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Effects of Past and Future Groundwater Development on the Hydrologic System of Verde Valley, Arizona

Communities in central Arizona's Verde Valley must manage limited water supplies in the face of rapidly growing populations. Developing groundwater resources to meet human needs has raised questions about the effects of groundwater withdrawals by pumping on the area's rivers and streams, particularly the Verde River. U.S. Geological Survey hydrologists used a regional groundwater flow model to simulate the effects of groundwater pumping on streamflow in the Verde River. The study found that streamflow in the Verde River between 1910 and 2005 had been reduced as the result of streamflow depletion by groundwater pumping, also known as capture. Additionally, using three hypothetical scenarios for a period from 2005 to 2110, the study's findings suggest that streamflow reductions will continue and may increase in the future.

The Verde River flows through the Verde Valley in the central part of Arizona and provides wildlife habitat and recreational opportunities. Groundwater development to meet the needs of growing communities has reduced base flow to the Verde River and will continue to do so in the future, according to recent U.S. Geological Survey study. (Copyright © John Rodger, used with permission.)

Introduction

The Verde River, in central Arizona's Verde Valley, is one of the State's largest perennial streams, having year-round flow that is fed by groundwater. Water is diverted from the Verde River and other perennial streams at more than 60 locations within the Verde Valley, primarily for irrigation of residential and cultivated fields. Verde Valley municipalities such as Camp Verde, Clarkdale, Cottonwood, and Sedona also pump groundwater to meet the needs of a growing population.

Groundwater pumping has the potential to reduce streamflow in the rivers and streams that are hydrologically connected to the groundwater system. Groundwater that seeps into the stream channel, known as base flow, is one component of streamflow potentially affected by groundwater pumping. Because of this connection, questions have been raised about the effects of groundwater pumping on Verde Valley streams and rivers, particularly on the Verde River, which provides wildlife habitat and recreational opportunities.

The Verde River Basin Partnership, a group of Federal, State, local, and other entities with water responsibilities and expertise, was established by Congress to prepare a plan for conducting water-resource studies in the Verde River Basin. The U.S. Geological Survey (USGS) assisted with the development of the plan.

This fact sheet summarizes key findings of a recent USGS study examining the effects of groundwater development in the Verde Valley, particularly how it affects streamflow in the Verde River. The study area is defined as a 1,500-square-mile area of the Verde Valley subbasin between two USGS streamflow-gaging stations on the Verde River: one located near Clarkdale, Arizona, and a second located downstream near Camp Verde, Arizona.

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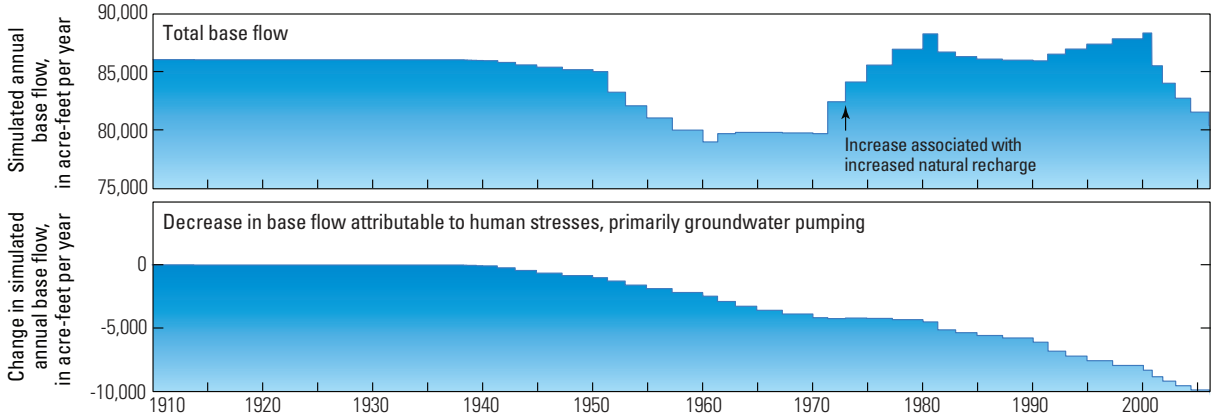

Base flow simulated by the Northern Arizona Regional Groundwater Flow Model, at Verde River near Camp Verde, USGS streamflow-gaging station 09506000. Top, absolute magnitude; bottom, relative change in base flow attributable to human stresses.

Study Methods

To understand changes taking place over time in the Verde Valley hydrologic system, USGS hydrologists used the Northern Arizona Regional Groundwater Flow Model (Pool and others, 2011) to develop water budgets for the portion of the study area's hydrologic system that flows through the subsurface as groundwater. A water budget estimates the amount of water and its rates of movement in an area using the same accounting principles as those used in financial accounting. Recharge is similar to income, discharge is similar to expenditures, and water stored within aquifers is similar to an account balance. Groundwater in the Verde Valley is primarily recharged naturally by rain or snowmelt that flows into and through aquifers. Groundwater leaves the local and regional aquifers by (1) discharging into streams from springs above and below the water surface, (2) moving into the atmosphere through evaporation and plant transpiration from vegetated areas near streams, or (3) pumping from wells.

Using the model, the study examined how human stresses on the hydrologic system in and around the Verde Valley from 1910 to 2005 affected streamflow in the Verde River. The study also considered future conditions using three hypothetical scenarios for 2005–2110: unchanged, increased, and decreased levels of human stresses. Groundwater withdrawals by pumping were the primary human stresses that were simulated by the study. Incidental and artificial recharge, processes that return some pumped water to the groundwater system through activities such as irrigation of croplands, were other human stresses that also were simulated.

Findings

Withdrawing groundwater from a well intrinsically alters the hydrologic system; water removed from the system by wells is not available elsewhere in the system. This study's findings indicate that human stresses to the groundwater system—namely, groundwater pumping—have affected base flow in the Verde River through streamflow capture. Streamflow capture is the process by which groundwater pumping intercepts groundwater that would otherwise have flowed to connected streams or draws water from the stream into the aquifer. Base flow is one component of overall streamflow; the other component is runoff, or precipitation that is not absorbed by the land surface and flows into waterways. The model used in this study did not simulate runoff, so all findings discussed here relate to base flow.

As of 2005, annual base flow at the Clarkdale gage was estimated to have decreased by about 4,900 acre-feet per year (acre-ft/yr) since 1910 as a result of pumping. An acre-foot is the volume of water it would take to cover 1 acre, or about the area of a football field, to a depth of 1 foot, which is about 326,000 U.S. gallons. From 2005 to 2110, depending on the amount of pumping, base flow at the Clarkdale gage was projected to decrease an additional 2,700 to 3,800 acre-ft/yr.

At the downstream Camp Verde gage, base flow as of 2005 had decreased by about 10,000 acre-ft/yr because of pumping between 1910 and 2005. Model simulations indicated that base flow at the Camp Verde gage could continue to decrease during the 2005–2110 period by 5,400 to 8,600 acre-ft/yr depending on the amount of groundwater pumped.

Groundwater storage in aquifers within the Verde Valley, as of 2005, was decreasing at about 29,000 acre-ft/yr; about 12,000 acre-ft/yr of this amount was attributable to pumping. Over time, the model projections suggest that the rate of groundwater-storage decrease would slow.

Conclusion

As of 2005, human stresses were found to have decreased the base-flow component of streamflow in the Verde River. Three hypothetical scenarios also indicate that human stresses were capable of causing continued and additional decreases in base flow in the future. These findings are consistent with (1) the concept of capture, (2) previous studies that have found surface-water and groundwater systems in the Verde River groundwater basin to be connected, and (3) the characterization of groundwater and surface water as a single resource. "All water discharged by wells is balanced by a loss of water somewhere," as C.V. Theis (1940) noted more than 70 years ago.

Further Information

A fuller exposition of these findings is in:

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. (Available at http://pubs.usgs.gov/sir/2013/5029/)

References Cited

Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F., 2011, Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010–5180, 101 p.

Theis, C.V., 1940, The source of water derived from wells: Civil Engineering, v. 10, p. 280.

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