Subsidence: Implications and Effects on Infrastructure

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2015 CSAC 121st Annual Meeting
CEAC Land Use Committee
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Drought Impacts

Western United States

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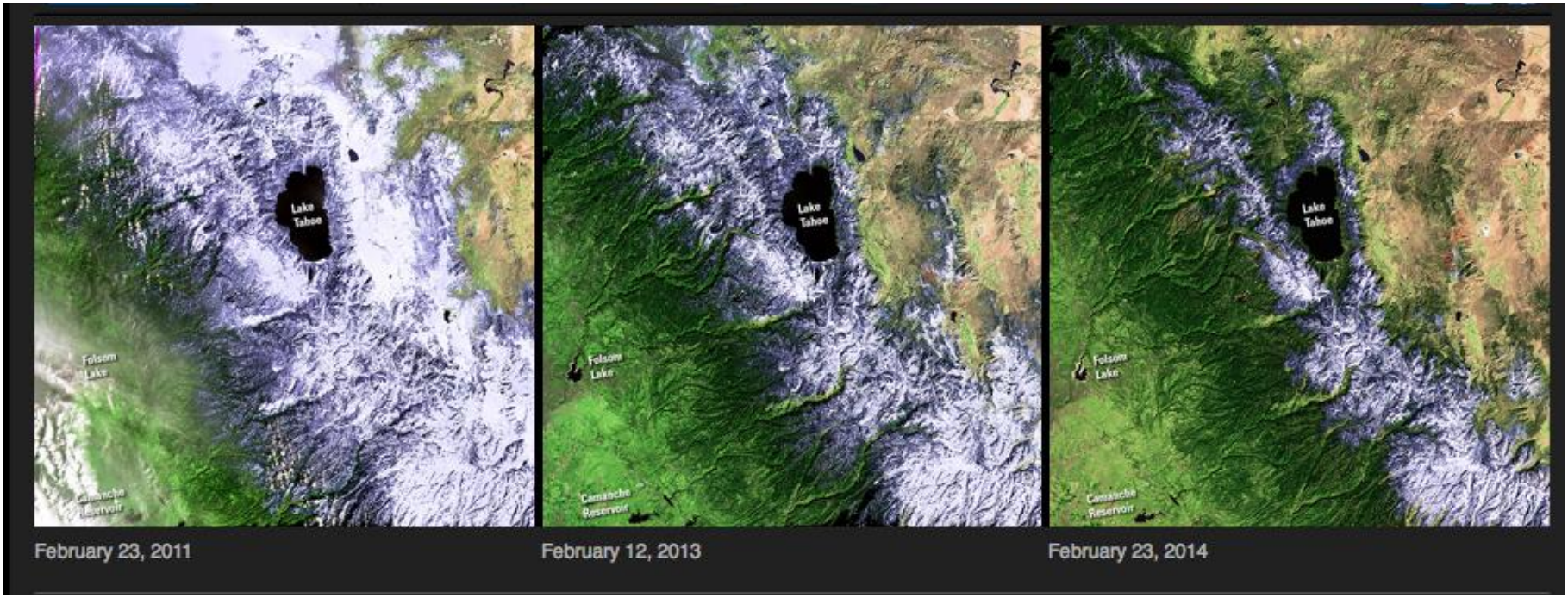
Lake Tahoe Snowpack



2011 2013 2014

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Lake Oroville in 2011

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Lake Oroville in 2014

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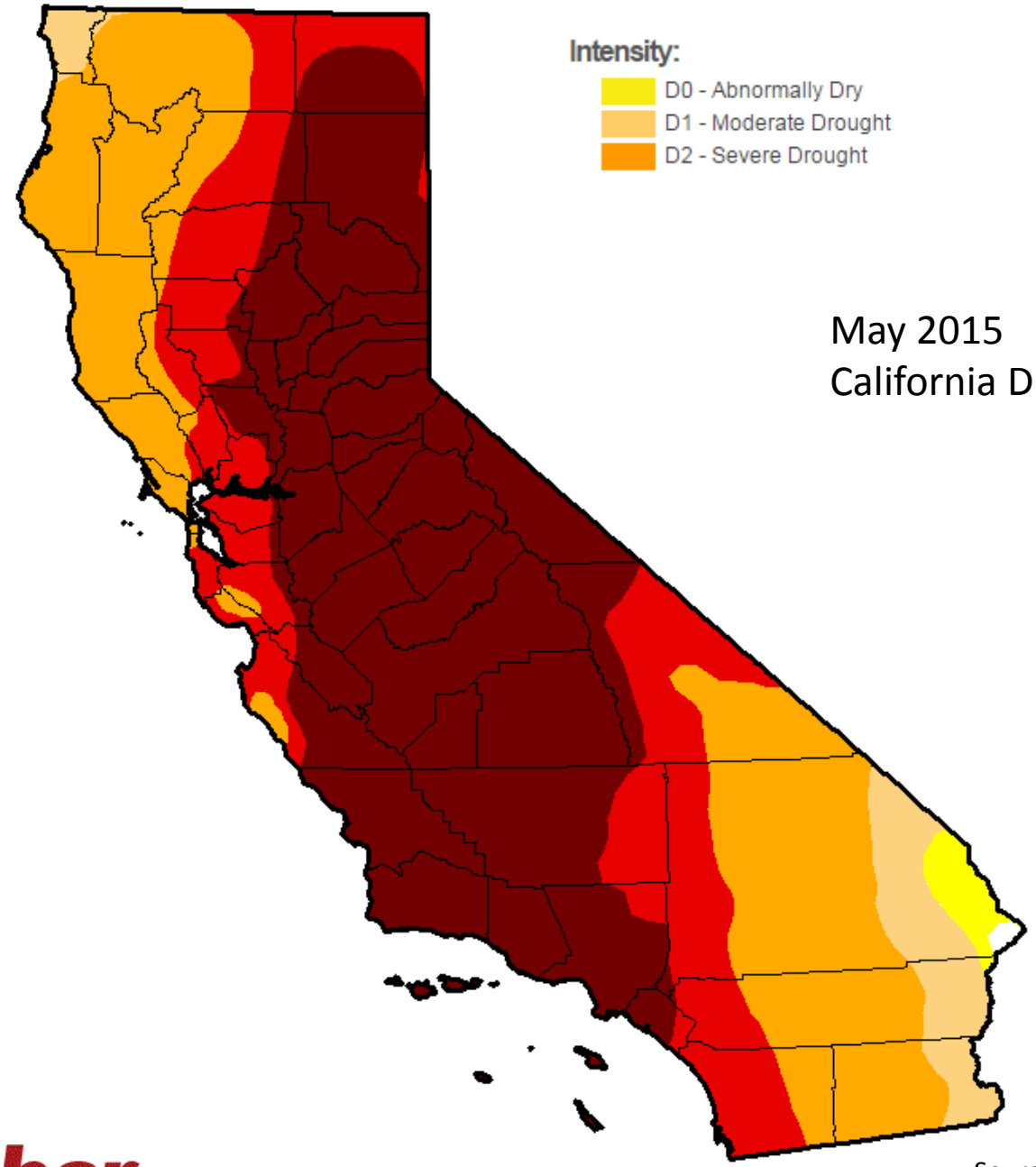

May 2015
California Drought Intensity

Source: USDA United States Drought Monitor

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Subsidence

How does this happen?

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Subsidence Defined

- Subsidence is the compaction/compression of unconsolidated and partly consolidated sediments

- Causes include
  - Mining Resources
  - Water mining
  - Salt Mining
  - Gas/Oil

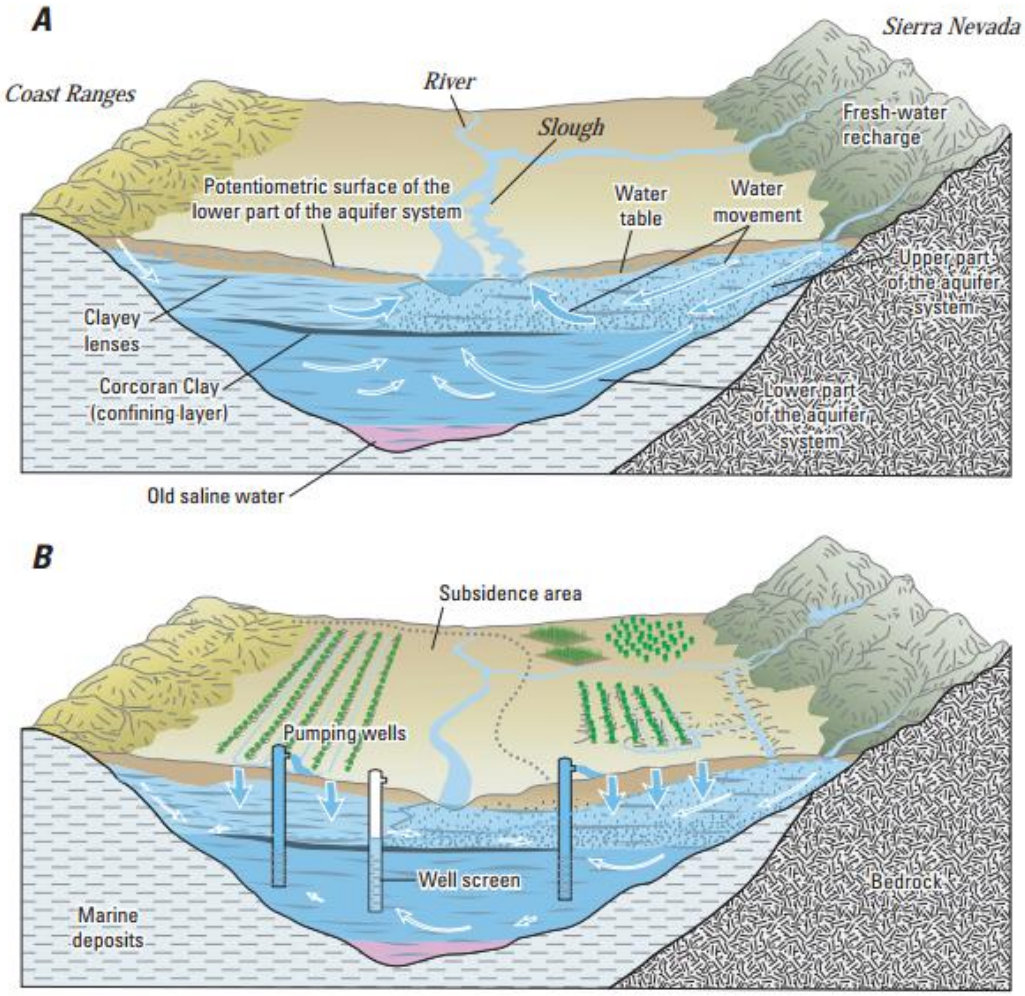

Figure 5. Relation of the Corcoran Clay to younger and older alluvium and aquifers and groundwater-flow regimes in the San Joaquin Valley, California, for *A*, pre-development and *B*, post-development (modified from Belitz and Heimes, 1990; Galloway and others, 1999; Faunt, 2009).

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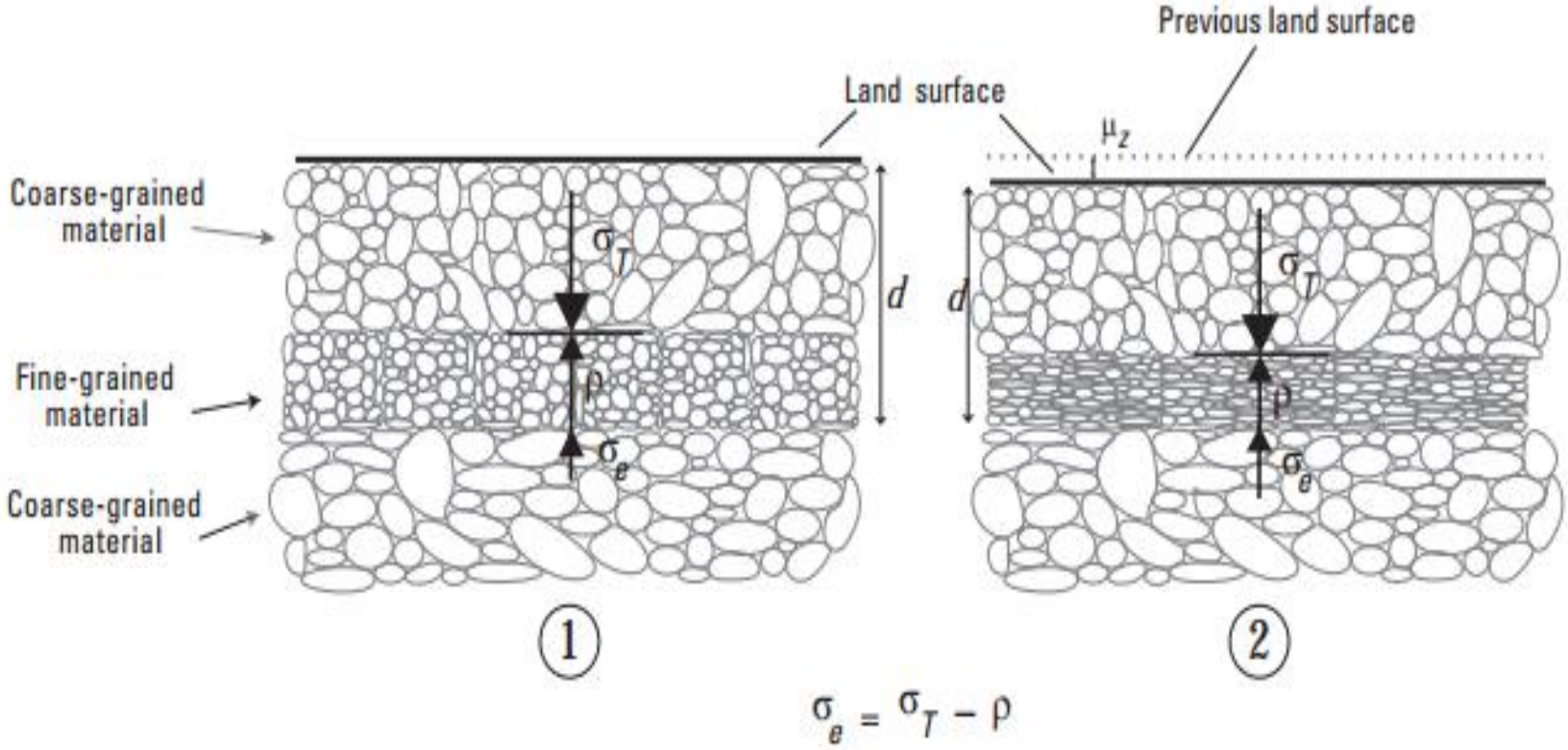
Mechanisms for Consolidation

- As water is taken out of the fine-grained and porous layer, the material loses pore-fluid pressure, causing the vertical stress to overcome stasis and compress the fine grained layer.
- As a result, the apparent land surface elevation decreases.



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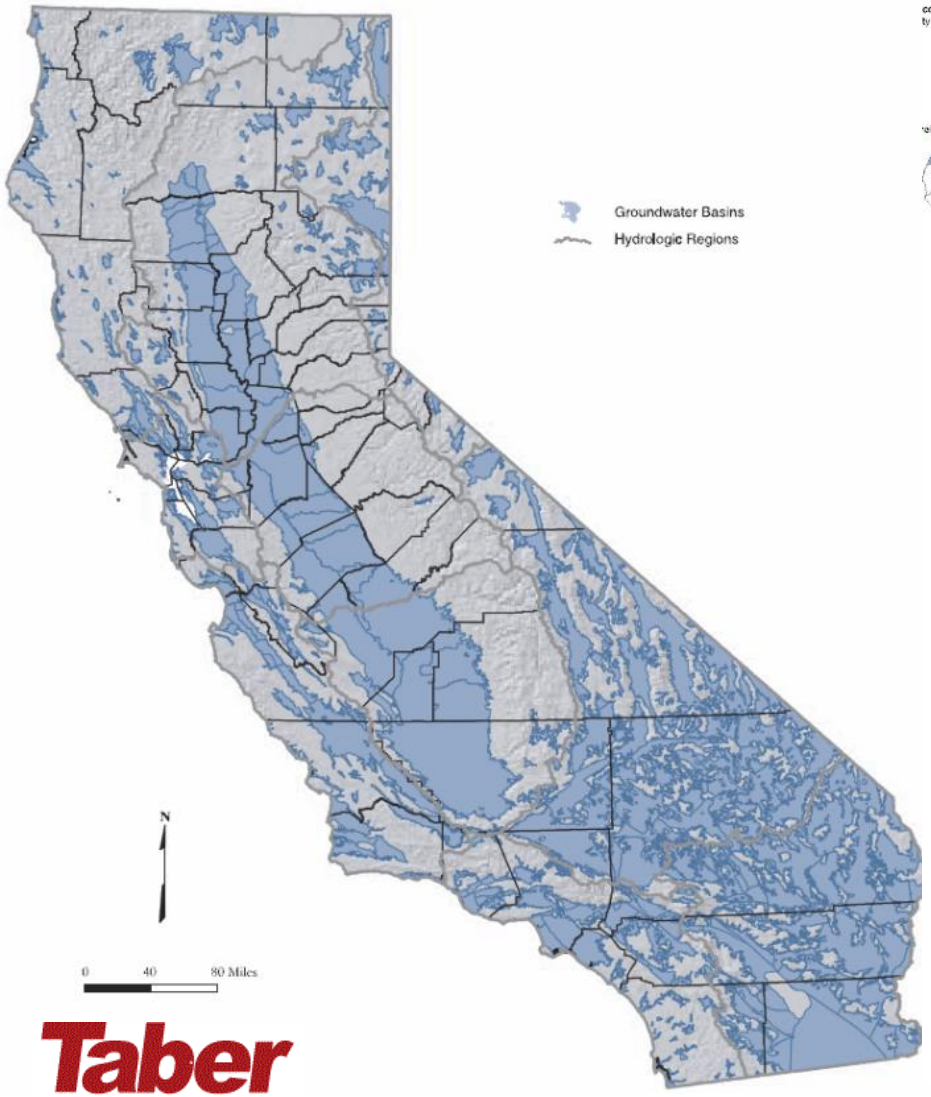
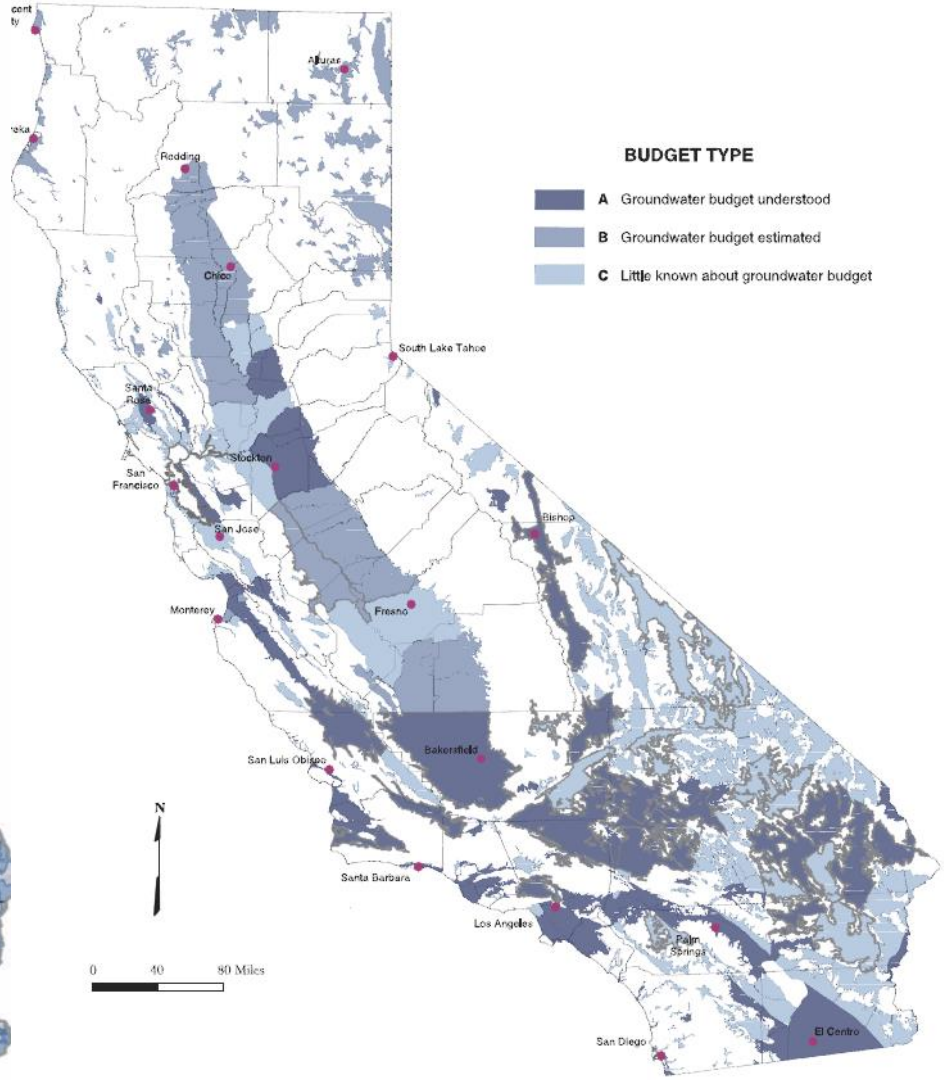
CA Groundwater Basins and Water Budget Understanding





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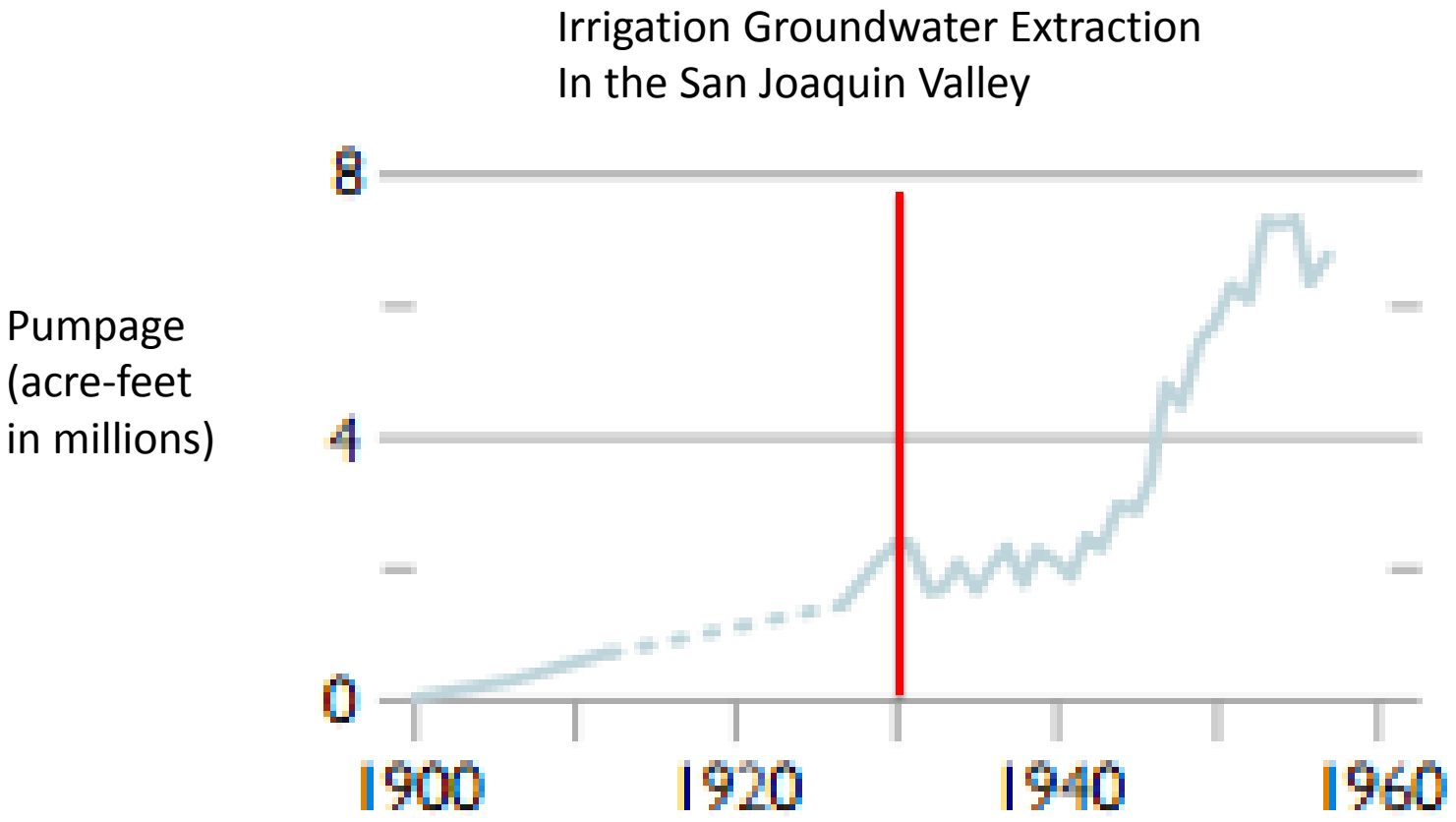
San Joaquin Valley and Groundwater Extraction



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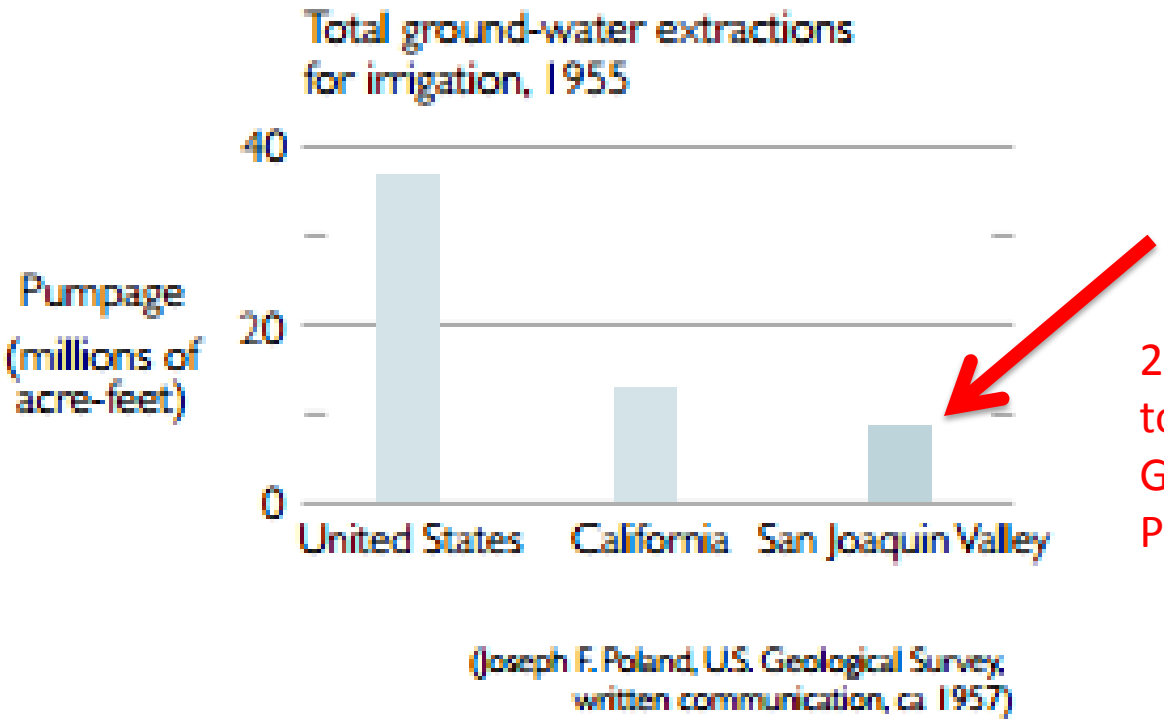

25% of total US Groundwater Pumping

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Subsidence

Examples of Groundwater Pumping,
Drawdown and Effects

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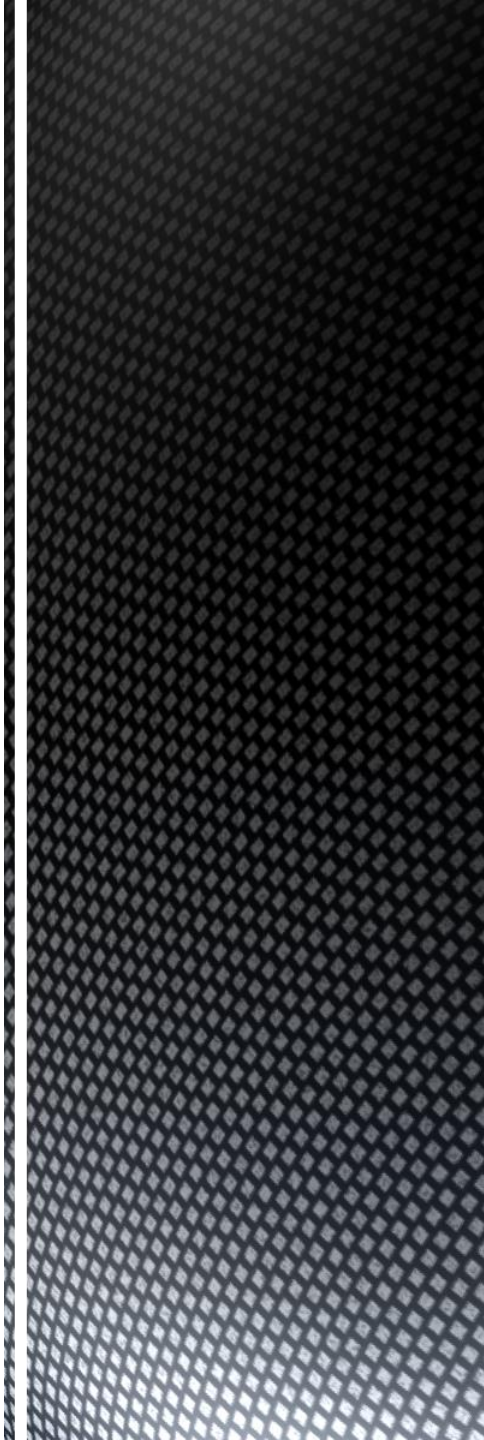

California Current and Historic Subsidence Locations

- Sacramento and San Joaquin Valleys
- Central Coast
- Antelope Valley
- Santa Ana Basin
- Mojave Desert
- Coachella Valley

Source: Ludhorff and Scalmanini, 2014

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General Effects on Infrastructure

- Damages the roads, railways, bridges and pipelines, putting them at risk for structural failure.
- Subsidence reduces channel and canal flow capacity and freeboard; increases flooding.
- Gravity dams require raising to maintain hydraulics.
- Earth fissures can create harm to humans, animals and rapidly damage infrastructure
- Constantly changing elevation datum

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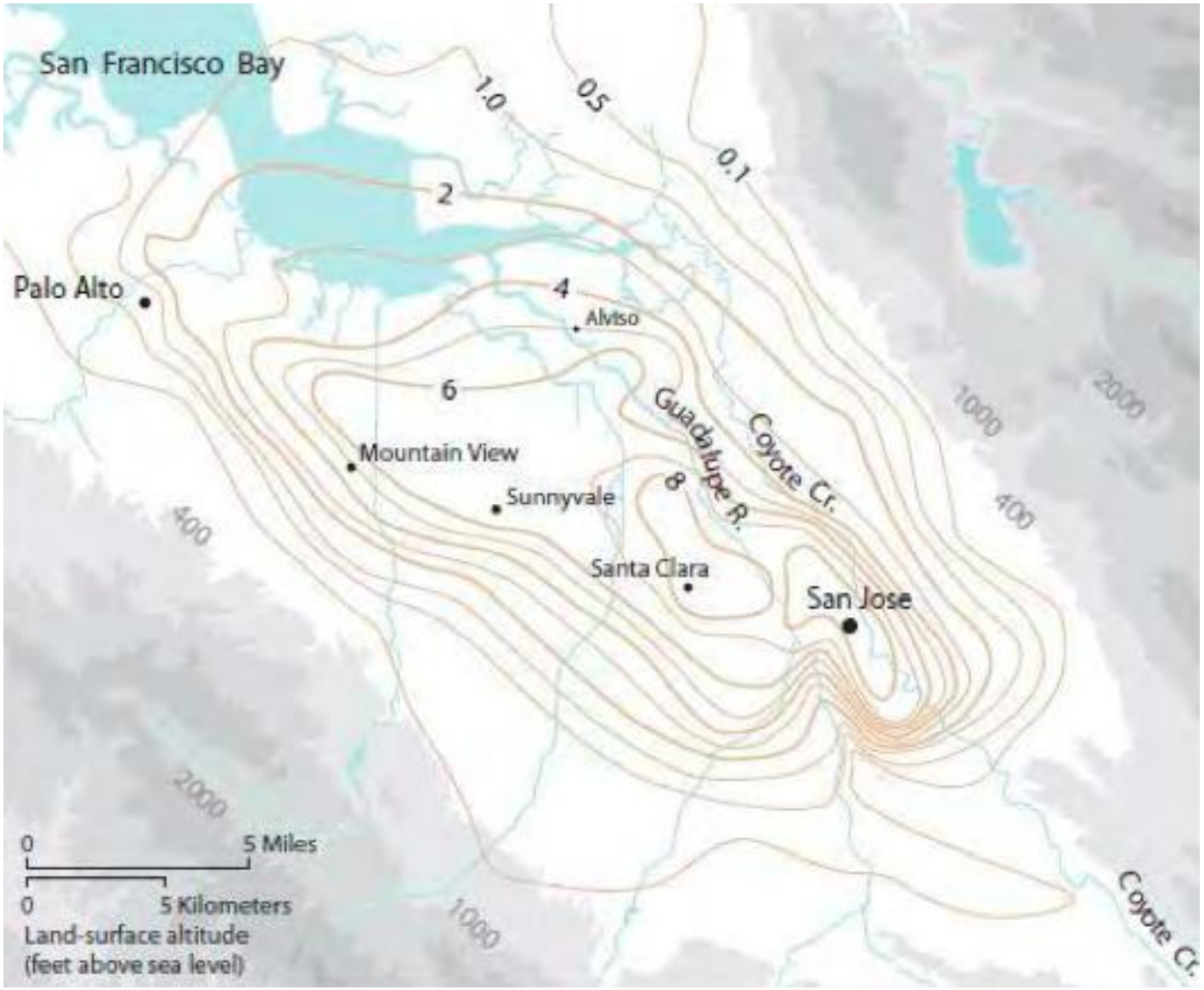
Santa Clara Valley Subsidence



Source: Ludhorff and Scalmanini, 2014

Subsidence: Economically Quantified*
Santa Clara Valley

- Water well damage/repair - $35 million.
- Sanitary Sewer Pump Stations - $48 million.
  - Operations - $28 million
- Roads/Bridges - $12 million
- Bayfront Levees - $305 million
- Stream Channels – $32 million
- Storm Drainage Pump Stations - $12 million
  - Operations - $283 million
- $756 Million estimated on subsidence remediation.

*2013 Inflation adjusted dollars

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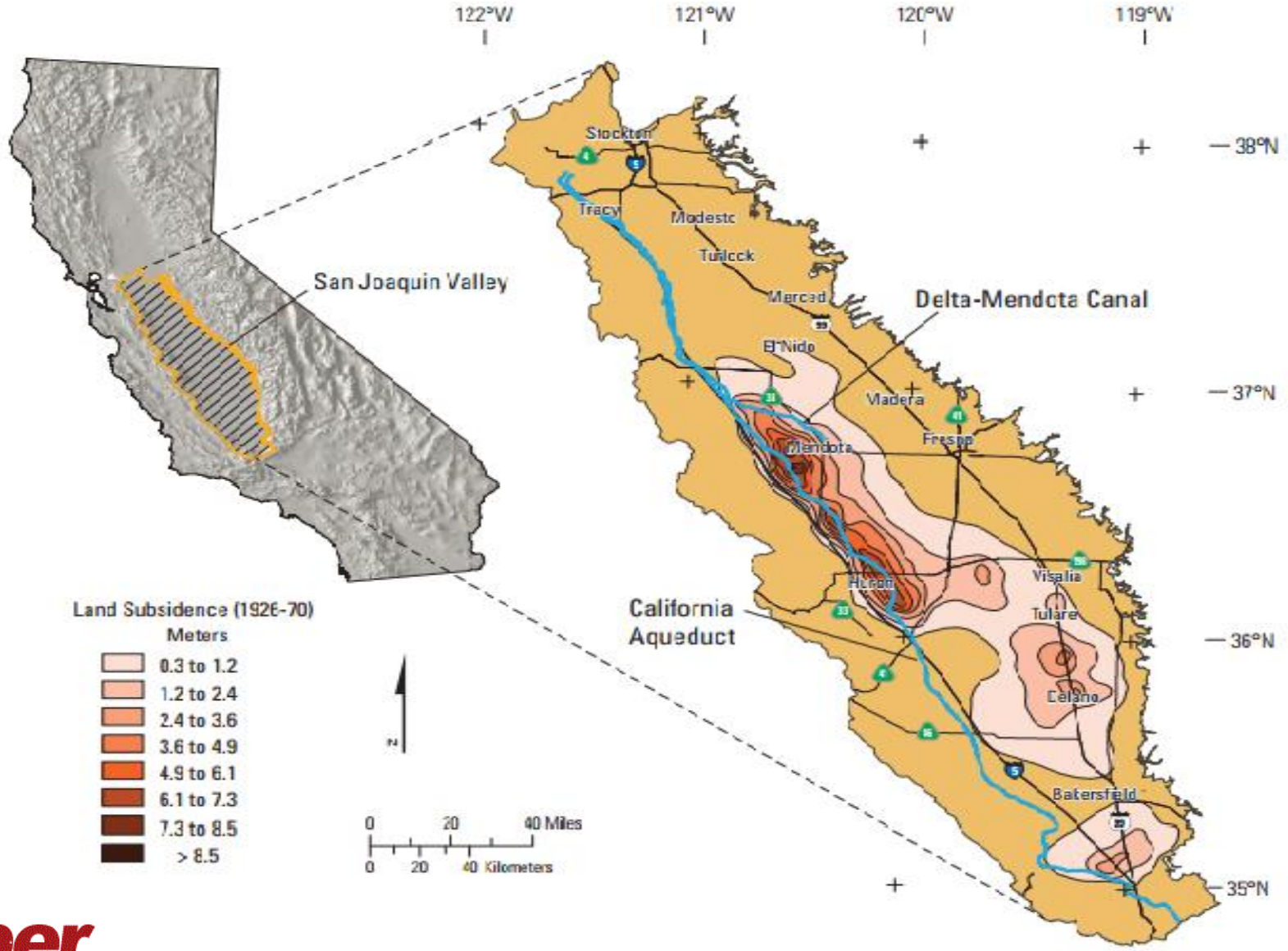
Subsidence as it occurs in the San Joaquin Valley: where?



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Subsidence: Economically Quantified*
San Joaquin Valley

- Friant-Kern Canal Repairs -- $ 15 million
  - 17 miles, recompaction, raising, new liner, drainage and pumping plants on new foundations, another $25 mil planned upstream
- Federal Canals and Drains - $ 88 million
- Replacement water wells (300) - $114 million
- Delta-Mendota Canal, the Outside Canal, the Friant-Kern Canal, and the San Luis Canal -- $134 million.
- San Joaquin Valley incurred ~$1.3 billion from 1955 to 1972.

*2013 Inflation adjusted dollars

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San Joaquin Subsidence Capacity Quantified*

- 5200 sq. mi. area affected by > 1 ft subsidence
- Central Valley aquifers lost 125 million-acre feet in capacity since folks settled the Central Valley.
- 20 million acre-feet lost in last 10 years.
- 80 million acre-feet lost since 1960.
- Quantity equals 4 Lake Mead volumes
- $2 billion in repair costs for Santa Clara and San Joaquin Valley alone.

*2013 inflation adjusted dollars

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Russell Avenue Bridge at Delta-Mendota Canal: bridge used to be inspected by boat under the bridge – Replacement estimated $2.5 million

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Alviso Yacht Club in southern San Francisco Bay – top 1914 bottom 1987 10-ft of dikes were required due to subsidence of the land below adjacent sea level

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Drought and Groundwater Over-pumping Impacts

- Degrading groundwater quality
  - Increased salinity (coastal and delta areas)
  - Potential increased contamination

- Increased electricity costs.
  - Pumping water from greater depths
  - 2011 City of Fresno - $9 million on electricity

- In California, $454 million to pump groundwater during drought

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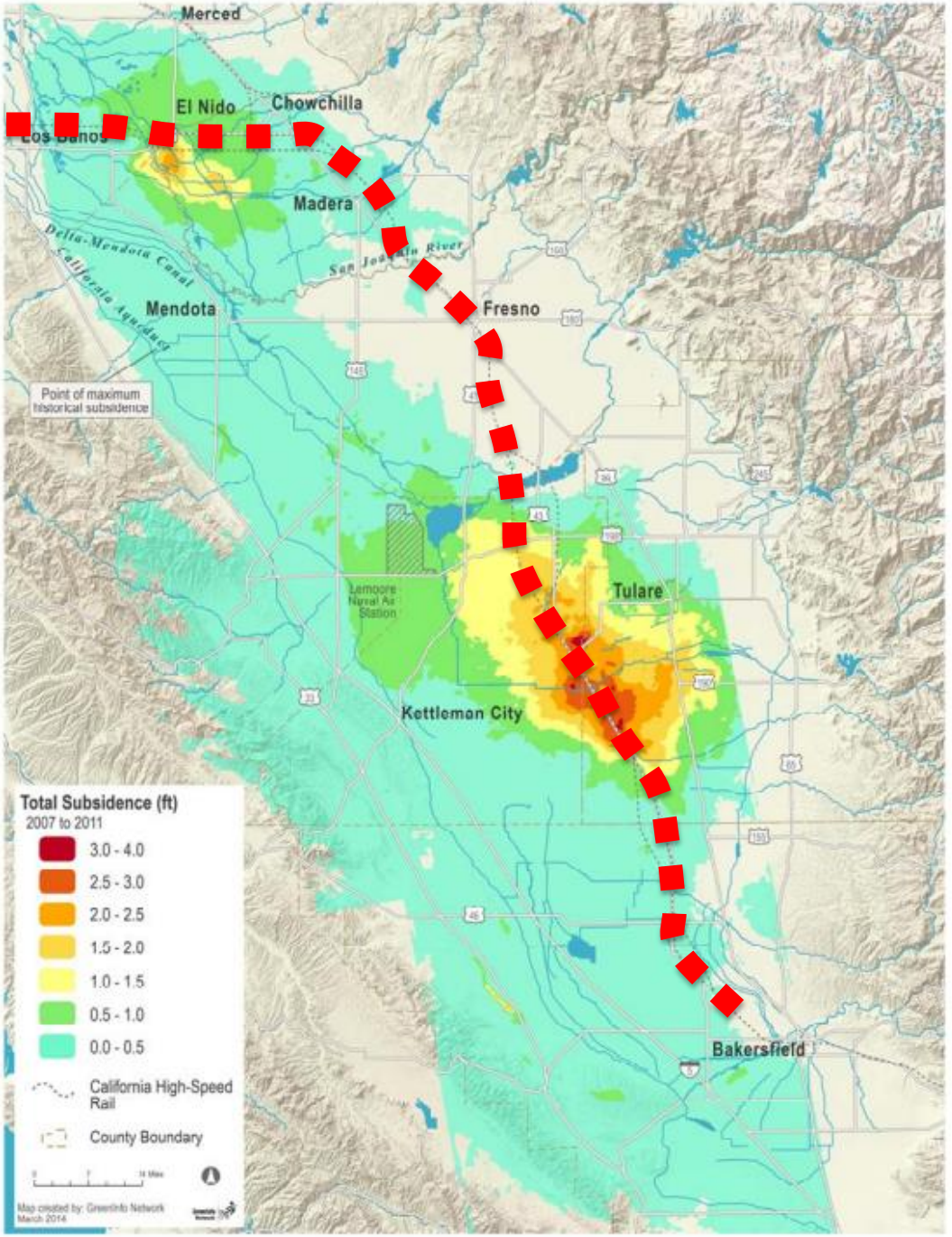
Central Valley Subsidence

2007 to 2011
Concentrated in new areas

California High Speed Rail



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Subsidence

Earth Fissures

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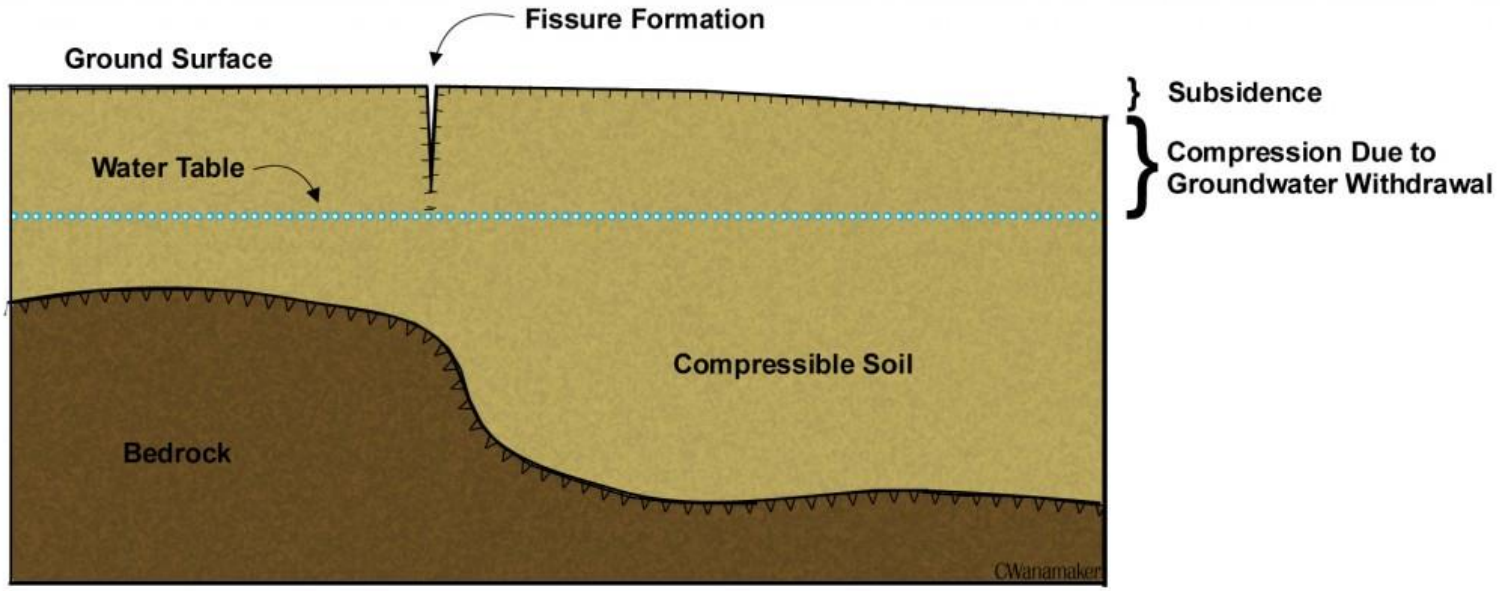
Spontaneous Earth Fissures

- Earth fissures are large ground cracks that are formed from differential land subsidence.
- Tension cracks are formed and the ground opens.
- Can potentially be hundreds of feet deep and miles long.



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Spontaneous Earth Fissures Hazards

- Cracked and collapsing roads
- Broken Pipes and Utilities
- Damaged or breached canals
- Cracked foundations/separated walls
- Livestock and wildlife injury or death
- Severed/Deformed railroad tracks
- Damaged wells
- Deflected/damaged drainage
- Surface contamination transport to aquifer
- Human injury or death

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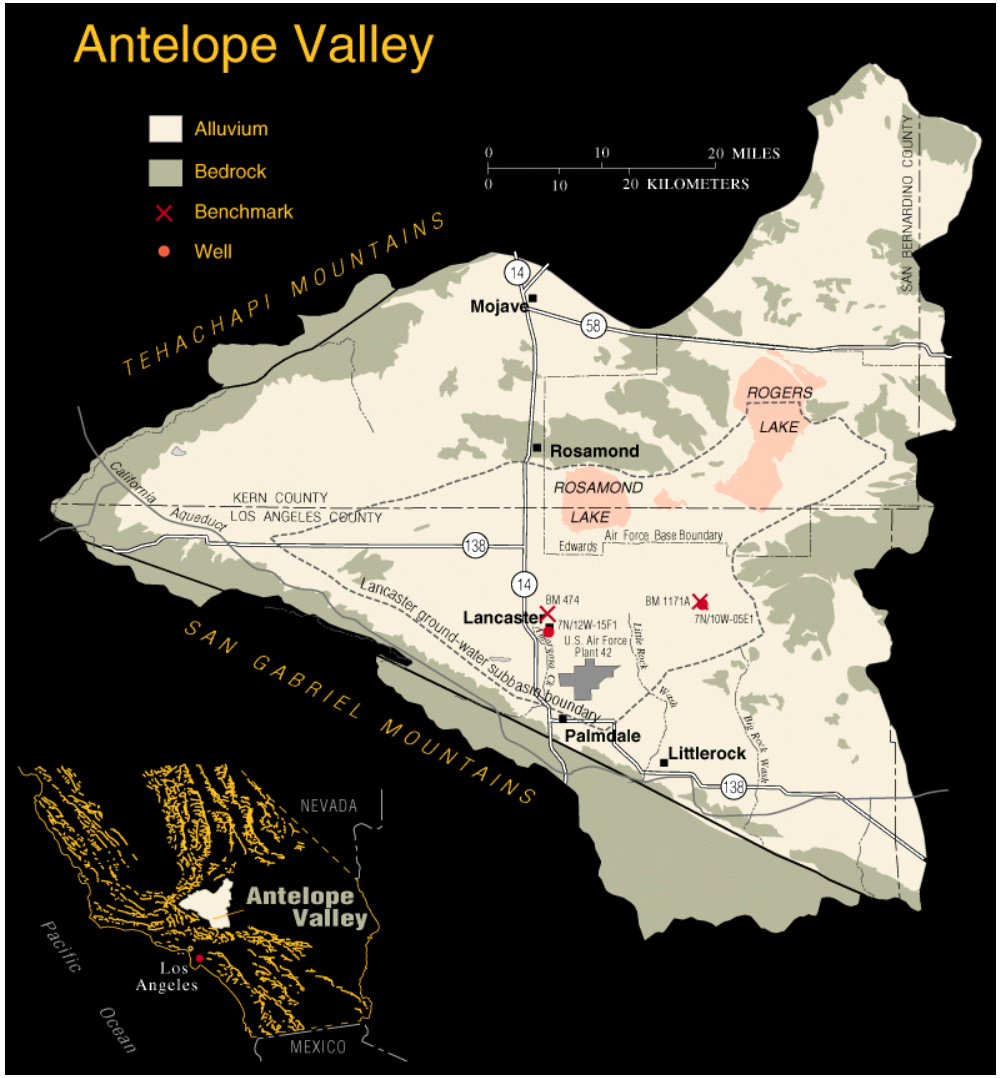
Subsidence: Antelope Valley

- 90% agricultural and urban use from groundwater.
- 300 ft decline in groundwater level since 1930s
- 1,900 foot long x 7.4 foot deep earth fissure opened northeast from Lancaster
- Edwards Air Force Base -- sink-like depressions, polygonal cracks, and large fissures on the lake bed of Roger's lake affected runways.
- Subsidence mostly north of Lancaster



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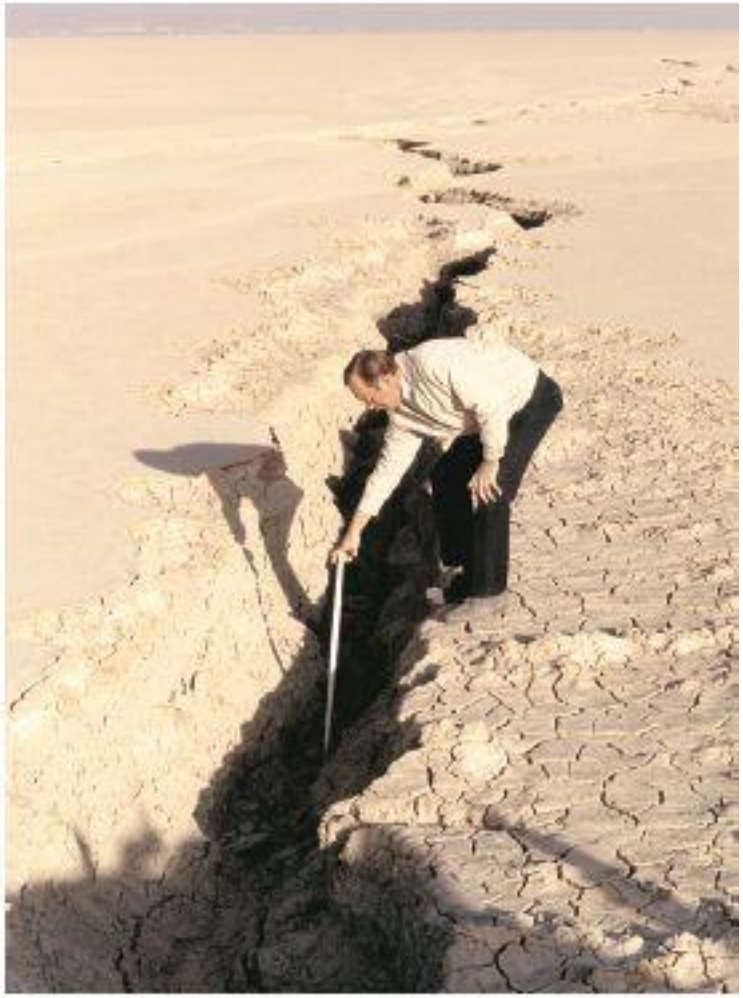

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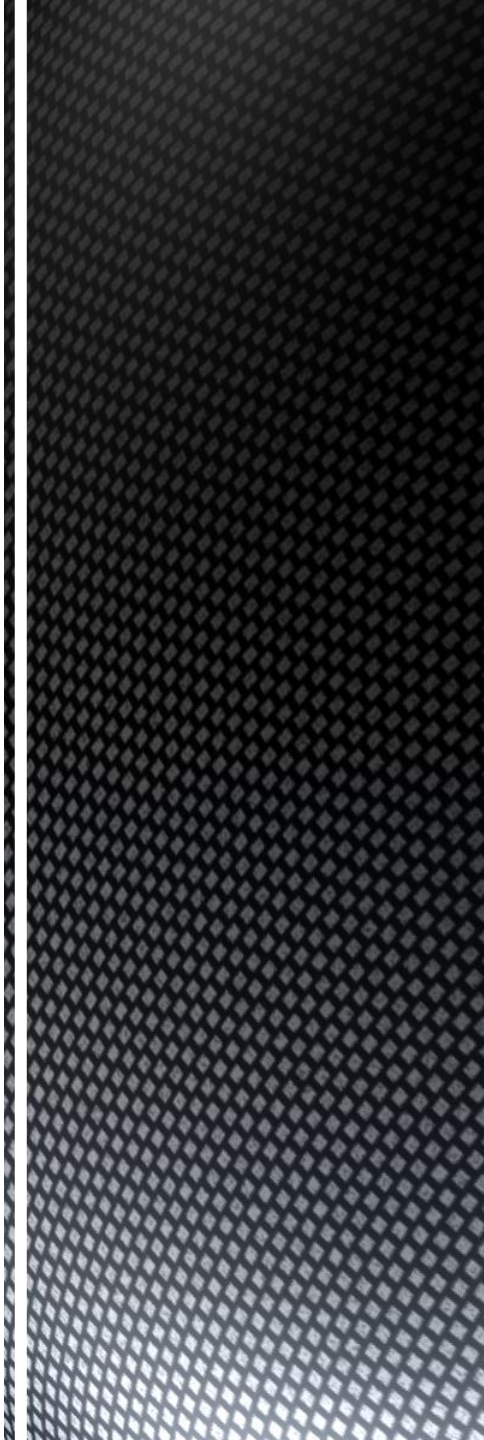
What Do We Do Now?

Management, Conservation and Legislation



Recent California Legislation

- **2002 – Senate Bill 1938**
  - Prepare and implement a groundwater management plans
    - monitoring and management of groundwater levels
    - groundwater quality degradation
    - subsidence, surface flow changes and surface water quality

- **2009 – Senate Bill X7 6**
  - authorized CADWR to establish permanent and locally-managed groundwater elevation monitoring for 515 alluvial groundwater basins.

- **2014 – Sustainable Groundwater Management Act (SGMA)**
  - Three bill package providing the monitoring and reporting framework for local authorities that form of Groundwater Sustainability Agency (GSA)
  - Adopt sustainability plans in 5 to 7 years with 5 year evaluations
  - By 2040±, achieve sustainability in high to medium priority basins

- **2015 – Senate Bill 13 Amending SGMA**
  - Allows DWR to referee GSA applications, overlapping basins and over reach into other basins

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What Do We Do Now?

- Develop comprehensive basin management plans
  - Defining subsurface geology is key
  - Increase basin water budget understanding
  - Identify safe yield of each basin
  - Model aquifer properties
  - Local districts use existing USGS, DWR and other agency data
  - Develop subsidence monitoring networks
  - Provide funding for oversight and expertise

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What Do We Do Now?

- Plan for Subsidence?
  - Increased freeboard requirements for infrastructure?
  - Increase planned maintenance budgets, how?
  - Develop requirements for well permits
    - Stanislaus County
      - groundwater modeling and sustainability

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What Do We Do Now?

- Groundwater Recharge and Storage?
  - Recharge Injection Wells/Recharge Ponds
    - Complications with SWRCB Resolution 68-18 (non-degradation policy)
    - $900 to $1,100 per acre-foot
  - Develop Storage
    - Raising Dams/Expanding Reservoirs
    - $1,700 to 2,700 per acre-foot
  - Reverse Osmosis/Desalinization
    - Convert sea or brackish water for recharge
      - $1,900 to over $3,000 per acre-foot
  - Increased gray water usage

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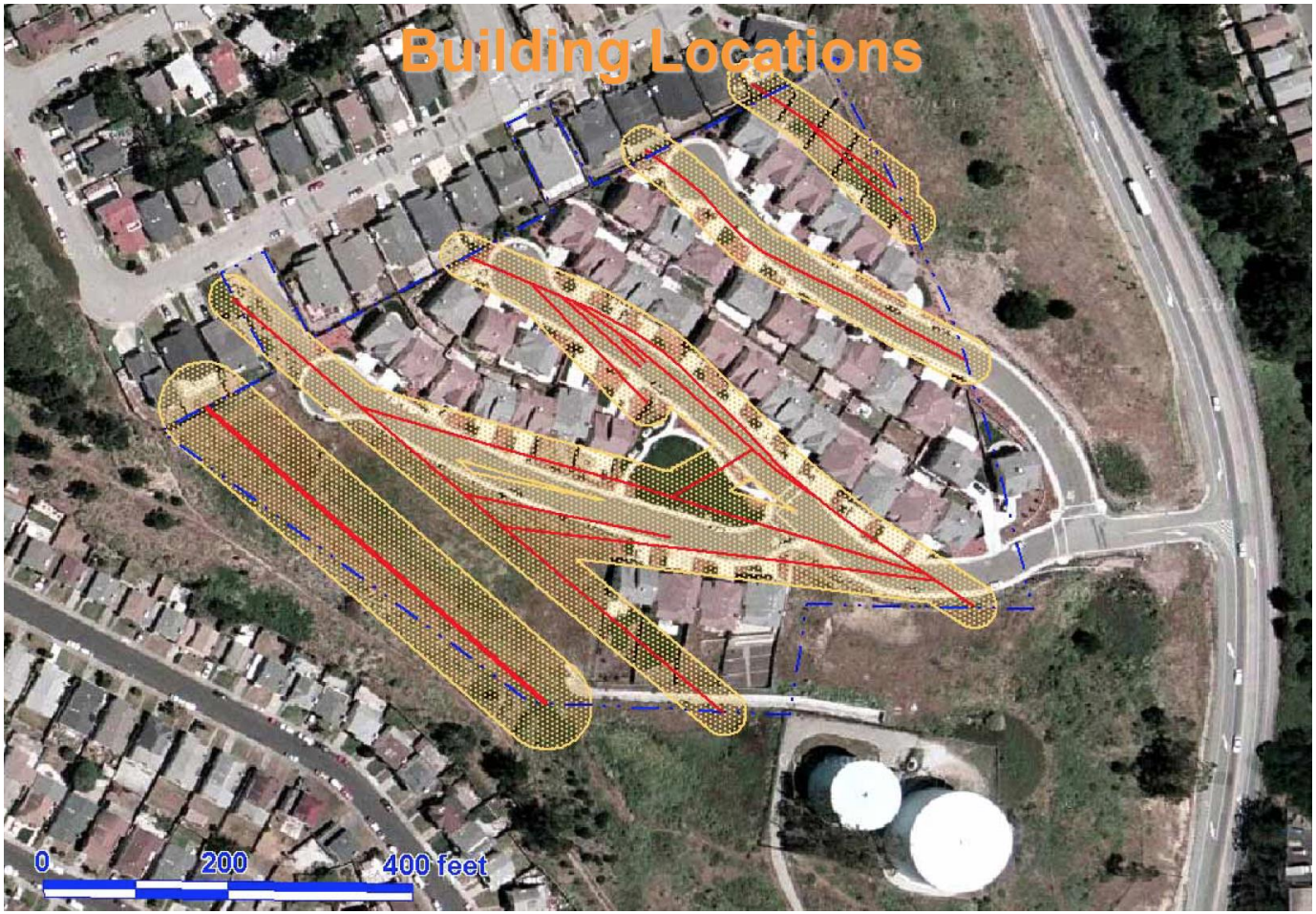
What Do We Do Now?

- Alquist Priolo



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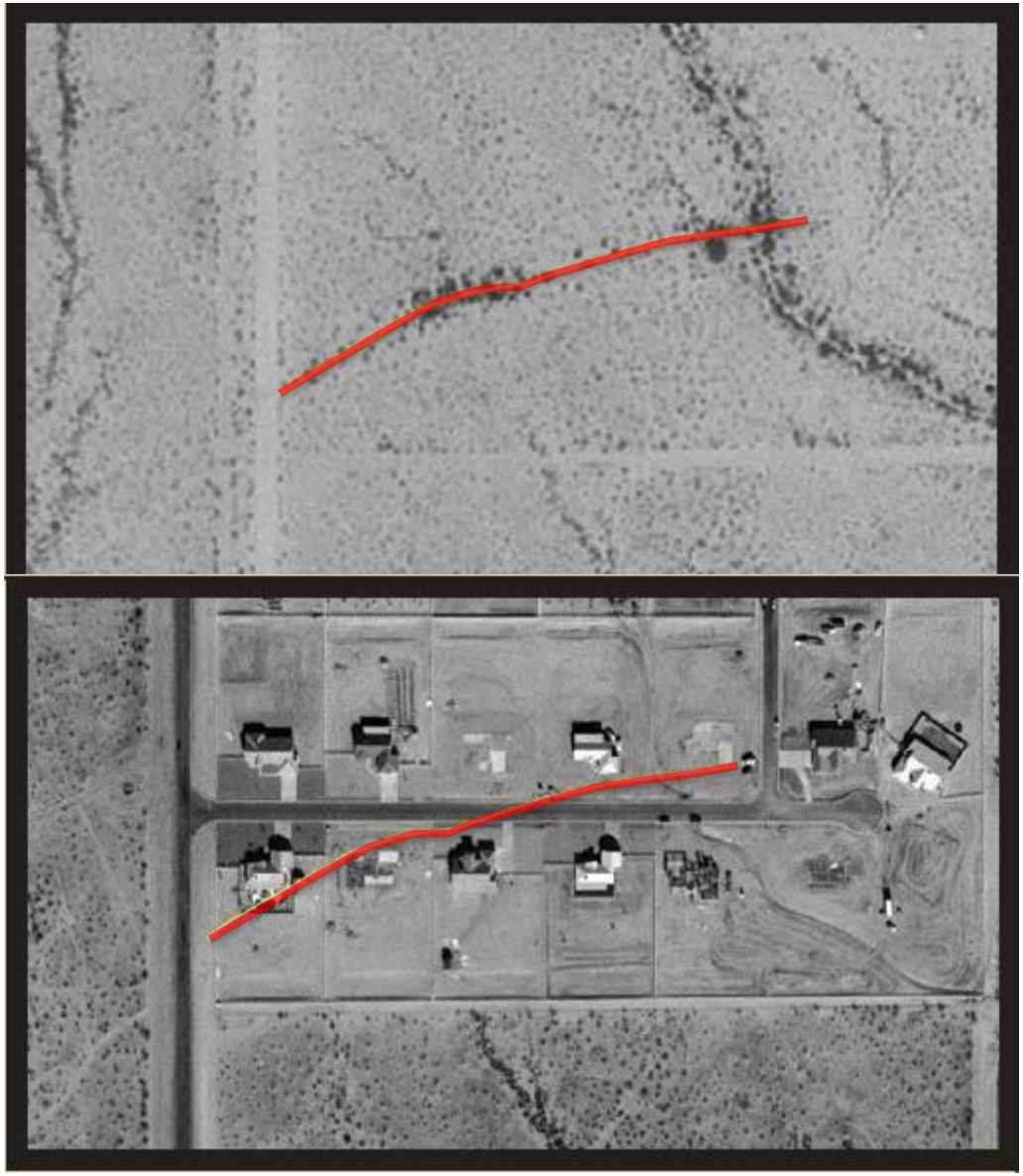
Source: Ludhorff and Scalmanini, 2014

What Do We Do Now?



Source: Arizona Geological Survey

What Do We Do Now?

- Land Use Strategies
  - Develop geologic hazard criteria
  - Avoid/mitigate problem areas
  - Staff education and data repository
  - Work with other agencies to develop minimum study and reporting criteria
  - CGS Publications SP 42, SP 117, etc.
  - Arizona Land Subsidence Group
    - Technical Advisory Committee
  - Still requires a sustainable groundwater plan

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Online Resources

Understanding California's Groundwater
http://waterinthewest.stanford.edu/groundwater/

Groundwater Ambient Monitoring and Assessment Program (GAMA)
http://www.waterboards.ca.gov/gama/

USGS California Water Science Center
http://ca.water.usgs.gov

California Water Foundation
http://californiawaterfoundation.org

California Department of Water Resources – Groundwater Page
http://www.water.ca.gov/groundwater/

For a PDF Copy of the Slides, Email: mmcilroy@taberconsultants.com

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Online Resources

Water Availability and Use Pilot: Methods Development for a Regional Assessment of Groundwater Availability, Southwest Alluvial Basins, Arizona
http://pubs.usgs.gov/sir/2011/5071/

Arizona Department of Water Resources
http://www.azwater.gov/azdwr/
http://www.azwater.gov/AzDWR/IT/Groundwater.htm

USGS Water Data for Nevada
http://waterdata.usgs.gov/nv/nwis/nwis

State of Nevada Division of Water Resources
http://water.nv.gov

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Questions?

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Selected References

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3. Bryant, William, Alquist Priolo Earthquake Fault Zoning Act, Surface Fault Displacement Workshop, Berkeley, California, May 20-21, 2009
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5. Harris, Ray and Allison, M. Lee, *Hazardous Cracks Running through Arizona,* Geotimes, August 2006, pgs. 24-27
6. Luhdorff and Scalmanini, Land Subsidence from Groundwater Use in California, April 2014
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