Assessment of Recent Land Subsidence in California:

examples from the Southern Central Valley

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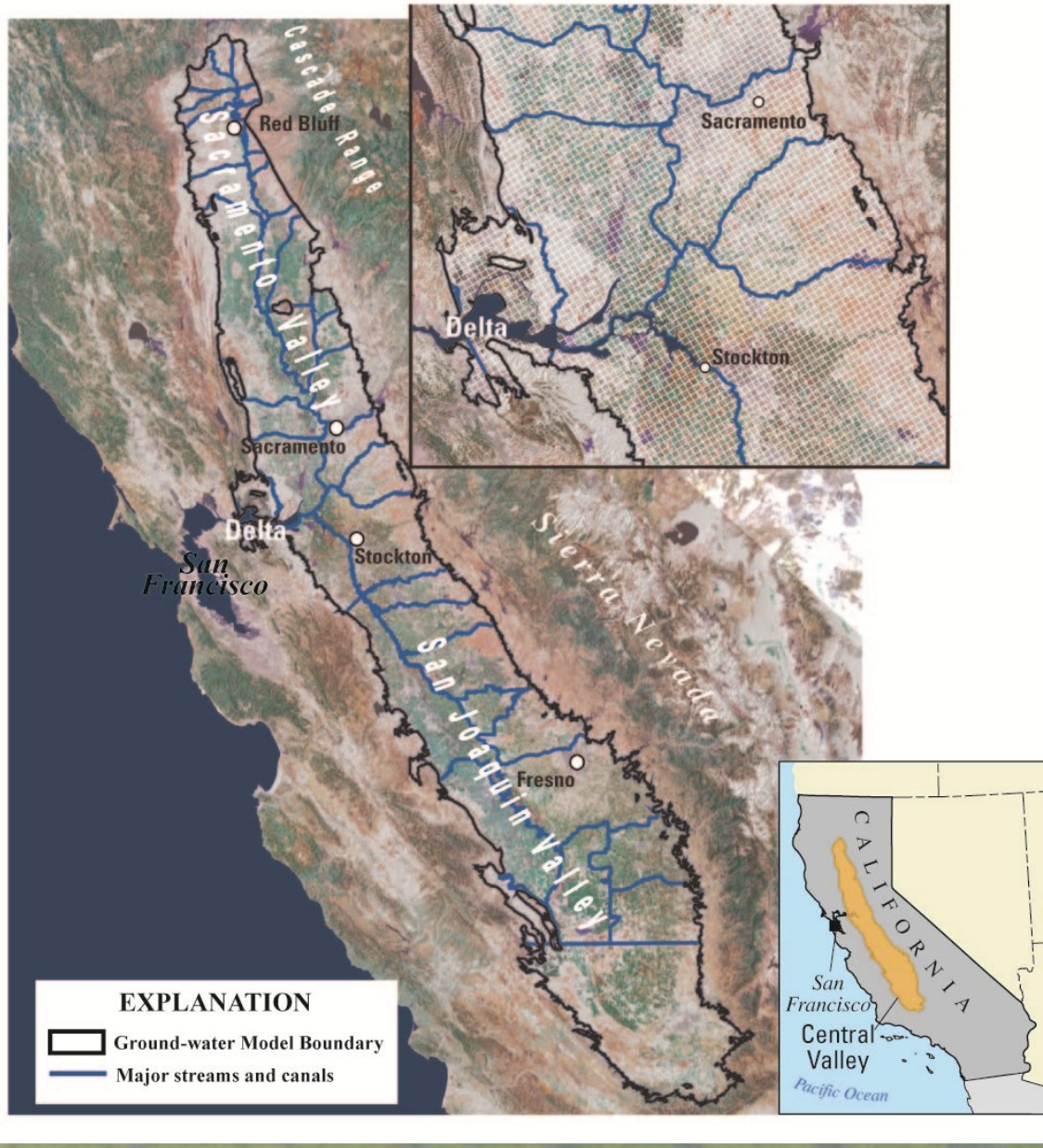
USGS
science for a changing world

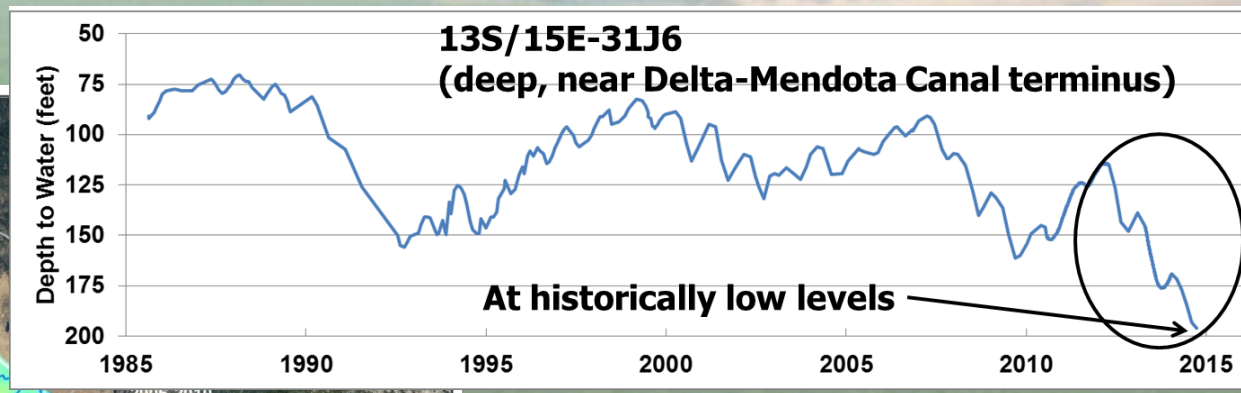
Central Valley Facts:

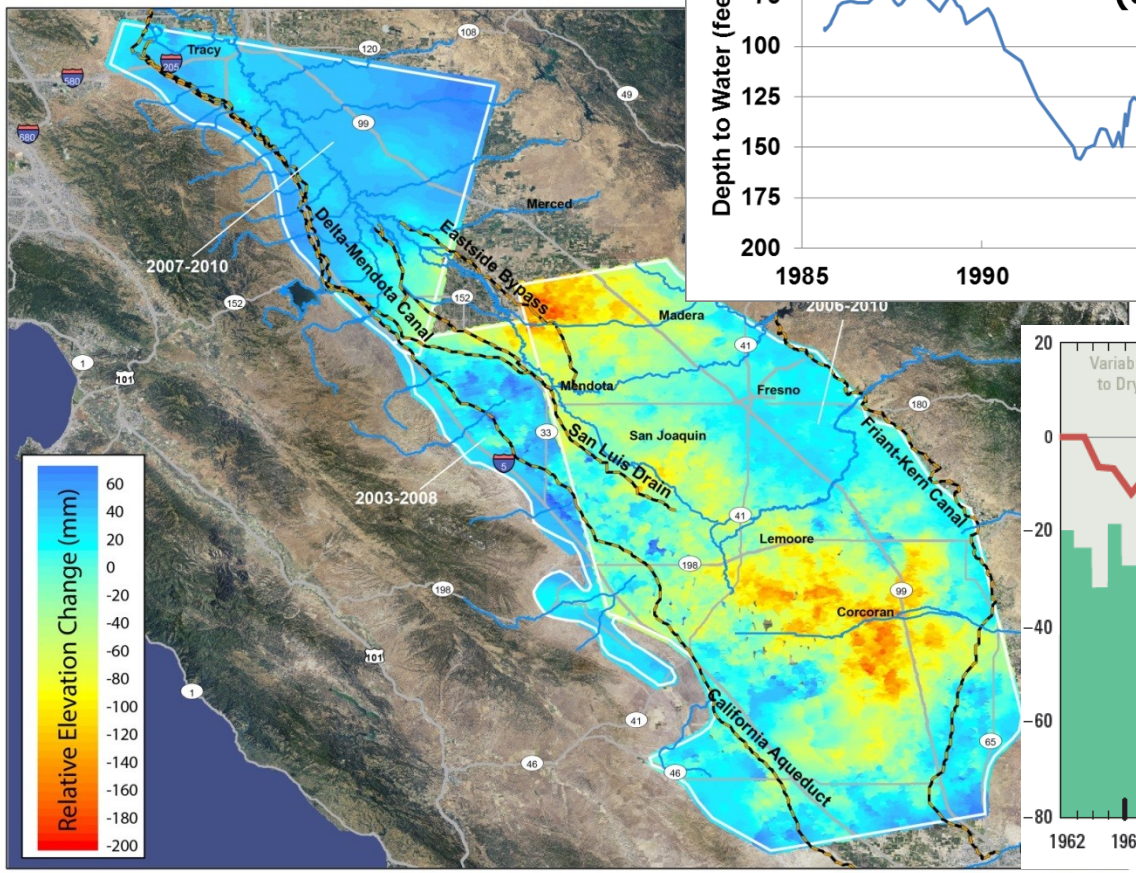
- 20,000 square miles
- Using about 1% of U.S. farmland, California's Central Valley
  - -Produces more than 250 different crops
  - -Supplies 7% of the U.S. agricultural output (by value) — 1/4 of the Nation's food, including about half of the Nation's fruits, nuts, and vegetables
- Approximately 20% of the Nation's groundwater is pumped from the Central Valley aquifer system.

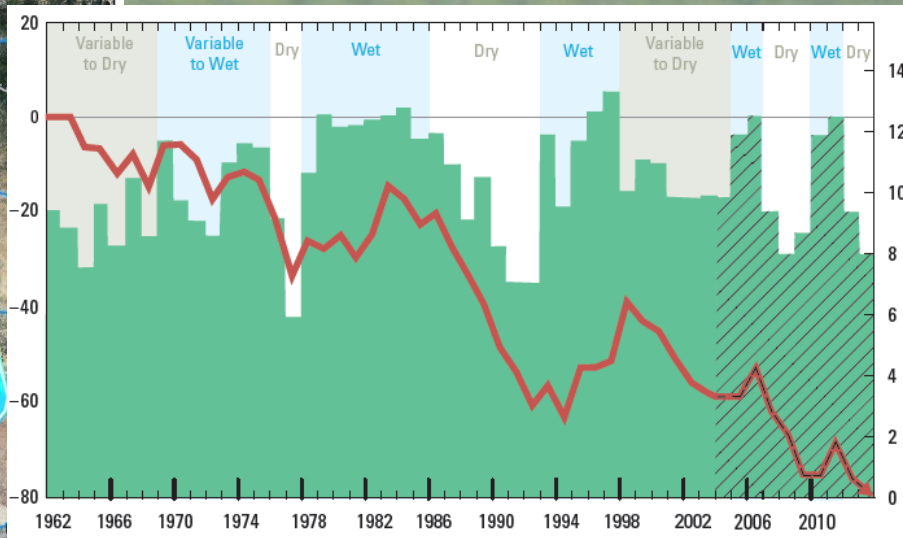


Effects on Central Valley:

The recent drought, land-use changes, and restrictions on surface-water flows have resulted in extensive pumping, large groundwater-level declines, and widespread land subsidence

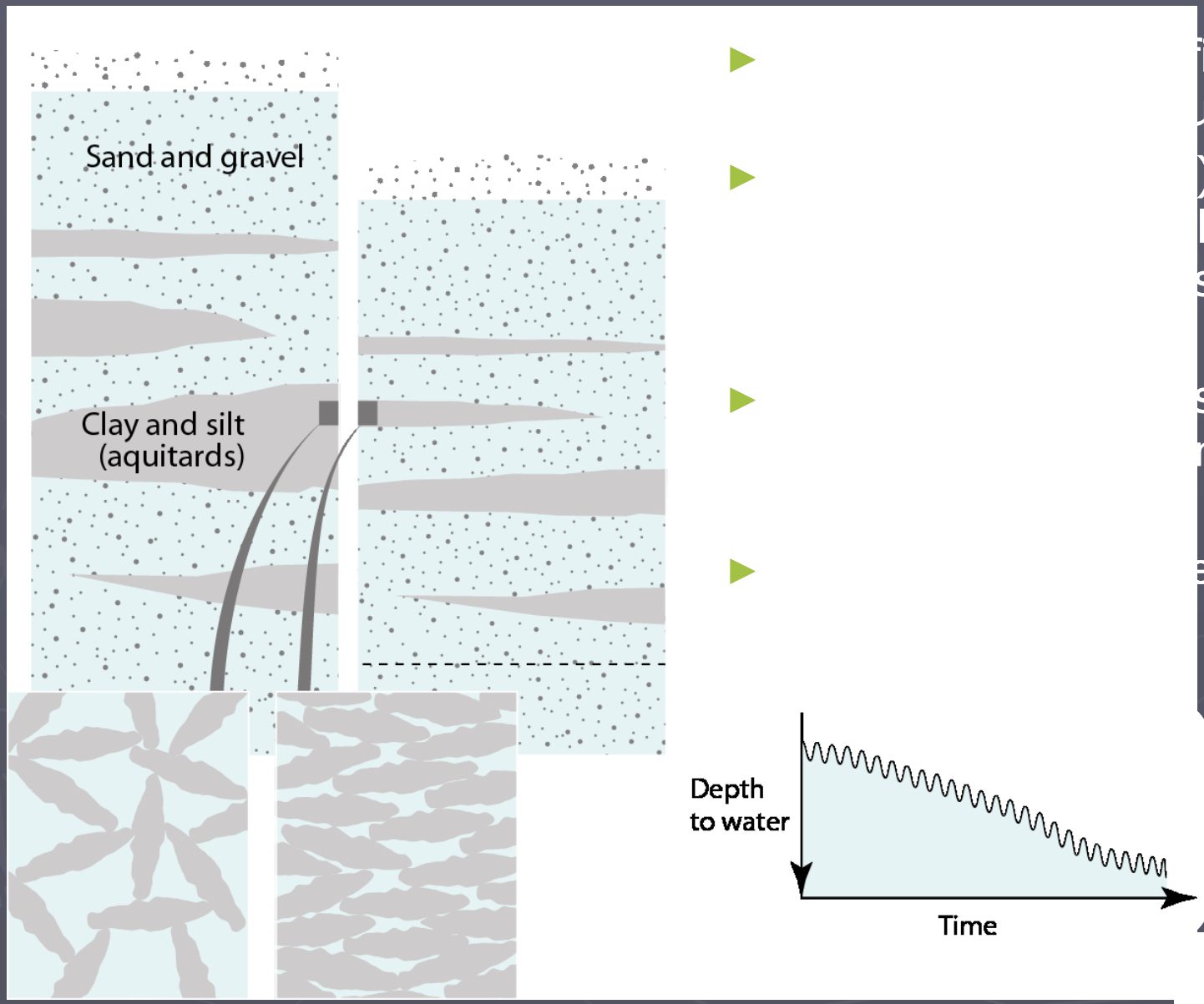






Land Subsidence in the San Joaquin Valley

A deep process: Aquifer-System Compaction



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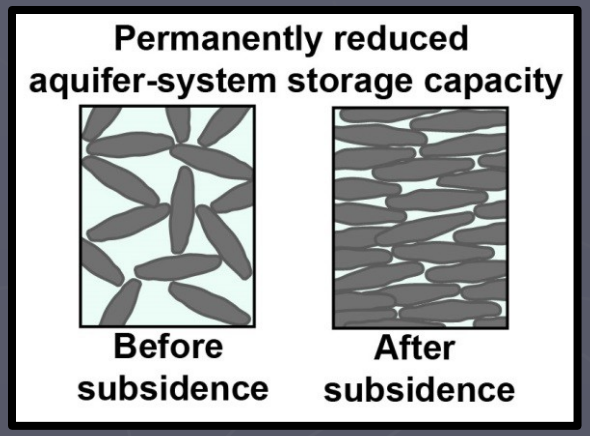
Galloway and others, 1999; USGS Circular 1182

Subsidence Damages Natural Resources

- Reduces aquifer-system storage capacity

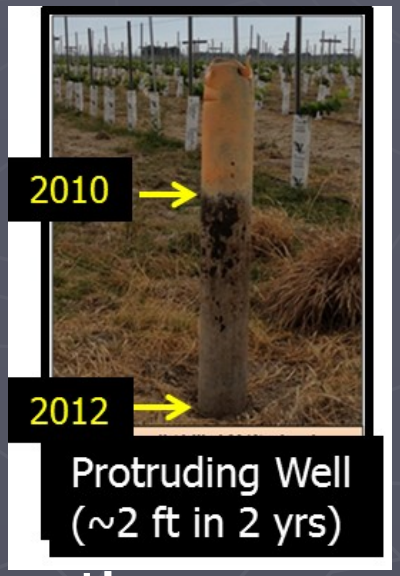


- Impacts to wetland, riparian, and aquatic ecosystems

- Restricted land uses

Subsidence Damages Infrastructure

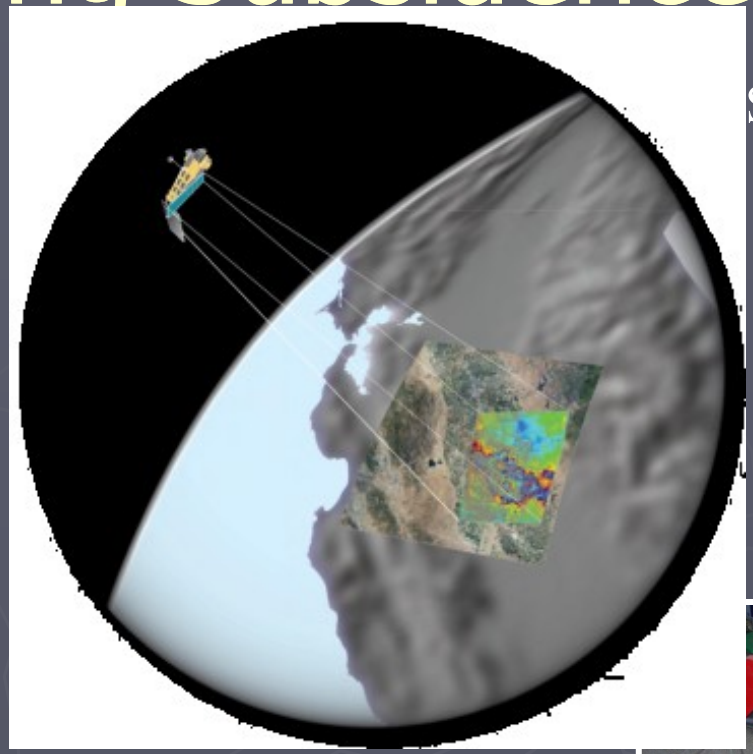
- Risk dependent on
  - Type of infrastructure
  - Magnitude of subsidence
  - Subsidence gradients (differential subsidence)
- Highest risk
  - Infrastructure built at specific elevations
    - Water conveyances
    - Freeway overpasses
  - Pipelines
- High risk
  - Infrastructure not dependent on specific elevations
    - Roads, railways, bridges, wells



Measuring Subsidence

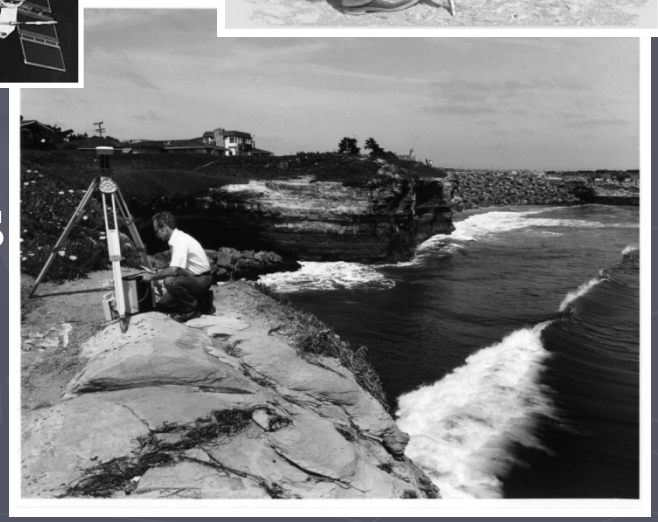
Bench Mark

Spirit Leveling



SAR

GPS



Extensometer*

*measures part of land subsidence

Subsidence Measurement Methods

Classification by Spatial Density

- One to Several Points
  - Borehole Extensometry*
- Tens of Points
  - Spirit Leveling
  - GPS (rtk/static/continuous)
- Millions of Points
  - InSAR
  - Airborne LiDAR

Classification by Temporal Density

- <One measurement/year
  - Spirit Leveling
  - GPS (Static)
- Several measurements/year
  - InSAR
  - Airborne LiDAR
- 1000's measurements/year
  - Borehole Extensometry
  - CGPS

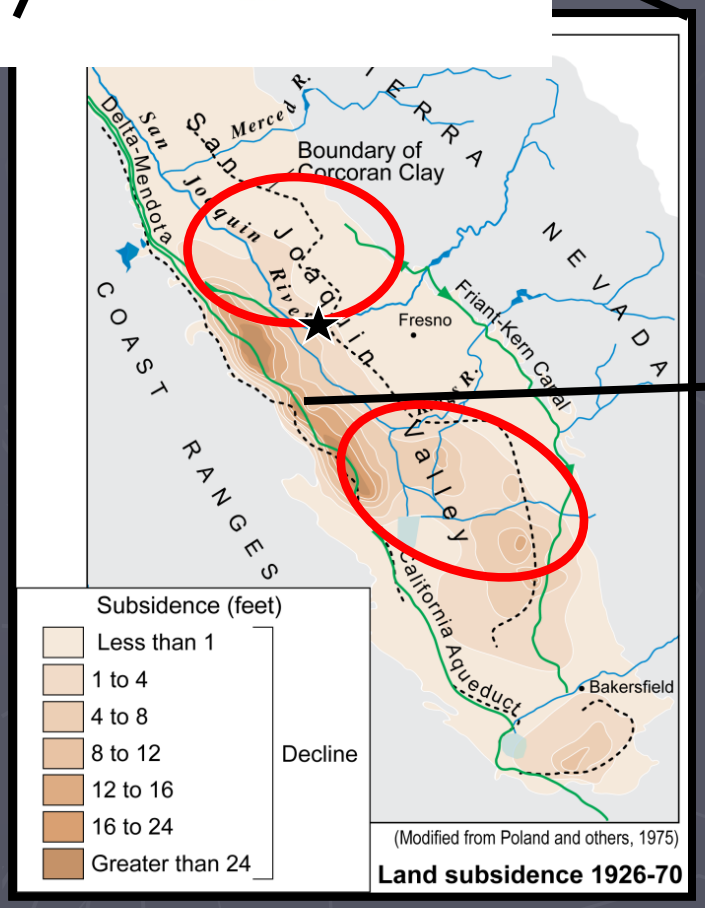
* Measures aquifer-system compaction

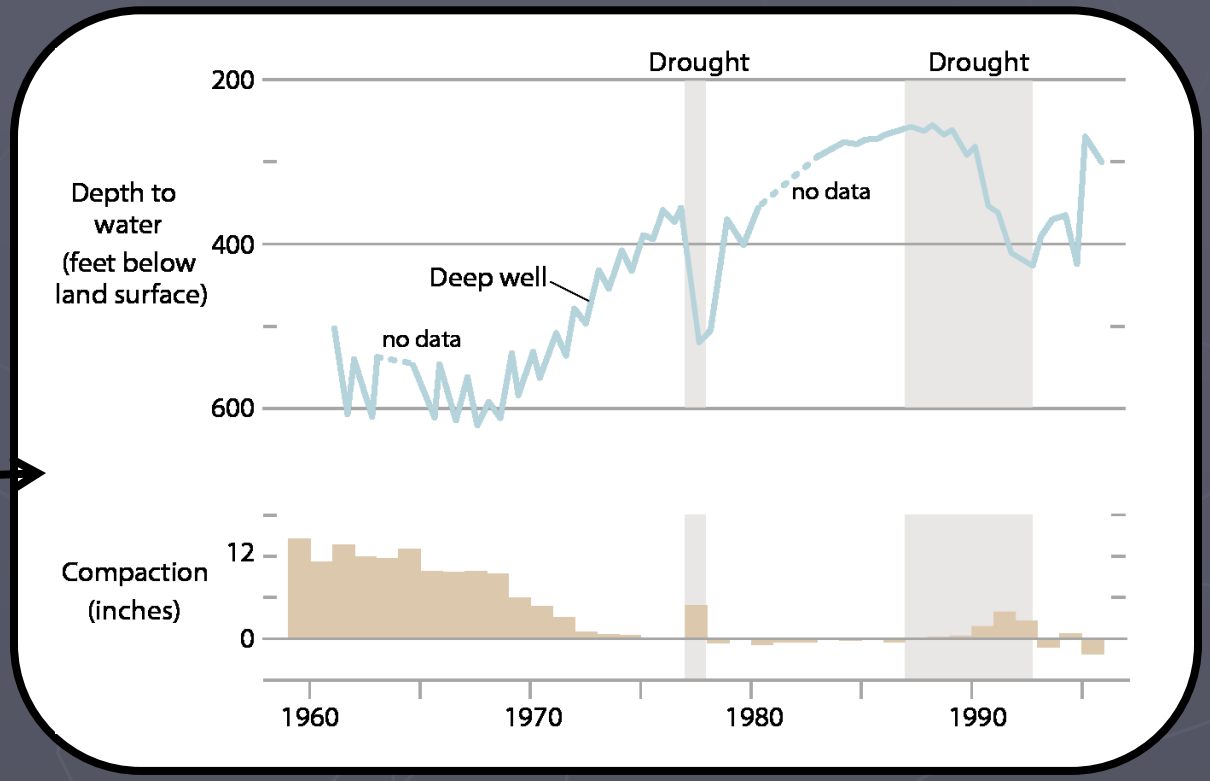
Combine Measurement Methods

- Guide terrestrial monitoring schemes
  - InSAR
- Ground truth InSAR data
  - Spirit leveling or GPS
- Improve spatial/temporal resolution of sparse data
  - InSAR (spatial and temporal)
  - CGPS (temporal)
- Determine depth intervals of compaction
  - GPS/InSAR/leveling data at an extensometer
- The list goes on…

ubsidence History

sive withdrawal of groundwater caused despread subsidence (1920s-1970)



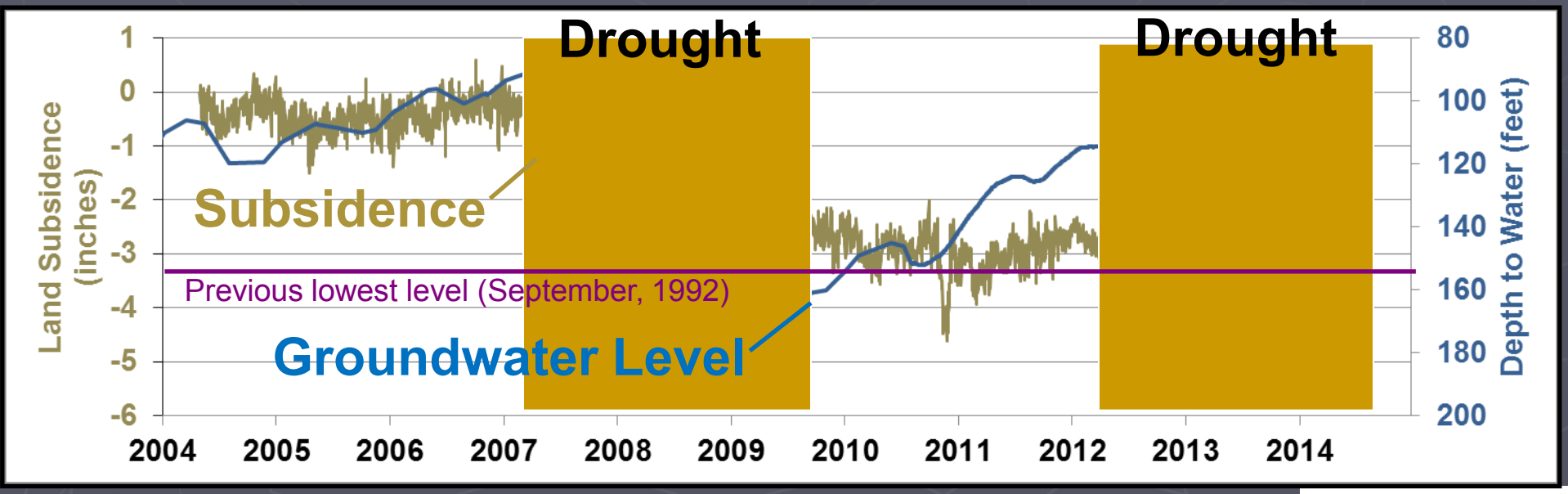


Surface-water deliveries caused widespread recovery and slowing or cessation of subsidence, except when deliveries were curtailed and groundwater pumping increased to meet demand

Galloway and others, 1999; USGS Circular 1182

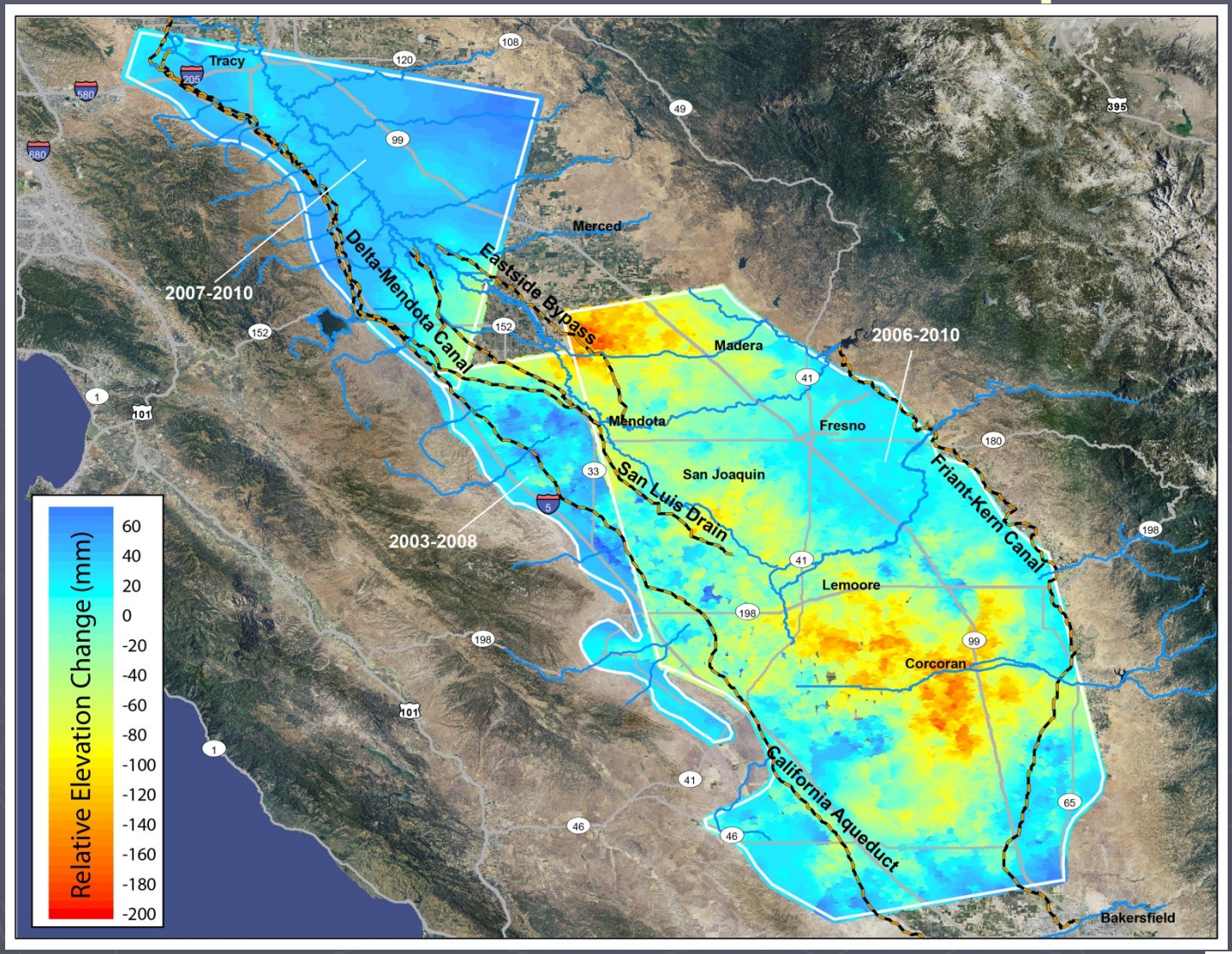
Recent Subsidence

- Renewed subsidence concern during 2007-09 drought and the current drought
  - Reduced surface water importation
  - More reliance on the groundwater resources
  - As it turns out…this is not just a problem during droughts for some areas without surface-water access

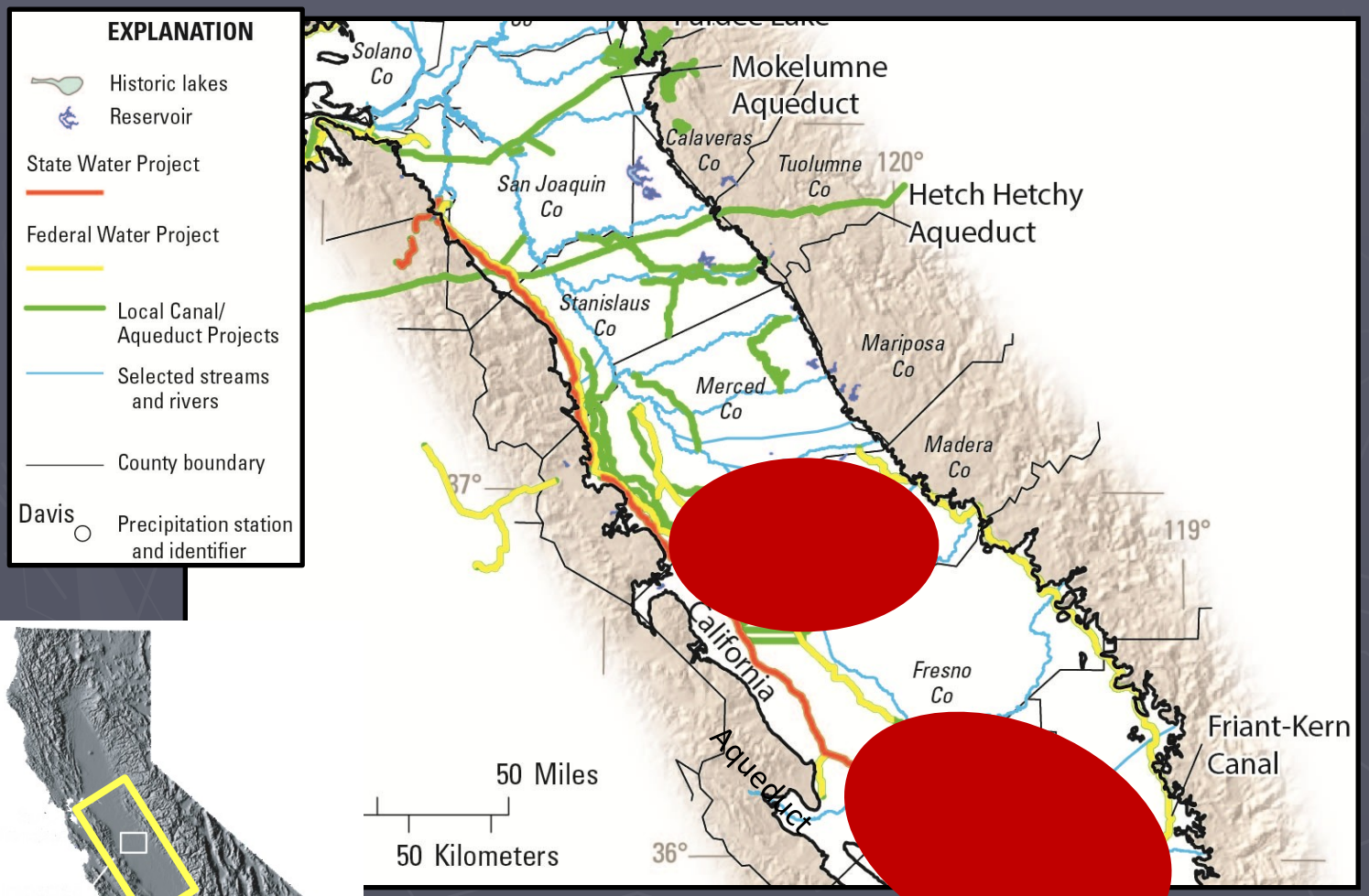


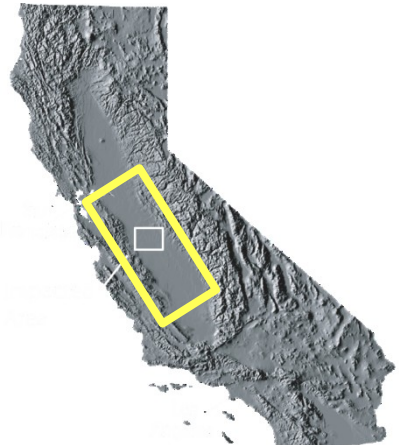
P304 data from UNAVCO; 2004-10 water-level data from Luhdorff and Scalmanini Consulting Engineers

Subsidence in the San Joaquin Valley



Federal, State, and Local Water Infrastructure in the Impacted Area

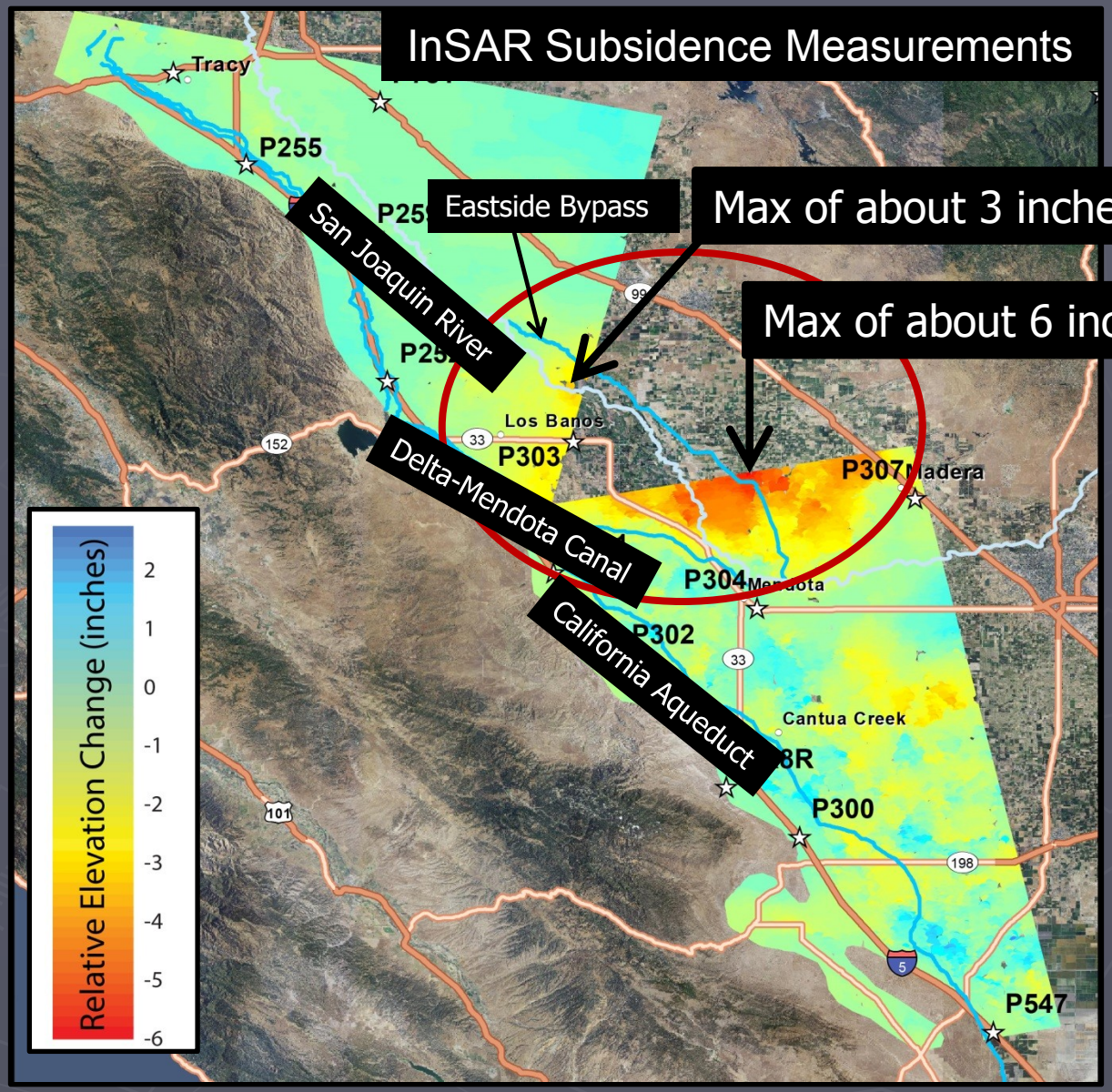




- **Delta-Mendota Canal**
- **California Aqueduct**
- **San Joaquin River (Restoration Area)**
- **Eastside Bypass**
- **Friant-Kern Canal**
- **Local canals and aqueducts**

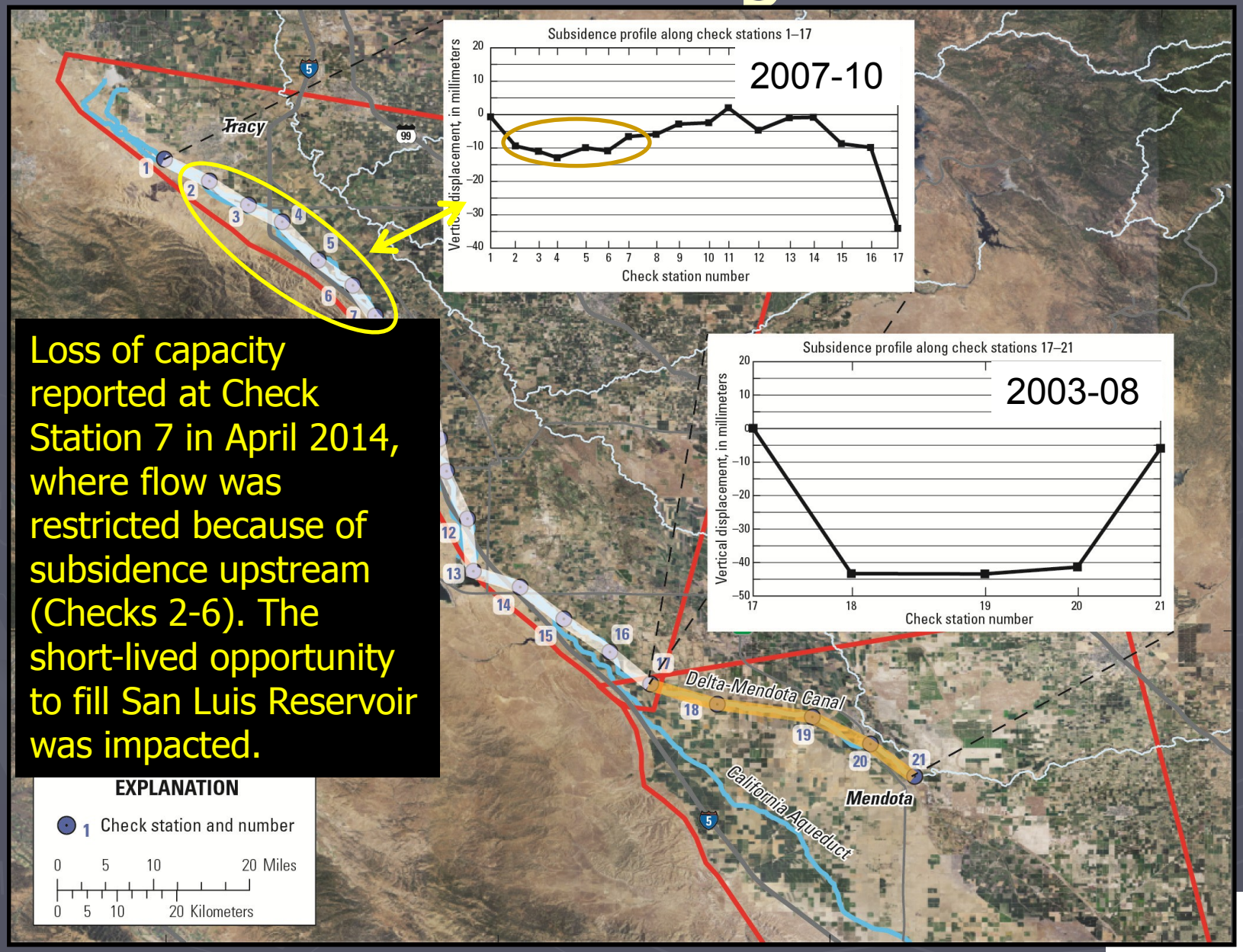
Modified from Faunt, 2009

Subsidence along the DMC



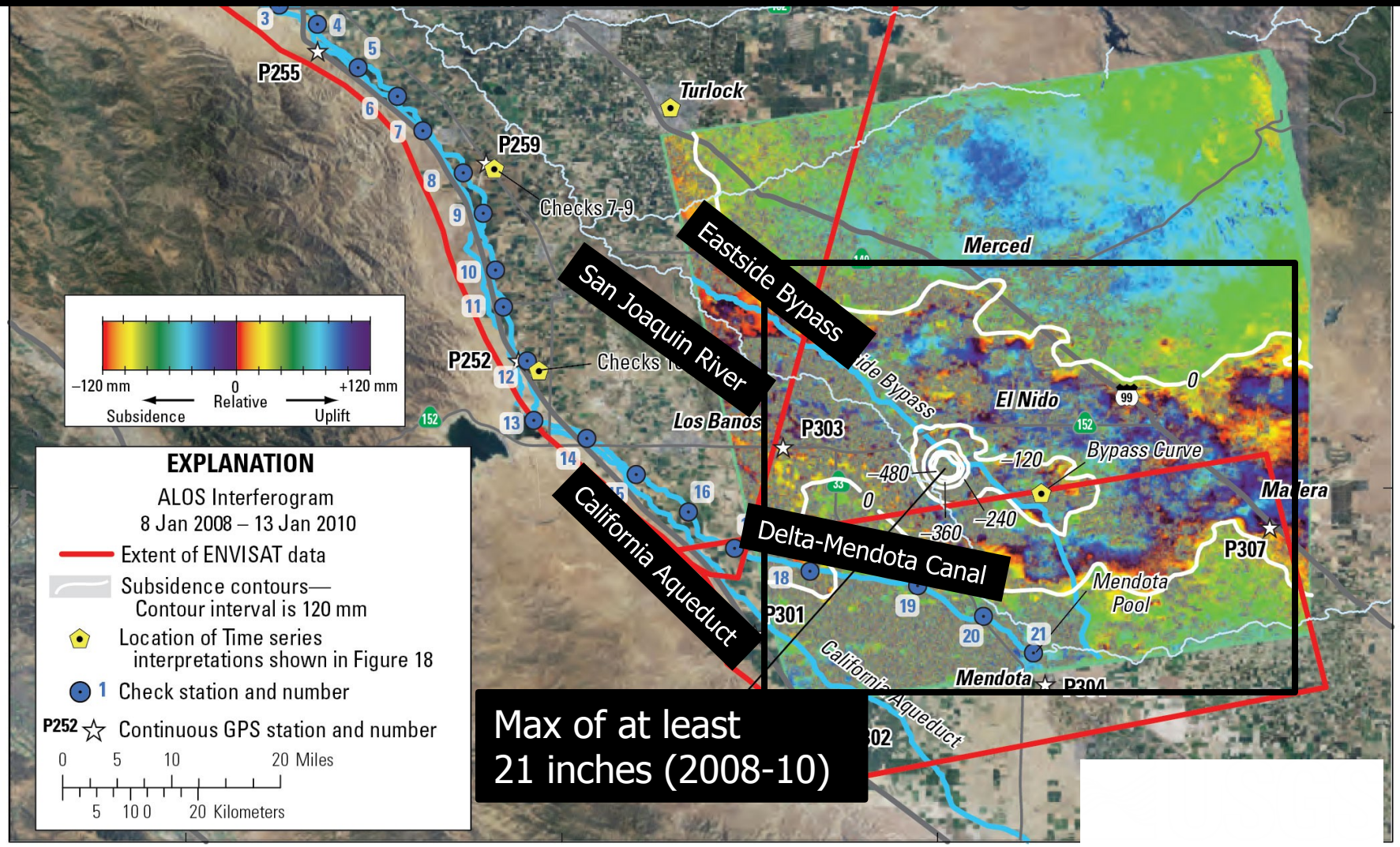
Preliminary and subject to revision

Subsidence along the DMC

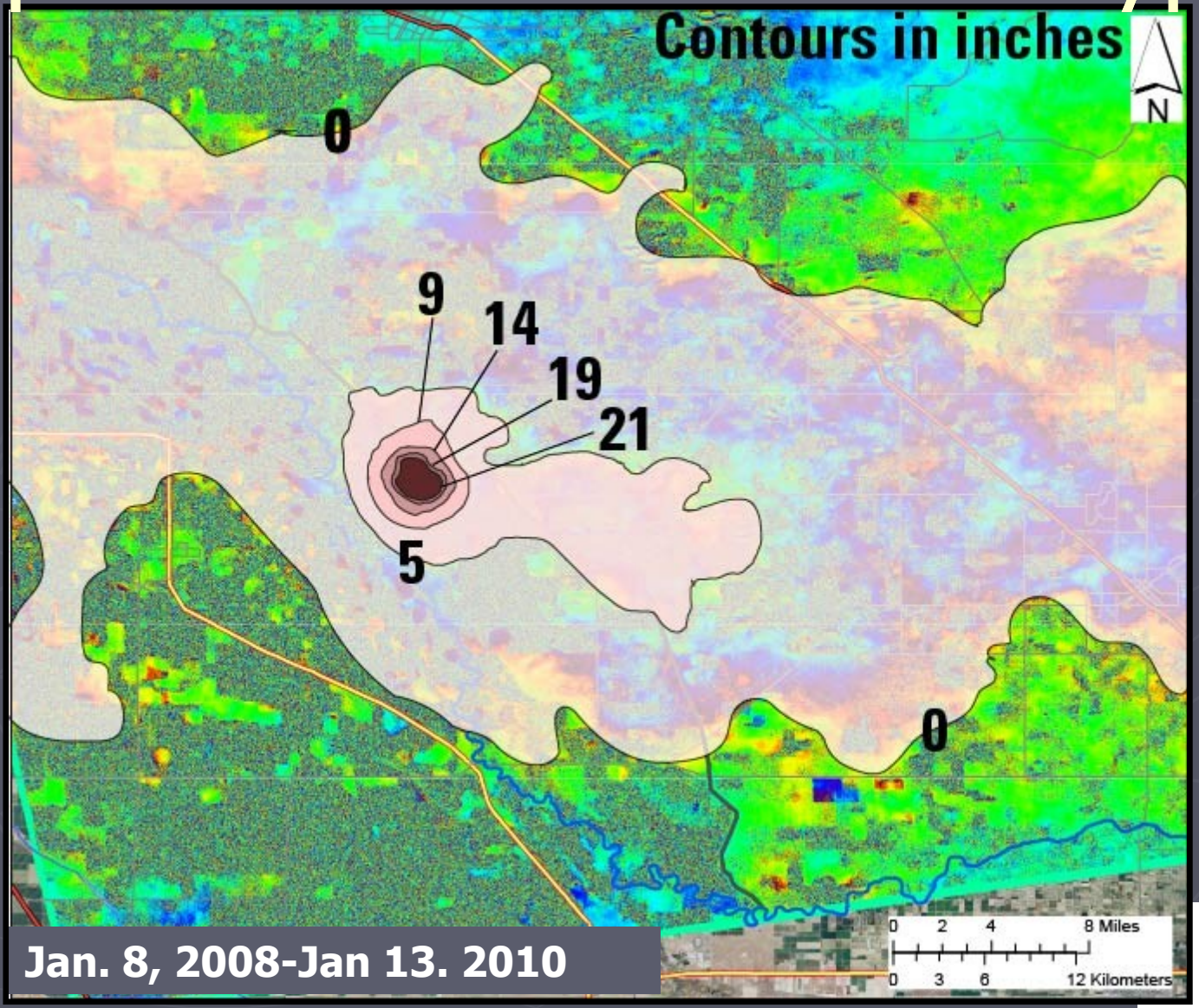


Loss of capacity reported at Check Station 7 in April 2014, where flow was restricted because of subsidence upstream (Checks 2-6). The short-lived opportunity to fill San Luis Reservoir was impacted.

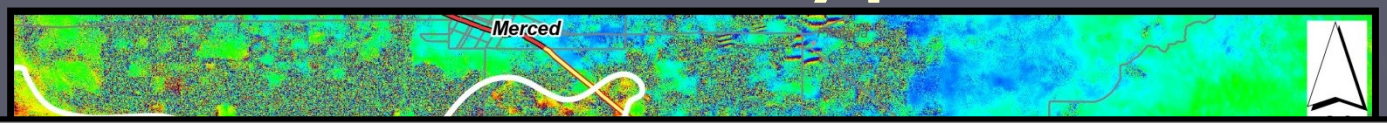
InSAR Subsidence Measurements: Maximum Subsidence Area near El Nido, between Eastside Bypass and San Joaquin River

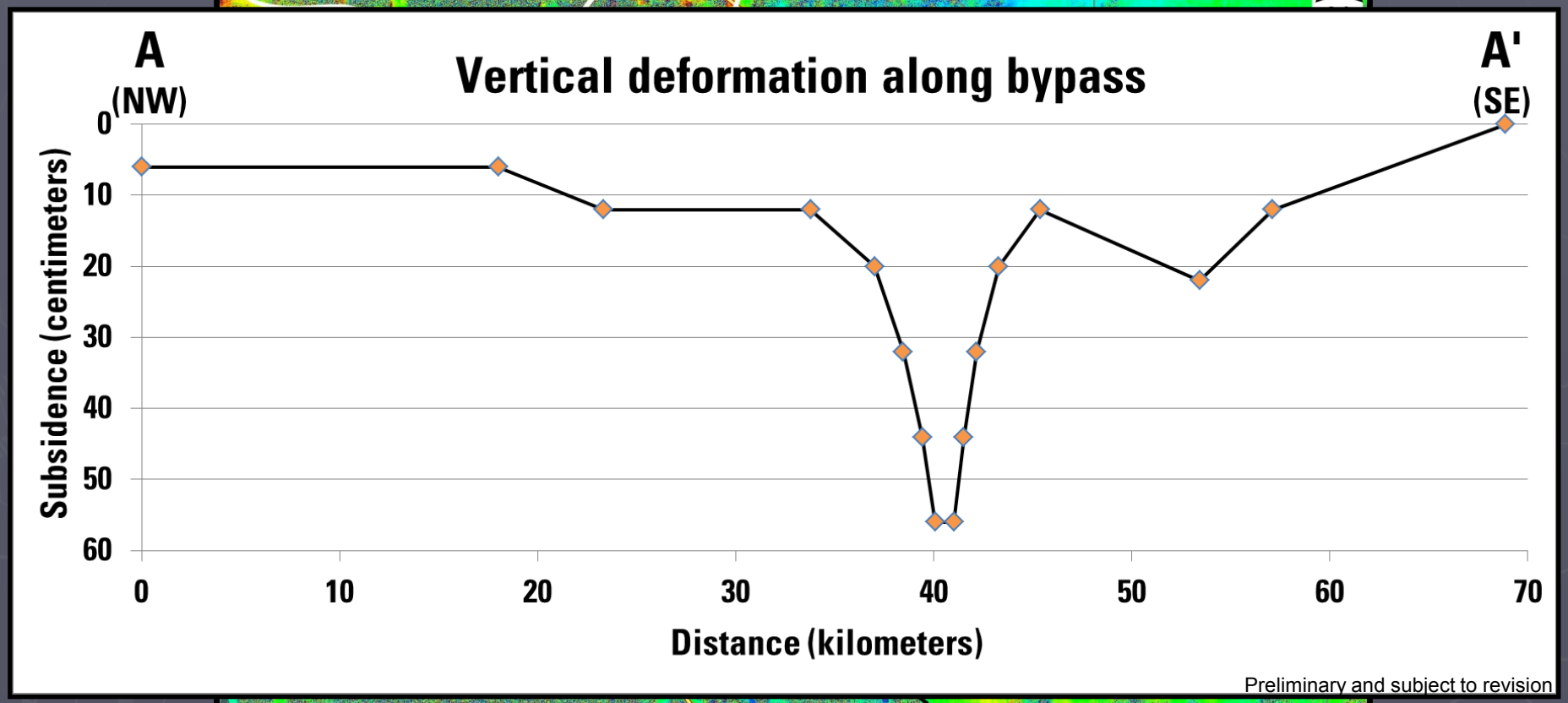


Highest Impact: Adjacent to San Joaquin River and Eastside Bypass

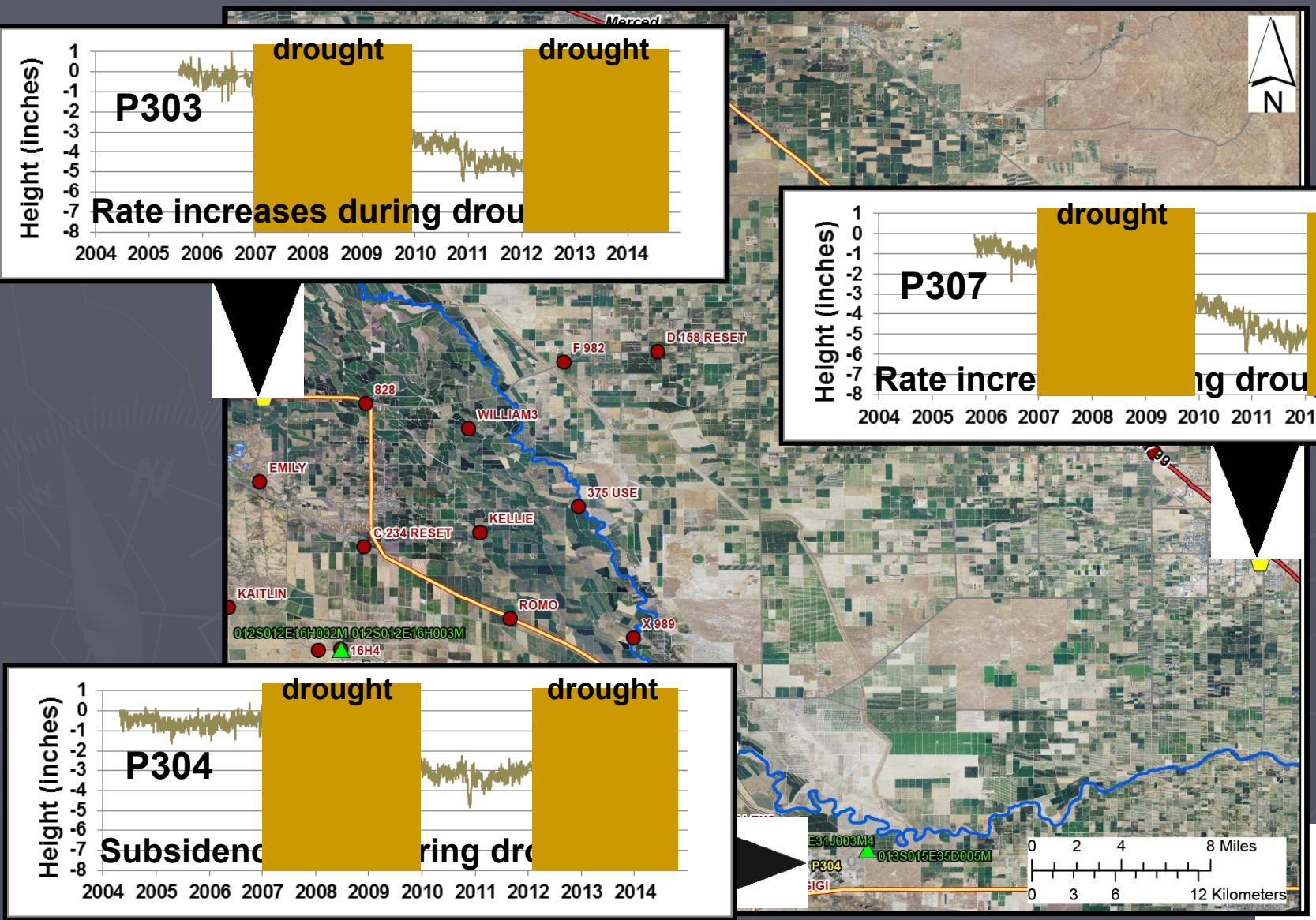


Subsidence along the Eastside Bypass



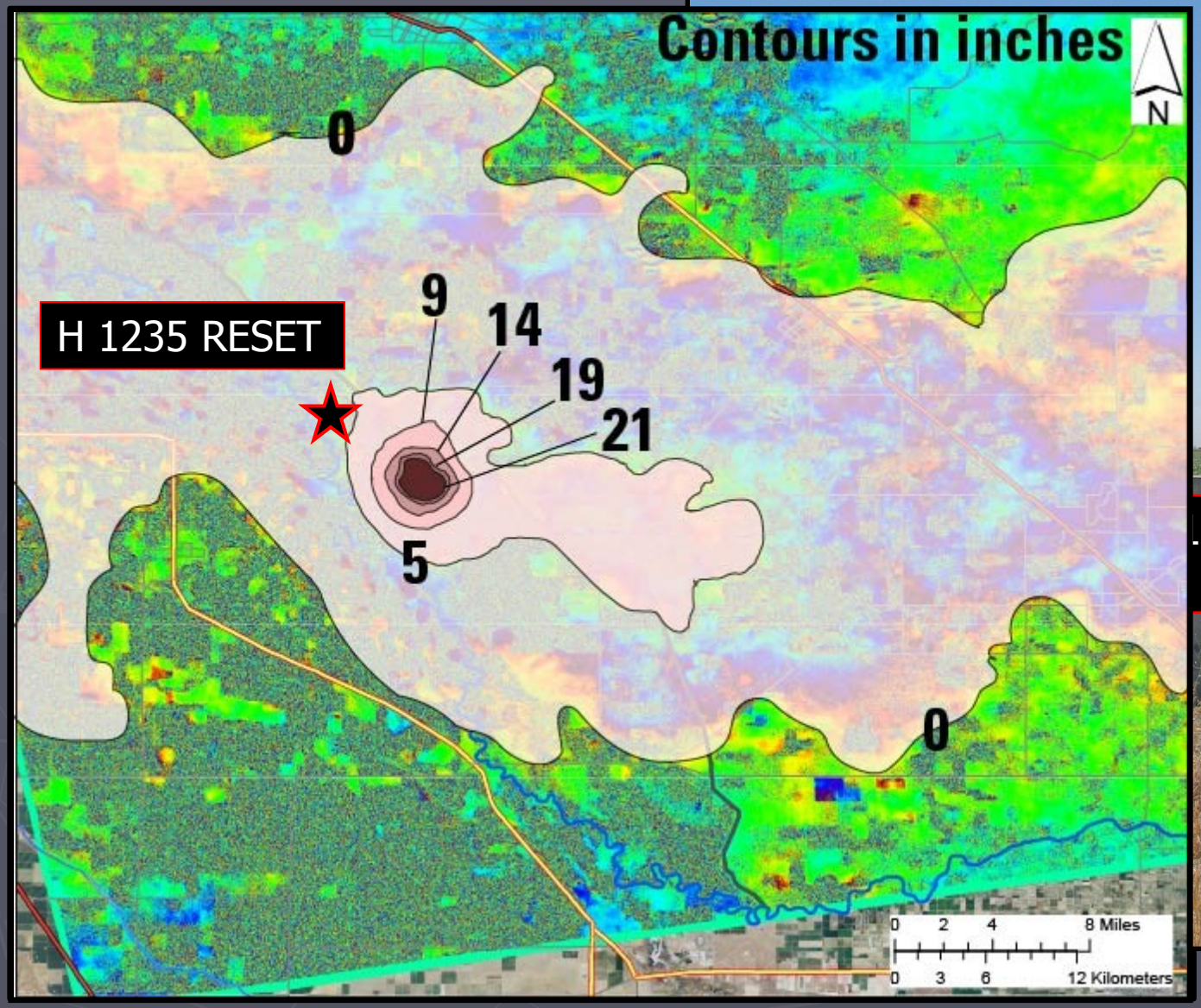


GPS Subsidence Measurements



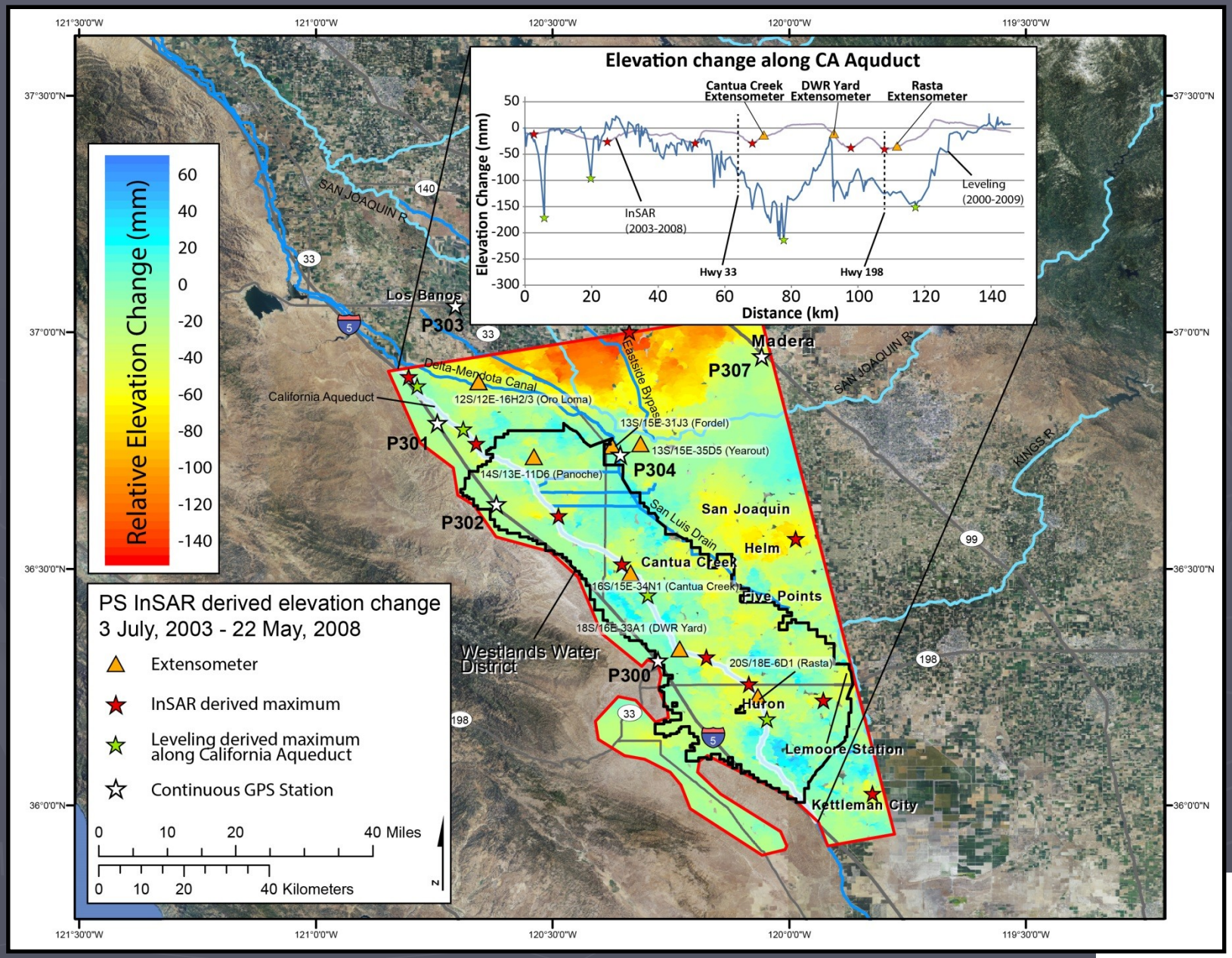
Data from UNAVCO

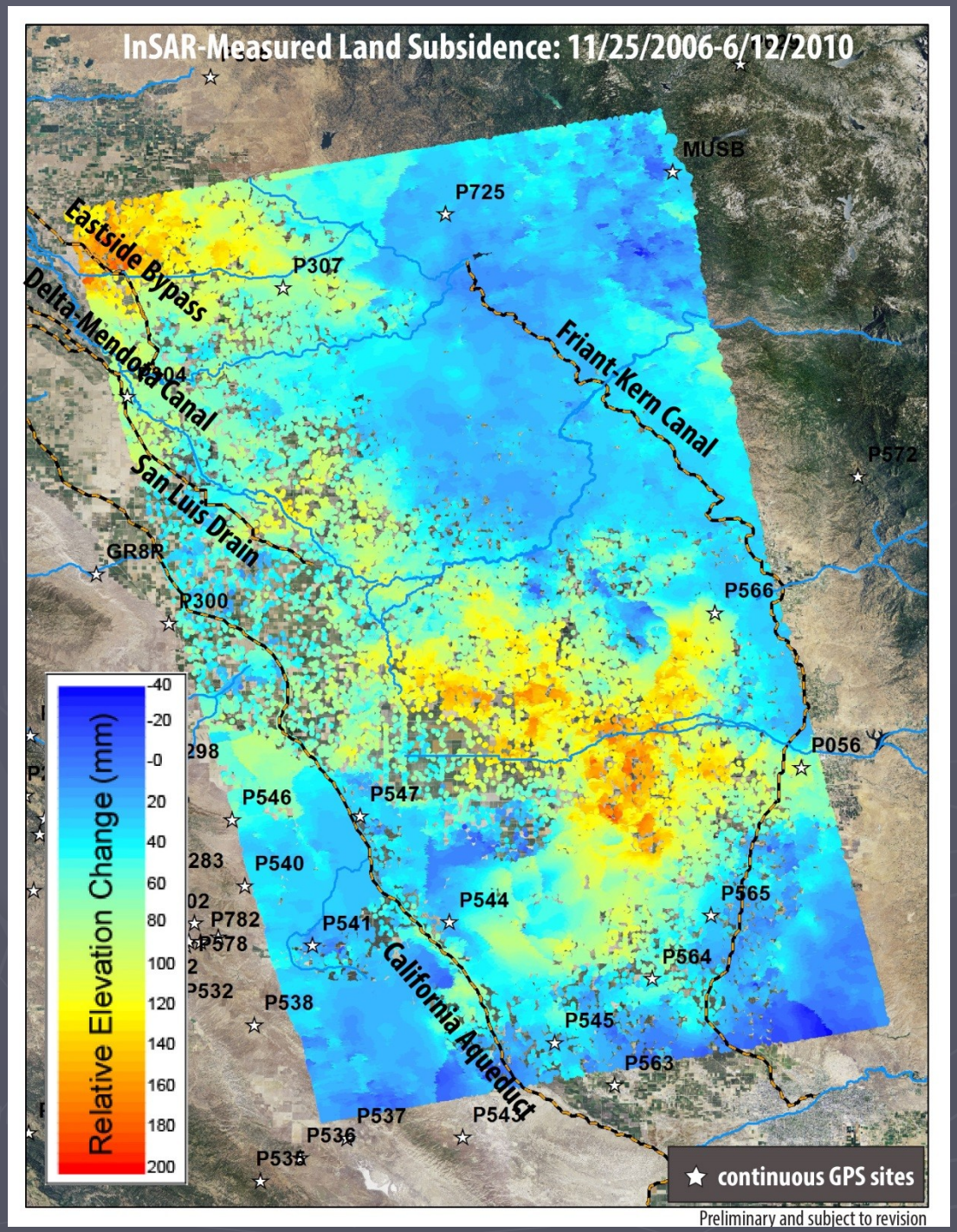
Elevation Comparisons



Data from National Geodetic Survey, Department of Water Resources, and Bureau of Reclamation

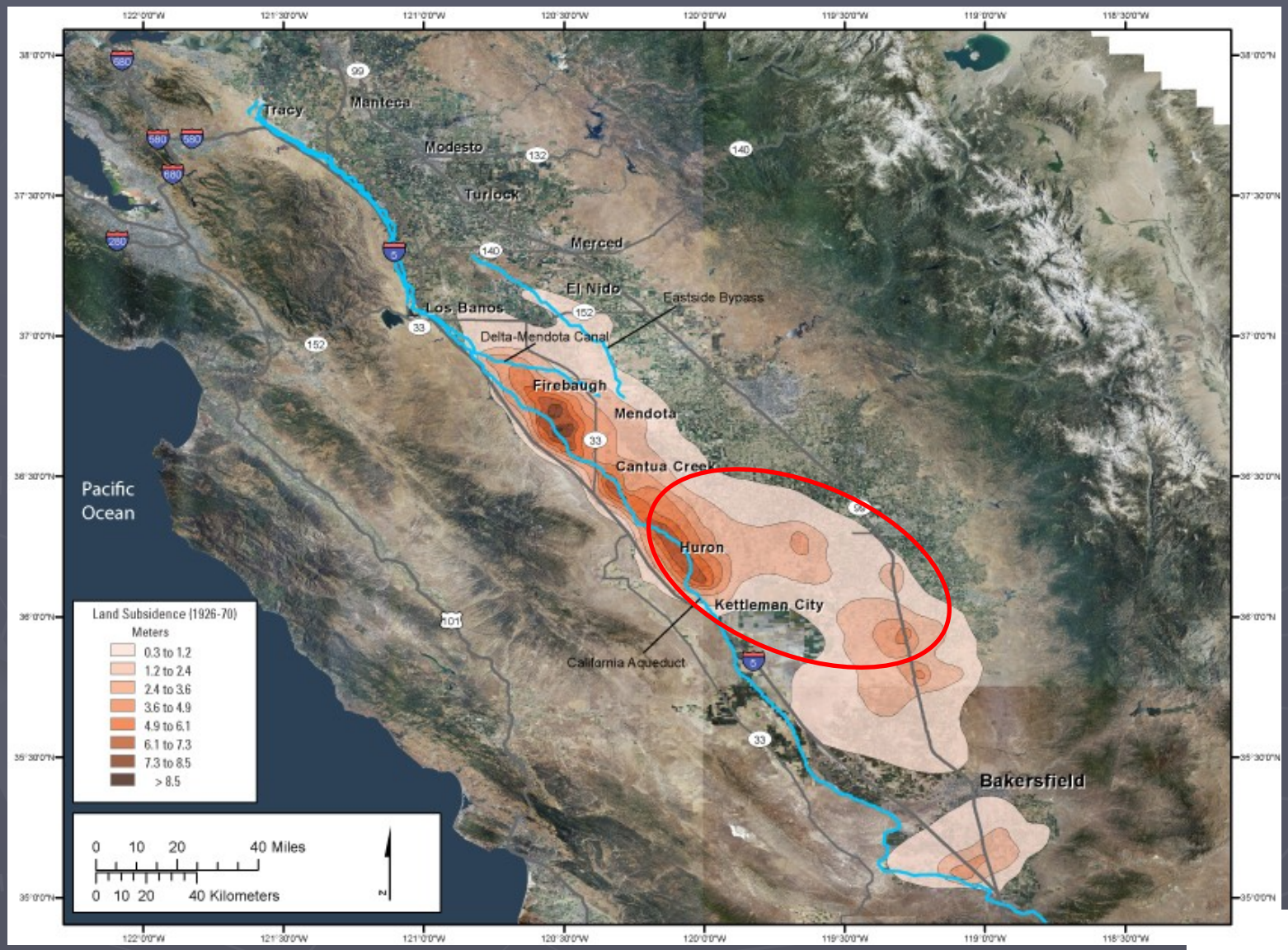
Subsidence along the CA Aqueduct





Subsidence in the Corcoran-Pixley Area and the Friant-Kern Canal

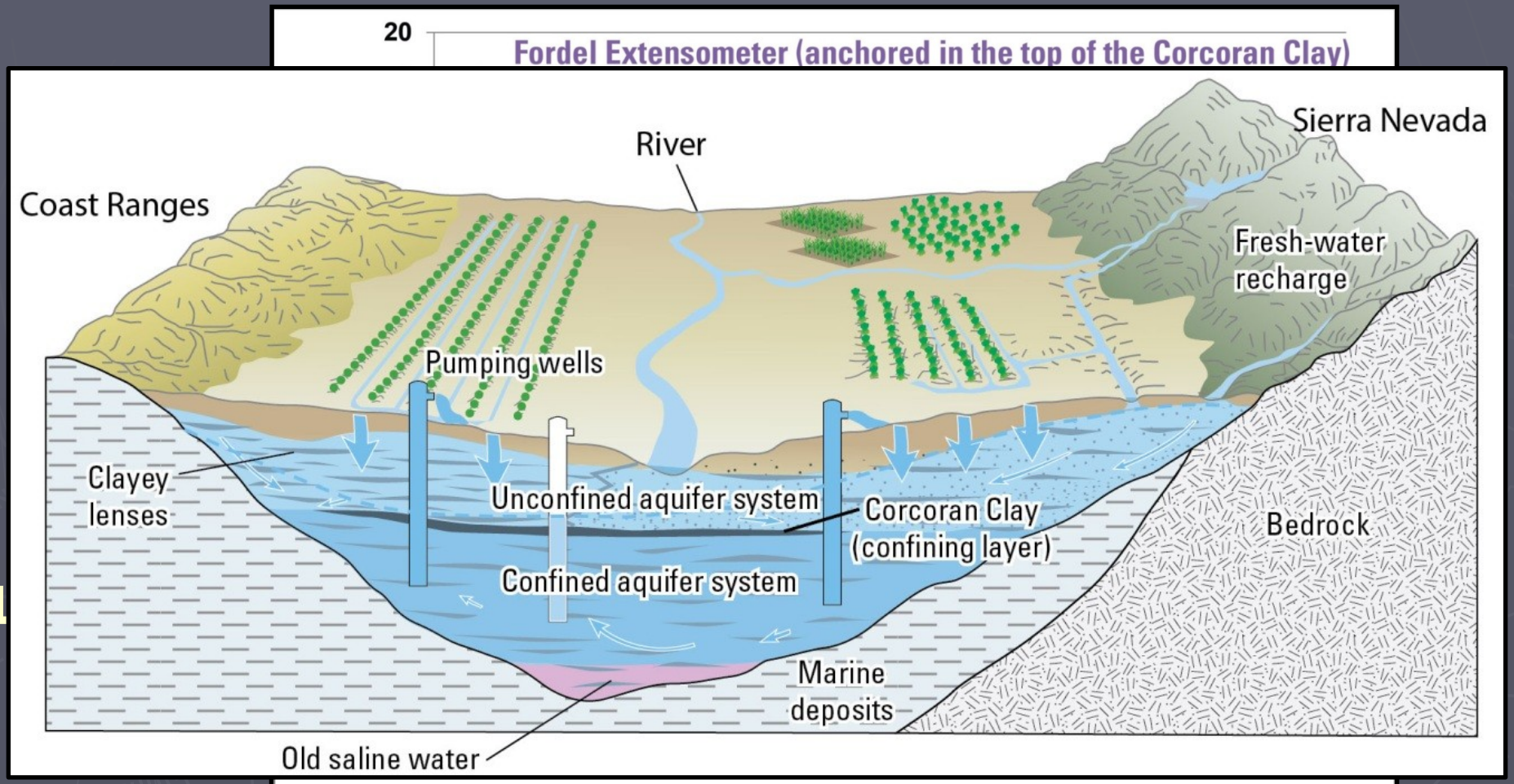
Historical Subsidence



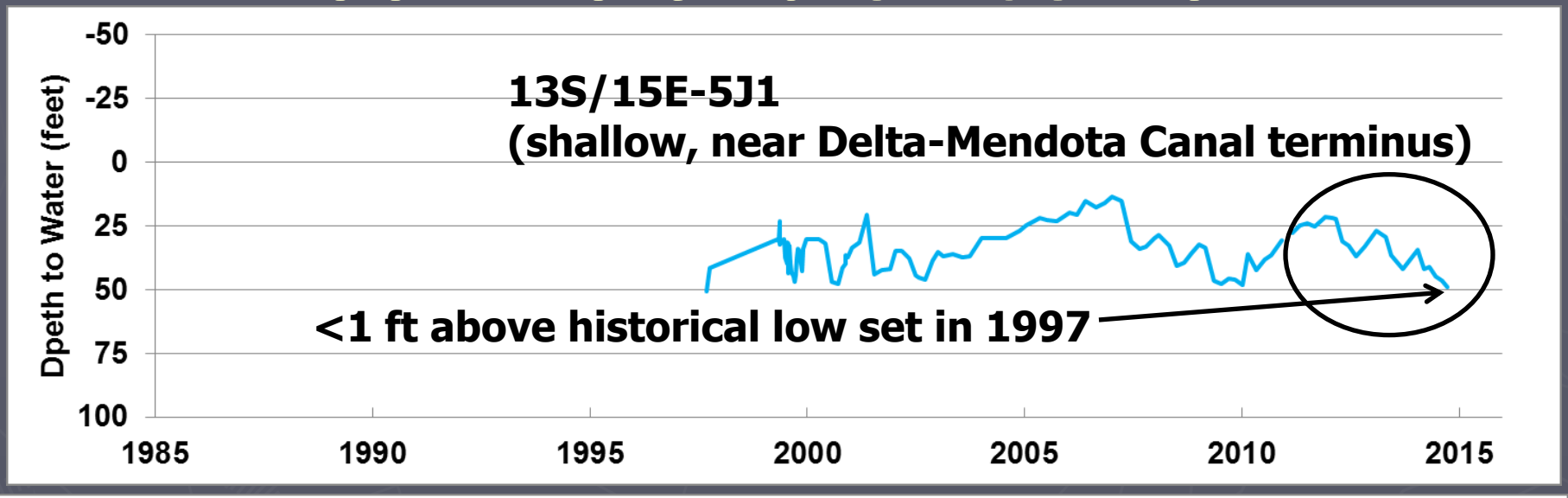
Groundwater-Level Declines and Geologic Setting are Causing High Subsidence Rates

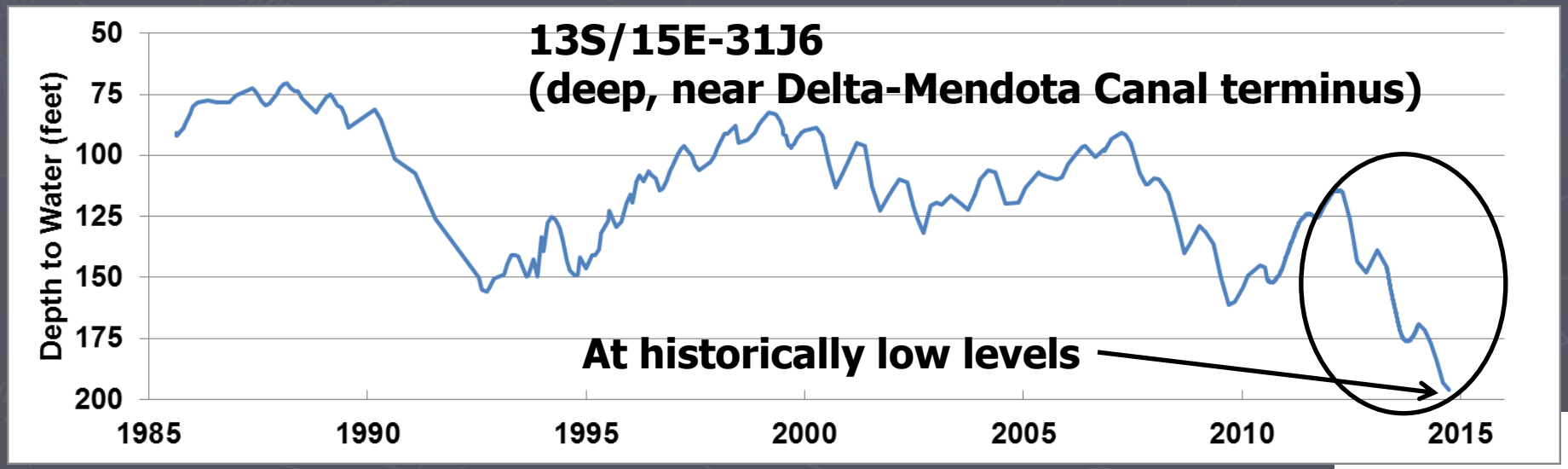
- Groundwater-level declines
  - More than 180 ft since the late 1960s
  - Some reached historical lows during 2007-10 and since 2013
- Geologic setting – presence of compactable materials (clay)
  - Sub-Corcoran fine-grained sediments
  - Chowchilla, Fresno, Kaweah, Tule River Fans

Most Compaction Occurred Below the Corcoran Clay



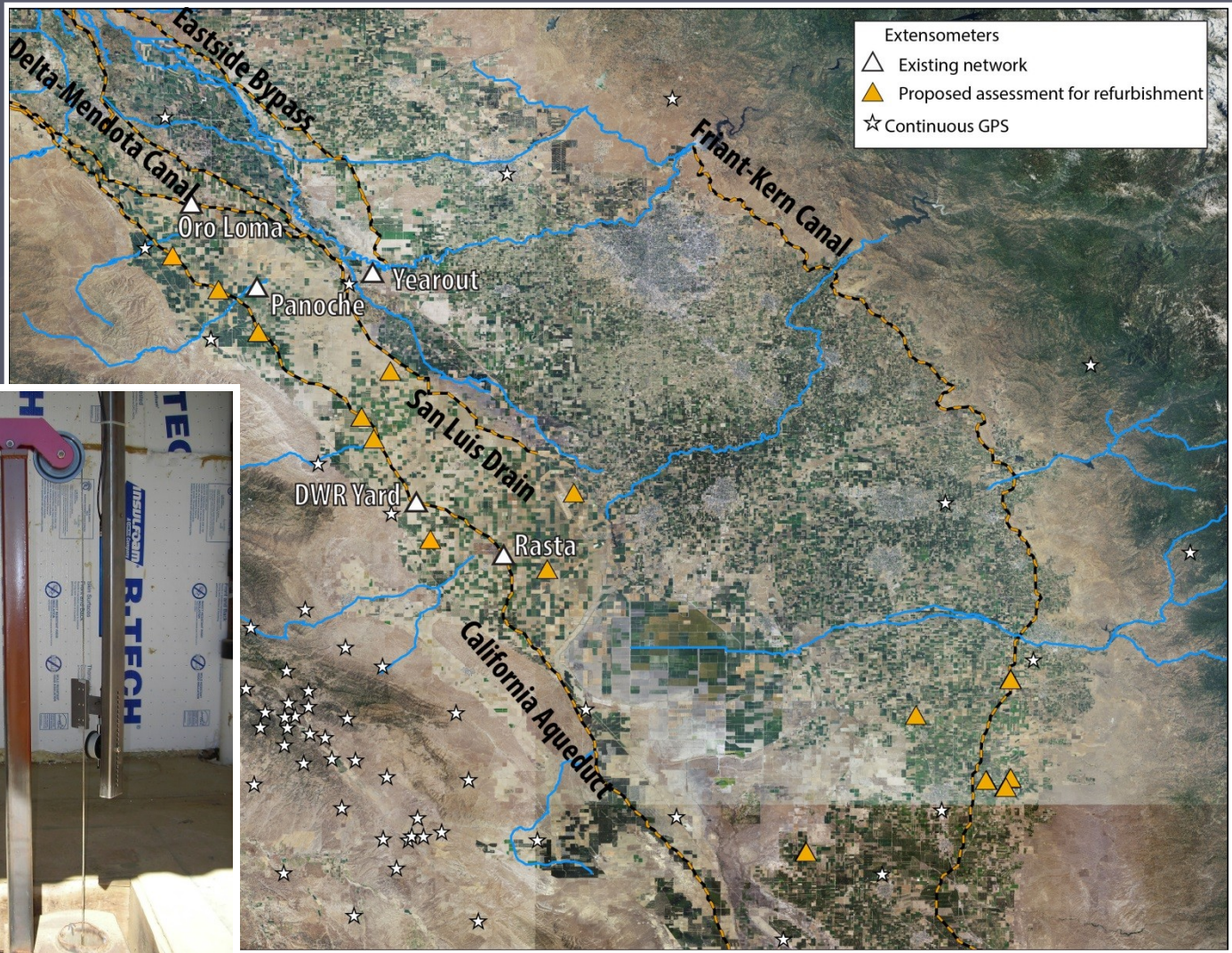
Groundwater Levels Declined 2007-10 and since 2012

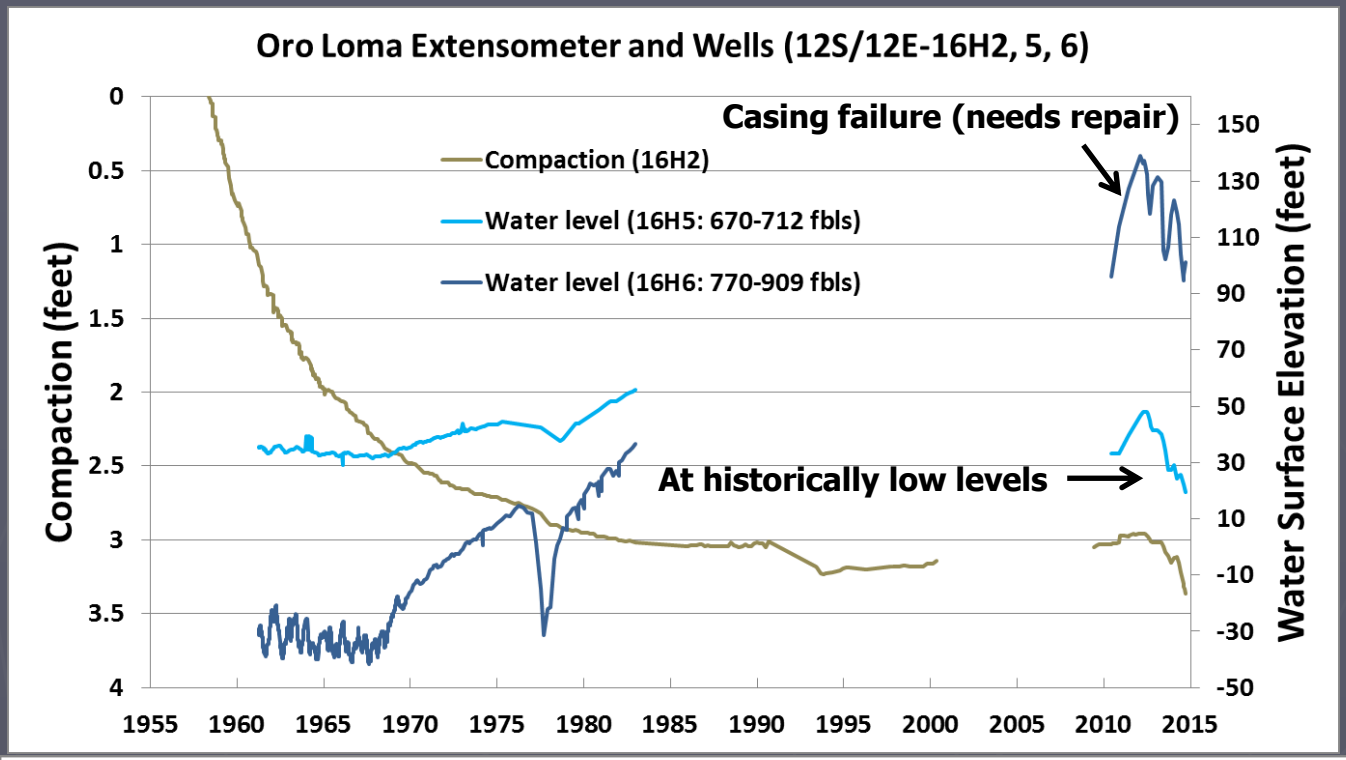




Preliminary and subject to revision

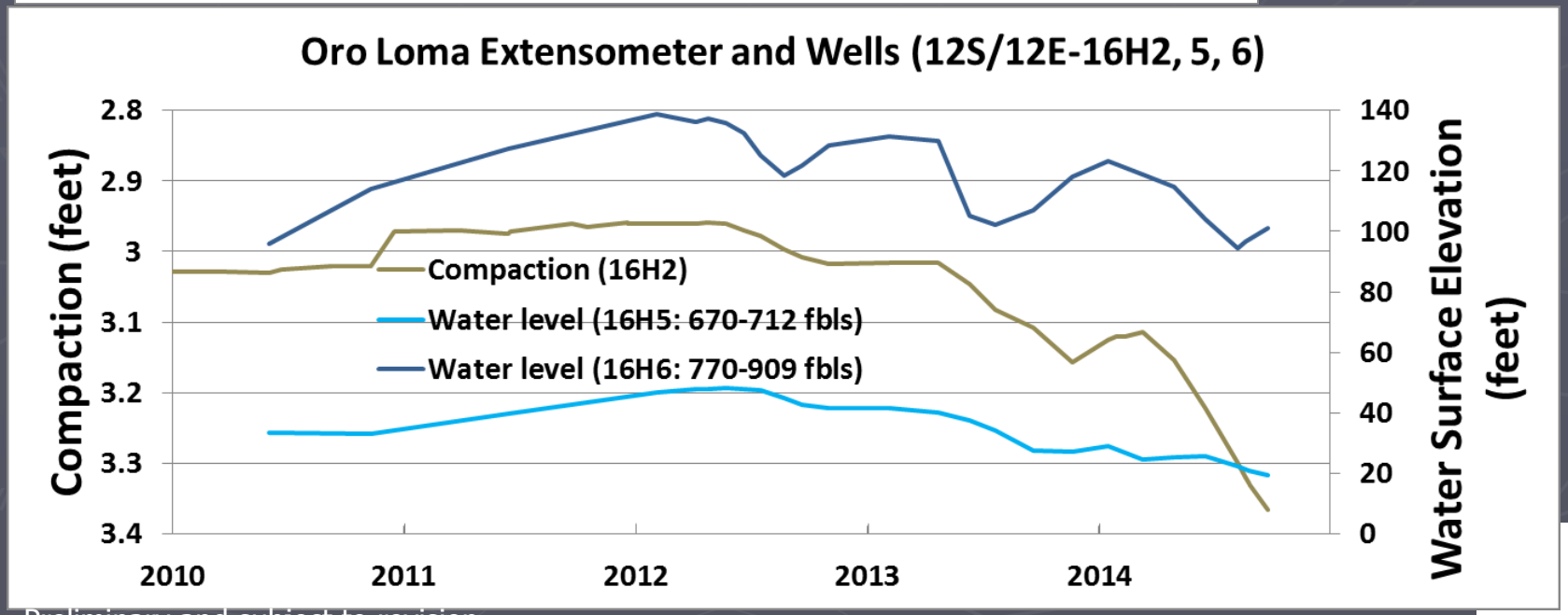
Existing and Potential Extensometer Network





Oro Loma

3 inches of compaction this summer



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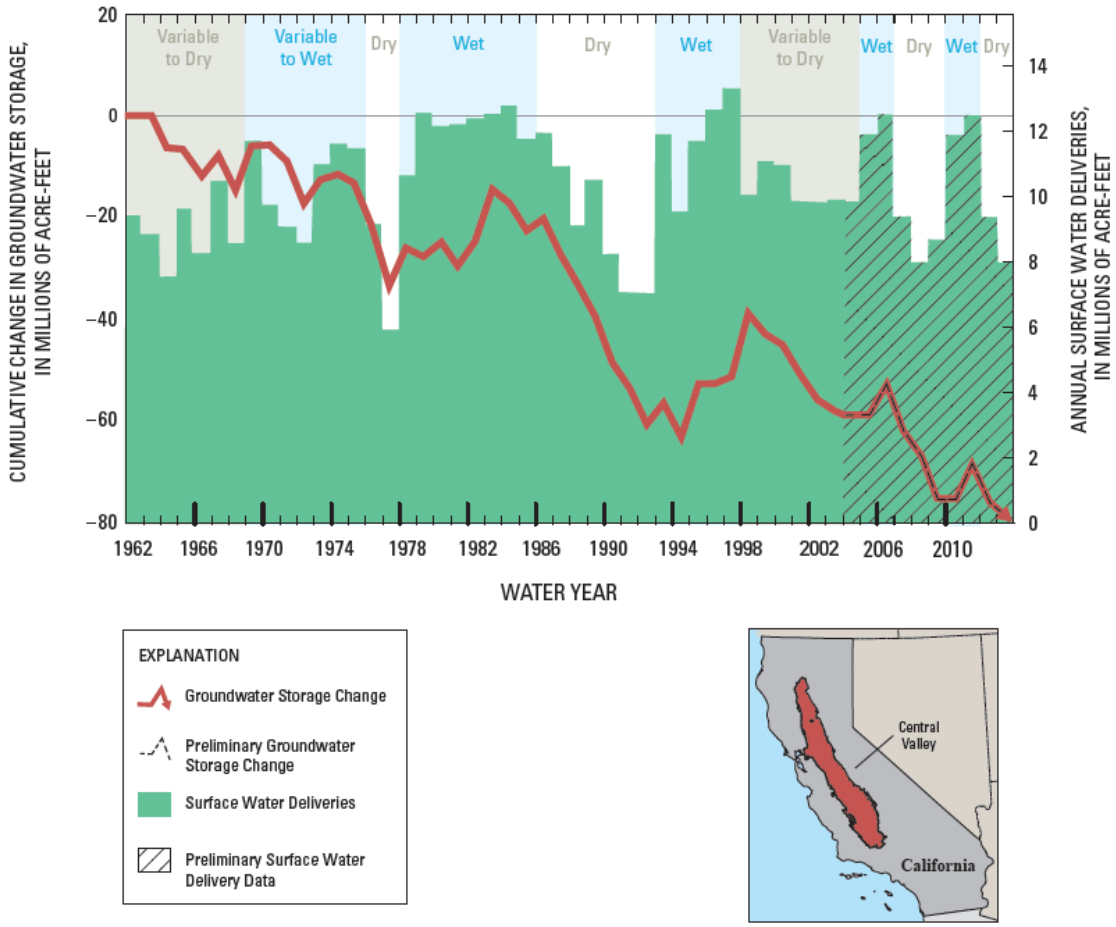
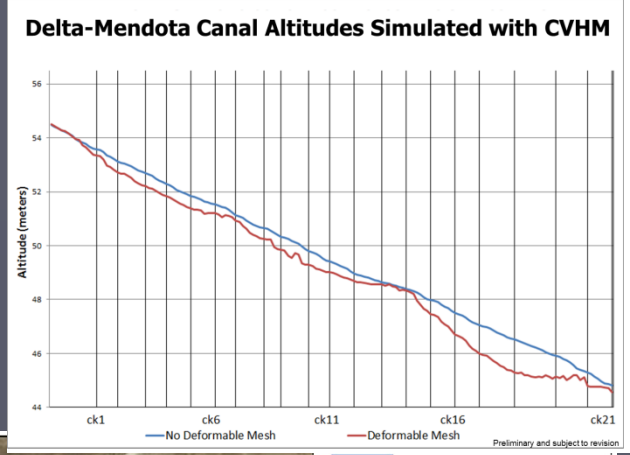
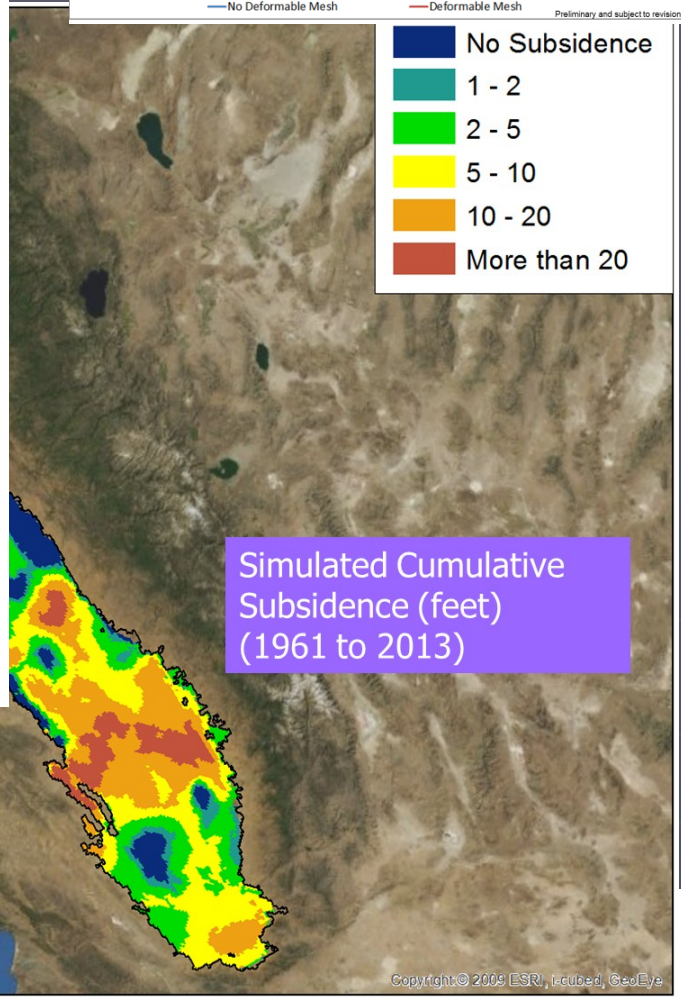
Numerical Simulations







Preliminary and subject to revision

Subsidence Summary

- 7,200 km^2 subsided 20-540 mm during 2008-10; data indicate these rates have continued through 2014
  - Includes El Nido-Madera area (published) and Corcoran-Pixley area (ongoing)
- Adversely affecting water conveyances and other infrastructure
  - Delta-Mendota Canal, San Joaquin River, Eastside Bypass system, Friant-Kern Canal, California Aqueduct, numerous local canals
  - Reduced conveyance capacity, panel damage; erosion/deposition in channels
- Subsidence is largely permanent
  - Reduced aquifer-system storage capacity also is permanent
- Subsidence occurred when groundwater levels declined to historically low levels as a result of pumping –water levels continue to decline
- Long-term monitoring of water levels and subsidence is needed to detect and track groundwater conditions for decision support
- Numerical modeling can be used for predictions and scenario testing

For more information:

http://ca.water.usgs.gov/projects/central-valley/index.html

What Can Be Done About It?

Models can be used as a tool to forecast information based on alternative scenarios

- Predict groundwater elevations and subsidence
- Simulate scenarios including
  - Extended drought/Climate change
  - Reduced surface water deliveries
  - Pumping (Reclamation)
  - Artificial Recharge

Long-term monitoring of water levels and subsidence is needed to track groundwater conditions

- Groundwater levels in the context of historical levels
- Track groundwater levels and subsidence in shallow and deep systems separately