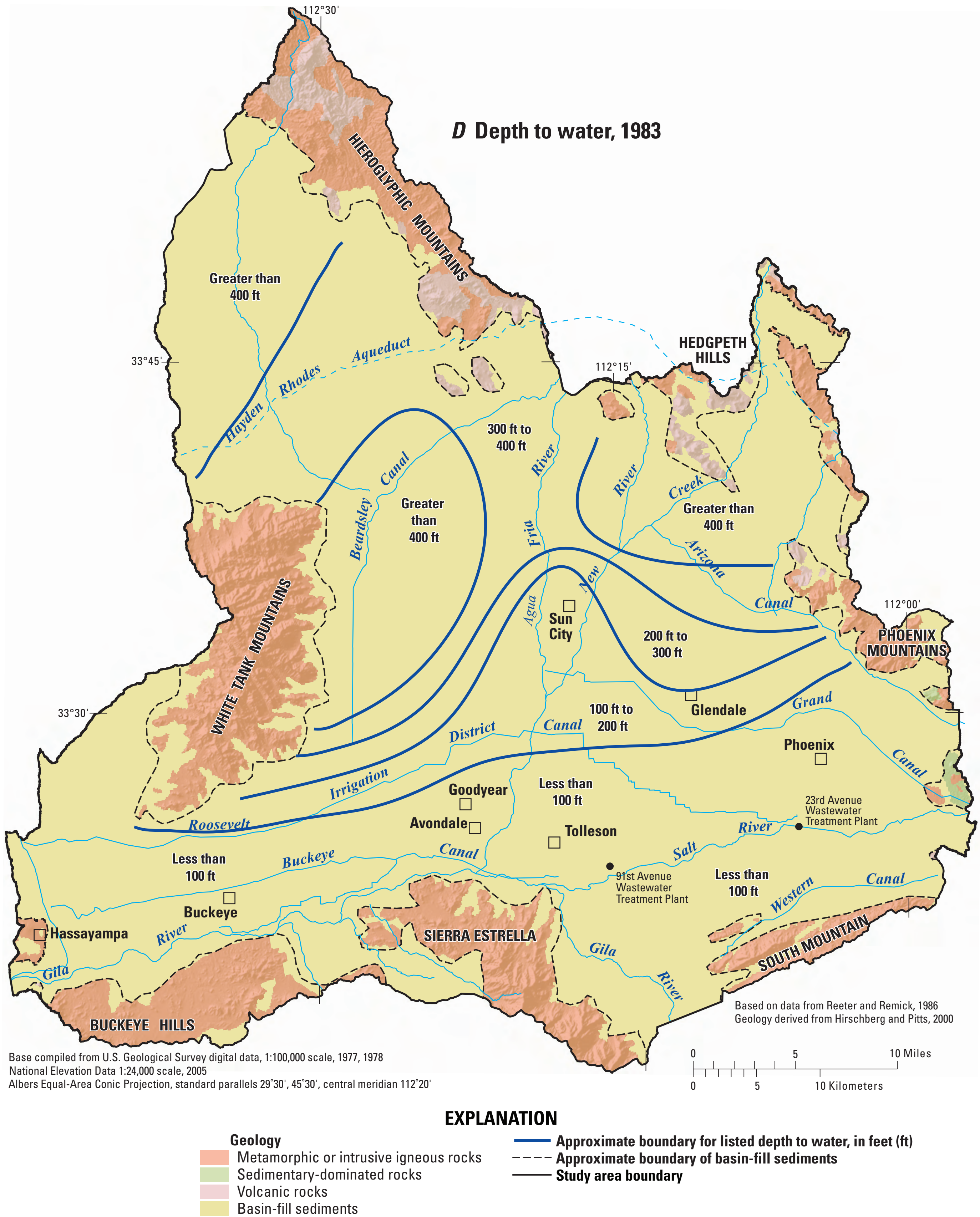


Figure 4. Water levels in the basin-fill aquifer of the West Salt River Valley, Arizona. (*A*) Water-level altitude, circa 1900. (*B*) Water-level altitude, 1985. (*C*) Water-level change for 1900–1980. (*D*) Depth to water, 1983—Continued.

Effects of Natural and Human Factors on Groundwater Quality

Groundwater quality in the West Salt River Valley is affected by the hydrogeology of the basin-fill aquifer, as well as land and water use on the ground surface (Edmonds and Gellenbeck, 2002; and Gellenbeck and Anning, 2002). These findings are based on analyses of data collected from 1996–98 as part of the following studies by the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program: (1) a basin-wide assessment of groundwater-quality conditions in the basin-fill aquifer, and (2) an assessment of groundwater-quality conditions specific to an area of predominantly agricultural land use (Edmonds and Gellenbeck, 2002; and Gellenbeck and Anning, 2002). Results of these studies are described in the remainder of this section and are integrated with findings from other water-quality investigations.

Groundwater-Quality Conditions Across the Valley

The basin-wide assessment of groundwater quality consisted of an analysis and interpretation of the chemical characteristics of samples from 35 wells completed in the basin-fill aquifer. The wells were selected, through a stratified-random sampling design, to represent the developed part of the aquifer. Most of the wells were used for domestic or commercial purposes and were greater than 100 ft deep. The occurrence, concentrations, and distribution of dissolved solids, nutrients, trace elements, pesticides, and volatile organic compounds (VOCs) in the water in the basin-fill aquifer across the valley are described below.

Concentrations of dissolved solids vary across the basin, and were higher in water from wells south of the Interstate-10 freeway (median = 790 mg/L) than in water from wells north of the freeway (median = 316 mg/L). Dissolved-solids concentrations in water from wells completed in the shallowest parts of the aquifer (less than 350 ft below land surface) were higher (median = 745 mg/L) than water from wells completed in deeper parts of the aquifer (median = 348 mg/L). Other investigations also found that dissolved-solids concentrations are lower in the northern part of the basin than in the southern part, near Buckeye (Thompson and others, 1984; fig. 5*A*), which may be due, in part, to groundwater in the southern part being affected by recharge of excess irrigation water (Brown and Pool, 1989). Brown and Pool found that concentrations of dissolved solids in the upper unit of the basin-fill aquifer generally were higher than those in the middle and lower units, and that concentrations in the middle and lower units are generally similar, except where the presence of evaporites increased concentrations in the lower unit. Eaton and others (1972) found dissolved-solids concentrations in groundwater were affected by the Luke Salt Body, and Brown and Pool (1989) noted that concentrations near the body range from 1,000 to 100,000 mg/L.

Median concentrations of dissolved nitrate (as nitrogen) and dissolved oxygen were 2.7 mg/L and 4.1 mg/L, respectively. Sources of nitrogen include dairies and feedlots, wastewater treatment plants, agricultural activities (manure from livestock, and application of fertilizers), and natural sources—decomposed vegetation or nitrogen fixed by bacteria associated with desert legumes (Gellenbeck, 1994). Elevated concentrations of nitrate and dissolved oxygen in the basin-fill aquifer of West Salt River Valley are possibly due to a lack of organic matter and associated biological processes in the aquifer matrix that typically consume oxygen and nitrate. On the basis of positive correlations with oxygen isotope data, Edmonds and Gellenbeck (2002) found that elevated concentrations of dissolved solids and nitrate resulted from the application of nitrogen fertilizers to crops and evaporation during irrigation of crops and landscaping. High nitrate concentrations detected in the samples corroborate the findings by Long and others (1997), who found that nitrate concentrations were correlated with dissolved-solids concentrations and who estimated that during the period 1986–90, nitrate exceeded the U.S. Environmental Protection Agency's (USEPA) primary drinking-water standard for nitrate of 10 mg/L (U.S. Environmental Protection Agency, 2009) in groundwater beneath a 190-mi^2 area near Phoenix and Glendale, and an 85-mi^2 area near Buckeye (fig. 5*B*).

Arsenic and uranium also are present in the water of the basin-fill aquifer. Arsenic was detected in samples from each of the 35 wells, and the median arsenic concentration was 6 µg/L. Concentrations of arsenic in samples from 11 wells (31 percent) exceeded the USEPA primary drinking-water standard for arsenic of 10 µg/L (fig. 6). The source of the arsenic is presumed to be minerals in the basin-fill deposits that originated from hydrothermal sulfide and arsenide deposits in the surrounding mountains (Robertson, 1991). The median uranium concentration was 3 µg/L, and concentrations for 4 wells (11 percent) exceeded the USEPA primary drinking-water standard for uranium of 30 µg/L (fig. 6).

Edmonds and Gellenbeck (2002) found that the water in 12 of the wells (34 percent) they sampled contained tritium (fig. 6), which indicated that part of the aquifer in which the wells were completed contained a component of groundwater that was recharged after 1953 (See Section 1 of this report for a discussion of groundwater age and environmental tracers). Organic compounds generally related to human activities on the land surface, such as pesticides and VOCs, were detected in samples from 11 of these 12 wells. This high detection rate of organic compounds for recently recharged groundwater emphasizes the susceptibility of the basin-fill aquifer to contamination.

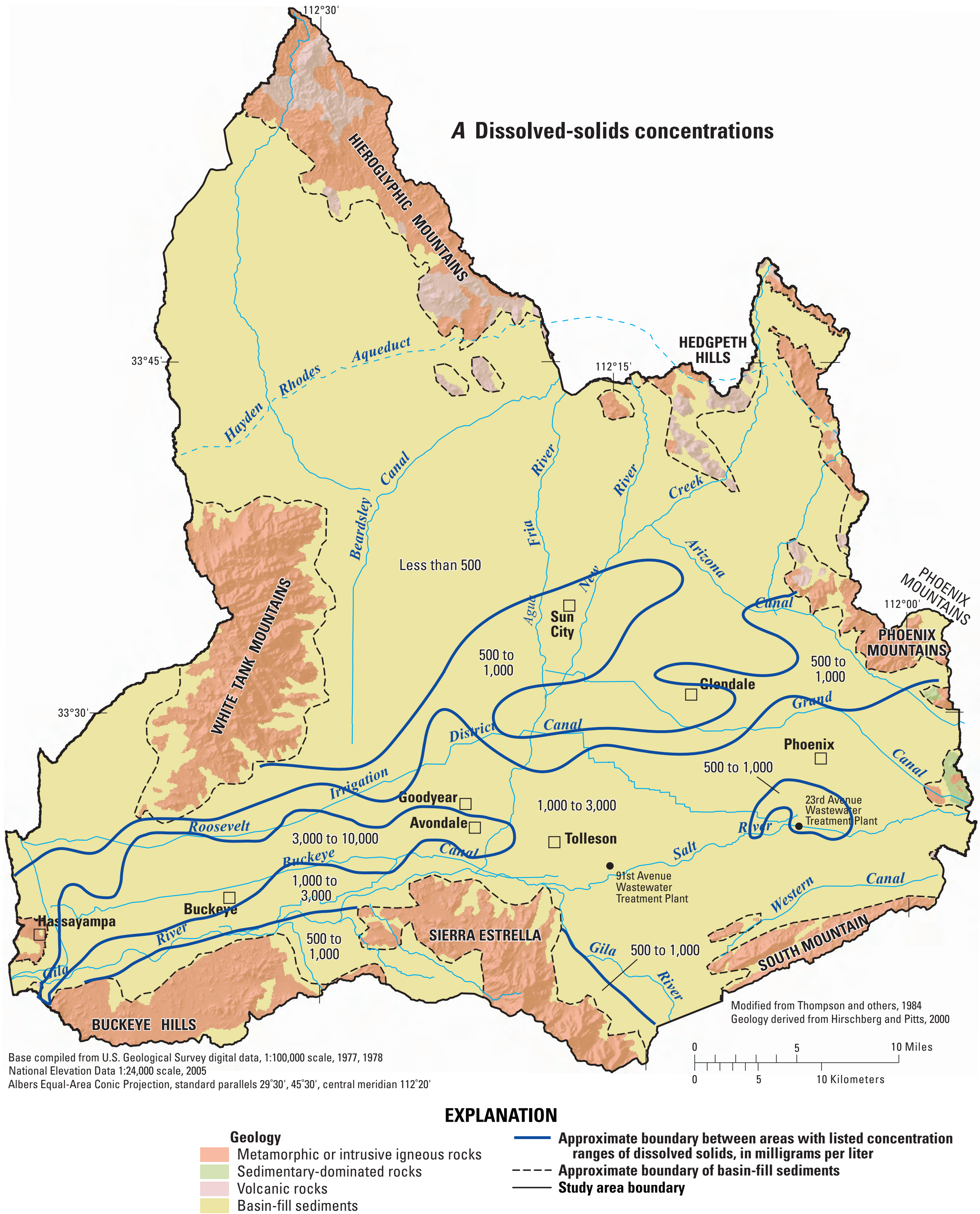
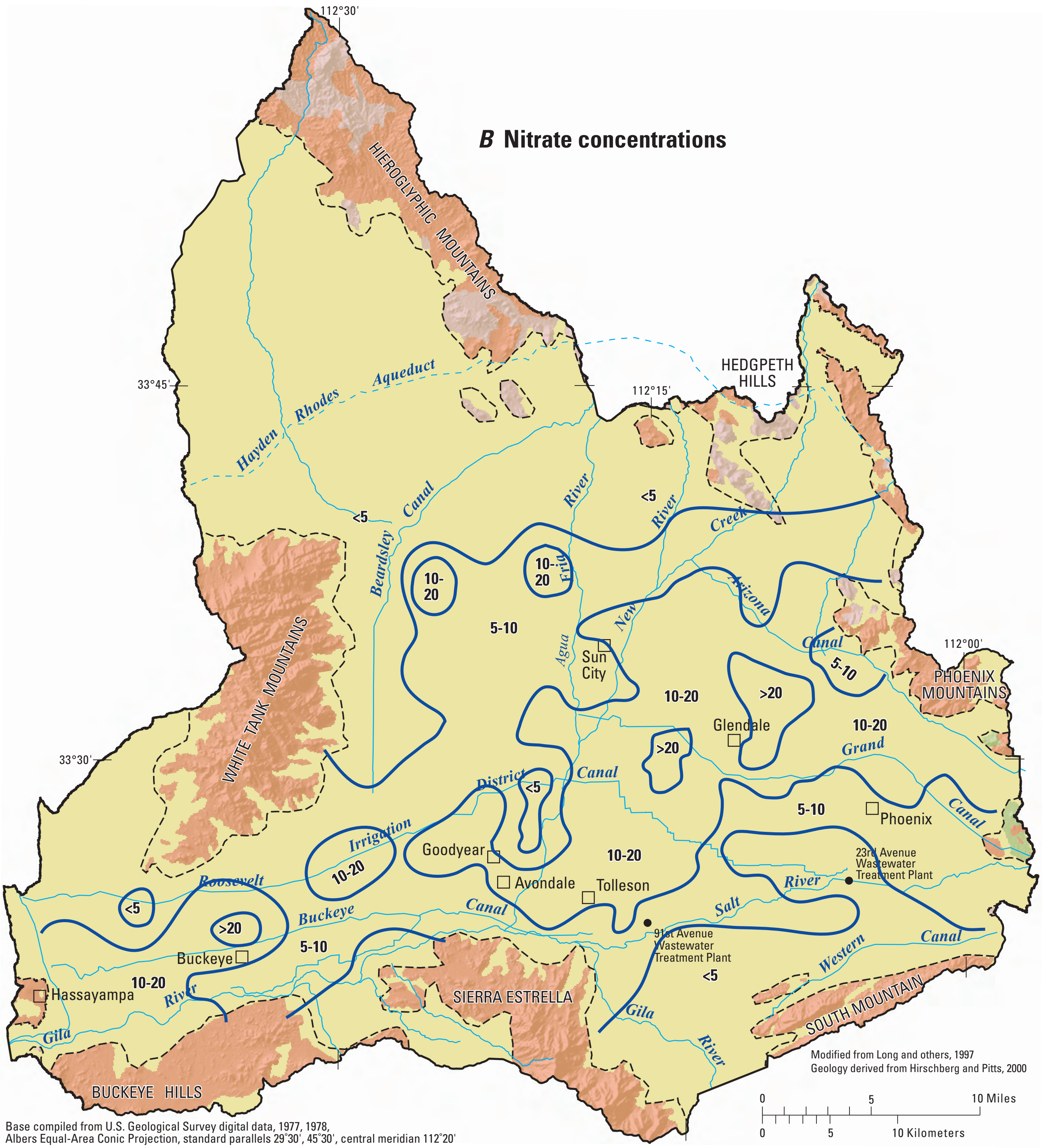


Figure 5. Concentrations of (*A*) dissolved solids and (*B*) nitrate in the basin-fill aquifer in the West Salt River Valley, Arizona.



EXPLANATION

Geology

- Metamorphic or intrusive igneous rocks
- Sedimentary-dominated rocks
- Volcanic rocks
- Basin-fill sediments

Approximate boundary between areas with listed concentration ranges of nitrate (as nitogen), in milligrams per liter— <, less than; >, greater than

Approximate boundary of basin-fill sediments

Study area boundary

Figure 5. Concentrations of (*A*) dissolved solids and (*B*) nitrate in the basin-fill aquifer in the West Salt River Valley, Arizona—Continued.

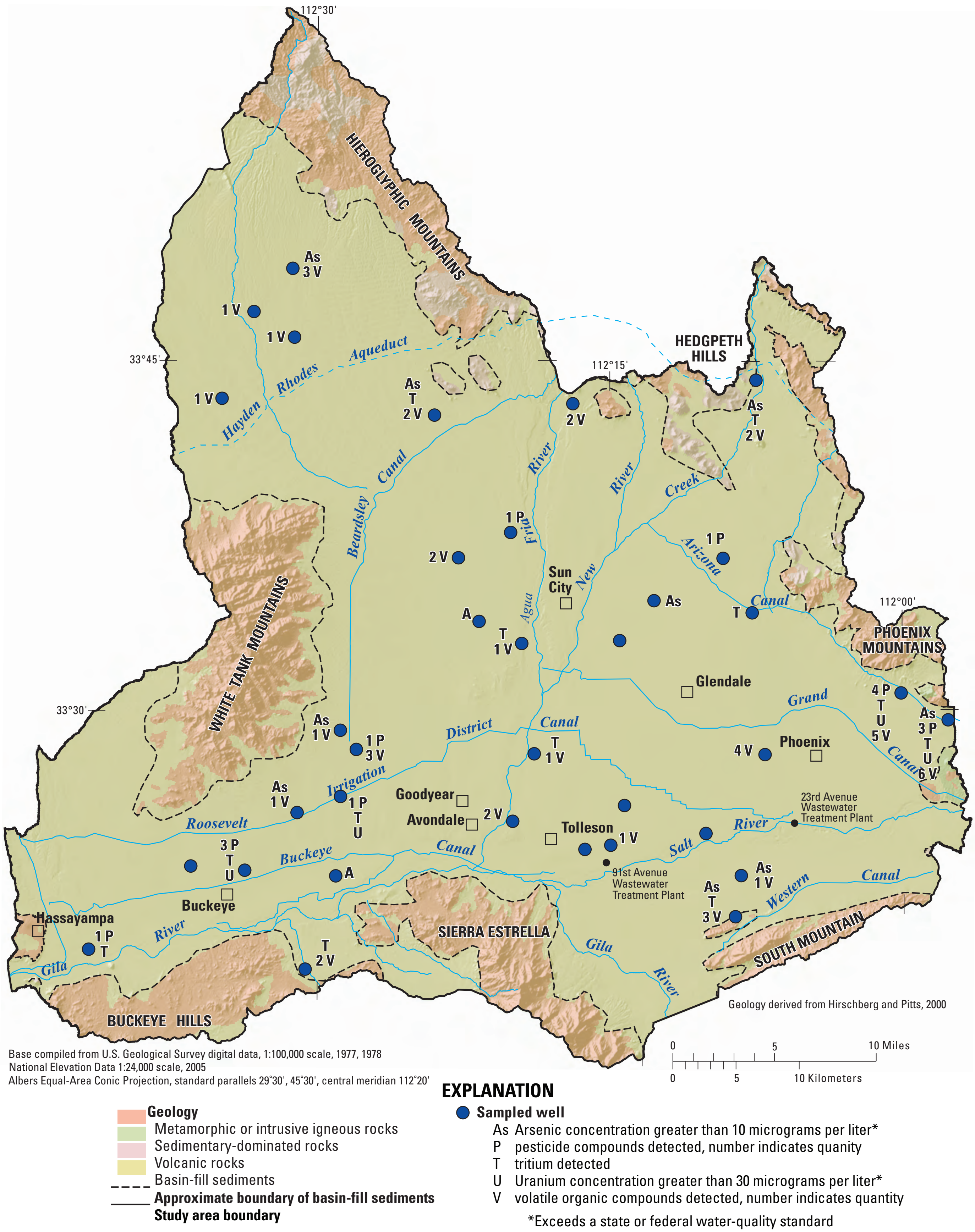


Figure 6. Elevated concentrations and detections of selected compounds in samples from the basin-wide water-quality assessment of groundwater in the West Salt River Valley, Arizona, 1996–98.

Of the 35 wells sampled in the study, one or more pesticides were detected in samples from 8 wells (fig. 6). Detected compounds include one insecticide degradation product: DDE, and seven herbicides and herbicide degradation products: atrazine, simazine, deethylatrazine, prometon, acetochlor, S-ethyl dipropylthiocarbamate, and triallate. None of the compounds were present at concentrations greater than any USEPA drinking-water standard. The spatial distribution of the detections indicates that pesticides applied at the land surface reached the groundwater in both agricultural and nonagricultural land-use settings. Also, pesticide detections did not directly correlate with the pesticide application rates in the valley (Gellenbeck and Anning, 2002).

Thirty-three detections of 18 different VOCs were identified in samples from 21 (70 percent) of the 30 wells that had VOC data (fig. 6). Detected compounds include:

1,2,4-trimethylbenzene (8 samples)	1,1-dichloroethane (2 samples)
Chloromethane (4 samples)	Methyl *tert*-butyl ether (MTBE; 2 samples)
Carbon disulfide (4 samples)	Benzene (1 sample)
Iodomethane (4 samples)	Trichlorofluoromethane (CFC-11; 1 sample)
Trichloromethane (chloroform; 3 samples)	1,1,1-trichloroethane (TCA; 1 sample)
Trichloroethene (TCE; 3 samples)	1,1,2-trichloro-1,2,2 trifluoroethane (1 sample)
1,4-dichlorobenzene (3 samples)	1-chloro-2-methyl benzene (1 sample)
Bromodichloromethane (2 samples)	1,1- dichloroethene (1 sample)
Tetrachloroethylene (PCE; 2 samples)	Acetone (1 sample)

The detected VOCs all have potential anthropogenic sources; however, a few of the detections may not necessarily indicate contamination of the aquifer due to human activities. Chloromethane and carbon disulfide have human sources, but could also have been produced by fungi and enter groundwater from that natural source (Gellenbeck and Anning, 2002). Also, the presence of trichloromethane and bromodichloromethane in groundwater samples can result from chlorination of a well as a treatment for bacteria and odors, and may not represent aquifer contamination. That said, the large variety of VOCs and the large area where samples contained VOCs, indicate that groundwater in the West Salt River Valley is affected by human activities (Gellenbeck and Anning, 2002).

Groundwater-Quality in an Agricultural Land Use Setting

In addition to assessing groundwater-quality conditions in the West Salt River Valley on a basin-wide scale, NAWQA investigators also sampled wells in an agricultural land use setting to characterize the effects of that land use on water quality. That assessment consisted of an analysis of samples from 9 monitoring wells in an agricultural area near Buckeye in the southwestern part of the valley (fig. 1). The monitoring wells were completed within the top 10 ft of the water table in the basin-fill aquifer, where the most recent recharge from excess irrigation water is expected to accumulate. Tritium activity levels in samples from the 9 wells were 15 pCi/L or greater, which confirmed the representation of recent recharge by the samples.

For several constituents, concentrations were higher and detections more frequent in samples from wells in the agricultural area than in samples from wells included in the basin-wide assessment. For example, median concentrations of dissolved solids, nitrate, fluoride, arsenic, barium, chromium, and strontium for wells in the agricultural area were greater than median concentrations for wells in the basin-wide assessment (Edmonds and Gellenbeck, 2002). Concentrations of these inorganic constituents were higher, in part, owing to evapotranspiration of the irrigation water before it percolated to the shallow groundwater body.

Pesticides were detected in samples from all nine monitoring wells, clearly indicating that pesticides are reaching the shallow groundwater and that the agricultural land use is affecting water quality (Gellenbeck and Anning, 2002). Samples were collected from each well both during and after the irrigation season. Ten different pesticides were detected during the irrigation season, whereas only seven different pesticides were detected afterward, which may reflect the degradation of pesticide compounds following the irrigation season.

The most commonly detected pesticides in samples from wells in the agricultural area were atrazine, which was detected in water from all nine wells, and deethylatrazine, a degradation product of atrazine, which was detected in water from 8 wells. Other detected pesticides include simazine, DDE, diuron, dieldrin, chlorpyrifos, acetochlor, prometon, metribuzin, and trifluralin. The compound DDE (1,1-dichloro-2,2-bis(chlorophenyl)ethylene), is a degradation product of DDT (1,1,1-trichloro-2,2-bis(chlorophenyl)ethane), an insecticide used in agricultural areas from 1944 until its use was banned in Arizona in 1965. 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 groundwater.

At least one VOC was detected in each of the nine wells sampled in the agricultural area, and a total of 20 VOCs were detected amongst samples from all the wells. Trichloromethane, a byproduct of the chlorination of drinking water also known as chloroform, was the most commonly detected VOC with occurrences in every sample during both sampling periods. Land in the agricultural area is irrigated with treated effluent from the Phoenix wastewater treatment plants that process chlorinated city water. Trichloromethane also can enter the groundwater in recharge of lawn irrigation water, leaking water-supply mains, and sewers. The presence of trichloromethane in the shallow groundwater in this area indicates that the water is affected by human activities.

The second most commonly detected VOC in samples from the agricultural area wells was tetrachloroethylene (PCE), which was detected in water from 5 of the 9 wells. PCE was detected in samples collected from three wells during both sampling periods, and trichloroethene (TCE) also was detected at one of these same wells. All but one of the detections were at concentrations below the minimum reporting level for non-estimated values in the laboratory analysis. Four of the five wells in which samples contained PCE or TCE are downgradient from a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site near Goodyear, where the groundwater is known to be contaminated with TCE and PCE (Gellenbeck and Anning, 2002). Another possible source of the PCE and TCE detections in these 5 wells is the local use of these compounds as solvents.

Relation of Groundwater Quality to Hydrogeology, Water Use, and Land Use

Edmonds and Gellenbeck (2002) developed a relation of groundwater quality to hydrogeology, water use, and land use by comparing dissolved-solids concentrations, nitrate concentrations, and pesticide detections for 5 different classes of wells sampled in the basin-wide assessment and the agricultural land use study, and for 15 other wells sampled as part of the NAWQA Program (table 2; fig 7). Water-quality conditions in wells in class A, which are in areas with minimal agricultural or urban development, served as indicators of reference, or background, conditions. The median dissolved-solids concentration (257 mg/L) and median nitrate concentration (1.7 mg/L) for these wells were the lowest amongst the different classes. In addition, no pesticides were detected in any samples from these wells.

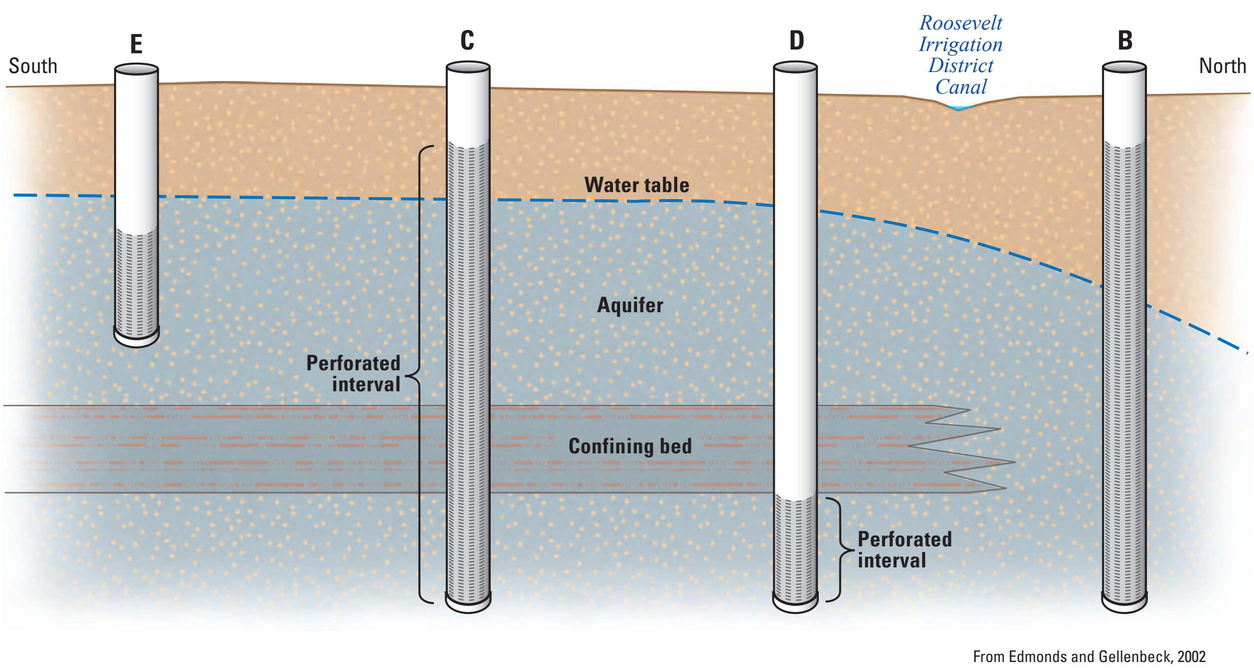


Figure 7. Construction typical of classified wells, West Salt River Valley, Arizona. (Class A wells not shown.)

Table 2. Summary of physical and water-quality characteristics for five classes of wells in the West Salt River Valley, Arizona.

[See figure 7 for typical well construction of classes B, C, D, and E. Data from Edmonds and Gellenbeck, 2002]

Well class and number of wells	A. 8 wells	B. 13 wells	C. 11 wells	D. 18 wells	E. 9 wells
Physical characteristics					
General location	Throughout the valley, but generally along margins	North of the Roosevelt Irrigation District Canal or east of the Agua Fria River	Southwestern part of valley	Southeastern and southwestern part of valley	Southwestern part of valley
Land use and irrigation supply	Undeveloped; no irrigation	Agricultural areas irrigated with groundwater or Agua Fria River water	Agricultural areas served by the Buckeye and Roosevelt Irrigation District Canals, which contain pumped groundwater, surface water and treated municipal effluent	Agricultural and urban areas; unspecified water supplies	Agricultural areas irrigated with groundwater and water from the Buckeye and Roosevelt Canals, which contain treated municipal effluent
Hydrogeology, confinement, and well perforations	Unspecified	No appreciable amounts of fine grained sediments penetrated by well, or perforations above any fine-grained confining beds	Perforations are above fine-grained confining beds of middle unit	Perforations are completely below fine-grained sediment beds of middle unit with unperforated casing extending from land surface through these beds	Monitoring wells were constructed to sample the top of the aquifer, with perforations above fine-grained confining beds of middle unit
Water-quality characteristics					
Median dissolved-solids concentration, milligrams per liter	257	668	3,050	747	3,350
Median nitrate concentration, milligrams per liter	1.7	11.4	19.0	2.0	16.9
Pesticide detections	0	11	35	0	78
Number of wells where pesticides were detected	0	6	10	0	9
Number of pesticide compounds detected	0	7	11	0	10

Although wells in class D are in both agricultural and urban areas, analyses of samples did not reflect any effects of recent recharge by excess irrigation water, probably because the wells are perforated below poorly permeable, fined-grained confining beds in the middle unit of the basin-fill aquifer (table 2, fig. 7). The lack of tritium detections in samples from these wells confirms this lack of recent recharge. Statistical analyses of the data indicated that median concentrations of dissolved solids (747 mg/L) and nitrate (2.0 mg/L) were comparable to those for samples from class A wells, but significantly less than those for class C and E wells which receive recharge from excess irrigation water. Brown and Pool (1989) also found that dissolved-solids concentrations were lower in the water in deeper aquifer units than in water in the uppermost saturated unit. No pesticides were detected in any samples from class D wells, further indicating the lack of effects of recharge from excess irrigation water.

Wells in classes C and E are in agricultural areas served by the Buckeye and Roosevelt Irrigation District canals, which convey pumped groundwater, surface water, and treated municipal effluent to agricultural fields. Fine-grained sediments of the middle unit of the basin-fill aquifer form confining beds in this area; however, in contrast to wells in class D, wells in classes C and E are perforated above these confining beds. Wells in class E are in agricultural areas and were designed to sample the top 10 ft of the basin-fill aquifer; results of analyses of samples from these wells were discussed above. As a consequence of being perforated above the confining beds, class E wells yield water in which median concentrations of dissolved solids (greater than 3,000 mg/L) and nitrate (greater than 16 mg/L) were higher than in water from well classes A, B, and D (table 2). In addition, pesticide detections, the number of wells in which pesticides were detected, and the number of compounds detected in samples from wells in classes C and E, were higher than those for wells in classes A, B, and D (table 2).

Wells in class B were in agricultural areas outside the Buckeye and Roosevelt Irrigation Districts that lack confining conditions created by the presence of fine-grained sediments. Median concentrations of dissolved solids and nitrate, and pesticide detections for wells in class B generally are in between the concentrations and detections frequency for well classes A and D, which were not affected by recharge of excess irrigation water, and wells in classes C and E, which were affected by recharge of excess irrigation water. The water table generally is deeper in wells in class B than in wells in classes C and E. The deeper water table in wells in class B may be the reason for the lesser effects of recharge of excess irrigation water on groundwater quality in these wells as compared to the effects detected in samples from wells in classes C and E.

Summary

The West Salt River Valley in central Arizona is an arid basin with significant water-resources development that supports agricultural and urban activities. The mountains surrounding the valley are composed primarily of granitic and metamorphic rocks, and the valley is a structural basin filled with consolidated to unconsolidated sediments. Where saturated, these sediments form the basin-fill aquifer. Water demands for municipal and agricultural needs are met using a variety of water sources, including groundwater from the basin-fill aquifer; surface water from the Agua Fria, Gila, Salt, and Verde Rivers, most of which is stored in reservoirs outside the valley; imported water from the Central Arizona Project; and recycled water from municipal wastewater-treatment plants.

The groundwater system is considered to have been under steady-state conditions prior to the beginning of water development by settlers in the 1860s. Groundwater fluxes were estimated to have been about 68,000 acre-ft/yr, and groundwater movement was primarily horizontal and towards and along the Salt and Gila Rivers. The natural groundwater flow system has been substantially altered by water-development related stresses such as withdrawals from regional pumping centers and recharge supplied by canal seepage and infiltration of excess irrigation water applied to croplands and turf. Estimated recharge under modern-day development conditions is estimated at about 457,000 acre-ft/yr, which is nearly seven times that before development began. Most of this increase is due to recharge from excess irrigation water. Estimated discharge under modern-day development is 524,000 acre-ft/yr, which is nearly eight times the rate for predevelopment conditions. Most of this increase is due to groundwater pumping, and in some areas, groundwater now flows towards large depressions in the water table caused by withdrawals at regional pumping centers.

Water-quality issues for the basin-fill aquifer include elevated concentrations of dissolved solids, nitrate, and arsenic; and the presence of pesticides and volatile organic compounds (VOC) in groundwater in parts of the valley. The occurrence and concentrations of these water-quality constituents result from natural and human-related factors such as hydrogeology, water use, and land use. Examples of natural factors that affect groundwater quality include occurrence of evaporites in the basin-fill deposits that elevate concentrations of dissolved solids, natural nitrogen fixation that elevate concentrations of nitrate, and geological sources and geochemical reactions that elevate arsenic concentrations (table 3). Examples of human-related factors that affect groundwater quality include irrigation of cropland and urban landscaped areas, which through multiple mechanisms, can elevate concentrations of dissolved solids, nitrate, and selected trace elements and result in pesticide and VOC detections (table 3).

Table 3. Summary of documented effects of natural and human-related factors on groundwater quality in the West Salt River Valley, Arizona.

[VOC, volatile organic compound]

Groundwater-quality effect	Cause	General location(s)	Reference(s)
		Primarily natural factors	
Elevated concentrations of dissolved solids	Dissolution of evaporites in the lower part of the lower unit of the basin fill	Areas adjacent to and downgradient of the Luke Salt Body	Eaton and others (1972), Brown and Pool (1989)
Elevated concentrations of nitrate	Transport of nitrogen from decomposed vegetation or nitrogen fixed by bacteria associated with desert legumes	Basin wide	Gellenbeck (1994)
Elevated concentrations of arsenic	Geochemical reactions between the groundwater and compounds in the basin fill that are presumed to come from hydrothermal sulfide and arsenide deposits in the surrounding mountains	Basin wide	Robertson (1991)
		Primarily human-related factors	
Elevated concentrations of nitrate and dissolved solids	Application of nitrogen fertilizers and evaporation during irrigation of crops and urban landscaped areas	Agricultural and urban areas, especially in the upper part of the aquifer above confining beds	Edmonds and Gellenbeck (2002), Brown and Pool (1989)
Elevated concentrations of nitrate	Transport of nitrogen from dairies and feedlots, wastewater treatment plants, and cultivated lands	Basin wide	Gellenbeck (1994)
Elevated concentrations of nitrate, dissolved solids, fluoride, arsenic, barium, chromium, and strontium	Evaporation of irrigation water before seeping to shallow groundwater	The shallow part of the aquifer in the western part of basin where wells in the agricultural area were sampled	Edmonds and Gellenbeck (2002)
Occurrence of pesticides	Application of pesticide compounds to croplands and urban landscaped areas	Agricultural and urban areas, especially in the upper part of the aquifer above confining beds	Edmonds and Gellenbeck (2002)
Occurrence of volatile organic compounds	Use of municipal wastewater containing VOCs for irrigation of crops and urban landscaped areas, and urban and industrial activities on the land surface and subsequent transport of compounds to aquifer	Agricultural and urban areas, especially in the upper part of the aquifer above confining beds	Edmonds and Gellenbeck (2002)

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