Possible Effects of Groundwater Pumping and Artificial Recharge on the Verde River and Tributaries

Stan Leake
U.S. Geological Survey
Tucson, Arizona
Study Area
Background

- The Verde Valley in north-central Arizona has experienced rapid population growth and increased groundwater use in recent decades.

- Managers need better information on timing of effects of groundwater pumping and artificial recharge on surface water and evapotranspiration.

- A new regional model is the best tool available for understanding these effects in the study area.

- A big-picture understanding of timing of effects could be done by mapping streamflow decrease or increase as a function of well or recharge location, as was done for the San Pedro Basin.
How Groundwater Pumping Can Affect Surface Water
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Sources of Water to a Pumped Well

When pumping starts:

Well A  
Well B

Relative amount of groundwater pumping rate coming from reduction in streamflow (depletion)

Relative amount of groundwater pumping rate coming from an aquifer storage (falling water table)
Sources of Water to a Pumped Well

When pumping starts:

After 10 years of pumping:

Well A

Well B

Relative amount of groundwater pumping rate coming from reduction in streamflow (depletion)

Relative amount of groundwater pumping rate coming from aquifer storage (falling water table)
Sources of Water to a Pumped Well

When pumping starts:

After 10 years of pumping:

After 50 years of pumping:

Well A

Well B

Stream

Relative amount of groundwater pumping rate coming from reduction in streamflow (depletion)

Relative amount of groundwater pumping rate coming from aquifer storage (falling water table)
Fate of Artificial Recharge

When recharge starts:
- Site A: 100%
- Site B: 100%

After 10 years of recharge:
- Site A: 70%
- Site B: 80%

After 50 years of recharge:
- Site A: 50%
- Site B: 60%

After infinite recharge time:
- Site A: 30%
- Site B: 40%

Relative amount of groundwater recharge rate going to increase in streamflow.
Relative amount of recharge rate going into aquifer storage (rising water table).

Stream

Recharge site A
Recharge site B
The timing of effects of pumping depends on
- Aquifer properties
- Distance to connected SW features
The timing of effects of recharge depends on
- Aquifer properties
- Distance to connected SW features

Change in groundwater storage (rising water table)

Total effect on stream and vegetation, possibly including:
- decreased inflow from stream
- increased outflow to stream
- increased evapotranspiration

The USGS logo is visible in the bottom right corner.
Effects of Artificial Recharge and Groundwater Pumping on a Stream Hydrograph

1. Hypothetical streamflow not affected by artificial recharge or groundwater pumping
Effects of Artificial Recharge and Groundwater Pumping on a Stream Hydrograph

2. A nearby artificial recharge project of 3 CFS starts at time = 1 year

Recharge project starts

Streamflow eventually is increased by 3 CFS
3. A nearby groundwater pumping project of 1 CFS starts at time = 4 years

Effects of Artificial Recharge and Groundwater Pumping on a Stream Hydrograph
Effects of Artificial Recharge and Groundwater Pumping on a Stream Hydrograph

4. Artificial recharge of 3 CFS begins at time = 1 year and groundwater pumping of 1 CFS begins at time = 4 years.

Recharge project starts
Pumping project starts
Net streamflow increase is 2 CFS
Possible Factors for Mitigation of Streamflow Depletion

1. Artificial recharge of external water or water from within basin that would not have otherwise recharged the aquifer.

2. Capture of previously rejected recharge.

3. Return flow of some of the pumped groundwater.
How can we compute the timing of depletion from groundwater pumping?

1. **Analytical solution**
   - used for regulatory purposes in Colorado and elsewhere
   - assumes the stream or river is straight
   - assumes the stream of river fully penetrates the aquifer
   - does not consider properties of different aquifer layers

2. **Groundwater-flow model**
   - used for regulatory purposes in Nebraska and elsewhere
   - can consider complex river and aquifer geometry
   - We have the newly developed Northern Arizona Regional Groundwater Flow Model that includes the Verde Valley sub-basin
Northern Arizona Regional Groundwater Flow Model

- 600 rows and 400 columns with 1-km grid spacing
- Three model layers representing different aquifer units
- Has no artificial boundaries
- Model report is “in press” and should be released soon
Flow Model in Study Area—hydrogeologic units

<table>
<thead>
<tr>
<th>HYDROGEOLOGIC UNITS</th>
<th>MODEL LAYERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUATERNARY ALLUVIUM</td>
<td>NOT SIMULATED</td>
</tr>
<tr>
<td>FLUVIO-LACUSTRINE FACIES OF THE VERDE FORMATION</td>
<td>LAYER 1</td>
</tr>
<tr>
<td>VOLCANIC ROCKS</td>
<td>LAYER 2</td>
</tr>
<tr>
<td>SAND AND GRAVEL FACIES OF THE VERDE FORMATION</td>
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<tr>
<td>UPPER AND MIDDLE SUPAI FORMATIONS</td>
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<td>LOWER SUPAI FORMATION</td>
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<td>REDWALL LIMESTONE AND OTHER CARBONATE ROCKS</td>
<td>LAYER 3</td>
</tr>
<tr>
<td>CRYSRTALLINE ROCK</td>
<td>LAYER 3</td>
</tr>
</tbody>
</table>
Flow Model in Study Area—active areas
Main Products of Study

- Report with select results including maps of total depletion for pumping locations in layers 1 and 2 for pumping times of 10 and 50 years

- A USGS fact sheet that shows main maps with explanations for less technical readers

- “Response functions” that can be used to make other maps or to compute effects of more complicated pumping and recharge scenarios
What is a response function?

Each transient response function for total depletion consists of depletion percentages for years 1-100. A separate response function exists for each pumping location.
Application for Verde Watershed—response at 10 years, layer 1
Application for Verde Watershed—response at 50 years, layer 1

USGS

Total change (decreased or increased surface-water flow and ET) as a percentage of pumping rate
Application for Verde Watershed—response at 10 years, layer 2
Application for Verde Watershed—response at 50 years, layer 2
Application for Verde Watershed—depletion at 50 years, layer 2

Areas where aquifer hydraulic conductivity in the model is the highest
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.

Part of map showing depletion in model layer 1 (the upper part of the Verde Formation) at a pumping time of 50 years (fig. 4b)

Total depletion (reduced flow and evapotranspiration) as a percentage of pumping rate
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**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.

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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 $0.65 \times 10$ acre-feet per year = 6.5 acre-feet per year of depletion at a pumping time of 50 years.
What is a response function?

Each transient response function for total decrease or increase in streamflow consists of percentages of pumping or recharge rate for years 1-100. A separate response function exists for each location.
Possible uses of response functions

Calculations of streamflow decrease or increase
• for times and locations (i.e. layer 3) not shown in report
• in select stream segments (transient or steady-state)
• from a well pumping at a variable rate, including intermittent pumping
• from multiple wells pumping at different locations and rates (an alternative to running the model for pumping scenarios)

Note: these applications assume reasonably linear behavior
Technical Report—

Simulated Effects of Groundwater Pumping and Artificial Recharge on Surface-Water Resources and Riparian Vegetation in the Verde Valley Sub-Basin, Central Arizona

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

The U.S. Geological Survey (USGS), in cooperation with The Nature Conservancy, has applied a groundwater model to simulate effects of groundwater pumping and artificial recharge on surface water in the Verde Valley, Arizona. Results are in two sets of maps that show effects of locations of pumping or recharge on streamflow. These maps will help managers make decisions that will meet water needs and minimize environmental impacts.

To be posted on the internet at http://pubs.usgs.gov/fs/2010/3108/
—will be printed in early 2011