Verde River Basin PARTNERSHIP

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Verde Watershed Association

Verde Watershed Currents

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A new USGS study released in April 2013, reports the application of the USGS Northern Arizona Regional Groundwater Flow Model to demonstrate the effects resulting solely from human stresses (groundwater pumping and artificial and incidental recharge) on Verde River base flow and the groundwater system of the Verde Valley. From 1910 through 2005, the modeled depletion of base flow owing solely to documented rates of human stress on the groundwater system is approximately 5,000 acre-feet per year at the Paulden and Clarkdale streamgages, and 10,000 acre-feet per year at the Camp Verde streamgage. Even if groundwater pumping were maintained exactly as in 2005, the study predicts that (1) those depletions of base flow would increase to approximately 8,000 and 17,000 acre-feet per year, respectively, by 2110; and (2) the depth to groundwater would increase by 2110 by more than 100 feet in the vicinity of Cottonwood, near Sedona, near the Village of Oak Creek, in the Woody Ridge area southeast of Flagstaff, and in the Lake Mary area southeast of Flagstaff.

Undeniably, the Verde River is at risk and groundwater to support future populations will become ever more difficult and more expensive to acquire. The issues, which involve citizens and municipalities in both the upper and middle Verde River basin, are compelling and demand timely solution.

Now is the time to plan.

HUMAN IMPACTS ON THE VERDE RIVER'S BASE FLOW AND THE VERDE VALLEY'S GROUNDWATER SYSTEM

Introduction

A new U.S. Geological Survey (USGS) study by Garner and others, released in April 2013, applies the USGS Northern Arizona Regional Groundwater Flow Model (NARGFM) to examine the response of Verde River base flow and the groundwater system of the Verde Valley to groundwater pumping in northern Arizona.

> Garner, B.D., Pool, D.R., Tillman, F.D., and Forbes, B.T., 2013, Human Effects on the Hydrologic System of the Verde Valley, Central Arizona, 1910-2005 and 2005-2110, Using a Regional Groundwater Flow Model: U.S. Geological Survey Scientific Investigations Report, 2013-5029, 47 p. http://pubs.usgs.gov/sir/2013/5029/

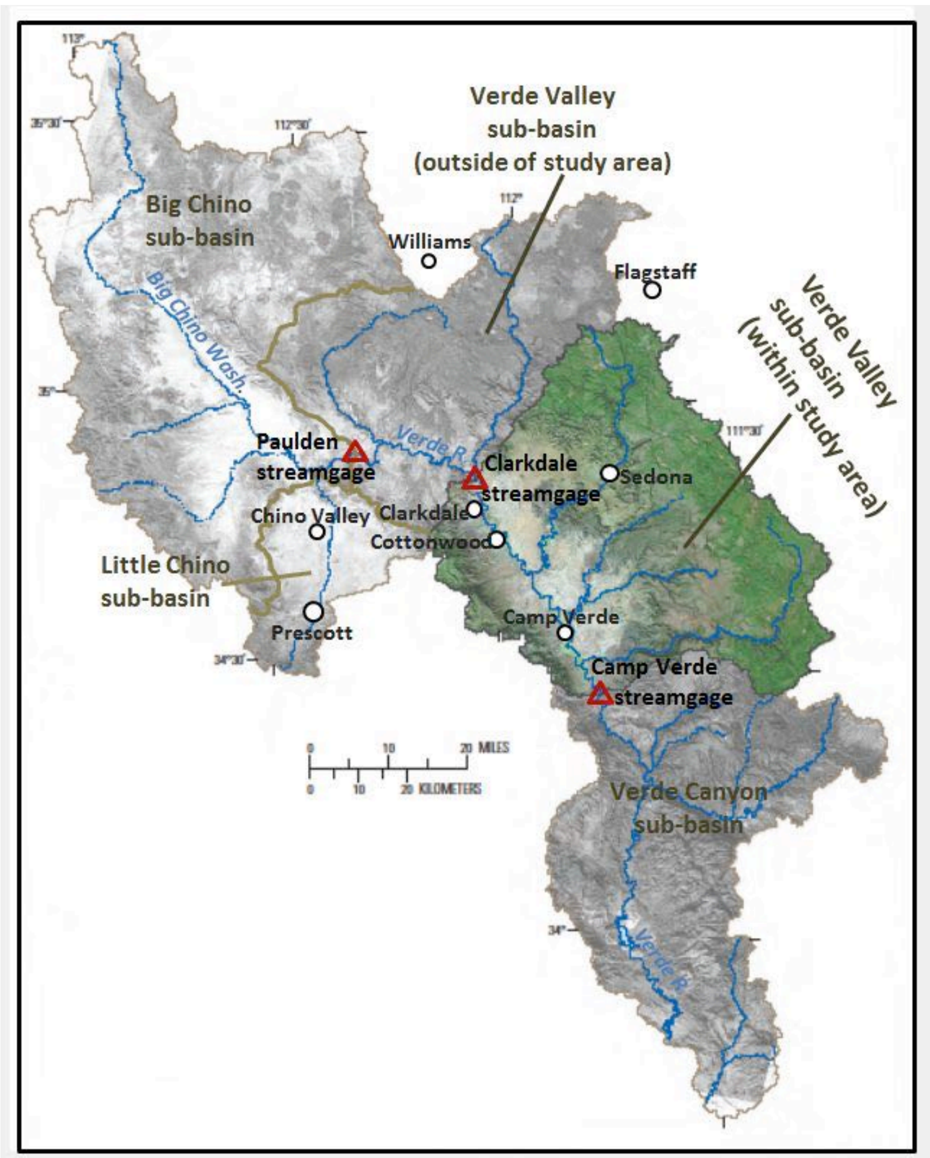


Figure 1. Map showing the upper (Big and Little Chino sub-basins), middle (Verde Valley sub-basin), and, in part, lower (Verde Canyon sub-basin) Verde River basin. The Verde Valley study area (green overprint) in the USGS report is the 1,500 square-mile area of the Verde Valley sub-basin located between the USGS streamgages Verde River near Clarkdale, Arizona (09504000) and Verde River near Camp Verde (09596000). Results also refer to the USGS stream gage Verde River near Paulden, Arizona (09503700). These are referred to herein, respectively as the Clarkdale, Camp Verde, and Paulden streamgages. (Modified from fig. 1 of Garner and others, 2013).

A grant from the Walton Family Foundation, plus USGS cooperative funding, supported the USGS study. The work plan was developed jointly by the USGS and the Verde River Basin Partnership. The USGS report fulfills a portion of Title II of the requirements of Federal Public Law 109-110, Northern Arizona Land Exchange and Verde River Basin Partnership Act of 2005. The portion it fulfills is the completion of a preliminary water-budget analysis of the Verde Valley and analysis of the potential long-term consequences of various water-use scenarios on groundwater levels and Verde River basin flows. The Town of Clarkdale received the Walton Family Foundation funds and administered the grant.

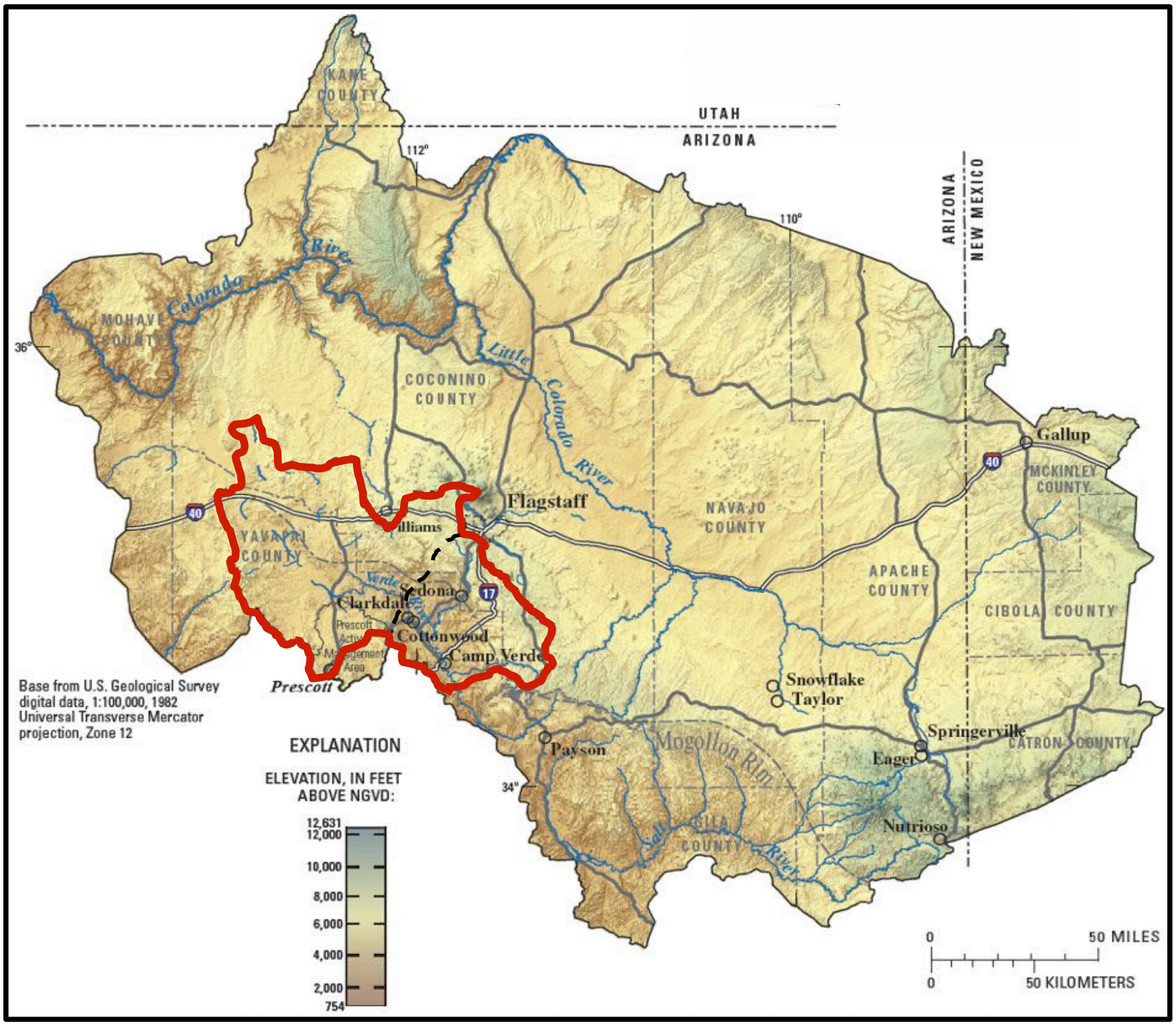


Figure 2. Map showing the area of the Northern Arizona regional groundwater-flow model. The red line outlines the upper and middle Verde River watersheds. The thick dashed black line is the approximate northwest boundary of the Verde Valley study area. (After Pool and others, 2011).

The NARGFM is a computerized simulation of the groundwater flow system throughout northern Arizona. It can represent recharge (the addition of groundwater to the system), the movement of groundwater through the system, and discharge (the release of groundwater from the system). The model's power is its applicability as a tool for examining the potential consequences of either natural or human-caused water-budget changes on the groundwater system and its connected surface water. Water-budget changes might include changes in recharge owing to long-term climate variation or human-induced changes such as groundwater pumping (a form of discharge) or the engineered return of treated wastewater to the groundwater system (a form of recharge). (For more information about the NARGFM, please see Verde River Basin Water-Resource Notes no. 3 at http://vrbp.org/wp-content/uploads/WRN-3-The-Northern-Arizona-Regional-Groundwater-Flow-Model.pdf.)

Purpose of the USGS analysis

The purpose of the USGS report was to demonstrate the specific effects of human stresses on the groundwater system of the Verde Valley (fig. 1) and Verde River streamflow. The primary human stresses evaluated are groundwater pumping and the return of pumped water to the aquifers via incidental recharge and artificial recharge. Accordingly, the evaluated human stresses are reported as net groundwater withdrawal.

Incidental recharge: gravity-driven return to the groundwater system of irrigation water that seeps below the root zone

Net groundwater withdrawal: pumpage minus incidental and artificial recharge

Artificial recharge: engineered return of treated wastewater to the groundwater system

Base flow: the component of streamflow that is supplied by groundwater exiting (discharging) from aquifers to the river

Human stresses were simulated across the entire NARGFM area (most of north-central and northeastern Arizona and part of western New Mexico; fig. 2). The responses of the hydrologic system of the Verde Valley to the human stresses that are of greatest concern from a water-management standpoint are expressed as change in base flow at the Paulden, Clarkdale, and Camp Verde streamgages and change in the depth to groundwater within the Verde Valley study area. The effects of human stresses on the groundwater system were evaluated for two time periods: 1910 through 2005, and 2006 through 2110.

The Power of the NARGFM for This Analysis

The power of the NARGFM for this analysis is that it provides for the first time a well-documented tool that enables examination of the effect of regional human stress (net groundwater withdrawal) on the groundwater system of the Verde Valley. Specifically, the model enables us to isolate the effect of human stress governing base flow from the overarching effect of decadal-scale climatic variation on natural recharge of the groundwater system (fig. 3).

Natural recharge: Natural replenishment of an aquifer, generally from snowmelt and runoff, via infiltration from the surface.

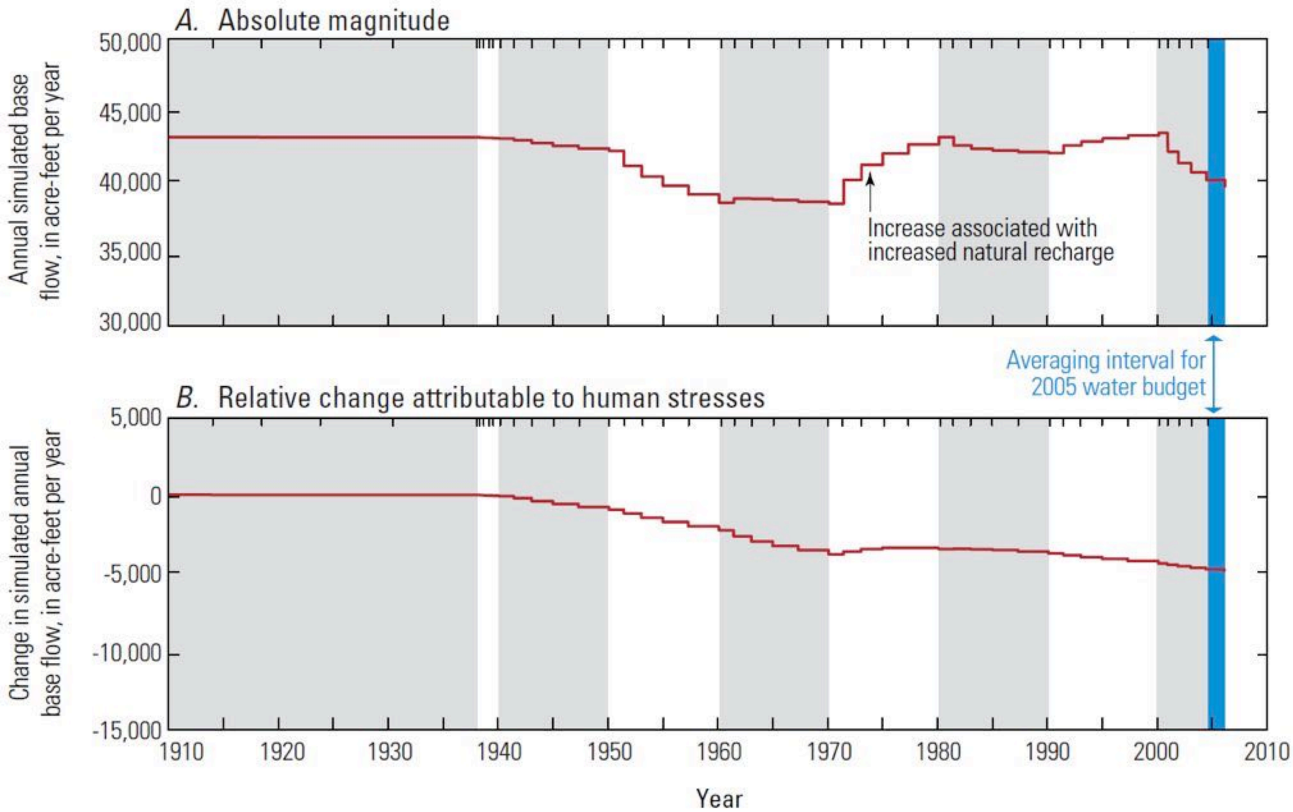


Figure 3. Plots of base flow simulated by NARGFM in the Verde River at the Clarkdale streamgage for the 1910–2005 model run. *A,* Absolute magnitude of base flow. *B,* Relative change in base flow attributable solely to human stresses. Gray and white bars indicate stress periods applied to model; tick marks at tops of panels denote time steps within modeled stress periods. (Garner and others, 2013, fig. 11).

Selected Results

Record-based Simulation – 1910 Through 2005

Years 1910 through 2005 coincide with the time period for which the NARGFM was calibrated. Thus, the full transient NARGFM model run (Pool and others, 2011) is the starting run for analyzing the effect of regional human stress (net groundwater withdrawal) on the groundwater system of the Verde Valley, including production of base flow. In this run, for the period 1910 through 2005, the magnitude and timing of human stresses as well as variation in natural recharge are based on analysis of the best available records as evaluated by Pool and others (2011). These records include decadal-scale variation in pumpage, incidental and artificial recharge, streamflow, and groundwater levels as well as decadal-scale estimates of natural recharge based on analysis of topography, soils, geology, vegetation, and records of such seasonal parameters as evapotranspiration, precipitation and other atmospheric conditions. The consumptive use of water derived from diversion of streamflow for crop irrigation in the Verde Valley was held at a constant rate of 10,000 acre-feet per year.

Calibration: Adjustment within reasonable limits of modeled transmissive properties of the hydrologic system to optimize the agreement of between actual measured values and simulated (model-generated) values

An additional model run, the so-called natural-conditions run, was required in order to isolate the effects of human stress. Thus, for the 1910 through 2005 time period, the documented decadal-scale variation in natural recharge was maintained, but the evaluated human stresses—groundwater pumping, incidental and artificial recharge—were omitted. The effects of human stresses across the model area on the Verde Valley groundwater system were obtained by subtracting the results of one model run from the other. Selected results expressed as relative change in water-budget values are given in figure 4 and table 1.

Change in Base Flow—1910 Through 2005

Simulated change in annual base flow, attributable solely to human stresses, decreased steadily from 1910 through 2005 (fig. 4). During this period human stress increased steadily, as represented as net groundwater withdrawal (table 1). By 2005 the simulated depletion in base flow at the Paulden, Clarkdale, and Camp Verde streamgages is approximately 4,800, 4,900, and 10,200 acre-feet per year, respectively. The net depletion of base flow within the Verde Valley (equals simulated change in base flow at the Camp Verde streamgage minus simulated change in base flow at the Clarkdale streamgage) by the end of 2005 is approximately 5,300 acre-feet per year.

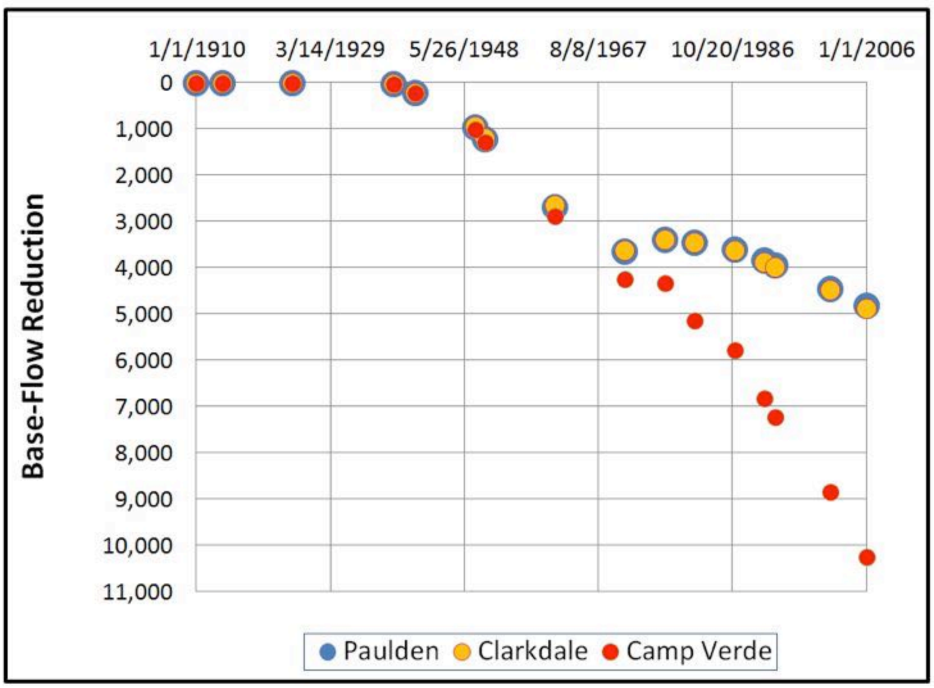


Figure 4. Change in base flow (acre-feet per year owed solely to human stresses, represented as net groundwater withdrawal, 1910 through 2005, at the Paulden, Clarkdale, and Camp Verde streamgages. Derived from data of table 1.2 of Garner and others (2013). Graph courtesy of William Meyer.

Notably, the depletion of base flow at the Paulden and Clarkdale streamgages is virtually identical (fig. 4) during the 1910 through 2005 time period. The onset of divergence in base-flow depletion at the Camp Verde streamgage with respect to base-flow depletion at the Paulden and Clarkdale streamgages is approximately coincident with the onset of substantial groundwater pumping in the Verde Valley that began in about 1941. Thereafter, the divergence steadily increases.

During the 1910 through 2005 time period, the rate of depletion of base flow as a percentage of net groundwater withdrawal increased. In 2005, the simulated annual depletion of base flow at the Clarkdale streamgage was 25 percent of the increase of net groundwater withdrawal above the gage; the annual depletion of base flow at the Camp Verde streamgage was 27 percent of the increase of net groundwater withdrawal above the gage. The depletion of base flow within the Verde Valley in 2005 was 30 percent of the net groundwater withdrawal in the Verde Valley (table 1).

	Clarkdale Streamgage			Camp Verde Streamgage			Verde Valley		
Year	∆Net GW with-drawal above gage, Af/y	∆Base flow at gage, Af/y	∆Base flow / ∆net with-drawal, Percent	∆Net GW with-drawal above gage, Af/y	∆Base flow at gage, Af/y	∆Base flow / ∆net with-drawal, Percent	∆Net GW with-drawal	∆Base flow	∆Base flow / ∆net with-drawal, Percent
1910	0	0	0	0	0	0	0	0	0
1913	200	-10	-2	200	0	-2	0	0	0
1930	200	-10	-2	200	-10	-2	0	0	0
1938	2,700	-50	-2	2,700	-40	-1	0	0	0
1941	9,300	-220	-2	11,300	-230	-2	2,000	-10	0
1951	18,200	-1,200	-7	18,800	-1,300	-7	600	-100	-17
1961	20,000	-2,700	-14	21,100	-2,900	-14	1,100	-200	-18
1971	20,800	-3,600	-17	24,600	-4,300	-17	3,800	-700	-18
1981	19,100	-3,500	-18	28,100	-5,100	-18	9,000	-1,600	-18
1991	17,800	–3,900	-22	31,000	-6,800	-22	13,200	-2,900	-22
2005	20,000	-4,900	-25	37,800	-10,200	-27	17,800	-5,300	-30

Table 1. Simulated annual change attributable solely to historic human stresses, 1910 through 2005, in net groundwater withdrawal above the Clarkdale and Camp Verde streamgages and in the Verde Valley, acre-feet per year; in base flow at the Clarkdale and Camp Verde streamgages and in the Verde Valley, acre-feet per year; and in base flow as percentage of net groundwater withdrawal. Derived from data (rounded herein) of table 1.2 of Garner and others (2013).

Forward-Looking Simulations - 2005 Through 2109

Three forward-looking (predictive) model runs from 2006 through 2109 were also undertaken to explore the effect on future base flow of both past and hypothetical future human stresses. The hypothetical human stresses in the three predictive runs were:

(1) net groundwater withdrawal for 2005 was gradually decreased by 15 percent through 2059 and then held constant through 2109;

(2) net groundwater withdrawal was held unchanged through 2109 at the same rates and at the same locations as in 2005;

(3) net groundwater withdrawal for 2005 was gradually increased by 15 percent through 2059 and then held constant through 2109.

No attempt was made in these runs to estimate future variation of climate. In order to isolate the effects of human stress, the natural-conditions run was extended from 2006 through 2109 using the long-term average value of natural recharge during 1910 through 2005, 59,000 acre-feet per year.

The attempted pumping could not be fully achieved in any of the three forward-looking model runs because some model cells became dry during the runs, especially in the Verde Valley. There the realized pumping in the three model runs fell short of the attempted pumping by approximately 2,700 to 2,900 acre-feet per year as model cells went dry.

It is important to understand that the forward-looking runs do not predict any reasonably expected reality in future water demand or future locations of population growth or pumping. Instead, they were designed simply to explore how groundwater pumping throughout the model area affects the Verde Valley's hydrologic system and Verde River streamflow. Indeed, even the most aggressive of the three forward-looking runs understates by nearly half the unmet water demand estimated for the Verde Valley in 2050 by the Central Yavapai Highlands Water Resources Management Study (see Phase 1 Results at http://www.yavapai.us/bc-wac/cyhwrms/).

Change in Base Flow 1910 Through 2110

Among the three predictive runs, depletion of base flow from 2005 through 2109 ranged from approximately 2,700 to 3,800 acre-feet per year at the Clarkdale streamgage, 5,400 to 8,600 acre-feet per year at the Camp Verde streamgage, and from 2,600 to 4,800 acre-feet per year in the Verde Valley. Hereafter, discussion of forward-looking runs is given only for the run that gave intermediate results—run 2, in which maintenance of 2005 pumping locations and magnitudes was attempted unchanged from 2006 through 2109.

Results for forward-looking model run 2, in which the attempt was to hold the 2005 pumping locations and net groundwater withdrawal rates (human stresses) constant through 2109 are summarized in fig. 5 and table 2. Changes in base flow predicted by that run are intermediate between the changes in base flow given in the run in which the attempt was to increase human stresses and the run in which the attempt was to decrease human stresses.

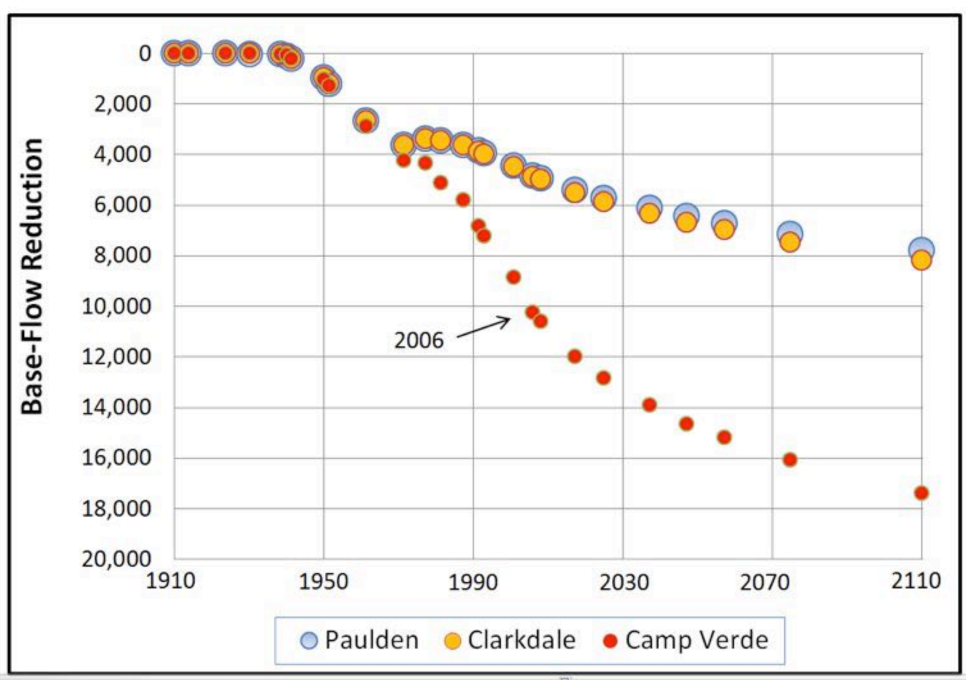


Figure 5. Change in base flow (acre-feet per year) owed solely to human stresses, represented as net groundwater withdrawal, 1910 through 2109, at the Paulden, Clarkdale, and Camp Verde streamgages. Based on simulated historic human stresses, 1910 through 2005, and an attempted hypothetical condition of unchanged human stress 2006 through 2109. Derived from data of tables 1.2 and 1.4 of Garner and others (2013). Graph courtesy of William Meyer.

Fig. 5 portrays human-induced depletion of base flow from 1910 through 2109 at the Paulden, Clarkdale, and Camp Verde streamgages. For 1910 through 2005, the simulated depletion of base flow is based on the historical records of pumpage, incidental and artificial recharge, streamflow, and groundwater levels that were used for model calibration. The graphed results through 2005 are identical to those of figure 4. Predicted human-induced depletions of base flow, 2006 through 2109, at the Paulden, Clarkdale, and Camp Verde streamgages are approximately, 3,000, 3,300, 7,200 acre-feet per year. Model-predicted total human-induced depletions of base flow at the three stream gages from 1910 through 2109 are, respectively, approximately 7,900, 8,200, and 17,400 acre-feet per year. Model-predicted total human-induced depletion of base flow from 1910 through 2109 in the Verde Valley is approximately 9,200 acre-feet per year (Table 2).

During the period from 2006 through 2109, the rate of depletion of base flow as a percentage of net groundwater withdrawal continued to increase from its 2005 values (table 2). Model-predicted total human-induced reductions of base flow as a percentage of net groundwater withdrawal at the Clarkdale and Camp Verde streamgages and within the Verde Valley from 1910 through 2109 are, respectively, 42, 51, and 62 percent.

	Clarkdale Streamgage			Camp Verde Streamgage			Verde Valley		
Year	∆Net GW with-drawal above gage, Af/y	∆Base flow at gage, Af/y	∆Base flow / ∆net with-drawal, Percent	∆Net GW with-drawal above gage, Af/y	∆Base flow at gage, Af/y	∆Base flow / ∆net with-drawal, Percent	∆Net GW with-drawal	∆Base flow	∆Base flow / ∆net with-drawal, Percent
2005	20,000	-4,900	-24	37,800	-10,200	-27	17,700	-5,400	-31
2010	20,100	-5,100	-25	37,200	-10,900	-29	17,100	-5,800	-34
2019	20,100	-5,700	-28	36,900	-12,300	-33	16,900	-6,700	-40
2029	20,100	-6,100	-30	36,500	-13,300	-36	16,500	-7,200	-44
2039	20,100	-6,400	-32	36,500	-14,100	-39	16,400	-7,700	-47
2049	19,900	-6,800	-34	35,800	-14,800	-41	16,000	-8,000	-50
2059	19,900	-7,100	-36	35,300	-15,300	-43	15,400	-8,300	-54
2084	19,900	-7,700	-39	34,800	-16,500	-47	14,800	-8,800	-59
2109	19,600	-8,200	-42	34,400	-17,400	-51	14,800	-9,200	-62

Table 2. Simulated annual change attributable solely to human stresses, 2005 through 2109, in net groundwater withdrawal above the Clarkdale and Camp Verde streamgages and in the Verde Valley, acre-feet per year; in base flow at the Clarkdale and Camp Verde streamgages and in the Verde Valley, acre-feet per year; and in base flow as percentage of net groundwater withdrawal. Derived from data (rounded herein) of table 1.4 of Garner and others (2013). Deviation of values for net groundwater withdrawal from the 2005 value reflects reduction of attempted pumpage owing to development of dry cells and the related simulated variation in incidental and artificial recharge.

Change in Depth to Groundwater in the Verde Valley

The USGS report also applied the NARGFM to examine the human-induced change in depth to the water table. The USGS results are given in a single map (fig. 6) that portrays the relative change in the altitude of the water table in the Verde Valley predicted by the forward-looking model run in which the attempt was to hold the 2005 pumping locations and net groundwater withdrawal rates (human stresses) constant through 2109. The report notes that "*maps for the decreased-human-stress and increased-human-stress conditions demonstrated a spatial pattern very similar to that for the unchanged-human-stress condition*" and thus they were not presented in the USGS report. The map portrays predicted water-table declines of more than 100 feet in the vicinity of Cottonwood, near Sedona, along Dry Beaver Creek near the Village of Oak Creek, in the Woody Ridge area southwest of Flagstaff, and in the Lake Mary area southeast of Flagstaff.

Water table: The upper surface of the groundwater. Wells pump their water from below the water table.

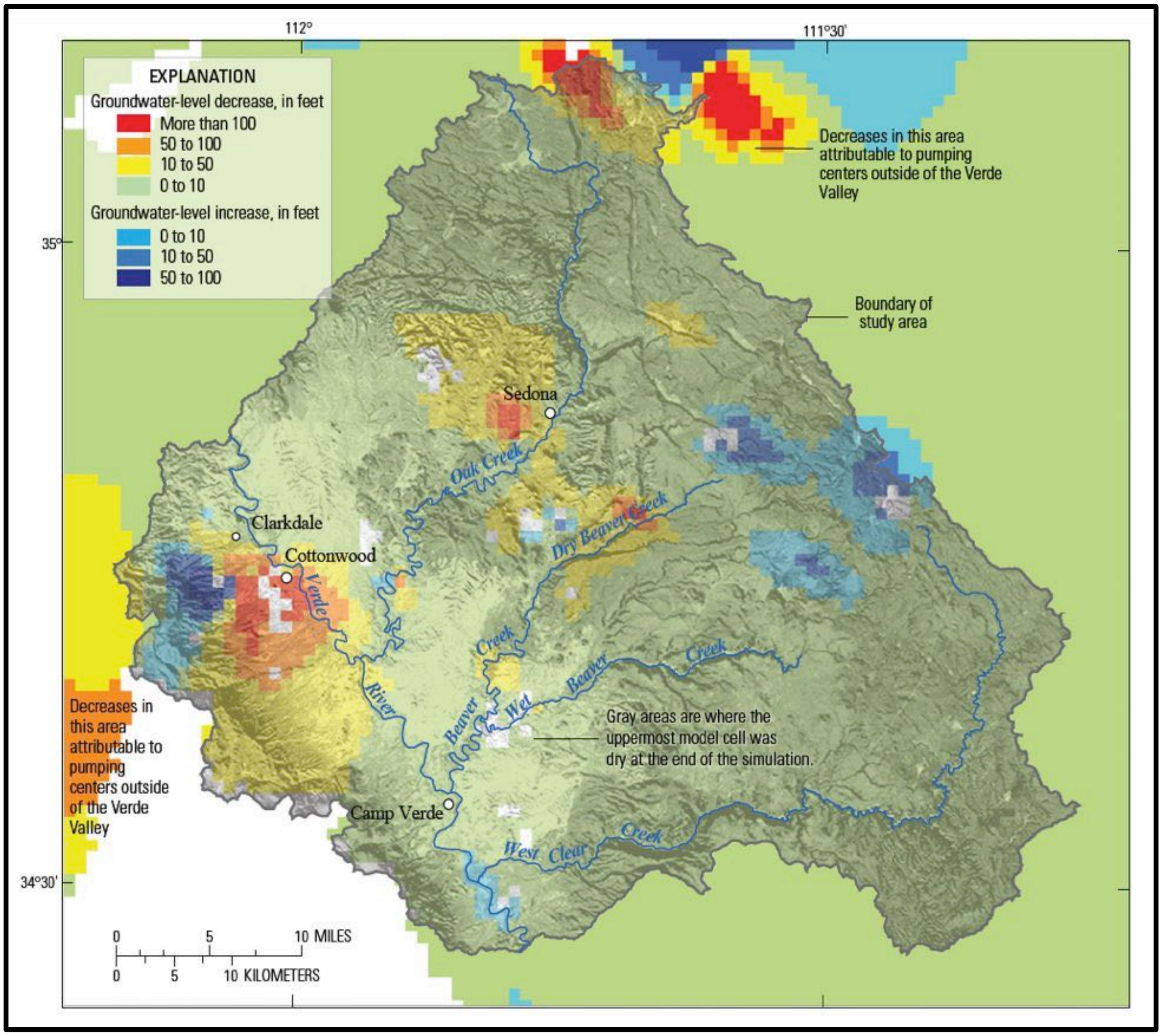


Figure 6. Map showing relative changes in water-table altitude attributed solely to human stresses simulated in the model run in which the 2005 pumping locations and net groundwater withdrawal rates (human stresses) were, insofar as possible, held constant through 2109. (Garner and others, 2013, fig. 10).

Other Model-Run Results

The USGS report describes and discusses other model-run results that evaluate human-induced changes from 1910 through 2009. Omitted herein as they seem less directly meaningful for water-management considerations, they include evaluation of human-induced changes in riparian evapotranspiration, groundwater storage, and underflow within the Verde Valley.

Other Results

Results are reported for several additional studies that relate to water-budget issues, but that do not directly apply the NARGFM to analysis of the rate of human-induced change over the next century to the Verde Valley water budget. These studies include: an analysis of evapotranspiration by riparian vegetation, 2000-2010, based on analysis of satellite-acquired remote-sensing data; an analysis of irrigation-water consumptive use in 2010, based on a crop-inventory approach; and production of 100-year capture maps for the Verde Valley for all three NARGFM model layers. These supplement previously published 10- and 50-year capture maps (Leake and Pool, 2010; see http://pubs.usgs.gov/sir/2010/5147/sir2010-5147.pdf).

Conclusions and Inferences

The new USGS report gives, for the first time, publicly-available numerical documentation of the effect that human water acquisition in northern Arizona has had and will continue to have on Verde River streamflow and the future accessibility of groundwater to sustain the Verde Valley's citizens and communities.

Groundwater pumping, both above the Clarkdale streamgage and in the Verde Valley, that became substantial in the 20th century, began to affect base flow in the same years in which pumping began and will continue to affect base flow well into the future. In 2005, the rate of human-induced depletion of base flow at the Clarkdale streamgage, as a percentage of net groundwater withdrawal above the gage that year, was 27 percent. The rate of depletion of base flow in the Verde Valley at that time was 30 percent of the rate of net groundwater withdrawal within the Verde Valley. By the end of 2109, the predicted rates (from the model run that attempted to hold 2005 rates and locations of net groundwater withdrawal unchanged through 2109) of human-induced depletion of base flow as percentages of net groundwater withdrawal above the Clarkdale streamgage and within the Verde Valley had increased to 42 and 62 percent, respectively. The progressive decrease in Verde River base flow, both historically and in the future, is in accord with the well-established concept of streamflow depletion (or capture).

Change in base flow is critical because the year-round (perennial) flow of the Verde River is dependent on maintaining the river's base flow. Without its base flow, the Verde, like so many other once-perennial rivers in Arizona, would flow only after storms or at times of voluminous snow melt.

> Streamflow depletion or capture: pumping-induced increased inflow to or decreased outflow from an aquifer (Barlow and Leake, 2012: see http://pubs.usgs.gov/circ/1376/).

The nearly identical model-estimated base-flow depletion at the Paulden and Clarkdale streamgages through time indicates that loss of base flow at the Paulden gage is transmitted essentially intact to the Clarkdale gage. This reflects the near absence of human water acquisition in the watershed area between the two gages. The USGS report notes that although the human stresses that caused the base-flow reduction at the Clarkdale streamgage *"likely are mostly located in areas of the Verde River groundwater basin up-gradient from the Clarkdale gage, some could have been located in other groundwater basins."*

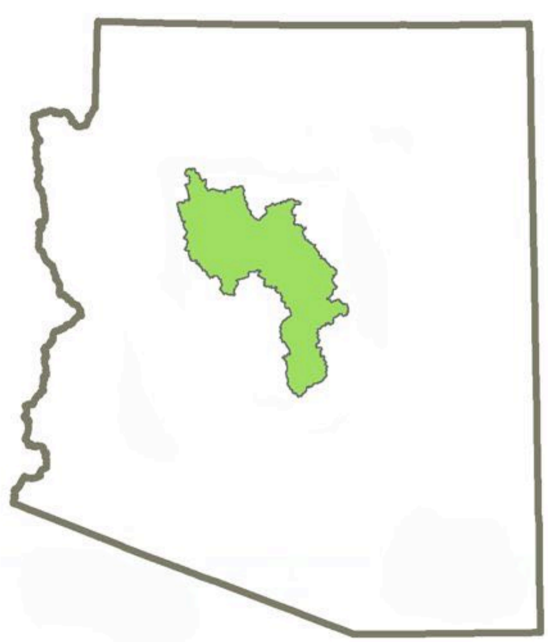
The same hypothetical scenario in which the human stresses on the groundwater system were unchanged after 2005 predicted increased depth to groundwater by 2110 of more than 100 feet in the vicinity of Cottonwood, near Sedona, along Dry Beaver Creek near the Village of Oak Creek, in the Woody Ridge area southeast of Flagstaff, and in the Lake Mary area southeast of Flagstaff.

Clearly the Verde River is at risk, and groundwater to support future populations will become ever more difficult and more expensive to acquire. The issues, which involve citizens and municipalities in both the upper and middle Verde River basin, are compelling and demand timely solution. Now is the time to plan.

Written by Edward W. Wolfe

VERDE WATERSHED - REVIEW OF 2013 MONSOON SEASON AND OUTLOOK FOR THE COMING WINTER

Unlike years past, there was not much talk and speculation going into Monsoon 2013. However, once the rains arrived the chatter began. By the end of July, gauges over the Verde were beginning to tally up near-record to record monthly rainfall amounts. This trend continued through the middle of September. After all was said and done, the Verde watershed accumulated 8.70 inches of rain, which was well above normal. In fact, compared to last year, the Monsoon 2013 bested 2012 by over one and a half inches. Looking further back, the Verde watershed has not observed this much summer rain since 1999, and over the last 30 years, 2013 ranks as the 3rd wettest Monsoon. With so much rain, one would expect significant rises on the Verde and its tributaries. Indeed this did occur; with the peak flow at the USGS's Camp Verde gauge rising to 2,660cfs on September 9.



With the summer behind, what does this winter have in store? The greatest predictor of winter precipitation for the Verde watershed is the El Niño Southern Oscillation (ENSO). ENSO relates Pacific Ocean sea surface temperatures along the equator to precipitation patterns over the United States. Positive ENSO (El Niño – warmer than average sea surface temperatures) usually indicates wetter conditions for the Southwest US, while negative ENSO (La Niña – cooler than average equatorial sea surface temperatures) typically leads dry conditions for the Southwest US. This year, like last year, ENSO is in a neutral state with current sea surface temperatures near normal and not expected to change much through the winter of 2014. Since 1980, there have been 11 years with ENSO neutral conditions. Of the 11 years, the Verde watershed has seen its wettest year (1993 – 19.34 inches of precipitation) and its driest year (2002 – 1.73 inches of precipitation), with the overall ENSO neutral precipitation average close to the current 30-year climate average. All this variability does not lend itself to much predictability. However, the official National Weather Service forecast places a higher probability of dry conditions this winter when compare to normal or wet winter.

Provided by the Salt River Project

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This issue of the Verde Watershed Currents was produced by the Verde Watershed Association (VWA), in collaboration with the Verde River Basin Partnership (Partnership). The VWA is currently in the process of merging with the Partnership.

The Verde Watershed Currents will continue as a news publication of the Partnership to present articles of public interest about the Verde watershed—its science, health, history, and prospects.

The Verde River Basin Partnership is on the web at www.vrbp.org.