National Water-Quality Assessment Program

Southwest Principal Aquifers Regional Ground-Water Quality Assessment

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey is conducting a regional analysis of water quality in the principal aquifers in the southwestern United States. The Southwest Principal Aquifers (SWPA) study is building a better understanding of the susceptibility and vulnerability of basin-fill aquifers in the region to ground-water contamination by synthesizing the baseline knowledge of ground-water quality conditions in 15 basins previously studied by the NAWQA Program (fig. 1). The improved understanding of aquifer susceptibility and vulnerability to contamination (these terms are defined on page 3) is assisting in the development of tools that water managers can use to assess and protect the quality of ground-water resources. The NAWQA Program is performing similar regional investigations for other principal aquifers across the country (Lapham and others, 2005).

Basin-fill aquifers underlie about 49 percent of the 409,000 mi^2 study area and are the primary ground-water supply for cities and agricultural communities. In several areas, these aquifers provide base flow to streams that support important aquatic and riparian habitats. When aggregated across the study area, the basin-fill aquifers comprise four of the principal aquifers of the United States: the Basin and Range basin-fill aquifers in California, Nevada, Utah, and Arizona; the Rio Grande aquifer system in New Mexico and Colorado; and the Coastal Basin aquifers and the Central Valley aquifer system in California (fig. 1; U.S. Geological Survey, 2003a).

About 46.6 million people live in the SWPA study area (LandScan Global Population Database, 2005), mostly in urban metropolitan areas, but also in rural agricultural communities that tend about 14.4 million acres of cropland (U.S. Geological Survey, 2003b). Other rural areas contain small communities with mining, retirement, and

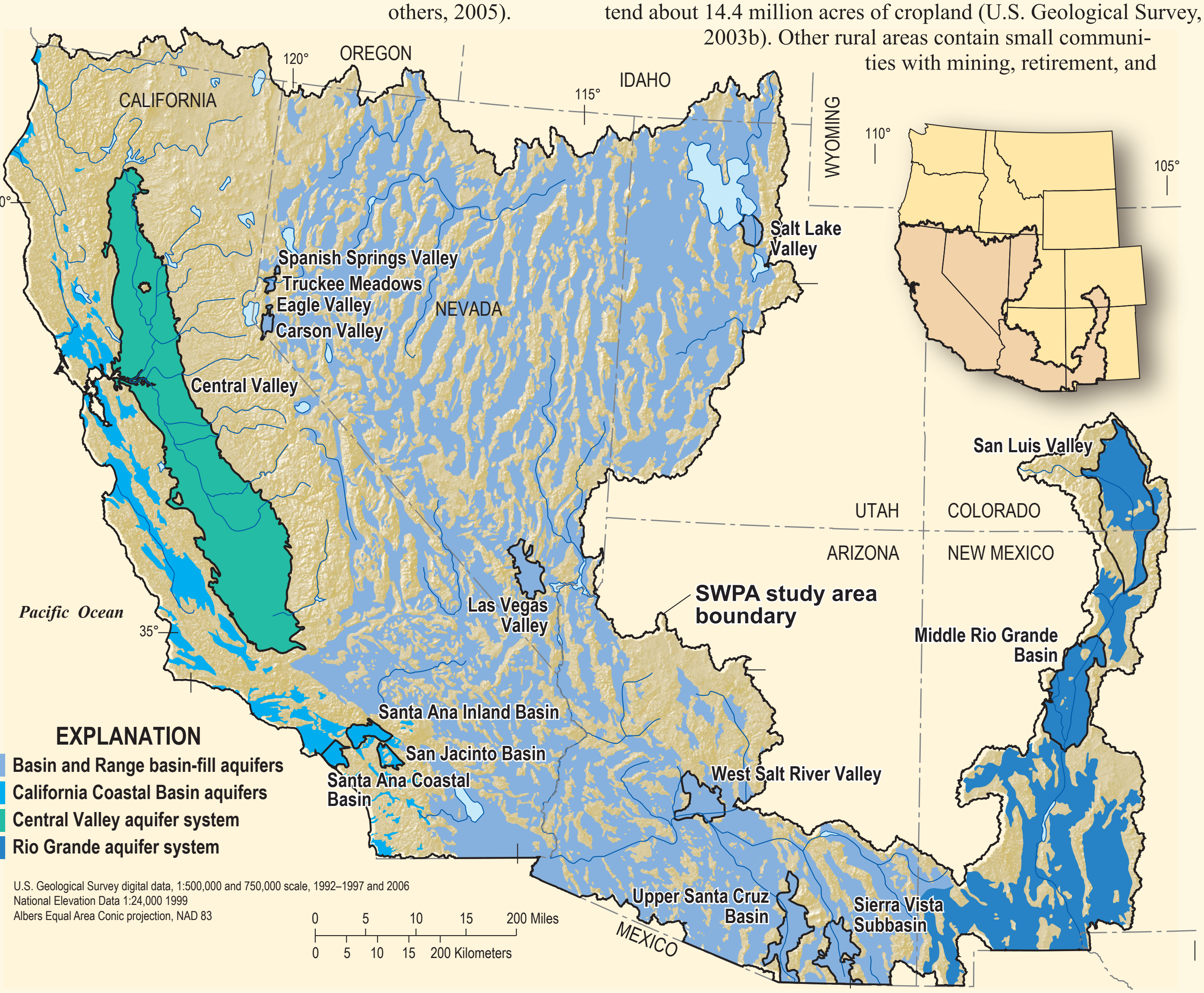


Figure 1. Principal aquifers and locations of 15 basins previously studied by the NAWQA Program in the Southwest Principal Aquifers study area.

(or) tourism/recreational-based economies. Due to the generally limited availability of surface-water supplies in the arid to semi-arid climate, cultural and economic activities in the region are particularly dependent on good-quality ground-water supplies. In the year 2000, about 33.7 million acre-feet of surface water was diverted from streams, and about 23.0 million acre-feet of ground water was withdrawn from aquifers in the SWPA study area (U.S. Geological Survey, 2008). Irrigation and public-supply withdrawals from basin-fill aquifers in the study area for 2000 were about 18.0 million acre-feet and 4.1 million acre-feet, respectively, and together account for about one quarter of the total withdrawals from all aquifers in the United States (Maupin and Barber, 2005).

Basin-Fill Aquifers

Basin-fill aquifers primarily consist of sand and gravel deposits that partly fill structurally formed depressions and are bounded by mountains (fig. 2). In some areas, fine-grained deposits of silt and clay are interbedded with the porous sand and gravel deposits and form confining units that retard vertical movement of ground water. Most basins contain thick sequences of basin-fill deposits, and the sediment becomes increasingly more compacted and less permeable with depth. Many basins are drained by a stream that flows through a gap in the consolidated rock, although some basins are closed and ground water and surface water are removed only by evapotranspiration. High-energy mountain streams form alluvial fans with coarse-grained sediment deposited along the mountain fronts. The unsaturated zones below alluvial fan surfaces usually are several hundred feet thick and underlain by an unconfined aquifer. Steep alluvial fans transition to a relatively flat valley floor where lacustrine and fluvial depositional environments often have created layers of fine-grained sediment interbedded with more permeable layers of sand and gravel. This usually results in confined conditions and upward vertical gradients in discharge areas in the central part of the basin.

The primary sources of natural recharge to the deeper parts of the basin-fill aquifers are precipitation on the surrounding mountains and infiltration from streams. Runoff from the surrounding mountains seeps into the coarser-grained stream-channel and alluvial-fan deposits near the basin margins. Precipitation also can infiltrate the consolidated mountain rock where it is fractured or porous and can move into the basin-fill deposits. Low precipitation rates, combined with high evaporation rates, result in a relatively small contribution of ground-water recharge from precipitation occurring on the basin floor. Much of that recharge is focused as infiltration through ephemeral stream channels. Some recharge occurs as subsurface inflow of ground water from adjacent basins.

Before human development of water resources began in the alluvial basins, ground-water recharge and discharge were in equilibrium. Ground-water discharge typically was by evapotranspiration of shallow ground water in wetlands or playas (in closed basins) and by discharge to streams flowing through the basin. In some basins, discharge occurs as subsurface outflow to adjacent basins; however, in other basins, faulting and constrictions in the bedrock that surrounds the aquifer restrict ground-water outflow.

With water development, some basin-fill aquifers have changed considerably as a result of an increase in the amount of and number of mechanisms for recharge and discharge. Total ground-water flux rates (recharge and discharge) increased by a factor of more than four in the Middle Rio Grande Basin, New Mexico, and by a factor of about seven in the West Salt River Valley, Arizona (figs. 2 and 3, respectively). Artificial recharge sources, several of which are shown in fig. 2 for the Middle Rio Grande Basin, include seepage of irrigation water applied to crops and lawns; seepage from canals, distribution pipes, sewer pipes and septic systems; infiltration of storm-water runoff from retention basins, recharge basins, and dry wells; seepage of treated wastewater through streambeds or irrigated fields; and infiltration in recharge ponds or well-injection of surface water or imported water. Recharge from these artificial sources introduces water to parts of the ground-water system that previously received little or no recharge from the land surface. The increase in recharge and redistribution of water to areas that previously did not receive recharge has resulted in increased saturated thicknesses, increased flow velocities, and changes in flow directions.

For many basins, withdrawal from pumping wells has become the primary source of ground-water discharge and is greater than ground-water recharge. For the West Salt River Valley, modern discharge is about 15 percent greater than modern recharge. In some basins, the imbalance between recharge and discharge has led to large decreases in ground-water storage and (or) decreases in ground-water discharge to streams and evapotranspiration. Water-level declines and changes in flow directions and magnitudes occur where ground-water withdrawals are large. The increased rates of recharge and discharge

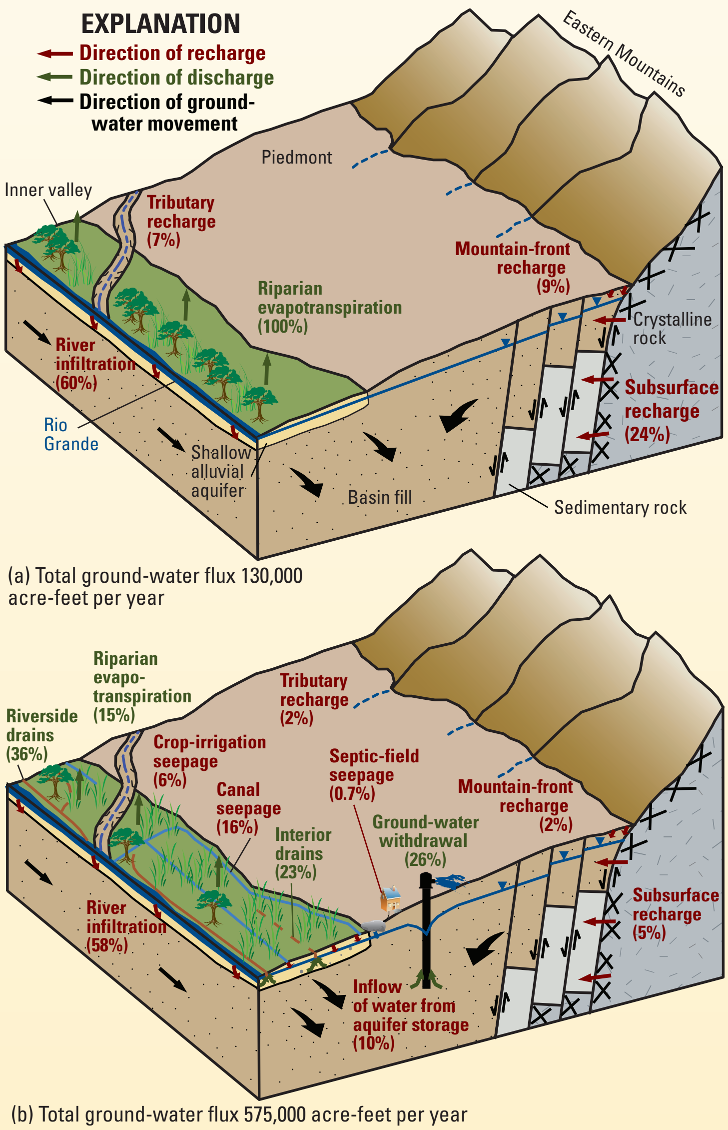


Figure 2. Generalized block diagram for the Middle Rio Grande Basin, New Mexico, showing components of the ground-water system under (a) predevelopment and (b) modern conditions. Component data from McAda and Barroll (2002).

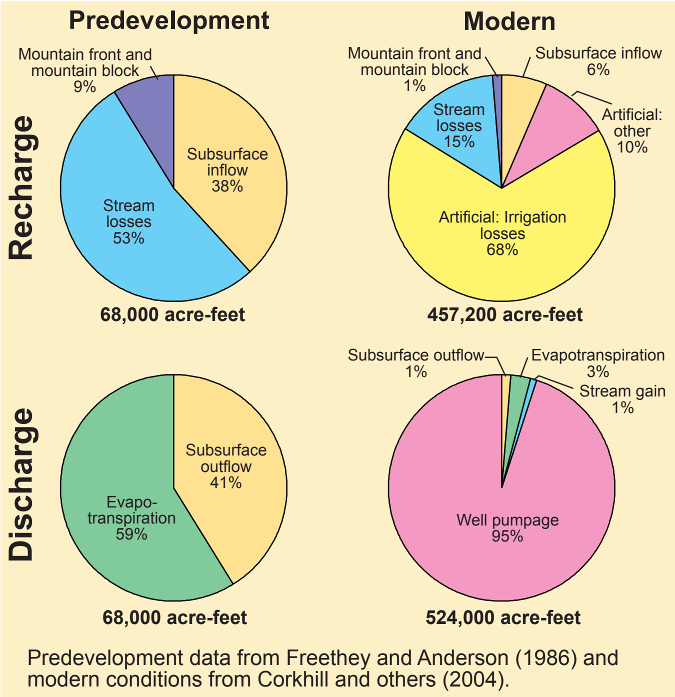


Figure 3. Estimated annual recharge and discharge water-budget components for predevelopment and modern conditions in the West Salt River Valley, Arizona.

associated with water development have increased flow through many basin-fill aquifers, especially from the land surface to the shallower parts of the aquifer. However, ground-water withdrawals from the deep wells typically used for public supply also have resulted in enhanced movement of ground water from shallower to deeper parts of basin-fill aquifers. Water development, therefore, typically results in aquifers being more susceptible to water-quality degradation by human activities occurring at the land surface and more vulnerable to contaminants where sources are present.

Susceptibility and Vulnerability to Contamination

The ease with which water enters and moves through an aquifer is described as its intrinsic susceptibility (Focazio and others, 2002). Aquifer susceptibility is dependent on the aquifer properties and other characteristics such as recharge rate, the presence or absence of an overlying confining unit, ground-water travel time, thickness and characteristics of the unsaturated zone, and pumping. The vulnerability of ground water to contamination is the probability for contaminants to reach a specified part of an aquifer after being introduced, usually at the land surface. Vulnerability is dependent on the properties of the ground-water system (susceptibility), the proximity of contaminant sources, and the contaminant's chemical characteristics. Long ground-water residence times and slow rates of contaminant degradation in basin-fill aquifers of the SWPA study area can make the process of contaminating ground water virtually irreversible and treatment prohibitively expensive or otherwise impractical. Therefore, it is imperative to understand the primary natural and human factors associated with the susceptibility and vulnerability of these aquifers to contamination, which allows water managers to plan for their optimal protection and utilization.

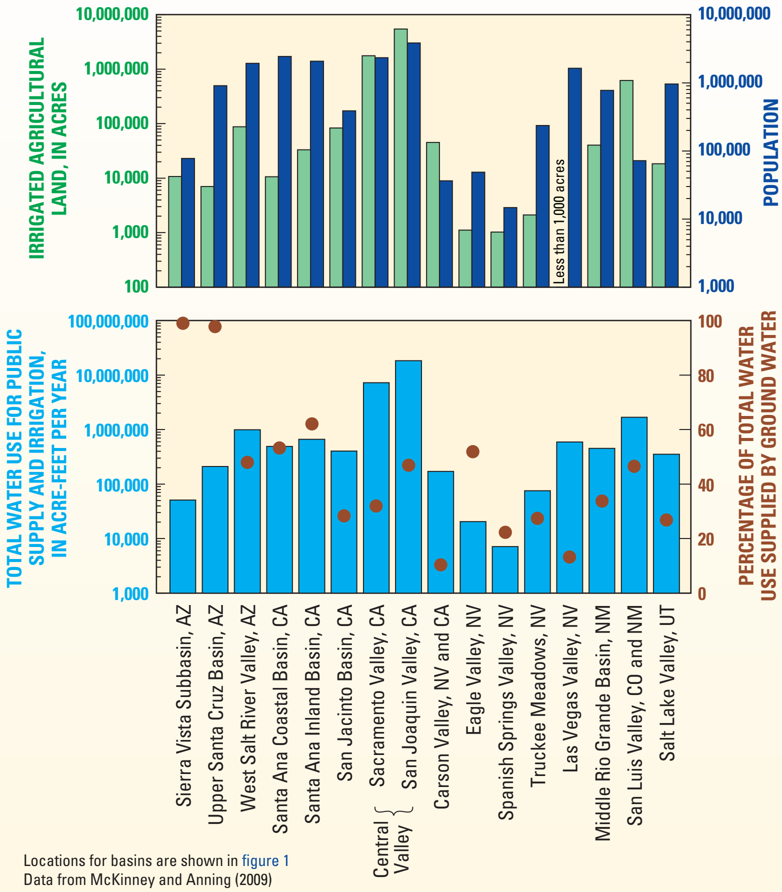
The SWPA study has completed two regional water-quality investigations for basin-fill aquifers. Paul and others (2007) investigated water quality of the shallow, upper parts of basin-fill aquifers in the SWPA study area and found them to be vulnerable to nitrate contamination (concentrations above 10 milligrams per liter) in areas where fertilizer is used, land is irrigated, and oxidizing conditions are present in the ground water. Similarly, Paul and others (2007) found that the occurrence of selected pesticides is affected by oxidation/reduction conditions, soil permeability, ground-water temperature, and depth to the well's screened interval. Occurrence of selected volatile organic compounds was found to be affected by oxidation/reduction conditions, pH, and industrial land use. Anning and others (2007) investigated salinity in the basin-fill aquifers of the SWPA study area and found that dissolved-solids concentrations typically increase along flowpaths as a result of geochemical reactions with the aquifer matrix, dissolution of disseminated salts and massive evaporite deposits, and evapotranspiration of shallow ground water by natural vegetation or by agricultural crops. Mixing with inflows of ground water, stream seepage, or irrigation seepage with higher concentration also causes increases in dissolved-solids concentrations along flowpaths.

Regional Analysis

Similarities in the hydrogeology, land- and water-use practices, and water-quality issues between the basin-fill aquifers of the SWPA study area allow for regional analysis. Regional analysis begins by determining the primary influential factors that commonly affect water quality, and the associated susceptibility and vulnerability of basin-fill aquifers to contamination, on the basis of data and information from a subset of information-rich basin-fill aquifers in the study area. Variations in the presence and magnitude of these influential factors across the basins allow for determination of the effects of each factor and for development of conceptual and mathematical susceptibility and vulnerability models of these effects. The models formed for these areas then can be extended to areas lacking ground-water quality data and interpretive studies. As part of the regional analysis activities, digital data sets that represent potential factors affecting water quality were produced by the SWPA study (fig. 4; McKinney and Anning, 2009). Potential factors such as population, land use, and water use (fig. 4) are general measures of the degree and type of human activities occurring on the land surface, and may reflect the magnitude and extent of contaminant sources and transport mechanisms.

During its first data-collection and analysis phase from 1991 to 2001, the NAWQA Program sampled wells and established baseline water-quality conditions for basin-fill aquifers in 15 basins across the study area (fig. 1). Ground-water quality also was investigated for relations to natural and human factors on the basis of a wide suite of constituents including major ions, nutrients, trace elements, pesticides, and volatile organic compounds. These studies developed detailed knowledge of local conditions and factors affecting ground-water quality for each basin, and the SWPA program is developing a regional understanding by synthesizing results from the 15 basin studies into a common set of factors and themes found to affect water-quality in basin-fill aquifers across the Southwestern United States. The synthesis consists of three major components:

1. A review that summarizes the status of, trends in, and influential factors affecting ground-water quality of basin-fill aquifers in the 15 individual basins previously studied by NAWQA;
2. Development of a conceptual model of the primary natural and human factors commonly affecting ground-water quality, leading to a regional understanding of the susceptibility and vulnerability of basin-fill aquifers to contaminants; and,
3. Development of statistical models that relate specific ground-water quality constituent concentrations or occurrence to natural and human factors linked to the susceptibility and vulnerability of basin-fill aquifers to contamination.



Locations for basins are shown in figure 1
Data from McKinney and Anning (2009)

Figure 4. Factors that likely affect the water quality of basin-fill aquifers include population, irrigated land, total water use for public supply and irrigation, and percentage of total water use supplied by ground water within the basin. Graphs above show approximate conditions for years 2000–2005.

Resource managers and scientists will be able to use the results of the SWPA regional water-quality studies in assessing the susceptibility and vulnerability of ground water to contamination in basins across the study area. By identifying natural and human factors and processes affecting the occurrence and transport of contaminants, the assessments will allow managers and scientists to apply findings to broader classes of contaminants. Regional-scale models and other decision-support tools that integrate aquifer characteristics, land use, and water-quality monitoring data will help water managers to estimate water-quality conditions in unmonitored areas, to assess the susceptibility and vulnerability of ground water under different future basin-development scenarios, and to develop cost-effective ground-water monitoring programs.

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