Groundwater Management—Past, Present, Future?

David K. Todd Distinguished Lecture Series

Carl Hauge
CSUs: Chico, Fresno, Monterey
UC Davis, GRA: San Francisco, Sacramento

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In theory there is no difference between theory and practice. In practice there is.

Yogi Berra, New York Yankees catcher

Topics

- Groundwater quality
- Groundwater management
- Stream flow depletion
- Groundwater substitution
- Subsidence
- Progress toward better management
- But is that enough?
- What more can be done?
- Conclusions

Groundwater quality

- Salt water underlies every aquifer
- Groundwater pumping can initiate movement upward into the aquifer
- Other contaminants have been added by *Homo sapiens*
- Contaminants from chemical constituents are still unregulated
- Recharge areas must be protected

Why does the state not have permitting jurisdiction over groundwater in California?

Water Commission

- Appointed by the legislature in 1911
- What should the state do about water resources?
- Took testimony
- Wrote the Water Commission Act including permitting jurisdiction over surface water **and** groundwater

Court cases relating to groundwater prior to 1911

- 1843—Acton v. Blundell—absolute ownership of groundwater below the property
- 1899—Los Angeles v. Pomeroy—definition of percolating groundwater
- 1903—Katz v. Walkinshaw—described correlative rights of landowners

Central Valley lobbyist

- Based on the 1843 court decision
- The Legislature can not take away the landowner's property rights of absolute ownership by providing the state with permitting jurisdiction over groundwater.

Legislative action

- Water Commission Act submitted to the Legislature included state permitting jurisdiction over both surface water **and** groundwater
- Amended to exclude permitting of groundwater
- Passed in 1913, went into effect in 1914

Why was groundwater not included?

- No documentation indicates why
- Apparently the Central Valley lobbyist was successful at convincing the legislators that the courts prevailed in determining groundwater law
- So the result is that:
  - Groundwater is ruled by judicial law
  - Surface water is ruled by statutory law

Do other states do a better job of managing groundwater?

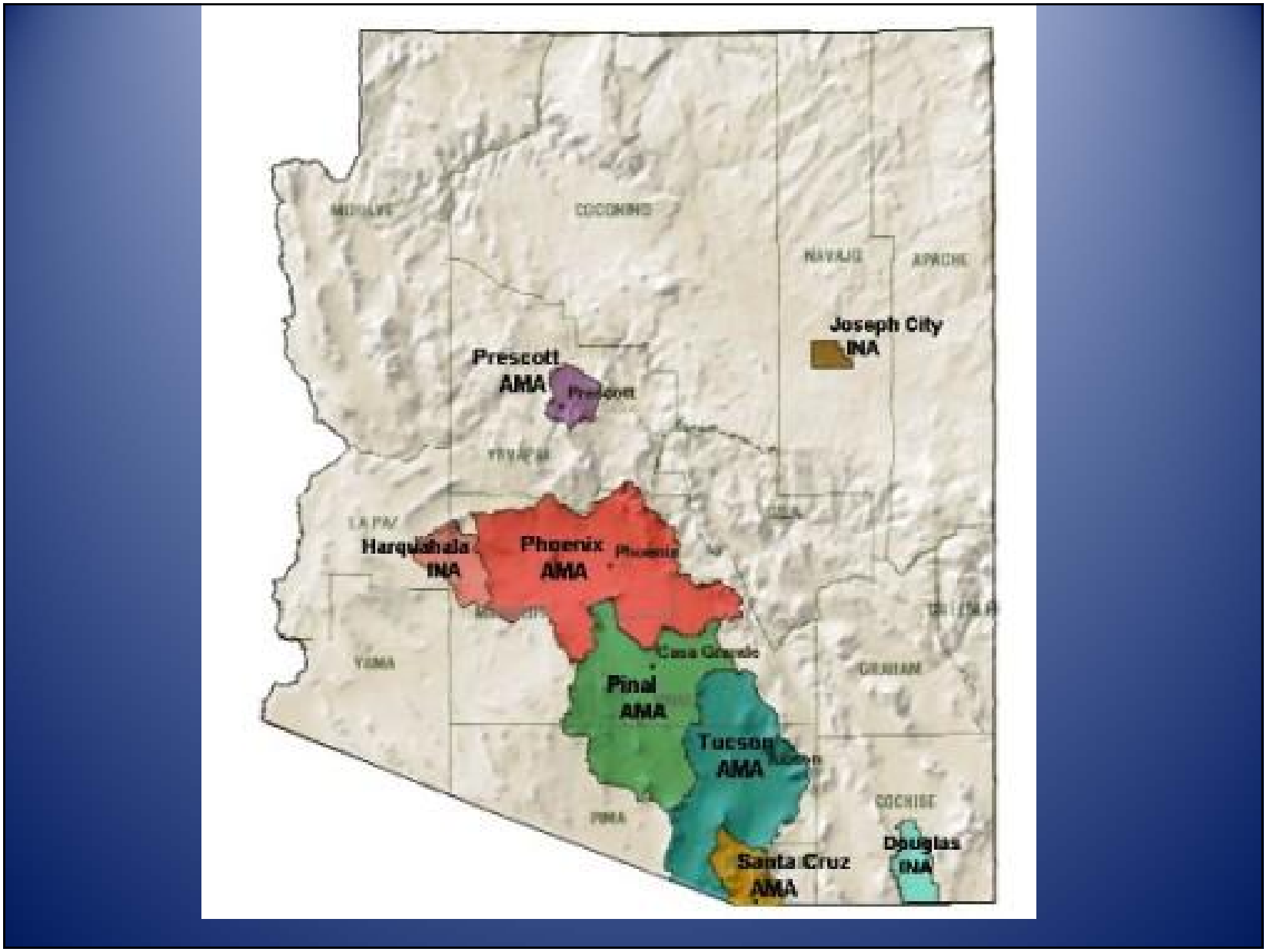
- Arizona
- Nevada
- Oregon
- Washington

Arizona

- Many court decisions in the 1800s
- Later decisions reversed earlier decisions
- 1980 Arizona Groundwater Management Code
- Requires formation of Active Management Areas where groundwater is actively mined

Arizona

- 5 AMAs were formed to determine and enact the safe yield limit on pumping by 1995
- None met that goal
- 2025 is the new date for meeting that goal


Joseph City
INA
Prescott
AMA
Harquahala
INA
Phoenix
AMA
Pinal
AMA
Tucson
AMA
Santa Cruz
AMA
Douglas
INA

Nevada

- 1866—first water law
- 1903—state engineer created, inventory of water use
- 1913—jurisdiction over wells tapping aquifers
- 1939—jurisdiction over all groundwater
- Map of basins showing perennial yield

Nevada

- A regional carbonate aquifer that feeds springs that support pupfish—complex geology & hydrology—thrust faults
- Exempt wells can pump 2 acre feet per year (1786 gpd)

Nevada

- Southern Nevada Water Authority (Las Vegas) laid claim to more than 11 times the annual groundwater recharge
- Studies claim that the effect of pumping will take about 500 years to show up in the carbonate aquifer
- State Engineer says that 500 years is beyond their planning capacity
- The claims were approved

Oregon

- A permit is required to appropriate any water —different statutes
- Water Resources Department has guidelines for approving or disapproving the permit
- Exempt wells require no permits
  - Domestic up to 15,000 gpd (10.4 gpm)
  - Industrial or commercial up to 5000 gpd (3.5 gpm)

Oregon

- Staff says that exempt wells are working out ok
- Up to 30 homes on a well do not exceed the 15,000 gpd limit
- When permits are sought for industrial or commercial wells the state reviews other constraints in the basin—may disapprove
- Fees help support state programs

Washington

- Surface water code, 1917
- Groundwater code, 1945
- Both require permits
- Exempt wells require no permits, 5,000 gpd (3.5 gpm)
  - Domestic, less than ½ acre, industrial, livestock
  - >> 100,000 exempt wells—significant
  - RCW 90.44.050

Washington

- Recent court case—Swinomish Tribe sued to protect salmon on Skagit River
- Court ruled against exempt wells allowed by the state
- Department of Ecology is now wrestling with that court decision and the state code
- Groundwater in the basalts in central and eastern Washington is being overpumped for agriculture

Conclusions about other states

- Each state has different statutes than California
- Although their state codes address groundwater, not all management issues have been resolved
- “Subterranean streams” are still a problem
- Whether they are managing groundwater better than California is yet to be determined

Read about other states with a disconnect between sw and gw

- "Water Follies" by Robert Glennon

What is the best way to manage groundwater?

- Local management agency
- Adjudication
- Integrated Regional Water Management

Local management agency

- The Legislature assumed that locals know the local political, legal, institutional, technical & economic constraints & opportunities
- Therefore they can manage better
- But have they taken action to manage gw?
- Some agencies have done so—others have not
- Future attempts may be challenged in court

Local management

- Governor Brown says that it is better if the locals manage their groundwater
- But if the locals do not, then the state should step in to manage groundwater
- The Legislature has had about 8 opportunities to do something about groundwater management and has declined each time

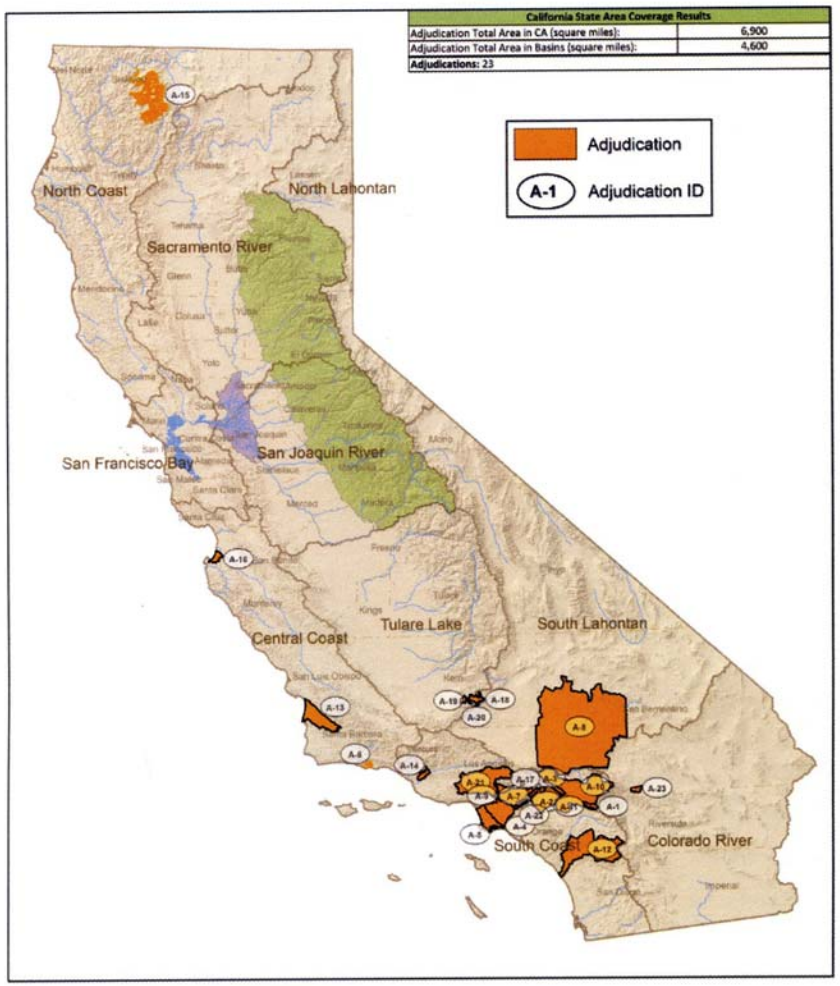
Adjudication

- 22 adjudicated basins
- Some took less than 2 years, 1 took 24 years
- The court appoints a watermaster who oversees the pumping of parties to the suit
- Each share of groundwater is apportioned to what is in the aquifer each year
- Early decisions relied on imported water
- Court requires litigants to hire consultants

Adjudication 2

- It is expensive
- Attorneys have said that eventually every basin will be adjudicated
- So rather than statutory law providing permitting jurisdiction it will be judicial law
- Thus, “correlative” groundwater rights will be established

Figure 3 - Map of Court Adjudications and Coverage



Integrated Regional Water Management

- Given the number of local agencies in each basin/subbasin, this approach will take coordination but it could be successful
- Convincing local agencies provides a major challenge & will take time
- Any plans are subject to challenges that will end up in court

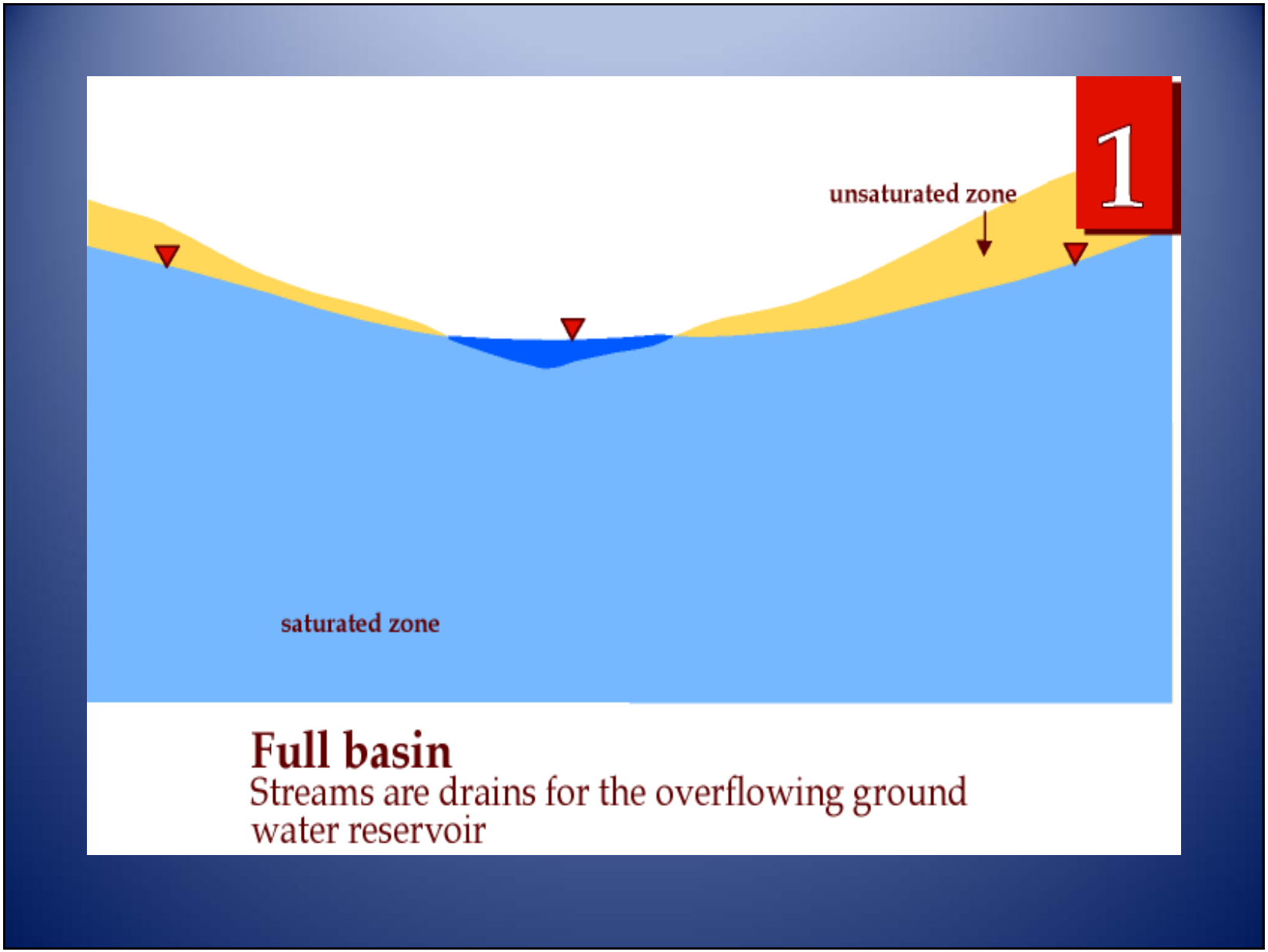

Fresno
Fresno I.D.
Clovis
Madera
Madera I.D.
Westlands W.D.
Mid-Valley W.D.
Tranquillity I.D.
James I.D.
Raisin City W.D.
Consolidated I.D.
Stinson W.D.
Liberty W.D.
Riverdale I.D.
Laguna I.D.
Kings County W.D.
Hanford
Alta I.D.
St. Johns W.D.
Clark's Fork Reclamation District
Lakeside Irrigation W.D.
Tulare I.D.
Empire West Side I.D.
Stratford I.D.
Salyer W.D.
Pleasant Valley W
Coalinga
Huron
Kings River W.D.
Fresno Slough W.D.
Alto W.D.
San Luis W.D.

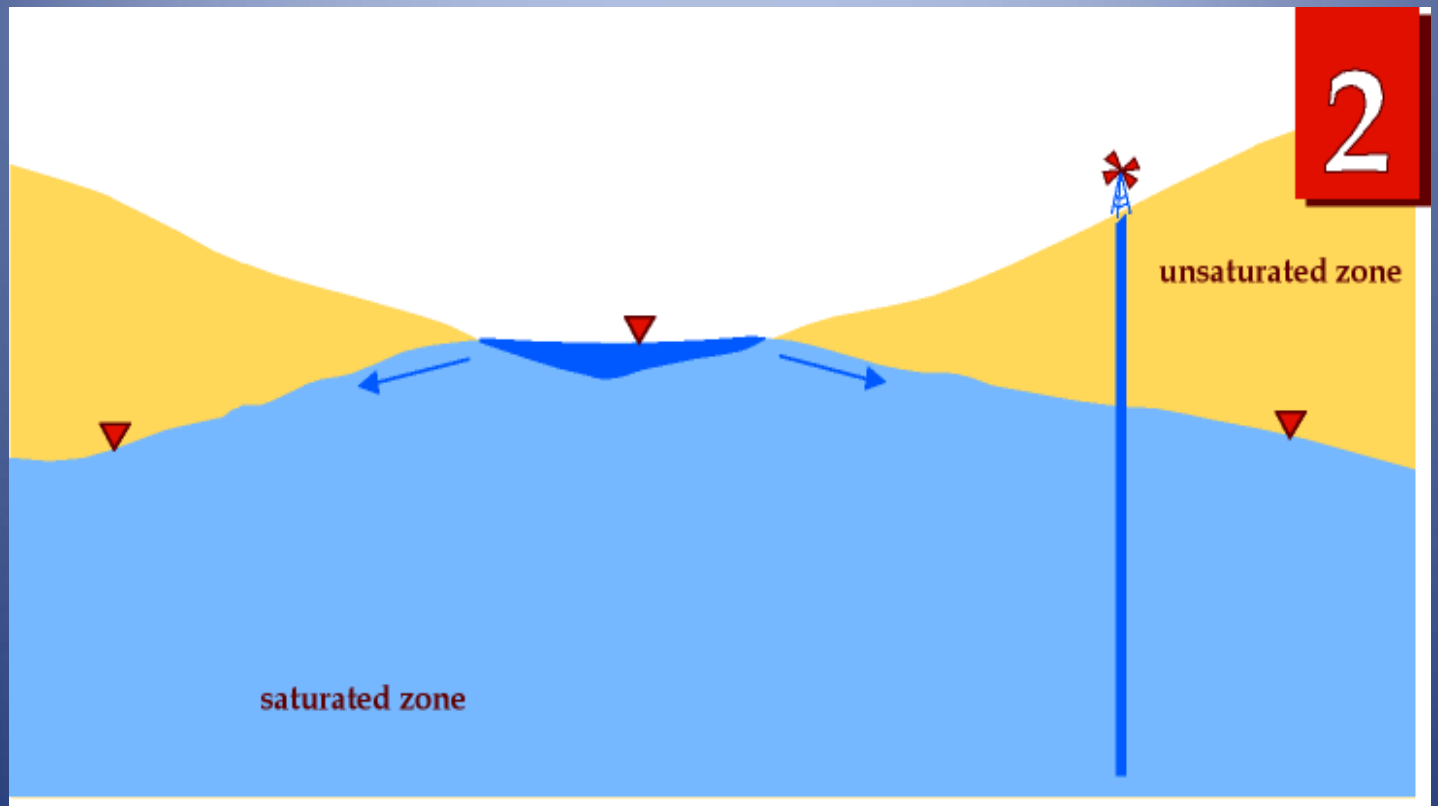
Determining factors

- No single procedure guarantees success
- What matters is the attitude of the people involved
- Either local management agencies or Integrated Regional Water Management agreements can be successful
- But someone can always file a court action leading to adjudication

Stream flow depletion

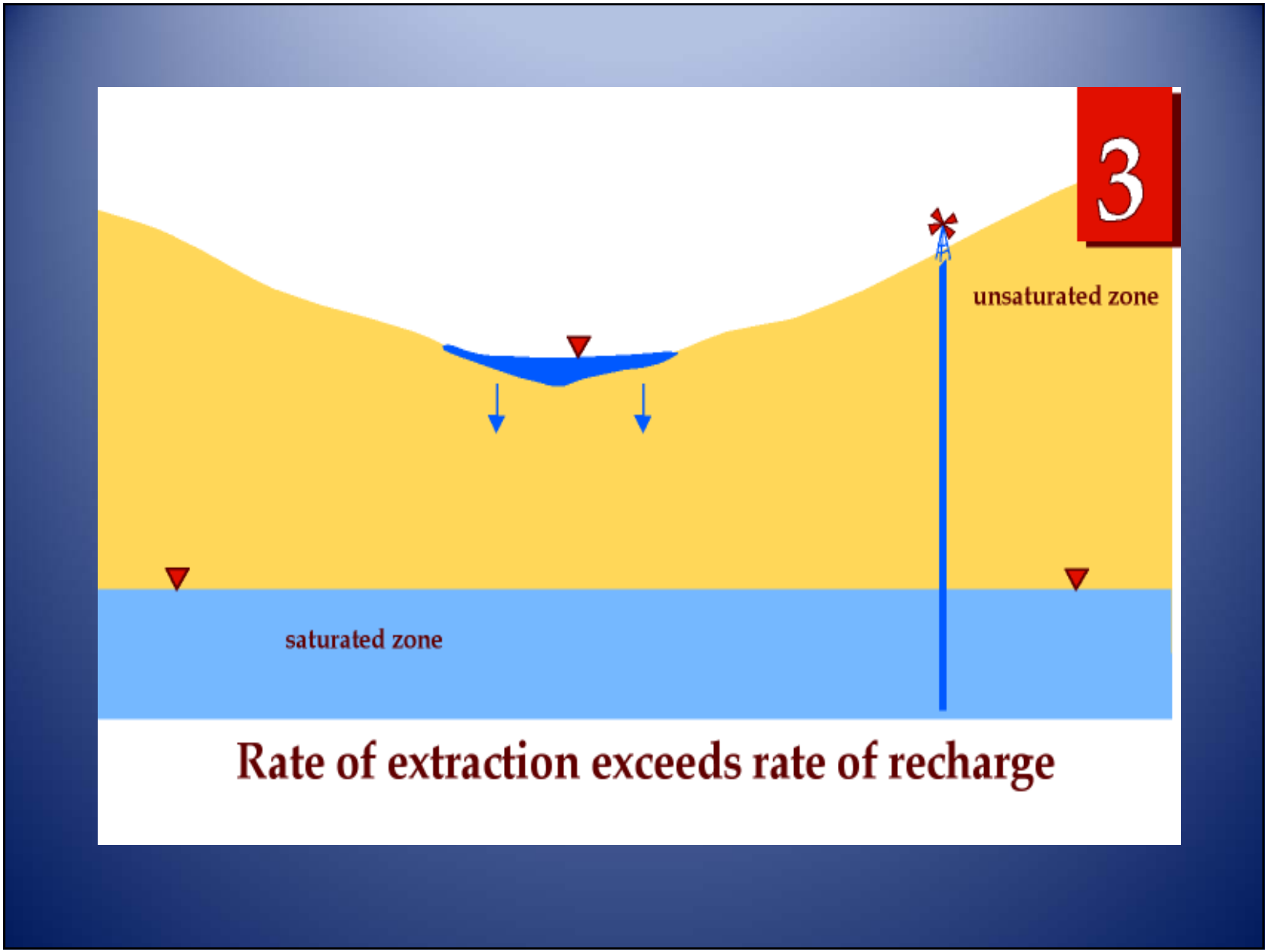
What did California rivers used to look like?

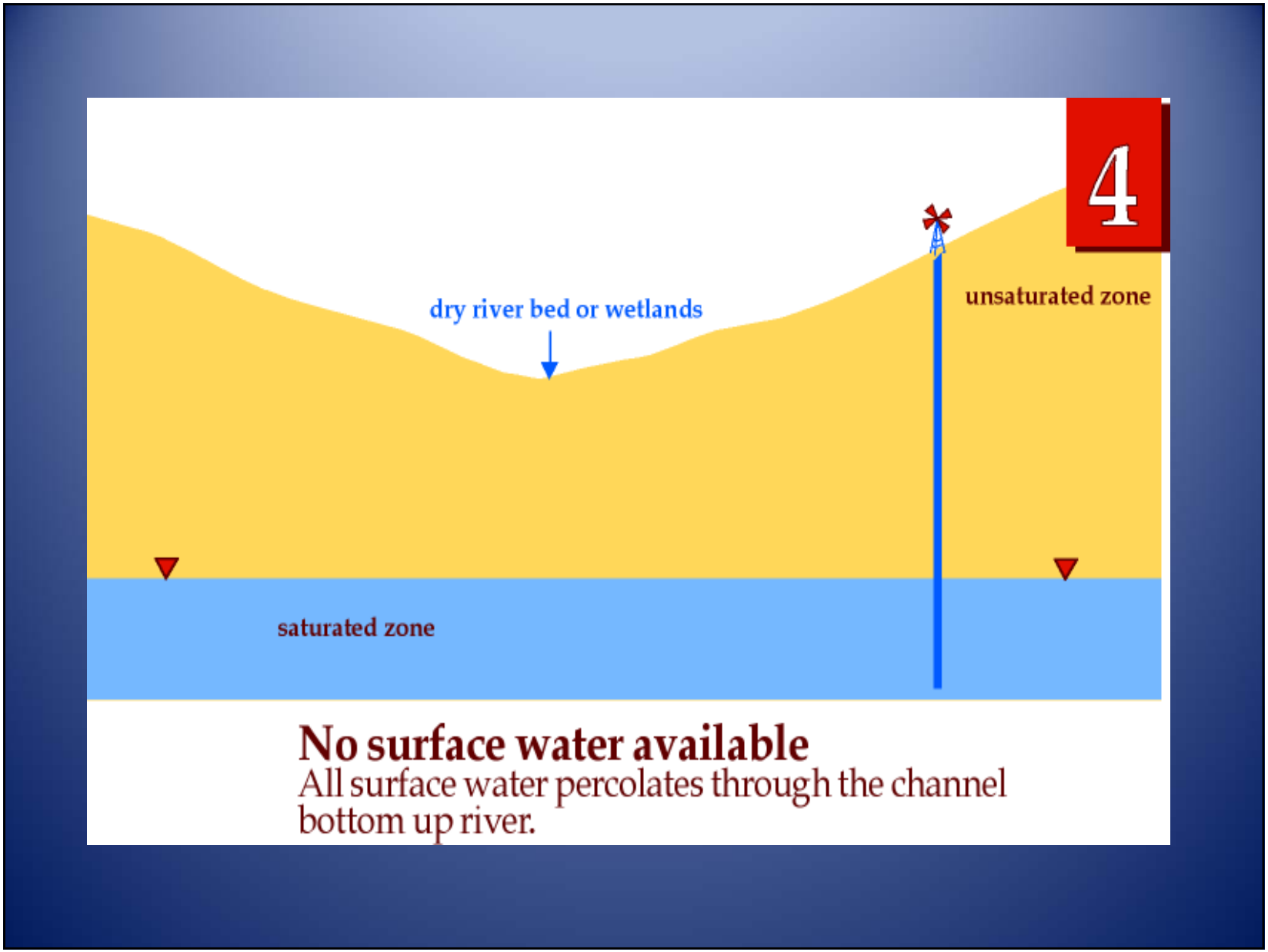

1
unsaturated zone
saturated zone
Full basin
Streams are drains for the overflowing ground water reservoir

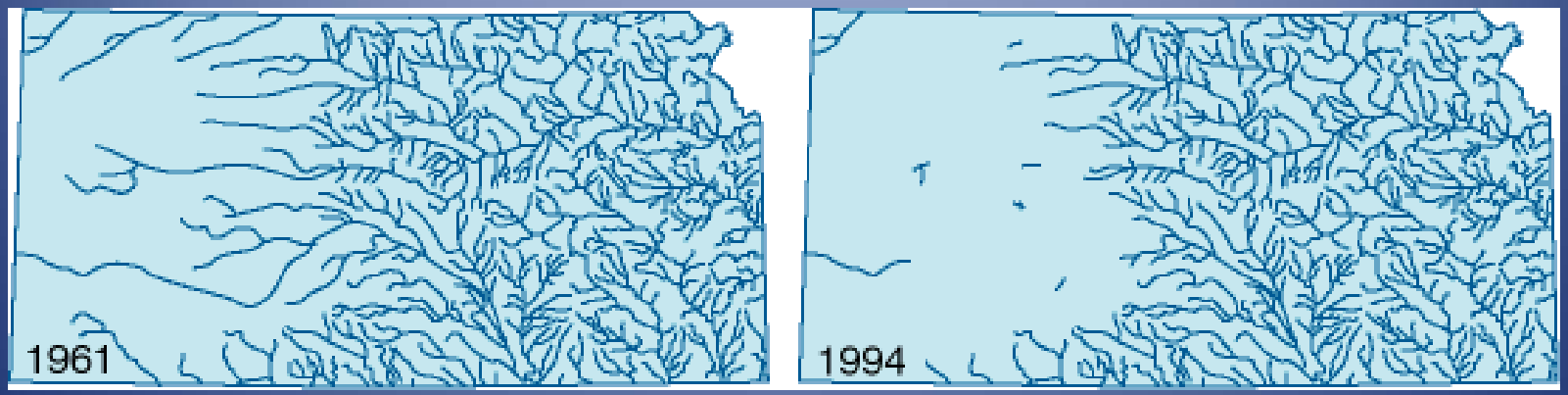


Some extraction of ground water

Storage capacity is made available for additional water and a gradient is created that induces recharge from streams


3
unsaturated zone
saturated zone
Rate of extraction exceeds rate of recharge


4
dry river bed or wetlands
unsaturated zone
saturated zone
No surface water available
All surface water percolates through the channel bottom up river.



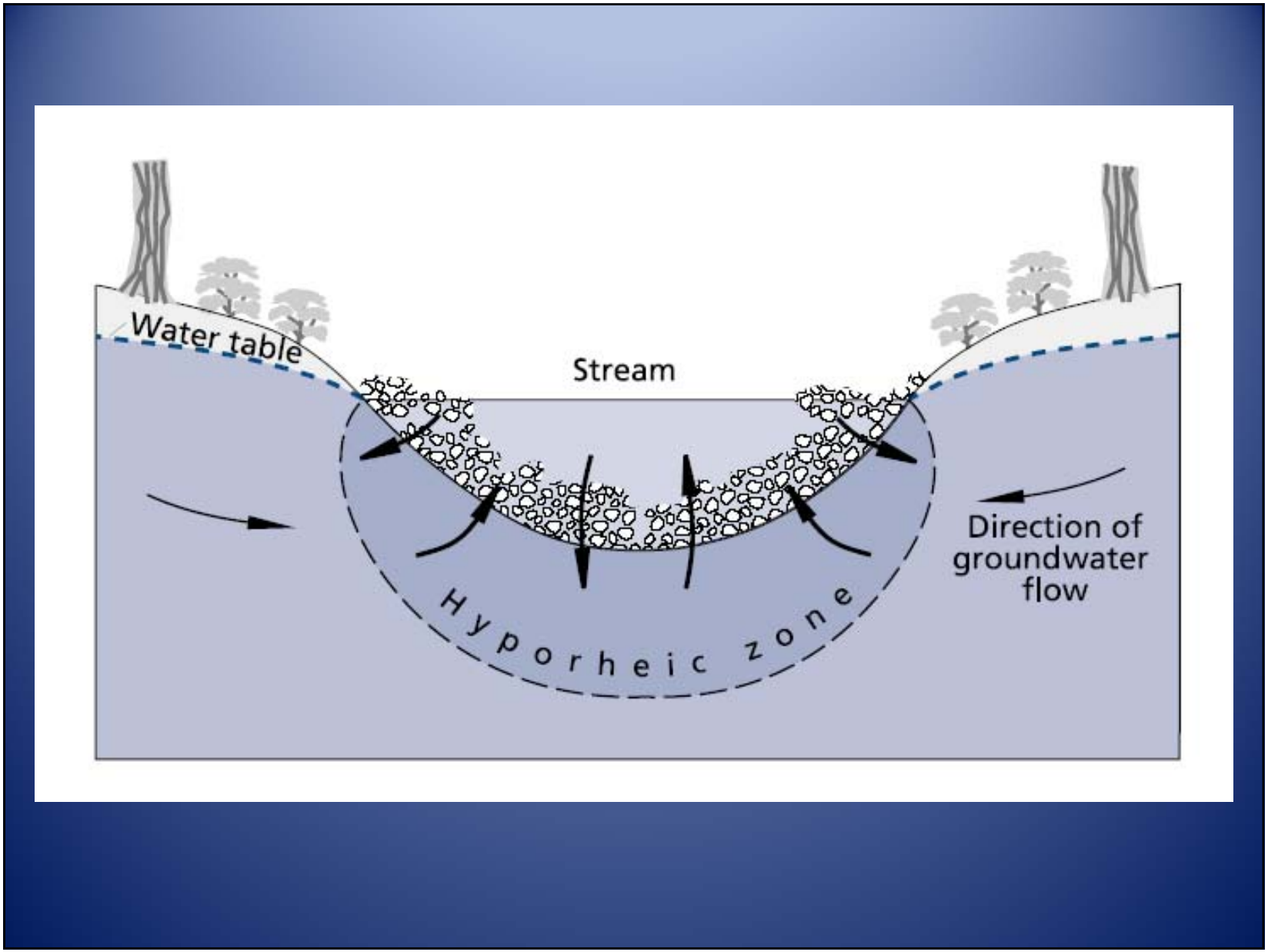
Perennial streams in Kansas

Cosumnes River

- No dams
- Low elevation watershed
- Front edge of the live stream has retreated in recent years
- Why? Because more wells have been built that extract water that is contiguous with stream flow, i.e., a losing stream
- A good example of what has happened to other rivers in California

What is the hyporheic zone?

- The region below & beside the stream where surface water and groundwater mix
- Centimeters to kilometers
- Water remains in the zone from minutes to months
  - Depends on flow path length and hydraulic conductivity


Water table
Stream
Direction of groundwater flow
Hyporheic zone

GW & SW nexus

- Water flows in and out depending on head
- Nutrients are added
- Nutrients remain longer in a large zone
- Meiofauna—0.5 to 0.045 mm
  - Arthropods, worms, 80 species at one site
- Found in groundwater 1 km from the stream
- Food source for fish

High productivity

- Bacteria, fungi, protozoa live on sediments
- Convert nutrients into food
- Nutrients delivered to the stream system
- Marine nutrients via dead salmon
- Redds receive oxygenated water
- Moderates winter & summer stream temp

Channelized rivers

- Hyporheic zone is eliminated or greatly reduced
- A decrease in
  - Interchange of sw & gw
  - Water quality benefits
  - Temperature buffering
  - Nutrients
  - Food sources

What is groundwater substitution?

- Landowners in Sacramento Valley leave their surface water entitlement behind the dam
- Instead of irrigating with surface water they irrigate with groundwater
- Their surface water entitlement can then be sold to others
- Can be conveyed thru the State Water Project

How much of that groundwater is being provided from stream flow?

- The amount of credit for surface water is being worked out in political circles
- Sellers must subtract 12% from the surface water they sell to allow for stream flow depletion when they irrigate with groundwater
- Need to increase scientific understanding of stream flow depletion by pumping wells
- The science is complex

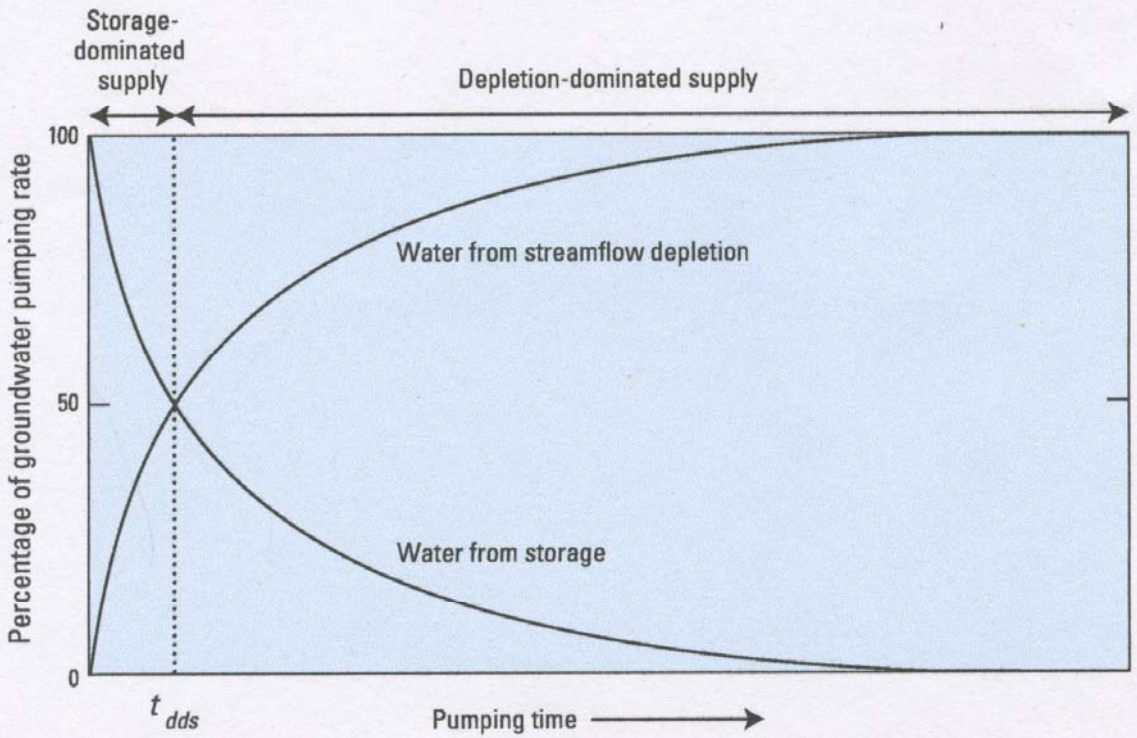


Figure 9. Relation of storage change and streamflow depletion as sources of pumped groundwater through time for a hypothetical well. Initially, the source of water (or supply) to the well is dominated by reductions in aquifer storage. At later times, streamflow depletion is the dominant source of supply. The condition of more than half of the pumping rate coming from streamflow depletion is designated as depletion-dominated supply, and variable t_{dds} is the time to reach the condition of depletion-dominated supply for a particular pumping location.

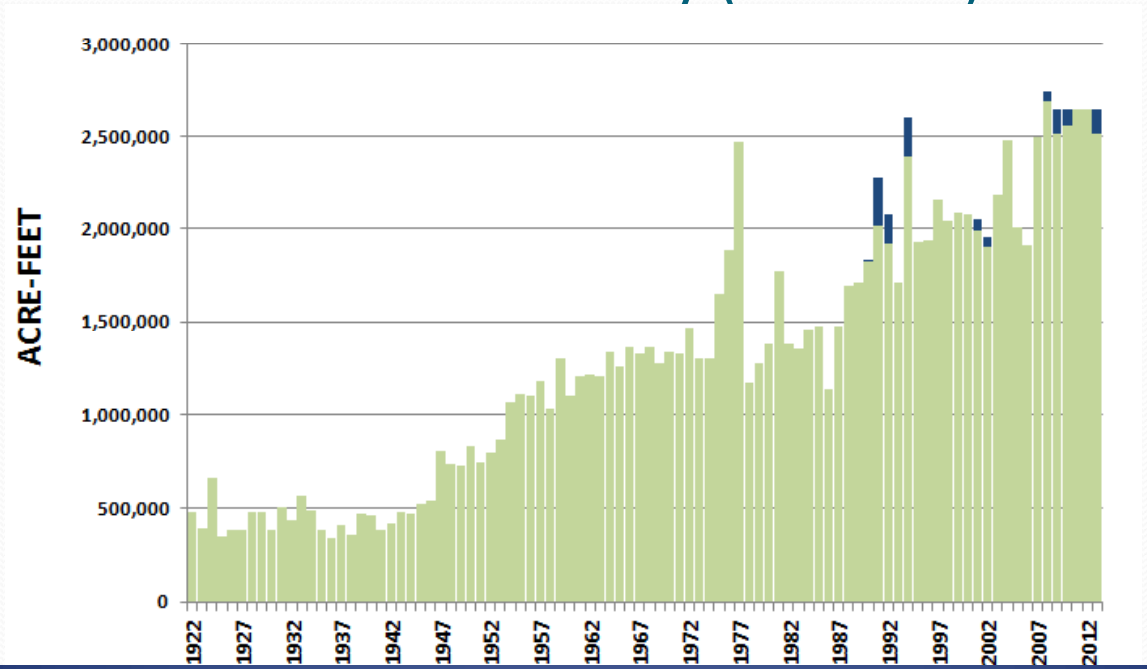
Reality

- When groundwater is pumped out of an aquifer, stream flow is diminished
- The size of the stream system and the amount of groundwater pumped determines when that decrease will show up
  - Small systems—fairly quickly
  - Large systems—after a longer period of time, up to decades

Groundwater pumping and decreased flow in rivers

- Occurs over many years, decades, several generations
- Changes in the river take place over years & therefore are not noticed by the persons who live there at the time
- Eventually the river is dry because the groundwater pumping has taken all the water

Estimate of Groundwater Pumping Sacramento Valley (91 Years)



Factors that determine timing & rate of streamflow depletion

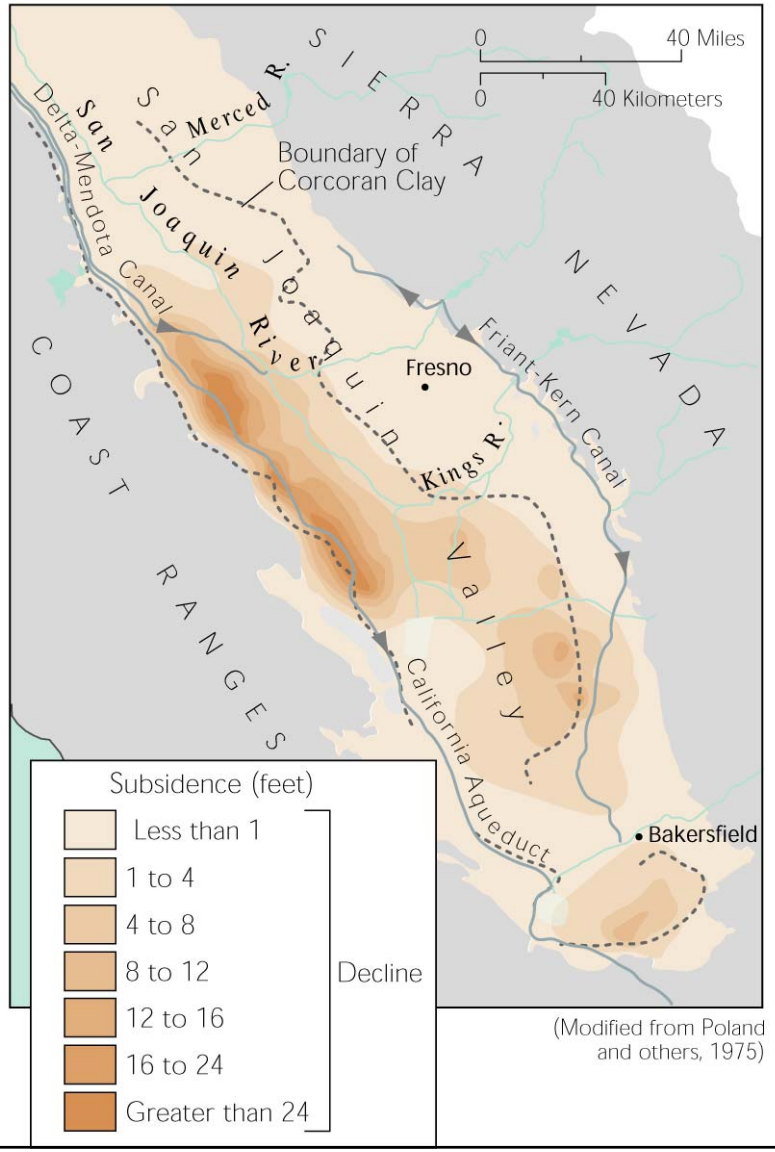
- Geologic structure
- Dimensions
- Hydraulic properties
- Locations & conditions of boundaries, including streams
- Horizontal & vertical distances of wells from streams

Myths

- The rate of recharge is the same as the “safe” or “sustainable” rate of extraction
- Streamflow depletion stops when pumping stops
- Pumping from below a confining layer does not cause streamflow depletion

Why is the Central Valley subsiding?

Land subsidence from 1926 to 1970



Causes of subsidence

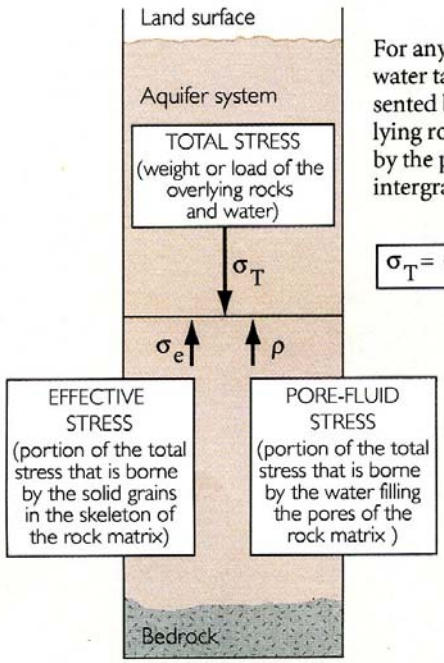
- Lithification
- Tectonic deformation
- Oxidation of peat
- Hydrocompaction
- Withdrawal of fluids (water or petroleum products)


RAFT
RIVER
SACRAMENTO
SANTA CLARA
SAN JOAQUIN
LANCASTER
LAS VEGAS
SAN JACINTO
LUKE
QUEEN CREEK
ELOY
STANFIELD
HOUSTON-GALVESTON
BATON
ROUGE
NEW
ORL
MEXICO
0
500
1000
KILOMETRES

Aquitard Drainage and Aquifer-System Compaction

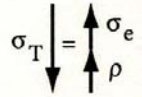
The Principle of Effective Stress

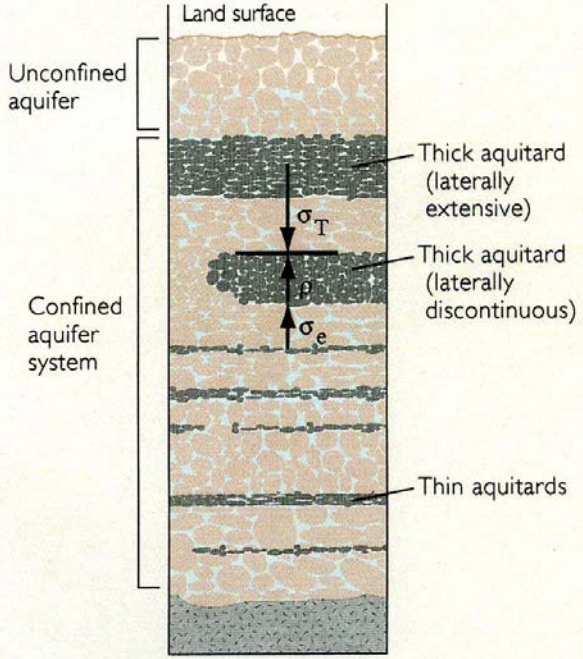
This principle describes the relation between changes in water levels and deformation of the aquifer system.

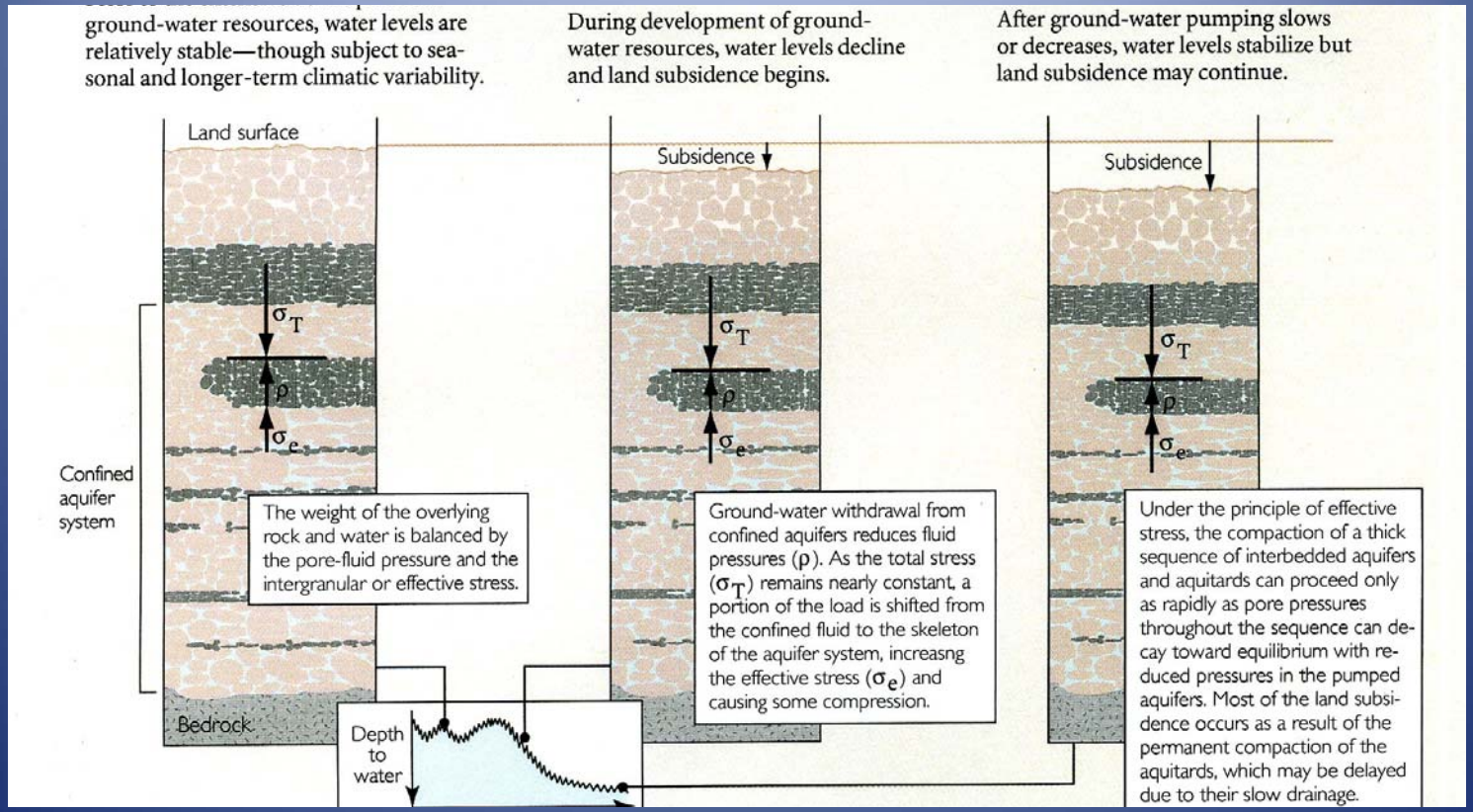


For any arbitrary plane below the water table, the total stress represented by the weight of the overlying rock and water is balanced by the pore-fluid pressure and the intergranular or effective stress.

$$\sigma_T = \sigma_e + \rho$$

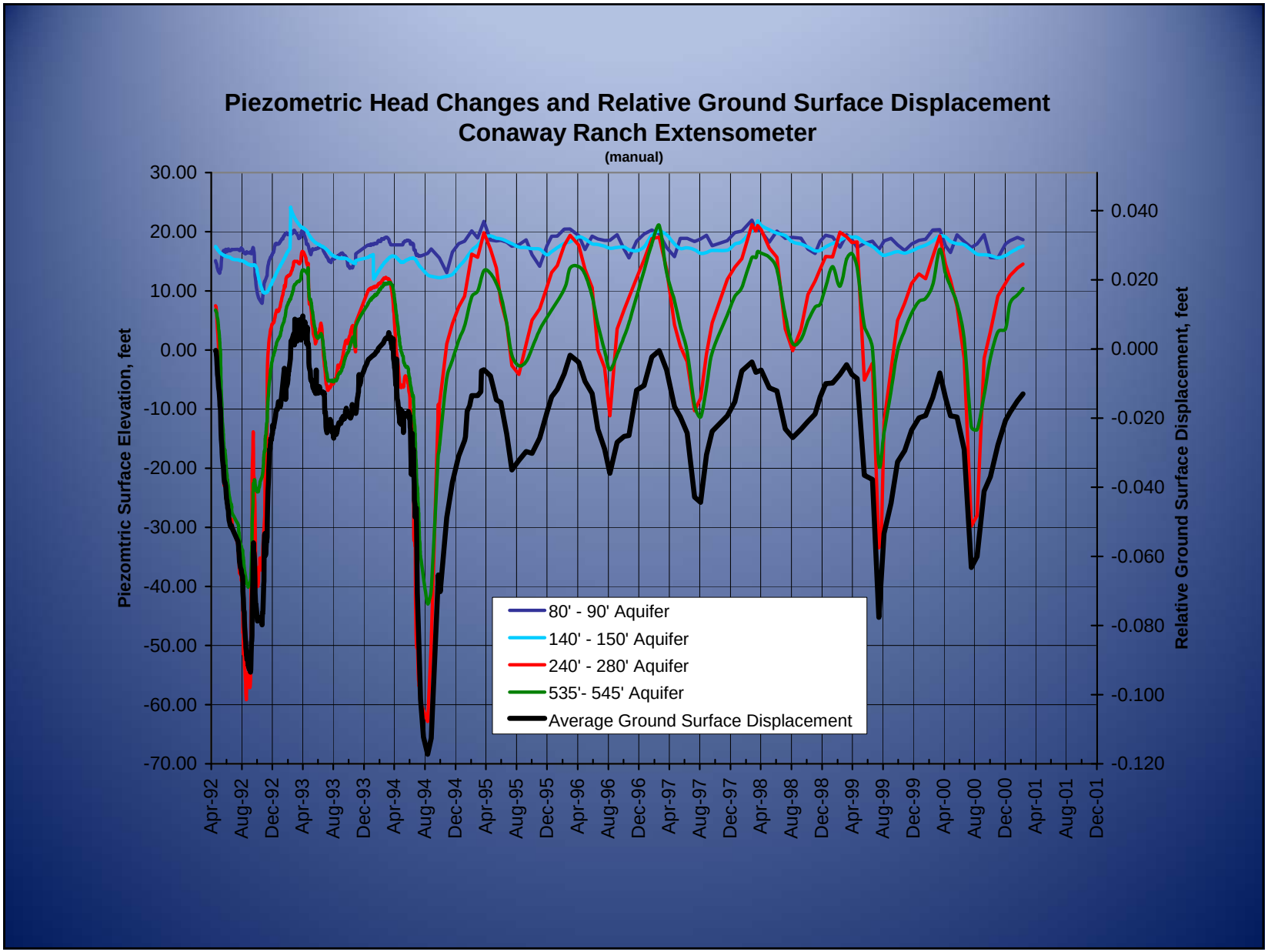





ground-water resources, water levels are relatively stable—though subject to seasonal and longer-term climatic variability.
During development of ground-water resources, water levels decline and land subsidence begins.
After ground-water pumping slows or decreases, water levels stabilize but land subsidence may continue.
Land surface
Subsidence
Subsidence
σ_T
ρ
σ_e
Confined aquifer system
Bedrock
Depth to water
The weight of the overlying rock and water is balanced by the pore-fluid pressure and the intergranular or effective stress.
Ground-water withdrawal from confined aquifers reduces fluid pressures (ρ). As the total stress (σ_T) remains nearly constant, a portion of the load is shifted from the confined fluid to the skeleton of the aquifer system, increasng the effective stress (σ_e) and causing some compression.
Under the principle of effective stress, the compaction of a thick sequence of interbedded aquifers and aquitards can proceed only as rapidly as pore pressures throughout the sequence can decay toward equilibrium with reduced pressures in the pumped aquifers. Most of the land subsidence occurs as a result of the permanent compaction of the aquitards, which may be delayed due to their slow drainage.

What about the loss of storage?

- Water that was stored in the clays that was pumped out will never be replaced
- The coarser-grained part of the aquifer system will continue to store water and release it to wells
- The aquifer will be recharged faster & pumping will lower groundwater levels faster but the aquifer will still be a useful reservoir
- Bottom line: the aquifer is not destroyed


Piezometric Head Changes and Relative Ground Surface Displacement
Conaway Ranch Extensometer
(manual)
Piezomtric Surface Elevation, feet
Relative Ground Surface Displacement, feet
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
0.040
0.020
0.000
-0.020
-0.040
-0.060
-0.080
-0.100
-0.120
Apr-92
Aug-92
Dec-92
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Apr-99
Aug-99
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Apr-00
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Dec-00
Apr-01
Aug-01
Dec-01
80' - 90' Aquifer
140' - 150' Aquifer
240' - 280' Aquifer
535'- 545' Aquifer
Average Ground Surface Displacement

Are we making any progress toward better groundwater management?

- CASGEM
- IRWM
- Identification of recharge areas
- California Water Plan
- Effective groundwater management plans

California Statewide Groundwater Elevation Monitoring (CASGEM)

- A great program that has been successful in establishing monitoring programs in many basins
- The Water Data Library has been integrated with CASGEM
- The groundwater levels recorded in CASGEM tell what our groundwater “management” or “mis-management has accomplished but they do not establish a water budget

Prioritizing groundwater basins CWC §10933

- Required as a part of CASGEM
  - Population in the basin
  - Projected growth of population
  - Number of public supply wells in the basin
  - Total number of wells in the basin
  - Irrigated acreage in the basin
  - Number of groundwater-dependent persons
  - Overdraft, subsidence, saline intrusion, quality degradation
  - Other information

Integrated Regional Water Management Programs

- **2002** - Senate Bill 1672 creates the Integrated Regional Water Management Act to encourage local agencies to work cooperatively to manage local and imported water supplies to improve the quality, quantity, and reliability.
- 2002, 2006 bonds passed to support IRWM
- Grants are available for planning & implementation

Identification of recharge areas

- If you pump groundwater, your next question should be, “Where is the recharge area and how much recharge occurs each year.”
- AB 359 requires that gwmps include a map of the recharge area

California Water Plan

- Includes more groundwater issues than ever
- Groundwater is being integrated into water planning
- More data are needed
- Resource Management Strategies
  - Groundwater and Aquifer Remediation
  - Conjunctive Management and Groundwater
- Future plans include water budgets

Groundwater Management Plans

- 117 groundwater management plans have been reviewed
  - Pre-SB 1938
  - Post-SB 1938
- Review determined how many components of SB 1938 were included

Figure 1 - Map of Groundwater Management Plan Coverage

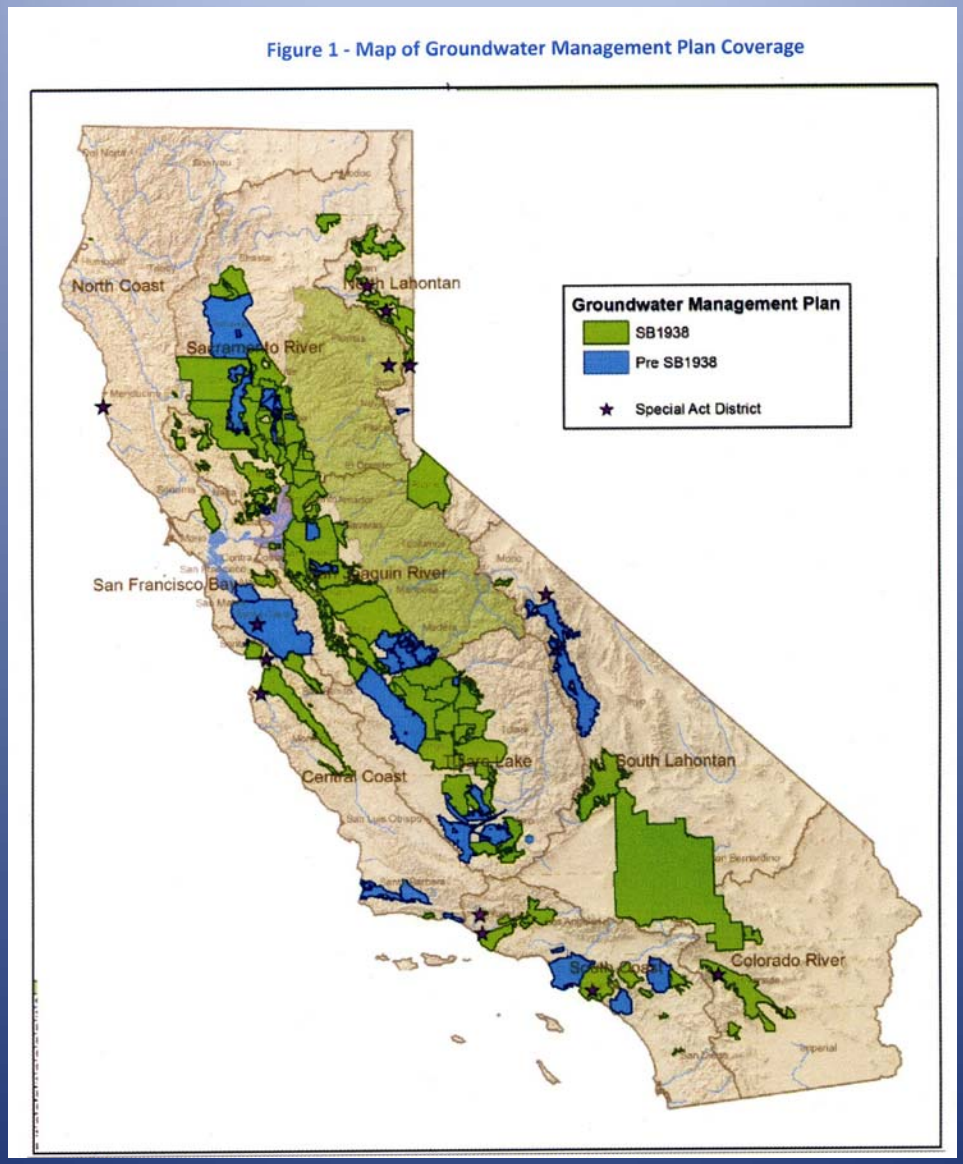
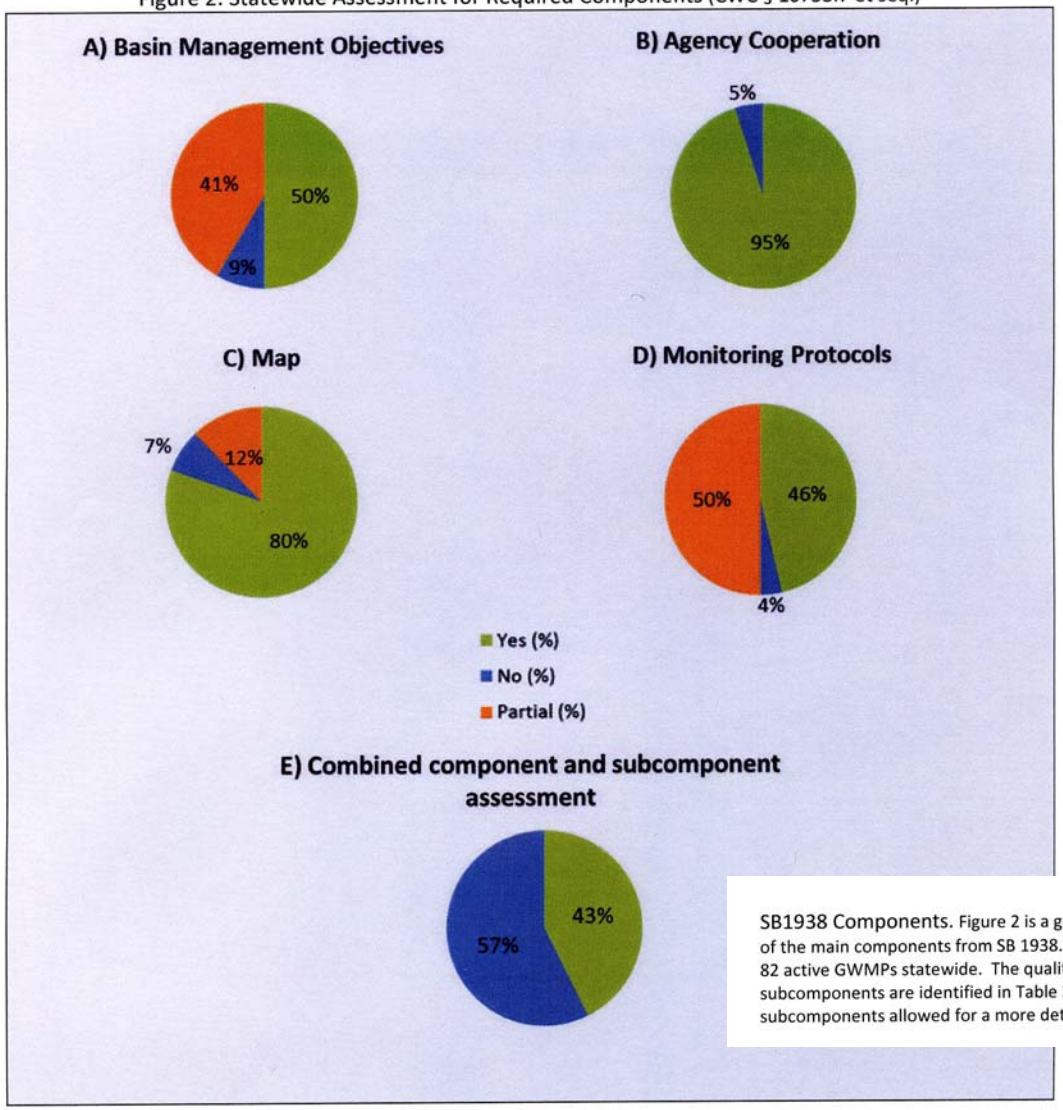


Figure 2: Statewide Assessment for Required Components (CWC § 10753.7 et seq.)



SB1938 Components. Figure 2 is a graphical presentation of the assessment results for each of the main components from SB 1938. Table 2 lists the overall assessment percentages for the 82 active GWMPs statewide. The qualitative analysis of the SB 1938 components and subcomponents are identified in Table 2 and are discussed in more detail below. The use of subcomponents allowed for a more detailed analysis of the assessed GWMPs.

But all of that is not enough!!!

- Every basin needs a water budget
- The amount of available water is limited
- The correlative right of each landowner should be established by gwmp, statute or court decision
- Municipalities, growers and industries need certainty for planning and safety
- But is that possible?

Inflow – Outflow = Change in storage

- Inflow
  - Infiltration from precipitation
  - Infiltration from streams and unlined canals
  - Groundwater flow into the aquifer
  - Artificial recharge
  - Deep percolation from irrigation
- Outflow
  - Groundwater entering streams flowing out of the basin
  - Groundwater flow out of the aquifer
  - Pumping
  - Consumptive use
  - evapotranspiration

Impediments to groundwater management

- Judicial & statutory action in the 1800s and early 1900s
- A plethora of local agencies complicate basin management
- Unknown amount of gw pumped
- Unknown amount of recharge
- Unknown correlative rights of property owners in each basin

Consider these heresies

- Many local agencies in the same basin make management difficult—should some local agencies be eliminated?
- 19th & 20th century laws may not be adequate for 21st century water demand & available supply--should those laws be amended?
- Have we exceeded the carrying capacity of our water supply?
- How can "investment backed expectations" be met when dealing with hydrologic reality?

And

- What about the effects of climate change and prolonged drought?
- “Nobody’s going to get the amount of water they are hoping for,” said Sally Jewell, U.S. Secretary of the Interior about today’s drought
- Or will this become the common theme of future water availability?

Conclusions

- If the state had permitting jurisdiction over groundwater would management be better?
- John Muir said, “Nothing that is dollarable is safe”
- At present groundwater is a commons
  - Everyone uses groundwater
  - No one is responsible for managing groundwater except in a few basins

Conclusions

- Court decisions (adjudication) are a form of permitting
- Groundwater extraction must be regulated to prevent more subsidence
- Groundwater extraction should be metered and reported to the groundwater management agency
- Political, legal, institutional, technical & economic constraints determine results

Good books

- **Water Follies** by Robert Glennon—Groundwater pumping and the fate of America's fresh waters
- **Unquenchable** by Robert Glennon—America's water crisis and what to do about it
- **The West Without Water** by B. Lynn Ingram and Frances Malamud-Roam—What past floods, droughts, and other climatic clues tell us about tomorrow
- **USGS Circular 1376**—Streamflow depletion

And finally---

- Barry Commoner's Laws of Ecology
  - Everything is connected to everything else
  - Everything has to go somewhere
  - Nature knows best
  - There is no such thing as a free lunch