Water level and subsidence recovery from managed recharge

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Workshop for Land Subsidence Prevention and Mitigation

Tainan, Taiwan

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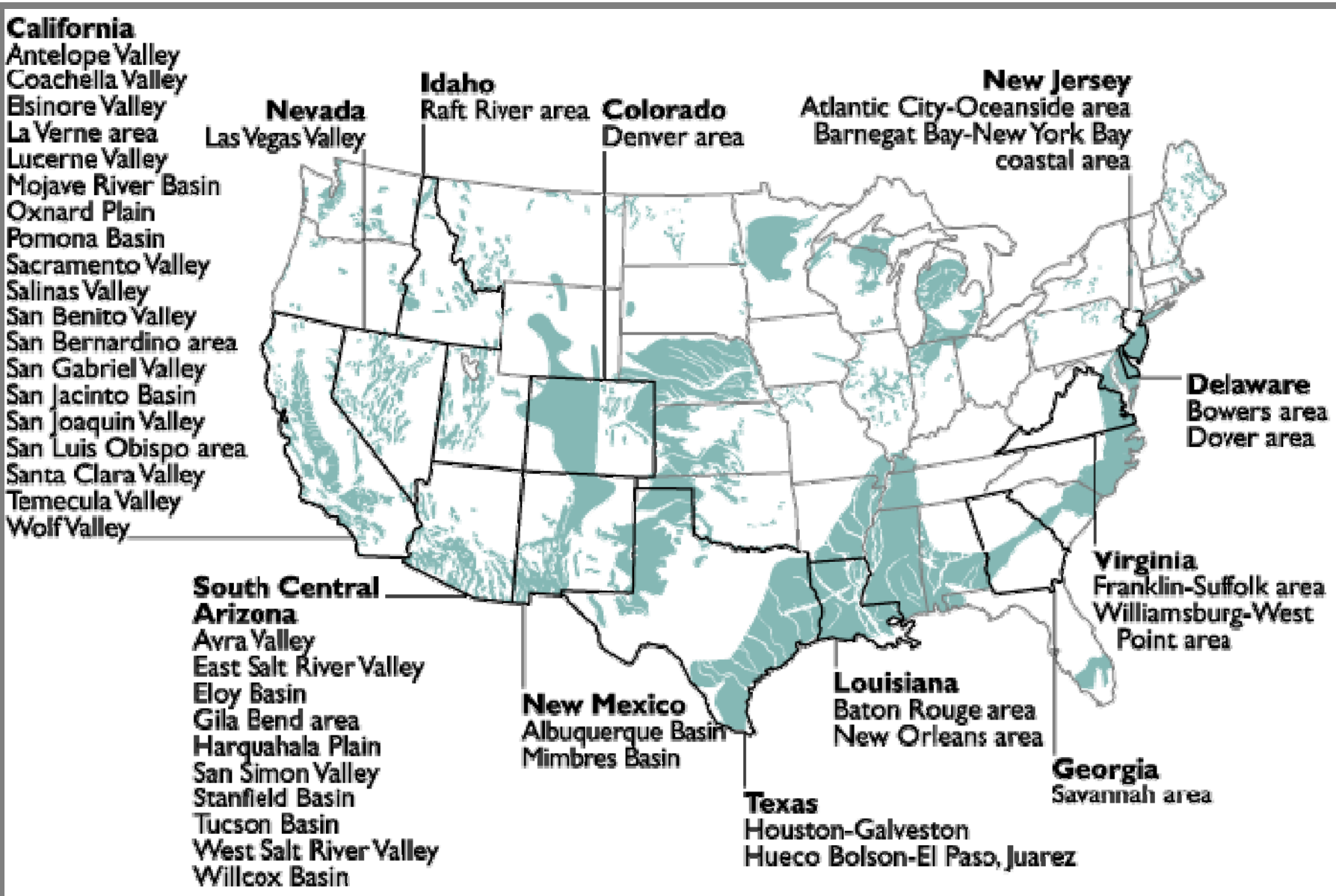


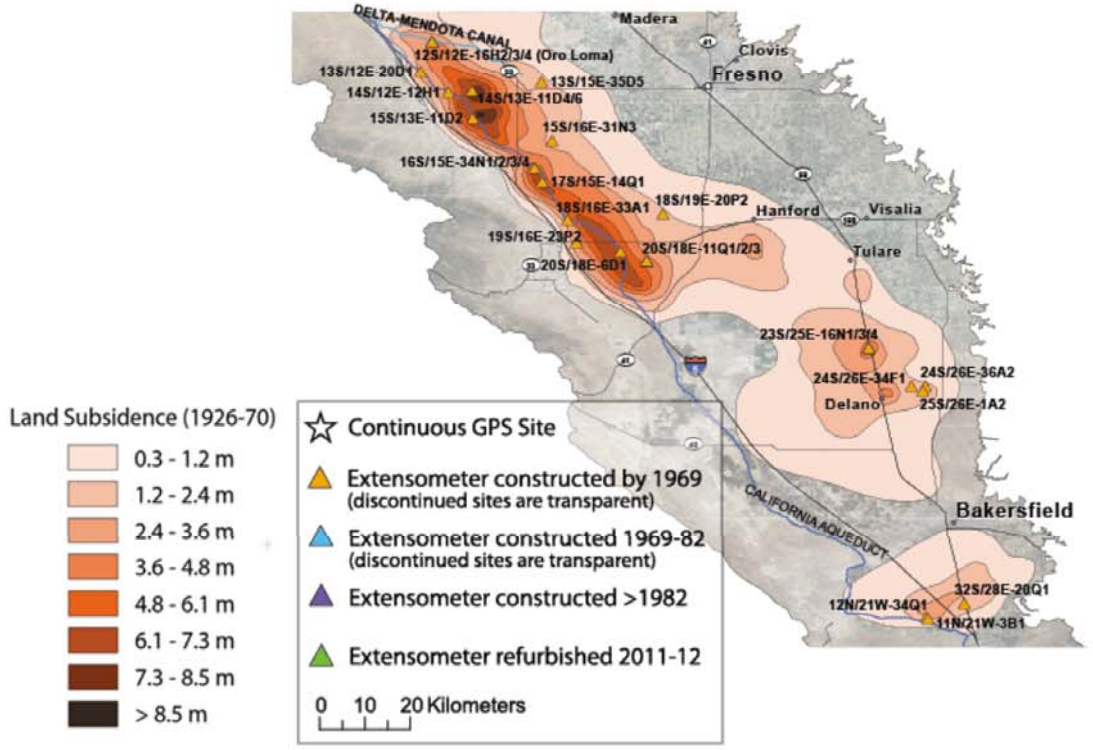
Aquifer-System Compaction

Historical Land Subsidence in the Central Valley of California

History of the Subsidence Monitoring Network

1960s and 1970s

- 31 extensometers operating at 21 sites
- Extensive spirit-leveling networks

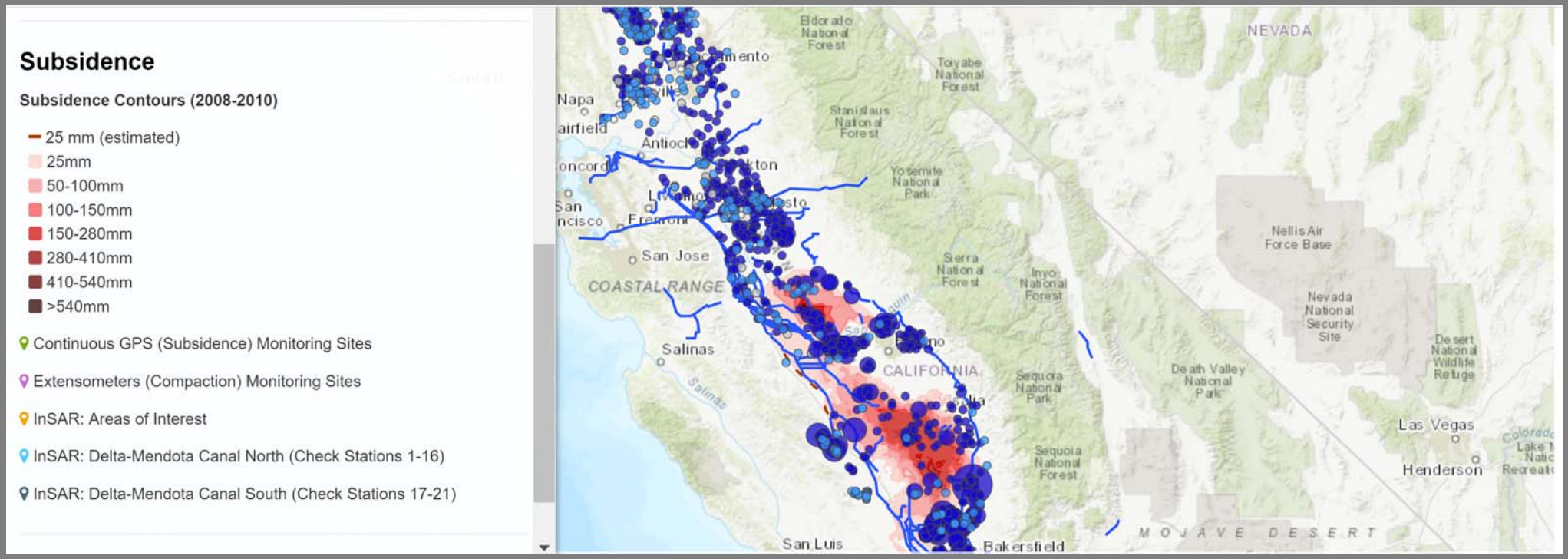


Land Subsidence

- Historical subsidence
  - Caused by groundwater pumping for largely agricultural use prior to surface water imports via aquaducts
- Today, subsidence is occurring in new areas and is exacerbated by water-law issues

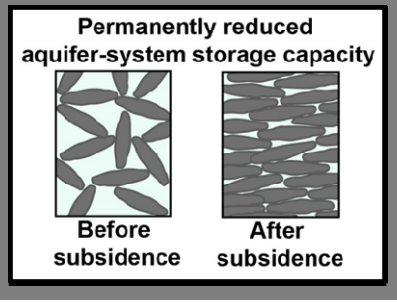
← San Joaquin Valley

Central Valley of California has renewed subsidence



Subsidence Damages Infrastructure & Natural Resources

- Flood Protection and Infrastructure
  - Damage to water conveyance systems and other infrastructure
    - Reduced conveyance capacity and freeboard, liner damage; water surface and liner misalignment; erosion/deposition in unlined channels
    - Roads, rails, bridges, pipelines, wells, etc.
- Natural resources
  - Reduces aquifer-system storage capacity
  - Impacts to wetland, riparian, and aquatic ecosystems
  - Restricted land uses



Managed recharge has been successfully used to mitigate land subsidence

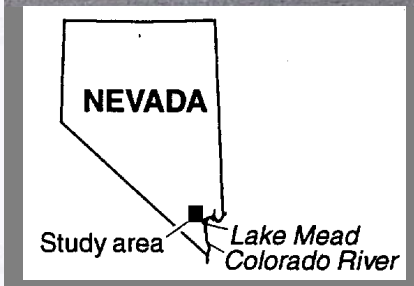
Managed recharge typically refers to using surface water appropriations for recharging or replenishing an aquifer either by direct injection or through percolation ponds.

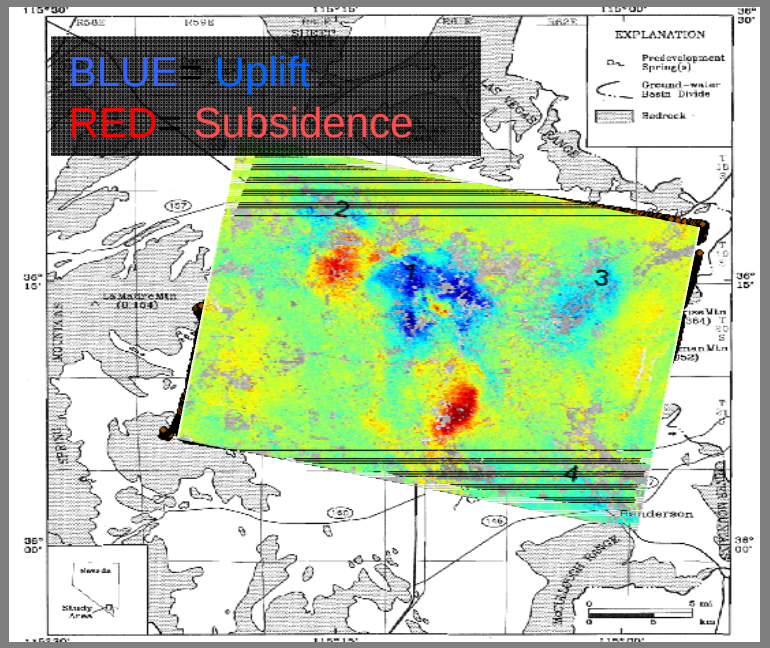
We'll look at two examples:

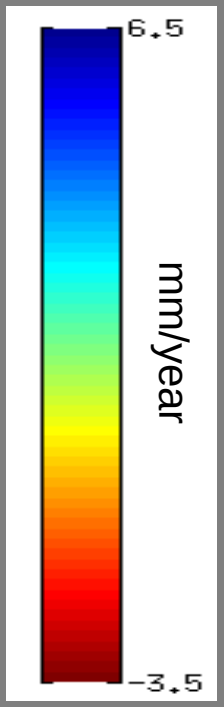
Las Vegas, Nevada

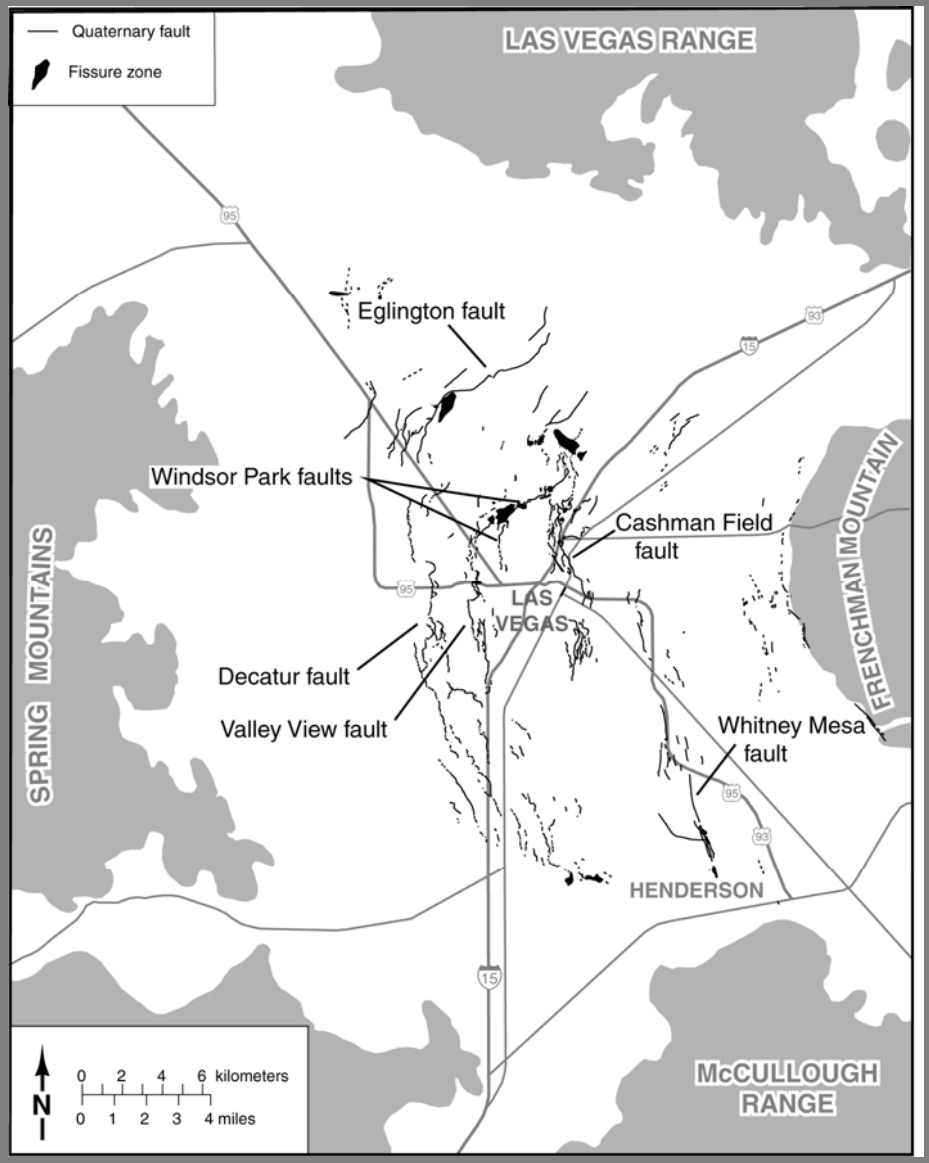
Coachella Valley, California

Las Vegas, Nevada, USA has implemented an ASR program to mitigate land subsidence









Basin-fill faults are prevalent throughout the Las Vegas valley

Earth fissures tend to occur near or adjacent to basin-fill faults

Groundwater is extracted from the Principal Aquifer, which is located at depths from 50-500 m below land surface

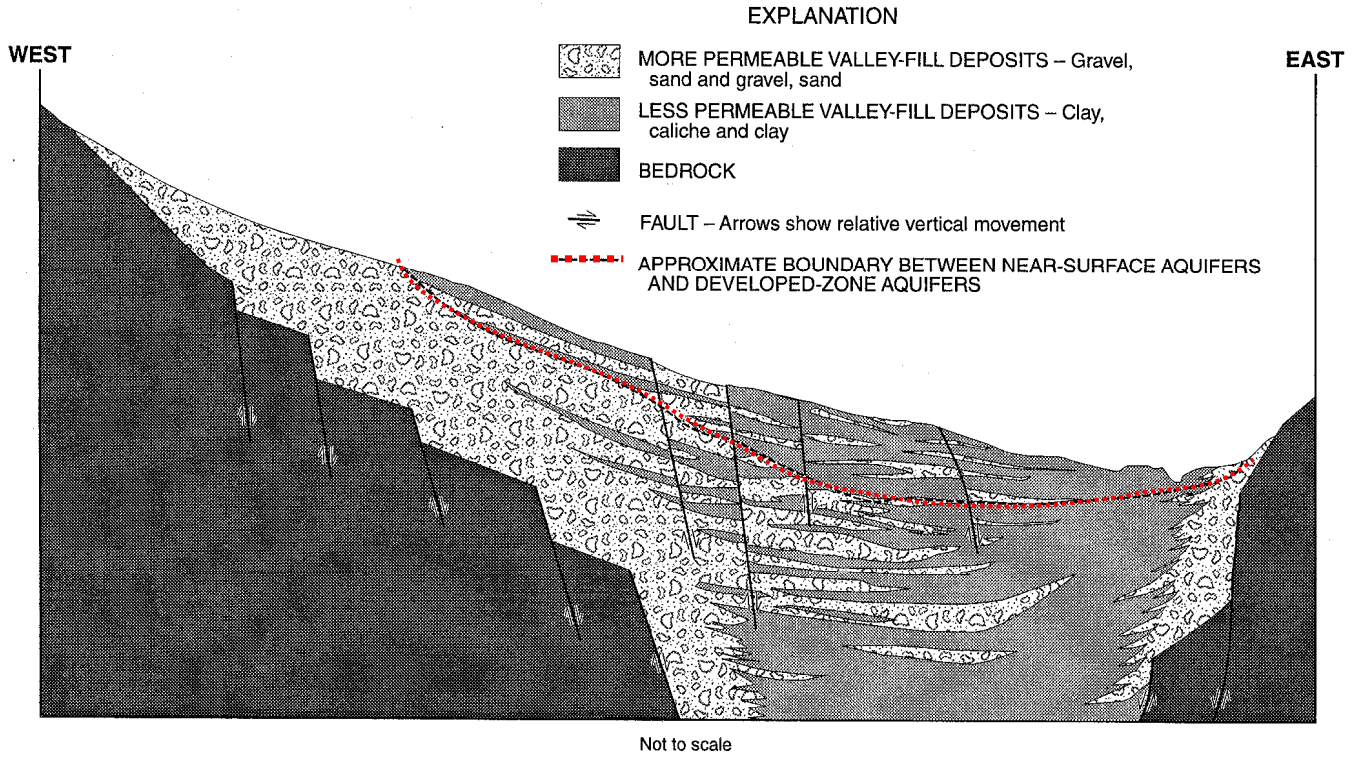
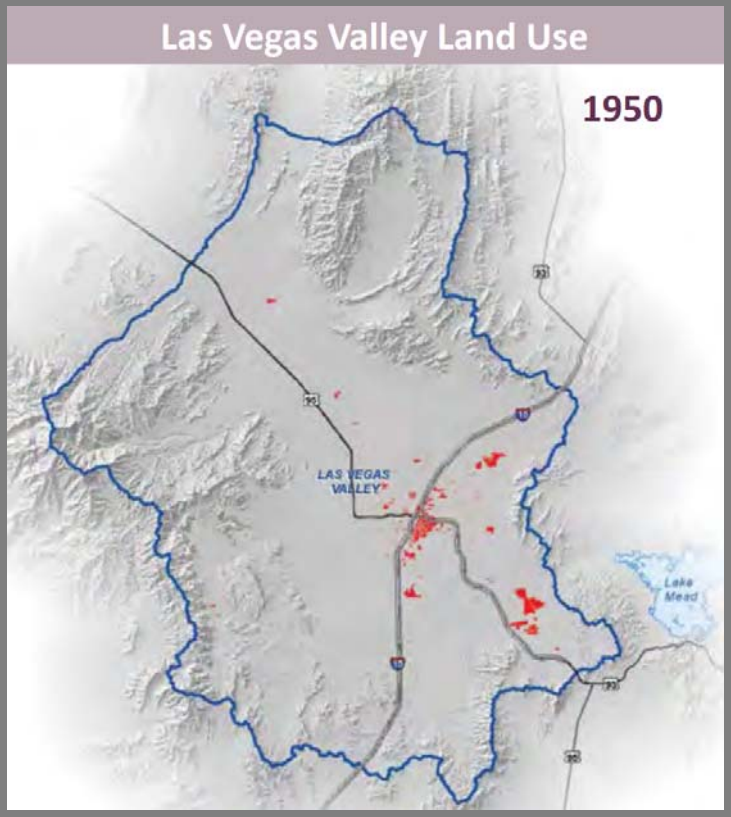
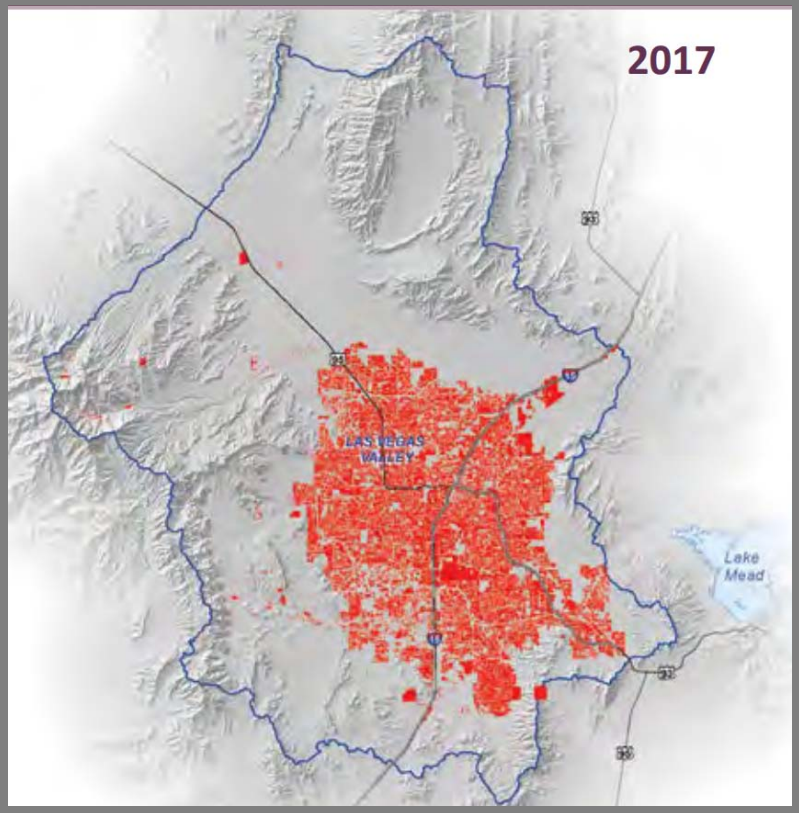


Figure 2.2-1. Generalized west-to-east hydrogeologic section of Las Vegas Valley. Modified from Maxey and Jameson (1948, pl. 6b).

Urban growth in Clark County has occurred at unprecedented rates over the past 70 years

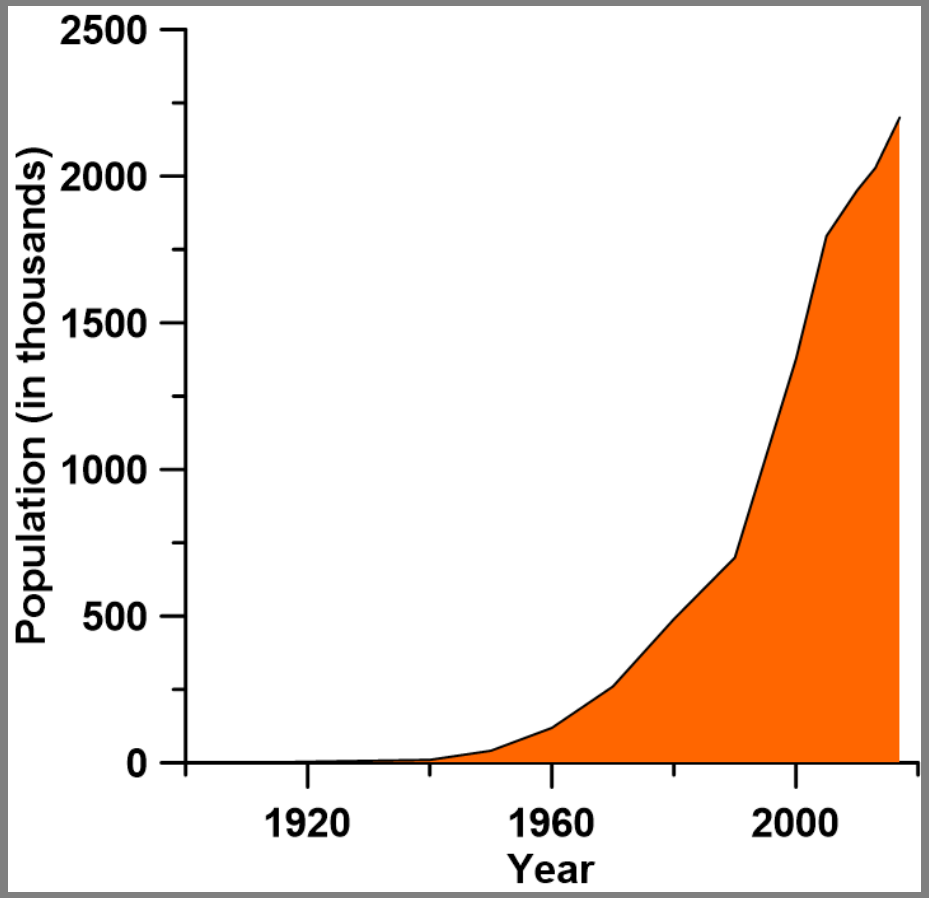


Population: 41,000



Population: 2,200,000

Las Vegas remains the fastest growing metropolitan community in the country



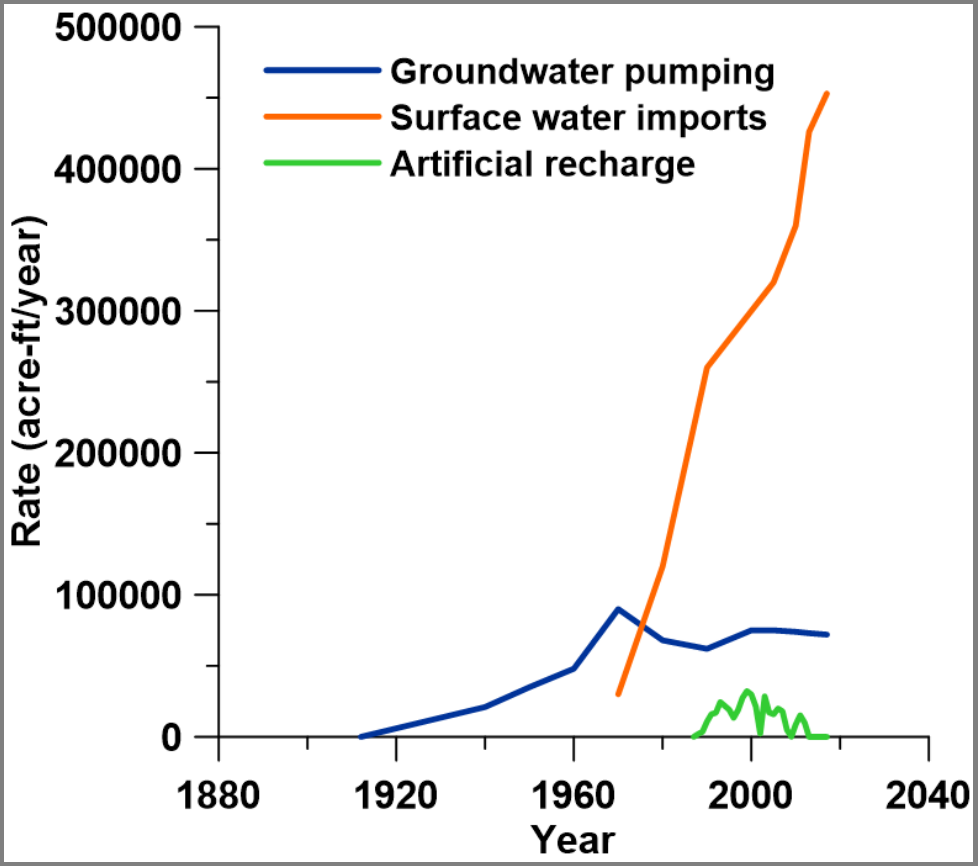
Las Vegas Valley continues to experience exponential population growth

Colorado River Allocations

In 1922 the Colorado River Compact defined the allocations for the Colorado River for each geographic region.
Nevada was allocated 300,000 ac-ft/yr.
The Hoover Dam was later built and completed in 1936 creating Lake Mead

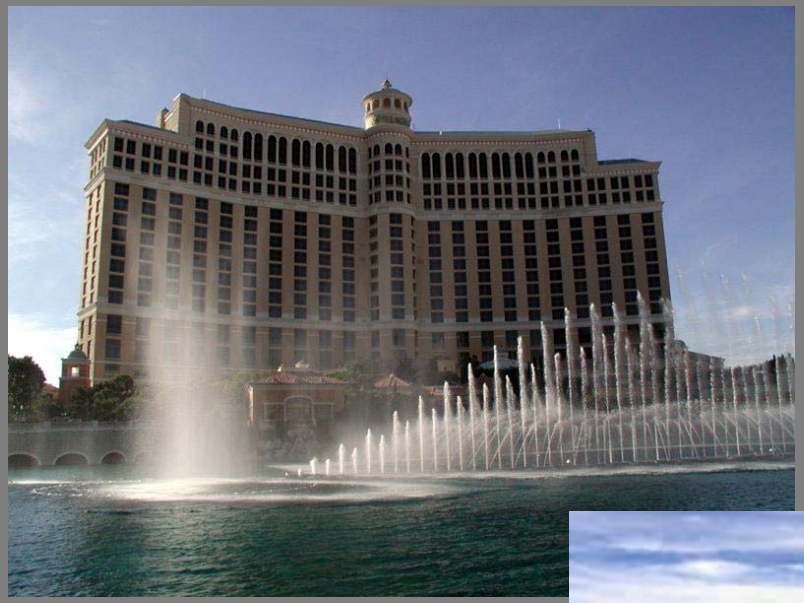
1 acre-ft = 1233.5 m^3

Water use has also grown at staggering rates and imports have continue to rise



Annual natural recharge to Las Vegas basin is only 25,000 to 35,000 acre-ft

35,000 acre-ft = 43 million cubic meters



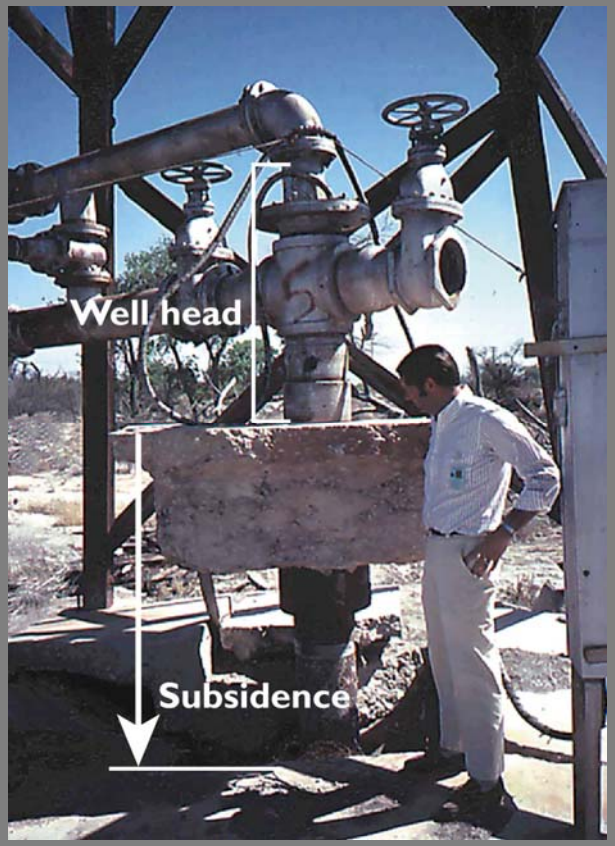
Water use in Las Vegas is extravagant to say the least.

Over 6000 wells exist in the basin

Effects of Groundwater Pumping

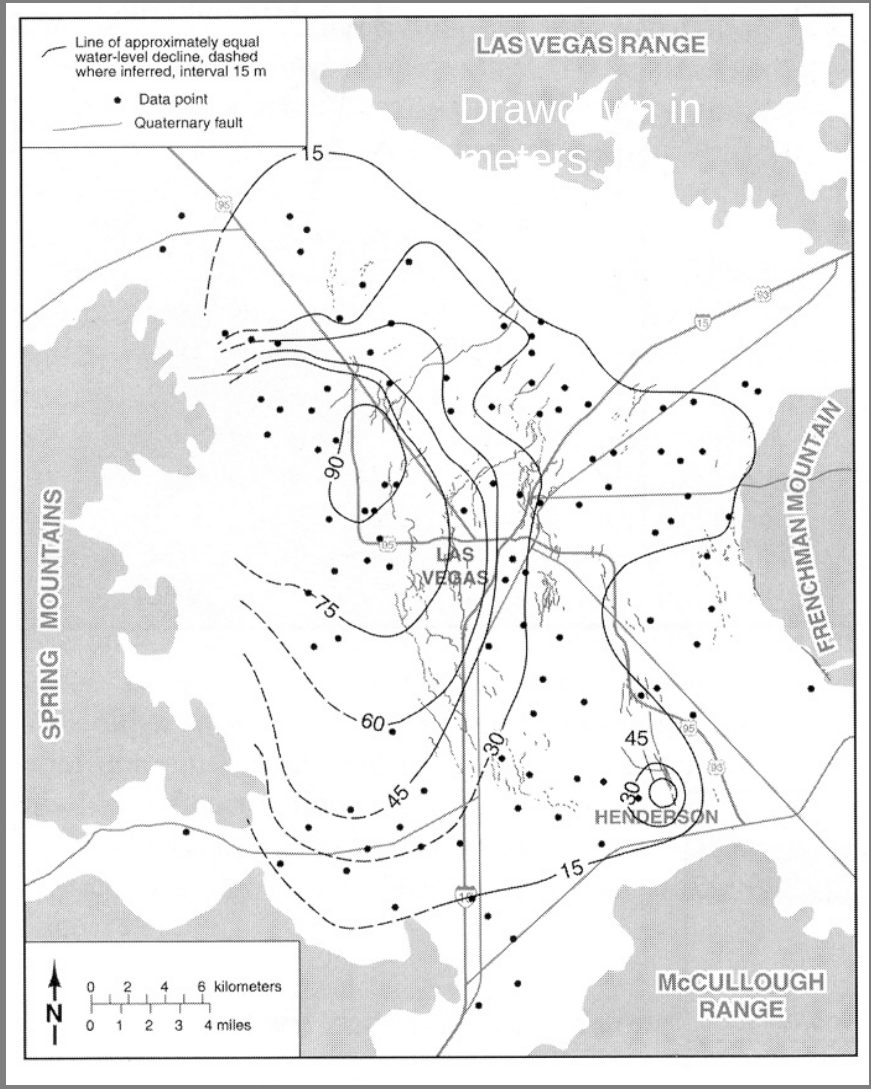
Aside from greatly reduced water levels and subsequent reduced storage in the Valley, land subsidence has become an important problem

Subsidence depends on (1) water-level declines, (2) compressibility of deposits, (3) thickness of compacting units



By 1990 drawdown from municipal pumping had reached over 90 m in the western part of the valley

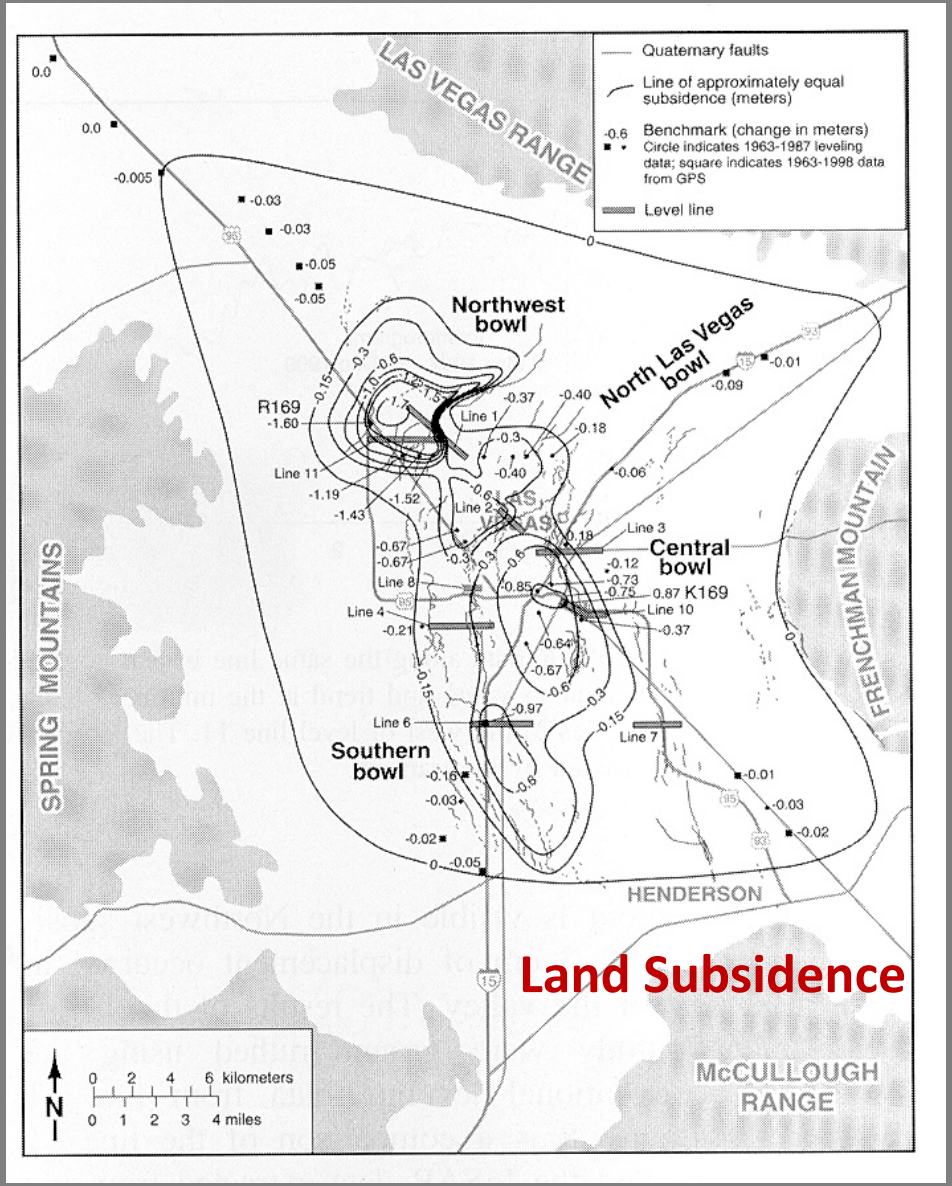
Since this time, a significant amount of recovery has occurred as a result of ASR activities



from Burbey, 1995

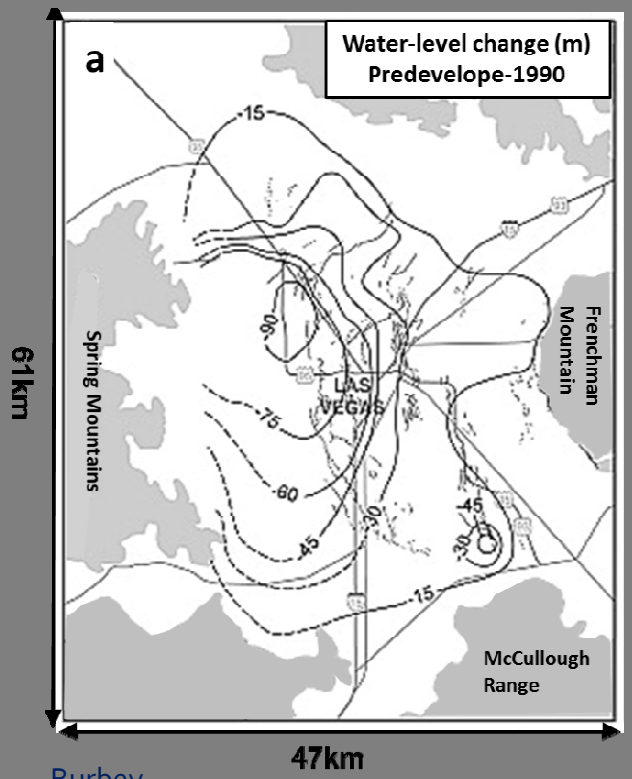
By 2000, four separate subsidence bowls were mapped

A maximum subsidence of nearly 2 m (6 ft) was measured from 1963-2000 in the northwest subsidence bowl

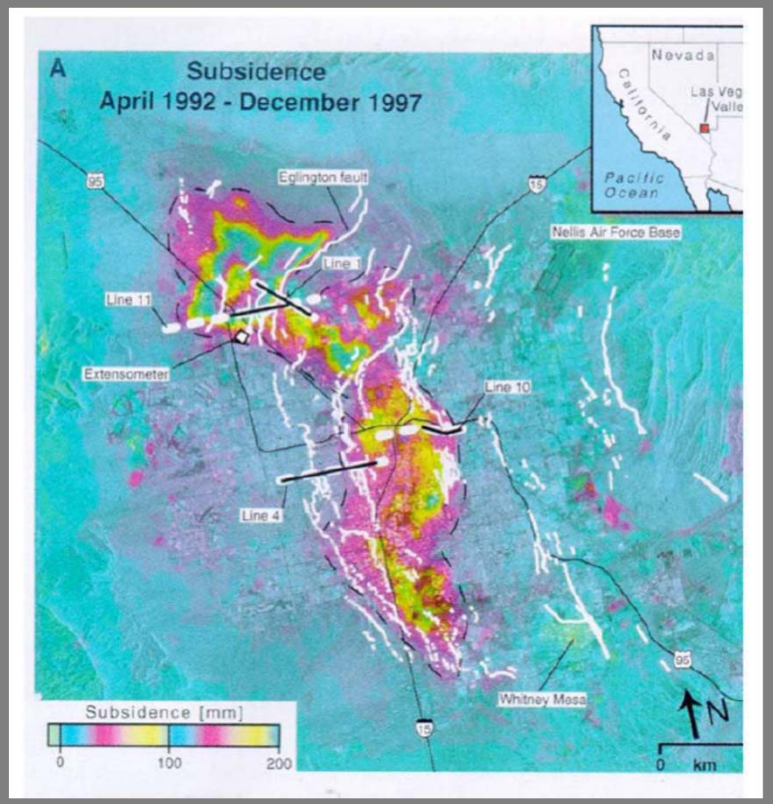


from Bell, et al, 2004

Water level changes do not reflect the deformation patterns in Las Vegas Valley

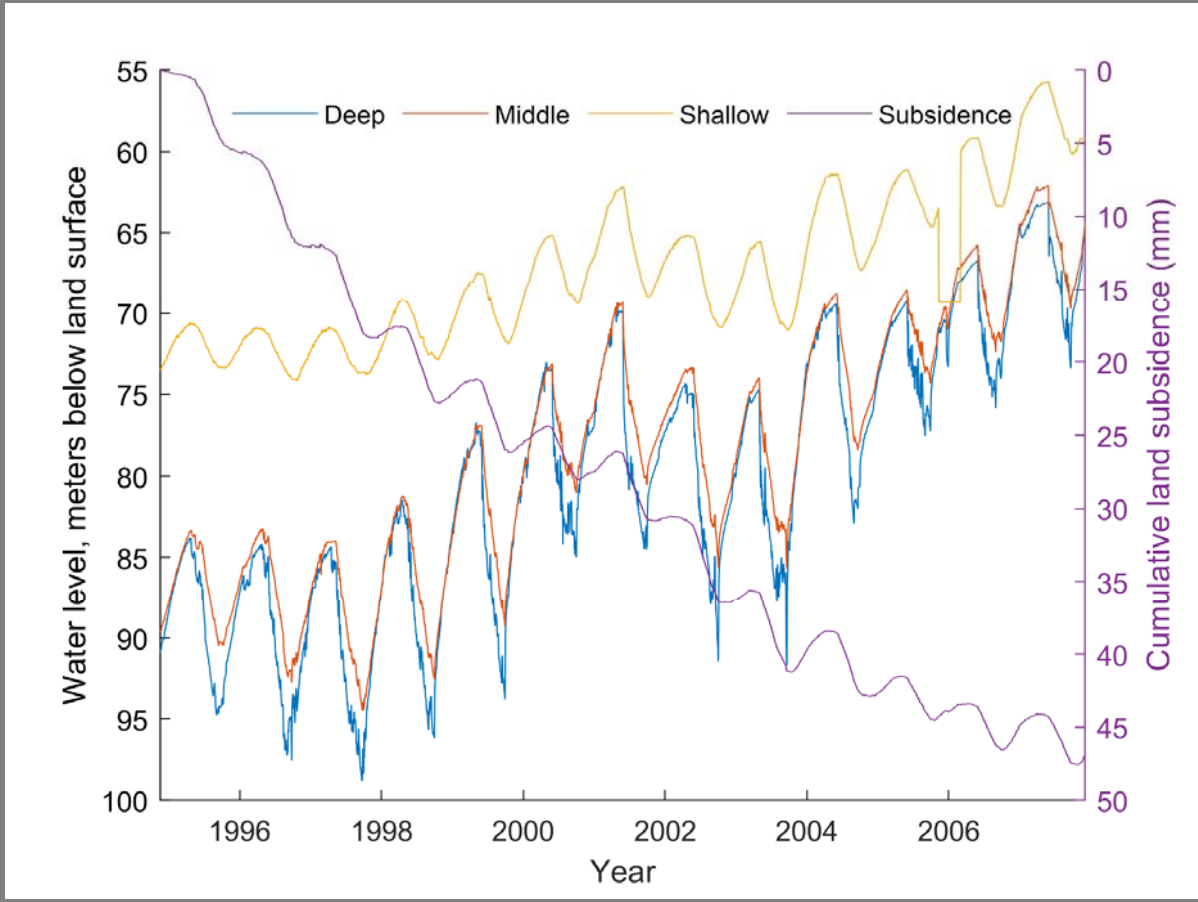


Burbey (1995)



Amelung et al. (1999)

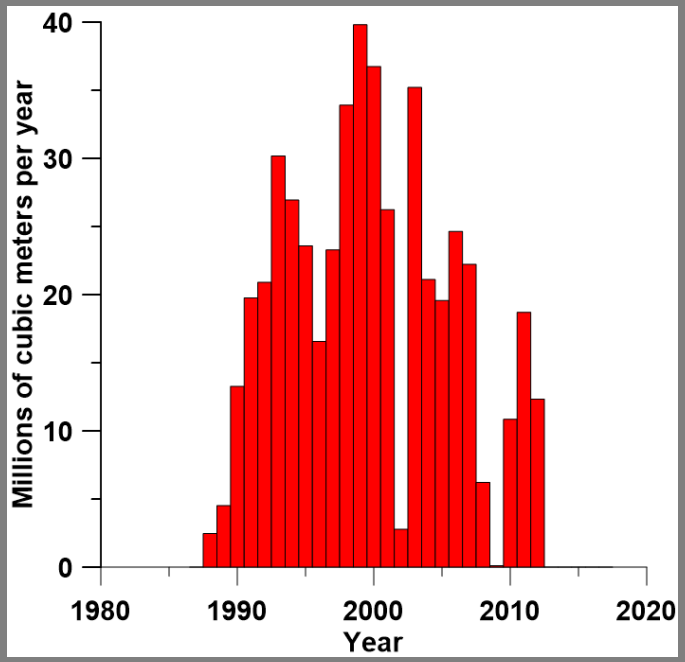
Extensometer and piezometer data near the northwest subsidence bowl

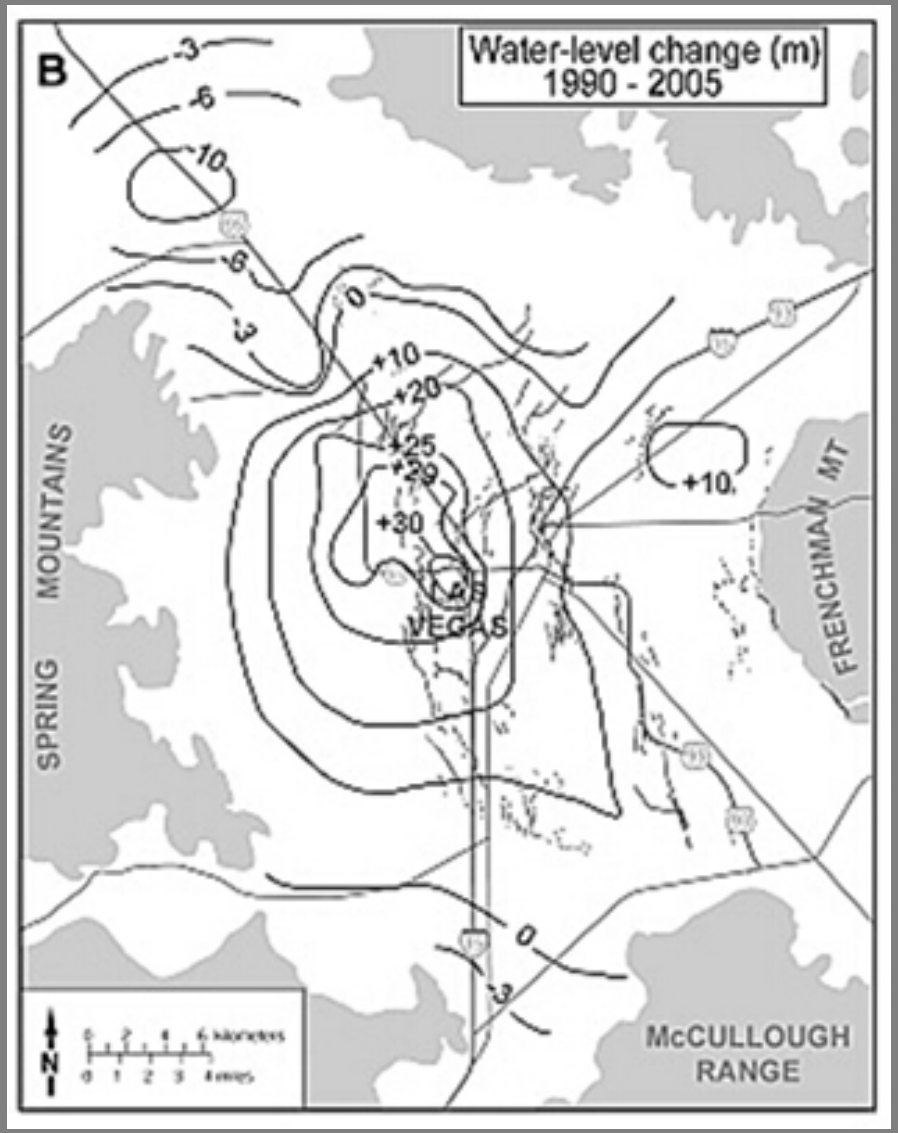


12 years of data exist for the Lorenzi extensometer site in Las Vegas

A number of wells that are used for pumping during the summer are used to artificially inject water back into the aquifer during the winter months

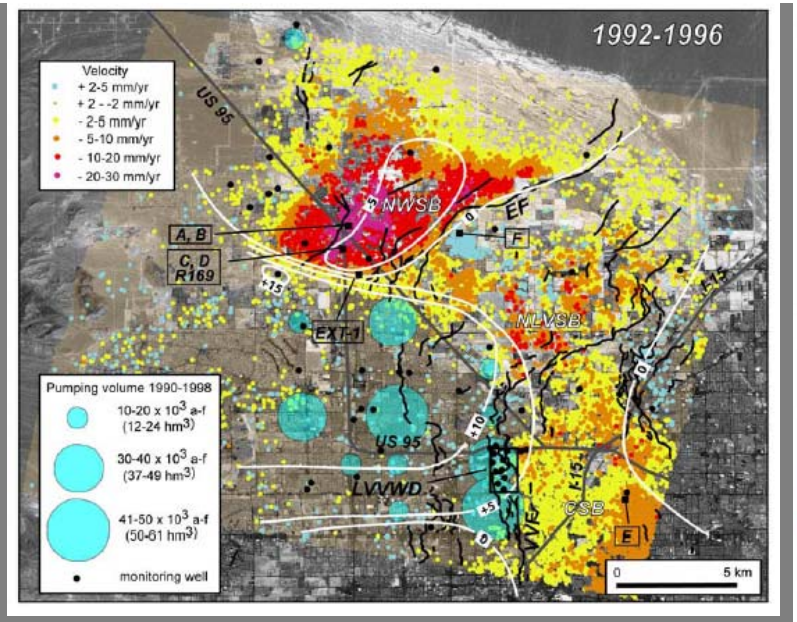
Artificial Recharge

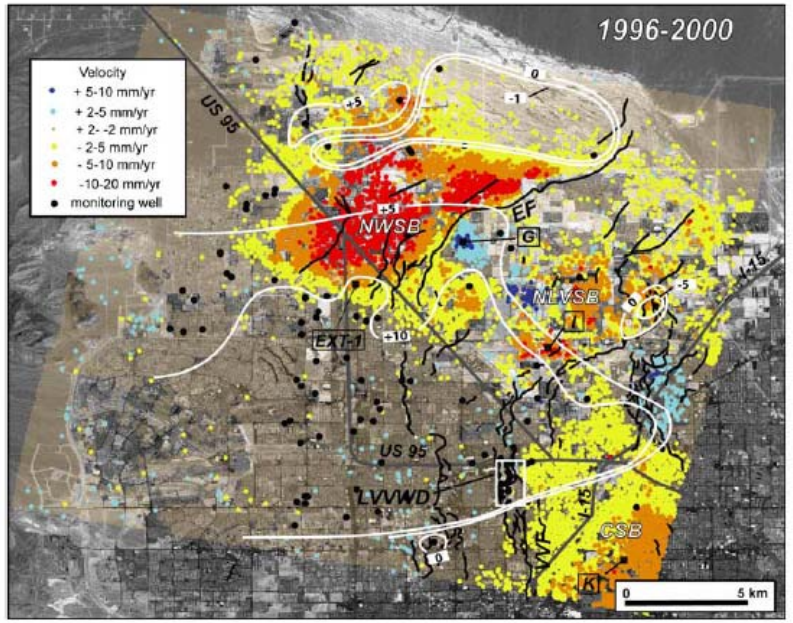


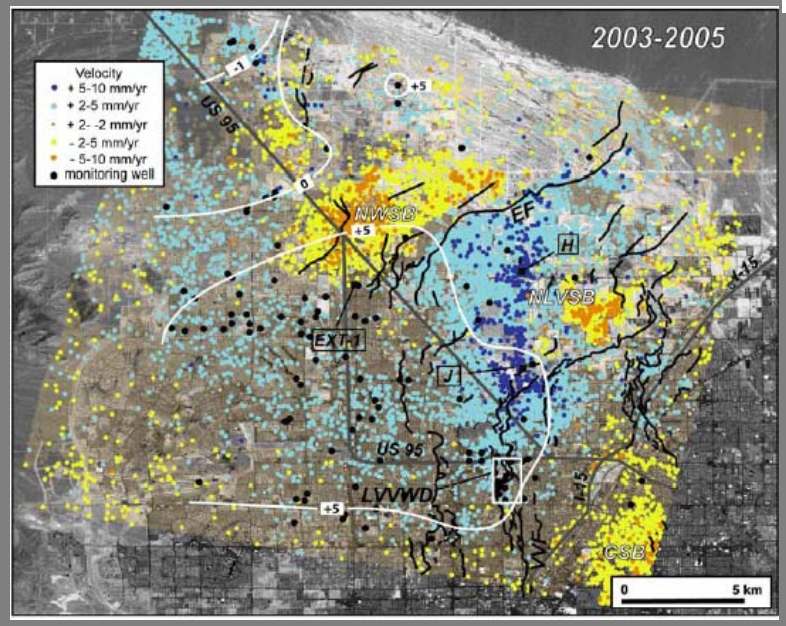


To help mitigate the ongoing occurrence of land subsidence, an artificial recharge program was initiated in 1988. This program resulted in a as much as 30 m of groundwater level increase between 1990 and 2005

From Bell et al., 2008





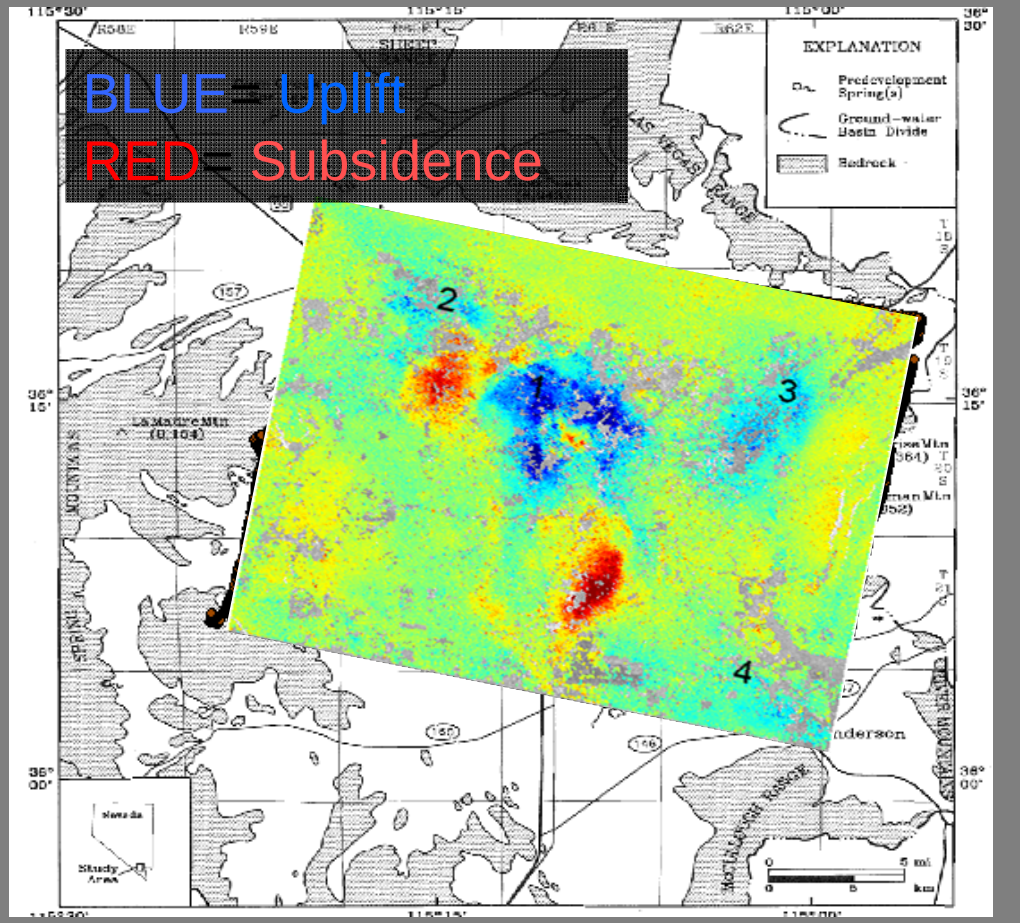


Artificial recharge has a profound impact on surface deformation

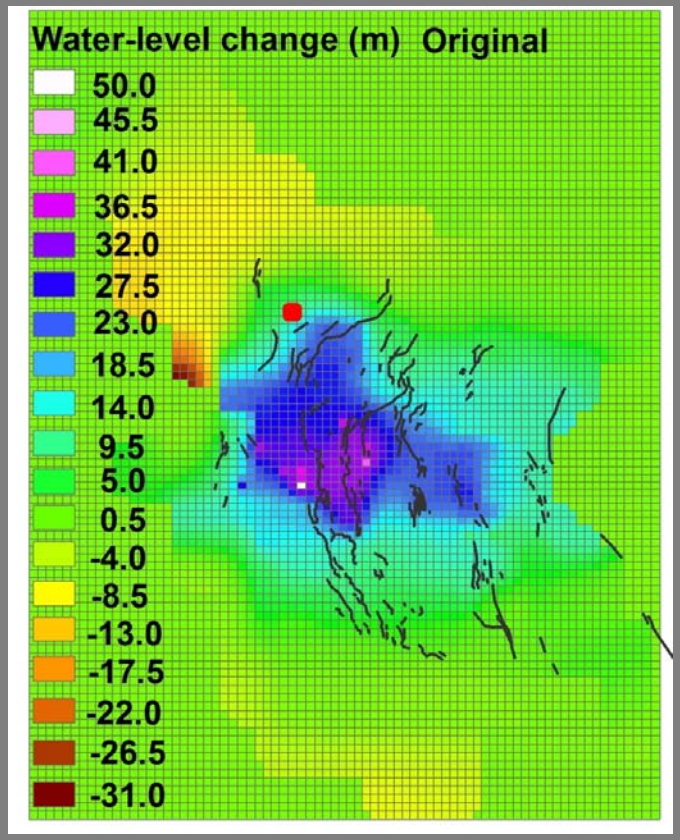
Seasonal changes in pumping are observed with permenant scatterer InSAR

Permanent scatterer velocity map (2002-2010) for Las Vegas shows complex aquifer response from recovery of water levels

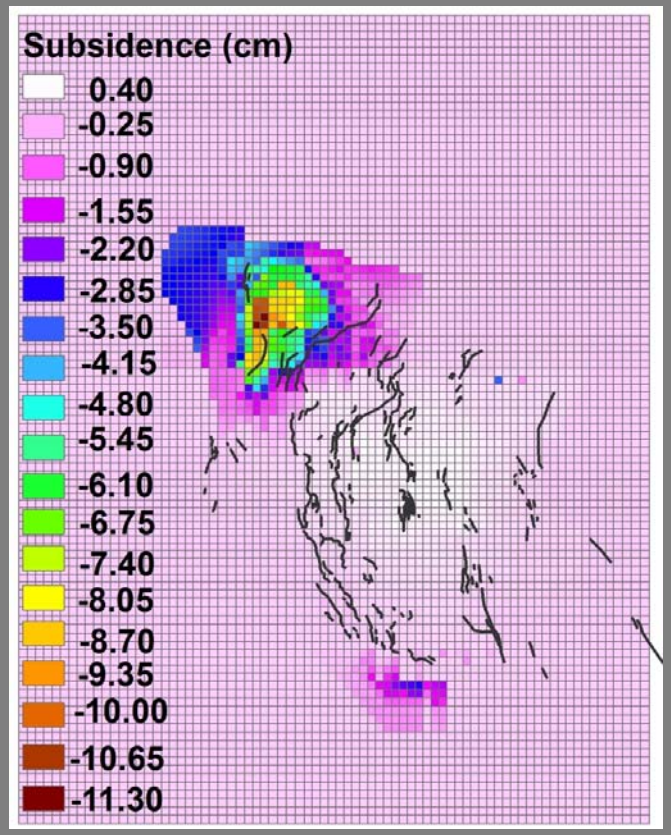
Example of an artificial reflector



Simulated future trends of water levels and land subsidence in Las Vegas Valley, 2011-2030



Water levels



Land subsidence

From Zhang and Burbey, 2016

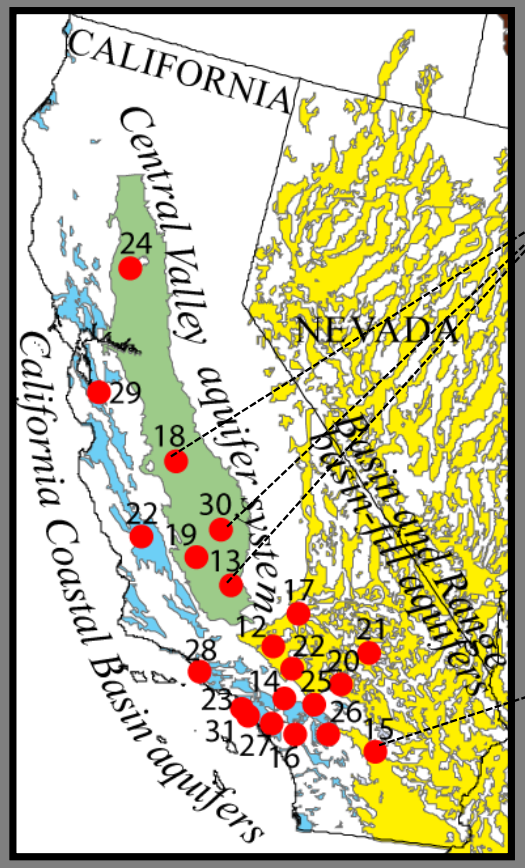
Summary

- Artificial recharge has had a profound impact on both water levels and surface deformations (Land subsidence and uplift) in Las Vegas Valley
- In spite of the success of managed injection, two areas of land subsidence are still evident and modeling suggests that these areas will continue to subside into the near future

Managed recharge in the Coachella Valley, southern California

Courtesy of Michelle Sneed, USGS

Groundwater-related subsidence in California



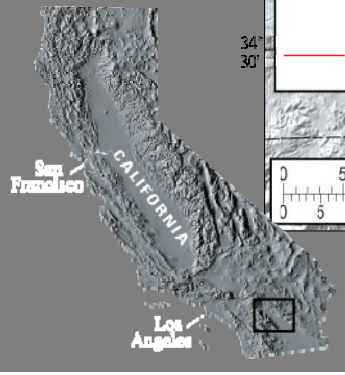
San Joaquin Valley

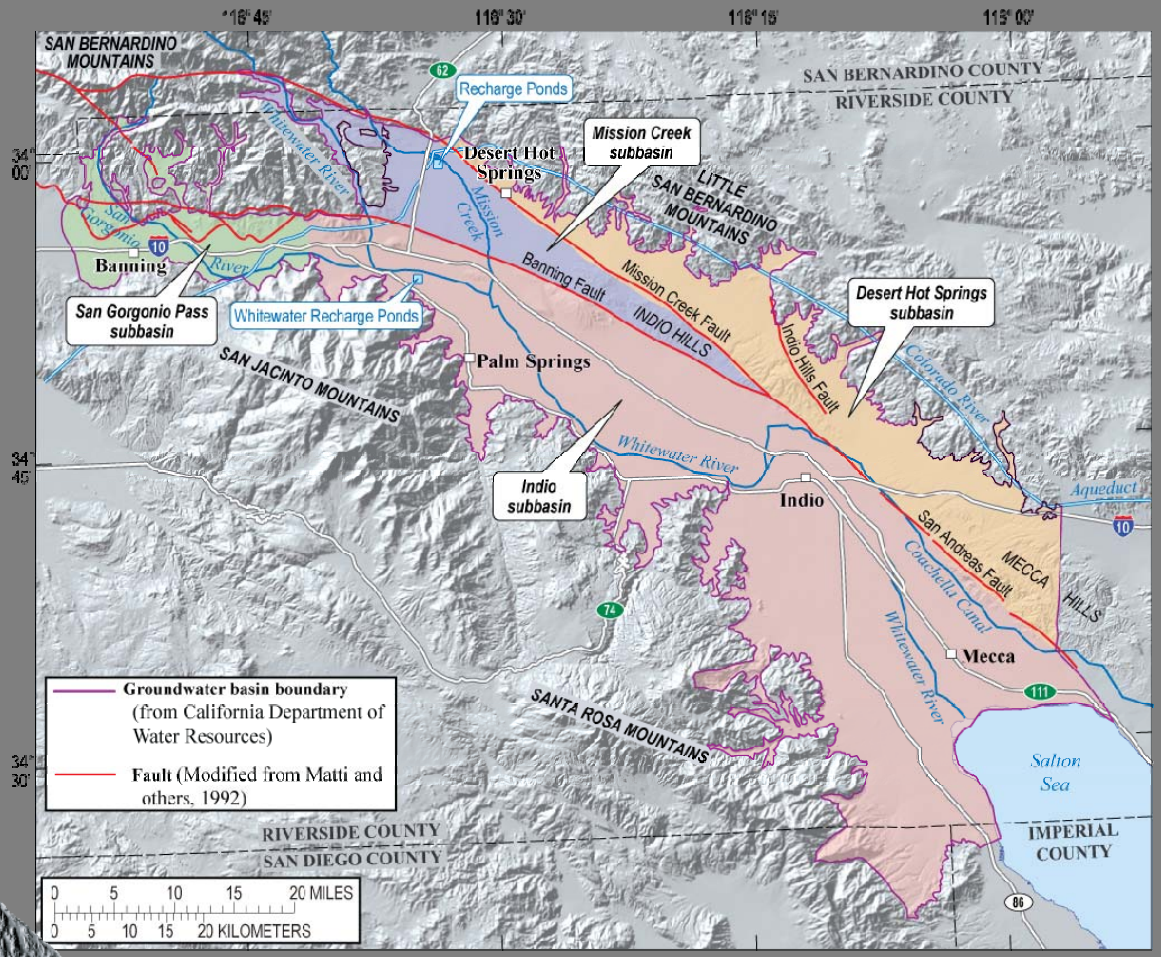
Coachella Valley

Courtesy of Devin Galloway, USGS

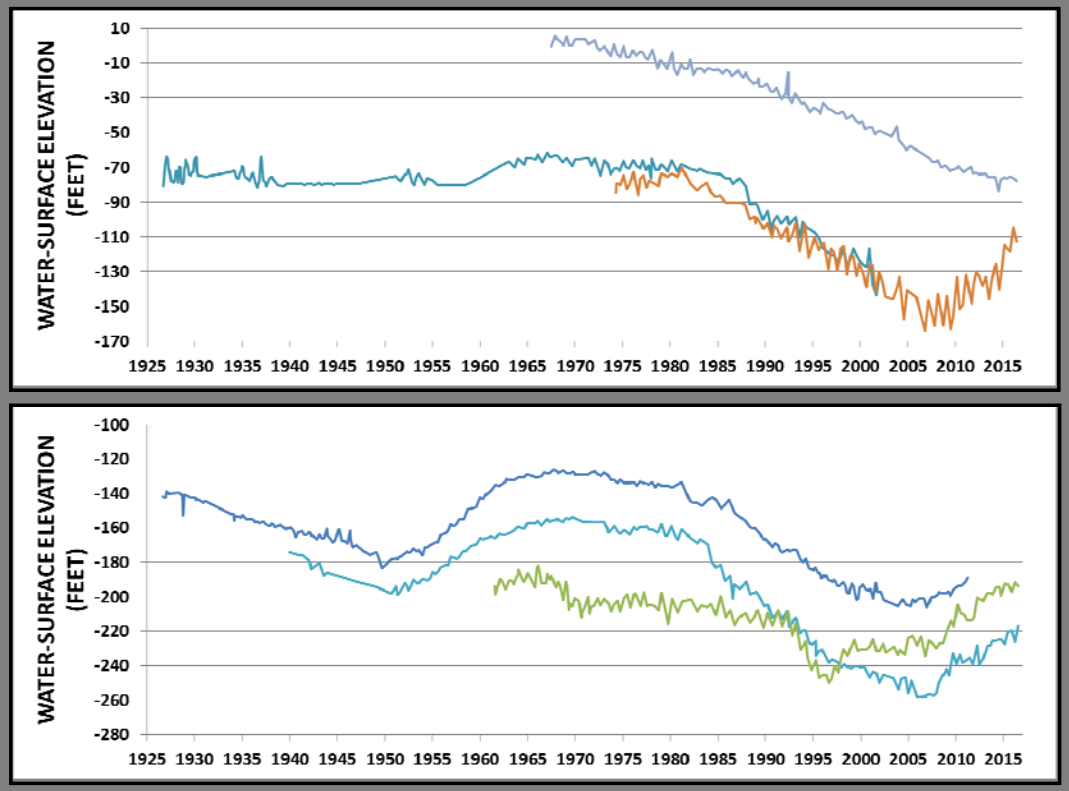
Coachella Valley Groundwater Subbasins

- Groundwater subbasins defined by
  - Groundwater levels
  - Groundwater chemistry
  - Geologic structure





Groundwater Resources Development

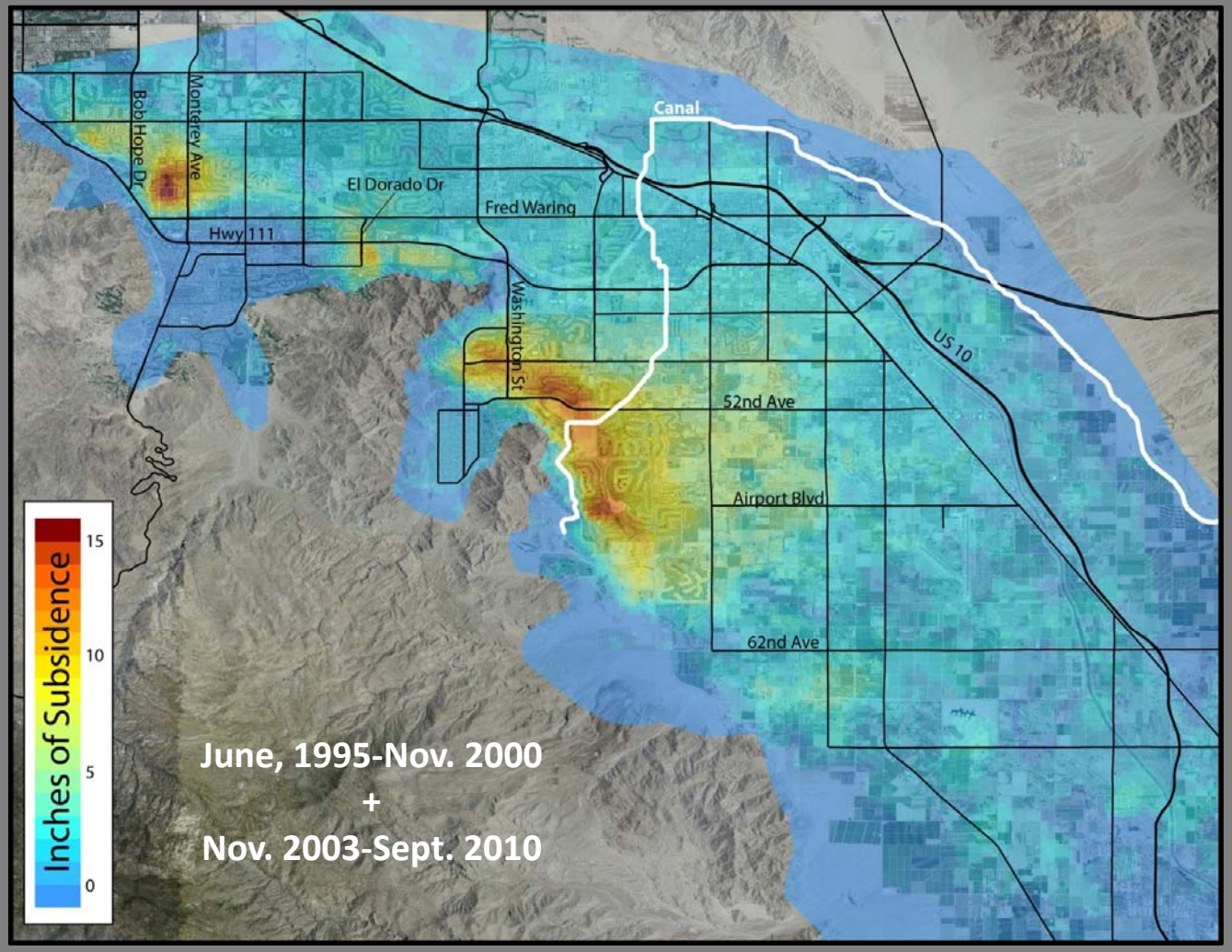


Indio Subbasin Hydrographs

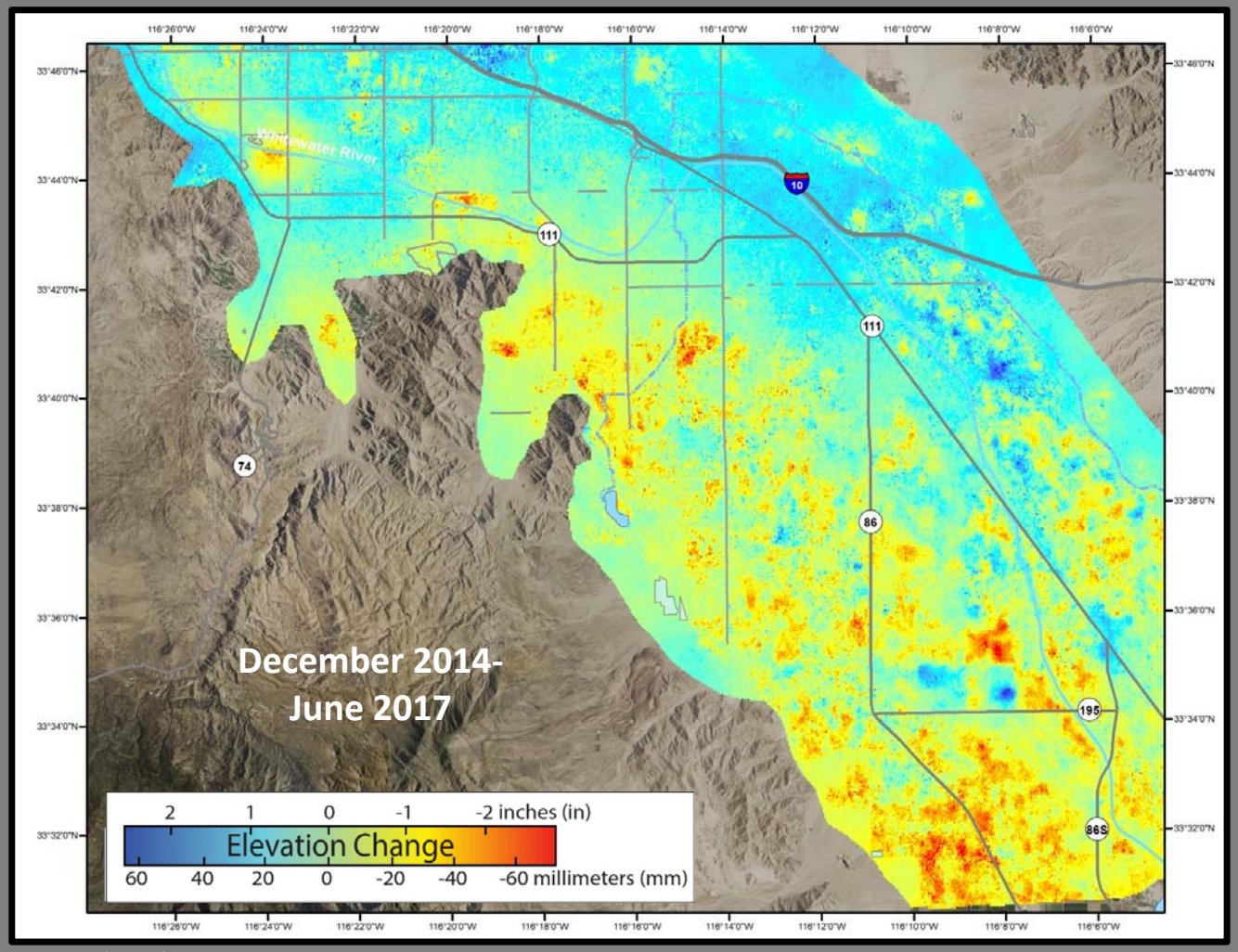
- Groundwater has been a major source of water supply
- Declined until 1949
- Raised 1949- ~1970
- Declined ~1970-~2009
  - Reached historically low levels
- Some rising since ~2009

Preliminary and Subject to Revision

Subsidence Map: That was Then

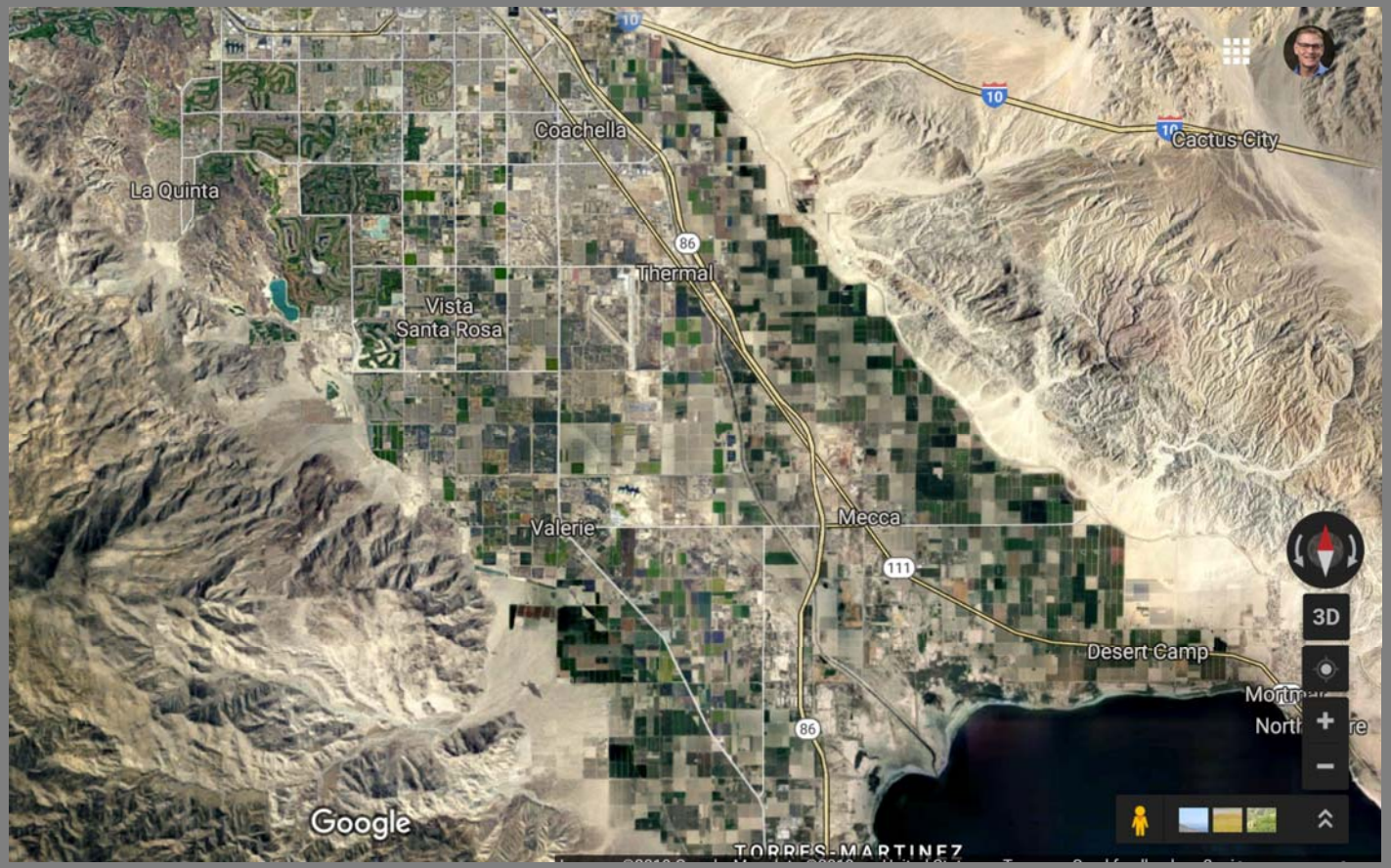


Subsidence Map: This is Now



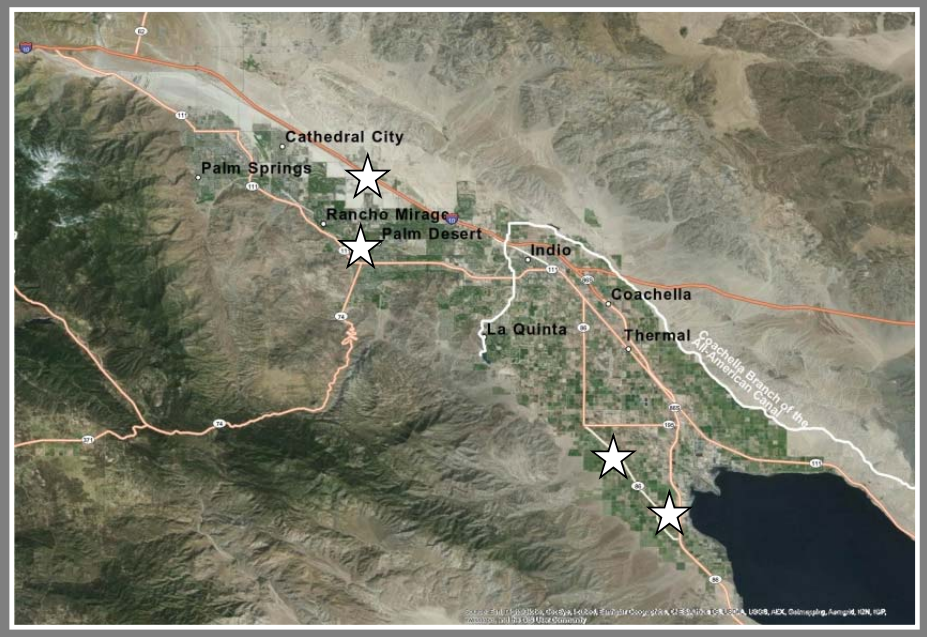
Preliminary and Subject to Revision

Agriculture and Tourism (golfing) have had a major impact on water use subsidence

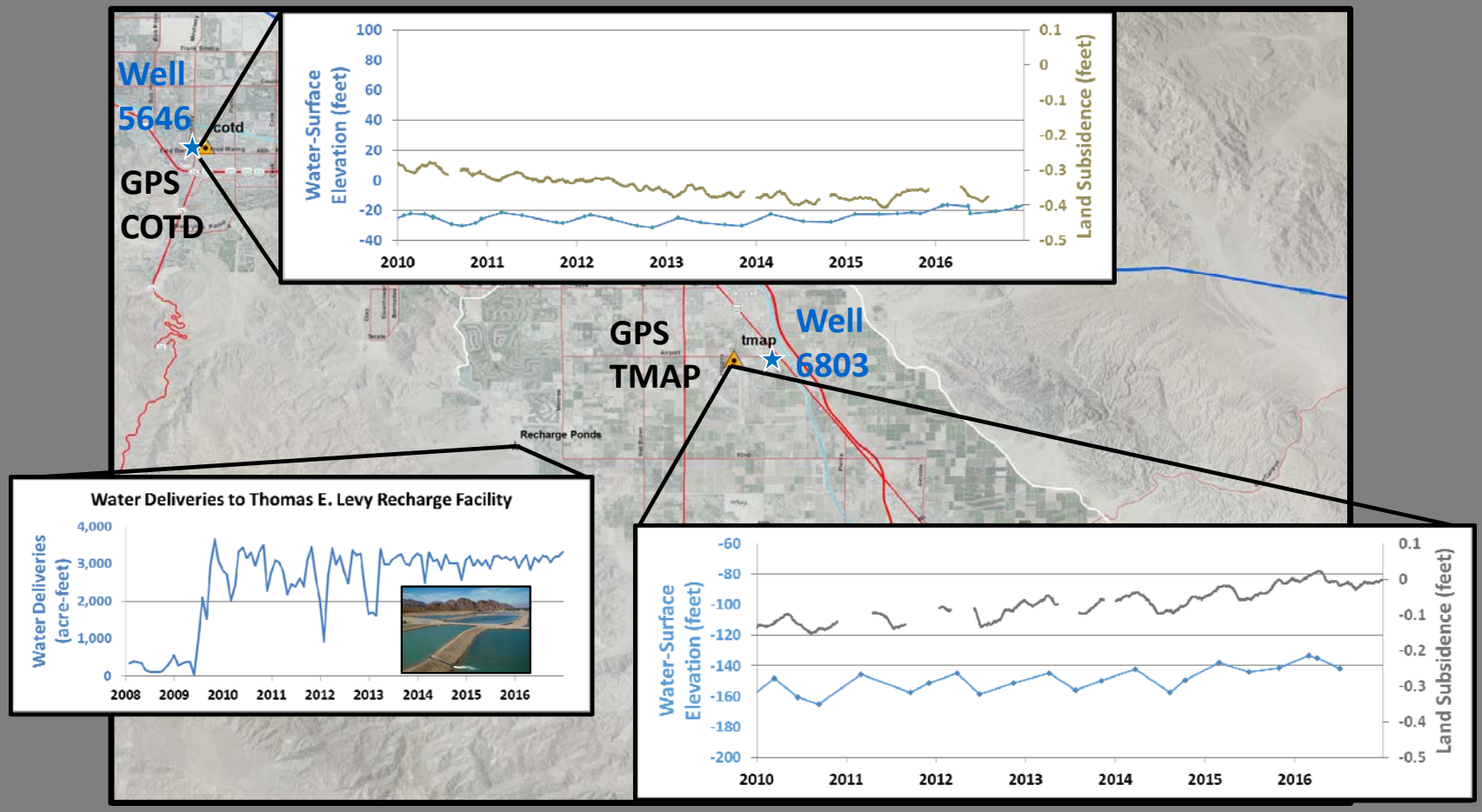


Percolation Ponds

- Whitewater River since 1973 (SWP)
- Mission Creek (near Desert Hot Springs) since 2002 (SWP)
- Martinez Canyon since 2007 (Colorado River)
- Thomas E. Levy Groundwater Replenishment Facility since October 2009 (Colorado River)



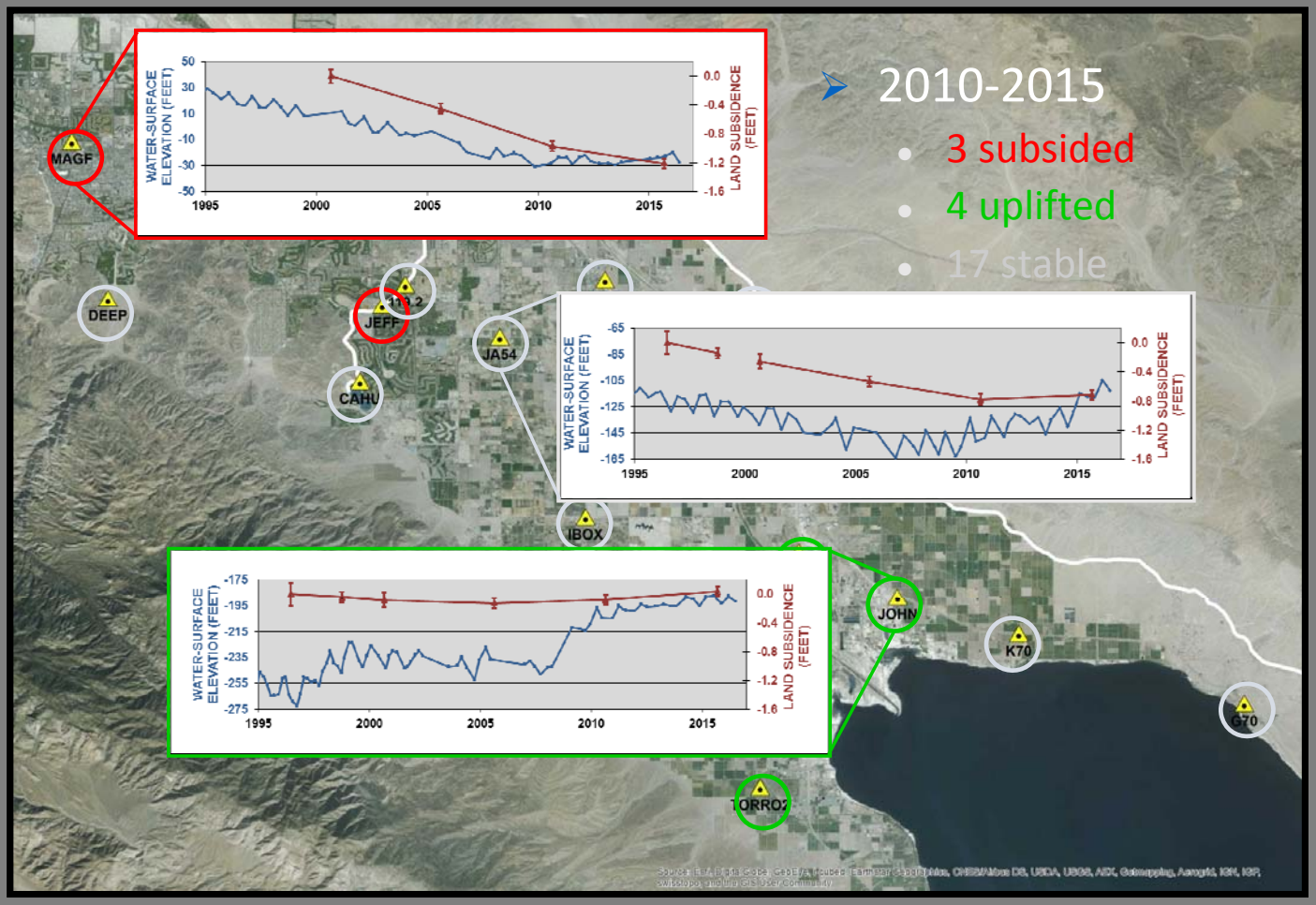
Continuous GPS



Preliminary and Subject to Revision

High-Precision GPS Surveys

Repeated Every 5 Years



- 2010-2015
  - 3 subsided
  - 4 uplifted
  - 17 stable

Preliminary and Subject to Revision

Summary

- Periods of groundwater-level declines since the 1930s have caused land subsidence in the Coachella Valley
- Groundwater levels in many parts of the valley have stabilized or risen during the last decade
  - Largely associated with managed recharge using percolation ponds
- The stable or rising water levels have resulted in slowed or stopped subsidence