An Update on Land Subsidence and Aquifer-Storage Change Monitoring in the Tucson Active Management Area

PIMA COUNTY LOCAL DROUGHT IMPACT GROUP
May 11, 2016

Cooperating Agencies:

Pima County, Town of Oro Valley, Metropolitan Domestic Water Improvement District, City of Tucson, Town of Marana, and Arizona Department of Water Resources

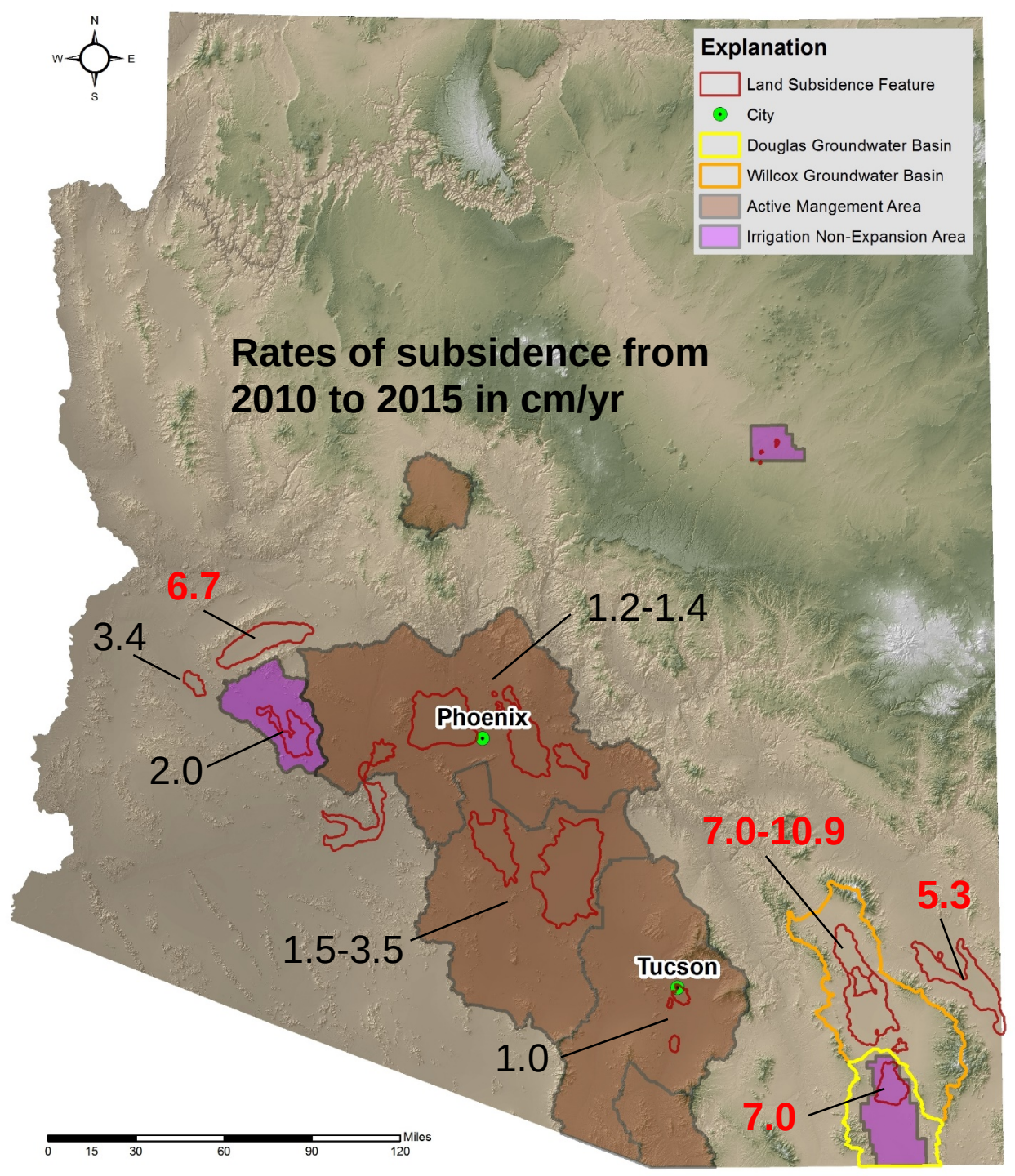
Rob Carruth
U.S. Geological Survey

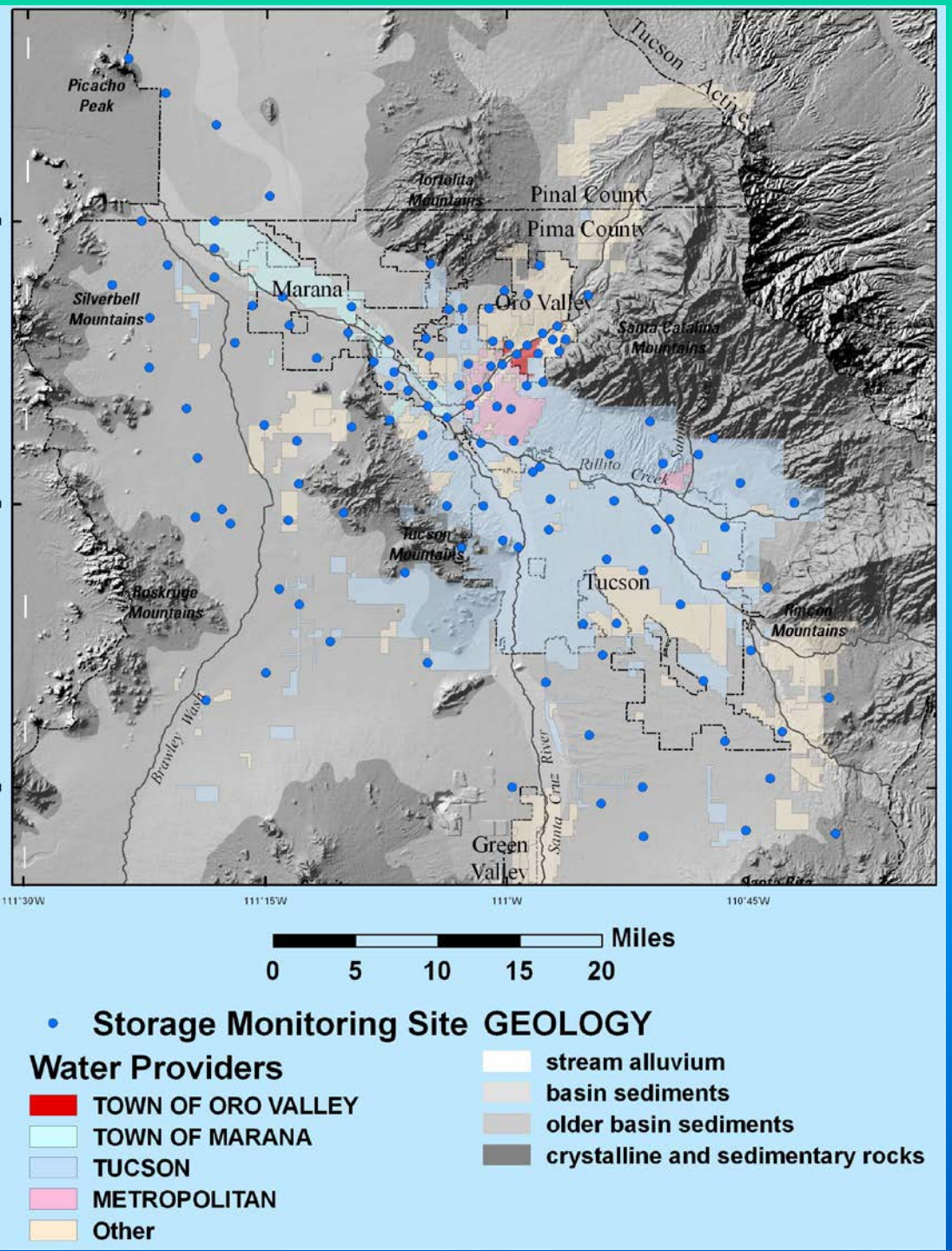
Brief Outline and Historical Background

- 1980 Groundwater Management Code
- Establishment of State AMA's and INA's
- Land subsidence and earth fissures caused by groundwater mining
- ADWR land subsidence monitoring program
- USGS microgravity methods to monitor aquifer-storage change
- Monitoring and analysis to track progress toward statutory goals of AMA's and INA's
- Cooperation with water providers to monitor groundwater conditions and to provide information for management of groundwater resources

Groundwater Management

- Groundwater Act of 1980 created ADWR, five Active Management Areas (AMA's), and three Irrigation Non-expansion Areas (INA's)
- These management areas have various types of groundwater management
  - Safe yield
  - 100-year assured water supply
  - Restrictions on new irrigated lands





Aquifer-Storage Change and Subsidence Monitoring Stations in the TAMA

Directed by Arizona ground-water law to attain an annual balance between ground-water withdrawals (Q_{out}) and recharge (Q_{in}) by the year 2025

$$Q_{in} = Q_{out}$$

$$\Delta Storage = 0$$

Objectives of the Project

1. **Monitor aquifer-storage change**

   Addressed by measuring changes in gravity. As water is added or removed from the aquifer, there is a change in mass and a corresponding measurable change in gravity.

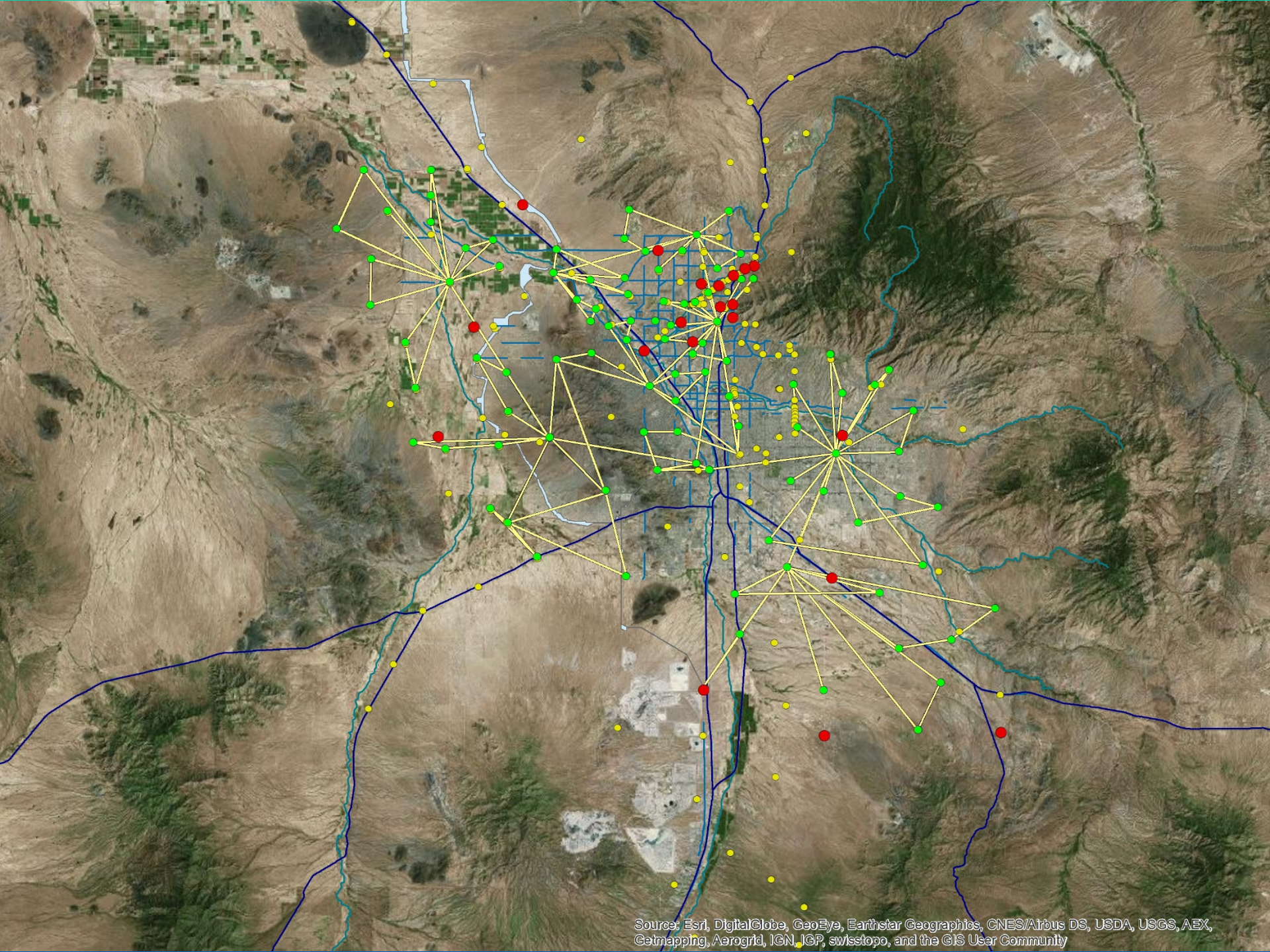
2. **Monitor Land-Surface Elevation Change**

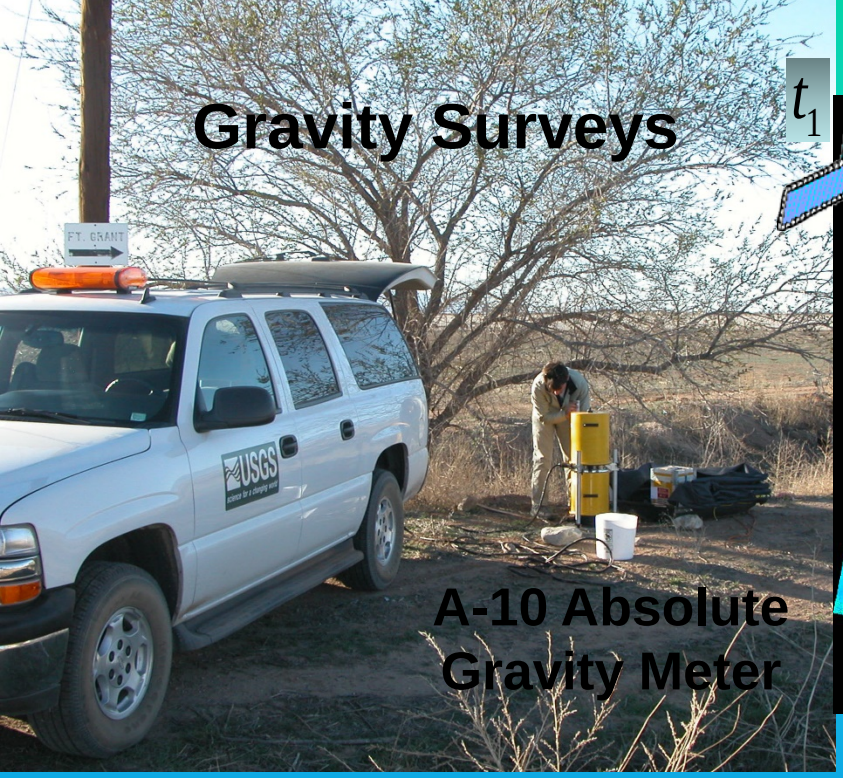
   Addressed by measuring changes in land surface elevation over time with InSAR, GPS, and a network of vertical extensometers.

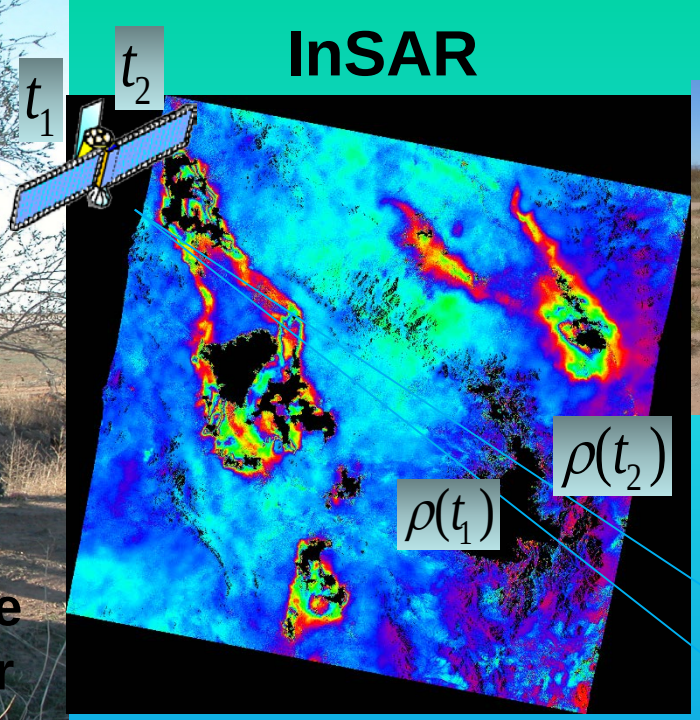
Note:

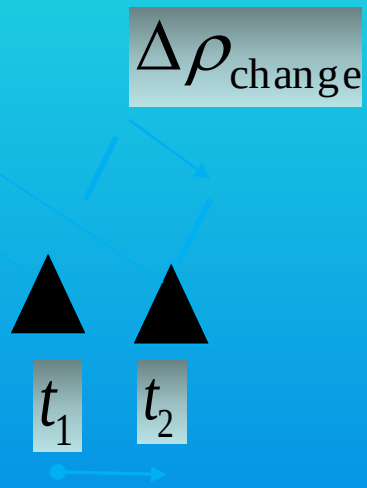
Storage changes have often been estimated using water-level changes
- storage properties of heterogeneous aquifers, multiple aquifer systems, difficult to get a sense of real change in storage

Water levels changes may be better indicators in changes in rates of ground-water flow


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community







METHODS

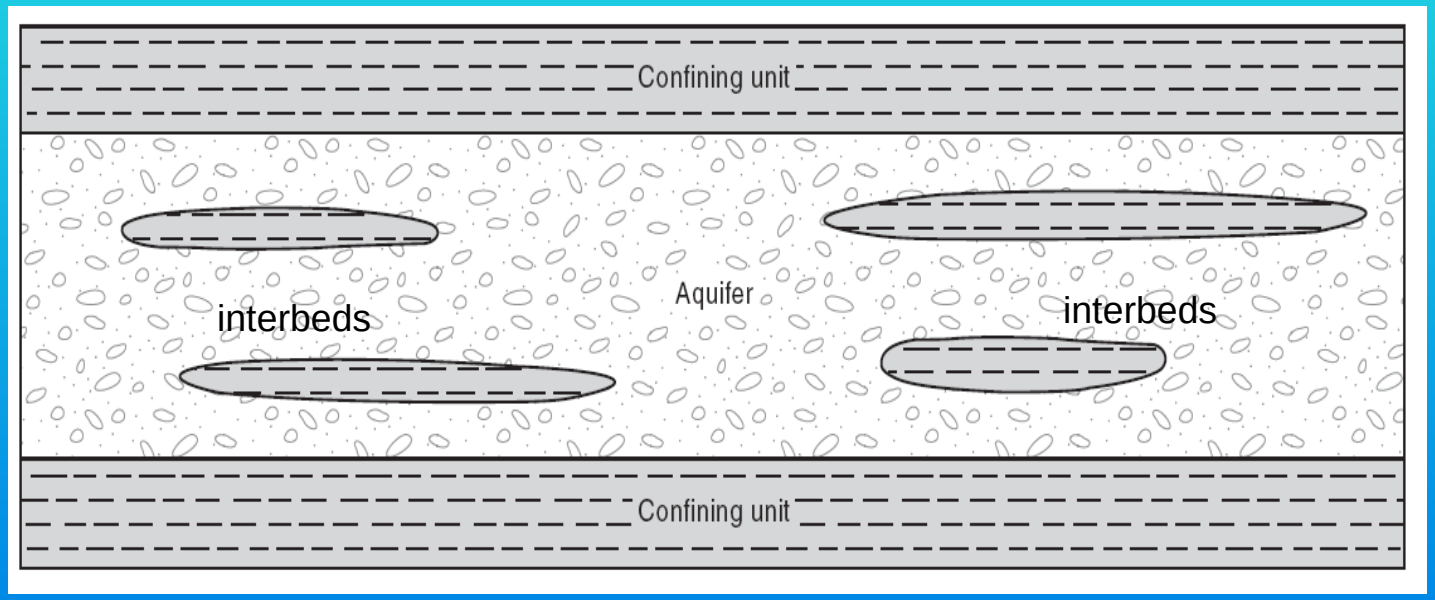
Repeat gravity and InSAR/GPS surveys

- Gravity – measures total mass (storage) change +/- 0.5 ft water
- InSAR and GPS – measures aquifer-compaction (subsidence) portion of storage change +/- 0.1 ft water

Subsidence from ground-water extraction occurs when fluid pressure in <u>compressible</u> sediments is reduced

Compressible (fine-grained) sediments can take the form of

- Continuous, mapable layers adjacent to less compressible coarse grained aquifer materials
- Discontinuous interbeds within coarse-grained aquifer materials



- Extensive compressible units can be treated explicitly in model grids
- Discontinuous interbeds within course-grained aquifer materials must be treated in a bulk manner
- In many subsiding areas, compaction of distributed compressible interbeds is the major component of subsidence

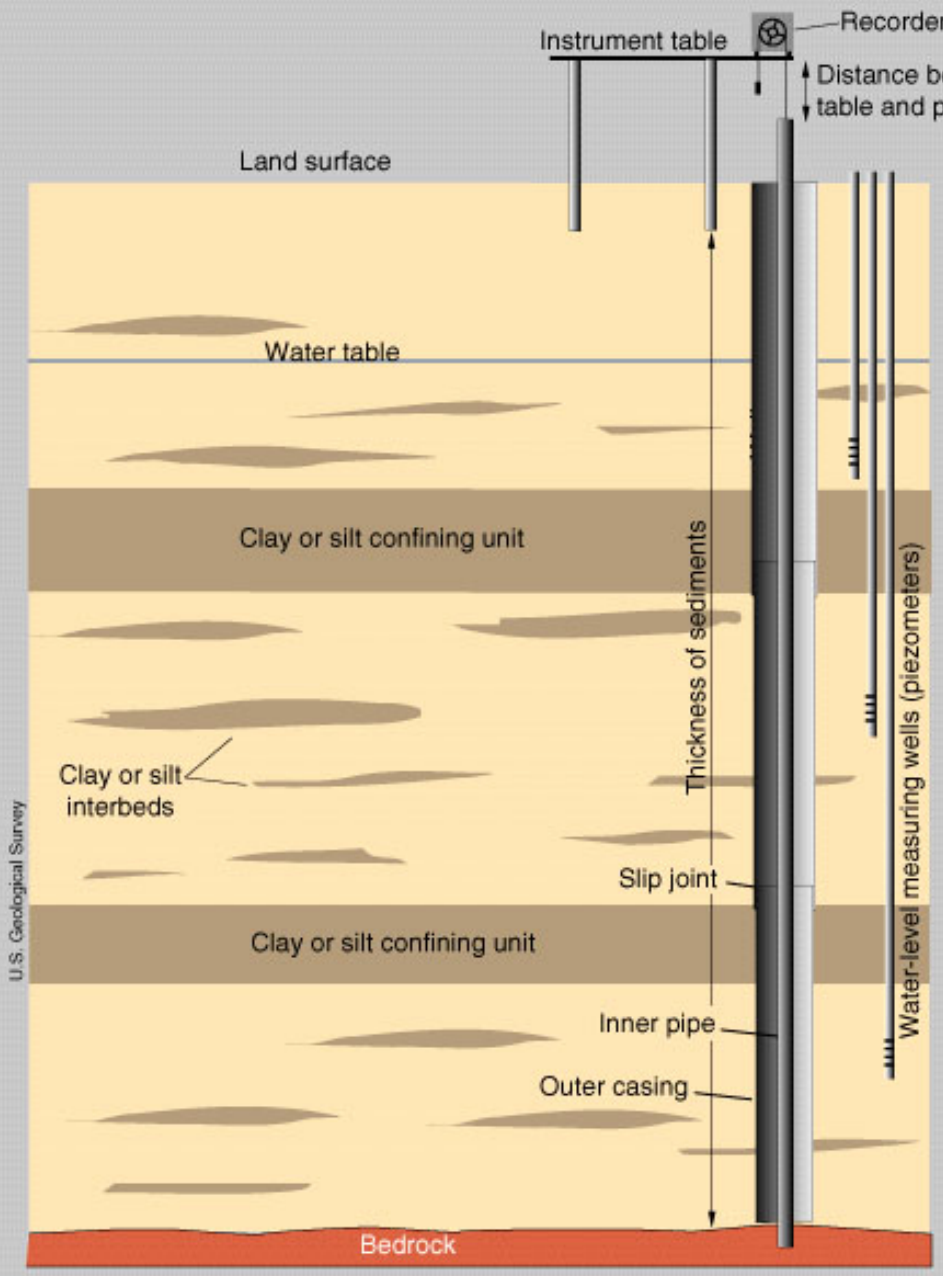


Figure 8. Compaction recorder (or vertical extensometer) for monitoring change in thickness of sediments. Instruments monitor change in distance between table and top of pipe, which is equivalent to change in thickness of sediments.

Schematic of a Compaction Recorder (Vertical Extensometer)

Used to monitor change in land-surface elevation resulting from change in thickness of sediments

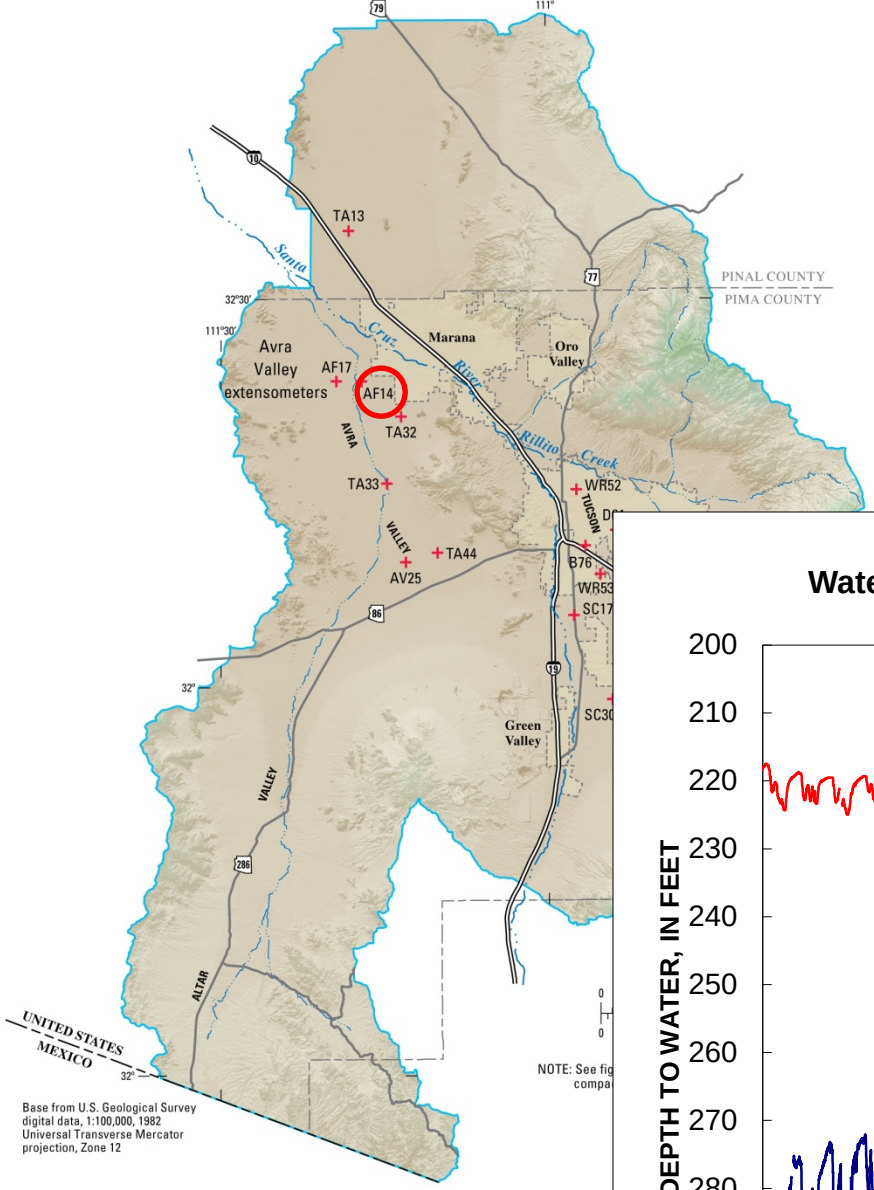
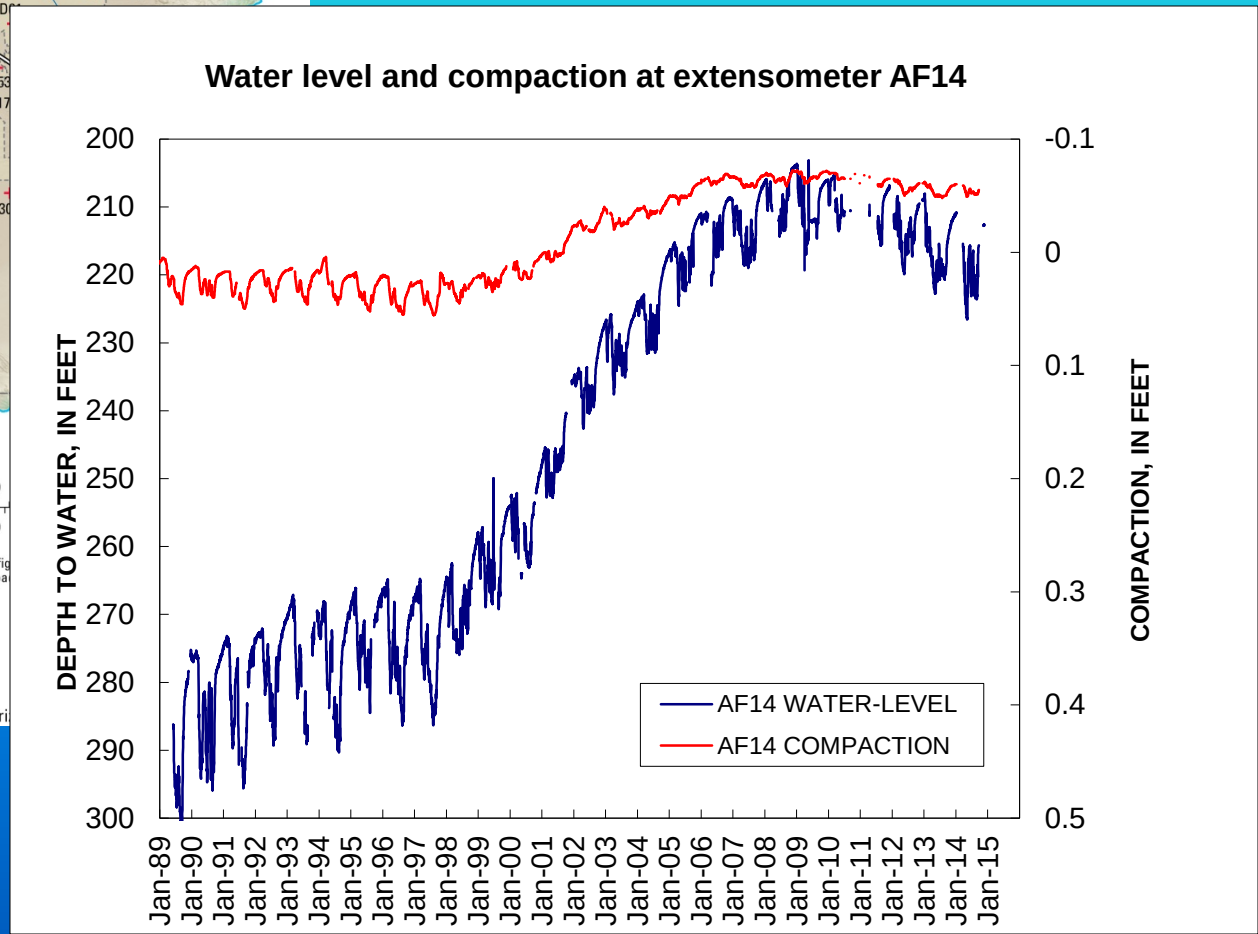
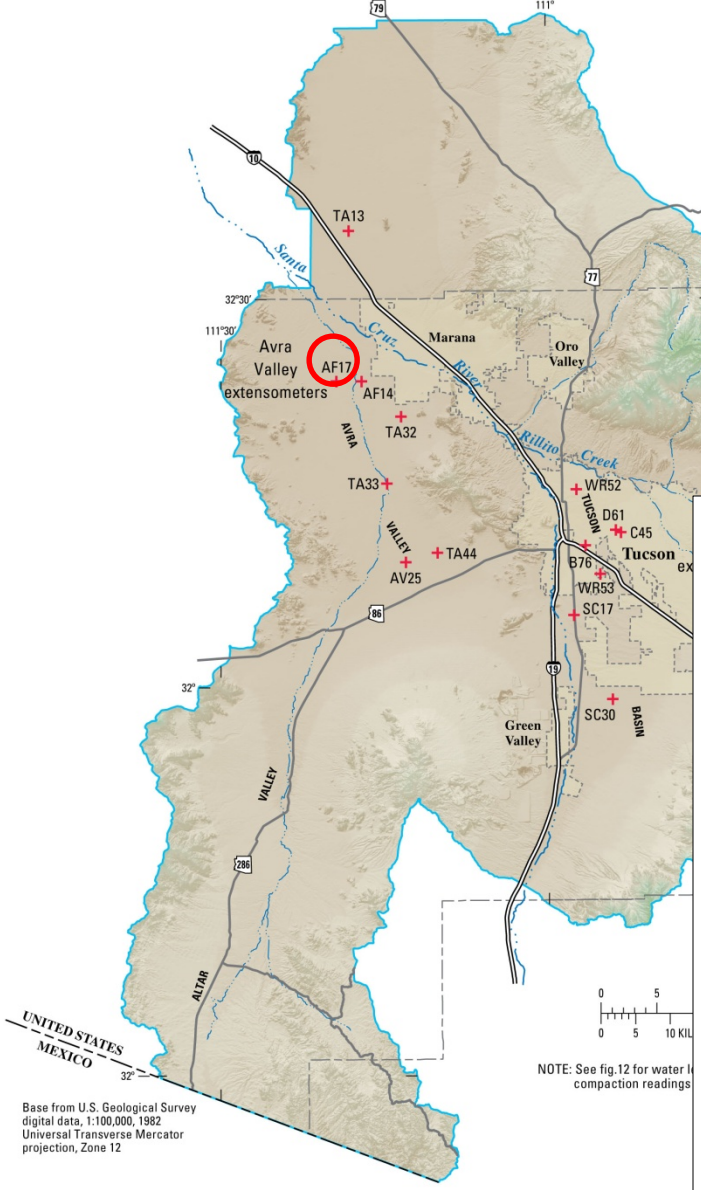


Figure 4. Tucson Active Management Area vertical extensometer stations, south-central Ari





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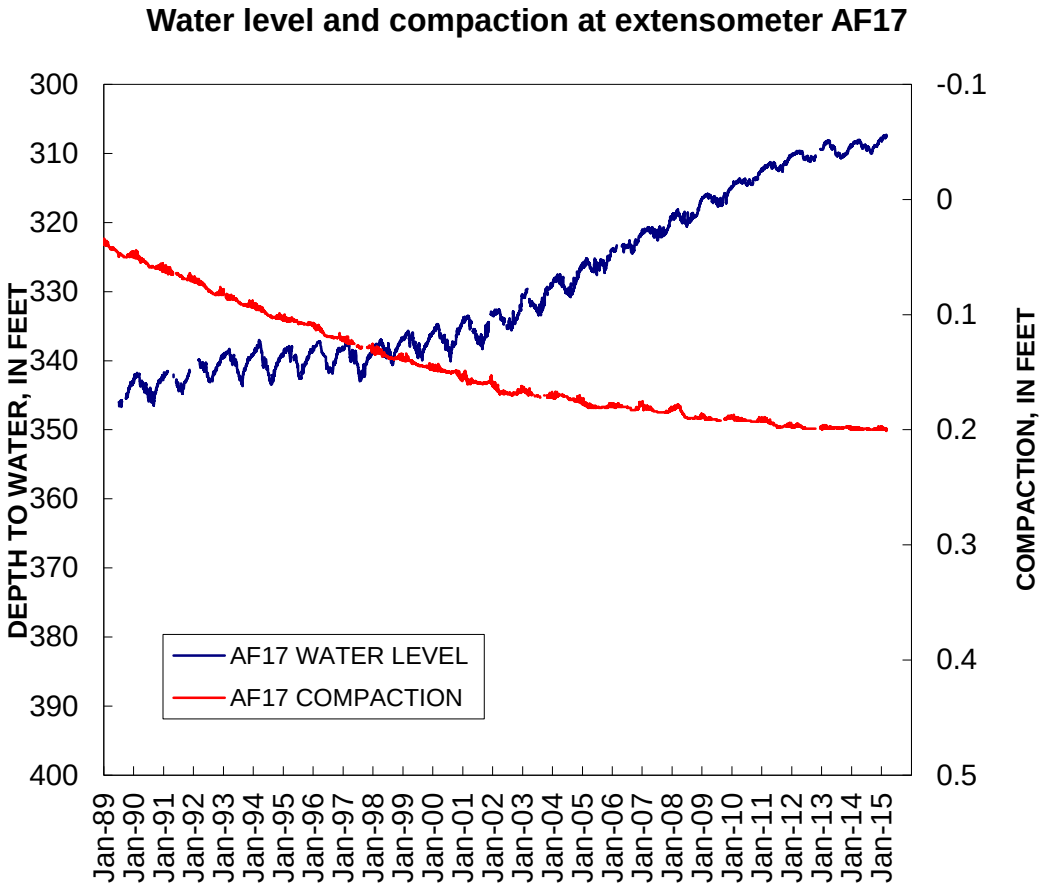
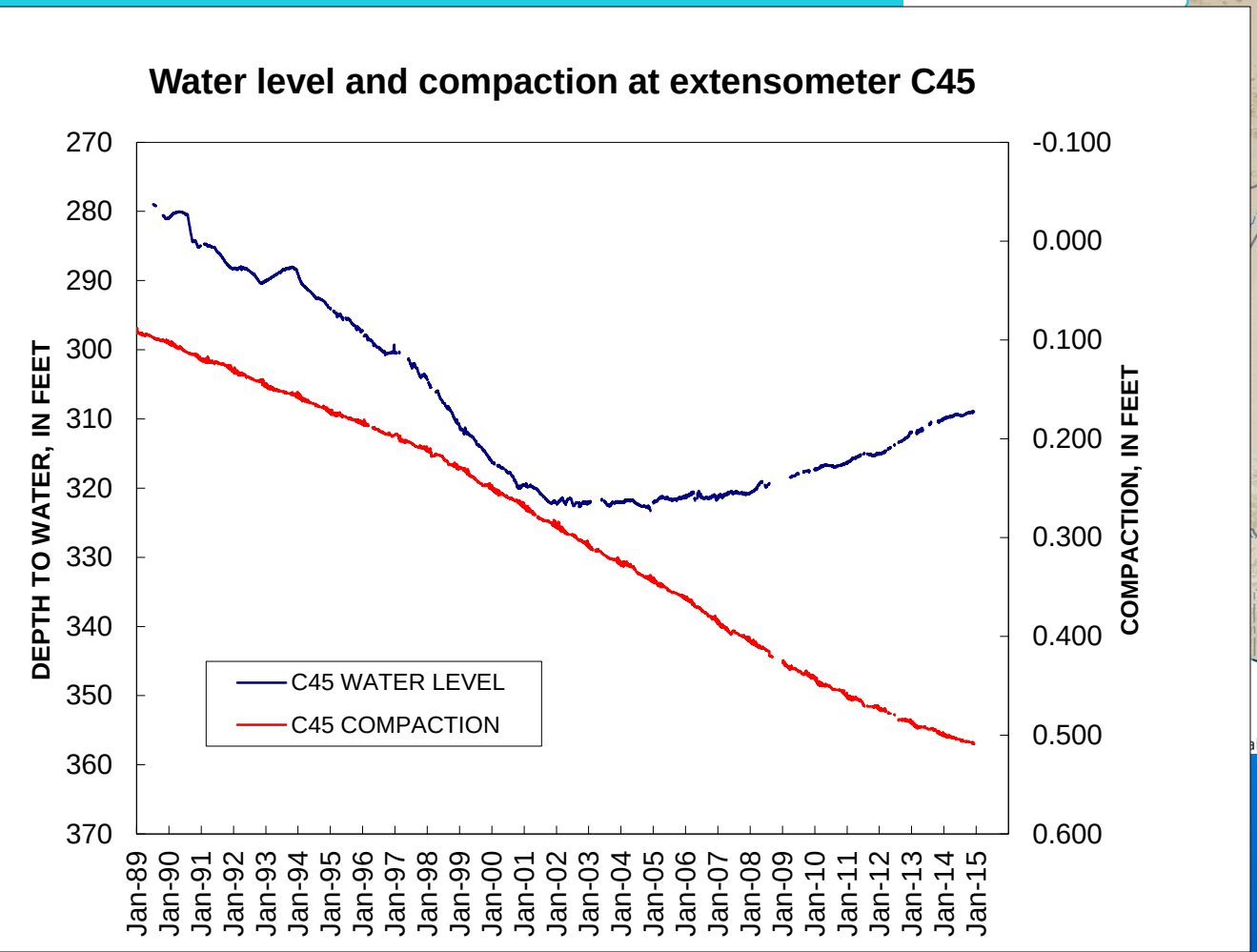
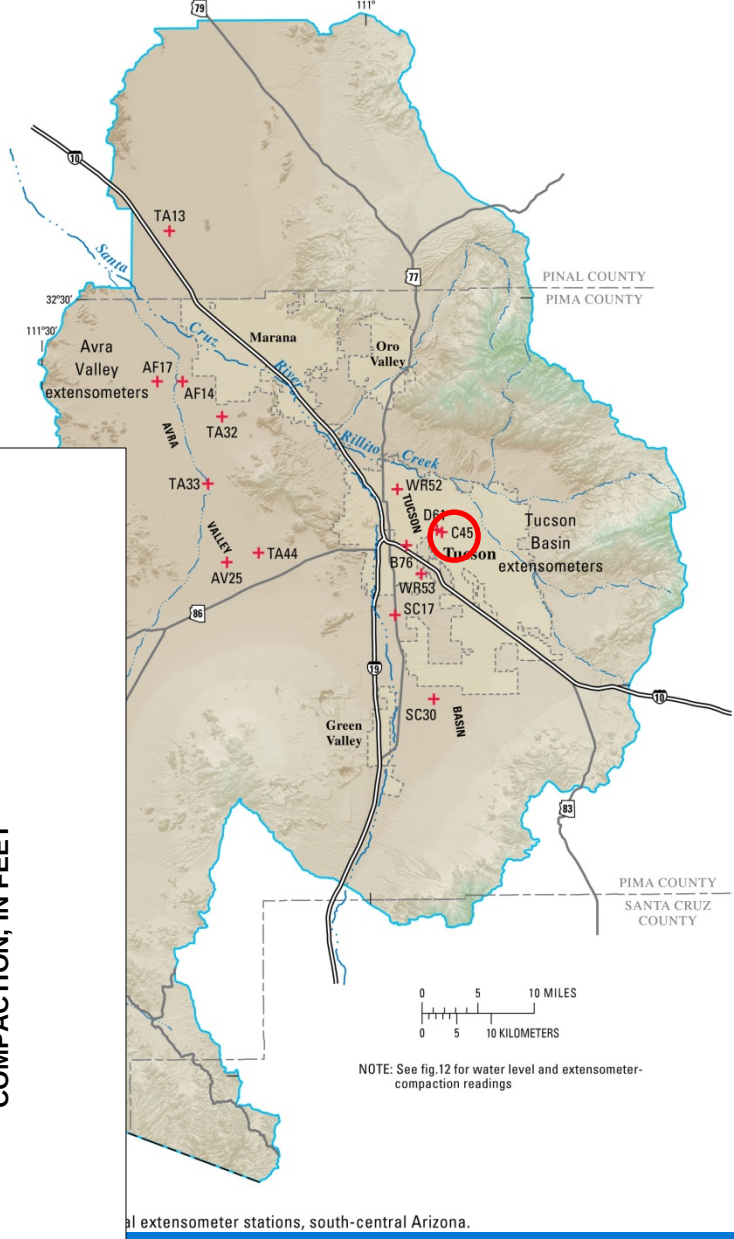


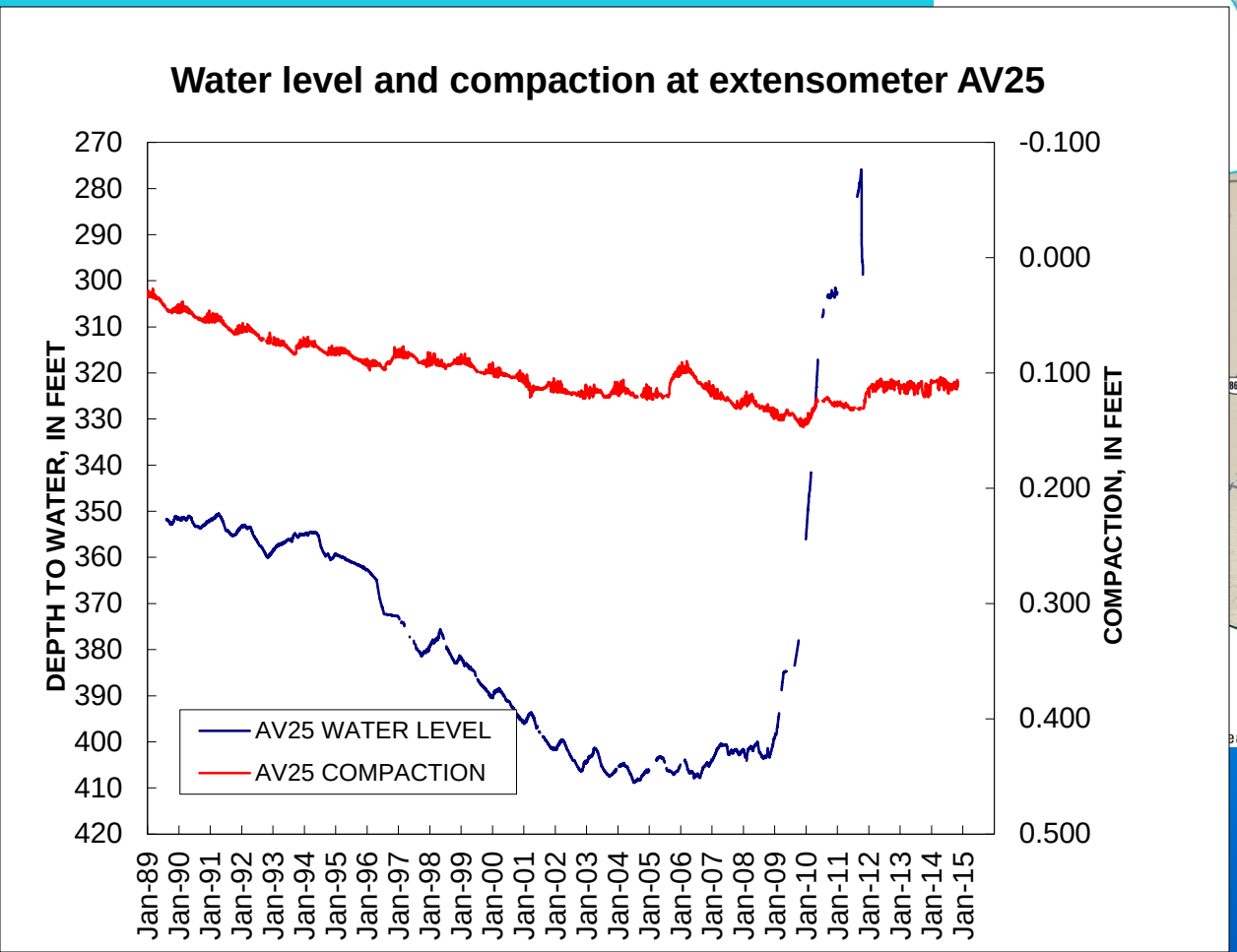
Lessons learned

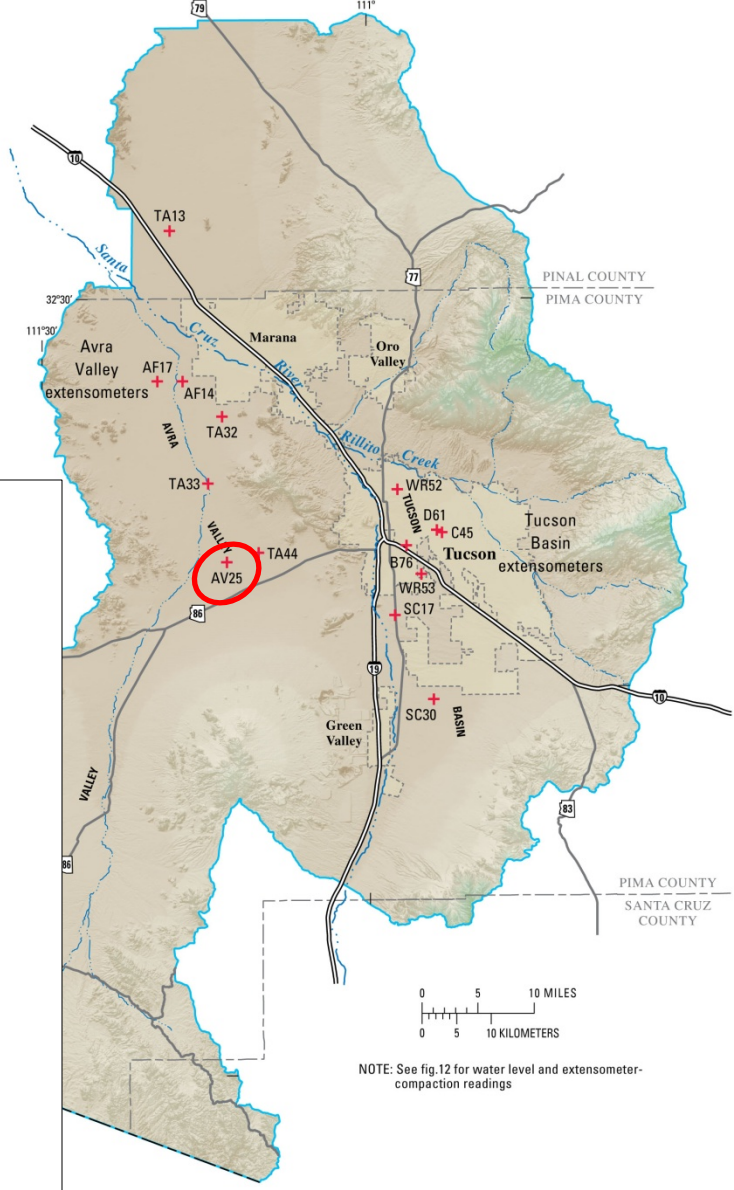
- **Subsidence due to delayed drainage of fine-grained units can continue for years after pumpage is reduced**





al extensometer stations, south-central Arizona.

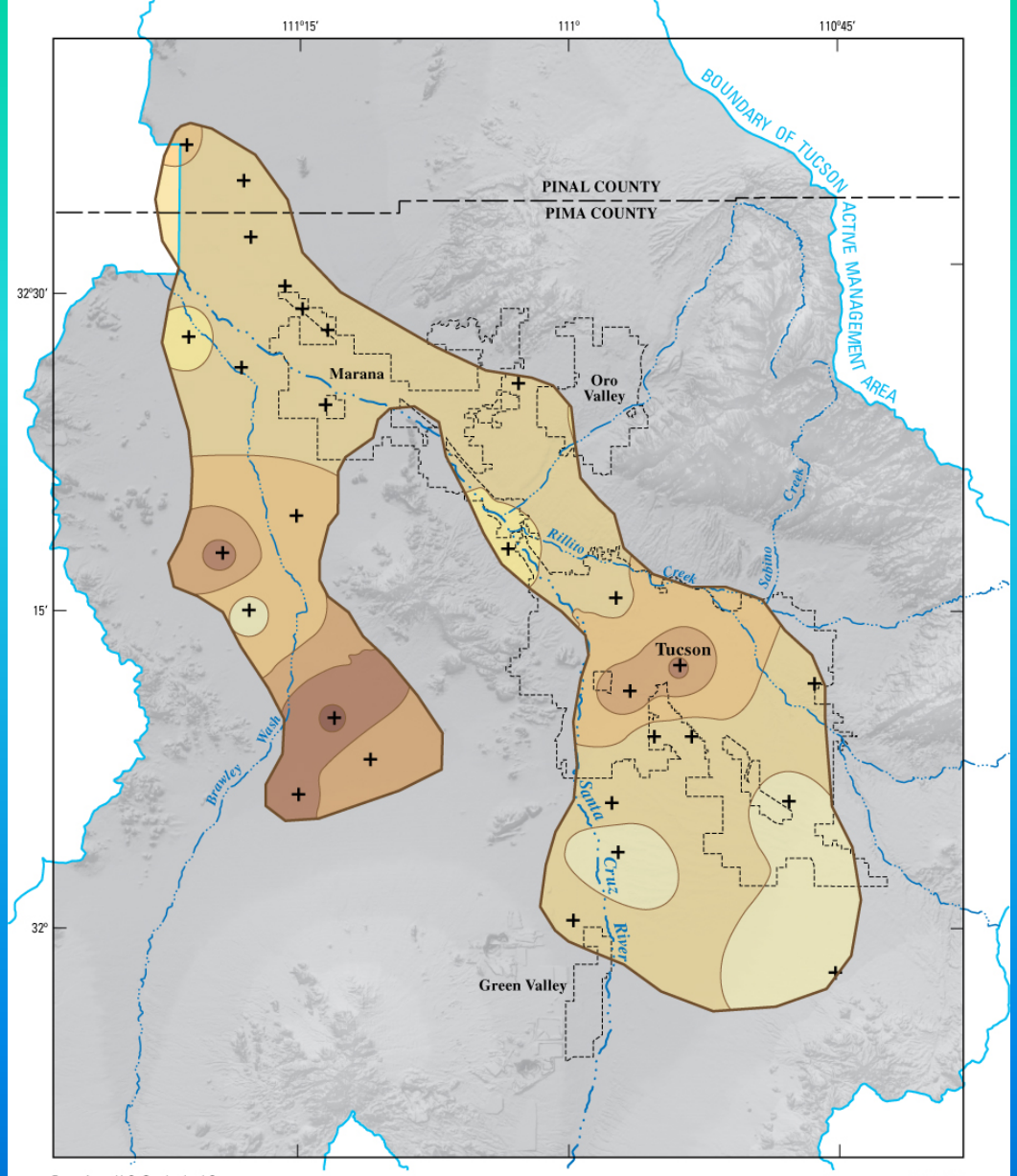




ea vertical extensometer stations, south-central Arizona.

Land Subsidence in the TAMA

2006 - 2008



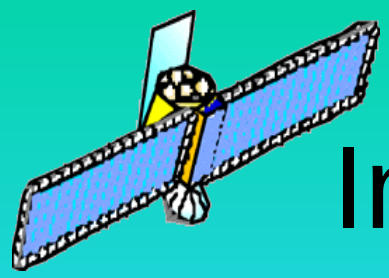
Subsidence from 2006 – 2008, in inches

+ BENCHMARK

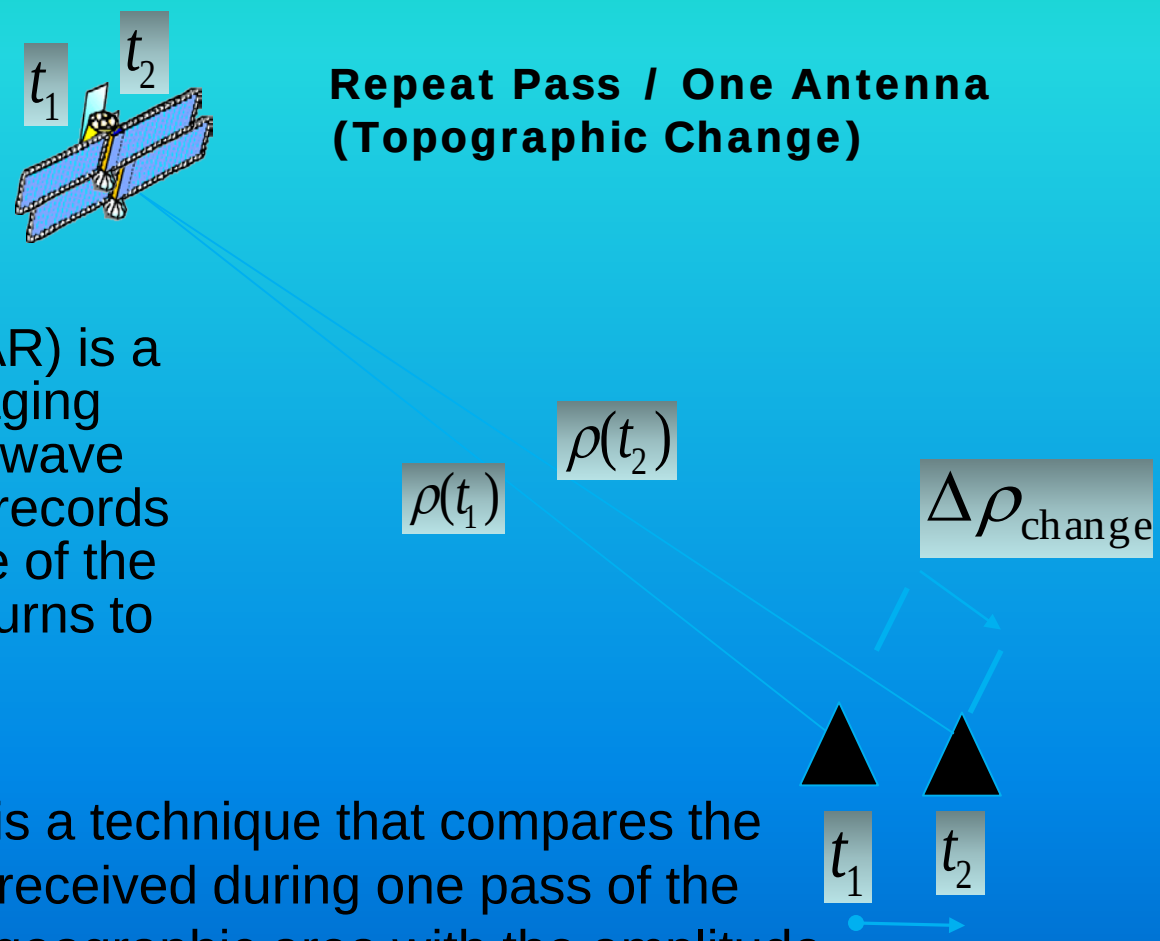
Maximum Subsidence

~ 0.5 inch Tucson Basin

~ 1 inch Avra Valley.



Interferometric SAR (InSAR)



Repeat Pass / One Antenna (Topographic Change)

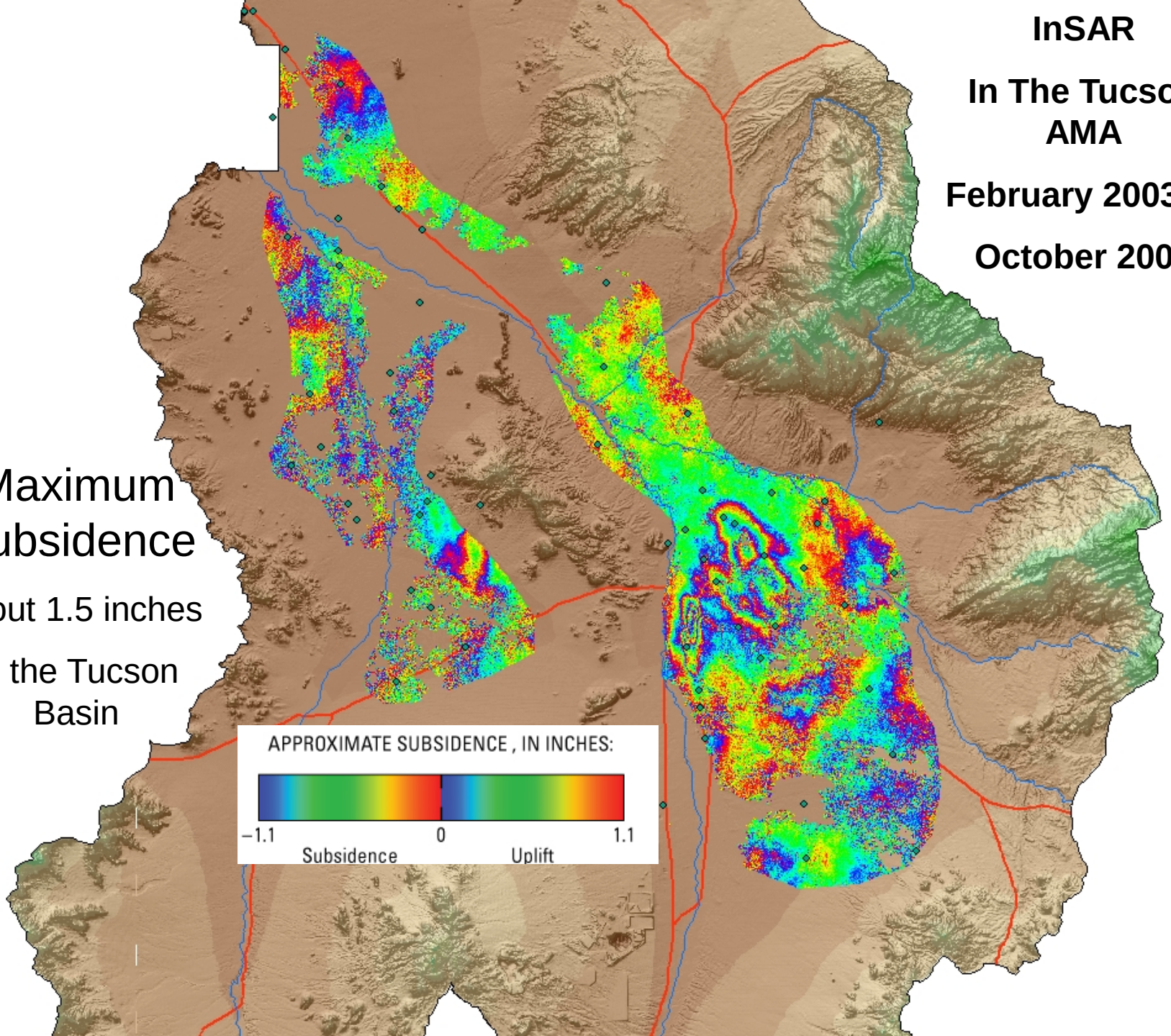
Synthetic Aperture Radar (SAR) is a side-looking, active radar imaging system that transmits a microwave signal towards the earth and records both the amplitude and phase of the back-scattered signal that returns to the antenna.

Interferometric SAR (InSAR) is a technique that compares the amplitude and phase signals received during one pass of the SAR platform over a specific geographic area with the amplitude and phase signals received during a second pass of the platform over the same area but at a different time.

InSAR

In The Tucson AMA

February 2003 to October 2006



Maximum Subsidence

about 1.5 inches

in the Tucson Basin

InSAR

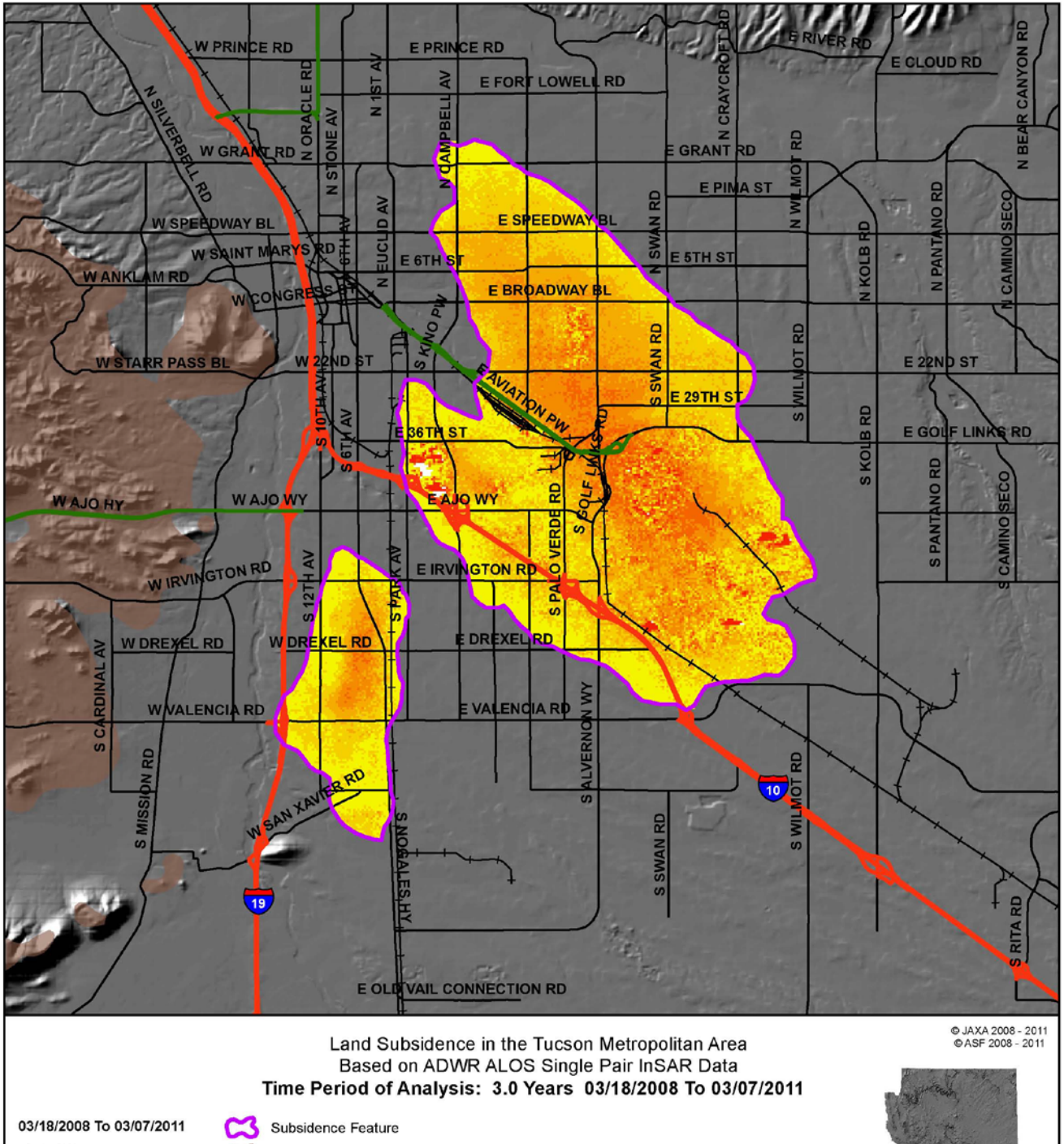
In The Tucson AMA

March 2008 to

March 2011

Subsidence

About 0.1–1.0 inch in the Tucson Basin



InSAR

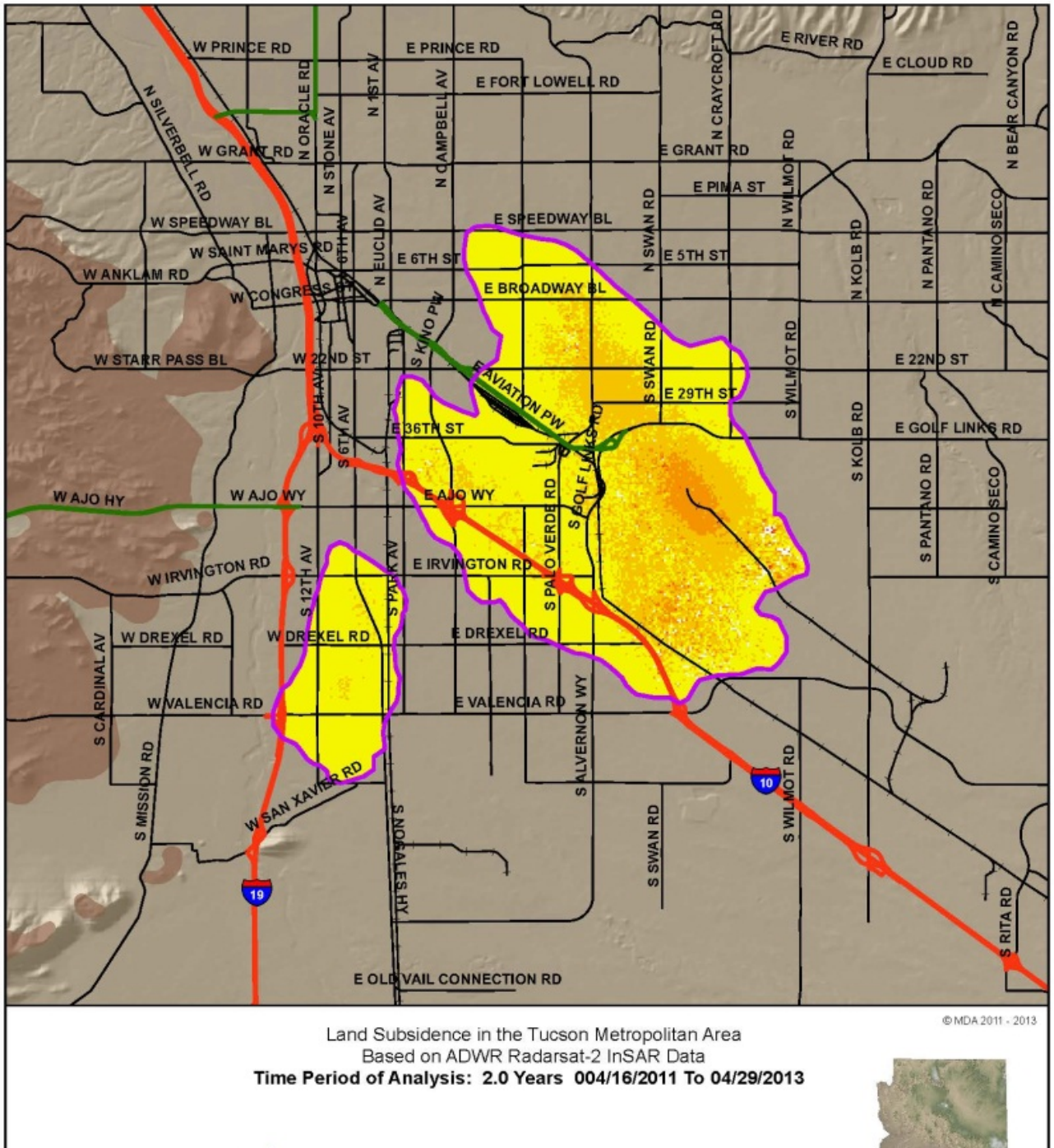
In The Tucson AMA

April 2011 to

April 2013

Subsidence

About 0 to 0.5 inches in the Tucson Basin

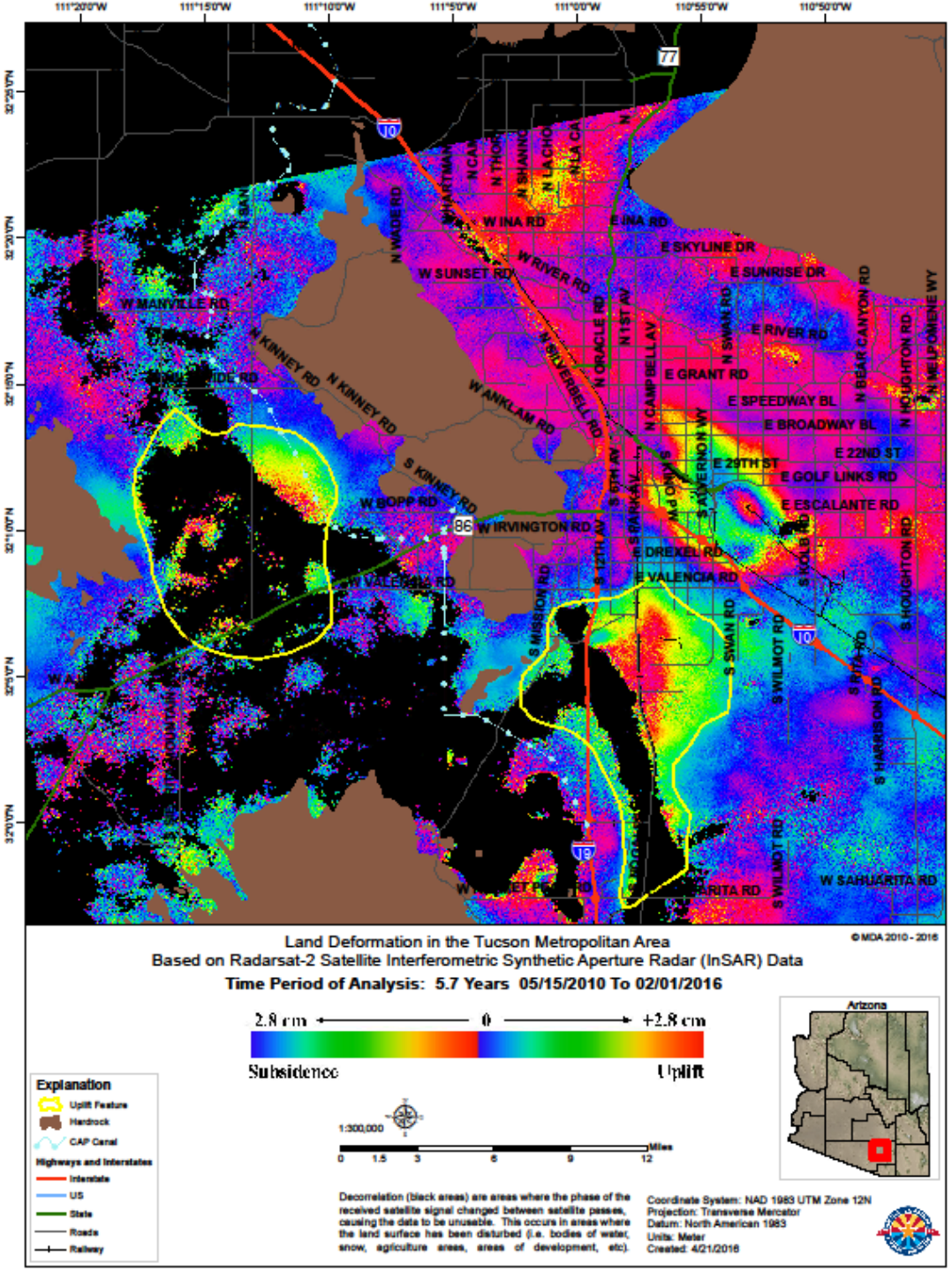


InSAR in The Tucson AMA

5.7 year period from May 15, 2010 to February 1, 2016

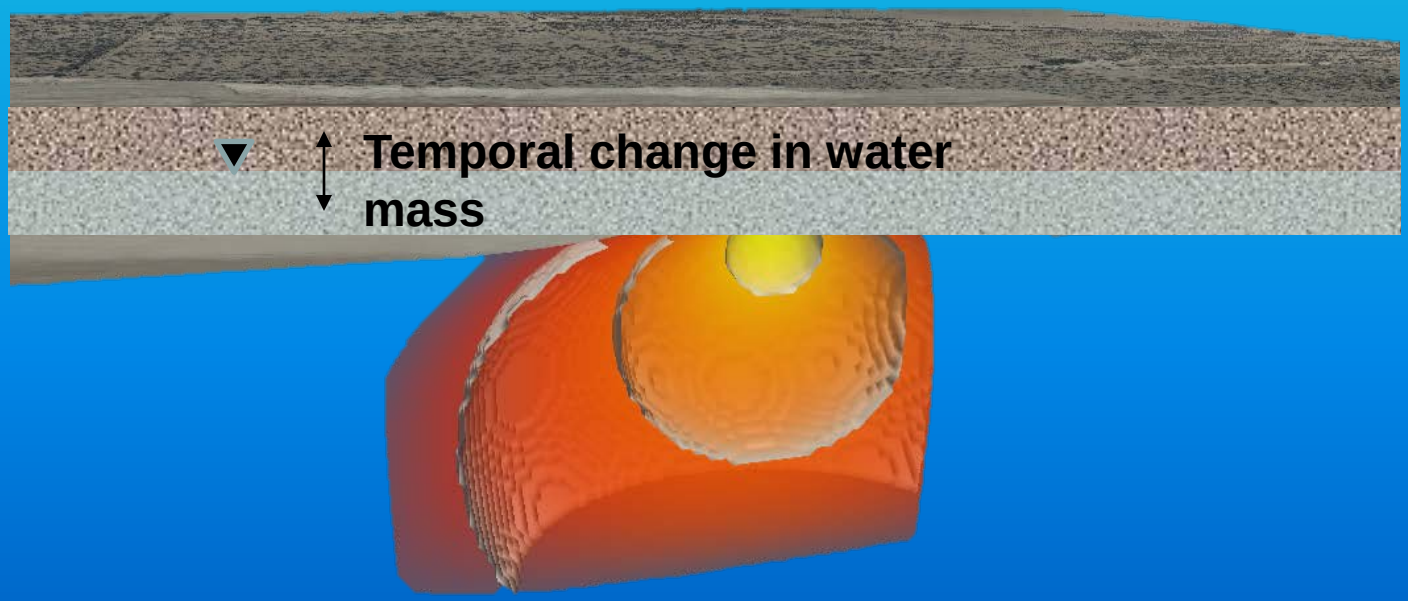
Recent indications:

1. Continued subsidence around the Tucson Well Field (primarily due to delayed drainage of fine-grained units); however, rates of subsidence are reduced—about 1 cm/yr or less
2. There are now uplift features associated with recharge of CAP water in Avra Valley and from Pima Mine Rd facility

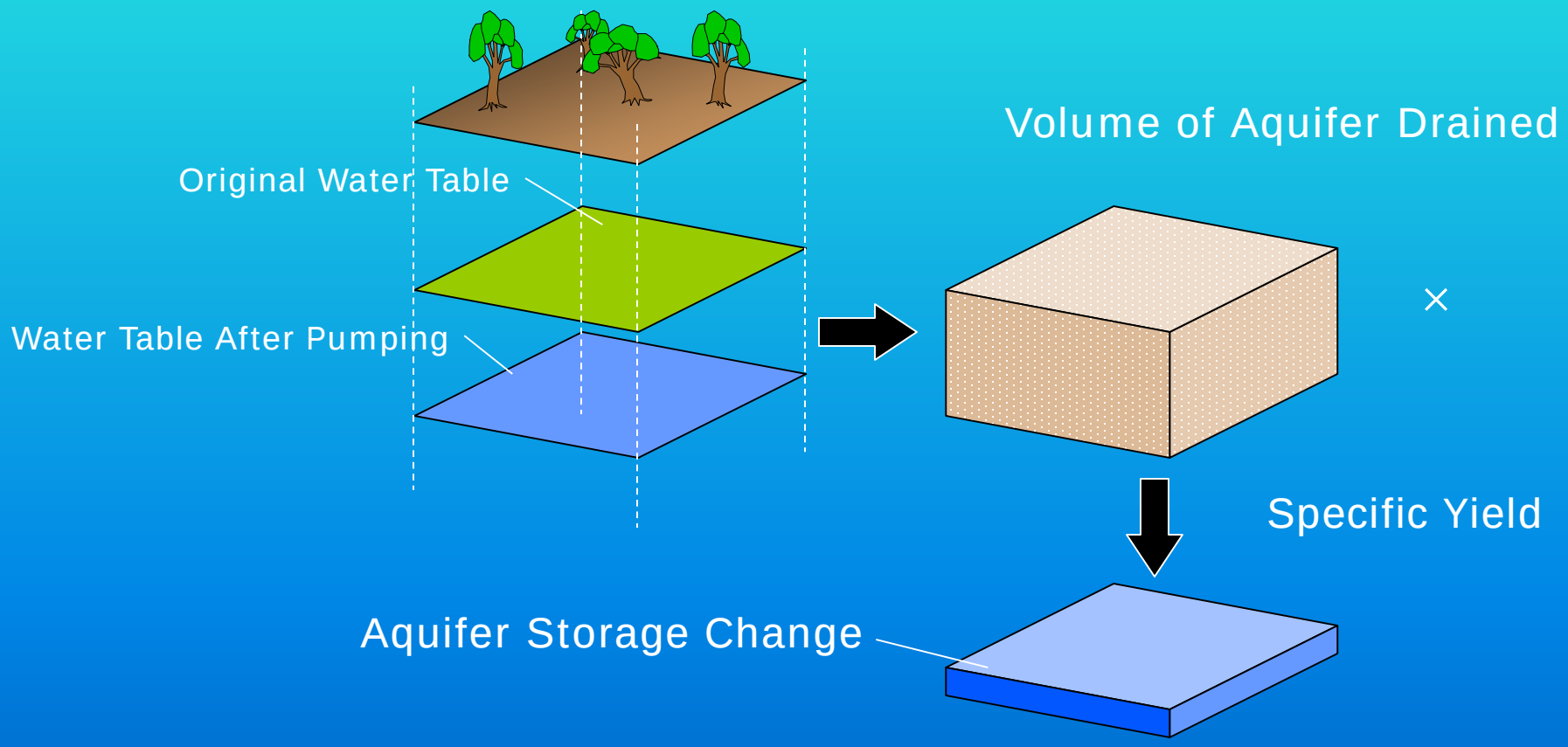


Variations in Gravity

- Acceleration of gravity, g = 9.800000xxx m/s^2
- More mass = higher gravity
- In alluvial groundwater basins gravimeters are used to monitor mass change over time at networks of benchmarks (aquifer-storage change)



Aquifer Storage Change



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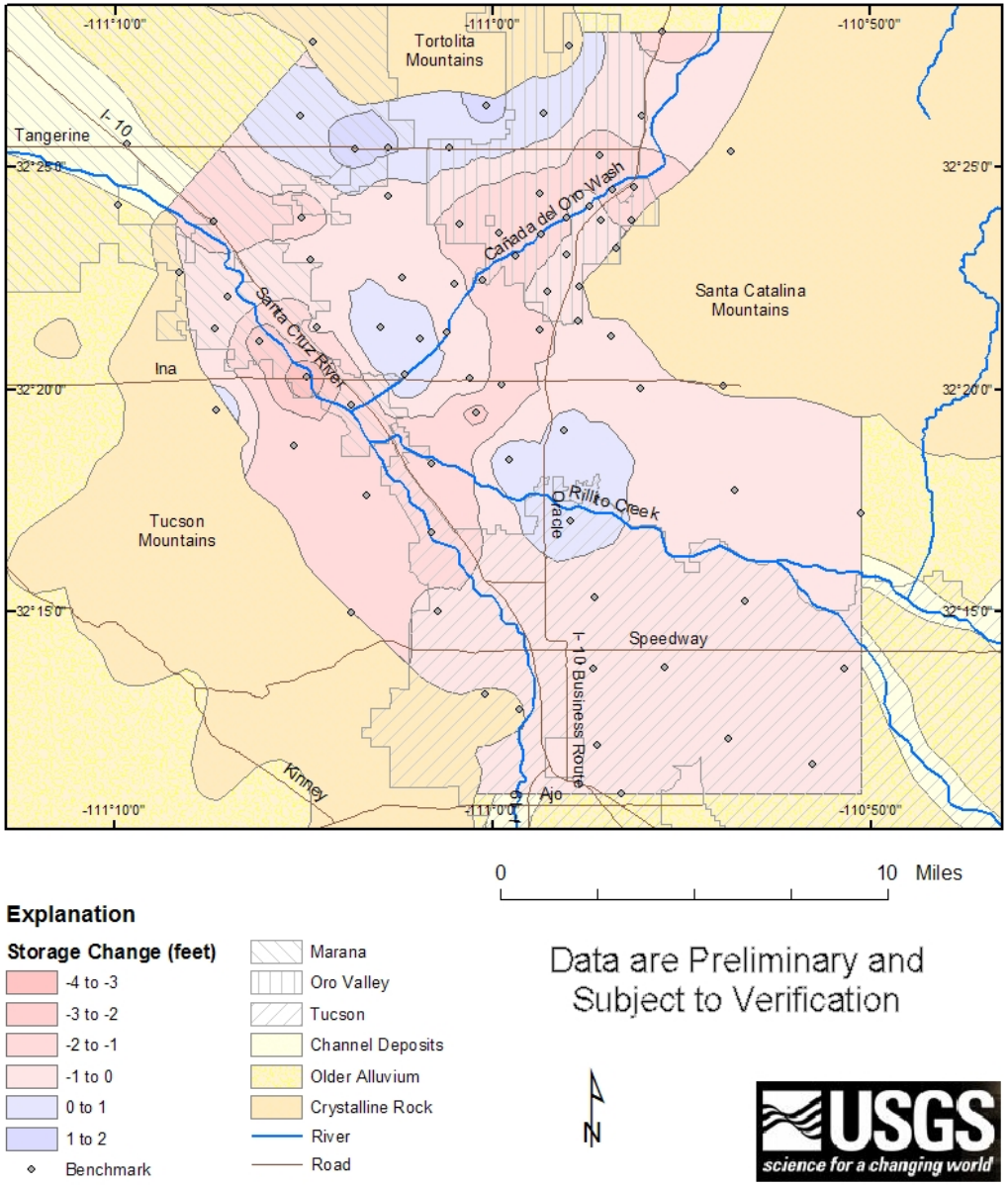
Storage Change in a portion of the Tucson Basin

2013 - 2015

-100,000 acre-ft
~ 0.3 ft per year



Aquifer-Storage Change and Land-Subsidence Monitoring in the Tucson Active Management Area

Considerations for continued program:

- **Review of existing network and target areas of interest**
  - **Pumpage, storage change, land subsidence and artificial recharge**
- **Work with project cooperators to use the long-term data sets**
  - **Further the understanding of how alluvial aquifer systems respond to ground-water withdrawal and evolving management scenarios.**

Resources (Google "USGS Arizona")

- **USGS Arizona Water Science Center: http://az.water.usgs.gov**
- **Publications tab: http://az.water.usgs.gov/publications/pubs-sir.html**

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Thank You !

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