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

Edited by Susan A. Thiros, Laura M. Bexfield, David W. Anning, and Jena M. Huntington

Executive Summary

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS) has been conducting a regional analysis of water quality in the principal aquifer systems in the southwestern United States (hereinafter, "Southwest") since 2005. Part of the NAWQA Program, the objective of the Southwest Principal Aquifers (SWPA) study is to develop a better understanding of water quality in basin-fill aquifers in the region by synthesizing information from case studies of 15 basins into a common set of important natural and human-related factors found to affect groundwater quality.

The synthesis consists of three major components:

1. Summary of current knowledge about the groundwater systems, and the status of, changes in, and influential factors affecting quality of groundwater in basin-fill aquifers in 15 basins previously studied by NAWQA (this report).

2. Development of a conceptual model of the primary natural and human-related factors commonly affecting groundwater quality, thereby building a regional understanding of the susceptibility and vulnerability of basin-fill aquifers to contaminants.

3. Development of statistical models that relate the concentration or occurrence of specific chemical constituents in groundwater to natural and human-related factors linked to the susceptibility and vulnerability of basin-fill aquifers to contamination.

As illustrated by the sections in this report describing the groundwater and water-quality characteristics of the 15 case-study basins, similarities in the hydrogeology, land- and water-use practices, and water-quality issues for the SWPA study area enable a regional analysis of those characteristics. Regional analysis begins by determining the primary factors that 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. Conceptual and mathematical models formed for these basins can then be used to provide insight on areas that are hydrologically similar, but that are lacking groundwater-quality data and interpretive studies, or on areas where water development has not progressed as far as in the modeled basins. Regional-scale models and other decision-support tools that integrate aquifer characteristics, land use, and water-quality monitoring data will help water managers to evaluate water-quality conditions in unmonitored areas, to broadly assess the sustainability of water resources for future supply, and to help develop cost-effective groundwater monitoring programs.

Basin-fill aquifers occur in about 200,000 mi^2 of the 410,000 mi^2 SWPA study area and are the primary source of groundwater supply for cities and agricultural communities. Four of the principal aquifers or aquifer systems of the United States are included in the basin-fill aquifers of the study area: (1) the Basin and Range basin-fill aquifers in California, Nevada, Utah, and Arizona; (2) the Rio Grande aquifer system in New Mexico and Colorado; (3) the California Coastal Basin aquifers; and (4) the Central Valley aquifer system in California. Because of the generally limited availability of surface-water supplies in the arid to semiarid climate, cultural and economic activities in the Southwest are particularly dependent on supplies of good-quality groundwater. Irrigation and public-supply withdrawals from basin-fill aquifers in the study area account for about one quarter of the total withdrawals from all aquifers in the United States.

Basin-fill aquifers in the Southwest consist primarily of sand and gravel deposits that partly fill structurally formed depressions and are bounded by mountains. In some areas, fine-grained deposits of silt and clay are interbedded with the more permeable sand and gravel deposits, forming confining units that impede the movement of groundwater. The primary source of natural recharge to the deep parts of most basin-fill aquifers is precipitation on the surrounding mountains.

Mountain runoff seeps into the coarse-grained stream-channel and alluvial-fan deposits near the basin margins or enters the basin as subsurface inflow from consolidated rock. Low precipitation rates combined with high evaporation rates in the Southwest result in a relatively small contribution of groundwater recharge from precipitation that falls on the basin floor (generally less than 5 percent of annual precipitation). Before human development of water resources began in the alluvial basins, discharge from the groundwater systems typically resulted from evapotranspiration from the lowest parts of the basins and along stream channels, from springs, and as seepage to streams flowing through the basin. Artesian conditions exist in the groundwater discharge areas of several basins where the upward flow of water is impeded by low-permeability layers of clay, creating large vertical hydraulic gradients. Constrictions in the surrounding consolidated rock and faulting restrict groundwater flow out of many of the basins.

Although there are many similarities between the SWPA case-study basins and their aquifers, there are also major differences. For example, basin areas range from about 23 mi^2 for Eagle Valley in Nevada, to about 20,000 mi^2 for the Central Valley in California. Population densities in 2005 ranged from about 15 people/mi^2 in the San Luis Valley in Colorado and New Mexico to about 7,000 people/mi^2 in the Santa Ana Coastal Basin in California. The area of irrigated agriculture in the case-study basins in 2001 ranged from less than 1 percent in Las Vegas Valley in Nevada and in the Upper Santa Cruz Basin in Arizona to about 60 percent in the Central Valley.

Water development has caused considerable change in some basin groundwater systems in the Southwest. Imported surface water and the redistribution of water from within the basin to areas that previously did not receive recharge have resulted in increased flow velocities, greater saturated thicknesses, and changes in flow directions for some basins. Recharge from excess irrigation water and discharge by pumping groundwater for irrigation and public supply are much greater than natural sources of recharge and discharge in some basins. For example, groundwater recharge under modern conditions is about seven times that of predevelopment conditions in the West Salt River Valley (Phoenix area) in Arizona and about six times that of predevelopment conditions in the Central Valley. The infiltration of pumped groundwater and surface water applied for irrigation has resulted in recharge water that has been exposed to agricultural chemicals and natural salts concentrated by evapotranspiration. Infiltration of this water changes the chemistry of groundwater in the shallow part of the aquifer system. Other artificial or human-related sources of recharge to Southwest basins include seepage of water applied to lawns; seepage from canals, leaky distribution and sewer pipes, and septic systems; infiltration at retention basins, recharge basins, and dry wells used to receive storm runoff; and seepage of treated wastewater through irrigated fields and through streambeds as a means of disposal or artificial recharge.

Withdrawal from wells has become the primary source of groundwater discharge from many of the basins at the expense of discharge to streams and evapotranspiration. Water-level declines and changes in flow directions and magnitudes occur where groundwater withdrawals are large. Water levels in the west-central part of West Salt River Valley have declined between 300 and 400 ft since the early 1900s. Recharge and discharge associated with water development have resulted in an increase in the flow of water through parts of many basin-fill groundwater systems, especially flow from the land surface to shallow and unconfined parts of the aquifer. Water development, therefore, typically results in aquifers being more susceptible to water-quality degradation by human activities at the land surface and more vulnerable to contamination where contaminant sources are present.

Many factors influence the quality of groundwater in the 15 case-study basins, but some common factors emerge from the basin summaries presented in this report. These factors include the chemical composition of the recharge water, consolidated rock geology and composition of aquifer materials derived from consolidated rock, and land and water use. Groundwater is generally oxic (oxygen-rich) in the coarser grained alluvial-fan deposits and is usually anoxic (oxygen-poor) in the finer grained deposits that are predominant near the centers of the basins. Geochemically reduced conditions commonly occur in discharge zones where long flow paths terminate and residence time and organic matter content increase.

The amount of coarse-grained sediments near the land surface can be a major factor in the susceptibility of groundwater to nitrate contamination. Sediment texture influences rates of infiltration and groundwater flow, which in turn control how rapidly water at the land surface (which may have elevated concentrations of nitrate as a result of human activities) can infiltrate the soil and move downward into the aquifer. Elevated concentrations of nitrate have been measured in shallow groundwater in many of the case-study basins. Probable sources of nitrate in the groundwater include leaching of applied nitrate fertilizers, flushing of natural vadoze-zone deposits, irrigation using treated sewage effluent, leaking sewer pipes, infiltration of water contaminated by animal waste, and septic-system effluent.

The effects of human activities on groundwater quality are most commonly observed in shallow parts of the basin-fill aquifers. Where the vertical hydraulic gradient is downward and where confining layers are discontinuous, the potential exists for contaminants from the land surface to be transported through shallow saturated sediment to deeper parts of the aquifer. Pumping and resulting alterations of hydraulic gradients can cause changes in groundwater quality by enhancing the downward movement of shallow groundwater and the vertical or lateral movement of water from adjacent bedrock to parts of the basin-fill aquifer used for water supply.

Chloroform, a byproduct of the chlorination of water for drinking, was the most frequently detected volatile organic compound (VOC) in groundwater sampled from urban areas of the case-study basins. Possible sources of chloroform in shallow groundwater include leaky water distribution lines and sewer pipes and the use of disinfected public-supply water to irrigate lawns and gardens. The pesticide atrazine and its degradation product deethylatrazine were among the most frequently detected pesticides in groundwater samples collected from the case-study basins. Although the concentrations of these compounds are typically very small and not a health concern, their presence in the aquifer indicates the potential for their movement from the land surface and the possibility that higher concentrations may occur in the future.

The major water-quality issues in many of the developed case-study basins are increased concentrations of dissolved solids, nitrate, and VOCs in groundwater as a result of human activities. For instance, most of the recharge to the three Santa Ana groundwater basins in southern California occurs artificially at facilities that receive local streamflow, treated municipal wastewater, or imported surface water, all of which have influenced groundwater quality. The addition of water to the basin-fill deposits in the Coastal Basin of the Santa Ana Basin by artificial recharge and the removal of water by pumping have increased the lateral rate of groundwater flow through the system, resulting in a widespread distribution of chemicals in the recharge areas. Although the Coastal Basin is a highly urbanized area, wells downgradient from the recharge areas are screened in confined aquifers that are generally insulated from the effects of overlying land uses. The confining layers impede the vertical movement of water from the land surface and make this part of the aquifer less vulnerable to contaminant sources in the immediate area.

Water imported from Lake Mead has enabled population growth in Las Vegas Valley. Recharge to the shallow groundwater system, mostly from excess landscape irrigation water (known as secondary recharge), is increasing with the expansion of urban areas in the valley, especially onto the areas underlain by coarse-grained sediments near the mountain fronts. This recharge water has to move through natural barriers of fine-grained sediment and caliche to recharge the deeper groundwater system. The mixing of secondary recharge water and artificially recharged, imported surface water with native groundwater could potentially result in an increase in concentrations of dissolved solids in parts of the basin-fill aquifer.

In the Salt Lake Valley in Utah, seepage of excess water from irrigated crops and urban turf areas, and from leaking canals, water distribution pipes, sewer lines, storm drains, and retention basins are now sources of recharge to the basin-fill aquifer. This valley recharge is more susceptible to transporting man-made chemicals than is runoff from the mountains (mountain-front recharge) and subsurface inflow from the adjacent mountains (mountain-block recharge). Dissolved-solids concentrations have increased more than 20 percent in some areas near the Jordan River and on the east side of the valley over approximately a 10-year period. Groundwater pumping has caused the vertical and lateral groundwater-flow gradients to change, which could allow shallow groundwater or water from other parts of the deeper aquifer with higher concentrations of dissolved solids to reach the wells in these areas.

Changes in urban water-supply strategies through time to ensure efficient use of limited regional water sources can introduce new potential effects on groundwater quality. For example, because of limited groundwater availability, a water-supply strategy was recently (during 2008) implemented in the Middle Rio Grande Basin of New Mexico to replace most groundwater pumping for public supply to Albuquerque residents with direct use of surface water. Additional strategies being implemented or planned to reduce groundwater withdrawals include the use of treated municipal wastewater, recycled industrial wastewater, and nonpotable surface water to irrigate urban turf areas. These water sources have the potential to impact groundwater quality in new ways if an unconsumed (excess) component recharges the basin-fill aquifer.

The information presented and the citations listed in this report serve as a resource for those interested in the groundwater-flow systems in the NAWQA case-study basins. The summaries of water-development history, hydrogeology, conceptual understanding of the groundwater system under both predevelopment and modern conditions, and effects of natural and human-related factors on groundwater quality presented in the sections on each basin also serve as a foundation for the synthesis and modeling phases of the SWPA regional study.

This page intentionally left blank.