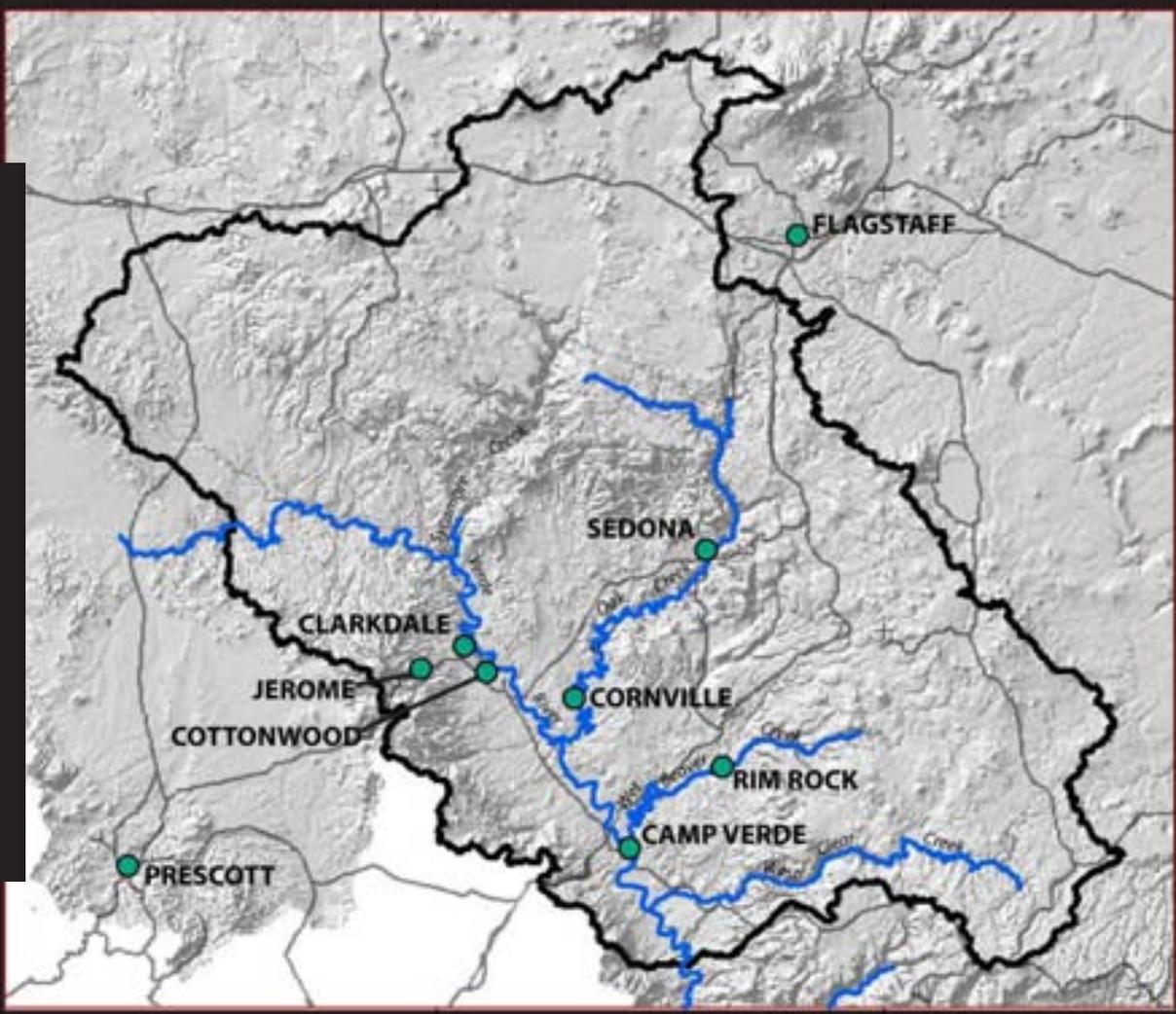


Possible Effects of Groundwater Pumping and Artificial Recharge on the Verde River and Tributaries

Stan Leake
U.S. Geological Survey
Tucson, Arizona



Study Area

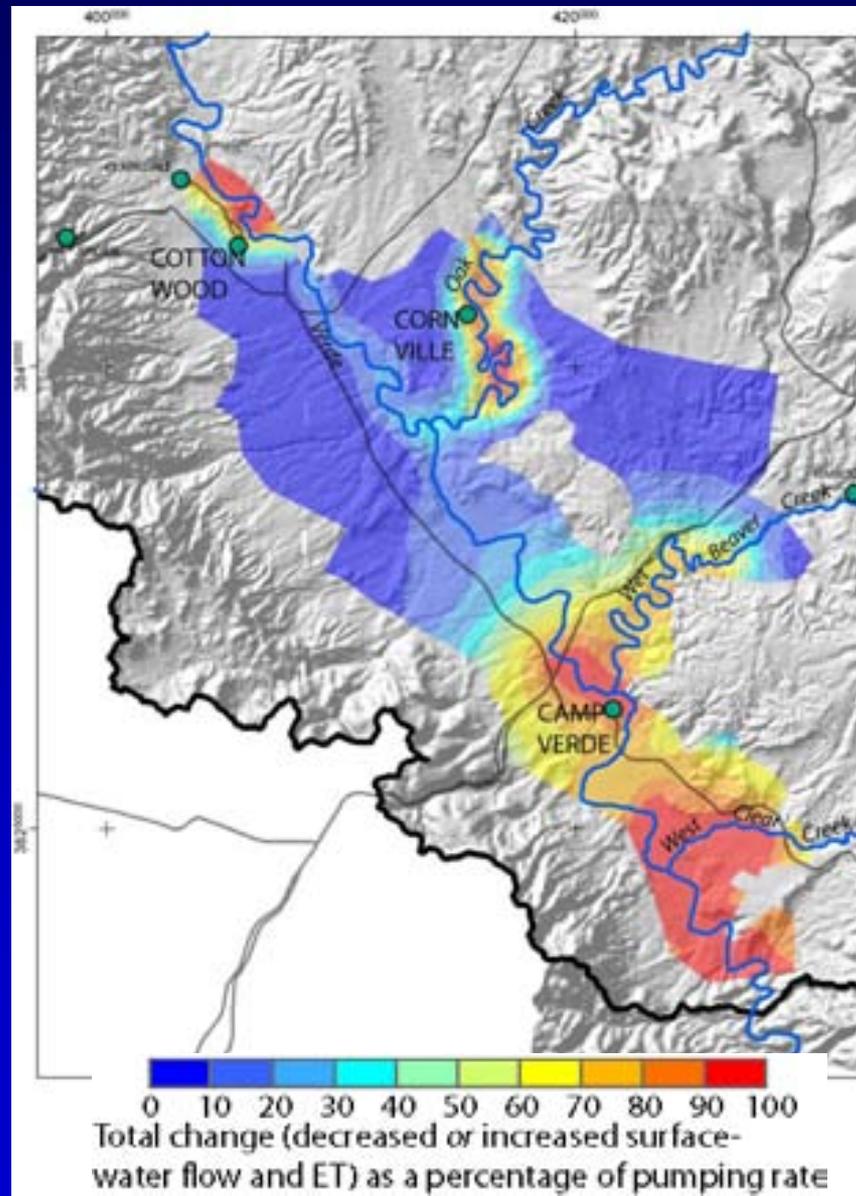


UTM
ZONE 12
NAD27

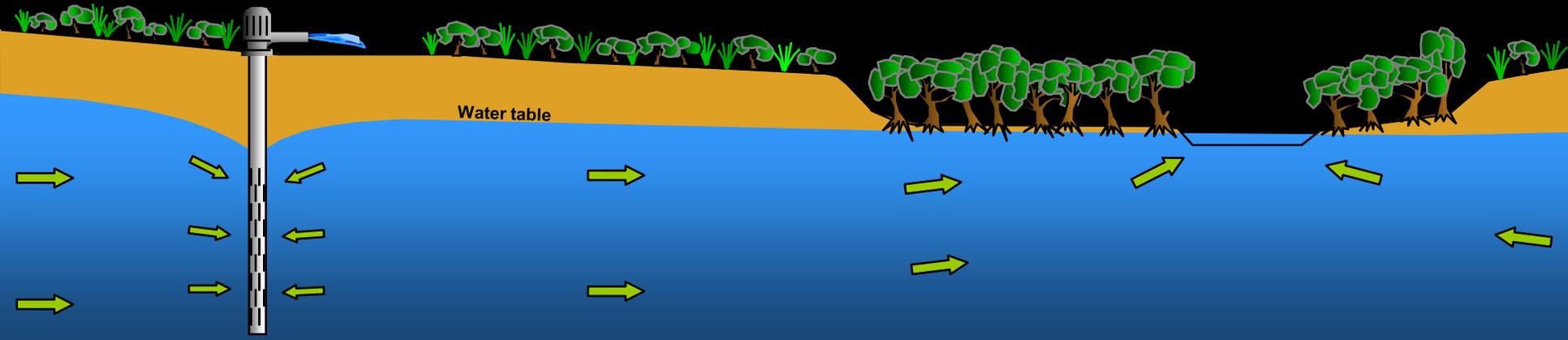
Background

- 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

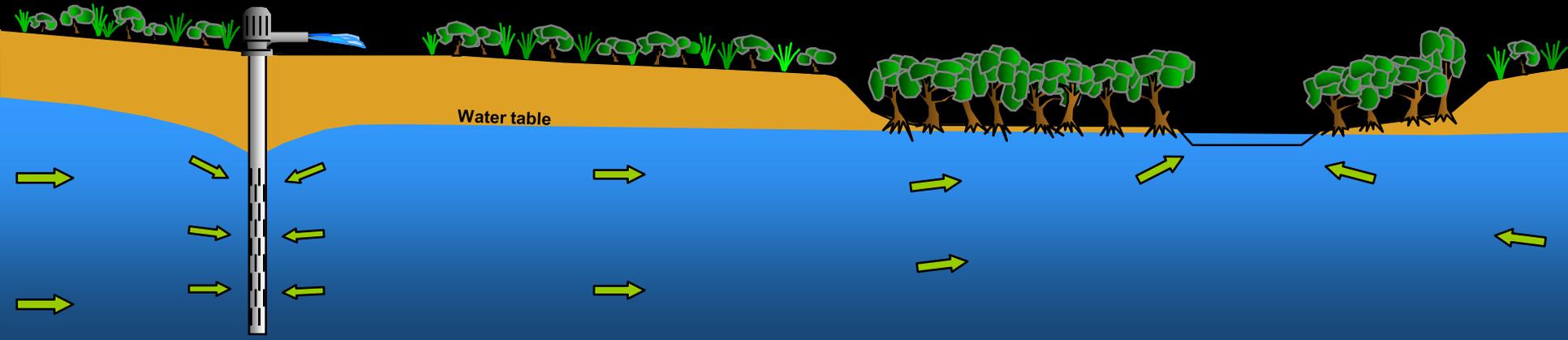
EXAMPLE MAP SHOWING EFFECTS OF PUMPING OR ARTIFICIAL RECHARGE ON SURFACE WATER



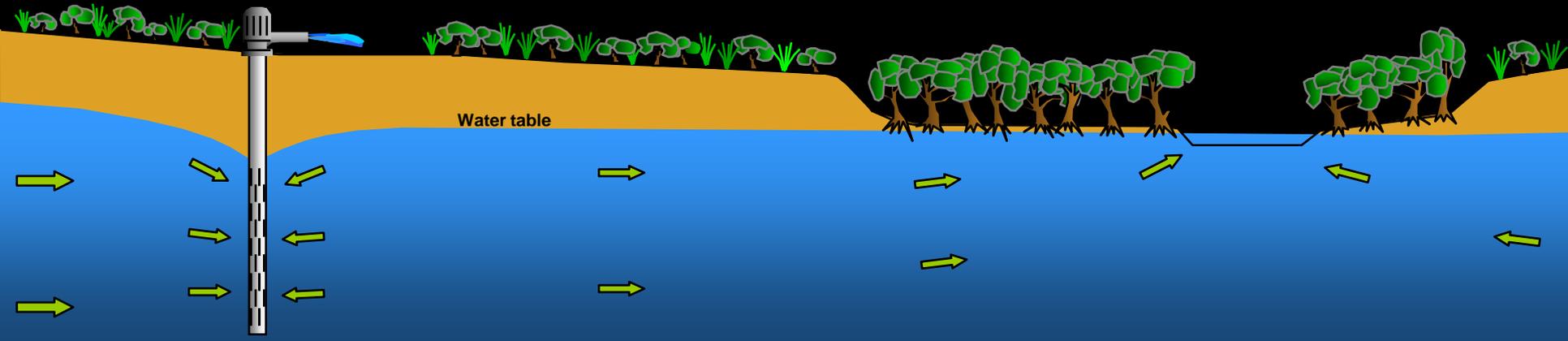
How Groundwater Pumping Can Affect Surface Water



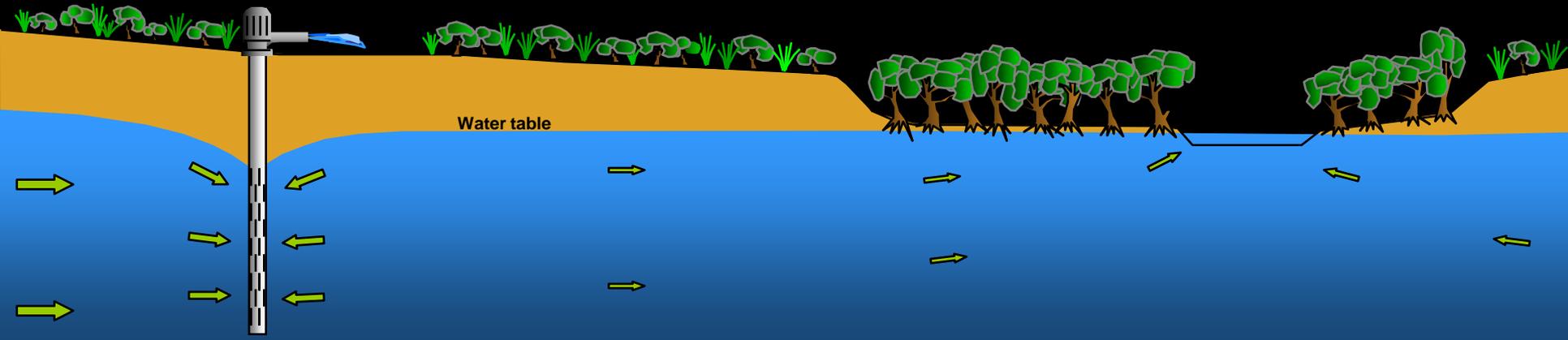
How Groundwater Pumping Can Affect Surface Water



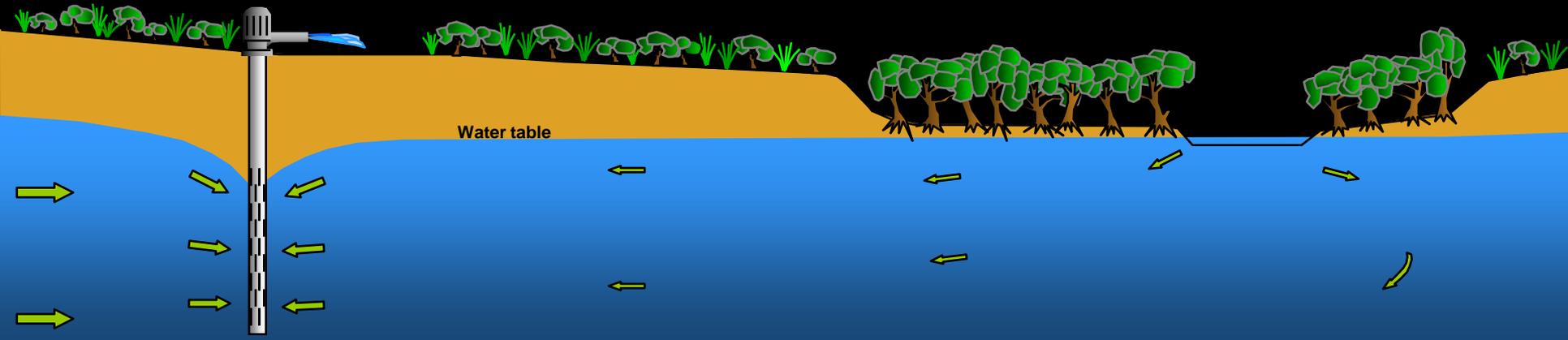
How Groundwater Pumping Can Affect Surface Water



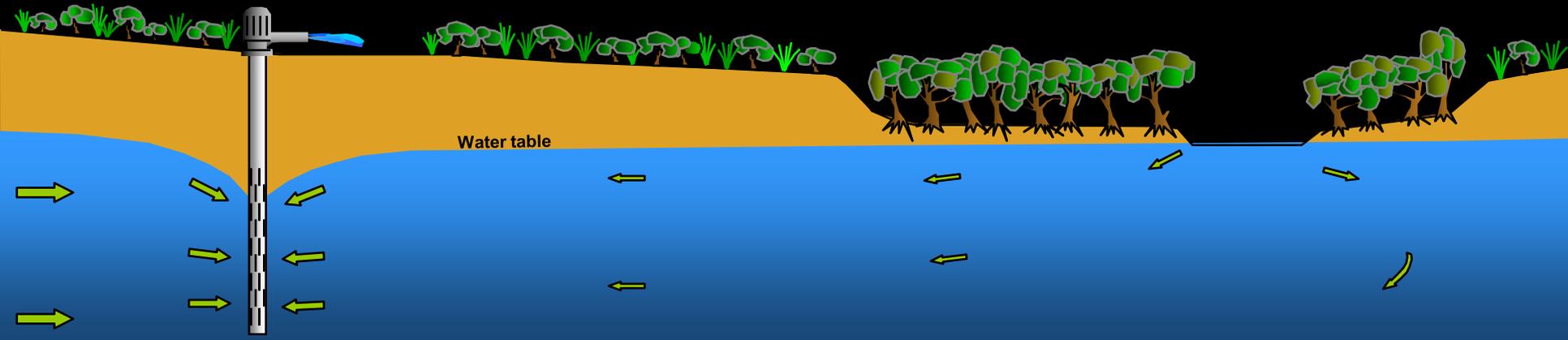
How Groundwater Pumping Can Affect Surface Water



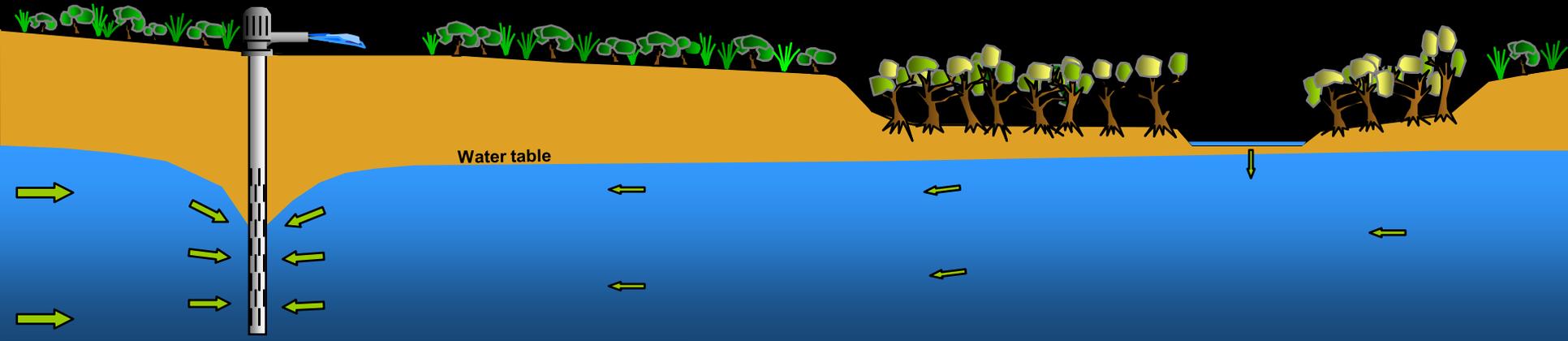
How Groundwater Pumping Can Affect Surface Water



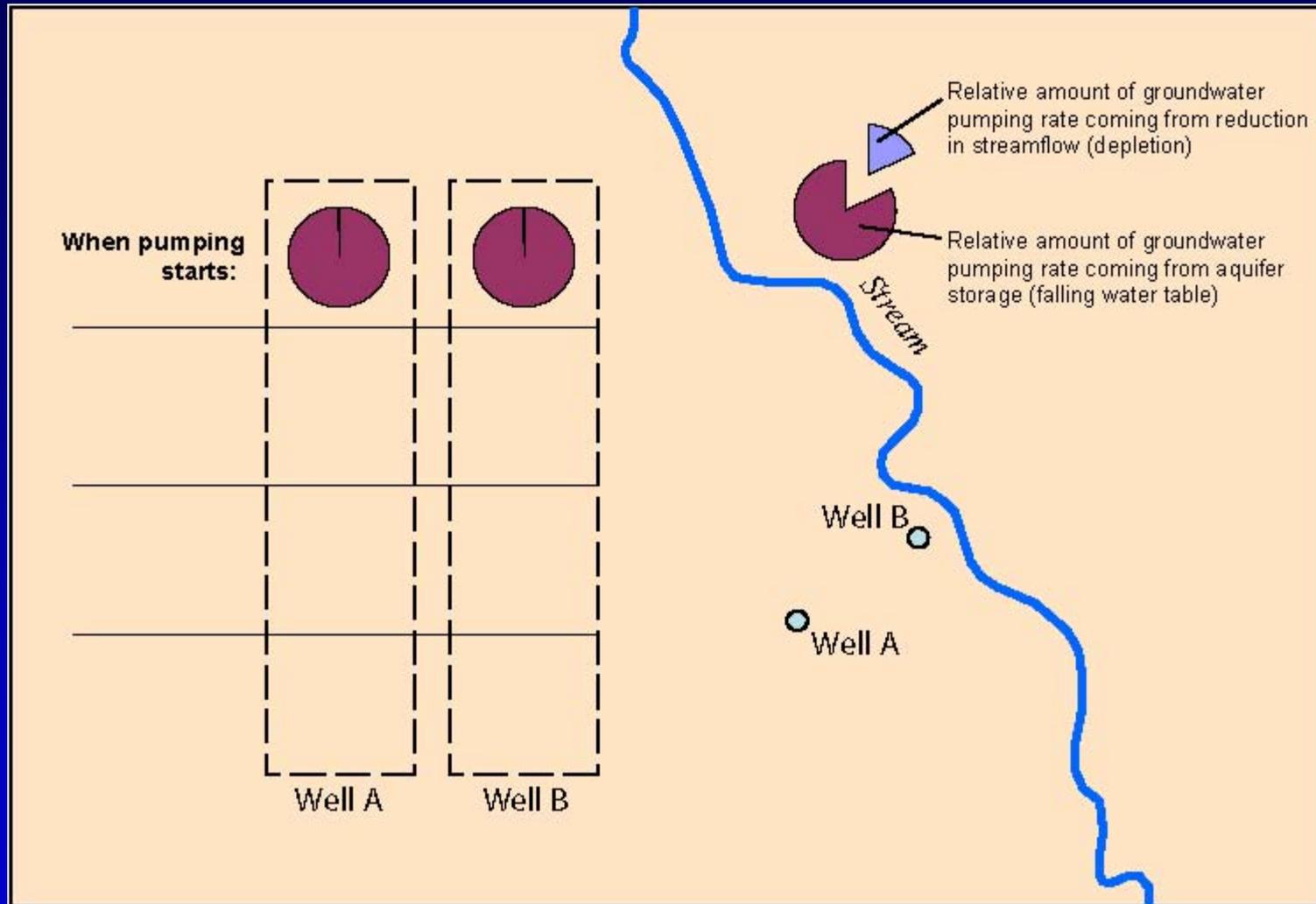
How Groundwater Pumping Can Affect Surface Water



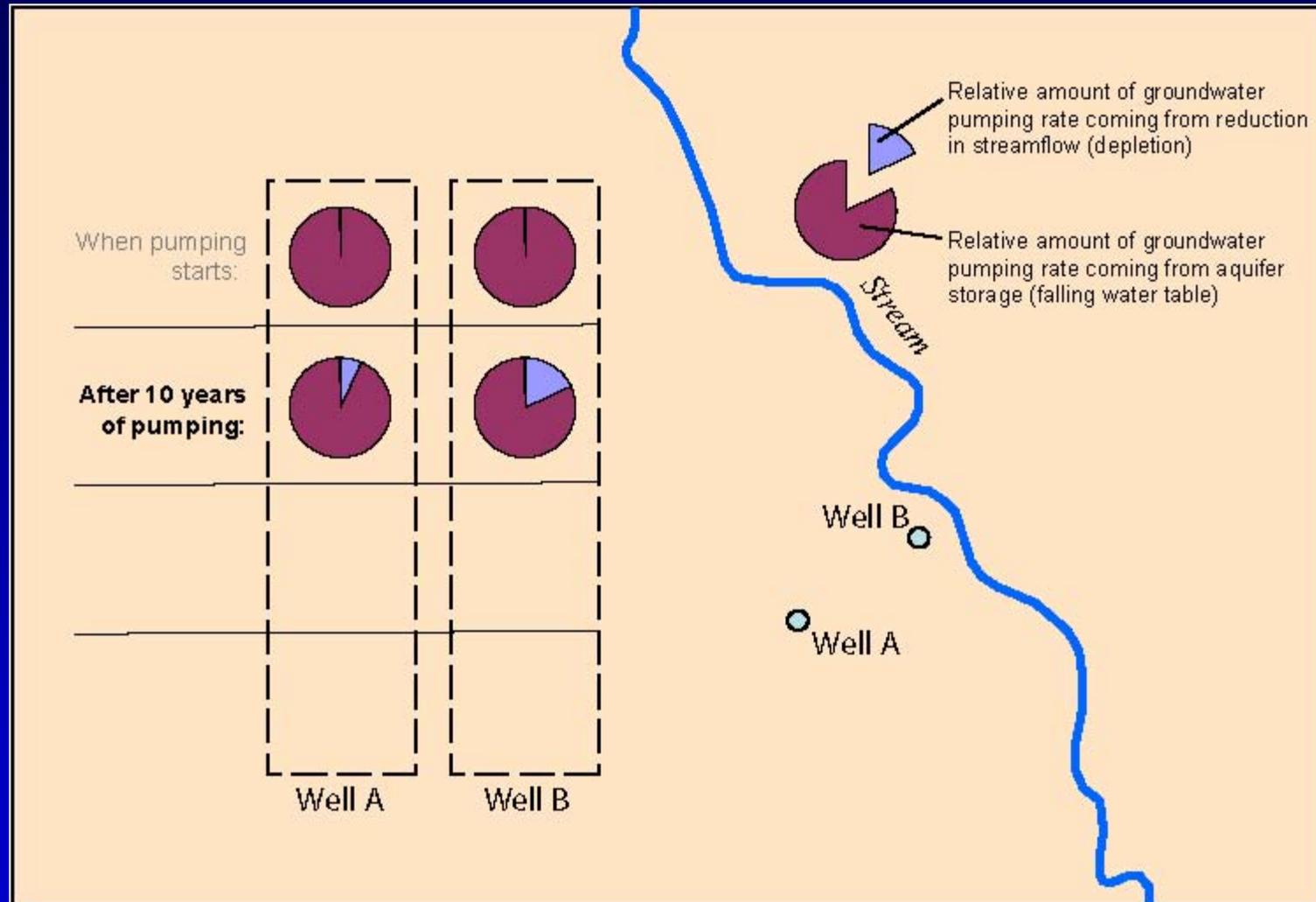
How Groundwater Pumping Can Affect Surface Water



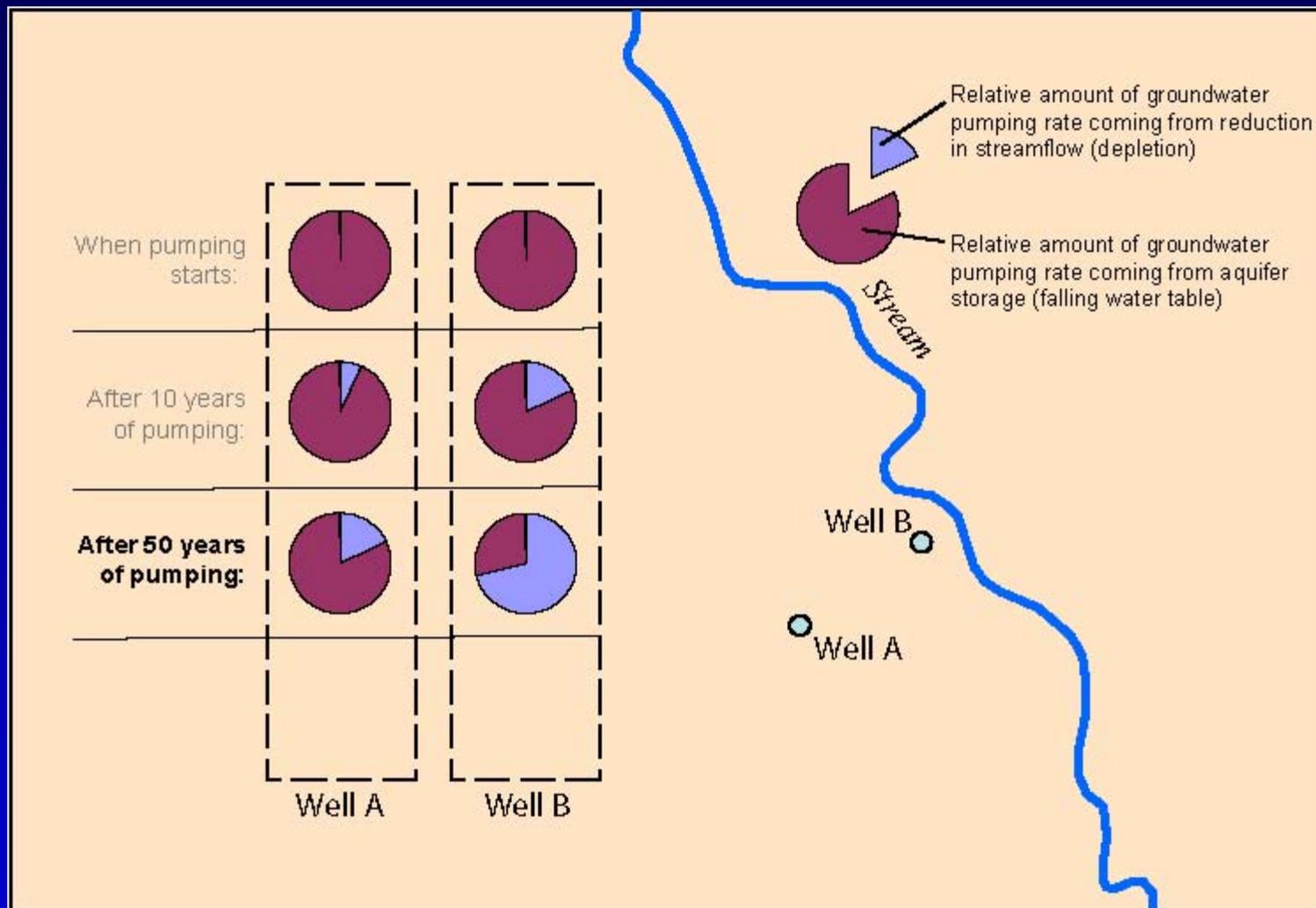
Sources of Water to a Pumped Well



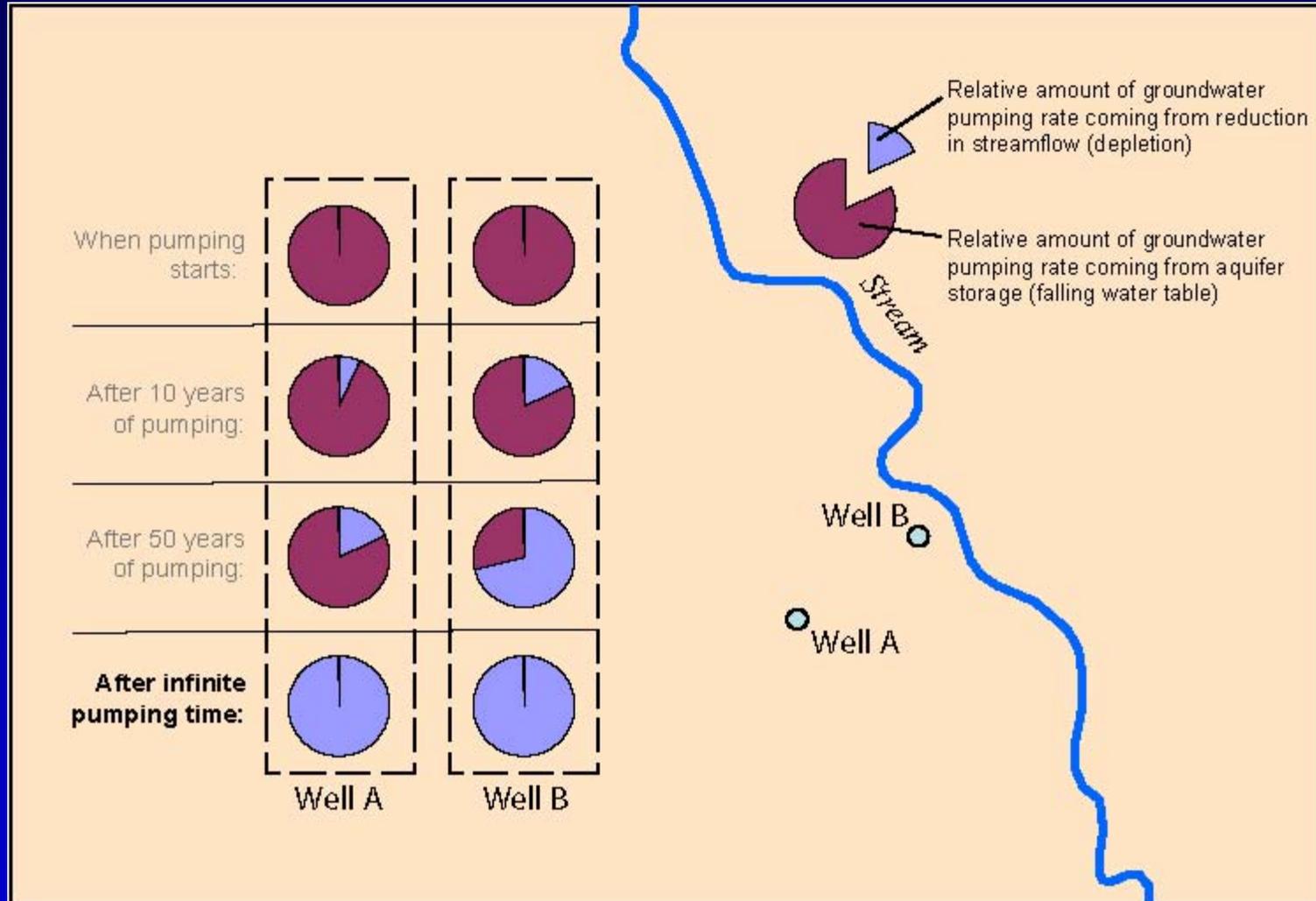
Sources of Water to a Pumped Well



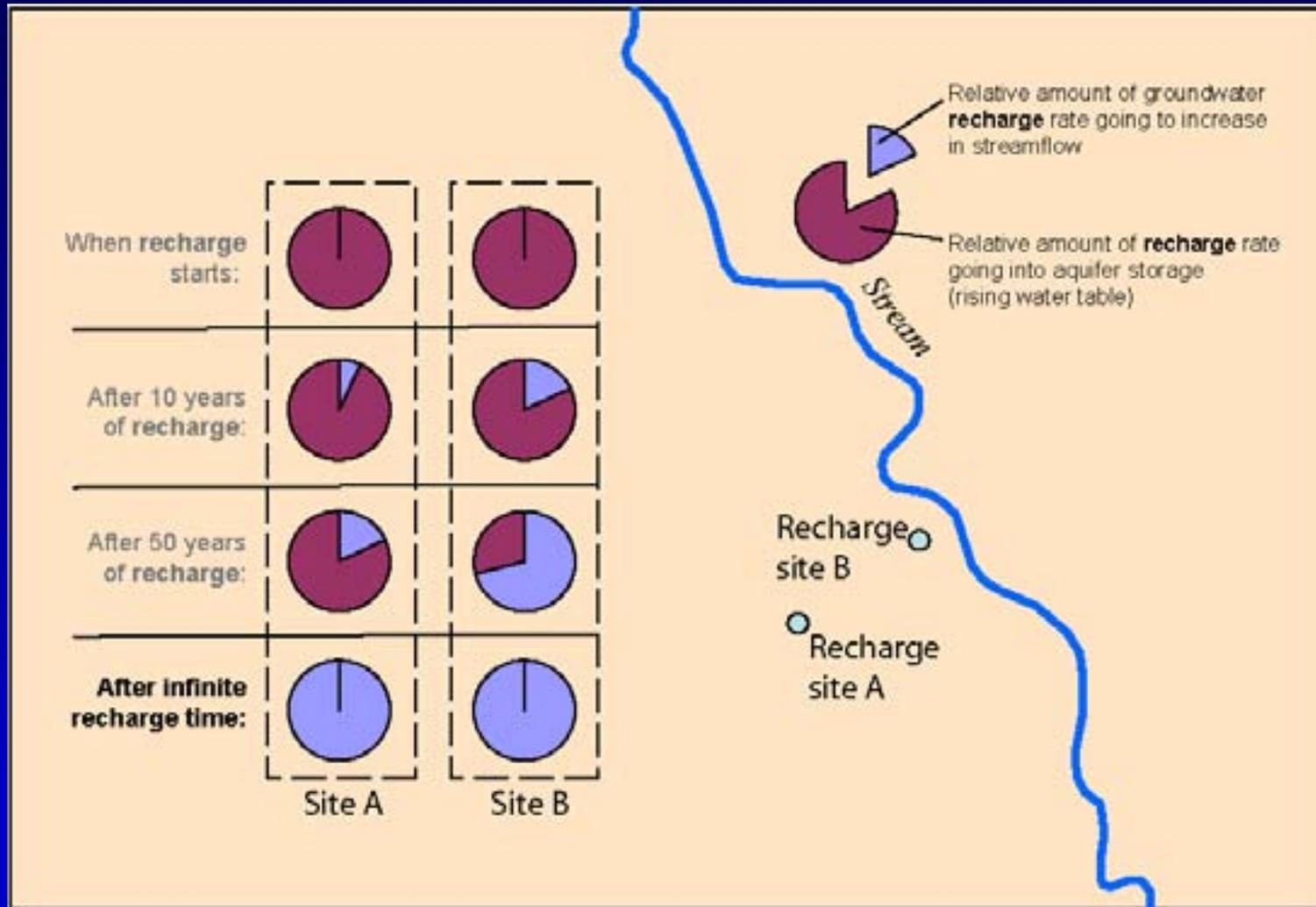
Sources of Water to a Pumped Well



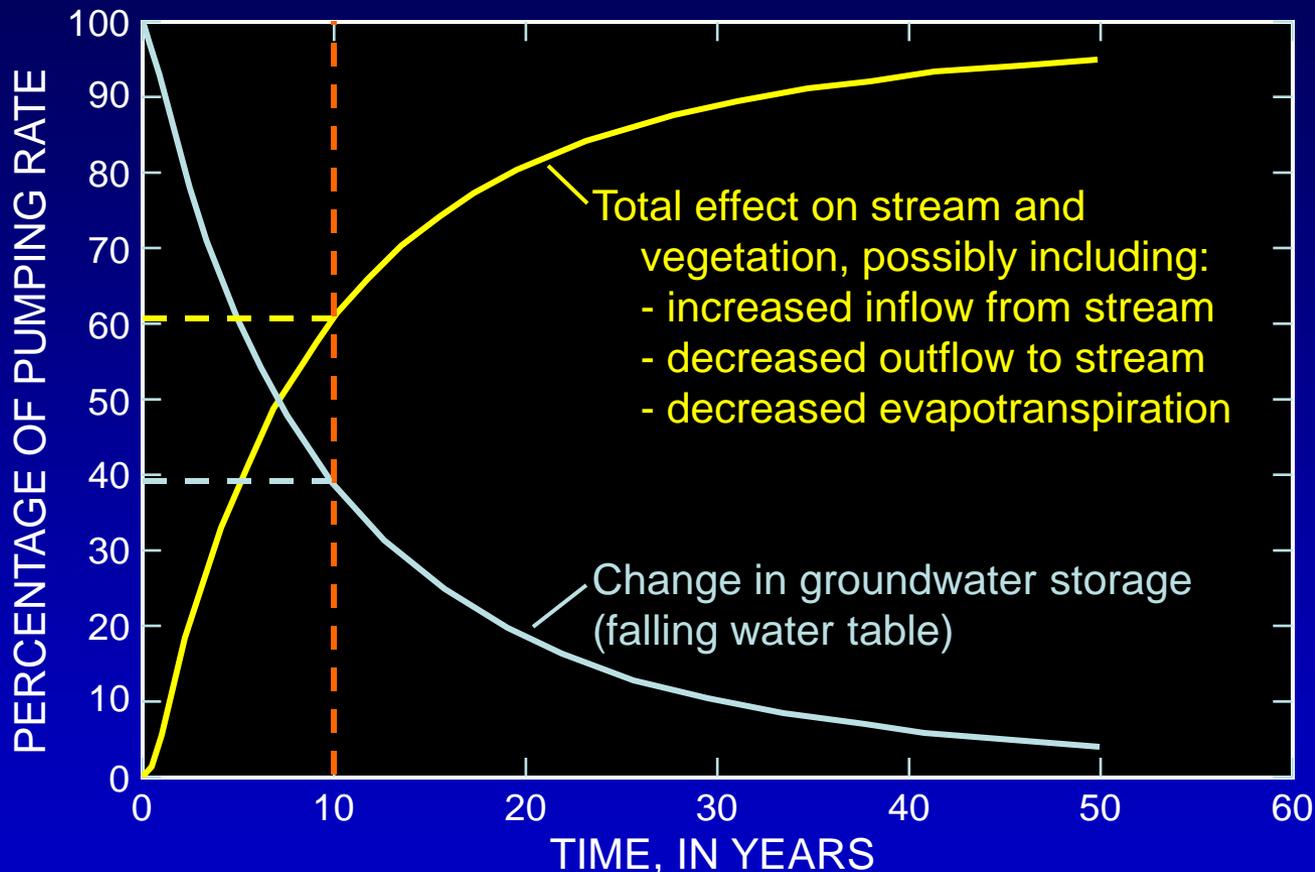
Sources of Water to a Pumped Well



Fate of Artificial Recharge



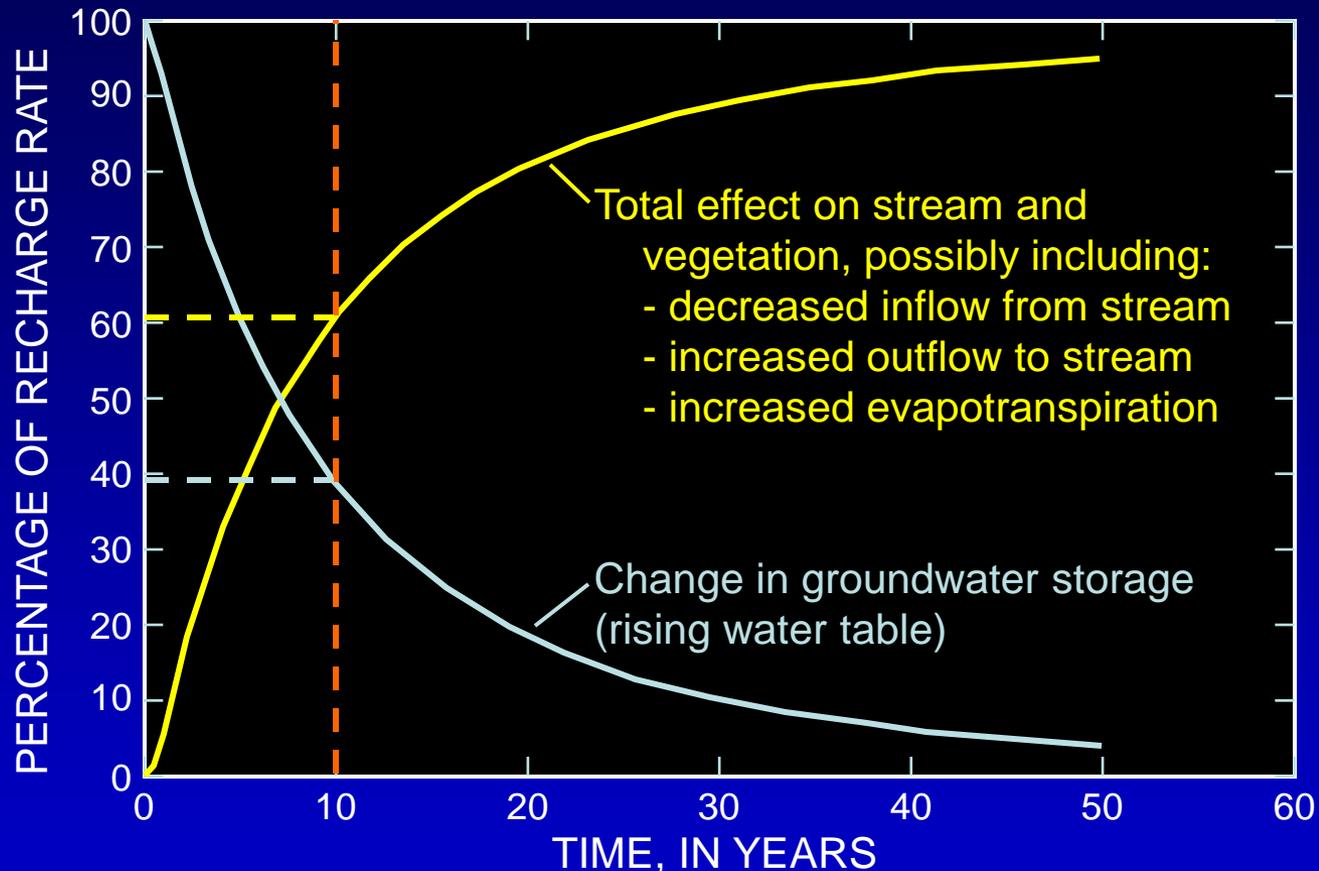
Sources of Water to a Pumped Well



The timing of effects of pumping depends on

- Aquifer properties
- Distance to connected SW features

Fate of Recharged Water

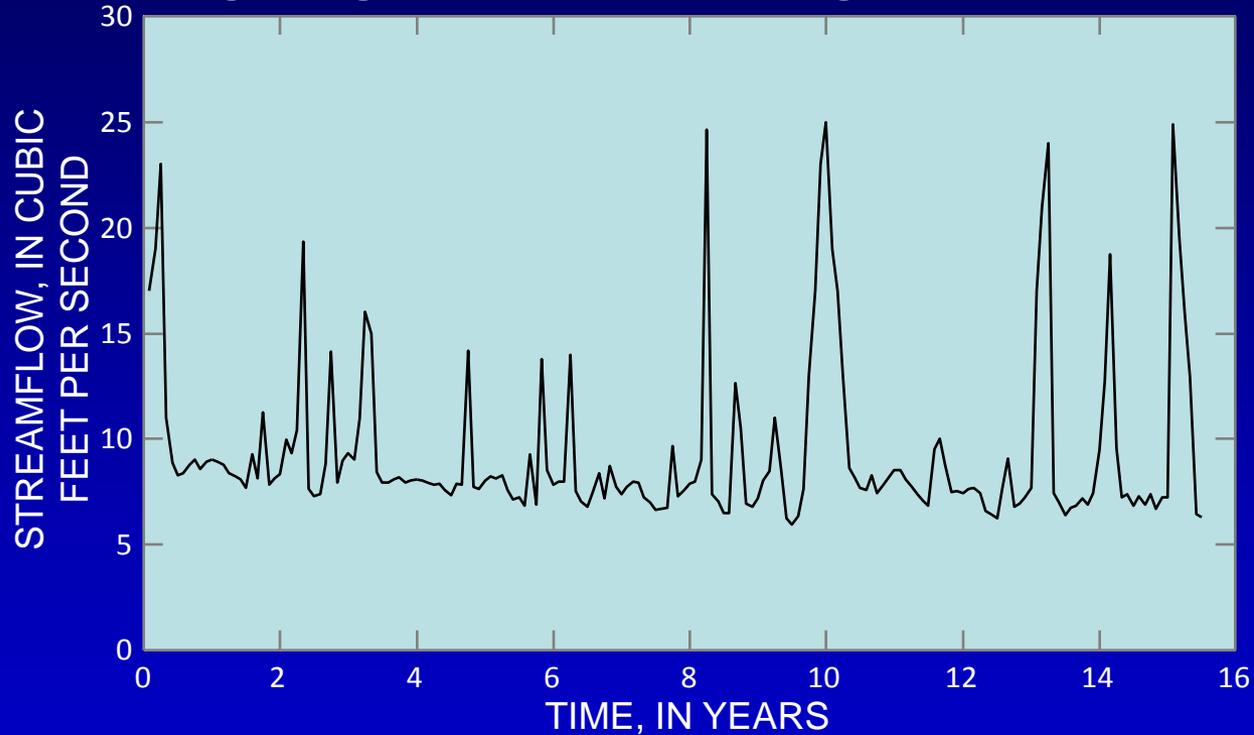


The timing of effects of recharge depends on

- Aquifer properties
- Distance to connected SW features

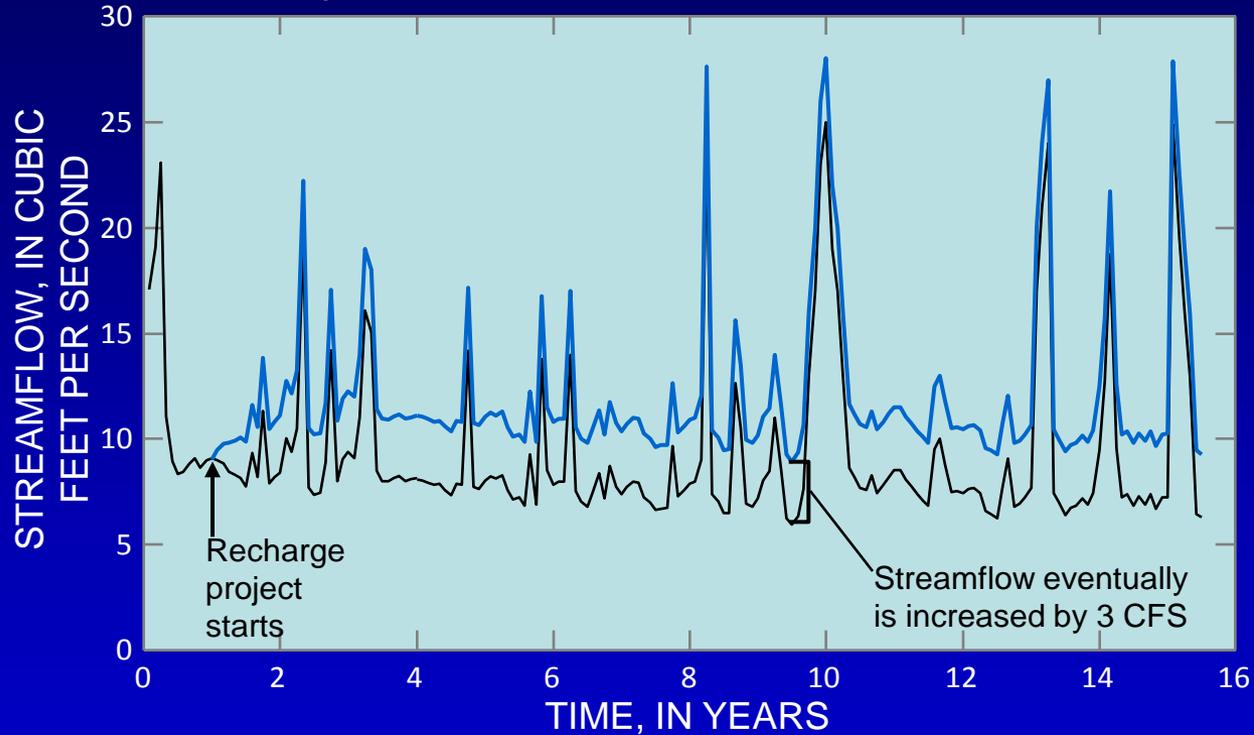
Effects of Artificial Recharge and Groundwater Pumping on a Stream Hydrograph

1. Hypothetical streamflow not affected by artificial recharge or groundwater pumping



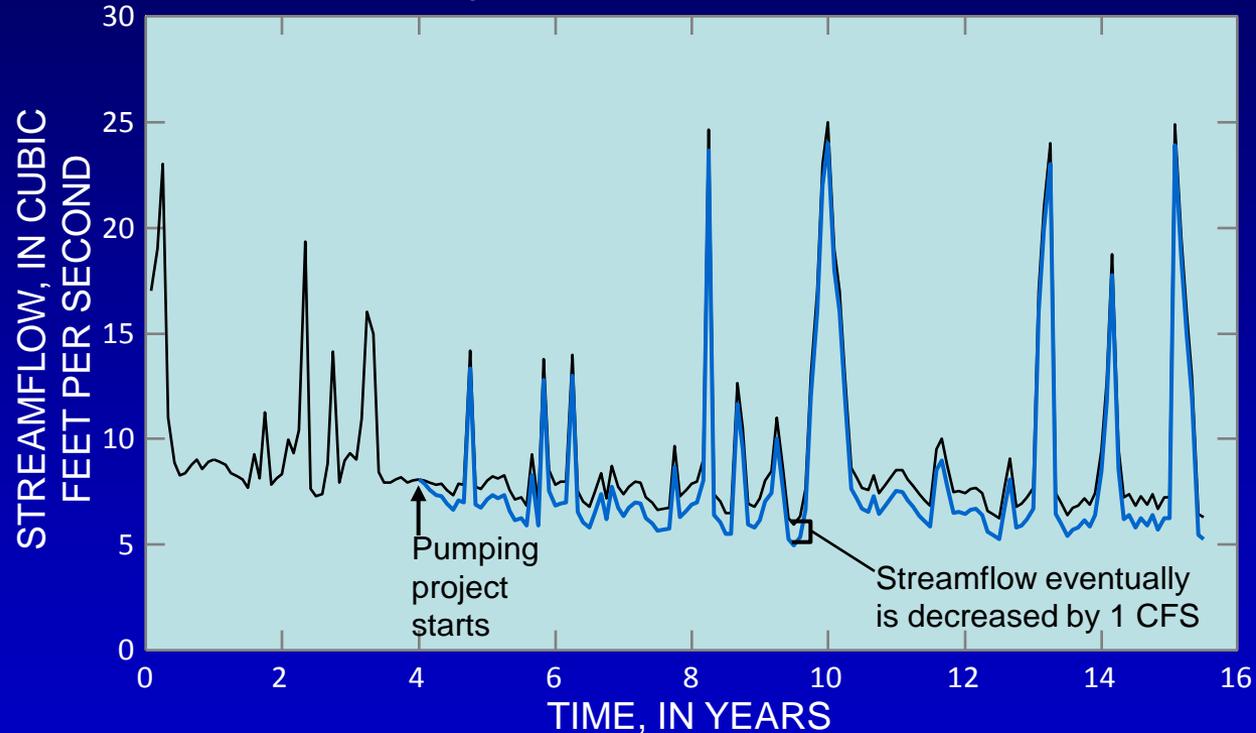
Effects of Artificial Recharge and Groundwater Pumping on a Stream Hydrograph

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



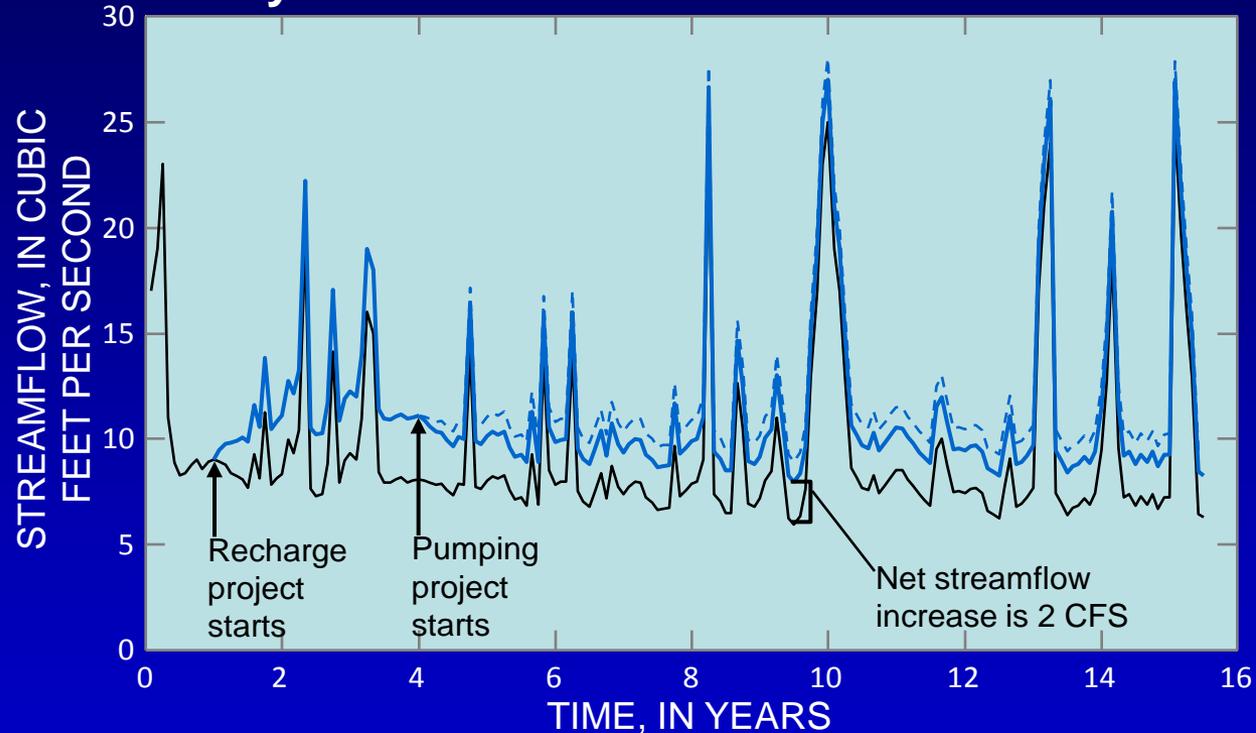
Effects of Artificial Recharge and Groundwater Pumping on a Stream Hydrograph

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

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



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?

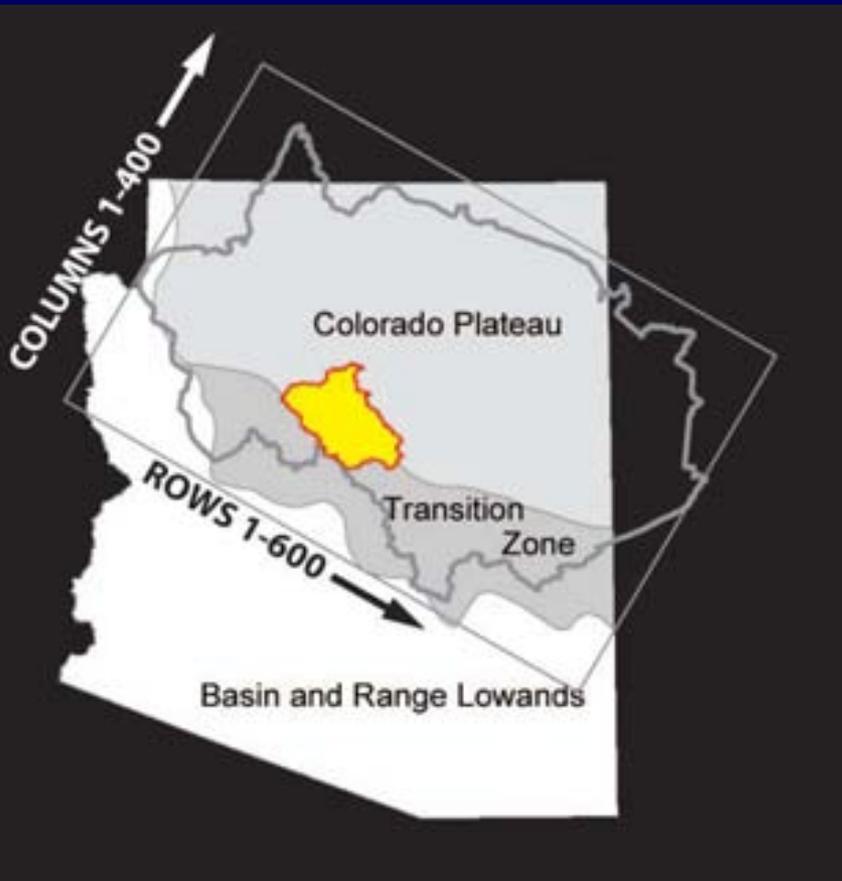
1. Analytical solution

- used for regulatory purposes in Colorado and elsewhere
- assumes the stream or river is straight
- assumes the stream or 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

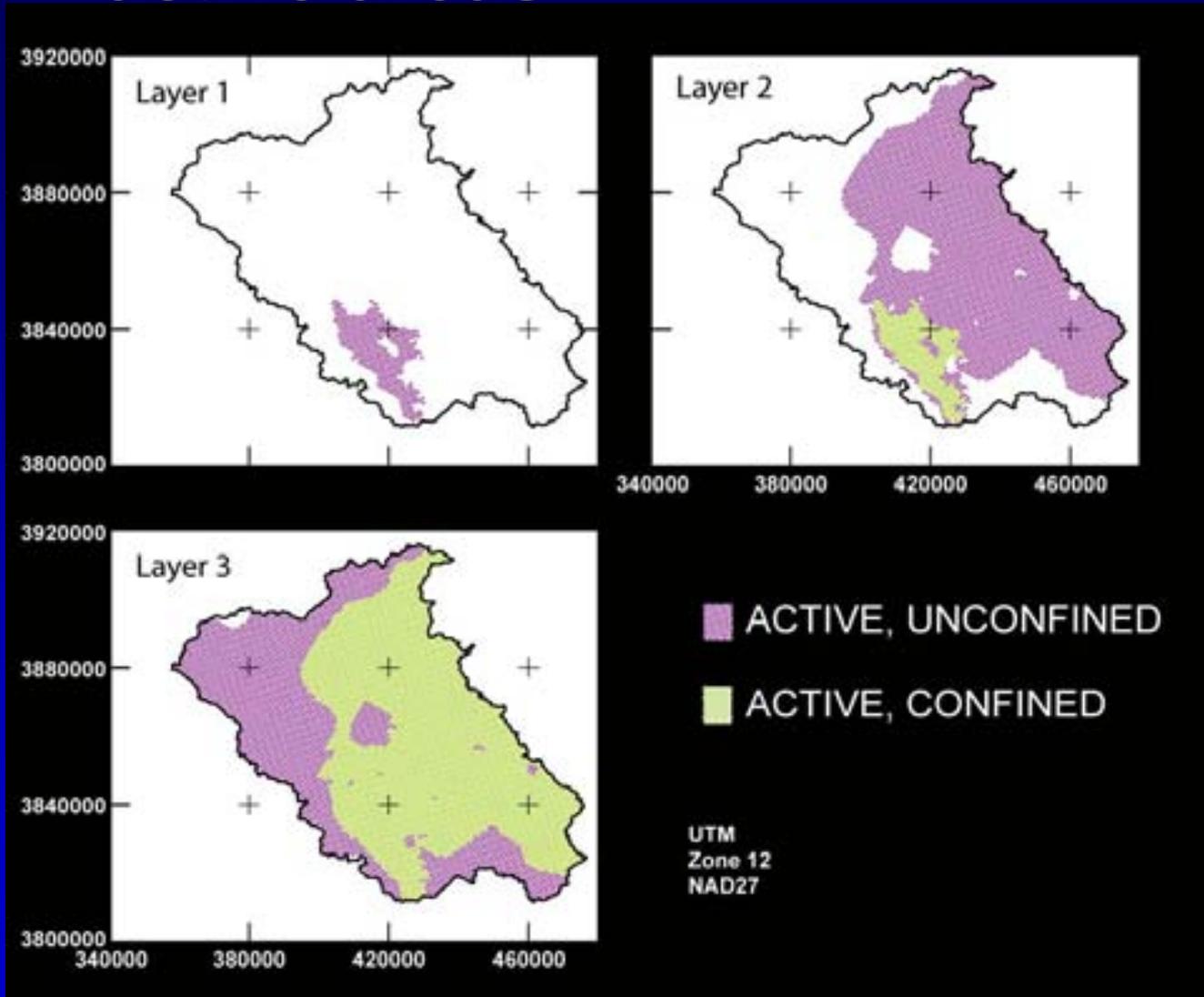


- 600 rows and 400 columns with 1-km grid spacing
- Three model layers representing different aquifer units
- Has no artificial boundaries
- Model report is “in press” and should be released soon

Flow Model in Study Area— hydrogeologic units

| HYDROGEOLOGIC UNITS | MODEL LAYERS |
|--|---------------|
| QUATERNARY ALLUVIUM | NOT SIMULATED |
| FLUVIO-LACUSTRINE FACIES OF THE VERDE FORMATION <div data-bbox="809 665 1112 758" style="border: 1px solid black; padding: 2px; display: inline-block;">BASALT</div> | LAYER 1 |
| SAND AND GRAVEL FACIES OF THE VERDE FORMATION <div data-bbox="629 829 817 922" style="border: 1px solid black; padding: 2px; display: inline-block;">VOLCANIC ROCKS</div> <div data-bbox="832 791 1170 885" style="border: 1px solid black; padding: 2px; display: inline-block;">UPPER AND MIDDLE SUPAI FORMATIONS</div> <div data-bbox="832 893 1170 988" style="border: 1px solid black; padding: 2px; display: inline-block;">LOWER SUPAI FORMATION</div> | LAYER 2 |
| REDWALL LIMESTONE AND OTHER CARBONATE ROCKS <div data-bbox="562 1005 1170 1153" style="border: 1px solid black; padding: 2px; display: inline-block;">CRYSTALLINE ROCK</div> | LAYER 3 |

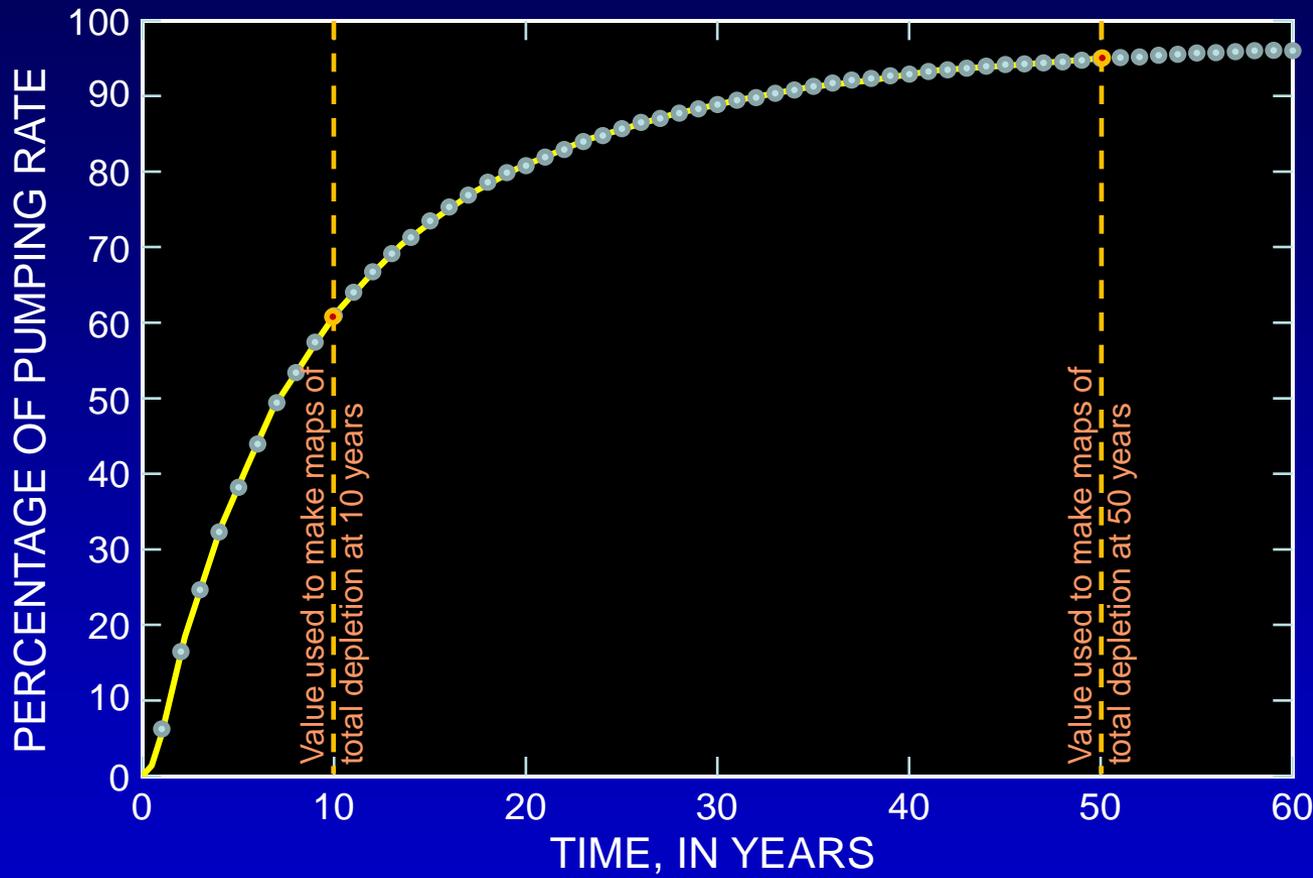
Flow Model in Study Area— active areas



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

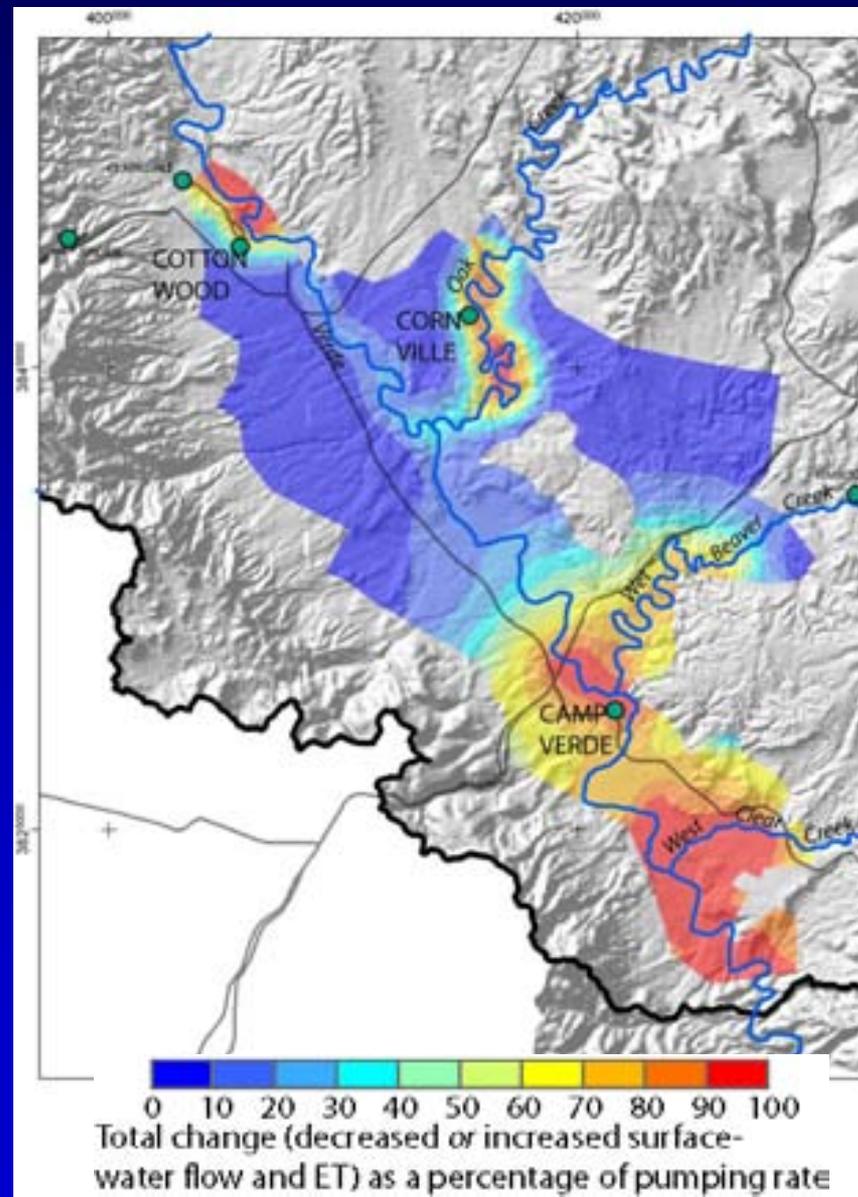
What is a response function?



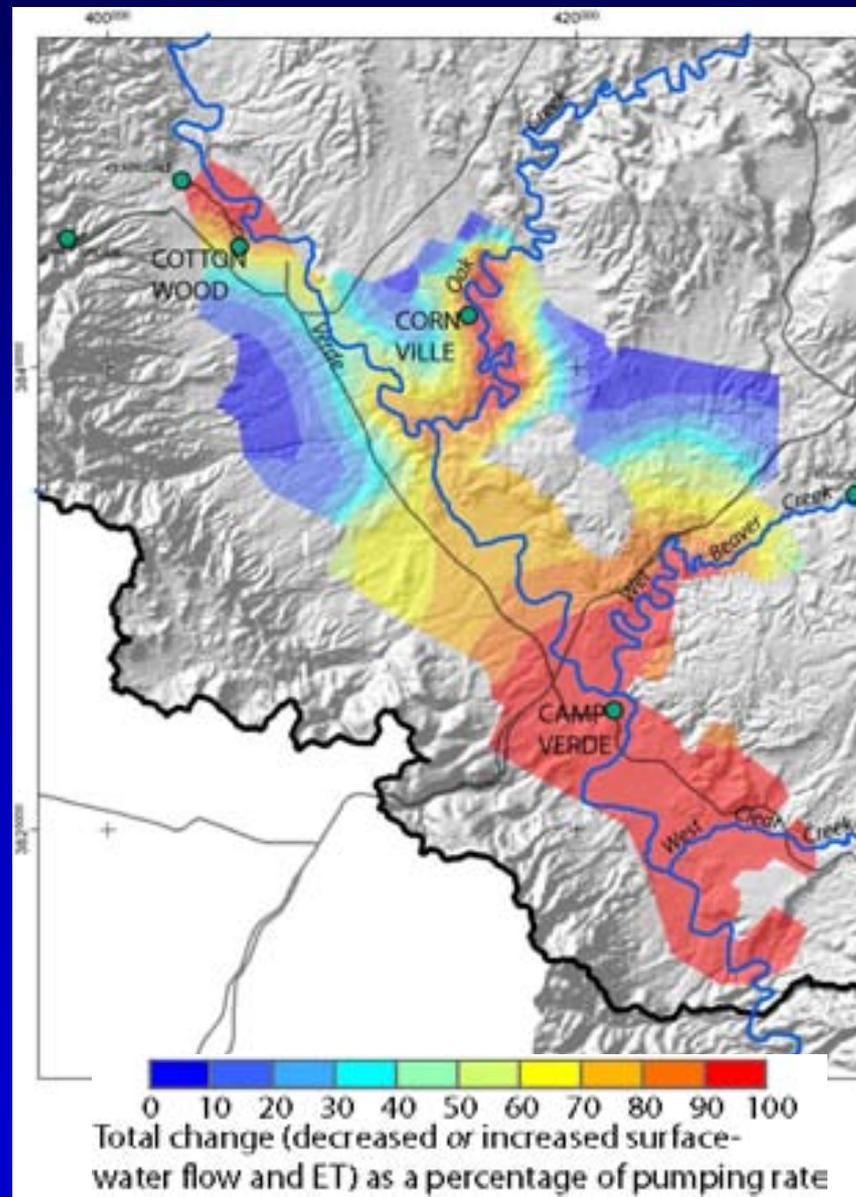
Each transient response function for total depletion consists of depletion percentages for years 1-100. A separate response function exists for each pumping location.



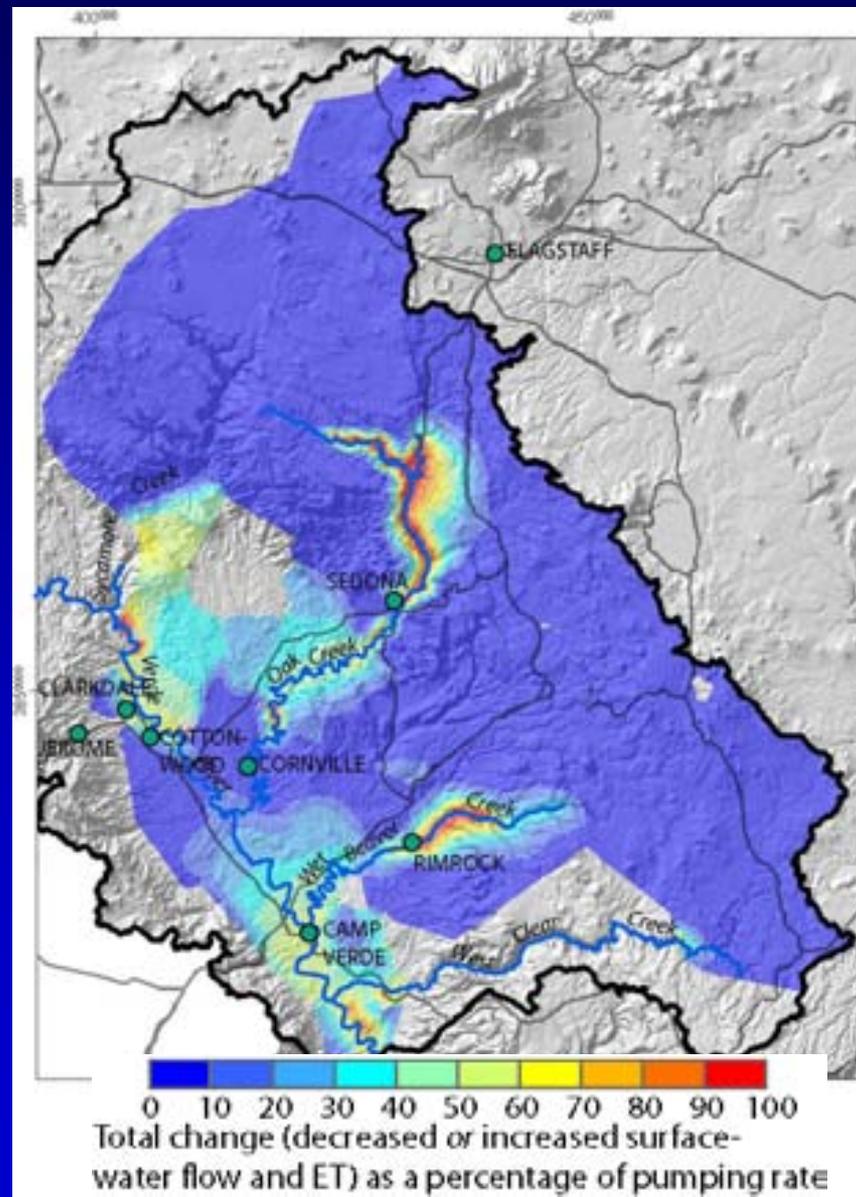
Application for Verde Watershed— response at 10 years, layer 1



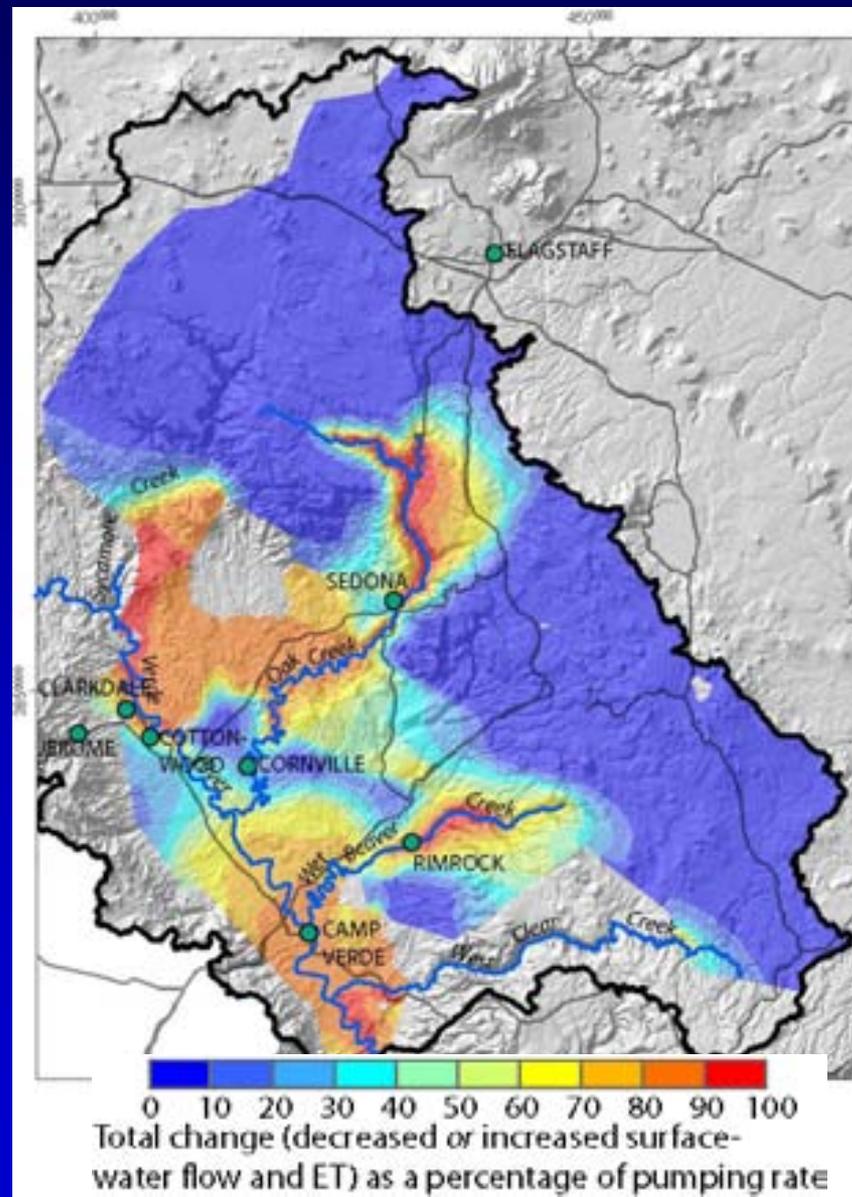
Application for Verde Watershed— response at 50 years, layer 1



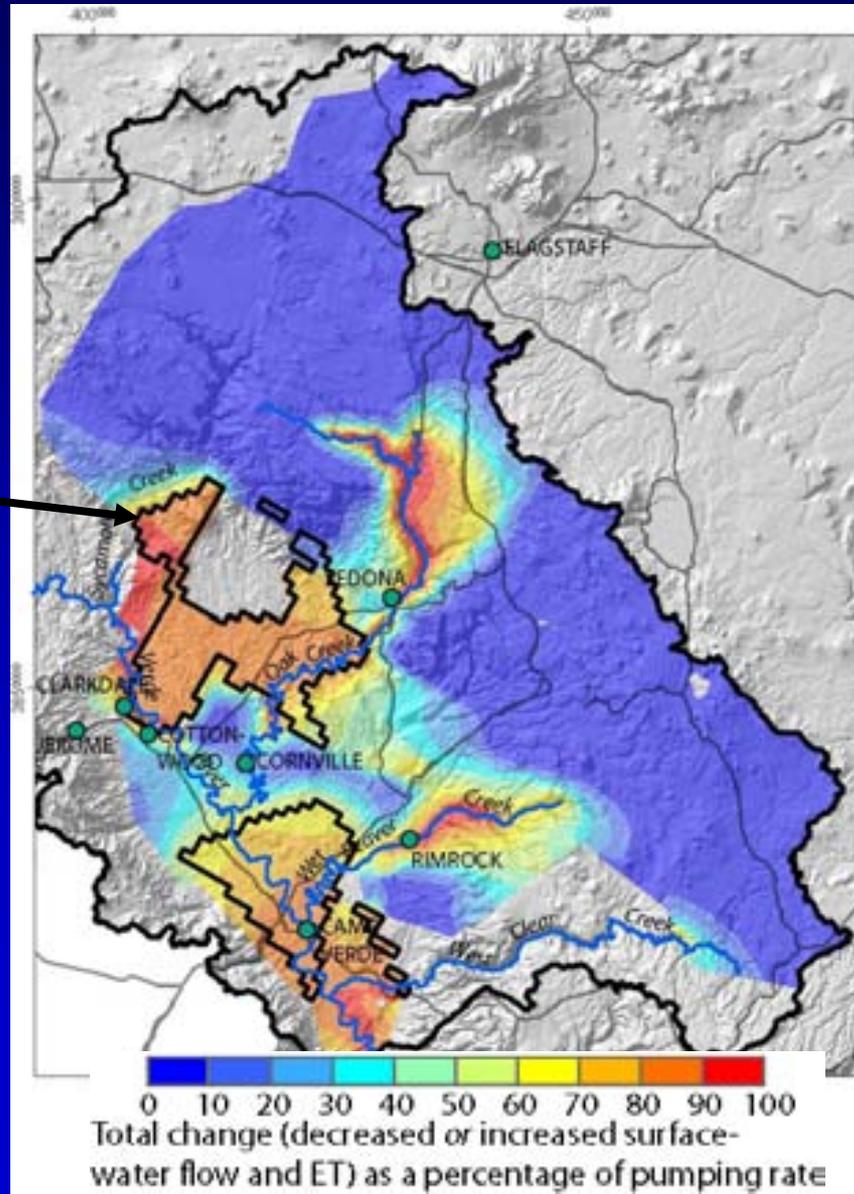
Application for Verde Watershed— response at 10 years, layer 2



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

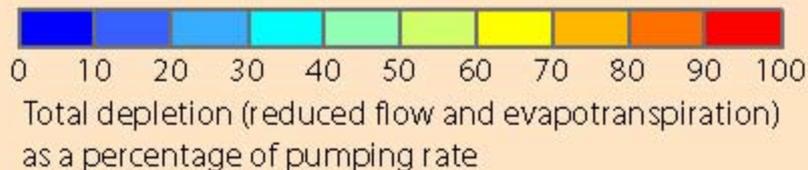
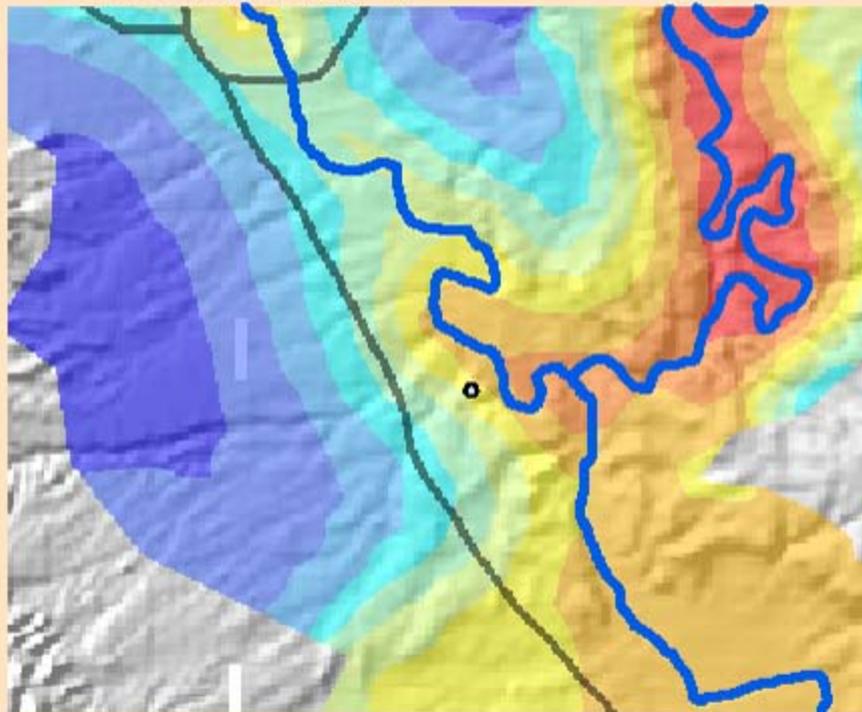
EXAMPLE USE OF MAPS TO CALCULATE DEPLETION FOR A SINGLE WELL

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)



EXAMPLE USE OF MAPS TO CALCULATE DEPLETION FOR A SINGLE WELL

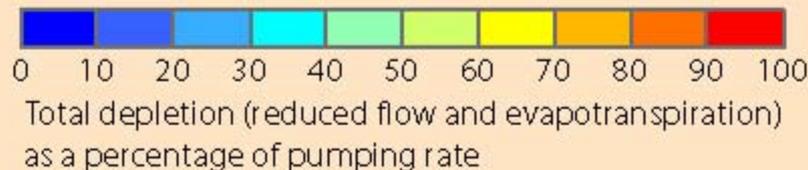
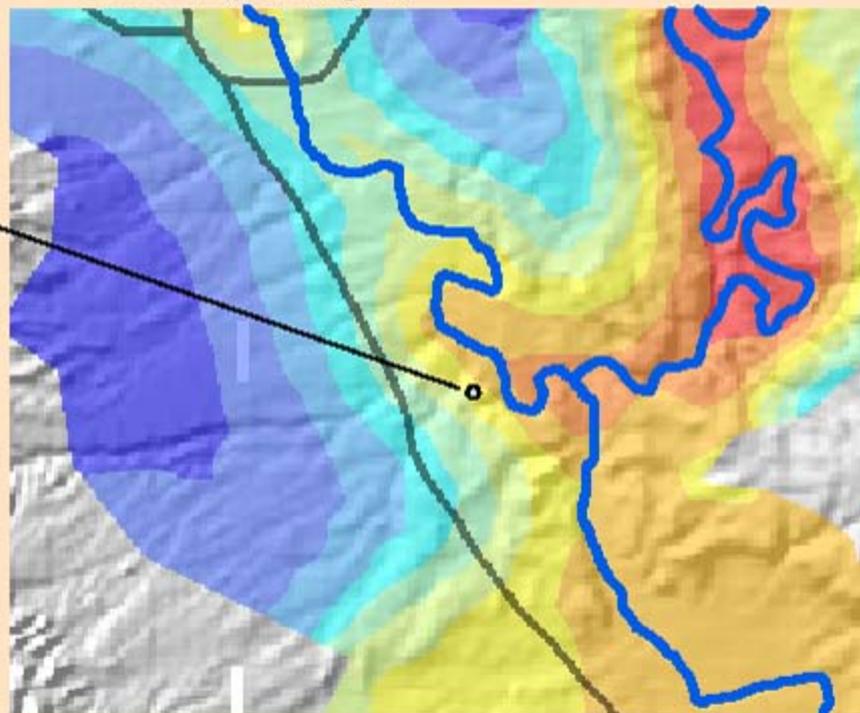
Well pumps an average of 10 acre-feet per year from the upper part of the Verde Formation for 50 years

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

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)



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

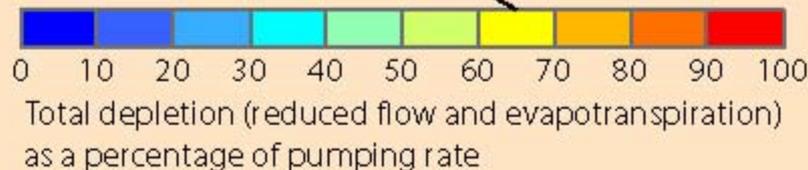
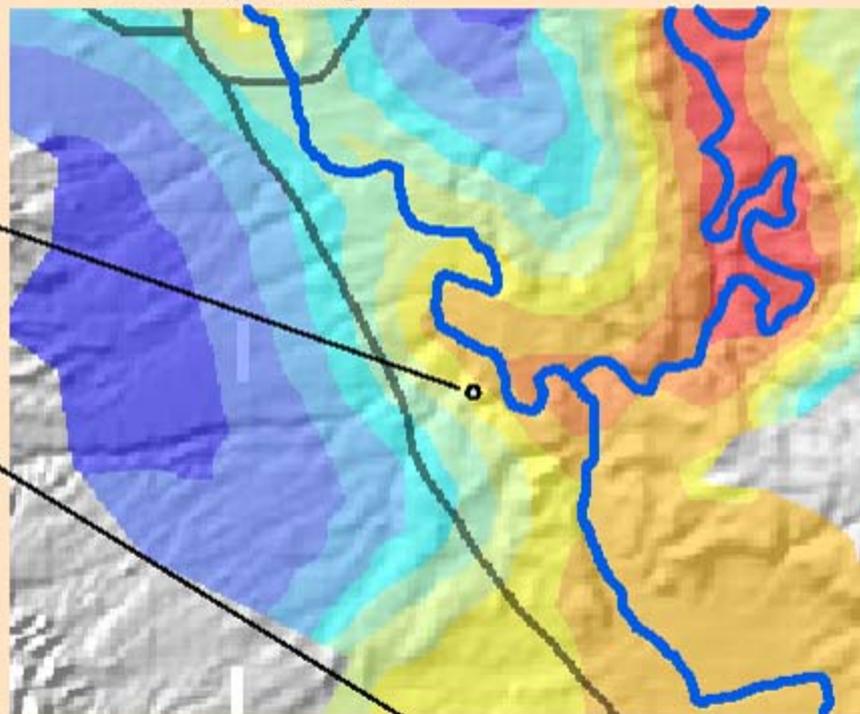
- Use figures 4a and 4b for wells open in the upper part of the Verde Formation.
- Use figures 5a and 5b for wells open in the lower part of the Verde Formation, the Supai Group, and volcanic rocks.

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.

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)



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

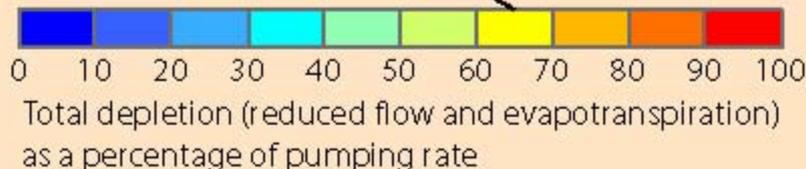
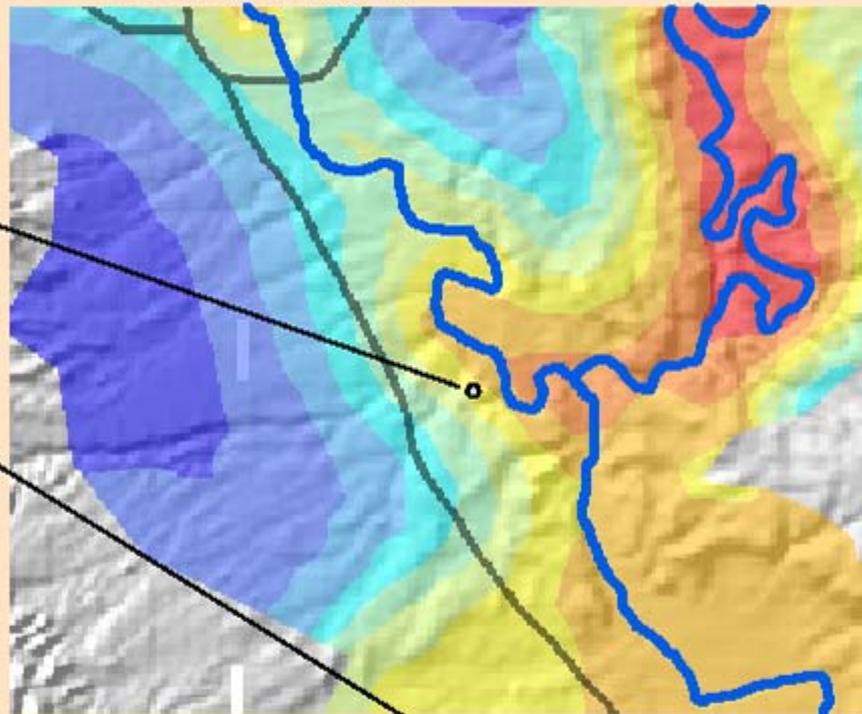
Step 3-Note the percent range on the color bar corresponding to color at well location on map

In this example the range is 60 to 70 percent.

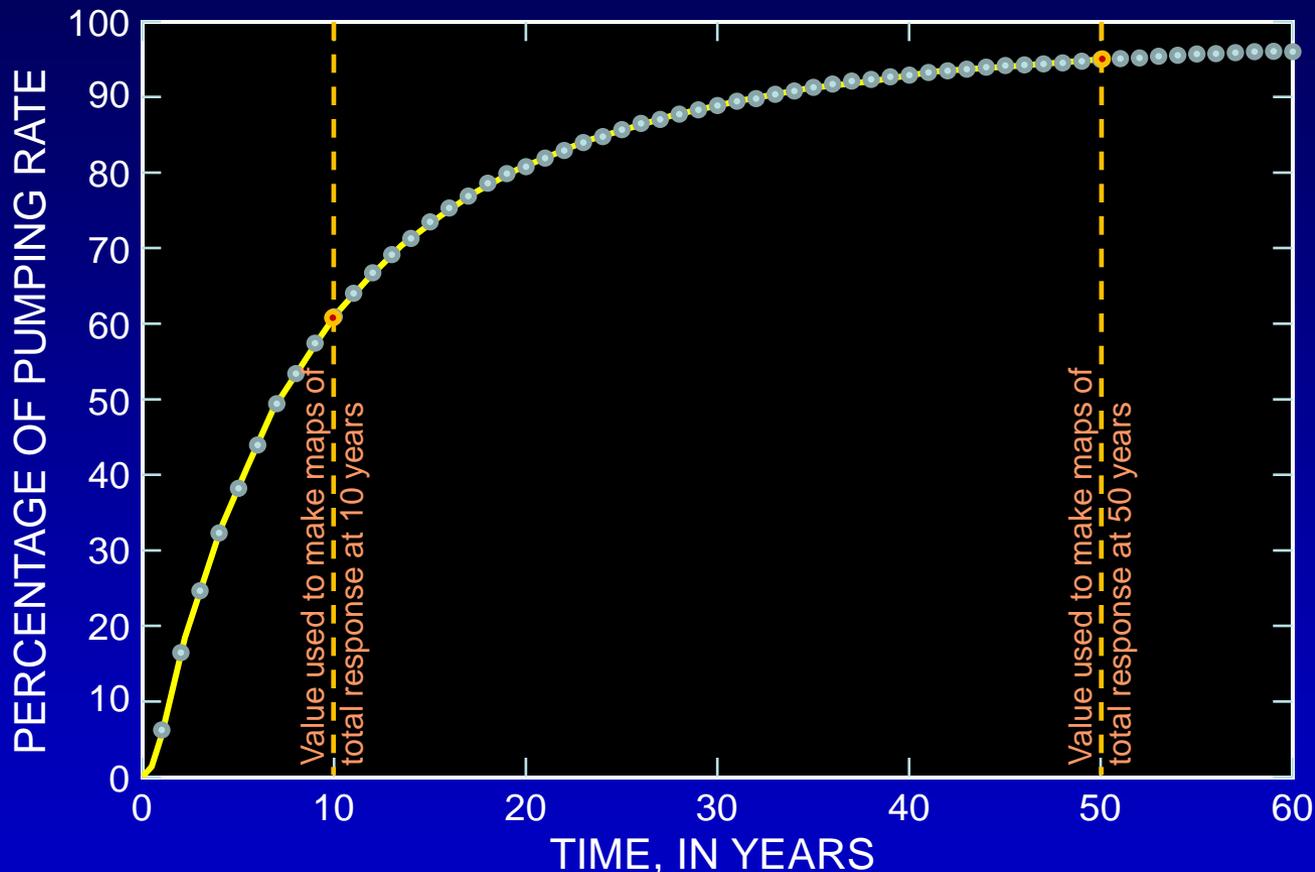
Step 4-Multiply corresponding fraction for color range by average well pumping rate to get average depletion rate

For the depletion range of 60 to 70 percent in this example, use a fraction of 0.65. Calculation is 0.65×10 acre-feet per year = 6.5 acre-feet per year of depletion at a pumping time of 50 years.

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)



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)

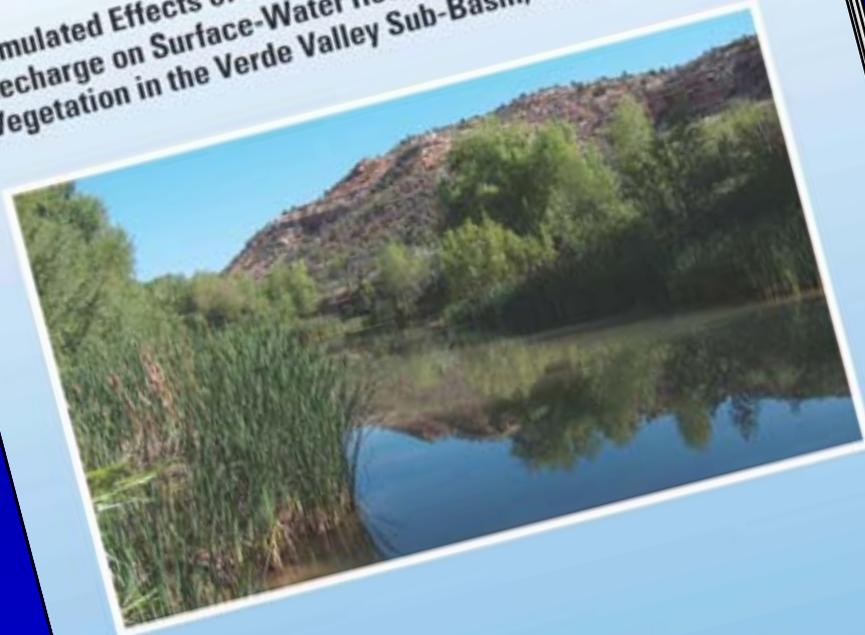
Note: these applications assume reasonably linear behavior

Technical Report—



Prepared in Cooperation with The Nature Conservancy

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



Scientific Investigations Report 2010-5147

U.S. Department of the Interior
U.S. Geological Survey

On the internet only at
<http://pubs.usgs.gov/sir/2010/5147/>



Fact Sheet—

USGS
science for a changing world

The Nature Conservancy
Protecting Nature. Planning Life.

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 sub-basin of Arizona. Results are in two sets of maps that show effects of recharge on streamflow. These maps will help managers make decisions that will meet water needs and minimize environmental impacts.

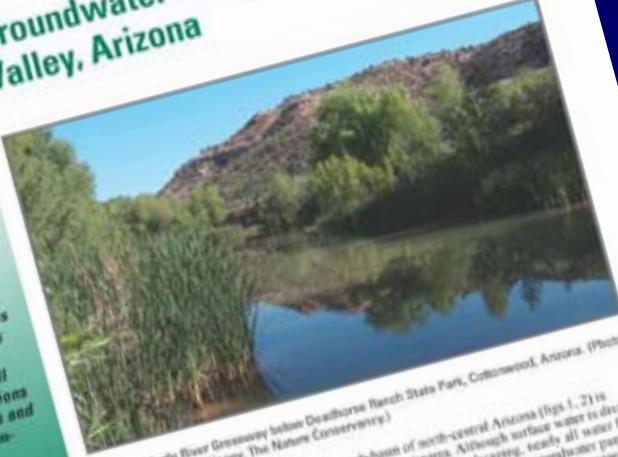


Figure 1. Verde River Greenway below Deathhorse Ranch State Park, Cottonwood, Arizona. (Photograph by Jeannette Hattery, The Nature Conservancy.)

The Verde Valley sub-basin of north-central Arizona (figs. 1–2) is drained with year-round flowing streams. Although surface water is diverted from the Verde River for agriculture and landscaping, nearly all water for public, domestic, and industrial supplies comes from groundwater pumping (Blanch and others, 2006). Groundwater use in the sub-basin increased more than tenfold in the latter half of the 20th century. A growing awareness of sustainable water management recognizes that development and water use 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.

Detailed information about surface-water and groundwater resources and their interconnections can help water managers and elected officials make good water-developmental decisions that minimize environmental impacts. A technique developed by the U.S. Geological Survey (USGS) 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 Post, 2010, <http://pubs.usgs.gov/of/2010/1147/>). 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 granite. Water occupies the open space between grains and in fractures. Aquifers may be stacked one upon another. Water enters aquifers from rain and snowmelt that percolates to the water table. Water moves through the



Figure 2. Location of Verde Valley sub-basin and extent of the Northern Arizona Regional Groundwater Flow Model.

U.S. Department of the Interior
U.S. Geological Survey

USGS Fact Sheet 210-108
2010

To be posted on the internet at
<http://pubs.usgs.gov/fs/2010/3108/>

—will be printed in early 2011