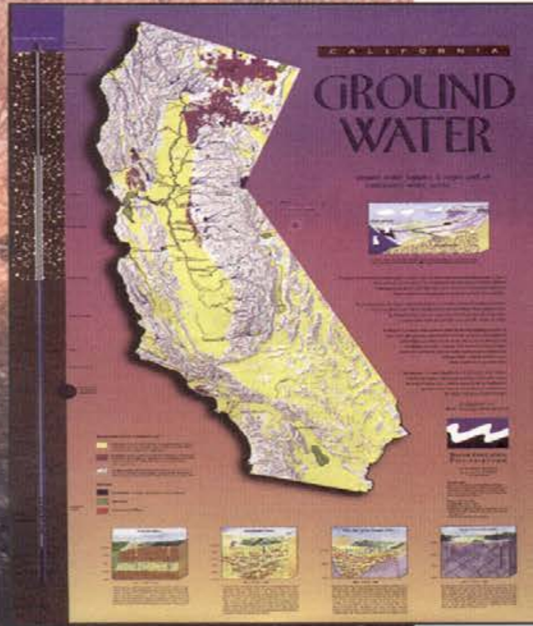
California Groundwater Overview

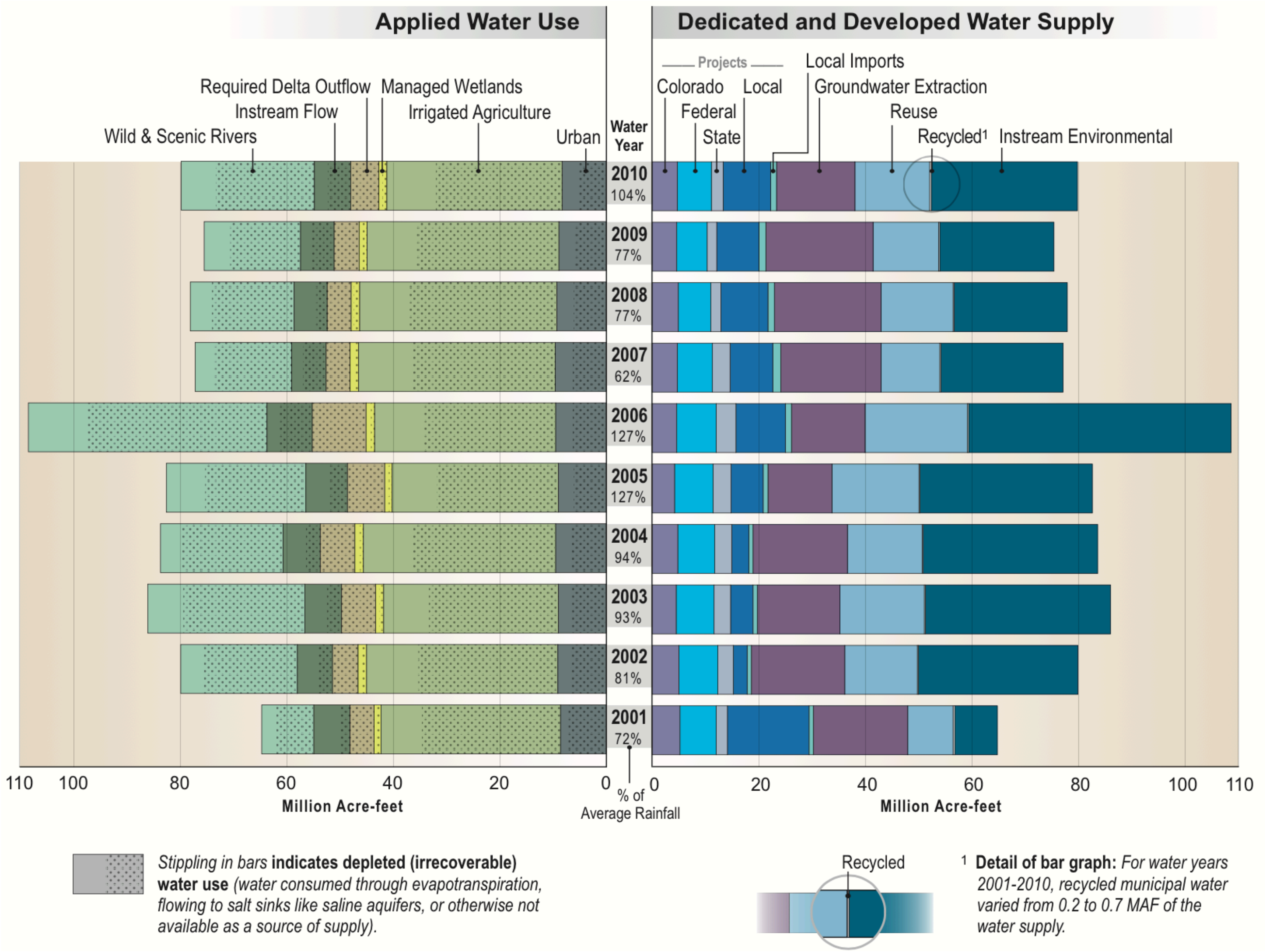


Graham Fogg
Groundwater Policy Seminar
UC Davis
January 5, 2015

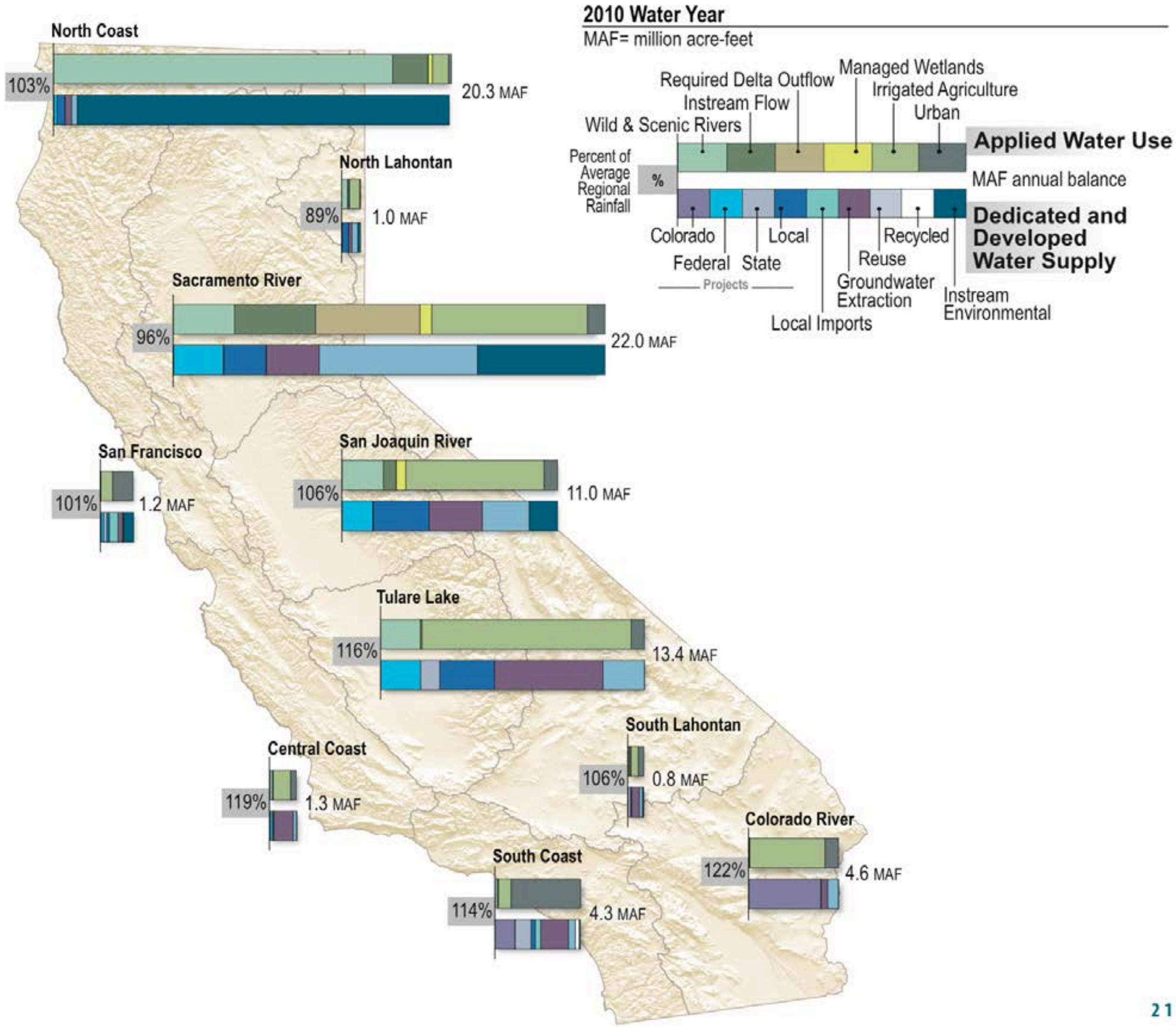
Outline

- Groundwater fundamentals
  - California groundwater occurrence & general background
  - Overdraft & negative consequences
    - Non-sustainable storage depletion
    - Subsidence
    - Surface water & ecosystem effects
    - Increased energy costs
    - Bad water intrusion from aquitards and from depth
    - Basin salt imbalance
    - Seawater intrusion
  - Sustainable yield
- Groundwater myths
  - Pumping of “fossil water” is non-sustainable
  - Groundwater storage depletion always takes a long time to recover
  - Groundwater levels tell us how much groundwater storage is changing
  - Quality of most groundwater is degraded
  - Good quality groundwater today is likely to stay that way
  - Potential myth: climate change will decrease groundwater recharge
- Case studies
  - Coachella Valley
  - Yolo County
  - Orange Co.

CA Water Use & Supply, CA Water Plan 2014

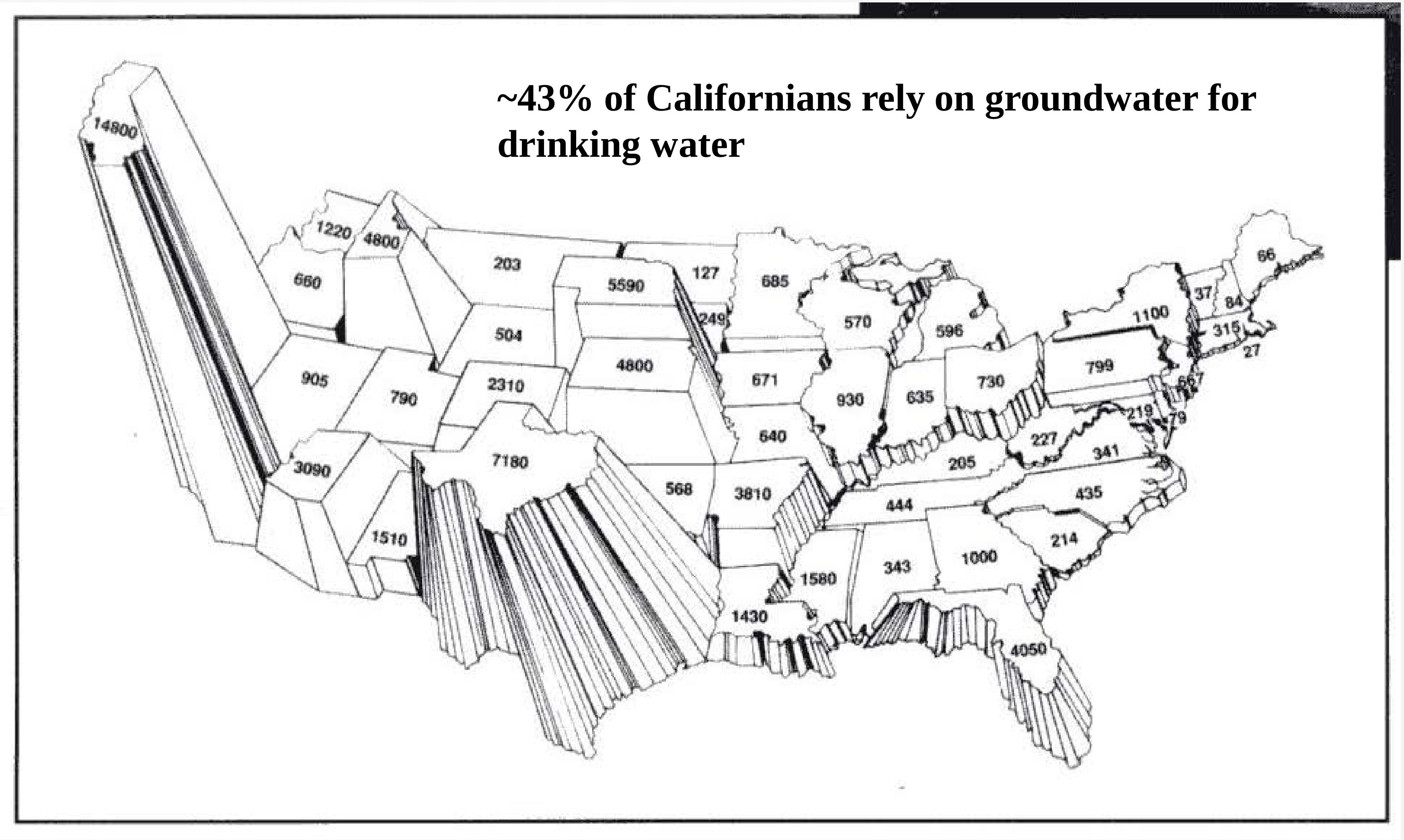


CA Water Use & Supply, CA Water Plan 2014



Groundwater Use in 1,000's of acre-feet

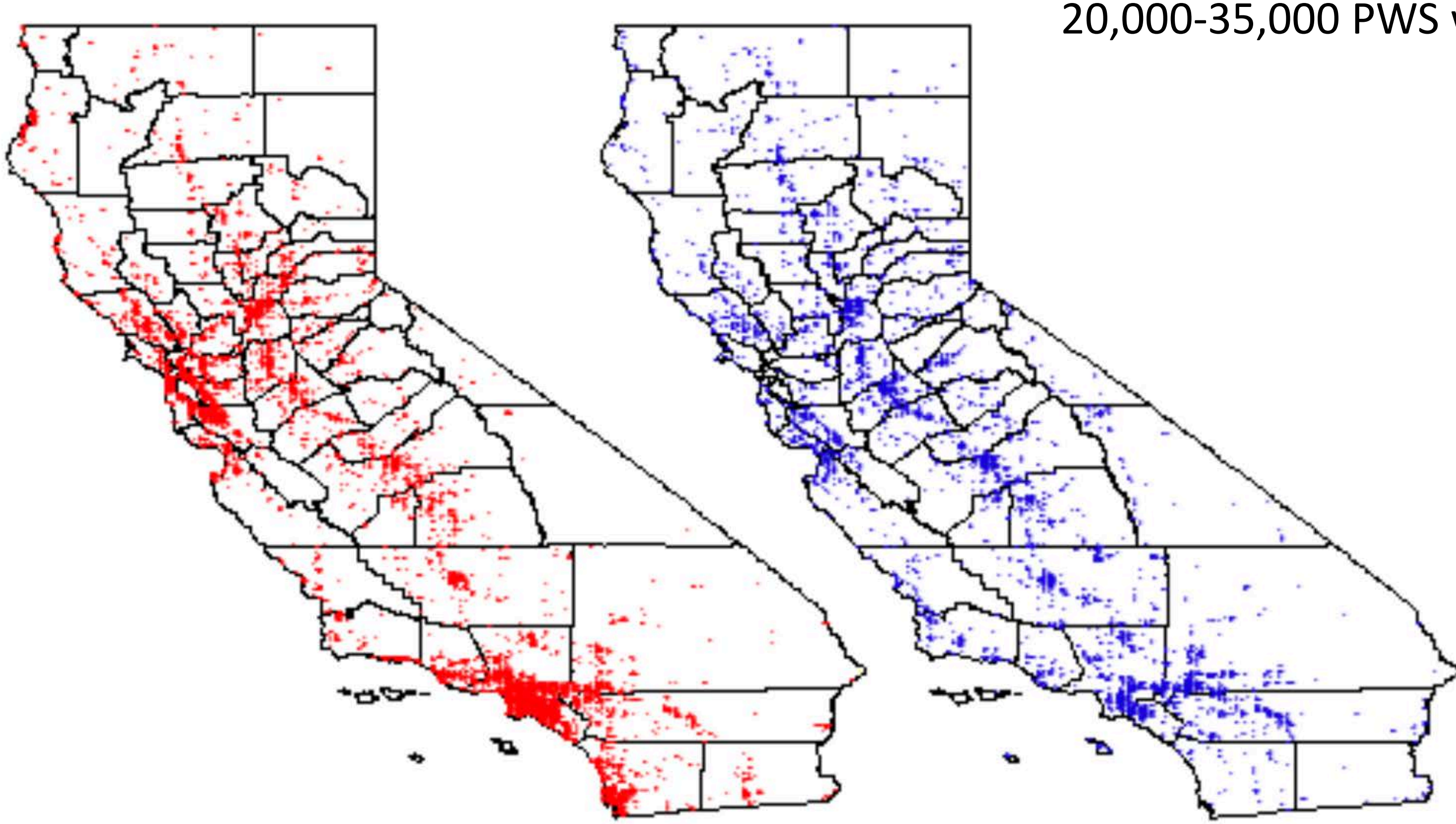
~43% of Californians rely on groundwater for drinking water



Locations of leaking underground fuel tanks (LUFTs) and public wells in California

LUFT Sites | Public Wells

20,000-35,000 PWS wells

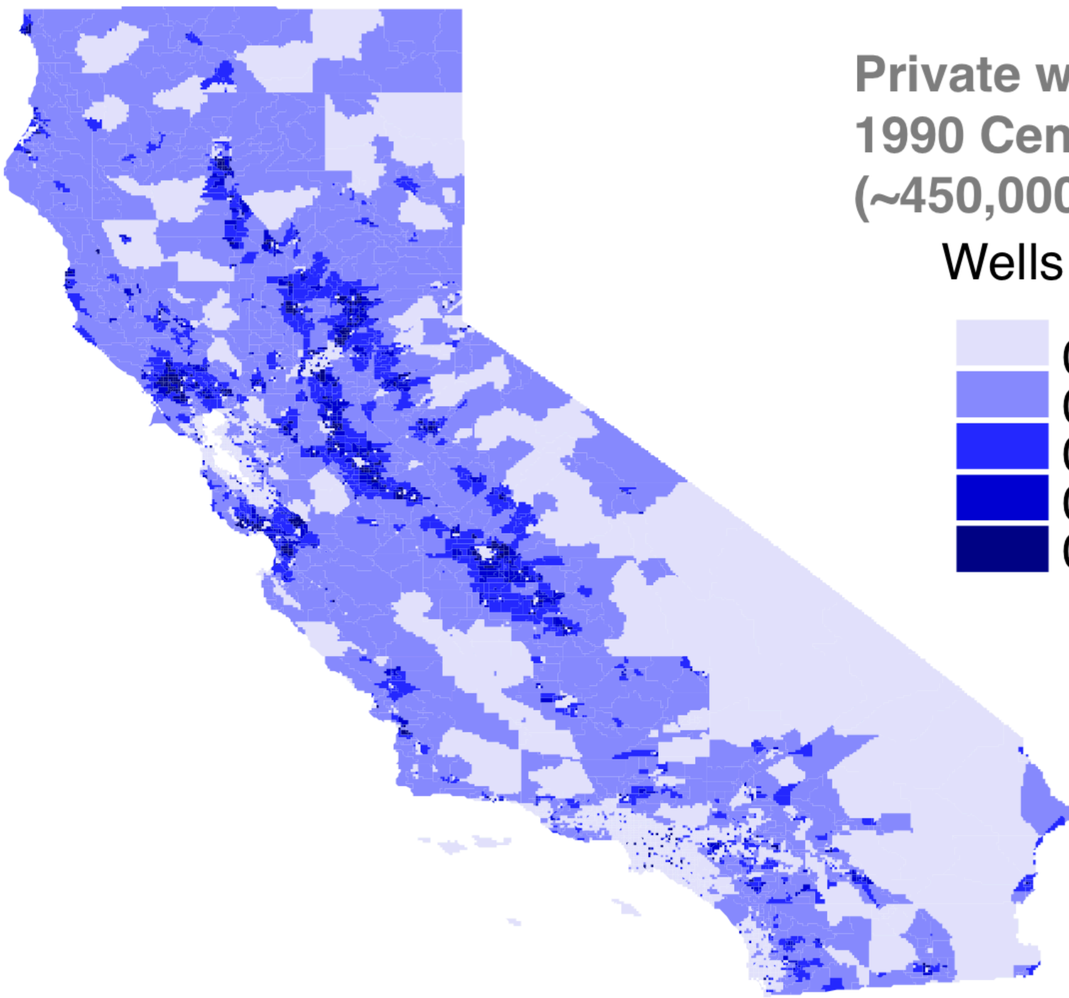


Happel, Dooher & Beckenbach, 1999

UCRL-MI-133696

Lawrence Livermore National Laboratory

Density of private wells in California



Private well density based on 1990 Census Block Group Data (~450,000 Private Wells)

Wells per Acre

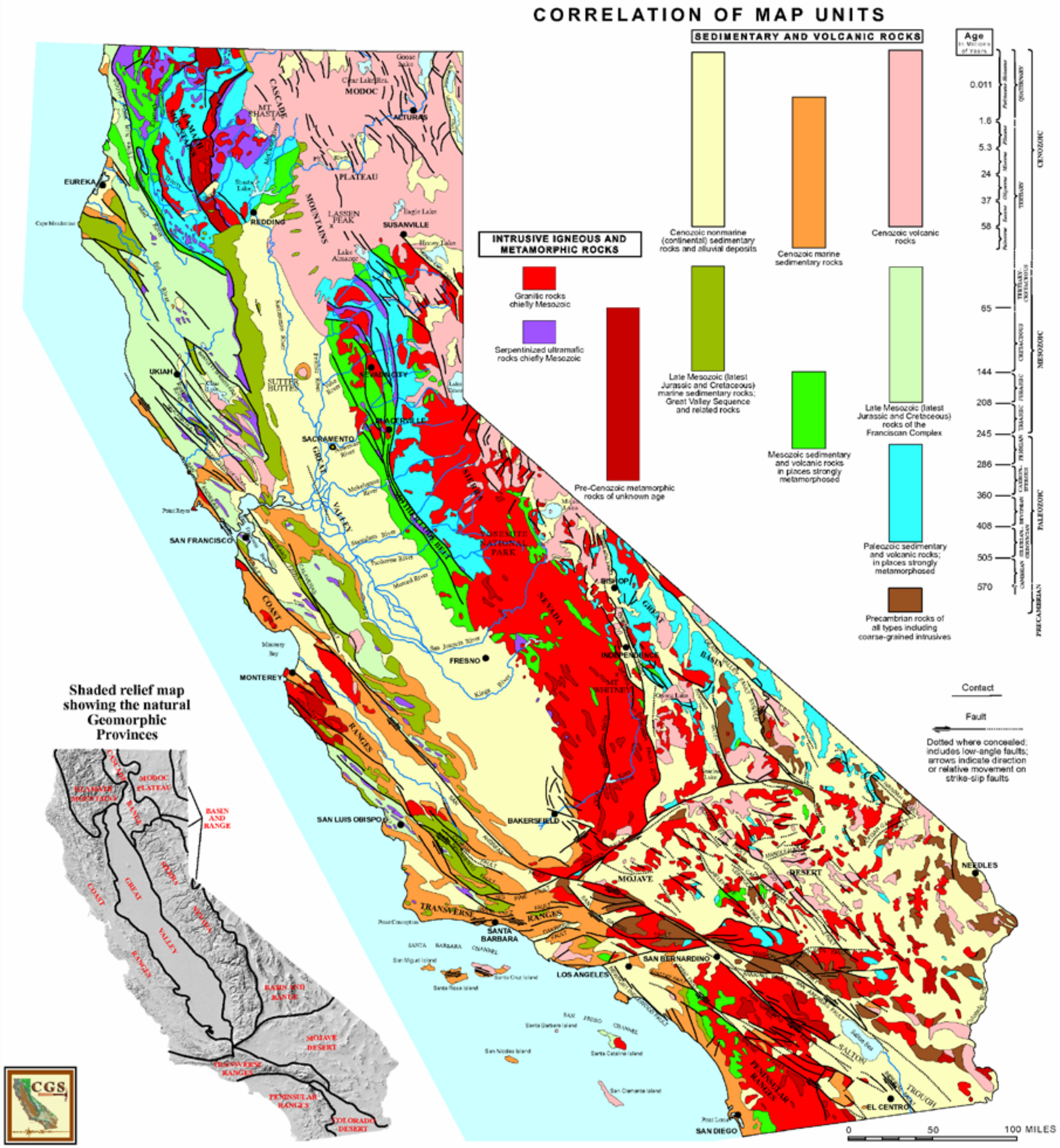
- 0
- 0.00 - 0.01
- 0.01 - 0.03
- 0.03 - 0.08
- 0.08 - 4.50

Happel, Dooher & Beckenbach, 1999

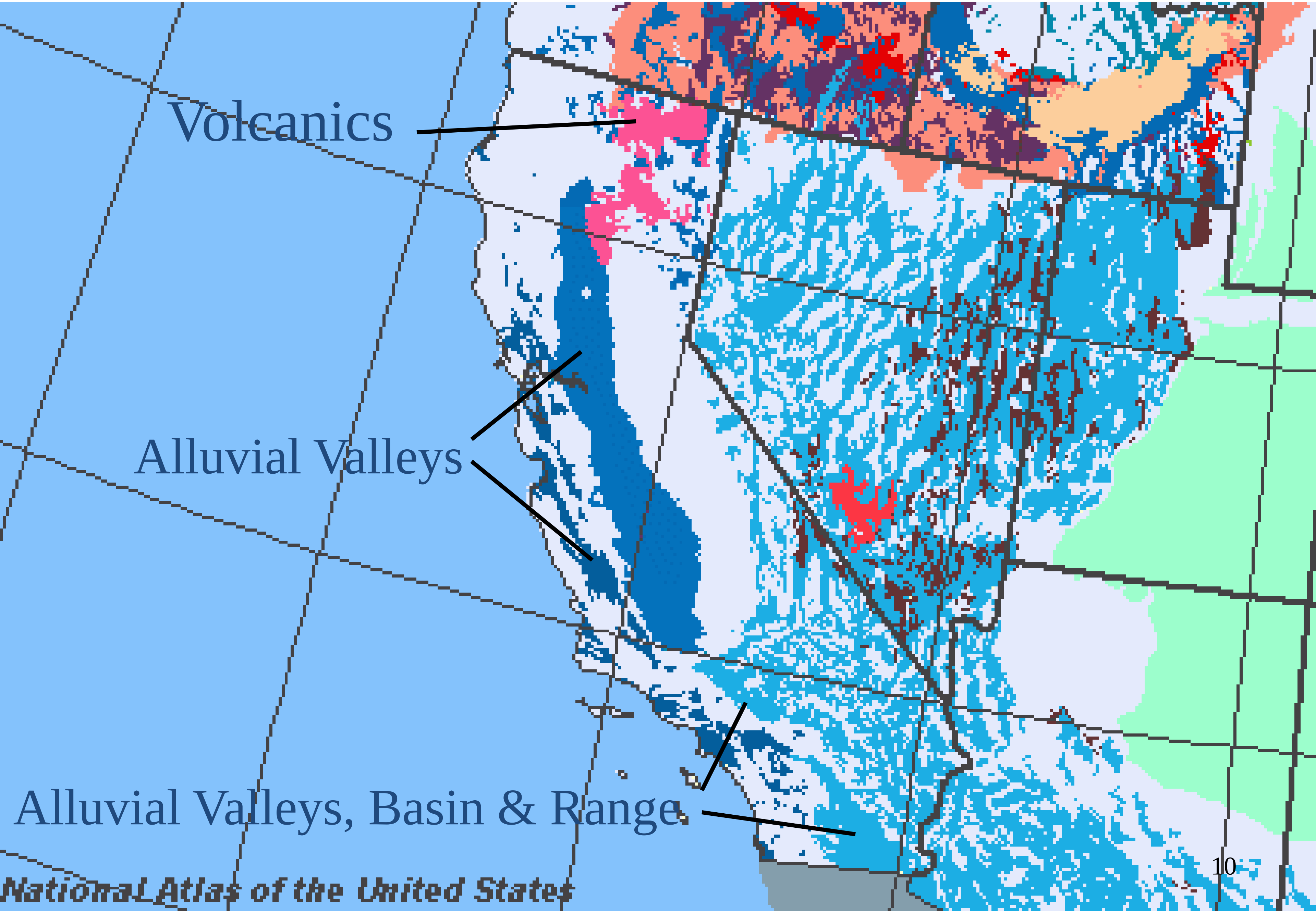
UCRL-MI-133696
Lawrence Livermore National Laboratory

Groundwater Occurrence

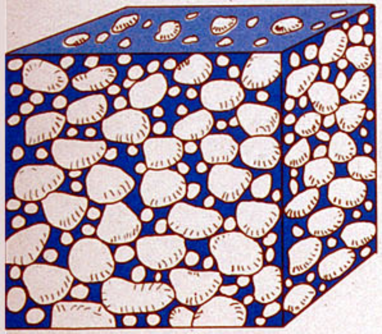
SIMPLIFIED GEOLOGIC MAP OF CALIFORNIA



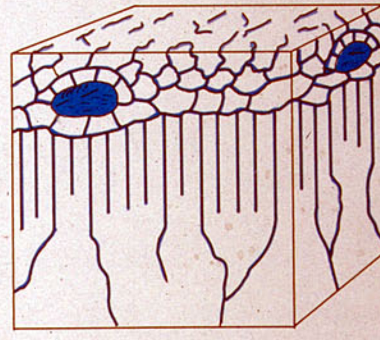
Major Aquifers (http://nationalatlas.gov/natlas/natlasstart.asp)



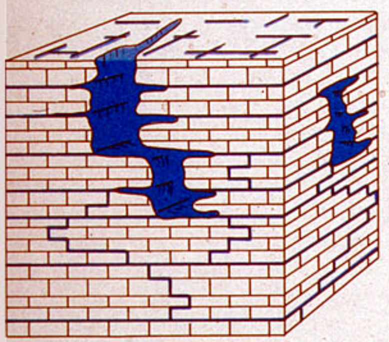
R. C. Heath



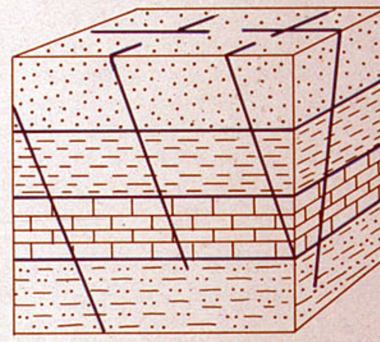
A. Pores in unconsolidated sedimentary deposits



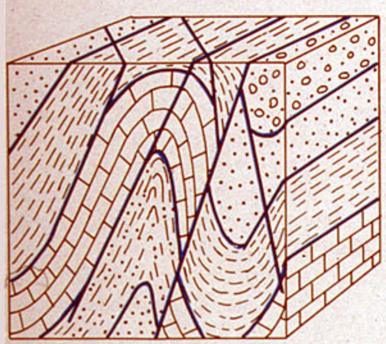
B. Lava tubes and cooling fractures in extrusive igneous rock



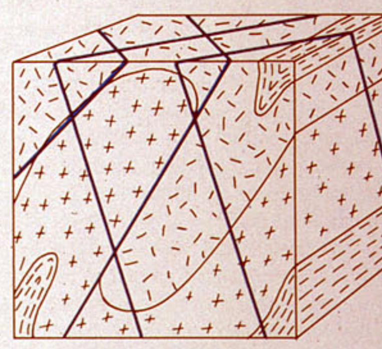
C. Caverns and other solution-enlarged openings in limestone



D. Joints in flat-lying consolidated sedimentary rock

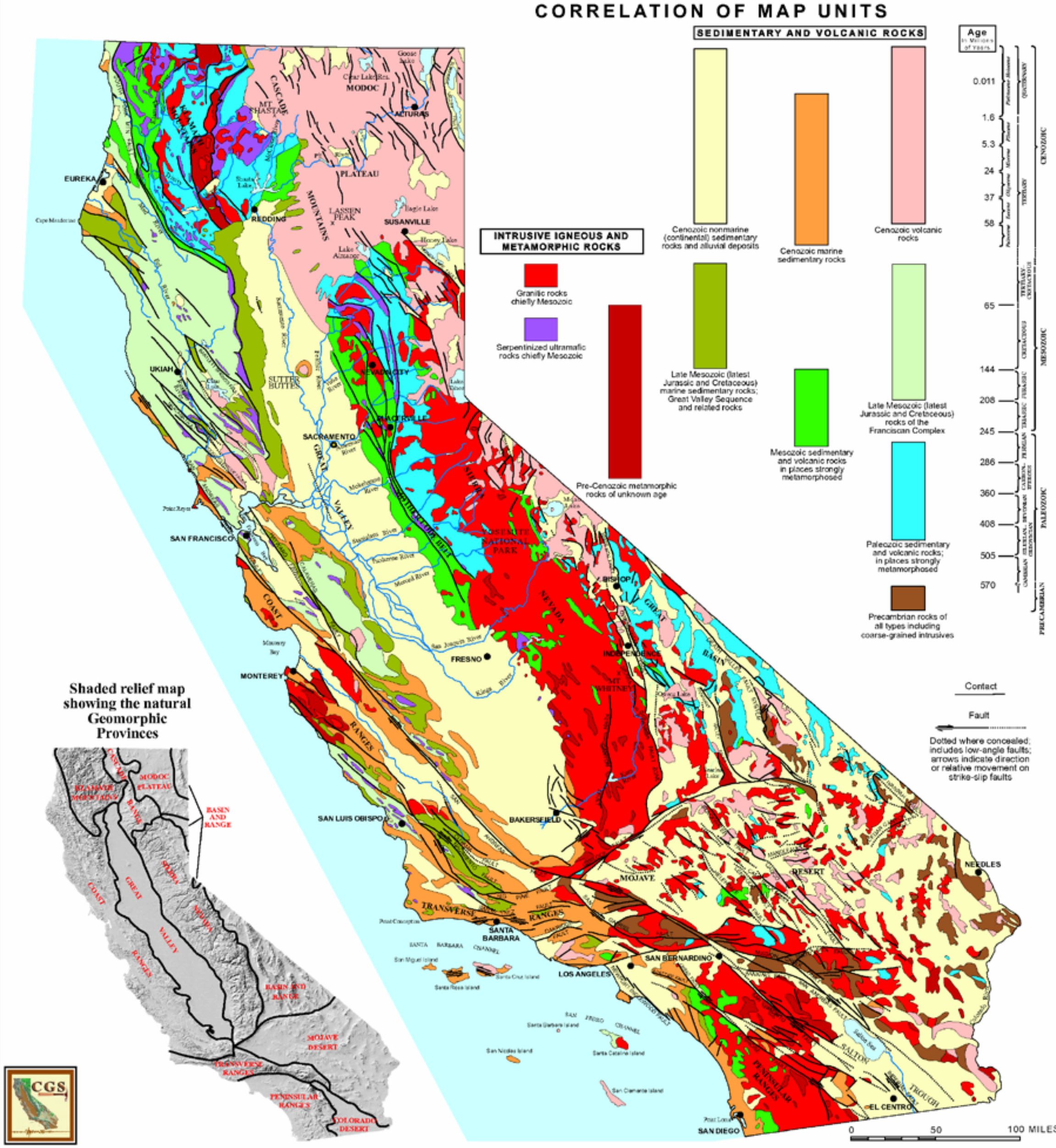


E. Joints and fault in folded consolidated sedimentary rock



F. Joints in metamorphic and intrusive igneous rocks

SIMPLIFIED GEOLOGIC MAP OF CALIFORNIA



Sierra Nevada Granitics (Green Lake area, Hoover Wilderness)

aa lava flow, Newbury Crater, Oregon

SIMPLIFIED GEOLOGIC MAP OF CALIFORNIA

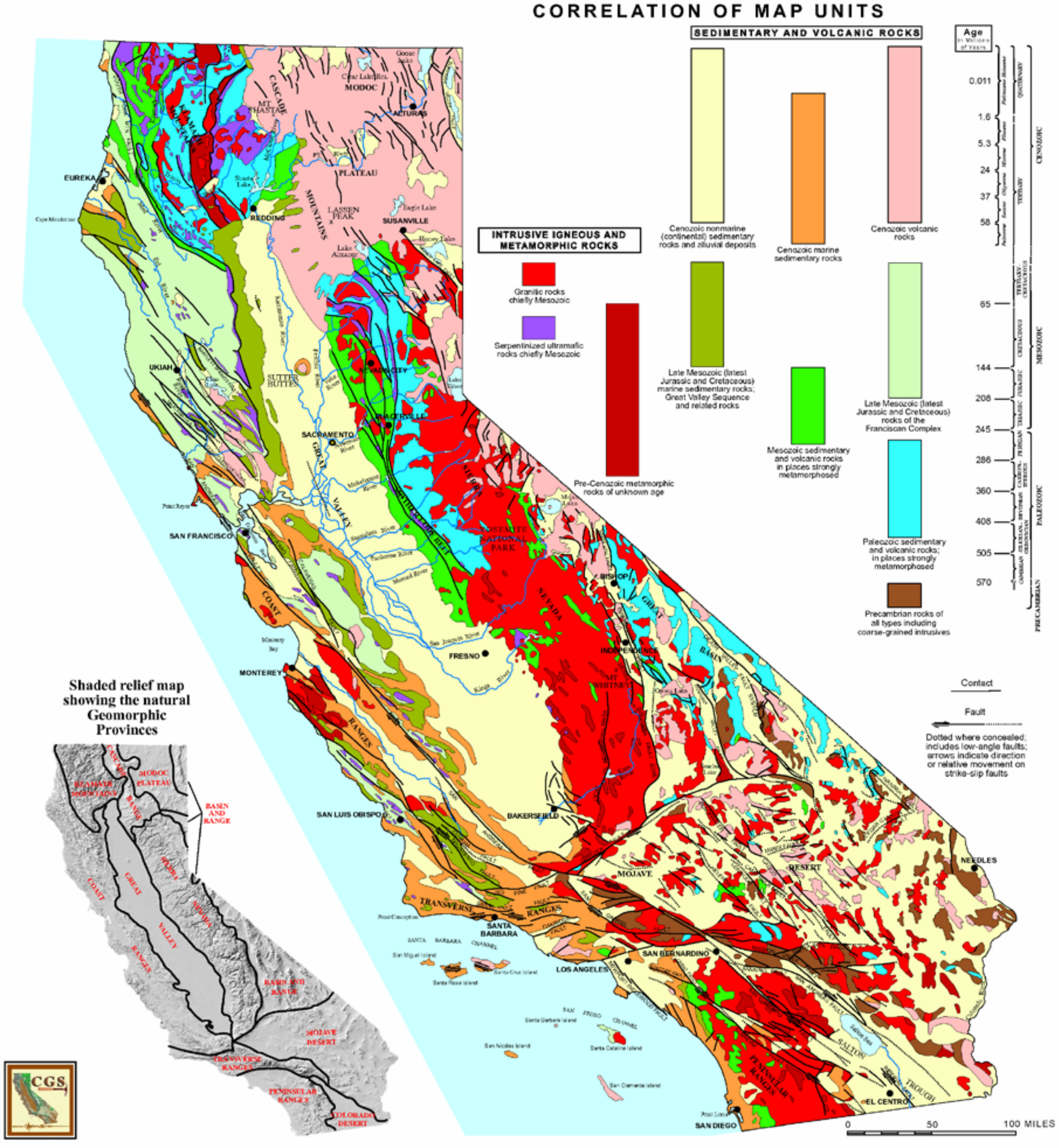


Figure 74. The Central Valley is a large structural trough that has been partially filled by marine sediments and continental deposits. The Sierra Nevada, which forms most of the eastern boundary of the valley, is the edge of a huge tilted granite block. The Coast Ranges, which form most of the western boundary, consist, for the most part, of folded and faulted marine rocks.

EXPLANATION

- **Continental deposits**
- **Marine sediments**
- **Crystalline rock**
- **Fault**—Arrows show relative direction of movement

Page, R.W., 1986, Geology of the fresh ground-water basin of the Central Valley, California, with texture maps and sections: U.S. Geological Survey Professional Paper 1401–C, 54 p.

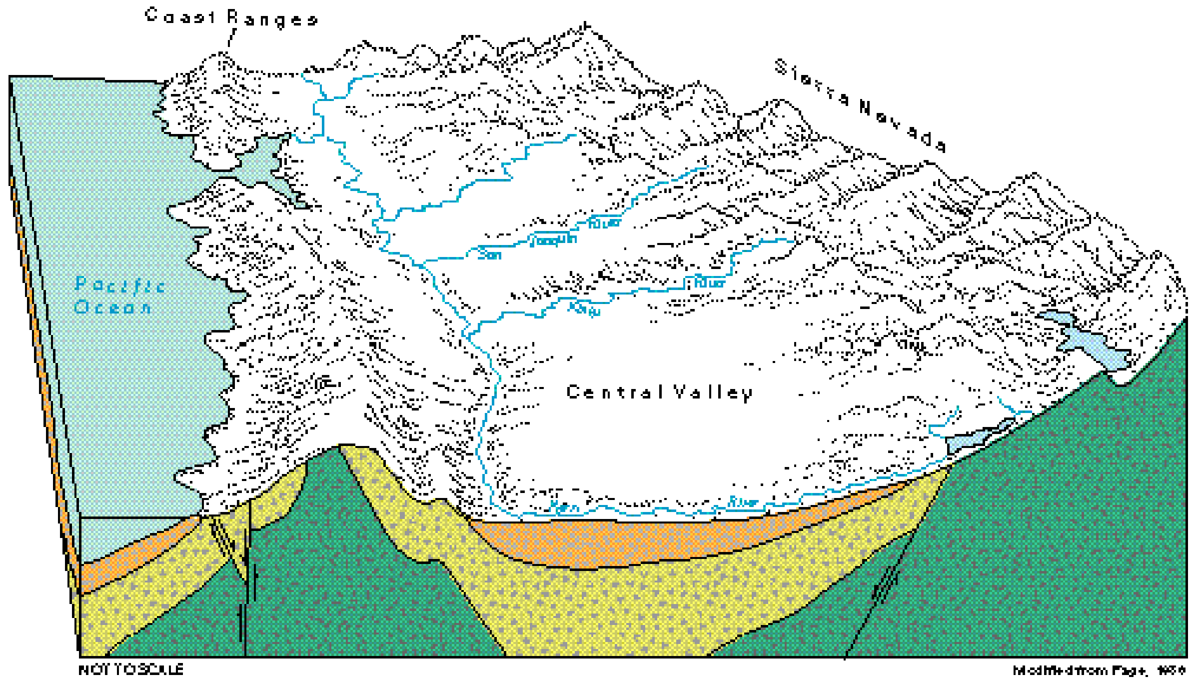
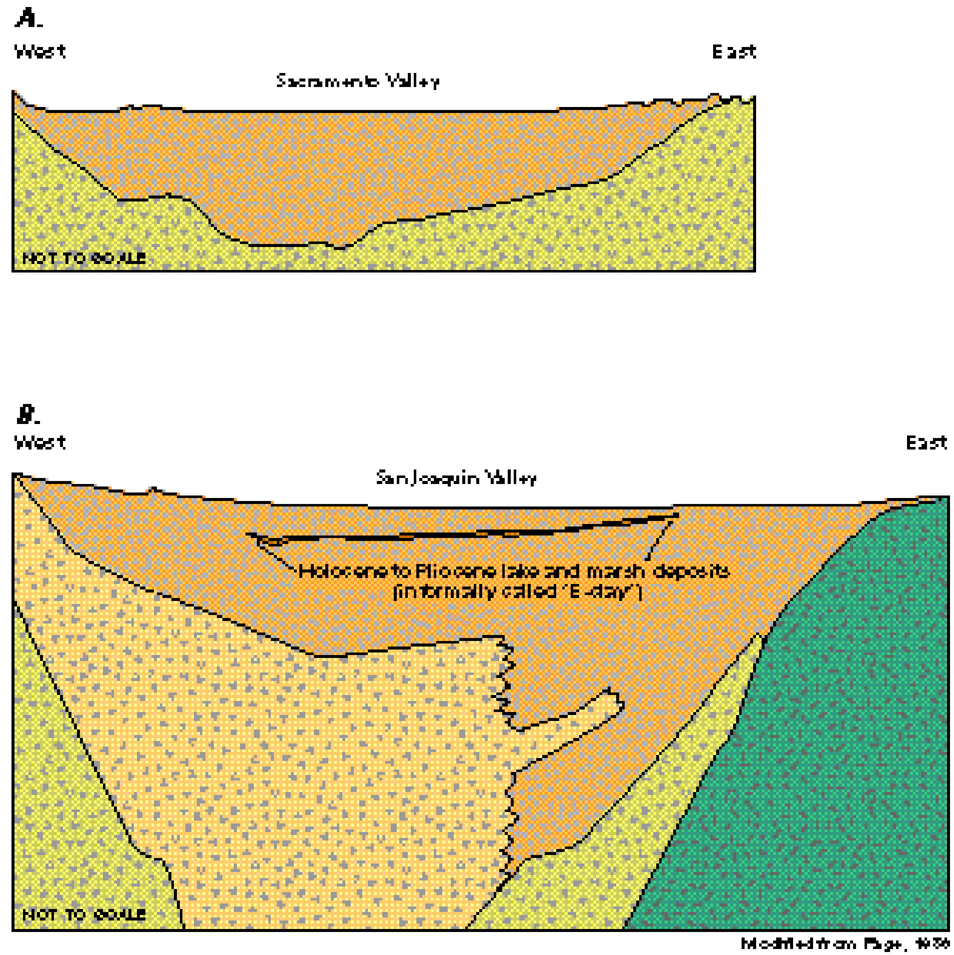


Figure 77. Diagrammatic geologic sections show that (A) the Sacramento Valley contains a relatively thin section of continental deposits, whereas these deposits are very thick in the San Joaquin Valley, and (B) the marine rocks and the lake and marsh deposits in the San Joaquin Valley have minimal permeability.

EXPLANATION

- **Holocene to Oligocene continental deposits**
- **Pliocene to Eocene marine rocks**
- **Oligocene to pre-Tertiary marine rocks and continental deposits**
- **Pre-Tertiary igneous and metamorphic rocks**

Page, R.W., 1986, Geology of the fresh ground-water basin of the Central Valley, California, with texture maps and sections: U.S. Geological Survey Professional Paper 1401–C, 54 p.

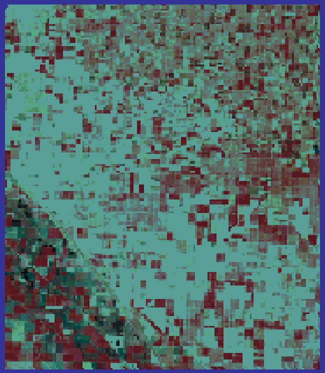


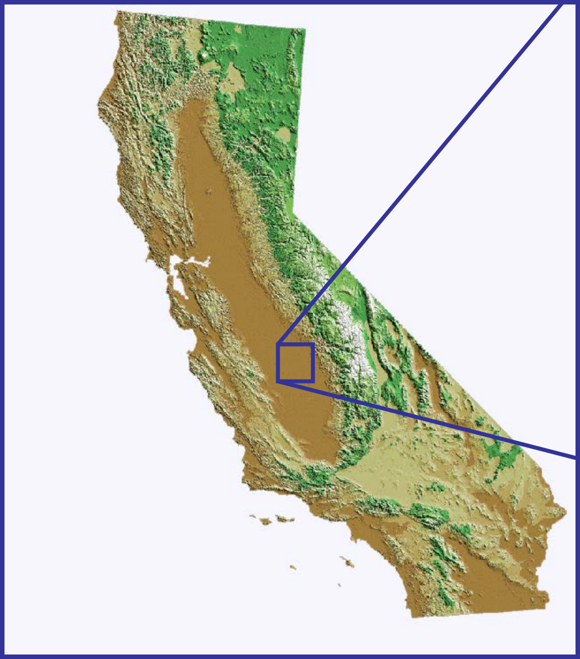
Alluvial Fan (near Bozeman, Montana)

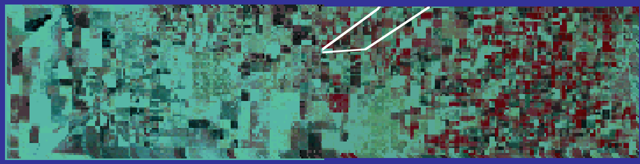
http://geology.about.com/library/bl/images/blalluvfan.htm

Kings River Fan Aquifer System

- Stream-dominated alluvial fan system (fluvial depositional system);
- Located southeast of Fresno, California;
- Study area located in medial fan area.

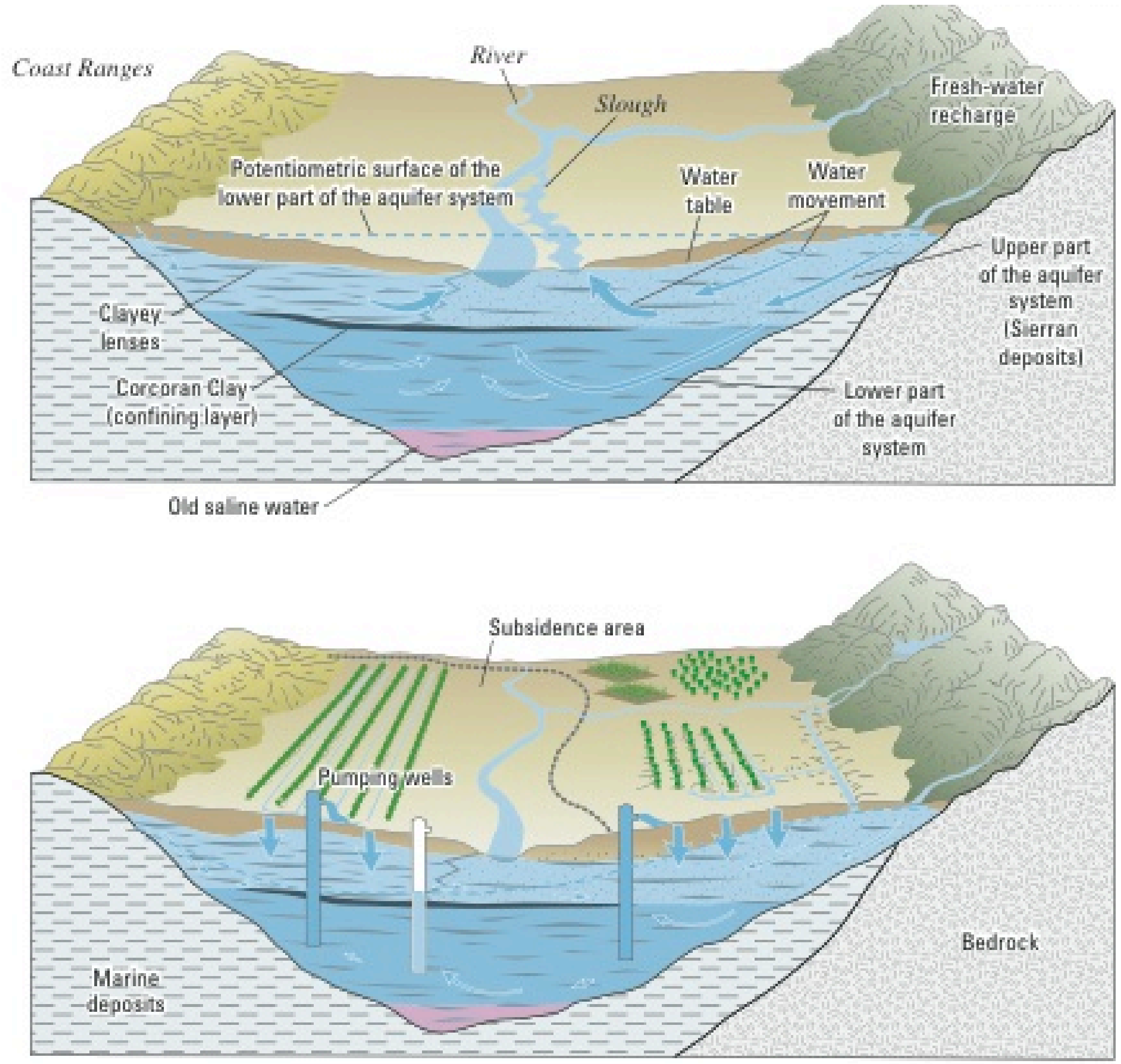






Kings River Alluvial Fan

San Joaquin Valley Groundwater (from Faunt, 2009)

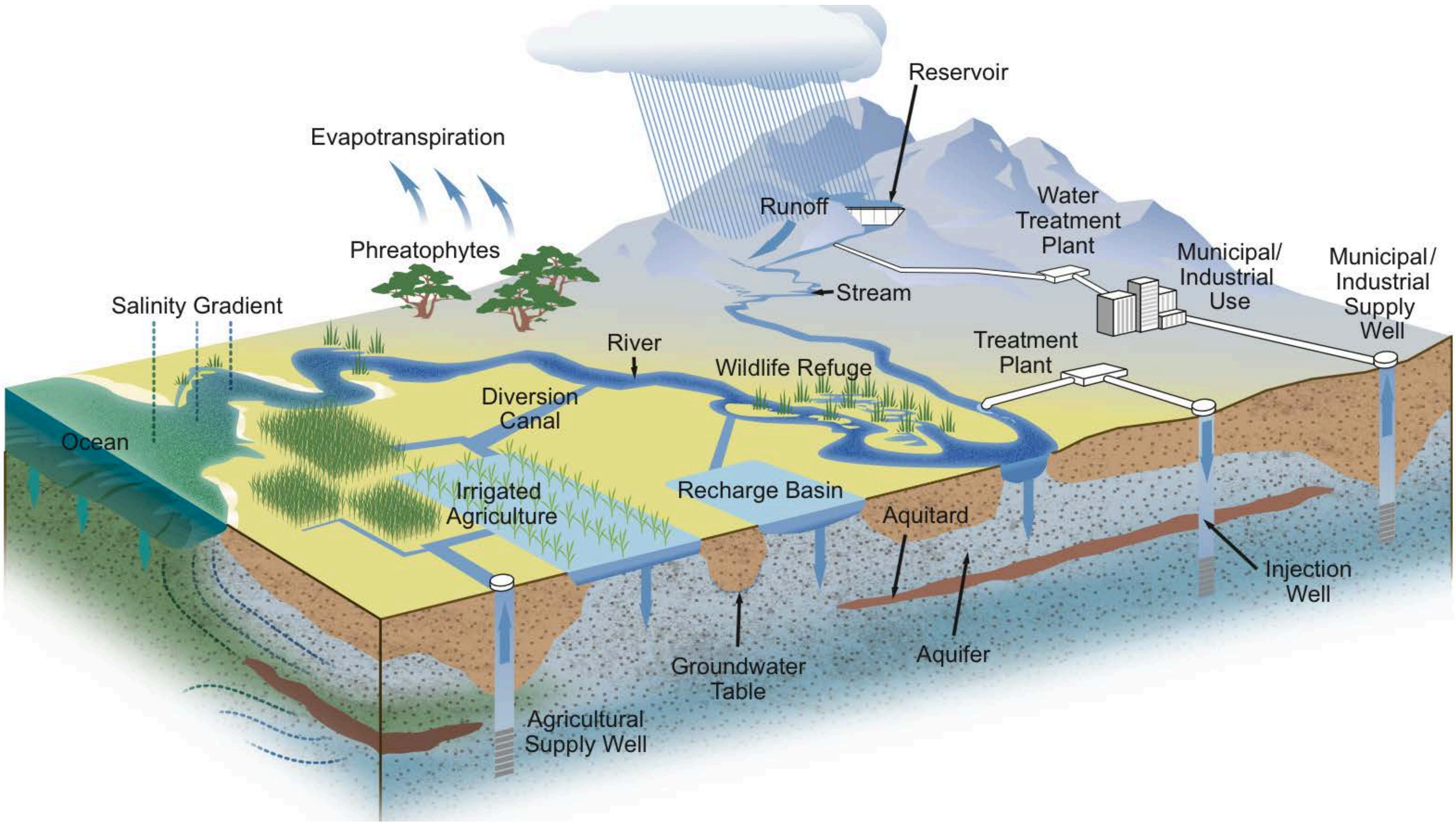


Pre-Development

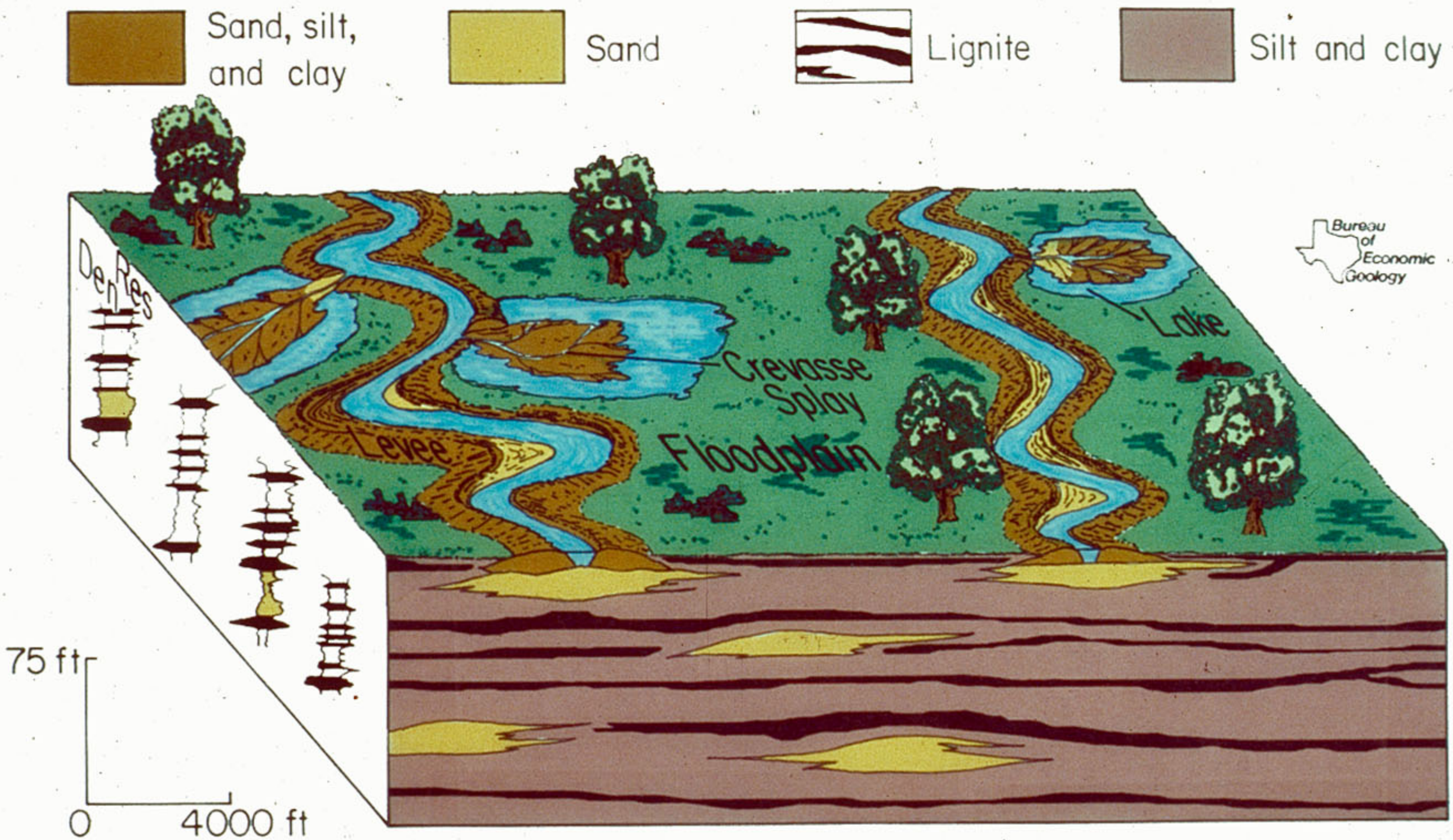
Post-Development

Figure A9. Continued.

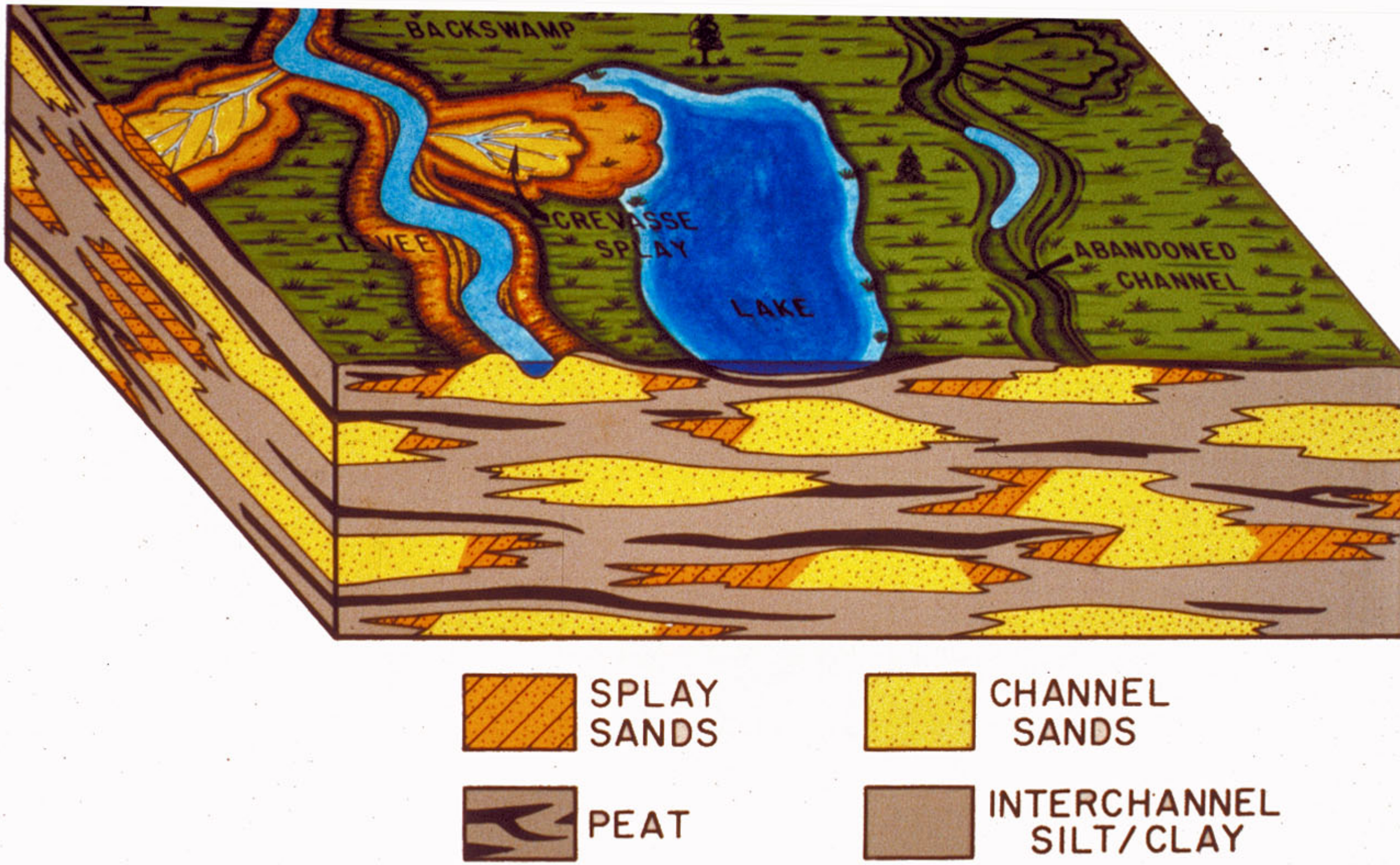
Groundwater and Surface Water



From CA Water Plan 2014



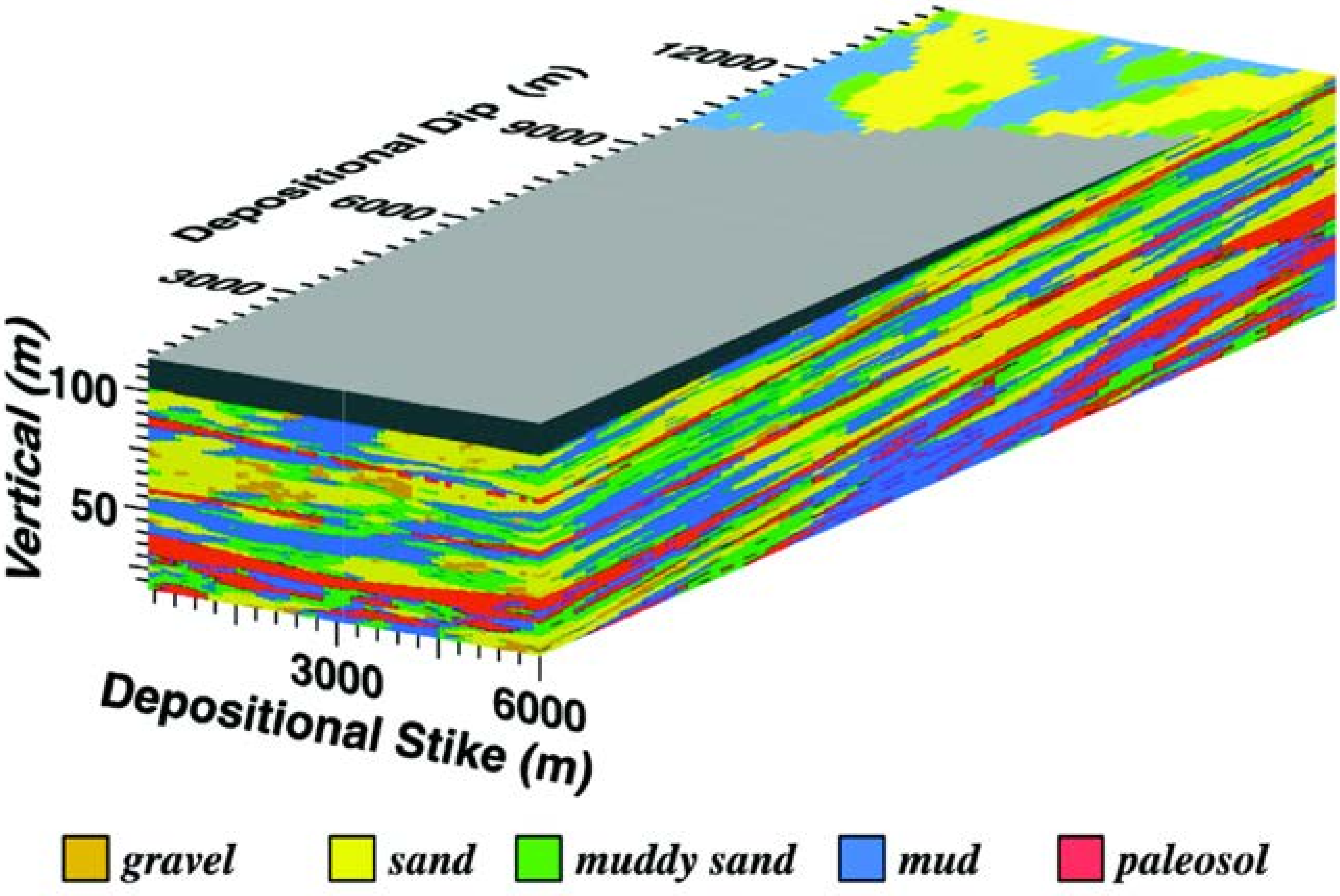
MIXED- AND SUSPENDED-LOAD CHANNEL SYSTEM
CALVERT BLUFF FORMATION



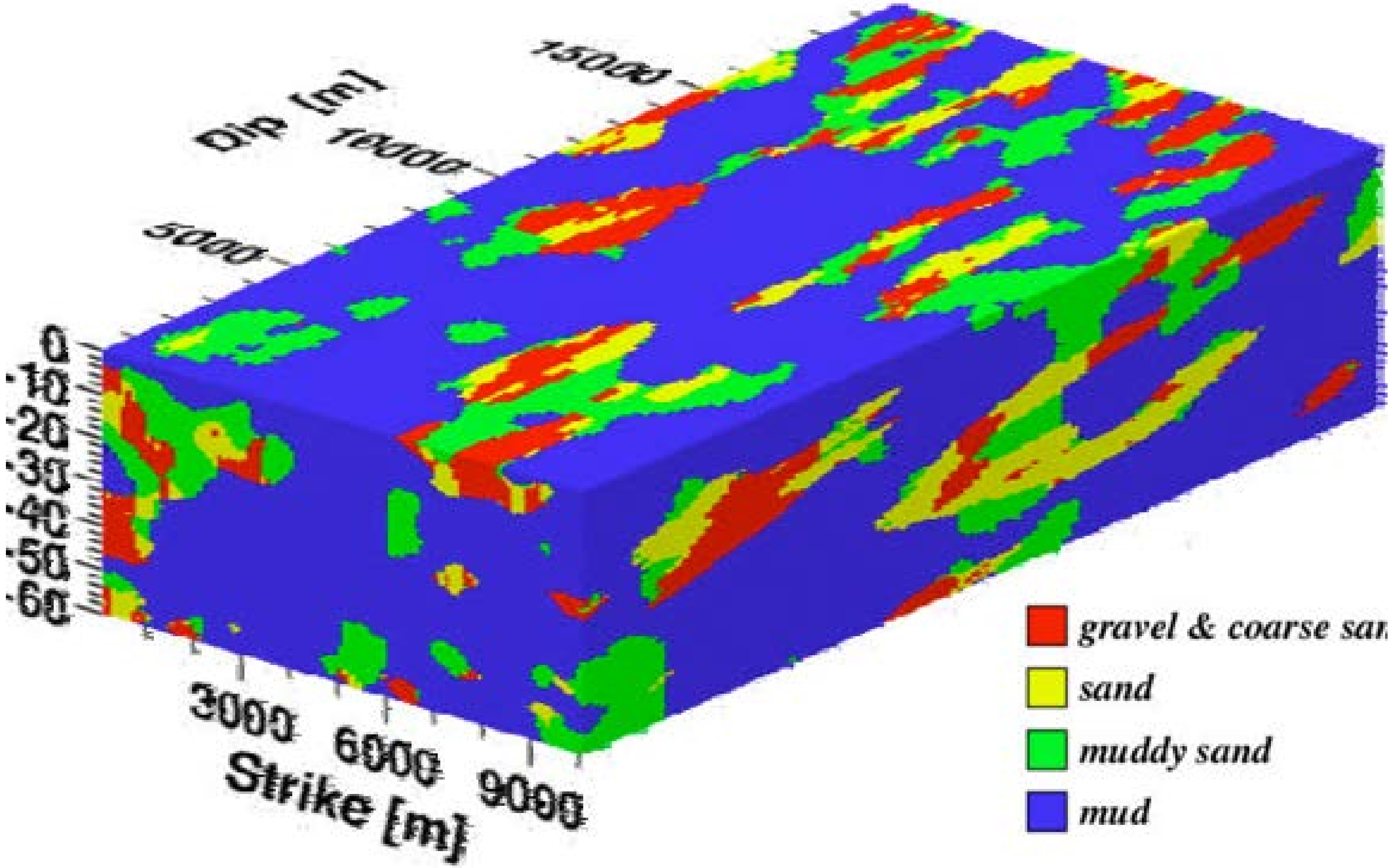
MIXED-LOAD CHANNEL SYSTEM

Kings River Alluvial Fan

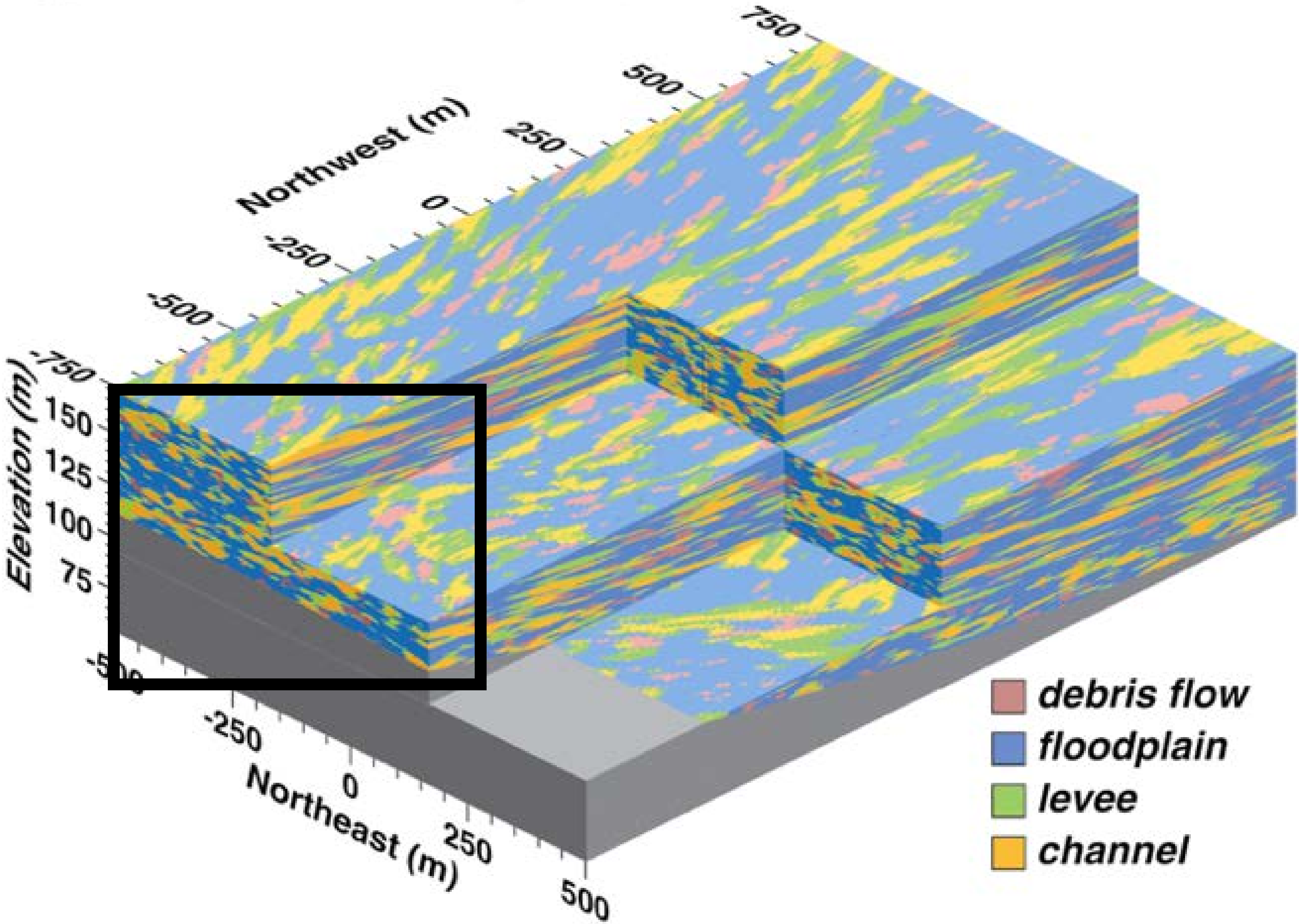
Realization 5

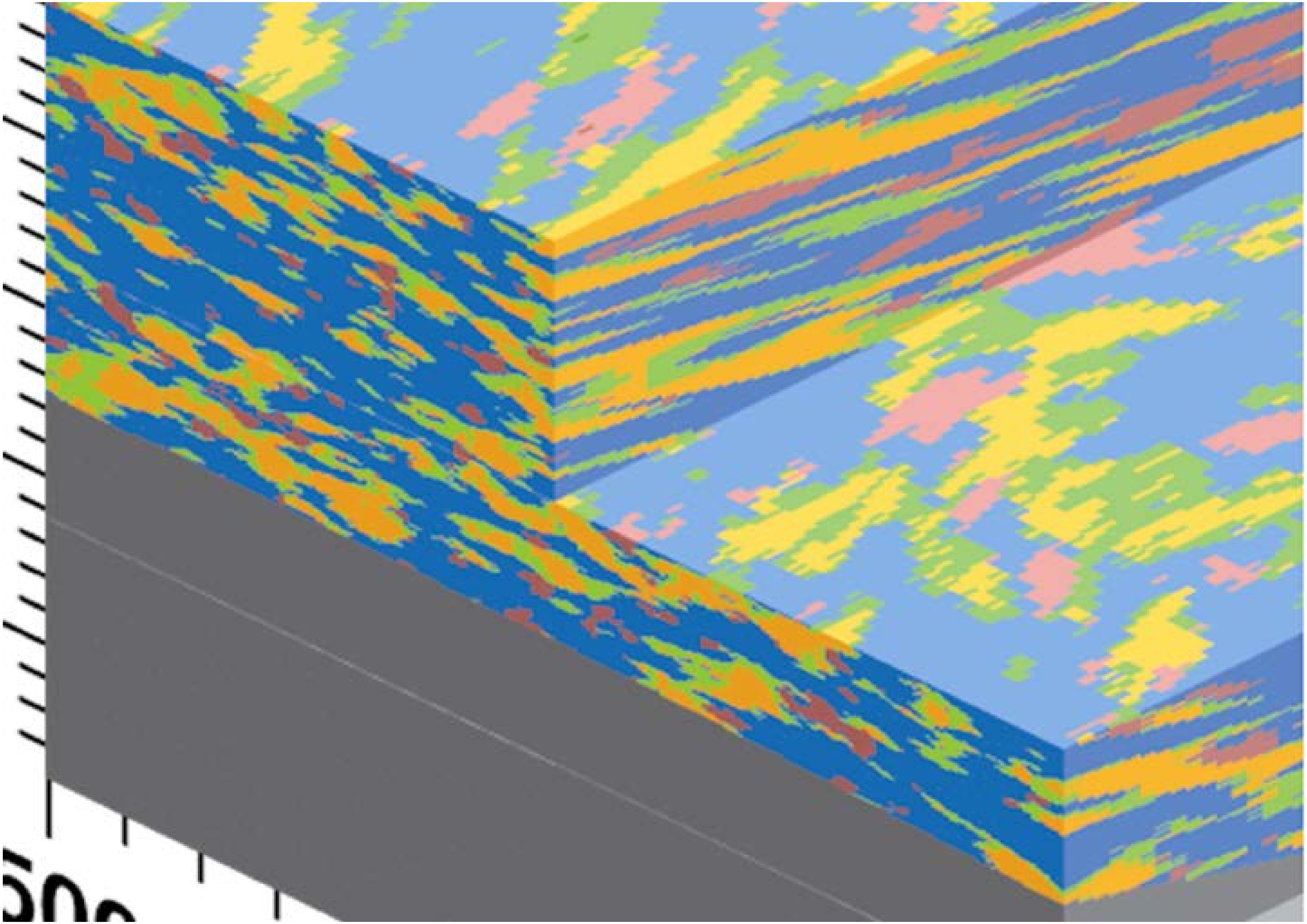


Cosumnes Alluvial Aquifer System

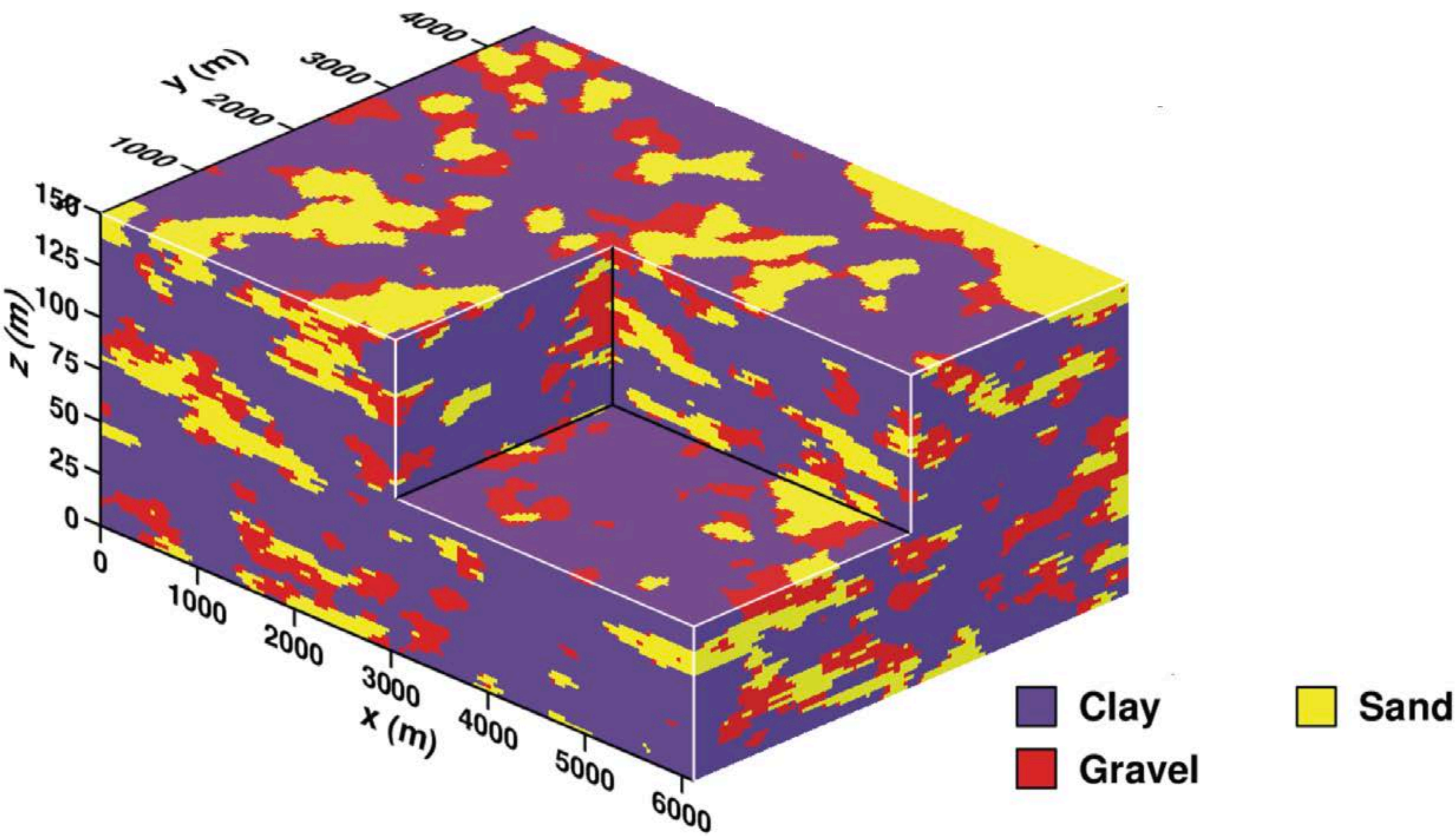


Typical Subsurface Complexty, LLNL Site (Carle & Fogg, 1996)

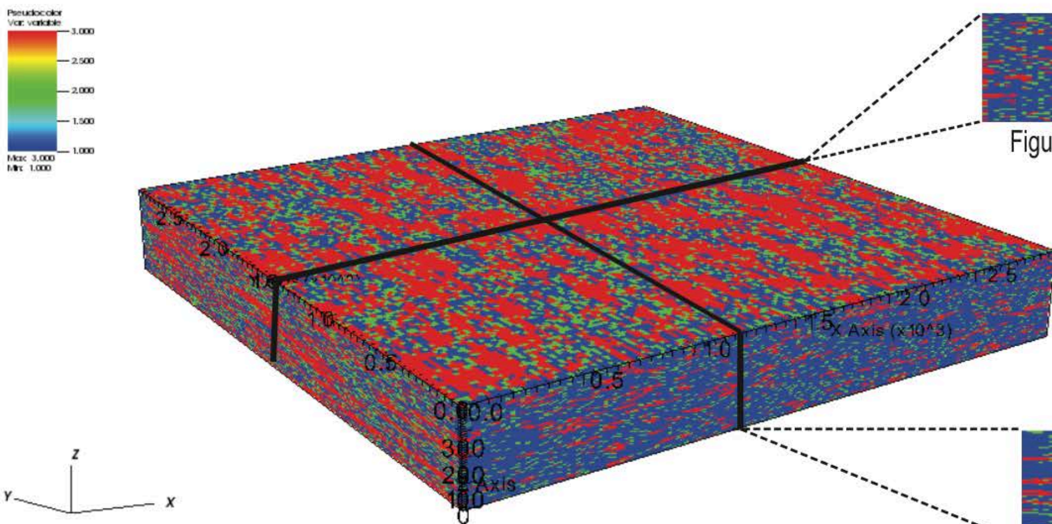




Woodland Area Aquifer System Network (Stephen Maples, HYD 273)



Davis Area Aquifer System Network (Katie Markovich, HYD 273)



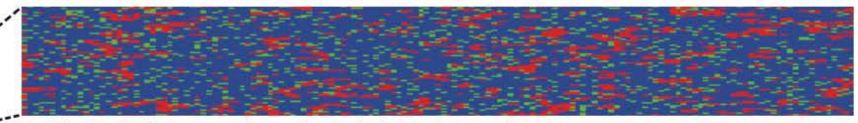


Figure 2. Cross-section oriented along the x-axis

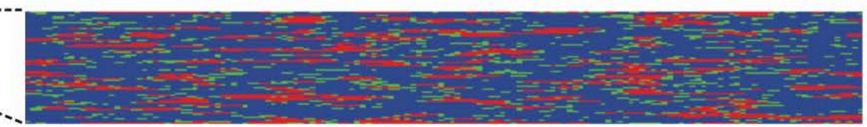
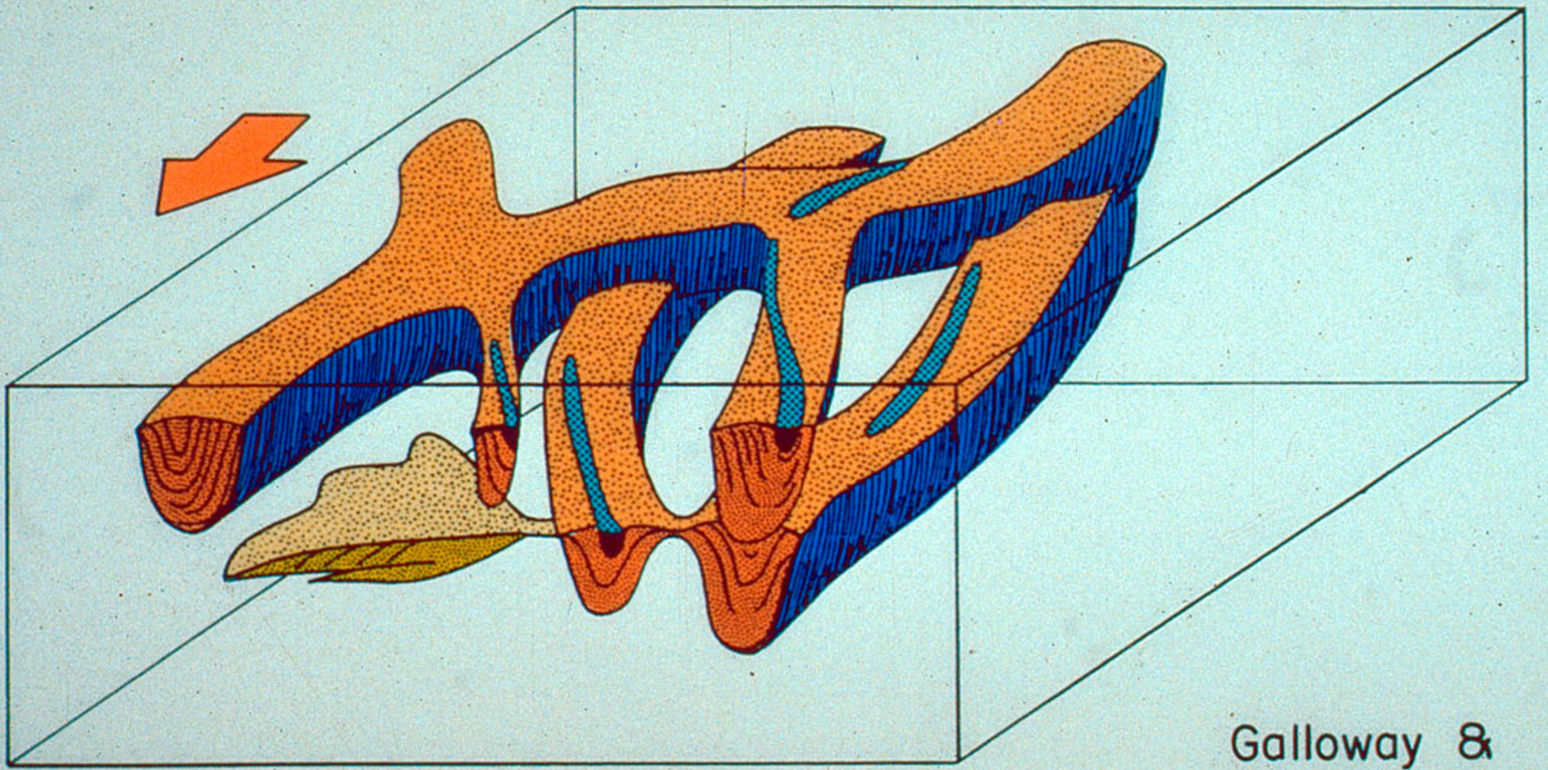


Figure 3. Cross-section oriented along the y-axis

FACIES ARCHITECTURE

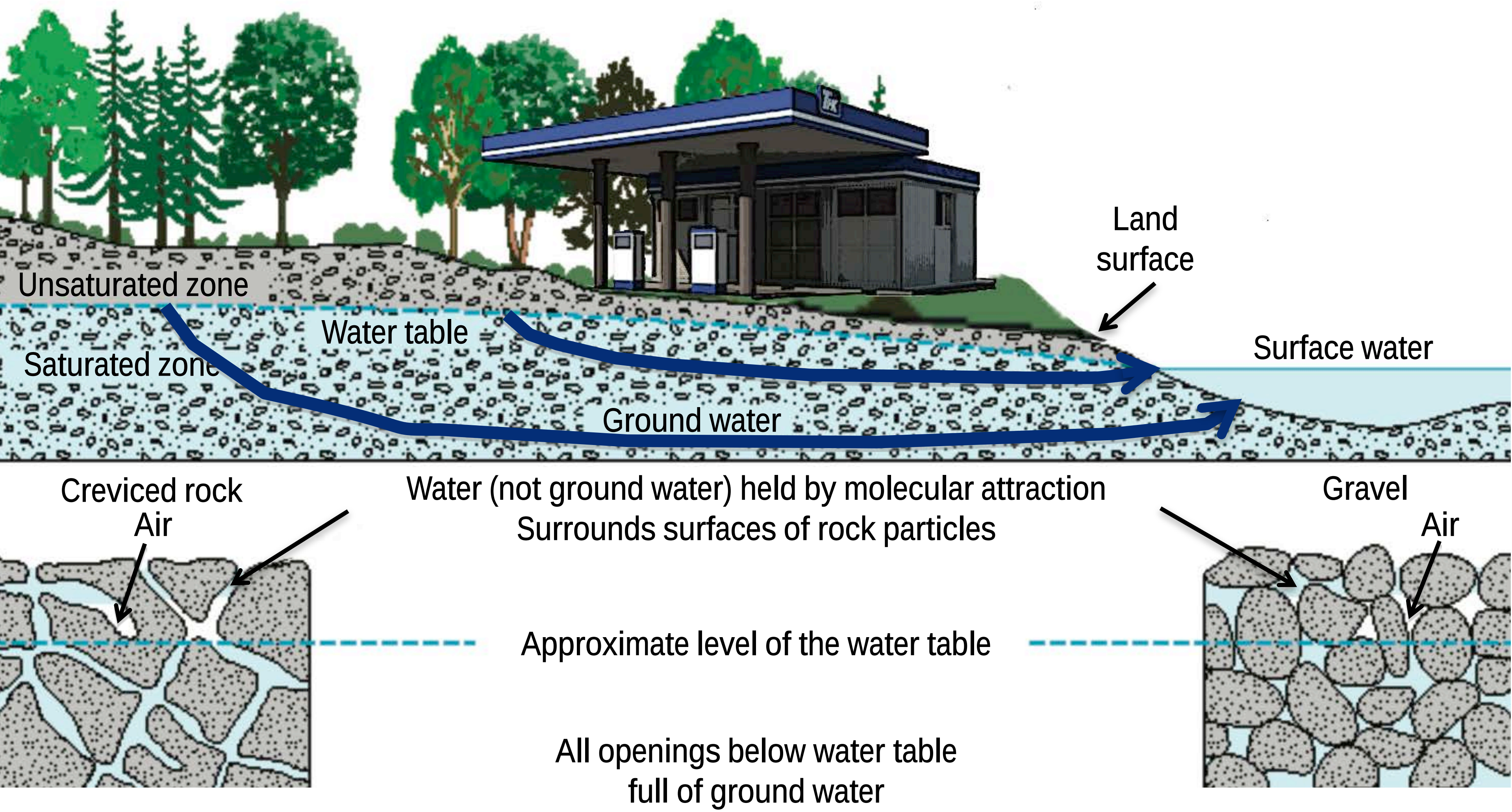


Suspended-load channel

Galloway &
Hobday 1983

Bureau of Economic Geology QA-2480

Groundwater



Confined Aquifer Schematic (from Driscoll, 1986)

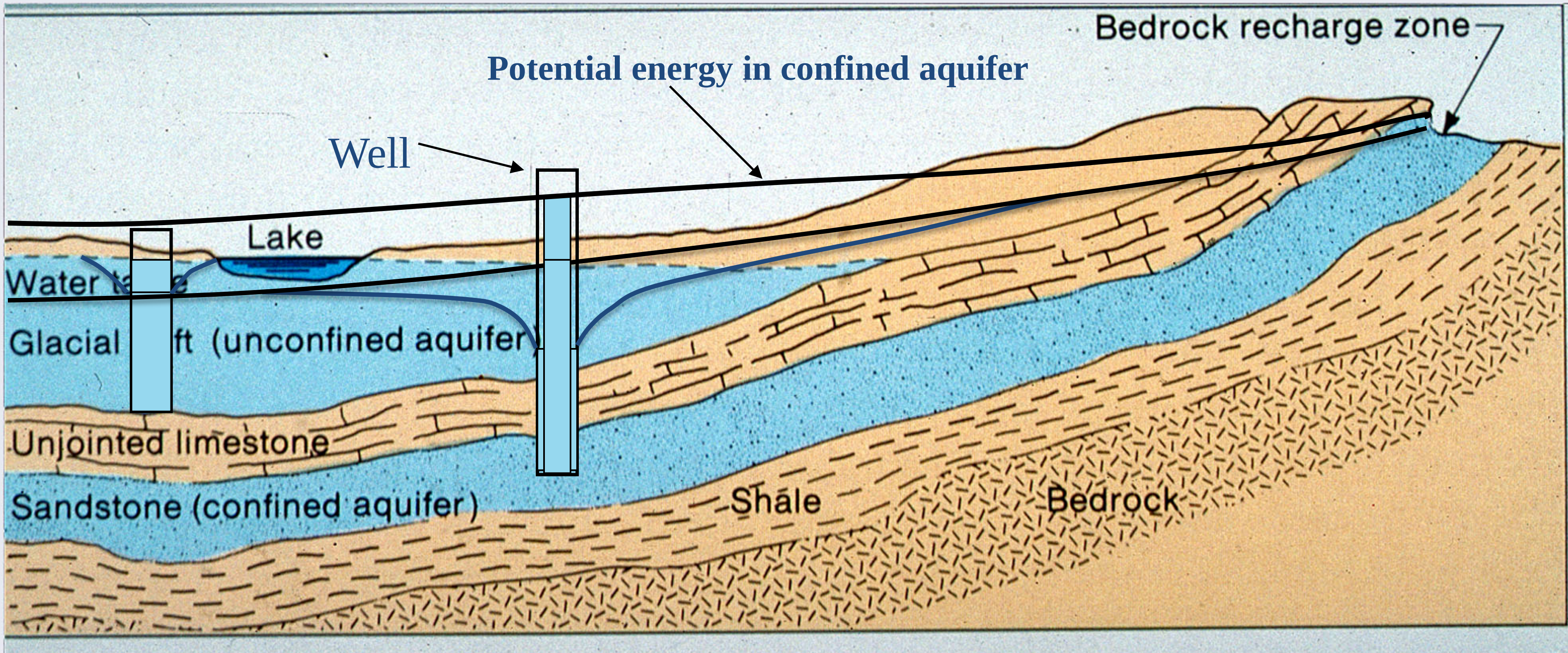
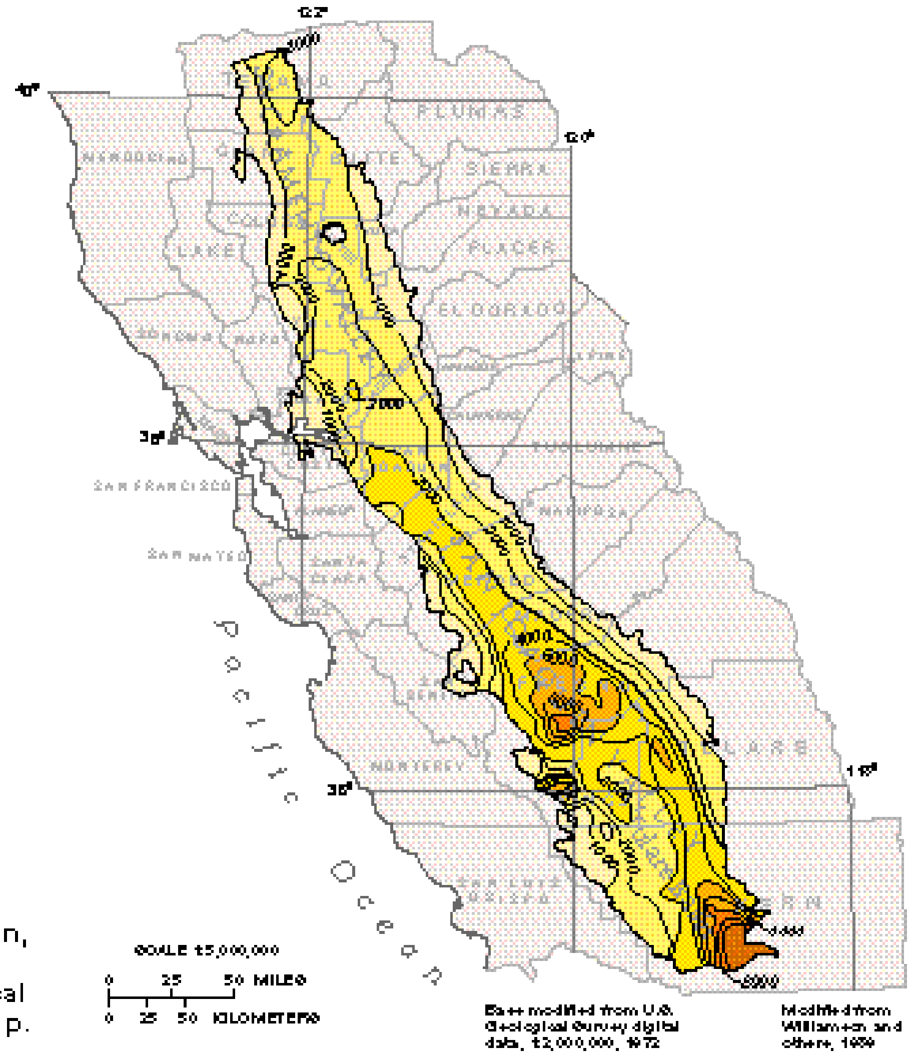


Figure 5.2. Groundwater exists in the underground in two major environments: unconfined and confined.

Myth: Old (1,000's of yrs) groundwater is fossil water that is not replenished enough to support pumping.


CALIFORNIA
GROUND WATER

Figure 76. Continental sediments form the Central Valley aquifer system. These sediments average 2,400 feet in thickness but are more than 9,000 feet thick in the Tulare Basin.



EXPLANATION

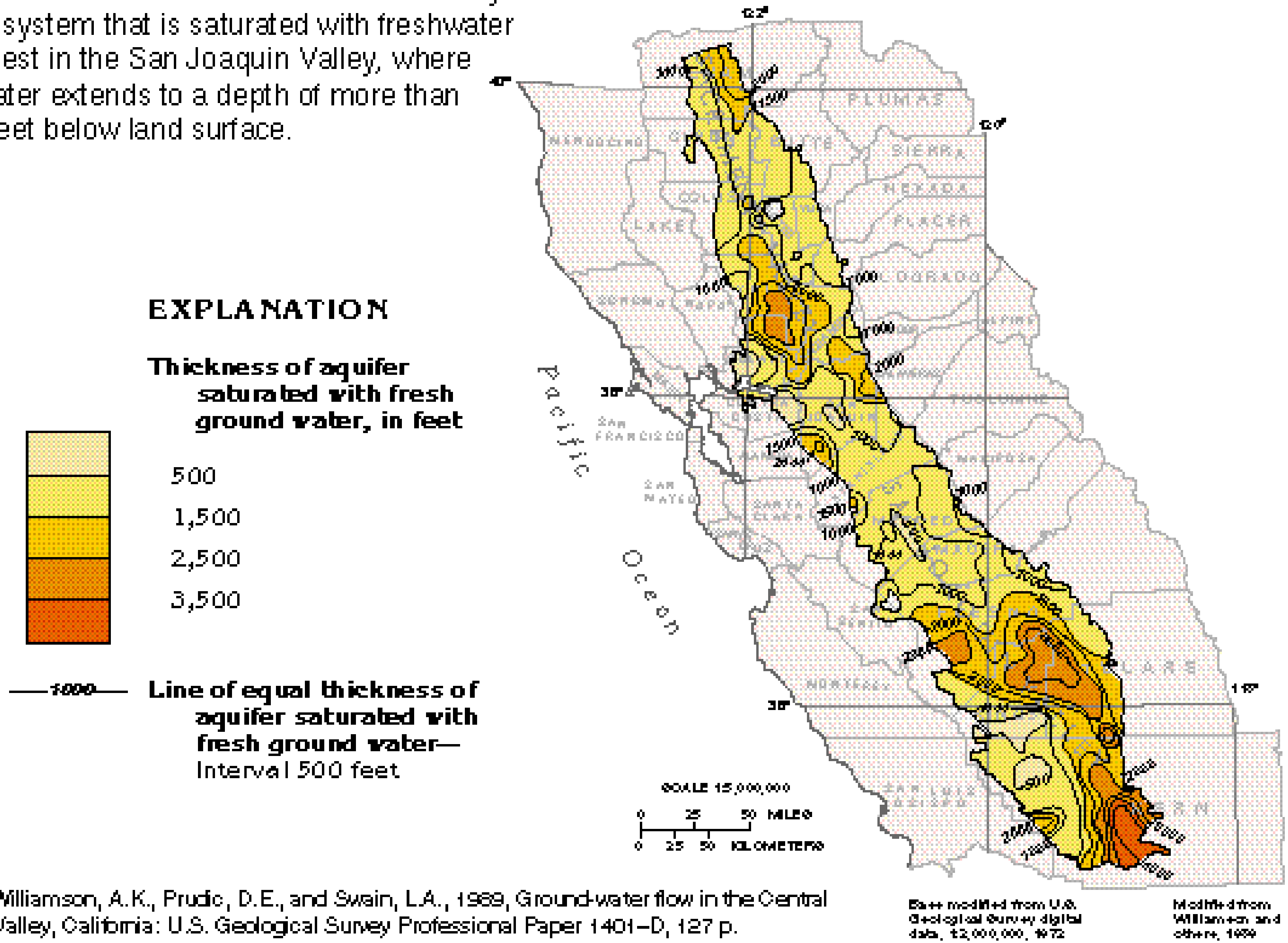
Thickness of continental deposits, in feet

1,000
3,000
5,000
7,000
9,000

—5000— **Line of equal thickness of continental deposits**—Interval 1,000 feet

Williamson, A.K., Prudic, D.E., and Swain, L.A., 1989, Ground-water flow in the Central Valley, California: U.S. Geological Survey Professional Paper 1401–D, 127 p.

Figure 98. The thickness of the Central Valley aquifer system that is saturated with freshwater is greatest in the San Joaquin Valley, where freshwater extends to a depth of more than 4,000 feet below land surface.



Williamson, A.K., Prudic, D.E., and Swain, L.A., 1989, Ground-water flow in the Central Valley, California: U.S. Geological Survey Professional Paper 1401–D, 127 p.

San Joaquin Valley Groundwater (from Faunt, 2009)

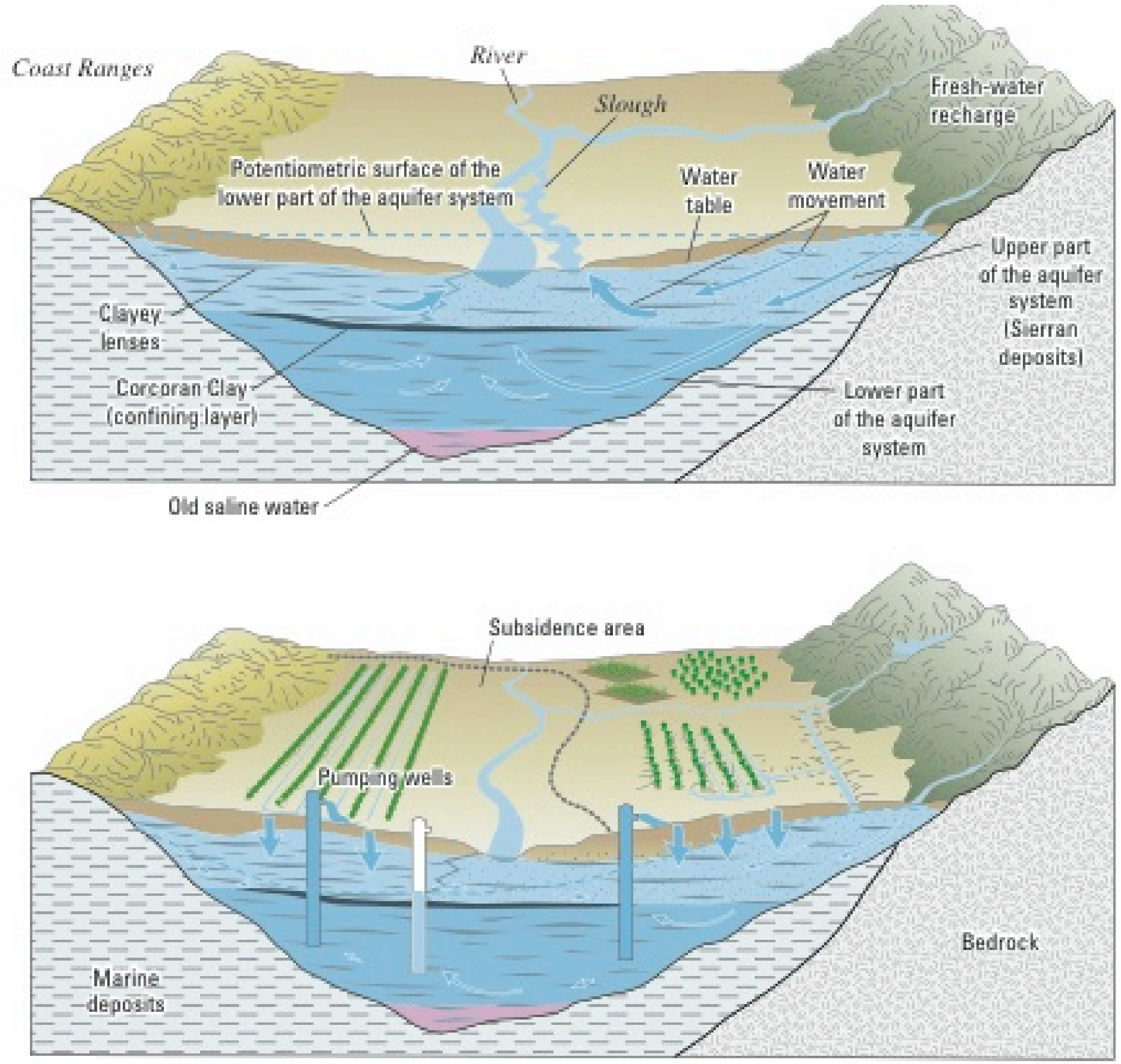


Figure A9. Continued.

Pre-Development

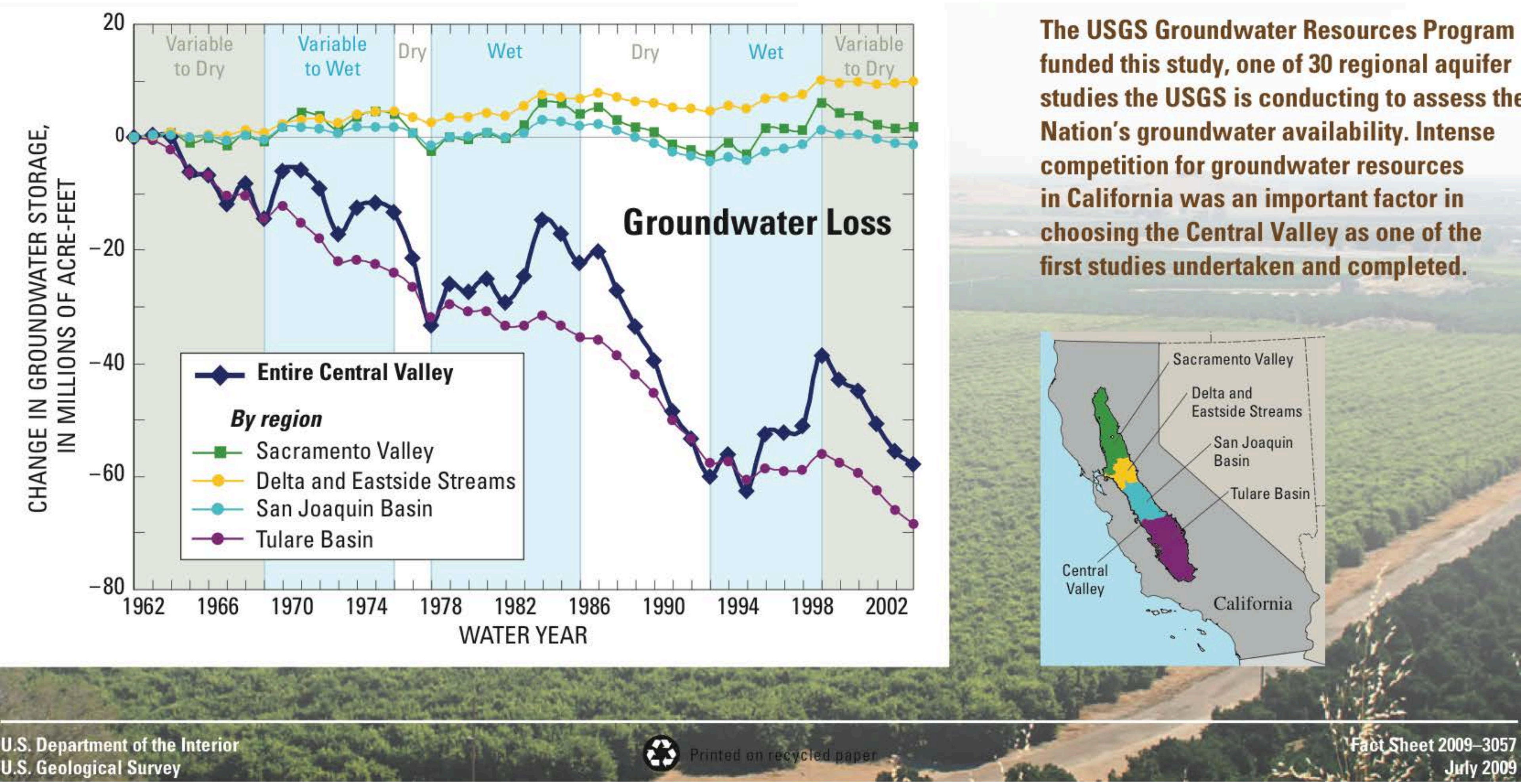
Post-Development

Groundwater Overdraft: Pumping more groundwater than the system can sustain

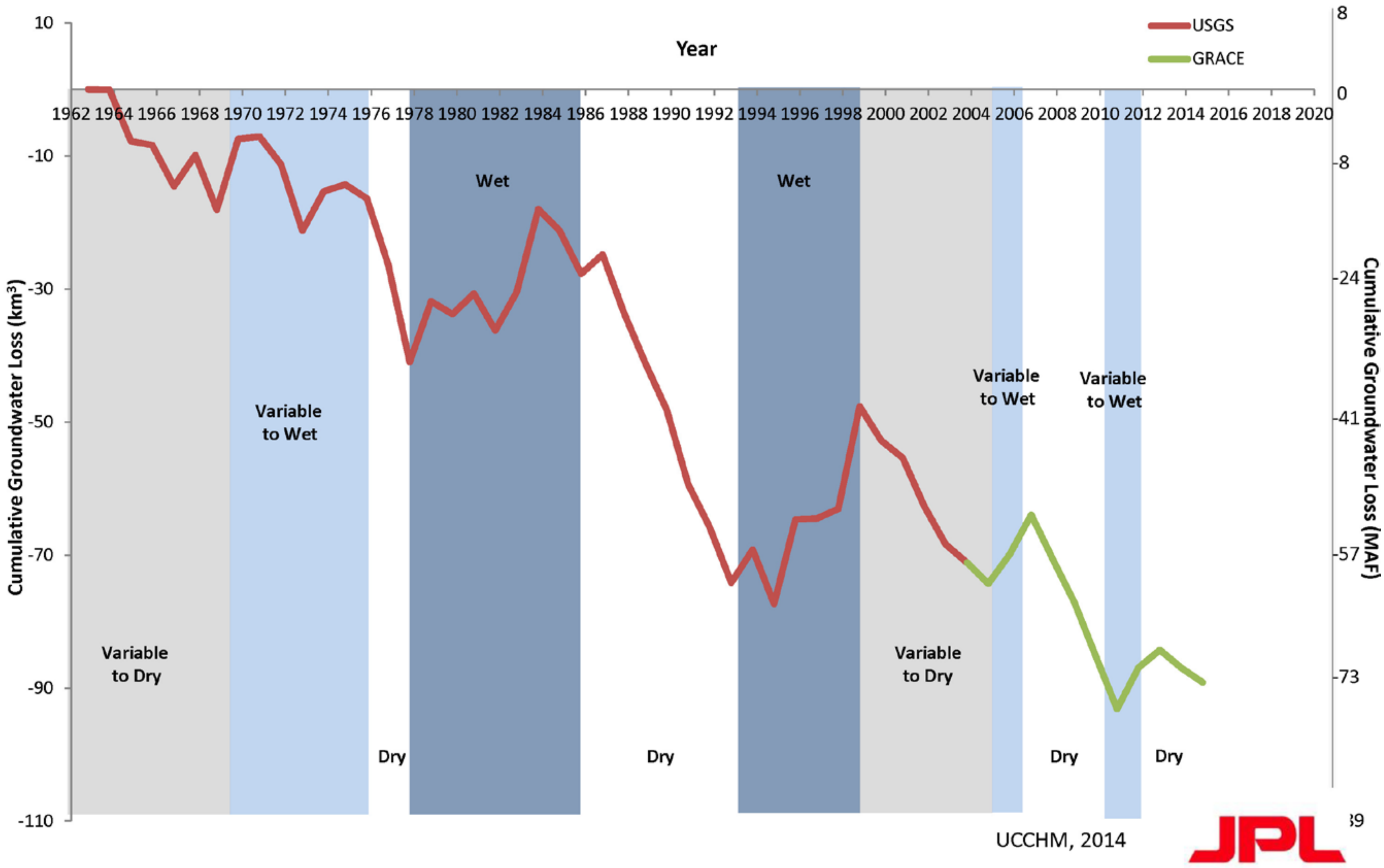
Potential consequences:

- Non-sustainable storage depletion
- Subsidence
- Surface water & ecosystem effects
- Increased energy costs
- Bad water intrusion from aquitards and from depth
- Basin salt imbalance
- Seawater intrusion

Groundwater Overdraft Trends, Central Valley

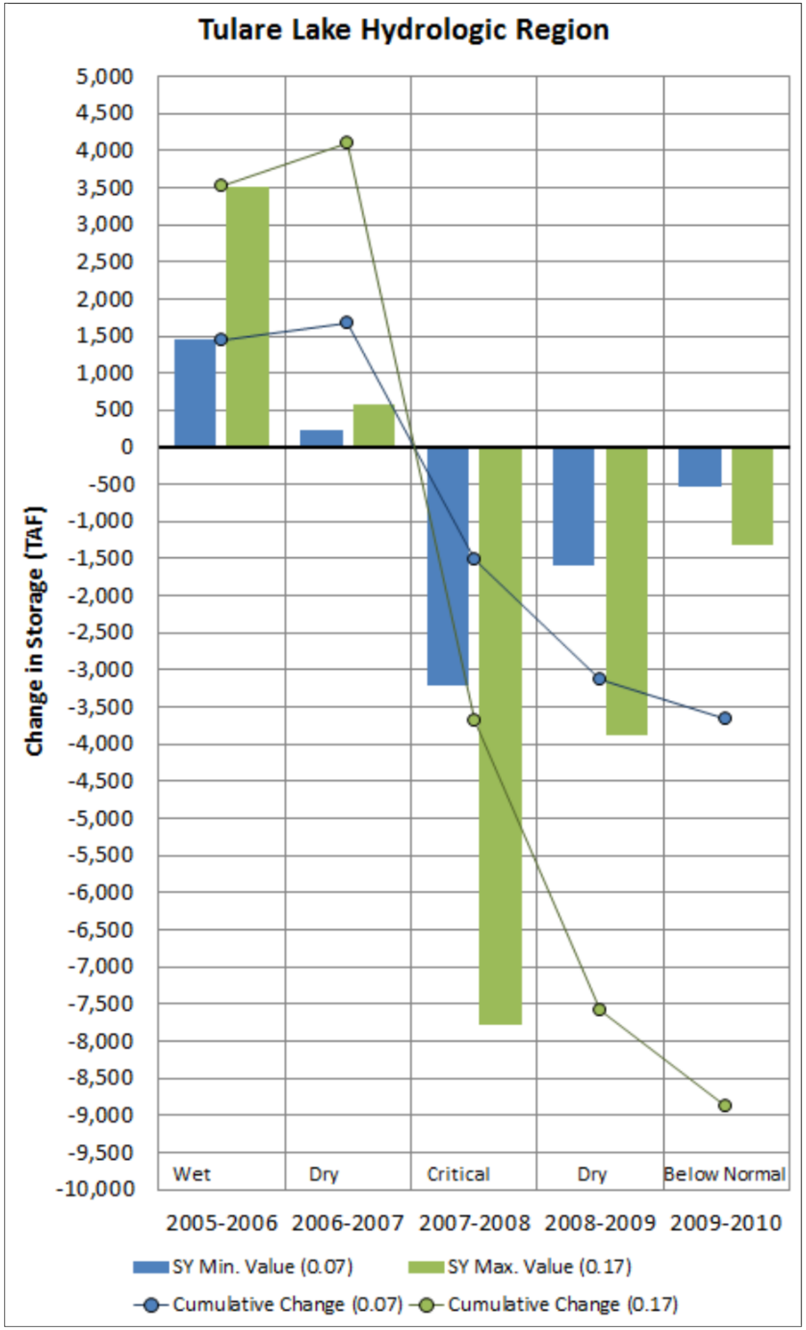


Cumulative Groundwater Depletion in California's Central Valley from USGS and GRACE



From presentation JE Reager, San Gabriel Valley Water Forum held October 2, 2014, Pomona, CA. [JT Reager, CA's drought]

Figure TL-29 Spring 2010 Annual Change in Groundwater Storage for the Tulare Lake Hydrologic Region



Groundwater Overdraft: Pumping more groundwater than the system can sustain

Potential consequences:

- Non-sustainable storage depletion
- Subsidence
- Surface water & ecosystem effects
- Increased energy costs
- Bad water intrusion from aquitards and from depth
- Basin salt imbalance
- Seawater intrusion

Mining Ground Water

San Joaquin Valley California

Approximate location of maximum subsidence in the United States identified by Joe Poland (pictured)

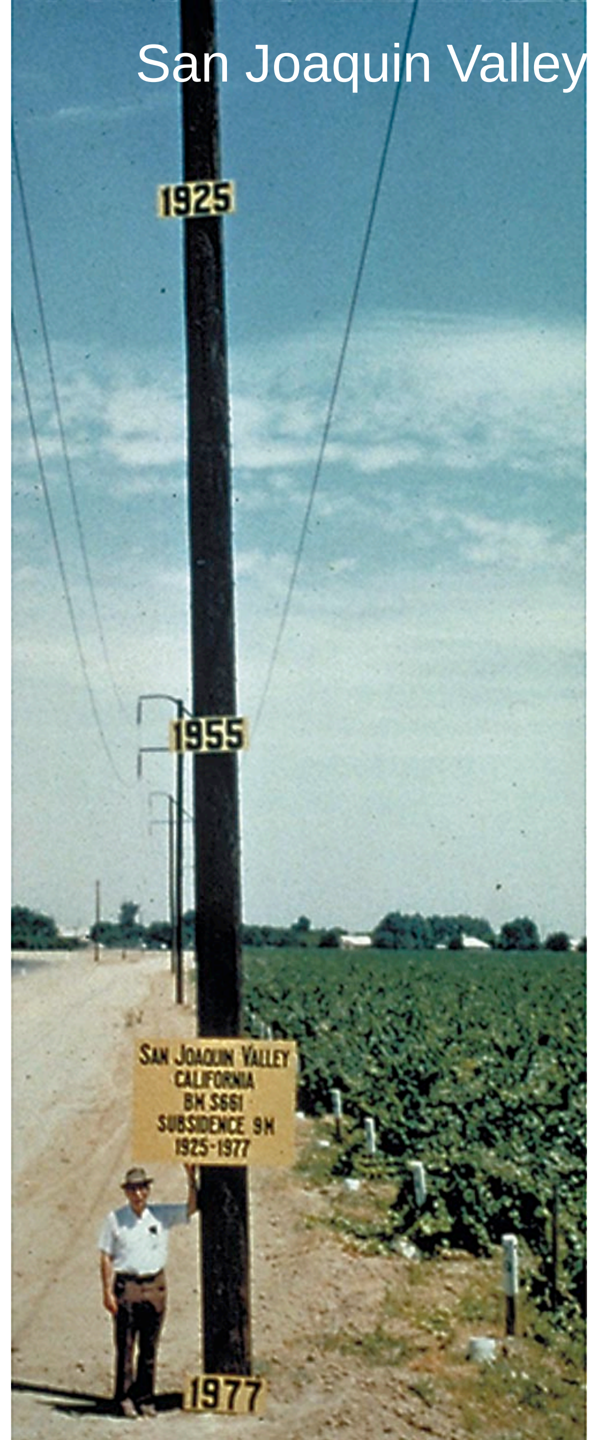
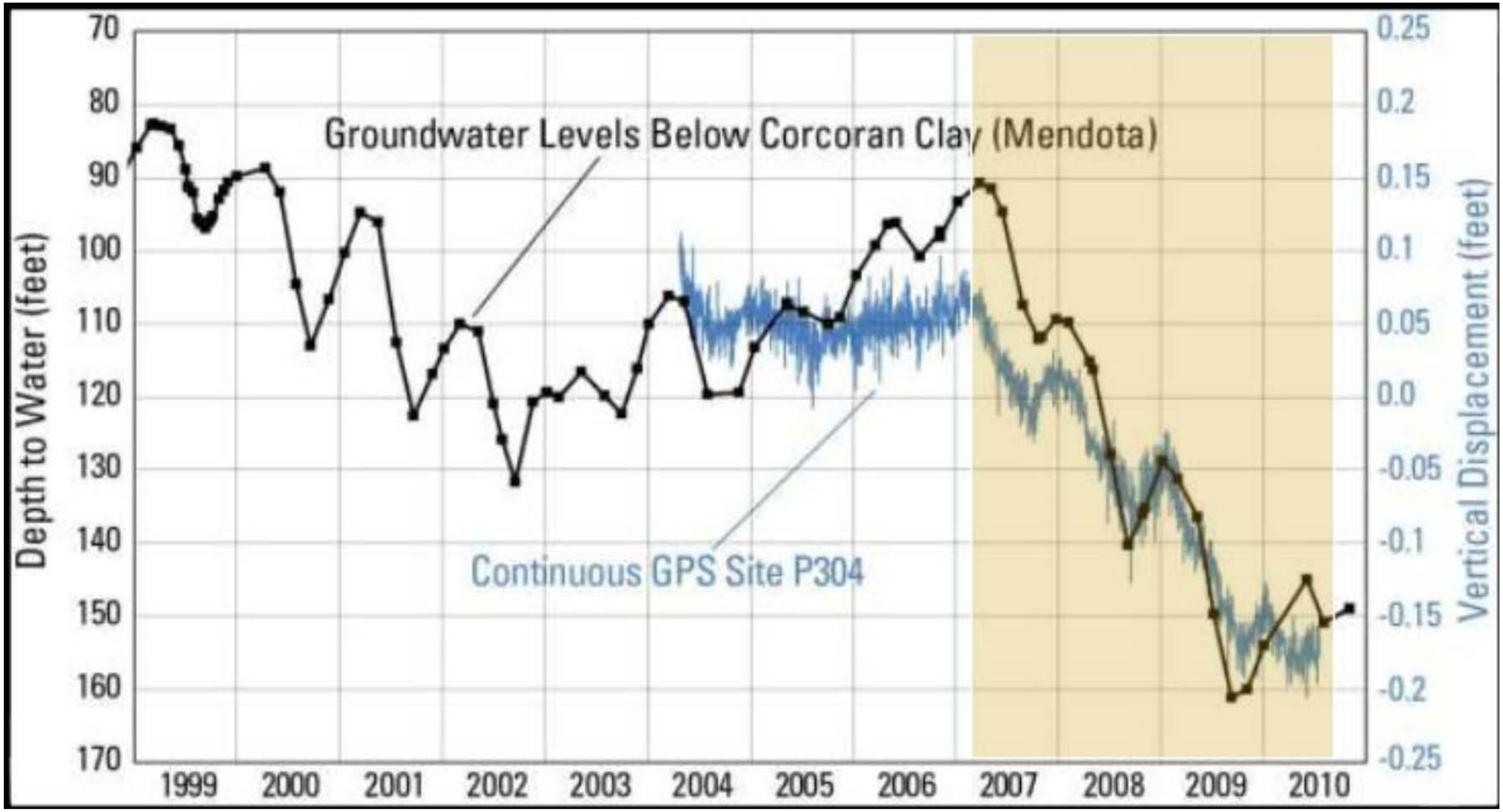
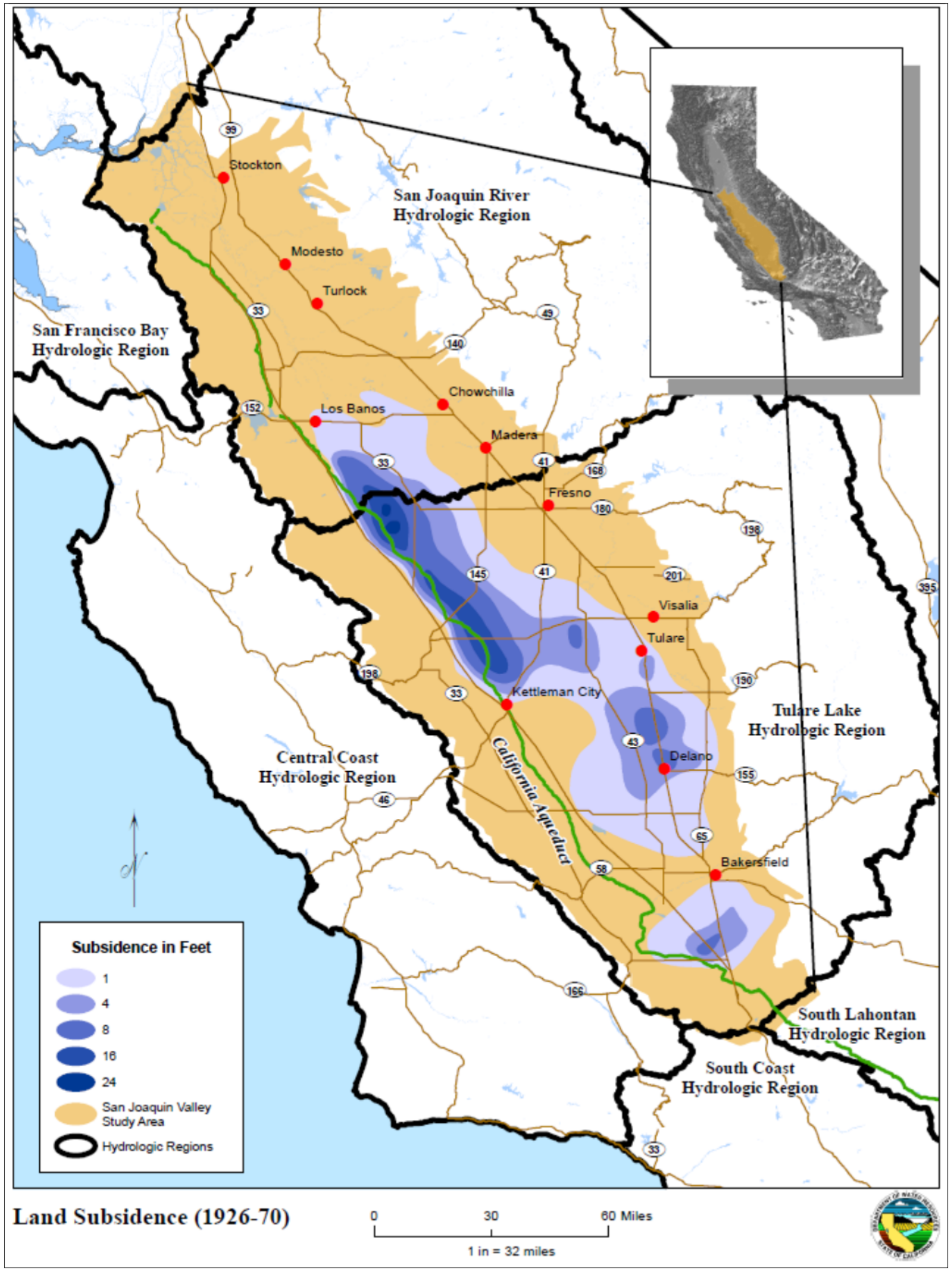


Figure TL-23 Depth to Groundwater Hydrograph and Vertical Land Surface Displacement at UNAVCO GPS Site 304, near the City of Madera



Source: USGS 2011 presentation on Central Valley subsidence. Land surface elevation data from UNAVCO Station 304; depth to water data provided by Luhdorff and Scalmanini Consulting Engineers

Figure TL-18 Land Subsidence in the San Joaquin Valley — 1926 to 1970
(Adapted from Ireland, 1984)



Groundwater Overdraft: Pumping more groundwater than the system can sustain

Potential consequences:

- Non-sustainable storage depletion
- Subsidence
- Surface water & ecosystem effects
- Increased energy costs
- Bad water intrusion from aquitards and from depth
- Basin salt imbalance
- Seawater intrusion

From Alley et al. (1999)

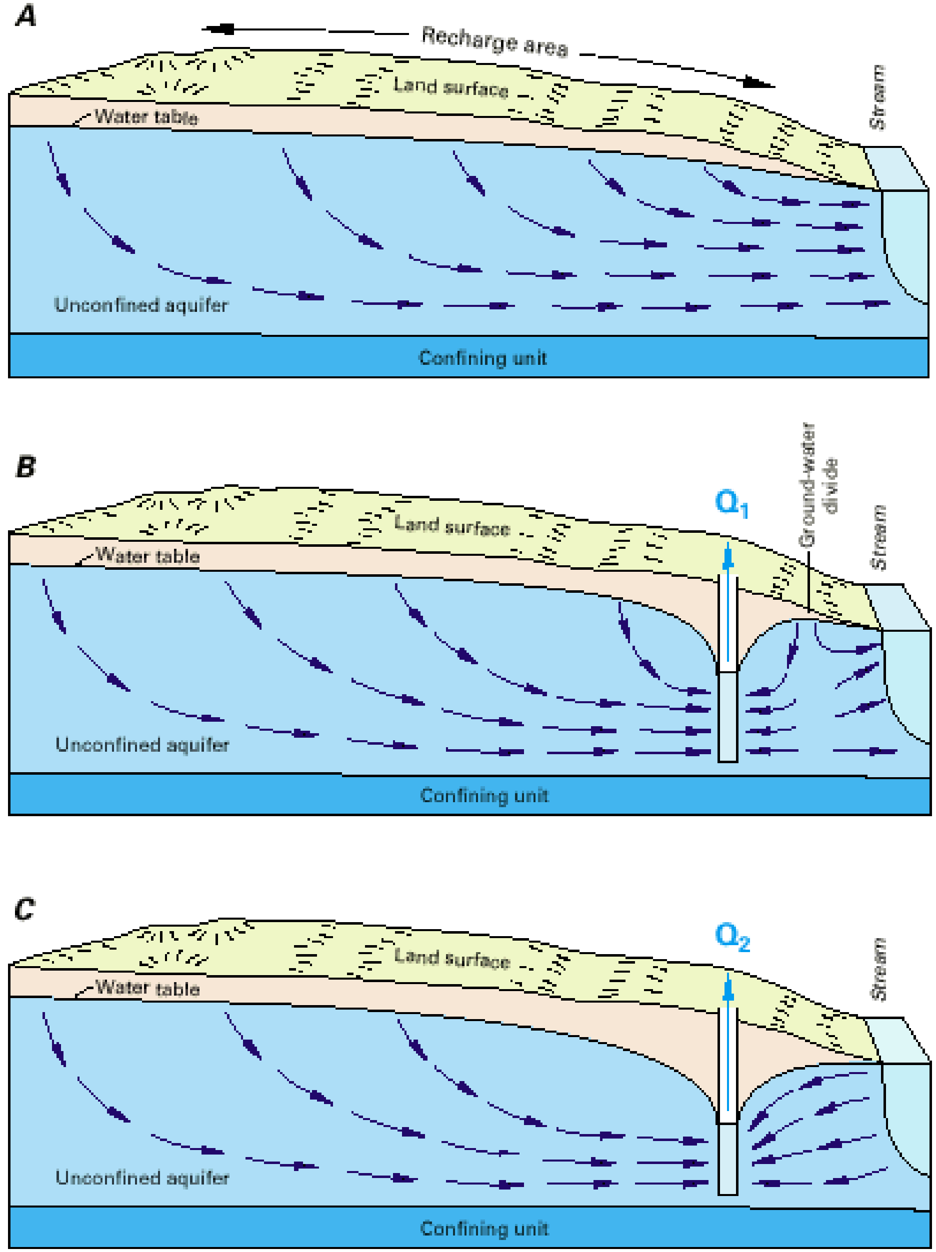
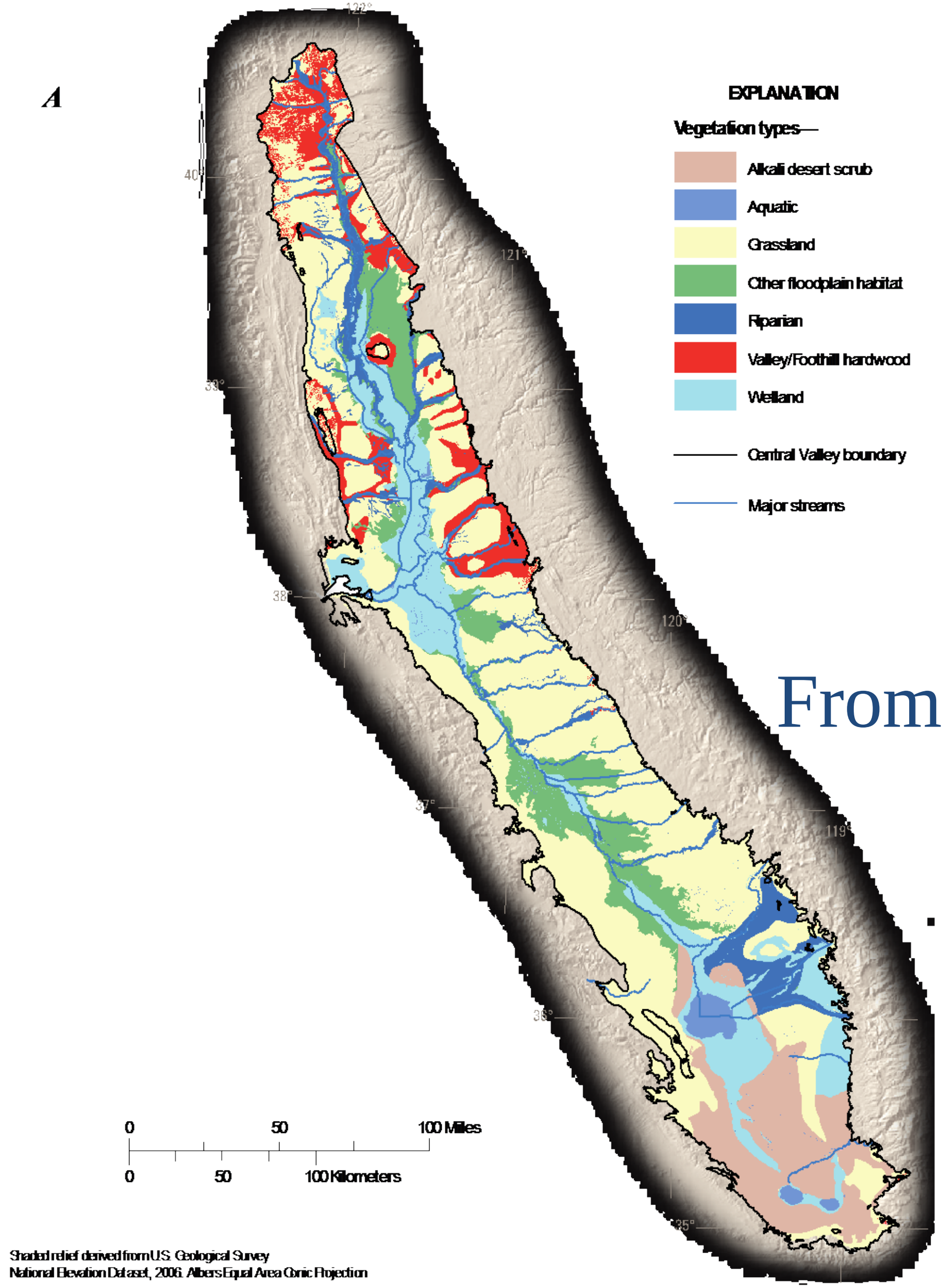


Figure 13. *Effects of pumping from a hypothetical ground-water system that discharges to a stream. (Modified from Heath, 1983.)*

Visualization of CA's Soggy Past

From http://www.geocurrents.info/geonotes/visualizing-californias-soggy-past



From Faunt (2009)

Figure A21. Distribution of *A*, Pre-1900 land-use patterns (modified from California State University, Chico, 2003), *B*, land-use patterns in 2000 (California Department of Water Resources, 2000) for the Central Valley, California.

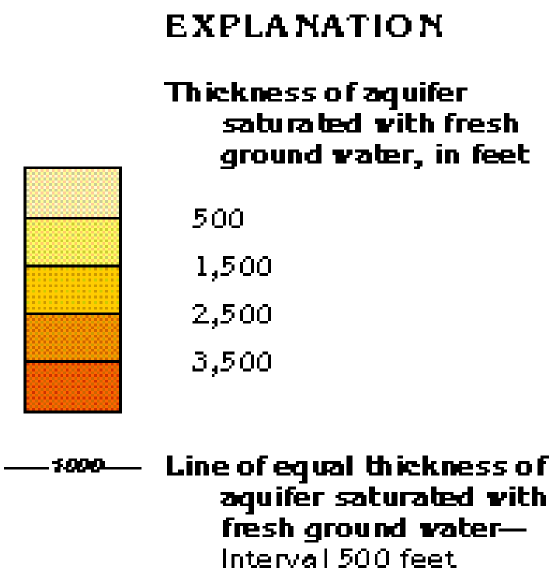
Groundwater Overdraft: Pumping more groundwater than the system can sustain

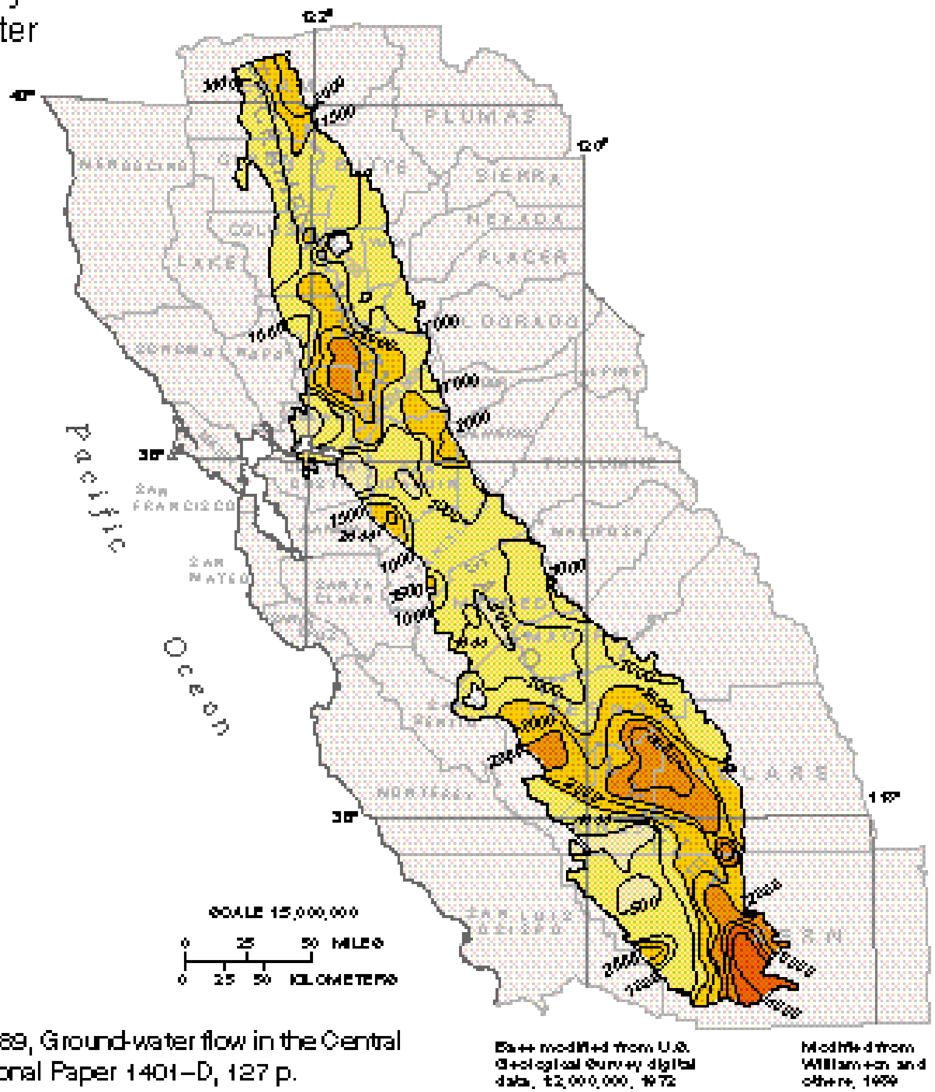
Potential consequences:

- Non-sustainable storage depletion
- Subsidence
- Surface water & ecosystem effects
- Increased energy costs
- Bad water intrusion from aquitards and from depth
- Basin salt imbalance
- Seawater intrusion

Potential for Water Quality Degradation from Below is Clear and Present, but Unaddressed

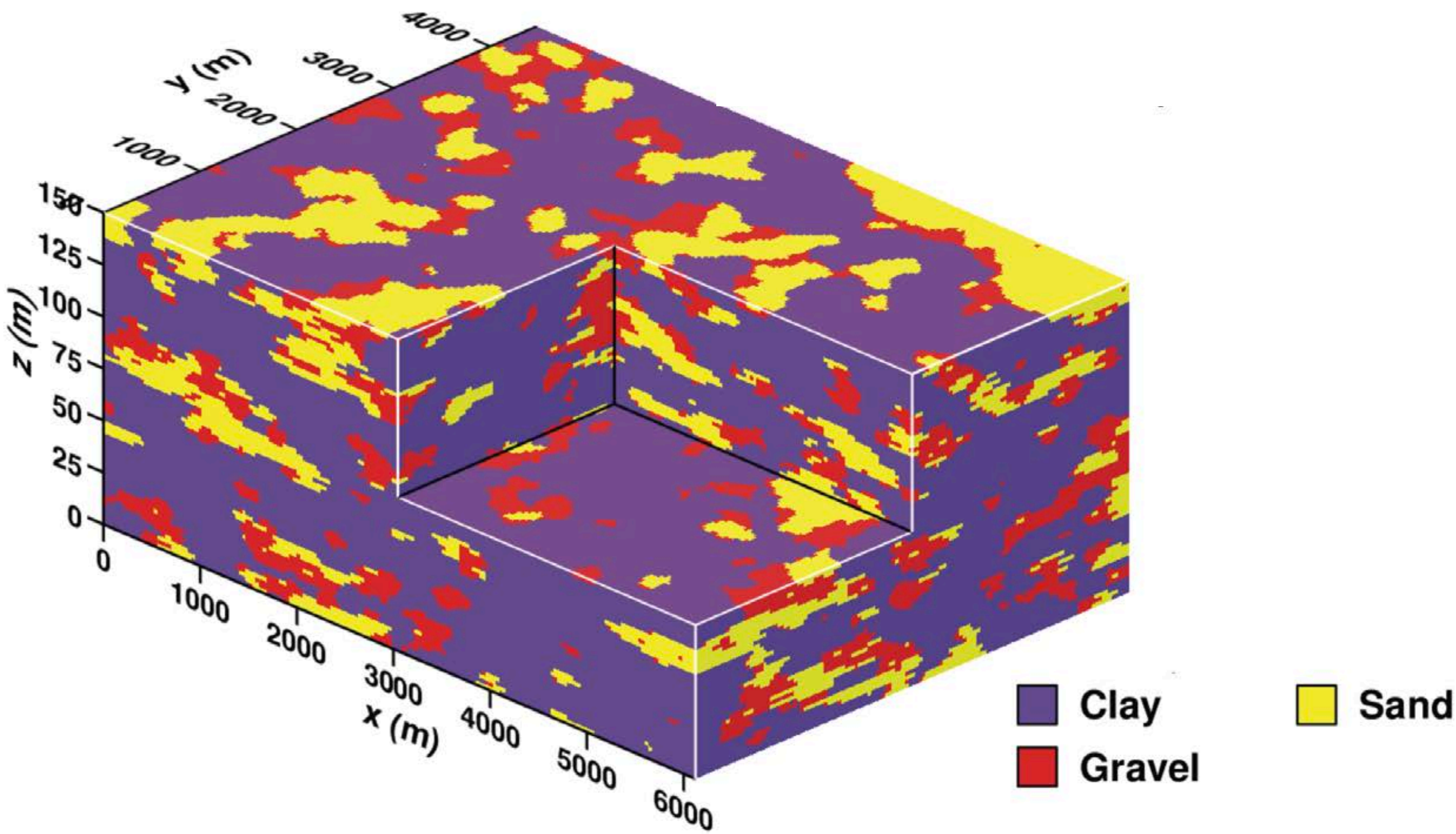
Figure 98. The thickness of the Central Valley aquifer system that is saturated with freshwater is greatest in the San Joaquin Valley, where freshwater extends to a depth of more than 4,000 feet below land surface.





Williamson, A.K., Prudic, D.E., and Swain, L.A., 1989, Ground-water flow in the Central Valley, California: U.S. Geological Survey Professional Paper 1401–D, 127 p.

Woodland Area Aquifer System Network (Stephen Maples, HYD 273)



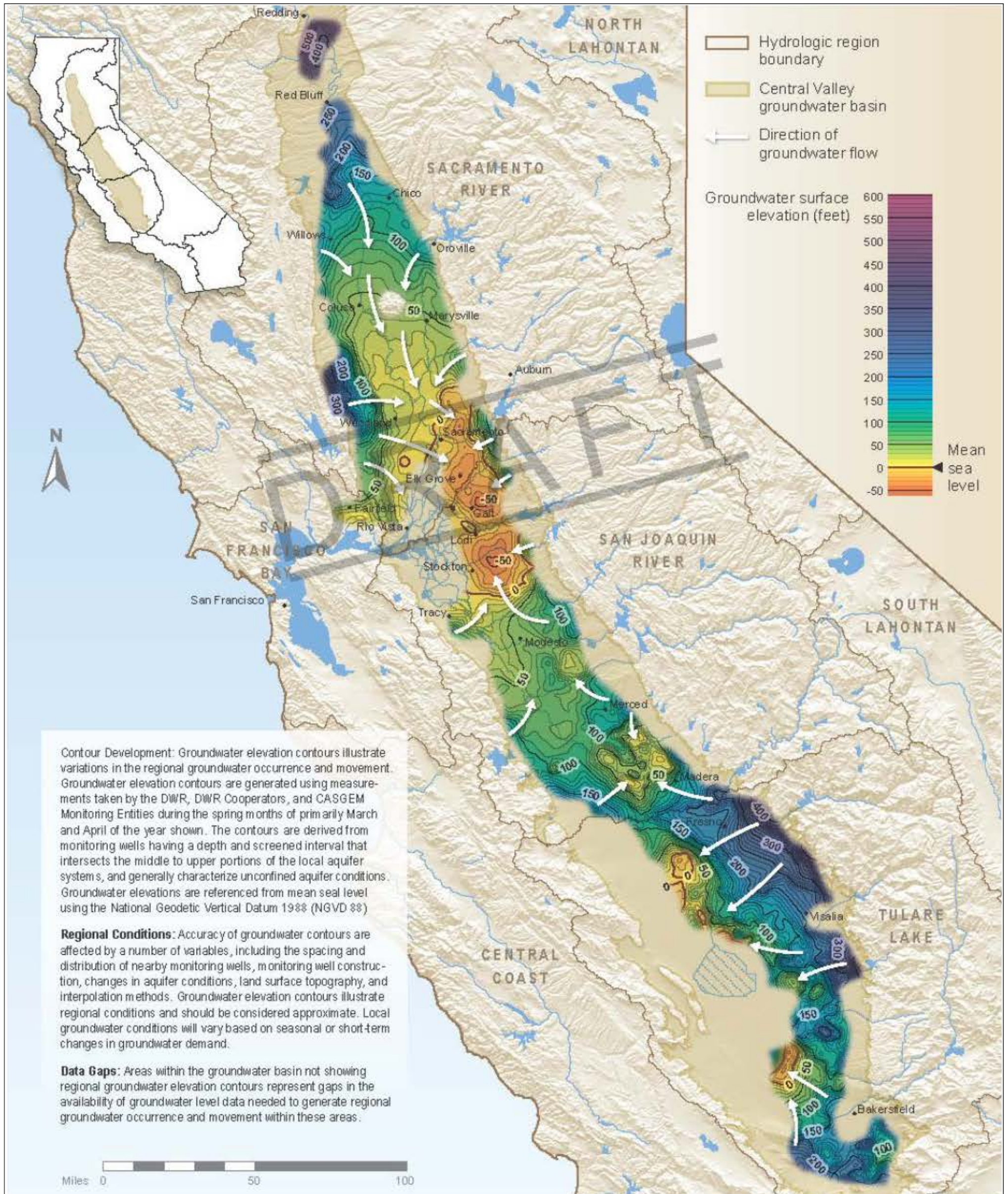
Groundwater Overdraft: Pumping more groundwater than the system can sustain

Potential consequences:

- Non-sustainable storage depletion
- Subsidence
- Surface water & ecosystem effects
- Increased energy costs
- Bad water intrusion from aquitards and from depth
- Basin salt imbalance
- Seawater intrusion

Figure TL-26 Spring 2010 Groundwater Elevation Contours for the Tulare Lake Hydrologic Region

[This figure is for the Central Valley; it will be updated with figure for the Tulare Lake Hydrologic Region]



Source: Department of Water Resources, CWP 2013

The danger of a hydrologic basin losing its outlet….

San Joaquin Valley Groundwater (from Faunt, 2009)

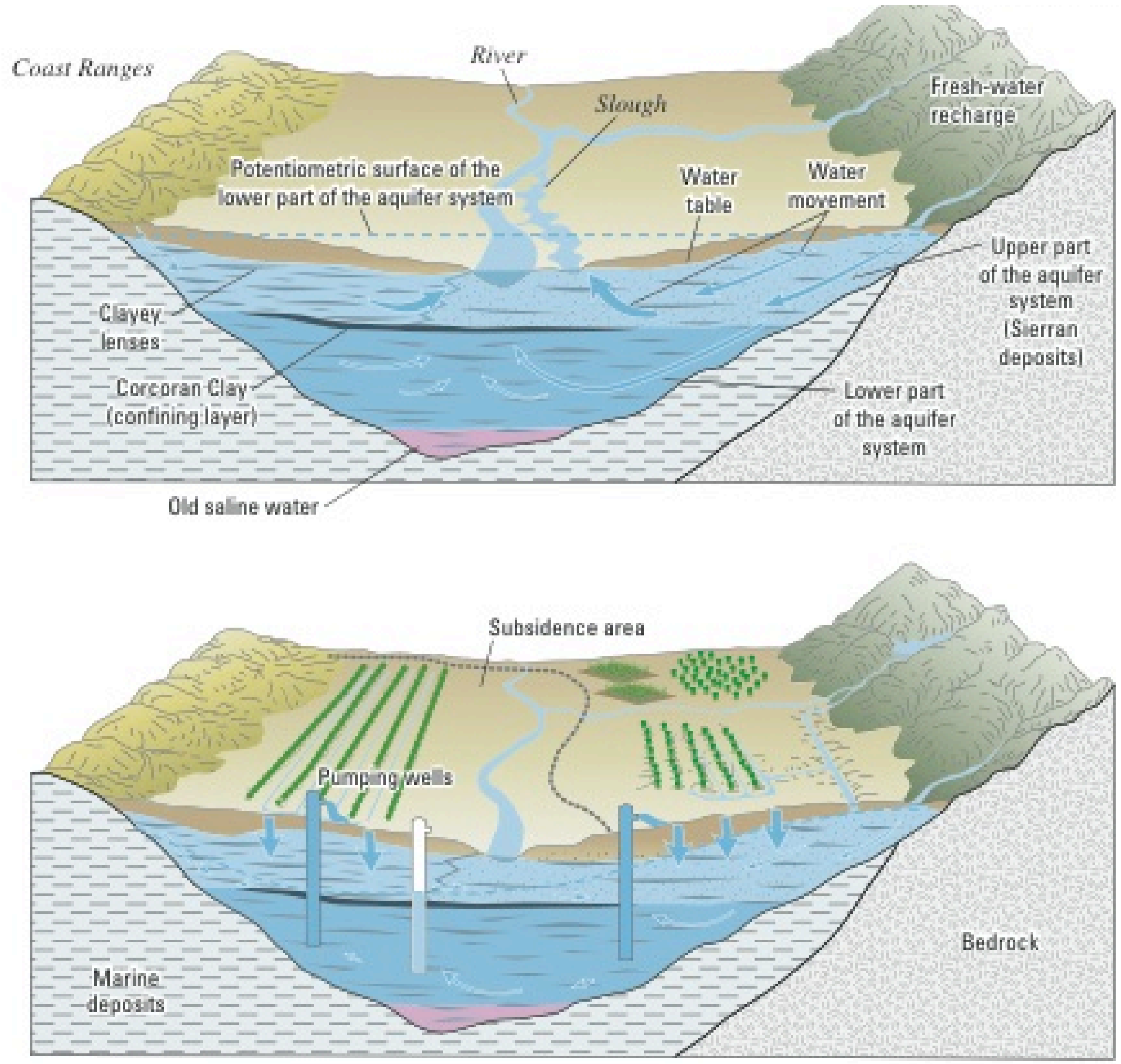


Figure A9. Continued.

Pre-Development

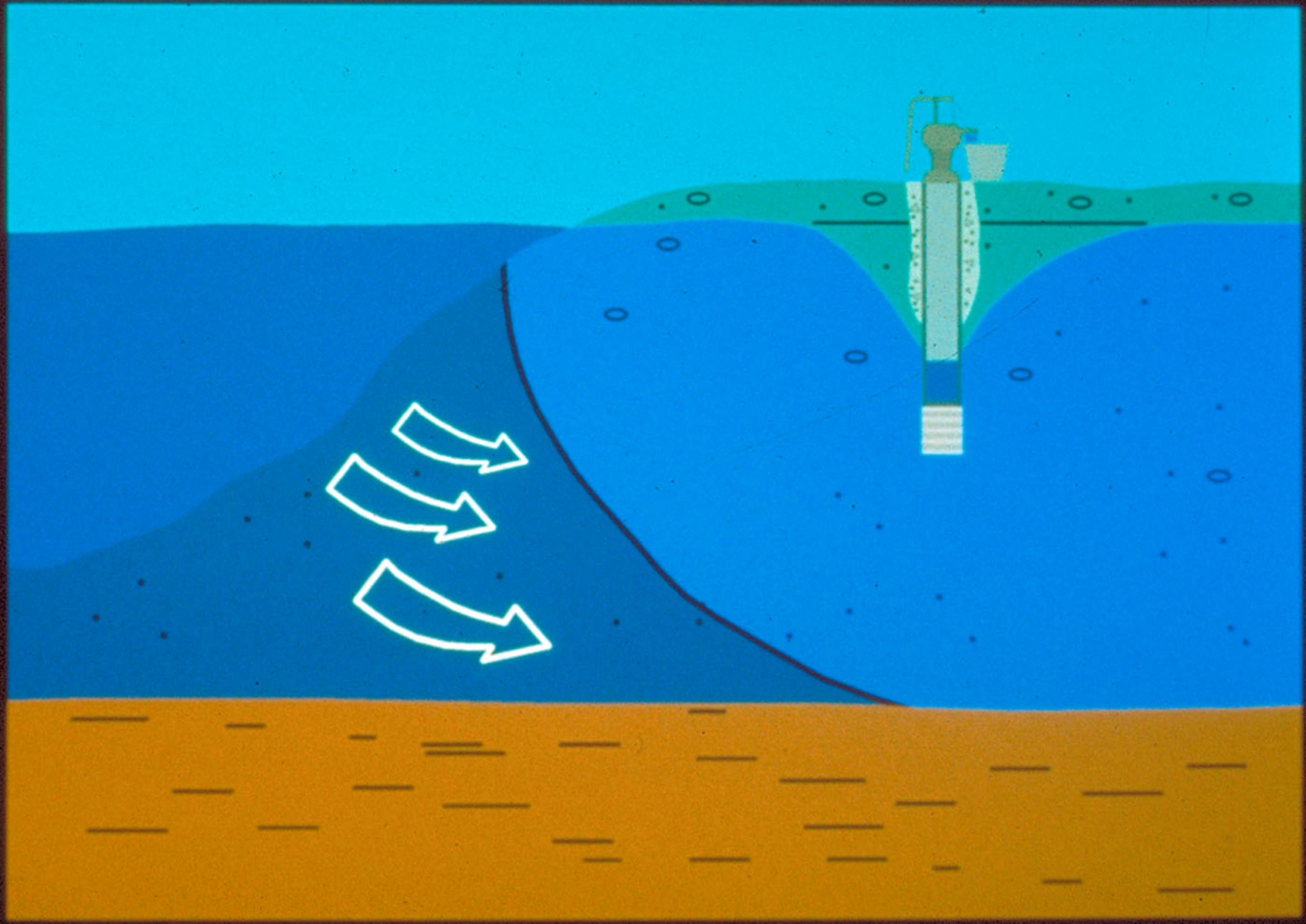
Post-Development

Groundwater Overdraft: Pumping more groundwater than the system can sustain

Potential consequences:

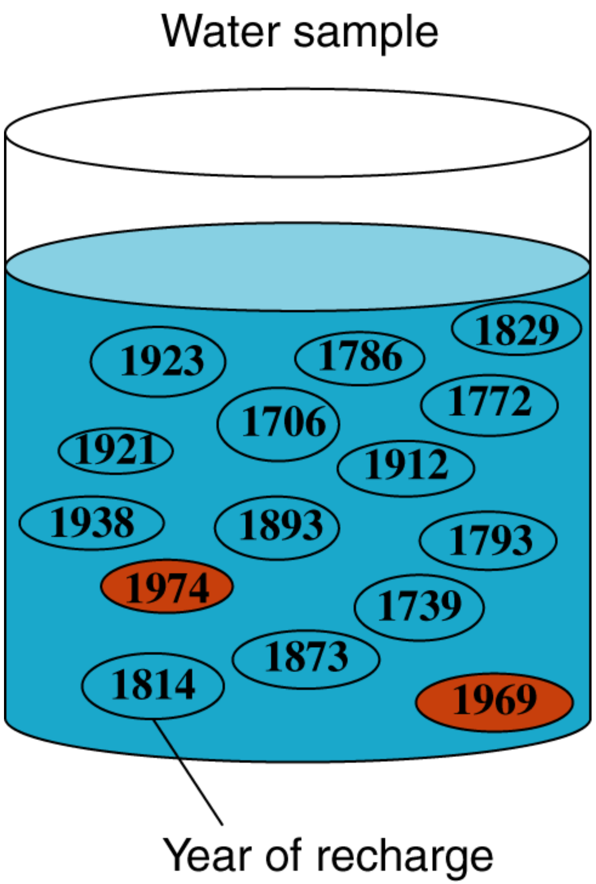
- Non-sustainable storage depletion
- Subsidence
- Surface water & ecosystem effects
- Increased energy costs
- Bad water intrusion from aquitards and from depth
- Basin salt imbalance
- Seawater intrusion

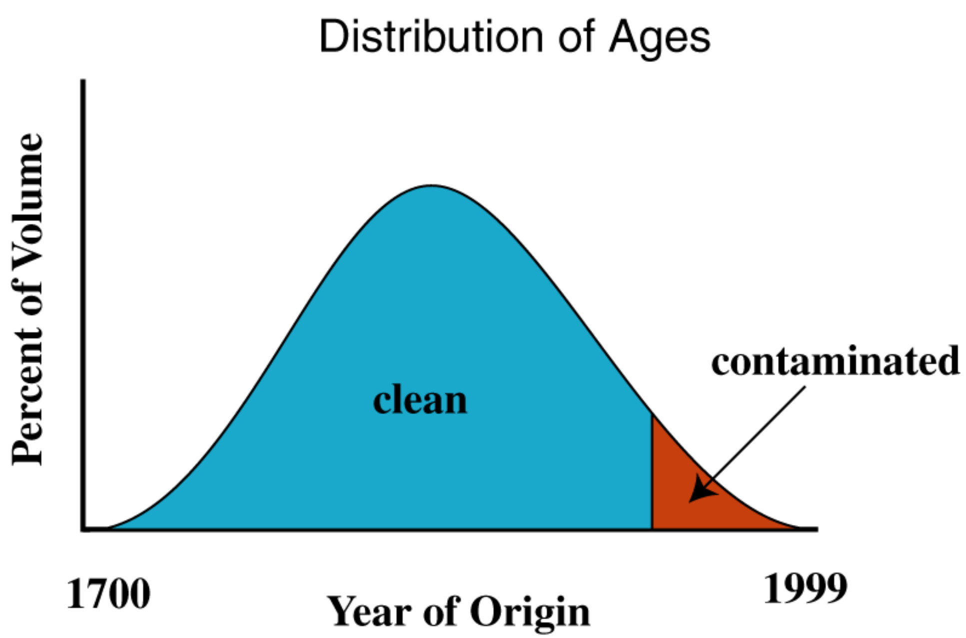
Salt Water Intrusion



Groundwater Quality is Degrading in Many Systems, But Most of the Groundwater Quality is Still Good

Age Distribution & Sustainability: Groundwater Ages are Highly Mixed!





This means that if we see contamination in the groundwater today, and if that contamination is from a persistent, non-point source, we can expect decades to centuries of worsening groundwater quality.

Groundwater quality sustainability is one of the major scientific and societal issues of our time...

- Most fresh groundwater resources are 10^2 - 10^3 yr old, yet most anthropogenic contaminants <50-60 yr old.
  - Especially in western alluvial basins, Gulf Coast, Atlantic coastal plain, etc.
  - Not so much in shallow, glacio-fluvial outwash, moist climates?
- Groundwater ages (even from short screens) are generally highly mixed.
  - Molecular ages typically range greatly (e.g., 10^1 - 10^2 or 10^3 yr) within a single sample (Fogg et al., 1999; Tompson et al., 1999; Weissmann et al., 2002; Bethke & Johnson, 2002).
  - In other words, in many systems there is significant potential for water quality to get much worse over the coming decades to centuries, depending on contaminant sources.

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WATER RESOURCES RESEARCH, VOL. 42, W03S05, doi:10.1029/2005WR004372, 2006

Motivation of synthesis, with an example on groundwater quality sustainability

Graham E. Fogg[1,2,3] and Eric M. LaBolle[1,2]

Received 29 June 2005; revised 20 October 2005; accepted 7 November 2005; published 14 March 2006.

[1] Synthesis of ideas and theories from disparate disciplines is necessary for addressing the major problems faced by society. The best motivation for broad, effective synthesis is the "big idea" that is sufficiently important and inspiring to marshal the appropriate collaborative efforts. Groundwater quality sustainability is posed as an example of one such idea that would potentially unify research efforts in both the sciences and social sciences toward a common, pressing objective.

Citation: Fogg, G. E., and E. M. LaBolle (2006), Motivation of synthesis, with an example on groundwater quality sustainability, *Water Resour. Res.*, *42*, W03S05, doi:10.1029/2005WR004372.

SBX2 1 (2008, Perata)

UC Davis Report to State Water Board
for its Report to the Legislature

NITRATE SOURCES, GROUNDWATER QUALITY, AND DRINKING WATER IN THE TULARE LAKE BASIN

USDA National Water Meeting

May 23, 2012

Presented by Doug Parker, Univ of California

Thomas Harter & Jay Lund, *Principal Investigators*

Jeannie Darby, Graham Fogg, Richard Howitt, Katrina Jessoe, Jim Quinn, Stu Pettygrove, Joshua Viers, *Co-Investigators*

Aaron King, Allan Hollander, Alison McNally, Anna Fryjoff-Hung, Cathryn Lawrence, Daniel Liptzin, Danielle Dolan, Dylan Boyle, Elena Lopez, Giorgos Kourakos, Holly Canada, Josue Medellin-Azuara, Kristin Dzurella, Kristin Honeycutt, Megan Mayzelle, Mimi Jenkins, Nicole de la Mora, Todd Rosenstock, Vivian Jensen, *Researchers*

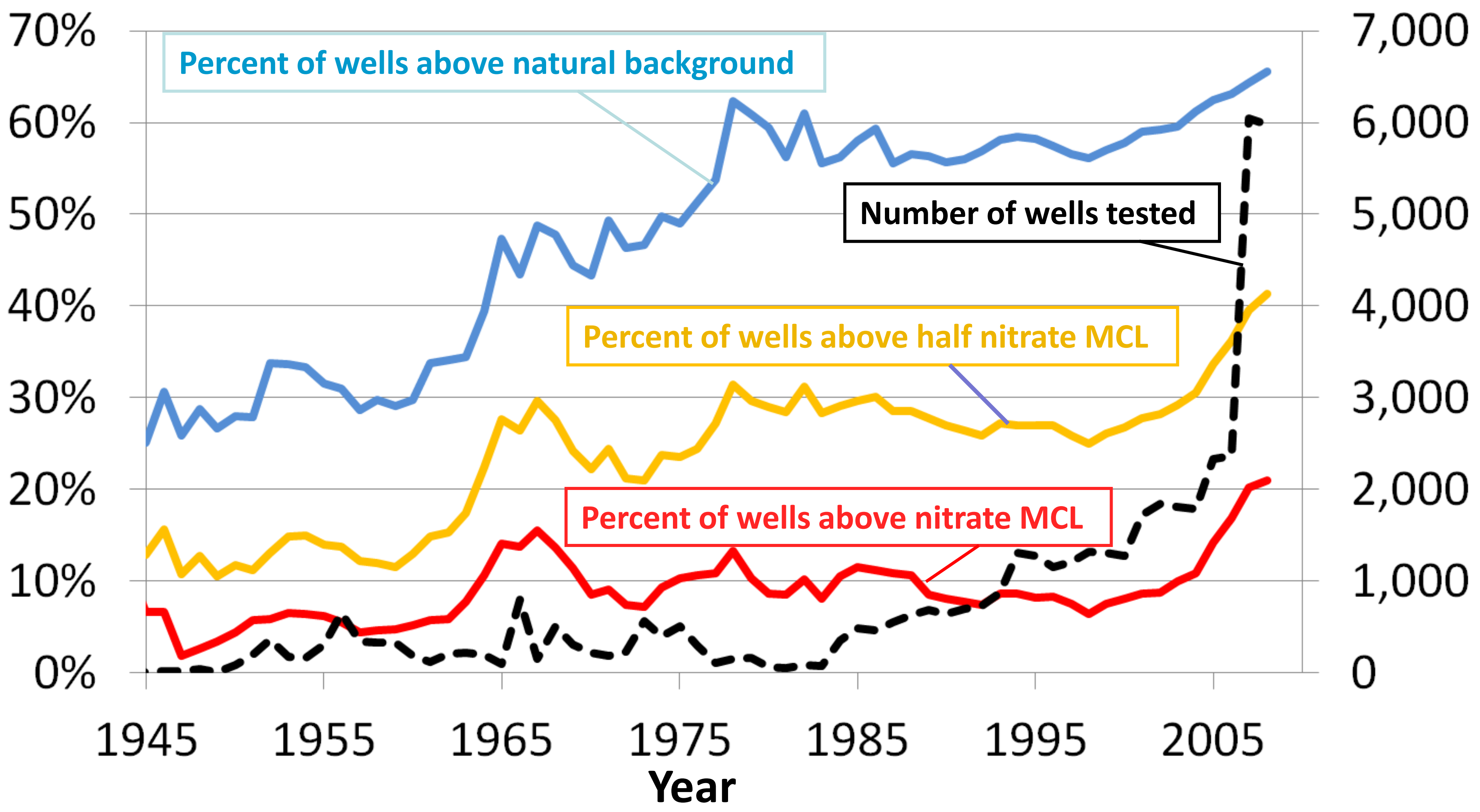
http://groundwaternitrate.ucdavis.edu

Watershed Science Center

University of California, Davis

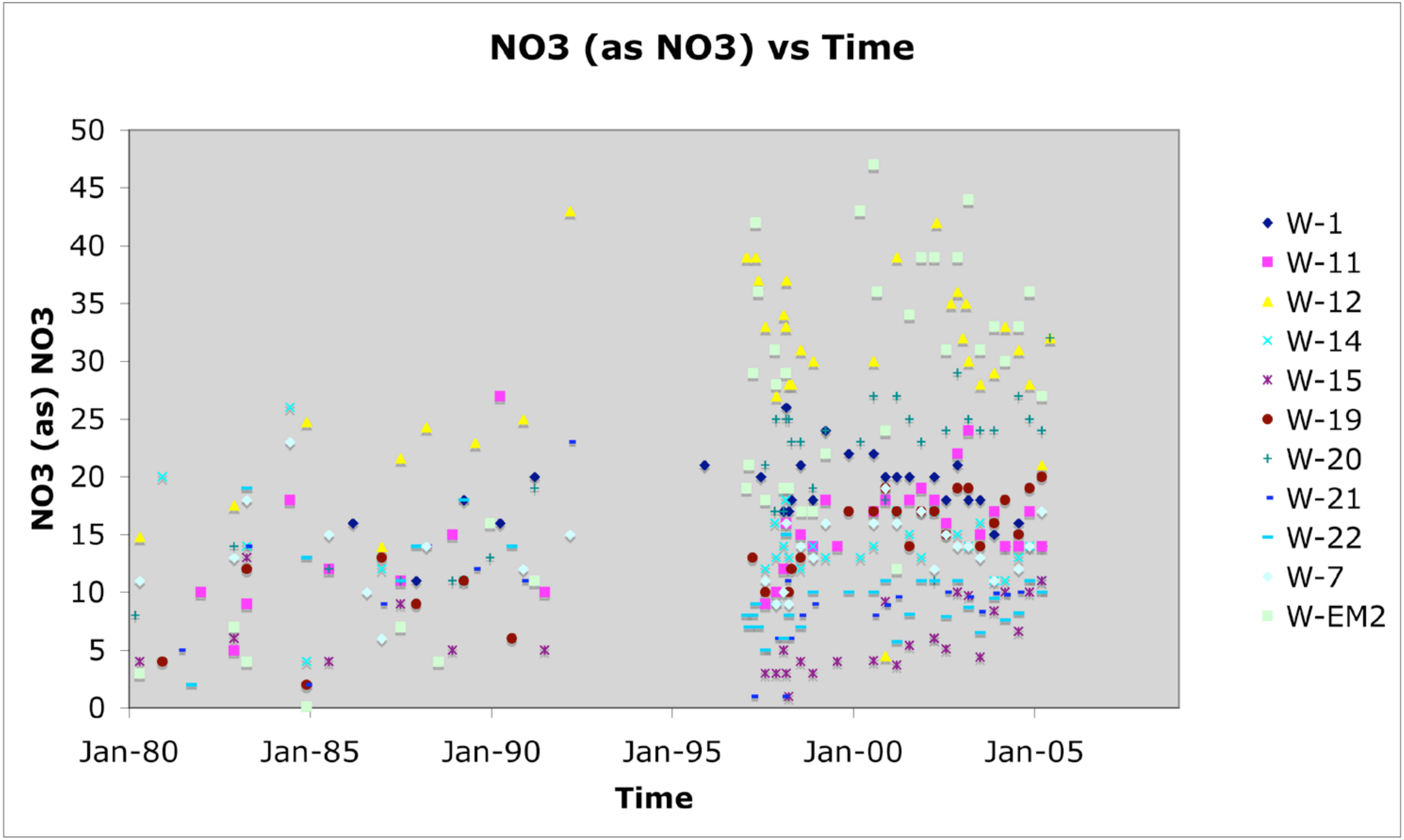
Contact: ThHarter@ucdavis.edu

Historic Nitrate Trends, TLB: Exceedance Rate

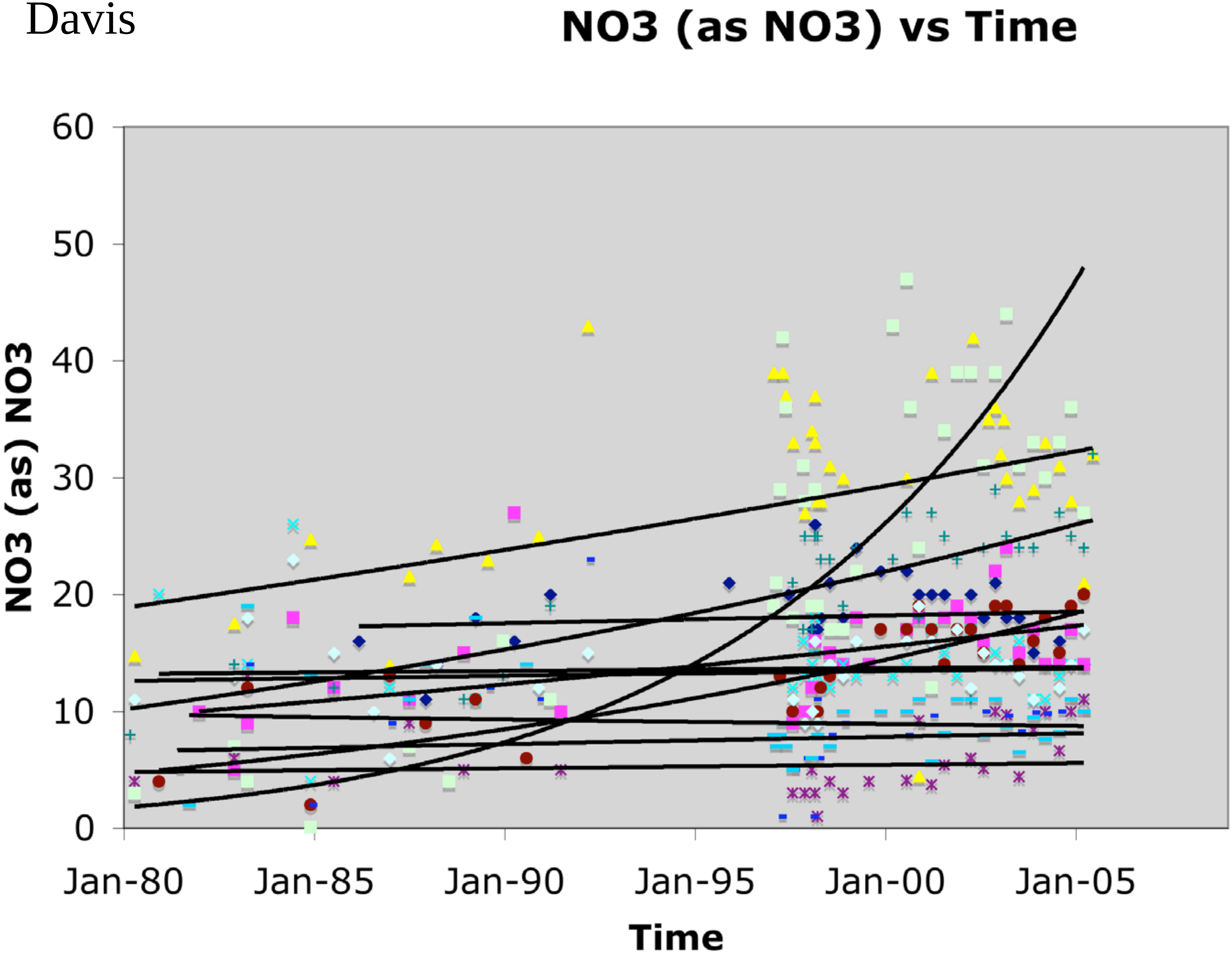


A Look at Davis, CA

City of Davis, CA Well Data, <135 m Depth

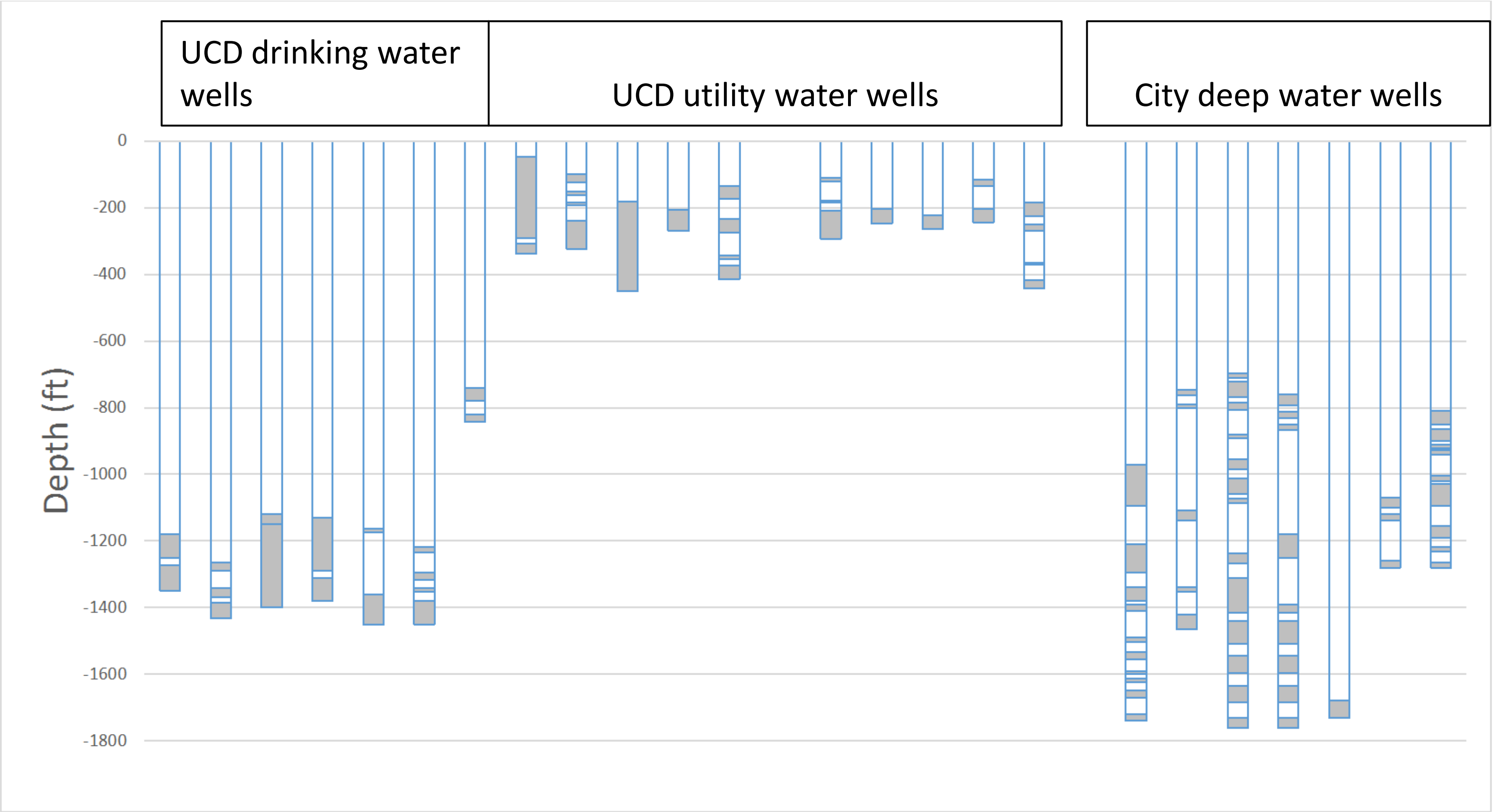


Davis



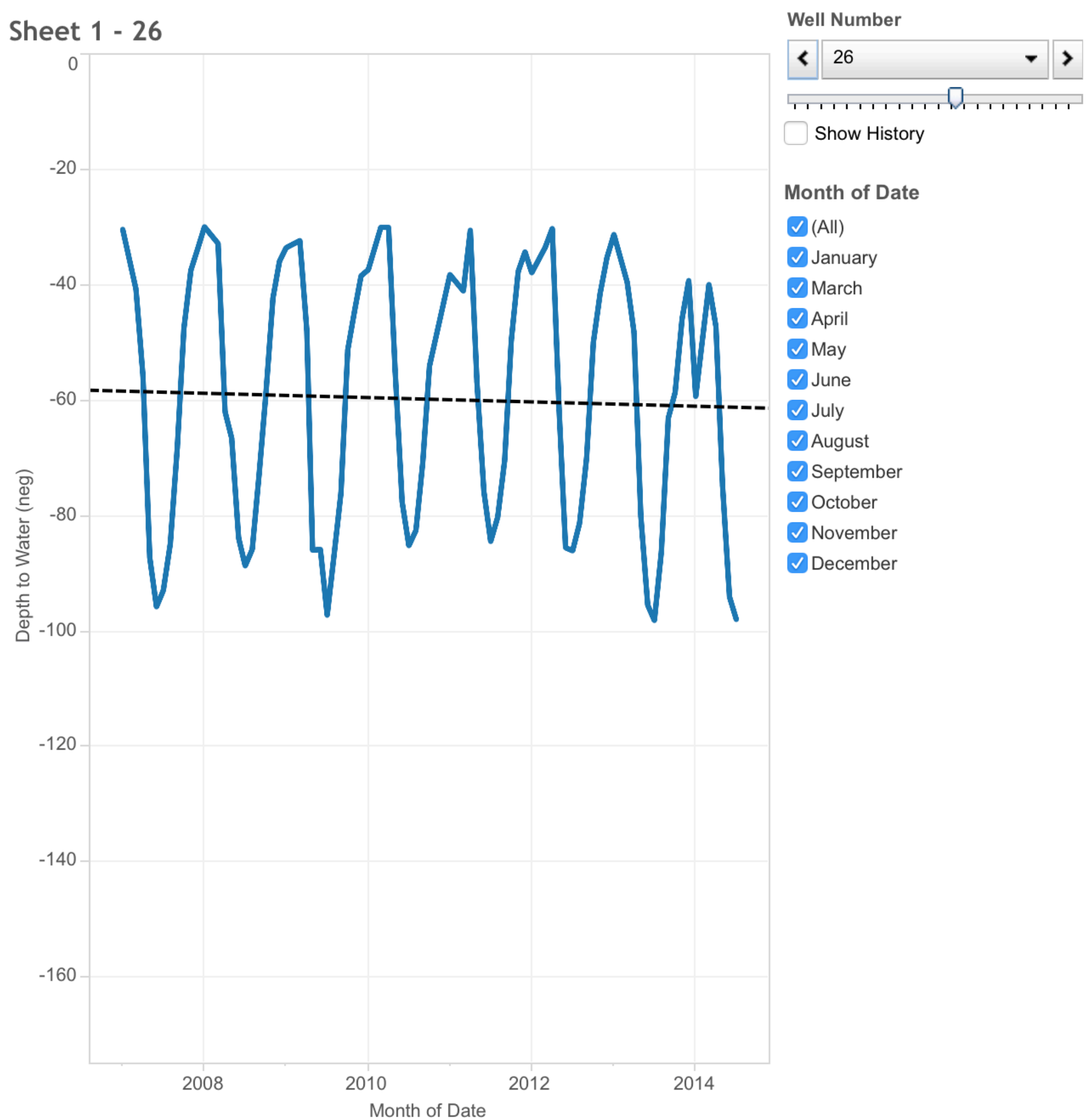
NO3 (as NO3) vs Time
60
50
40
30
20
10
0
NO3 (as) NO3
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Time

UCD and City of Davis Well Screened Intervals



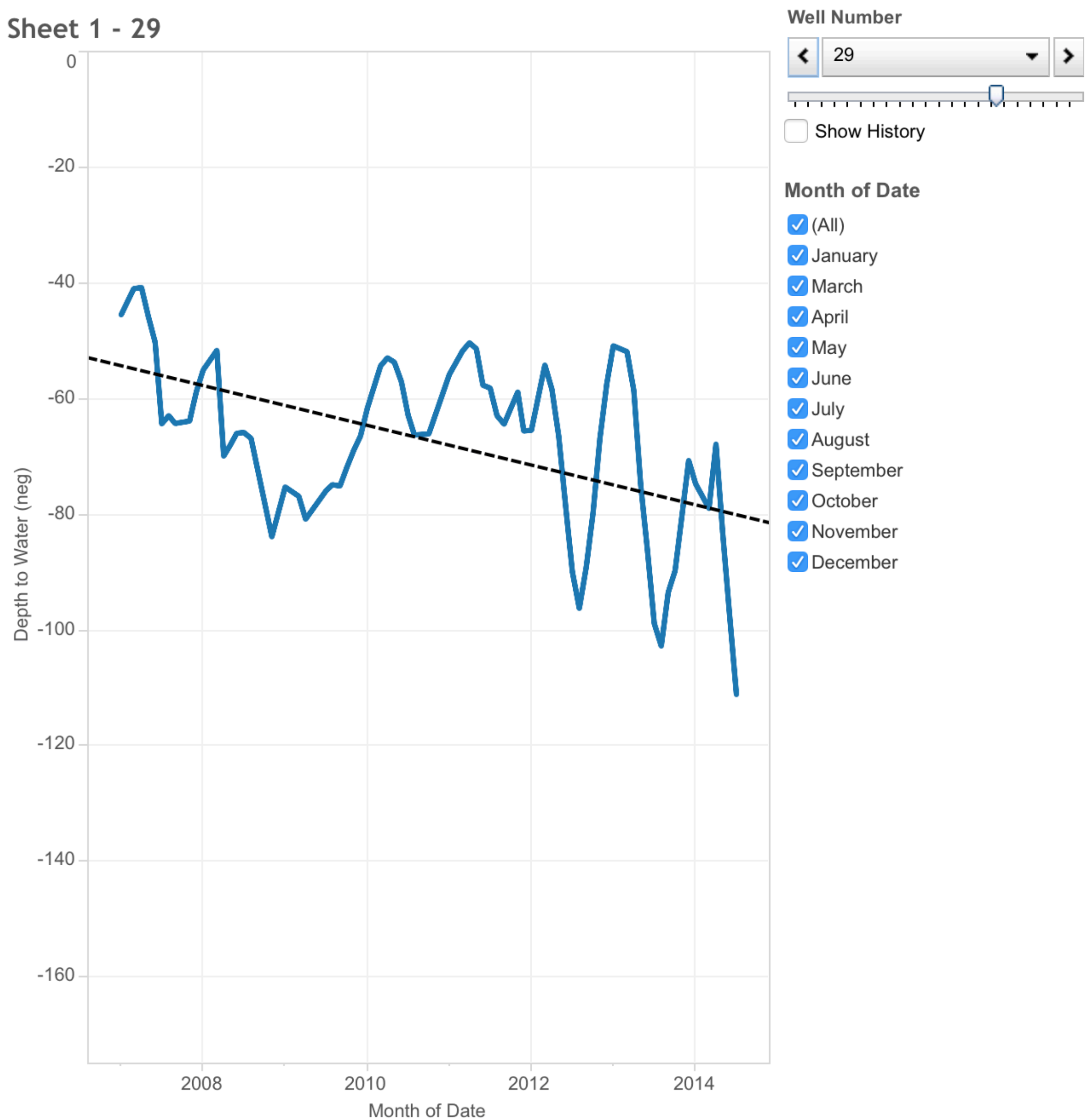
City of Davis Groundwater Levels, Intermediate-Depth Aquifer

Online plots from Elizabeth Case

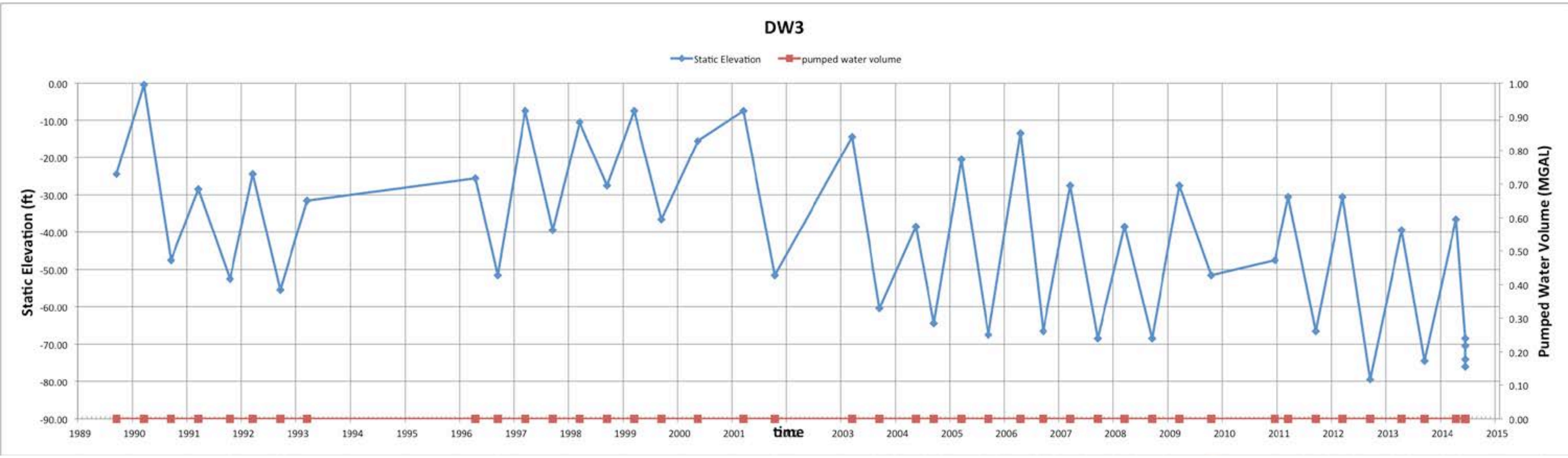


City of Davis Groundwater Levels, Deep Aquifer

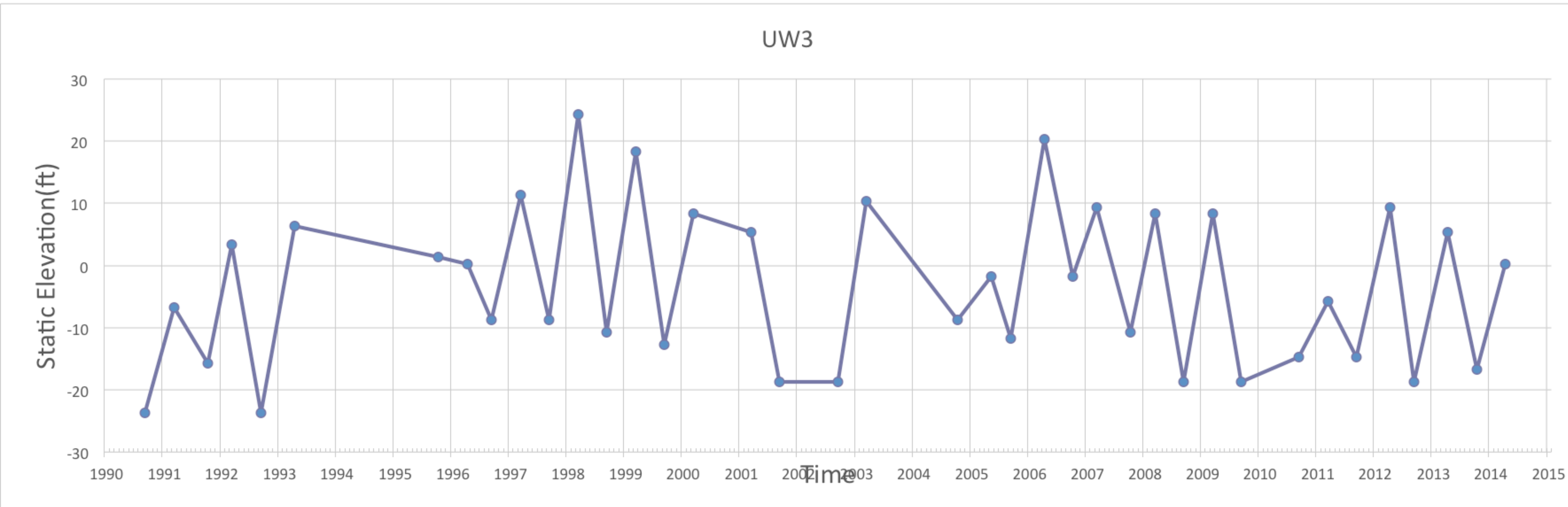
[Online plots from Elizabeth Case]



Trend in UCD Drinking Water Wells (Deep Aquifer)



Trend in UCD Utility (landscape and ?) Wells (Intermediate-depth Aquifer)



Case Study: Coachella Valley Groundwater Systems: Work with Harvey O. Banks during 1987-96

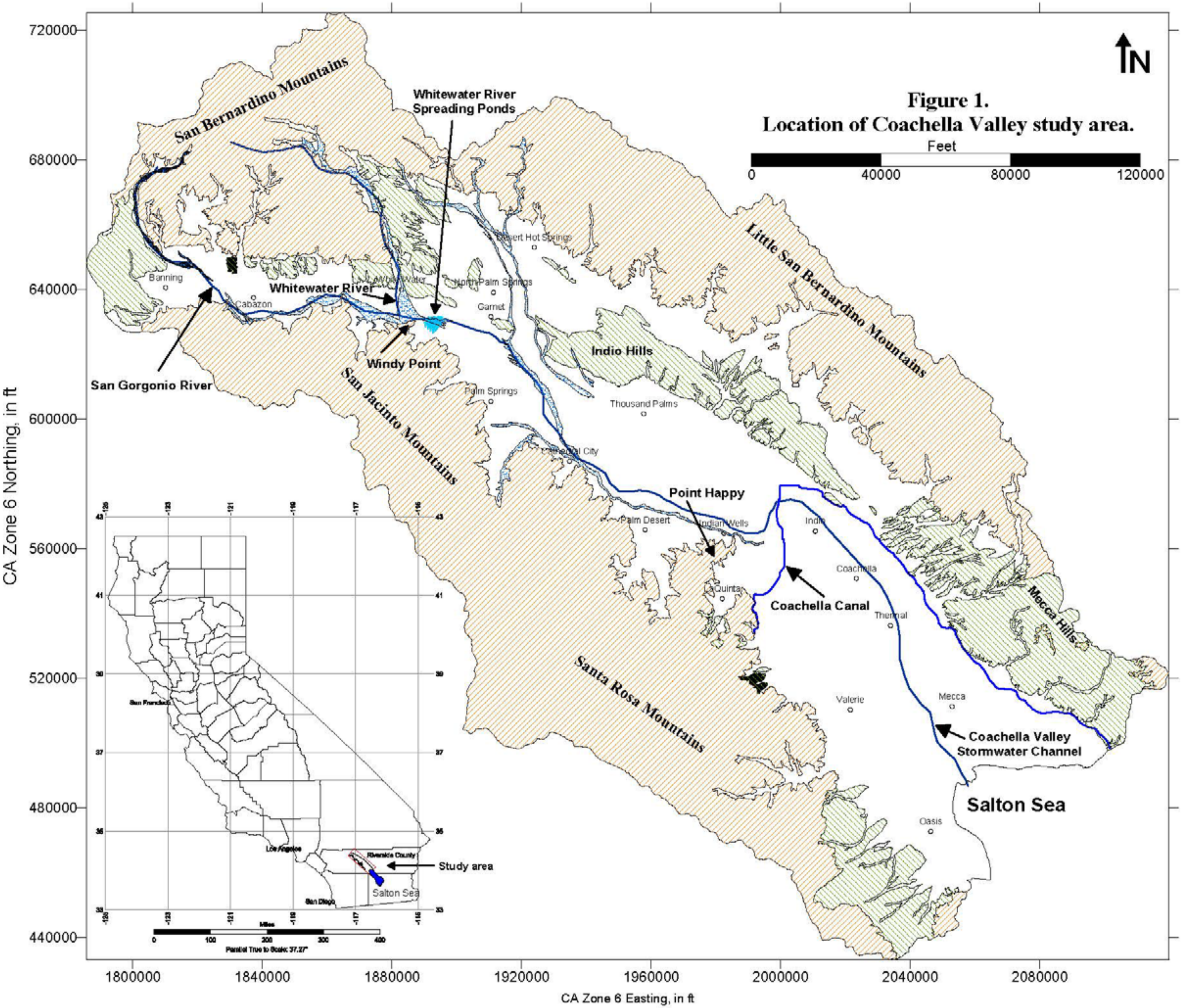


Figure 1.
Location of Coachella Valley study area.

Figure 12.
Hydrograph of lower valley well 06S07E22B01S.

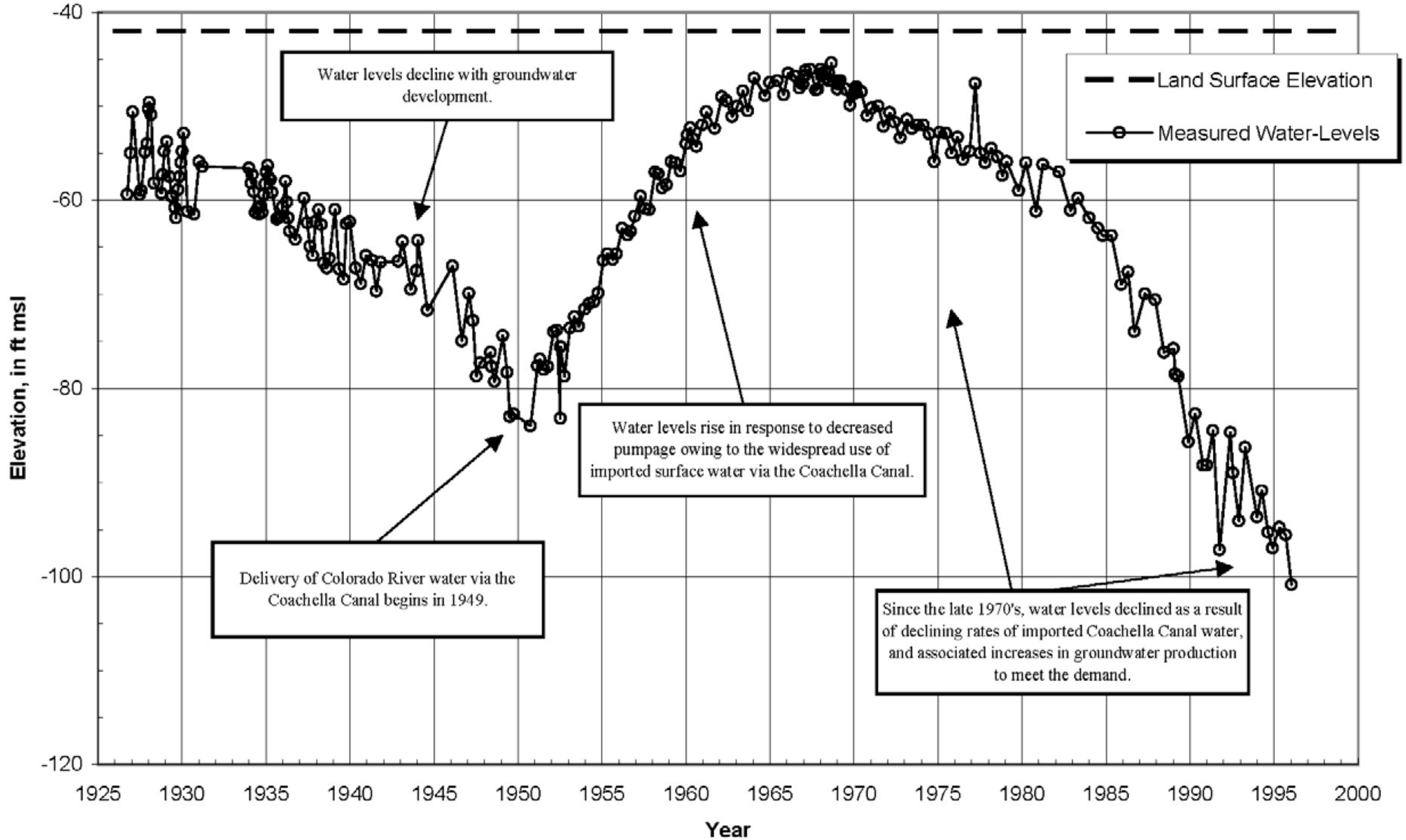


Figure 13.
Total farm acreage served by drains.

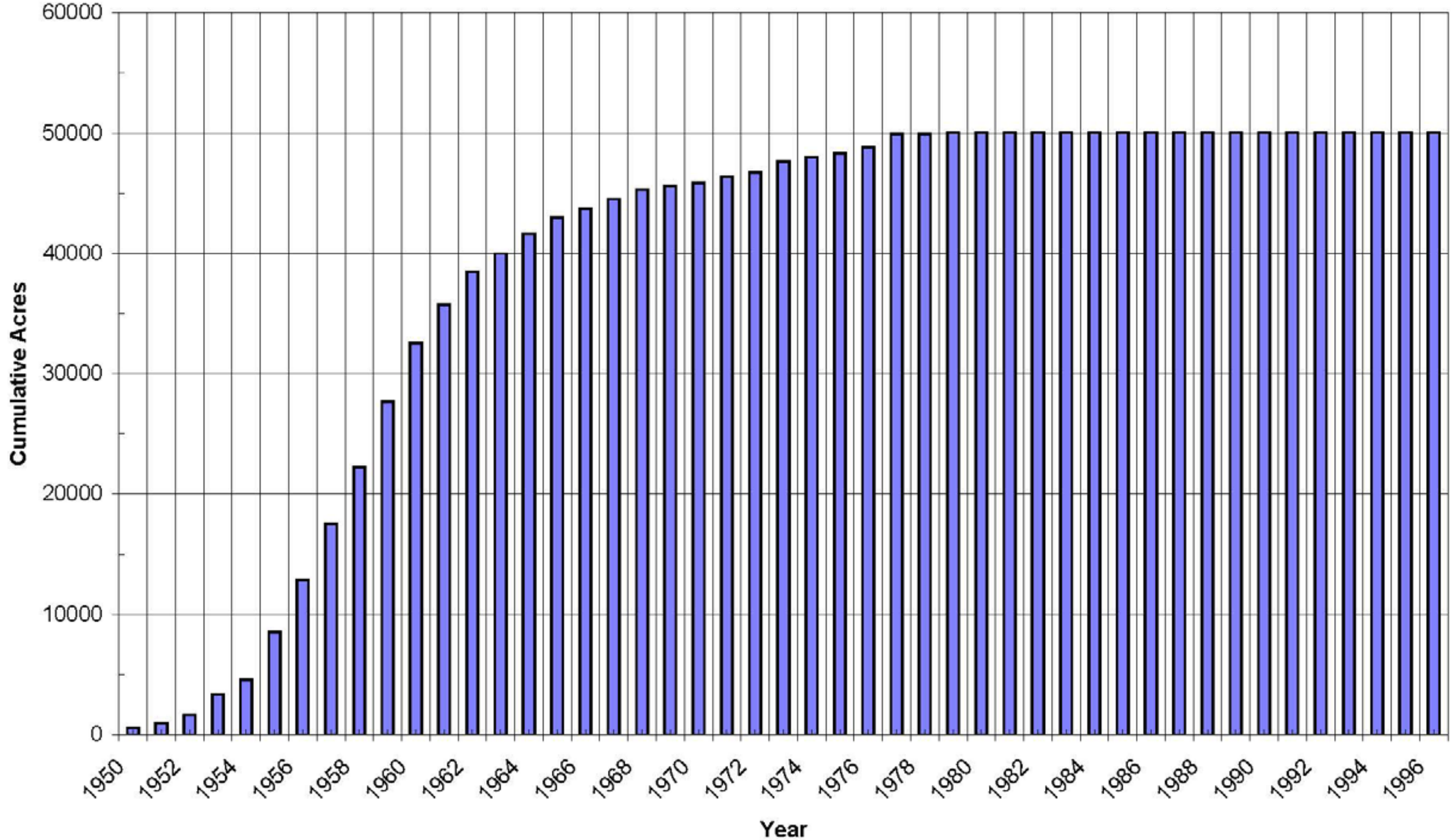


Figure 14.
Total annual agricultural drain flows.

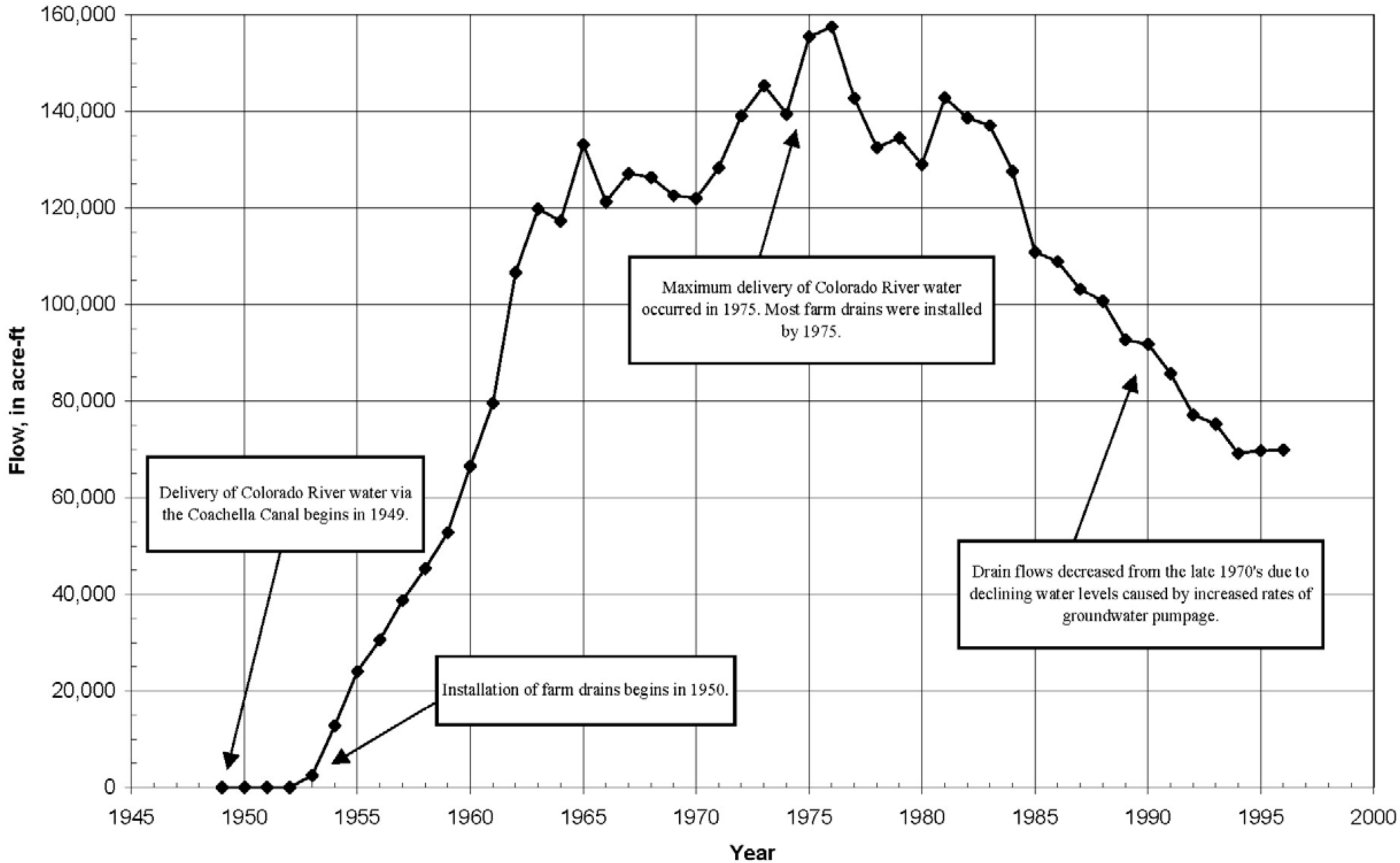


Figure 16.
Hydrograph of Upper Valley well 04S04E15J01S.

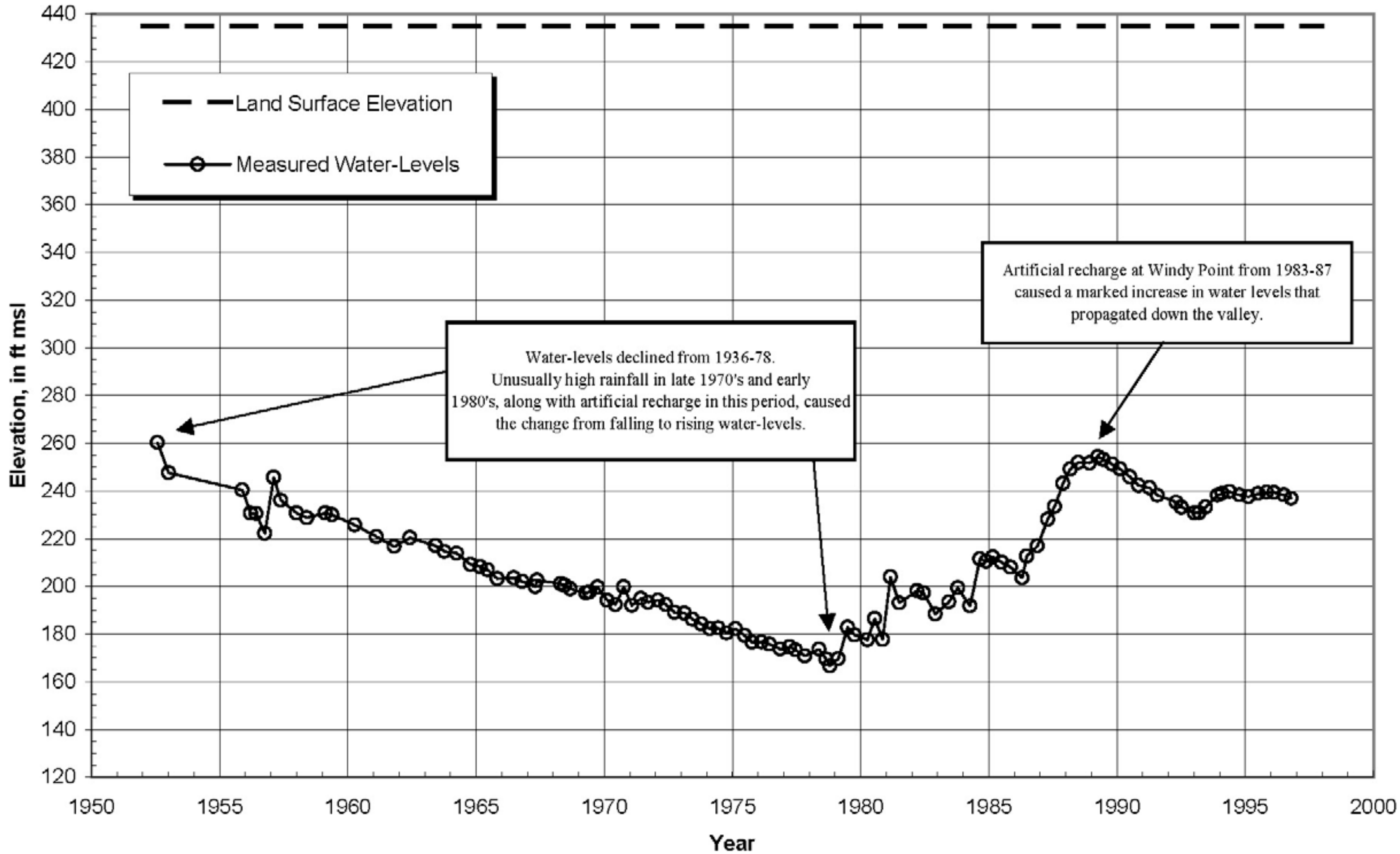


Figure 24.
Measured and simulated groundwater levels in selected wells.

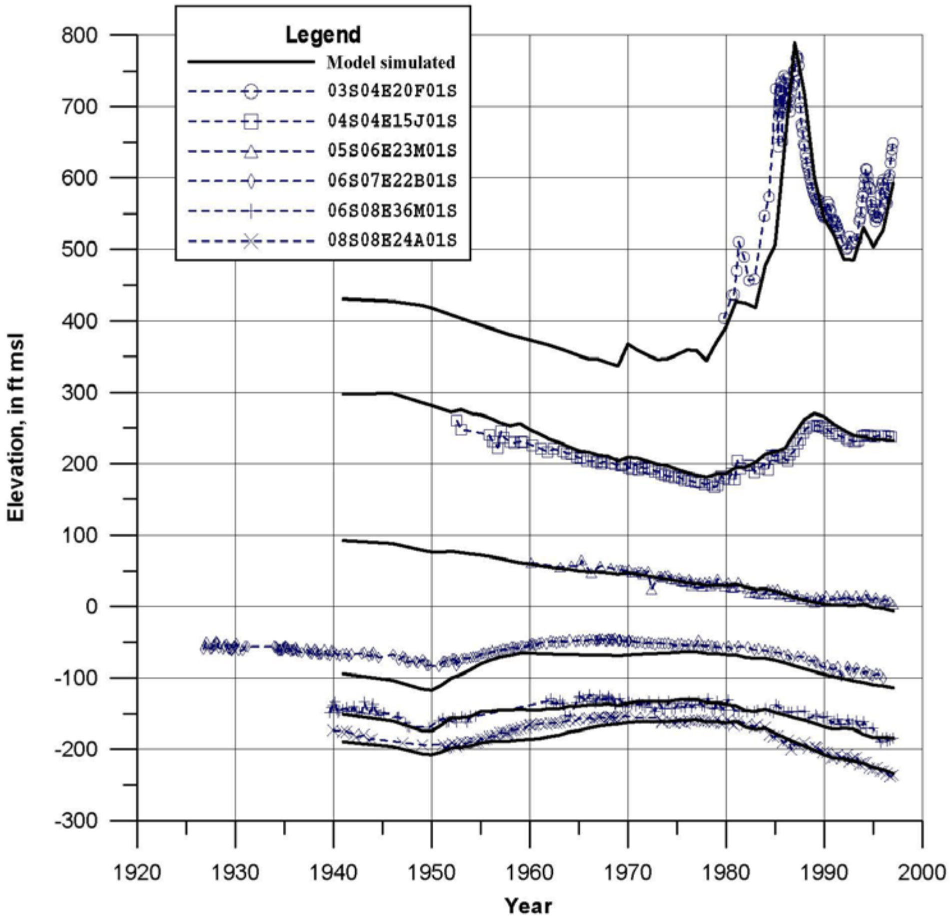
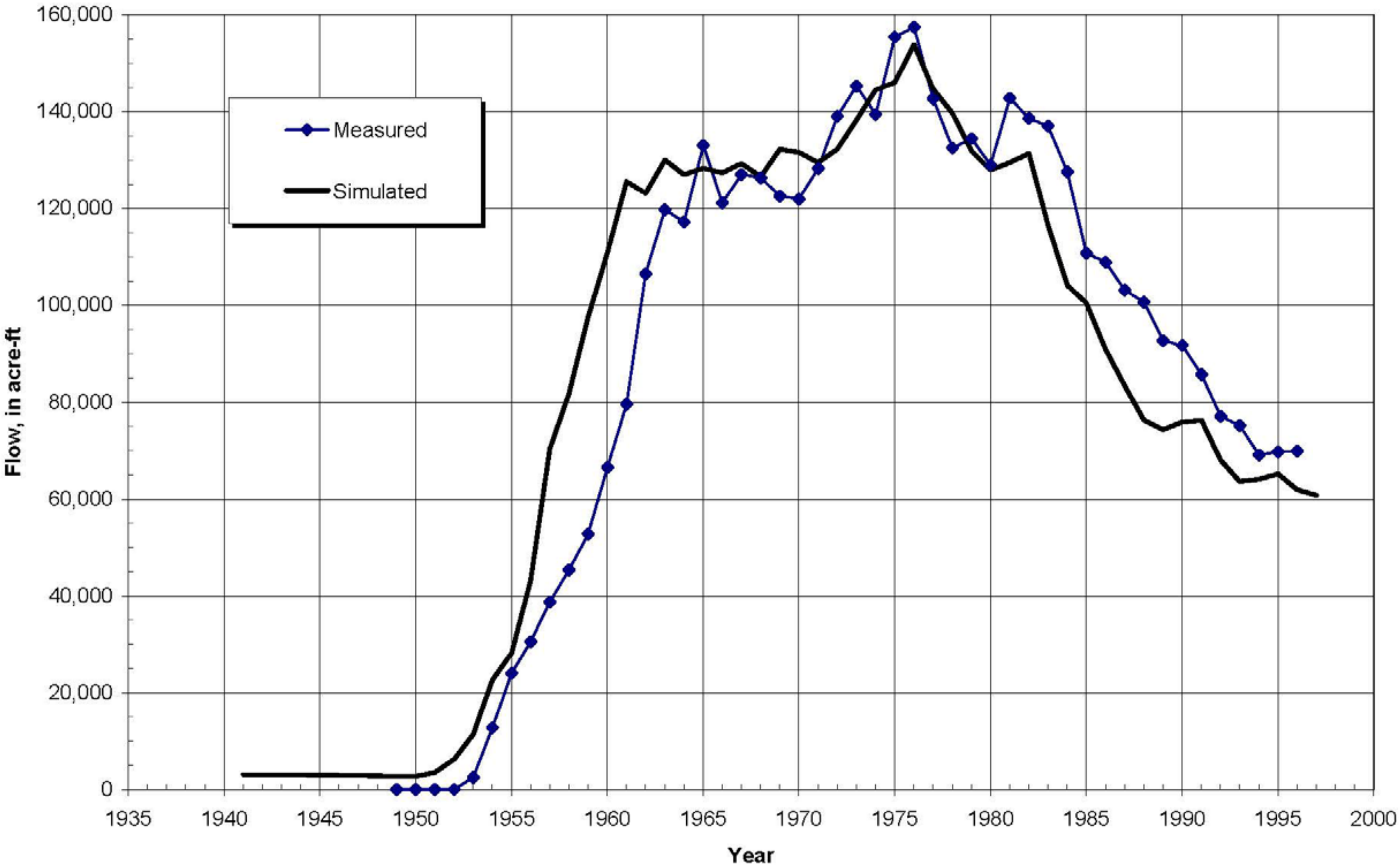


Figure 32.
Measured and simulated agricultural drain flows.



Overview of Orange County Water District's Managed Aquifer Recharge System

Recharge System Tour

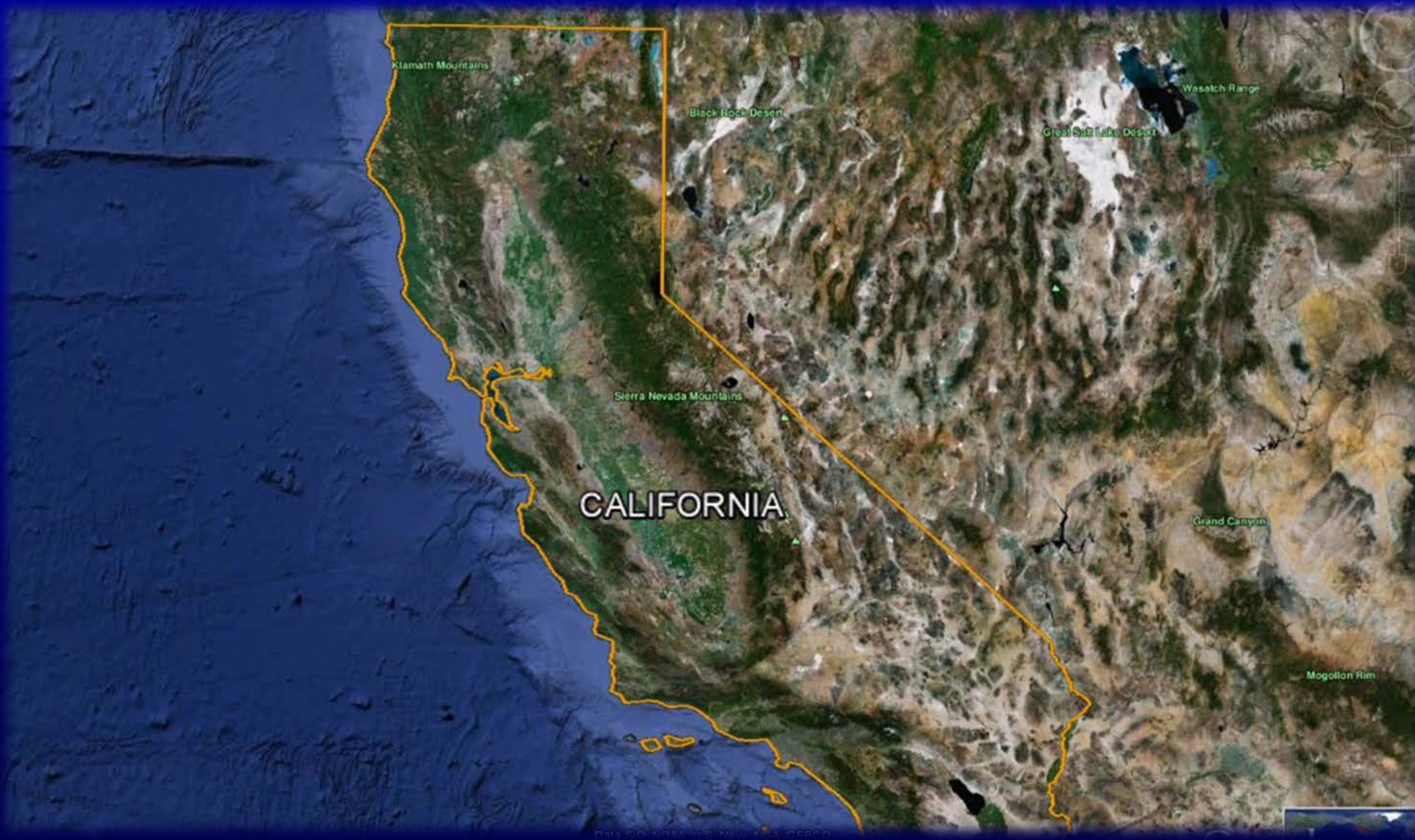
Slides Courtesy of Roy Herndon and Adam Hutchinson, OCWD

Overview of Orange County Water District's Managed Aquifer Recharge System

Recharge System Tour

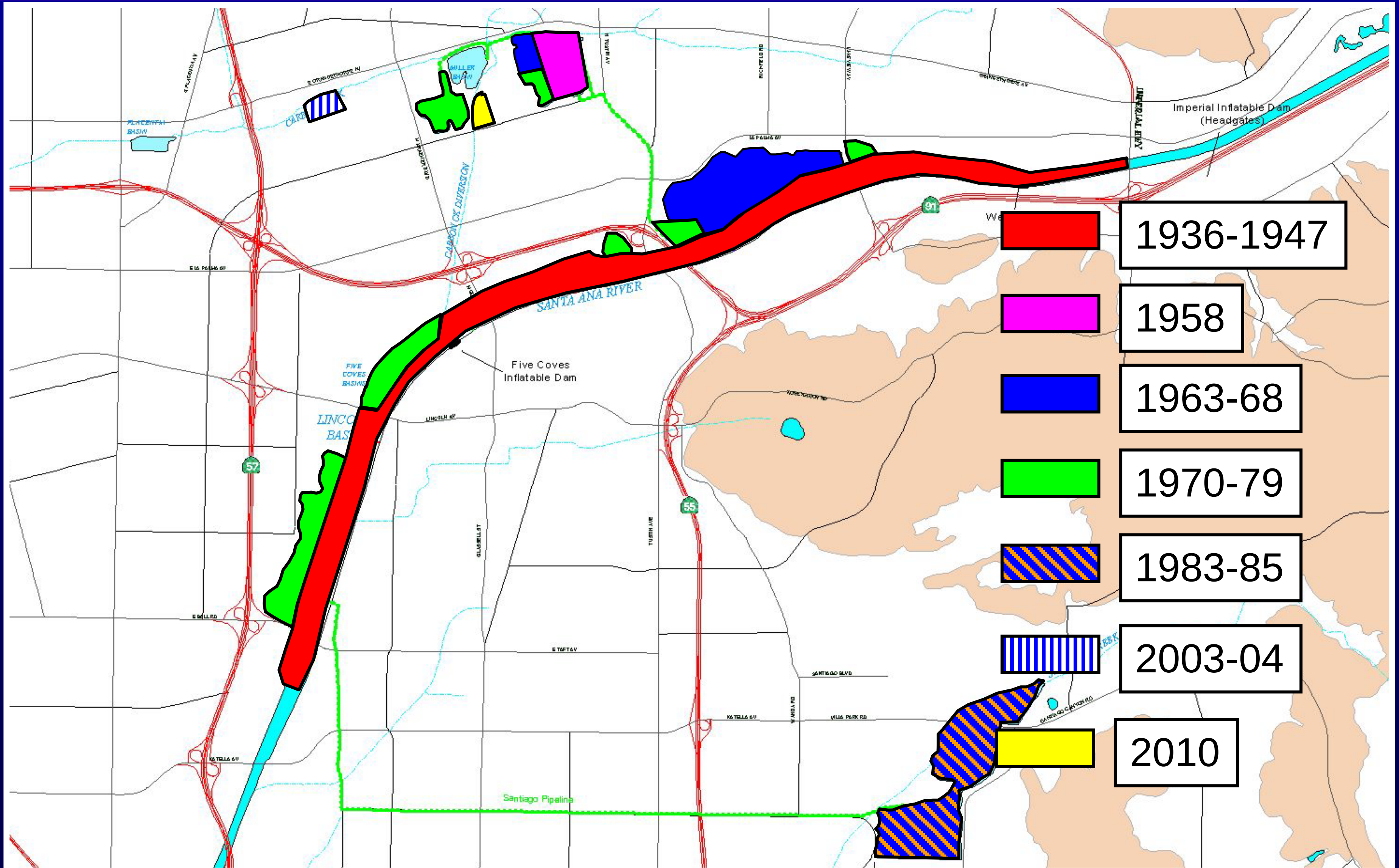
Slides Courtesy of Roy Herndon and Adam Hutchinson, OCWD

The Orange County groundwater basin lies at the base of the Santa Ana River watershed.

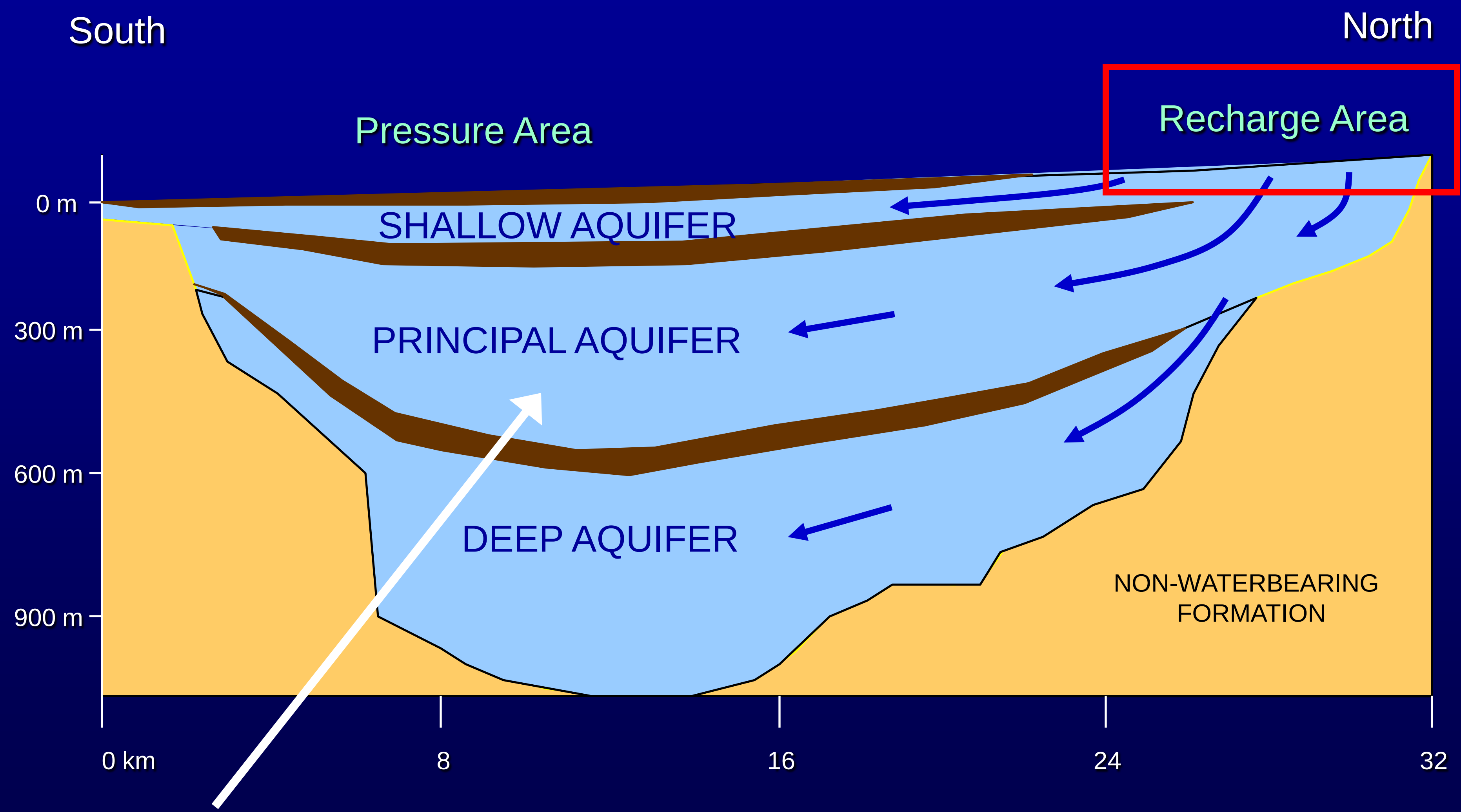


- Longest coastal river in Southern California
- 130 km from highest mountains to Pacific Ocean
- Watershed covers 690,000 hectares

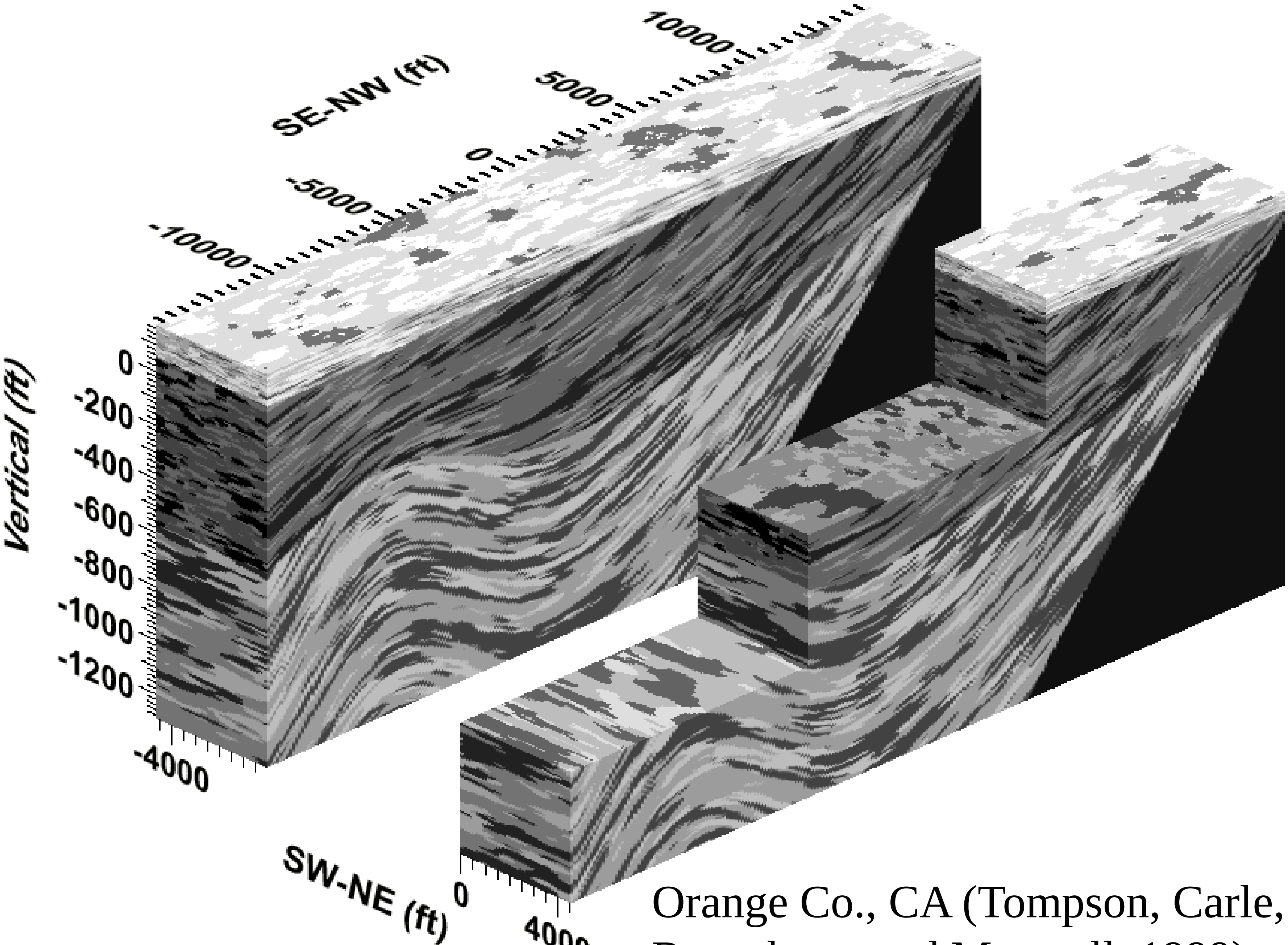
Over the course of 75 years, the District has purchased 600 hectares for recharge.



Basin geology limits the area where surface MAR can be used.

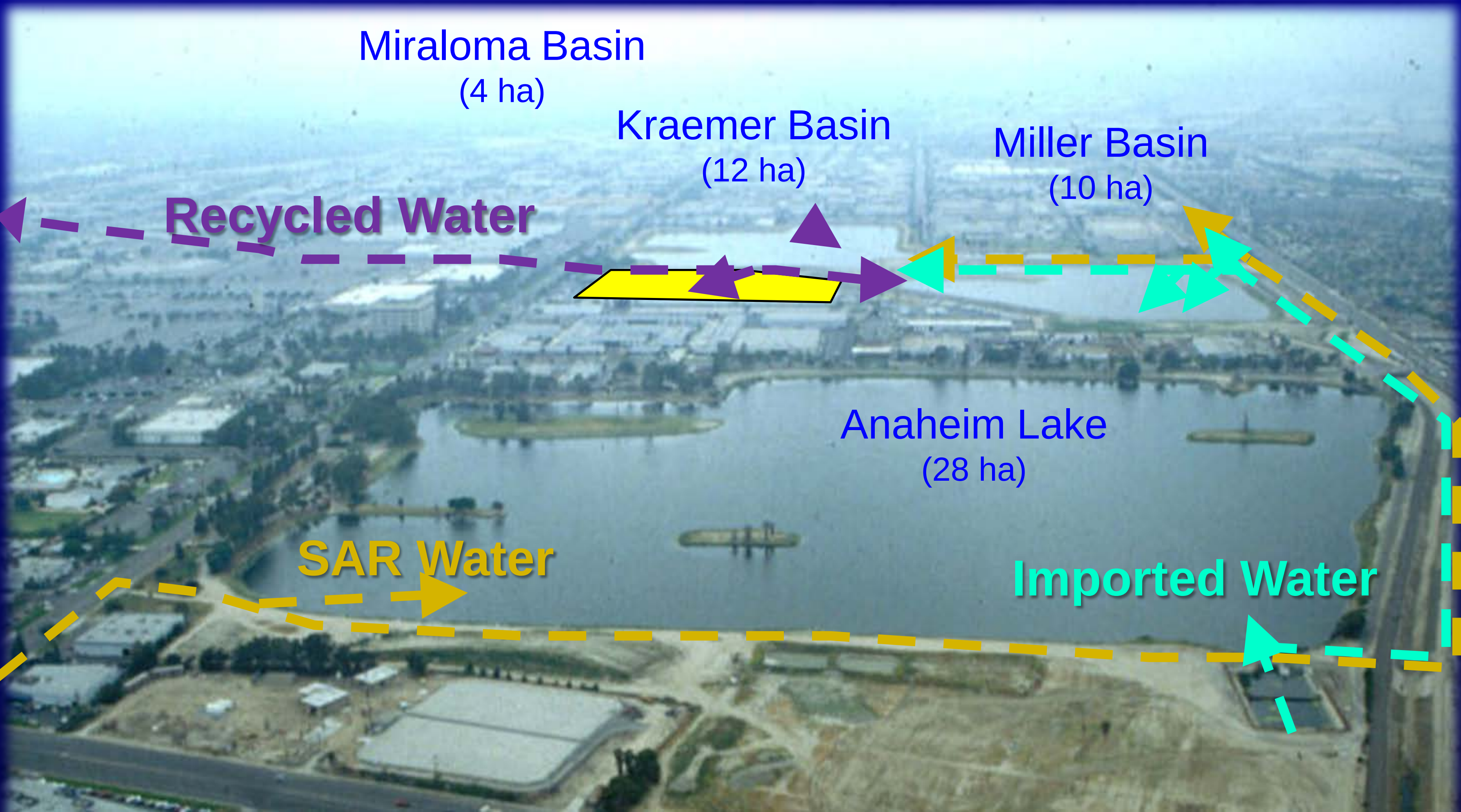


Most groundwater production is from the Principal Aquifer.

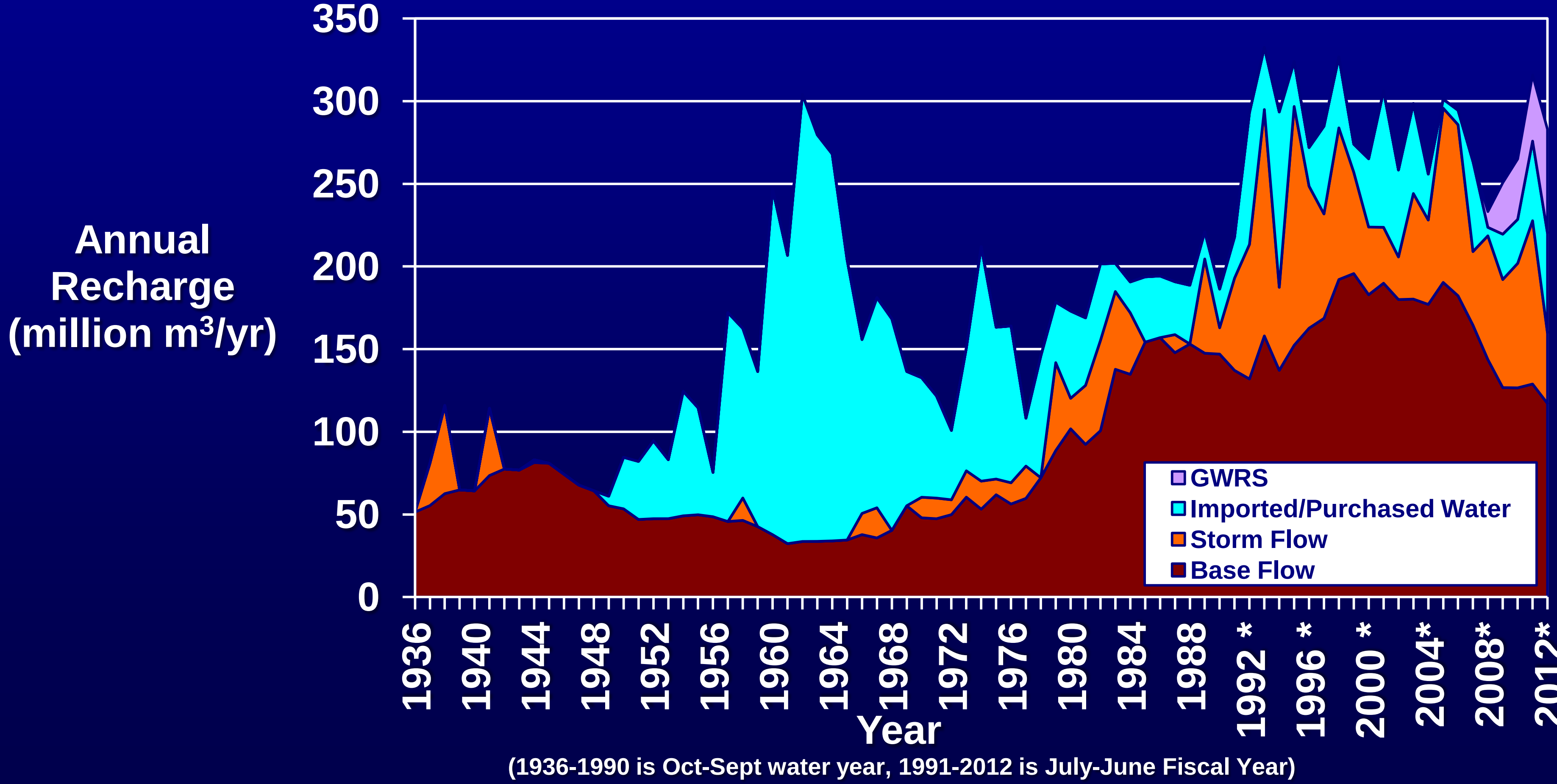


Orange Co., CA (Tompson, Carle, Rosenberg, and Maxwell, 1999)

The Anaheim Lake complex covers 60 hectares and can recharge SAR, imported and recycled water.



Over the past decade, surface water recharge has averaged 274 million m^3 per year from a variety of sources.



Outline

- Groundwater fundamentals
  - California groundwater occurrence & general background
  - Overdraft & negative consequences
    - Non-sustainable storage depletion
    - Subsidence
    - Surface water & ecosystem effects
    - Increased energy costs
    - Bad water intrusion from aquitards and from depth
    - Basin salt imbalance
    - Seawater intrusion
  - Sustainable yield
- Groundwater myths
  - Pumping of "fossil water" is non-sustainable
  - Groundwater storage depletion always takes a long time to recover
  - Groundwater levels tell us how much groundwater storage is changing
  - Quality of most groundwater is degraded
  - Good quality groundwater today is likely to stay that way
  - Potential myth: climate change will decrease groundwater recharge
- Case studies
  - Coachella Valley
  - Yolo County
  - Orange Co.

Confined Aquifer Schematic (from Driscoll, 1986)

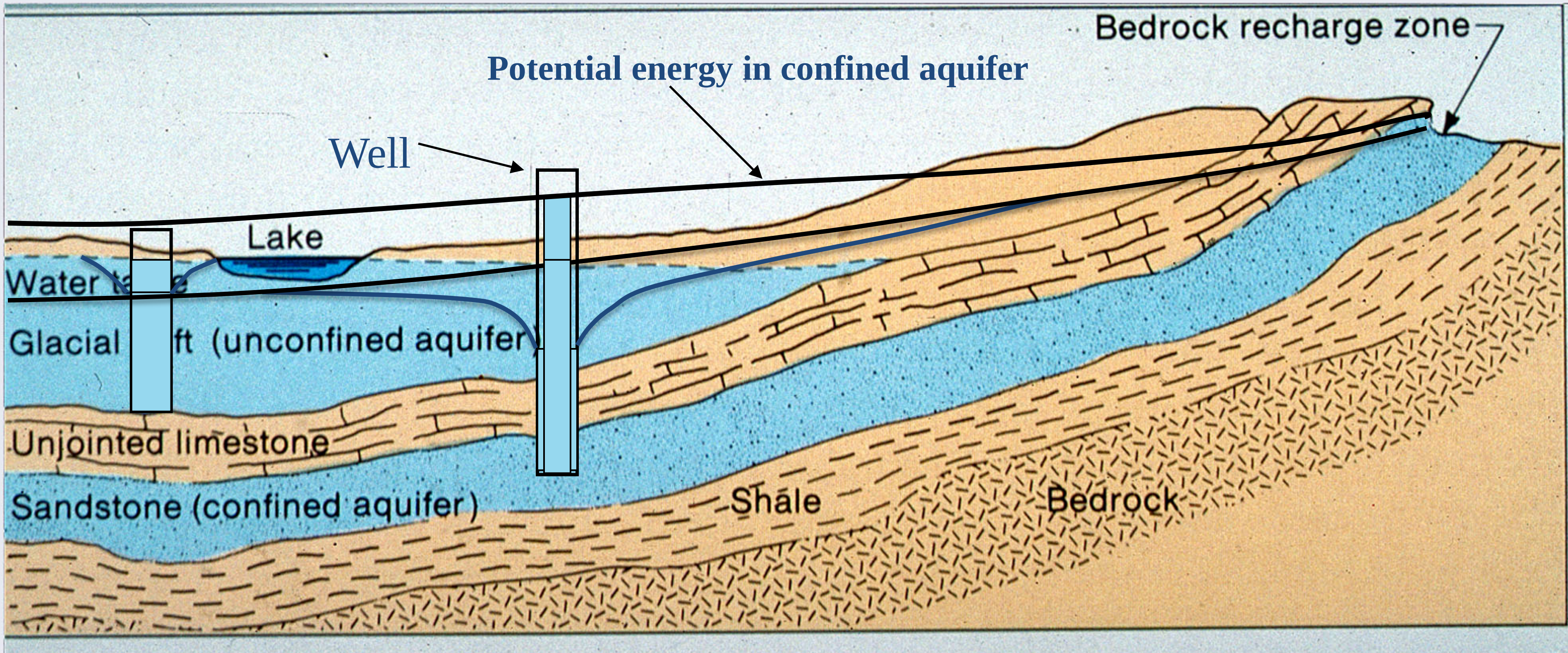
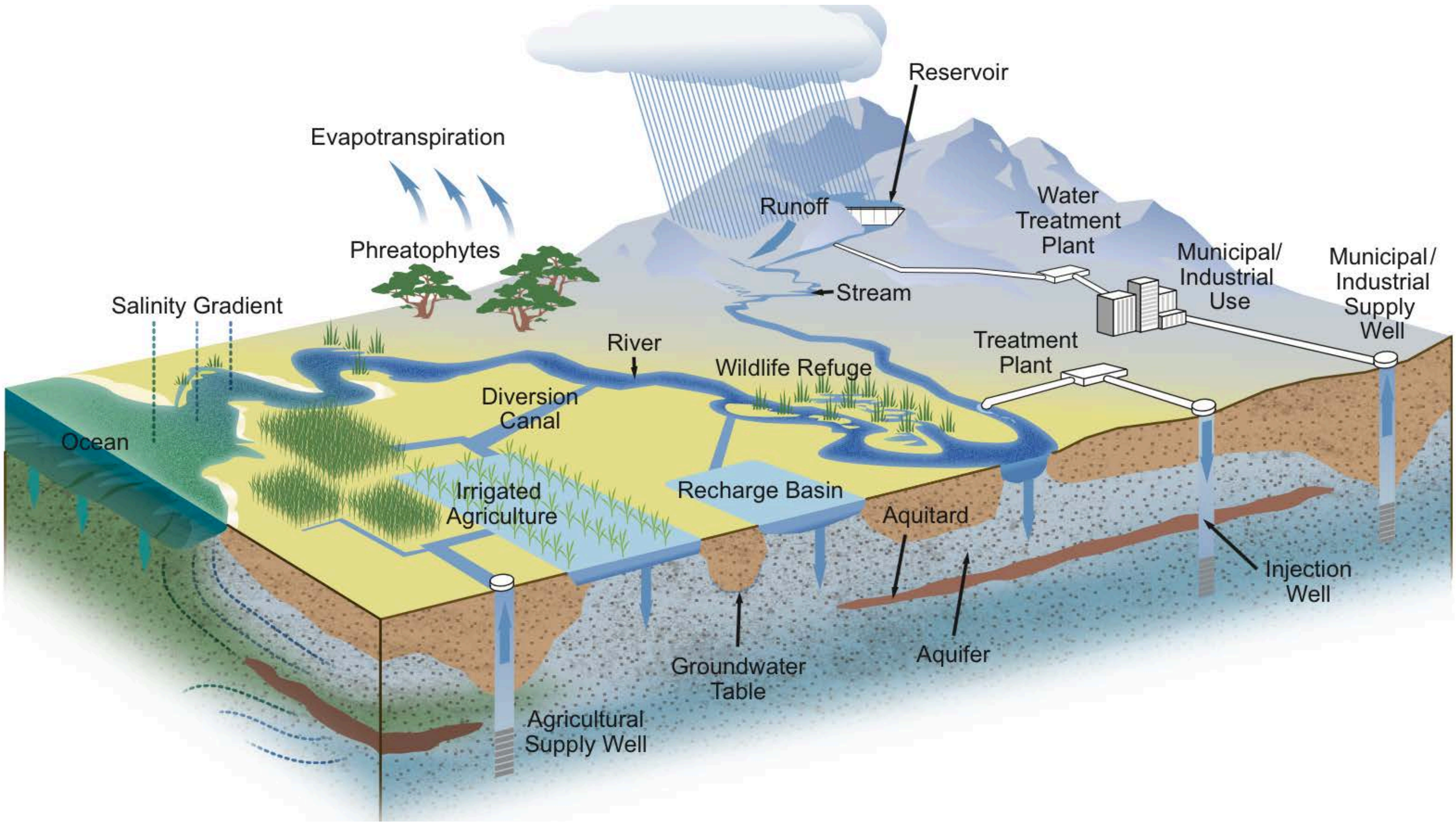


Figure 5.2. Groundwater exists in the underground in two major environments: unconfined and confined.

Myth: Old (1,000's of yrs) groundwater is fossil water that is not replenished enough to support pumping.

Groundwater and Surface Water



From CA Water Plan 2014