

Chapter 3

Verde River Hydrology

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Introduction

The Central Arizona Highlands are a distinct biogeographic, climatic, and physiographic province that forms a diverse ecotone between the more extensive Colorado Plateau to the north and the Sonoran Desert ecoregions to the south (Ffolliott 1999). The Highlands coincide closely to the Arizona Transition Zone identified by ecologists, geologists, and others (Karlstrom and Bowring 1988; Hendricks and Plescia 1991; Ezzo and Price 2002). The Central Arizona Highlands have been the focus of a wide range of research efforts designed to learn more about the effects of natural and human-induced disturbances on the functions, processes, and important components of the region's ecosystems, including hydrology (Arizona State Land Department 1962; Baker 1999).

The UVR area of north-central Arizona overlaps the Central Highlands and the Plateau Uplands biogeographic provinces. The UVR watershed characteristics and physiography (figs. 1.1 and 1.2) were introduced in Chapter 1. The UVR watershed encompasses the northern valley of the Verde River. The greater Verde River watershed is bounded on the north and west by the Colorado River, on the east by the Little Colorado River, and on the south by the Salt River. Perennial flow in the Verde River is a major contributor to the water resources and hydrology of Arizona since it is the only free-flowing water source in a large portion of the central and northwestern part of the state.

The Prescott National Forest manages much of the drainage area of the UVR watershed where flow is perennial. Other areas of mostly intermittent flow to the north, northeast, and east where elevations are higher are managed by the Kaibab and Coconino National Forests. Some of these tributaries have perennial flow but mostly in their lower reaches. The bulk of the UVR watershed headward of the start of perennial flow is mainly private and State of Arizona lands. Because of the unique flora and fauna of the UVR, there is a lot of public interest in landscape management surrounding the UVR.

Hydrologic regimes in the Southwest are influenced by the interactions between the amount of precipitation (generally increasing with elevation), evapotranspiration, type of vegetation, and type of parent material (Baker and others 2003). Precipitation and elevation influence vegetation as conditioned by the geologic parent material. The runoff regime is naturally influenced by the amount and distribution of precipitation, but a major factor influencing streamflow response is the geologic parent material. As previously explained in Chapter 1, parent materials that are deeply weathered and fractured and those that weather to a fine-textured regolith have a strong influence on the growth and development of vegetation. These different parent materials and subsequent differences in soil texture and depth also play an important role in runoff regimes (Baker 1987).

The shape of a runoff hydrograph is a reflection of the hydrologic responsiveness of the basin and is determined by the delivery rate of water and length of

the flow path to the source area. Baker (1987) used hydrographs from gauged watersheds at Beaver Creek (fig. 1.1), Three Bar D, Castle Creek, Thomas Creek, and Workman Creek in water year 1973 (an exceptionally wet year) in Arizona to illustrate how various factors affected streamflow response and to show how much these factors interact in different areas of Arizona. Runoff efficiency rates (ratio of runoff to precipitation) nearly doubled or tripled in 1973 relative to pre-1973 data on all of the same observed basins, showing the influence of precipitation on streamflow (Baker 1987). The Three Bar D chaparral basin is at the lowest elevation of the watersheds analyzed by Baker (1987), but it received the second highest average annual precipitation (750 mm or 29.5 in). This watershed had the most attenuated or least responsive hydrograph, even though it received the second highest amount of precipitation (1,350 mm or about 53.0 in) during 1973. It also had the deepest soil (about 9 m or about 30 ft). Similar chaparral basins have been shown to be capable of producing perennial flow once the chaparral overstory is converted to grass. This occurred on a watershed at Beaver Creek following mechanical and herbicidal removal of trees and demonstrates the influence of soil depth on precipitation storage and eventual release (Hibbert and others 1974).

The most responsive or peaked hydrographs occurred on the Beaver Creek drainage area (fig. 1.1) with a mean soil depth of just under 1 m (3 ft). The Utah juniper basin at Beaver Creek received the lowest mean annual precipitation amount (about 460 mm or 18.1 in). However, the influence of the soil depth and the relatively impermeable B horizon is apparent in the highly responsive daily streamflow peaks (Baker 1987). Daily peak discharge rates, even from snowmelt, were relatively large and receded rapidly (in hours), which suggests a small soil water storage capacity and short flow paths (overland flow and shallow subsurface flow). The ponderosa pine basin on the Beaver Creek watershed had similar soil characteristics and similar responsive daily peaks. However, its higher elevation (up to 2,600 m or 8,500 ft) usually resulted each year in a delay of snowmelt of two months (from February to April). Streamflow on Beaver Creek generally terminated within a few days of the disappearance of the snowpack, though it often lasted longer on other sites in Arizona with deeper soil depths (Baker 1986, 1987; Gottfried and others 2003).

Annual precipitation on the mixed conifer basin at Workman Creek on the Sierra Ancha Experimental Forest east of Phoenix was the highest of those studied (810 mm or 31.9 in; Baker 1987), and streamflow was normally perennial. Hydrograph responsiveness was similar to that on the ponderosa pine basin, but daily peaks were higher in the beginning of the melt period and lower toward the end, demonstrating the influence of the heavy reduction in overstory basal area on snowmelt rates. Rates of snowmelt are inversely proportional to tree density and basal area due to the effect of tree canopy in shading the underlying snowpack. Streamflow in mixed conifer on the Castle Creek watershed in the White Mountains of eastern Arizona was similar to that on Workman Creek but was less responsive or more attenuated—the result of the influence of the higher elevation (2,500 m or 8,200 ft) in reducing snowmelt rates. Daily snowmelt peaks were still recognizable on Castle Creek but were greatly reduced.

The mixed conifer type on Thomas Creek watershed in the White Mountains of eastern Arizona was located at the highest elevation (2,650 m or 8,700 ft) and received the second highest annual precipitation amount (740 mm or 29.1 in) (Baker 1987). Daily snowmelt peaks were barely apparent, indicating much more resistance or longer flow distance to the channel. Overland flow or evidence of overland flow was seldom observed on this basin. Mean annual streamflow on these basins was relatively uniform (80 to 90 mm or 3.2 to 3.5 in), even though

mean annual precipitation ranged from 650 to 810 mm (25.6 to 31.9 in). Although some attenuation of the hydrographs on the two higher mixed conifer basins was the result of lower snowmelt rates, the high annual precipitation amounts, longer streamflow period, and lower runoff efficiencies suggest that the major factor was the influence of soil depth and texture.

The Lower Colorado River Basin below the altitude of the UVR received an average of 330 mm (13.0 in) of annual precipitation (Hibbert 1979). The proportion of precipitation yielded as streamflow in the Lower Basin was 3 % (10 mm or <0.5 in) of streamflow in the Upper Basin. The high loss to evapotranspiration (97%) was similar to the environment that the UVR exists in. These evapotranspiration losses reflected the arid environment of the UVR and why the UVR's streamflows are important to the terrestrial, aquatic, and riparian ecosystems the river supports.

The objective of this chapter is to provide a background of the hydrological setting for the UVR. The perennial flow of the UVR makes this river fairly unique in the Southwest. Most other perennial rivers like the Colorado River or Rio Grande River drain huge basins and have snowmelt as the source of their flows. Very little of the UVR derives from snowmelt.

Hydrogeology

Blasch and others (2006) produced an extensive and detailed report on the UVR titled "Hydrogeology of the Upper and Middle Verde River Watersheds, Central Arizona." The following section contains excerpts that cover the geology of the region and the hydrological interactions with the geology. The geologic diversity of the UVR terrain provides the framework for the hydrology of the region and the diversity of plants and animals that occupy it.

Geological Setting

The UVR watershed lies within the Transition Zone between the Colorado Plateau to the north and northeast and the Basin and Range Province of Arizona to the southwest (Fenneman 1931; Wilson and Moore 1959). The Transition Zone is the locale for the UVR (fig. 3.1). It has characteristics of both geologic provinces that reflect episodes of geologic extension and compression. The result is a geologic region that has been deformed by faulting and uplift and that contains alluvial sediments from both bordering Provinces (Anderson and others 1992; Blasch and others 2006).

The stratigraphic sequence of rocks in the Verde River region consists of Precambrian metamorphic and igneous units that are overlain by Cambrian to Permian sedimentary units and then alluvial units or Tertiary to Quaternary-aged basalt flows and lake deposits (figs. 3.2 and 3.3). Precambrian rocks are generally not important aquifers, except where they have been highly fractured and weathered (Blasch and others 2006). Paleozoic rocks from the Tapeats Sandstone up to the Upper Supai Formation contain variable amounts of water. Tertiary-aged basalt flows are generally poor aquifers in the UVR region. It is the Basin and Range erosional sediments at the top of the stratigraphic sequence that provide most of the water-bearing formations that feed the UVR baseflows.

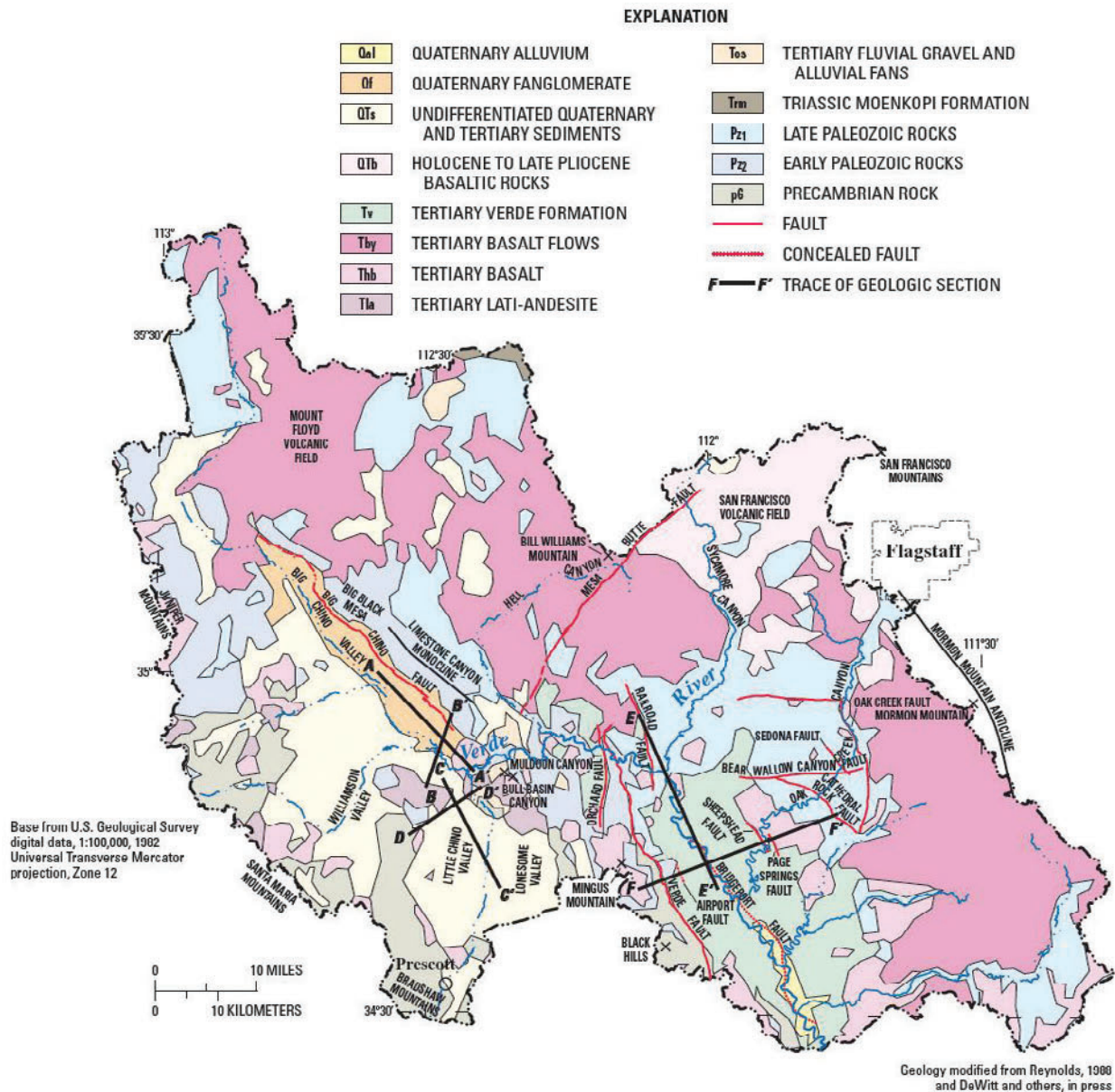


Figure 3.1—Generalized geology and geologic structures of the UVR and Middle Verde Watersheds, Yavapai County, Arizona. The Transition Zone lies northwest to southeast along the center of the geologic map (from Blasch and others 2006; based on DeWitt and others 2005).

A. Upper Verde River watershed

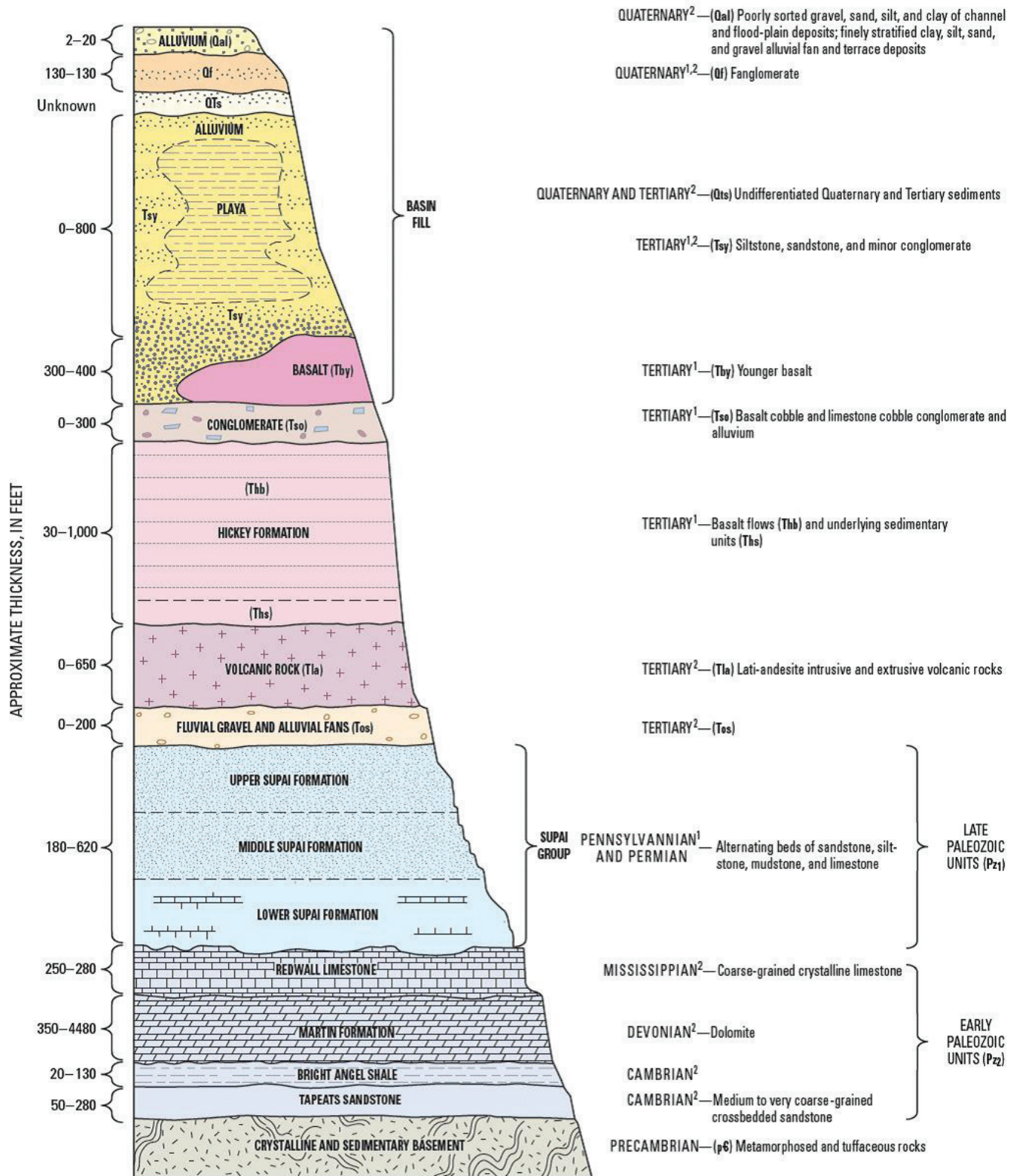
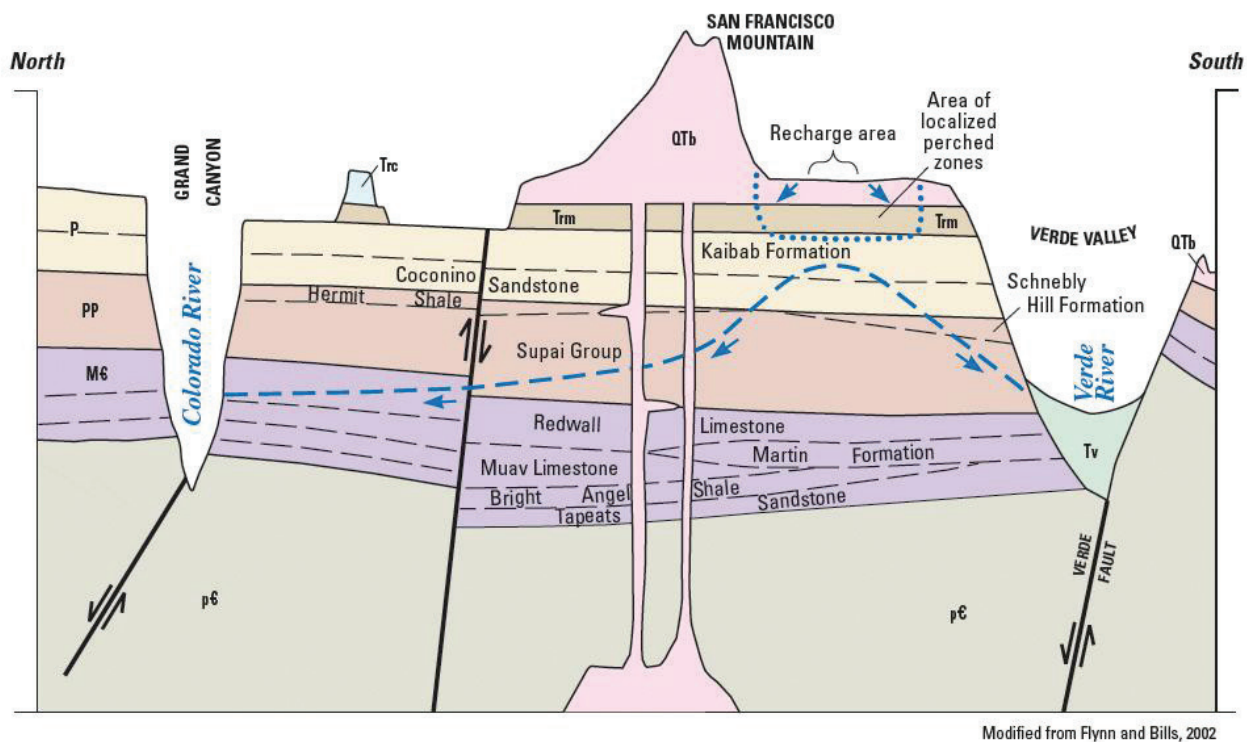


Figure 3.2—Generalized stratigraphic section of the UVR, Yavapai County, Arizona (from Blasch and others 2006; based on DeWitt and others 2005).



EXPLANATION

QTb	HOLOCENE TO LATE PLIOCENE BASALTIC ROCKS
Tv	TERTIARY VERDE FORMATION
Trc	TRIASSIC CHINLE FORMATION
Trm	TRIASSIC MOENKOPI FORMATION
P	PERMIAN SEDIMENTARY ROCKS—Includes Kaibab Limestone and Coconino Sandstone
PP	PERMIAN AND PENNSYLVANIAN SEDIMENTARY ROCKS—Includes Hermit Shale, Schnebly Hill Formation, and Supai Group
M6	MISSISSIPPIAN, DEVONIAN, AND CAMBRIAN SEDIMENTARY ROCKS—Includes Redwall Limestone, Martin Formation, Muav Limestone, Bright Angel Shale, and Tapeats Sandstone
p6	PRECAMBRIAN ROCK
—	REGIONAL WATER TABLE
←	DIRECTION OF GROUND-WATER FLOW
≡≡	FAULT—Arrows indicate direction of movement

Figure 3.3—Cross section from the Colorado Plateau through the Transition Zone and into Basin and Range Formations (from Blasch and others 2006).

Geologic Structure and Aquifer Characteristics

The main structural features of the UVR and adjacent areas are the northwest to north valleys and mountain ranges as well as faults that are typical of the Basin and Range Province and associated shear zones (Blasch and others 2006). Valleys such as the Big Chino, Little Chino, Williamson, Lonesome and Verde Valley were formed by faulting which resulted in the juxtaposition of ancient Precambrian crystalline rock against younger sediments and alluvium. Valley floors consist primarily of unconsolidated to consolidated Tertiary and Quaternary sediments and stream alluvium.

An important source of water for the UVR is the Big Chino subbasin. This 4,790 km² (1,850 mi²) basin consists of the Big Chino Valley, Williamson Valley, Big Black Mesa, and the western part of the Coconino Plateau. The Big Chino Valley is a 45 km (28 mi) long northwest trending structure that formed 10 to 2 million years ago in faulting associated with a crustal extension during the Basin and Range Province formation (DeWitt and others 2005). The graben associated with the valley formation is 3 km (about 2 mi) wide at its northwest end and 10 km (6 mi) at its southeast end near Paulden, where flow on the UVR begins. Alluvial deposits filled the graben to a depth of 870 m (2,500 ft). The associated Williamson Valley is slightly shallower and smaller in dimension. Together, the two valleys contain 260 km³ (about 210 x 10⁶ ac-ft) of interbedded alluvial sediments that are 74% saturated with water.

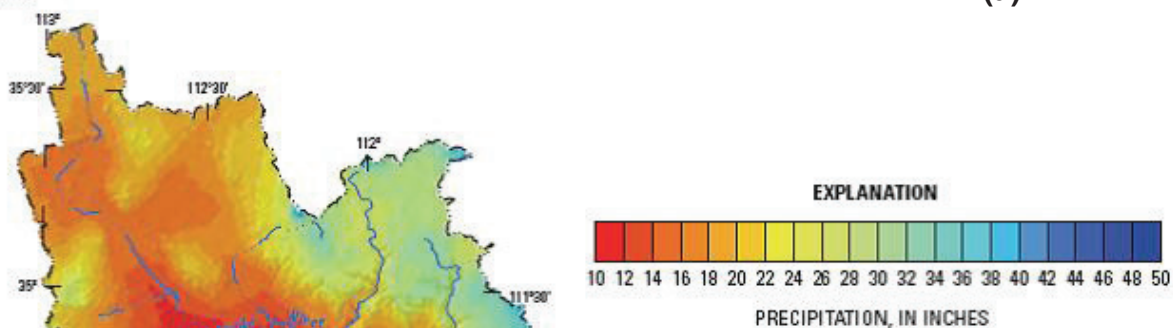
Groundwater in the Big Chino subbasin resides in two primary aquifers. The upper aquifer consists of unconsolidated sedimentary deposits and interbedded volcanic rocks to an average depth of 133 m (435 ft). The upper aquifer is a major source of irrigation water and domestic supplies and is being targeted as a potential water supply for Prescott and Prescott Valley municipal areas. Average discharge rates vary from 3.0 to 18.9 m³ min⁻¹ (800 to 5,000 gal min⁻¹). The lower aquifer consists of Paleozoic rocks that underlie the upper aquifer throughout the Big Chino Valley (figs. 3.1 and 3.2) and has both confined and unconfined units. Discharge rates from these aquifer units are lower (<3.0 m³ min⁻¹ or 800 gal min⁻¹) (Blasch and Bryson 2007, Montgomery and Harshbarger 1992; Wirt and Hjalmarsen 2000;).

Hydrology

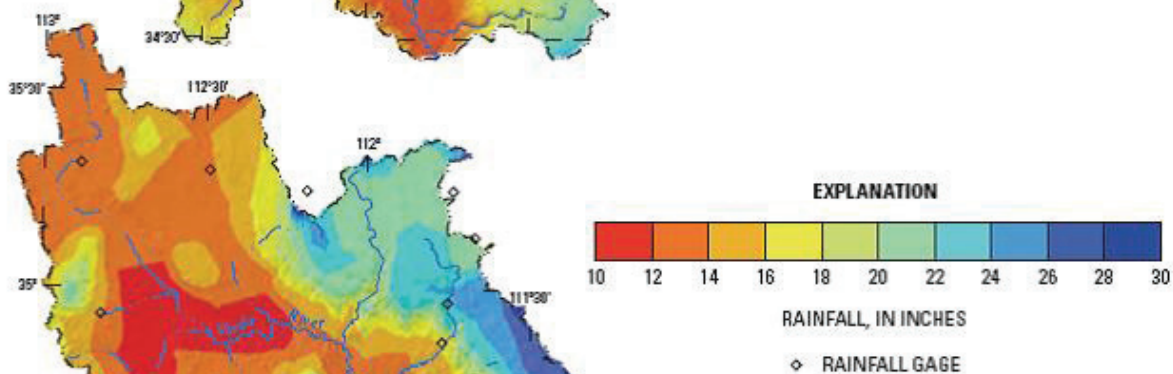
Climate

The UVR section of the Verde River Valley is semi-arid in nature with precipitation averaging less than 460 mm (18.0 in) (fig. 3.4a; from Blasch and others 2006). The signature characteristic of climate of this region is not the average, but the wide range in extremes. Except for higher terrain to the north that provides streamflow for Sycamore Canyon and Hell's Canyon, most of the precipitation occurs as rainfall rather than as snow (fig. 3.4). Monthly precipitation varies by over a factor of five from the spring dry period (13 mm or 0.5 in) to the summer monsoon period (70 mm or 2.8 in). Over the past century, rainfall in the UVR region has gone through several cycles of wet and dry periods (fig. 3.5). Blasch and others (2006) analysis of rainfall records since 1900 has shown that the UVR is in a lower rainfall cycle that started in 1994 and that snowfall for the UVR and Middle Verde watersheds has been mostly below normal since 1955 (fig. 3.5). Potential

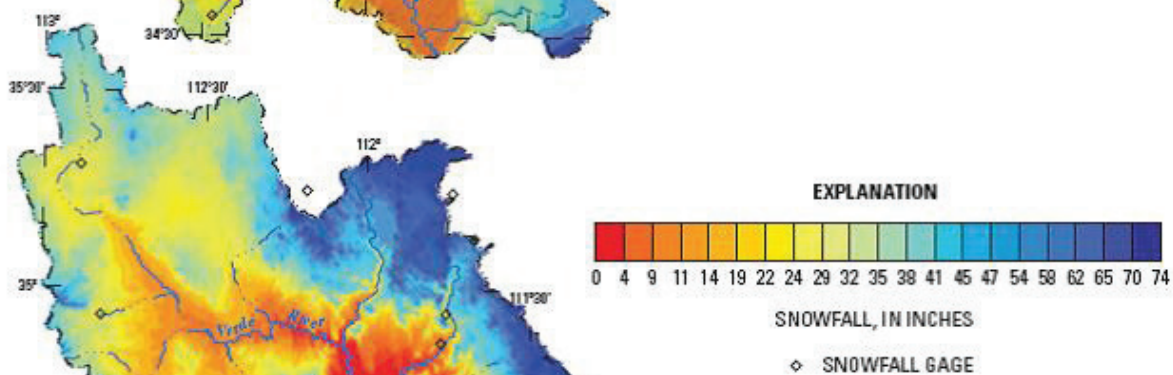
A. Precipitation



B. Rainfall



C. Snow



Base from U.S. Geological Survey
digital data, 1:100,000, 1982
Universal Transverse Mercator
projection, Zone 12

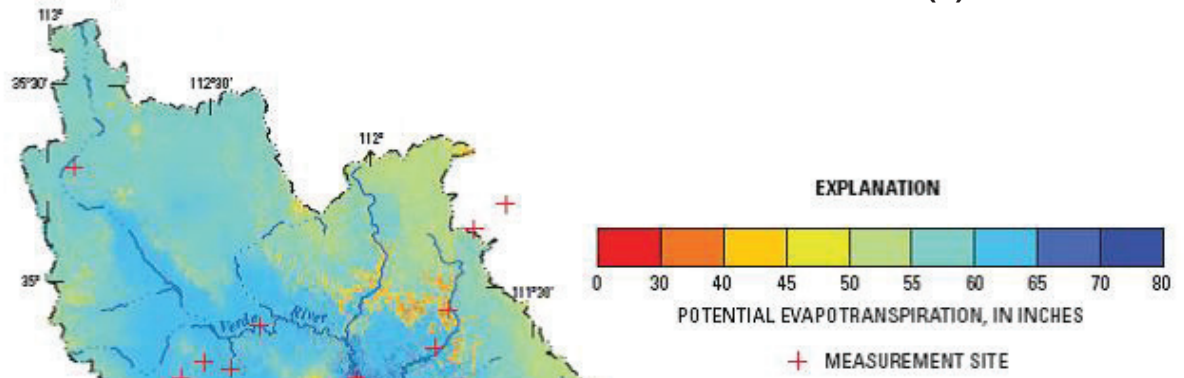
0 20 MILES
0 20 KILOMETERS

(a)

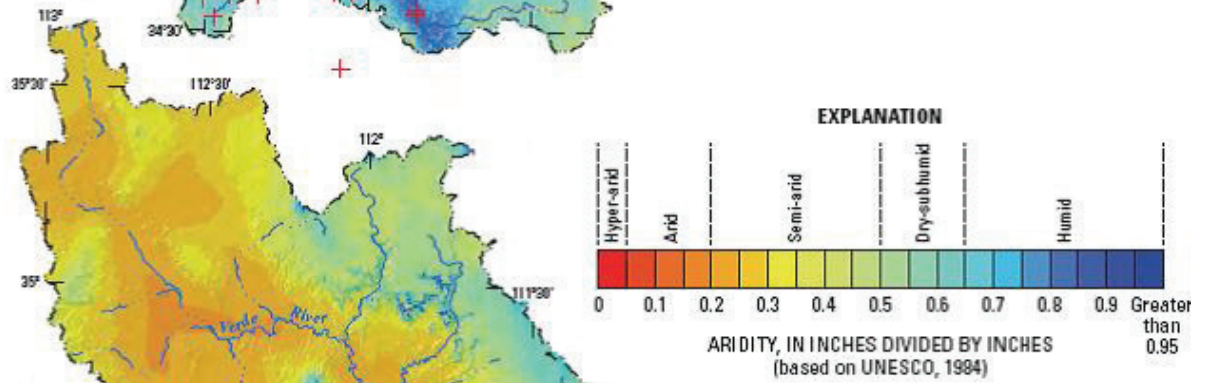
Figure 3.4—Average annual climate values for the UVR and Middle Verde River watersheds: (a) precipitation, rainfall, and snowfall; and (b) potential evapotranspiration, aridity, and excess precipitation (from Blasch and others 2006).

(b)

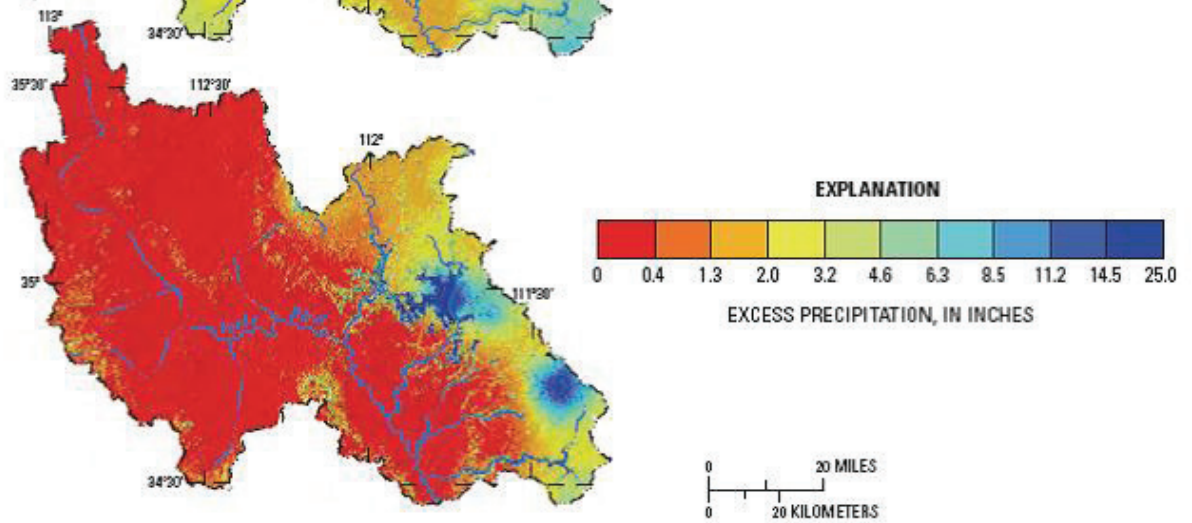
D. Potential evapotranspiration



E. Aridity



F. Excess precipitation



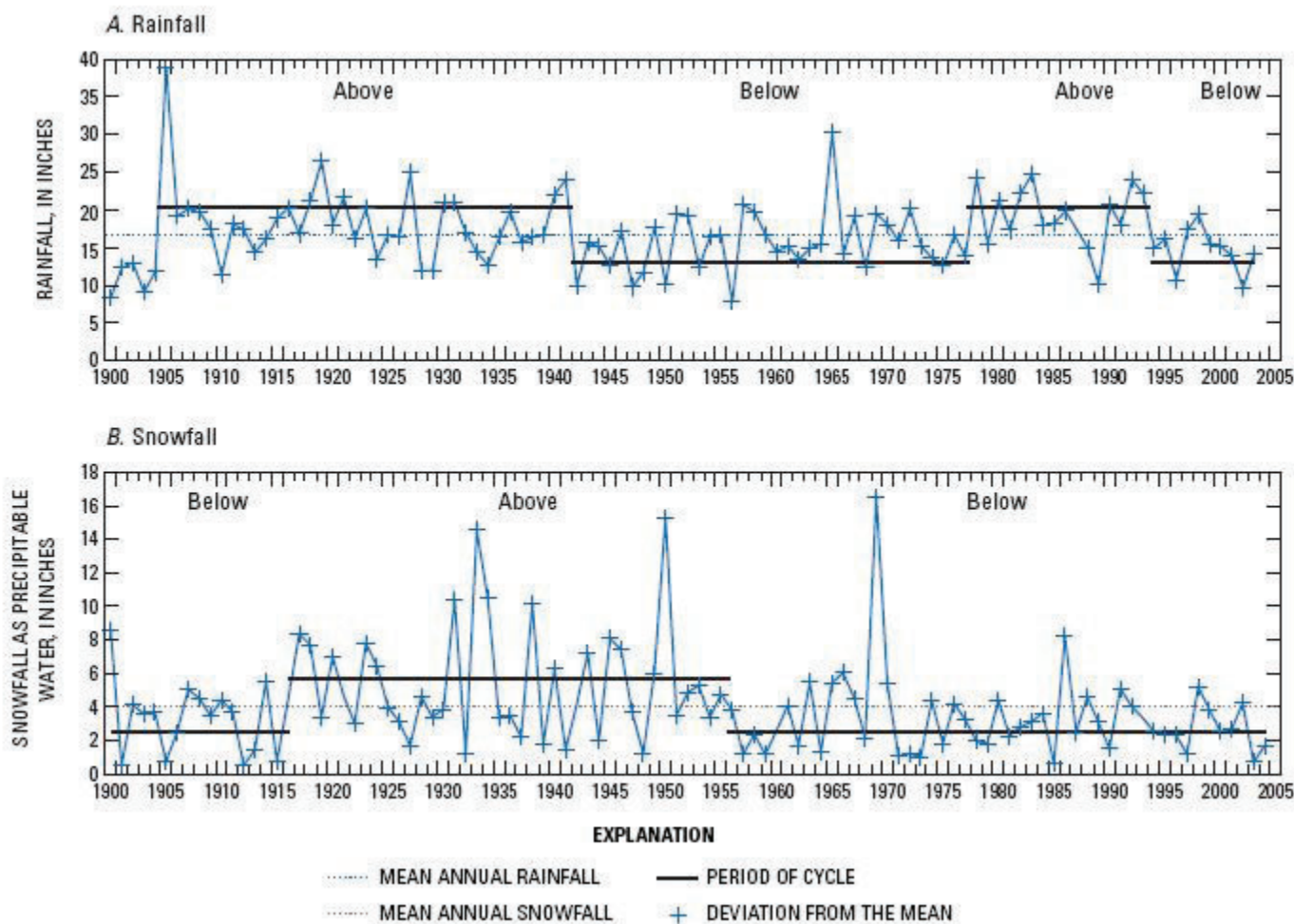


Figure 3.5—Annual deviations in rainfall and snowfall for the UVR and Middle Verde River basins, 1900 to 2005 (from Blasch and others 2006).

evapotranspiration rates average in excess of 1520 mm (60.0 in yr⁻¹), which creates the semi-arid conditions (fig. 3.4b).

UVR Groundwater

Background—The steady baseflow that characterizes the UVR is supplied by a series of river-channel springs emanating into the river near the beginning of the perennial reach (Wirt and Hjalmarson 2000). The UVR distance designations of River Kilometer (RK) and River Mile (RM) used in this chapter follow the conventions of Wirt and Hjalmarson (2000) and Blasch and others (2006). Most of the baseflow discharge up stream of Perkinsville at RK 42 (RM 26) occurs in the upper reach between RKs 3 and 6 (RM 2 and 4), respectively (figs. 1.1 and 1.5). Other small sources are discrete streambank springs and interflow from the Granite Creek sand and gravel bed (fig. 2.19). Average baseflow reported by Wirt and Hjalmarson (2000) from 1963 to 2000 for the USDI Geological Survey Paulden gauge (RK 16 or RM 10) was 0.70 m³ sec⁻¹ (24.9 ft³ sec⁻¹), but mean daily baseflow ranges from 60 to 133% of that amount. Although the source springs are fairly well defined, the sources of the groundwater feeding these springs are quite complex. The springs supply a steady source of baseflow that is important for aquatic fauna such as the threatened spikedace (*Meda fulgida*, see Chapter 9),

other aquatic fauna, riparian vegetation, and downstream water uses as far south as Phoenix. The USDI Fish and Wildlife Service (1999) considered designating the Verde River below Sullivan Dam (figs. 2.14 through 2.18) as critical habitat for several native fish species. In 1984, Congress declared parts of the Verde River in the middle and lower sections below Camp Verde as Wild and Scenic River areas. There have been discussions amongst local environmental groups of nominating parts of the UVR in canyon-bound reaches as Wild and Scenic River areas.

The UVR watershed is mostly within the fastest growing non-metropolitan county in Arizona (Yavapai County). It has a growth rate of 3.4%, which is four times the national average (Woods & Poole Economics, Incorporated 1999). Population is expected to rise from 37,000 in 1970 to 313,000 by the year 2020 (Woods & Poole Economics, Incorporated 1999). Since there are no significant surface water sources in the Prescott area, much of this growth has relied on groundwater in the Little Chino aquifer. Since 1940, groundwater levels in Little Chino Valley have receded by more than 23 m (75 ft) in the margin of the basin closest to the source springs of the Verde River (Arizona Department of Water Resources 1998, 1999). Although the Little Chino and Big Chino Valleys route all surface-water drainage to the UVR above Hell Canyon, there have been on-going discussions between local, State, and Federal officials and scientists over the issue of these basins being a major source of groundwater flow versus aquifers to the north of the river. Wirt and Hjalmarson's (2000) analysis clearly points out the overriding importance of the Big Chino and Little Chino aquifers.

Wirt and Hjalmarson's (2000) review appears to leave no doubt that groundwater discharge from Little Chino Valley to the Verde River has substantially declined during the past six decades when groundwater withdrawals have increased due to urbanization of the Prescott area. Perennial flow that was once continuous from Del Rio Springs into Lake Sullivan and that served as the head of perennial flow in the UVR no longer occurs (Krieger 1965). Del Rio Springs is fed by the Little Chino artesian aquifer, which has been depleted substantially since the 1940s. Surface discharge from Del Rio Springs has also been diverted for municipal and agricultural uses.

Demand for water in the UVR Valley is increasing because of rapid population growth near the city of Prescott. There is concern that over-use of Big and Little Chino Valley groundwater could eventually deplete baseflows in the UVR and dry up the river during low-flow periods (Neary and Rinne 1998, 2001a). In the past several decades, baseflow in the UVR has actually increased slightly due to a wet climate cycle and decreasing agricultural irrigation in Big Chino Valley. Improved understanding of groundwater sources and their relative contributions to the baseflow of the UVR, flow pathways, and future consumptive uses are needed so that the water resources in Big and Little Chino aquifers can be managed effectively to maintain UVR baseflow.

Geology—The geology of the UVR headwaters and aquifers is extremely complex (fig. 3.1). However, a simplified conceptual view presents a better picture of the groundwater flows that feed the perennial baseflows of the UVR (fig. 3.6). Paleozoic limestones form the basement rocks of a structurally controlled half graben. Both the Little Chino and Big Chino valleys are filled with unconsolidated alluvium and 4.5 million-year-old basalt intrusions. The alluvium consists of gravels inter-bedded with fine-textured lake bottom sediments. The Big Chino Fault is an important structural feature relevant to the hydrology of the Big Chino Valley because it is a large regional feature that has been delineated running northwest of Paulden for 42 km (26 mi) (Krieger 1965). Substantial groundwater flow occurs along and through this fault. Solution features in the limestone such as caves,

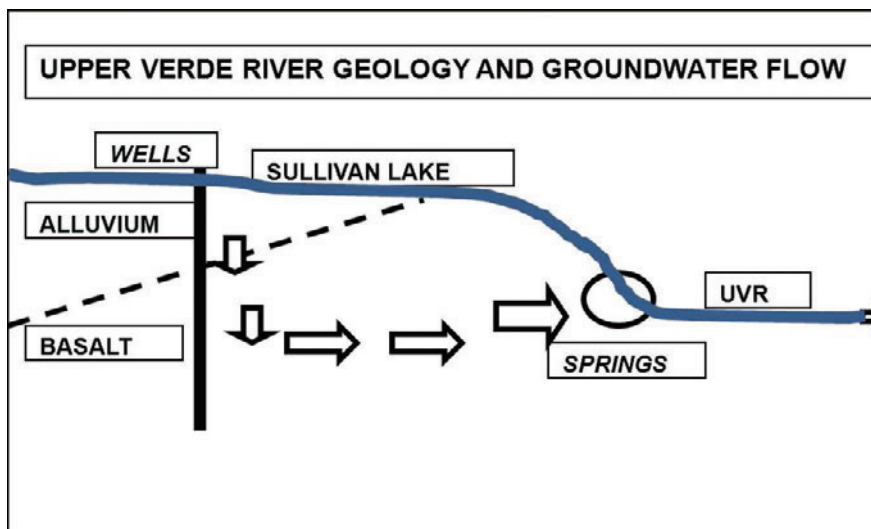


Figure 3.6—Simplified schematic of the UVR geology and groundwater flow (adapted from Wirt and Hjalmarson 2000).

joints, fractures, and faults as well as other irregular subsurface characteristics provide the likely hydrologic connection between Big Chino Valley and the UVR springs that begin the perennial baseflow of the river (fig. 3.6).

Wells and Spring Discharge—According to Wirt and Hjalmarson (2000), groundwater changes in the Big Chino Valley have been relatively small as a result of human activities. Initial changes were due to agricultural withdrawals that have diminished in recent years as municipal pumping has increased. Conversely, the Little Chino artesian aquifer has been extensively developed for public water supply, industry, and agriculture since the late Nineteenth Century. The perennial flow at Del Rio Springs was once known as a reliable source of water to the earliest explorers and settlers. Camp Whipple was established at Del Rio Springs on December 23, 1863, to provide the territorial governor’s entourage with a secure base for further exploration (Henson 1965). Accounts by these explorers reported that Del Rio Springs (then named Cienega Creek) was the headwater tributary of the Verde River. The springs were developed in the early part of the century for water supply and irrigation. Krieger (1965) reported that in 1901, the City of Prescott built a 34-km (21-mi) pipeline that pumped $1,890 \text{ m}^3 \text{ day}^{-1}$ ($500,000 \text{ gal day}^{-1}$) (Baker and others 1973) from Del Rio Springs to Prescott from 1904 to 1927 (Matlock and others 1973). Although the supply of water was adequate for Prescott’s needs, the cost of pumping was considered excessive and the pipeline was eventually disassembled (Krieger 1965). One hundred years later, the groundwater supply of the Big Chino aquifer is being considered as the solution to water supply shortages in Prescott and Prescott Valley. Impacts on streamflow in the UVR could become significant if this inter-basin groundwater transfer is allowed.

Well drilling and pumping out of the Little Chino aquifer began around 1925. Wells were developed for local use in the town of Chino Valley, Prescott, and for the Santa Fe Railroad. According to sources listed by Wirt and Hjalmarson (2000), groundwater levels have dropped by as much as 23 m (75 ft) (Remick 1983, Corkhill and Mason 1995, Arizona Department of Water Resources 1998, 1999). Artesian wells that used to flow at the surface or to within a few meters of the ground surface no longer do so. Groundwater flows from the Little Chino aquifer system toward the UVR headwaters have declined from pre-development flows of $4.93 \text{ to } 6.17 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$ (4,000 to 5,000 ac-ft yr^{-1}) to less than $2.47 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$ (<2,000 ac-ft yr^{-1}).

A large cienega below Del Rio Springs supported permanent baseflow from lower Little Chino Creek to Sullivan Lake. Since the early 1970s, the lower reach of Little Chino Creek has been ephemeral. Sullivan Lake (figs. 2.10 and 2.11) has been mostly dry except during winter and monsoon storm runoff from Big Chino Wash, Williamson Valley Wash, or Little Chino Creek. The first 1.6 km (1 mi) of the UVR below Sullivan Lake has lacked any sustained flowing water due to declining flow from Del Rio Springs as a result of extensive groundwater pumping (Corkhill and Mason 1995).

Conclusions—Wirt and Hjalmarson (2000) concluded at the end of their report on the UVR that virtually all of the baseflow in the UVR originates in the spring networks of the Big Chino Springs and Lower Granite Springs. They noted that there is a strong hydrologic connection between the Big Chino Valley groundwater and Big Chino Springs. This source of water accounts for 80% of the total baseflow of the UVR, not the Ash Fork, Big Black Mesa, and Bill Williams Mountain aquifers north of the river. Wirt and Hjalmarson (2000) pointed out that higher-altitude drainages such as Williamson Valley Wash and Walnut Creek are the most likely sources of recharge to the Big Chino Valley aquifer. They reported that the most likely sources of Lower Granite Spring, a major contributor to UVR baseflow, is a combination of the Little Chino Valley aquifer and the Big Chino unconfined aquifer. Another overriding finding was that groundwater discharge to the UVR has declined in the past 20 to 30 years due to a number of natural and human-caused impacts on the aquifers.

The most important implication of the Wirt and Hjalmarson (2000) report is that continued urbanization and use of the Big Chino aquifer may have substantial negative impacts on baseflows of the UVR. This would, in turn, seriously affect habitat of the native fish fauna of the UVR and other uses of the UVR flows, including irrigation in the Middle Verde River reach and municipal water supply for Phoenix via the Verde and Salt Rivers reservoir system.

UVR Streamflow

General Characteristics—Streamflow is composed of two components: surface runoff and base flow. Surface runoff has little effect on the amount of water available for use in the UVR area since it occurs over short periods of time and no major impoundments are present for the storage of high flows or flow regulation (Owen-Joyce and Bell 1983; Wirt and Hjalmarson 2000). Consequently, baseflow is an extremely important source of water for in-stream flows, especially for the fish fauna of the UVR. In some reaches, baseflow increases downstream because of groundwater discharge; in other reaches, it is depleted by evaporation and transpiration by riparian vegetation. The availability of streamflow, therefore, is limited by natural low flows and upstream usage.

Flows are gauged in the UVR at Paulden and Clarkdale (figs. 1.1 and 2.10). The discussion in this chapter will use data from the Paulden gauge only. Paulden has a period of record extending from 1963 to the present (2011). Flows at Clarkdale are higher numerically, but they follow the same trends. The Paulden gauge is in Yavapai County, Arizona. Its Hydrologic Unit Code is 15060202. The gauge, with a natural control section, is located at latitude 34°53'42", longitude 112°20'32" at 1,255 m (4,120 ft) above sea level. It has a drainage area of 6,490 km² (2,507 mi²) (USDI Geological Survey 2009). At the Paulden gauge, the mean annual discharge over 45 years of record is 1.26 m³ s⁻¹ (44 ft³ s⁻¹) (USDI Geological Survey 2009). The mean minimum daily discharge, a critical flow for fish habitat, is 0.60 m³ s⁻¹ (22 ft³ s⁻¹), and the mean maximum daily peakflow is 95.40 m³ s⁻¹ (3,369 ft³ s⁻¹)

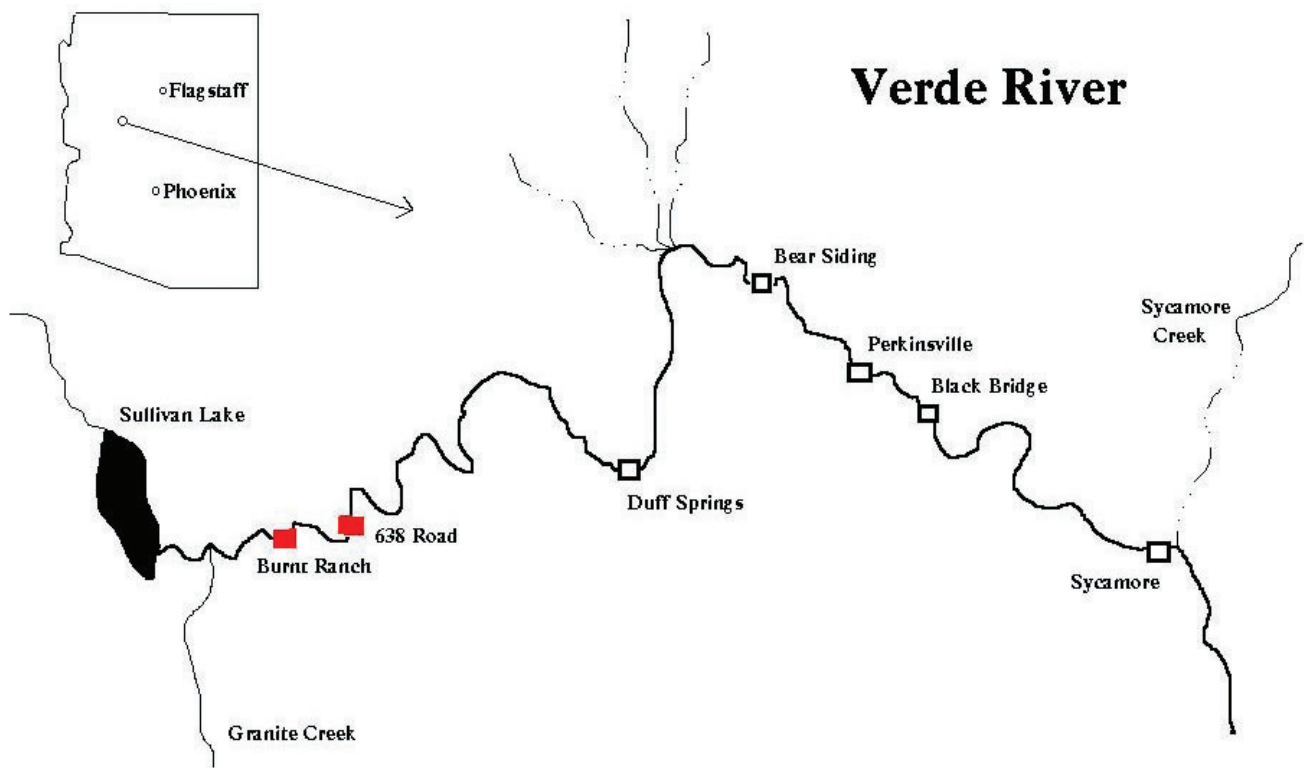


Figure 3.7—Sullivan Lake, UVR study sites, and USDI Geological Survey Paulden Gauge, Yavapai County, Arizona (Gauge #09503700).

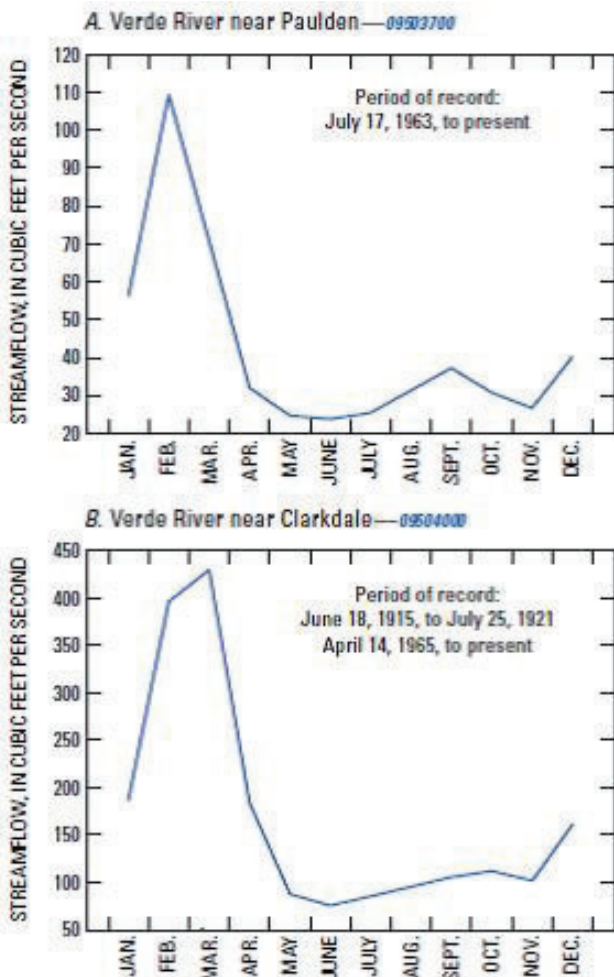


Figure 3.8—Average monthly streamflow for the Paulden Gauge (09503700) and Clarkdale Gauge (09504000) (adapted from Blasch and others 2006).

with a range over three orders of magnitude from 2.04 to 657.00 m³ s⁻¹ (72 to 23,200 ft³ s⁻¹). Nearly 50% of the annual flow is produced in three months from January through March. The remainder of the year flow is dominated by baseflows (fig. 3.8).

The important flows for aquatic organisms like fishes are the minimum low flows and the peak flows. Low flows affect the amount of aquatic habitat, produce organism stress, and magnify predation effects by confining fish in smaller volumes of water such as pools. Bankfull flows are the major channel-forming flows in the short term (Rosgen 1994). However, large, episodic peak flows produce significant disturbances in the aquatic environment and move large channel sediments around. They play an important role in forming UVR channels and cleaning coarser sediments. Peak flows stress all fish species, but the native fishes are adapted to the episodic, high peak flows of Arizona rivers while nonnative fishes are not (Rinne and Stefferud 1997; Rinne 2003a, 2006). Native fish reproduction also is stimulated by flood flows. Because of its importance in the flow regime and habitat maintenance of the spinedace, baseflow is emphasized more than surface storm runoff in the following analyses of streamflow.

Baseflow—The baseflow characteristics of the UVR and its major tributaries are a function of precipitation on the landscape and the properties of the regional aquifers. The capacity of the aquifers to receive, store, and transmit water has a significant effect on baseflow. Long-term changes in the baseflow may indicate changes in the volume of water stored in the aquifer and how discharge from the aquifer is distributed among well pumpage, stream flow, and evapotranspiration losses.

The baseflow in the Verde River (fig 3.9) and in most tributaries varies seasonally in relation to the amount of water used by plants (Wirt and Hjalmarson 2000; fig. 3.8). Baseflow is at a maximum in January and February and at a minimum in July and August. The year-to-year variation in base flow that enters the Middle Verde River valley by way of the UVR and tributaries can be small or quite large depending on the climate of the region (fig. 3.10). Since much of the flow of the UVR is dependent on annual rainfall, the wet and dry cycles typical of the Southwest are reflected in baseflow. Future climate change of increased aridity in the Southwest



Figure 3.9—Baseflow on the UVR downstream of the Verde River Ranch. (Photo by Alvin L. Medina).

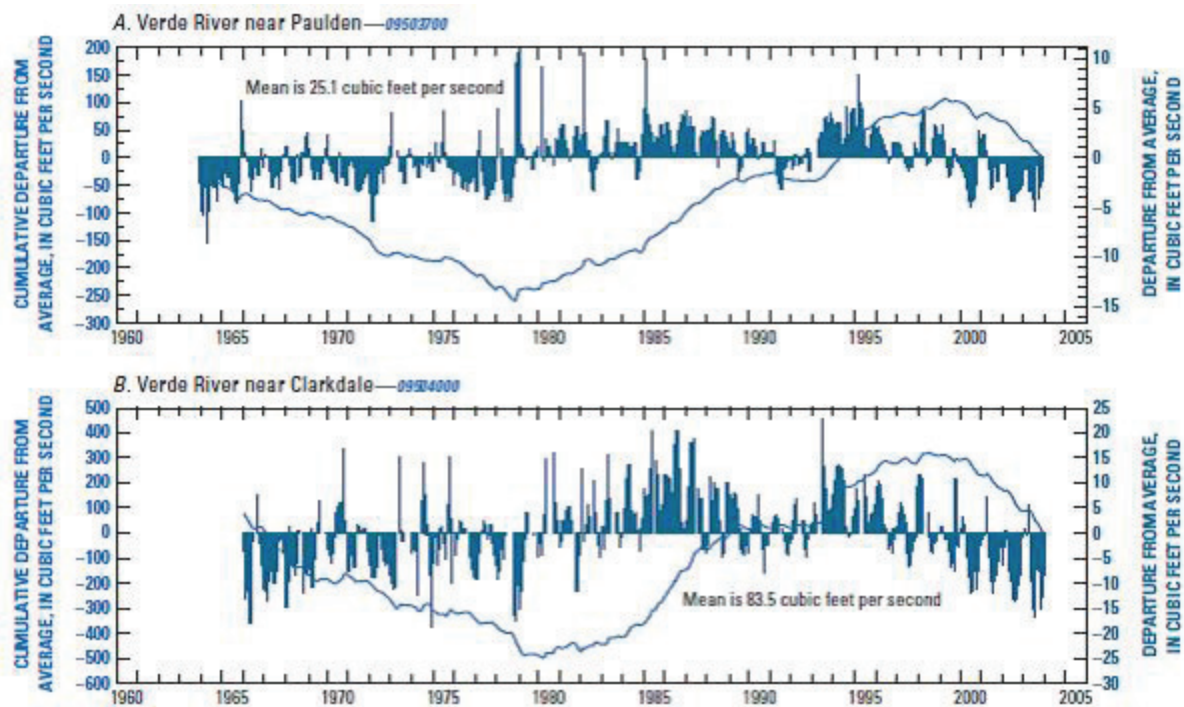


Figure 3.10—Cumulative departure from average winter base flow for the Paulden and Clarkdale gauges (adapted from Blasch and others 2006).

will probably affect baseflow on the UVR to a greater extent than in the past. Following a series of wet years from 1993 to 2000, baseflows are declining from the long-term mean. The seasonal variation in baseflow is an indication of evapotranspiration losses in the drainage area upstream from a gaging station. Baseflow is at a maximum in January and February when plants are dormant and evaporation is low. The high baseflow in January represents the average groundwater discharge from the regional aquifers.

Perennial flow in the UVR begins near Granite Creek (fig. 2.10), the first tributary downstream of Sullivan Lake (fig. 2.19). Sullivan Lake is a misnomer since the lake was filled in not too long after its construction at the turn of the Twentieth Century; it now functions as a channel step. Discharge measurements made in 1977 indicate that the Verde River gained $0.57 \text{ m}^3 \text{ s}^{-1}$ ($20 \text{ ft}^3 \text{ s}^{-1}$) between Granite Creek and Burnt Ranch (Owen-Joyce and Bell 1983; Wirt and Hjalmarsen 2000). Between Burnt Ranch and the Verde River near Paulden gauge, discharge measurements indicated a gain of $0.20 \text{ m}^3 \text{ s}^{-1}$ ($7 \text{ ft}^3 \text{ s}^{-1}$). Baseflow at the Paulden gauge is relatively constant and ranges from 0.57 to $0.74 \text{ m}^3 \text{ s}^{-1}$ (20 to $26 \text{ ft}^3 \text{ s}^{-1}$) during the year. The seasonal variation in the median baseflow hydrograph is from 0.62 to $0.68 \text{ m}^3 \text{ s}^{-1}$ (22 to $24 \text{ ft}^3 \text{ s}^{-1}$). Between the gauge near Paulden and the gauge near Clarkdale, baseflow increases to 1.70 to $2.63 \text{ m}^3 \text{ s}^{-1}$ (60 to $93 \text{ ft}^3 \text{ s}^{-1}$), and the seasonal variation in median baseflow is from 1.93 to $2.35 \text{ m}^3 \text{ s}^{-1}$ (68 to $83 \text{ ft}^3 \text{ s}^{-1}$). Discharge measurements made in 1977 and 1979 (Levings and Mann 1980; Wirt and Hjalmarsen 2000; Wirt 2005) show a gain in flow attributed to groundwater of about $0.62 \text{ m}^3 \text{ s}^{-1}$ ($22 \text{ ft}^3 \text{ s}^{-1}$) at Mormon Pocket, $0.25 \text{ m}^3 \text{ s}^{-1}$ ($9 \text{ ft}^3 \text{ s}^{-1}$) from below Mormon Pocket to Sycamore Creek, and $0.34 \text{ m}^3 \text{ s}^{-1}$ ($12 \text{ ft}^3 \text{ s}^{-1}$) downstream from Sycamore Creek. No groundwater discharges to the Verde River occur in the 3-km (2-mi) reach below the Paulden gauge, but about $0.06 \text{ m}^3 \text{ s}^{-1}$ ($2 \text{ ft}^3 \text{ s}^{-1}$) discharges between there and in Mormon Pocket. Tributary inflow from Sycamore Creek is $0.25 \text{ m}^3 \text{ s}^{-1}$ ($9 \text{ ft}^3 \text{ s}^{-1}$).

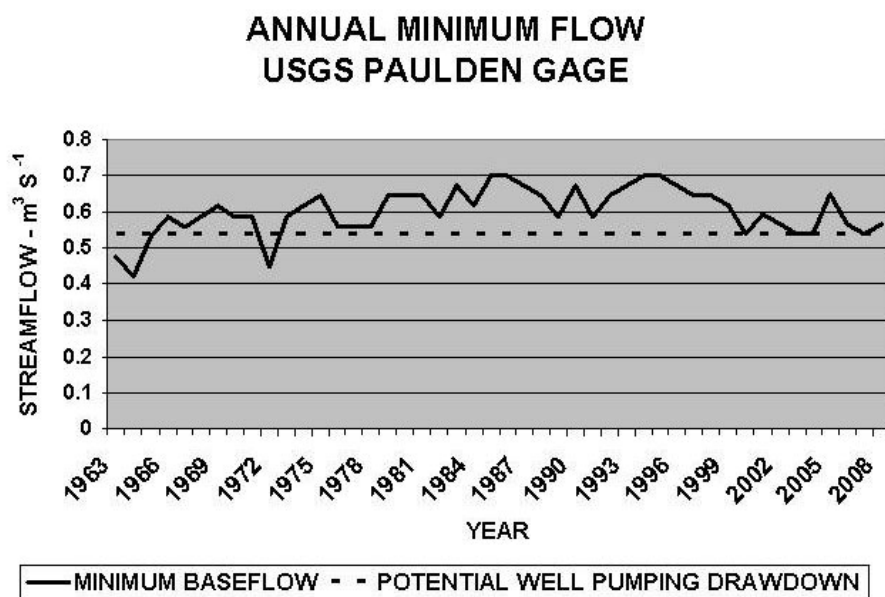


Figure 3.11—Minimum baseflow variation in the UVR, Paulden gauging site 1963 to 2008 (USDI Geological Survey 2009).

The small seasonal variation at the Paulden and Clarkdale gauges is associated with the low water use in this region and low loss of water from the river surface to evapotranspiration. The water lost to evapotranspiration between Sullivan Lake and Clarkdale is only 8% of the loss that occurs below Clarkdale (Anderson 1976). Records for the station near Clarkdale from June 1915 to June 1921 indicate that the base flow is identical to the base flow calculated for data collected from April 1965 to September 1978. The lack of change suggests that the groundwater system upstream from Clarkdale is still in an equilibrium condition.

A critical baseflow parameter for fish species such as the spinedace is the annual minimum flow (Neary and Rinne 1998, 2001a). Loss of physical habitat is absolutely critical to aquatic species since they don't survive well in ephemeral systems. Figure 3.11 shows the annual minimum baseflow at the Paulden gauge. There have been cyclical oscillations in baseflow, with a period of increase from 1982 to 1998 (Neary and Rinne 1998, 2001a) that appeared to indicate a trend of increasing baseflows. However since then, the trend has been downward, reflecting regional drought trends and increased urbanization of the Little and Big Chino Valleys. This is in response to rainfall patterns over the period of record. The absolute minimum baseflow over the period of record was $0.42 \text{ m}^3 \text{s}^{-1}$ ($15 \text{ ft}^3 \text{s}^{-1}$) in 1964.

The level line in fig. 3.11 indicates the potential pumping rate from proposed municipal well development in Chino Valley for the city of Prescott. The line does not suggest that pumping will immediately consume that amount of water from the UVR. It is just an indication of a potential effect given the linkage between baseflow of the Verde River and groundwater elucidated by Owen-Joyce and Bell (1983). It is a warning that groundwater pumping in the Chino Valley to support rapid urbanization on the Prescott area may pose a significant threat to fish in the UVR that goes beyond all existing threats. Well pumping to export water just to Prescott could de-water the UVR and put aquatic habitat in jeopardy. Other groundwater usage not accounted for in this analysis would just exacerbate the situation.

Prescott Consumptive Use of the Big Chino Aquifer—In 2004, the City of Prescott proposed pumping up to 170 million m^3 (45 billion gallons) of groundwater from the Big Chino Basin could seriously impact minimum daily flows on the

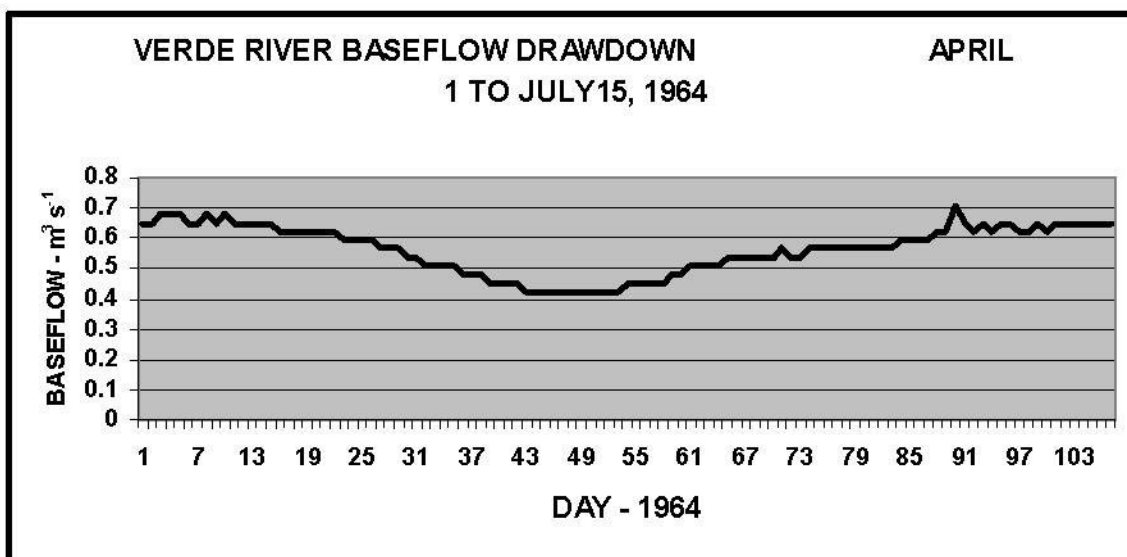


Figure 3.12—Baseflow drawdown from groundwater pumping in the Chino Valley, Paulden Gauge, April 1 to July 15, 1964.

Verde. Pumping the full allotment (equivalent to $0.54 \text{ m}^3 \text{ s}^{-1}$ or $19 \text{ ft}^3 \text{ s}^{-1}$; dotted line in fig. 3.11) could significantly affect baseflow in the UVR in the driest of the past 46 years. Wirt and Hjalmarson (2000) concluded that 80% or more of the UVR's baseflow comes from interconnected aquifers in the Big Chino Valley. The authors also noted that groundwater pumping at a rate of $24.61 \text{ m}^3 \text{ min}^{-1}$ ($6,500 \text{ gal min}^{-1}$) in the spring of 1964 to fill several lakes decreased baseflows at Paulden by 25% (fig. 3.12). The 1964 groundwater pumping was two-thirds the potential maximum rate that the Prescott pumping would involve. With baseflow reductions, both native and nonnative fish populations would be forced into remnant pools, thereby aggravating an already serious predation problem that is contributing to the decline of native fish species.

Flow-Duration Curve—A flow-duration curve is a cumulative frequency curve that shows the percentage of time during the period studied that a specified rate of flow was equaled or exceeded. The curve provides a useful method for analyzing the availability and variability of streamflow without regard to the sequence of the flow events. The distribution of streamflow with respect to time is a function of many variables such as the amounts and type of precipitation, topography, soils, geology, vegetal cover, groundwater movement, and water-use patterns. A steeply sloping duration curve indicates high variability in flow rates and small amounts of natural storage, and a gently sloping curve indicates a low variability, which is characteristic of a consistent component of baseflow per unit drainage area.

The flow-duration curve for Paulden is shown in fig. 3.13. It is indicative of high variability in flow rates between peak flow and base flow. It also indicates that the UVR is usually in stable baseflow most of the time—large storm flows occur <1% of the time, but it is those large peakflows that shape channels and move sediment. The stable baseflows are important for maintaining aquatic habitat in a semi-desert to desert region.

Peak Flows—Peak flows are the channel-forming flows that occur episodically during floods on desert rivers like the UVR (fig. 3.14). The maximum daily instantaneous peak flows in each year for the period of record are presented in fig. 3.15. Only 15 of the 45 years had instantaneous peak flows that exceeded the 5-year return period maximum 24-hour peak flow rate of $57.48 \text{ m}^3 \text{ s}^{-1}$ ($2,030 \text{ ft}^3 \text{ s}^{-1}$). The

FLOW DURATION CURVE UVR PAULDEN GAGE 1963-2008

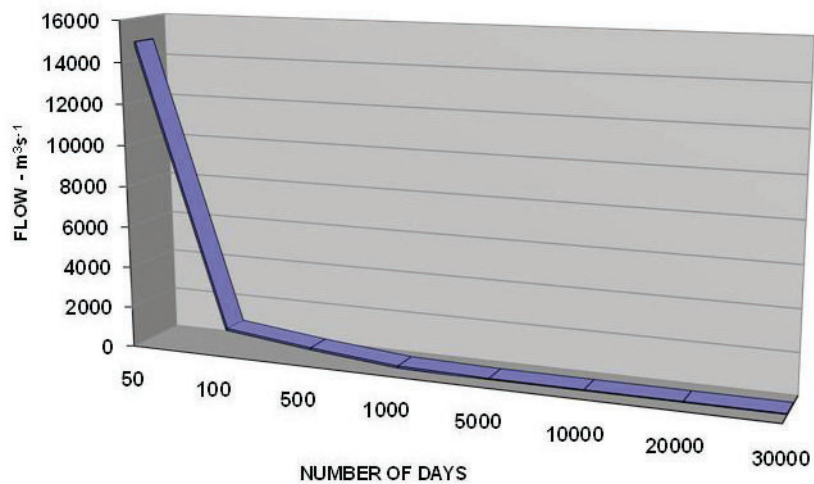


Figure 3.13—Flow-duration curve for the UVR, Paulden Gauge 1963 to 2008 (USDI Geological Survey 2009).

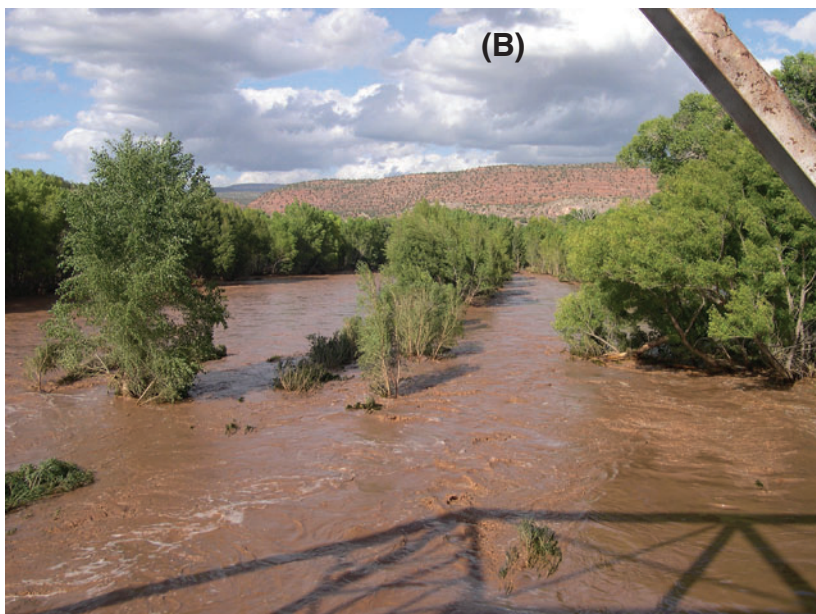
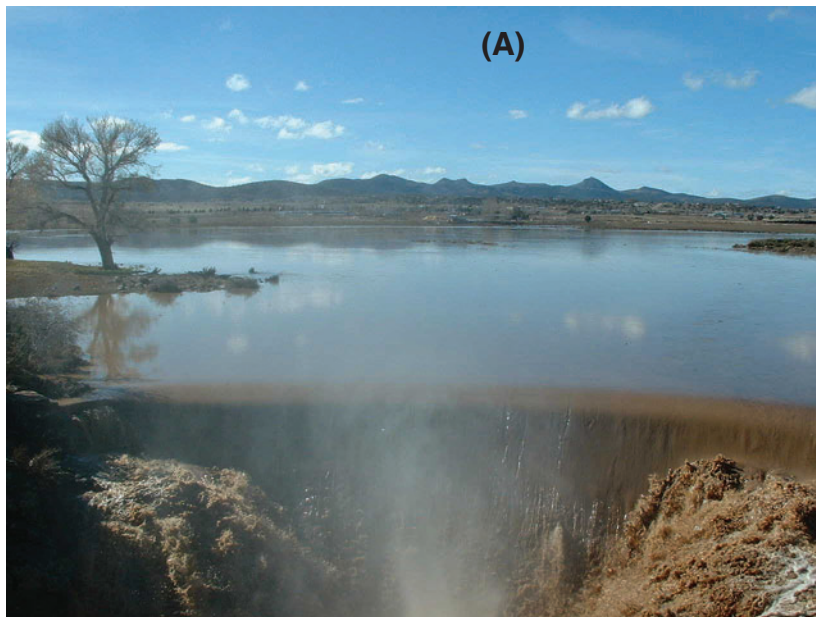


Figure 3.14—Flood flows on the UVR at: (a) Sullivan Dam and (b) Perkinsville. (Photos by Alvin L. Medina.)

UVR MAXIMUM PEAKFLOWS IN $\text{m}^3 \text{s}^{-1}$ 1963 - 2009

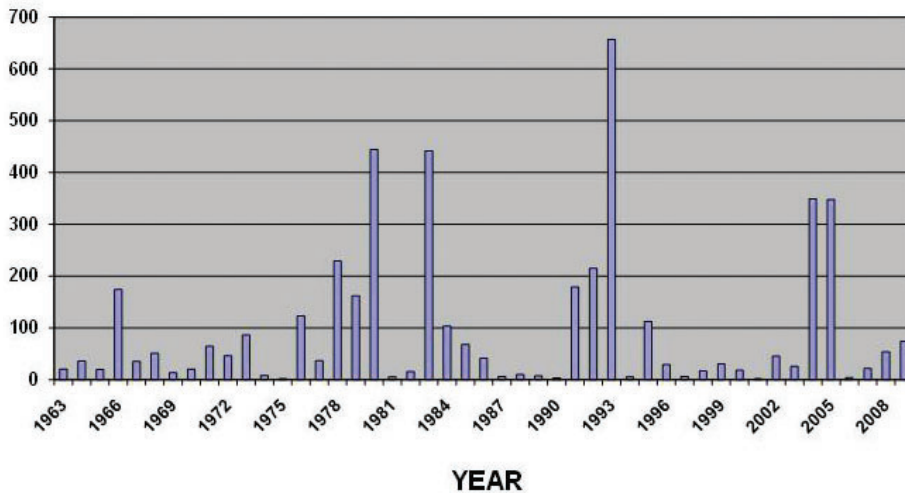


Figure 3.15—Maximum daily instantaneous peak flows, UVR at Paulden, 1963 to 2008 (USDI Geological Survey 2009).

largest storm (in 1993) had a 24-hour flow of $40.80 \text{ m}^3 \text{s}^{-1}$ ($1,441 \text{ ft}^3 \text{s}^{-1}$). Based on UVR records of 24-hour flows, this was a 37-year return interval storm. The instantaneous peak flow for that storm, shown in fig. 3.15, was 16 times higher at $656.92 \text{ m}^3 \text{s}^{-1}$ ($23,199 \text{ ft}^3 \text{s}^{-1}$) with a return interval of 72 years. This information again points out the episodic nature of large storm events on the UVR. The vast majority of sediment transported in the UVR over the 37-year period of record can be attributed to one storm, the 1993 flood with the record peak flow. The episodic nature of UVR peak storm flows is also noticeable in fig. 3.15 in that the five-year return interval storms in the data record have been clumped in nature. There is also a trend toward increasing peak flows over the period of record for the Paulden gauge that correlates with precipitation patterns (Neary and Rinne 1998, 2001a).

Supporting Data From Beaver Creek

Large storms like the 1993 flood on the UVR are major, clock-setting events for riparian areas and channel systems. Much of the sediment transported over many decades can be traced back to one storm. The hydrologic, geomorphic, and sedimentation effects are usually a function of precipitation intensity and often occur irrespective of past or present land use. The Labor Day Storm of 1970 was one such event. This storm produced a peakflow at the Paulden gauge on the UVR of just under $20 \text{ m}^3 \text{s}^{-1}$, considerably less than peakflows measured further south at Beaver Creek and Tonto Creek in the same storm. Hydrological and meteorological information on that same storm was available from the intensively studied Beaver Creek watersheds located south of the UVR in a tributary of the Middle River section (see figs. 1.5 and 1.6). That information is presented here to provide another perspective on large floods in Central Arizona and, in particular, on the 1993 UVR flood.

The 1970 Labor Day Storm caused more loss of human life than any other storm in Arizona's recent history, many dwellings, roads, bridges, and other structures were also damaged or destroyed (Thorud and Ffolliott 1971, 1972). Most of the widespread and unprecedented losses, both economic and of human life, occurred in central and northeastern Arizona with other losses reported in southeastern Utah and

southwestern Colorado (Roeske and others 1978). Although it is difficult to assess the total dollar cost of the storm, it has been estimated that initial expenditures to repair or replace storm-damaged infrastructures totaled nearly \$25 million by today's standards.

Conditions that led to the Labor Day Storm developed with a northward advance of moist, unstable air associated with tropical storm Norma from the Pacific Ocean and Gulf of California. The triggering mechanisms that contributed to the heavy rainfall in Arizona included orographic uplift associated with strong southerly winds in the lower atmosphere, the invasion of an unusually intense late summer cold air mass from the Pacific Northwest with its associated frontal activity, and daytime heating over the Arizona desert valleys. Rainfall totals of 130 mm (5 in) or more (a 100-year event in many areas of Arizona) were associated with the Mogollon Rim and other high country areas of Arizona. New precipitation records for a 24-hour period were established. Rainfall intensities of greater than 80 mm (3 in) in four hours were reported and easily exceeded the infiltration rates on many watersheds with shallow soils on top of bedrock, thereby facilitating a large amount of surface runoff and high peak stream flows.

Peak discharges of several streams in central Arizona exceeded the 20-to 25-year flood event with much higher return periods on small watersheds of 64.7 km² (<25 mi²). At least 30 USDI Geological Survey gauging stations in the Gila River Basin measured record peak stream flows (Roeske and others 1978). An estimated peak flow of about 521 m³ s⁻¹ (18,400 ft³ s⁻¹) occurred on upper Tonto Creek and combined with high flows from two tributaries (Christopher and Haigler Creeks), resulting in a peakflow of 1,064 m³ s⁻¹ (38,000 ft³ s⁻¹) on upper Tonto Creek near Gisela, Arizona. The upper Tonto Creek peak streamflow was 162% of the UVR peakflow in the 1993 storm.

Many stream channels on upland watersheds were detrimentally altered as a result of flooding. Damage included accumulations of uprooted trees and other materials in debris dams, depositions of boulder field, channel scouring (to bedrock in some cases), and bank cutting. Massive boulder fields were deposited at various locations. Some deposits were 3 to 9 m (10 to 30 ft) in depth, extending the width of the channel, and up to 0.8 km (0.5 mi) in length. Damage to fisheries was extensive. Streams were sometimes split into multiple channels by rock piles, often with insufficient flow to support fish populations. Other conditions detrimental to fishes and invertebrates included channel scouring to bedrock; filling of pools with boulders, sand, and silt; and the diversion of channels.

On one pair of pinyon-juniper woodland watersheds, total runoff, peak stream flows, and total sediment yields were found to be higher on the treated watershed that had been mechanically cleared (cabled) of its overstory (Clary and others 1974). Peak rainfall intensity was 36 mm hr⁻¹ (1.4 in hr⁻¹). On another pair of watersheds, the peak discharge occurred on the untreated watershed where rainfall peaked at 46 mm/hr (1.8 in hr⁻¹). The overall maximum peak flow response for Beaver Creek during the Labor Day Storm came from an untreated ponderosa pine watershed where peak rainfall intensity was 50 mm hr⁻¹ (2.0 in hr⁻¹). Rainfall intensity, not vegetation treatment, determined peak flow response and concomitant watershed and riparian area damage. Thus, it is very important that the real cause of peak flow increases (peak rainfall intensity) be determined instead of it being blamed on vegetation management treatments (Thorud and Ffolliott 1971, 1972).

Restoration activities on the larger, perennial streams included corrective actions taken to mitigate the effects of boulder accumulation, timber-related debris, vertical stream banks, channel scour, sand and silt deposits, stream channel diversions, road and trail damage, loss of streamside vegetation, and bank-hanging and

pedestaled trees. The most extensive of these restoration activities occurred on Tonto Creek, the East Verde River, and Christopher Creek. Approximately 22 km (14 mi) of stream channel required restoration activities of some kind because of potential hazard to life and property. All of this work was performed within the riparian zones of the various streams.

Insights to the degree of damage mitigation in the first 30 years after the Labor Day Storm were derived from limited and largely qualitative observations from the Tonto Creek and Beaver Creek watersheds areas using color photographs (Ffolliott and Baker 2001). Trees and other vegetative materials in the debris dams have largely decomposed. Only a few larger tree parts and some of the larger accumulated sediment remain visible. Channel restoration on some of the streams after the flood has further obliterated signs of the dams. Vegetation has become established in some of the boulder fields and many of the scoured areas contain accumulations of sediment. The fishery resource has responded favorably. Creation of pools and riffles and re-establishment of streamside vegetation have benefitted trout populations. The Tonto Creek Hatchery was rebuilt by the Arizona Game and Fish Department after it was destroyed by an 11 m (36 ft) high leading edge of a flash flood during the storm.

Observations on impacts of the storm flows and the effectiveness of restoration activities suggest that the hydrologic functioning of both the restoration-treated and unrestored streams was largely returned to normal dynamic conditions. These types of damaging storms are natural components of the hydrologic cycle in the Southwest. Current bank erosion is not excessive, streamflow response to precipitation appears relatively slow, and baseflow is sustained between storms. Streamside vegetation consisting of small trees, shrubs, and herbaceous plants was re-established artificially and naturally to stabilize most banks and help maintain water temperatures in a range favorable to trout populations.

Management Implications

There are two major management implications relative to the hydrology of the UVR. The first is that future urban growth could adversely affect baseflows in the river. Consumptive use of groundwater by urban populations in Prescott, Prescott Valley, and Chino Valley has already produced groundwater level depressions. Evidence is already in the hydrologic record of UVR baseflow impacts from excessive well pumping. Projected future use of the Little Chino and Big Chino aquifers could dry up parts or all of the UVR. This is not a process that the Prescott National Forest can manage. Any land management activities it conducts with the objective of improving habitat for native aquatic fauna might have no net positive effect. Compared to de-watering of the UVR from aquifer overuse by municipal entities, other land management activities will have minimal effects.

Secondly, flood flows that occur on the UVR are episodic in nature and increase flows by three or four orders of magnitude but are beyond the ability or jurisdiction of the Prescott National Forest to manage. They are important flows for the geomorphology of the river and the creation of aquatic habitat for endangered species like the spikedace (*Meda fulgida*).

Summary and Conclusions

In this chapter, the geology and hydrology of the UVR were examined with special reference to the peak flows that form river geomorphology and habitat, and baseflows that support the aquatic fauna and riparian vegetation. Research is being conducted by a number of non-governmental organizations and State, and Federal agencies to improve understanding of the UVR. Flows in the river are mostly stable baseflows due to steady contributions of groundwater flow from the Big Chino and other aquifers. This river is unique in Arizona because of that important feature. Like other stream systems in Arizona, the UVR is subject to rare, episodic flood flows that rise three to four orders of magnitude above its baseflows. While drought can have an impact on the steady baseflows of the river, the overwhelming future impact on the sustainability of UVR perennial flow is urbanization of the Prescott and Chino Valley areas.