Prepared in cooperation with the
ARIZONA DEPARTMENT OF WATER RESOURCES and YAVAPAI COUNTY

Investigation of the Geology and Hydrology of the Upper and Middle Verde River Watershed of Central Arizona: A Project of the Arizona Rural Watershed Initiative

The upper and middle Verde River watershed in west-central Arizona is an area rich in natural beauty and cultural history and is an increasingly popular destination for tourists, recreationists, and permanent residents seeking its temperate climate. The diverse terrain of the region includes broad desert valleys, upland plains, forested mountain ranges, narrow canyons, and riparian areas along perennial stream reaches. The area is predominantly in Yavapai County, which in 1999 was the fastest-growing rural county in the United States (Woods and Poole Economics, Inc., 1999); by 2050, the population is projected to more than double. Such growth will increase demands on water resources. The domestic, industrial, and recreational interests of the population will need to be balanced against protection of riparian, woodland, and other natural areas and their associated wildlife and aquatic habitats. Sound management decisions will be required that are based on an understanding of the interactions between local and regional aquifers, surface-water bodies, and recharge and discharge areas. This understanding must include the influence of climate, geology, topography, and cultural development on those components of the hydrologic system.

In 1999, the U.S. Geological Survey (USGS), in cooperation with the Arizona Department of Water Resources (ADWR), initiated a regional investigation of the hydrogeology of the upper and middle Verde River watershed. The project is part of the Rural Watershed Initiative (RWI), a program established by the State of Arizona and managed by the ADWR that addresses water supply issues in rural areas while encouraging participation from stakeholder groups in affected communities. The USGS is performing similar RWI investigations on the Colorado Plateau to the north and in the Mogollon Highlands to the east of the Verde River study area (Parker and Flynn, 2000). The objectives of the RWI investigations are to develop: (1) a single database containing all hydrogeologic data available for the combined areas, (2) an understanding of the geologic units and structures in each area with a focus on how geology influences the storage and movement of ground water, (3) a conceptual model that describes where and how much water enters, flows through, and exits the hydrogeologic system, and (4) a numerical ground-water flow model that can be used to improve understanding of the hydrogeologic system and to test the effects of various scenarios of water-resources development. In 2001, Yavapai County became an additional cooperator in the upper and middle Verde River RWI investigation.

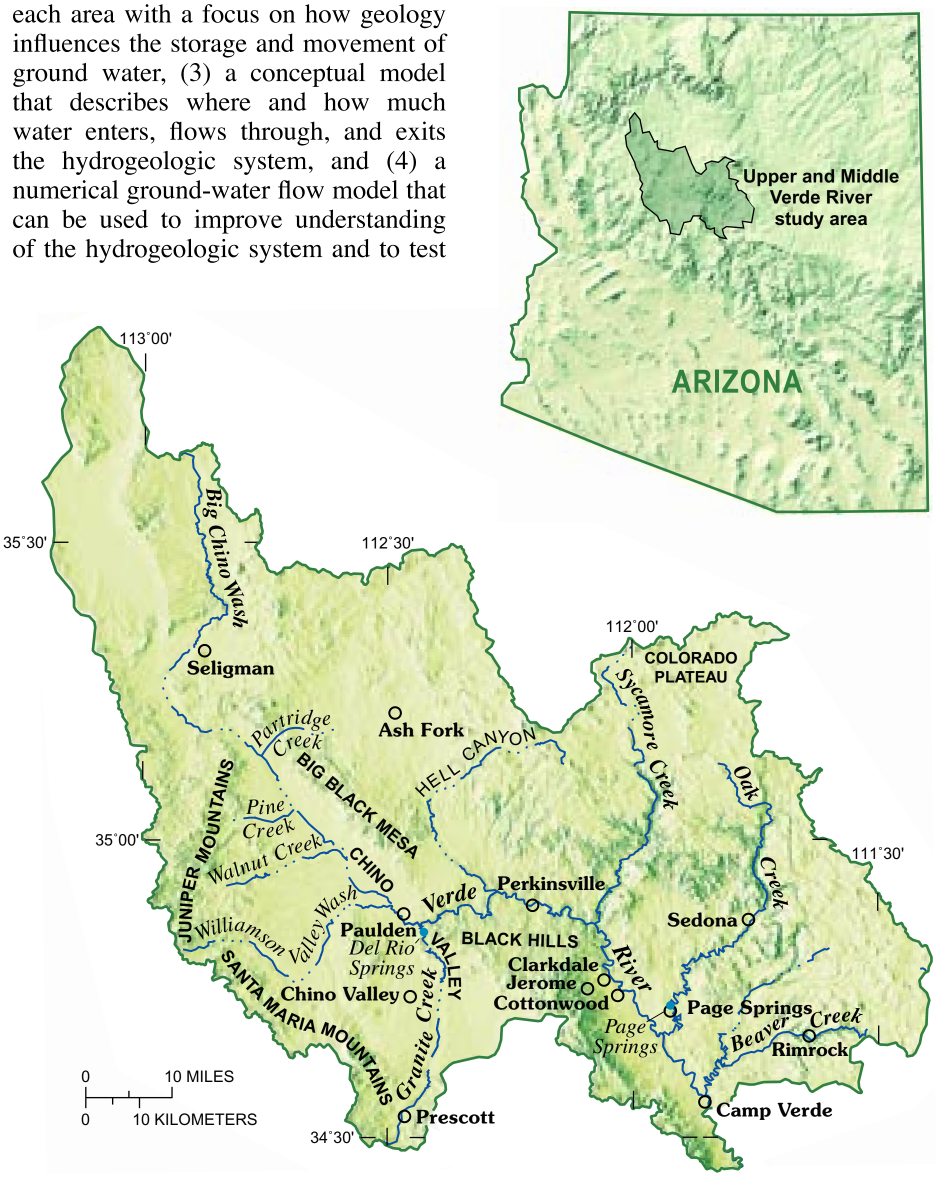

Figure 1. Location of the upper and middle Verde River study area.

Physical Setting

The upper and middle Verde River watershed covers an area of about 5,000 square miles southwest of Flagstaff, Arizona (fig. 1). Perennial streams in the area include the Verde River, which begins approximately 2 miles southeast of Paulden, and its tributaries: Beaver Creek, Oak Creek, and Sycamore Creek. The Verde River valley ranges in elevation from about 4,200 ft at its headwaters to about 3,000 ft near Camp Verde at the downstream boundary of the study area. The valley is surrounded by discrete mountain ranges and upland areas, including the Black Hills, the Juniper Mountains, the Santa Maria Mountains, Big Black Mesa, and the Colorado Plateau, that range in elevation from about 6,000 to more than 7,800 ft. The average annual precipitation ranges from less than 12 inches on the lower valley floors to about 30 inches at higher elevations. Most precipitation occurs during summer monsoons and winter frontal storms. Average annual temperatures range from a minimum of 41° F to a maximum of 73° F. Vegetation consists of semiarid grassland in the lower elevations, a mix of grassland, plains, and chaparral in elevations from about 3,500 to 5,000 ft, and chaparral, piñon pine, juniper, and ponderosa pine forests at the higher elevations.

In 2000, the population of Yavapai County, excluding Prescott Valley and the half of Prescott that is outside the study area, was estimated to be 118,000. About 50 percent of the population lives in the incorporated towns of Prescott, Sedona, Cottonwood, Camp Verde, Chino Valley, Clarkdale, and Jerome (Arizona Department of Economic Security, 2001). Nearly three-quarters of the land in Yavapai County is publicly owned—38 percent by the U.S. Forest Service, 24.6 percent by the State of Arizona, 11.6 percent by the Bureau of Land Management, and less than 0.5 percent by other public agencies. Private owners account for one-quarter of the land ownership, and the Yavapai-Prescott Tribe owns less than 0.5 percent (Arizona Department of Commerce, 2002).

Geology

The upper and middle Verde River watershed lies in the Transition Zone between the Basin and Range Physiographic Province to the south and southwest and the Colorado Plateau to the north and northeast. The uplands surrounding the valley generally consist of Precambrian intrusive, volcanic, and metamorphic rocks overlain by Paleozoic sedimentary strata and capped by Cenozoic volcanic rocks (fig. 2). Sparse outcrops of Mesozoic rocks appear above the Paleozoic sequence in the upper parts of Sycamore Creek and Oak Creek canyons. Various components of the Paleozoic sequence and the Cenozoic volcanics may be partly or entirely absent, leaving a patchwork of exposed outcrops throughout the uplands (Krieger, 1965; Owen-Joyce and Bell, 1983; Ostenaa and others, 1993).

The Chino Valley and the Verde River valley, from Clarkdale to Camp Verde, are relatively broad and are composed of late Cenozoic basin fill and alluvium underlain by Paleozoic sedimentary rocks (fig. 2). The fill ranges from fine grained to coarse grained and is greater than 2,500 ft thick in some parts of Chino Valley. Lacustrine sediments and volcanic rocks are interbedded with the basin fill. From the headwaters area to Clarkdale, the river flows in a narrow canyon incised into Paleozoic rocks that contains little or no alluvium (Owen-Joyce and Bell, 1983; Ostenaa and others, 1993).

The predominant structural features of the watershed are northwest- to north-trending normal faults that include the Big Chino fault along the northeast margin of Chino Valley and the Verde fault zone along the southwest side of the Verde River Valley. Many other subparallel faults are associated with the main faults. These Cenozoic faults are the primary influence on the present-day topography in the region. Structurally significant folds generally are not present in the area; the Mormon Mountain anticline northeast of Sedona has a maximum dip of 4 degrees, but is noteworthy because it forms a ground-water divide (Owen-Joyce and Bell, 1983).

Hydrology

The major streams in the upper part of the Verde River watershed are the Verde River (perennial below its confluence with Granite Creek); Big Chino Wash (ephemeral); Williamson Valley Wash, Walnut Creek, and Granite Creek (all with perennial flow in their upper reaches and ephemeral farther downstream); and Pine Creek and Partridge Creek (intermittent). In the middle Verde River watershed, the major streams are the Verde River, Sycamore Creek, Oak Creek, Beaver Creek (all perennial), and Hell Canyon (ephemeral).

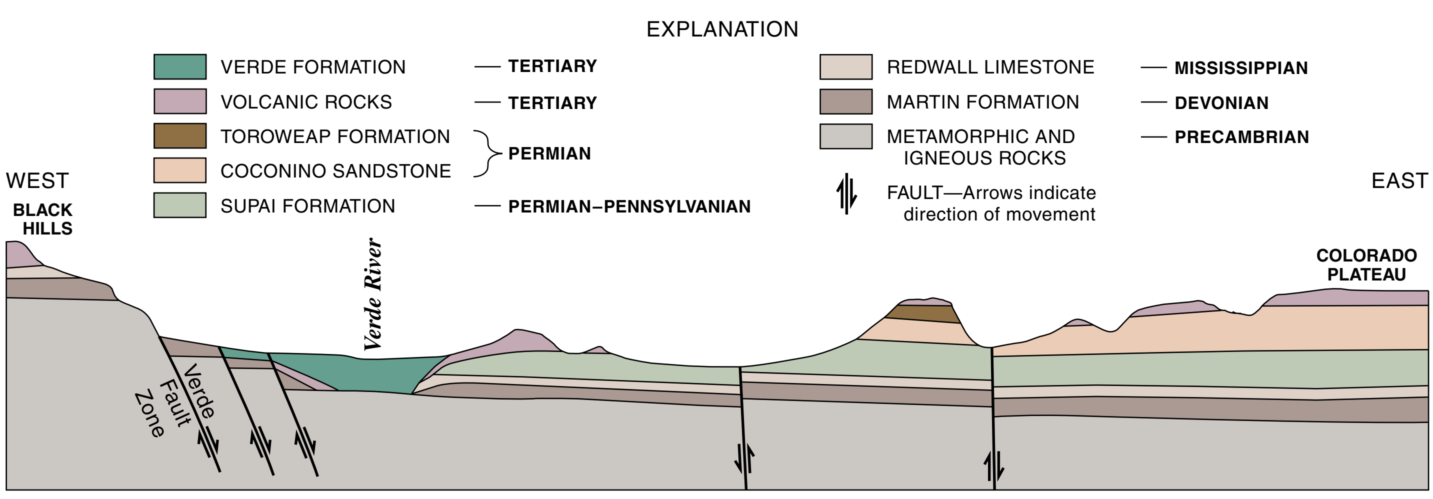

Figure 2. Schematic diagram of the study area showing a generalized west to east cross section.

The Arizona Supreme Court's 2000 definition of subflow as underground water associated with a stream could have implications for the many owners of wells completed in the alluvium or the Verde Formation, depending on the ADWR's eventual interpretation of the ruling.

The water that comprises the upper and middle Verde River hydrologic system enters the system as precipitation, predominantly in the higher elevations and upper reaches of the watershed. In the upper part of the watershed, precipitation enters the subsurface through the soil and fractures in the rock, and in the mountainous areas, it emerges a short distance later as springs. These springs are the headwaters of such drainages as Pine Creek, Walnut Creek, Partridge Creek, and Williamson Valley Wash. The creeks typically flow for some distance in the stream channel before the water percolates down to the water table, a process known as recharge. The ground water then flows through the basin-fill sediments and volcanic rocks of such valleys as Chino Valley, Williamson Valley, and Little Chino Valley, emerging again downstream as a second set of springs near, or in, the Verde River, comprising the base flow of the river. Farther downstream in the watershed, springs fed by preci-pitation recharge on the Colorado Plateau and other high elevations contribute additional base flow to the perennial stream reaches.

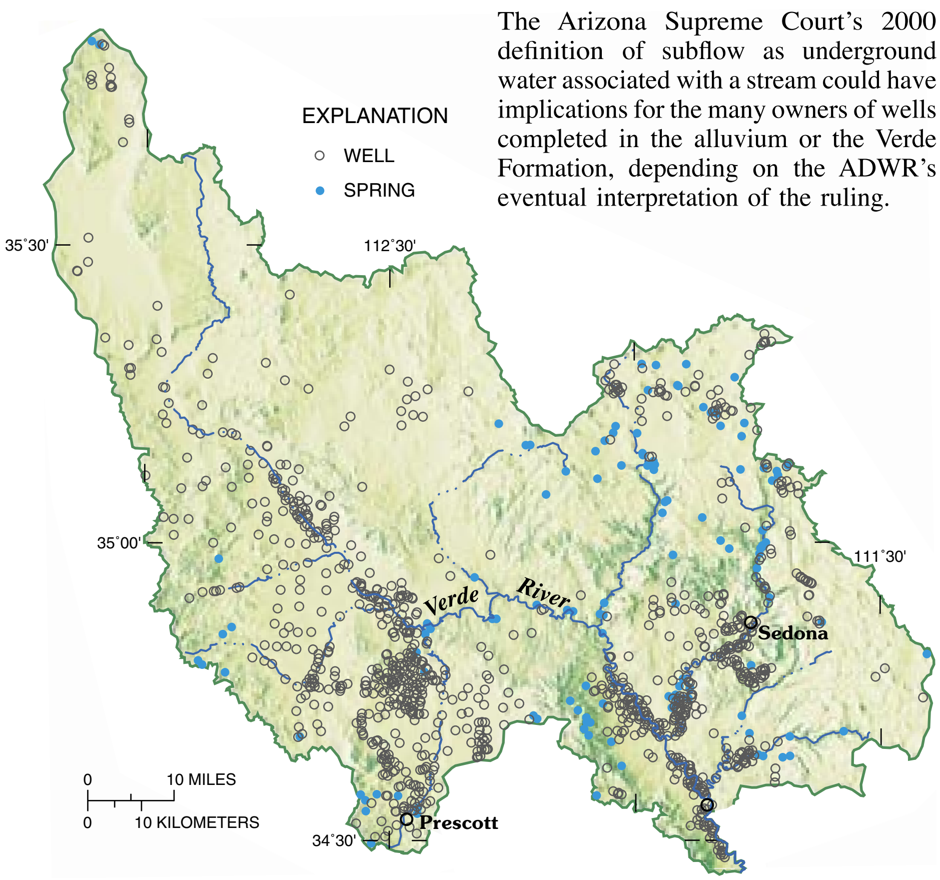

Figure 3. Location of wells and springs in the study area.

The USGS National Water Information System (NWIS) ground-water database lists more than 2,000 wells in the study area (fig. 3). About 75 percent of these wells are completed in formations of Cenozoic age: typically the Verde Formation in the middle Verde River watershed, and volcanic rocks or basin-fill sediments or both in the upper watershed. The remaining wells are completed in Paleozoic sedimentary rocks, with the exception of a few wells that are completed in Precambrian granite or gneiss. Well production varies widely within each of the major water-bearing formations, ranging from a few tens to more than 1,000 gallons per minute (gpm), depending locally on the degree of fracturing, faulting, and (or) solution channel development. The depth to water is less than 200 ft in approximately 80 percent of the wells; about 50 percent of these have depths to water of less than 55 ft. In some areas of the middle Verde watershed, the water table is above land surface and wells flow naturally; however, water-table declines in recent years have reduced the number of such wells. The recent alluvium adjacent to the Verde River in the middle Verde River watershed is in most places hydraulically connected to the Verde Forma-tion (Owen-Joyce and Bell, 1983).

The NWIS database contains infor-mation for about 150 springs in the upper and middle Verde River watershed (fig. 3); roughly half discharge from Cenozoic formations and half from Paleozoic rocks (particularly limestone formations) or, in a few instances, from Precambrian rocks. More than half the springs discharge less than 10 gpm, and approximately 80 percent discharge less than 100 gpm. The largest springs in the study area are Page Springs, which discharges about 10,000 gpm, and Del Rio Springs, which discharges about 900 gpm (fig. 4).

Figure 4. Discharge from Del Rio Springs.

Water Use

The primary use of surface water in the Verde River watershed is irrigation; many irrigation ditches downstream from the USGS streamflow-gaging station near Clarkdale divert water from the Verde River. Ground water (including springs) is the source of all domestic water use and serves municipal, industrial, and additional irrigation demands. Ground water is supplied by private water companies serving from a few to many thousands of customers and by a few public water companies. In addition, hundreds of private wells are known to exist throughout the watershed. The ADWR (2000) surveyed 59 private and municipal water companies in the upper and middle Verde River watershed. It is estimated that in 1997, the combined total annual water pumped by private and municipal water providers was greater than 14,000 acre-feet. Annual water demand for human use from combined surface-water and ground-water resources in their area of investigation was estimated to be 69,160 acre-feet, of which 67 percent was for agricultural use, 20 percent was for municipal use, 9 percent was for private industrial use, and 4 percent was for domestic use.

Table 1. Values for selected water chemistry properties in the upper and middle Verde River watershed

[µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; USEPA, U.S. Environmental Protection Agency; MCL, Maximum Contaminant level; SMCL, Secondary Maximum Contaminant level; N, number of analyses; R, range; Mn, mean; Md, median]

	pH			Specific conductance (µS/cm)			Dissolved solids (mg/L)			Arsenic, dissolved (mg/L)		
	N	R	Mn/Md	N	R	Mn/Md	N	R	Mn/Md	N	R	Mn/Md
USEPA MCL											0.05	
USEPA SMCL		6.5–8.5						500				
Wells	623	6.20–9.00	7.56/7.50	999	8–18,000	698/500	563	91–4,810	380/380	231	<.001–0.22	0.019/0.012
Springs	91	6.30–8.90	7.40/7.43	127	98–1,620	536/471	107	87–1,260	325/276	30	<.001–0.14	0.019/0.006
Streamflow	354	6.40–9.15	8.18/8.20	362	35–1,060	495/500	305	32–651	281/1,280	151	<.002–0.024	0.015/0.017

Water Quality

Data for surface-water and ground-water quality in the upper and middle Verde River watershed are variable, as shown in the summary of selected water-quality information from the USGS database (table 1). Surface and ground water have exceeded some of the U.S. Environmental Protection Agency's (USEPA) Primary and Secondary Maximum Contaminant Levels. The Arizona Department of Water Quality (ADEQ) is currently developing a water-quality improvement plan to address turbidity in the Verde River from Sycamore Creek to Oak Creek. The ADEQ also is monitoring fecal coliform and e. coli concentrations in Oak Creek, and nitrogen and phosphorus concentrations in the Verde River and Oak Creek. Ground-water quality has exceeded Secondary Maximum Contaminant Levels for dissolved solids and pH in some wells and springs throughout the region, particularly in wells open to the Verde Formation and Cenozoic basin fill. In the Camp Verde/Rimrock area, ground water from some wells in the Verde Formation and alluvium has exceeded the Maximum Contaminant Level for arsenic.

Remaining Questions

Although much is known about the upper and middle Verde River watershed, many questions about the hydrogeologic system remain. These questions include:

1. Where are the primary recharge areas, and how much recharge is occurring?
2. Where are the ground-water divides that mark the boundaries between ground water that flows toward the Verde River and ground water that flows away from it?
3. Where is the water going in sections of the Verde River in which streamflow decreases in the downstream direction?
4. What is the shape of the alluvial basins; what are the hydrologic properties of the material that fills them; and what geologic structures control ground-water flow into and out of them?
5. Can the ground-water sources and recharge areas of springs that contribute base flow to the Verde River be more accurately identified?
6. How much water is lost to evapotranspiration in various parts of the watershed?
7. How has human use of water resources affected the hydrogeologic system, and how and where might it affect the system in the future?

Possible Approaches

The first 2 years of the project have been devoted to the design and population of the regional database, the installation of equipment for long-term monitoring of water-level elevations, and collection of new data to supplement the existing data. The collection of new data will continue for the duration of the project. These data will be used in the development of interpretive models, which will be refined as additional data are available. Data collection efforts include the following:

1. Analyses of isotopes and hydro-chemistry of surface-water, ground-water, and spring samples, will be used to evaluate ground-water flow paths.
2. Geophysical and geological investi-gations will provide information about the geometry of the basins, basin boundaries, and structures that affect where and how rapidly ground-water flows through the subsurface.
3. Sensitivity analyses will be used to determine what kinds of data are most valuable in describing the ground-water flow system in the watershed.
4. Analyses of precipitation data, vege-tation extents and diversity, and soil or rock cover will enable estimates of recharge and evapotranspiration to be made.
5. Spatial relations among elevations of streams, springs, ground water in wells, and geologic features will be used to construct conceptual models of ground-water flow.
6. Regional features outside the water-shed boundaries will be evaluated to determine external influences on the hydrogeologic system.

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