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Groundwater Modeling Basics

What's the controversy?

Jim Leenhouts
USGS Arizona Water Science Center
July 10, 2013

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

Outline

- Basics on GW/SW interactions
- Models for analysis of complicated problems
- Political challenges and how to respond to questions about models

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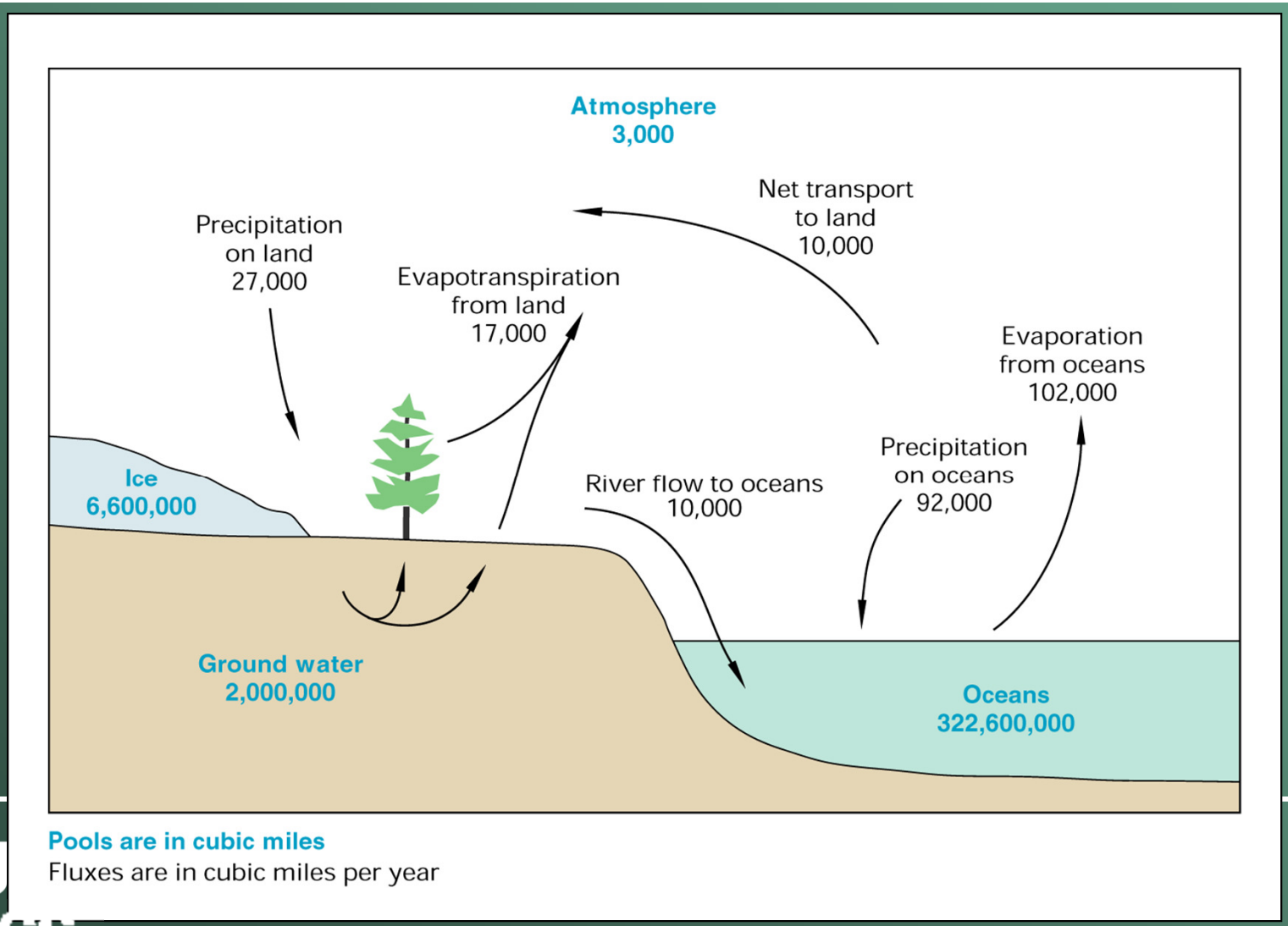
Groundwater is part of the hydrologic cycle



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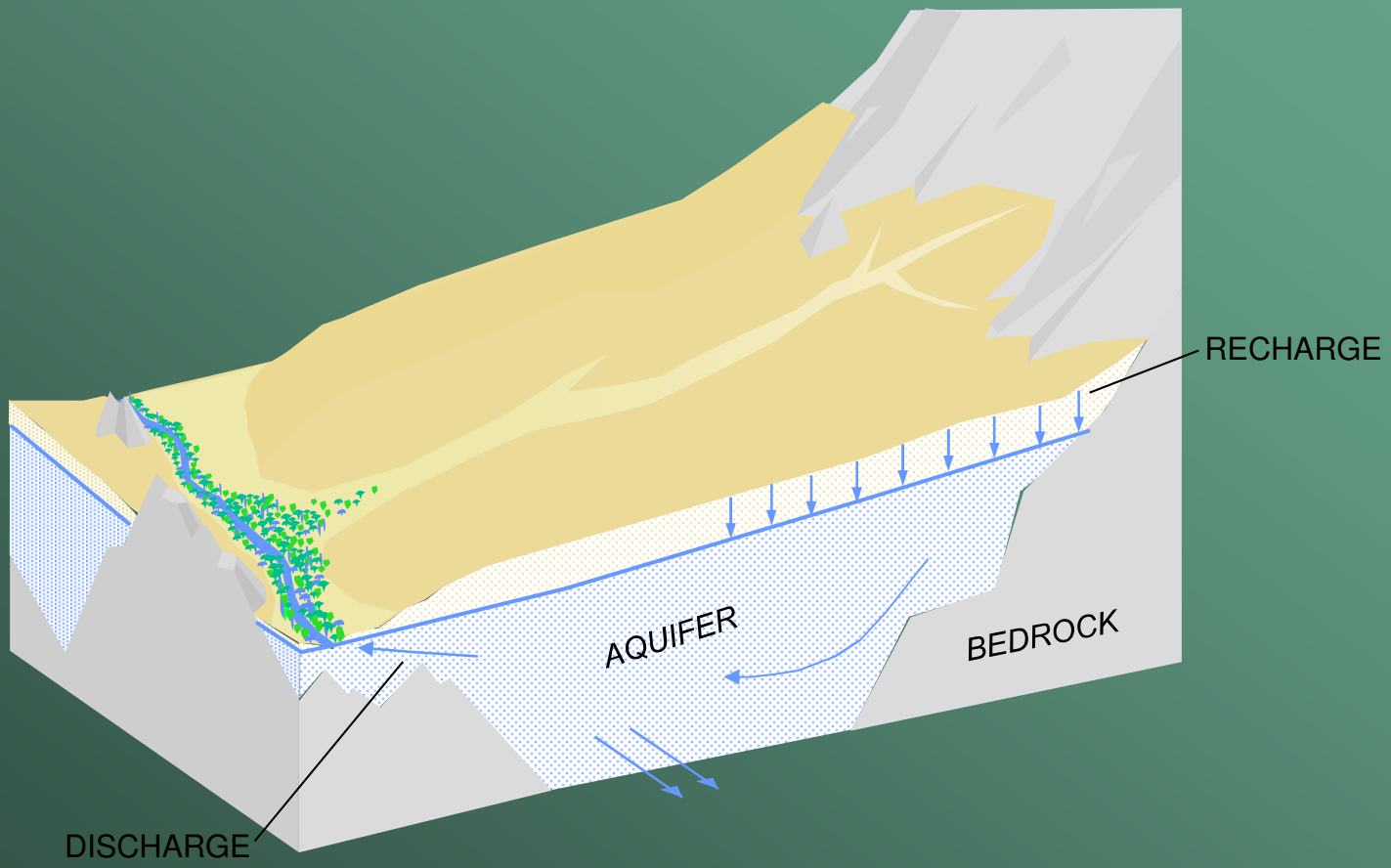
Real aquifers are 3-dimensional!



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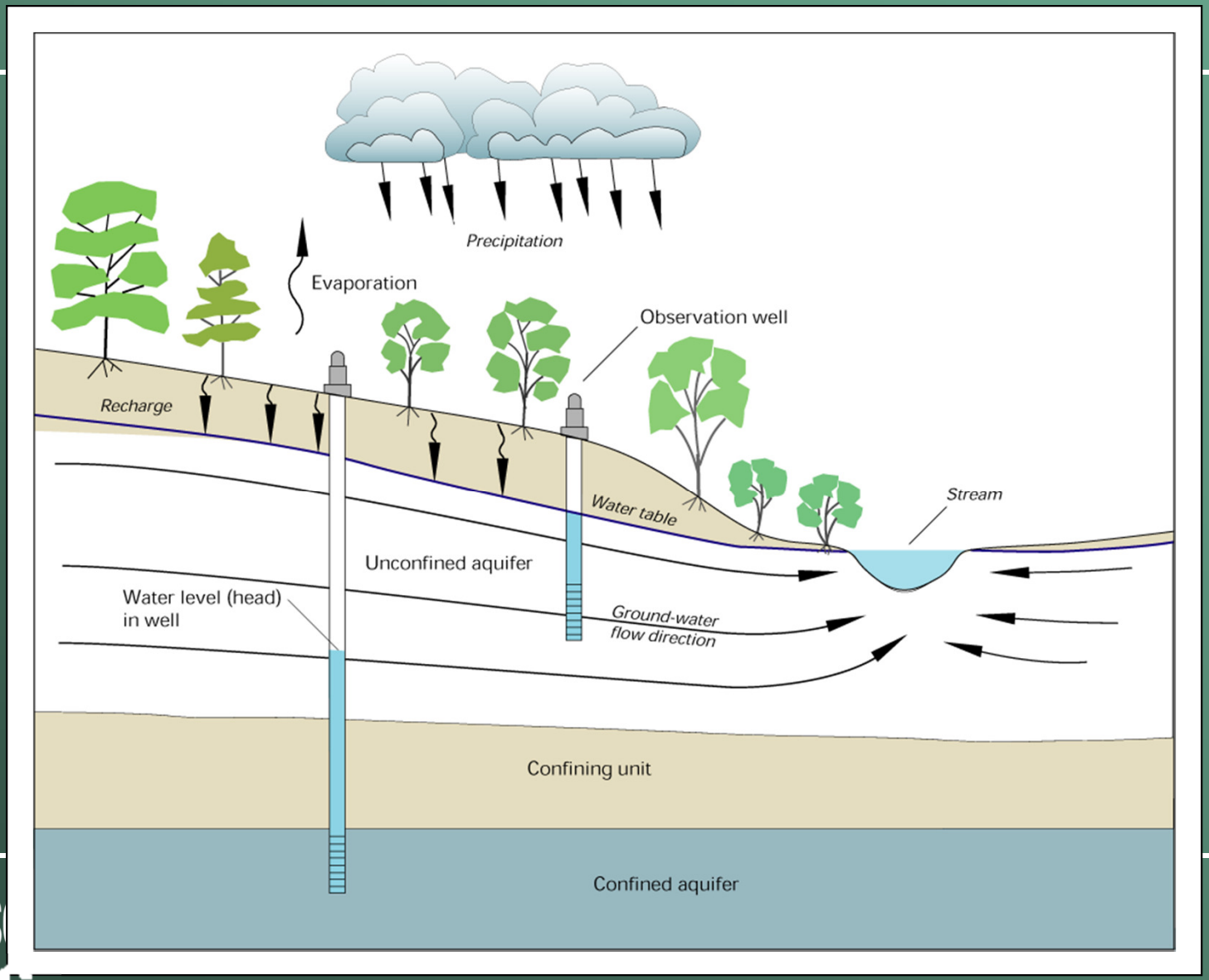
Typical ground-water flow system



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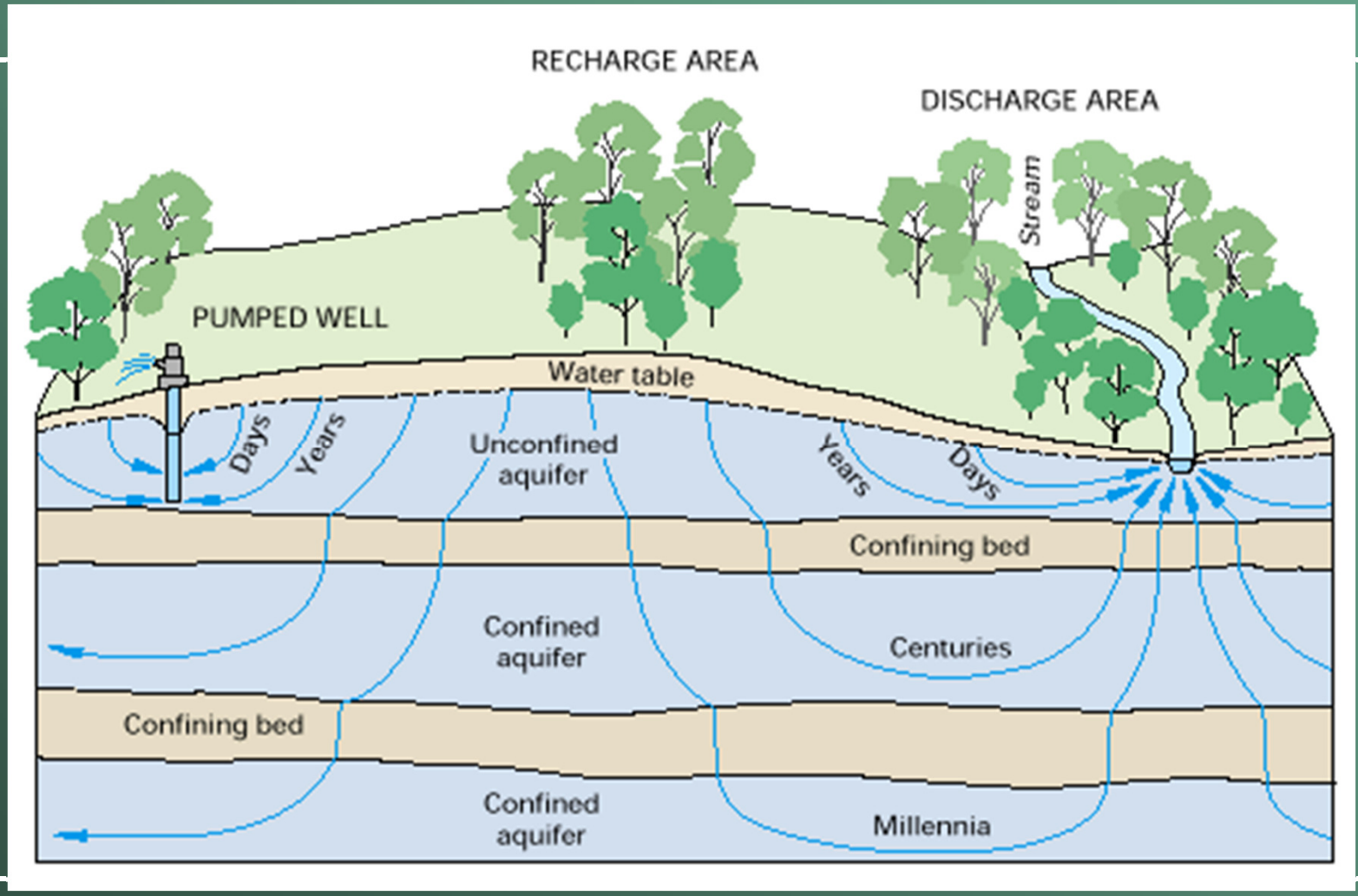
Simple….yet complicated!



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Objectives in Groundwater Management

- Water-level declines
- Subsidence
- Changes to water budgets

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What are the sources of water to pumping wells?

- Initially, a well draws water from storage
- With time, greater percentages of pumped water is derived from capture of available ground-water discharge
  - from streams
  - from evapotransipration
  - from springs
  - from ground-water flow to adjacent downstream aquifers
  - Also can capture recharge areas in adjacent basins

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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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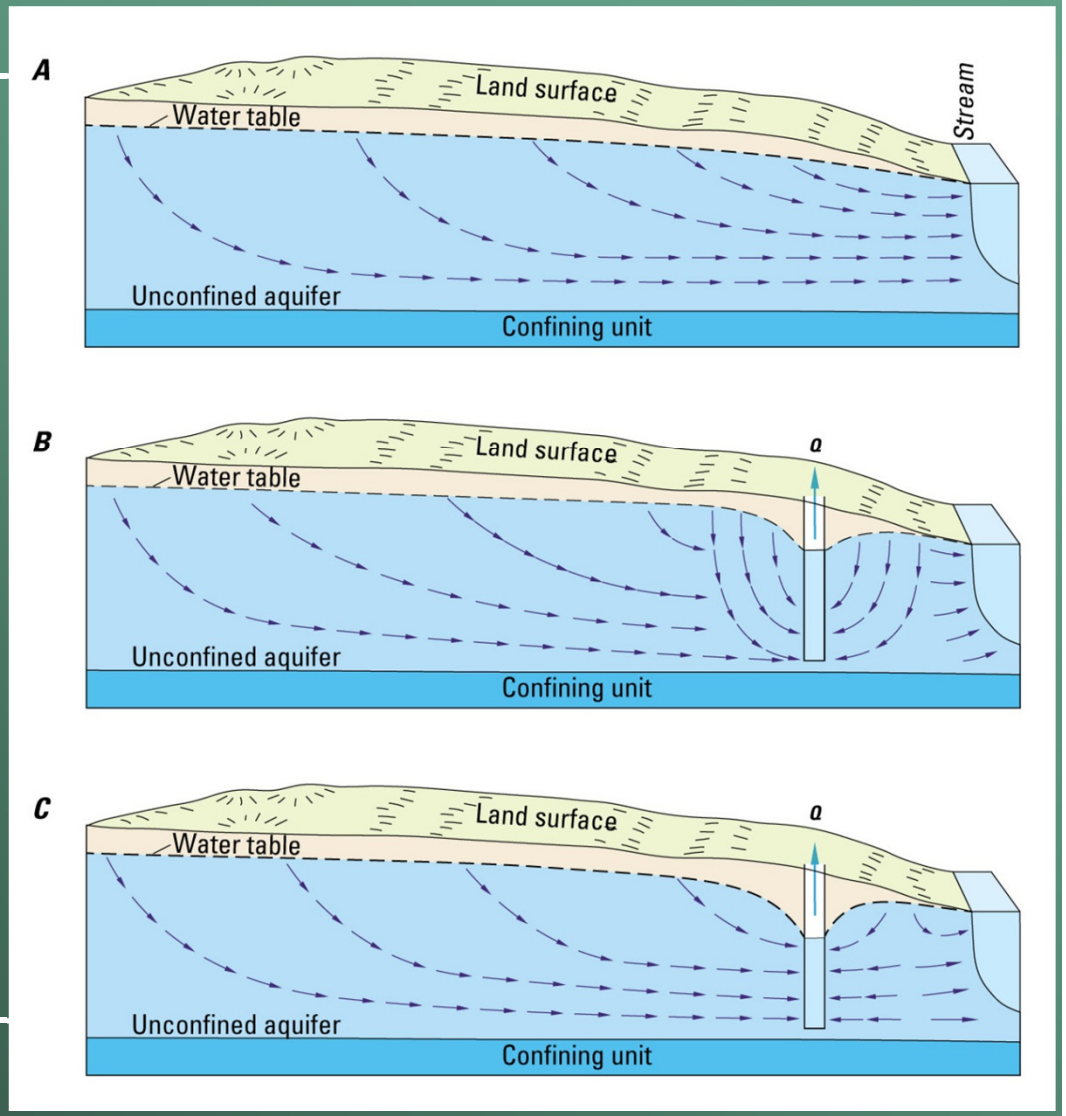

Capture (streamflow depletion)

- C.V. Theis (1940) – seminal paper
- Increase in recharge+decrease in discharge
- Factors that affect capture
- All about “where” and “when”

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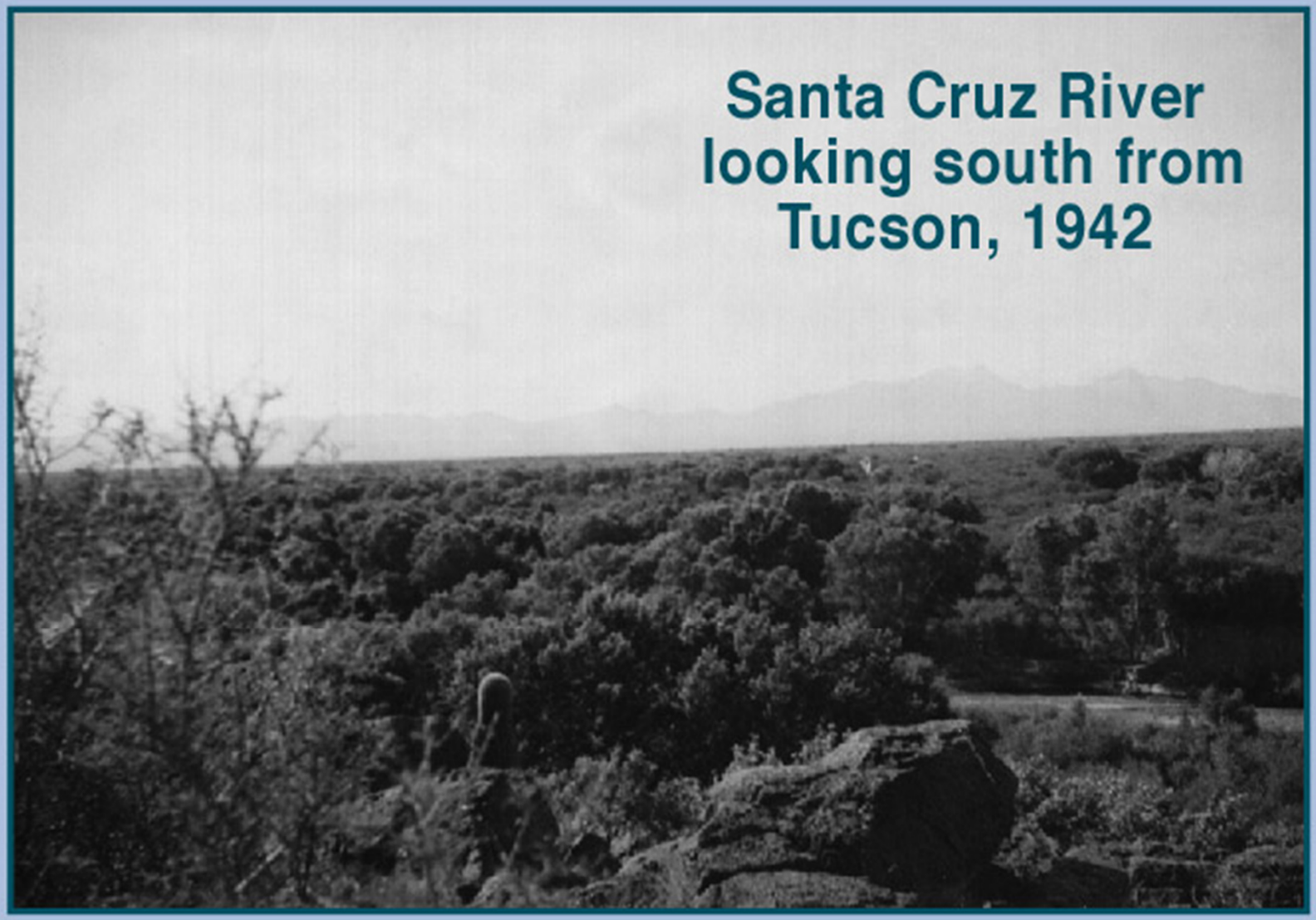
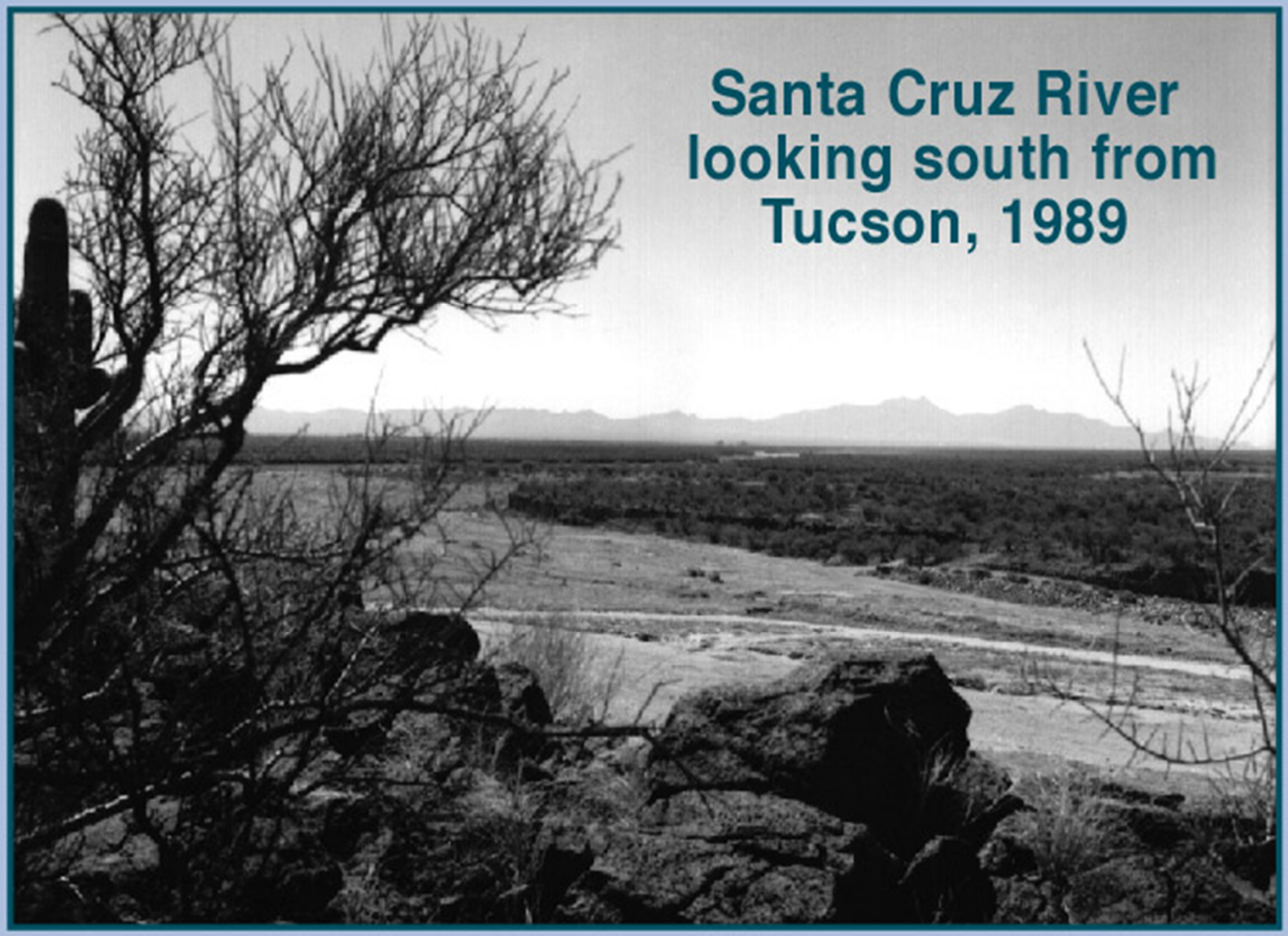
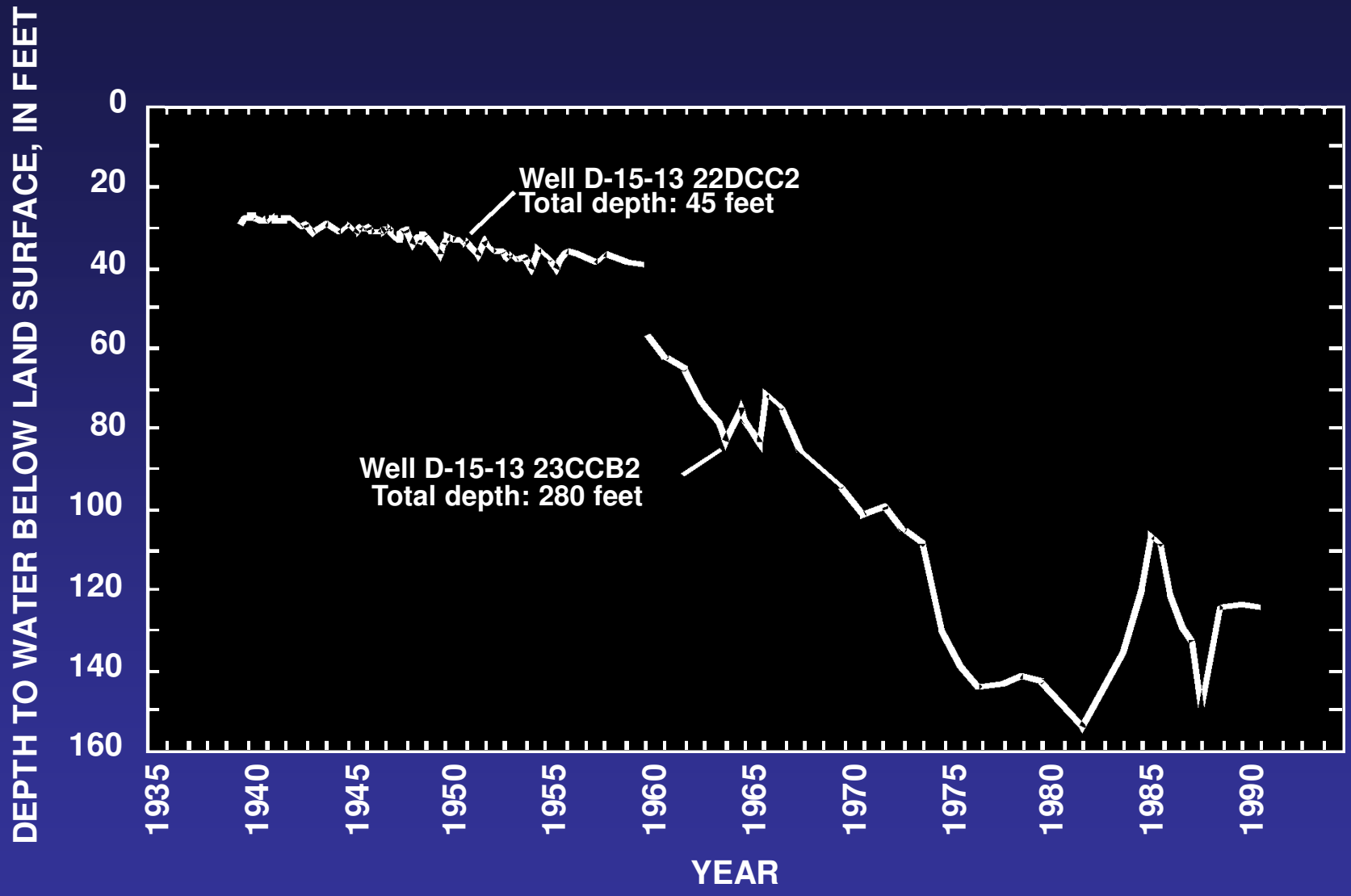
Effects of GW withdrawals

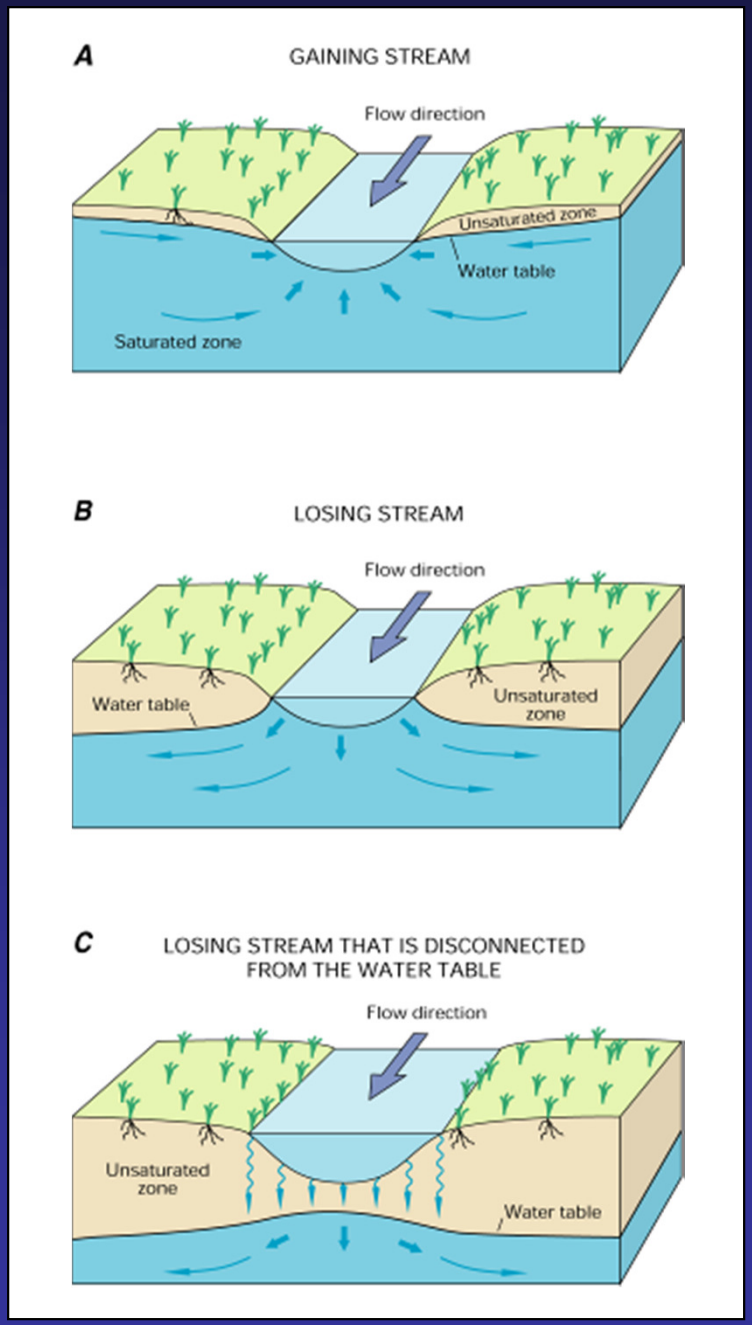


Effects of GW withdrawals

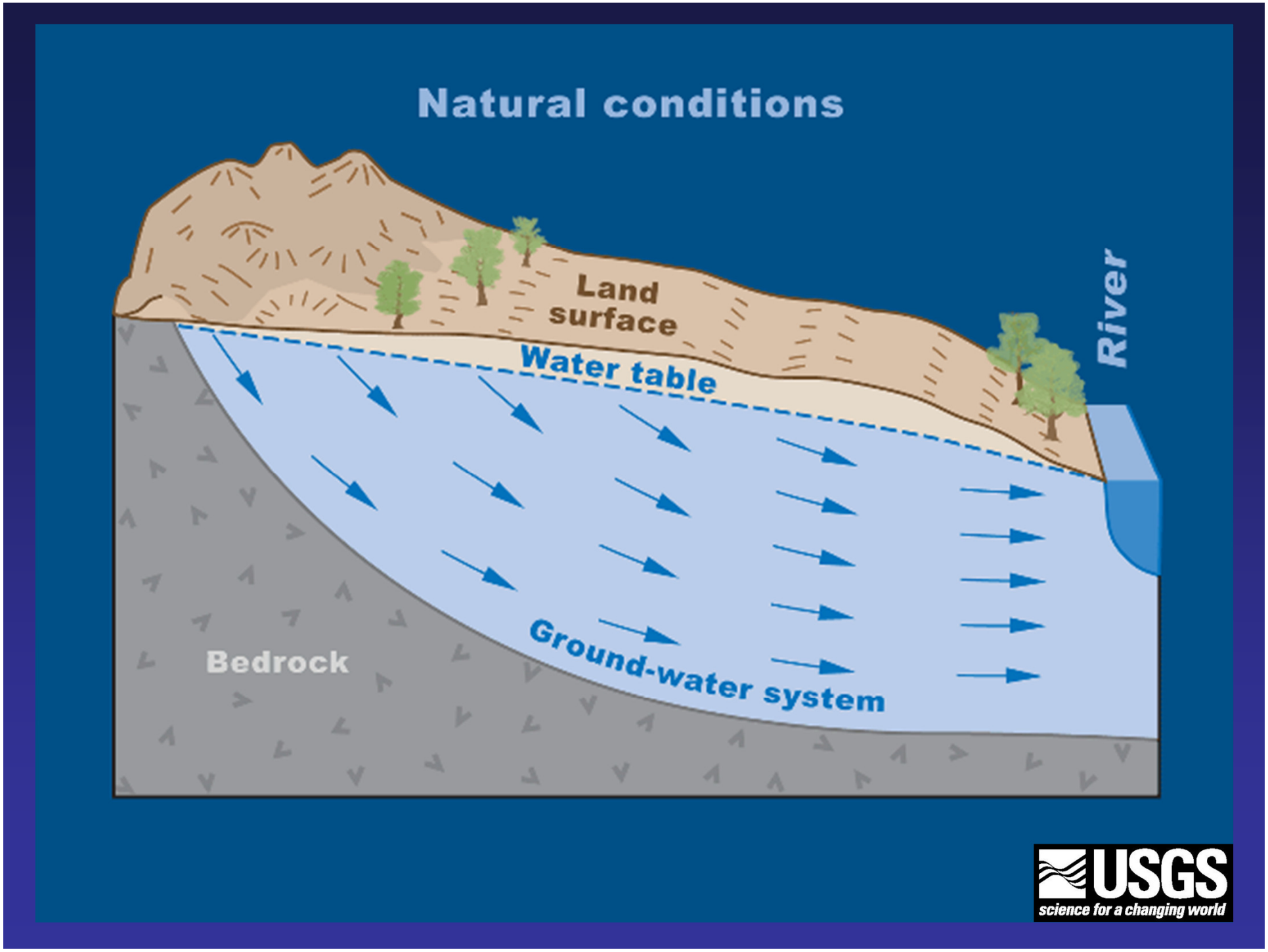


Well near Martinez Hill




A
GAINING STREAM
Flow direction
Unsaturated zone
Water table
Saturated zone
B
LOSING STREAM
Flow direction
Water table
Unsaturated zone
C
LOSING STREAM THAT IS DISCONNECTED FROM THE WATER TABLE
Flow direction
Unsaturated zone
Water table

USGS


Natural conditions
Land surface
Water table
River
Bedrock
Ground-water system
USGS
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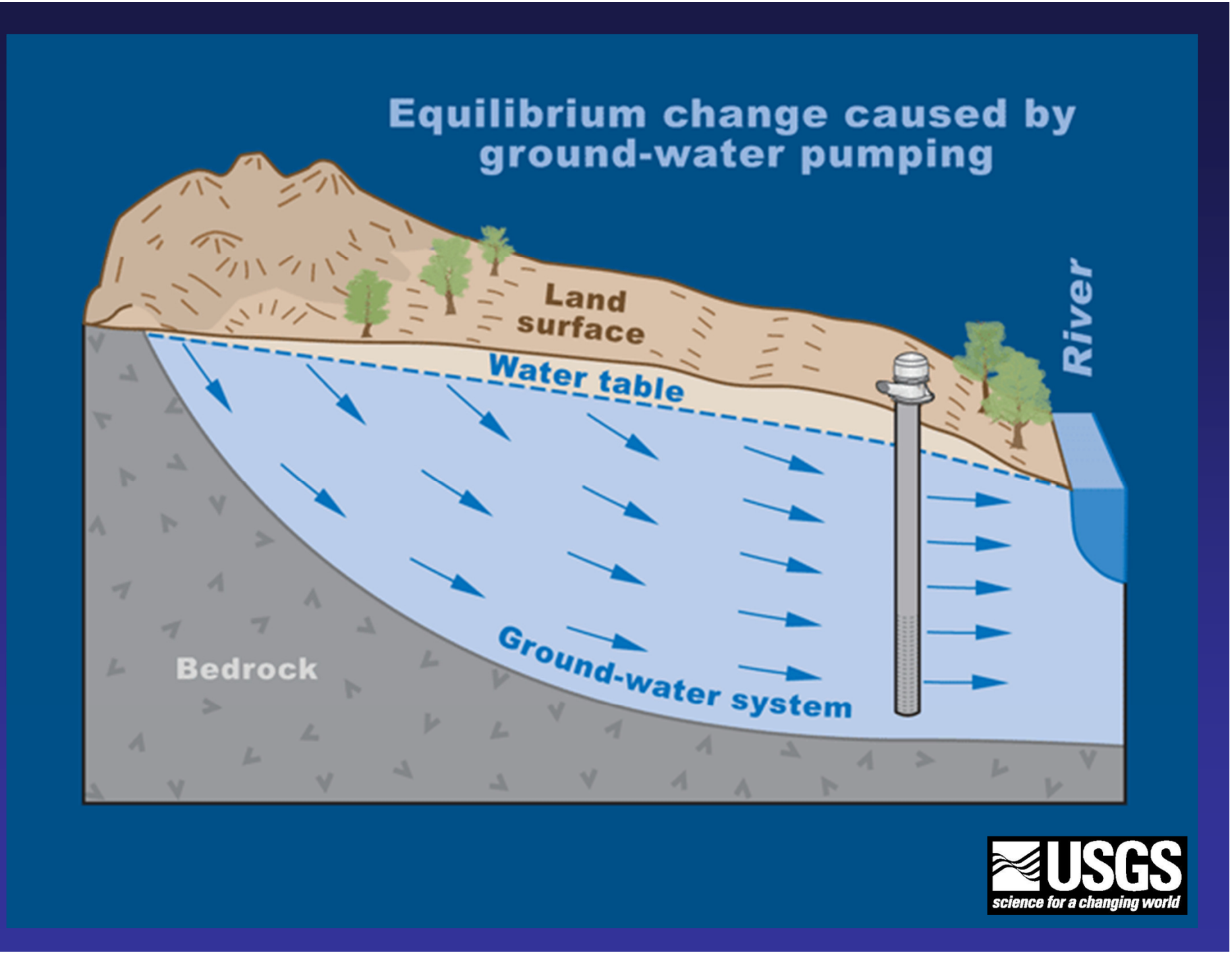
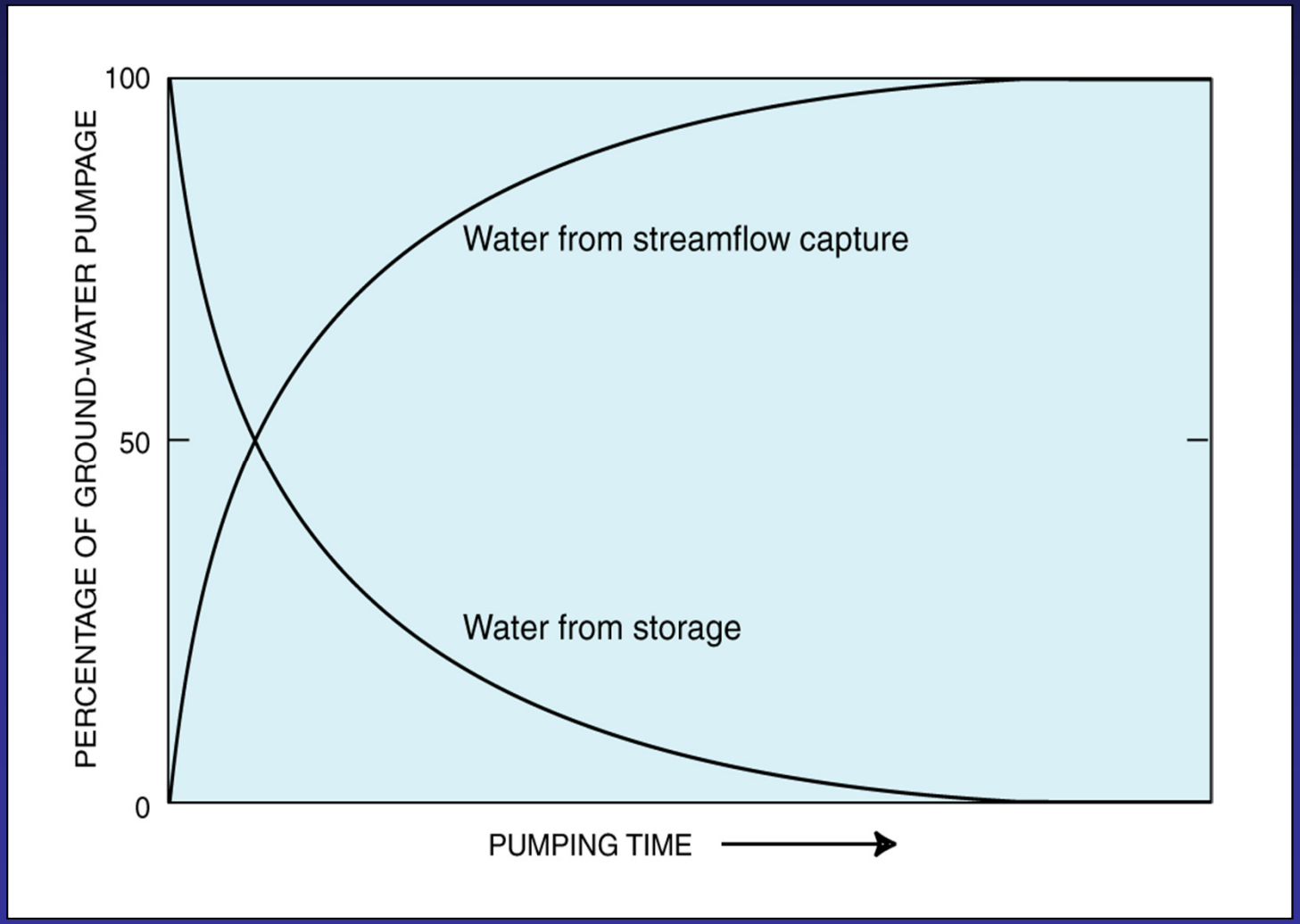

Equilibrium change caused by ground-water pumping
Land surface
Water table
River
Bedrock
Ground-water system
USGS
science for a changing world

The Classic “Capture Curve”



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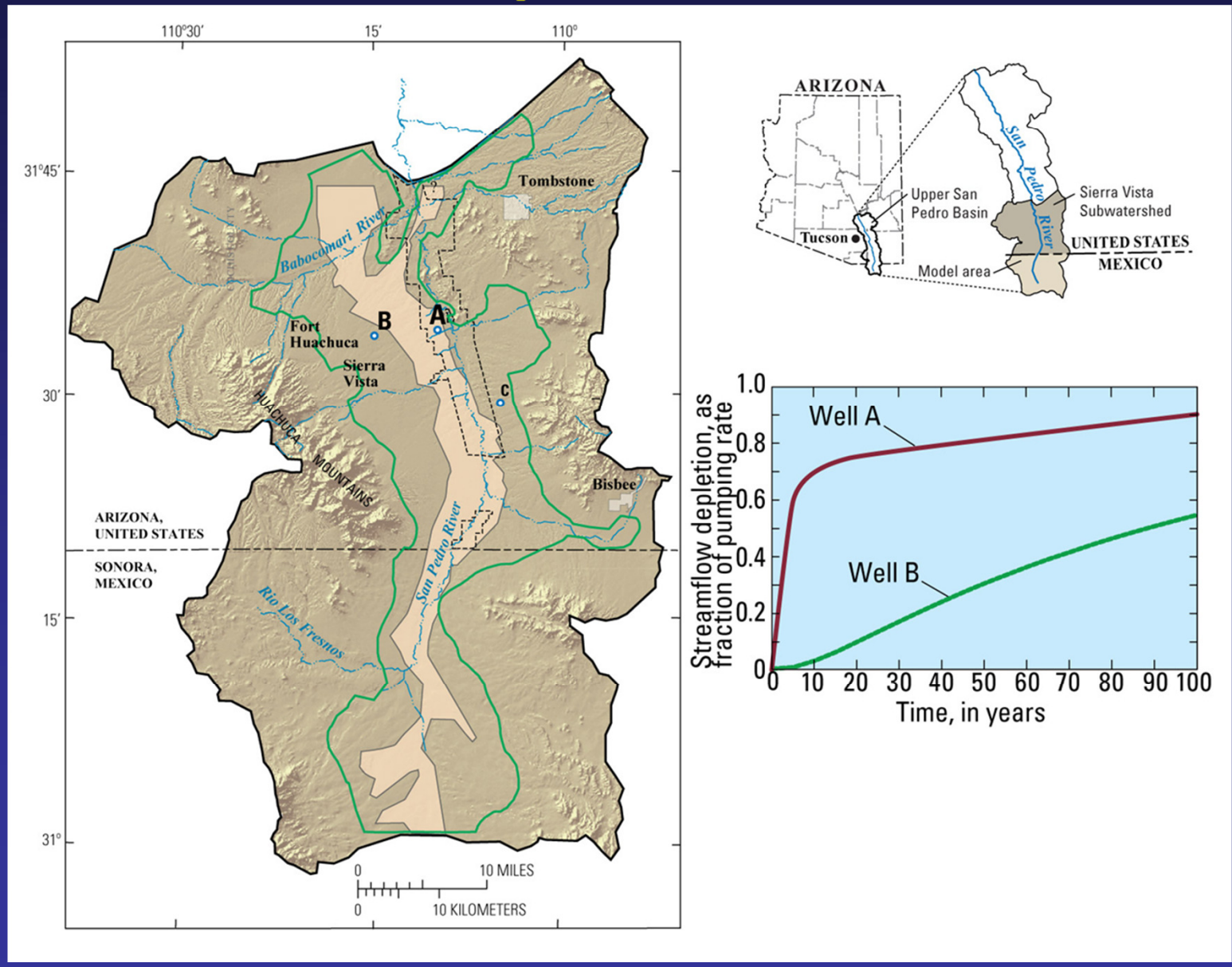
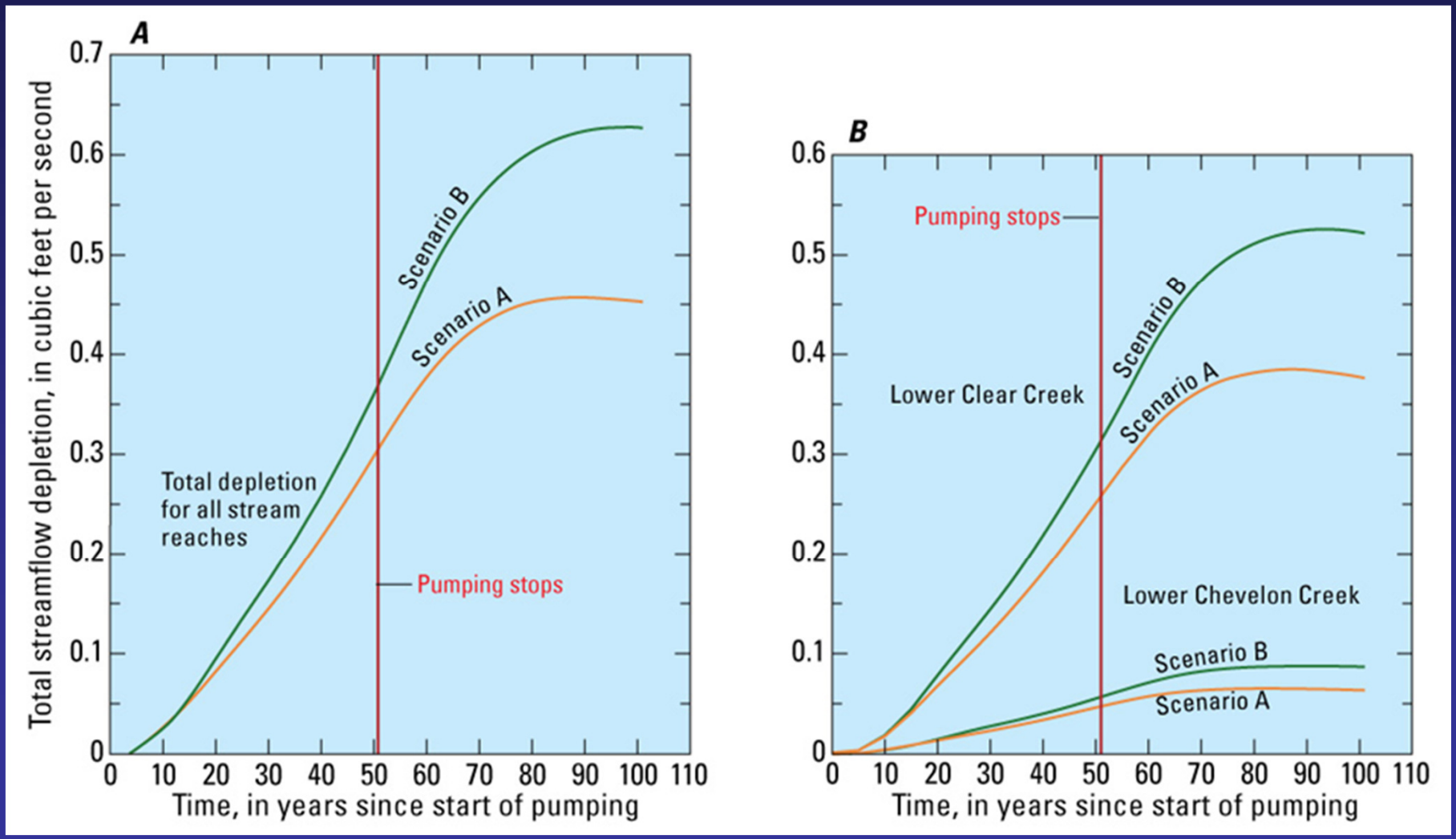
Complications



More Complications



What is a groundwater model?

- A replica of a “real-world” groundwater system
- Can be:
  - Sand packed in a glass container
  - Electrical analog
  - Viscous liquid
  - Numerical

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Model and lab experiment

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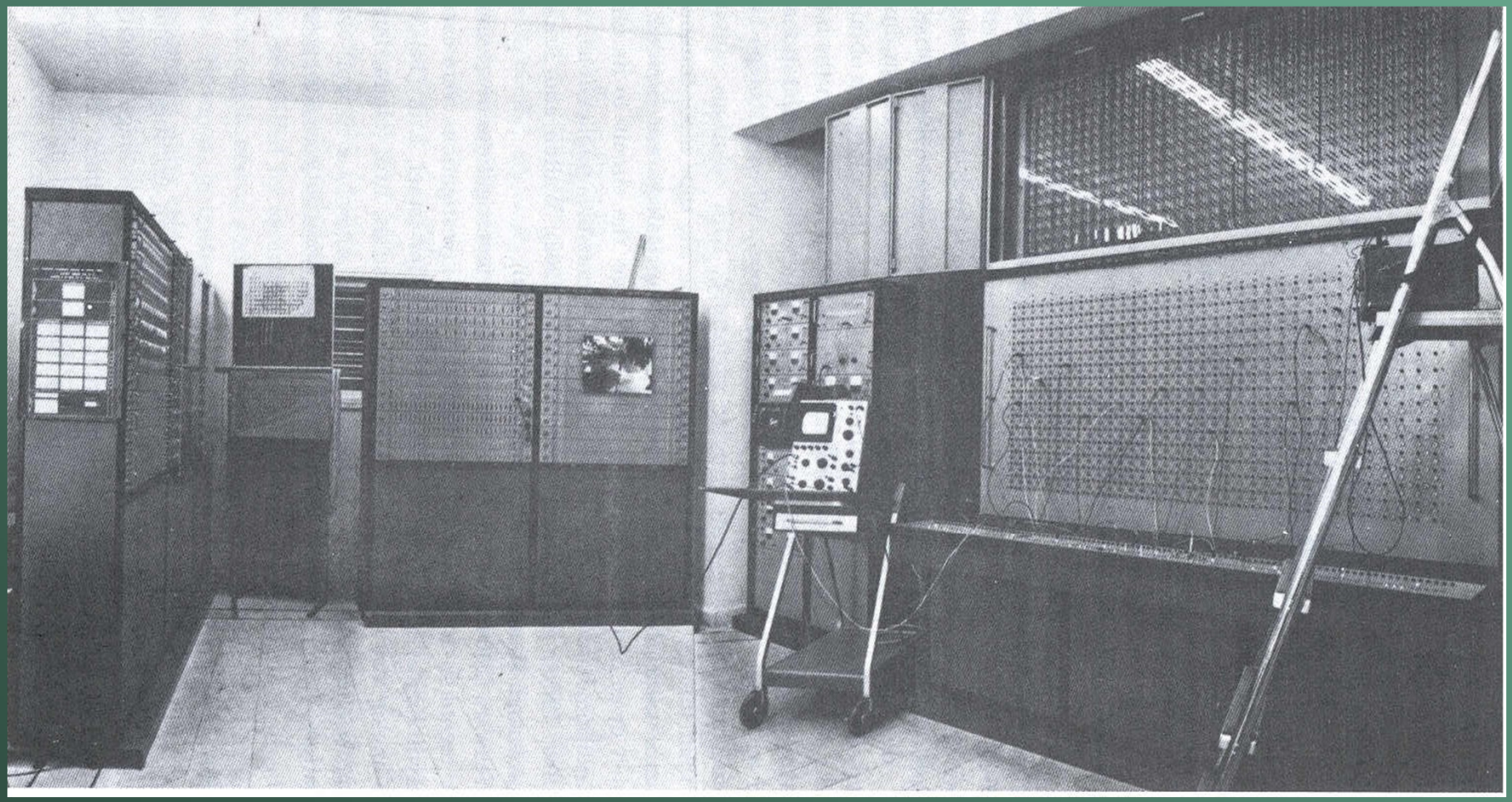
Electrical Analog Model



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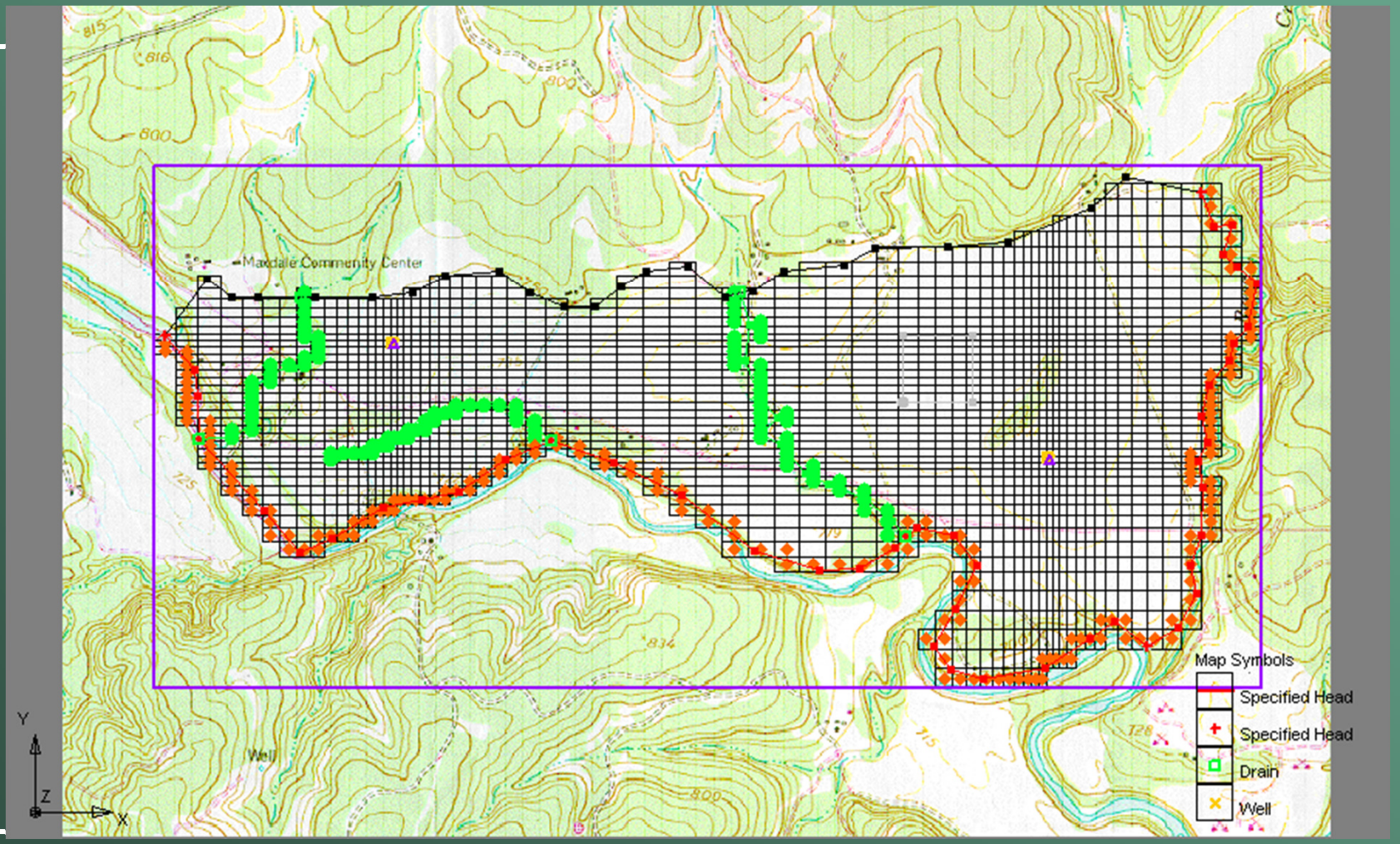
Numerical Model



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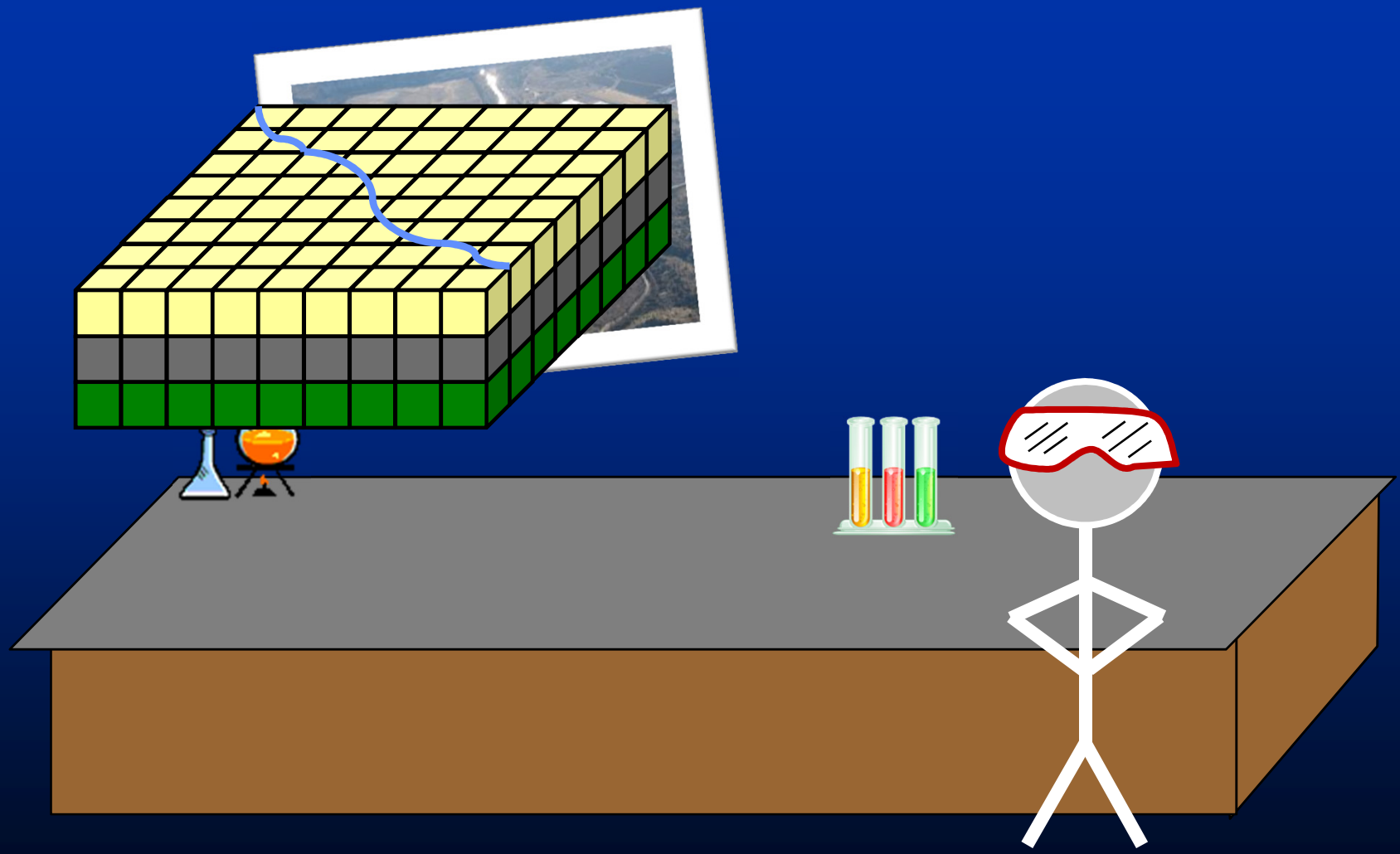
Experiment on model



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Model Accuracy

- Dependant of the level of understanding of the flow system
- Requirements:
  - Some level of site investigation
  - Accurate conceptualization
- Old quote: “All models are wrong but some are useful”
- Accuracy is always a trade-off between resources and goals

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Types of Models

(from Anderson and Woessner, 1992 *Applied Groundwater Modeling*)

1. Predictive— Purpose is to predict system response to stresses. Requires calibration to heads, flow, etc. This is the type of model that most of us try to construct.

2. Interpretive— Purpose is to try to understand how a system works, organize field data. Not necessarily calibrated.

3. Generic— Purpose is to analyze dynamics of hypothetical systems that may incorporate important characteristics of actual systems.

The Bad and the Good of Models

Bad …

- Costly to construct
- Time consuming
- Difficult to test alternate conceptual models
- Solutions are rarely unique
- Predictions are rarely accurate

The Bad and the Good of Models

Good

Models can…

- assimilate all information in a system
- account for complex properties and geometry of the real-world
- test concepts and hypotheses
- test multiple scenarios in a consistent way
- Evaluate data needs
- Tell you which pieces of information are most important

Philosophy

"The purpose of computing is insight, not numbers"

—R.W. Hamming

Northern Arizona Groundwater-flow Model

- Large swath of state
- No artificial boundaries

NARGWFM Boundary
AZ, NM, CO, UT
Major Roads
Selected Towns

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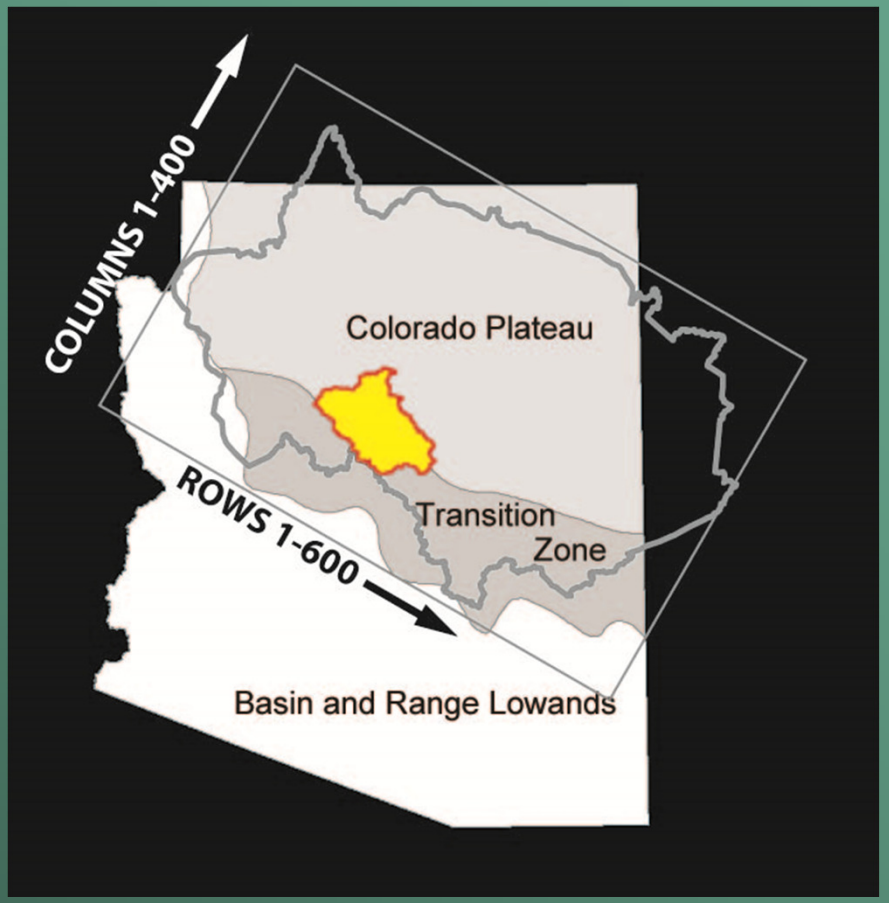
Northern Arizona Groundwater-flow model

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



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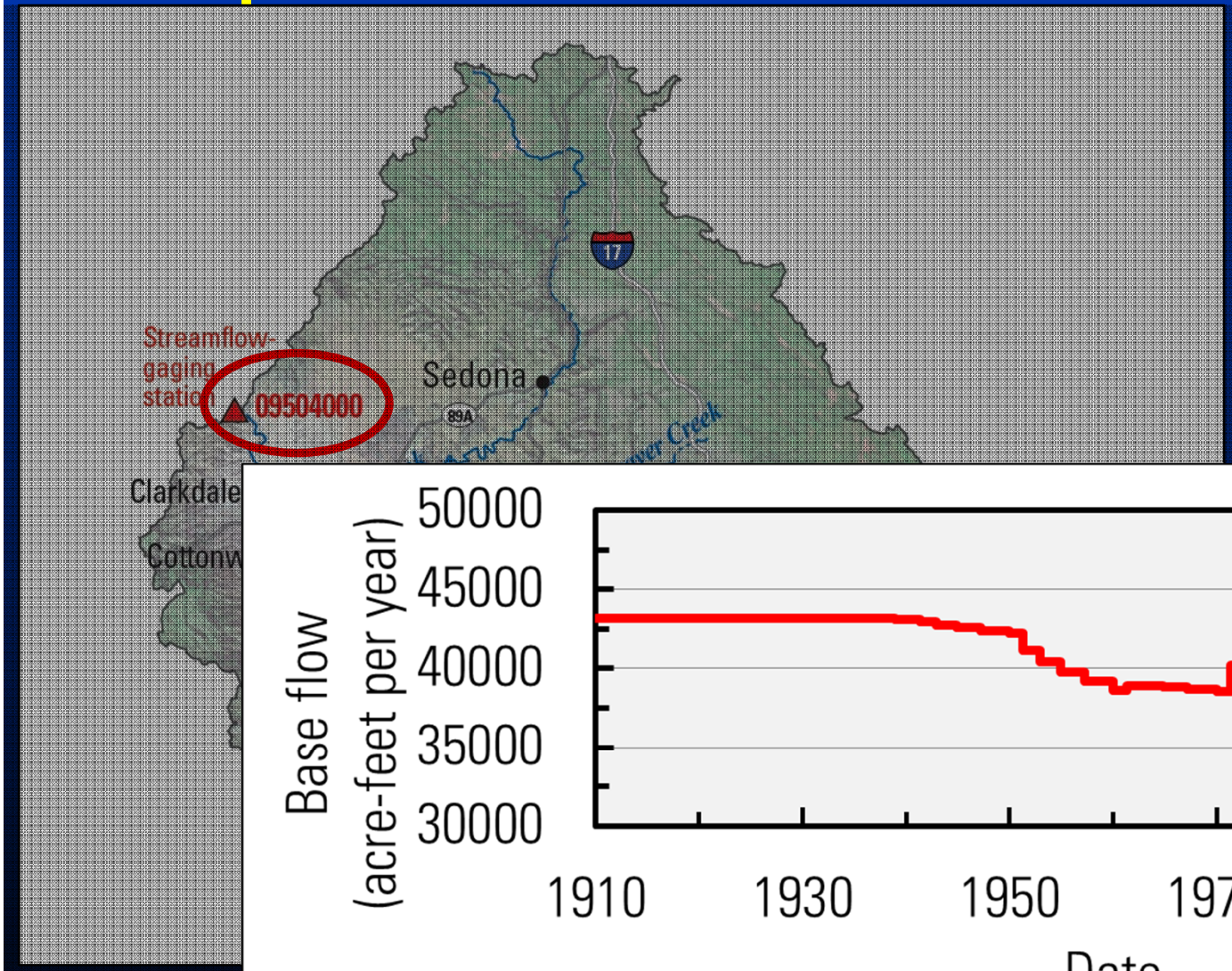
The past: 1910–2005 modeled base flow

Upstream Clarkdale gage

USGS

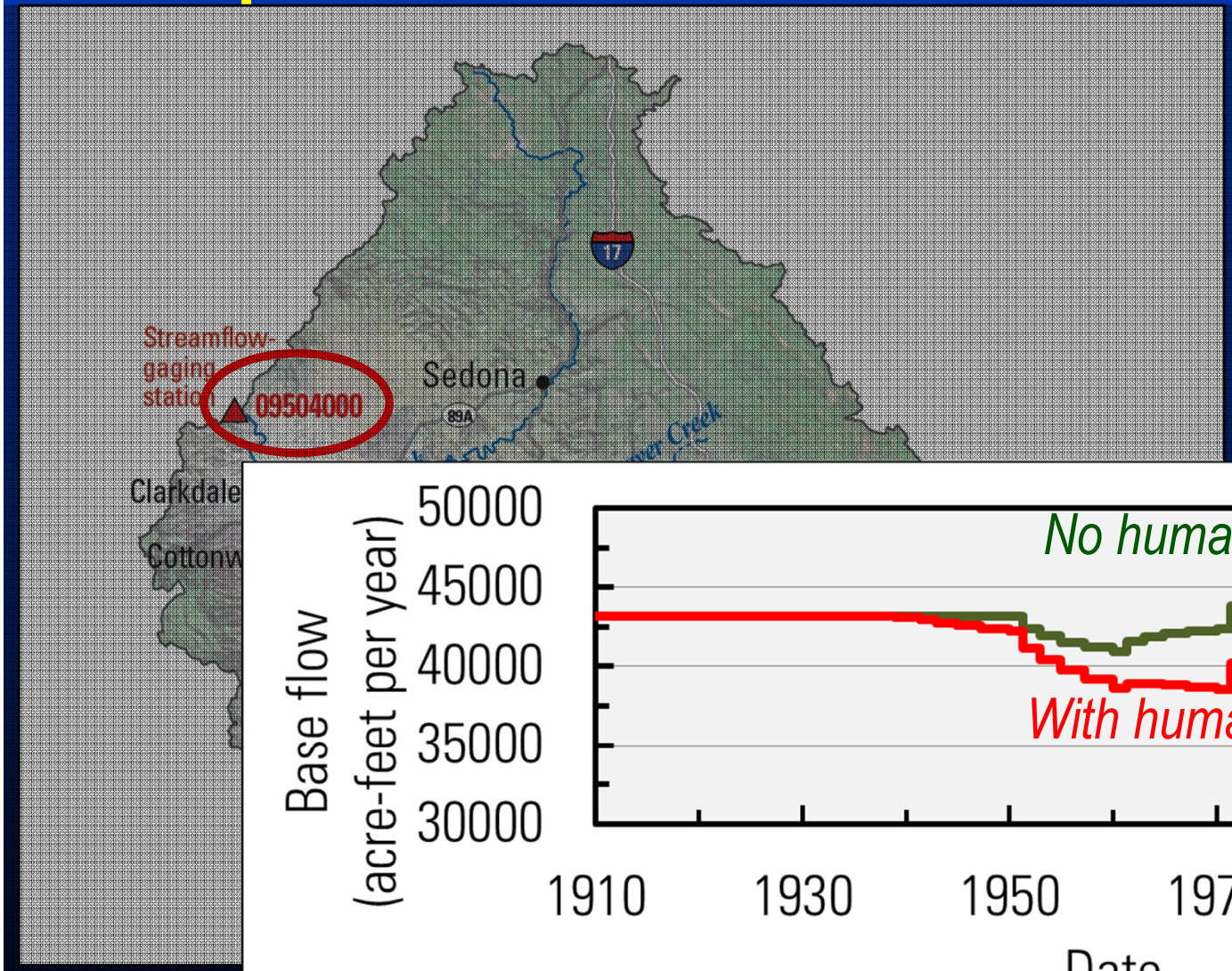
The past: 1910–2005 modeled base flow



Upstream Clarkdale gage

USGS

The past: 1910–2005 modeled base flow



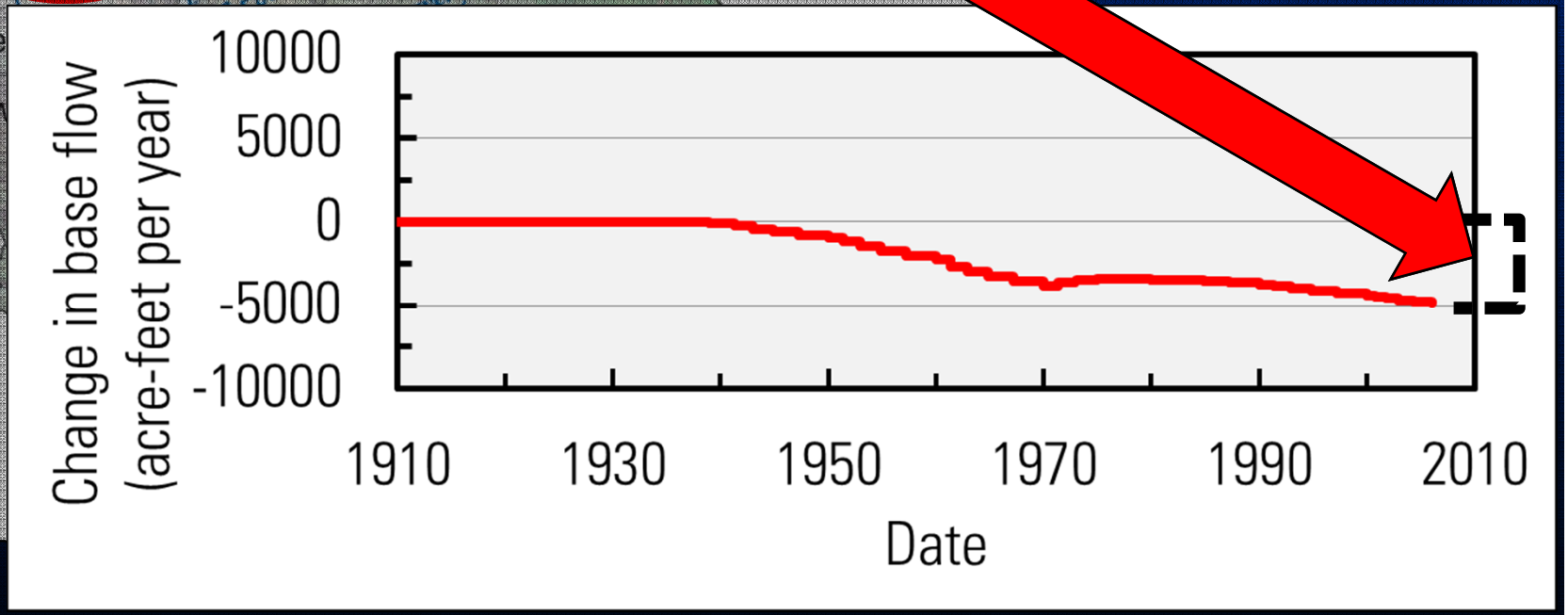
Upstream Clarkdale gage

USGS

1910–2005 modeled base flow

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

Upstream Clarkdale gage



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The hypothetical future

Upstream Clarkdale gage

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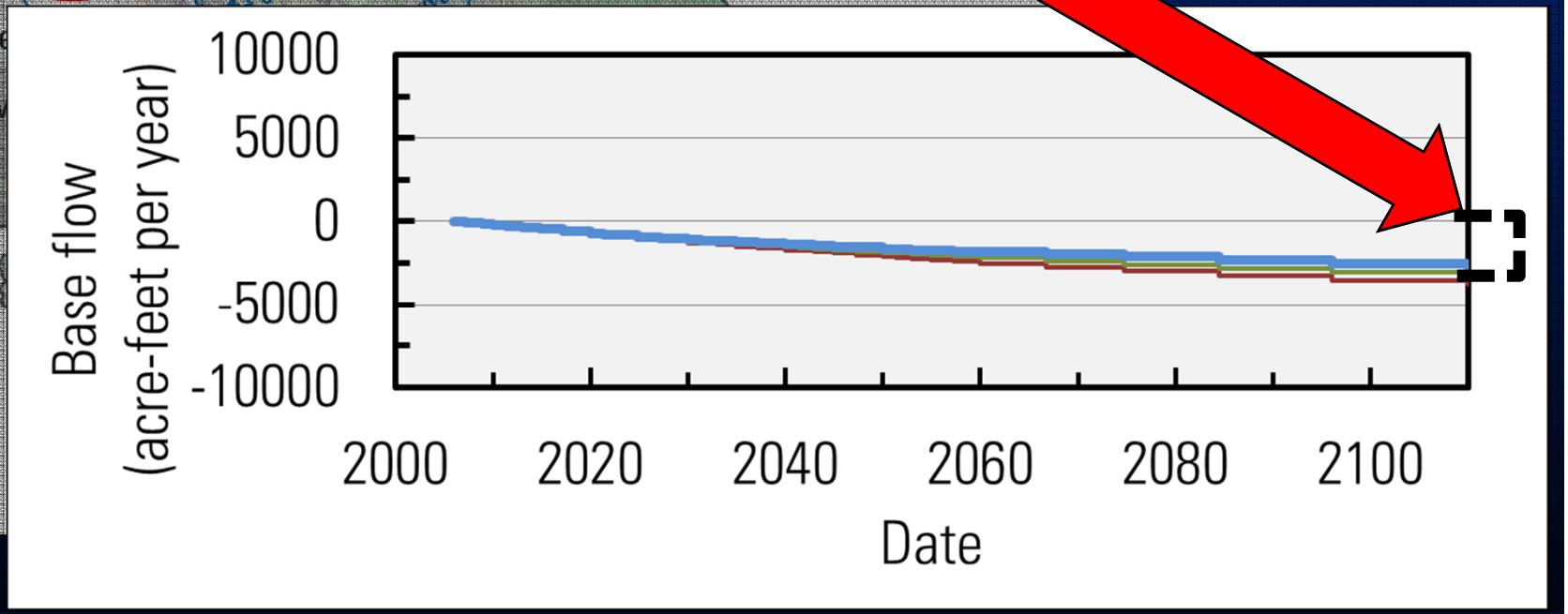
The hypothetical future

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

Upstream Clarkdale gage



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Verde Valley Capture Maps

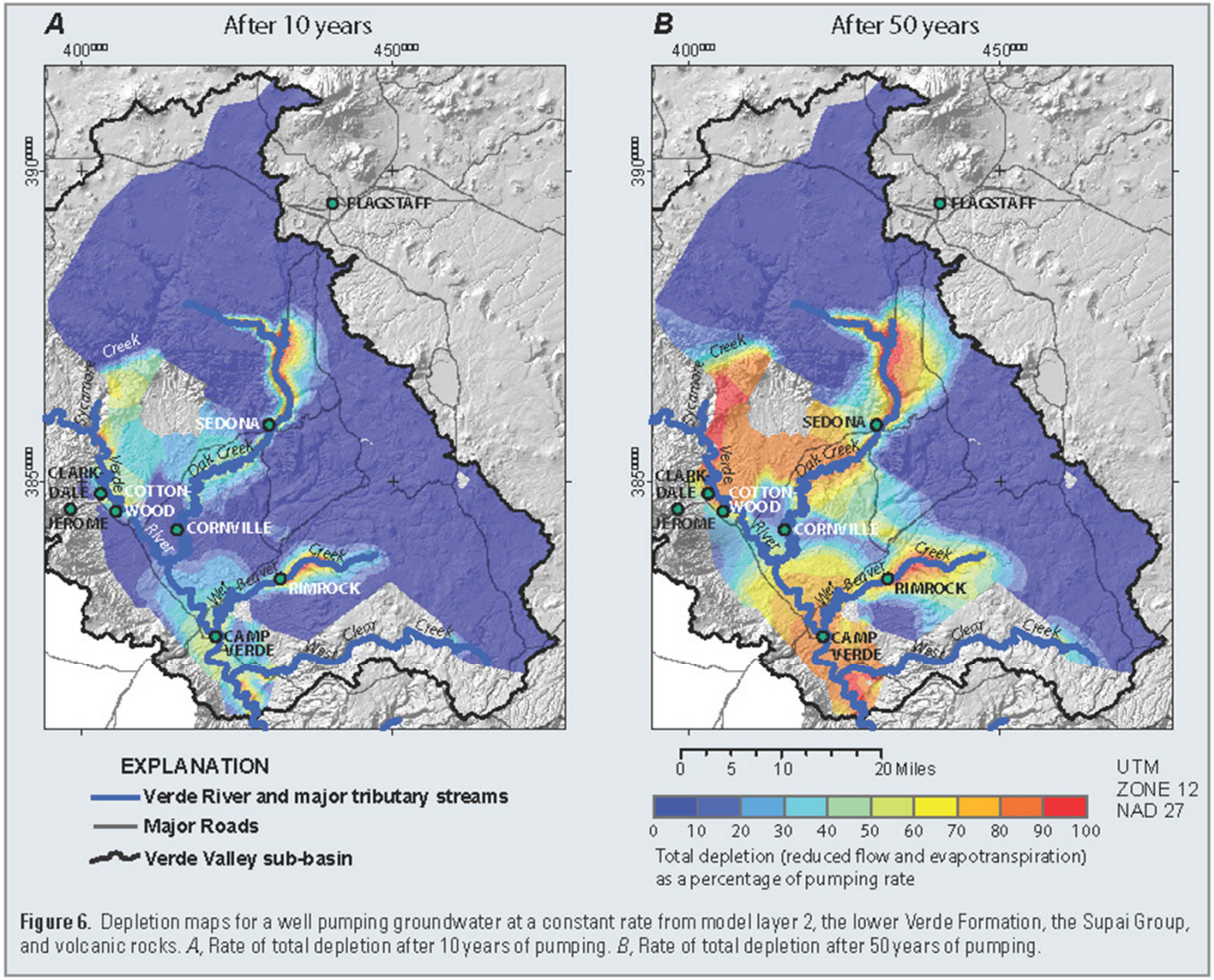

Figure 6. Depletion maps for a well pumping groundwater at a constant rate from model layer 2, the lower Verde Formation, the Supai Group, and volcanic rocks. *A*, Rate of total depletion after 10 years of pumping. *B*, Rate of total depletion after 50 years of pumping.

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Where's the controversy?

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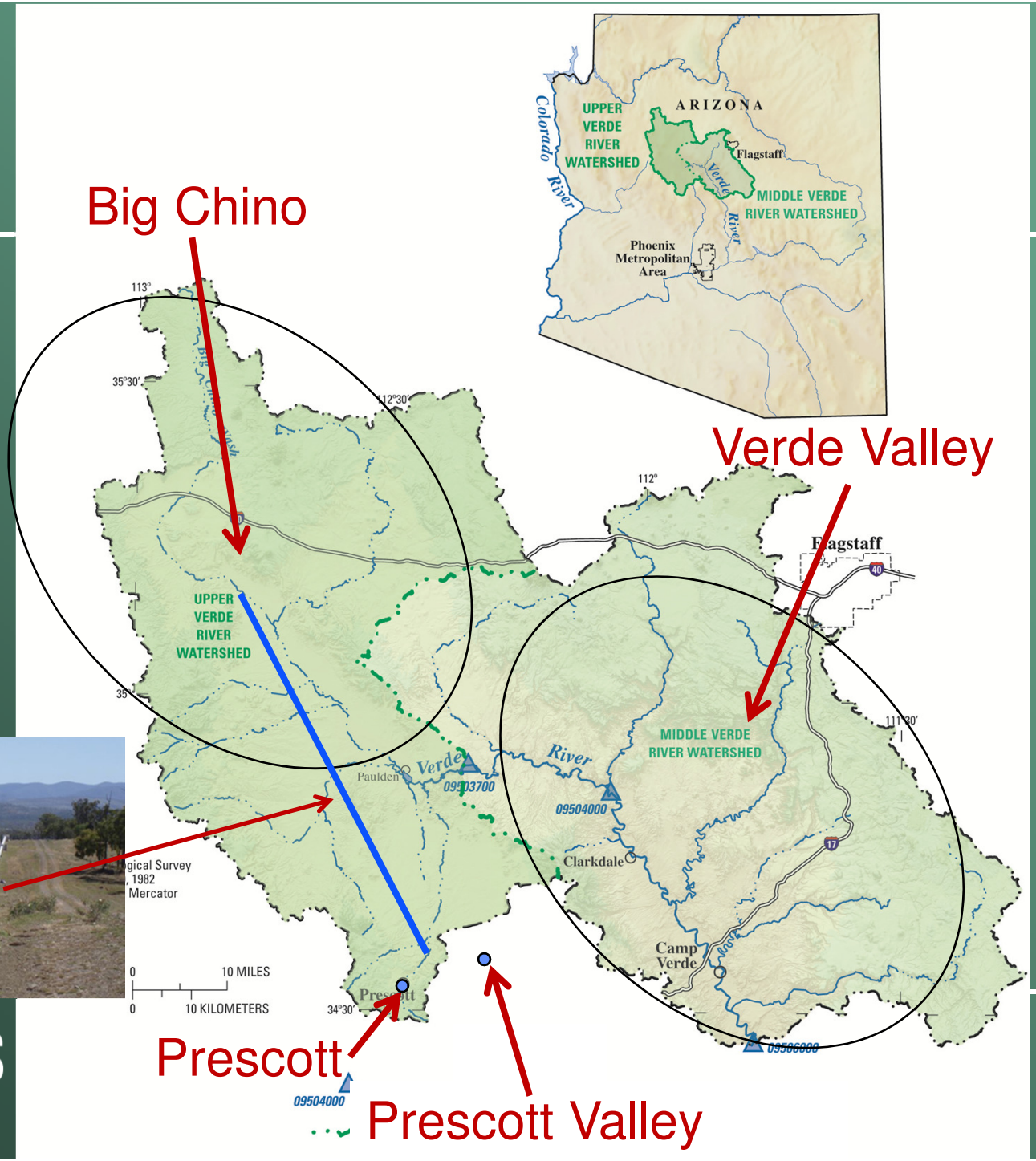
Big Chino
Verde Valley
Prescott
Prescott Valley
ARIZONA
UPPER VERDE RIVER WATERSHED
MIDDLE VERDE RIVER WATERSHED
Colorado River
Flagstaff
Phoenix Metropolitan Area
Verde River
Paulden
Clarkdale
Camp Verde
09503700
09504000
09506000
0 10 MILES
0 10 KILOMETERS

GW-SW Connections

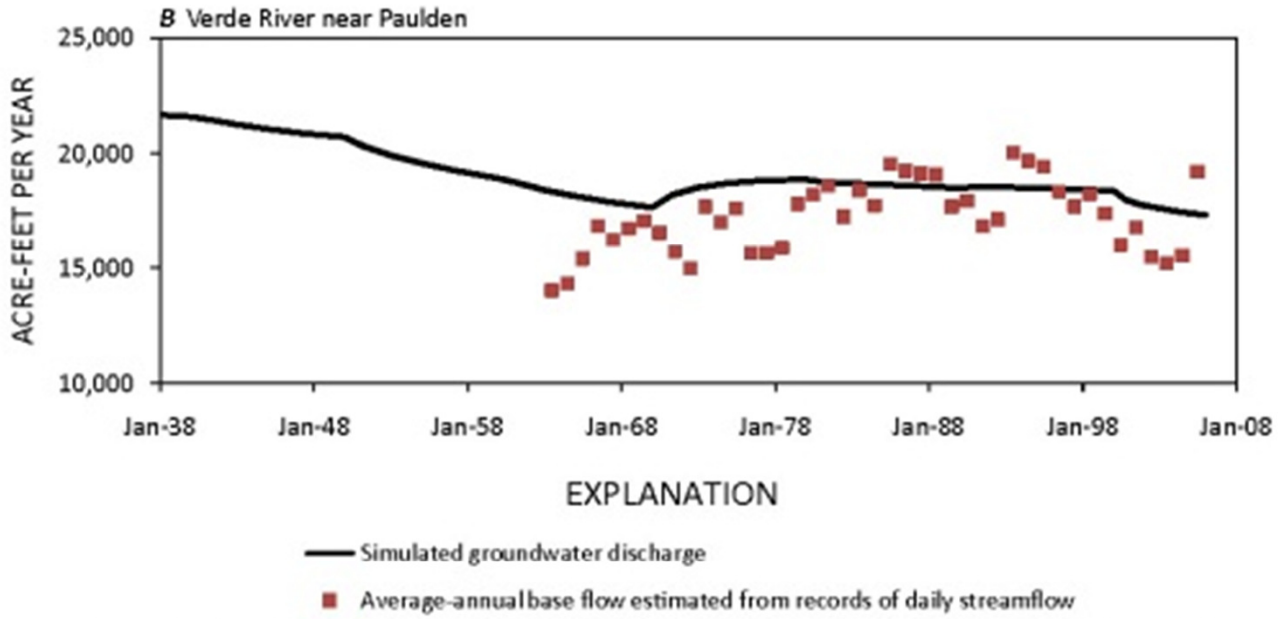

Figure 25. Simulated groundwater budgets for the (*A*) Big Chino sub-basin and (*B*) simulated and estimated base flow discharge at the Verde River near Paulden, which includes contributions from both the Big and the Little Chino sub-basins.

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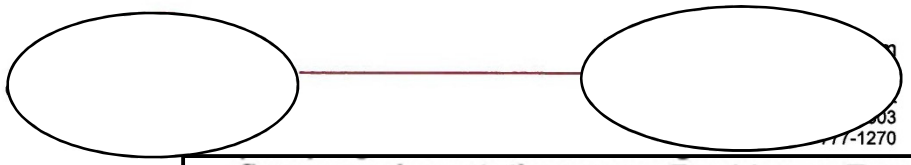
Running afoul of the law!



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.

USGS-Arizona Wa
Water Resources I
520 N. Park Ave, S
Tucson, Arizona 85
Attn: Director John

Re: Regional Groundwater-Flow Model of Northern and Central Arizona Aquifers

Dear Director Hoffman:

It is our understa
groundwater-flow
coarsely simulate
Arizona groundw
River. The purp
report and the un

Although the US
framework for mo
appears to be d
pumping in the L
flow gauging sta
between the use
that the extractio
contravention of l

The coarse assu
recently construc
been subjected
Resources ("ADW
Assured Water S
independent Adm
Prescott's ground
the extraction of
diminishment of flow in the Verde River over a 100-year period. *See* Administrative Law Judge Decision, AOAH No. 08A-AWS001-DWR (October 29, 2009). In contrast, the pending USGS report appears to rely on assumptions made in earlier discredited USGS reports that were found by the Administrative Law Judge to have serious problems, raising a "valid issue" as to their reliability. *See id.* at pp. 16-17, n. 12.

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.

One thing leads to another….

"That y ho
doesn' 490

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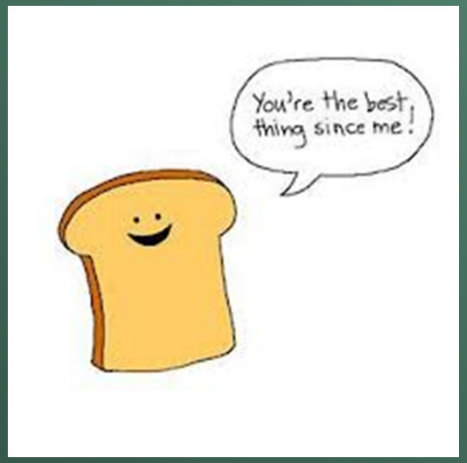
USGS

Uncertainty?

- Best thing since sliced bread!



- It's worthless!

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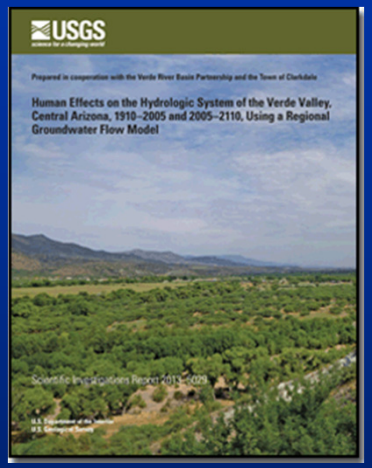
The NARGFM can be used for:

Scientific Experiments



Policy neutral,

yet policy relevant

Water-Resources Management

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Thank you!

Questions?

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GW-SW Connections

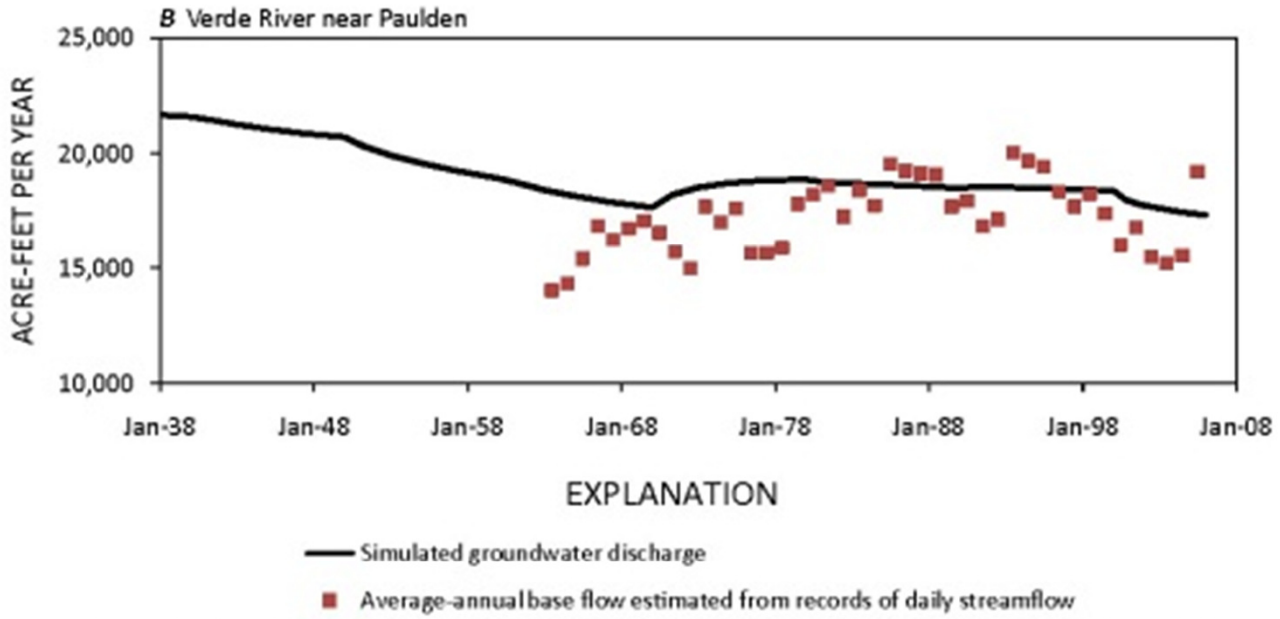

Figure 25. Simulated groundwater budgets for the (*A*) Big Chino sub-basin and (*B*) simulated and estimated base flow discharge at the Verde River near Paulden, which includes contributions from both the Big and the Little Chino sub-basins.

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MYTHBUSTING

- **Misconceptions of GW-SW relations**
  - **Are often intuitive (and therefore hard to debunk)**
  - **Are broadly shared by public, resource managers, and technicians alike**
  - **Are my lead in to "water security"!**
  - **Four myths……**

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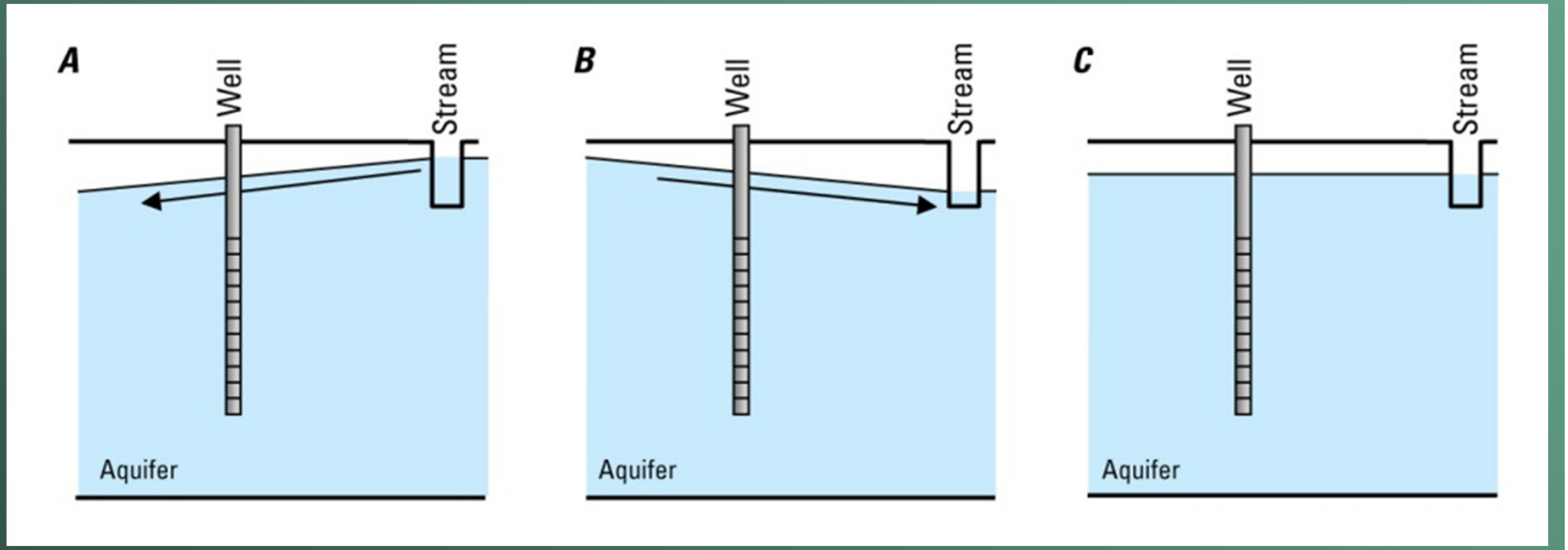
Myth 1: Dire tters



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Myth 2: With[illegible]erage recharge are[illegible]

- Withdrawal = recharge means no GW outflow
- Amount of capture depends on withdrawals, not recharge
- Other effects at withdrawals < recharge include subsidence, water-table declines, reductions in water quality

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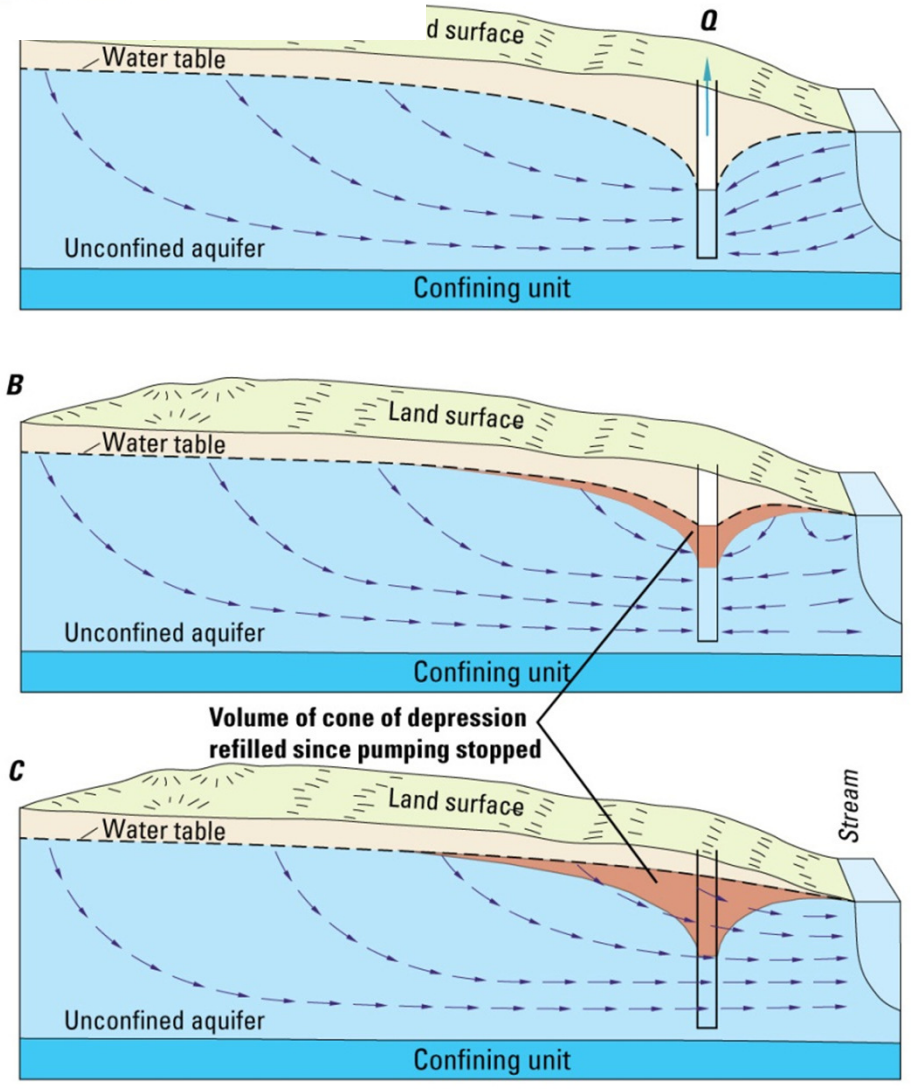
Myth 3: Dep… …n pumping ce…

BUSTED

- A. Well pumping
- B. Well off, cone refilling
- Cone refilled, flow system restored



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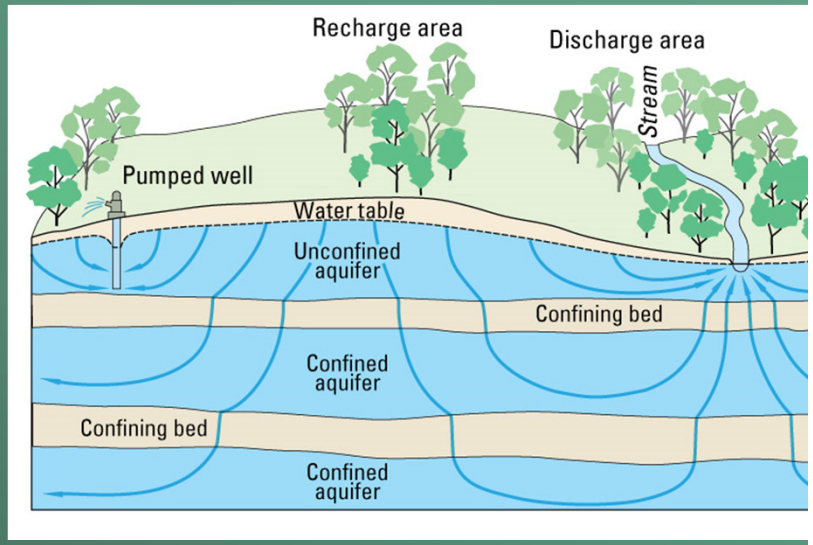
Myth 4: Co…event capture

- Confined aquifers never completely isolated
- Gradients (slope) demonstrate recharge and discharge (connected somewhere)
- Confining layers can slow down…….or speed up capture!
- Models are needed to understand effects of confining layers



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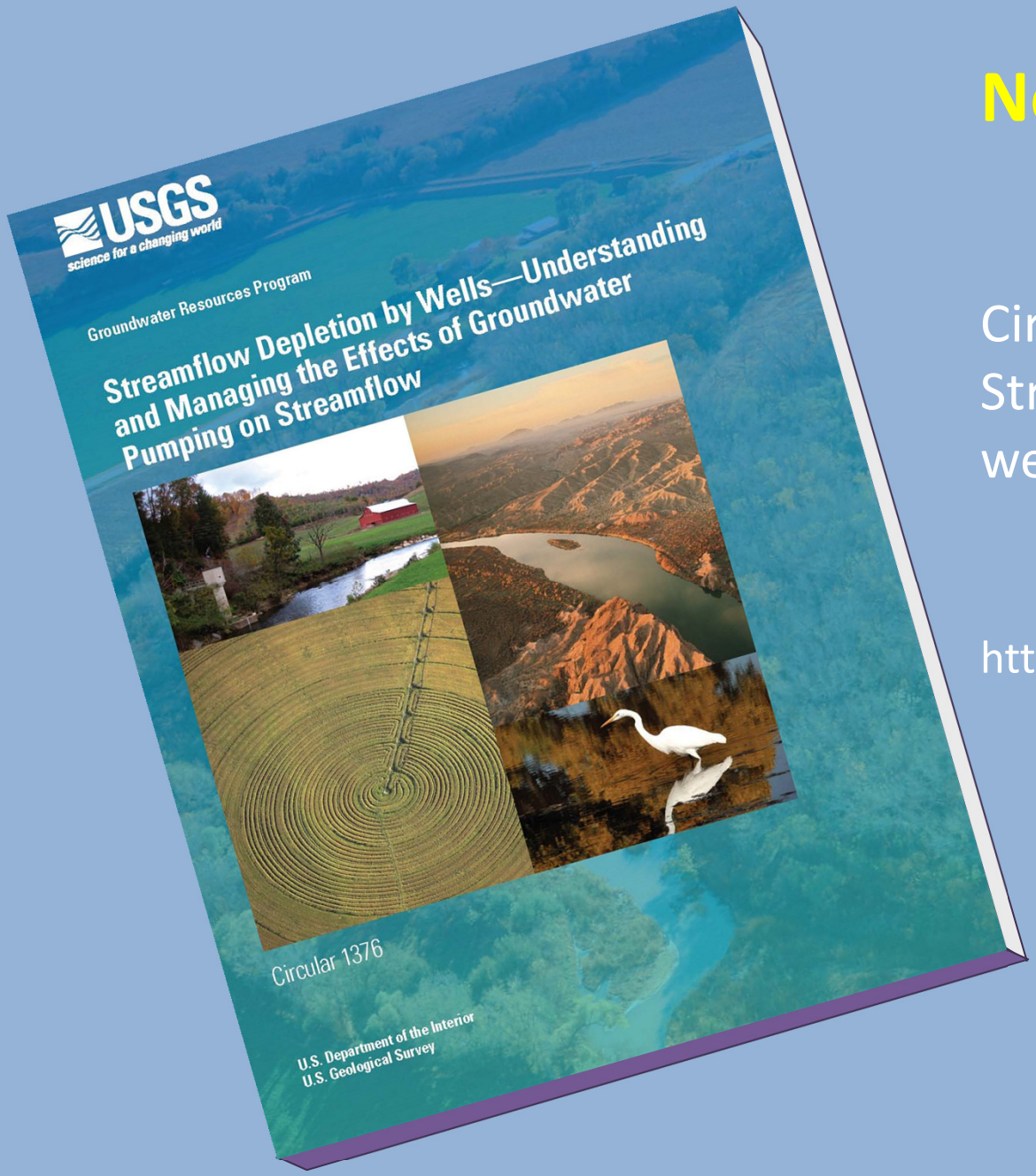
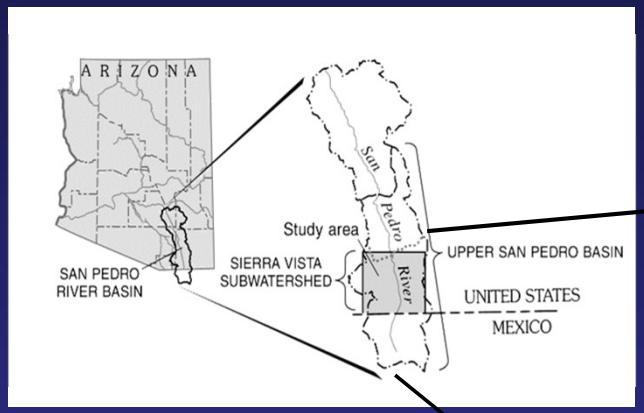


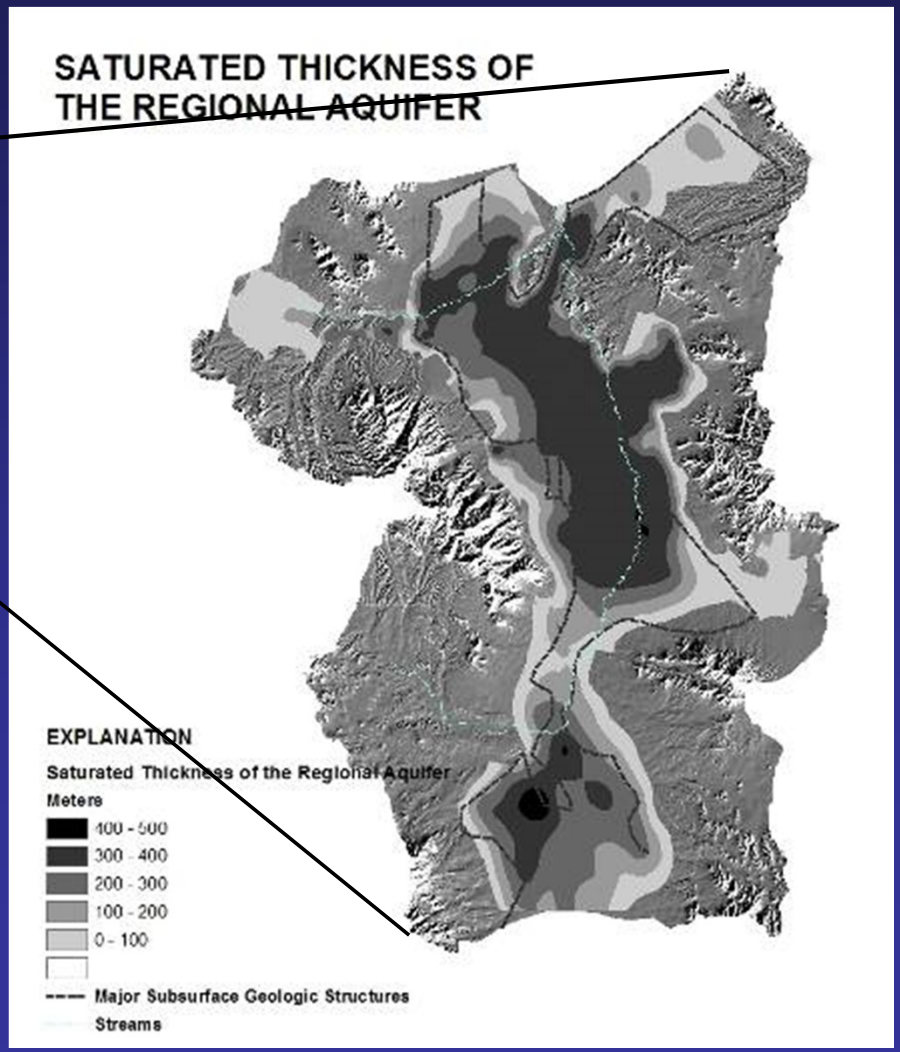
New USGS report:

Circular 1376—
Streamflow depletion by wells

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

Case Study—GW Model of the Upper San Pedro Basin





Simulating GW flow system within

Sierra Vista Subwatershed

and Sonora, Mexico

Regional alluvial aquifer-system

and bedrock aquifers

Need for a GW Model

- Population in Sierra Vista and Fort Huachuca is rapidly increasing
- All water supply is from wells in the alluvial-basin aquifer
- Ground-water discharge also supports streamflow in the San Pedro River and adjacent riparian vegetation
- Many groups including the Riparian Conservation Area are concerned that continued ground-water pumping could dry up the river and kill the vegetation
- A well-constructed model will help in understanding the amount and timing of effects of the GW withdrawals on the riparian system

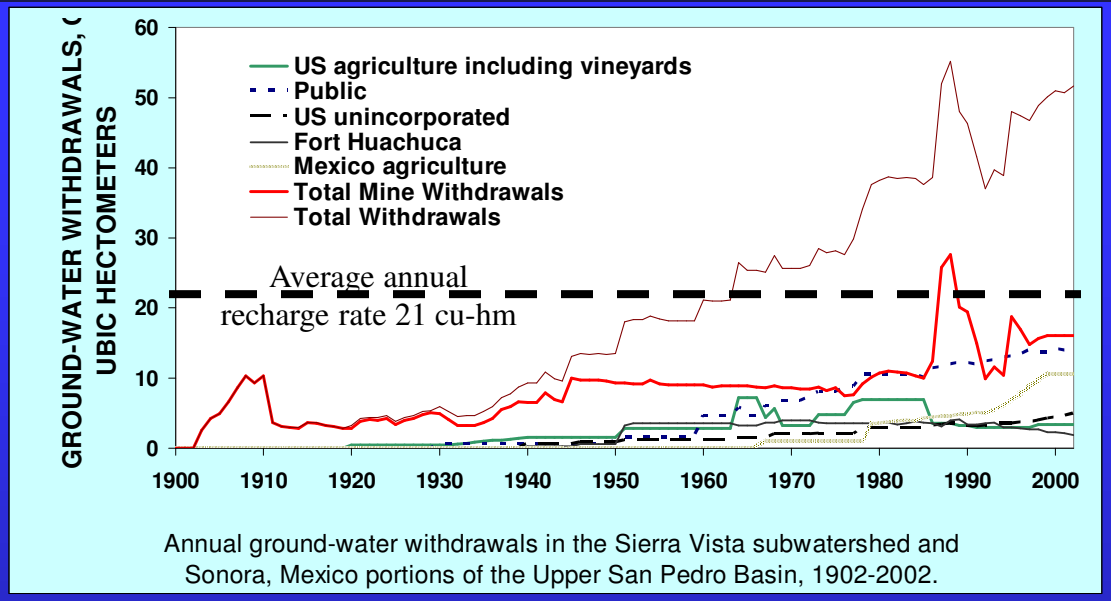
GW Model of the Upper San Pedro Basin

- Purpose of New GW Model

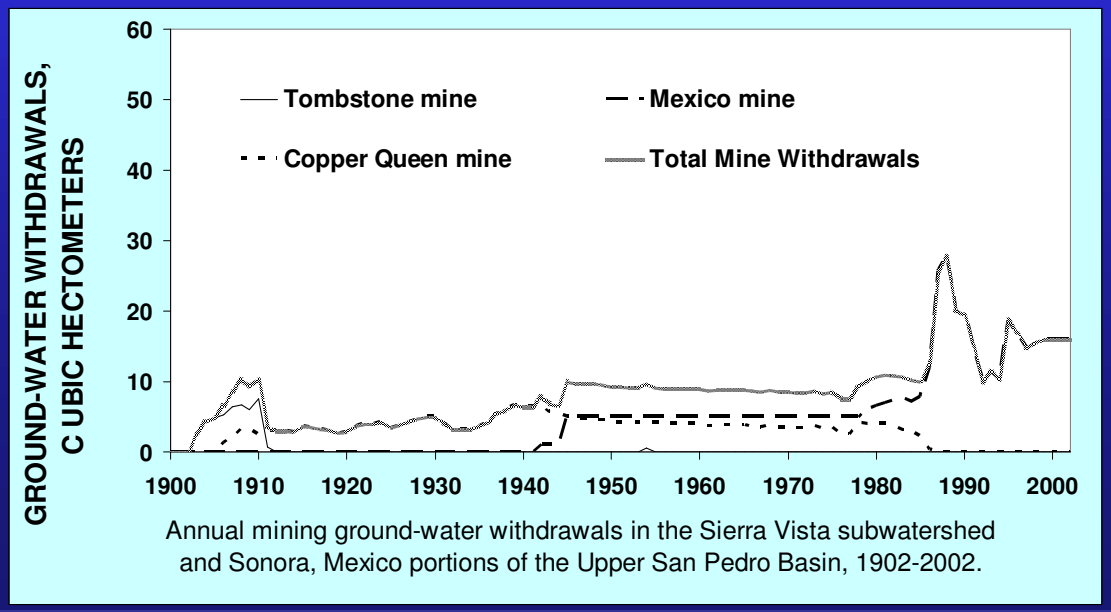
  (as opposed to existing models)

  - Incorporate better understanding of the GW flow system
  - Provide San Pedro Partnership with a GW model tool that can be linked to the DSS.
  - More accurate representation of stream-aquifer interactions and results of Partnership activities

GW BUDGET



Annual ground-water withdrawals in the Sierra Vista subwatershed and Sonora, Mexico portions of the Upper San Pedro Basin, 1902-2002.



Annual mining ground-water withdrawals in the Sierra Vista subwatershed and Sonora, Mexico portions of the Upper San Pedro Basin, 1902-2002.

GW FLOW SYSTEM

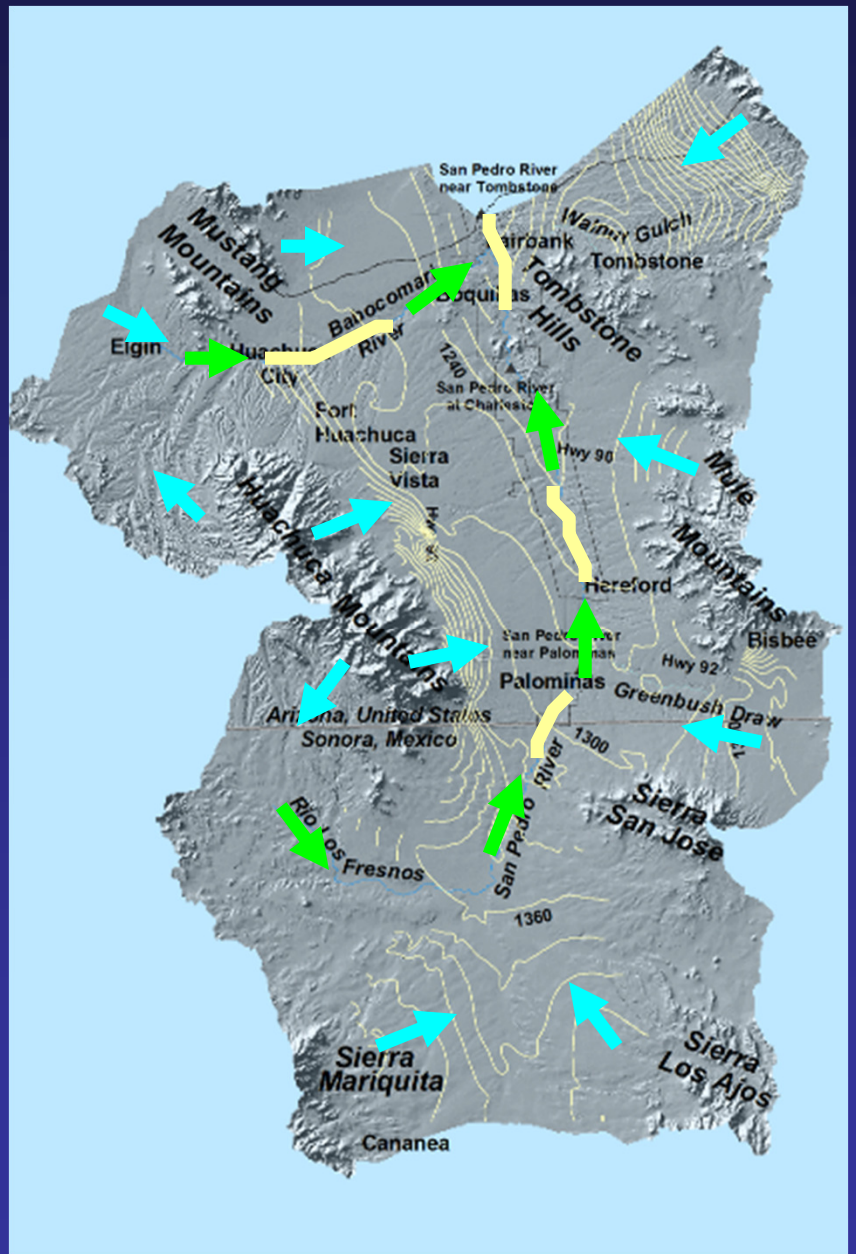
Water-Level Altitude 2002

C.I. 20 METERS

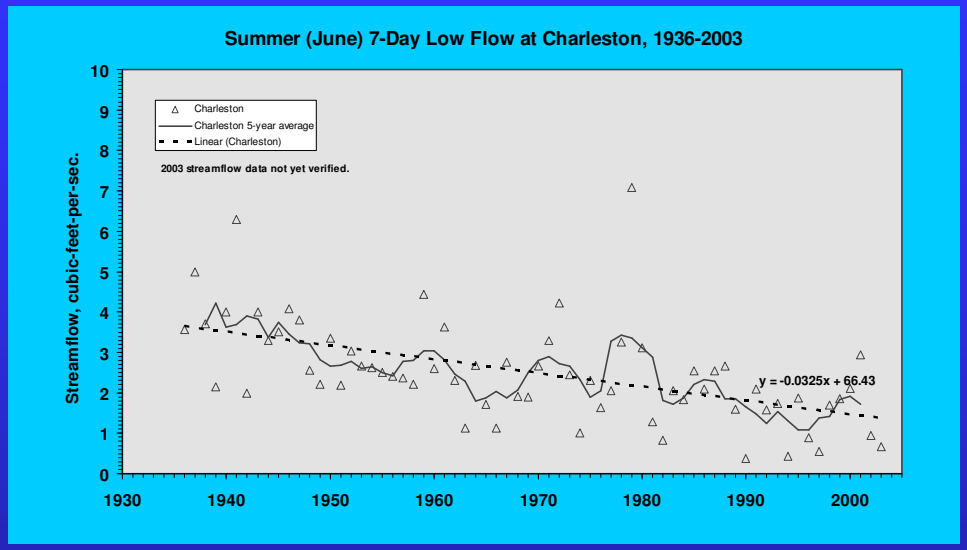
Recharge

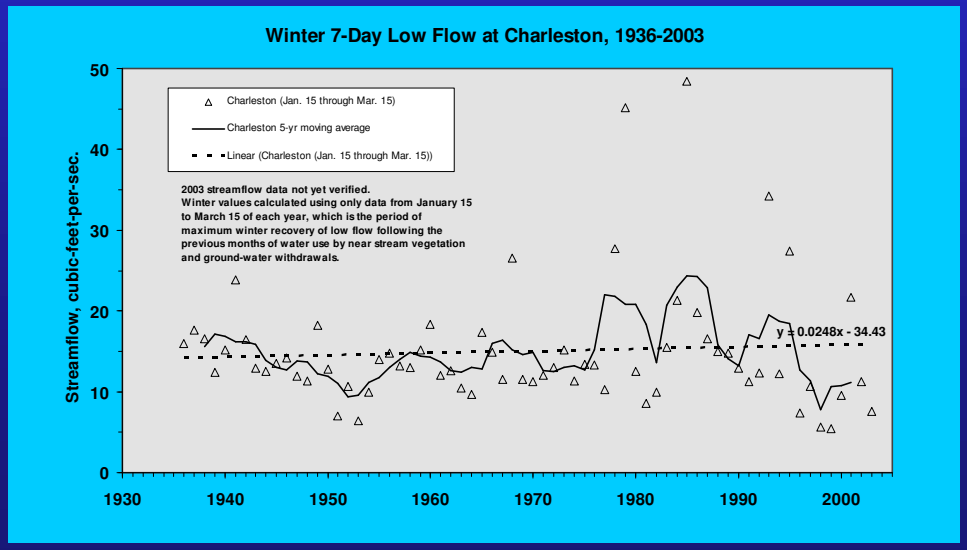
Perennial GW discharge

Losing stream reach



Charleston Baseflow

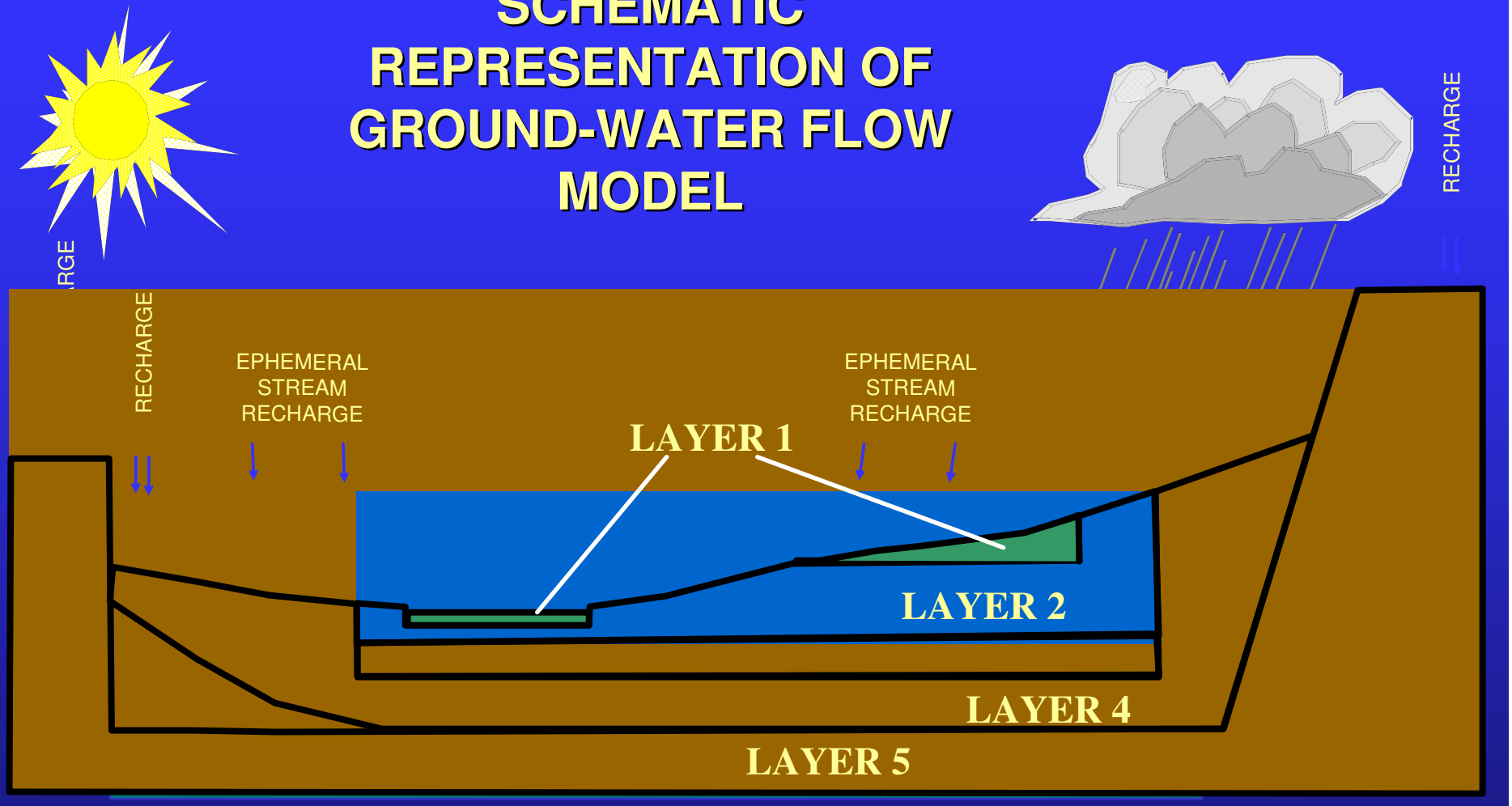




EAST

WEST

SCHEMATIC REPRESENTATION OF GROUND-WATER FLOW MODEL



USGS

Theoretical Capture of Ground-Water Discharge at 50 years

Model layer 4
The primary alluvial aquifer