

Arizona's Land Subsidence Monitoring Program



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CGSIC
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Protecting Arizona's Water Supplies
For Its Next Century



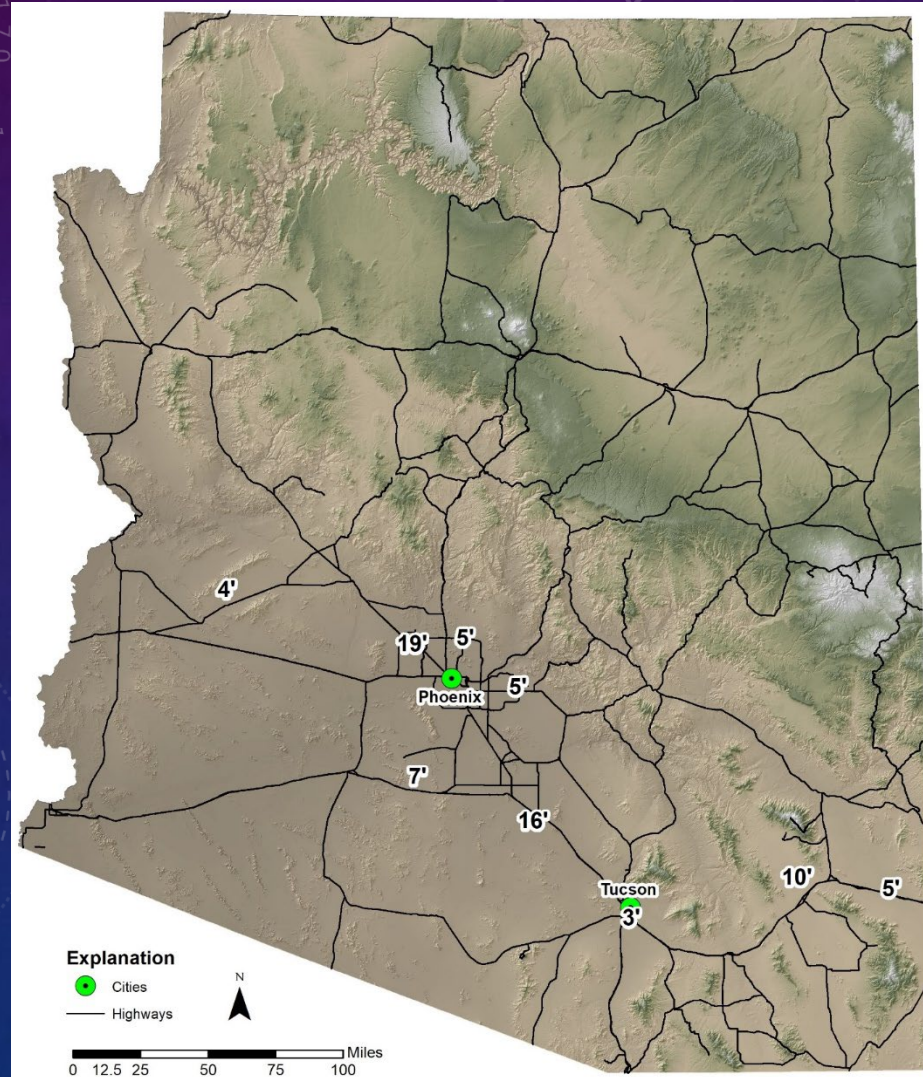
planetvids.com





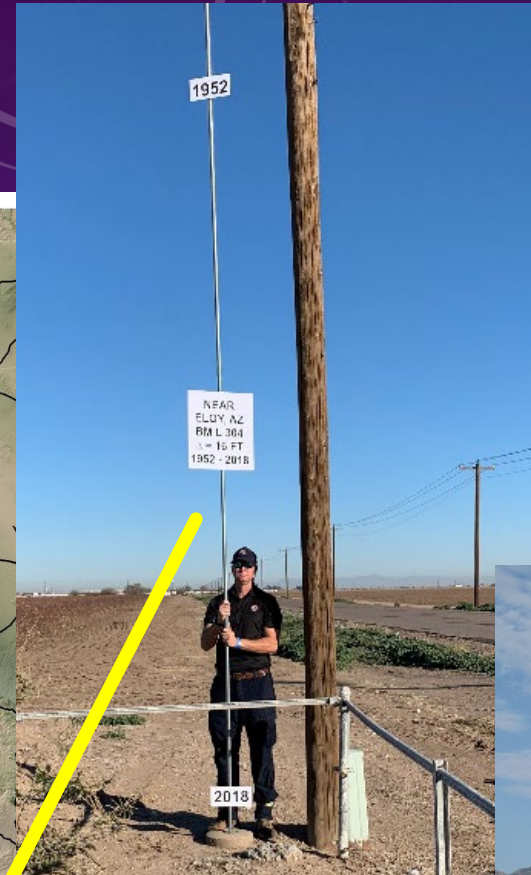
ADWR's Land Subsidence Monitoring Program

- Repeat surveys revealed land subsidence up to 19 feet



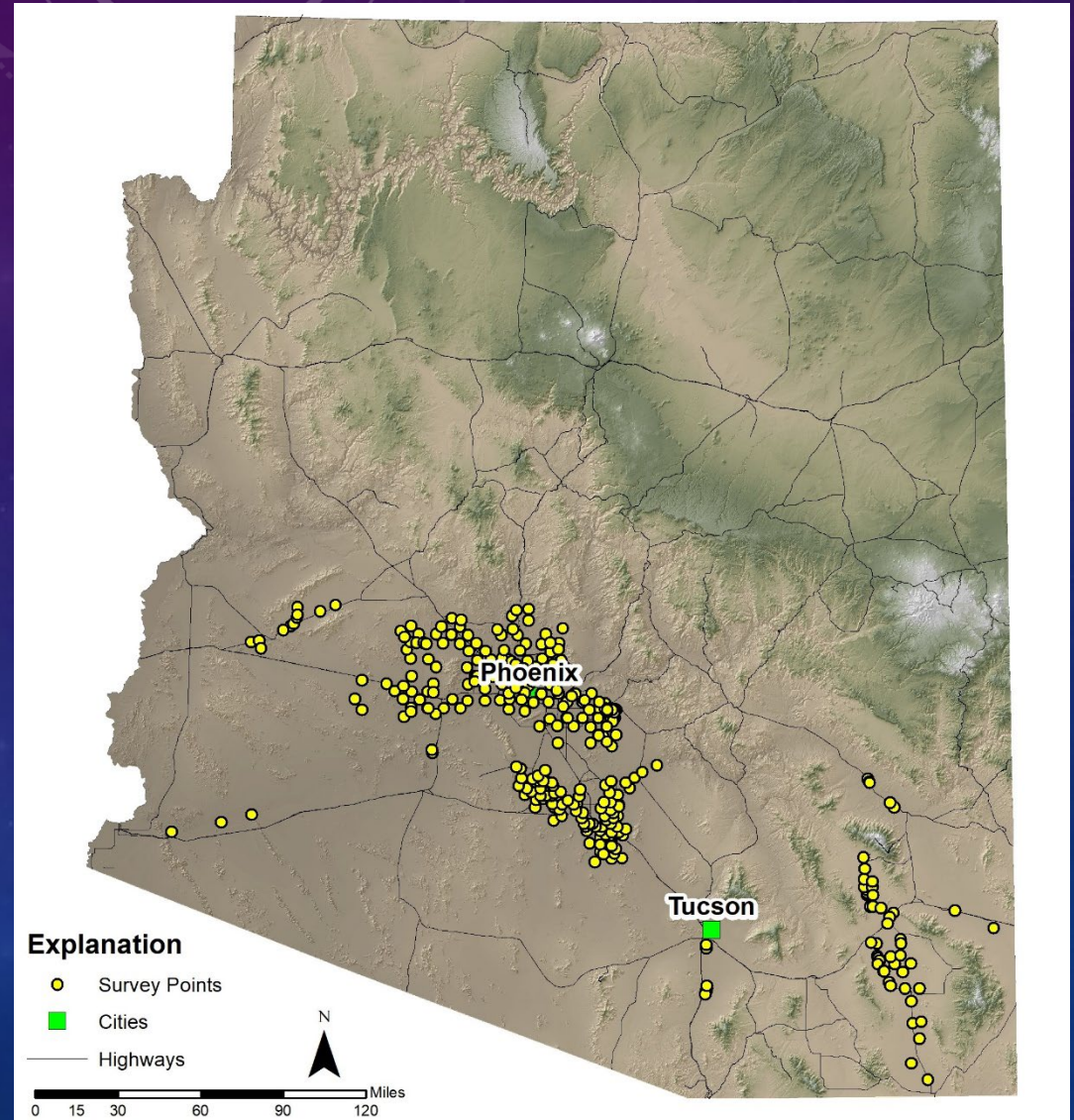
ADWR's Land Subsidence Monitoring Program

- Repeat surveys revealed land subsidence up to 19 feet



ADWR's Land Subsidence Monitoring Program

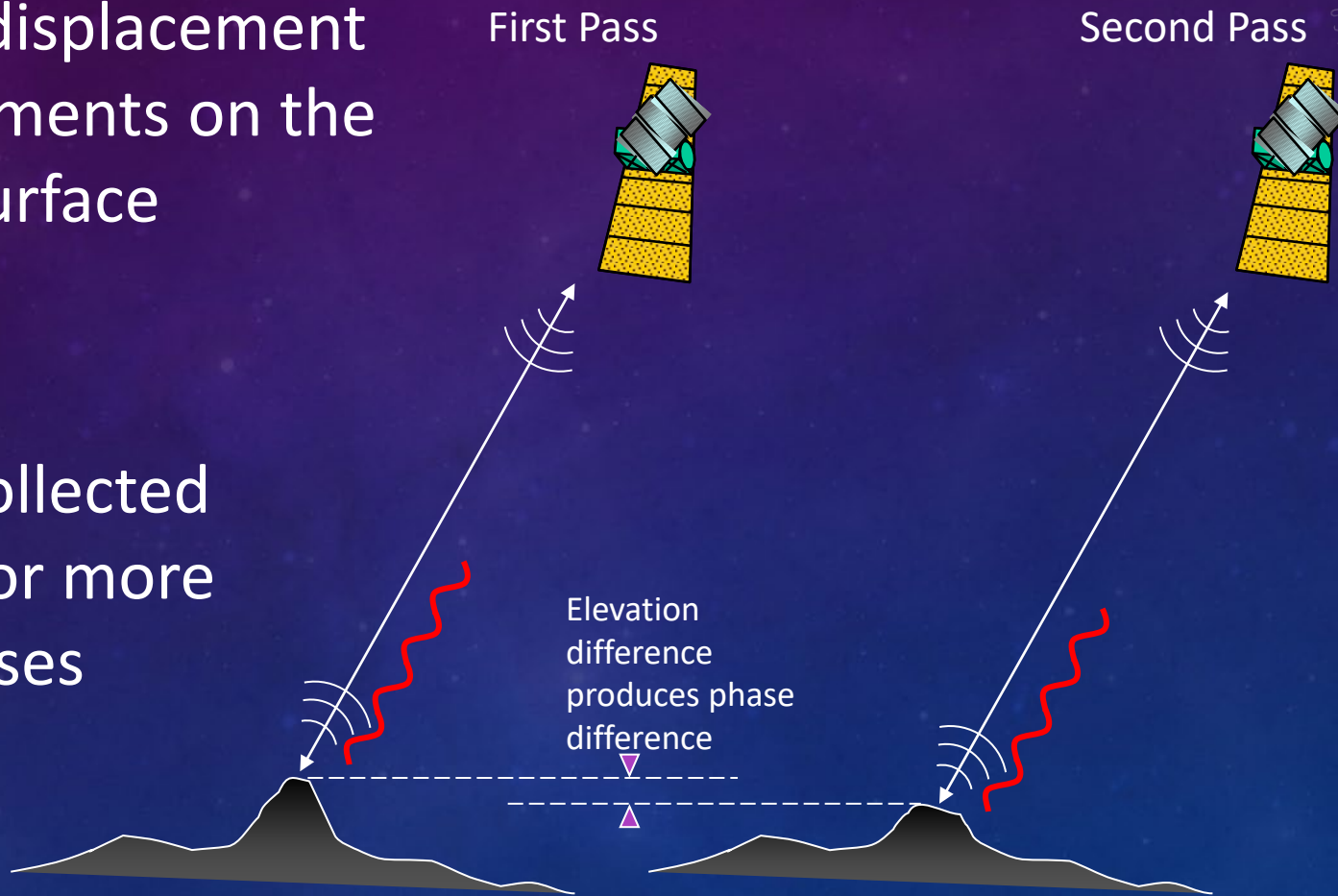
- Have been completing GNSS surveys since 1998
- Data is processed using Trimble Software, NGS OPUS, OPUS-Share, and OPUS Projects
- Networks have been expanded to improve monitoring
- Surveys vary from monthly, seasonally, and annually



Synthetic Aperture Radar Interferometry (InSAR)

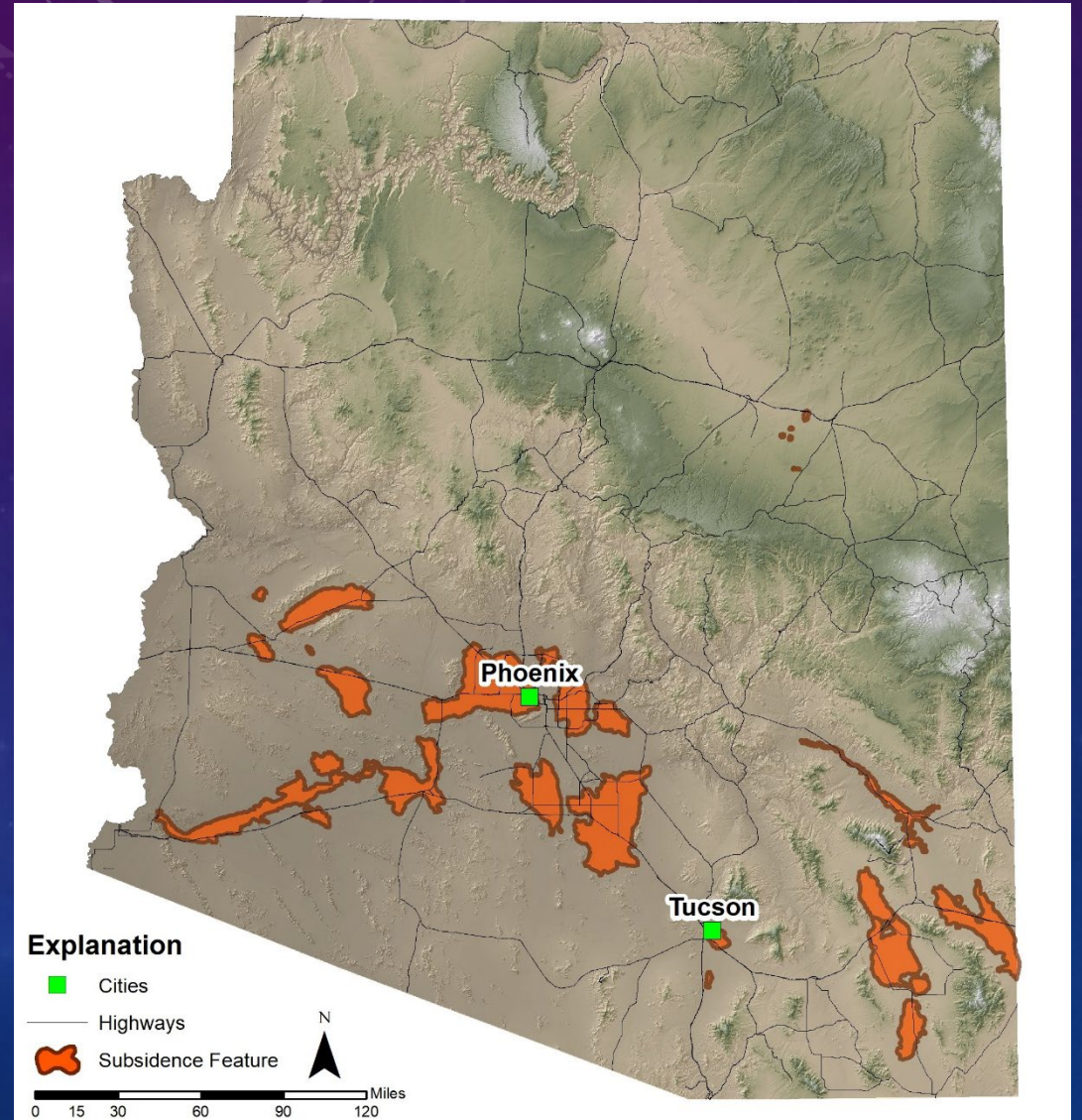
Enables displacement measurements on the Earth's surface

Uses data collected during two or more satellite passes



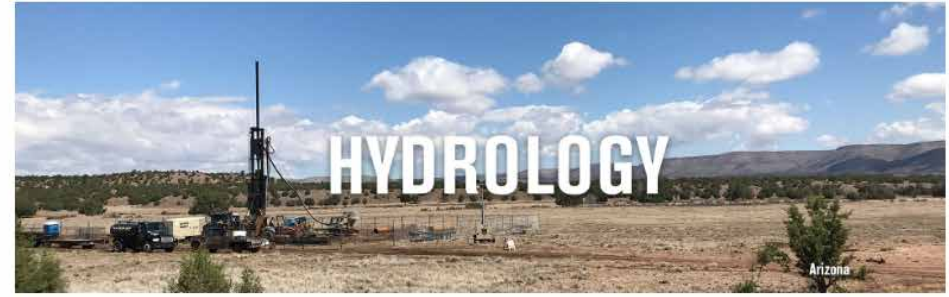
ADWR's Land Subsidence Monitoring Program

- Started in 2002 from a NASA grant
- Have an extensive InSAR library, data between 1992 and present
- By 2022, identified 30 individual land subsidence features covering an area greater than 4,100 square miles
- Cost of the InSAR data has exceeded \$2.0 million dollars



ADWR's Land Subsidence Website

- ADWR's website has a dedicated land subsidence section
- Each land subsidence feature has a dedicated webpage
- A total of 699 land subsidence maps are available for download
- The InSAR-derived maps cover various periods of time between 1992 and 2000, 2004 to 2010, and 2010 to present



LAND SUBSIDENCE IN ARIZONA



Land subsidence has been occurring across Arizona since the early 1900s. Millions of people around the world live in active land subsidence areas, many of whom may not even realize it. Most of the time, there is no clear and identifiable sign that land subsidence has occurred in an area. Areas in Maricopa and Pinal Counties have subsided more than eighteen feet since the early 20th Century.

Land subsidence in the basins of Arizona is generally due to compaction of alluvium caused by lowering of the water table. As the water table declines, pores in the alluvium once held open by water pressure are no longer supported and collapse. Collapse and subsequent lowering in elevation of the land surface is defined as land subsidence. This subsidence is generally not recoverable. If this subsidence occurs over areas of bedrock, differential subsidence can occur.

Differential subsidence is when adjacent areas subside at different rates. Bedrock will not compress like the surrounding alluvium, creating a subsurface platform. Differential subsidence occurs where shallow bedrock and deep bedrock are adjacent to each other, creating a zone of differential change in surface elevation. Because of these different amounts of subsidence, tension can build in the alluvium layer at this differential subsidence zone, forming an earth fissure.

ARIZONA LAND SUBSIDENCE AREAS

- | | | |
|---------------------------------------|------------------------------------|-----------------------------------|
| Scottsdale/NE Phoenix | Harquahala Valley | Tucson |
| West Valley | Ranegras Plain | Green Valley |
| Hawk Rock | Gila Bend | Fort Grant Road |
| Buckeye | East Valley | Kansas Settlement |
| Holbrook Basin | Picacho/Eloy | Elfrida |
| McMullen Valley | Maricopa-Stanfield | Bowie/San Simon |

- EARTH FISSURES >
- IMPACTS OF LAND SUBSIDENCE AND EARTH FISSURES >
- LAND SUBSIDENCE MONITORING >



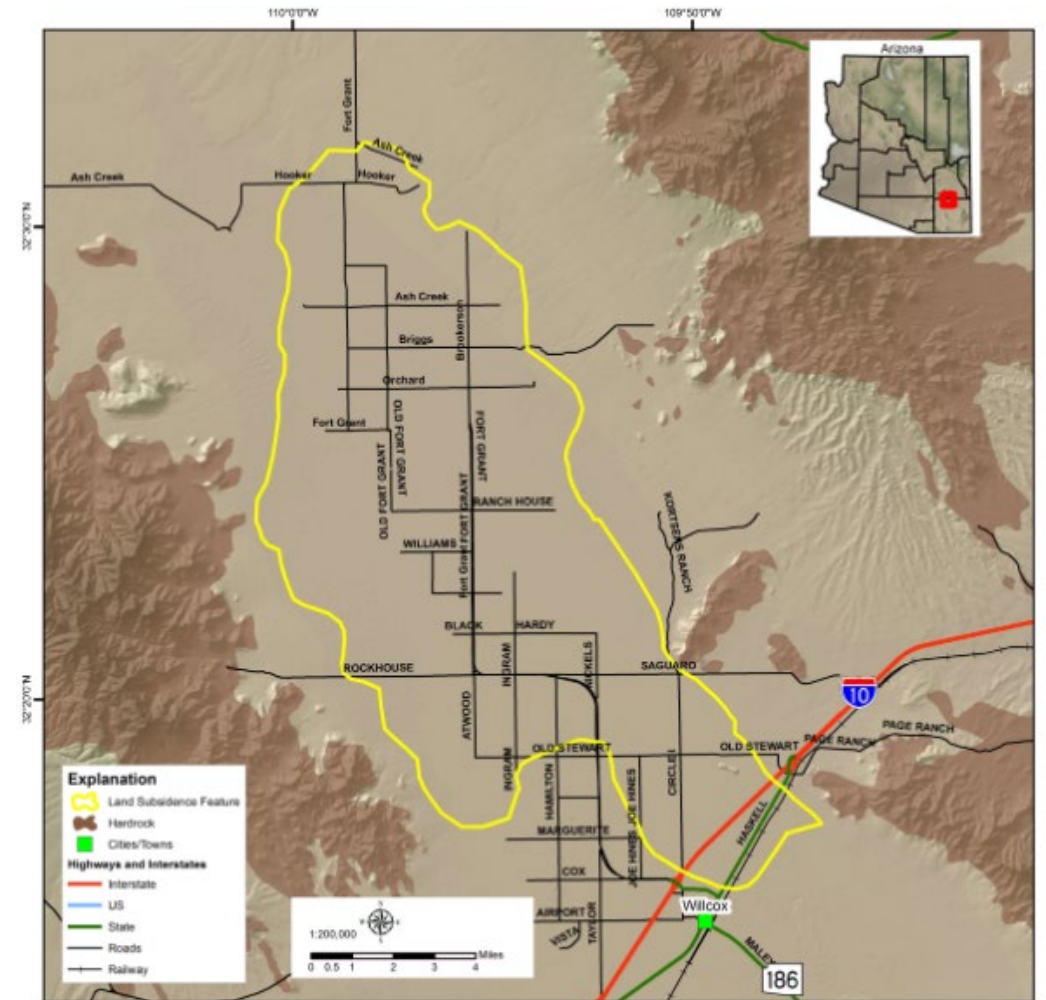
- Overview
- Statewide Monitoring Program
- Basic Data Unit
- Geophysics / Surveying Unit
- GPS
- Gravity
- InSAR
- Land Subsidence in Arizona
- Groundwater/Land Subsidence
- 3rd Party Water Level Portal
- Hydrology Publications (eLibrary)
- Groundwater Modeling
- Contact Us



hydrology@azwater.gov
(602) 771-8680

ADWR's Land Subsidence Website

- Able to access both land subsidence maps and land subsidence rate maps



FORT GRANT ROAD LAND SUBSIDENCE

The Fort Grant Road land subsidence feature is located in southeastern Cochise County. Unincorporated State Trust, Bureau of Land Management, and private lands are located within the Fort Grant Road land subsidence feature.

- [Land Subsidence Maps](#)
- [Land Subsidence Rate Maps](#)

ADWR's Land Subsidence Website

- Clicking any time-period will open up a pdf land subsidence map displaying the magnitude or rate of land subsidence for that time-period

Land Subsidence Maps

LAND SUBSIDENCE MAPS

2010-MAY to 2022-JUN	2021-MAR to 2022-JAN	2020-JAN to 2022-JAN
2017-FEB to 2022-JAN	2020-APR to 2021-APR	2019-APR to 2021-APR
2010-MAY to 2021-MAY	2010-MAY to 2020-APR	2018-FEB to 2020-APR
2019-APR to 2020-APR	1937 to 1974	2018-JAN to 2019-MAY
2017-FEB to 2019-MAY	2010-MAY to 2019-MAY	2017-APR to 2019-MAY
2016-FEB to 2018-MAY	2010-MAY to 2018-MAY	2010-MAY to 2017-APR
2016-FEB to 2017-APR	2015-APR to 2017-APR	2010-MAY to 2016-APR
2015-APR to 2016-APR	2014-MAR to 2016-APR	2008-DEC to 2015-APR
2010-MAY to 2015-APR	2013-MAR to 2015-APR	2014-FEB to 2015-APR
2010-MAY to 2014-MAR	2013-MAR to 2014-MAR	2012-MAR to 2014-MAR
2010-MAY to 2013-MAR	2012-MAR to 2013-MAR	2011-APR to 2013-MAR
2010-MAY to 2012-MAR	2011-MAR to 2012-MAR	2010-MAR to 2011-FEB
2009-MAY to 2010-JAN	2008-MAY to 2009-MAY	2008-DEC to 2011-FEB
1996-JAN to 1996-DEC	1992-NOV to 1993-NOV	

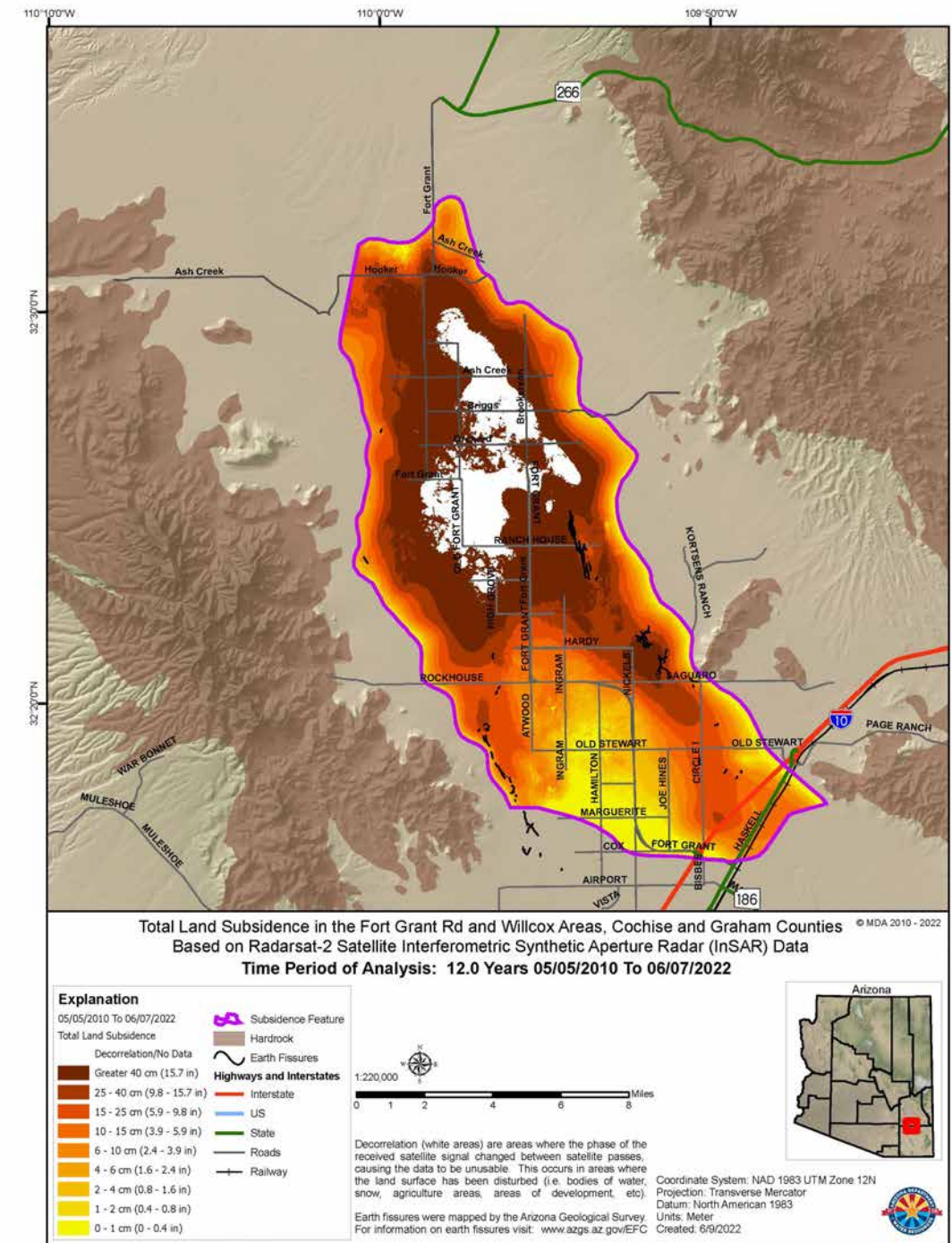
Land Subsidence Rate Maps

LAND SUBSIDENCE RATE MAPS

2021-MAR to 2022-JAN	2019-APR to 2020-APR	2017-APR to 2019-MAY
2015-APR to 2016-APR	2014-FEB to 2015-APR	2013-MAR to 2014-MAR
2009-JAN to 2010-JAN	1996-JAN to 1996-DEC	

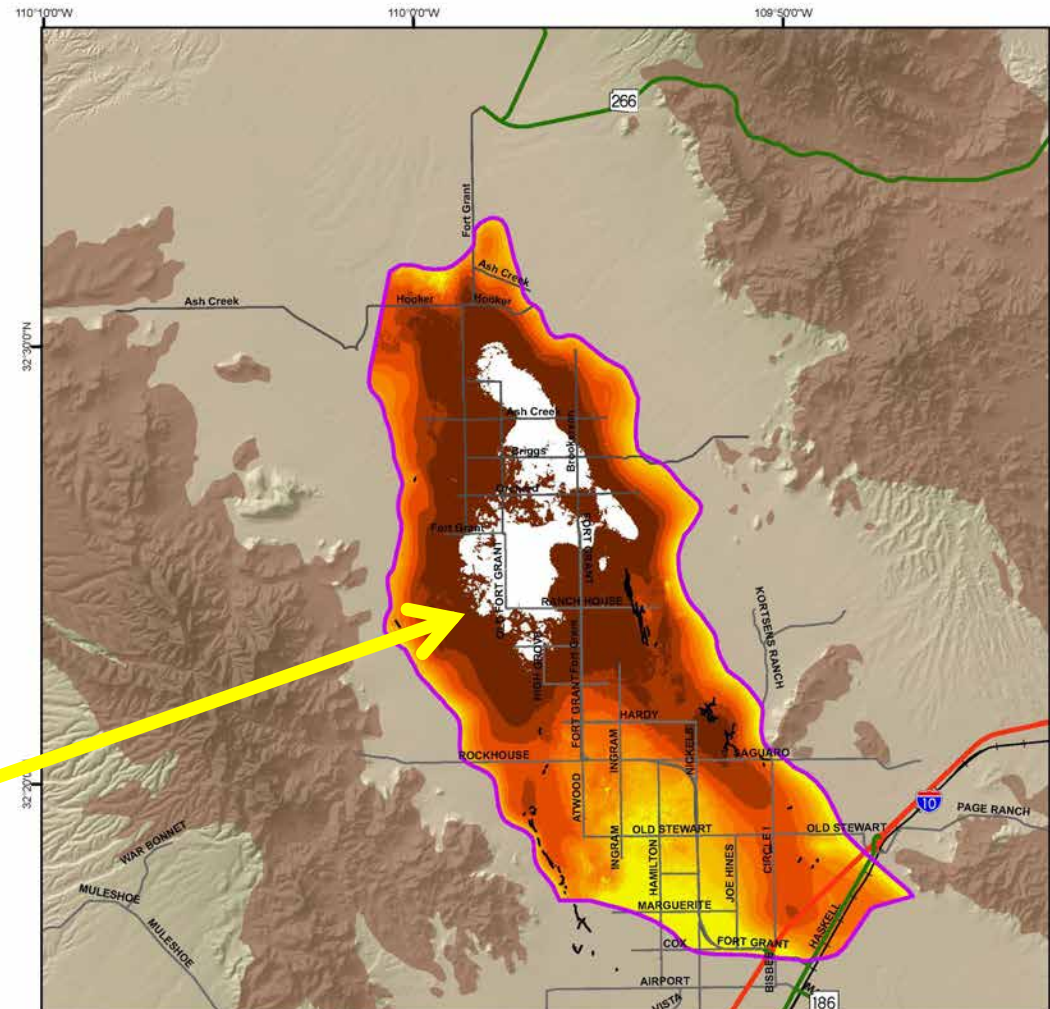
ADWR's Land Subsidence Website

- Land subsidence map for the Fort Grant Rd land subsidence feature in the Willcox Groundwater Basin between May 2010 and June 2022
- Subsidence as high as 137cm (4.5 feet)



ADWR's Land Subsidence Website

- Subsided over 11 feet between 1969 and 2022

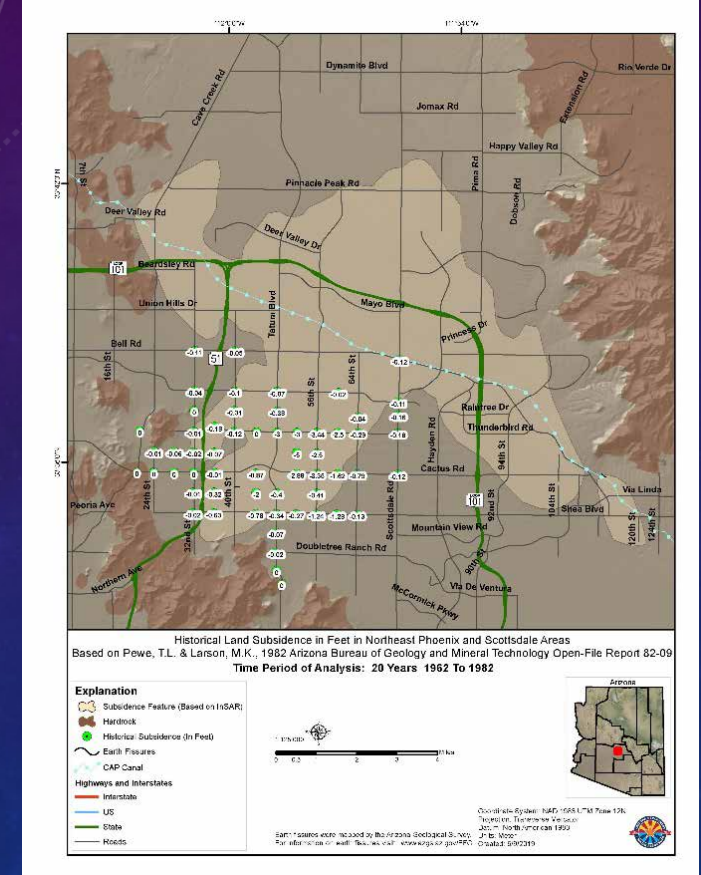
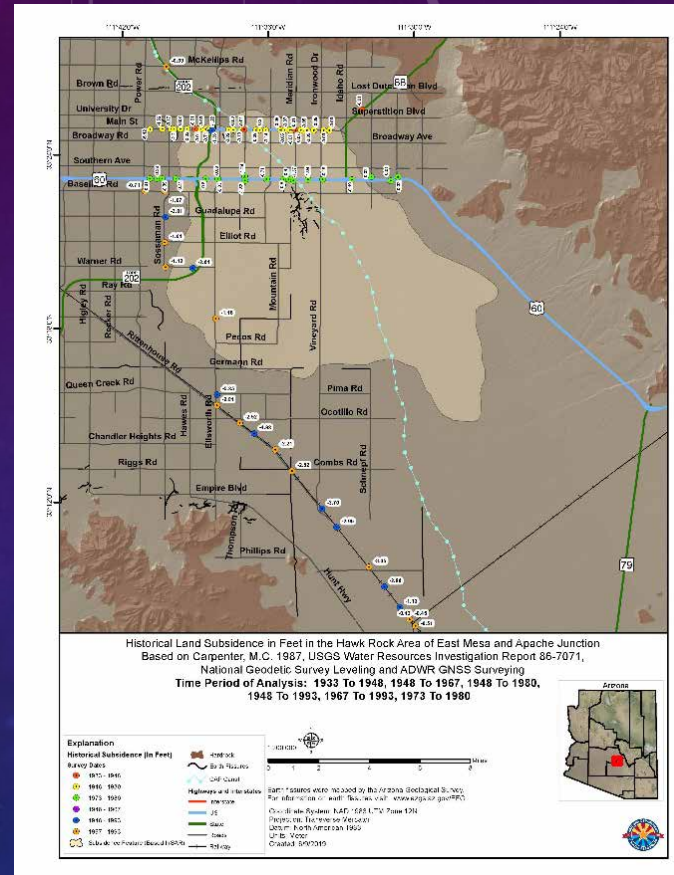
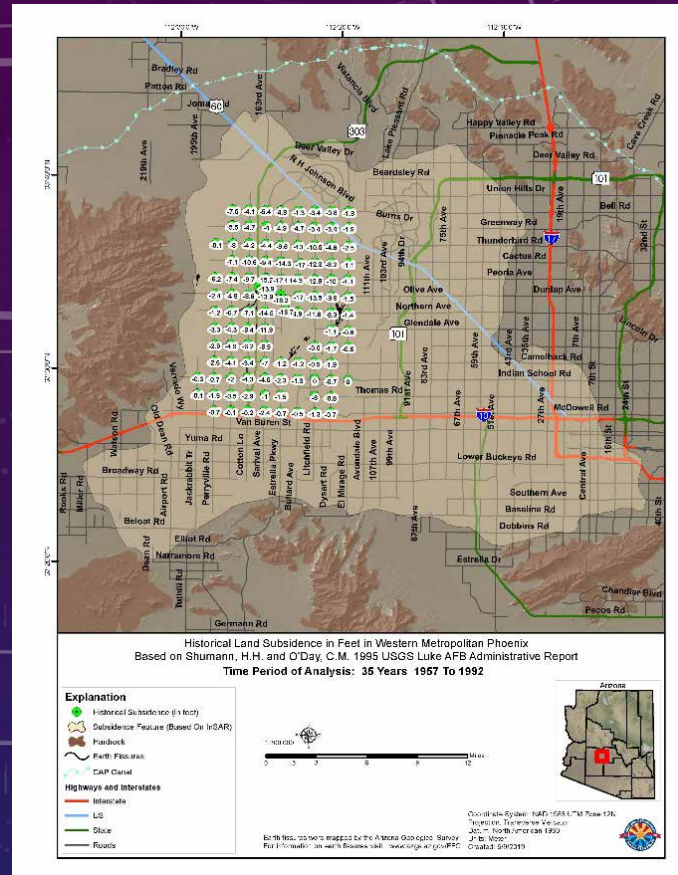


Total Land Subsidence in the Fort Grant Rd and Willcox Areas, Cochise and Graham Counties
 Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 12.0 Years 05/05/2010 To 06/07/2022

Explanation	
05/05/2010 To 06/07/2022	Subsidence Feature
Total Land Subsidence	Hardrock
Decorrelation/No Data	Earth Fissures
Greater 40 cm (15.7 in)	Highways and Interstates
25 - 40 cm (9.8 - 15.7 in)	Interstate
15 - 25 cm (5.9 - 9.8 in)	US
10 - 15 cm (3.9 - 5.9 in)	State
6 - 10 cm (2.4 - 3.9 in)	Roads
4 - 6 cm (1.6 - 2.4 in)	Railway
2 - 4 cm (0.8 - 1.6 in)	
1 - 2 cm (0.4 - 0.8 in)	
0 - 1 cm (0 - 0.4 in)	

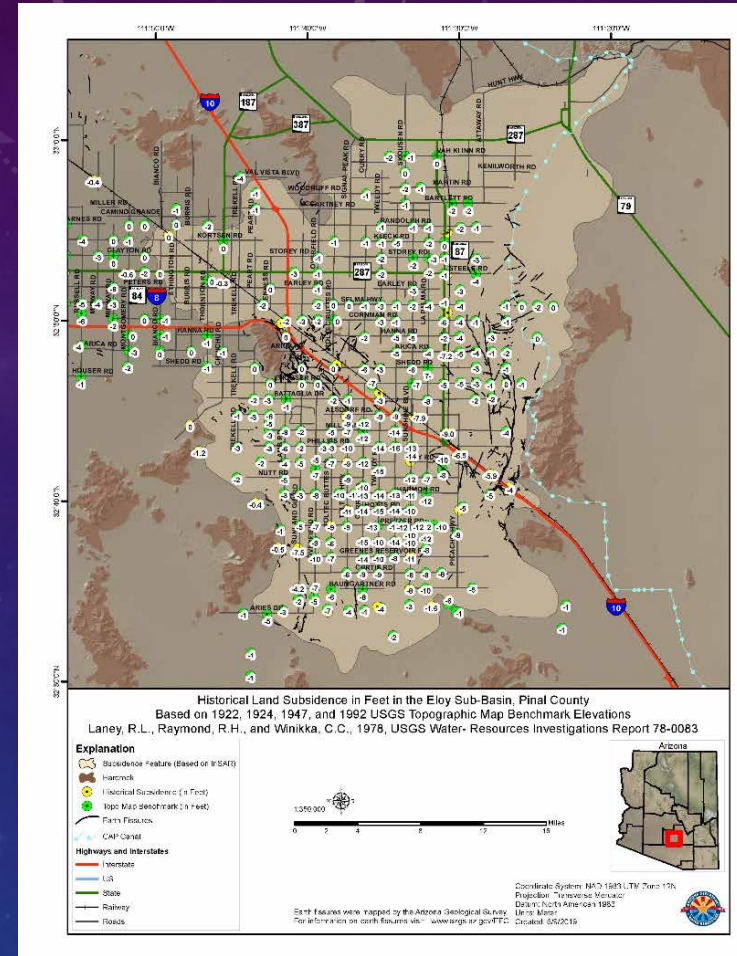
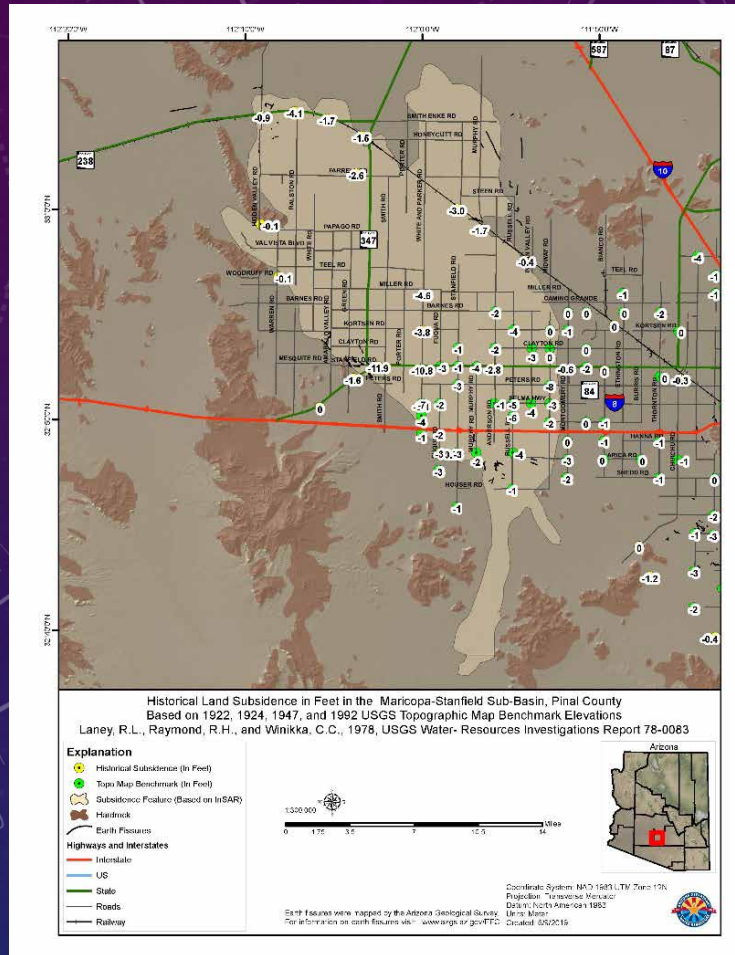
Decorrelation (white areas) are areas where the phase of the received satellite signal changed between satellite passes, causing the data to be unusable. This occurs in areas where the land surface has been disturbed (i.e. bodies of water, snow, agriculture areas, areas of development, etc).
 Earth fissures were mapped by the Arizona Geological Survey. For information on earth fissures visit: www.azgs.gov/EFC
 Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 6/9/2022

Documenting Historical Land Subsidence



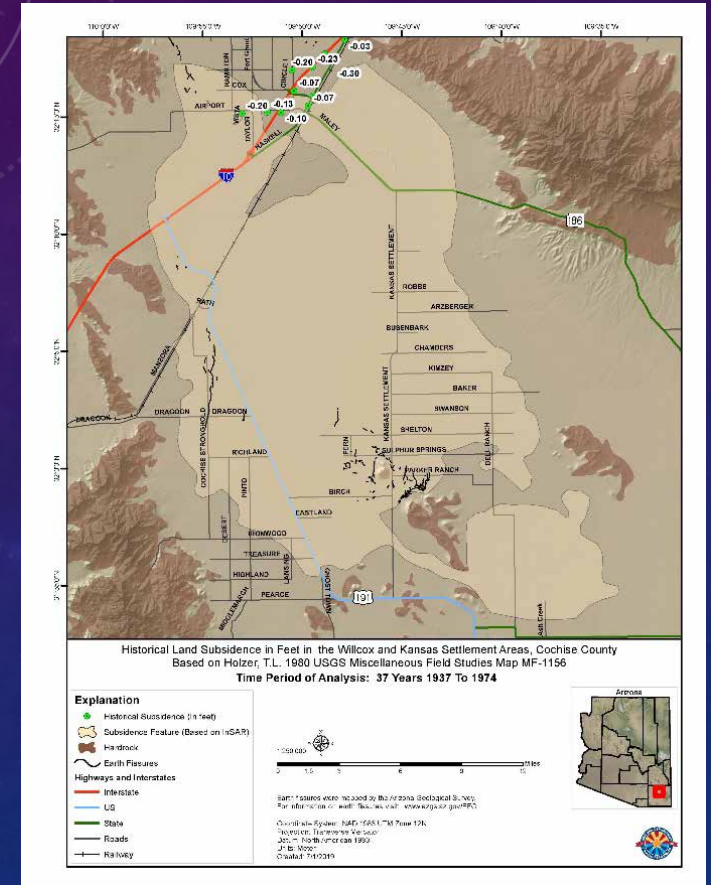
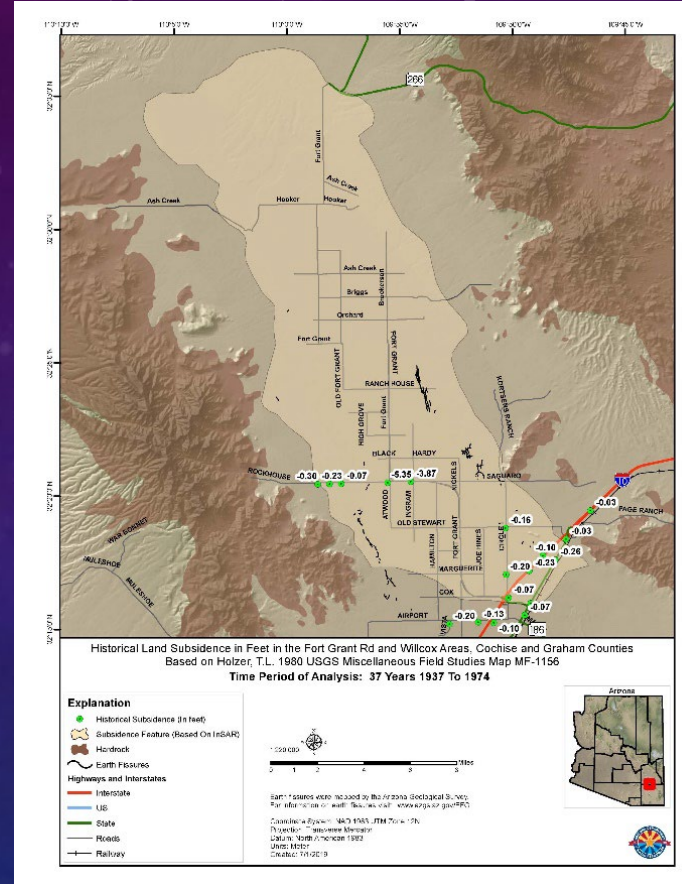
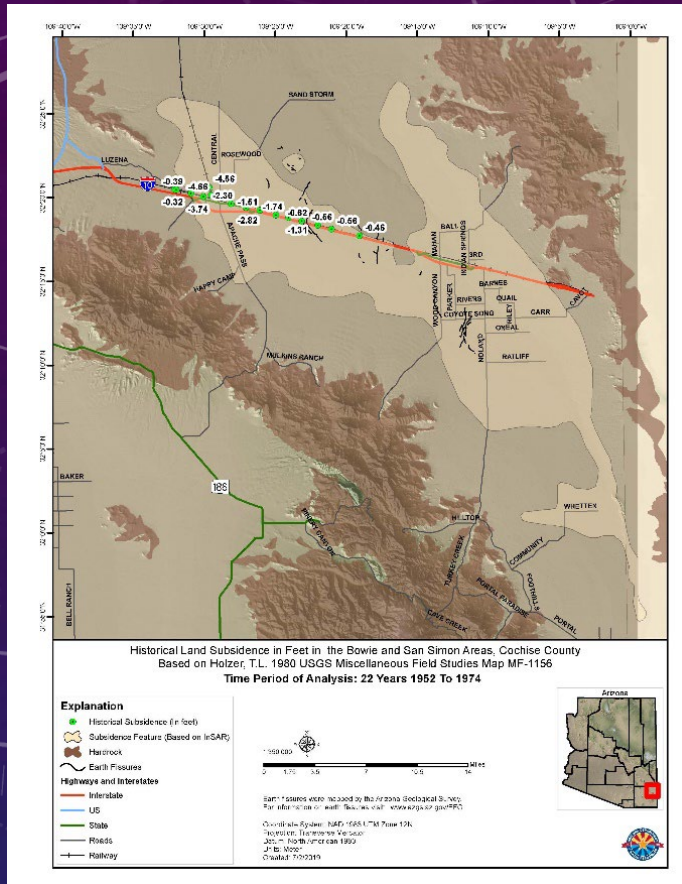
Phoenix Active Management Area Land Subsidence U.S. Geological Survey & National Geodetic Survey Reports & Datasets

Documenting Historical Land Subsidence



Pinal Active Management Area Land Subsidence
U.S. Geological Survey & Topo Quad Reports & Datasets

Documenting Historical Land Subsidence



Willcox Groundwater Basin and San Simon Valley Groundwater Sub-basin USGS Reports

Applications of InSAR in Arizona

Using InSAR for Groundwater Management

- InSAR data has been used to better document on going land subsidence in the Tucson area
- Groundwater management has resulted in decreased land subsidence rates and groundwater recovery

ERS-1 & 2
11/1993 - 09/2000

Radarsat-2
04/2018 - 03/2019

Using InSAR Data to Monitor Land Subsidence and Changing Rates

- Land subsidence rates have tripled in the Willcox Groundwater Basin between 1996 and 2019 InSAR datasets

ERS-1 & 2
01/1996 - 12/1996

Sentinel-1
01/2018 - 05/2019

Using InSAR to Monitor Earth Fissures

- InSAR data is used to not only monitor earth fissure activity, but to also identify areas for potential earth fissuring where differential land subsidence is occurring

Areas of differential land subsidence and shallow bedrock

Using InSAR for Artificial Recharge

- Large groundwater recharge project 30 miles west of Phoenix
- Started recharging in 2006
- By October 2010, more than 500,000 acre-feet of water was recharged

Photo courtesy of CWRCC

Groundwater Management

Land Subsidence

Earth Fissures

Recharge

Using InSAR for Seasonal Deformation

- InSAR is being used to monitor seasonal uplift and subsidence related to groundwater pumping and groundwater decline/recovery

Using InSAR for Infrastructure Monitoring

- InSAR is being used for monitoring and mitigating land subsidence and earth fissures around infrastructure (flood control structures, canals, highways, pipelines, power plants, powerlines gas lines, etc.)

Hawk Rock Area, 2010-2015
10,000X Exaggeration

Hawk Rock bedrock high

Using InSAR for Floodplain Monitoring

- Land subsidence has altered the Centennial Wash floodplain, resulting in the flooding of the Town of Wenden during high flow events
- McMullen Valley Groundwater Basin was an area of unknown subsidence until InSAR was collected

Explanation

Legend of Wenden

Centennial Wash

08/08/1992 To 04/06/2018

Total Land Subsidence

Legend

40 cm (16.1 in)

25 cm (9.8 in)

10 cm (3.9 in)

5 cm (1.9 in)

2 cm (0.8 in)

1 cm (0.4 in)

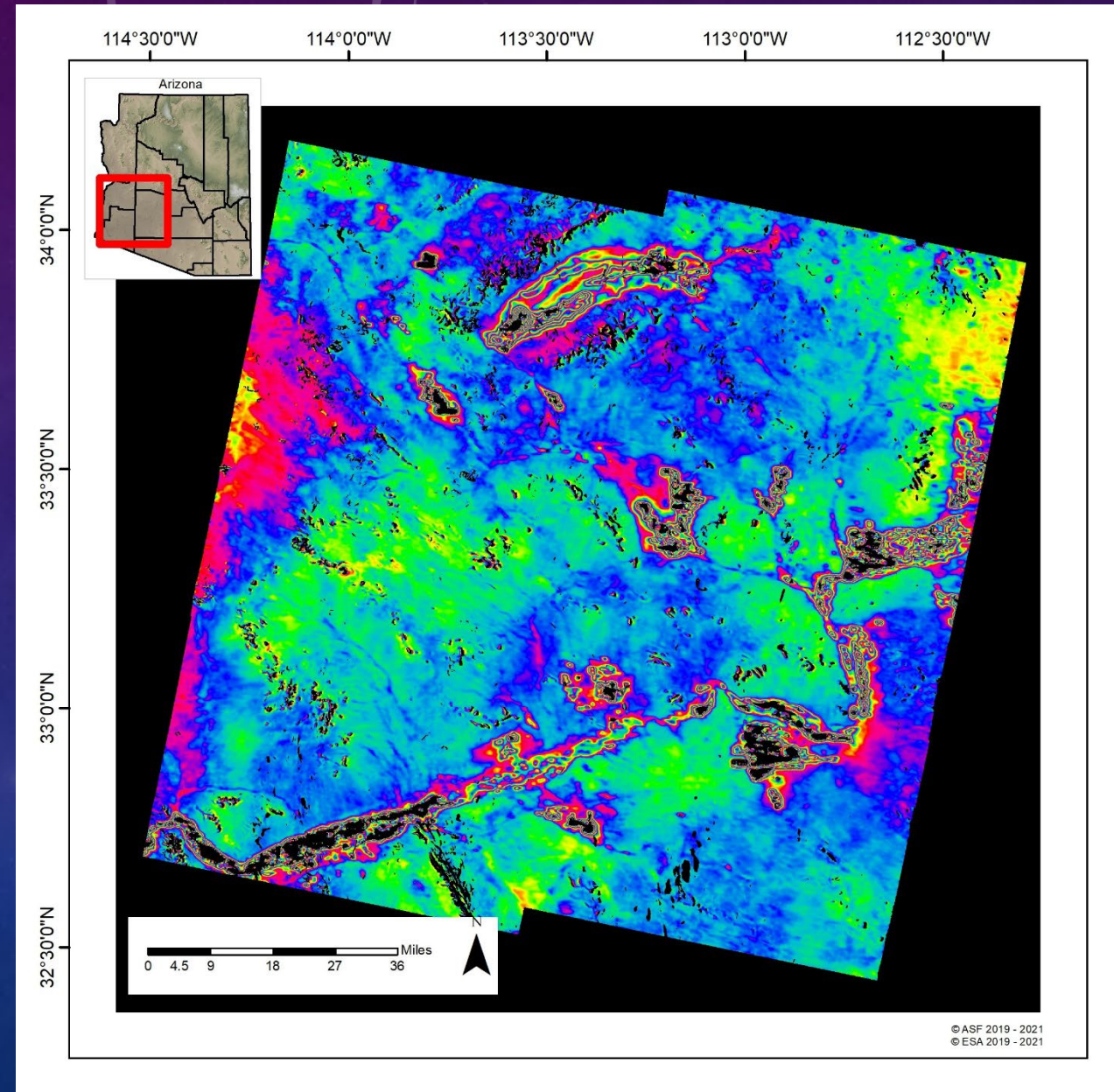
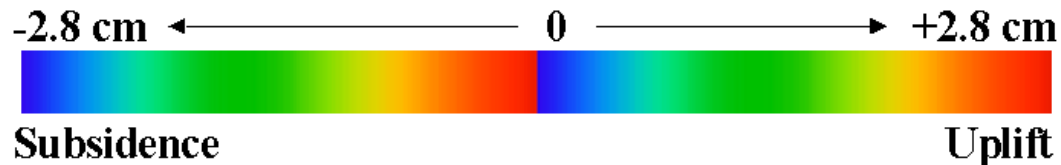
Seasonal Deformation

Infrastructure

Floodplains

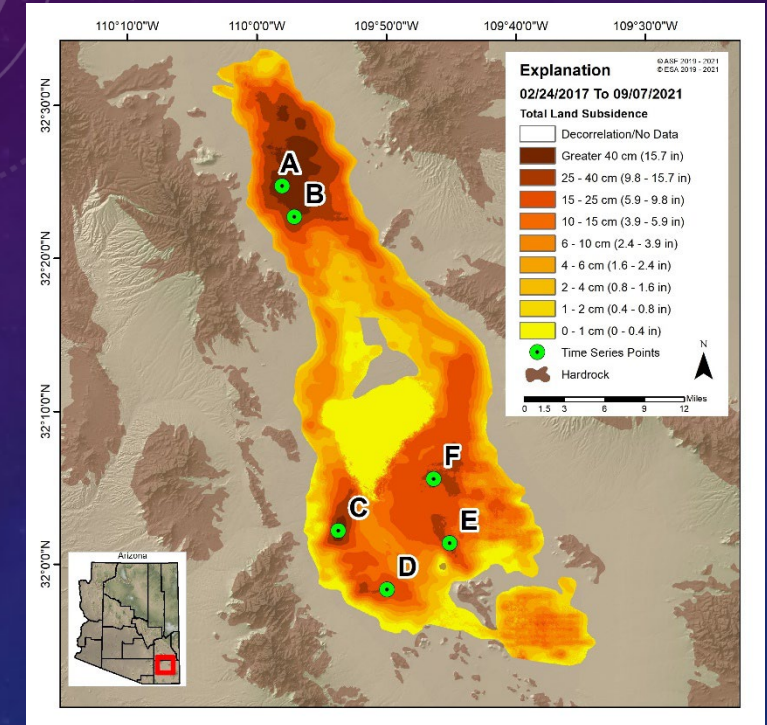
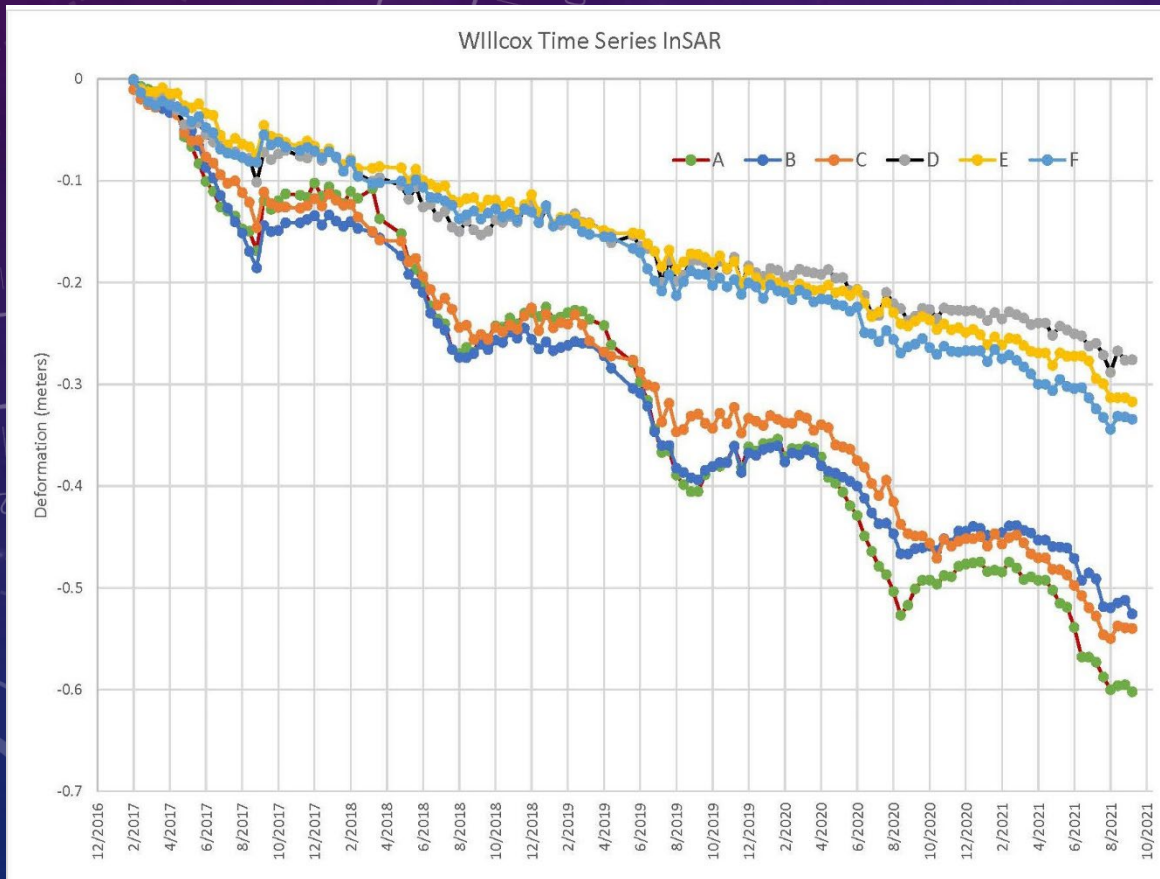
Sentinel-1 Data

- Open data policy (FREE!!)
- Short temporal baselines (12-day repeat)
- Larger swath
- 02/2017 - 01/2021 interferogram
- Stack uses 112 collects



Sentinel-1 Data

- Able to leverage large data stacks (133 collects of Sentinel-1) to evaluate seasonal deformation and annual land subsidence



Sentinel-1
02/2017 – 09/2021
Fort Grant Rd and
Kansas Settlement
Subsidence Features

Documenting and Preserving GNSS Data

Shared Solution

PID: DV1479
Designation: X 479
Stamping: X 479 1981
Stability: Most reliable; expected to hold position well
Setting: Mat foundation or concrete slab other than pavement
Mark
Condition: G
Description: X 479 is located in the McMullen Valley land subsidence feature being monitored by the Arizona Department of Water Resources using Interferometric Synthetic Aperture Radar (InSAR) data. In addition to the InSAR data, ADWR collects static GNSS data on several monuments in the area annually. This elevation should be verified before using as a vertical control point. For more information on the McMullen Valley land subsidence feature or land subsidence in Arizona, visit www.azwater.gov
Observed: 2022-04-26T14:01:00Z [more obs 2020-11-09](#)
Source: OPUS - page5 2008.25



Close up View

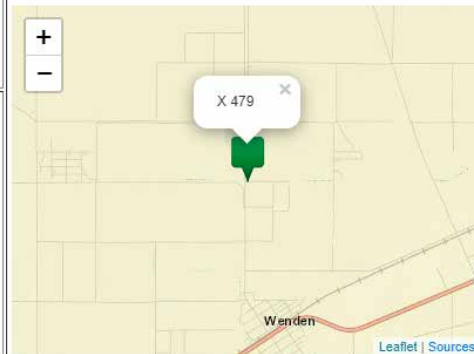
REF_FRAME: NAD_83(2011)	EPOCH: 2010.0000	SOURCE: NAVD88 (Computed using GEOID18)	UNITS: m	SET PROFILE	DETAILS
LAT: 33° 50' 29.04871" ± 0.008 m					
LLN: -113° 32' 40.76372" ± 0.005 m					
ELL HT: 552.525 ± 0.014 m					
X: -2118569.464 ± 0.011 m					
Y: -4862009.779 ± 0.011 m					
Z: 3532156.407 ± 0.007 m					
ORTHO HT: 583.065 ± 0.056 m					
		UTM 12	SPC 203(AZ W)		
		NORTHING: 3747484.198m	315093.283m		
		EASTING: 264541.028m	232364.539m		
		CONVERGENCE: -1.41776111°	0.11435556°		
		POINT SCALE: 1.00028351	0.999993778		
		COMBINED FACTOR: 1.00019675	0.99985105		

CONTRIBUTED BY

[bnmihl@azdwr.com](#)
[Arizona Department of Water Resources](#)



Horizon View



The NGS Data Sheet

See file [dsdata.pdf](#) for more information about the datasheet.

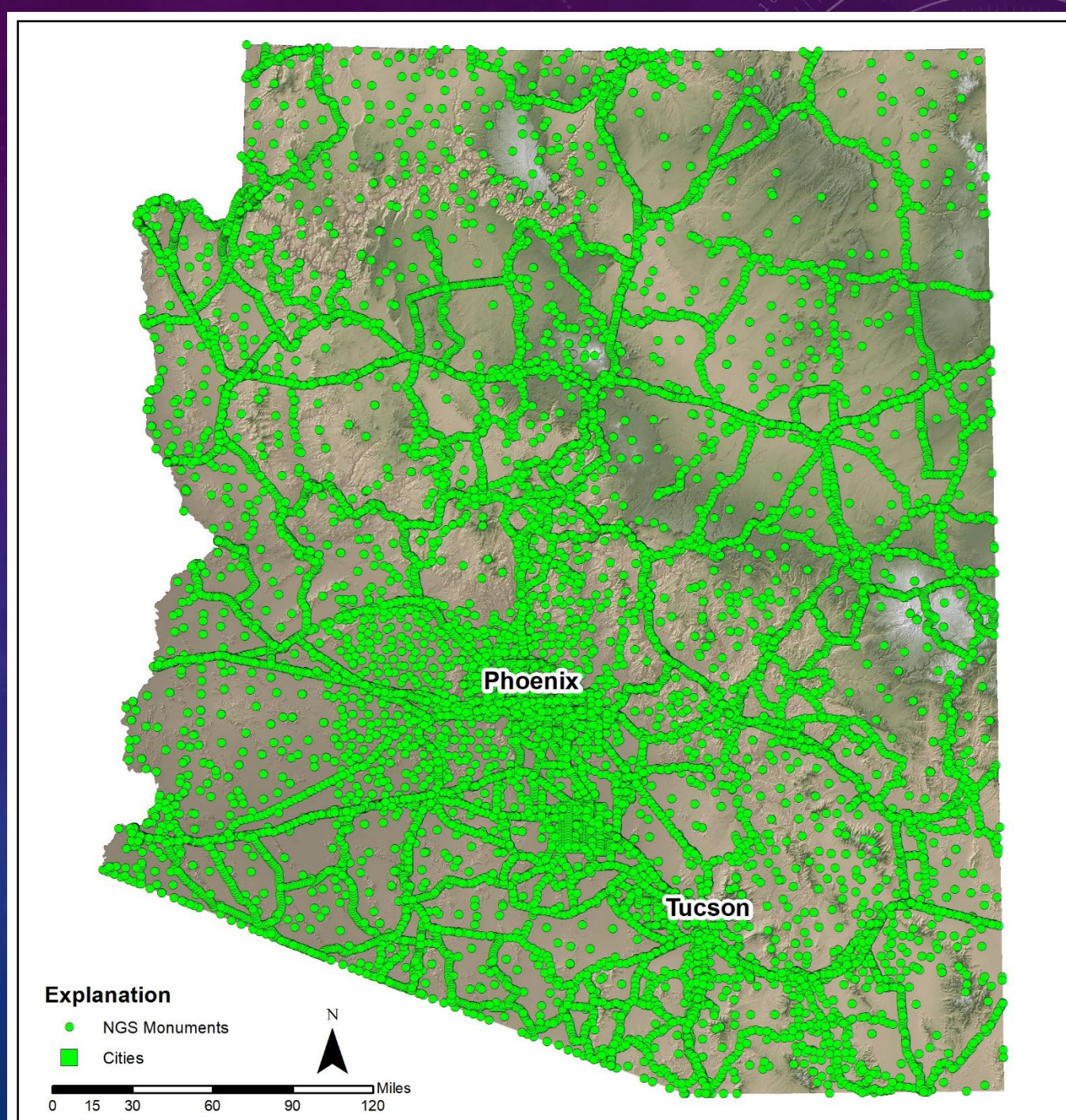
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1 National Geodetic Survey, Retrieval Date = SEPTEMBER 23, 2019
DV1479 *****
DV1479 DESIGNATION - X 479
DV1479 PID - DV1479
DV1479 STATE/COUNTY- AZ/LA PAZ
DV1479 COUNTRY - US
DV1479 USGS QUAD - SALOME (1990)
DV1479
DV1479 *CURRENT SURVEY CONTROL
DV1479
DV1479* NAD 83(1986) POSITION- 33 50 29.04 (N) 113 32 40.76 (W) HD_HOLD1
DV1479* NAVD 88 ORTHO HEIGHT - 584.679 (meters) 1918.23 (feet) ADJUSTED
DV1479
DV1479 GEOID HEIGHT - -30.540 (meters) GEOID18
DV1479 DYNAMIC HEIGHT - 583.987 (meters) 1915.96 (feet) COMP
DV1479 MODELED GRAVITY - 979,434.7 (mgal) NAVD 88
DV1479
DV1479 VERT ORDER - FIRST CLASS II
DV1479
DV1479.The horizontal coordinates were determined by differentially corrected
DV1479.hand held GPS observations or other comparable positioning techniques
DV1479.and have an estimated accuracy of +/- 3 meters.
DV1479.
DV1479.The orthometric height was determined by differential leveling and
DV1479.adjusted by the NATIONAL GEODETIC SURVEY
DV1479.in June 1991.
DV1479
DV1479.Significant digits in the geoid height do not necessarily reflect accuracy
DV1479.GEOID18 height accuracy estimate available here.
DV1479
DV1479.Click here to see if photographs exist for this station.
DV1479
DV1479.The dynamic height is computed by dividing the NAVD 88
DV1479.geopotential number by the normal gravity value computed on the
DV1479.Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45
DV1479.degrees latitude (g = 980.6199 gals.).
DV1479
DV1479.The modeled gravity was interpolated from observed gravity values.
DV1479
```

584.679 meters in 1991 and 583.065 meters in 2022

-1.614 meters (-5.30 feet) of land subsidence since 1991

Surveying

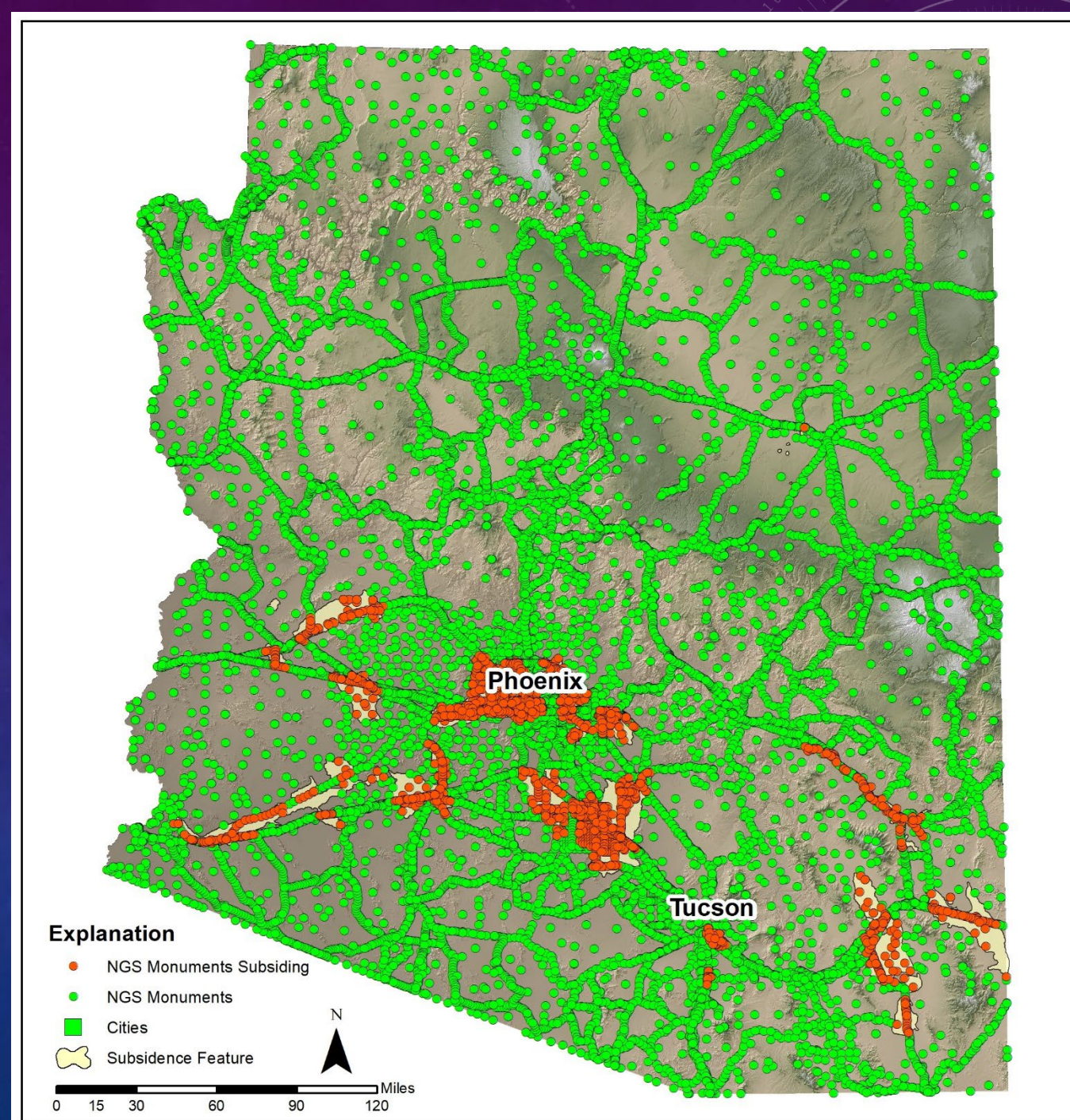
- Is Surveying Control Stable?



Surveying

- Land subsidence is compromising vertical surveying control monuments
- Surveying control should be verified

**2,669 Monuments Affected
by Land Subsidence**

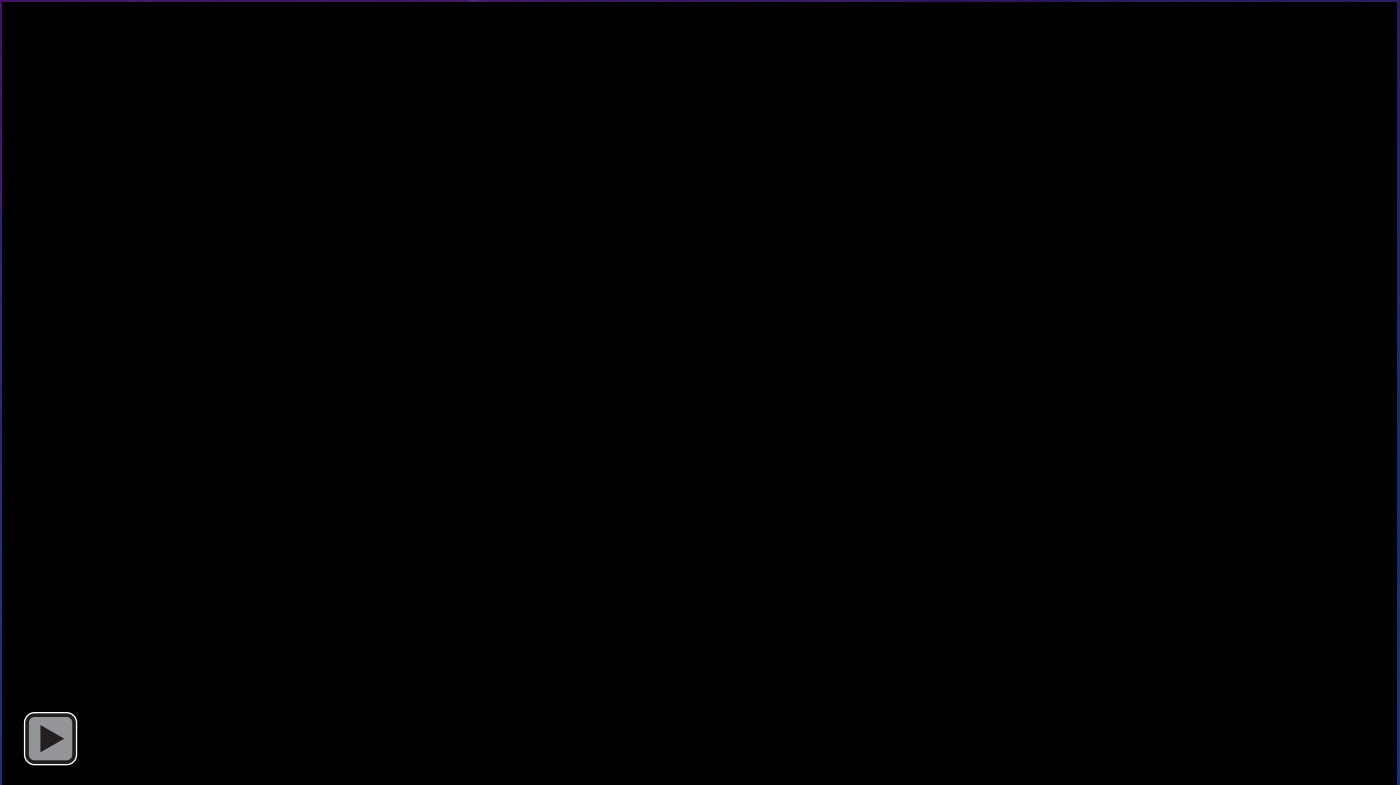


Surveyed Elevations May Not Be Accurate



NISAR Mission

- A dedicated U.S. and Indian InSAR mission, optimized for studying hazards and global environmental change
- Launch Date – January 2024
- Open data (FREE!)
- 12-day repeat
- L-Band and S-Band
- Data and products available through Alaska Satellite Facility



Using InSAR for Decision Making in Arizona

- A major step with the InSAR program is providing the data to those who need it for their own monitoring, mitigation, planning, and design projects
- Land subsidence maps are updated every spring which reflect the past 12 months of InSAR data collection
- InSAR data (wrapped and unwrapped interferograms) can be requested by anyone (consultant, public, other agency, etc.)
- The land subsidence maps/InSAR data, earth fissure data, groundwater level data, groundwater pumping data, and well-log data are a data synergy and are all critical datasets that are needed to properly monitor, investigate, and mitigate land subsidence and are all accessible through ADWR's website

What does the Future Hold?

- Continue collecting InSAR data and making data available to public
- Continue to push for elevation data from NGS for level lines in Arizona
- Continue to collaborate with the scientific community in Arizona in regard to subsidence monitoring, support/expand the CORS network however we can, and participate with geodetic surveying campaigns when available

Thank you

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www.azwater.gov

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