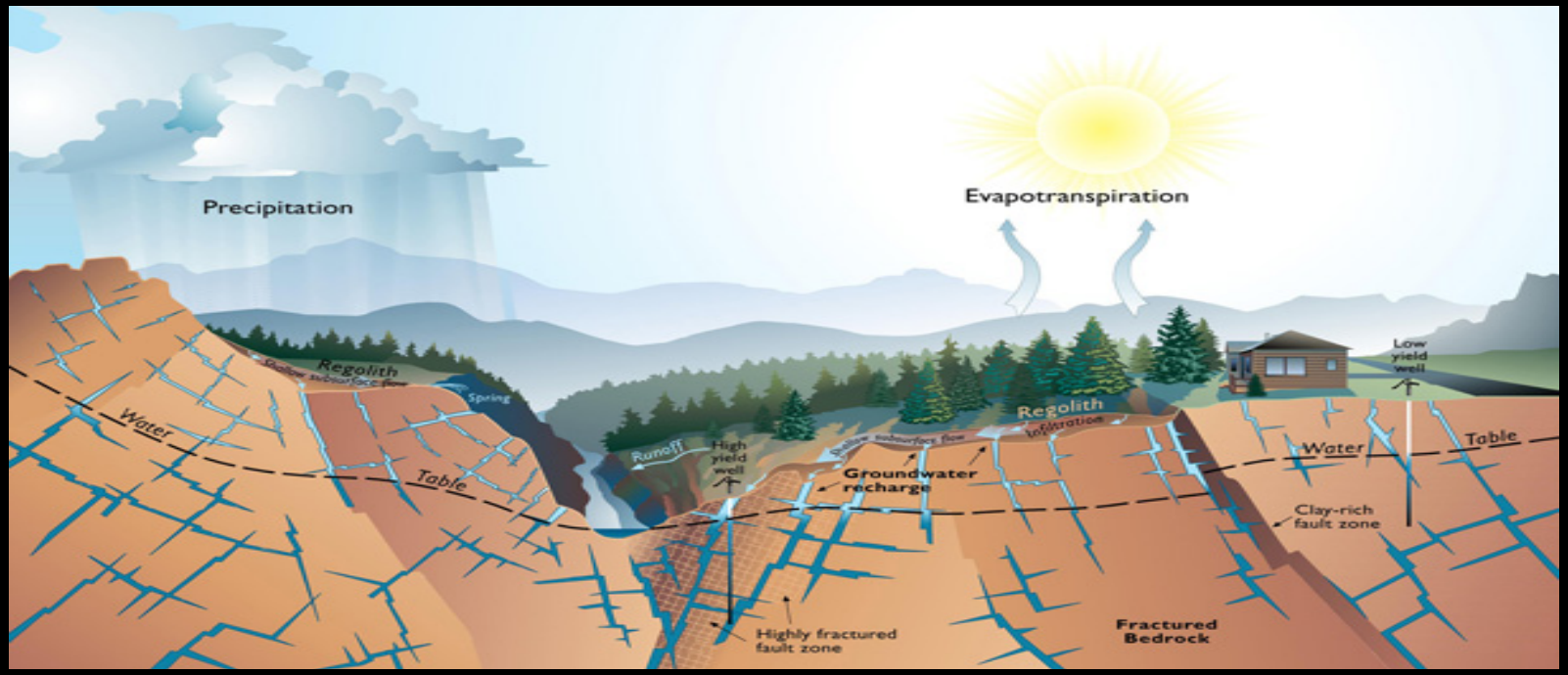
Groundwater in Fractured Rock Aquifers
Well Location, Yield, and Sustainability



Water Education Foundation Briefing
Water Year 2016: San Joaquin Valley Groundwater Conditions

John Kirk, PG, CEG, CHG
Engineering Geologist
Division of Integrated Regional Water Management
South Central Region Office

DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA

Burning Questions

- What is a fractured rock aquifer?
- How does it differ from an alluvial aquifer?
- How much water is stored in fractures?
- What are typical well yields?
- Is pumping sustainable?
- What about groundwater quality?

What is a Fractured Rock Aquifer?

There are two main types of aquifers: alluvial and fractured rock.

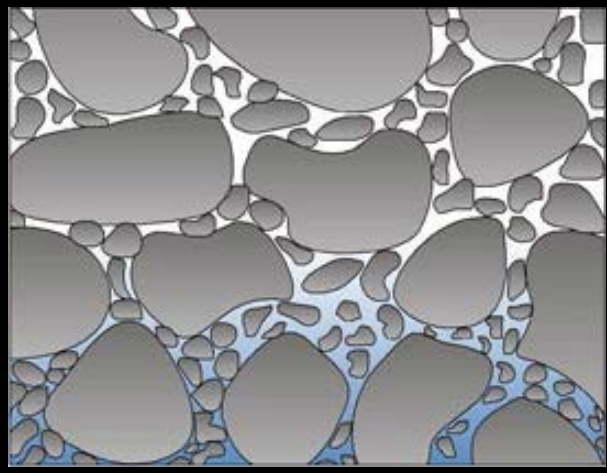
The primary distinction:

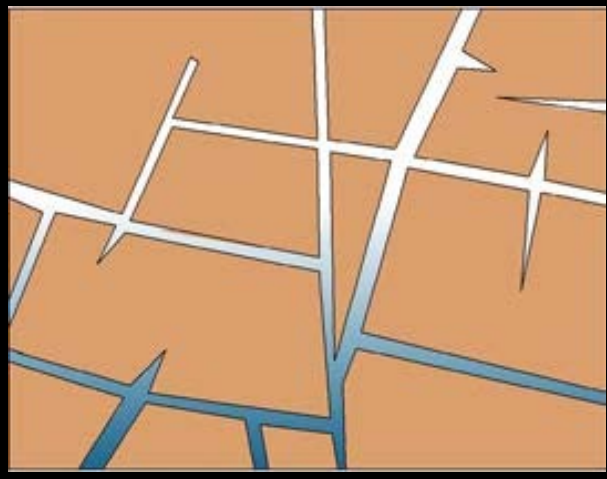
- An alluvial aquifer stores and transports water through sediment pores

- A *fractured rock aquifer has limited storage capability and transports water along planar breaks.

*aka bedrock, crystalline rock, hard rock, basement.

(Alluvial Aquifer)

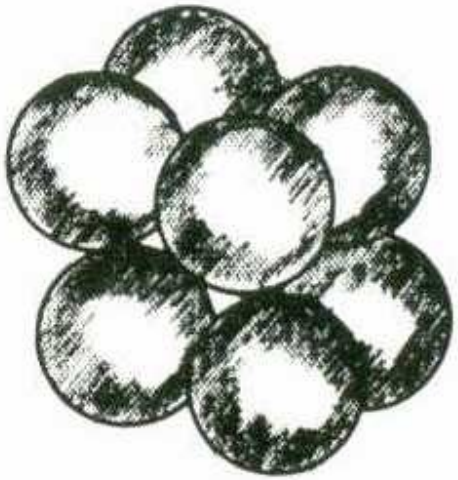




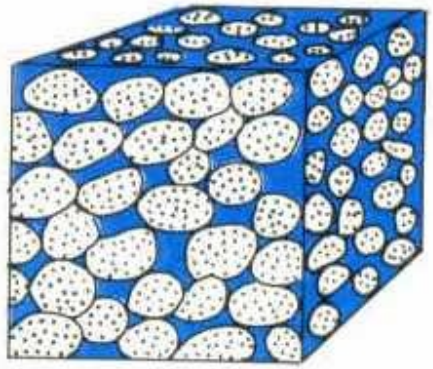
(Water Bearing Fractured Rock)

Porosity

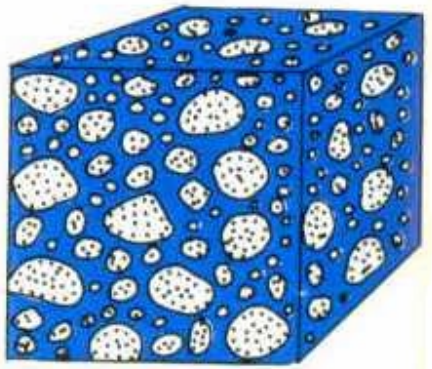
Primary Porosity



POROUS MATERIAL

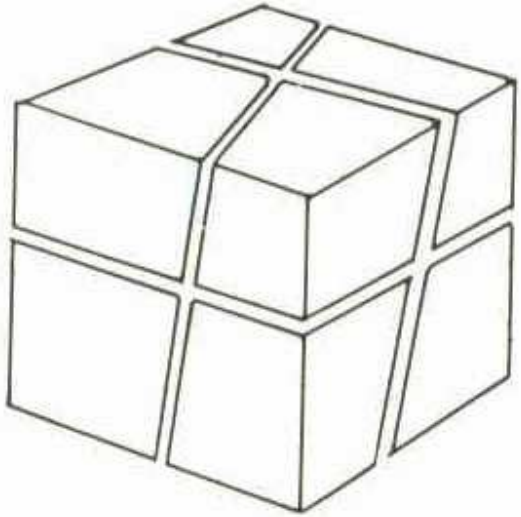


WELL-SORTED SAND

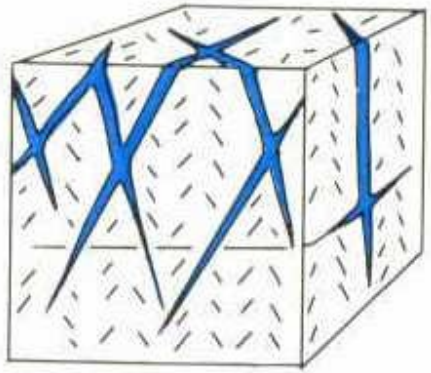


POORLY-SORTED SAND

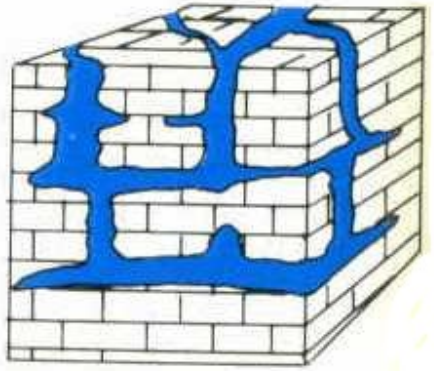
Secondary Porosity



FRACTURED ROCK



FRACTURES IN GRANITE

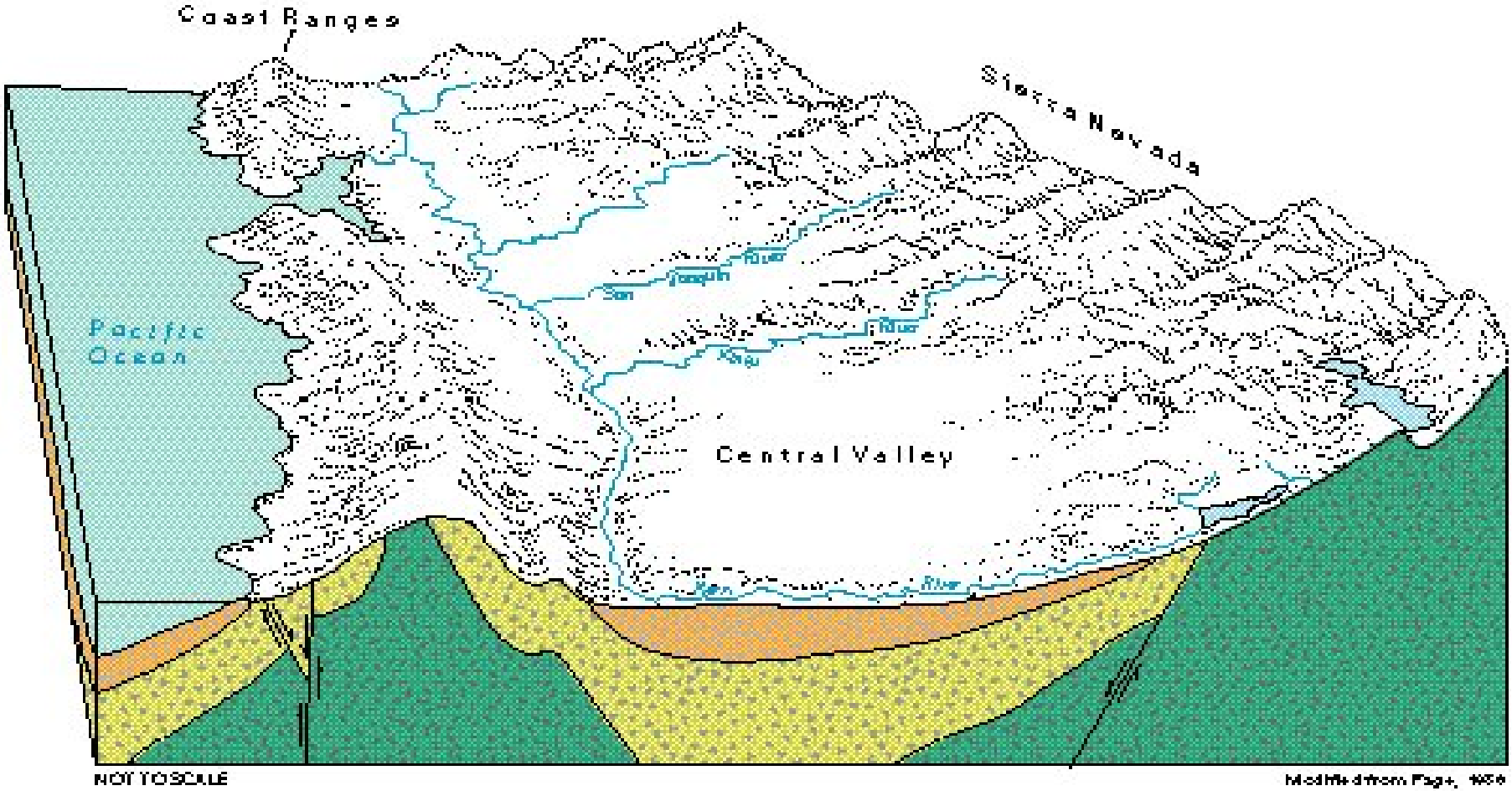


CAVERNS IN LIMESTONE

USGS

Alluvial Aquifers

- Unconsolidated sediment
- Underlies valley floors & coastal plains



California's Groundwater Basins

Alluvial aquifers –

Fractured rock need not apply

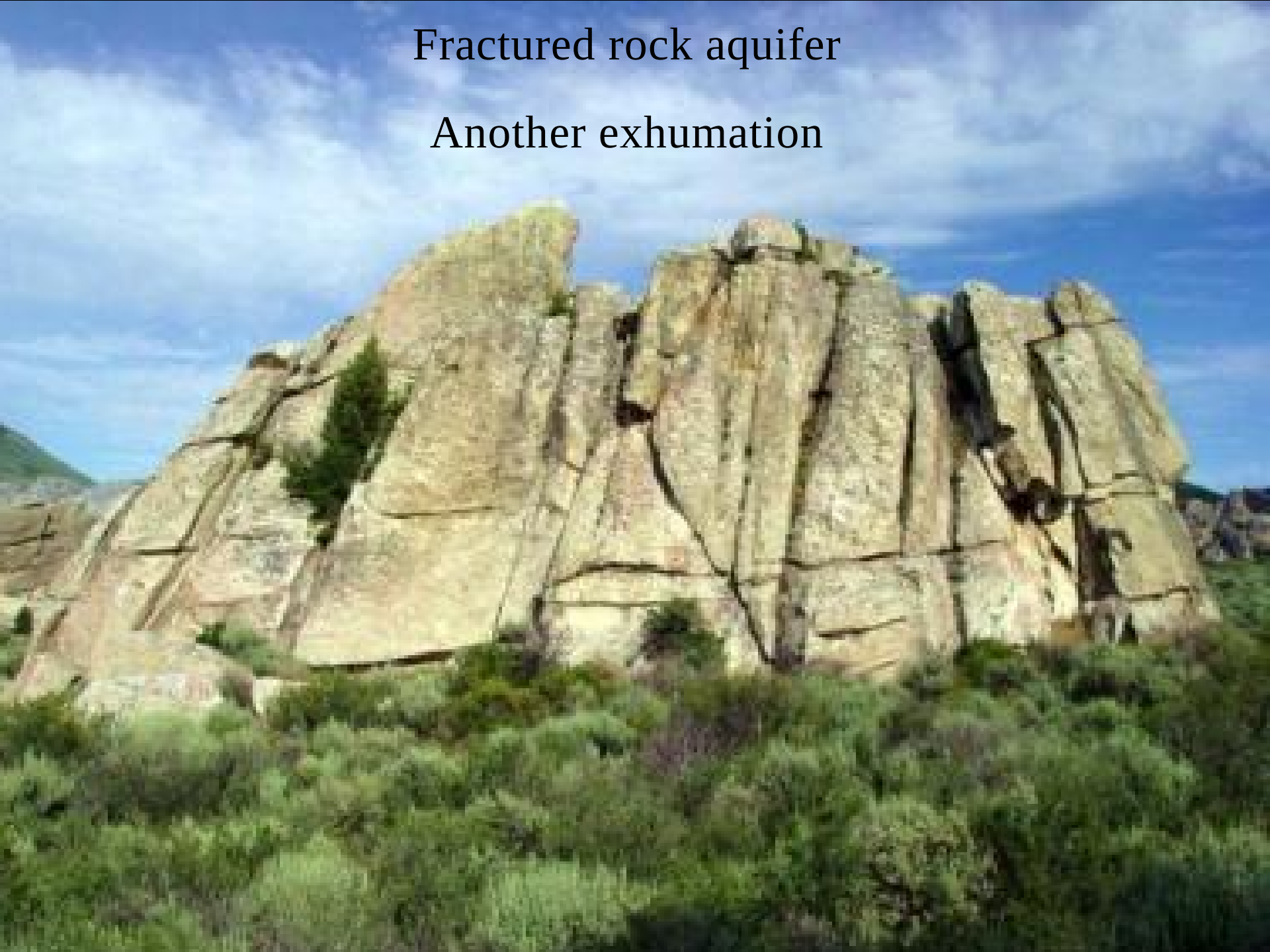
515 alluvial basins/subbasins

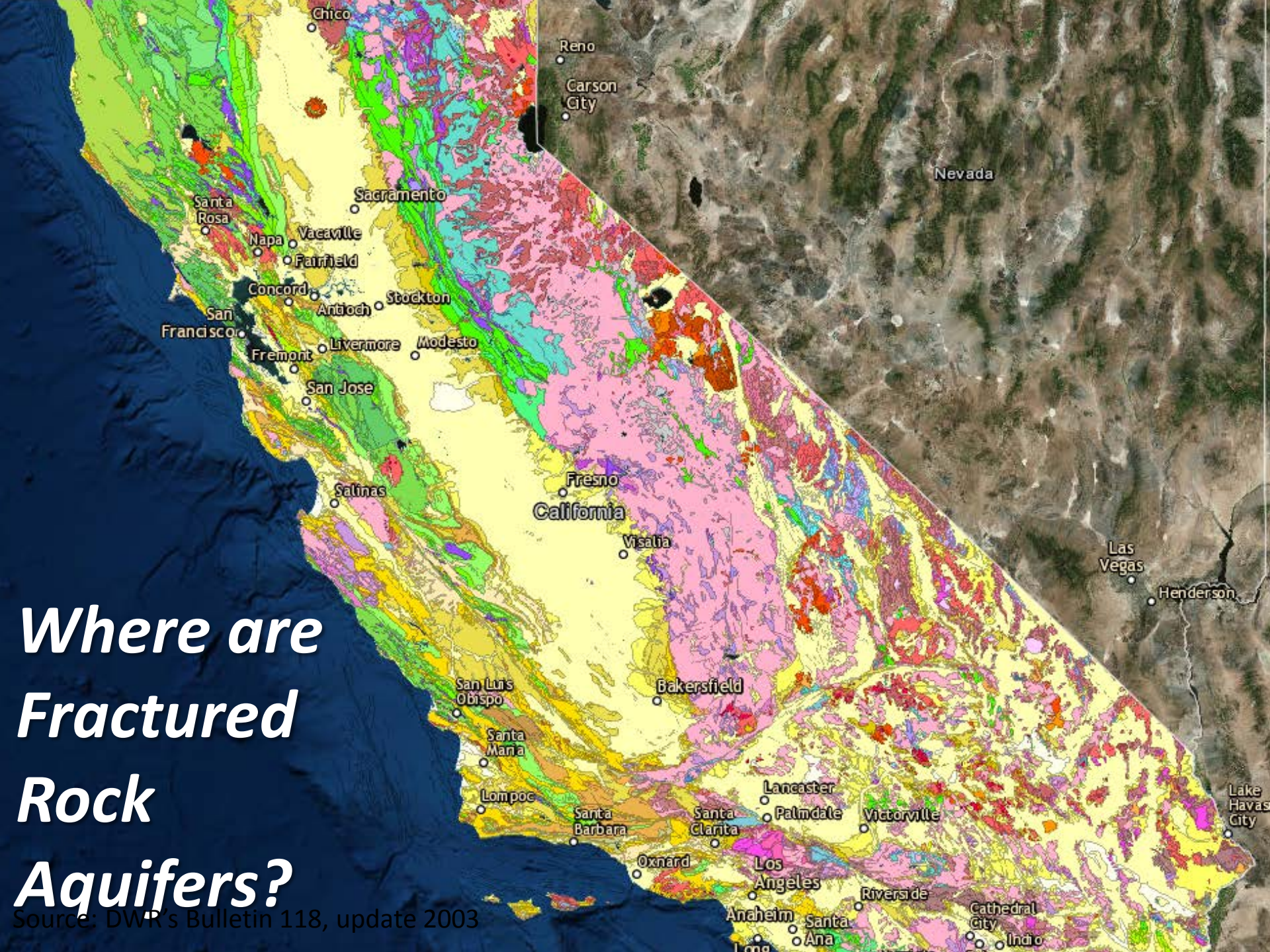
Source: DWR's Bulletin 118, update 2003


I-80
Exit Street View
An alluvial aquifer
exhumed for your viewing
© 2015 Google
© 2015 Google
Google earth
Report a problem

Fractured rock aquifer

Another exhumation

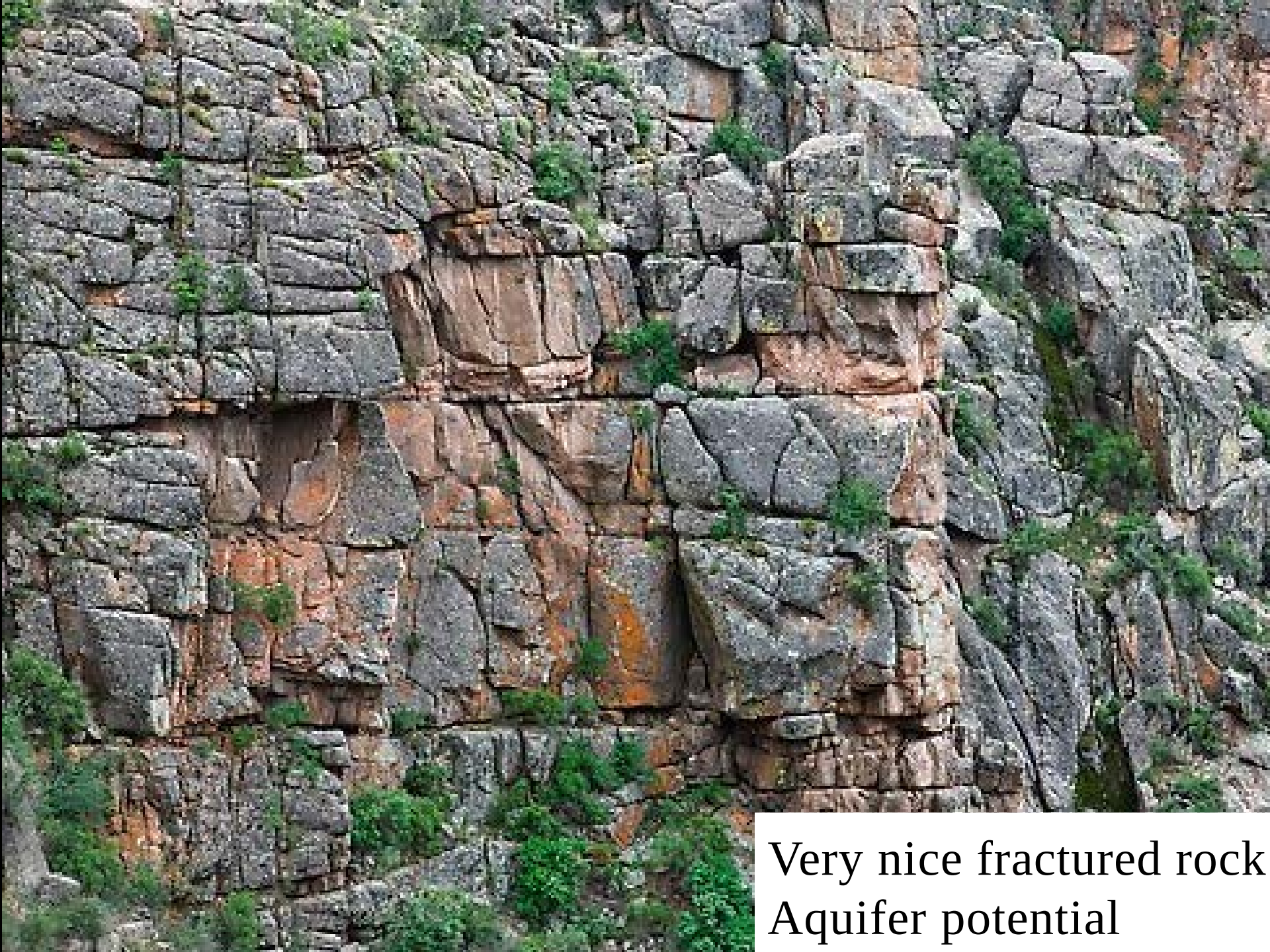




Where are Fractured Rock Aquifers?

Source: DWR's Bulletin 118, update 2003

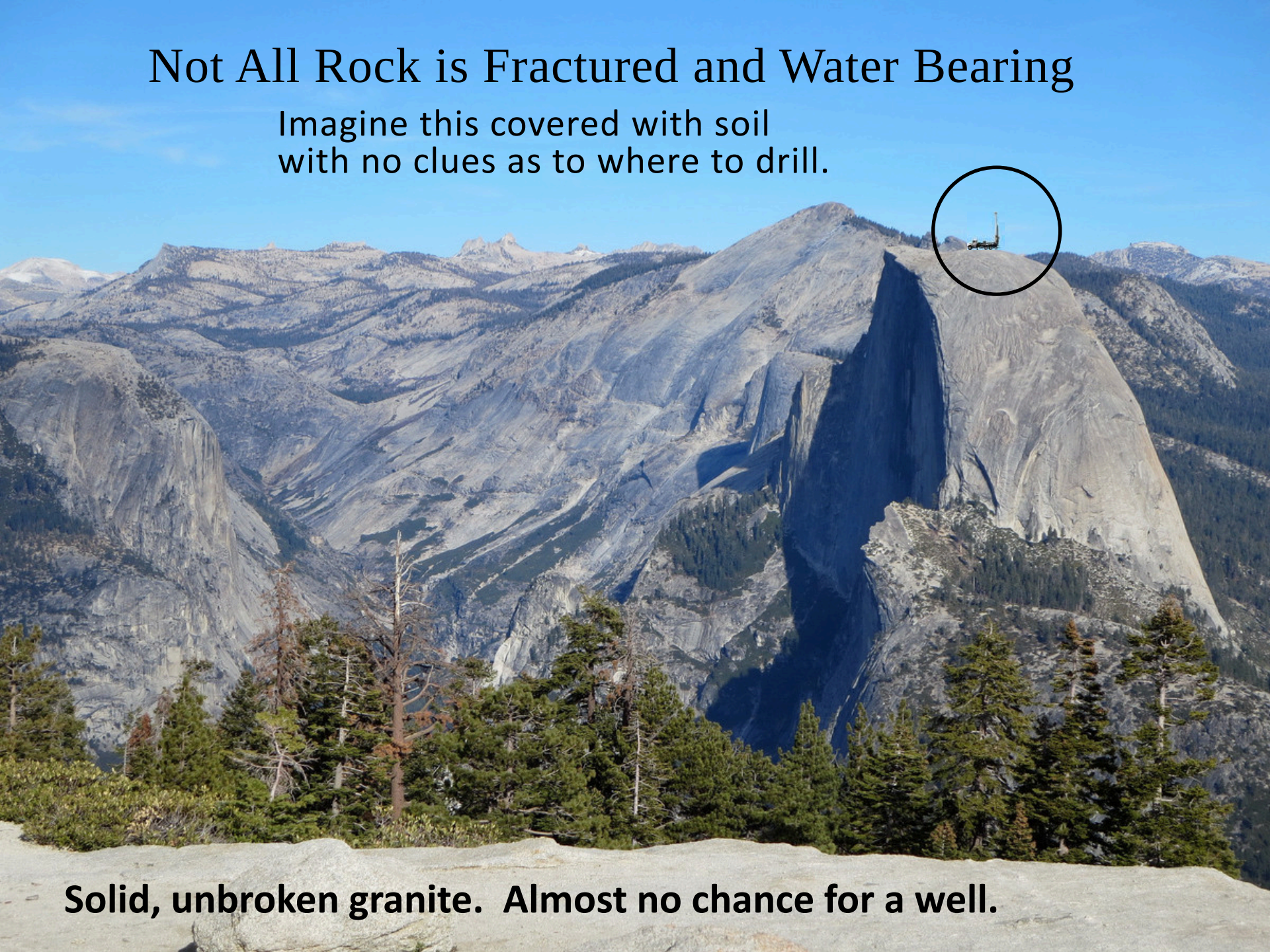

Regular fracture pattern, closely spaced cracks with large openings. Drill here!



Very nice fractured rock
Aquifer potential

Not All Rock is Fractured and Water Bearing

Imagine this covered with soil
with no clues as to where to drill.



Solid, unbroken granite. Almost no chance for a well.

Hints to an aquifer’s location.

Hints to an aquifer’s location.

What is the Relationship between Fractures and Well Production?

Fractures are the main or only way groundwater is stored and transmitted.

How much water a well produces depends on:

- Size and depth of fracture opening
- Fracture spacing
- Interconnection of fractures
- A source of recharge

Source: DWR Water Facts 1.

Fractured Rock Aquifers

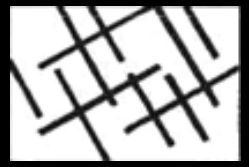
Storage & Permeability Depends on Secondary Porosity

Fracture Characteristics

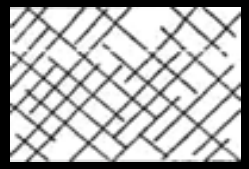
Unfavorable

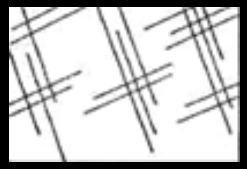
Favorable

-Size and Depth –

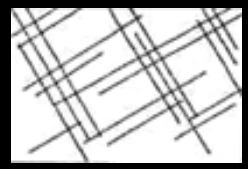


- Spacing –





- Interconnection –



How Much Water is Stored in Fractures?

1 cubic foot of:

- unconsolidated alluvial sediment with a porosity of 15%-50% contains:

1.4 to 3.7 gallons of water

- impermeable rock with a fracture 1 mm in width contains:

0.03 gallons of water

Groundwater stored in a fractured rock aquifer is much less than 2% of the rock volume.

Source: DWR Water Facts 1.

Well Yield

How will you know if you'll get a high production well?

You won't.

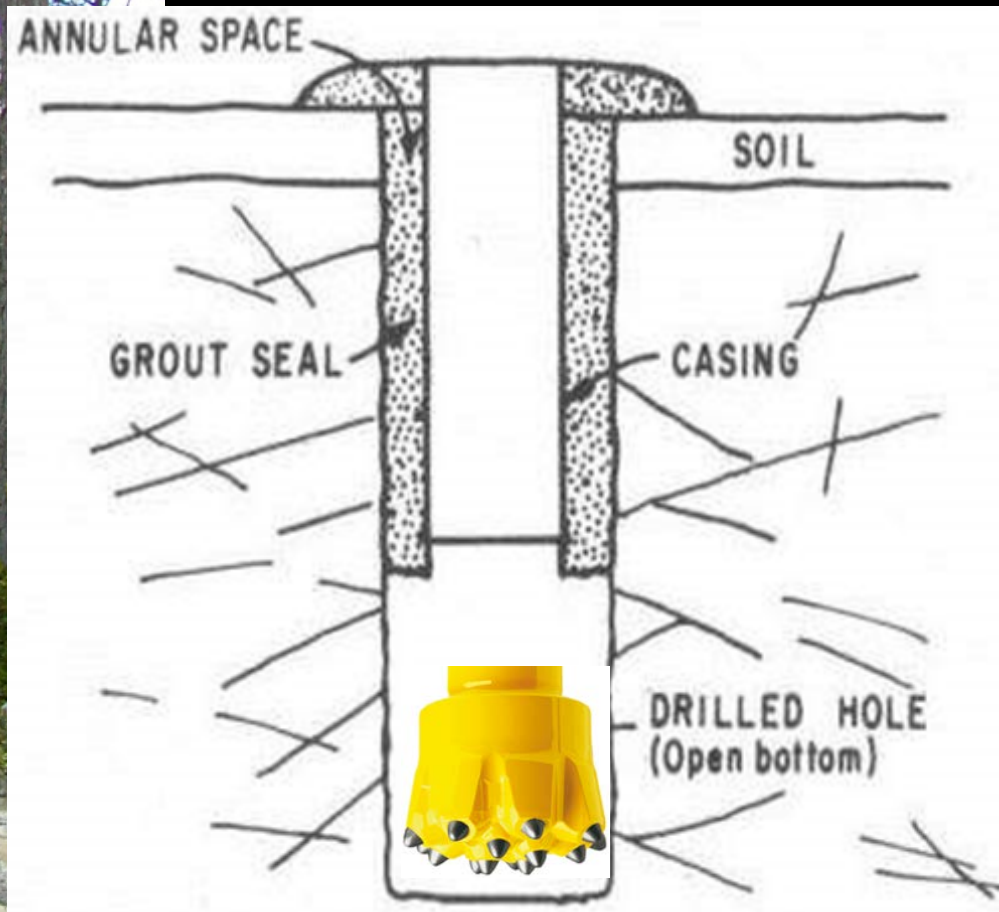
- Half of all hard rock wells yield 0 to 10 gpm. Depending on the area, 10% or more of the wells drilled could be dry.
- Wide range in well production: dry to several hundred gpm.

Well Yields in Fractured Rock Aquifers

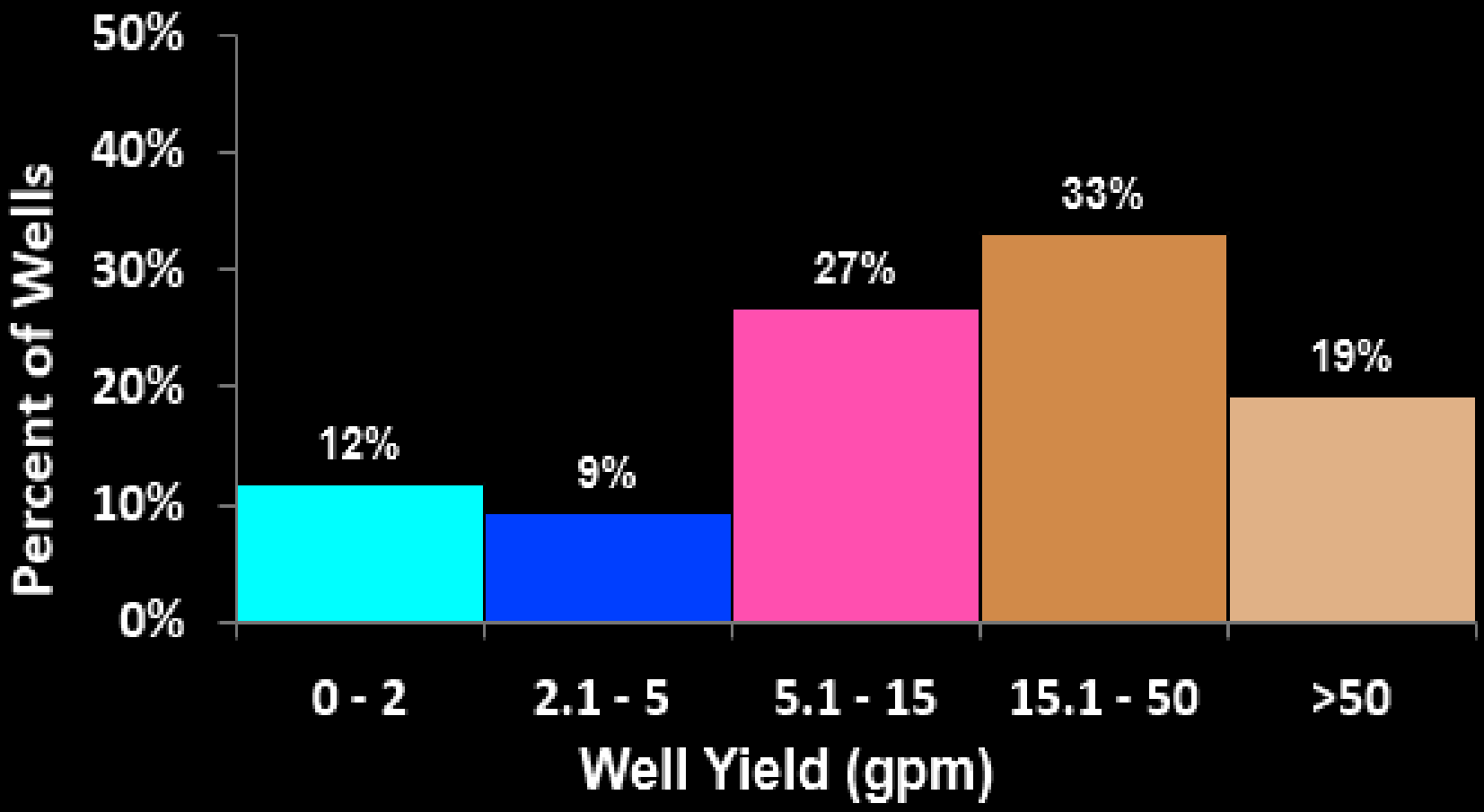
Higher Yields	Lower Yields
Gentle slopes	Steep slopes
Swales or valley bottoms	Hilltops
W/in 100 feet of lineament	No lineaments
Near surface water	No surface water
Fractures on major trends	No fracture trend
Large drainage area	Small drainages
Commercial well	Shallow, private well

Source: USGS Prof. Paper 1660, “Factors Related to Well Yield in the Fractured-Bedrock Aquifer of New Hampshire.

Require Specialized Drilling Equipment



*Well Yields in the Three Rivers Area



*Well yields were estimated by air lift at the time of drilling. These are only rough estimates of the wells long-term pumping capacity.

A rule of thumb to estimate in-use pumping capacity is 1/4 to 1/2 of the air lift test.

Dry Wells

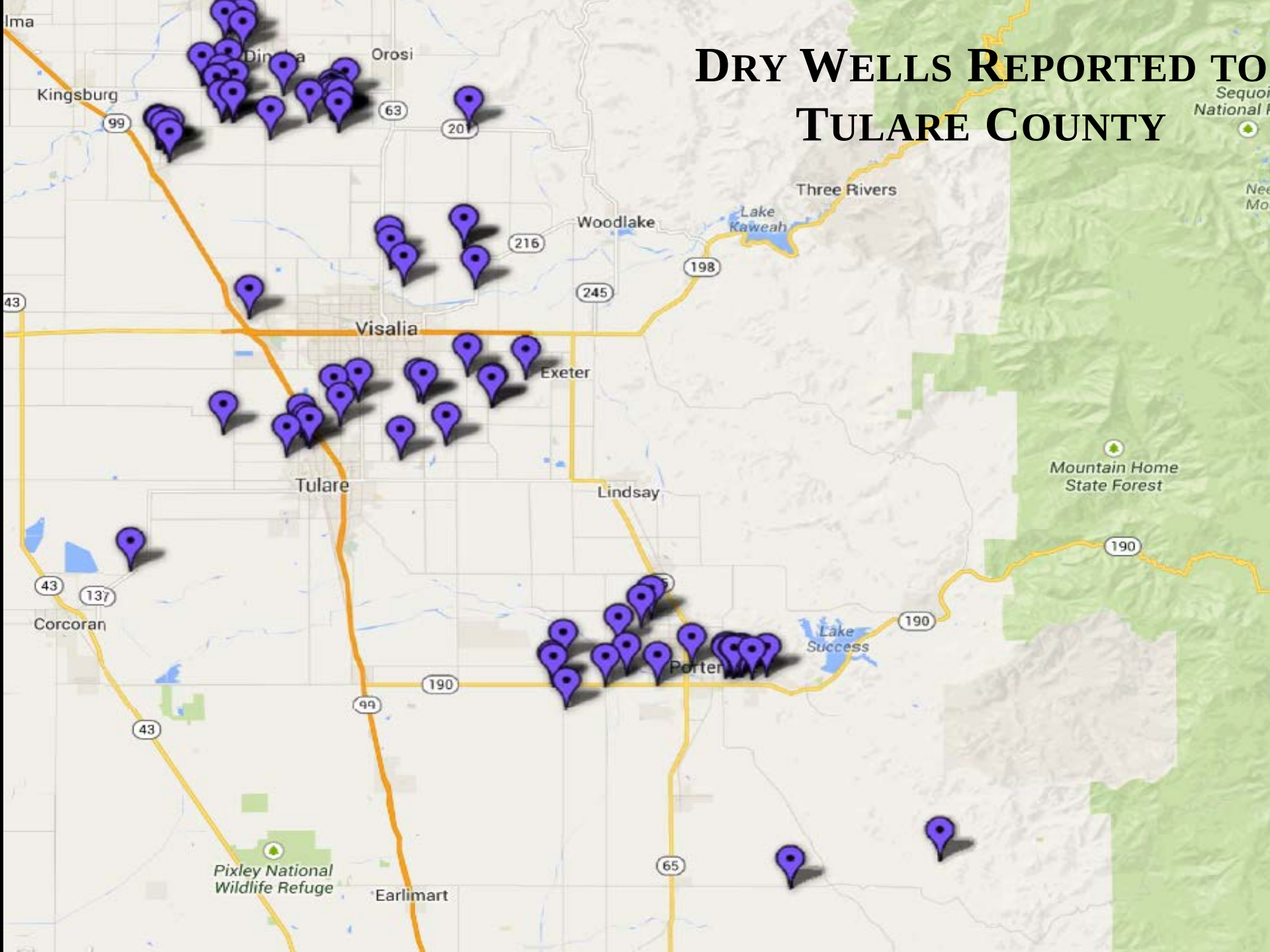
There is no requirement to report a dry well and little is known about their occurrence.

Anecdotal information comes from visits to DWR by worried homeowners with dry wells.

There have been areas where individual homesites and/or groups of homes have dry wells with failed repeated attempts to re-drill.

Shallow wells or wells with only shallow fractures dry up first.

Dry Wells Reported to Tulare County



How Deep Should I Drill?

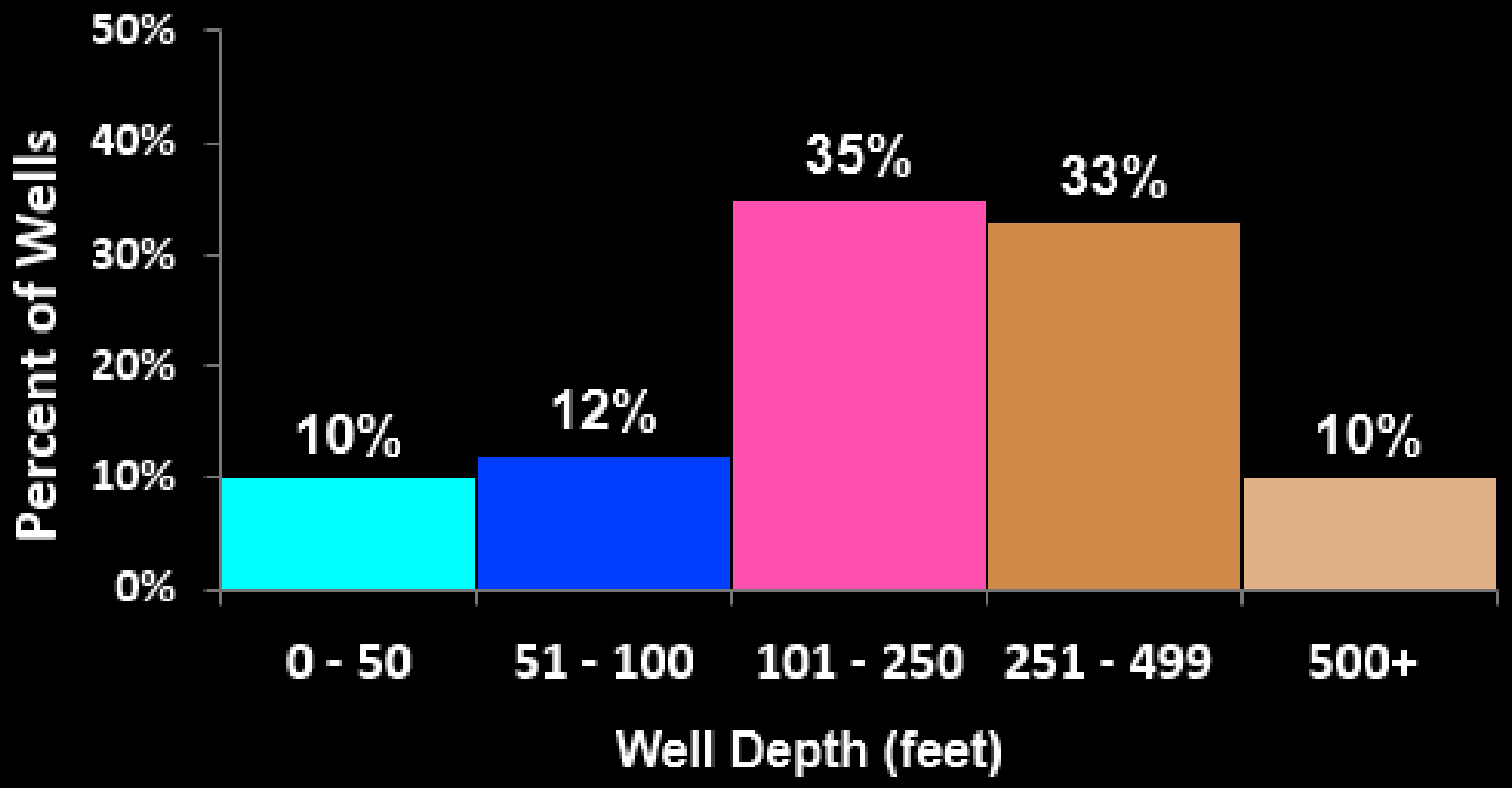
Common practice concludes that fracture size and interconnection decrease with depth.

- A USGS Nevada County study concluded that most fractures occur above 215 feet. Below this depth there is an abrupt decrease in well yield.

- A USGS study “Optimum Depth of Wells in Crystalline Rocks” concluded wells should be less than 150 to 250 feet and commercial wells less than 600 feet.

- A Shaver Lake study found most wells were above a depth of 180 feet with yields of 3 to 17 gpm.

Well Depths in the Three Rivers Area

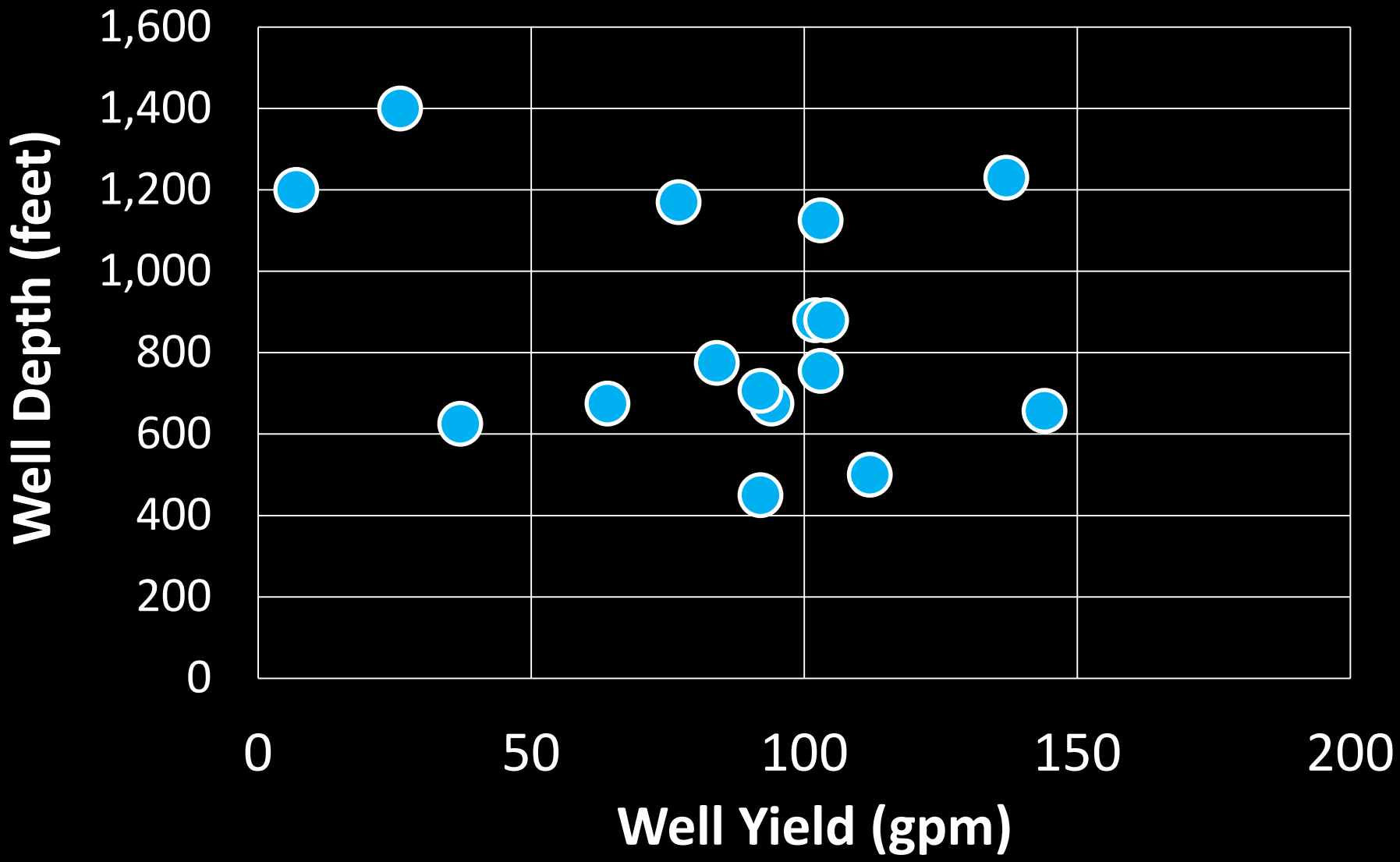


On the Other Hand

Deep fractures may provide higher yielding wells. Examples:

- Fishcamp resort development with 5 wells 1,000 feet deep all producing 50 to more than 100 gpm
- Millerton Lake land development where a single fracture at 970 produced >100 gpm.
- Coarsegold residential development with higher yields.

Coarsegold Area Development



Should I stay or should I go?

This raises the question: If while drilling, few water-bearing fractures are encountered, should I

1. stop drilling at my current depth and find a 2nd drill site, or
2. continue drilling to greater depths?

Answer: seek advice from experienced professionals.

How Much Water Do I Need from My Well?

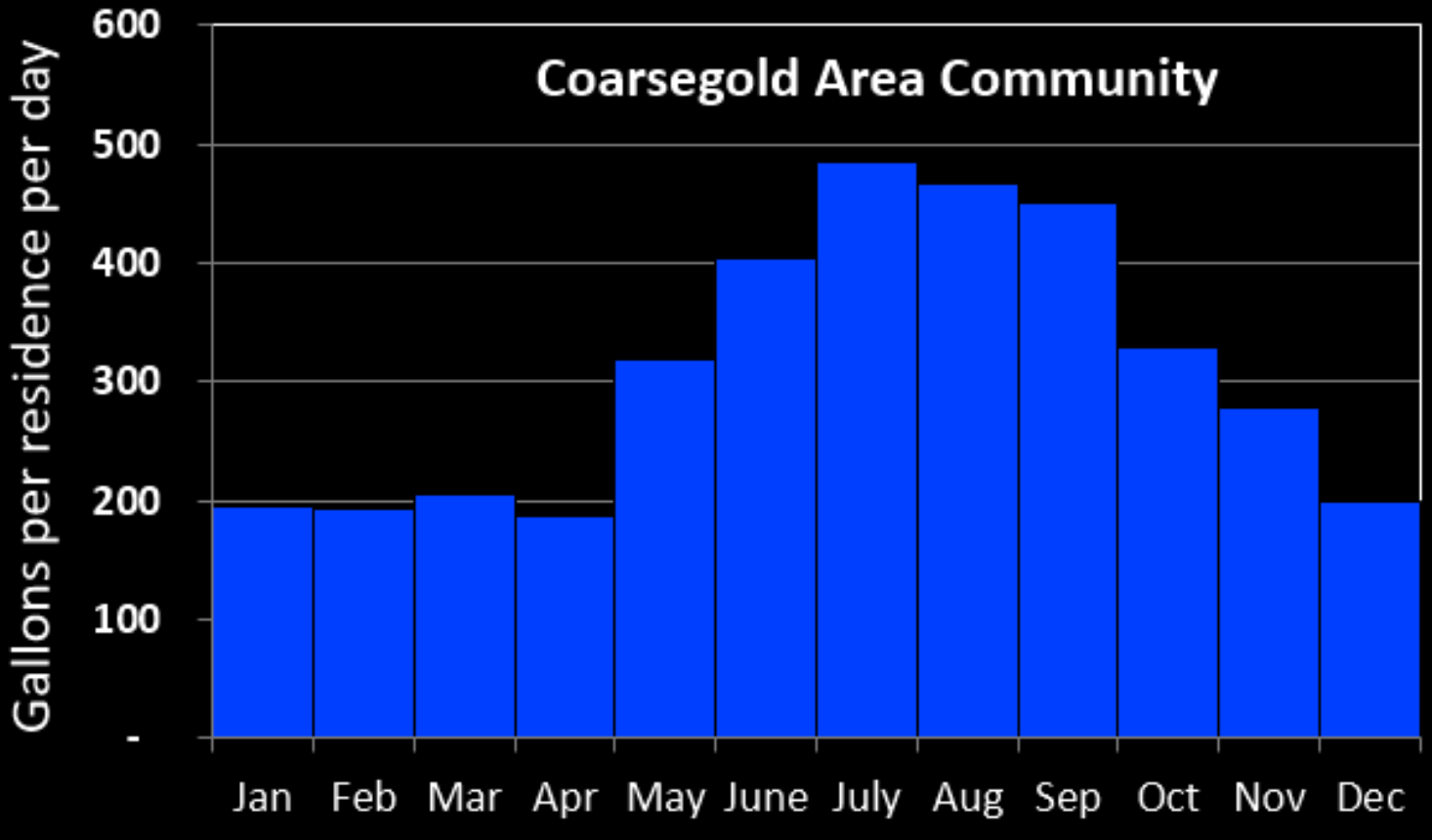
Water Demand For An Individual Household

Annual Water Use

- US EPA estimate: 300 gallons/day.
- 2011 California single-family estimate: 360 gallons/day.
- Foothill community near Coarsegold: 310 gallons/day – average
  (from water meters so includes all water use).
- County building/health departments commonly require more for minimum well capacity.

But, Water Demand Varies Greatly by Season

- Winter: 195 gallons/day (0.15 gpm continuous pumping)
- Summer: 480 gallons/day (0.35 gpm continuous pumping)
- Annual use: 110,000 gallons per home (0.34 acre-feet).

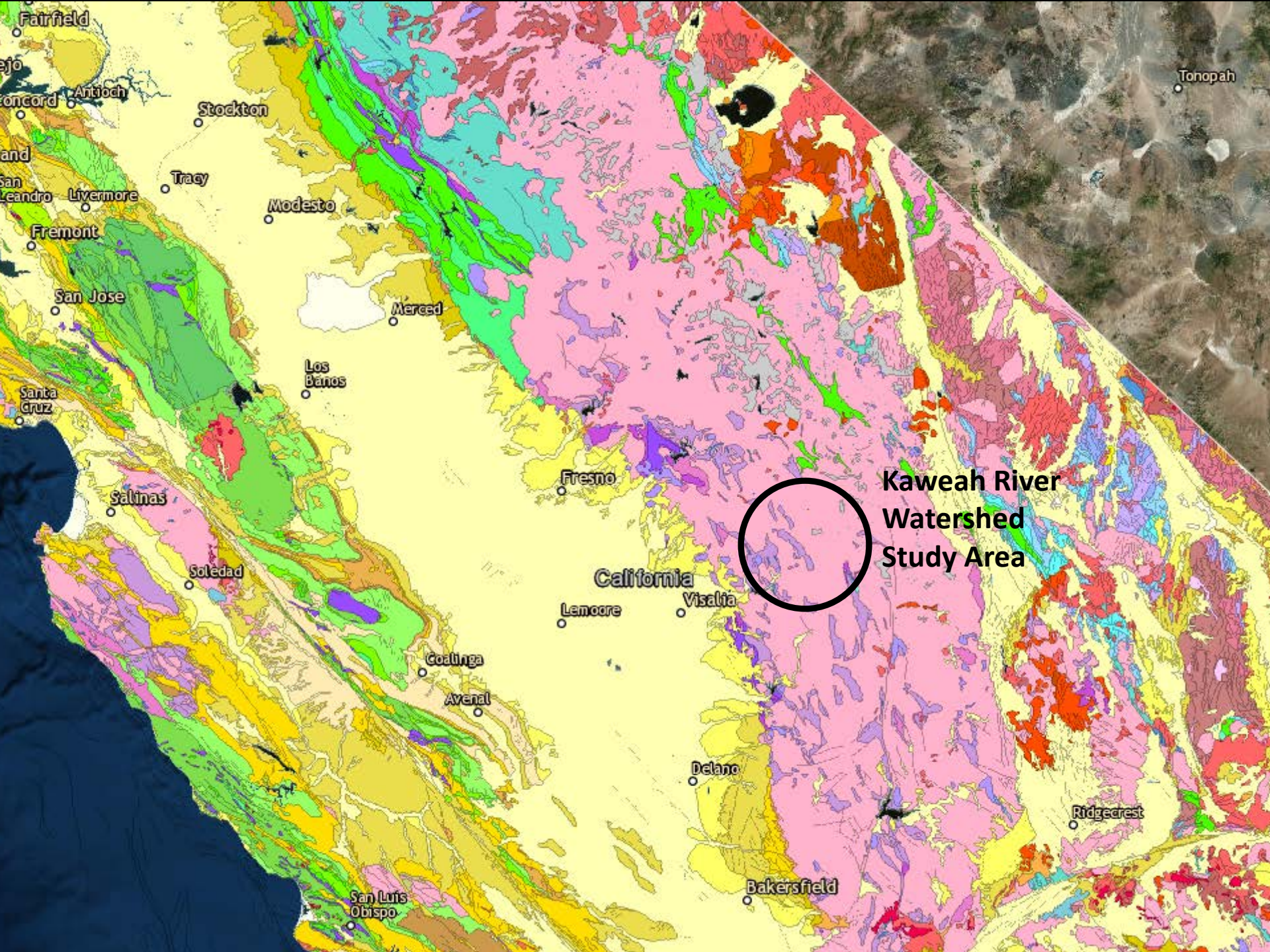


How Sustainable is Pumping?

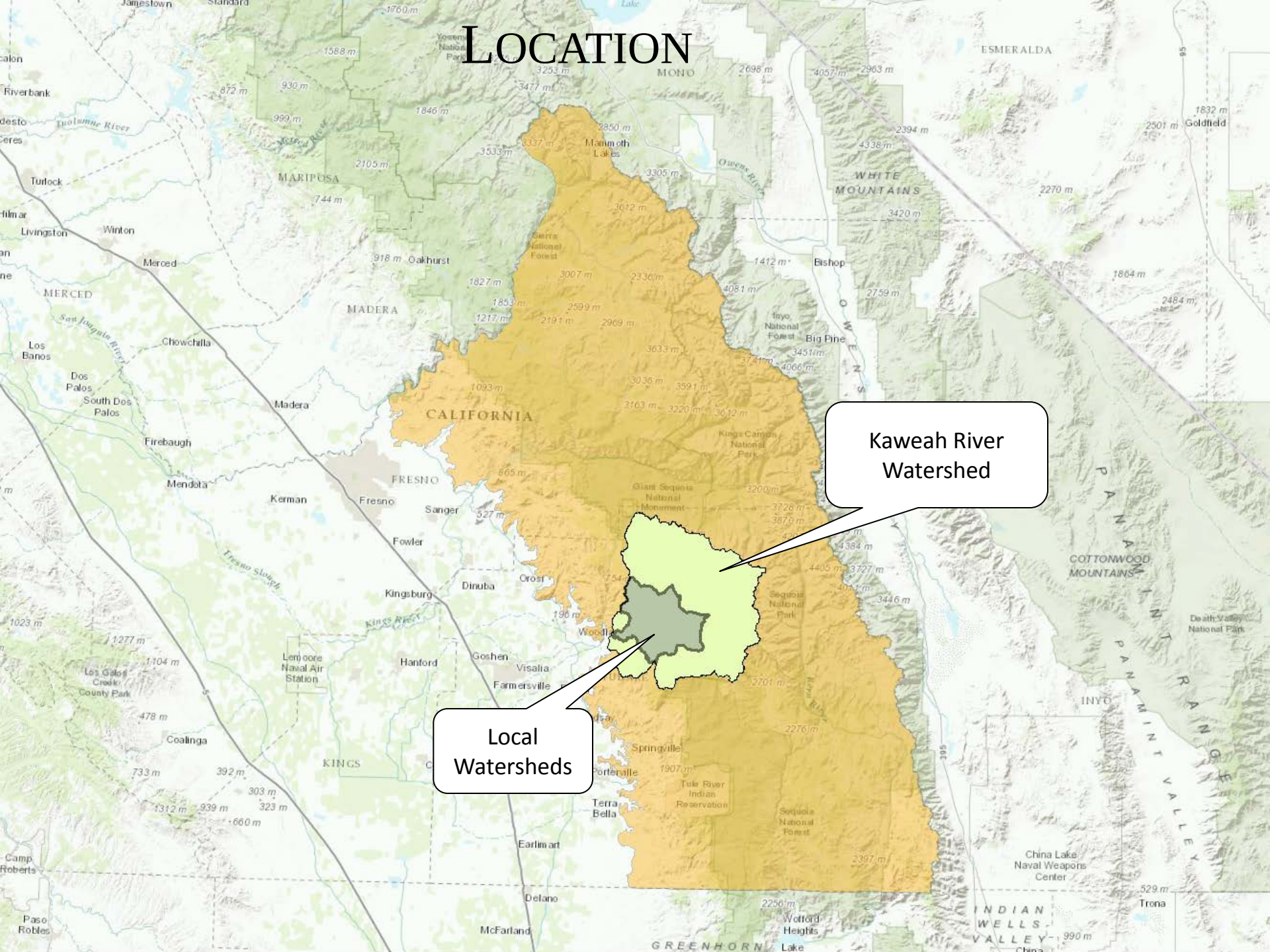
Two Methods Used

- **Water balance (Three Rivers area)**
- **Groundwater hydrographs (Coarsegold area)**

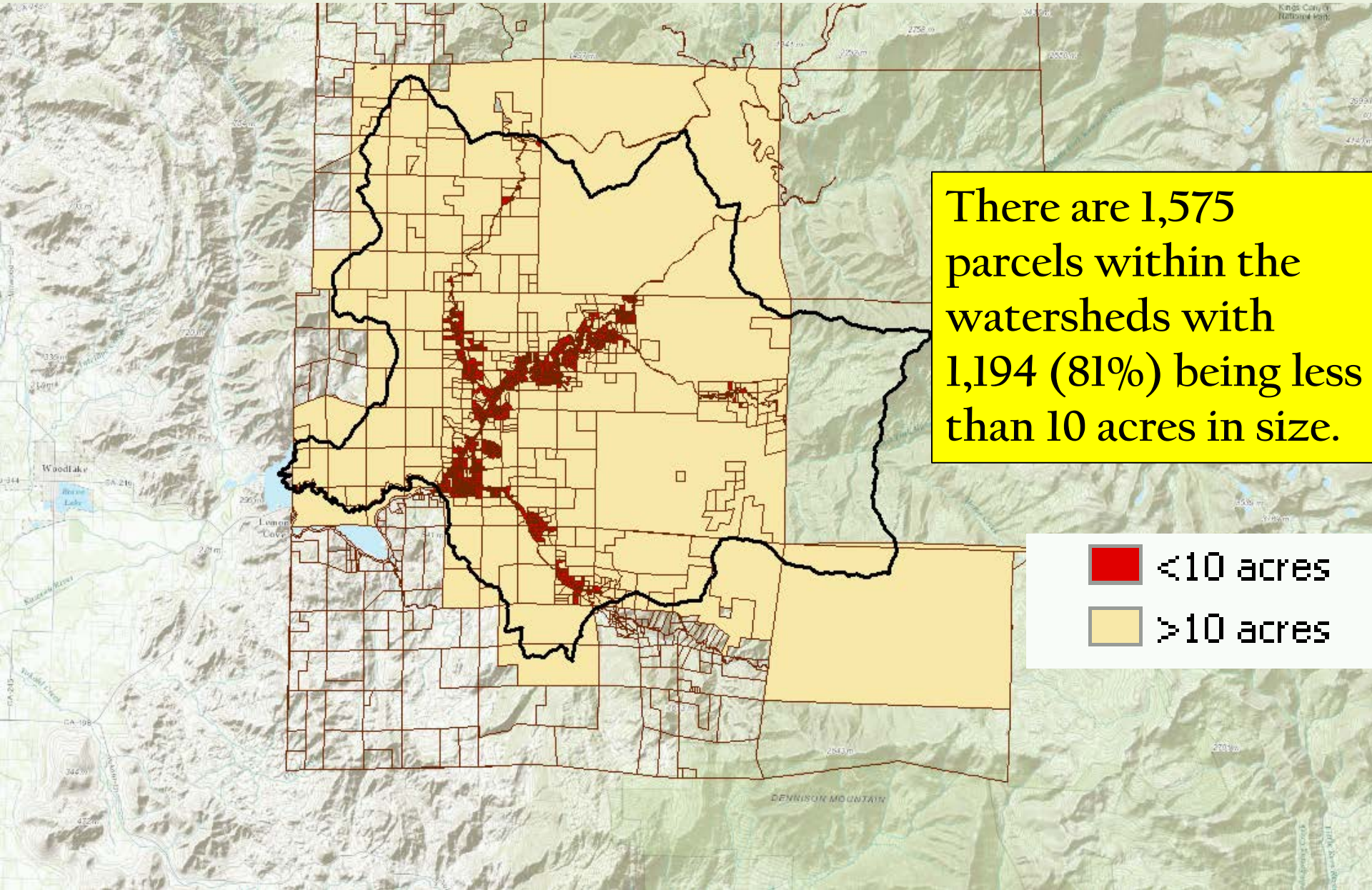
Water Balance Example from Three Rivers Kaweah River Watershed


Fairfield
Antioch
Stockton
Tracy
Livermore
Modesto
Fremont
San Jose
Merced
Los Banos
Santa Cruz
Salinas
Soledad
Fresno
California
Visalia
Lemoore
Coalinga
Avenal
Delano
Bakersfield
Ridgecrest
Tonopah
San Luis Obispo
Kaweah River Watershed Study Area

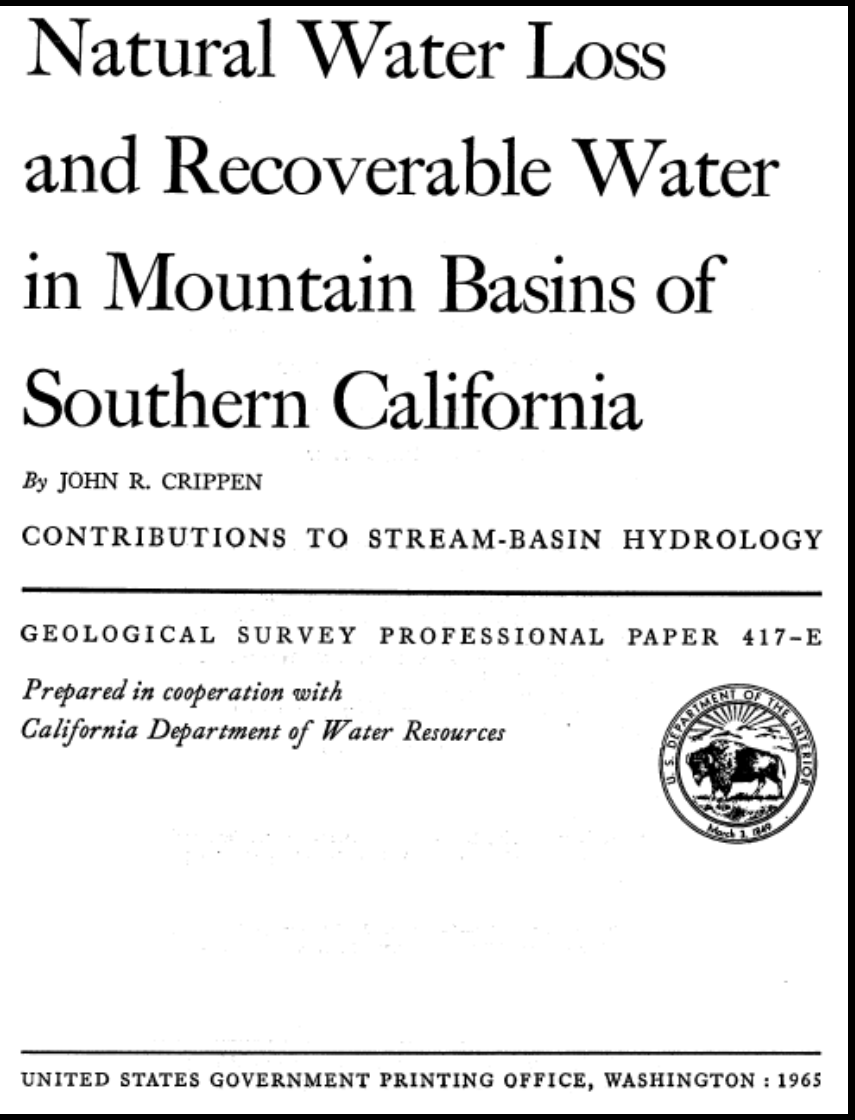
LOCATION


Kaweah River Watershed
Local Watersheds
CALIFORNIA
MONO
MARIPOSA
MADERA
FRESNO
KINGS
INYO
MERCED
ESMERALDA
WHITE MOUNTAINS
COTTONWOOD MOUNTAINS
PANAMINT RANGE
INDIAN WELLS VALLEY
Mammoth Lakes
Bishop
Big Pine
Oakhurst
Merced
Madera
Fresno
Clovis
Sanger
Kingsburg
Dinuba
Orosi
Visalia
Tulare
Hanford
Goshen
Farmersville
Lemoore Naval Air Station
Coalinga
Firebaugh
Mendota
Kerman
Chowchilla
Los Banos
Dos Palos
South Dos Palos
Turlock
Livingston
Winton
Riverbank
Jamestown
Springville
Porterville
Terra Bella
Earlimart
Delano
McFarland
Woodlake
Exeter
Lindsay
Tule River Indian Reservation
Sequoia National Forest
Sierra National Forest
Inyo National Forest
Kings Canyon National Park
Giant Sequoia National Monument
Sequoia National Park
Death Valley National Park
China Lake Naval Weapons Center
Trona
Goldfield
Owens River
Kings River
Tuolumne River
San Joaquin River
Fresno Slough
Los Gatos Creek County Park
Camp Roberts
Paso Robles
Wofford Heights
Lake

Watersheds and Residential Lots of the Three Rivers Area



Groundwater Recharge
Methodology



Natural Water Loss and Recoverable Water in Mountain Basins of Southern California

By JOHN R. CRIPPEN

CONTRIBUTIONS TO STREAM-BASIN HYDROLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 417-E

Prepared in cooperation with California Department of Water Resources

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

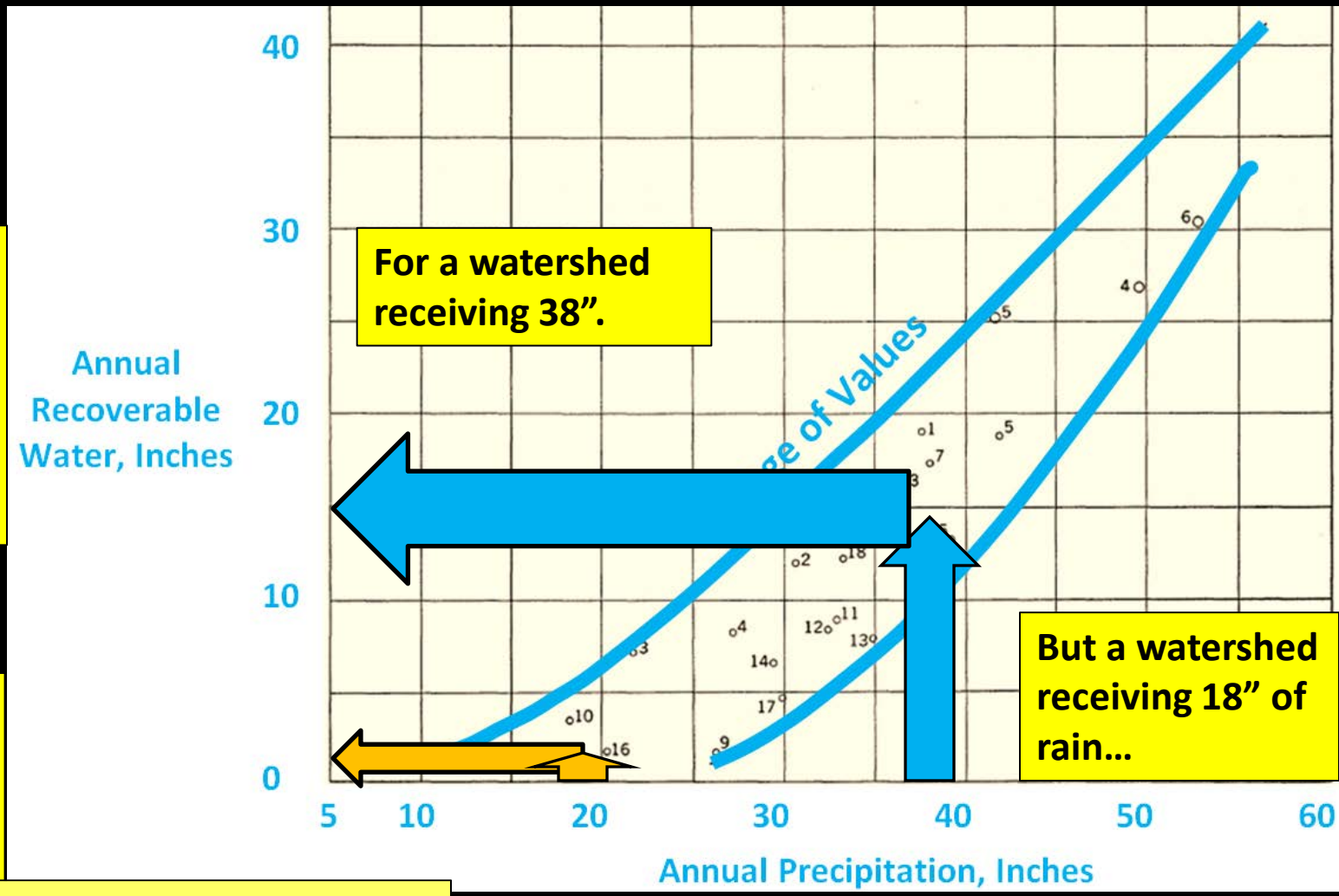
An older method that can be used to broadly estimate groundwater

Although the method has limitations, it can provide a simple and quick generalized estimate of regional recharge.

Groundwater Recharge for Mountain Basins Estimated from:

- **Amount of precipitation**
- Evapotranspiration (vegetation cover, temperature and elevation effects)
- Physiography
- Elevation
- Geology
- Runoff
- Climate

Groundwater Recharge Estimation



About 15 inches, almost 40%, infiltrates into the subsurface and recharges the groundwater.

Less than 2 inches, or about 10%, recharges the groundwater.

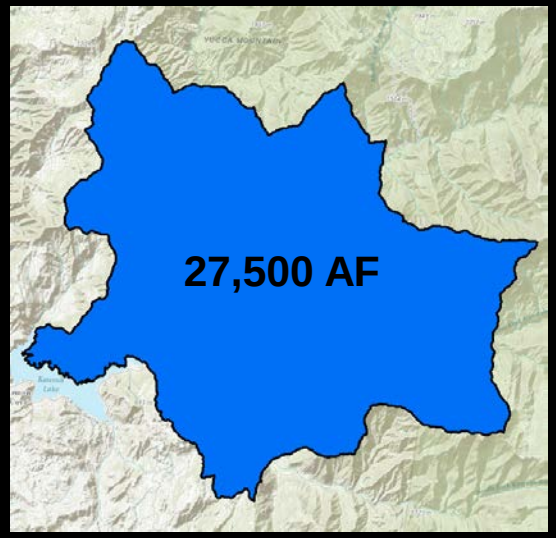
And the range of values is 0 to 5 inches.

Is Water Use and Water Supply in Balance?

Water Balance

Average Precipitation Across the Kaweah River Watershed = 22.5 inches.
Estimated groundwater recharge = 4 inches.

Groundwater Recharge



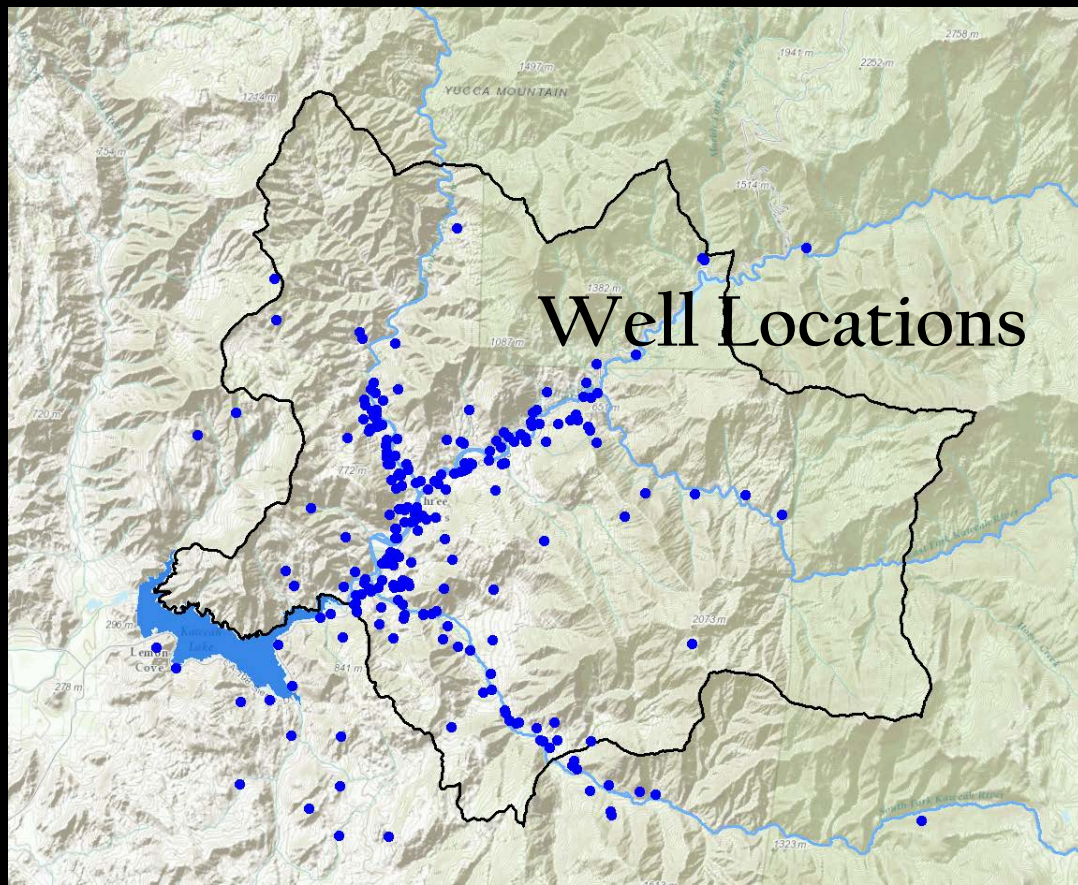
Groundwater Use

Is Water Use and Water Supply in Balance?

Overall, yes. But not for all.

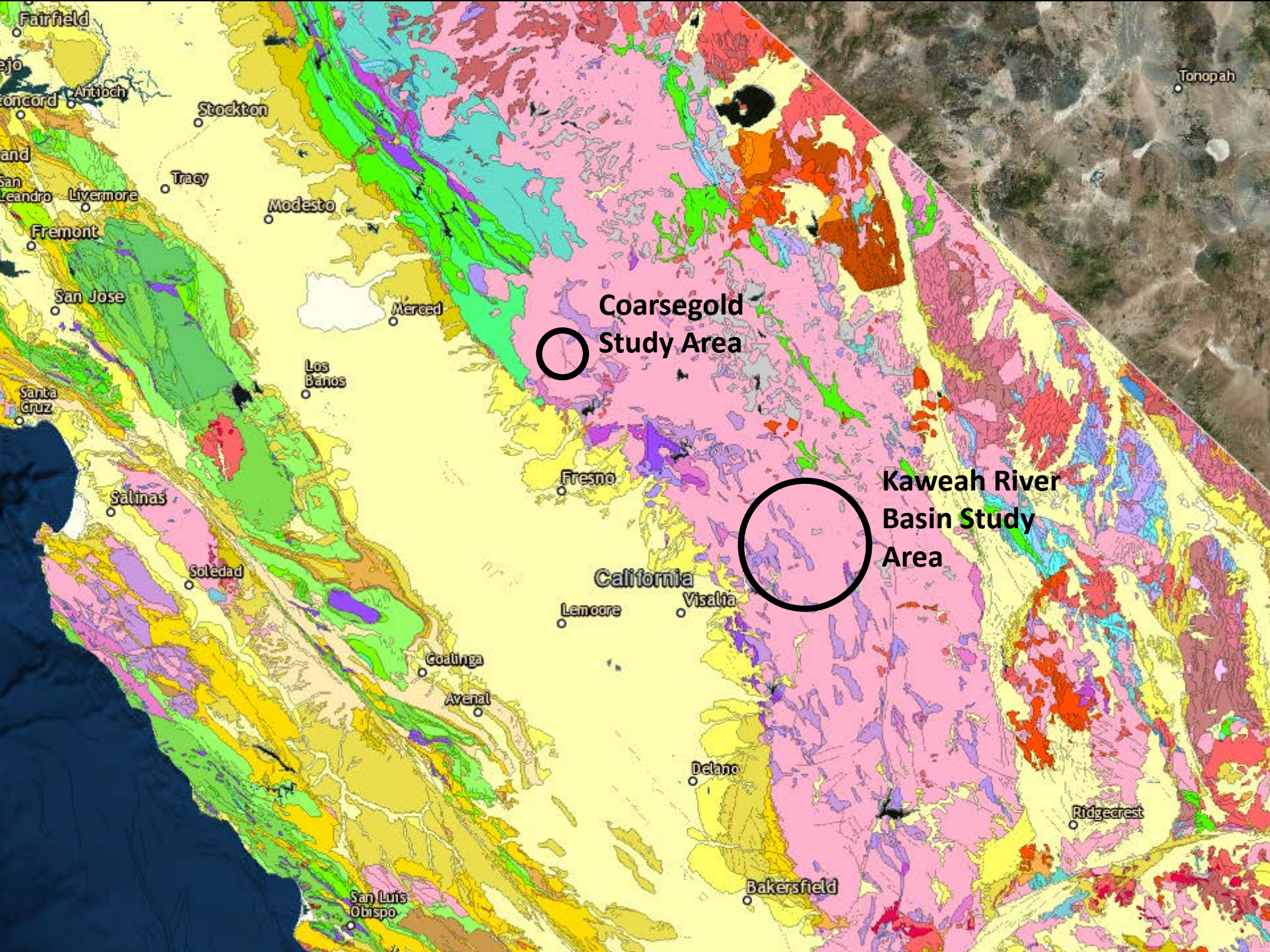
- Estimate is based on <u>average</u> precipitation.
  - A dry year or consecutive years of drought will severely constrain the estimate.

- Estimate is for the <u>entire watershed</u>.
  - Lower, river floor areas will be more sustainable than ‘view lots’.

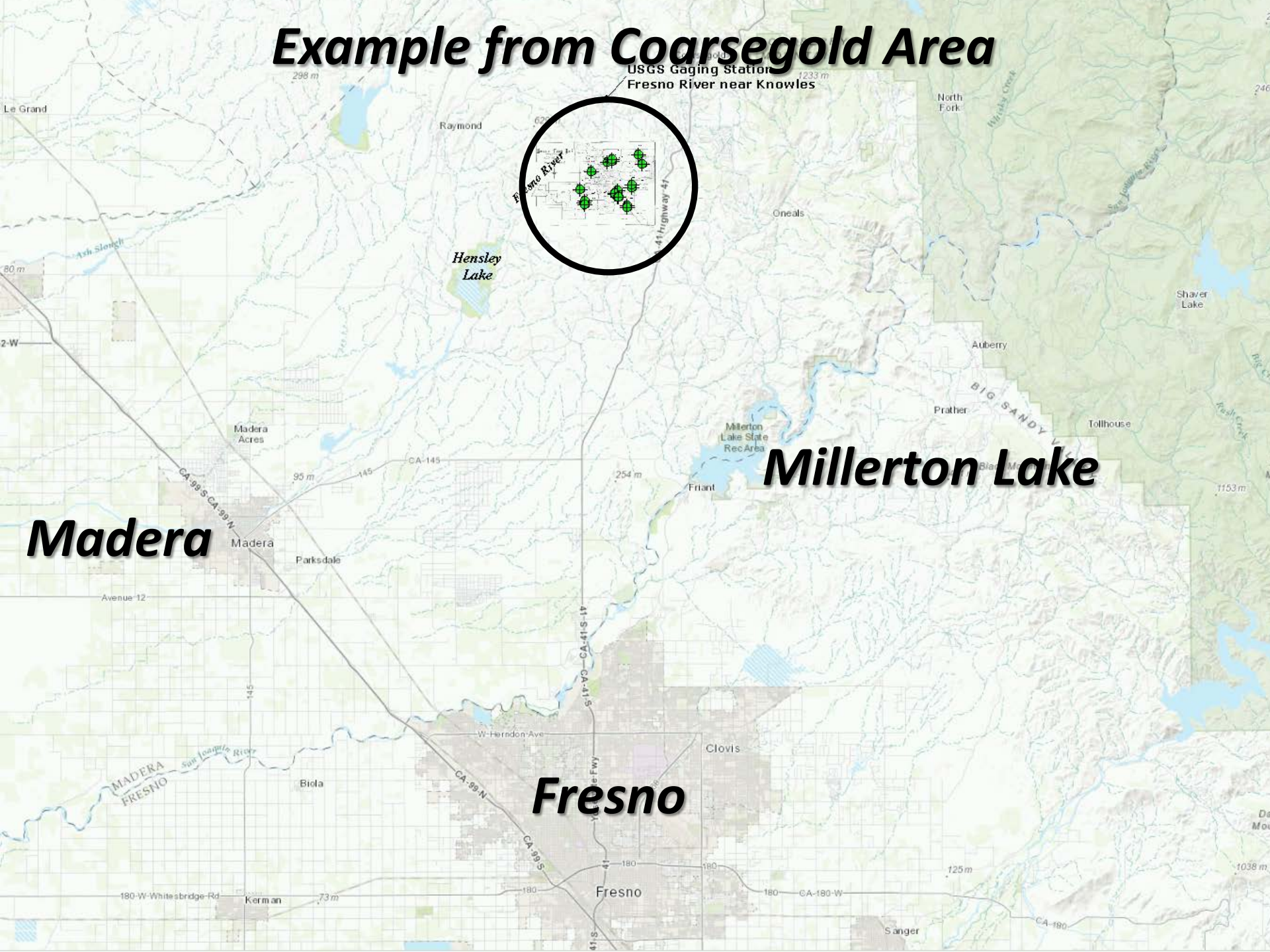


Sustainability Estimated from Groundwater Hydrographs

Example from Coarsegold Area


Fairfield
Antioch
Stockton
Tracy
Livermore
Modesto
Fremont
San Jose
Merced
Los Banos
Santa Cruz
Salinas
Soledad
Fresno
California
Visalia
Lemoore
Coalinga
Avenal
Delano
Bakersfield
Ridgecrest
Tonopah
San Luis Obispo
Coarsegold Study Area
Kaweah River Basin Study Area

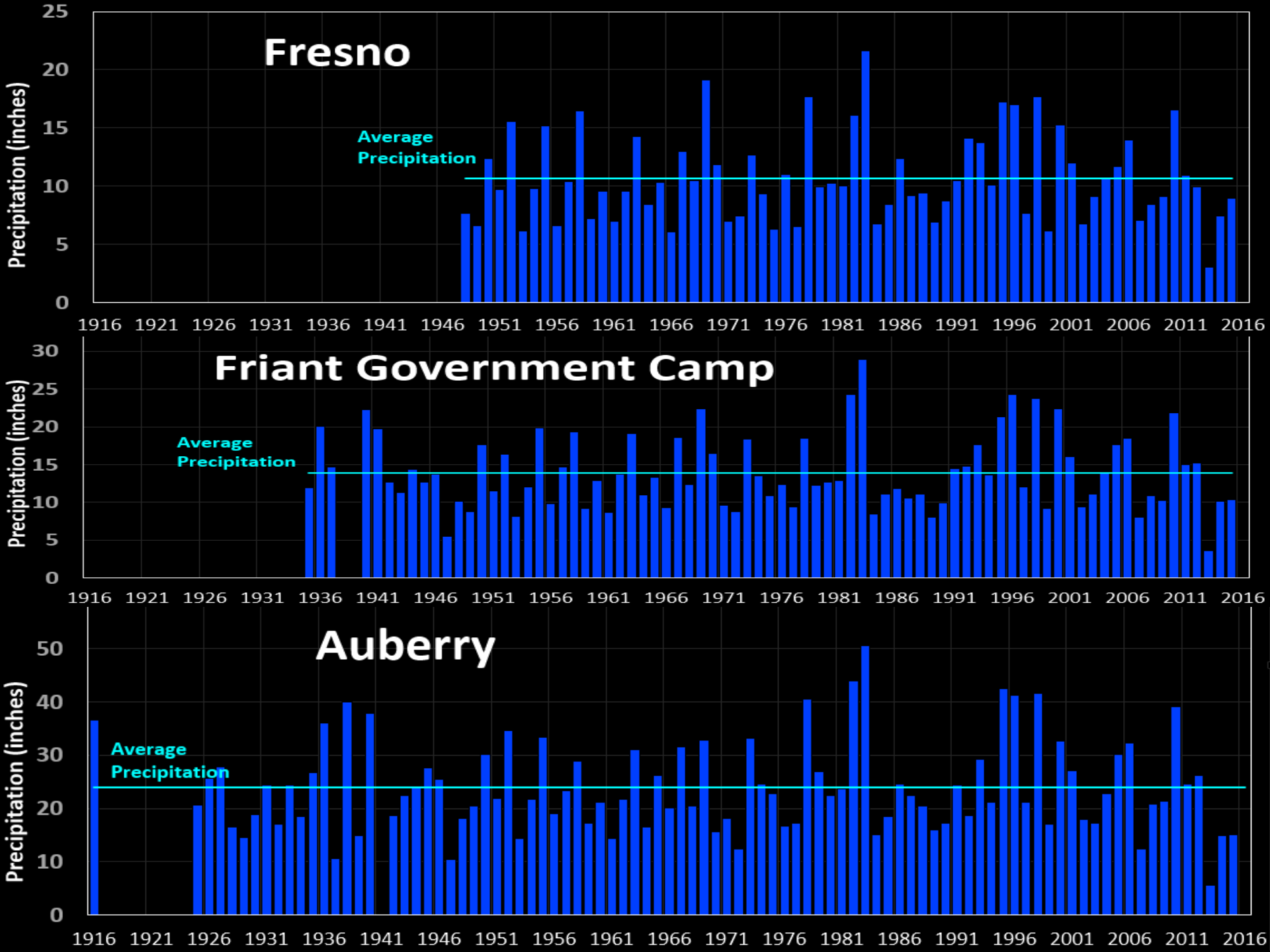
Example from Coarsegold Area

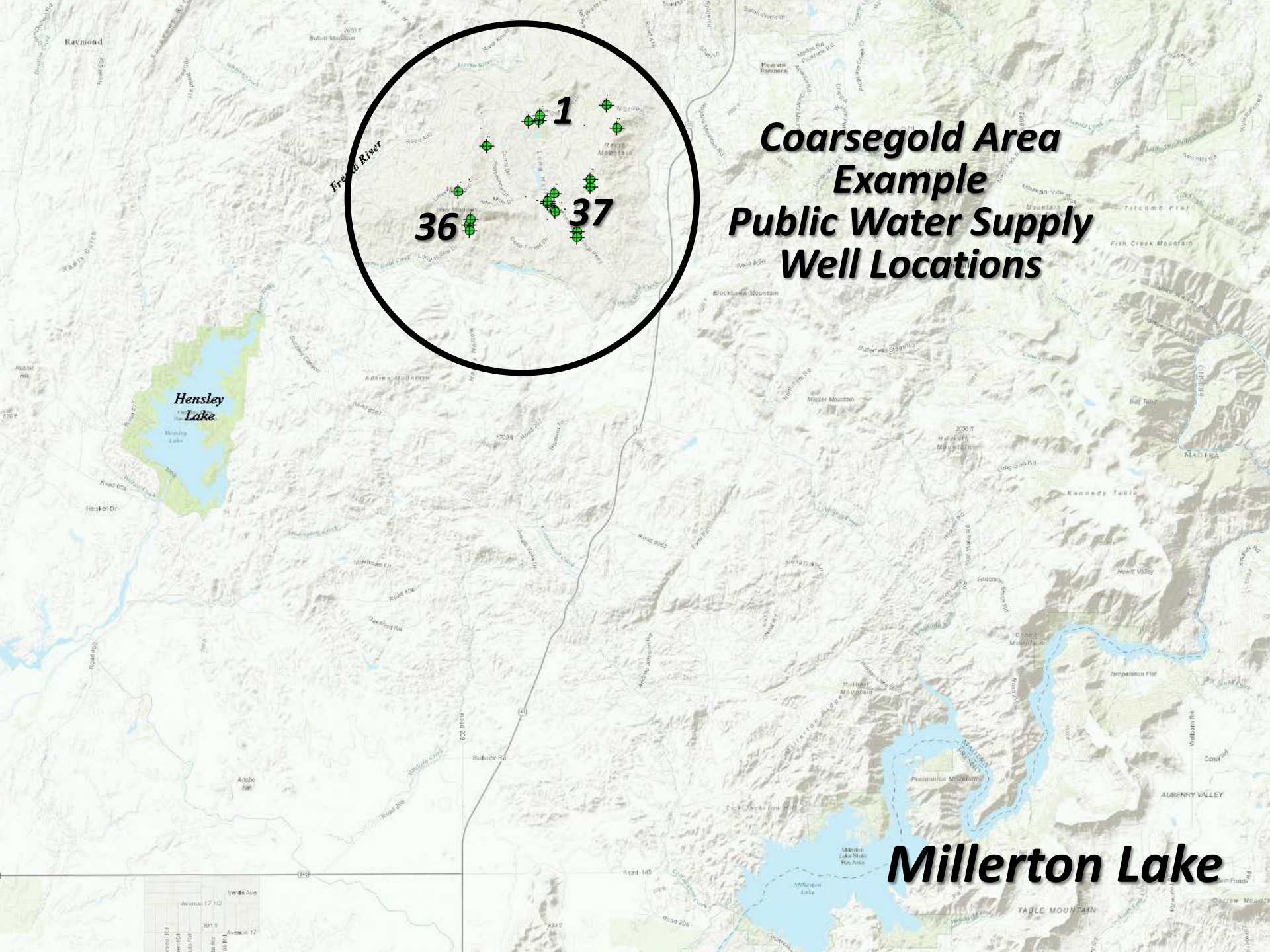


Madera

Millerton Lake

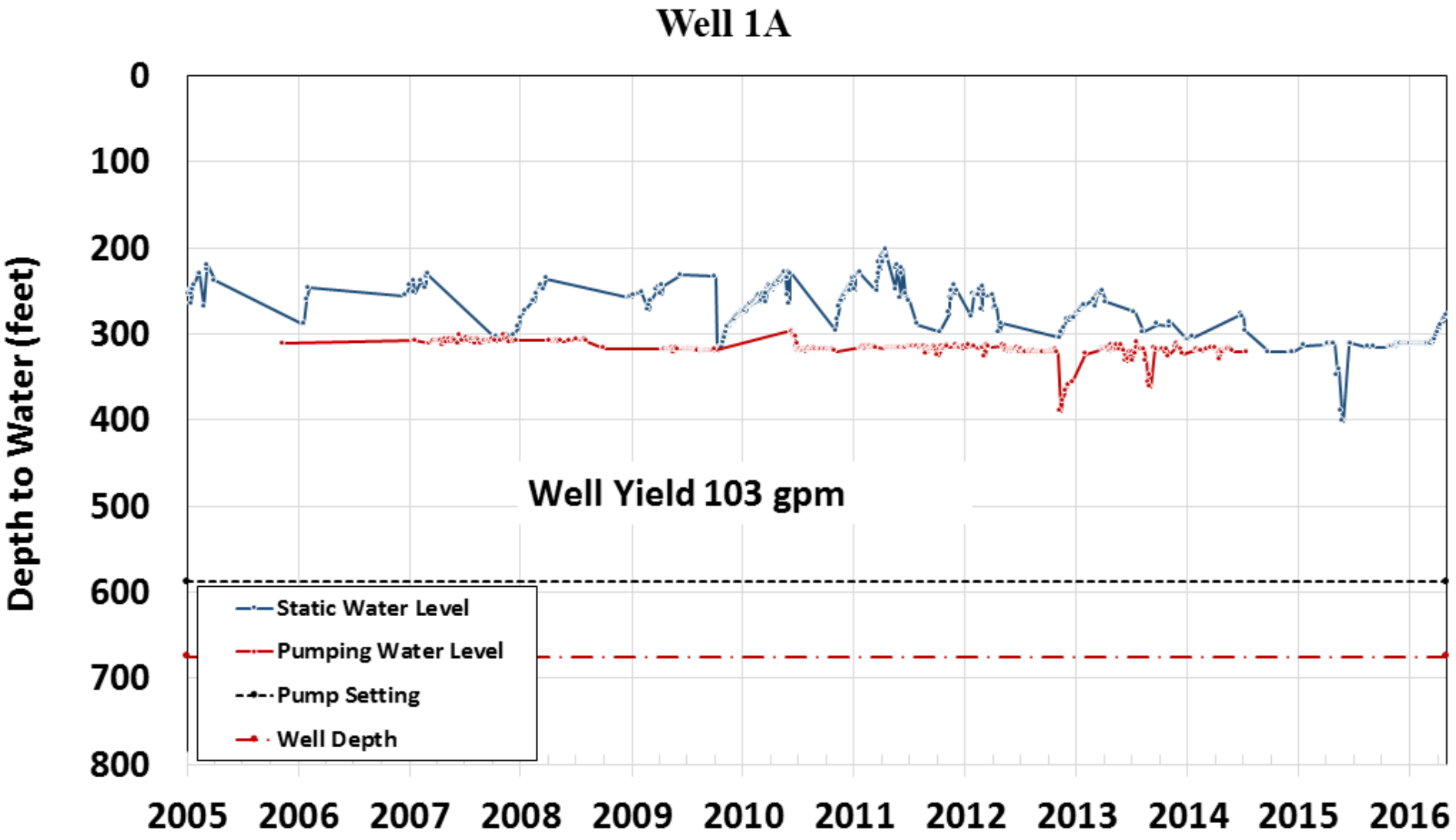
Fresno


Fresno
Average Precipitation
Precipitation (inches)
0
5
10
15
20
25
1916 1921 1926 1931 1936 1941 1946 1951 1956 1961 1966 1971 1976 1981 1986 1991 1996 2001 2006 2011 2016
Friant Government Camp
Average Precipitation
Precipitation (inches)
0
5
10
15
20
25
30
1916 1921 1926 1931 1936 1941 1946 1951 1956 1961 1966 1971 1976 1981 1986 1991 1996 2001 2006 2011 2016
Auberry
Average Precipitation
Precipitation (inches)
0
10
20
30
40
50
1916 1921 1926 1931 1936 1941 1946 1951 1956 1961 1966 1971 1976 1981 1986 1991 1996 2001 2006 2011 2016

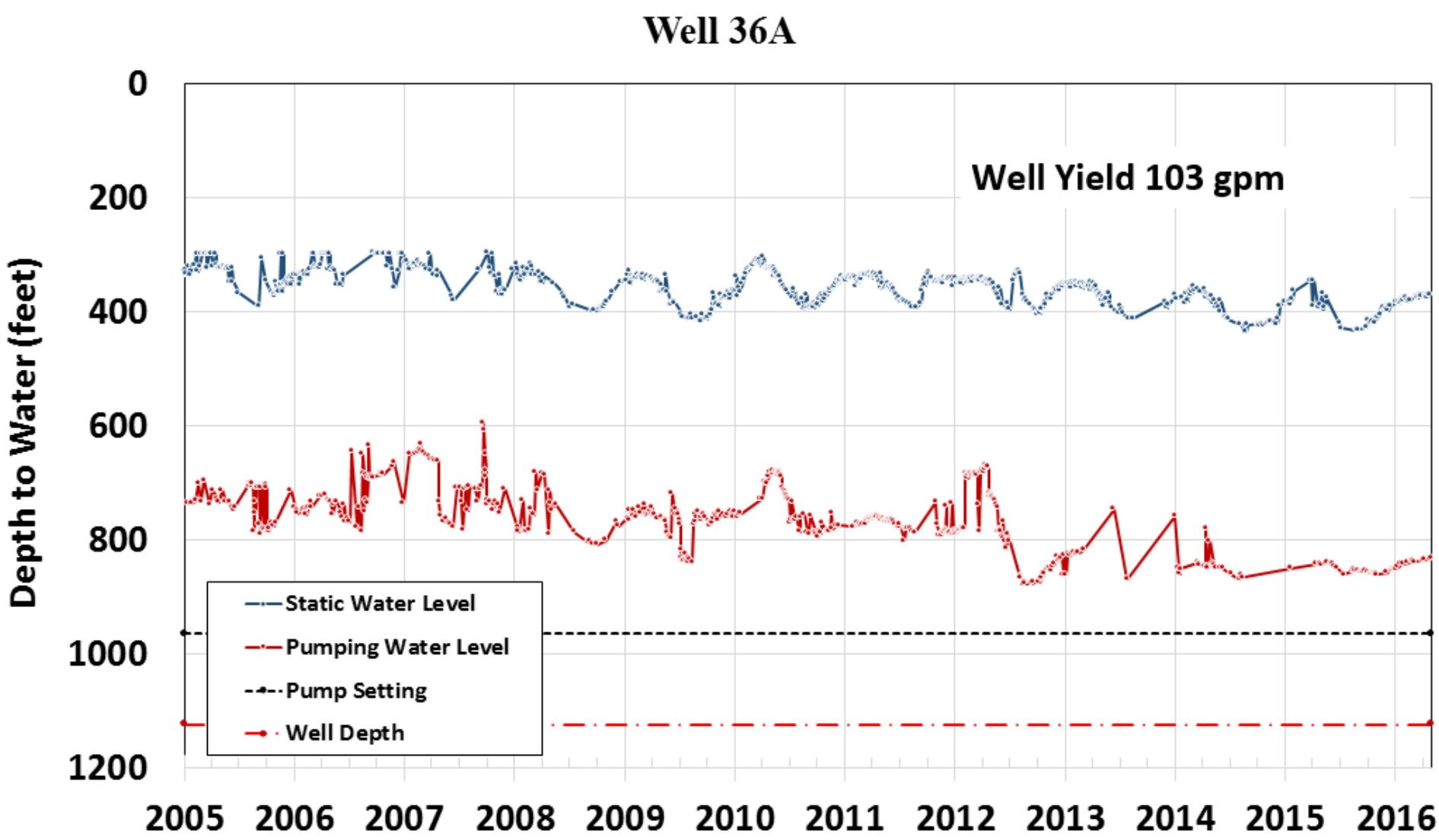


Coarsegold Area Example Public Water Supply Well Locations

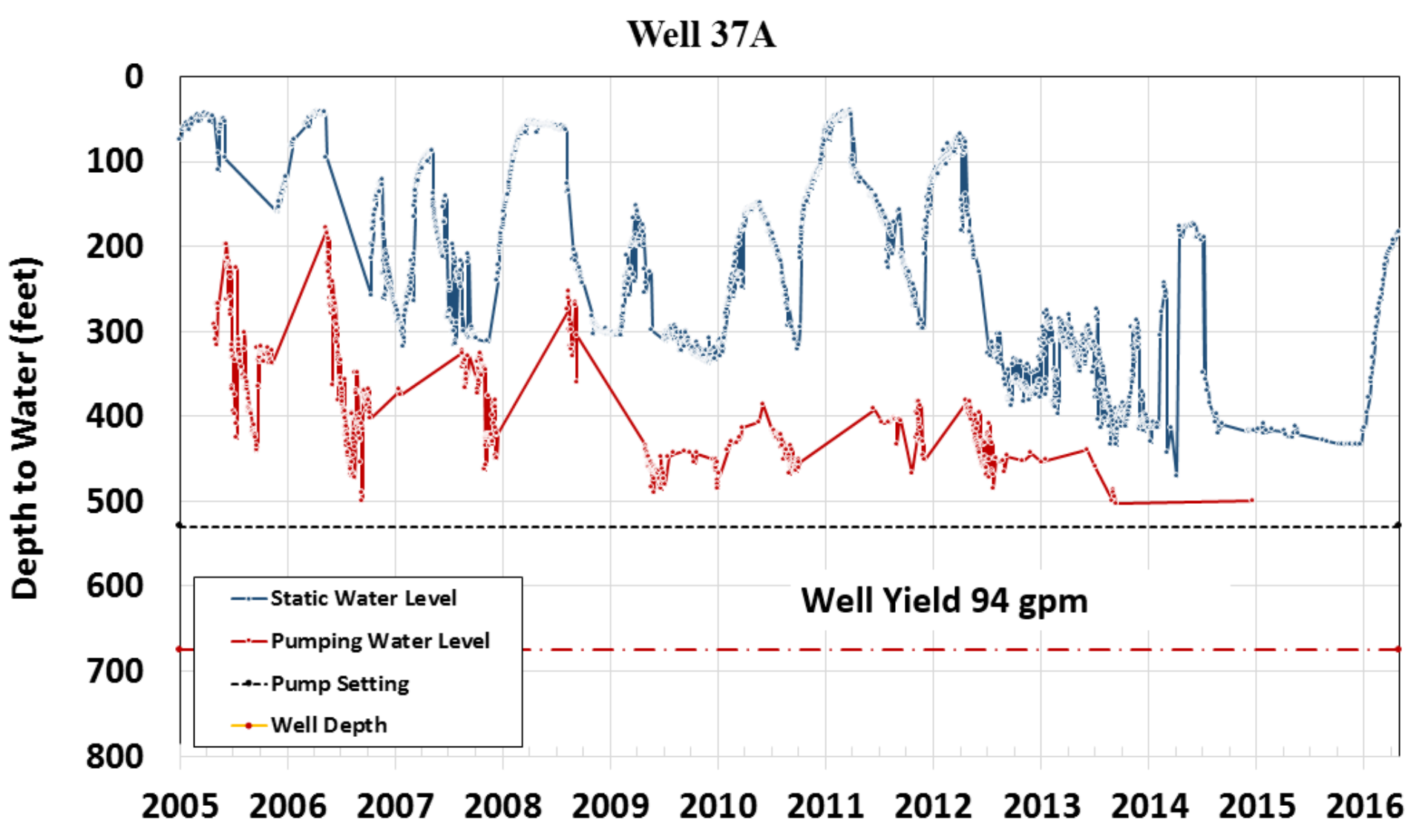
Sustainability Evaluated by Hydrographs



Sustainability Evaluated by Hydrographs



Sustainability Evaluated by Hydrographs



What About Groundwater Quality?

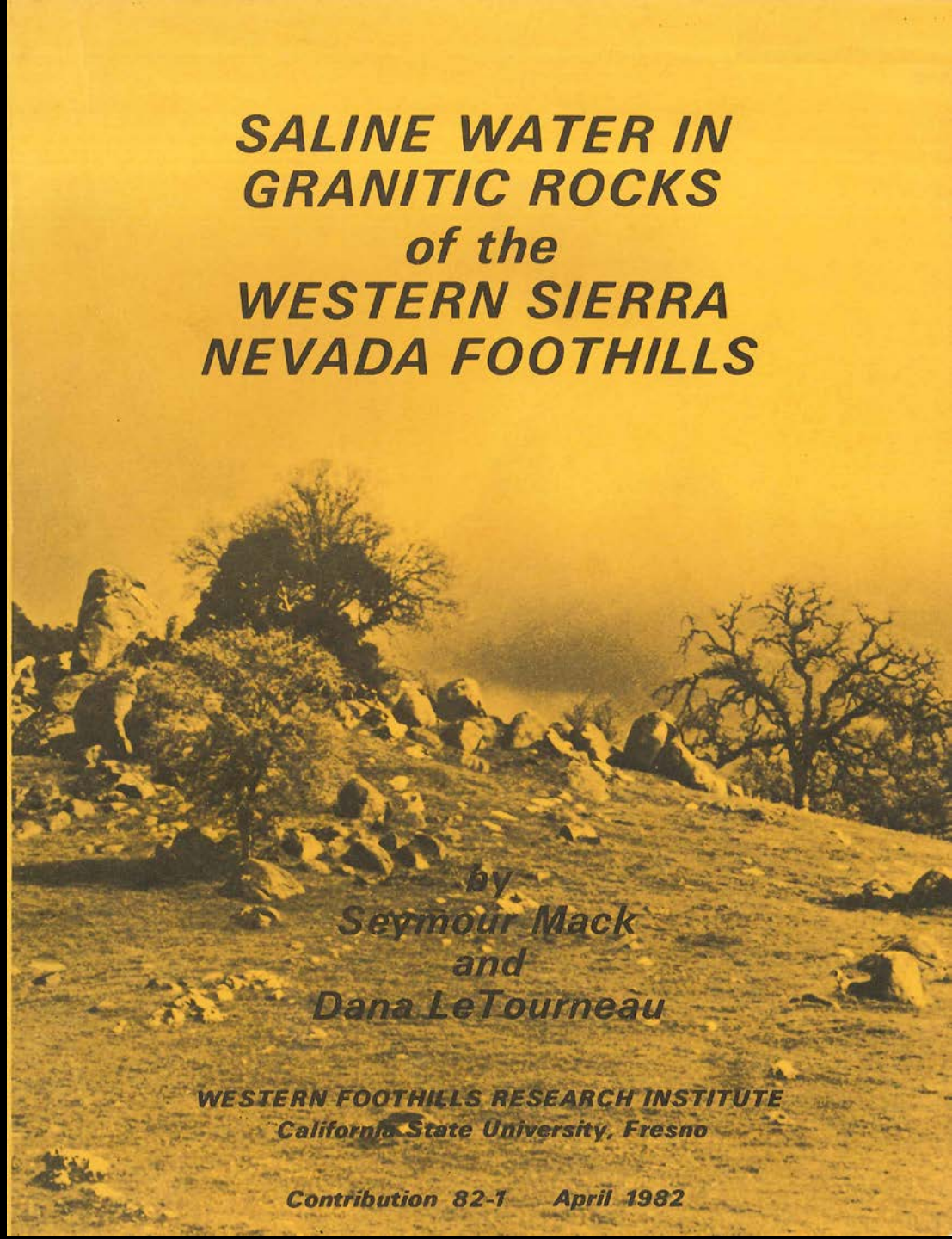
Typically very good quality with low mineral content in a properly constructed well.

- Common problem constituents:
  - Silica
  - Iron and manganese

- Some areas contain naturally occurring radioactive materials: uranium, radon, and gross alpha.

- Some areas contain naturally occurring saline water, H_2S and/or thermal groundwater commonly associated with the Foothills Lineament.

Groundwater Quality Issues and the Foothill Lineament



The Foothill Lineament

Salt, Thermal Water, and Hydrogen Sulfide

References: Seymour Mack and Dana Le Tourneau, *Saline Water in Granitic Rocks of the Western Sierra Nevada Foothills*, Western Foothills Research Institute. Three Rivers Water Supply Study, DWR.

Burning Questions

- What is a fractured rock aquifer?
- How does it differ from an alluvial aquifer?
- How much water is stored in fractures?
- What are typical well yields?
- Is pumping sustainable?
- What about groundwater quality?

Questions?

John Kirk, PG, CEG, CHG
Engineering Geologist
Division of Integrated Regional Water Management
South Central Region Office