Possible Effects of Groundwater Pumping on Surface Water in the Verde Valley, Arizona

Figure 1. Location of Verde Valley sub-basin and extent of the Northern Arizona Regional Groundwater Flow Model.

Introduction

The Verde Valley sub-basin of north-central Arizona (fig. 1) is blessed with year-round flowing streams. Surface water is diverted from the Verde River for agriculture and landscaping; however, nearly all water for public, domestic, and industrial supplies comes from groundwater pumping (Blasch and others, 2006). Groundwater use in the sub-basin has increased by more than ten-fold in the latter half of the twentieth century. A growing awareness of sustainable water management recognizes that development of groundwater affects connected surface-water. With increasing population and water use, sustainability of water resources and long-term health of the Verde River are of concern.

Water managers and elected officials are seeking information that will help them make good decisions about water development that minimizes environmental impacts. A technique developed by the U.S. Geological Survey allows use of a groundwater flow model to map the effects of groundwater pumping or artificial recharge on surface water through time. This technique has been applied in the Verde Valley and a detailed scientific report is available on the internet (Leake and Pool, 2010, http://pubs.usgs.gov/sir/2010/5147/sir2010-5147.pdf, accessed October 1, 2010). This fact sheet presents basic information from the scientific report to help water managers and others understand possible long-term effects of groundwater pumping or artificial recharge on the Verde River and adjacent groundwater-dependent vegetation.

Overview of Groundwater and Aquifers in the Verde Valley

When useful amounts of water can be extracted from a well, the subsurface material that contains the water is called an "aquifer." Aquifers may consist of loose materials, such as sand, gravel, silt and clay, or of solid rock, such as sandstone, limestone, or siltstone. Water occupies the open space between grains and in fractures (cracks in the rock). Aquifers may be stacked one upon another in the subsurface, with each aquifer having different physical properties due to the different composition of earth materials and the different degrees of fracturing. Water enters aquifers from rain and snowmelt that percolates to the water table, especially at the higher elevations. Water moves through the aquifer system and eventually flows out at lower elevations. Thus, where the land surface intersects water-filled sediments, fractures, or solution channels, groundwater becomes surface water, and supports flow and habitat at a spring, river, or wetland.

In the Verde Valley, groundwater is present in several aquifer layers. The Verde Formation consists of an upper part with mostly limestone and siltstone, and a lower part with mostly sand and gravel. The upper part of the Verde Formation occurs in the central part of the sub-basin and most wells in Clarkdale, Cottonwood, Camp Verde, and Cornville pump water from that part of the formation. The lower part of the Verde formation is more extensive. Beneath the Verde Formation and extending laterally beneath Sedona is the "C-aquifer", dominated by rocks of the Supai Group. Beneath the C-aquifer is the "R-aquifer", dominated by rocks of the Redwall Limestone.

How Groundwater Pumping Effects Surface Water and Riparian Vegetation

Under natural or "predevelopment" conditions, long-term average rate of inflow to and outflow from an aquifer system are equal. Removal of groundwater by wells changes an aquifer system through time. Figure 2 shows the development of a "cone of depression" in the water table around a well and later stages of effects as that cone expands to a nearby stream and area of trees that use groundwater. Figure 3 shows that when pumping starts, all of the pumped water comes from storage in the aquifer. As pumping time continues, however, a greater percentage of the pumping can come from "depletion," which is reduced flow in the stream and reduced use of groundwater (evapotranspiration) by plants. At any time since the start of

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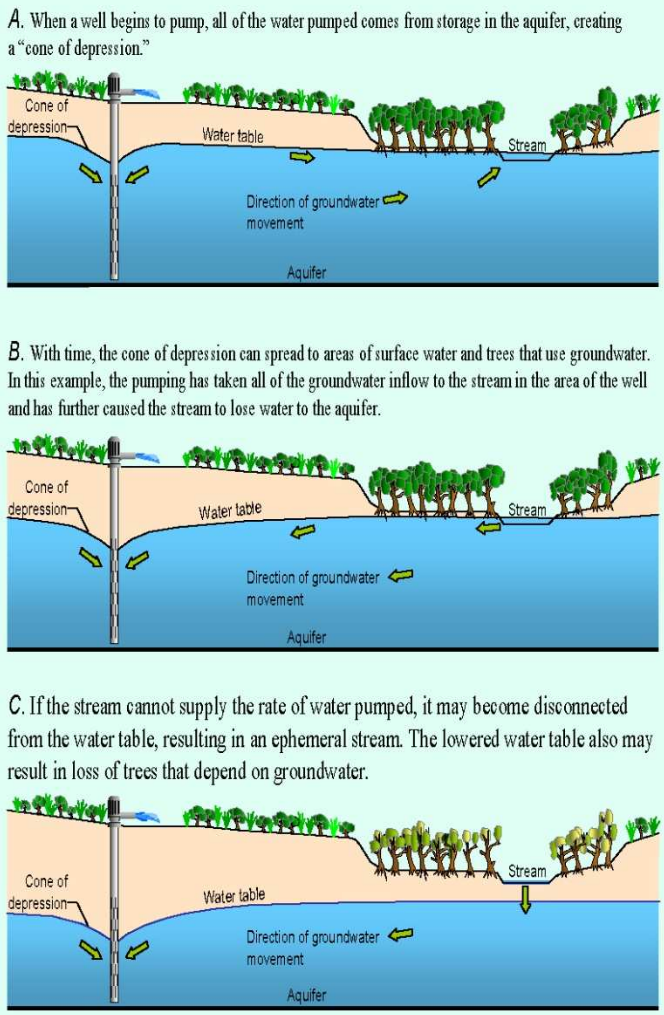

Figure 2. Effects of a groundwater pumping on the water table and on a nearby stream and area of trees that use groundwater (modified from Webb and others, 2007).

pumping, the only sources of pumped water are aquifer storage and reduced streamflow and evapotranspiration.Percentages of these sources vary through time and are affected by distance to the surface water, as shown in figure 3, and by the properties of the aquifer.

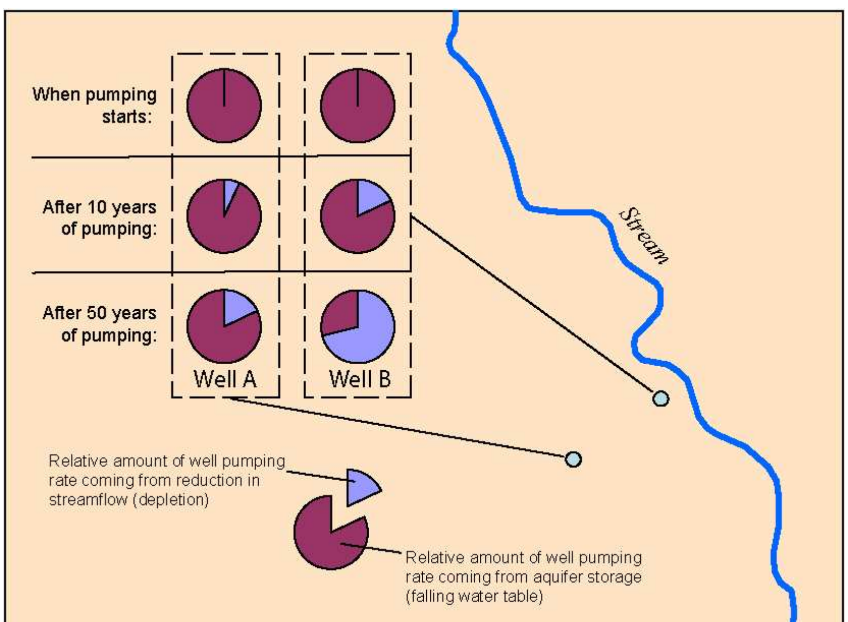

Figure 3. Sources of water for two hypothetical well locations for pumping times of 10 and 50 years.

The Northern Arizona Regional Groundwater Flow Model (NARGFM)

Because the aquifer system underlying the Verde Valley sub-basin is complex, a groundwater flow model is needed to understand the timing of effects of groundwater pumping on surface water and riparian vegetation. The Northern Arizona Regional Groundwater Flow Model (NARGFM) by Pool and others (in press) is the most comprehensive and up-to-date groundwater-flow model that includes the sub-basin. NARGFM simulates groundwater flow in an area much larger than the sub-basin, including parts of the Colorado Plateau, the Verde River Basin, and adjacent areas (fig. 1). In spite of the large extent of the model, it is well-suited to simulate general conditions in the Verde Valley sub-basin.

NARGFM uses three distinct layers to simulate the different aquifers underlying the Verde Valley. The upper model layer (layer 1) represents the upper part of the Verde Formation. The middle model layer (layer 2) represents chiefly the lower part of the Verde Formation, the C-aquifer dominated by the Supai Group, and also includes volcanic rocks. The lower model layer (layer 3) represents chiefly the R-aquifer. For details on the model and attributes for streams and springs in the Verde Valley sub-basin, see Pool and others (in press).

Possible Effects of Groundwater Pumping on Streamflow in the Verde Valley

Using NARGFM to estimate effects of groundwater pumping on surface water and riparian vegetation in the Verde Valley is a process that requires numerous steps and calculations, and summing of results in maps. The maps show the total reduced streamflow as a percentage of pumping rate. Thus, estimated depletion for any pumping rate, and for any time period after pumping begins, can be determined. For more details on method used, see Leake and Pool (2010). Because depletion of streamflow by pumping wells (or enhancement by artificial recharge) is location and time dependent, a reference time period must be chosen to examine effects at any given location. Streamflow depletion also varies depending on the aquifer (model layer) in which pumping or artificial recharge is occurring. Results at 10 and 50 years for pumping from model layers 1 and 2 are shown in Figures 4 and 5. Results are contoured as "percentages", meaning the percentage of pumping that is derived from streamflow. Percentages are color-coded, as shown in the color bar at the bottom of Figs. 4 and 5, with smaller percentages (0 to 40 percent) shown in blue colors, mid-range percentages (40 to 70 percent) shown in green to yellow, and large percentages (70 to 100 percent) shown in orange and red. For artificial recharge, the color coded-numbers refer to percentage of recharged water that would supplement streamflow. Use of the maps is further discussed below, with examples provided. Results for layer 1 (for wells pumping in the upper part of the Verde Formation) are shown in figures 4A and 4B. At a pumping time of 10 years (fig. 4A), results indicate greatest percentages of steamflow depletion (yellow to red colors; 70 to 100 percent) along the Verde River between Clarkdale and Cottonwood and from

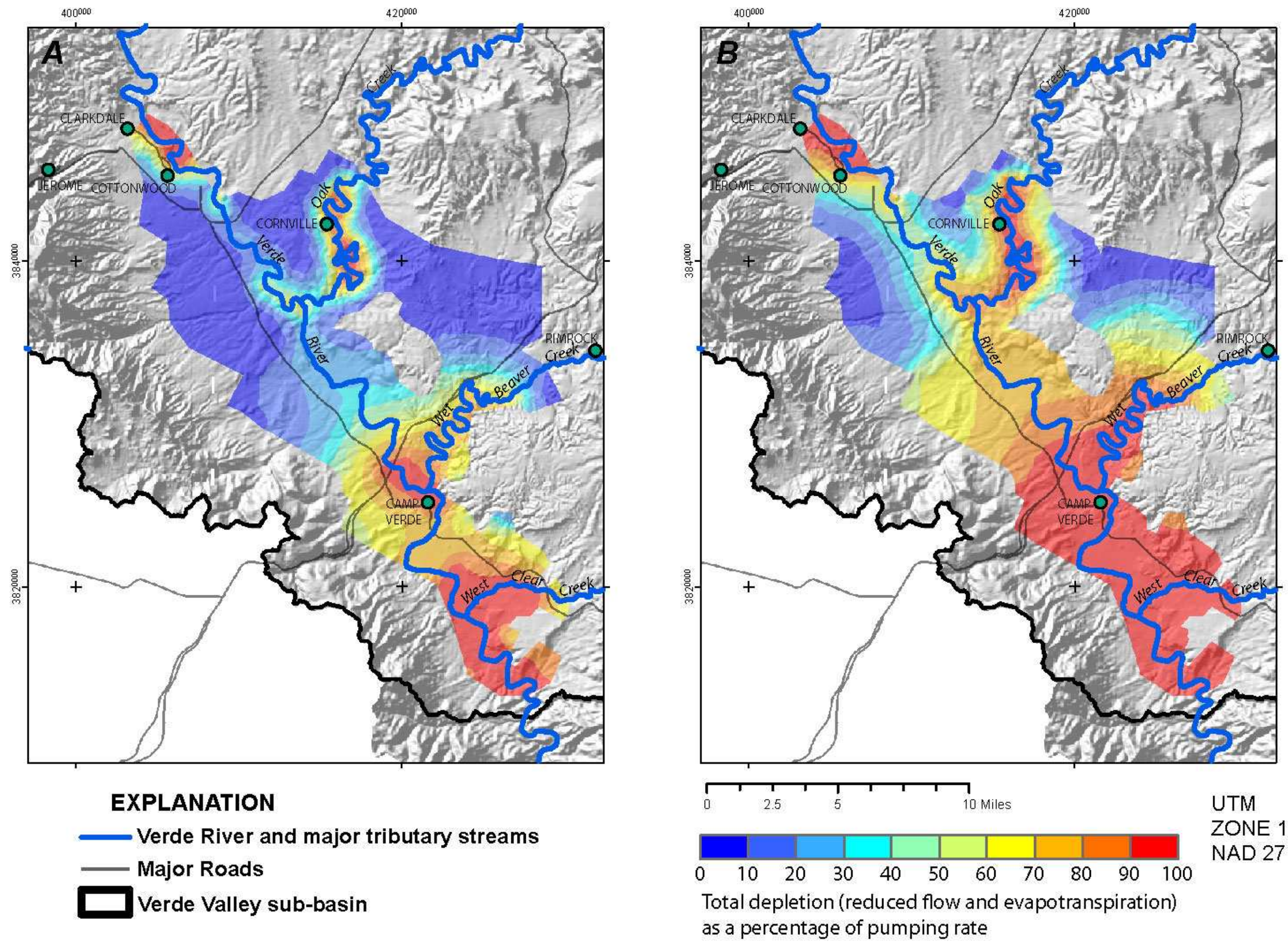

Figure 4. Depletion maps for wells pumping water from model layer 1, the upper part of the Verde Formation. *A*, rate of total depletion after 10 years of pumping. *B*, Rate of Depletion after 50 years of pumping.

several miles upstream of Camp Verde to the sub-basin boundary. Depletion is also higher along Oak Creek upstream and downstream from Cornville. Values are lower along an 11-mile stretch of the Verde River below Cottonwood. Results for layer 1 at a pumping time of 50 years (fig. 4B) indicate similar patterns of higher and lower percentages of streamflow depletion, but with higher overall fractions because of the additional pumping time. Numerous municipal and private water company wells, and thousands of individually owned domestic wells, pump from this aquifer.

Results for layer 2 (C-aquifer) are shown in figures 5A and 5B. Because layer 2 covers a greater extent of the Verde Valley than does layer 1, the maps in Fig 5 show a larger area, extending beyond Sedona. Results indicate that for a pumping time of 10 years (fig. 5A), the greatest percentages of streamflow depletion (yellow to red colors; 70 to 10 percent) occur along the Verde River upstream from Cottonwood and downstream from Camp Verde, along reaches of Oak Creek, and along Wet Beaver Creek upstream from Rimrock. Results for layer 2 at a pumping time of 50 years (fig. 5B) indicate general increases in effects along the surface-water features and at greater distances from these features. Many of the private water company wells in the Sedona area pump from the C-aquifer.

The maps shown in figures 4 and 5 give the percent depletion for 10 and 50 years for a single pumping well, as a function of the location of that well. The procedure for using the maps is outlined in figure 6.

Applicability and Limitations

The procedure used for the analysis described in this report depicts responses to pumping or artificial recharge over large areas of an aquifer. The results are meant give resource managers and the public a general understanding of areas in which pumping or artificial recharge would result in faster or slower responses in surface-water flow and evapotranspiration. The distributions shown on Figs. 4 and 5 do not mean that groundwater pumping and (or) artificial recharge to the aquifer at all locations is appropriate or even technically feasible. Responses shown are based on features represented in the part of the NARGFM underlying the Verde Valley sub-basin. Although NARGRM is the most comprehensive and up-to-date tool available to examine effects from groundwater pumping or artificial recharge in the sub-basin, it is a regional model that cannot represent a high degree of local detail. For more information on these and other technical aspects of the results presented here, see Leake and Pool (2010).

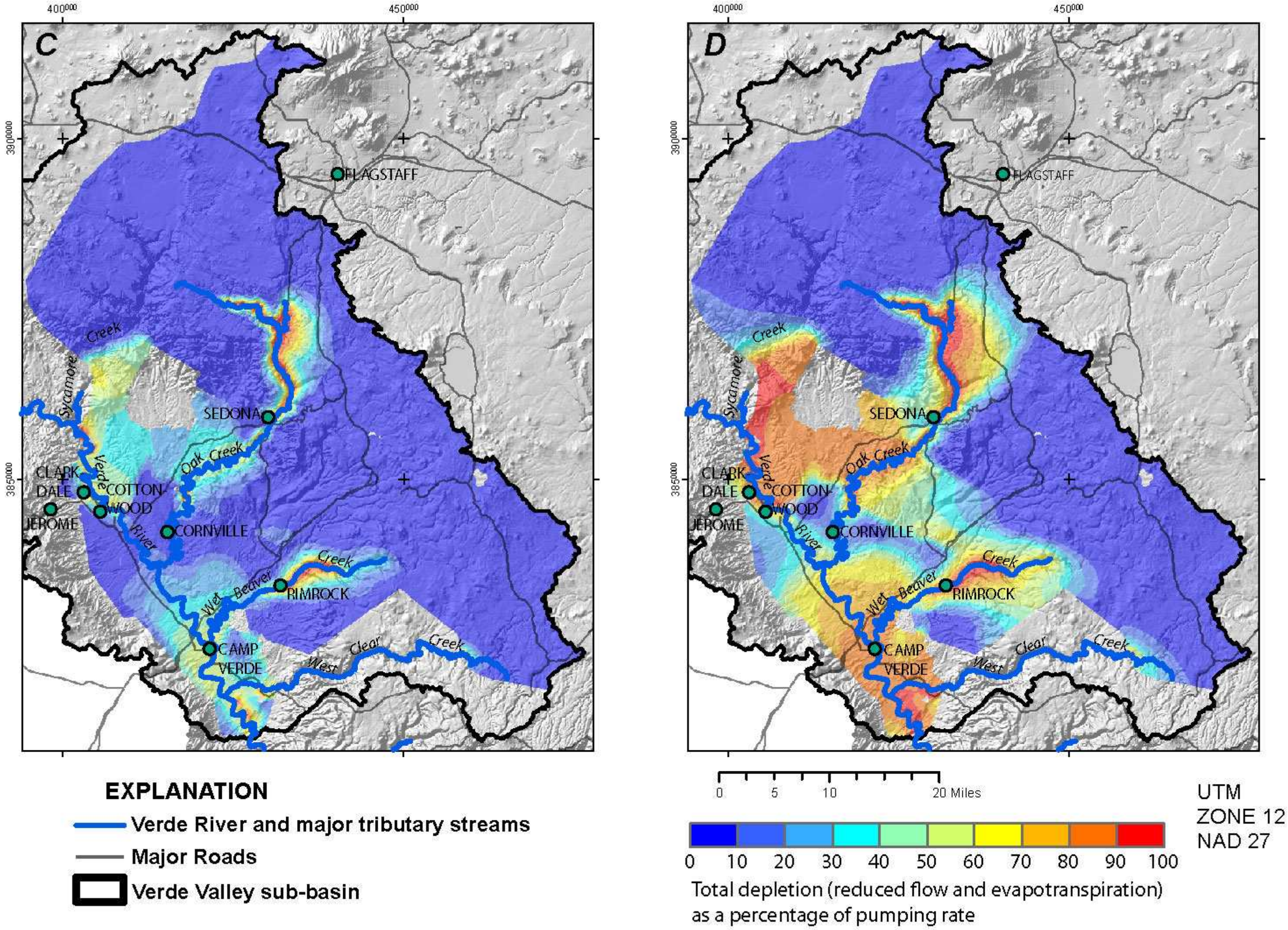

Figure 5. Depletion maps for wells pumping water from model layer 2, the lower part of the Verde Formation, the Supai Group, and volcanic rocks. *A*, rate of total depletion after 10 years of pumping. *B*, Rate of Depletion after 50 years of pumping.

EXAMPLE USE OF MAPS TO CALCULATE DEPLETION FOR A SINGLE WELL

Well pumps an average of 10 acre-feet per year from the upper part of the Verde Formation for 50 years

Step 1-Select the right map
- Use figures 4a and 4b for wells open in the upper part of the Verde Formation.
- Use figures 5a and 5b for wells open in the lower part of the Verde Formation, the Supai Group, and volcanic rocks.

Step 2-Find the location of the well on the map

Step 3-Note the percent range on the color bar corresponding to color at well location on map
In this example the range is 60 to 70 percent.

Step 4-Multiply corresponding fraction for color range by average well pumping rate to get average depletion rate
For the depletion range of 60 to 70 percent in this example, use a fraction of 0.65. Calculation is 0.65 x 10 acre-feet per year = 6.5 acre-feet per year of depletion at a pumping time of 50 years.

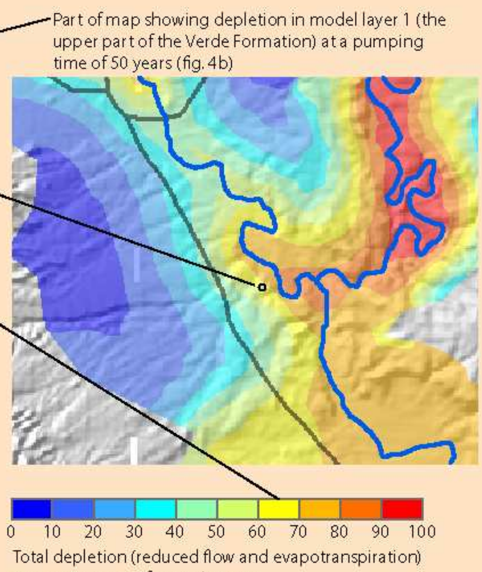

Figure 6. Example use of depletion maps shown in figures 4 and 5.

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