Streamflow Depletion by Wells—Concepts and Approaches for Understanding Groundwater-Pumping Impacts on Streamflow

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

Streamflow Depletion by Wells: An Important Issue Affecting Water and Environmental Management

- Populations are growing rapidly in many areas where groundwater is a major source of supply
- Desire to protect aquatic and riparian ecosystems, as well as the aesthetic and recreational benefits of streams
- Holders of existing surface-water rights do not want flows reduced by groundwater pumping

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Streamflow Depletions Result in:

- Reduced streamflow rates
- Changes in the mix of sources of water to a stream
- Associated changes in water quality and temperature
- Impacts on aquatic and riparian biota

Terminology

- **"Capture"** – A reduction in the natural discharge rate of GW from an aquifer or an increase in recharge rate to an aquifer

- **"Streamflow Depletion"** – A type of capture that can include both decreases in discharge from an aquifer and, in some cases, increases in recharge to an aquifer via induced infiltration of streamflow
  - *In many settings, streamflow depletion is equivalent, or nearly equivalent, to total capture.*

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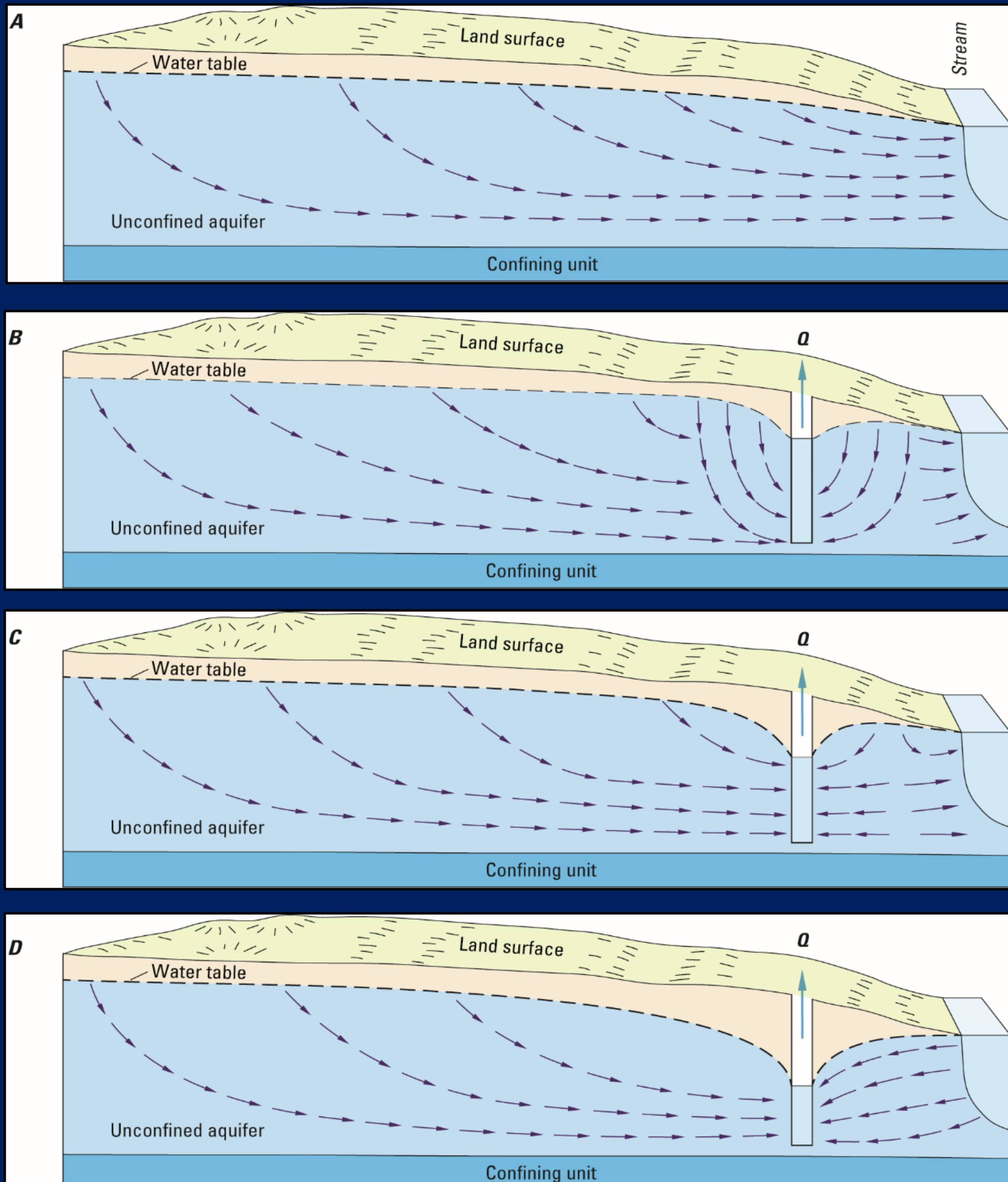
Streamflow Depletion by Wells



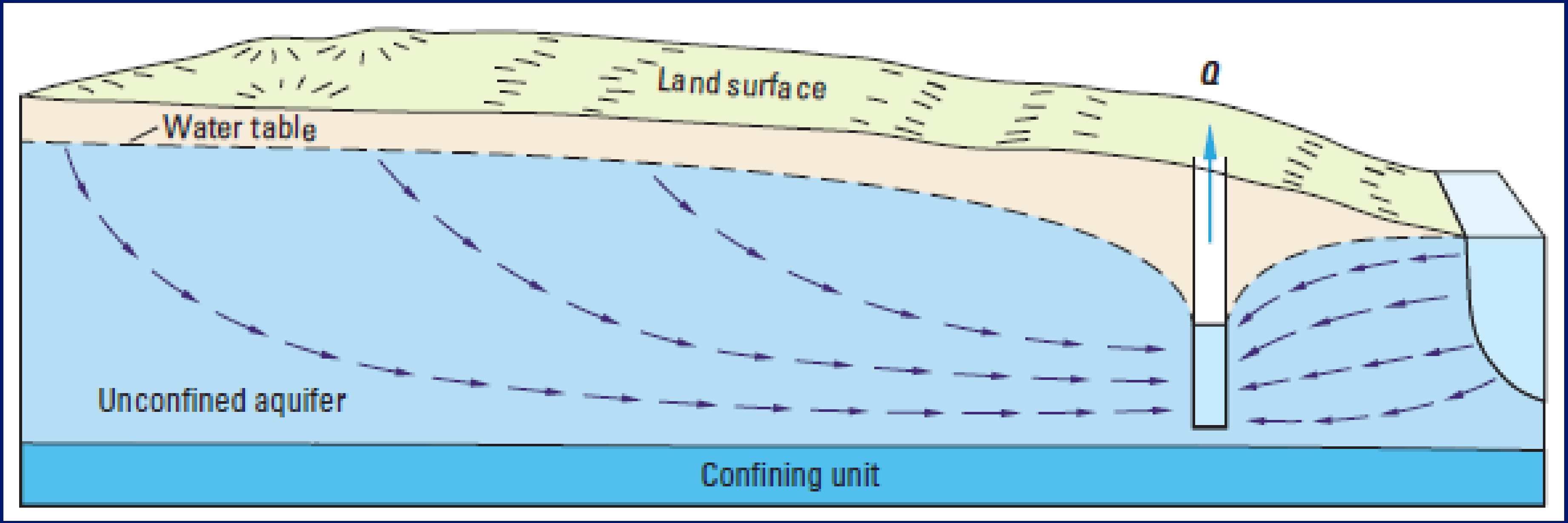
Pre-pumping conditions

Aquifer storage predominates

Captured ground-water discharge

Captured ground-water discharge and induced infiltration of streamflow

Streamflow Depletion by Wells



Streamflow Depletion =
Captured Groundwater Discharge +
Induced Infiltration of Streamflow

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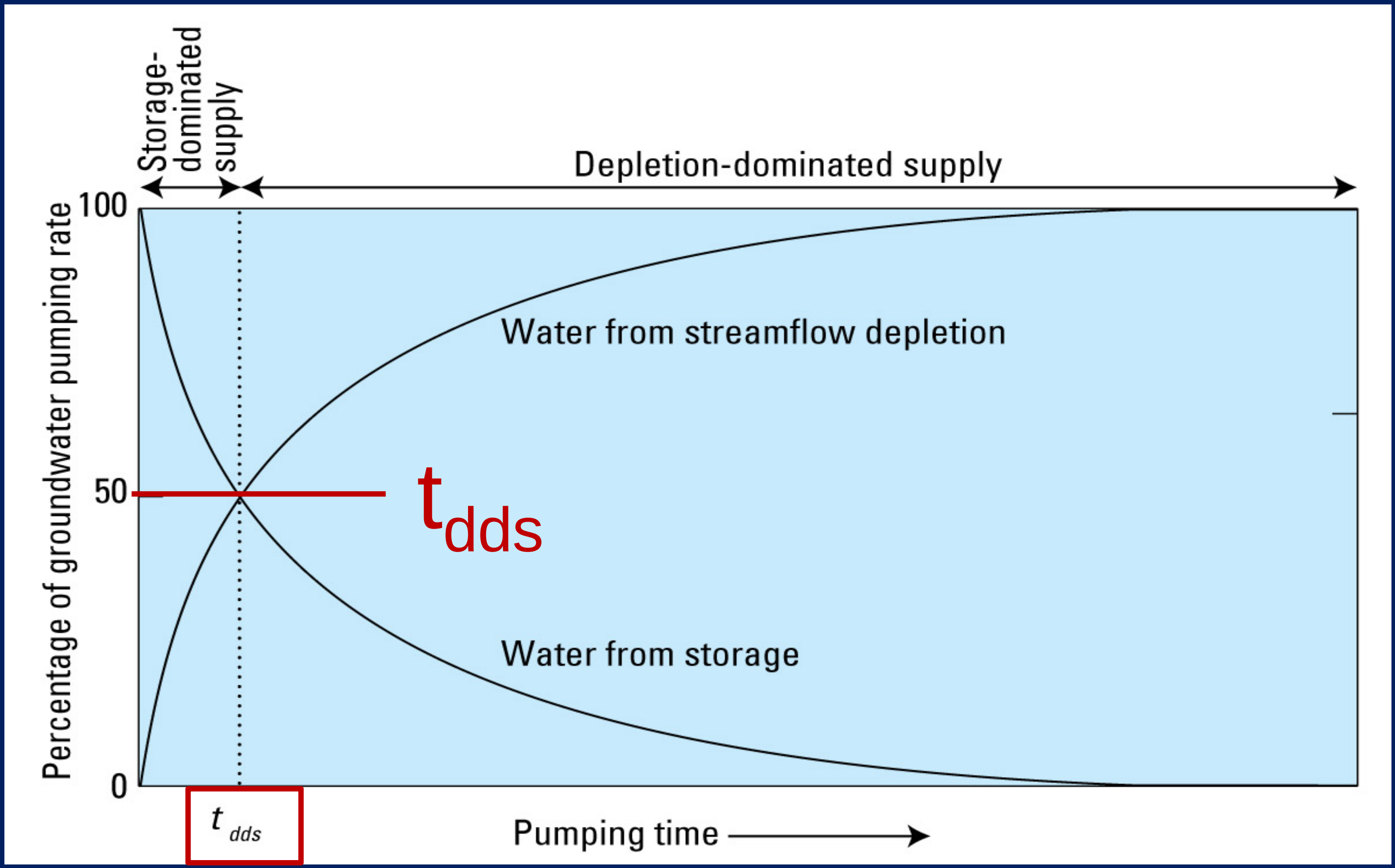
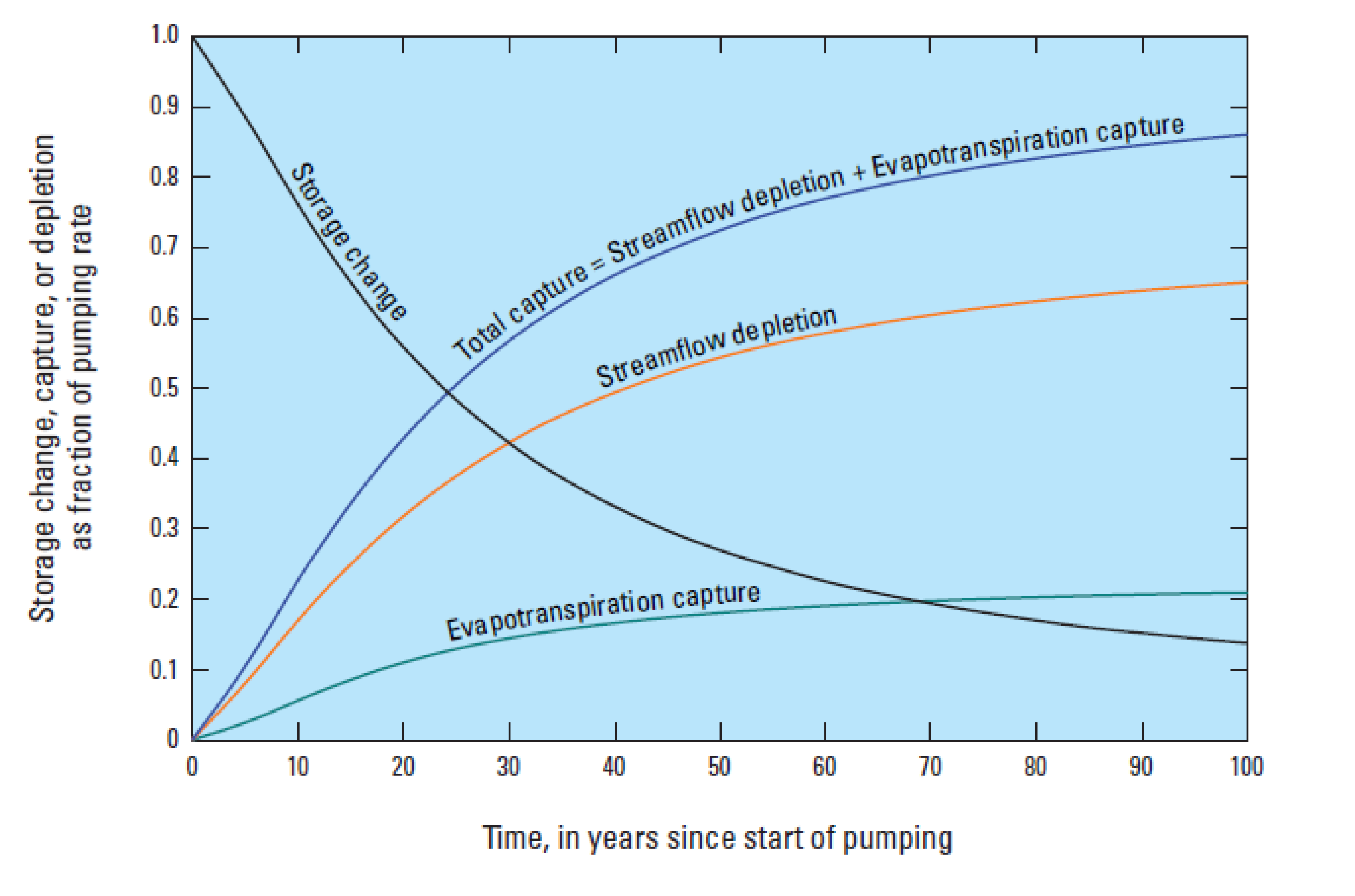
Timing of Streamflow Depletion



There can be a substantial delay between the start of pumping and the onset of streamflow depletion.

Capture versus Streamflow Depletion



Model-computed streamflow depletion, evapotranspiration capture, and total capture for a well pumping in the Upper San Pedro Basin, AZ

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Factors that Affect the Timing of Streamflow Depletion Responses

- **Geology**
- **Lateral and vertical extent of aquifers**
- **Hydraulic Properties**
- **Boundary Conditions**
- **Well Location (Vertical & Horizontal Distance from Streams)**
- **Pumping Schedules**

> *The timing of streamflow depletion varies substantially among aquifer systems, and even within aquifer systems.*

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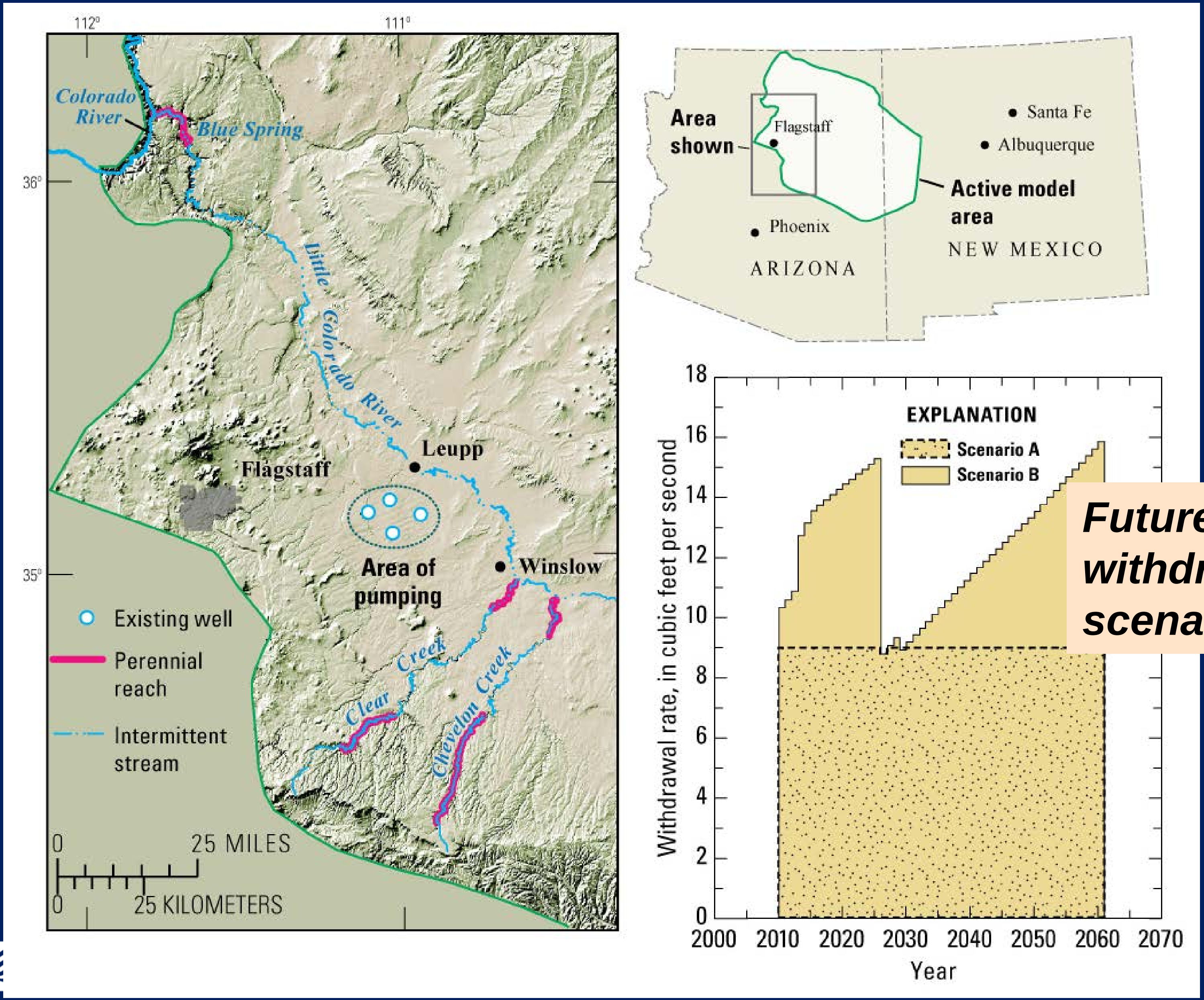
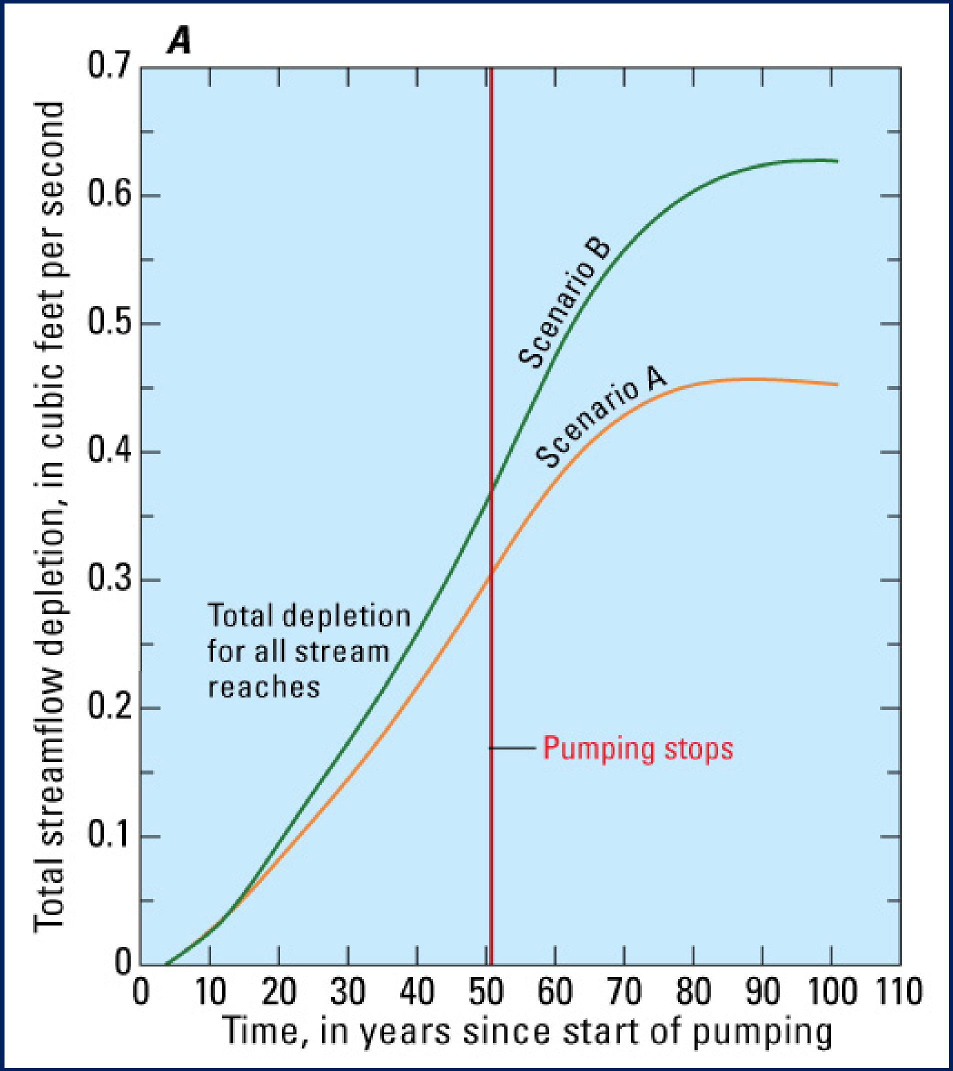
Depletion after Pumping Stops: Residual Effects



Future withdrawal scenarios

Modified from Leake et al., 2005, USGS SIR 2005-5277

Depletion Continues Long After Pumping Stops



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Maximum depletion rates occur about 30–40 years after pumping stops.

Three General Approaches for Analysis of Streamflow Depletion

- Field Techniques
- Analytical Models
- Numerical Models

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Field Techniques

- Data-Driven Studies
  - Short-term, local-scale studies of individual and multiple wells on nearby streams
  - Long-term analyses of basin-wide development
- Several Techniques:
  - Streamflow measurements
  - Stream-stage and near-stream gw levels
  - Seepage meters
  - Geophysical techniques
  - Chemical or thermal techniques
  - Basin-wide groundwater-level measurements

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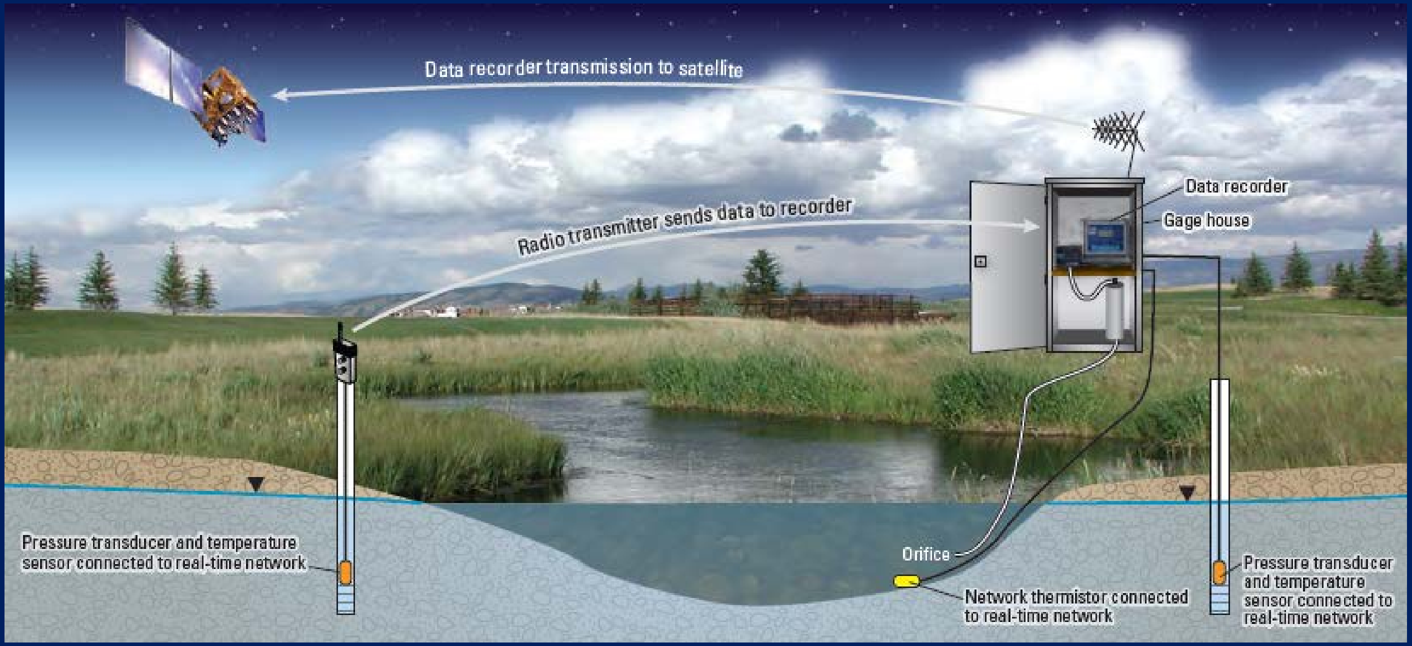
Streamflow Measurements

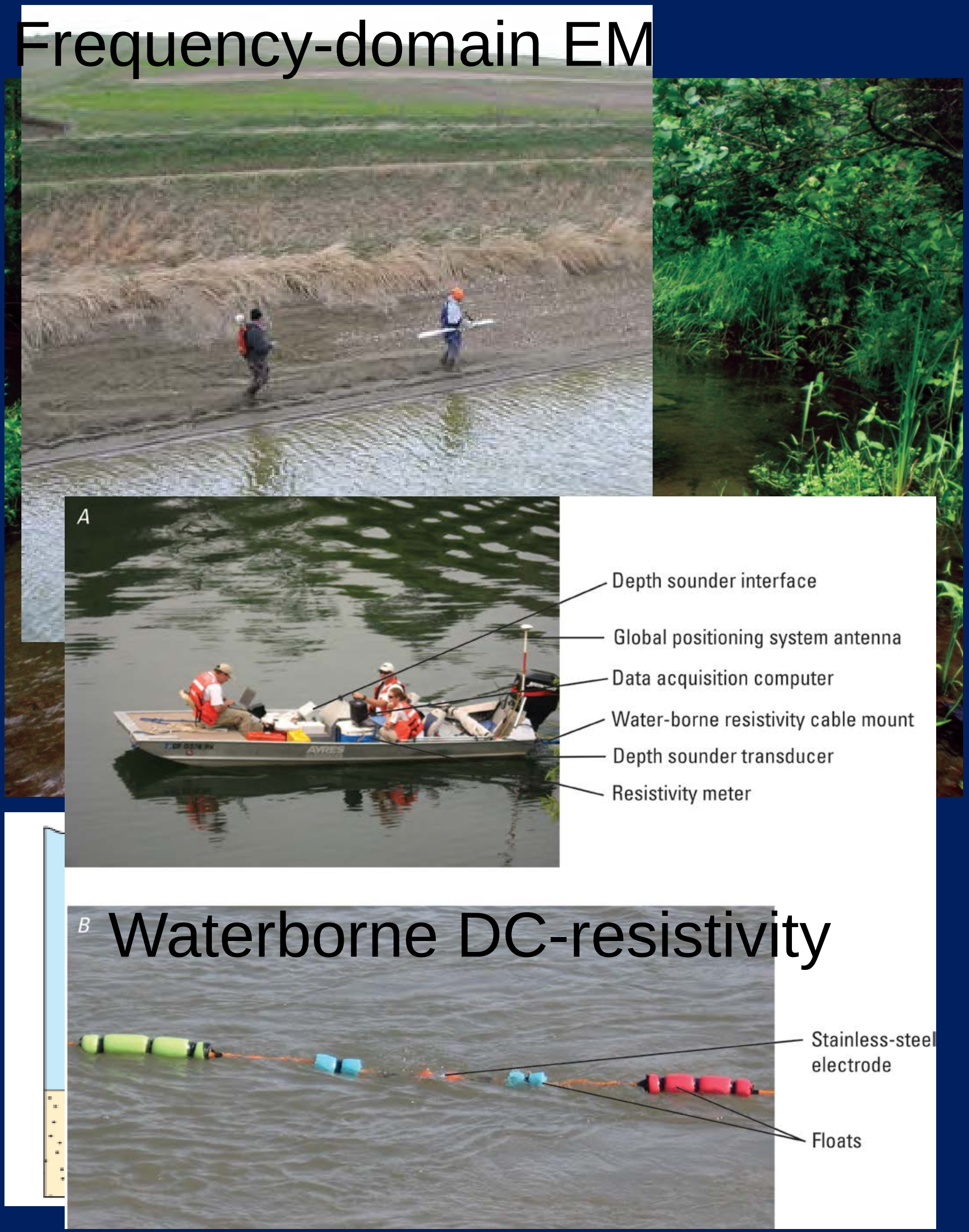
- At a single streamgage over time
- At two or more streamgages at a single time: seepage runs
- Coupled groundwater-streamflow gages



(from USGS Fact Sheet 2012-3054)

Field Techniques:

- **Seepage Meters**
- **Surface geophysical Techniques**



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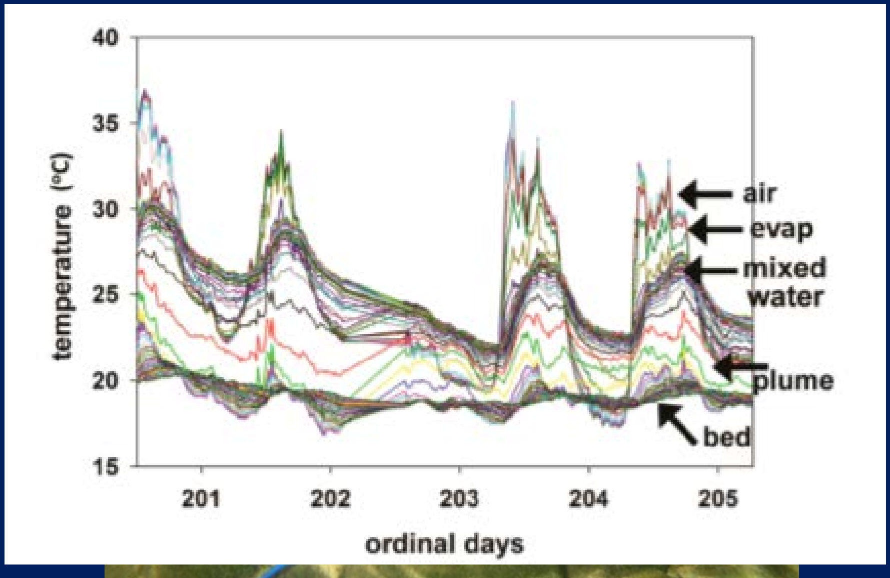
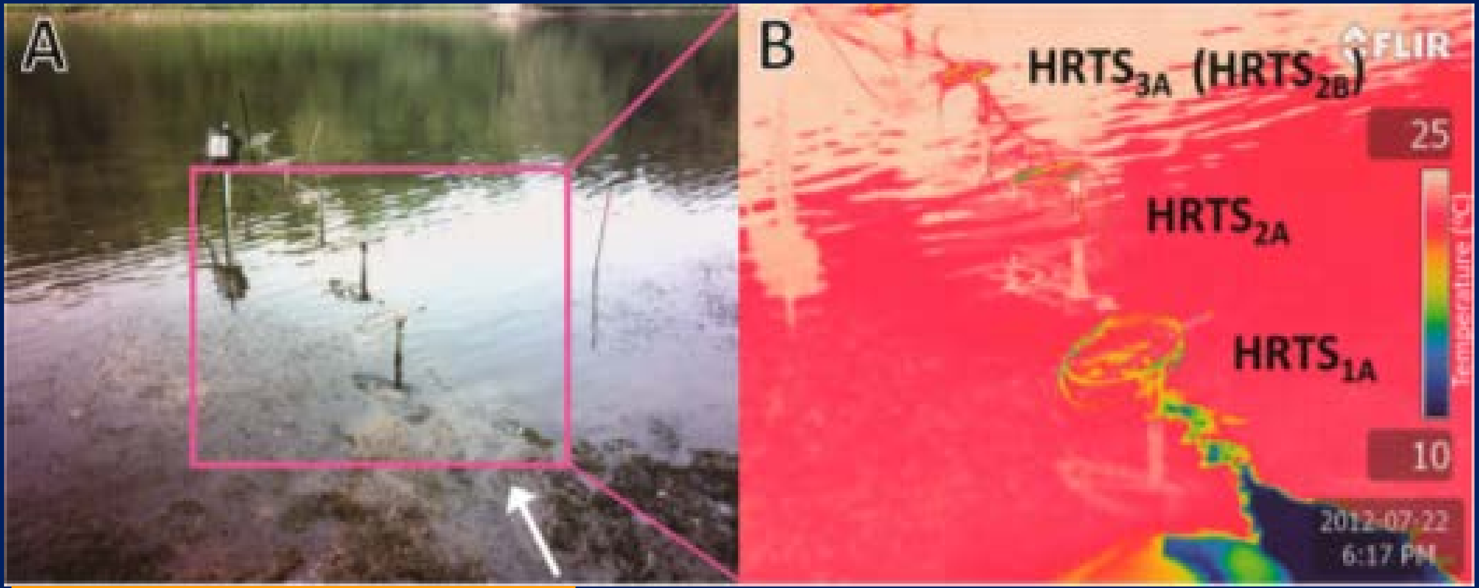
Field Techniques:

- Seepage Meters
- Surface geophysical Techniques
- Thermal Sensing Technology

Fiber-optic distributed temperature



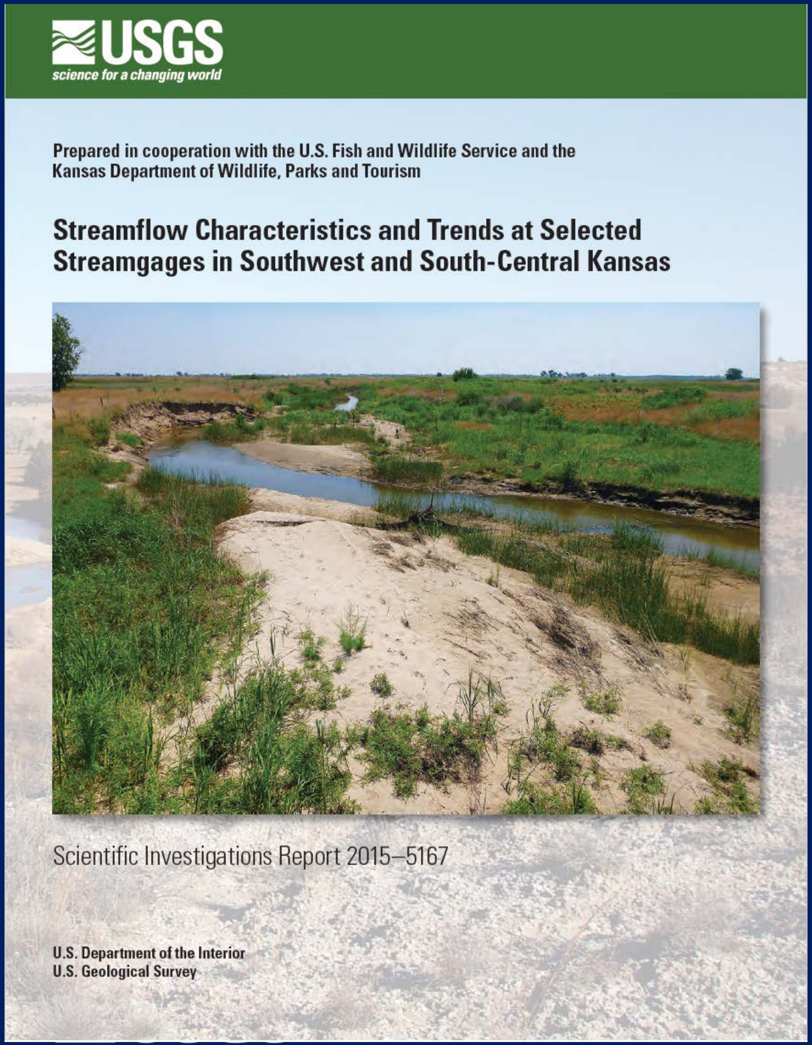


Briggs et al, ES&T, 2013

Forward-Looking Infrared (FLIR) Camera

Temperature Tidbits

Data Driven Example:
Long-Term Analysis of Basin-Wide GW Development



- **Historic streamflow data (1951-2013) at 9 gaging stations and calculated streamflow characteristics**
- **Precipitation and GW withdrawal information**
- **Assessed trends by linear regression analysis in Excel**

https://pubs.usgs.gov/sir/2015/5167

Need for Numerical Models

- Three-dimensional aquifer systems; irregular geometry of aquifer boundaries
- Aquifer heterogeneity
- Irregular geometry of surface-water features (e.g., meandering streams)
- Shallow streams
- Multiple wells, complex pumping histories
- Specific stream reaches or surface-water features of interest
- Comprehensive water budgets

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Surface Water-Quality Concerns

- Reduced groundwater discharge to streams affects chemistry and temperature of surface.
  - GW discharge at a nearly constant temperature provides stable environment for fish and aquatic organisms in both summer and winter
  - Low DO concentration of GW discharge at the streambed interface allows for important geochemical processes to occur such as denitrification (nitrate is removed in streambed/ riparian zone before entering surface water)
- Induced infiltration of SW to a pumping well
  - Impacts groundwater quality of underlying aquifer
    (pH, DO, Temp, SC, redox potential)
  - Can cause changes of naturally occurring geochemical transformation
  - Surface water can be a source of contamination to a groundwater system

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Challenges

- Geologic complexities: 3D structure and heterogeneity
- Configuration and types of hydrologic boundaries
- Tens to thousands of pumping wells with complex pumping histories
- Time delays
- Difficulty identifying streamflow depletion in streamflow records

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Questions?

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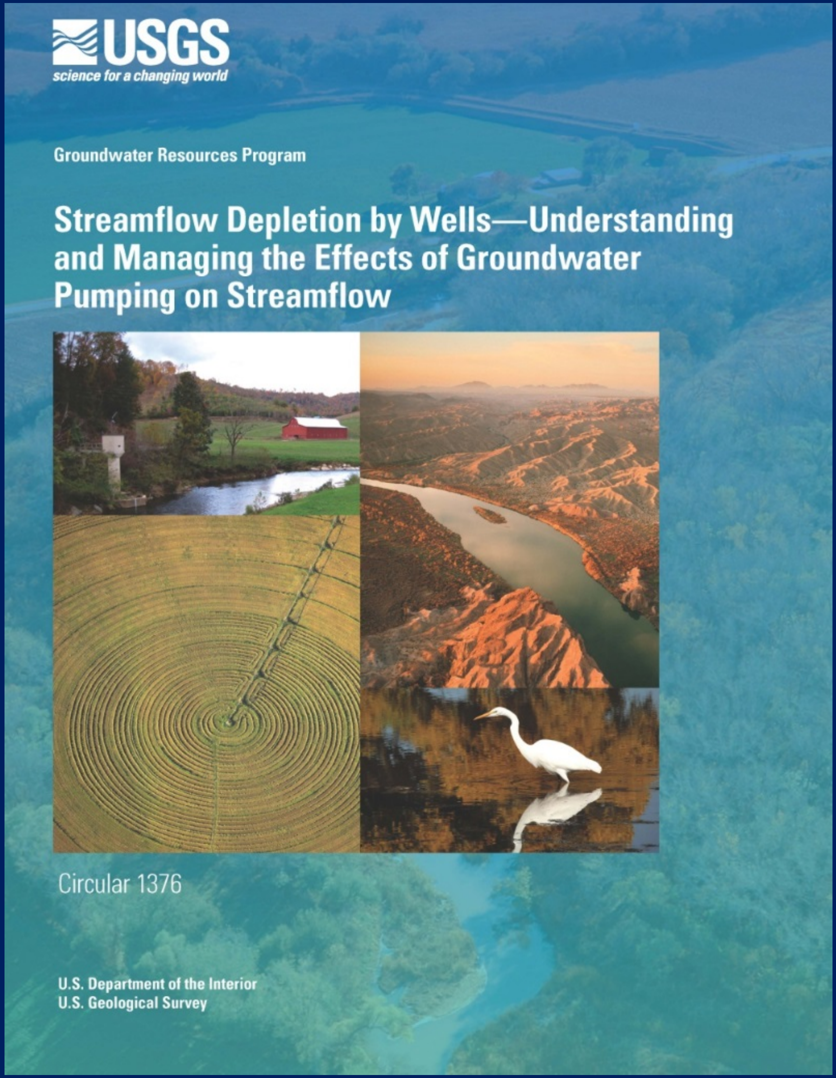
- http://water.usgs.gov/ogw/



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http://pubs.usgs.gov/circ/1376/