Surface-water/Groundwater Interactions in Arizona

Experiences in the Real Worlds

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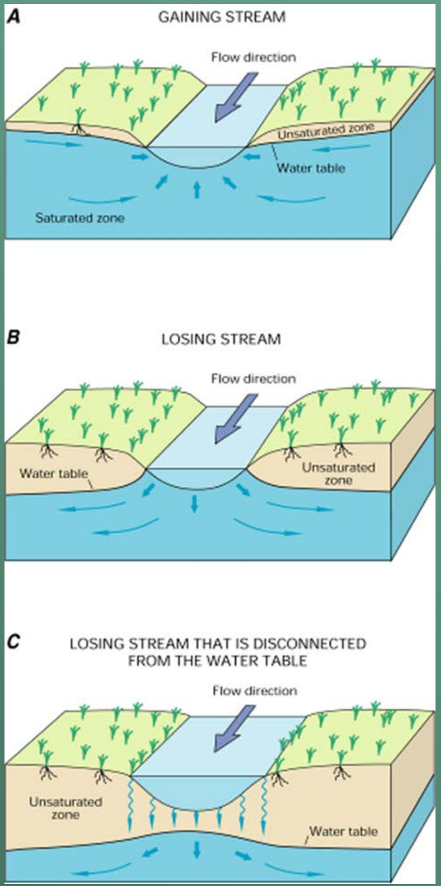
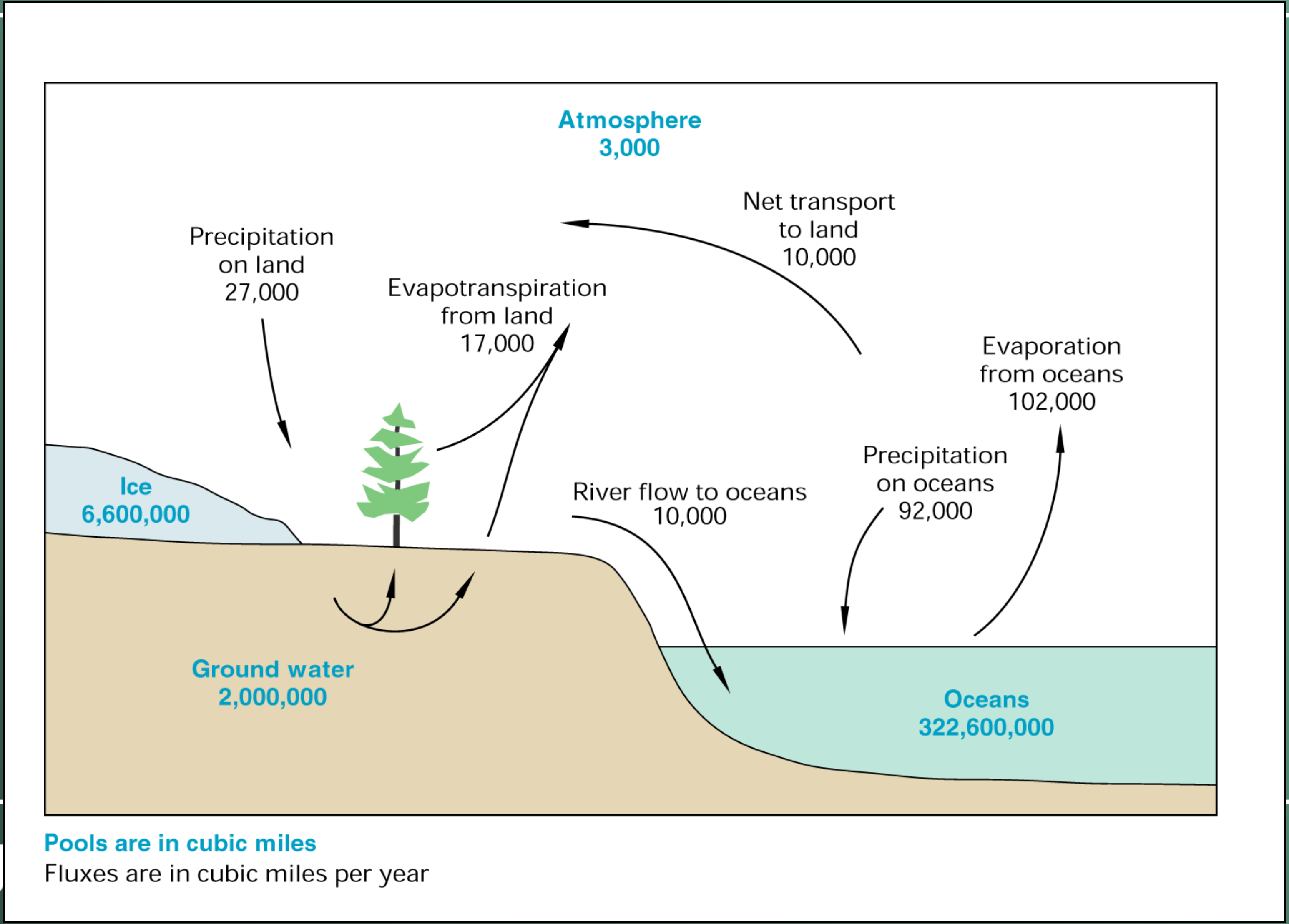
USGS Arizona Water Science Center

December 4, 2014

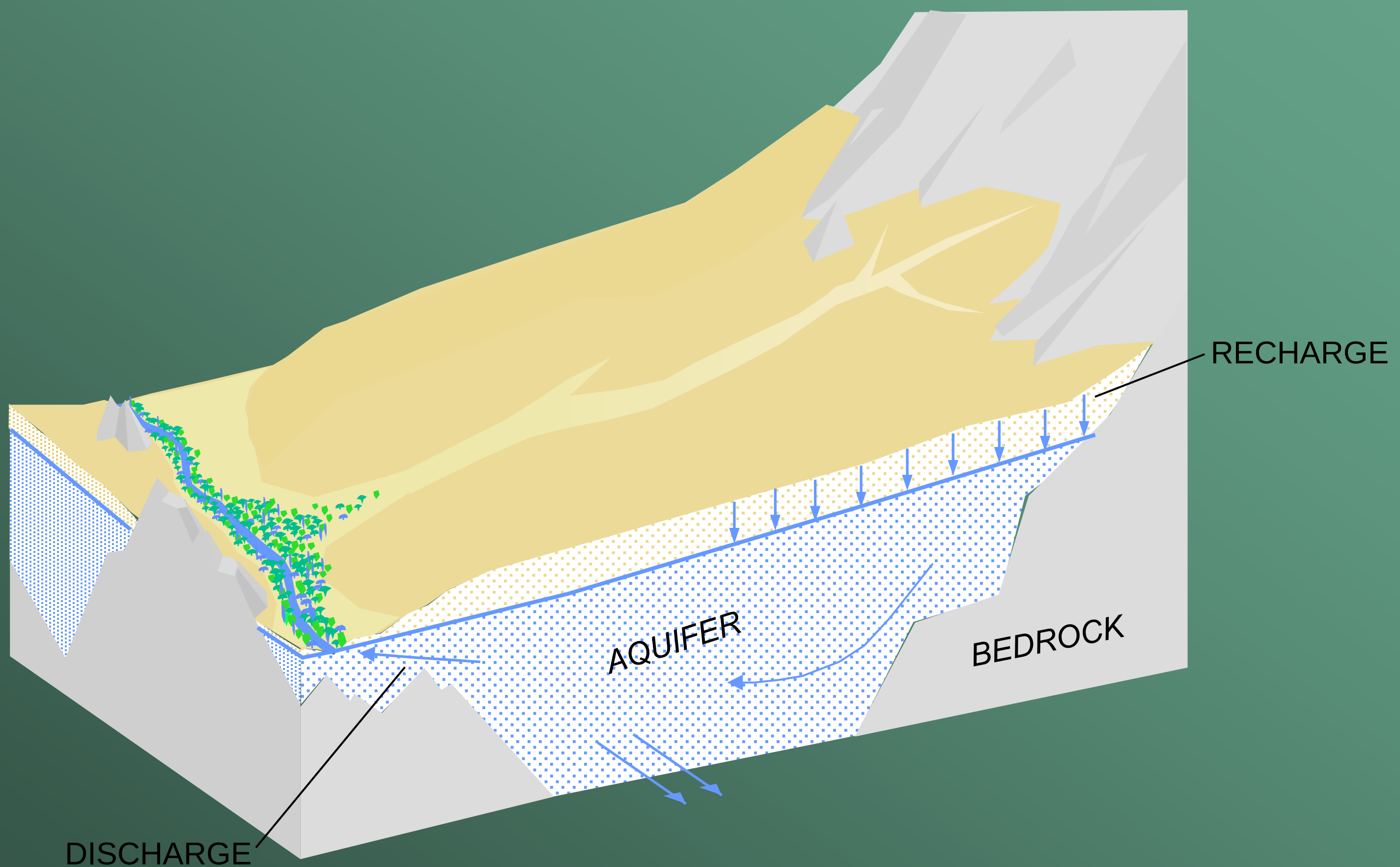


U.S. Department of the Interior
U.S. Geological Survey

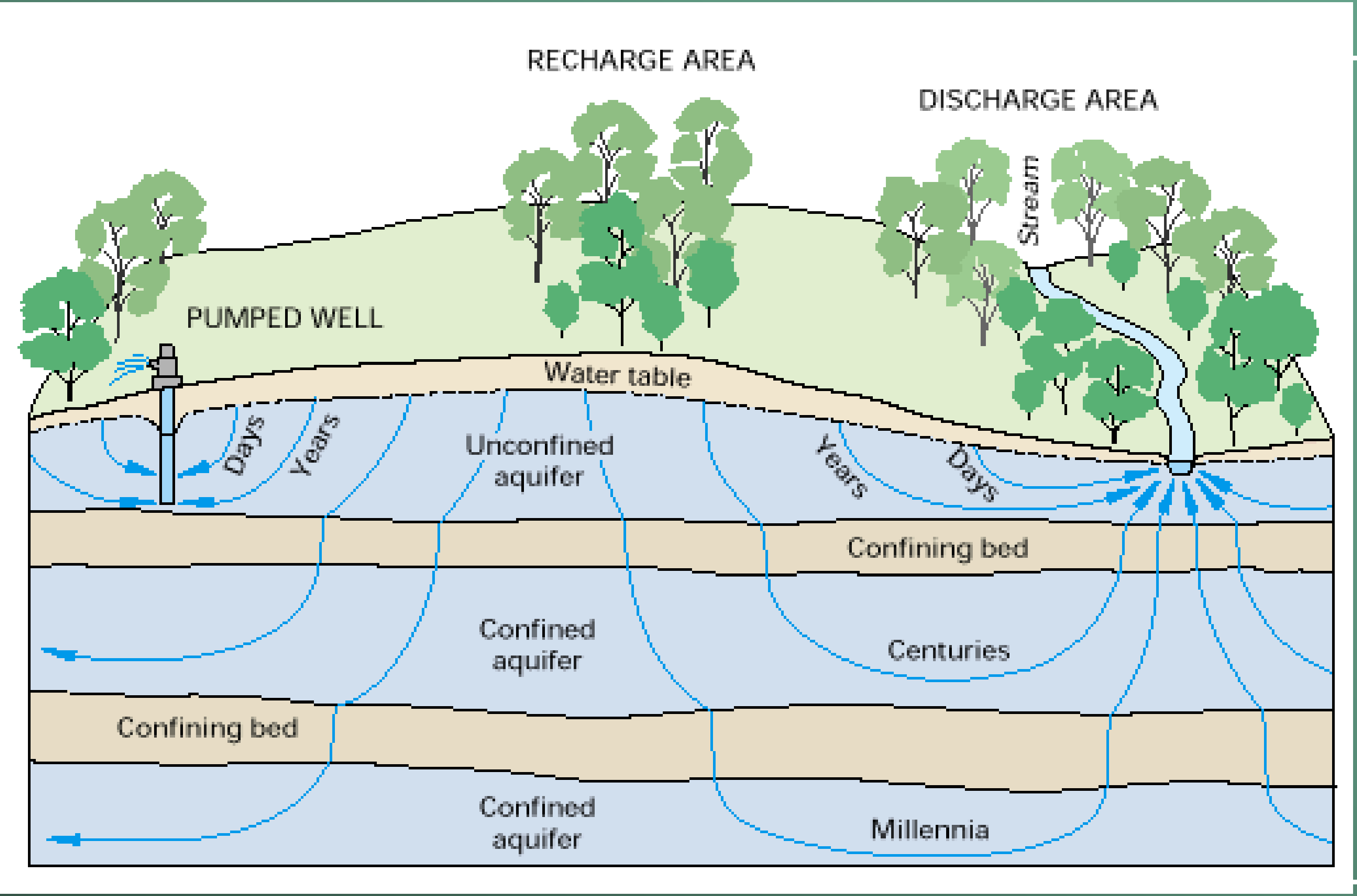
Groundwater is part of the hydrologic cycle



Real aquifers are 3-dimensional!



Simple….yet complicated!



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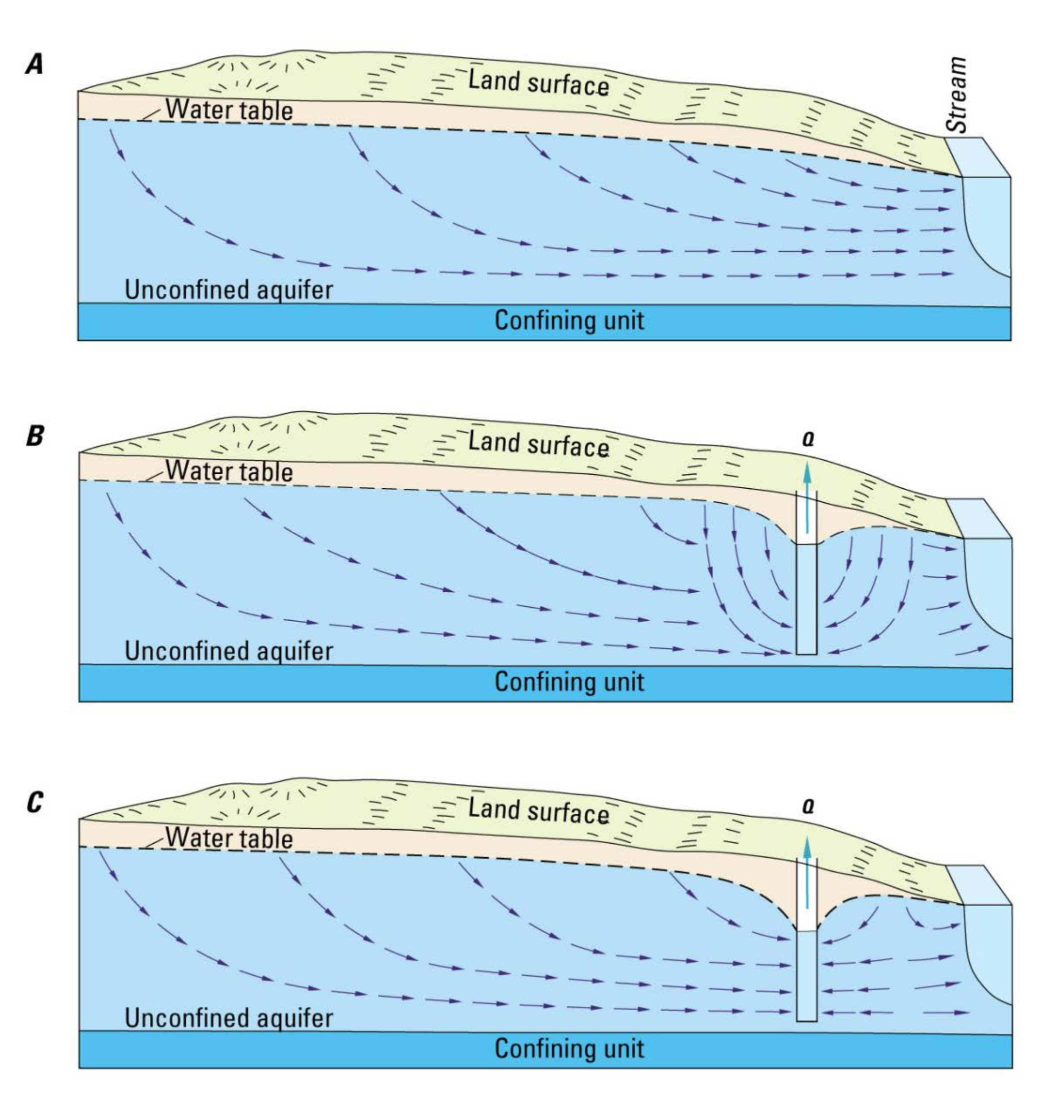
Groundwater/ Surface Water 101

A. Initial Steady State

B. All flow to well from storage

C. Changing gradients change flow system

Extreme case - flow previously toward stream reversed



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Two Sources of Water to a Well

1. Aquifer Storage

2. Capture
   1. Increased recharge
   2. Decreased discharge
      - Streamflow or Evapotranspiration

Capture (streamflow depletion)

- C.V. Theis (1940) – seminal paper
- Increase in recharge+decrease in discharge
- Not about “if”
- All about “where” and “when”

USGS

What Influences Capture Rate?

1. Aquifer properties (diffusivity)

2. Distance between well or recharge and stream

- (Not flow rate, not recharge, not direction of flow, not pumping rate)

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Aquifer Diffusivity

- D = T/S
  - D = Diffusivity
  - T = Transmissivity
  - S = Storage

- Where and when are the only questions
- Recharge, flow direction, pumping rate are not factors

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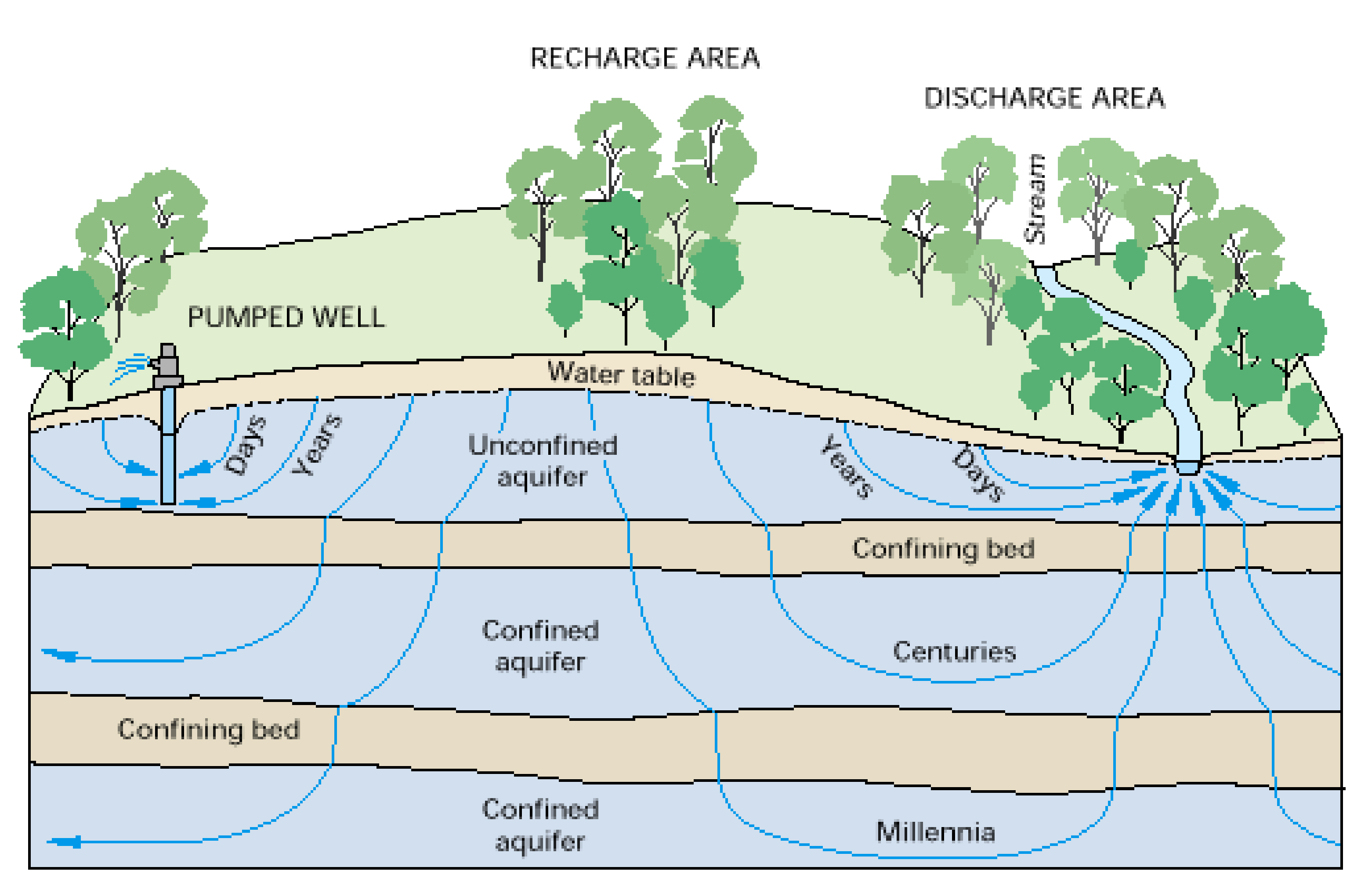
Simple….yet complicated!



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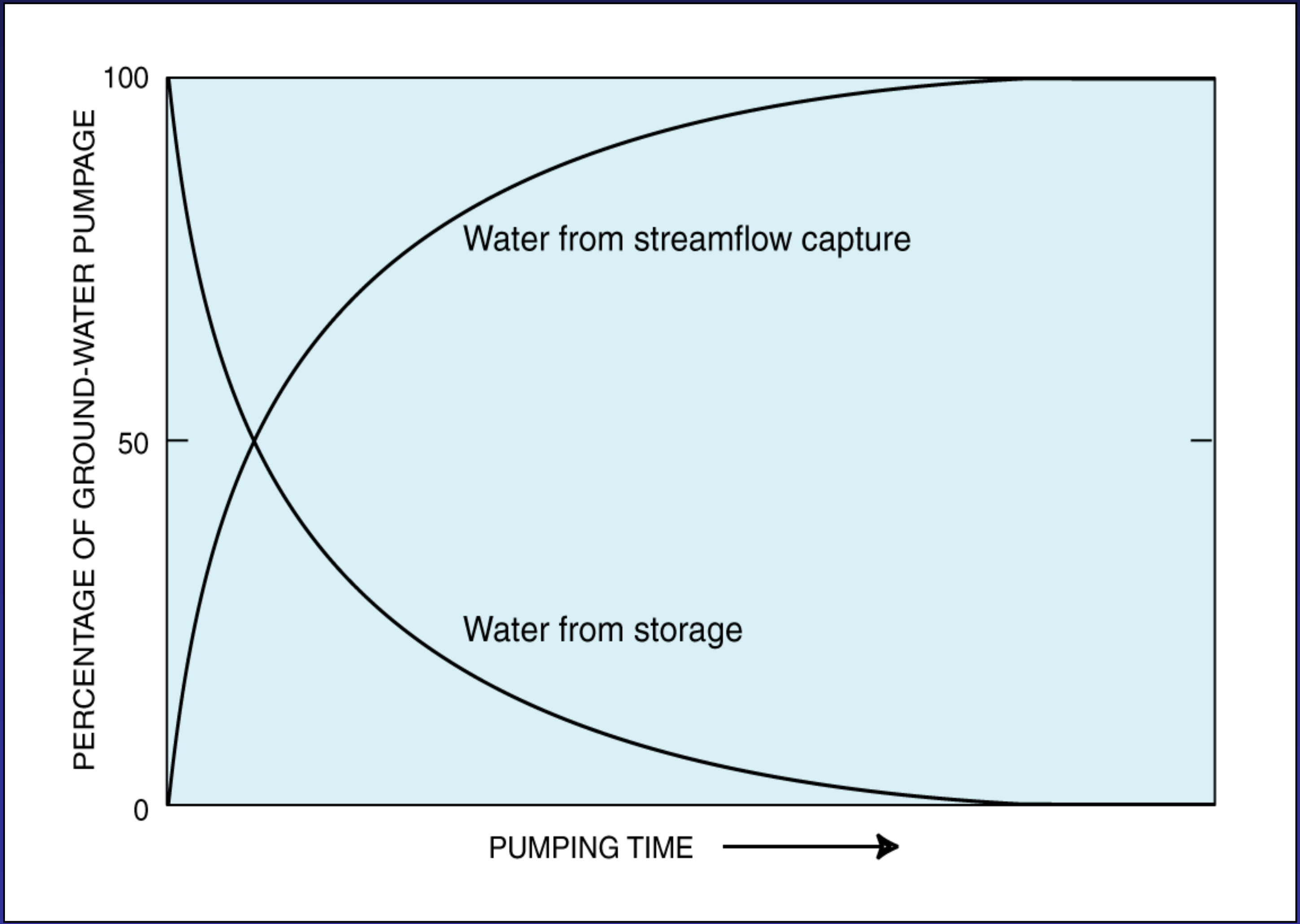
The Classic "Capture Curve"



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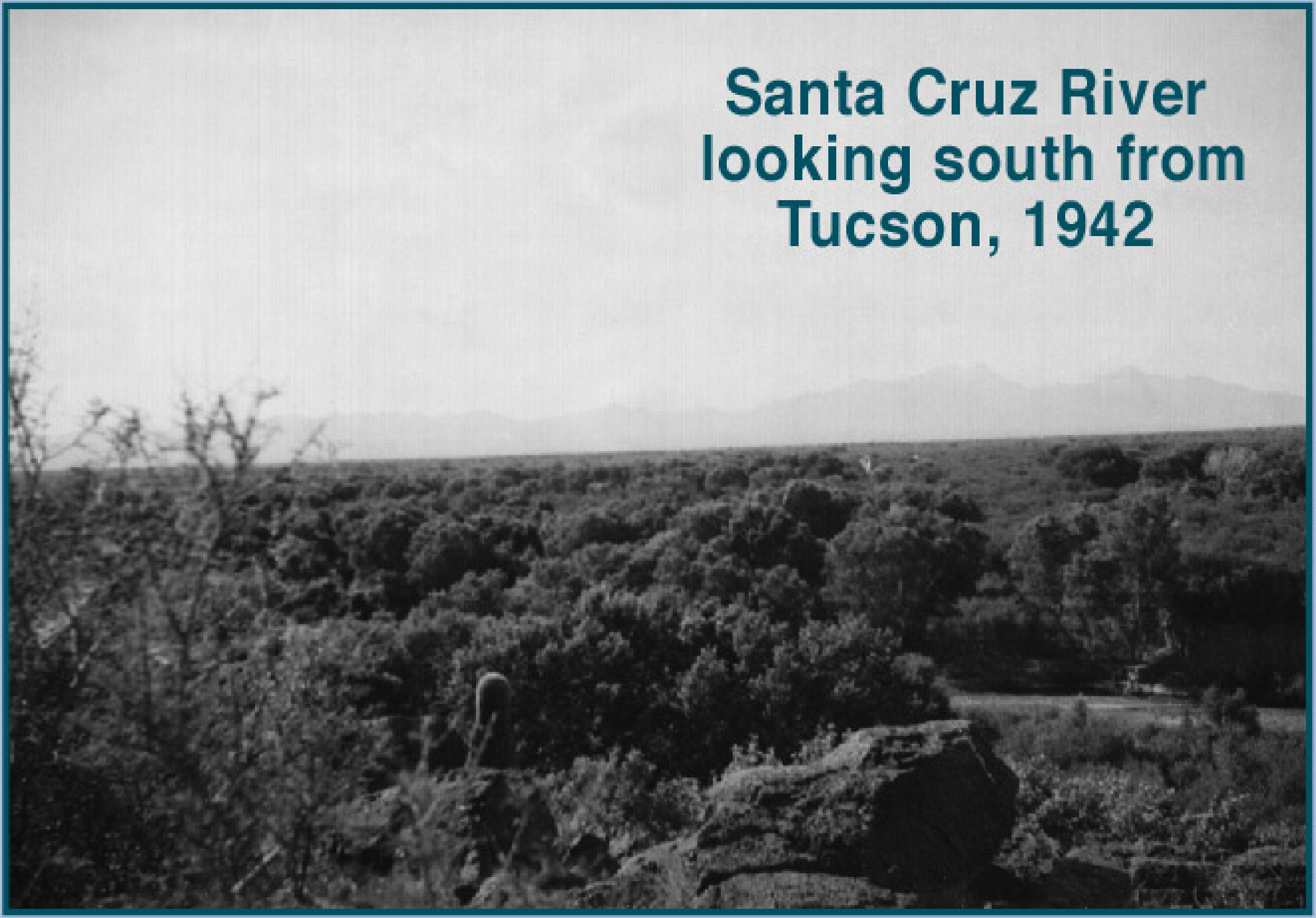
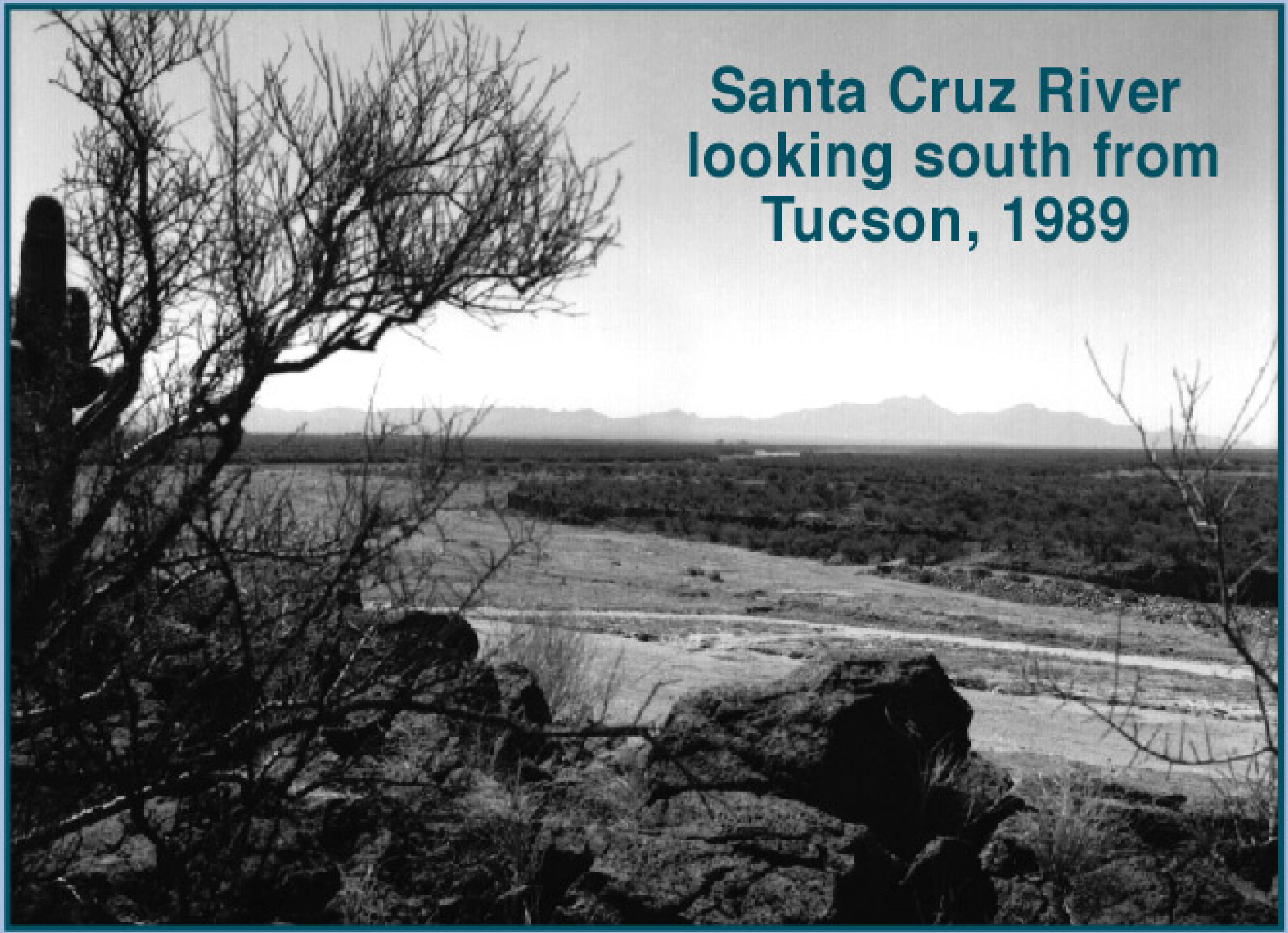
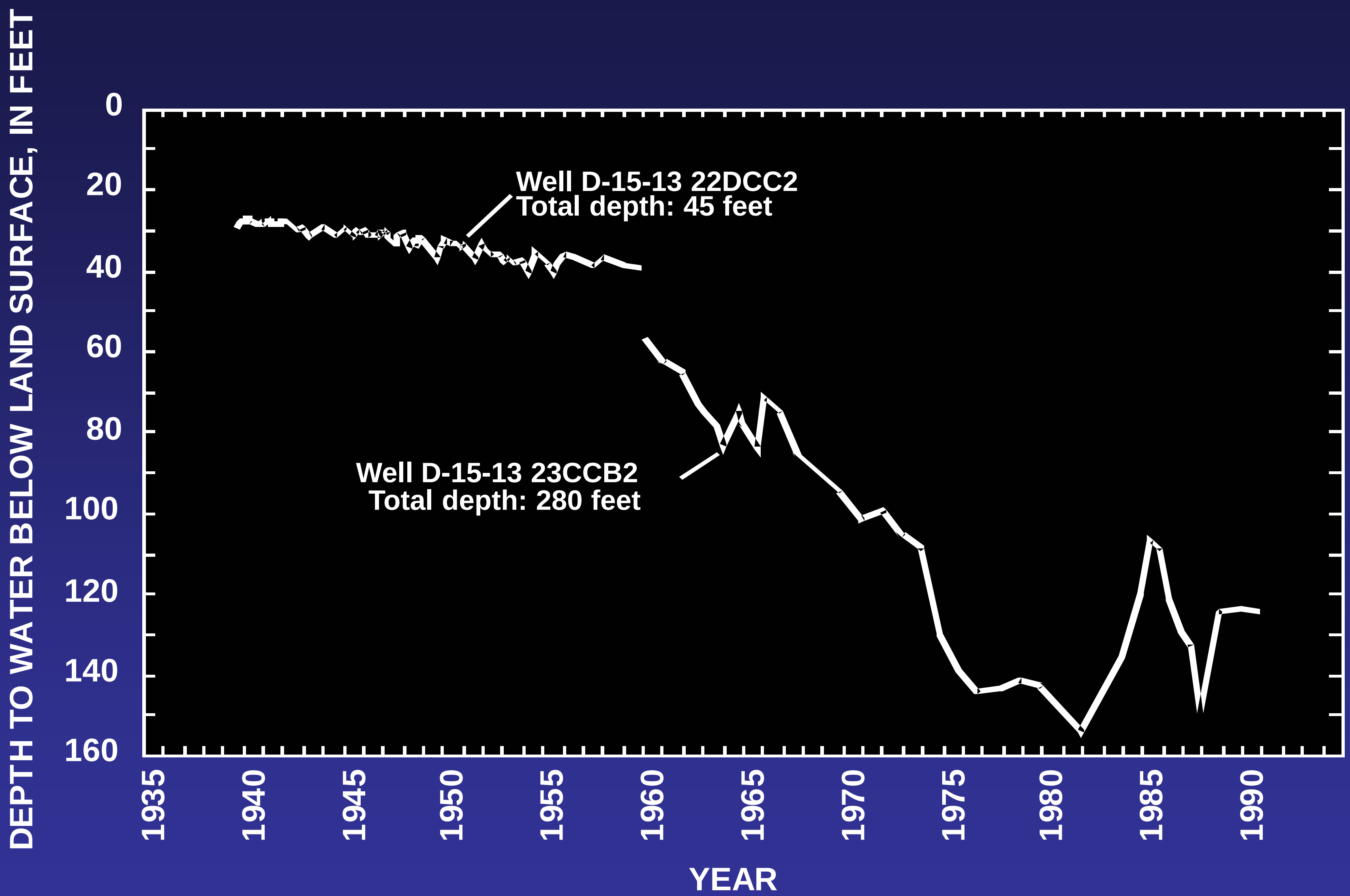
Effects of GW withdrawals



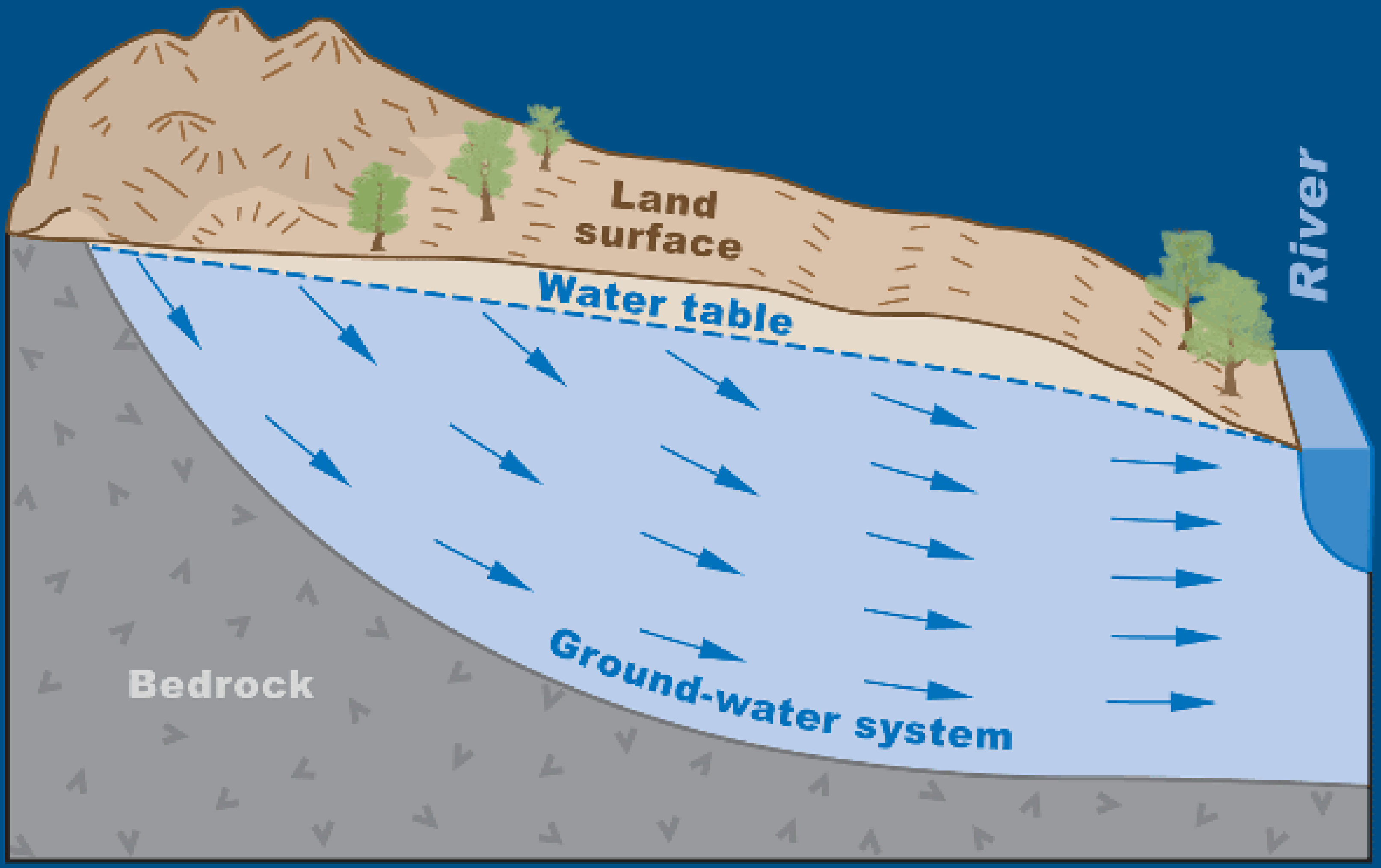
Effects of GW withdrawals



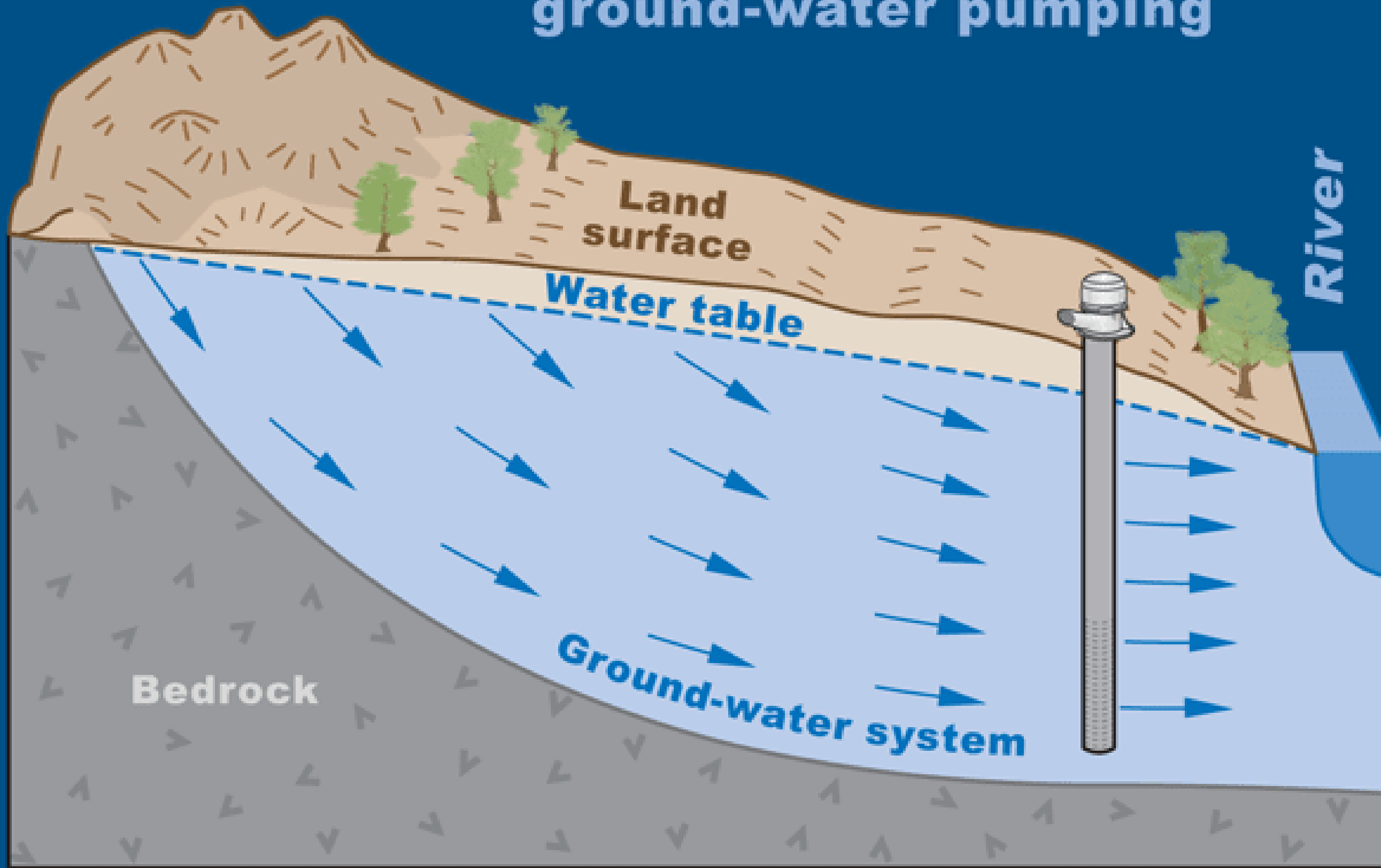
Well near Martinez Hill



Natural conditions



Equilibrium change caused by ground-water pumping



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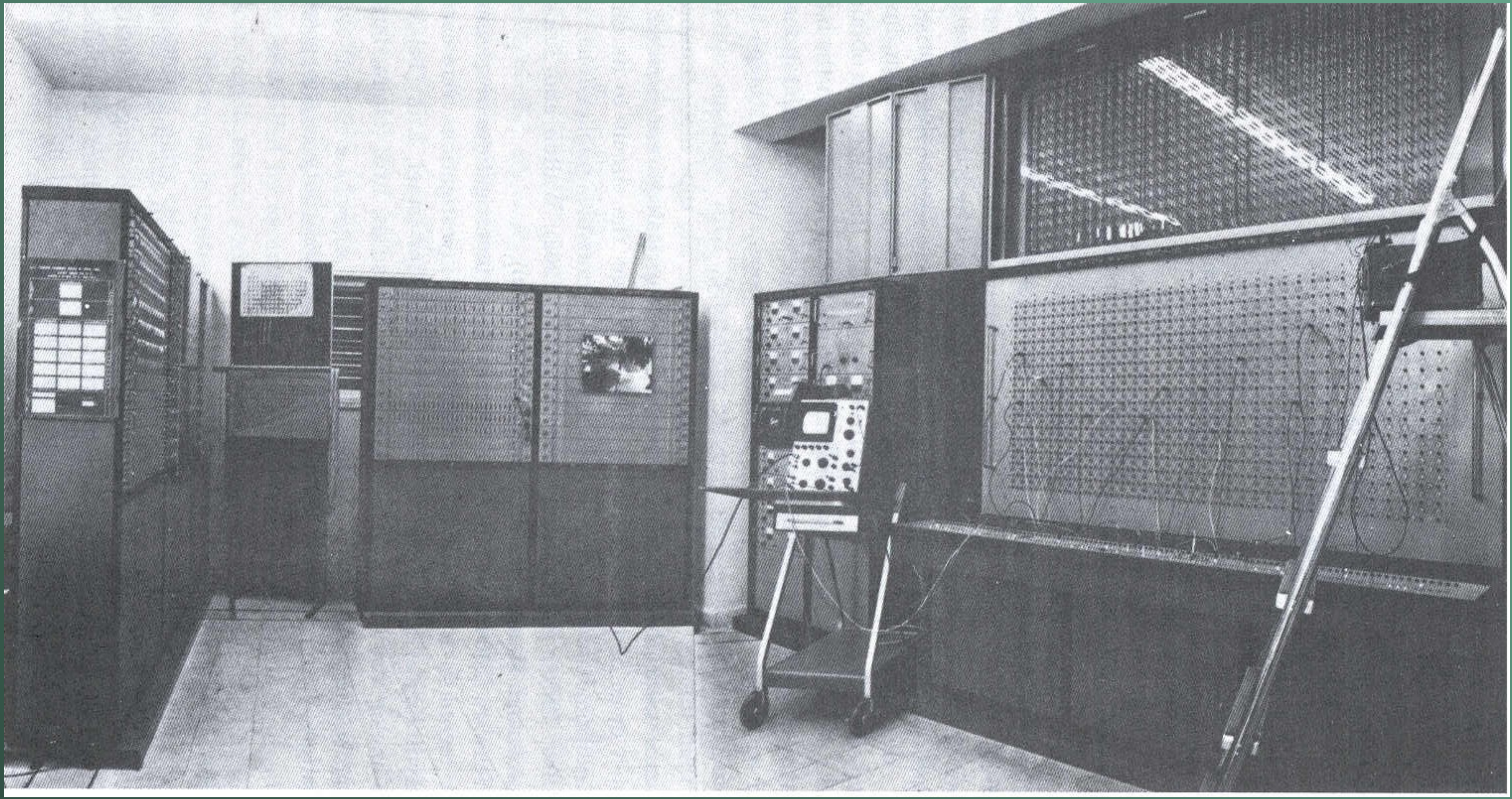
science for a changing world

Groundwater models – simulating reality

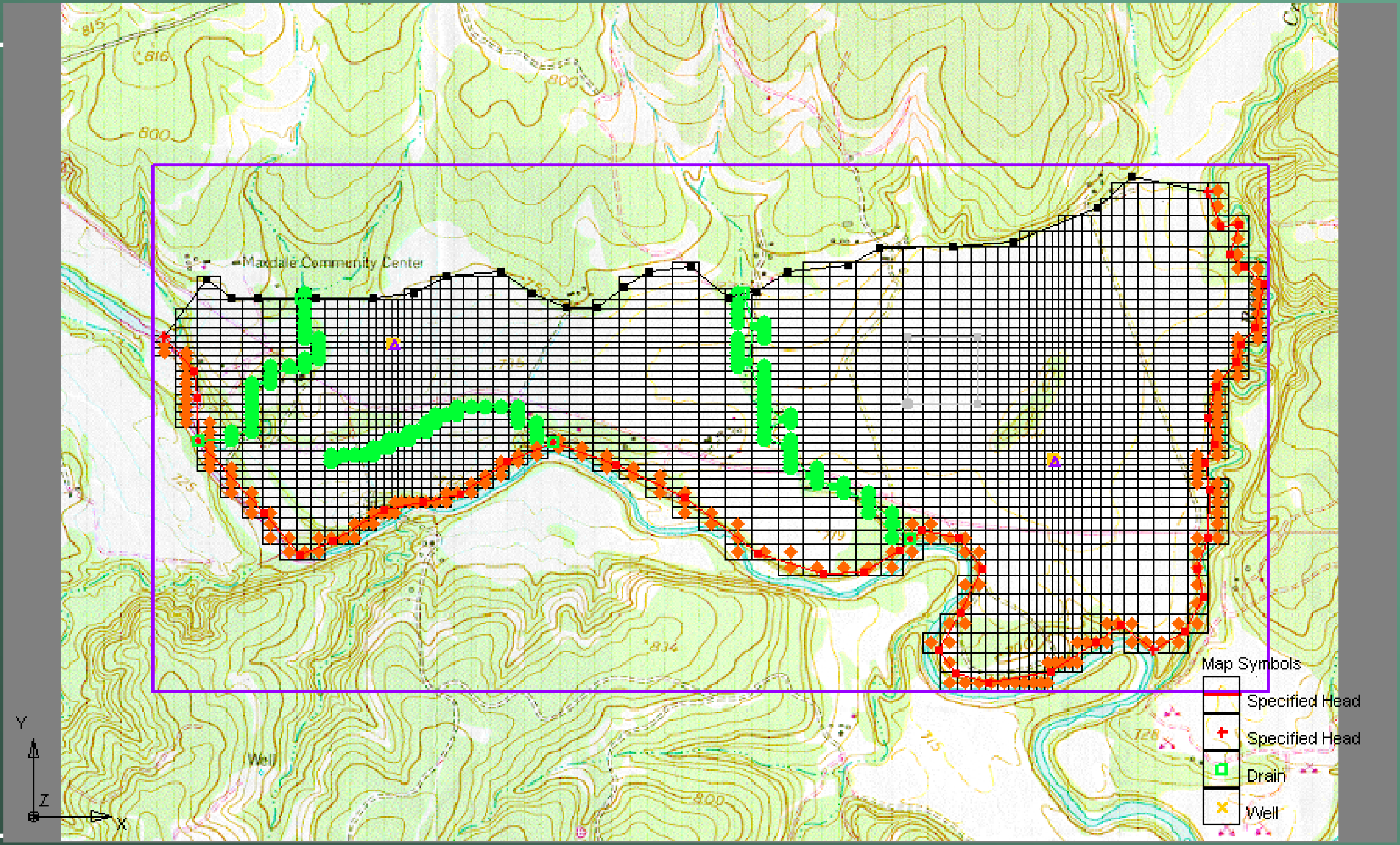
- A replica of a “real-world” groundwater system

- Can be:
  - Sand packed in a glass container
  - Electrical analog
  - Viscous liquid
  - Numerical

Electrical Analog Model



Numerical Model



Model and lab experiment

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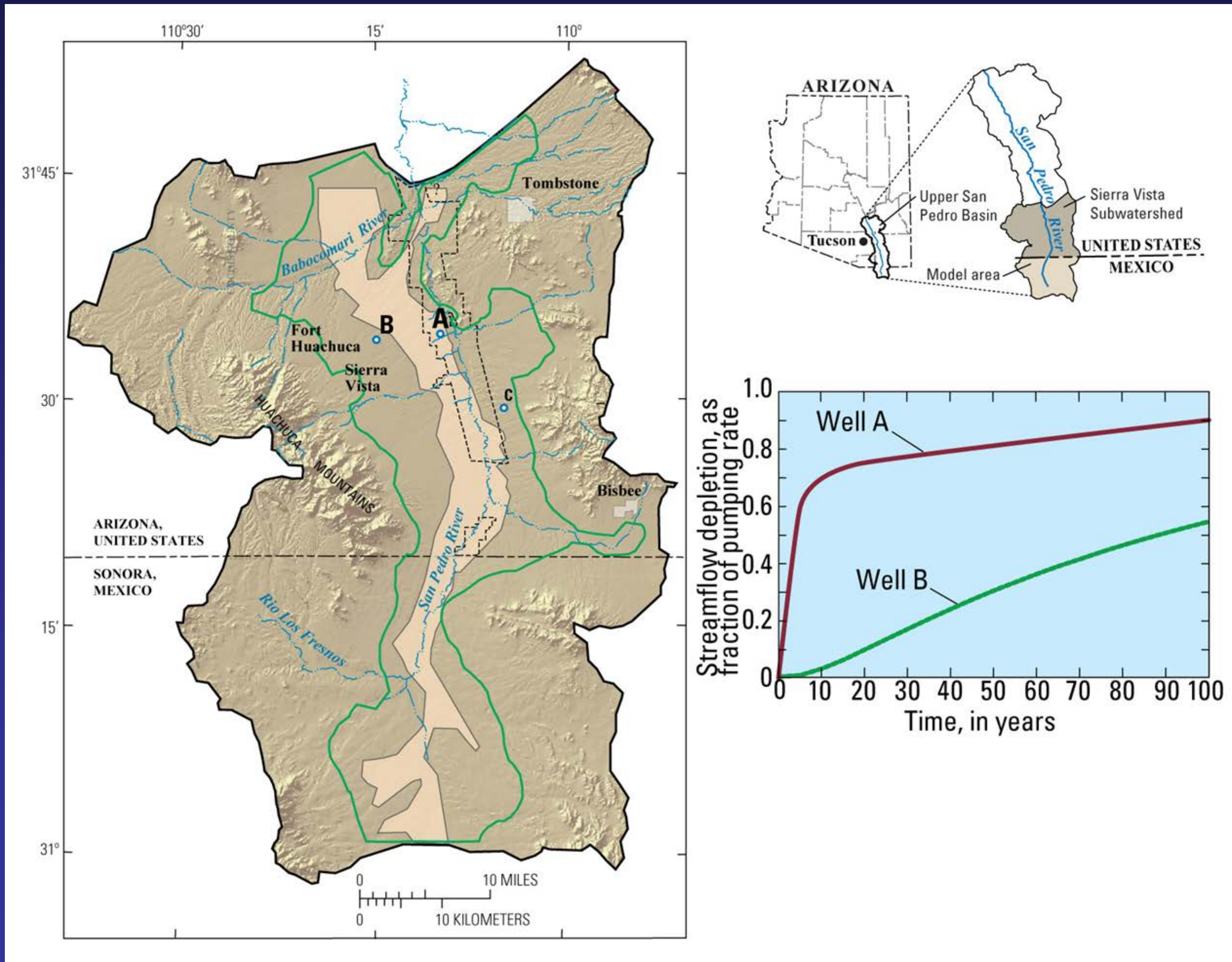
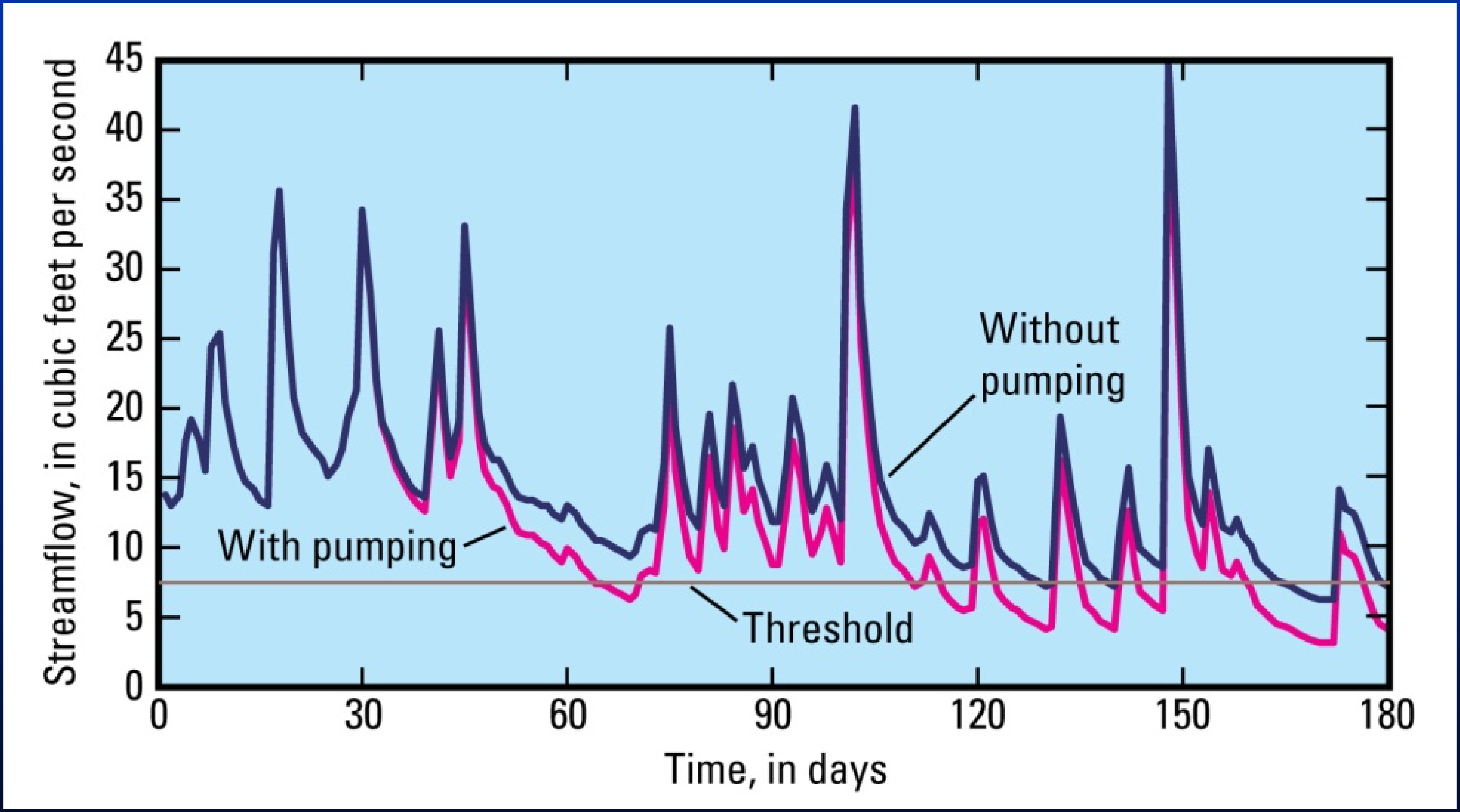
Modeling in the "Real World"



Superposition Analysis



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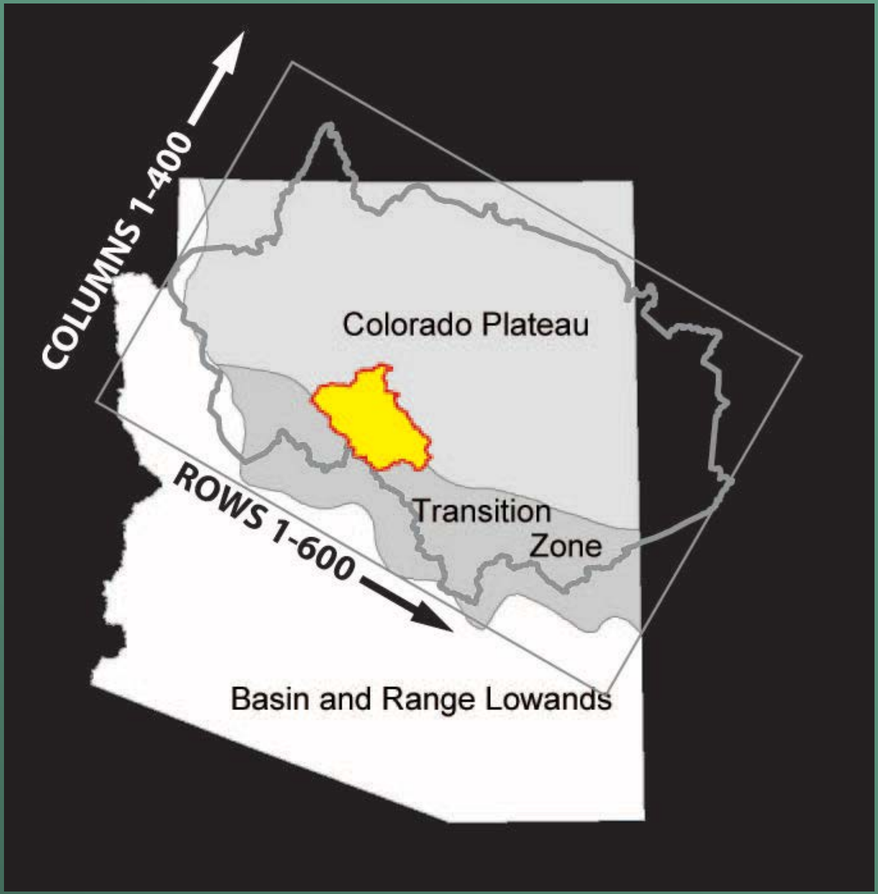
Northern Arizona Groundwater-flow model

- Purpose
  - Test assumptions
  - Develop water budgets
  - Analyze development scenarios
  - *Stream-aquifer interactions*
- Synthesizes knowledge of systems
- Calibrated to data



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GW-SW Connections

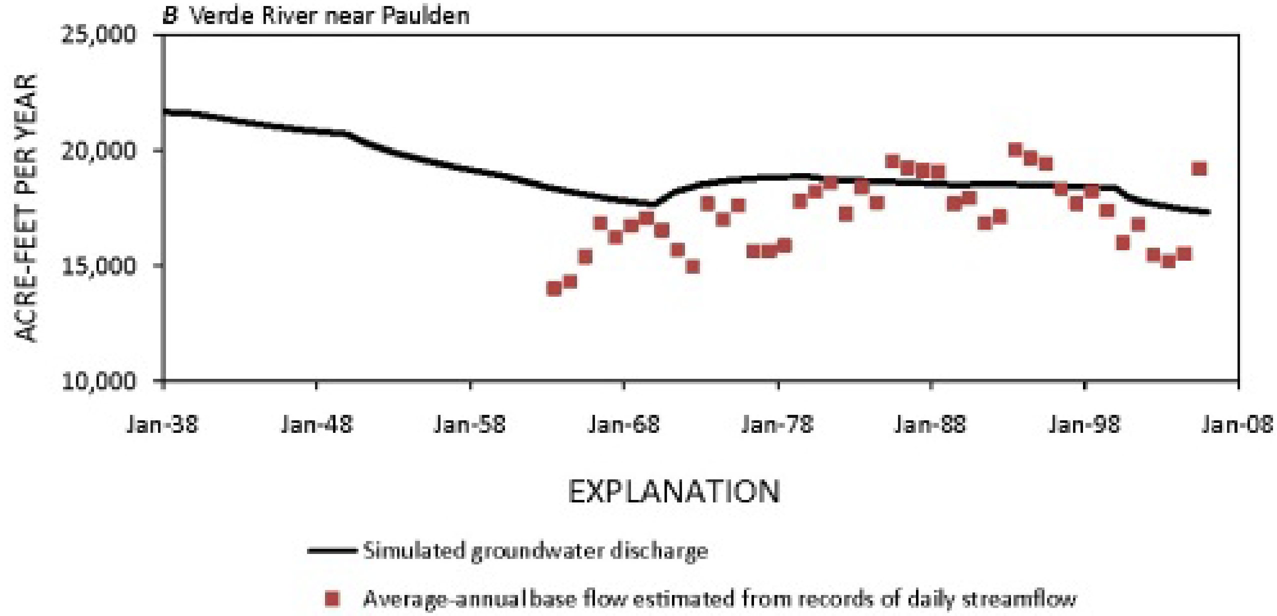

Figure 25. Simulated groundwater budgets for the (*A*) Big Chino sub-basin and (*B*) simulated and estimated base flow discharge at the Verde River near Paulden, which includes contributions from both the Big and the Little Chino sub-basins.

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......is this the Real World?

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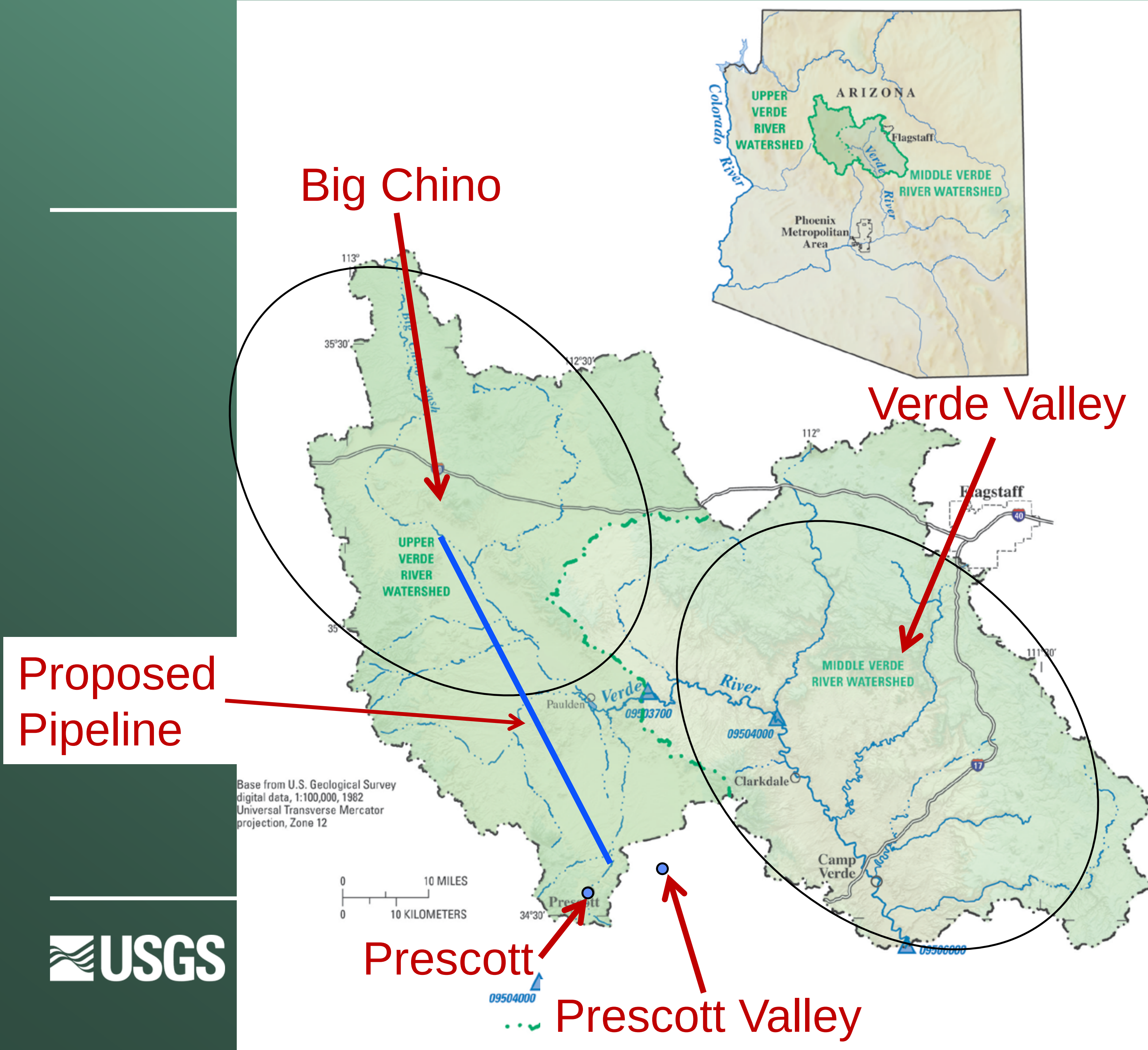
Big Chino
Verde Valley
Proposed Pipeline
Prescott
Prescott Valley
ARIZONA
UPPER VERDE RIVER WATERSHED
MIDDLE VERDE RIVER WATERSHED
Colorado River
Verde River
Flagstaff
Phoenix Metropolitan Area
Paulden
Clarkdale
Camp Verde
09503700
09504000
09506000
113°
112°30′
112°
111°30′
35°30′
35°
34°30′
Base from U.S. Geological Survey digital data, 1:100,000, 1982 Universal Transverse Mercator projection, Zone 12
0 10 MILES
0 10 KILOMETERS

Upper Verde Area's Problem

- State Groundwater Management Law
- Surface-water resources (limited)
- Limited groundwater resources

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Phoenix's Problem

- **Verde River accounts for significant supply**
- **Growing populations**
- **State Law – SW/GW connection (or not)**

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Running afoul of the law!

flow gauging station near Paulden. Essentially, the model assumes a direct 1:1 relationship between the use of groundwater and the depletion of distant streams, thereby endorsing the notion that the extraction of groundwater equals the extraction of appropriable surface water in direct contravention of long-standing Arizona water law, water policy and water management.

In Arizona, groundwater and surface water are governed under separate rules of law. Groundwater is an important source of water in this state, comprising approximately 40% of Arizona's water budget. Most rural communities in Arizona are totally dependent on groundwater for their municipal water supplies, and Arizona has long adhered to the rule that use of such water, even if it is tributary to a flowing stream, is available to these communities for the health and welfare of their citizens. *See In Re The General Stream Adjudication Of All Rights To Use Water In the Gila River System And Source*, 198 Ariz. 330; 9 P.3d 1069 (2000). Complex litigation is well underway to determine the relative rights in the use of groundwater and surface water in the Arizona general stream adjudications, and the use of simplistic assumptions in the creation of any groundwater model only serves to confuse and prolong these on-going proceedings. Thus, the USGS' Regional Groundwater-Flow Model of Northern and Central Arizona Aquifers, as currently constructed, is a disservice to Arizona. It is also a disservice to the long-standing tradition of high-quality work at the USGS.

EDITORIAL

The drought you can't see

Marcia McNutt
Editor-in-Chief
Science *journals*

The Western Hemisphere is experiencing a drought of crisis proportions. In Central America, crops are failing, millions are in danger of starvation, and if the drought doesn't break soon, even vessels transiting the Panama Canal will need to lighten their loads, which will increase prices for goods transported globally. In the western United States, the drought-stricken region spans a vast area responsible for much of the nation's fruits, vegetables, and beef. As the drought's grip has tightened, water users have turned to tapping groundwater aquifers to make up the deficit for people, crops, livestock, and industry. But even when the rain does return, regreening the landscape and filling again the streams, lakes, and reservoirs, those aquifers will remain severely depleted. It is this underground drought we can't see that is enduring, worrisome, and in need of attention.

"It is high time we started managing our precious water supplies in harmony with the laws of nature."

The Gravity Recovery And Climate Experiment (GRACE) satellites have provided a global look at groundwater depletion by monitoring small temporal changes in Earth's gravity field. GRACE confirmed massive losses of groundwater from the aquifer underlying California's agriculturally important Central Valley since the 1980s.* In the decade between 2003 and 2012, the drawdown was equivalent to the entire water storage volume of Lake Mead, the nation's largest surface reservoir.† The extraction of groundwater has caused wells to run dry and produced detectable regional uplift or rebound of the land due to water displacement (see Borsa *et al.*, p. 1587).

Underground reservoirs are a natural long-term water storage solution. Taking advantage of aquifers avoids the expense and environmental issues of dam construction. Unlike surface reservoirs, aquifers are not subject to evaporative loss, but under natural conditions they are only recharged slowly as excess precipitation percolates into the aquifer. In some cases, the average age of groundwater can be many thousands of years old, dating back to a time when the climate was wetter. But when water is withdrawn through pumping at prodigious rates, hydrologic processes are not sufficient to fully recharge the reservoirs, especially when land development has created impervious surfaces.

Forty years ago, the state of Arizona reached a critical juncture that called for action, with rapidly falling water tables, dry wells, subsiding land surface, and deteriorating water quality. Now, in the Tucson area for example, water from the Colorado River is used to artificially recharge the aquifers with excess water in wet years that can later be tapped during dry years. The statewide 1980 Groundwater Management Act guarantees that over a 10-year period, the aquifer cannot be overdrawn. The current crisis has prompted the legislature of California—the last state in the west without groundwater regulation—to pass a series of bills that establish state-level oversight of pumping from aquifers.

Surface- and groundwater are all part of one coupled system, responding on different time scales to changes in precipitation. Five years ago when I was director of the U.S. Geological Survey (USGS), an Arizona congressman had some concerns about a USGS report on the impact of overpumping of groundwater on surface stream flows. The congressman declared, "You all should be aware that according to Arizona state law, surface water and groundwater flows are decoupled." Jim Leenhouts, the USGS associate director for the Arizona Water Science Center responded, without hesitation, "Thank you, congressman. Here at the USGS we follow the laws of nature, not the laws of man." It is high time we started managing our precious water supplies in harmony with the laws of nature.

– Marcia McNutt

*http://pubs.er.usgs.gov/publication/fs20093057. †J. S. Famiglietti, M. Rodell, *Science* **340**, 1300 (2013).

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PHOTOS: (INSET) JUSTIN SULLIVAN/GETTY IMAGES; (RIGHT) STACEY PENTLAND PHOTOGRAPHY

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One thing leads to another….

“That y … /ho
doesn’ … 490

USGS

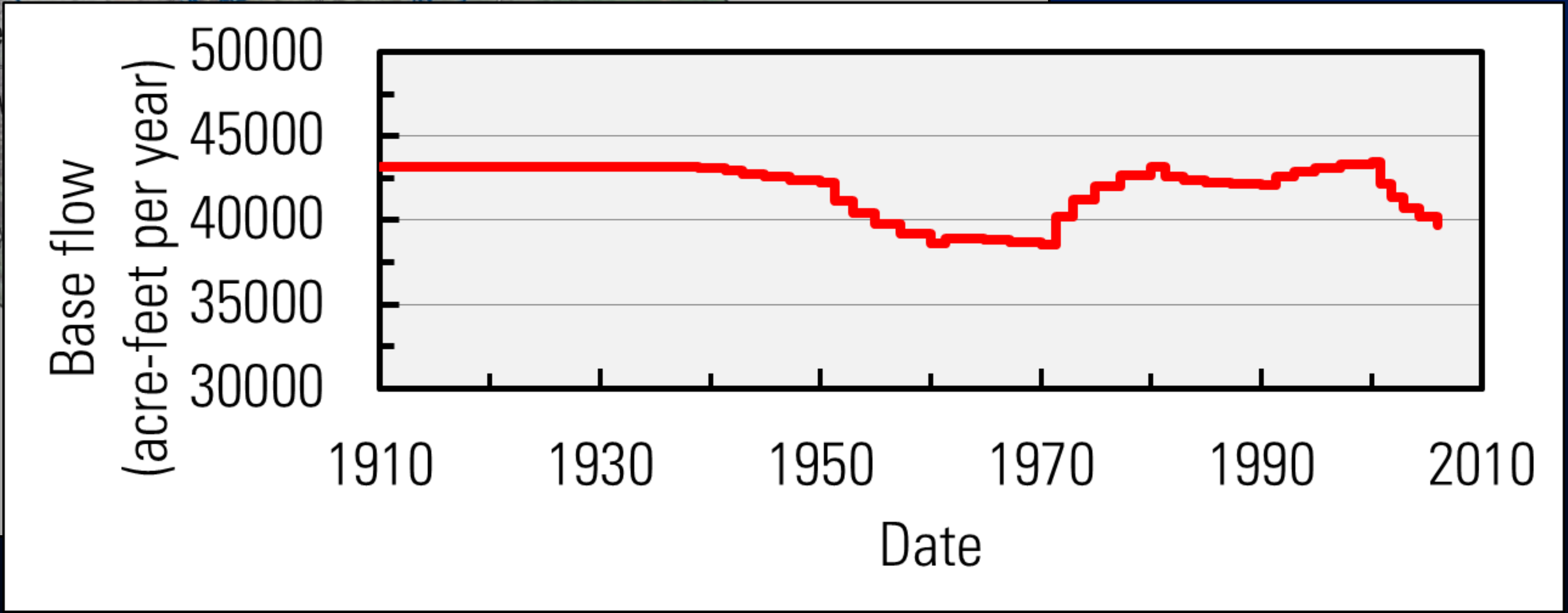
The past: 1910–2005 modeled base flow

Upstream Clarkdale gage

USGS

The past: 1910–2005 modeled base flow

Upstream Clarkdale gage



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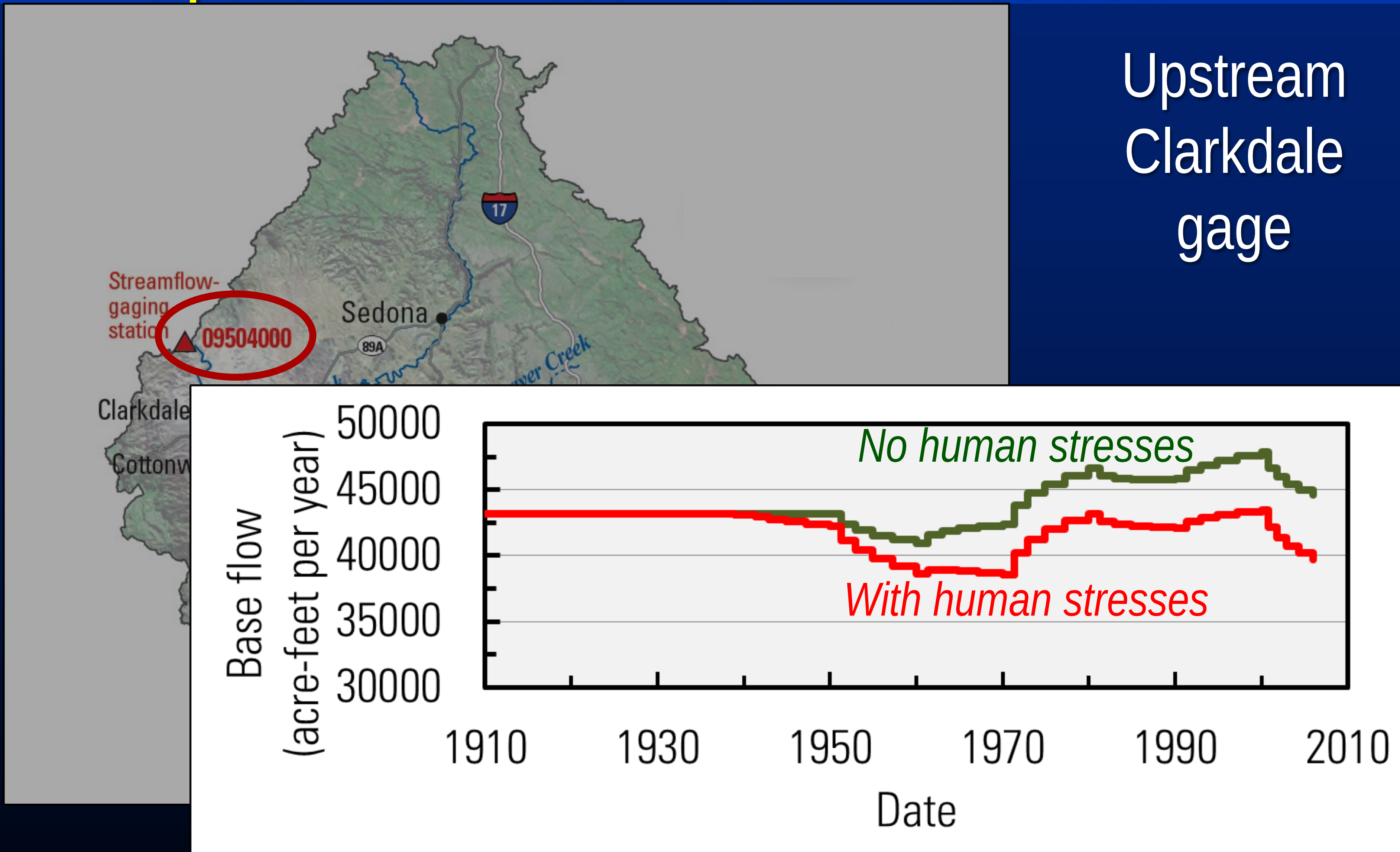
The past: 1910–2005 modeled base flow

Upstream Clarkdale gage



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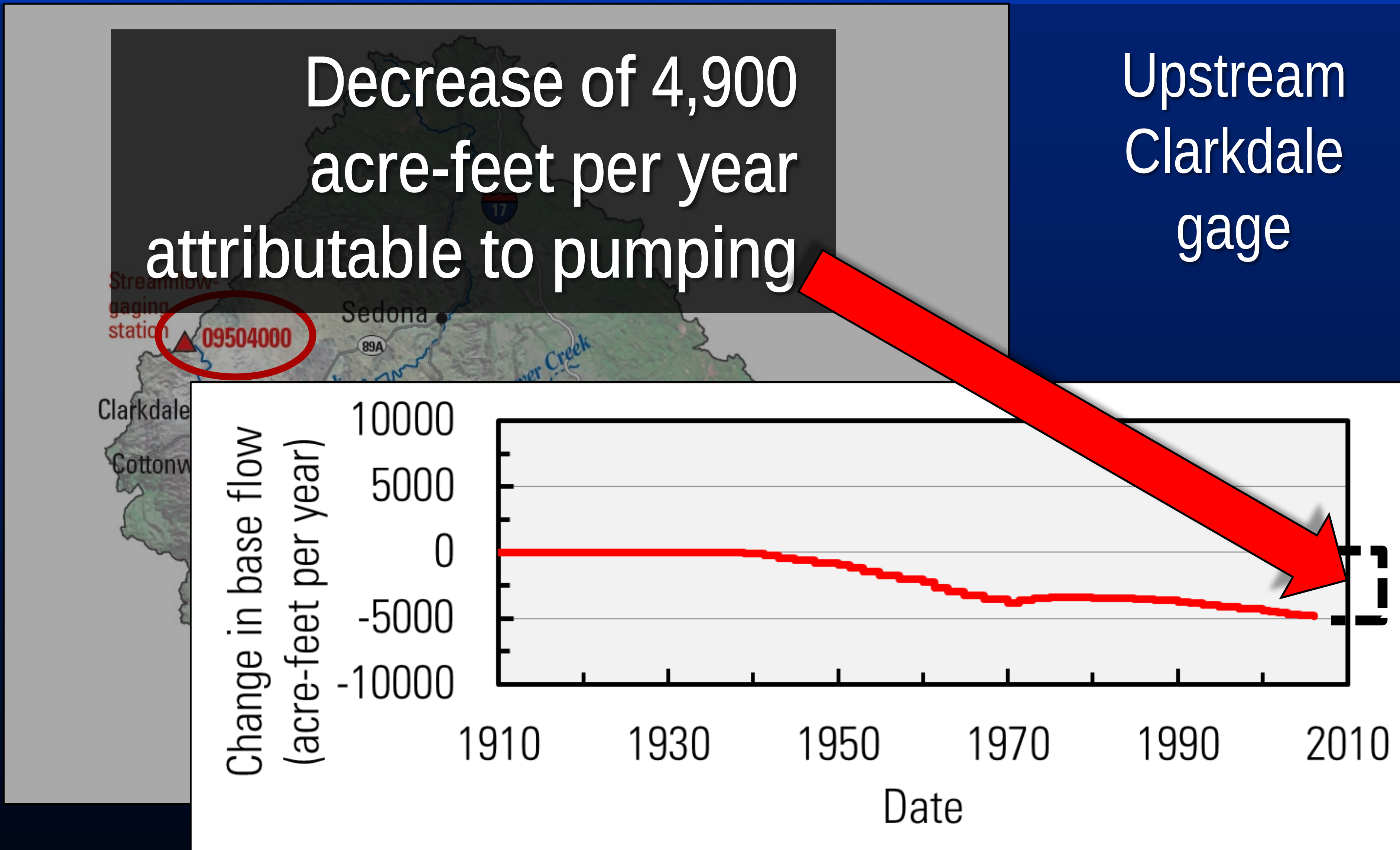
1910–2005 modeled base flow

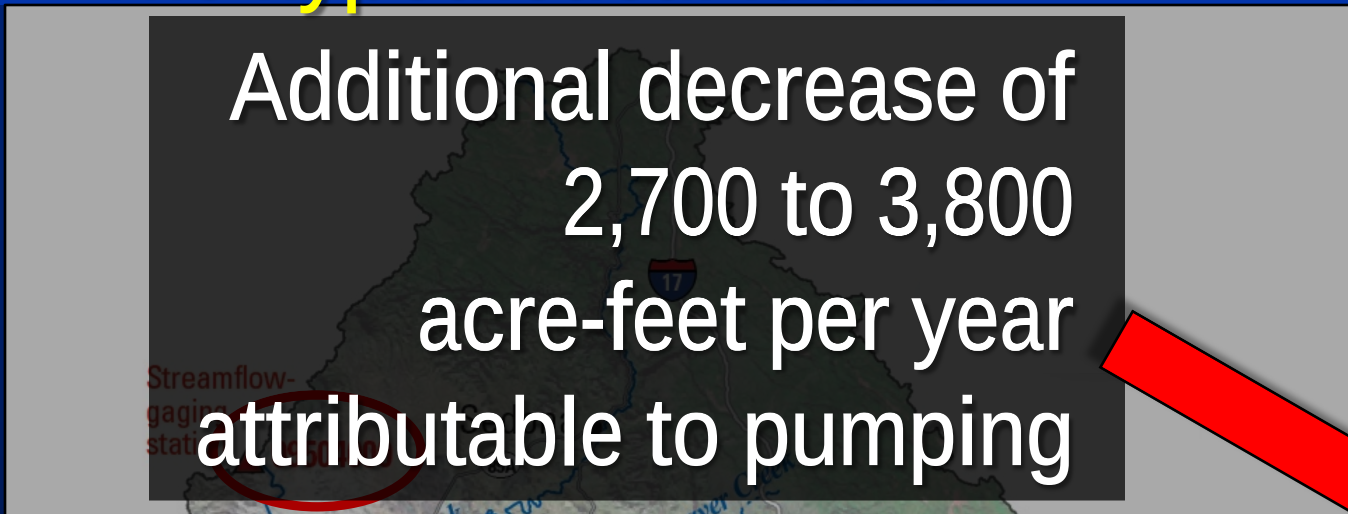
Decrease of 4,900 acre-feet per year attributable to pumping



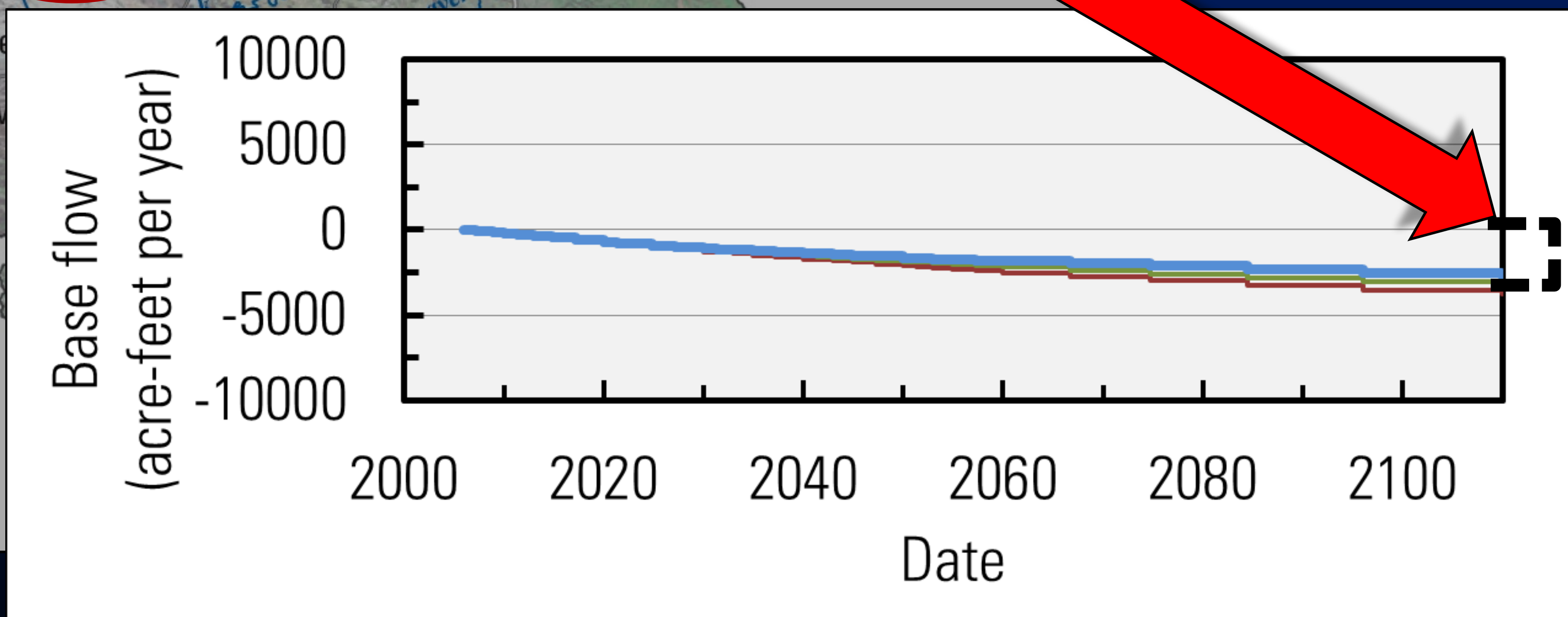
Upstream Clarkdale gage

The hypothetical future

Additional decrease of 2,700 to 3,800 acre-feet per year attributable to pumping



Upstream Clarkdale gage



Epilogue

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