Going With the Flow

A summary of five years of Water Sentinels flow data collection on the Upper Verde River

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Title page photo: Birth of a Threatened River – Mile Zero on the Verde
Photo credit: Gary Beverly

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Figure 1. Upper Verde River
Photo credit: Gary Beverly

"The mere existence of rivers makes the world a more attractive and a more interesting place; without them we should be spiritually as well as materially deprived….Knowledge about rivers isn't the private preserve of professional scientists, however. Anybody who keeps their eyes open, and makes deductions from what they see, can learn a considerable amount. Much of the information…can be checked by anybody, merely by observation and without using expensive equipment; still more can be gained simply from thinking about rivers and paying conscious attention to self-evident but seldom-contemplated facts….Becoming aware of one's own knowledge is one of the bonuses of paying attention to the natural world; observing rivers and streams, with their never-ending movement and change, is particularly rewarding."

E.C. Pielou
Freshwater

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We would like to thank Steven Westwood and Jennifer Hummer at the Salt River Project (SRP) who provided data from the SRP Campbell Ranch low-flow stream gage for use in this report. The data from this stream gage were invaluable in understanding the amount of base flow discharged from Verde Springs, the source springs of the upper Verde River.

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Introduction

This report is a call to action to preserve the base flow of the upper Verde River, one of the last remaining and most important perennial rivers in Arizona. The Verde River has flowed for millions of years, but recent flow data indicate that some reaches of the upper 25 miles of the river may become intermittent within the next 10–20 years if drought conditions and current flow trends continue unchanged. The upper Verde River has been retreating downstream from its former headwaters for at least the last 40 years. As the river retreats downstream and its base flow decreases, the upper Verde River is literally "going with the flow."

The Arizona Water Sentinels have been making monthly discharge measurements at three sites on the upper Verde River since December 2006 in order to gain a better understanding about what is happening to the base flow of the river [*See* Appendix B]. Our flow monitoring protocols are found in Appendix C. Also, Salt River Project (SRP) and the U.S. Geological Survey (USGS) operate stream gaging stations that continuously monitor the flow of the upper Verde River. Our monthly discharge measurements and USGS and SRP stream gage records show that base flow has decreased over the last six years. Base flow has, in general, been less than the historic average base flow as determined over a 49-year period of record at the USGS Paulden stream gage.

The reasons for recent decreases in base flow are not entirely understood. It is likely that the observed decreases are caused by a combination of continuing drought and groundwater pumping in the watershed. We do know that the base flow of the river has, in fact, decreased over the last five years, however. The data indicate that some perennial reaches of the river, particularly the reach downstream of the USGS Paulden stream gage and upstream of the Perkinsville Bridge, are losing base flow and may become intermittent within the next 10–20 years if current trends continue. These reaches of the upper Verde River may be the first to share the fate of many other Arizona streams and rivers that no longer flow perennially but only for short periods of time during the spring runoff season or after large storm events.

The upper Verde River has been extensively studied by hydrologists and other scientists. So, why is the Sierra Club doing another report? We write this report because we want to share what the Arizona Water Sentinels have learned over the last six years and to sound an alarm to focus public attention on the decrease in base flow which poses an existential threat to the river.

There has never been a time in the history of the Verde River when credible data and "good science" have been so important. Difficult management decisions regarding the use of limited surface and groundwater resources will need to be made in the future. Unbiased information and data are necessary to help elected officials, water resource managers, and citizens make informed decisions about how finite water resources will be managed, how groundwater will be used in Yavapai County, and whether the preservation of the base flow of the upper Verde River will factor into decision-making. The stakes are high. The quality of life and the futures of Prescott, Prescott Valley, Chino Valley, Clarkdale, Cottonwood, and Camp Verde are at stake. The continued existence of the upper Verde River and its remarkably diverse animal and plant communities are at stake, too. The decisions we make *or fail to make* will, in large part, determine whether the upper Verde River "goes with the flow."

Figure 2. The dry streambed of Railroad Draw, an ephemeral tributary of the Verde River. Is this the future of the upper Verde River? Photo credit: Gary Beverly

The Big Picture: The Verde River Watershed

The Verde River watershed is located in central Arizona [*See* Figure 3 below]. The Verde River is a tributary of the Salt River which, in turn, is a tributary of the Gila River. The Gila River flows intermittently across southwestern Arizona and joins the Colorado River near Yuma. The Verde River watershed is a sub-watershed nested within the greater Colorado River Basin. The entire watershed covers an area of approximately 6,188 square miles, representing 5.8 percent of the total land area of the State of Arizona.[1]

The upper Verde watershed is largely within Yavapai County and encompasses an area of approximately 2,500 square miles.[2] The upper watershed contains several alluvial valleys, including the Big Chino Valley, Little Chino Valley, and Williamson Valley. These valleys are surrounded by hills and mountain ranges that are between 6,000 and 9,000 feet in elevation. The surrounding mountains include the Bradshaw Mountains and Black Hills to the south, the Juniper Mountains and Santa Maria Mountains to the west, and Big Black Mesa and the Colorado Plateau to the north.[3] These mountains and the Colorado Plateau are the primary hydrogeological boundaries controlling the movement of surface- and groundwater at the watershed scale.[4]

Major tributary streams to the upper Verde River include Big Chino Wash, Granite Creek, and Hell Canyon.[5] Big Chino Wash is the principal drainage in the northwestern region of the upper Verde watershed; it is an ephemeral stream that drains in a southeasterly direction through the Big Chino Valley and terminates at Sullivan Dam near Paulden. Pine Creek, Walnut Creek, Williamson Valley Wash, and Little Chino Wash are tributaries to Big Chino Wash. The upper Verde River, as defined in this report, begins at Sullivan Dam near Paulden (river mile 0.0) and extends to the Perkinsville Bridge, the only road crossing over the upper Verde River, located approximately 24 river miles downstream of Sullivan Dam.[6]

The upper Verde watershed consists primarily of two groundwater basins.[7] These are the 1,850 square-mile Big Chino Subbasin of the Verde River Groundwater Basin (hereafter the “Big Chino Subbasin”) and the 310 square-mile Little Chino Subbasin of the Prescott Active Management Area (hereafter the “Little Chino Subbasin”).[8] Major physical features of the Big Chino Subbasin include the Big Chino Valley,

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[1] Arizona Department of Water Resources. Arizona Water Atlas; Central Highlands Planning Area Hydrology - Surface Water (Salt River and Verde River Watersheds), retrieved from http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/CentralHighlands/PlanningAreaOverview/SurfaceWaterSaltVerdeWatersheds.html.

[2] Wirt, Laurie. 2005. *The Verde River Headwaters, Yavapai County, Arizona* in Wirt, Laurie, DeWitt, Ed, and Langenheim, V.E., eds. *Geologic Framework of Aquifer Units and Groundwater Flowpaths, Verde River Headwaters, North Central Arizona*: U.S. Geological Survey Open File Report 2004-1411 at p. A11.

[3] Blasch, K.W., Hoffmann, J.P., Graser, L.F., Bryson, J.R., and Flint, A.L. 2006. *Hydrogeology of the upper and middle Verde River Watersheds, central Arizona*: U.S. Geological Survey Scientific Investigations Report 2005–5198 at p. 5.

[4] Id.

[5] Id.

[6] Wirt (2005), *Table A1. Distance from Sullivan Lake dam to major springs, tributaries, and other geographic locations along the upper Verde River, Arizona*, at p. A4.

[7] Blasch et al. (2006) at p. 5.

[8] Id.

Williamson Valley, Big Black Mesa, and Verde Springs. Major physical features of the Little Chino Subbasin include Granite Creek, Little Chino Creek, and Del Rio Springs.[9] An adjoining carbonate aquifer located north of the upper Verde River between Big Black Mesa and Perkinsville also contributes groundwater to maintain base flow of the upper Verde River.

Figure 3. Map of the Verde River Watershed.
Credit: Tiffany Sprague

The Verde River

The Verde River is one of the longest free-flowing perennial rivers in Arizona. It is a rare treasure in our desert state – a river that flows continuously through the desert for the entire year. “Verde” is the Spanish word for the color green. The Verde River is particularly well-named because the river and its riparian corridor are green arteries of life flowing through the heart of central Arizona’s arid and semiarid landscapes.

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[9] Id.

The Verde River tells a story of many connections. Its watershed is nested within the larger Colorado River Basin and, through its tributary connection to the Colorado River, the river is ultimately linked to the oceans through the global hydrologic cycle. Groundwater and surface water in the Verde River watershed are inextricably connected to each other. The river contains Arizona's longest stretch of continuous riparian habitat, providing critically important migration corridors for wildlife and birds. The river connects Wild and Scenic Rivers, wilderness areas, national monuments, wildlife management areas, and state parks. It supports an amazing web of life with incredible biodiversity. The river, its riparian habitats, and the living creatures that depend on its life-giving water (including human beings) are deeply connected to each other.

The Verde River is millions of years old, but geologists tell us it formed in relatively recent geologic time. Approximately 5–10 million years ago, the upper Verde watershed was a closed basin with shallow lakes and playas. Entrenchment and down-cutting of the modern Verde River began around 2.5 million years ago when surface water eroded through the basalt flows at the lowest point of what is now the Big Chino Valley. The Verde River has cut down hundreds of feet over the past two million years, leaving behind terrace deposits as a record of the former river valley floors. The long-term trend of downcutting by the Verde River has continued to the present day. The ancient river terraces now can be found 200 feet above the stream bed of the modern river channel.[10]

The Verde River flows approximately 190 river miles from its headwaters near Paulden, Arizona, to its confluence with the Salt River, east of the Phoenix metropolitan area.[11] The towns of Clarkdale, Cottonwood, and Camp Verde are the primary population centers located along the river. The river is largely free-flowing and undammed for approximately 140 miles from its headwaters until it reaches Horseshoe Reservoir, the first of two major storage reservoirs on the river operated by the SRP. The other storage reservoir is Bartlett Lake located downstream of Horseshoe Reservoir. Water is stored in these reservoirs before it flows into the Salt River and is diverted for use by downstream cities, agriculture, and industry in the Phoenix metropolitan area. The Verde and Salt rivers are important sources of renewable water supply. The City of Phoenix states that 50 percent of their water supply comes from the Salt River Project, of which approximately 40 percent is from the Verde River watershed.[12]

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[10] Pearthree, Phillip A. 1996. *Historical Geomorphology of the Verde River*, Arizona Geological Survey, Open File Report 96-13 at pp. 1-2.

[11] Ed Wolfe (personal communication, 2013).

[12] Verde River Basin Partnership website, retrieved April 18, 2013, from http://vrbp.org/#arizona.

Map of the Verde River headwaters area

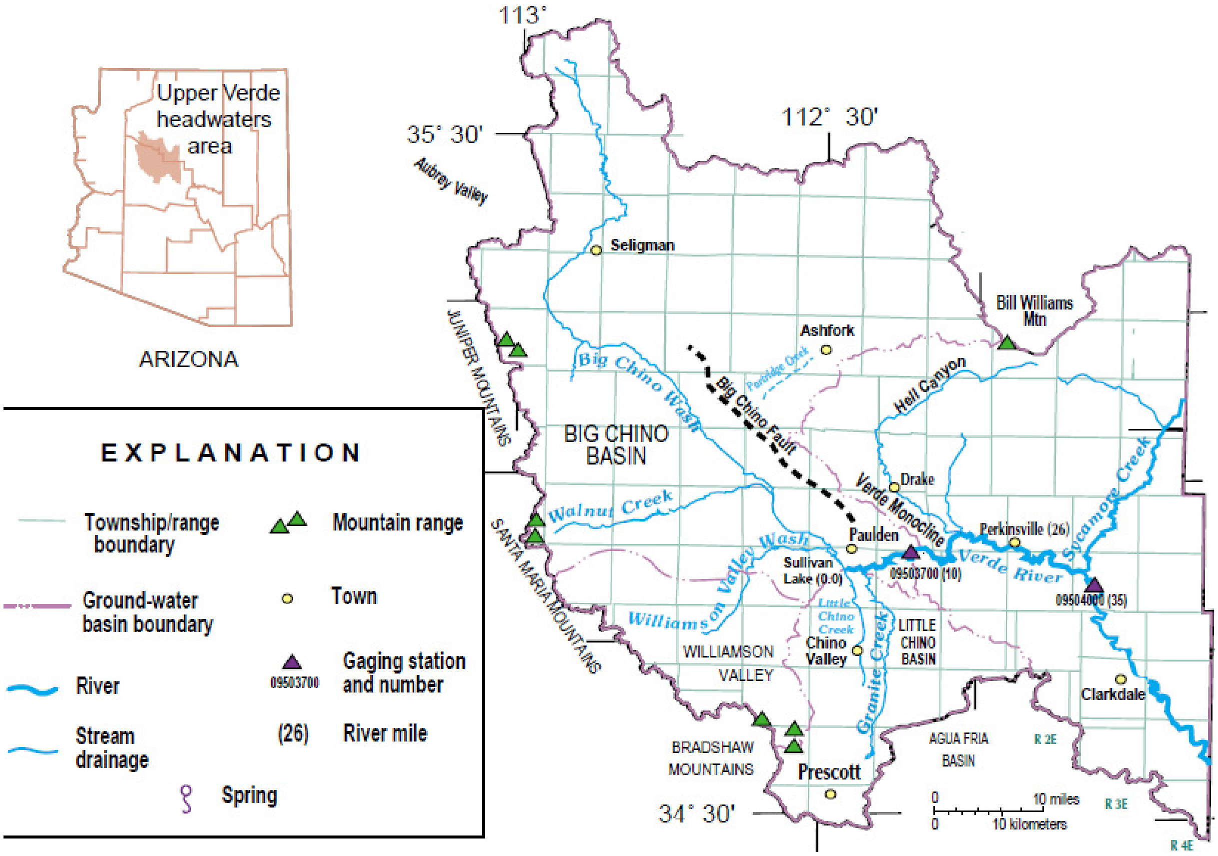

Figure 4. Major geographical features of the Verde River headwaters area.
Source: Wirt and Hjalmarson (2000)[13]

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[13] Wirt, Laurie and Hjalmarson, H.W. (2000). *Sources of springs supplying base flow to the Verde River headwaters, Yavapai County, Arizona,* USGS Open File Report 99-0378 (on-line version), retrieved from http://greenwood.cr.usgs.gov/pub/open-file-reports/ofr-99-0378 at p. 5.

Tributaries of the upper Verde River

The major streams in the upper Verde River watershed that are tributary to the river or that recharge the groundwater system sustaining the base flow of the river above the USGS Paulden gage include Big Chino Wash, Little Chino Wash, Williamson Valley Wash, Granite Creek, Walnut Creek, Pine Creek, and Partridge Creek.[14] These tributary streams are mostly intermittent or ephemeral. An intermittent stream is one that flows seasonally for several months out of the year. An ephemeral tributary is normally dry and contains flow only in direct response to precipitation. Some of these tributary streams have short, perennial reaches at higher elevations within their individual sub-watersheds that flow continuously through the entire year. Seasonal surface runoff in occasional wet years sometimes connects these tributaries with the perennially flowing upper Verde River at Verde Springs.[15]

Tributaries to the upper Verde River between the USGS Paulden gage and Perkinsville include numerous unnamed ephemeral streams. Named canyons with ephemeral tributaries to the upper Verde River include Muldoon Canyon, Bull Basin, Gold Basin, King Wash, Duff Canyon, Hell Canyon, MC Canyon, Government Canyon, and Wildcat Draw. There are no stream gages for these tributaries so the frequency and the amount of water contributed to the river from each are unknown.[16]

Blasch and others report that, similar to flows of the main stem of the upper Verde River, the average monthly stream flow of tributaries is greatest in the winter and spring and least in early summer and fall.[17] The USGS also has found that there typically is a secondary peak in average monthly stream flow caused by surface runoff from summer monsoon storms in August or September.[18]

The data from USGS stream gages on tributaries to the upper Verde River show that surface runoff from tributary streams in the Little Chino Valley, Williamson Valley, and the upper reaches of Big Chino Wash only infrequently reach the main stem of the upper Verde River above Verde Springs. Surface runoff that makes it to upper Verde River to flow past the USGS Paulden stream gage is mostly from the lower reaches of Big Chino Wash and only rarely from the lower reaches of Granite Creek. Occasionally, after large, intense storm events with large flood flows, surface runoff from Big Chino Wash and Granite Creek will travel the full distance of the watershed and reach the upper Verde River.[19]

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[14] Blasch et al. (2006) at p. 19.
[15] Wirt and Hjalmarson (2000) at p. 20.
[16] Gary Beverly (personal communication, 2013).
[17] Blasch et al. (2006) at p. 21.
[18] Id.
[19] Id.

Climate of the upper Verde River watershed

The climate of the upper Verde River watershed is arid to semiarid and characterized by wide ranges in precipitation and temperature. Precipitation varies greatly from place to place and from one year to another.[20] Climate conditions are correlated with altitude; higher elevations in the watershed are described as having moderate summers and severe winters and lower elevations as having hot summers, mild winters, and low to moderate precipitation. The upper Verde watershed is subject to extended dry periods or droughts.[21]

Average annual precipitation, rainfall and snowfall, varies geographically and is strongly correlated with elevation. In general, the amount of precipitation increases with altitude. Wirt reports that mountain regions in the watershed received more than 20 inches of precipitation annually with some precipitation falling as snow.[22] In contrast, the lower valleys of the watershed near the towns of Chino Valley (4,600 feet) and Paulden (4,400 feet) generally receive about 10 to 12 inches of precipitation annually.[23]

Precipitation in the upper Verde watershed has a bimodal distribution, meaning it occurs primarily during two seasons of the year. One season is the summer "monsoon," which typically begins in July and extends through September. During the summer months, moisture-laden air from the Gulf of Mexico and the Sea of Cortez moves into central Arizona over the varied topography of the upper Verde watershed and summer thunderstorms often occur. Summer thunderstorms are usually of short duration (less than 1 hour) and greater intensity (greater than 1 inch of precipitation per hour) and are usually highly localized (affecting about 100 square miles).[24] Storm water runoff from these summer thunderstorms causes occasional flooding.

The second season when precipitation typically occurs is December through March. During the winter, westerly winds bring low pressure systems and frontal storms from the Pacific Ocean into Arizona. Winter storms typically are longer in duration (12 to 48 hours), less intense (less than 0.25 inch of precipitation per hour), and more widespread in area (500 square miles) than are summer "monsoon" storms.[25]

Temperatures in the watershed vary seasonally and because of differences in altitude. High temperatures are common in the summer at low elevations in the watershed. Temperatures range from more than 95 degrees Fahrenheit in the summer to below freezing at night in the coldest winter months at higher elevations in the watershed. Large shifts can occur between day and night temperatures.[26]

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[20] Wirt (2005) at p. A12.
[21] Blasch et al. (2006) at p. 9.
[22] Wirt (2005) at p. A13
[23] Id.
[24] Blasch et al. (2006) at p. 13.
[25] Id.
[26] Wirt (2005) at p. A13.

The upper Verde River watershed is getting hotter

Temperature records for the Verde River watershed date back to the end of the 19th century. USGS analysis of these temperature data shows that the upper Verde River watershed has been getting warmer over the last 100 years.[27] Mean annual temperatures have increased by about 1–3°F over the last century. Furthermore, annual mean temperatures within the watershed have increased since 1990.[28] The USGS found that annual mean temperatures from 1990–2004 were above the long-term mean temperature for 14 of the 15 National Oceanic and Atmospheric Administration (NOAA) climate stations in the Verde River watershed.[29] A warming watershed is confirmed by recent data obtained from the Climate Assessment for the Southwest (CLIMAS), which shows that the Southwest has experienced abnormally high temperatures in recent years. The warmest January to June period on record was in 2012.[30]

Climate scientists predict that temperatures will continue to rise in the American Southwest because of climate change. Average temperatures are projected to increase by 3–10°F by the end of the 21st century.[31] The climate models project an increase of 2–3°F in the Southwest by 2020 and 3–5°F by 2050. The prospect of rising temperatures raises concern over the likelihood of more frequent, longer, and more severe drought in the future. Given the lack of progress in reducing greenhouse gas emissions globally, it is likely that we will see a warmer Arizona under the higher emissions scenarios in the climate models. Warmer temperatures mean higher evaporation rates from water and land surfaces, greater rates of evapotranspiration by plants, and increased water demand. Water lost to the atmosphere through evaporation and evapotranspiration means less water will be available for groundwater recharge of the regional aquifers sustaining the upper Verde River and ultimately, less groundwater discharged to the river, thus increasing the risk that the river will “go with the flow” in the future.

The upper Verde River watershed is getting drier

Blasch and others analyzed precipitation data from 18 NOAA precipitation gages in the Verde River watershed and found decades-long cycles during which rainfall was greater or less than the long-term average. These relatively wetter and dryer cycles extended for periods of as much as 30 to 40 years. Rainfall in the upper Verde watershed was greater than average from the early 1900s to 1940, less than average from 1940 through 1977, greater than average from about 1977 through about 1994, and generally drier than average from 1994 to 2004. The cyclical rainfall pattern suggests that the current period of less-than-average rainfall that began in the mid-1990s could be part of a long-term cycle that could last another decade or more.[32]

Climate scientists predict that the American Southwest will get drier. Scientists with the U.S. Global Climate Change Program predict that spring runoff in the Southwest could decrease as much as 10–40

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[27] Blasch et.al. (2006) at p. 13.

[28] Id.

[29] Id.

[30] The University of Arizona. *Home Page | Climate Assessment for the Southwest*. Retrieved August 20, 2012, from http://www.climas.arizona.edu.

[31] U.S. Environmental Protection Agency Climate Change. Future Climate Change webpage: http://www.epa.gov/climatechange/science/future.html#Temperature (Retrieved September 25, 2012).

[32] Blasch et al. (2006) at p. 14.

percent by the end of the 21st century.[33] Projections of less precipitation and higher temperatures mean it is likely that the upper Verde watershed will experience extended drought conditions, possibly for decades to come. Extended drought conditions means less surface water runoff. Less precipitation will affect rates of groundwater recharge that, over the long-term, could affect the amount of groundwater discharged at the springs that sustain the base flow of the upper Verde River.

Winter snowpacks are predicted to be below average in the future

The amount of the winter snowpack in the higher elevations of the watershed has both a direct and an indirect effect on the flow of the Verde River. Melting snow infiltrates into the ground and recharges regional aquifers that are sources of groundwater sustaining the upper Verde River. The amount of water recharged affects the amount of groundwater in storage in the aquifers and, over the long-term, affects the amount of groundwater discharged from springs to the river. Early spring runoff from melting snow has a more direct effect, contributing surface water runoff to the river by overland flow via intermittent and ephemeral tributaries.

Long-term records of snowfall in the Verde River watershed indicate that, similar to rainfall cycles, there was a period of greater-than-average snowfall from 1916 to 1955 and a period of less-than-average snowfall from 1955 to 2003.[34] Like rainfall, snowfall is correlated to altitude with greater amounts of snow at higher elevations in the watershed.[35] For example, average snowfall at Tuzigoot National Monument (at 3,470 feet) near Clarkdale was only two inches per year from 1982 through 2003. The average snowfall at Jerome (at 5,135 feet) above the Town of Clarkdale was nine inches per year for the same period.[36] Snowfall can approach 25 percent of the total annual precipitation at higher altitudes in the watershed, while, in the low altitude alluvial basins, it is less than 5 percent of total annual precipitation.[37] On average, snowfall in the upper Verde watershed is greatest during December, and January and February are the second and third snowiest months, respectively.[38]

Blasch and others estimated total snowfall for the upper and middle Verde River watersheds using data from 15 snow gages over a 22-year period of record (1981 through 2003). They estimated that snowfall accounted for about 695,000 acre-feet (af) of precipitation per year or about 16 percent of the annual total precipitation from 1981 to 2002.[39]

Melting snow is an important source of groundwater recharge for the regional aquifers in the watershed and an important source of water during the spring runoff period. Blasch and others estimate from water balance calculations that about 1–2 percent of total annual precipitation is recharged to the regional aquifers of the Big Chino and Little Chino subbasins.[40] Warmer temperatures and less snowfall mean declines in winter snowpack, less groundwater recharge, earlier surface water runoff in the spring, and, ultimately, less base flow in the river during early summer, the driest time of the year.

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[33] United States Global Change Research Program. Global Climate Change Impacts in the United States, 2009 Report, Projected Change in Spring Precipitation, 2080-2099, retrieved April 18, 2013, from http://nca2009.globalchange.gov/southwest.
[34] Blasch et al. (2006) at p. 14.
[35] Id.
[36] Id.
[37] Id.
[38] Id.
[39] Id.
[40] Ibid at p.1

Drought and the upper Verde River

The Southwest region has been suffering from drought conditions since the late 1990s. Recent climate data describe some of the driest years scientists have seen in Arizona in centuries. Higher temperatures, less precipitation, warmer winters, and decreasing winter snowpack are combining to contribute to drought conditions that may rival, if not surpass, the dry conditions present during the 1950s and the Dust Bowl years of the 1930s.[41]

The current drought conditions in the Southwest are part of the larger phenomenon of global climate change. Climate modeling results published in the International Panel on Climate Change (IPCC) Fourth Assessment Report in 2007 project that the American Southwest will grow appreciably drier in the 21st century.[42] Dr. Jonathan Overpeck, Director of the University of Arizona Institute of the Environment, provides a grim assessment of future drought conditions in the Southwest:

> *"The Southwest is going to dry out on average. We're going to have more drought, more frequent drought, and longer drought…and when it rains, it's going to rain more intensely on average, meaning more floods."[43] Climate change, he said, will produce winners and losers, and "in the Southwest, we're going to be losers. There's no doubt.[44]*

This grim assessment is echoed by Dr. Richard Seager, a scientist with the Lamont-Doherty Earth Observatory at Columbia University, who describes a "new normal" for climate in the American Southwest. According to Dr. Seager, the "new normal" is that the Southwest will likely be as dry as the region has been in centuries: "[P]eople will have to recalibrate their expectations to the new idea of what 'normal' stands for…the droughts of the future will be…unlike anything people in the region have known since the late medieval times."[45]

Short-term predictions from the National Weather Service and the Climate Prediction Center indicate that the Southwest will see temperatures that are above historical averages for most seasons until the end of 2013. These short-term and long-term predictions, along with the precipitation trends discussed previously, point to a hotter and drier Arizona in the future. How will this affect the base flow of the upper Verde River? It is likely that both peak flows and the base flow will be affected. A hotter, drier climate will lead to an intensification of the hydrologic cycle, more extreme weather, and more intense monsoon storm events. More intense storms will result in larger flood events and higher peak flows during the summer monsoon season. Warmer winters, decreased snowpack, and extended drought conditions will decrease surface runoff and groundwater recharge rates, ultimately decreasing discharges of groundwater from the source springs of the upper Verde River that sustain the river's base flow.

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[41] Romm, J. (n.d.). *USGS on Dust-Bowlification*: *Drier conditions projected to accelerate dust storms in the U.S. Southwest* | ThinkProgress. Retrieved August 20, 2012, from http://thinkprogress.org/climate/2011/04/07/207853/usgs-dust-bowl-storms-southwest.

[42] DeBuys, William. 2011. *A Great Aridness – Climate Change and the Future of the American Southwest*, Oxford University Press, New York, NY., p. 25.

[43] Ibid at p. 28.

[44] Ibid at p. 10.

[45] Ibid at p. 23.

The surface water hydrology of the upper Verde River

The upper Verde River is a *perennial* river, meaning it flows continuously throughout the year. Its flow varies considerably during the year. Flows peak in the winter and spring months of January through April and reach a minimum in the summer months of May through July. Historically, monthly median flows of the upper Verde River were highest in March and lowest in July.[46] Flow is affected by many factors, including seasonal changes in climate (i.e., changes in the amount of precipitation and drought), surface runoff, rates of groundwater pumping, surface water diversions, streambed infiltration, and rates of evapotranspiration.[47]

The perennial flow of all rivers has two basic components: 1) surface runoff and 2) base flow.[48] Surface runoff is derived from precipitation and melting snow in the watershed and typically occurs in direct response to seasonal melting of the winter snowpack or local storm events.[49] Surface runoff usually is of relatively short duration.[50] Surface runoff is highly variable in time and space for different parts of the upper Verde watershed.

The base flow of the upper Verde River is sustained by the continuous discharge of groundwater from springs and seeps to the river. Without its base flow, the upper Verde River would be an intermittent stream or a dry wash that flows only in direct response to storm events or melting snow.[51] Changes in the base flow of the upper Verde River are functions of the amount of recharge to the regional aquifers supplying groundwater to the river, the amount of groundwater in aquifer storage, groundwater pumping, changes in local water table elevations, and other changes in aquifer characteristics such as changes in the direction of groundwater flow paths.[52] In general, base flow increases in a downstream direction as a result of additional inputs of groundwater to the upper Verde River. Decreases in base flow are caused by evaporation from water surfaces, transpiration by plants, streambed infiltration, and surface water diversions.[53]

The upper Verde River begins to flow perennially at Verde Springs, a network of springs and seeps located a short distance below the confluence of Granite Creek and the main stem of the upper Verde River. The base flow of the river is created and sustained by the discharge of groundwater from Verde Springs, supplemented by intermittent storm water discharges. There are small gains in base flow from other springs and seeps located farther downstream near Muldoon Canyon (approximately 2 cfs) and Duff Spring (approximately 2.5 cfs).[54]

The following line graph from Blasch and others illustrates the increase in base flow of the Verde River from the mouth of Granite Creek (at mile 0 on the graph) to the USGS stream gage on the Verde River

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[46] National Wild and Scenic River Systems website, Verde River at http://www.rivers.gov/rivers/rivers/verde.php.

[47] Id.

[48] Blasch et al. (2006) at p. 24.

[49] Wirt (2005) at p. A17.

[50] Id.

[51] Ed Wolfe, *A Cautionary Tale of Two Streamgages with Appendix*, Revised January 20, 2011, Retrieved March 28, 2013 from Verde Watershed Association website at http://www.vwa.org/newsletters/the-verde-river-a-cautionary-tale-of-two-streamgages-full-version.pdf.

[52] Blasch et al. (2006) at p. 24.

[53] Blasch et al. (2006) at p. 29.

[54] Wirt (2005) at p. A24.

near Camp Verde at approximately river mile 90.[55] In general, base flow of the Verde River increases as the river flows downstream, increasing from essentially no flow (less than one cubic foot per second [cfs]) at the mouth of Granite Creek, to about 25 cfs at the USGS Paulden gage, to about 79 cfs at the Verde River near Clarkdale gaging station, to approximately 200 cfs at the USGS gage near Camp Verde.[56] The base flow of the river *decreases* along a 16-mile "losing" reach between the USGS Paulden gage and Perkinsville.

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[55] Blasch et al. (2006) at p. 26.

[56] Ibid at p. 29.

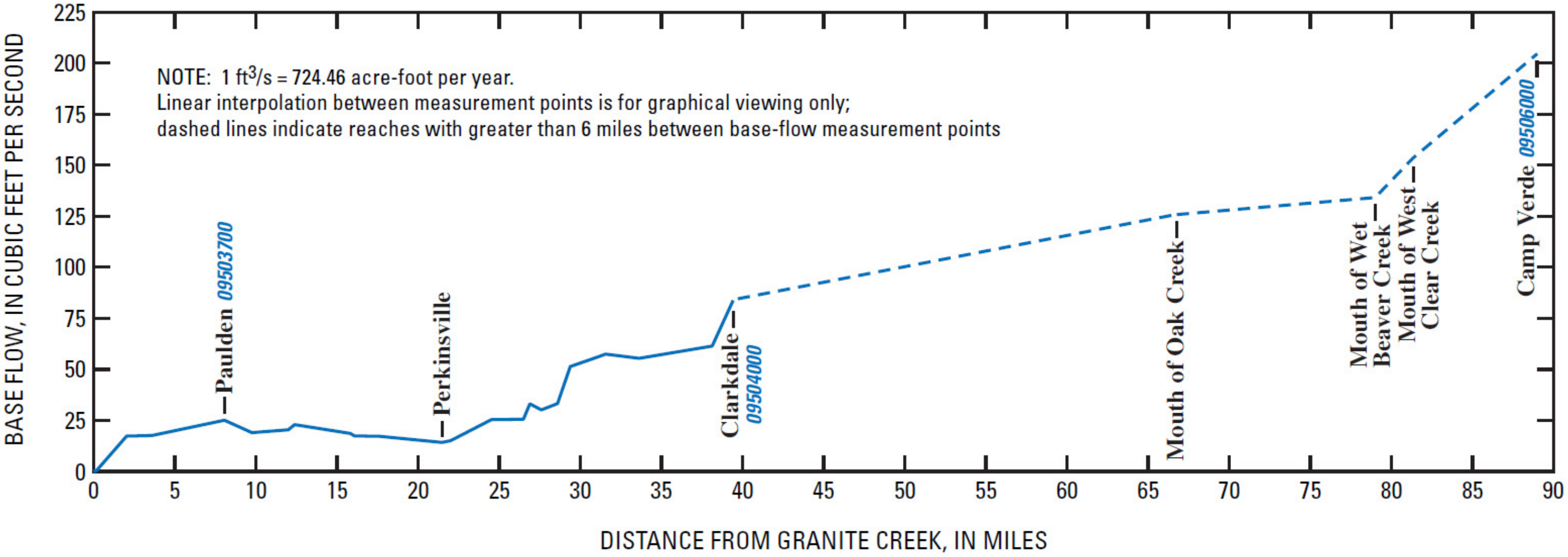

Figure 5. Base flow in the Verde River from the mouth of Granite Creek to the gaging station near Camp Verde (0950600).
Source: Blasch et al. (2006) [57]

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[57] Ibid at p. 26.

The upper Verde River contains both gaining and losing reaches within its first 25 miles. The graph above shows that base flow increases from essentially zero flow at the confluence of Granite Creek to approximately 25 cfs in its first 8 miles (i.e., a “gaining” reach). The river loses base flow between the USGS Paulden gage at river mile 8 and Perkinsville at approximately river mile 24 (i.e., “a losing” reach). Below Perkinsville, the river gains flow again from springs and tributaries that contribute water to the river. By the time the river reaches the USGS stream gage near Clarkdale, base flow has increased to about 79 cfs.[58] The flow continues to increase as tributary streams such as Sycamore Creek, Oak Creek, Beaver Creek, and West Clear Creek contribute water to the river. By the time the river reaches the USGS stream gaging station near Camp Verde, base flow has increased to about 205 cfs.[59]

Blasch and others determined that the average annual base flow of the upper Verde River as measured at the USGS Paulden gage for 1964-2003 is 24.4 cfs or 17,700 af/yr.[60] The average annual base flow is less than the average winter base flow for the same period of 25.1 cfs or 18,200 af/yr.[61] They estimated that the base flow of the river decreased at a rate of about 0.5 cfs per year at the USGS Paulden gage between 1993 and 2003.[62]

The base flow of the upper Verde River exhibits a long-term cyclical pattern. According to Blasch and others, the base flow of the river has generally been less than the long-term average during the 1960s and 1970s, greater than the long-term average from the 1980s through the mid-1990s, and less than the long-term average from the mid-1990s through 2003.[63] Water Sentinels calculations of monthly mean data for the USGS Paulden gage are consistent with the USGS finding of below average flow from the mid- 1990s to 2003. Our monthly mean calculations show that base flow at the USGS Paulden gage between 2007 and 2011 generally has been less than the long-term average of 25 cfs.

The flood history of the upper Verde River

The flow of the upper Verde River is highly variable. The river flows at about 25 cfs at the USGS Paulden gage when there are no contributions of surface runoff from storm events or melting snow during the spring runoff season. The river occasionally experiences very high flows much greater than 25 cfs. For example, the highest peak stream flow recorded at the USGS Paulden gage occurred on February 20, 1993, when peak stream flow was measured at 23,200 cfs!

High flows caused by storm water runoff typically occur during the winter, early spring, or during the summer monsoon season. The largest historical floods on the Verde River have occurred in the winter and typically were caused by winter storms that produced heavy rain or snow, which generated large amounts of runoff in the watershed.[64]

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[58] Id. Note: The average annual base flow of 79 cfs is based on Blasch and others analysis of USGS Clarkdale stream gage records for the period of record from 1966 to 2003.

[59] Id. Note: The average annual base flow of 205 cfs is an estimate of average winter base flow by Blasch et.al. (2006) at p. 29.

[60] Id.

[61] Id.

[62] Ibid at p. 31.

[63] Id.

[64] Haney, J.A., D.S. Turner, A.E. Springer, J.C. Stromberg, L.E. Stevens, P.A. Pearthree, and V. Supplee. 2008. *Ecological Implications of Verde River Flows. A report by the Verde River Basin Partnership, Arizona Water Institute, and The Nature Conservancy* at p. 24.

Figure 6. Winter storm flood flow overtopping Sullivan Dam (January 21, 2010).
Photo credit: Gary Beverly

The table below shows the annual peak stream flows of the upper Verde River at the USGS Paulden gage from 1990 through 2011. Annual peak flows are highly variable, ranging from only 83 cfs in 2000 (a very dry year!) to the record high flood of 23,200 cfs on February 20, 1993.[65]

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[65] USGS National Water Information System Web Interface, Peak Streamflow for Arizona, USGS 09503700 Verde River near Paulden, retrieved on April 9, 2013, from http://nwis.waterdata.usgs.gov/az/nwis/peak?site_no=09503700.

Table 1. Peak stream flow at USGS Paulden gage (1990–2011)

Year	Date	Gage Height (ft)	Streamflow (cfs)
1990	07/15/90	1.99	123
1991	03/02/91	9.07	6320
1992	02/14/92	5.79	1590
1993	02/20/93	14.25	23200
1994	09/02/94	2.48	192
1995	02/15/95	7.33	3960
1996	07/15/96	4.53	1030
1997	08/30/97	2.61	208
1998	08/31/98	3.75	592
1999	09/24/99	4.67	1070
2000	08/25/00	1.93	83
2001	10/28/00	3.97	633
2002	09/10/02	5.31	1610
2003	08/15/03	5.31	909
2004	09/20/04	13.08	12350
2005	01/12/05	12.08	12300
2006	07/31/06	2.64	124
2007	08/14/07	4.72	770
2008	01/28/08	6.33	1880
2009	08/22/09	7.08	2600
2010	01/22/10	10.8	8910
2011	10/07/10	2.77	111

A river in retreat

The upper Verde River has been retreating downstream for the last 40 years. Prior to the 1970s, the historical headwaters of the upper Verde River began at Del Rio Springs at the north end of the Little Chino Valley.[66] The cienega fed by Del Rio Springs provided base flow to the upper Verde River via four miles of lower Little Chino Creek to Sullivan Lake.[67] Surface water flowed for another two miles below Sullivan Dam through the basalt canyon of the upper Verde River to the mouth of Granite Creek. Historical photographs of the construction of Sullivan Dam (now considered mile zero of the Verde River) show surface water flowing in Little Chino Creek and lower Big Chino Wash upstream of Sullivan Dam, pictured under construction in the photo below.

Today, there is no perennial water flowing down lower Little Chino Creek or in lower Big Chino Wash upstream of Sullivan Dam. Both tributary streams are intermittent or ephemeral, flowing only in response to spring runoff or in direct response to large storm events. The perennial flow of the upper Verde River that used to originate near Del Rio Springs *is now about 5.7 miles downstream at Verde Springs*.[68] The perennial flow to Sullivan Lake via Little Chino Creek disappeared in the early 1970s.[69] Since then, the lower reach of Little Chino Creek has been ephemeral. Today, the first mile of the upper

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[66] Wirt and Hjalmarson (2000) at p. 15.

[67] Id.

[68] Gary Beverly (personal communication, 2012).

[69] Wirt (2005) at p. A11.

Verde River *below* Sullivan Dam is intermittent, flowing only in response to spring and storm water runoff. Put simply, we have lost about six miles of perennially-flowing upper Verde River since the 1970s.

Figure 7. Construction of Sullivan Lake and Dam near Chino Valley (Call Number: dam132pq). Photo courtesy of Sharlot Hall Museum, Library and Archive, Prescott, Arizona

Water Sentinels "Above Verde Springs" Discharge Measurement Site

The upper Verde River begins at Sullivan Dam (river mile 0), near the community of Paulden, Arizona. About a mile below Sullivan Dam, the river cuts down through the narrow basalt canyon to expose the underlying Devonian Martin limestone formation. A spring in the Devonian Martin formation discharges groundwater to the river channel to create a mile-long pond called Stillman Lake.[70] Stillman Lake is a shallow, run-of-the-river impoundment that is fully contained within the main channel of the upper Verde River. Groundwater discharged from Stillman Lake Spring to the main channel is impounded by a sand and gravel bar that spans the river channel at the confluence of Granite Creek (at approximately river mile 2.0). This sand and gravel bar forms a natural dam that causes the groundwater discharged from the spring to back up into the main river channel. Surface water flow over the sand and gravel bar occurs only during flood events. The Water Sentinels have measured some flow in a small channel immediately below the sand and gravel bar. The upper Verde River is generally dry at the mouth of Granite Creek.[71] The disappearance of perennial flow here is attributed to subflow through the sandy alluvium near the confluence.[72] Perennial flow of the river begins a few hundred yards downstream of the Granite Creek confluence at a network of seeps and springs called Verde Springs.[73]

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[70] Wirt (2005) at p. A23.

[71] Id.

[72] Wirt and Hjalmarson (2000) at p. 18.

[73] Id.

Figure 8. Stillman Lake.
Photo credit: Gary Beverly

The Water Sentinels established a discharge measurement site immediately below the sand and gravel bar impounding Stillman Lake near the mouth of Granite Creek at river mile 2.0. We call this site "*Above* Verde Springs" (AVS) because it is located upstream of the network of seeps and springs known as Verde Springs that begin downstream at about river mile 2.1. There is a small measurable discharge of water in a small channel located immediately below the sand and gravel bar backing up Stillman Lake at our AVS site. In general, the reach of the upper Verde River at the mouth of Granite Creek is ephemeral. The lack of surface flow in the main channel at the confluence of Granite Creek is attributed primarily to water moving as subflow through the sandy alluvium in the reach where our AVS site is located.[74]

The graph below shows discharge measurements made by the Water Sentinels at our AVS site between December 2, 2006 and February 18, 2012 [*See* Appendix B for Water Sentinels discharge measurements at the AVS site]. **All** of the discharge measurements made by the Water Sentinels at the AVS site are less than one cfs and most measurements since 2010 have been less than 0.2 cfs. Zero flow was observed at this site during four sampling events. The trend line through our data indicates a steady decreasing trend since 2006 with discharge measurements approaching zero in Fall of 2009 and 2010. The graphed data points are presented here to document that the upper Verde River is essentially dry at the AVS site upstream of Verde Springs.

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[74] Wirt (2005) at p. A23.

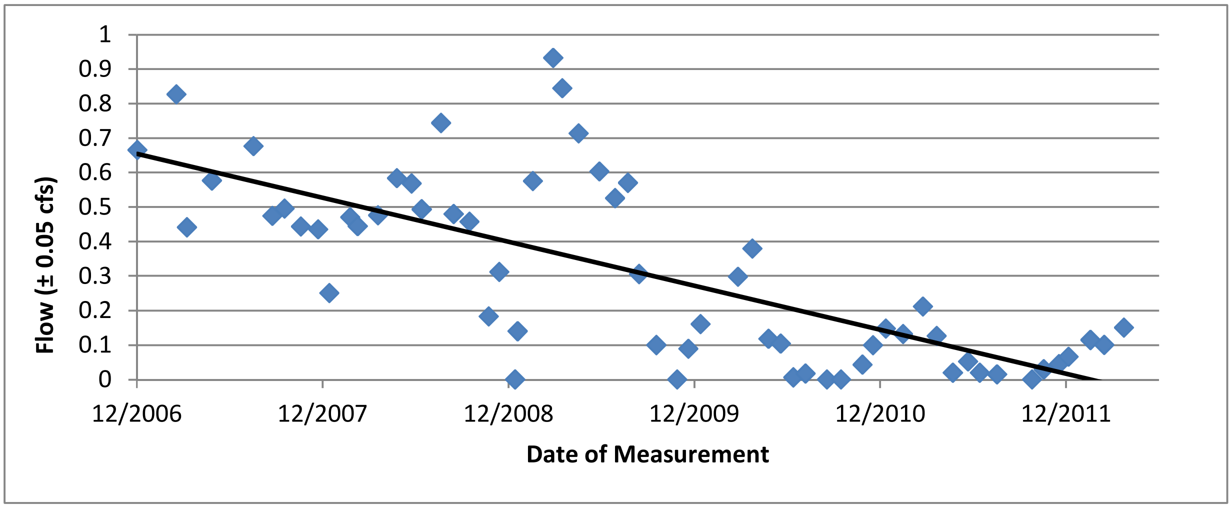

Chart 1. Flow rate data: Above Verde Springs site.

Wirt and Hjalmarson also found that there was little or no measurable current in the upper Verde River at the downstream end of Stillman Lake.[75] They determined through isotope studies that infiltration was occurring under the sand and gravel bar creating Stillman Lake. They also found that the water level of Stillman Lake appeared to vary little, indicating that a state of equilibrium existed between the amount of groundwater discharge from Stillman Lake Spring at the upper end of Stillman Lake and the amount of discharge from the lower end of Stillman Lake.

During high flow events, storm water runoff from the upper Verde watershed flows down the basalt canyon above Stillman Lake. The inflow of surface water runoff sometimes overtops the sand and gravel bar creating a continuous connection to the perennially flowing upper Verde River farther downstream. Stillman Lake has a surface connection to the downstream Verde River only during these large runoff events. Wirt and Hjalmarson's finding that infiltration occurs under and through the sand and gravel bar impounding Stillman Lake is supported by Water Sentinels observations and discharge measurements at our AVS site over the last six years; it is likely that the flow we have measured at the AVS site is seepage from Stillman Lake or some fraction of the subflow [76] moving through the sandy alluvium at the site.

It also is possible that Water Sentinels may have measured some fraction of the subflow from lower Granite Creek at our AVS site. Lower Granite Spring is located about 1.6 miles above the confluence of Granite Creek with the upper Verde River. The spring contributes about one cfs to the base flow of lower Granite Creek. In winter, surface water flows in the channel of lower Granite Creek and typically reaches to within a few hundred yards of the confluence with the upper Verde River before the surface water sinks into the abundant sandy alluvium. In summer, lower Granite Creek ends about one mile above its confluence with the upper Verde River. Evapotranspiration by the cottonwood-willow gallery forest in the riparian area along lower Granite Creek consumes water that normally flows farther downstream during the winter. The amount of subflow from lower Granite Creek to the upper Verde River is unknown. The USGS has conducted subflow analyses near the mouth of Granite Creek but found it difficult to quantify the amount of subflow moving through the shallow alluvium.[77]

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[75] Wirt and Hjalmarson (2000) at p. 18.

[76] Blasch et al. (2006) define "subflow" as "ground water flowing adjacent to streams and rivers in the stream channel alluvium that is not measured by stream-flow gaging stations" at p. 32.

[77] Id.

The AVS site data **cannot** be used to quantify the flow of the upper Verde River at the confluence of Granite Creek because of many uncertainties associated with our AVS dataset, including the following:

- There are high measurement errors associated with the AVS dataset, in the range of 15–20 percent, because of the very low flows (<1 cfs) measured at the site.
- The AVS site does not meet ideal selection criteria for a discharge measurement site. Ideally, a discharge measurement site is established at a location with a stable channel morphology that is not aggrading or degrading. The AVS site is characterized by unstable channel morphology that is aggrading with a sand and gravel bar spanning the entire river channel at the AVS site.
- The Water Sentinels moved the AVS site several times over the last six years because of beaver activities within the reach. Ponding behind beaver dams slows the velocity of the water, resulting in inaccurate discharge measurements.
- The measured discharge at the AVS site cannot be attributed to a specific source. It is possible that the Water Sentinels are measuring seepage infiltrating through or under the sand and gravel bar that backs up Stillman Lake. It also is possible that the Water Sentinels have measured an unknown fraction of the subflow moving through the shallow alluvium from lower Granite Creek or a combination of these two flow components at the AVS site.

Verde Springs: The source of base flow for the upper Verde River

The perennially-flowing Verde River begins at Verde Springs, a network of springs and seeps that begins approximately one-quarter of a mile below the Water Sentinels AVS site. According to Wirt, the basin-fill aquifers of the Big Chino and Little Chino subbasins and an adjoining carbonate aquifer discharge about 25 cfs of groundwater at Verde Springs to create the base flow of upper Verde River at approximately river mile 2.1.[78] Most of these groundwater discharges occur within the first few miles of the upper Verde River.

Figure 9. The upper Verde River near Verde Springs.
Photo credit: Gary Beverly

Wirt and Hjalmarson hypothesized that groundwater moved from major recharge areas in the Big Chino Valley toward and along the Big Chino Fault, a northwest to southeast trending fault that crosses the upper Verde River channel about 1500 feet downstream of the confluence of Granite Creek.[79] Groundwater moves through fractures and solution features in the Martin Limestone formation and ultimately is discharged to the upper Verde River between river miles 2.3 and 4.0.[80] The location of the Big Chino Fault corresponds with increases in the discharge of groundwater from Verde Springs.

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[78] Wirt (2005) at p. A1.
[79] Wirt and Hjalmarson (2000) at p. 12.
[80] Ibid at p. 13.

Discharges of groundwater from Verde Springs are the primary source of the base flow of the upper Verde River, **accounting for at least 80 percent of total base flow as measured at the downstream USGS Paulden gage** (at mile 10).[81] The flow of the upper Verde River increases from less than one cfs at the Water Sentinels AVS site at river mile 2.0 to about 4.6 cfs near river mile 2.3.[82] Base flow increases to about 19 cfs at the SRP Campbell Ranch low-flow gage at river mile 3.2. [83] Base flow is about 25 cfs at the USGS Paulden gage at river mile 10.[84] Most of the gain in base flow of the upper Verde River occurs within the first two miles after groundwater is first discharged to the main river channel at Verde Springs between river mile 2.1 and river mile 4.0. According to Wirt, base flow does not increase substantially between the SRP Campbell Ranch low-flow stream gage and the USGS Paulden gage at river mile 10.[85]

Wirt describes the base flow of the upper Verde River downstream of Verde Springs as “steady” changing little in response to precipitation from year to year and within a year.[86] This relatively steady, constant flow is consistent with the definition of base flow (i.e., base flow is defined as that component of flow sustained by the relatively constant discharge of groundwater). Wirt found that the historic average base flow of the river at the USGS Paulden gage was nearly constant over a 34-year period of record from July 1963 to 1997 ranging between 22 and 26 cfs.[87]

The range of base flows observed by Wirt is similar to the range of monthly mean flows at the USGS Paulden gage calculated by the Water Sentinels for 2007 through 2011 [*See* Appendix A]. For example, in 2007, the calculated monthly means at the USGS Paulden gage ranged between 20–33 cfs with monthly means ranging between 20–24 cfs in 11 out of 12 months. In 2008, the range of monthly means was 20–61 cfs with 10 out of 12 months ranging between 20–27 cfs. In 2009, the range of monthly means was 21–25 cfs. In 2010, a relatively wet year, there was a broader range of flows, reflecting elevated flows associated with greater amounts of precipitation and surface runoff from winter storms, spring runoff, and summer monsoon storms. The range of monthly means for January–March 2010 was 49–126 cfs. These temporary high flows indicate a wet winter with large amounts of surface water runoff in the late winter and early spring of 2010. It is interesting to note that the range of base flows returned to between 19–26 cfs for most of the rest of 2010. In 2011, the range of monthly means at the USGS Paulden gage was 18–24 cfs. The Water Sentinels calculations of monthly means for 2007 to 2011show that the low end of the range of monthly mean flows observed by the Sentinels (i.e., 18 to 21 cfs) is less than the low end of the range observed by Wirt for the 1963 to 1997 time period (i.e., 22 cfs).

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[81] Id.

[82] Ibid at p.18.

[83] Wirt (2005) at p. A23.

[84] Wirt and Hjalmarson (2000) at p. 18.

[85] Id.

[86] Wirt (2005) at p. A21.

[87] Id.

Base Flow at the SRP Campbell Ranch Low-Flow Gage

In April 2005, SRP installed the Campbell Ranch low-flow stream gage (hereafter referred to as the "Campbell Ranch gage") at river mile 3.2 on the upper Verde River. The Campbell Ranch gage is an important source of data because it is the closest stream gage located downstream of Verde Springs, the primary source of base flow of the upper Verde River.

Figure 10. Campbell Ranch Low-Flow Gage.
Photo credit: Gary Beverly

The flow of the upper Verde River at the Campbell Ranch gage is measured and logged every 15 minutes, and the data are telemetered to SRP, where the data are archived in SRP databases. The Water Sentinels program obtained daily mean flow data from the SRP archives for the period from the date of the installation of the stream gage in April 2005 through December 2011. Where sufficient data were available, we calculated monthly mean flows for each month in this period [*See* Appendix A]. Calculated monthly mean values ranged from a low of about 16 cfs for August 2011 to a maximum of almost 33 cfs in December 2008. The majority of calculated monthly means at the Campbell Ranch gage range between 17 and 20 cfs.

The graph below, which presents our monthly mean calculations from the Campbell Ranch gage dataset, clearly shows a decreasing trend in monthly mean flows between April 2005 and December 2011. Calculated monthly mean values are generally higher for 2005 (approximately 20–22 cfs) and lower in 2011 (16–18 cfs). The monthly mean flow of the upper Verde River from April 2005 to December 2011 ranged between 17 and 20 cfs for most of the 5½-year period of record. The trend line through the data indicates a decreasing linear trend with a total decrease in monthly mean flow of about 3 cfs between

April 2005 and December 2011. While there are a few scattered outliers indicating temporary high flow events over the last 5½ years, there has been a steady decrease in the base flow of the river since installation of the Campbell Ranch gage in April 2005.

The data from the Campbell Ranch gage indicate that groundwater discharges at Verde Springs are gradually decreasing. The river appears to be gradually "going with the flow".

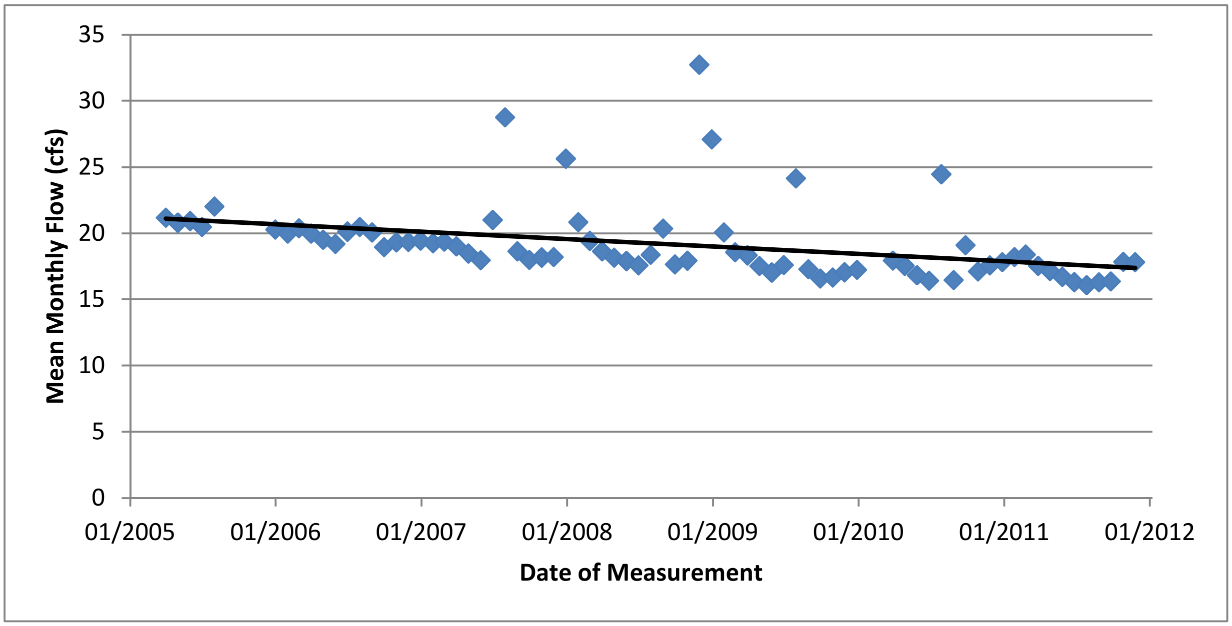

Chart 2. Monthly mean flow – SRP Campbell Ranch Gage.

There appears to be a seasonal pattern to the monthly mean flows of the river calculated for the Campbell Ranch gage. Generally, flows are higher in late summer and during the winter because of runoff from summer monsoon and winter storms. Monthly mean values greater than 20 cfs generally occur during the summer monsoon season (usually in August) or during the winter in December or January (*See* Appendix A).

In contrast, the lowest monthly mean flows at the Campbell Ranch gage typically occurred during June or July – before the start of the summer monsoon season – or in October – before the winter storm season began.

Below the Campbell Ranch gage, the upper Verde River is a narrow, free-flowing stream about 10–20 feet wide and less than 3 feet deep; with deeper and wider pools in a few locations.[88] The base flow of the river does not increase significantly between the Campbell Ranch gage and the USGS Paulden gage.[89] Wirt reports that there is a small discharge of at least 2 cfs of groundwater from seeps on both banks of the Verde River near the mouth of Muldoon Canyon at river mile 8, and an estimated 2.5 cfs of groundwater is discharged from Duff Spring, located below the USGS Paulden gage near river mile 14.[90]

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[88] Wirt (2005) at p. A 24.

[89] Wirt and Hjalmarson (2000) at p. 18.

[90] Wirt (2005) at p. A 24.

USGS Stream Gage near Paulden

The USGS Paulden gage (09503700) is located approximately 10 river miles below Sullivan Dam and a little more than six miles below the Campbell Ranch gage.

Figure 11. USGS stream gage near Paulden.
Photo credit: Gary Beverly

According to Blasch and others, the average annual base flow at the USGS Paulden gage for the period of record from 1964 to 2003 was 24.4 cfs, or 17,700 af of water, per year.[91] They also determined that average winter base flow was 25.1 cfs, or 18,200 af per year, slightly higher than the annual average base flow.[92] Wirt and Hjalmarson determined from USGS Paulden gage records that average base flow in the upper Verde River was 24.9 cfs based on a 34-year period of record from 1963 to 1997.[93] The USGS Paulden gage now has a 49-year period of record, and the USGS has calculated a mean daily discharge of 26 cfs and a median daily discharge of 24 cfs over this longer period of record.

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[91] Blasch et al. (2006) at p. 29.
[92] Id.
[93] Wirt and Hjalmarson (2000) at p. 19.

Blasch and others have determined the statistical probability of exceedances of different stream flows for the USGS Paulden gage.[94] Exceedance probabilities are statistical estimates of the percentage of time that a specified stream flow is equaled or exceeded over a specific period of record. They estimated that a stream flow of 22 cfs was equaled or exceeded 90 percent of the time at the USGS Paulden gage from 1964 to 2003. Stream flow of the upper Verde River equaled or exceeded 29 cfs and was less than 22 cfs only ten percent of the time from 1964 to 2003. In general, the range of stream flows is 22–29 cfs, and the median base flow is 25 cfs at the USGS Paulden gage.[95] Stream flows less than 22 cfs were relatively infrequent, occurring less than 10 percent of the time between 1964 and 2003.

According to Blasch et al.,[96] the average monthly stream flow for the USGS Paulden gage is usually greatest in February and March because of winter precipitation and snowmelt and is at its lowest in May, June, and July. Monthly average stream flows for September and October are sometimes higher because of runoff from summer monsoon storms.[97] The graph below illustrates this seasonal pattern of average monthly stream flows at the USGS Paulden gage. The first spike in the graph is associated with the early spring runoff period, and the secondary peak in September is associated with higher flows during the summer monsoon season.

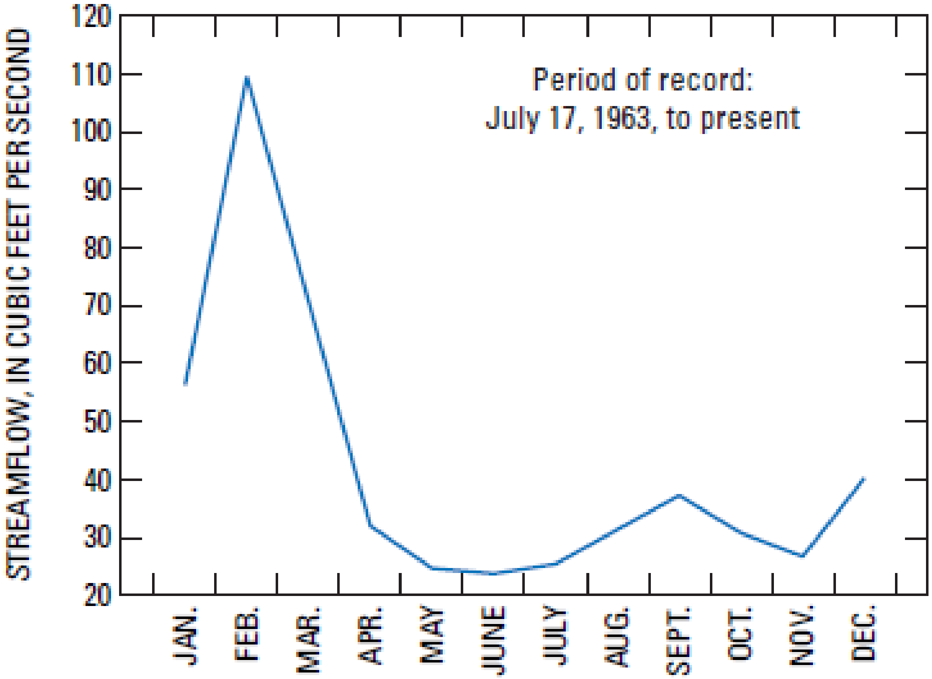

Figure 12. Average monthly stream flow at the Verde River near Paulden for the period of record from July 17, 1963, to March 31, 2004.
Source: Blasch et al. (2006)[98]

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[94] Blasch et al. (2006) at p. 18.
[95] Id [*See* Table 3 in Blasch et al. (2006). Average annual streamflow and selected annual exceedance level streamflows at gaging stations on the main stem of the Verde River in the upper and middle Verde River watersheds for respective periods of record].
[96] Ibid at p. 19.
[97] Id.
[98] Reproduced from Blasch et al. (2006) at p. 19.

Wirt describes base flow conditions at the USGS Paulden gage as follows:

> Base flow in the upper Verde River is steady, changing little in response to precipitation or lack thereof, from year to year, and within a year. Base flow for the Verde River near Paulden has been nearly constant over its historical period of record (July 1963 to present).[99]

The Water Sentinels obtained monthly statistics from the USGS National Water Information System Web Interface to determine monthly average flows at the USGS Paulden gage between 2007 and 2011.[100] We calculated monthly means from USGS daily mean data published for the USGS Paulden gage. The following graph and table show the results of these calculations. The relative flatness of the plotted monthly means from January 2007 to September 2011 confirm Wirt's observation that base flow at the USGS Paulden gage is "steady" and "nearly constant." The majority of monthly mean values calculated by the Water Sentinels for 2007 through 2011 range between 20–25 cfs. As the "flatness" of the graph shows, there does not appear to be either an increasing or decreasing trend in monthly average flows over the last five years at the stream gaging station.

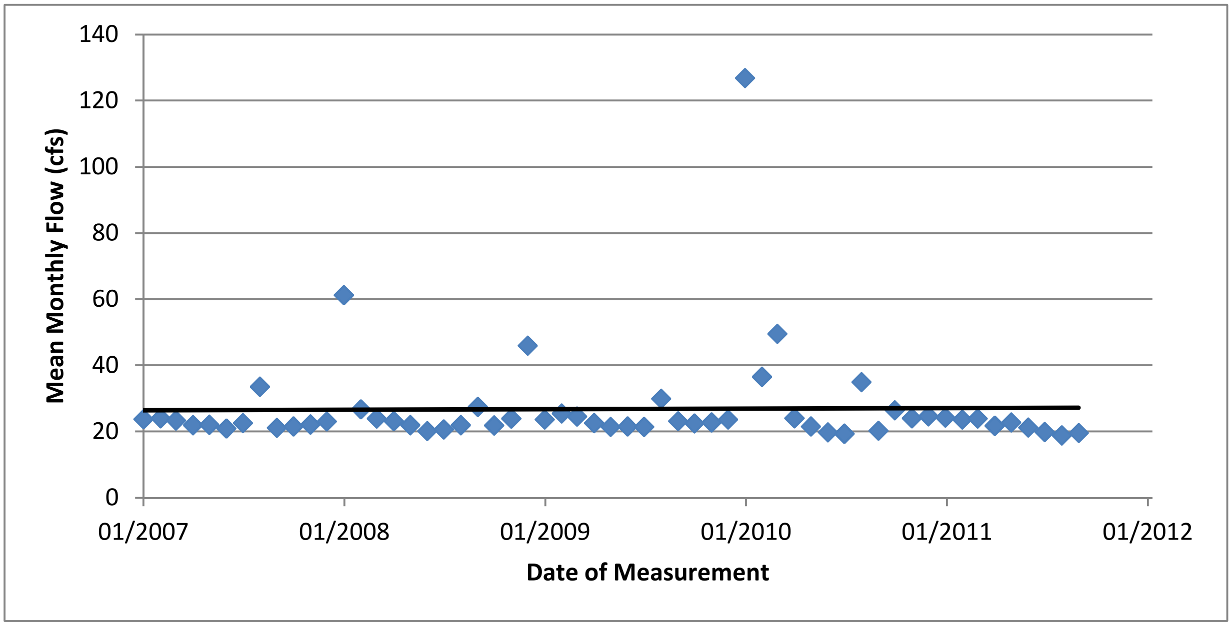

Chart 3. USGS Paulden Gage monthly mean flow data.

The table below shows the monthly mean flows calculated by the Water Sentinels for each month from January 2007 to September 2011 and plotted on the graph.

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[99] Wirt (2005) at p. A21.

[100] Retrieved from National Water Information System web interface at http://waterdata.usgs.gov/nwis/nwisman/?site_no=09503700&agency_cd=USGS.

Table 2. Monthly means at Paulden Gage.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2007	23.7	24	23.3	21.9	22	20.9	22.5	33.5	21.1	21.5	22.1	23
2008	61.2	26.7	23.9	23.1	21.9	20.1	20.6	21.9	27.4	21.8	23.9	45.9
2009	23.6	25.4	24.5	22.5	21.4	21.5	21.4	29.9	23.1	22.4	22.7	23.6
2010	126.8	36.5	49.5	24	21.5	19.7	19.3	34.9	20.2	26.4	24.0	24.6
2011	24.2	23.6	23.9	21.7	22.7	21.2	19.8	18.8	19.5			

Table 2 shows that the upper Verde River typically has higher monthly mean flows during the months of January, February, March, and during the summer monsoon season in the months of August and September. June and July are typically the driest months of the year with the lowest average monthly flows. Monthly mean flows in August and September of 2011 were atypically low for a summer monsoon season, with monthly mean values *less than 20 cfs* (18.8 and 19.5 cfs, respectively).

Over the last five years, the monthly mean flow of the upper Verde has been less than the long-term average flow of about 25 cfs, based on the 49-year period of record at the USGS Paulden gage. Water Sentinels calculations from 2007 to 2011 show that monthly mean flows ranged between 20 cfs and 25 cfs [*Compare* to the range of base flows of 22 to 29 cfs determined by Blasch and others. [101]]. The Water Sentinels calculated a significant number of monthly means *below 22 cfs* (n=21) over the last five years. It is interesting to compare the number of monthly mean values less than 22 cfs to the exceedance probabilities determined by Blasch and others – i.e., stream flows at the USGS Paulden gage were less than 22 cfs about ten percent of time from 1964–2003[102] compared to approximately 37 percent of the time from 2007–2012.[103] Finally, in June and July of 2010 and in July, August, and September of 2011, the monthly mean flow values at the USGS Paulden gage reached historic lows of less than 20 cfs.

The decrease in the monthly mean flow at the USGS Paulden gage over the last five years may be part of a cyclical pattern observed by Blasch and others who determined that average flow at the USGS Paulden gage was less than the long-term average of 25 cfs from 1963 to the late 1970s, greater than the long-term average from the 1980s to the early 1990s, and less than the historic average from the mid-1990s through 2003.[104] Water Sentinels analyses of monthly mean data for the USGS Paulden gage indicate that the base flow of the upper Verde River has continued to be less than the long-term historic average of 25 cfs between 2006 and 2011 with monthly mean flow values ranging between 20 and 25 cfs.

The finding by Blasch and others that base flow of the river has decreased at the USGS Paulden gage since the mid-1990s is supported by an analysis of seven-day average low-flow data obtained for the USGS Paulden gage for winter and summer from 1993 to 2012 by Ed Wolfe, a retired USGS geologist.[105] Seven-day average low flows are frequently used by hydrologists to represent seasonal base flow conditions. To represent base flow during the winter season (i.e., December, January, and February), Wolfe used the average of the seven consecutive days of lowest flow at the USGS Paulden gage during those three winter months in each year. To represent summer base flow, he used the average for the seven consecutive days of lowest flow during the summer months (May through September).

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[101] Blasch et al. (2006) at p. 18.

[102] Id.

[103] Based on Sentinels calculations.

[104] Blasch et al. (2006) at p. 31.

[105] Ed Wolfe, retired USGS geologist (personal communication).

These seven-day average low-flow values in the table below show that, in general, the seven-day average low flow of the river has decreased in winter and summer from 1993 to 2012. The following table presents the calculated seven-day average low-flow values at the USGS Paulden stream gage from 1993 to 2012.

Table 3. Calculated average seven-day low-flow values at the USGS Paulden gage from 1993–2012

Year	Winter (cfs)	Summer (cfs)
1993	26	25
1994	27	26
1995	26	25
1996	27	24
1997	26	23
1998	25	23
1999	25	22
2000	23	20
2001	26	21
2002	24	20
2003	21	19
2004	21	19
2005	25	24
2006	24	20
2007	23	19
2008	23	20
2009	23	20
2010	23	18
2011	24	18
2012	22	18

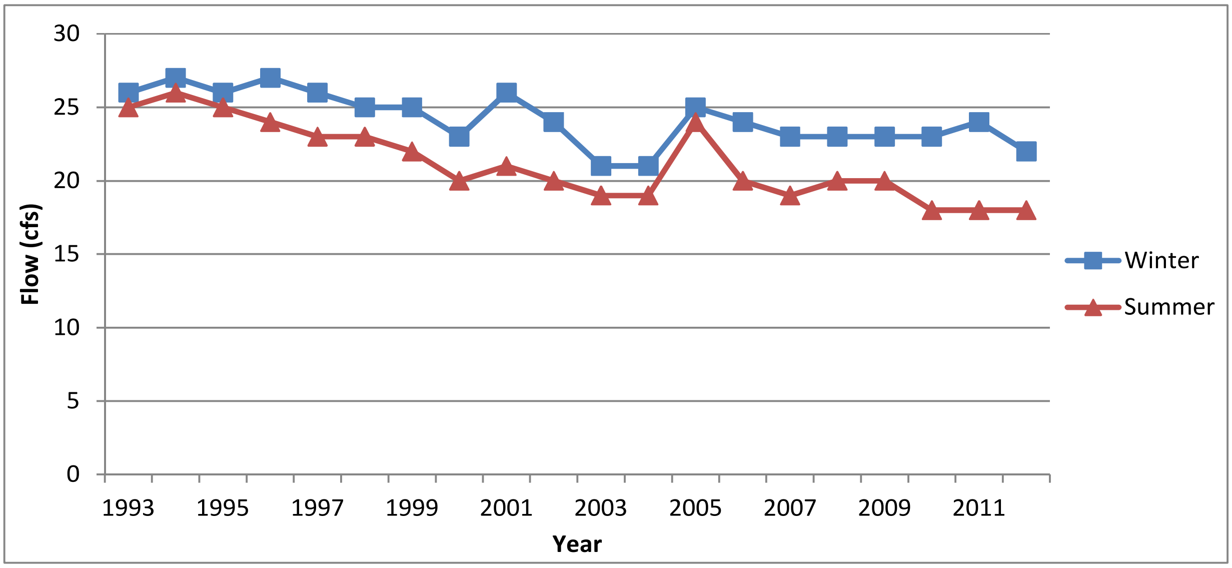

Chart 4. Calculated seven-day average low-flow values at the USGS Paulden gage from 1993–2012.

Estimated seven-day average low flows in winter at the USGS Paulden gage range from a high of 27 cfs in 1994 and 1996 to a low of 21 cfs in 2003 and 2004. Calculated seven-day average low flows in winter have been less than historic average of approximately 25 cfs for the USGS Paulden gage every year since water year 2002.

Calculated seven-day average low flows in summer at the USGS Paulden gage between 1993 and 2012 range from a low of 18 cfs for the 2010–2012 water years to a high of 26 cfs in 1994. Seven-day average low flows in summer have been less than the long-term average of about 25 cfs for 17 consecutive water years (since 1996). With the exception of a relatively wet year in 2005 (24 cfs), the summer base flows at the USGS Paulden stream gage have ranged between 18–20 cfs for more than a decade.

In summary, it appears that monthly average flow has decreased over the last five years. The range of monthly average flow values calculated by the Water Sentinels for the last five years are grouped around the lower end of the spectrum of flows predicted by the 10 percent exceedance probability estimated by Blasch and others.[106] Recent decreases in monthly average flow at the USGS Paulden gage are cause for concern. Recent decreases in flow could be part of the long-term cyclical pattern observed by Blasch and others.[107] On the other hand, below-average flows at the USGS Paulden gage in recent years may be an indication of a “new normal” –- a signal of the impact of continuing drought in the upper Verde watershed. Low summer base flow values in recent years are of particular concern. The seven-day average low-flow data tell a worrisome story of continuing decreases in base flow during the summer months at the USGS Paulden gage. In 2012, the upper Verde River was flowing at about 75 percent of the summer base flow that the river had in the mid-1990s. **In other words, the river appears to have lost approximately a quarter of its average summer base flow over the last 20 years.**

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[106] Blasch et al. (2006) at p. 18.

[107] Blasch et al. (2006) at p. 31.

Water Sentinels' "Bear Siding" Discharge Measurement Site

The Water Sentinels monitored the flow of the upper Verde River at Bear Siding at river mile 19.4 between February 2007 and October 2009. The reach of the upper Verde River downstream of the USGS Paulden gage to Bear Siding is about 9.4 miles long. The river is free-flowing and wild and there are no road crossings, no surface water diversions, and little evidence of human impact within the reach.

Figure 13. Verde River at Bear Siding in winter.
Photo credit: Tom Slaback

The Water Sentinels monitored flow at Bear Siding because it is one of the few locations on the upper Verde River that is reasonably accessible by motor vehicle between the Campbell Ranch gage and Perkinsville, which was important for our water quality monitoring at the time. We discontinued flow measurements at Bear Siding in October 2009 because we decided that continued collection of flow data at that site was not justified because of the amount of time required to access and measure flow, the availability of continuous monitoring data from the upstream USGS Paulden gage, and the proximity of another Water Sentinels flow monitoring site at Perkinsville.

Our monthly discharge measurements at Bear Siding indicate that the flow of the river is generally less than the mean monthly flow at the USGS Paulden gage. Discharge measurements made at Bear Siding ranged from a minimum of 8.3 cfs to a maximum of 45.87 cfs.

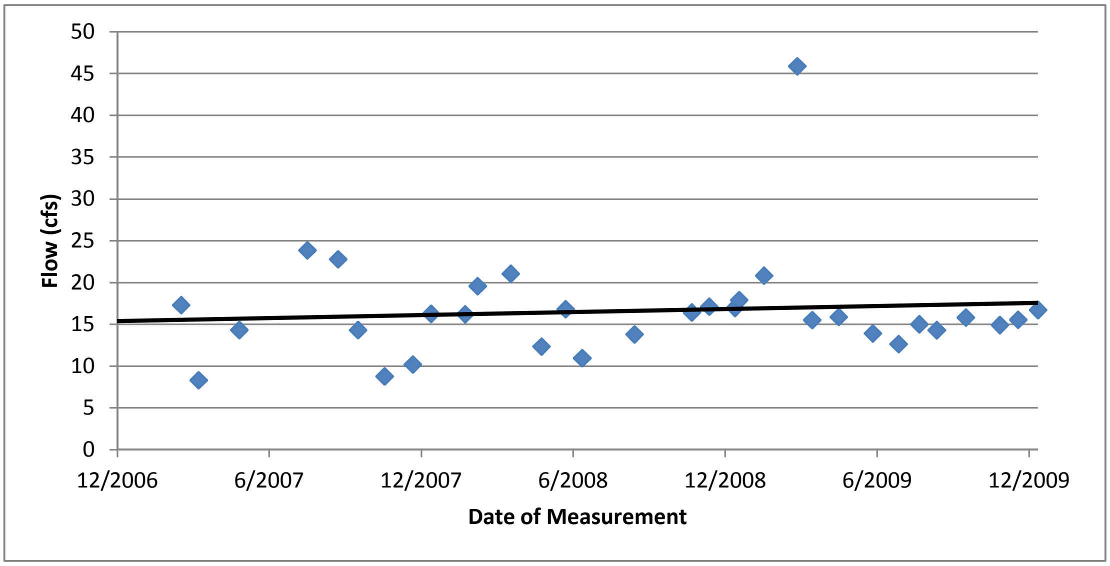

Chart 5. Flow rate data: Bear Siding site.[108]

Our flow measurements at Bear Siding were relatively constant, with most discharge measurements ranging between 10–20 cfs. This range of discharge measurements is approximately 5–15 cfs less than the historic long term average flow of 25 cfs at the USGS Paulden gage located only 8 miles upstream. These consistently lower discharge measurements made by the Water Sentinels at Bear Siding indicate that the reach of the upper Verde River between the USGS Paulden gage and Bear Siding is a "losing" reach.

Wirt also observed a decrease in base flow in this reach of the upper Verde River, observing in June 2000 that there was a more than 30 percent decrease in flow between Duff Spring and Perkinsville.[109] Wirt and Hjalmarson also noted temporary flow losses in the reach of the upper Verde River downstream of river mile 15. They attributed these flow losses to evapotranspiration by riparian vegetation (~2 cfs) and streambed infiltration through fractures and karst features in the limestone geology of the streambed within the losing reach.[110]

There are few contributions of water to the upper Verde River from tributaries or springs between the USGS Paulden gage and Bear Siding. There is a small discharge of about 1–3 cfs of groundwater from Duff Spring, a small tributary spring at approximately river mile 13, about four river miles downstream of the USGS Paulden gage.[111]

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[108] Three atypically low and questionable Bear Siding data points from 2007 have been graphed in Chart 5. See notes at the bottom of Appendix B on pp. 58-59 for a more detailed explanation of data quality concerns about these questionable data points.

[109] Wirt (2005) at p. A25.

[110] Wirt and Hjalmarson (2000) at p. 19.

[111] Id.

The Water Sentinels' "Perkinsville" Discharge Measurement Site

The Perkinsville site is the most downstream of the three Water Sentinels flow measurement sites on the upper Verde River. The site is located about 100 yards upstream of the Perkinsville Bridge at river mile 24.

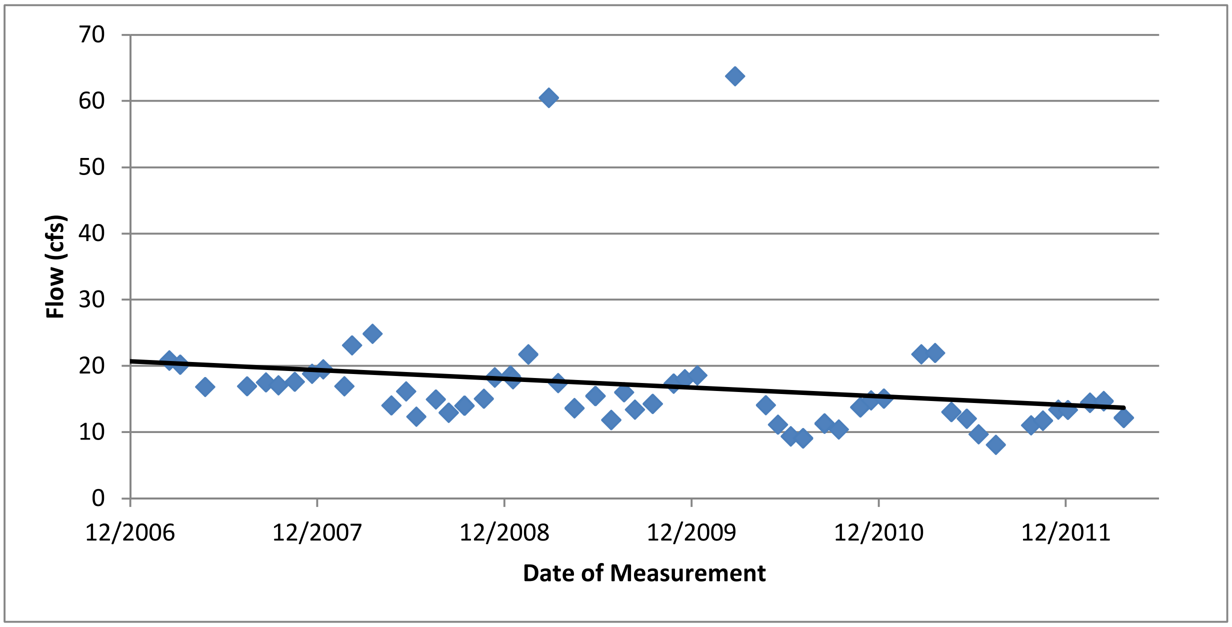

Chart 6. Flow rate data: Perkinsville site.

The chart above shows Water Sentinels discharge measurements obtained at our Perkinsville site [*See Appendix B. Water Sentinels Discharge Measurements For All Sites* for actual discharge measurements]. The plotted data points reveal the same decreasing trend in flow observed in the data from the upstream Campbell Ranch gage site. The trend line shows that the flow of the upper Verde River at Perkinsville has decreased steadily over the past five years in all seasons of each year.

In 2007, Water Sentinels data show that the flow of the Verde River at Perkinsville ranged between 16–21 cfs. In 2011 and 2012, the flow at Perkinsville was between 9–15 cfs, a decrease of about 25 percent. In general, base flow decreases in the 14-mile stretch between the USGS Paulden gage at river mile 9.8 and Perkinsville at river mile 24 identify this reach of the upper Verde River as a "losing" reach. This "losing" reach may be due to a combination of several factors, including evaporation from water surfaces, streambed infiltration, and evapotranspiration by riparian vegetation. The Water Sentinels estimate a growing-season evapotranspiraton rate of approximately 0.1 cfs/mile, or about 1.3 cfs of flow loss over the reach between the USGS Paulden gage and Perkinsville.[112]

The chart shows a rate of decrease in discharge measurements of approximately 1 cfs per year over the last five years at Perkinsville. For example, when the Water Sentinels began measuring discharge at the Perkinsville site in February 2007, the measured discharge was 20.8 cfs. By February 2012, the measured discharge was 14.7 cfs (a difference of -6.1 cfs). The decrease in summer base flow at Perkinsville is even

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[112] Based on an ET value of 70–76 af/yr/mile from Blasch et al. (2006), p. 36, Table 10.0. See also discussion of evapotranspiration values on p. 38.

more pronounced. In July 2007, the measured discharge at Perkinsville was about 16 cfs. The Sentinels made a record low discharge measurement of only 9.1 cfs at Perkinsville on June 30, 2012 (a difference of almost -7 cfs from July 2007). The record low flow in June 2012 is less than 50 percent of the historic average flow of the upper Verde River at the USGS Paulden gage. These data tell us that the flow of the upper Verde River decreases substantially as it flows downstream of the USGS Paulden gage. The flow is now reaching historically low summer-time levels at our Perkinsville site. If the flow of the river decreases another 10 cfs at the USGS Paulden gage, then it is likely that some reaches of the upper Verde River upstream of the Perkinsville Bridge will lose perennial base flow and become intermittent. The upper Verde River only has approximately 10 cfs to lose before it starts going dry in the summer.

Assuming that the slope of the decreasing trend line remains the same as it has been over the last five years (a gradual decrease in base flow of about 1 cfs per year), some reaches of the upper Verde River upstream of Perkinsville could start drying up by Summer 2023. Of course, there is no certainty that base flow will continue to decrease at the same rate or in the same linear way over the next 10 years. There is always a possibility of non-linear change occurring in the amount of base flow that either increases or decreases the base flow of the river at Perkinsville. Given the recent five-year trend and the predictions of climate scientists for a hotter and drier Arizona for the short term and the remainder of the 21st century, as well as increasing demand for groundwater, it is likely that the flow of the river will continue to decrease. If our assumptions prove to be correct, it is only a matter of time before reaches of the upper Verde River between the USGS Paulden gage and Perkinsville reach critical low flows and the river is reduced to a dry streambed for at least part of the year.

Base Flow Loss between USGS Paulden gage and Perkinsville

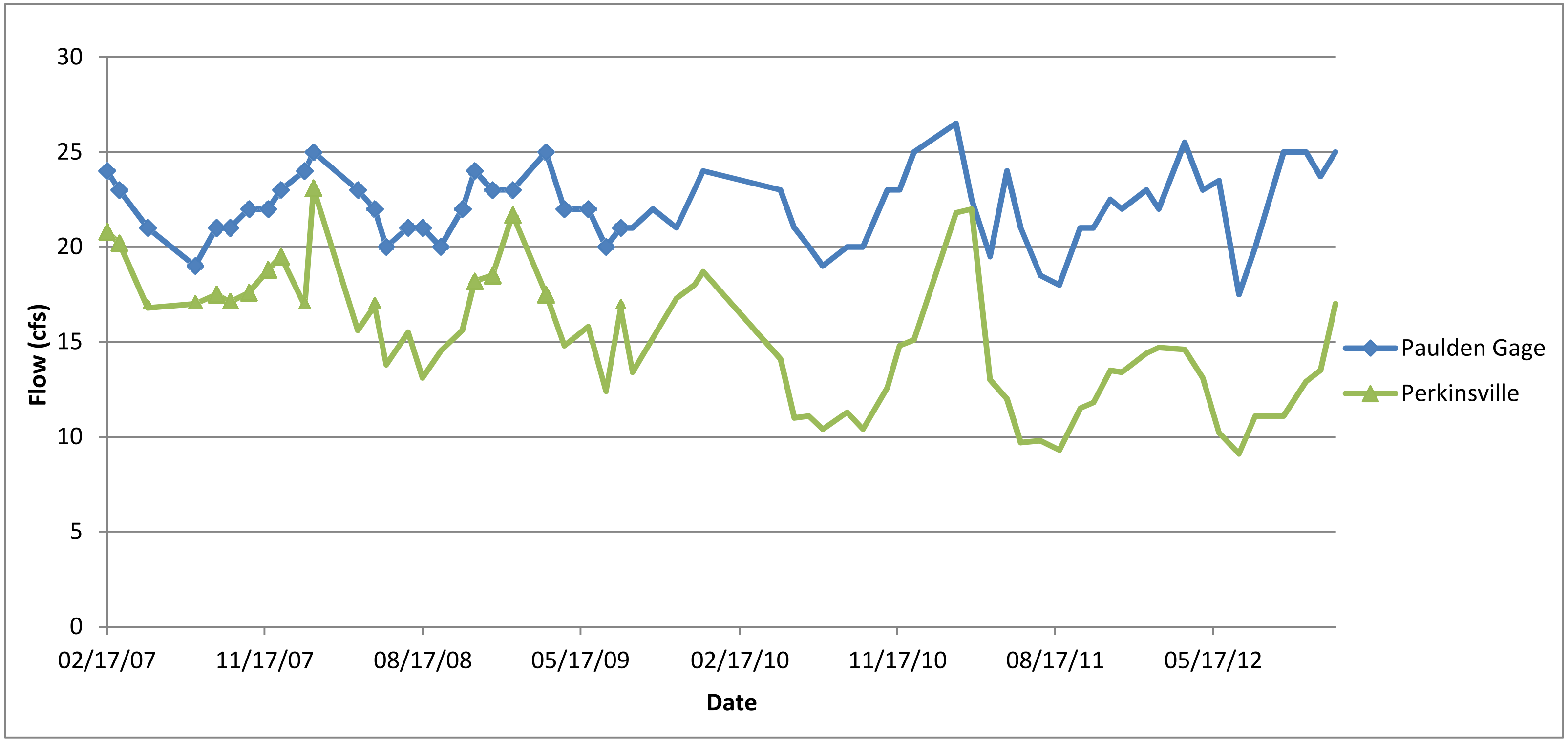

Chart 7. Perkinsville daily average flow and daily flow from 02/17/07 through 11/17/2012.

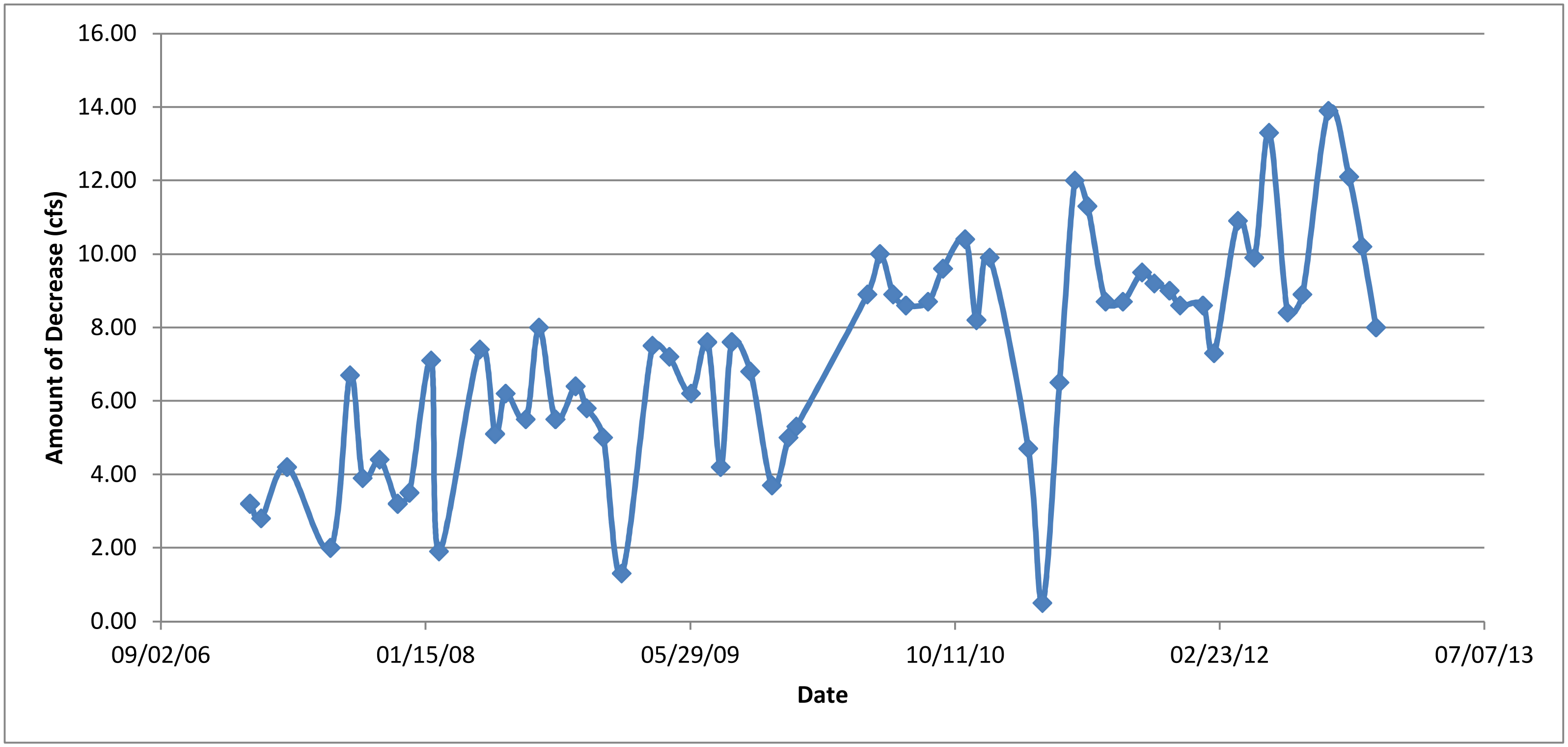

Chart 8. Base flow decrease: Paulden to Perkinsville.[113]

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[113] Flow loss calculated by subtraction of Perkinsville flow measurements from the USGS Paulden gage daily mean flow between February 17, 2007, and December 14, 2012. Seven data points have been omitted from the chart because base flow conditions did not exist due to local precipitation events.

The graphs on the previous two pages show the base flow losses between the USGS Paulden gage and Perkinsville and the amount of the decrease in base flow over time. Base flow decreases shown in the graphs were calculated using the simple formula below:

(Base Flow Decrease) = (FP) – (FPk), where:
(FP) = Daily mean flow recorded at USGS Paulden
(FPk) = Instantaneous flow measured by Water Sentinels above Perkinsville Bridge

The base flow losses between the USGS Paulden gage and Perkinsville Bridge have steadily increased over the last six years from a loss of about 3 cfs in Winter 2007 to a loss of 12.9 cfs in October 2012. For example, on June 30, 2012, when the USGS Paulden gage recorded a daily mean flow of 17.7 cfs, the measured discharge at the Perkinsville site was a record low of 9.1 cfs. The base flow decrease graph depicts the calculated decreases in cubic feet per second between the USGS Paulden gage and the Perkinsville site (n=61). As Chart 8 clearly shows, losses of base flow have steadily increased between 2007 and 2012, at a rate of approximately 1.2 cfs per year. Detailed field inspections have found no other sources or diversions in this reach to explain these losses.

To explain why the flow loss at Perkinsville is increasing over time, consider that the surface flow difference consists of the following factors:

- *Evapotranspiration (ET) losses*. ET loss is seasonally variable – greater during the summer growing season. Blasch and others, using the difference between winter and growing season base flow, estimated that ET in the perennial section of the upper Verde River above the USGS Paulden gage was about 70 af/yr/mile, or an annual loss of about 560 af/yr, and between the Paulden and Clarkdale gages 76 af/yr/mile. [114]Applying the range 70–76 af/yr/mile to the reach between the Paulden and Perkinsville, we estimate a growing-season ET value of approximately 0.1 cfs/mile, or about 1.3 cfs of flow loss over the reach, which is insufficient to explain the observed loss in base flow from Paulden to Perkinsville. It is unlikely that the water demand of riparian vegetation between the Paulden and Clarkdale gages has changed significantly during the six-year period of interest; therefore, ET losses do not explain the increasing flow losses we have observed.
- *Groundwater discharge from Duff Spring*. Wirt estimated the discharge of groundwater from Duff Spring to be 2.5 cfs.[115] The discharge of groundwater likely exhibits minor seasonal variations, and it is reasonable to assume that the discharge increases during wet periods and decreases during dry precipitation cycles.
- *Bank storage*. A likely source for discharge to the river is the river bank and adjacent floodplains, which may become saturated during high-water, high-flow events. Bank storage would be expected to contribute more water following major flood events and smaller contributions as a dry cycle continues. During a flood event when there are elevated flows, flood water inundates and may saturate the stream banks and adjacent floodplains, where some water may be stored for gradual release back to the upper Verde River during dry seasons. During dry years following these flood events, the water held in bank storage is slowly released back to the river to help maintain base flow. Over time, contributions of water from bank storage to the river gradually

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[114] Blasch et al. (2006), p. 36, Table 10.
[115] Wirt (2005A) at p. A24.

decline. With extended drought conditions, the amount of water in bank storage gradually decreases until there is insufficient water in bank storage to discharge to the river

- *Infiltration into the streambed*. If the groundwater level near the river declines below the streambed altitude, more of the river's length may be exposed to infiltration to the groundwater table, thus increasing flow losses. There is no information on groundwater levels to support or refute this hypothesis.

Together, these dynamic processes may explain the flow losses between the USGS Paulden gage and the Perkinsville Bridge. Additional research and data collection are required to better understand the flow losses that are occurring in this reach of the upper Verde River.

The Water Sentinels flow data for Perkinsville Bridge define the lower limit of flow discharges from Verde Springs to maintain a perennial upper Verde River between the USGS Paulden gage and Perkinsville. At this time, if discharges from Verde Springs had been diminished by an additional 9 cfs during the summer of 2012, the river would have been dry at Perkinsville Bridge.

The question is not whether reaches of the upper Verde River between the USGS Paulden gage and Perkinsville will dry up, but when. Our data indicate that the "dry up" of some reaches of the upper Verde River is likely to happen in early summer, after the spring runoff period and before the summer monsoon season typically starts, when base flow of the river typically is lowest. We predict that a "dry up" may occur as early as the next 10–15 years if current flow trends continue unchanged. Reaches of the upper Verde River between the USGS Paulden gage and Perkinsville may become intermittent, meaning they will flow seasonally during the early spring, in the winter, and after large storm events, but they will dry back to pools or dry streambed during the summer months.

Due to the importance of these results, the Water Sentinels plan to expand our study of flows between the USGS Paulden gage and Perkinsville by resuming monthly flow measurements at Bear Siding and by conducting a seepage run between USGS Paulden gage and Perkinsville Bridge. These additional data will increase our understanding of where the flow losses are occurring within these "at risk" reaches of the upper Verde River. The Water Sentinels will continue to monitor the flows at Perkinsville Bridge. We do not yet know how low the flow will go.

Why flow matters: The ecological implications of reduced base flow of the upper Verde River

The Verde River watershed is one of the most biologically rich and diverse areas in Arizona, supporting 270 bird species and 176 reptile and mammal species.[116] The river supports a large fraction of Arizona's vertebrate species, including 78 percent of breeding bird species, 89 percent of bat and mammal carnivore species, 83 percent of native ungulate species, and 76 percent of reptile and amphibian genera (including 94 percent of lizard and 68 percent of snake genera) in Arizona.[117] Ecologists estimate that 80 percent of vertebrate species in the watershed depend on the Verde River or its riparian habitat for some or all of their life cycle.[118]

The flora and fauna of the Verde River include plants and animals listed under the Endangered Species Act or recognized as special status species by the State of Arizona. Endangered or threatened species include the southwestern willow flycatcher (*Empidonax traillii extimus*), the candidate Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*), the threatened spikedace (*Meda fulgida*), the endangered razorback sucker (*Xyrauchen texanus*), and the endangered Colorado pikeminnow (*Ptychocheilus lucius*).

Figure 14. Southwestern willow flycatcher.
Photo credit: U.S. Fish and Wildlife Service

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[116] Verde River Basin Partnership, "The Verde River Guiding Principles" Fact Sheet.
[117] Upper Verde Wild & Scenic River, A Citizen's Proposal. August 2001, Executive Summary, p. 4.
[118] Id.

Other species classified as sensitive by the U.S. Forest Service live along the Verde River. These species include the common black hawk (*Buteogallus anthracinus*), the American peregrine falcon (*Falco peregrinus*), Abert's towhee (*Pipilo aberti*), western red bat (*Lasiurus blossevillii*), pale Townsend's big-eared bat (*Corynorhinus townsendii pallescens*), the pocket free-tailed bat (*Nyctinomops femorosaccus*), lowland leopard frog (*Rana yavapaiensis*), Arizona toad (*Bufomicroscaphus microscaphus*), and the narrow-headed garter snake (*Thamnophis rufipunctatus*). The Arizona Game and Fish Department has identified several Wildlife Species of Concern including the candidate least bittern (*Ixobrychus exilis)*, the river otter (*Lontra canadensis sonora*), the belted kingfisher (*Megaceryle alcyon*), and the fringed myotis bat (*Myotis thysanodes*).[119] The Verde River also provides important nesting and breeding habitat for bald eagles (*Haliaeetus leucocephalus*).

The Verde River provides some of the best aquatic habitat for native fish in Arizona. Native fish species currently present in the Verde River include the Sonora sucker (*Catostomus insignis*), desert sucker (*Catostomus clarkia*), roundtail chub (*Gila robusta*), longfin dace (*Agosia chrysogaster*), speckled dace (*Rhinichthys osculus*), and, as mentioned above, spikedace, razorback sucker, and an experimental population of Colorado pikeminnow. The upper Verde River has been designated as critical habitat for the razorback sucker, loach minnow, and spikedace. The roundtail chub is a candidate species for listing under the Endangered Species Act.[120]

Figure 15. Spikedace.
Photo credit: U.S. Fish and Wildlife Service

Approximately 10 percent of Arizona's remaining Fremont Cottonwood/Gooding Willow habitat, the rarest forest type in North America, is found along the Verde River.[121]

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[119] Id.
[120] Id.
[121] Verde River Basin Partnership, "The Verde River Guiding Principles" Fact Sheet.

There is clear scientific evidence that plants and animals living in the river and along its banks depend on adequate river flows and would be adversely affected by a decrease in base flows.[122] Reduced base flow of the upper Verde River will alter aquatic habitats and could reduce or eliminate populations of animals and plants that depend on open water conditions for part of their life cycles.[123] According to Haney and others, if base flow decreases and the flow regime of the upper Verde River changes from perennial to intermittent, there will be greater seasonal and year-to-year variability in groundwater levels, and the depth to the water table near the river could increase. These changes would, in turn, affect the composition and diversity of the riparian forest along the upper Verde River. There would be a decline in cottonwood and willow abundance, a decrease in the structural diversity of the riparian forest, and an increase in non-native plant species.[124]

Changes in plant communities would ripple through the rest of the ecosystem, affecting animal communities that live in and along the river. Changes in the structural diversity of the riparian forest and declines in certain plant species would likely cause shifts in the bird community with reductions or the loss of some bird species. Haney and others point out the need for more research to quantify the water needs for the Verde River ecosystem and to determine quantitative thresholds where species will be adversely affected by reduced base flows.[125]

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[122] Haney, J.A., D.S. Turner, A.E. Springer, J.C. Stromberg, L.E. Stevens, P.A. Pearthree, and V. Supplee. 2008. *Ecological Implications of Verde River Flows. A report by the Verde River Basin Partnership, Arizona Water Institute, and The Nature Conservancy,* Executive Summary, p. vii.

[123] Id.

[124] Id.

[125] Id.

What does the future hold for the upper Verde River?

In 2006, American Rivers listed the Verde River as one of America's ten most endangered rivers.[126] American Rivers included the Verde River on its "top ten list" because of threats from increasing demands for water associated with rapid growth and development in Prescott, Prescott Valley, Chino Valley, and in the unincorporated parts of Yavapai County near the headwaters of the Verde River.

The basic facts that led to listing the Verde River as a "top ten" endangered river haven't changed significantly in the past six years. The threat of groundwater depletion in the Big Chino Subbasin, the regional aquifer that is the primary source of the groundwater sustaining the upper Verde River, is as great today as it was in 2006. In fact, the risk of stream depletion of the upper Verde River may be greater today because of the growing population and ever-increasing demand for groundwater. Municipalities have plans to extract thousands of acre-feet of groundwater from the Big Chino Subbasin annually to meet this projected water demand and to support more growth and development.

For example, the Big Chino Water Ranch and pipeline project remains a major component of the water resource management plans for the City of Prescott and the Town of Prescott Valley. As of 2012, municipalities in the Prescott Active Management Area have legal authority to pump and export up to 18,616 af or approximately *6 billion gallons*[127] *of pumped groundwater annually* from the Big Chino Subbasin if the Big Chino Water Ranch and pipeline are constructed and fully implemented.

There also are plans to construct new residential and commercial developments in the Big Chino Valley.[128] One proposed development, Yavapai Ranch, could result in the construction of as many as 12,500 new homes with 95 acres of commercial property on 51,000 acres in the Big Chino Subbasin. At full build out, it is estimated that the residential part of Yavapai Ranch alone will consume more than 912 million gallons of groundwater each year, or an estimated 2,800 af of pumped groundwater annually.[129]

Finally, there have been discussions about a proposal to build a pumped storage hydroelectric power generating facility in the Big Chino Valley. The proposed Longview Pumped Storage Hydroelectric Project ("the Longview Project") would require the one-time extraction of up to 17,500 af of groundwater at project start-up (approximately 5.7 billion gallons of groundwater) and up to 1,200 af of pumped

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[126] American Rivers. 2006. America's Most Endangered Rivers of 2006. Available online at http://act.americanrivers.org/MER/PDFs/MER_2006.pdf.

[127] There are 325,851 gallons of water in an acre-foot.

[128] Joanna Dodder Nellans, "*Commission Narrowly Favors Yavapai Ranch Development Plan*," Prescott Courier, October 3, 2012.

[129] This estimate assumes 12,500 homes at full build out of Yavapai Ranch, assuming 2 persons per home, a gallons per capita per day (gpcd) assumption of 100 gallons, multiplied by 365 days in a year. Using these factors and conservative assumptions, the result is an estimated 912,500,000 gallons of pumped groundwater annually for the residential part of the proposed Yavapai Ranch project. When divided by 325,851 gallons per acre-foot, the estimated annual groundwater use is approximately 2,800 acre-feet per year.

groundwater annually (about 391 million gallons of groundwater each year) to make up for evaporative losses from proposed storage reservoirs that would be constructed for the Longview Project.[130]

The pace of growth and development in Yavapai County has slowed in recent years with the Great Recession of 2008. However, local economies are slowly recovering. People will continue to move to Yavapai County because it is an attractive place to live. New residents will need water, and water providers will turn to the only available source, groundwater, to meet new demand. The Big Chino Water Ranch, Yavapai Ranch, and the Longview Project alone will result in the pumping of *billions of gallons of groundwater annually* over their project lifetimes if implemented as planned. Unmitigated groundwater withdrawals from the Big Chino Subbasin eventually will turn the first 25 miles of the upper Verde River into a dry wash, flowing only after precipitation events or seasonal runoff.

Continuing rapid growth and development, a decade of drought that shows no signs of abatement, and emerging impacts of climate change in the American Southwest will combine to create a water crisis in the upper Verde River watershed. The American Southwest has been described as "ground zero" for climate change in the United States.[131] If predictions of the climate scientists prove to be accurate, the challenge of preserving the base flow of the upper Verde River will become even more daunting in the future.

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[130] Joanna Dodder Nellans, "*Proposed hydroelectric plant near Seligman would use Big Chino groundwater*" Prescott Courier, January 18, 2012. This is an article on the Longview Energy Exchange Pumped Storage Hydroelectric Project, Arizona's first closed-loop hydroelectric power facility, which would utilize Big Chino groundwater. The project would pump as much as 17,500 acre-feet of groundwater from the Big Chino aquifer 1,400 feet uphill into large reservoirs. When peak electric power is needed, the pumped groundwater would be released to flow down through turbines to generate hydroelectric power to meet peak demand. Retrieved from Arizona Geology blog of the Arizona State Geologist at http://arizonageology.blogspot.com/2012/01/pumped-storage-power-project-proposed.html on October 4, 2012.

[131] Vergano, Dan. 2007. *Climate change threatens new dust bowl in Southwest*, USA Today, updated April 6, 2007. See http://www.usatoday.com/tech/science/discoveries/2007-04-05-dust-bowl-study_N.htm. Retrieved on September 25, 2012.

A Summary of Key Findings and Conclusions

- The available data from SRP indicate a decrease in the base flow of the upper Verde River as measured at the SRP Campbell Ranch low-flow stream gage over the last five years. The monthly average flow of the upper Verde River as measured at the SRP Campbell Ranch low-flow gage ranged from 15–17 cfs in 2012.

- The historic average flow at the USGS Paulden gage, based on a 49-year period of record, is about 25 cfs. The monthly average flow at the USGS Paulden gage over the last five years has been less than the long-term average, ranging between 20–25 cfs.

- The flow of the upper Verde River measured at the Water Sentinels flow monitoring site at Perkinsville has decreased over the last five years. Recent Water Sentinels discharge measurements indicate that summer base flow of the river at Perkinsville has been as low as 9 cfs. Water Sentinels data indicate a decreasing trend in summer base flow at Perkinsville of about 1 cfs per year.

- Some reaches of the upper Verde River between the USGS Paulden gage and Perkinsville may become intermittent if base flow decreases another 10 cfs at the USGS Paulden gage. If current rates of decrease in base flow continue, the upper Verde River could lose another 10 cfs at Perkinsville within the next 10 years.

- There is a strong hydrologic connection between groundwater levels in the Big Chino Subbasin and the discharge of groundwater from Verde Springs to the upper Verde River. Multiple lines of evidence show that the Big Chino Subbasin supplies 80–86 percent of the total base flow of the upper Verde River. There is evidence that groundwater pumping from the Big Chino Subbasin directly affects the discharge of groundwater to the upper Verde River at Verde Springs.

- Climate models predict that the American Southwest will get hotter and drier over the remainder of the 21st century. Hotter temperatures, less precipitation, and greater rates of evapotranspiration mean corresponding decreases in rates of groundwater recharge and surface runoff. Predicted climate change will result in more frequent, longer, and more intense drought conditions that likely will reduce the base flow of the upper Verde River.

- The demand for groundwater from the Big Chino Subbasin is projected to increase to 25,000 af/yr by 2050. This potential unmet water demand converts to approximately 24 cfs, which is about equal to the long-term historic average base flow at the USGS Paulden gage. If groundwater is pumped to satisfy the projected total unmet water demand in 2050, it will reduce and eventually consume the entire base flow of the upper 24 miles of the Verde River.

Recommendations

It would be easy to be pessimistic about the long-term future of the upper Verde River, given the current evidence of decreasing base flow, projected demands on finite groundwater resources of the upper Verde watershed, and the predicted impacts of climate change in the Southwest. At some intuitive level, we know that continuing, unmitigated extraction of billions of gallons of groundwater each year from the Big Chino and Little Chino Subbasins is unsustainable. Although there is a vast amount of groundwater in storage in the regional aquifers, we know that groundwater resources are finite.

Unmitigated groundwater pumping from the Big Chino Subbasin will inevitably lower water tables. As the water table lowers, discharges of groundwater from Verde Springs and base flow of the upper Verde River will gradually decrease. Already, the base flow of the upper Verde River is estimated to have declined by a third from predevelopment levels. At some point in the future, the cumulative effects of groundwater pumping will cause the water table to fall below the elevation of the subbasin discharge outlet at Verde Springs, and the discharge of groundwater at Verde Springs will cease. When that happens, the uppermost 24 miles of the Verde River will dry up.

There is a growing body of evidence from the USGS, SRP, and the Water Sentinels documenting that **the base flow of the upper Verde River is decreasing now.** If the current rate of decrease in base flow continues, a window of opportunity to preserve the base flow of some reaches of the upper Verde River may start to close as early as 2025. The loss of as little as another 10 cfs of base flow will mean that the river will start drying back to pools in reaches between the USGS Paulden gage and Perkinsville. When that happens, it will be “game over” for a perennially flowing upper Verde River. It is likely that the reach of the river from the USGS Paulden gage to Perkinsville will be the first to transition from a perennial to an intermittent stream if we do not take steps now to preserve the discharge of groundwater that currently sustains the base flow of the river.

We must act to mitigate groundwater pumping to avoid stream depletion of the upper Verde River. Any course of action that mitigates groundwater withdrawals from the Big Chino Subbasin now will extend the life of the river in the future.

Implement the precautionary principle to prevent harm to the upper Verde River. “Precaution” literally means using caution in advance. All definitions of the precautionary principle have two elements in common. First, decision-makers need to anticipate harm before it occurs. Under the precautionary principle, it is the responsibility of decision-makers or the proponents of a project (e.g., a project that involves large-scale groundwater mining of the Big Chino Subbasin) to show that the proposed project will not or is very unlikely to cause significant harm. Second, if the level of harm from a proposed project may be high, decision-makers should take steps to prevent or minimize potential harm *even when scientific uncertainty makes it difficult to predict the likelihood of harm occurring or the level of harm should it occur*.

Implementing the precautionary principle in water resource management means changing the way we think about the groundwater resources of the Big Chino Subbasin and acknowledging that resources are finite and cannot be exploited *ad infinitum*. We should make preservation of the base flow of the upper Verde River a management priority when making land use and water resource management decisions.

We can preserve or extend the life of the upper Verde River by **not** implementing projects that rely on large-scale groundwater mining, that accelerate groundwater capture, or that ultimately hasten stream depletion of the upper Verde River. We can stop, downsize, or mitigate projects requiring the withdrawal of large amounts of groundwater from the Big Chino Subbasin. At the very least, we can carefully consider the location, scale, projected water demand, and reasonably foreseeable environmental impacts of proposed projects and plan to mitigate any adverse impacts.

We should ask the following questions: How may groundwater withdrawals for this project affect the base flow of the upper Verde River? Can adverse impacts to the river be mitigated? If so, how? If there are feasible, practical ways to mitigate stream depletion, project proponents should be required to implement mitigation measures to minimize large-scale groundwater mining and to preserve the upper Verde River. If there are no practical mitigation measures, the proposed project should not proceed.

Recognize the need for regional planning for a sustainable water future. At the present time, there is no effective regional water management for the upper Verde watershed. ADWR has no responsibility to prepare an implementable water management plan to achieve safe yield in the Prescott AMA. Yavapai County does not have a water resource plan. The Tri-City communities each have individual water resource plans to develop available water resources to support goals of meeting the increasing water demands of their growing populations and fostering economic growth in their communities. For each planning entity, there are no incentives or effective requirements to use water more efficiently. Water management is fragmented and reduced to little more than a competition for limited available water supplies. Water management is reduced to a race to acquire and develop available water supplies before some other community gets there first.

In this case, the available water supply for rural Yavapai County and the Tri-City communities is the groundwater in the regional aquifers underlying the upper Verde watershed. Current management of this common groundwater resource is reduced to this: Whoever has the deepest well and the biggest pumps and whoever develops the groundwater resource first wins. The losers are the communities that come in second (or later) in the race and private property owners in the watershed who do not have the financial resources to compete with large municipal water providers. Of course, the biggest loser of all is the upper Verde River, which under Arizona water laws is relegated to spectator status in the race for remaining groundwater, but bears all of the environmental costs associated with unsustainable and unmanaged exploitation of the regional aquifers sustaining the river’s base flow.

To preserve the upper Verde River, it is necessary to implement shared management of water resources. One way to achieve regional management would be to form a Water Resource Management District to manage the upper and middle Verde River watersheds for a sustainable water future. The proposed Water Resource Management District should be structured to include a diverse group of community representatives that is democratically elected and that operates in an open and transparent manner. The Water Resource Management District should be advised by scientists who can provide objective, credible, and apolitical scientific data and information to inform management decisions by the elected members of the district.

Strengthen water management authority and the planning role of the Arizona Department of Water Resources (ADWR) to effectively manage groundwater development in the upper Verde River watershed. Strengthening the ADWR framework regarding active management areas could go a long way towards preserving and extending groundwater resources in the upper Verde watershed. Expanding Active Management Areas to cover entire watersheds would provide important planning tools for state water managers. Current AMAs cover only 13 percent of the state and there are critical groundwater management problems in areas outside of the current AMAs. The time has come for active management of groundwater statewide and more integrated regional water management on the watershed scale. Moreover, this should include some further recognition of the groundwater-surface water connection.

There is a critical need to adequately fund water resource management in Arizona. The Arizona Legislature created ADWR by enacting the Groundwater Management Act of 1980 to administer and manage groundwater use in the state. At a time of increasing water scarcity, increasing water stress, and increasing risk of regional water conflicts, funding for ADWR has been cut. In addition to being underfunded, ADWR is understaffed, and agency resource constraints severely limit the agency's ability to accomplish its core mission and management responsibilities. For example, ADWR is years behind schedule on development of AMA management plans. Additional funding and staff are needed to meet critical water resource planning and management needs and to find solutions to water scarcity problems facing communities across the state. Furthermore, the agency needs to include management and preservation of flowing rivers in its core mission.

Use less water. The groundwater that municipalities pump from the Little Chino and Big Chino subbasins and use in homes and businesses was destined to flow in the Verde River. **We are connected to the river through our water use.** Decreasing consumptive uses of water will reduce water demand and the stress we place on the regional aquifers sustaining the upper Verde River. Water conservation is the least expensive, most practical, and the most easily implemented step that we can take to help preserve the river.

There are many things that can be done to reduce current and projected water demand and to improve water efficiency. Municipal governments of the Tri-City communities (Prescott, Prescott Valley, and Chino Valley) have taken some positive steps to implement water conservation measures that have achieved moderate success, but much more needs to be done. For example, the City of Prescott has implemented a comprehensive water conservation program, reducing its system-wide average water use from 193 gallons per capita per day (gpcd) in 2003 to 167 gpcd in 2008. Other Tri-City communities have made less progress with their water conservation programs. The reduction in water consumption by the City of Prescott represents significant progress, but the Tri-City municipalities can and should go even further by setting even more ambitious water conservation goals. For example, the cities could implement programs such as the 90 by 20 water conservation program, which sets a goal of reaching 90 gallons per person per day by 2020.[132] This is enough water for the daily needs of most people. However, even if the 90 by 2020 goal was achieved, it would not be enough to achieve safe yield in the Prescott AMA. It is estimated that the City of Prescott would need to reduce water consumption *to less than 40 gpcd* to achieve safe yield in the Prescott AMA. There is still a long way to go.

To make a significant difference, these communities must aggressively implement water conservation measures to further reduce water demand and to minimize future groundwater withdrawals from the Big Chino Subbasin. For example, municipal and county plumbing codes could **require** low-flow toilets

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[132] See *90 by 20: A Call to Action for the Colorado River* at http://www.90by20.org.

and water-saving fixtures in all new residential and commercial construction. They can establish retrofit programs and provide financial incentives and rebates for installation of low-water-use fixtures in existing homes and businesses. Retrofit programs are particularly important for buildings constructed before adoption of the 1994 revisions to the Plumbing Code. There are an estimated 17,000 pre-1994 structures in the Tri-City municipalities. Implementation of an aggressive retrofitting strategy that targets pre-1994 code structures could significantly decrease water use.

The City of Prescott Water Smart program identifies landscape maintenance and outdoor irrigation as the major water use in the city. The City of Prescott estimates that at least 50 percent of water consumed by city households is used outdoors. By adopting ordinances that provide incentives to replace lawns, turf areas, and high-water-using landscape plants with low-water using native plants and appropriate landscaping designs, it is possible to create attractive residential and commercial landscapes that require little or no irrigation. The Tri-City municipalities could adopt ordinances that require xeriscaping for all new residential, commercial, and landscaping of public spaces. They can adopt water smart ordinances to provide financial incentives to encourage water efficiency, rainwater harvesting, and gray water reuse in their communities.

Local municipalities and water providers can send even stronger price signals to encourage water conservation and efficiency. In a time of increasing water scarcity, water is still dirt cheap. In fact, the water itself is essentially free. Consumers' water bills reflect the cost of water treatment and distribution infrastructure, not the value of the water itself. The Tri-City communities have already made some progress on establishing tiered rate structures for their communities. These municipalities should consider revision of their block rate structures, in which the unit price of water increases with each of several preset consumption blocks. An affordable "base tier" unit price must be included in the rate structure so that everyone, even the most disadvantaged, can afford a base level of water consumption. However, water should be priced to reflect its true value, to discourage waste, and to encourage greater efficiency. Increasing tiered water rates sends a very strong water conservation message to a water supplier's customer base – the more water you use, the more you pay. This type of tiered rate structure, when accompanied by an effective customer education and information program, can produce desired levels of water conservation that can make a difference.

Finally, we need to conduct additional research on the comparative effectiveness of water conservation programs to identify best conservation practices that are the most efficient, practical, and that result in the greatest water savings.

Pursue water recycling to augment or "stretch" the existing water supply. Municipalities can augment the current water supply and reduce reliance on pumped groundwater from the Big Chino and Little Chino subbasins by aggressively implementing water reclamation projects in their communities. Water reclamation and the direct reuse of reclaimed water are attractive options for conserving and extending limited water supplies. Water reclamation for non-potable reuse has been used successfully in Arizona to meet non-potable water demands in many water-scarce areas. In fact, reclaimed water (aka "recycled water," "effluent," or "treated wastewater") represents one of the few growing sources of water supply available to growing communities because the supply of recycled water increases as communities grow and produce more wastewater.

Adequately treated reclaimed water can be substituted for pumped groundwater that is currently used for non-potable uses, thereby conserving groundwater for potable use and extending the water supply. For example, reclaimed water has been used safely for toilet flushing at Grand Canyon and for turf irrigation of parks, schoolyards, and college campuses (e.g., Northern Arizona University), and for golf course irrigation. The Tri-City communities should explore potential water reclamation opportunities and make targeted investments within their communities to recycle water, including exploring the use of reclaimed water for artificial recharge to mitigate groundwater withdrawals. New golf courses in the watershed should be prohibited and irrigation systems for existing golf courses that have not already done so should be required to convert to irrigating with reclaimed water.

Establish a minimum in-stream flow for the upper Verde River. Enough is now known about the average monthly flow of the upper Verde River at the USGS Paulden gage to establish a minimum in-stream flow to preserve environmental flows of the upper Verde River. For example, it is well-established from a 49-year period of record at the USGS Paulden gage that the average monthly flow of the upper Verde River is about 25 cfs. Recent USGS and Water Sentinels data indicate that average monthly flow at the USGS Paulden gage has ranged between 20–25 cfs over the last five years. We need to draw a "line in the river" by establishing 20 cfs as a minimum in-stream flow right to protect the base flow of the river. This in-stream flow right should be established "from time immemorial" under Arizona's water law. ADWR should have the authority to regulate groundwater pumping that causes stream depletion or that would decrease the base flow of the upper Verde River below the minimum in-stream flow of 20 cfs.[133]

Consider a variety of other measures – think outside the box. Communities could seek ways to encourage residents to utilize rainwater harvesting to water landscaping and gardens. Considering that much of the water is used for landscaping, this could significantly reduce the need for additional groundwater pumping. Evaluation of tools such as recharge of groundwater with treated effluent can also be considered. This tool comes with concerns about water quality and the emerging contaminants that are not measured or removed in the treatment process. The area could also look seriously at how many people the area can sustain over the long-term and consider methods of limiting development.

Collect more data and continue research in the upper Verde watershed to gain a better understanding of regional groundwater resources that sustain the river. We need credible data and good science to support effective water management and decision-making in the upper Verde watershed. ADWR and USGS need adequate funding and staff to continue critically important data collection and modeling efforts. Better data collection will result in a better scientific understanding of the cumulative effects of groundwater pumping and will provide critically important information to populate input variables that can used in groundwater models, such as the USGS Northern Arizona Regional Groundwater Flow Model. Better scientific information will lead to a better understanding of the regional groundwater system and, if applied, will lead to more informed water management decisions by water policy makers.

Develop a long term vision. To preserve the upper Verde River, we need to take a long-term perspective that looks beyond the immediate interests of the current generation to value the interests and welfare of future generations. The leaders of the Iroquois Nation describe this vision in the Great Law of the Iroquois, urging the current generation to live sustainably and to work responsibly for the benefit of the seventh generation to come (about 140 years in the future). Chief Oren Lyons, Faithkeeper of the Onondaga Nation, expresses this concept this way: "We are looking ahead, as is one of the first

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[133] Glennon, Robert. 2002. *Water Follies, Groundwater Pumping and the Fate of America's Fresh Waters*, Island Press, Washington, p. 218.

mandates given us as chiefs, to make sure and to make every decision that we make relates to the welfare and well-being of the seventh generation to come."[134]

In making land use and water development decisions, we should, at the very least, look beyond narrow self-interest to protecting water resources and the quality of life for future generations. What will our children and grandchildren have? Will there be an adequate water supply and a flowing upper Verde River for them? Will the seventh generation have a living, flowing river 140 years from now, or will the Verde River be only a distant memory? The Water Sentinels are hopeful that the upper Verde River will not "go with the flow" and that it instead will flow for many generations to come. Although the challenges we face are enormous and complex, we can solve our water problems if we work together and act responsibly. We can preserve the upper Verde River but only if we start taking action now to save it.

Long live the Verde River.

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[134] Oren Lyons, Faithkeeper, Onondaga Nation, "Looking Toward the Seventh Generation." Presentation, American Indian Studies Program, University of Arizona, Tucson, Arizona, April 17, 2008, at http://nnidatabase.org/db/video/oren-lyons-looking-toward-seventh-generation.

Appendix A. SRP Campbell Ranch Low-flow gage Data

Month	Monthly Average (cfs)	Notes
04/2005	21.1633	
05/2005	20.7932	
06/2005	20.9144	
07/2005	20.4644	
08/2005	22.0208	
09/2005		High flows, loss of data
10/2005		High flows, loss of data
11/2005		High flows, loss of data
12/2005		High flows, loss of data
01/2006	20.2700	High flows, loss of data
02/2006	19.9770	
03/2006	20.3676	
04/2006	19.9700	
05/2006	19.5104	
06/2006	19.1910	
07/2006	20.1200	
08/2006	20.4630	
09/2006	20.0580	
10/2006	18.9470	
11/2006	19.3010	Float tap came off of encoder shaft
12/2006	19.3390	
01/2007	19.4270	
02/2007	19.2478	
03/2007	19.3550	
04/2007	19.0095	
05/2007	18.4710	
06/2007	17.9544	
07/2007	20.9950	
08/2007	28.7540	
09/2007	18.6270	
10/2007	17.9775	
11/2007	18.1600	
12/2007	18.1965	
01/2008	25.6296	
02/2008	20.8328	
03/2008	19.4168	
04/2008	18.6310	
05/2008	18.1445	
06/2008	17.8932	
07/2008	17.5696	

Month	Monthly Average (cfs)	Notes
08/2008	18.3686	
09/2008	20.3467	
10/2008	17.6344	
11/2008	17.9231	
12/2008	32.7342	High flows, loss of data
01/2009	27.0945	High flows, loss of data
02/2009	20.0517	
03/2009	18.5645	
04/2009	18.3289	
05/2009	17.5229	
06/2009	17.0276	
07/2009	17.5984	
08/2009	24.1481	
09/2009	17.2783	
10/2009	16.5824	
11/2009	16.6510	
12/2009	17.0484	
01/2010	17.2310	High flows, loss of data
02/2010		High flows, loss of data
03/2010		High flows, loss of data
04/2010	17.9357	High flows, loss of data
05/2010	17.5340	
06/2010	16.8281	
07/2010	16.4047	
08/2010	24.4513	Missing data due to power outage
09/2010	16.4652	
10/2010	19.0895	
11/2010	17.1149	
12/2010	17.5682	
01/2011	17.8068	
02/2011	18.1930	
03/2011	18.3789	
04/2011	17.5357	
05/2011	17.1451	
06/2011	16.6985	
07/2011	16.2988	
08/2011	16.0743	
09/2011	16.2820	
10/2011	16.3588	
11/2011	17.8407	
12/2011	17.8180	

Notes on Appendix A: Sometimes it was not possible to calculate a monthly average because of high flows of the upper Verde River greater than 100 cfs or because the stream gage was out of service. Monthly average values in the table highlighted in yellow represent averages calculated from an incomplete dataset. When this occurred, the reason for missing or incomplete data is listed in the notes column. Blank fields indicate that there were no data for that month; we included these blank fields for information purposes. The reader is cautioned that the Water Sentinels calculations of monthly average values without data reflecting higher flows greater than 100 cfs in a month are biased. Data highlighted in yellow are qualified because the monthly average value is less than it otherwise would be if accurate higher flow data were included in the calculation of the monthly average.

Appendix B. Water Sentinels Discharge Measurements For All Sites

Date	Flow (cfs)		
	Above Verde Springs	**Bear Siding**	**Perkinsville**
12/2/2006*	0.67	N/A	N/A
2/17/2007*	0.83	17.29	20.81
3/10/2007*	0.44	8.30 **	20.19
4/28/2007*	0.58	14.31	16.83
7/19/2007	0.68	23.85	16.91
8/25/2007	0.47	22.77	17.49
9/18/2007	0.50	14.31	17.05
10/20/2007	0.44	8.77 **	17.60
11/23/2007	0.44	10.20 **	18.79
12/15/2007	0.25	16.25	19.49
1/25/2008	0.47	16.20	16.91
2/9/2008	0.45	19.56	23.10
3/20/2008	0.48	21.05	24.85
4/26/2008	0.58	12.34	14.01
5/25/2008	0.57	16.81	16.14
6/14/2008	0.49	10.95	12.34
7/22/2008	0.74	N/A	14.93
8/16/2008	0.48	13.79	12.93
9/16/2008	0.46	N/A	13.99
10/24/2008	0.18	16.41	15.03
11/14/2008	0.31	17.11	18.24
12/15/2008	0.00	16.98	18.53
12/20/2008	0.14	17.89	17.99
1/19/2009	0.58	20.81	21.73
2/28/2009	0.93	45.87	60.48
3/18/2009	0.84	15.51	17.42
4/19/2009	0.71	15.88	13.61
5/30/2009	0.60	13.90	15.44
6/30/2009	0.53	12.63	11.82
7/25/2009	0.57	15.00	15.99
8/15/2009	0.31	14.30	13.38
9/19/2009	0.10	15.81	14.28
10/30/2009	0.00	14.91	17.33
11/21/2009	0.09	15.54	18.00
12/15/2009	0.16	16.71	18.56
1/24/2010	60.01	N/A	N/A
2/27/2010	0.30	N/A	63.76
3/27/2010	0.38	N/A	N/A
4/28/2010	0.12	N/A	14.08
5/22/2010	0.10	N/A	11.12

Date	Flow (cfs)		
	Above Verde Springs	Bear Siding	Perkinsville
6/16/2010	0.01	N/A	9.36
7/10/2010	0.02	N/A	9.07
8/21/2010	0.00	N/A	11.29
9/18/2010	0.00	N/A	10.41
10/30/2010	0.04	N/A	13.75
11/20/2010	0.10	N/A	14.78
12/15/2010	0.15	N/A	15.07
1/18/2011	0.13	N/A	N/A
2/26/2011	0.21	N/A	21.76
3/25/2011	0.13	N/A	21.95
4/26/2011	0.02	N/A	13.03
5/26/2011	0.05	N/A	12.02
6/18/2011	0.02	N/A	9.68
7/22/2011	0.02	N/A	8.09
9/29/2011	0.00	N/A	11.04
10/22/2011	0.03	N/A	11.73
11/21/2011	0.05	N/A	13.39
12/10/2011	0.07	N/A	13.35
1/22/2012	0.11	N/A	14.43
2/18/2012	0.10	N/A	14.67
3/28/2012	0.15	N/A	12.16

Notes on Appendix B: Data marked with an asterisk (*) represent discharge measurements obtained before the Water Sentinels Flow Monitoring Protocols dated July 2007. Data marked with a double asterisk (**) indicate questionable data points. Double asterisked discharge measurements are atypically low and inconsistent with stream gage records for the same day at the upstream USGS Paulden gage and flow measurements made by the Water Sentinels at the downstream Perkinsville site. For comparison, on March 10, 2007, the discharge measurement reported by the Water Sentinels at Bear Siding was 8.3 cfs. The daily mean flow at the USGS Paulden gage on that day was 23 cfs, and the downstream Perkinsville measurement was 20.19 cfs. On October 20, 2007, the discharge measurement made by the Sentinels at Bear Siding was 8.77 cfs. On the same day, the daily mean flow at the USGS Paulden gage was 22 cfs, and the downstream Perkinsville discharge measurement was 17.6 cfs. Finally, on November 23, 2007, the Water Sentinels reported a discharge measurement of 10.2 cfs at Bear Siding while, on the same day, the daily mean flow at the Paulden gage was 22 cfs and the discharge measurement at the downstream Perkinsville site was 18.79 cfs. These inconsistencies call into question the accuracy of the discharge measurements made at Bear Siding on these three dates. A review of calculations indicated those were accurate. A review of the field data sheets for the questionable discharge measurements shows that water velocities measured on March 10, 2007, October 20, 2007, and November 23, 2007, were all extremely low at the Bear Siding site. Individual discharge measurements along the measured transect were either within or very close to the limits of accuracy of the Marsh-McBirney flow meter used to make the discharge measurements (± 0.5 ft/sec).

Appendix C. Water Sentinels Flow Monitoring Protocol

FLOW MONITORING PROTOCOL

Prepared by

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202 East McDowell Road, Suite 277
Phoenix, Arizona 85004

July 2007

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SITE SELECTION

Transects should be located in a straight, uniform section of the river or stream away from objects that may alter or hinder the stream flow (e.g. bridges, sandbars, or large boulders). The flow should be relatively uniform, free of eddies or excessive turbulence.

Mark each site using a Global Positioning System (GPS) unit. Locations should be marked as latitude/longitude in the NAD27 CONUS datum using degrees, minutes, and seconds. Ensure that each transect is placed in the same location during subsequent monitoring sessions.

MATERIALS

The Grand Canyon Chapter uses a Marsh-McBirney Flo-mate Model 2000 meter. This meter includes an electromagnetic sensor that should be mounted onto a top-setting wading rod. Prior to use, the sensor should be cleaned with soap and water to remove any oils or dirt. The meter must be calibrated less than 24 hours prior to field measurements. Refer to the manual for instructions on how to calibrate the meter.

List of materials

- Marsh-McBirney Flo-mate 2000
- Wading rod
- Tape measure
- Compass
- GPS unit
- Datasheets and field notebook
- Directions to the monitoring sites
- Waders
- Life preservers
- First aid kit

MEASURING WIDTH

A tape measure should be used to mark the transect and to measure the width. Stretch the measuring tape from one bank to the other, ensuring that all areas with water are included, even if they are too shallow to measure flow. Record the total width of the river or stream on the datasheet.

Divide the channel into subsections so that each subsection has no more than 10% of the total discharge. Ideally, there should be 20-30 subsections, but this will vary based on the bottom of the channel. If the bottom is relatively uniform, measurements can be taken at larger intervals (preferably no more than 5.0 ft apart in a wide channel). If the depth varies greatly due to rocks or changes in the channel, measurements should be taken at smaller intervals (no less than 0.5 ft apart).

Depth and velocities should be measured at the centerline of each subsection. Record the centerline tape measure reading on the datasheet. For example, if the tape reading at the left bank of the river is 0 and measurements are taken every 1 foot, the first velocity reading should be taken at 0.5 ft (0.5 should be recorded under "tape reading" on the datasheet; the width should be recorded as 1). The next measurement should be taken at 1.5 ft, and so forth. Although it is not always possible, try to divide the channel into equal subsections to make it easier to find the centerline and calculate width.

Be sure to record the tape readings and the depth, if any, at each edge of the water. This will simplify calculation of the width and area of the outer sections, especially if those section widths are not equal to the central sections.

MEASURING DEPTH

Velocity measurements should be taken at 60% depth (from the top). The wading rod can be pre-set to this value so that only minor adjustments need to be made in the field. Refer to the manual for instructions if the rod needs to be reset.

Depth should be measured using the scale on the top-setting wading rod and should be recorded to the nearest 0.05 ft. Each single mark represents 0.10 ft; each double mark represents 0.50 ft; and each triple mark represents 1.0 ft.

Place the rod at the selected point along the transect. If a large boulder occurs at that point, place the rod on top of the boulder. Read the depth on the wading rod and record it on the datasheet. Once the total depth is measured, move the sliding rod to the appropriate mark on the top-set. For example, if the total depth is 2.7 ft, the 2 on the sliding rod should be matched with the 7 on the top-set. Refer to Figure 1.

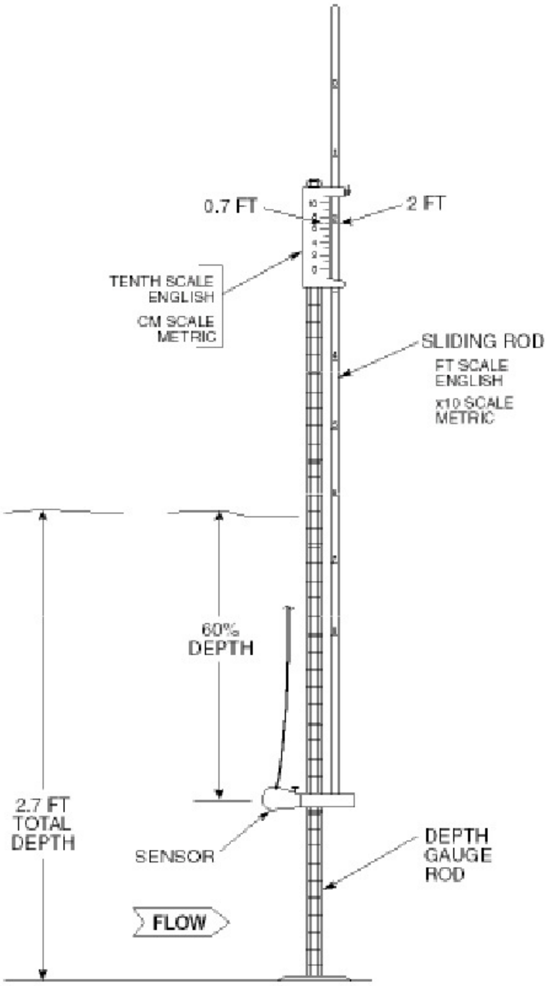


Figure 1. How to set the sensor at the proper depth (Marsh-McBirney 1990).

MEASURING VELOCITY

Depth must be greater than 0.2 ft in order to measure flow. If the depth is less than 0.2 ft, record a dash in the velocity column on the datasheet and continue to the next point.

If depth is at least 0.2 ft, place the wading rod so that the sensor is facing directly into the flow. Stand downstream and to the side of the meter to minimize disturbance of the flow. Ensure that the wading rod is held vertically.

Streamflow velocity naturally fluctuates (see figure 2). To accommodate for this fluctuation, the meter should be allowed to stabilize for at least 40 seconds before the measurement is recorded. To do this, set the time period on the meter to 20 seconds (refer to manual) and allow the meter to average the velocity twice (two 20-second periods). Record the velocity exactly as it appears on the meter after the second period, unless one of the following two conditions applies:

- If the velocity reading is negative after the first period, turn the rod so that the sensor is facing directly into the flow. Typically, this will be at an angle other than perpendicular to the transect, so follow the instructions in the next section. Be sure to record the new reading as a negative number. Negative velocities will later be subtracted from the overall flow in the calculations.
- If the velocity reading after the second period is significantly different from the reading after the first period, continue measuring for 20-second periods until the reading stabilizes. If the readings do not stabilize after 4 minutes and field time is limited, record the best average on the datasheet.

Although the Marsh-McBirney meter has a zero stability reading of ±0.05 ft/s, measurements of +0.05 should be recorded as 0.05, and measurements of -0.05 should be recorded as -0.05 to ensure consistency among field volunteers. These will be corrected to 0 in the spreadsheet calculations.

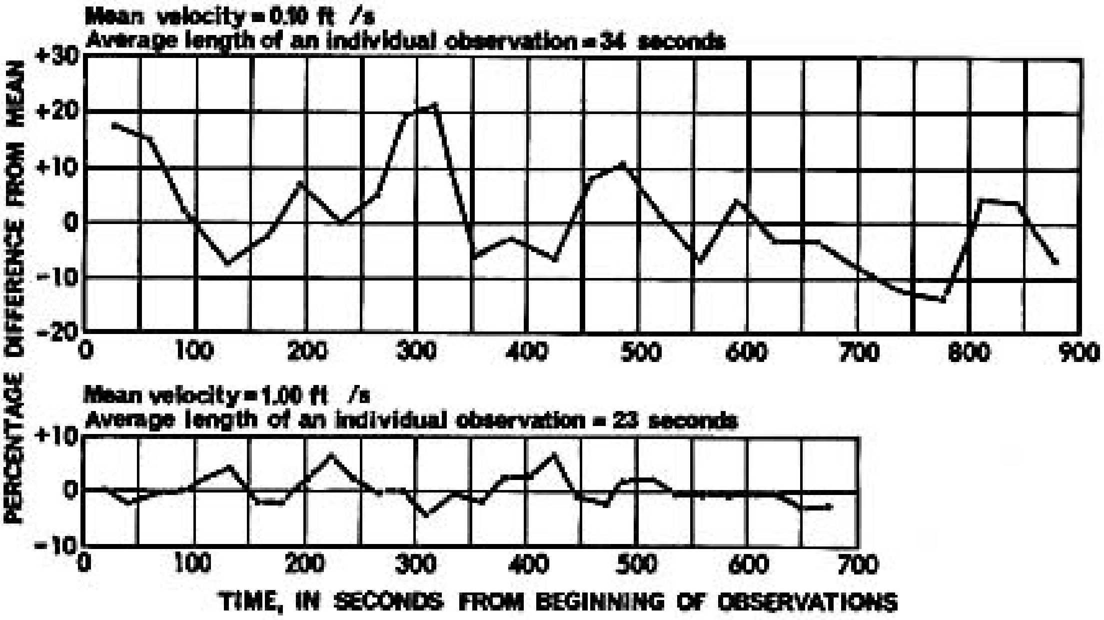


Figure 2. Fluctuations in velocity over time (Rantz 1982).

Measuring velocity when the flow is not perpendicular to the transect

Along some portions of the transect, the water may flow at an angle other than perpendicular to the transect. This could be the result of plants, boulders, or other materials altering the direction, as well as natural eddies in the channel. In this case, the sensor should be pointed directly into the flow, and the angle should be measured (± 5 degrees) with a compass. If the direction of the flow is not readily apparent, use small bits of floating matter to determine the angle. The angle should be measured off of the perpendicular (angle “a” in Figure 3). The corrected velocity is then measured by multiplying the velocity directly into the flow by the cosine of the angle. The spreadsheet automatically calculates this correction when the angle and velocity measurements are entered.

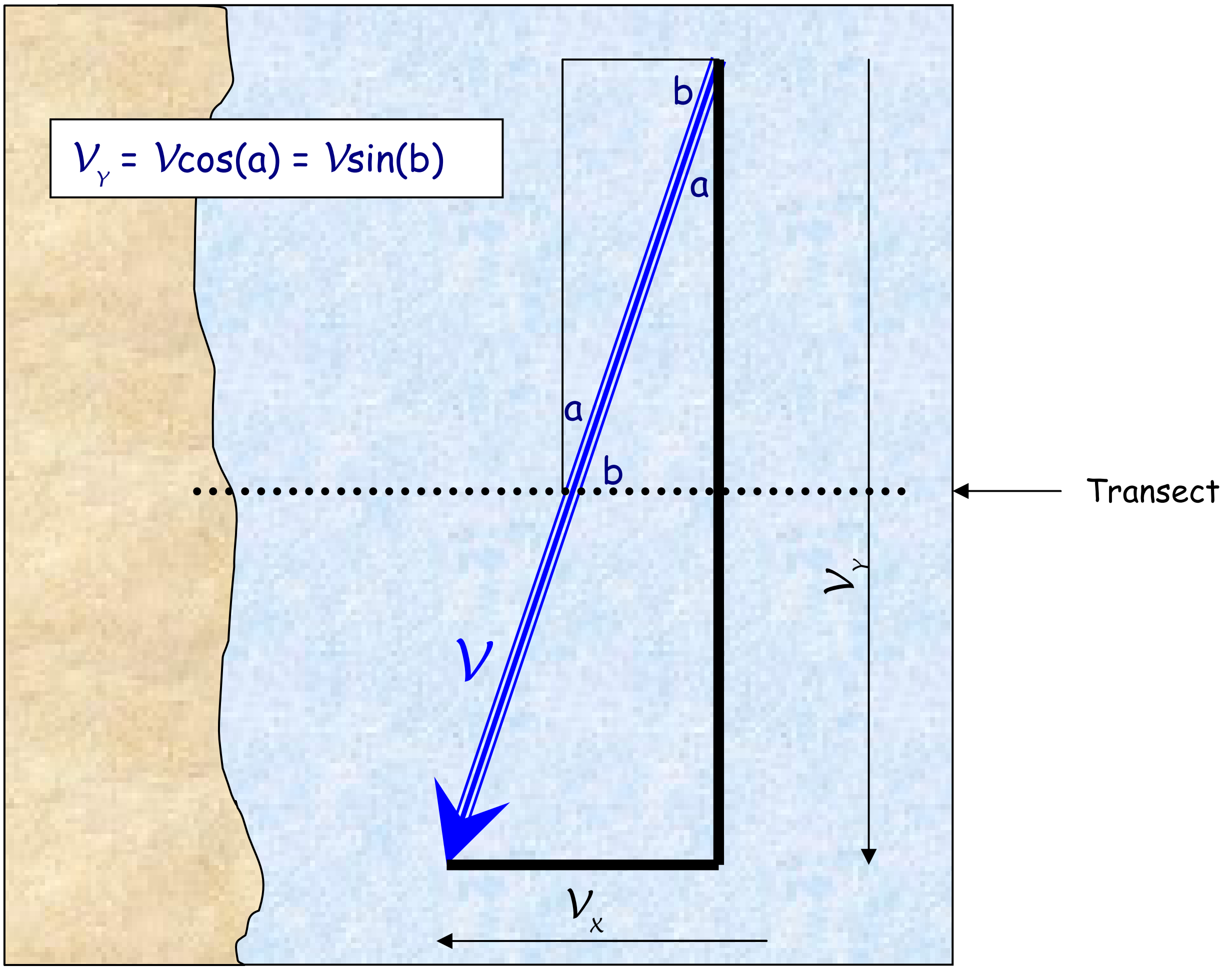


Figure 3. How to calculate velocity when flow is not perpendicular to the transect.

RECORDING DATA

Be sure to fill out the datasheet completely. The following sections must be filled out in the field:

- Date
- Start and End Time
- Site Name
- Field Crew
- Latitude/Longitude (if different than established transect)

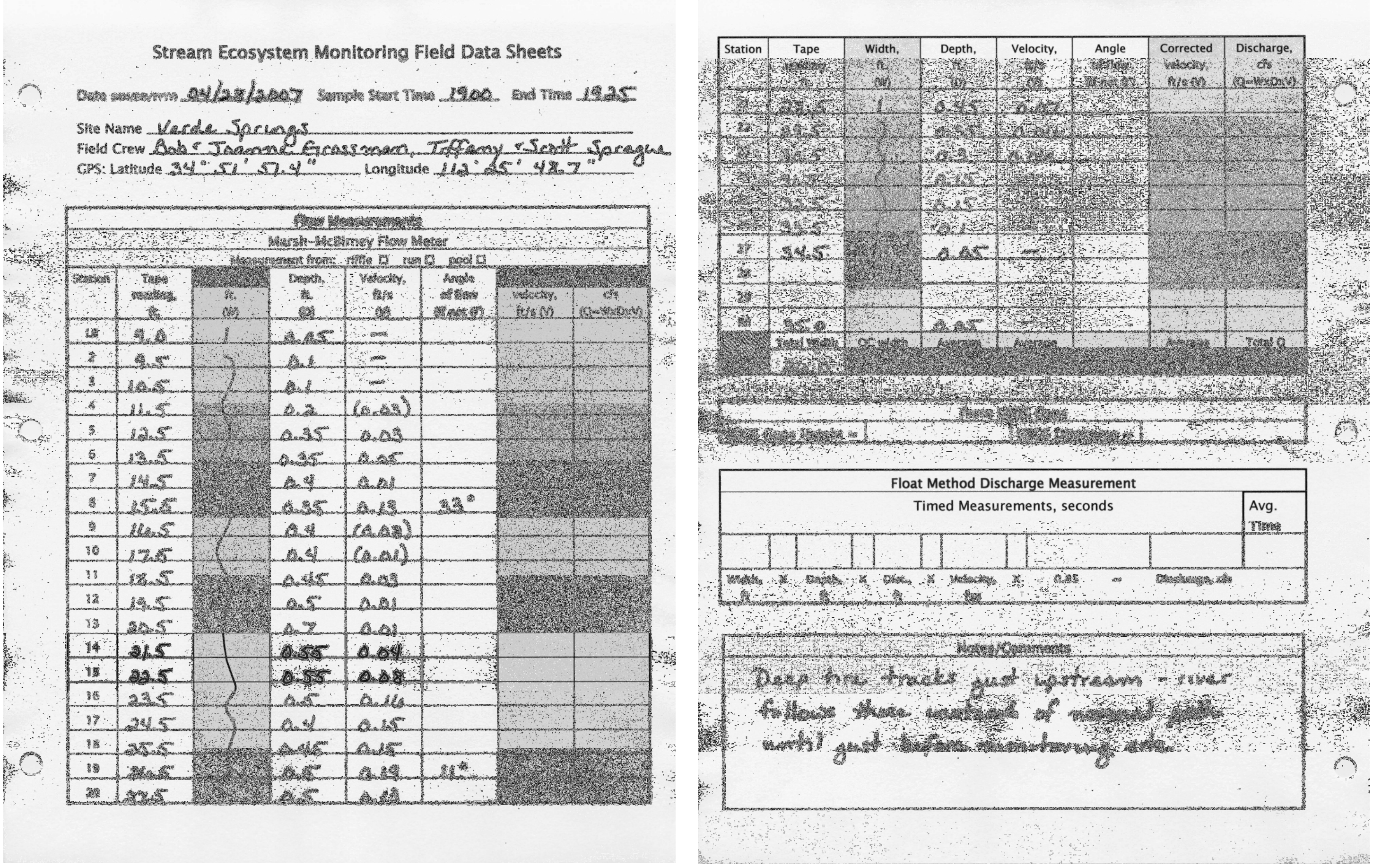
- Tape Reading of each bank and subsection centerline
- Depth at each bank and subsection centerline
- Velocity at each reading (and angle of flow, if applicable)
- Total Width
- Comments (if applicable)

If any of the depth or velocity readings are missing for a tape reading, or if a tape reading was skipped, measurements must be taken again at those locations prior to leaving the site. Otherwise, the other data points cannot be used to calculate total discharge at that site.

The columns that do not need to be completed in the field are shaded on the datasheet.

Any abnormal conditions, occurrences, or weather conditions should be recorded in the comments section.

Copies of completed datasheets need to be sent to the Grand Canyon Chapter's Phoenix office.



Stream Ecosystem Monitoring Field Data Sheets

Date mm/dd/yyyy 04/28/2007 Sample Start Time 1900 End Time 1925

Site Name Verde Springs

Field Crew Bob & Joanne Grossman, Tiffany & Scott Sprague

GPS: Latitude 34° 51' 57.4" Longitude 112° 25' 48.7"

Flow Measurements

Marsh-McBirney Flow Meter

Measurement from: riffle ☐ run ☐ pool ☐

Station	Tape reading, ft.	ft. (W)	Depth, ft. (D)	Velocity, ft/s (V)	Angle of flow (if not 0°)	velocity, ft/s (V)	cfs (Q=WxDxV)
1B	9.0	1	0.45	—			
2	9.5		0.1	—			
3	10.5		0.1	—			
4	11.5		0.2	(0.03)			
5	12.5		0.35	0.03			
6	13.5		0.35	0.05			
7	14.5		0.4	0.01			
8	15.5		0.35	0.13	33°		
9	16.5		0.4	(0.02)			
10	17.5		0.4	(0.01)			
11	18.5		0.45	0.03			
12	19.5		0.5	0.01			
13	20.5		0.7	0.01			
14	21.5		0.55	0.04			
15	22.5		0.55	0.08			
16	23.5		0.5	0.16			
17	24.5		0.4	0.15			
18	25.5		0.45	0.15			
19	26.5		0.5	0.19	11°		
20	27.5		0.5	[illegible]			

Station	Tape reading, ft.	Width, ft. (W)	Depth, ft. (D)	Velocity, ft/s (V)	Angle of flow (if not 0°)	Corrected velocity, ft/s (V)	Discharge, cfs (Q=WxDxV)
[illegible]	28.5	1	0.45	[illegible]			
[illegible]	29.5		[illegible]	[illegible]			
[illegible]	30.5		0.3	[illegible]			
[illegible]	[illegible]		0.15	[illegible]			
[illegible]	[illegible]		0.15	[illegible]			
[illegible]	[illegible]		0.1	[illegible]			
27	34.5		0.05	—			
28							
29							
[illegible]	35.0		0.05	—			
	Total Width	CC width	Average	Average		Average	Total Q

Float Method Discharge Measurement

Timed Measurements, seconds | Avg. Time

Width, ft X Depth, ft X Dist., ft X Velocity, fps X 0.85 = Discharge, cfs

Notes/Comments

Deep tire tracks just upstream - river follows these instead of natural path until just before monitoring site.

Figure 4. Example of front and back side of datasheet completed in field.

CALCULATING DISCHARGE

Once all of the width, depth, and velocity measurements are recorded at a site, the total discharge through that area can be calculated. This can be done in the field, although it is often easier to wait until you return from the field. Calculations should be double-checked with a calculator or computer program after leaving the field. A spreadsheet has been developed to automatically calculate width, corrected velocity, discharge, and other components.

Discharge (Q) through each subsection is calculated by multiplying the width (W), depth (D), and velocity (V) at each point ($Q = W \times D \times V$). Negative calculations should be recorded as negative numbers. Total discharge for that site is then calculated by summing all of the subsection calculations. Discharge is given in cubic feet per second (cfs).

SAFETY

Do not attempt to measure flows during inclement weather, including heavy rain or lightning, or during periods of high discharge or flooding.

Always wear a personal floatation device when entering the water. Waders are also recommended in heavily used areas and during colder weather.

When entering the water, go slowly and use a tall stick to test the depth ahead. If the water is too deep, do not measure flows at that point. Test the depth of the water at sections just up or downstream of the established site. If the stream is traversable at one of those points, measure at that location. Be sure to record this in the comments section of the datasheet and record the new latitude/longitude.

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