Human Effects on the Hydrologic System of the Verde Valley, Central Arizona, 1910–2005 and 2005–2110, Using a Regional Groundwater Flow Model

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Summary

This report describes the results of an investigation into the degree to which human stresses have affected and might in the future affect the hydrologic system of the Verde Valley, using water budgets as the central analytical tool. For the purposes of this report, the Verde Valley is the 1,500 sq-mi area of the Verde Valley subbasin located between USGS streamflow-gaging stations Verde River near Clarkdale, Arizona (the Clarkdale gage) and Verde River near Camp Verde (the Camp Verde gage). Residents in the Verde Valley use a combination of groundwater and surface water to meet their water demands.

The Northern Arizona Regional Groundwater Flow Model (NARGFM) was used in this study, including the 1910–2005 human and natural stresses provided with the model. Three profiles of hypothetical future human stresses for the period 2005–2110 were executed by the NARGFM—increased, decreased, and unchanged human stresses. The NARGFM was run as needed for the full 1910–2110 period, including a special version of the model that included no human stresses whatsoever. The resulting water budgets were then extracted from model-output files. Finally, water budgets were added and subtracted to isolate only the relative changes in their values that were attributable to human stresses.The model demonstrates that human stresses between 1910 and 2005 have affected the hydrologic system of the Verde Valley, and likely will continue to affect the hydrologic system between 2005 and 2110 through groundwater withdrawals by pumping and through incidental and artificial recharge.Natural recharge as of 2005 was about 44,000 acre-ft/yr (61 ft^3/s) in the Verde Valley. Incidental and artificial recharge together were about 1,600 acre-ft/yr (2 ft^3/s), although this could be an underestimate. A net of about 4,900 acre-ft/yr (7 ft^3/s) of groundwater entered the study area from adjoining areas (underflow) as of 2005. Simulations indicated that net underflow changed very little between 1910 and 2005, but underflow could increase between 2005 and 2110. Groundwater withdrawals in 2005 were about 19,000 acre-ft/yr (27 ft^3/s). Riparian evapotranspiration (ET) was about 9,200 acre-ft/yr (13 ft^3/s) in 2005; riparian ET was shown to be capable of being decreased by human stresses by as much as 500 acre-ft/yr between 2005 and 2110, which is consistent with the concept of capture.

Groundwater storage in aquifers within the Verde Valley was decreasing at about 29,000 acre-ft/yr as of 2005, although only 12,000 acre-ft/yr of this was attributable to human stresses. As time proceeded in the simulated 2005–2110 period, the rate of groundwater-storage decrease slowed down, which is consistent with the concept that the source of water to a well changes over time—from depletion of groundwater storage toward the capture of natural discharge.

At the upstream Clarkdale gage, base flow was about 40,000 acre-ft/yr (55 ft^3/s) in 2005, which is less than other published values of base flow at this gage. Base flow at the Clarkdale gage, as of 2005, was estimated to have decreased by about 4,900 acre-ft/yr (7 ft^3/s) as a result of human stresses between 1910 and 2005. During the 2005–2110 period, the model showed that base flow at the Clarkdale gage may decrease an additional 2,700 to 3,800 acre-ft/yr (4 to 5 ft^3/s) because of human stresses. Net groundwater discharge (equivalent to net surface-water inflow from groundwater) throughout the Verde Valley was about 51,000 acre-ft/yr (70 ft^3/s), and as of 2005 had decreased by about 5,400 acre-ft/yr (7 ft^3/s) because of human stresses. At the downstream Camp Verde gage, base flow was about 80,000 acre-ft/yr (111 ft^3/s) as of 2005, and had decreased by about 10,000 acre-ft/yr (14 ft^3/s) between 1910 and 2005 because of human stresses.

This 10,000 acre-ft/yr decrease represents the combined effects on base flow at the Camp Verde gage of all human activities upstream and upgradient of this gage that occurred 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 (7 to 12 ft^3/s) because of human stresses.

Withdrawing groundwater from a well intrinsically
alters the hydrologic system: “All water discharged by wells is balanced by a loss of water somewhere” (Theis, 1940, p. 280). Water withdrawn from a well is derived from one or more of these sources: (1) decrease in groundwater storage; (2) reduction in natural discharge; and (3) increase in natural recharge. The sum of components 2 and 3 is known as capture. The results presented in this report indicate that human stresses to the groundwater system have affected base flow in the Verde River through the process of streamflow capture and can continue to do so into the future.

Base flow in the Verde Valley is not constant over time, as sometimes is (incorrectly) assumed. Many factors contribute to the variability of base flow at varying time scales. Ditch diversions that are prevalent in the Verde Valley reduce base flow directly by diverting water and change it in more complex ways by redistributing water across the floodplain. Groundwater withdrawals capture streamflow and decrease base flow. Variations in natural recharge driven by climate and climate change also can change base flow. In summary, human stresses were found to have decreased base flow in the Verde River between 1910 and 2005, and under hypothetical forward-looking scenarios, human stresses were capable of causing continued and additional decreases in base flow. These findings are consistent with (a) the concept of capture, (b) previous studies that have found surface-water and groundwater systems in the Verde River groundwater basin to be connected, and (c) the characterization of groundwater and surface water as a single resource.