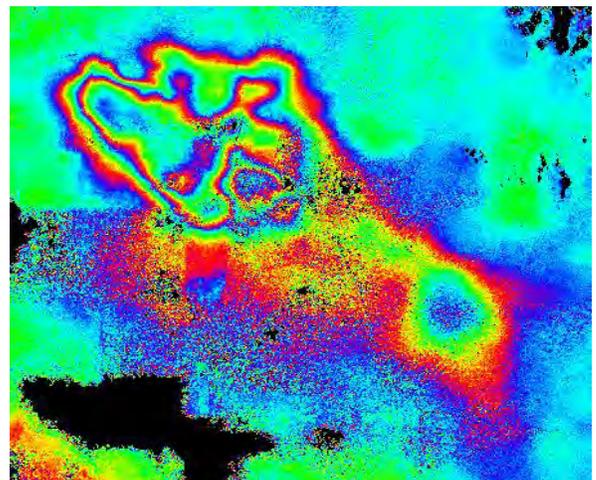


Arizona Department of Water Resources

Land Subsidence Monitoring Report No. 2



August 2014

By Brian D. Conway



**PROTECTING ARIZONA'S
WATER SUPPLIES**
for ITS NEXT CENTURY

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The help provided by these individuals and all those not listed is deeply appreciated.

Executive Summary

In 1997, the Arizona Department of Water Resources (ADWR) created a land subsidence monitoring program. The program initially focused on monitoring land subsidence in the east valley of the Phoenix Metropolitan area using survey-grade Global Positioning System (GPS) equipment. In 2002, ADWR was awarded a 3-year \$1.3 million NASA grant to expand the land subsidence monitoring program to include Interferometric Synthetic Aperture Radar data (InSAR). Upon completion of the NASA grant in 2005, ADWR quickly migrated to a land subsidence program that primarily utilized InSAR data using GPS surveying to support the program. With the InSAR data, ADWR has identified more than 25 individual land subsidence features in Arizona, collectively covering more than 1,200 square miles of the state (Figure 1). In addition, the program now cooperates with 14 entities whose financial assistance allows the Department to fund the InSAR data collection. ADWR provides land subsidence maps for download from ADWR's website. As of May 2014, 199 land subsidence maps are available for download and are used on a daily basis by geologists, hydrologists, engineers, planners, surveyors, floodplain managers, GIS analysts, and water resources managers.

ADWR Land Subsidence Monitoring Program

In 1997 the installation of numerous non-exempt wells (wells that pump more than 35 gallons per minute) was proposed in the Apache Junction and Luke Air Force Base areas, both areas noted for significant historic land subsidence and earth fissuring. Arizona Department of Water Resources (ADWR) management had concerns over the potential for the new wells to cause unreasonable increasing harm due to regional land subsidence, which led to a Directorate level decision to begin a land subsidence monitoring program. The Geophysics/Surveying Unit (GSU) of the Hydrology Division was created and started monitoring land subsidence by collecting survey-grade GPS data on survey monuments in the Hawk Rock land subsidence area located in east Mesa and Apache Junction. In 2002, ADWR was awarded a \$1.3 million NASA grant to develop a land subsidence monitoring program over three years to process satellite-based synthetic aperture radar (SAR) data using interferometry (InSAR). Upon completion of the NASA grant in 2005, ADWR permanently established a land subsidence program that primarily utilized InSAR data with GPS surveying to support the program.

ADWR InSAR Program

Synthetic Aperture Radar (SAR) is a side-looking, active (produces its own illumination) radar-imaging system that transmits a pulsed microwave signal towards the earth and records both the amplitude and phase of the back-scattered signal that returns to the antenna. InSAR is a technique that utilizes interferometric processing that compares the amplitude and phase signals received during successive passes of the SAR platform over a specific geographic area at different times. InSAR techniques, using satellite-based SAR platform data, can be used to produce land-surface deformation products with centimeter (cm)-scale vertical resolution. Changes in land elevation are detected through the change in phase of the radar signal. InSAR is used to detect surface displacement over otherwise undisturbed open land and deformation along active faults, on volcanoes, landslides, sinkholes, and other geologic features and hazards.

ADWR has developed an extensive library of over 1,300 SAR scenes used to process InSAR data, covering an area greater than 150,000 square miles at a cost of more than \$1million, predominantly purchased through grants and cooperators (Figure 1). ADWR has compiled a state-wide dataset for the active land subsidence areas identified with InSAR data in Arizona. Most datasets cover time periods between 1992 to 2000, 2004 to 2010, 2006 to 2011, and 2010 to present. Using these data, ADWR has identified more than 25 individual land subsidence features in Arizona, collectively covering more than 1,200 square miles (Figure 2). ADWR provides land subsidence maps for download from ADWR's website. As of May 2014, 199 land subsidence maps are available for download and are used on a daily basis by geologists, hydrologists, engineers, planners, surveyors, floodplain managers, GIS analysts, and water resources managers. The maps can be accessed at this link:

<http://www.azwater.gov/AzDWR/Hydrology/Geophysics/LandSubsidenceInArizona.htm>

ADWR also provides an interactive land subsidence map that utilizes a Google Maps interface and can be accessed at this link:

<https://maps.google.com/maps?q=http://www.azwater.gov/AzDWR/Hydrology/Geophysics/ArizonaLandSubsidenceAreas.kmz>

ADWR uses InSAR data not only for monitoring land subsidence, but also for: monitoring seasonal deformation (uplift and subsidence) and natural and artificial recharge events; as a tool for geological mapping and investigations; locating earth fissures; and identifying areas where conditions may exist for future earth fissure formation. In addition, InSAR data can be used for dam mitigation and land subsidence modeling.

ADWR cooperates with the following groups: Flood Control District of Maricopa County, Pinal County Flood Control District, Metropolitan Domestic Water Improvement District, Central Arizona Project, Arizona Department of Transportation, Arizona State Land Department, Arizona Geological Survey

(AZGS), Community Water Company of Green Valley, City of Scottsdale, Cochise County, Salt River Project, Petrified Forest National Park, City of Mesa, and the City of Phoenix.

ADWR currently collects InSAR data over more than 50,000 square miles throughout Arizona. InSAR data are collected throughout the year with the majority of the data being collected during the fall and spring months to capture any seasonal deformation signals. ADWR uses primarily the Radarsat-2 satellite at this time to fulfill its InSAR data needs. ADWR uses primarily conventional interferometry processing techniques, but has recently started to process areas using the PS-InSAR technique. Interferograms and xyz files are freely available by request to other agencies, consultants, cooperators, and the public.

ADWR InSAR Results

ADWR initially started focusing the InSAR data collection efforts on the Phoenix and Tucson Active Management Areas (AMAs), where there were already identified and well-documented land subsidence features. Three land subsidence features in the Phoenix AMA known as the West Valley (Figure 3), Northeast Phoenix/Scottsdale (Figure 4), and the Hawk Rock (Figure 5) land subsidence features, and two land subsidence features in the Tucson AMA known as the Central Well-field and the Valencia (Figure 6) land subsidence features (both part of the Tucson land subsidence feature) were readily identified by ADWR using archived InSAR data from the 1990's.

By cooperating with other federal, state, county, and local agencies and water companies, ADWR was able to greatly expand its data collection efforts to cover the entire State. The additional InSAR data provided ADWR the necessary resources to identify a dynamic land subsidence feature south of Tucson called the Green Valley (Figure 7) land subsidence feature that has seasonal uplift and land subsidence. InSAR data for the Pinal Active Management Area confirmed two well-documented land subsidence areas known as the Maricopa-Stanfield (Figure 8) and the Picacho-Eloy (Figure 9) land subsidence features.

InSAR data for west-central Arizona helped ADWR identify three new land subsidence features in far western Maricopa and eastern La Paz Counties known as the McMullen Valley (Figure 10), Harquahala Valley, (Figure 11) and the Ranegras Valley (Figure 12) land subsidence features. ADWR also identified two more land subsidence features in southwestern Maricopa County known as the Buckeye and Gila Bend features.

InSAR data for southeastern Arizona helped ADWR identify four land subsidence features in Cochise County. The Cochise County features currently have the highest magnitude of land subsidence in the entire State, greater than 8 centimeters/year (3.1 inches/year) and are known as the Fort Grant Rd (Figure 13), Kansas Settlement (Figure 14), Elfrida (Figure 15), and the Bowie/San Simon (Figure 16) land subsidence features. Over the last four years, cumulative land subsidence of 0.31 meters (1 foot) has occurred in both the Fort Grant Rd and Kansas Settlement land subsidence features.

InSAR data for the Holbrook Basin helped ADWR identify three land subsidence features in Navajo County. These features are known as the Holbrook Basin (Figure 17) land subsidence features and appear to be related to naturally occurring sinks and dissolution features. InSAR data is also being collected to establish a baseline for any existing land subsidence around the Petrified Forest National Park before planned underground potash mining activity begins in the area.

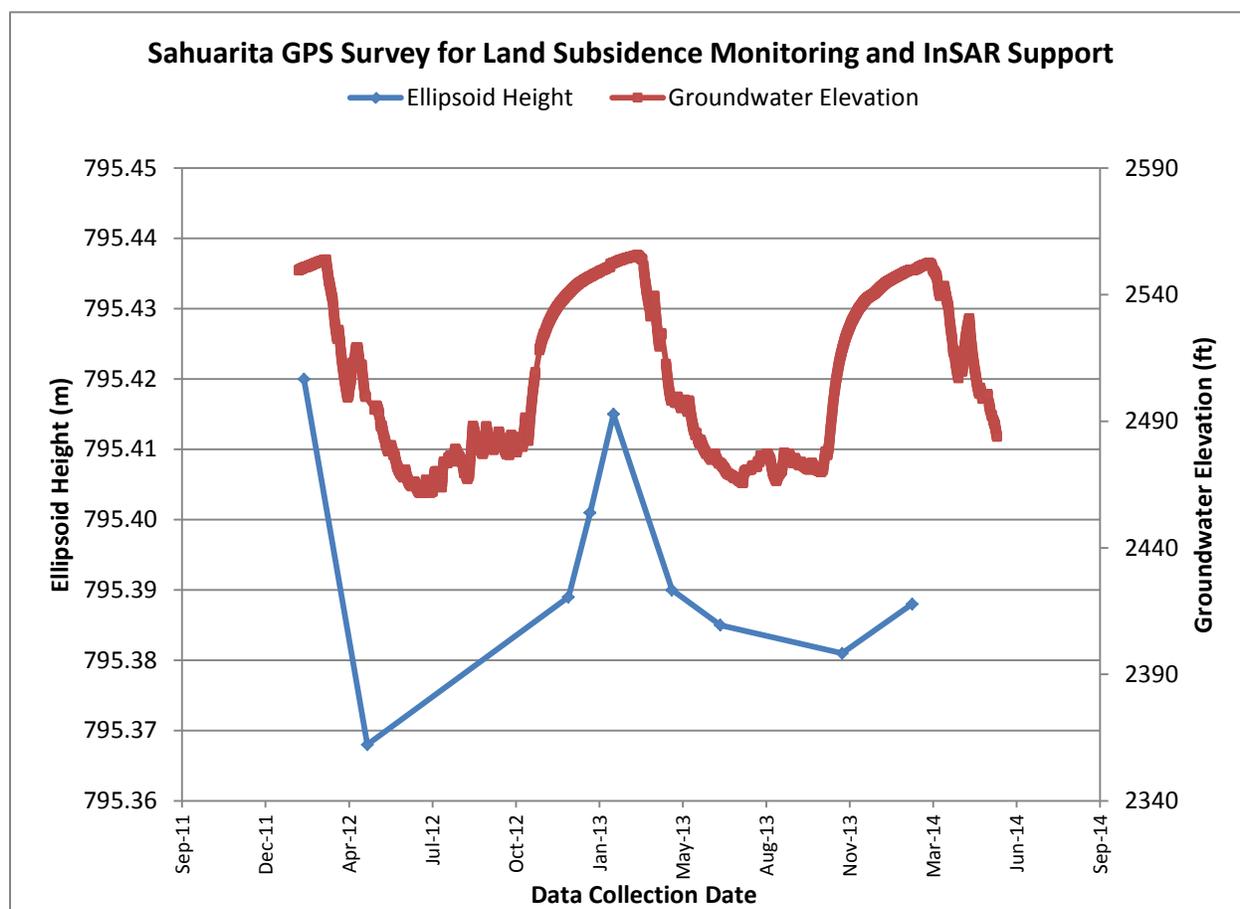
The most recent land subsidence feature identified with ADWR InSAR data is located in the eastern Metropolitan Phoenix area and is known as the East Valley Feature (Figure 18). This feature began to show deformation in late 2011. A review of ADWR automated groundwater monitoring site (transducers) hydrographs (Figure 19) in the area indicate that the land subsidence is a result of groundwater level declines due to increased groundwater pumping.

GPS Surveying

ADWR collects survey-grade GPS data for validating (“ground-truthing”) the InSAR data. The GPS data is also used for land subsidence monitoring in the Hawk Rock Area in East Mesa and Apache Junction (Figure 5), the Sahuarita/Green Valley Area (Figure 7), the McMullen Valley/Wenden Area (Figure 10), the Harquahala Area (Figure 11), the Dragoon Rd Area in Cochise County (Figure 14), the Chimney Canyon land subsidence feature in the Holbrook Basin (Figure 17), and the East Valley land subsidence feature (Figure 18).

Green Valley/Sahuarita Results

Comparison of recent GPS surveying data (Photo 1) with ADWR groundwater elevation data (Photo 2) from the Sahuarita/Green Valley Area has shown a striking correlation. Seasonal groundwater pumping demands have caused both seasonal groundwater declines and subsequent recoveries of approximately 110 feet between February and May (period of decline) and November and February (period of recovery). The groundwater level changes have resulted in both seasonal land subsidence and uplift that reflect the groundwater level changes (Graph 1).



Graph 1 – GPS Survey and transducer groundwater data for the Green Valley Land Subsidence Feature



Photo 1 - GPS Surveying along Sahuarita Rd in Green Valley



Photo 2 - Collecting groundwater elevation data at the Rosemont West transducer, Green Valley

Cochise County/Willcox Basin Results

ADWR started collecting InSAR data over Cochise County in 2010 and that InSAR data has documented land subsidence of as much as 11 centimeters (4.3 inches) in a twelve month period.



Photo 3 - Earth Fissure warning sign along Dragoon Rd in Cochise County

ADWR also collects survey-grade GPS data in the center of one of the subsidence-bowls, located along Dragoon Rd between the towns of Dragoon and Willcox, within the Kansas Settlement land subsidence feature. ADWR was able to recover and re-measure an old survey monument, V 261, which was established in 1945 by the National Geodetic Survey (NGS) along Dragoon Rd a mile west of US HWY 191 (Figure 17). Comparing recent (2014) ADWR GPS data with the historical 1945 data, ADWR was able to determine that a total of 1.26 meters (4.14 feet) of land subsidence has occurred at this location since 1945, and 36 centimeters (1.2 feet) of land subsidence has occurred between 2011 and 2014 (Graph 2).

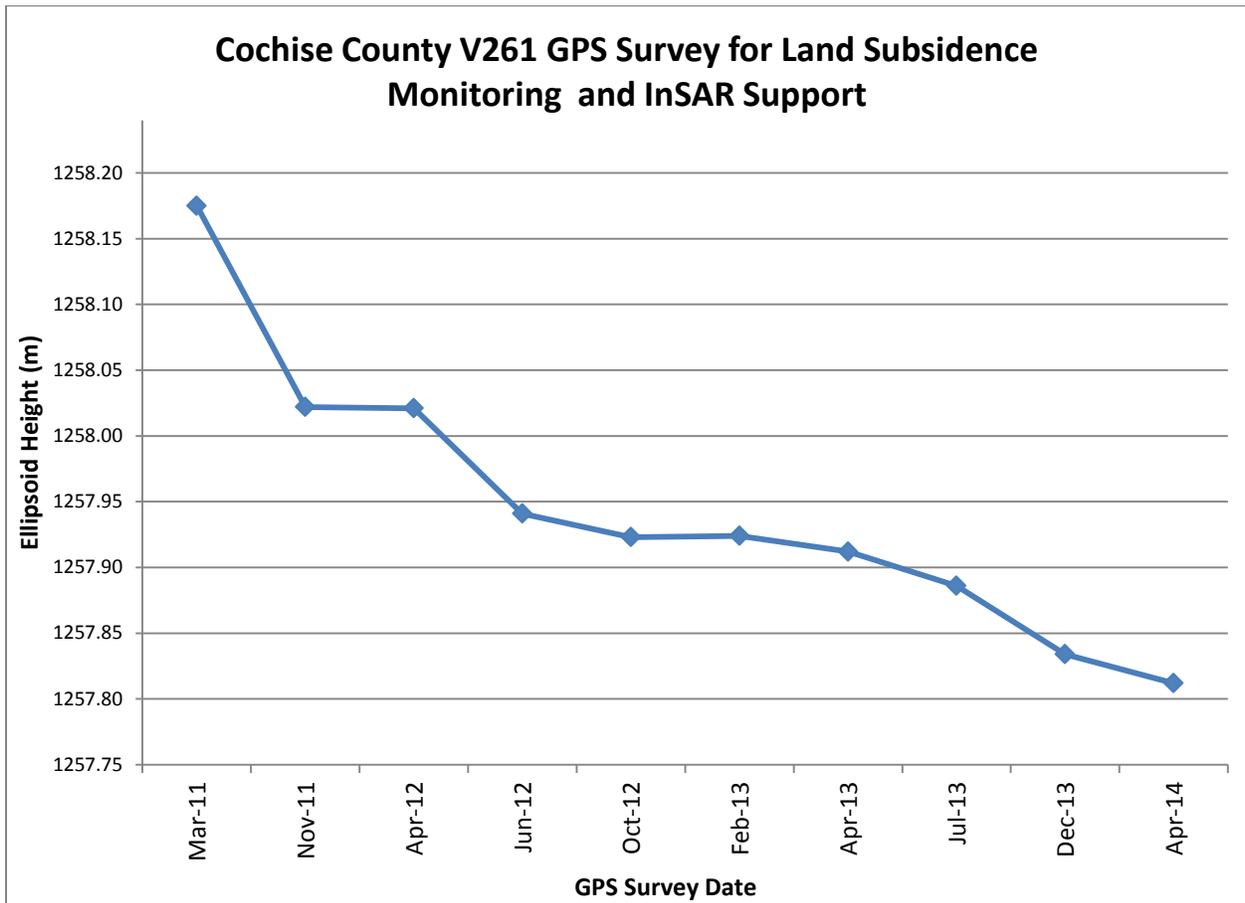
A protruding well casing (Photo 4) about a mile northwest of the V 261 survey monument, and numerous earth fissures located in the Willcox Basin (Photo 5), further document the amount of historical land subsidence that has occurred in the immediate area, as well as the need to continue surveying V 261 for land subsidence in this area.



Photo 4 - Exposed well casing in Cochise County



Photo 5 - Sulfur Hills earth fissure in Cochise County



Graph 2 – GPS Survey data for land subsidence along Dragoon Rd in the Kansas Settlement Land Subsidence Feature

McMullen Valley Basin Results

ADWR first delineated land subsidence in the McMullen Valley in 2008 with InSAR data. In 2010, the Town of Wenden, located in the McMullen Valley, was flooded for the second time in ten years by Centennial Wash. The Town of Wenden is located within a land subsidence bowl which has exacerbated the recent flooding events. ADWR recently recovered three historical NGS monuments (A 480, Y 479, X 479) in the Wenden Area (Photo 7) that will be used for on-going ground-truthing of the InSAR data and for land subsidence monitoring in the McMullen Valley.



Photo 6 - Centennial Wash flooding the Town of Wenden in 2010 (Photo credit La Paz County)



Photo 7 - GPS Surveying in the McMullen Valley



Photo 8 –Recently identified and mapped earth fissure in the McMullen Valley (Photo Credit AZGS)

Comparing recent ADWR GPS survey data collected during February 2013 and March 2014 at monument X 479, demonstrates that there was 6.4 centimeters (2.5 inches) of land subsidence. ADWR will continue to survey all three survey monuments for monitoring land subsidence in the McMullen Valley (Figure 10).

The AZGS recently identified and mapped earth fissures in the McMullen Valley near the Town of Aguila (Photo 8).

Hawk Rock Results

ADWR has conducted several GPS surveys in the Hawk Rock Area since 1997. The monument, SGC 17, was first measured in 1973. Comparing the SGC 17 elevation from 1973 and a re-surveyed elevation from 2014, SGC 17 has subsided just over 1.55 meters (5.1 feet) in over 40 years. Numerous earth fissures (Photo 9) have also been identified and mapped in the Hawk Rock area (Figure 5).



Photo 9 - Earth Fissure located at Baseline Rd and Meridian Rd in the Hawk Rock feature



Photo 10 - Rogers earth fissure located in the Harquahala Valley (Photo Credit AZGS)

Harquahala Valley Results

ADWR last delineated land subsidence in the Harquahala Valley in 2008 with InSAR data. Land subsidence was first documented in the Harquahala Valley with the opening of the Rogers earth fissure in September 1997 following a large rain event during Hurricane Nora. ADWR recently recovered a Maricopa County Department of Transportation survey monument, 4BR1, which was established in 2000 in the Harquahala Valley (Figure 11). This monument will be used for on-going ground-truthing of the InSAR data and for land subsidence monitoring in the Harquahala Valley.

Comparing recent ADWR GPS data with the historical 2000 data for 4BR1, a total of 8.7 centimeters (3.4 inches) of land subsidence has occurred since 2000. ADWR will continue to survey the 4BR1 survey monument for monitoring land subsidence in the Harquahala Valley. The AZGS recently re-mapped the Roger’s earth fissure (Photo10) and discovered that the earth fissure has extended an additional 620 feet to the southeast since it was last mapped in 2008.

East Valley Results

ADWR first detected new land subsidence in Eastern Metropolitan Phoenix, which includes portions of the Cities of Mesa, Chandler, and Scottsdale, in 2012 (Figure 18). After the land subsidence feature was detected in 2012, ADWR recovered a Maricopa County Department of Transportation survey monument, 1BJ1, which was established in 2000 in the East Valley (Photo 11). This monument will be used for on-going ground-truthing of the InSAR data and for land subsidence monitoring in the East Valley. The difference between the 2013 and 2014 GPS survey results indicate that the 1BJ1 monument has subsided 1.9 centimeters (0.75 inches) over a one-year period. As mentioned earlier, this new land subsidence feature is a result of declining groundwater levels (Figure 19) due to increased groundwater pumping in the area.



Photo 11 - GPS Surveying in the East Valley



Photo 12 - San Tan Mountain Bedrock CORS

Continuous Operating Reference Station

Over the past five years, ADWR has played an important role in site-selection and installation of several GPS Continuous Operating Reference Station (CORS) sites in Arizona. Many of the CORS sites are operated by the Arizona Department of Transportation (ADOT) and all the data is managed by the National Geodetic Survey. There are more than twenty CORS sites located throughout Arizona that provide precise GPS data that are then used for both real-time and post-processed surveying projects. For those projects that require accurate and precise elevations, it is crucial that the survey control is stable and not subsiding. As a result, ADWR has provided guidance to ADOT and other entities for locating stable sites away from land subsidence areas.

ADWR has worked with the ADOT, Central Arizona Project, Maricopa County Department of Transportation, and Maricopa County Parks to install two new stable CORS sites that are located on bedrock in Eastern Maricopa County at Usery Mountain and San Tan Mountain Parks (Photo 12). These sites will provide stable vertical control around the Hawk Rock land subsidence feature (Figure 20).

Additional Critical Data for Monitoring Land Subsidence

Land subsidence maps and InSAR data are important tools for monitoring and understanding land subsidence in an area. There are several other critical datasets which should be examined when studying land subsidence, including groundwater level data and pumping data which are freely accessible through ADWR's website. ADWR provides Statewide groundwater level data for more than 44,340 wells through its website (majority are ADWR collected), of which 1,783 are Index Wells (wells that are measured at least annually, if not quarterly or bi-annually) and 126 are automated groundwater monitoring sites (80 of which are equipped with telemetry and provide near real-time groundwater elevation measurements) (Figure 21). All groundwater level data can be downloaded and the user has the ability to display hydrographs for both the manual and automated (if equipped) groundwater measurements. All well construction, well logs, and other well-related information are also available on ADWR's website. The well logs help provide insight into the sub-surface geology and are used to better understand land subsidence in an area. Historical groundwater pumping data from 1984 to the present are also available for online viewing or download.

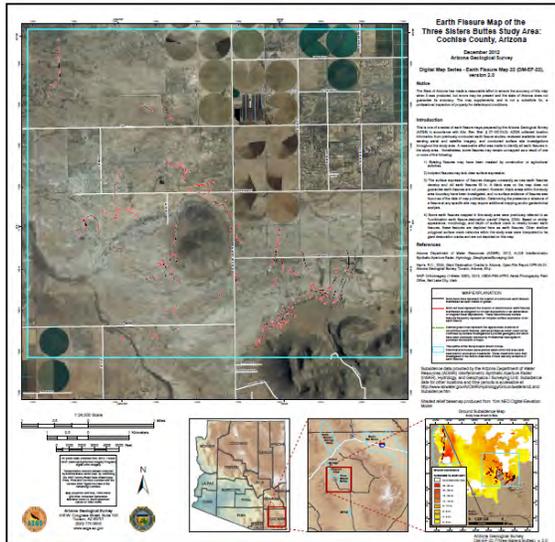


Photo 13 – AZGS Earth Fissure Map

Earth Fissure Monitoring and Mapping

Earth fissures are cracks at or near the earth's surface that are the result of differential land subsidence. Earth fissures start out as small cracks and may not be visible on the surface. They grow and widen from surface water flowing in the crack, eroding material from the sides. Earth fissures have caused millions of dollars in property and infrastructure damage, damaging pipelines, roads, canals, flood retention structures, bridges, building, and private property.

The AZGS is responsible for monitoring and mapping earth fissures around the State (<http://www.azgs.az.gov/EFC.shtml>). The AZGS has identified and mapped more than 153 miles of earth fissures throughout Arizona. The AZGS provides earth fissure maps (Photo 13) for each earth fissure study area that are available for download through their

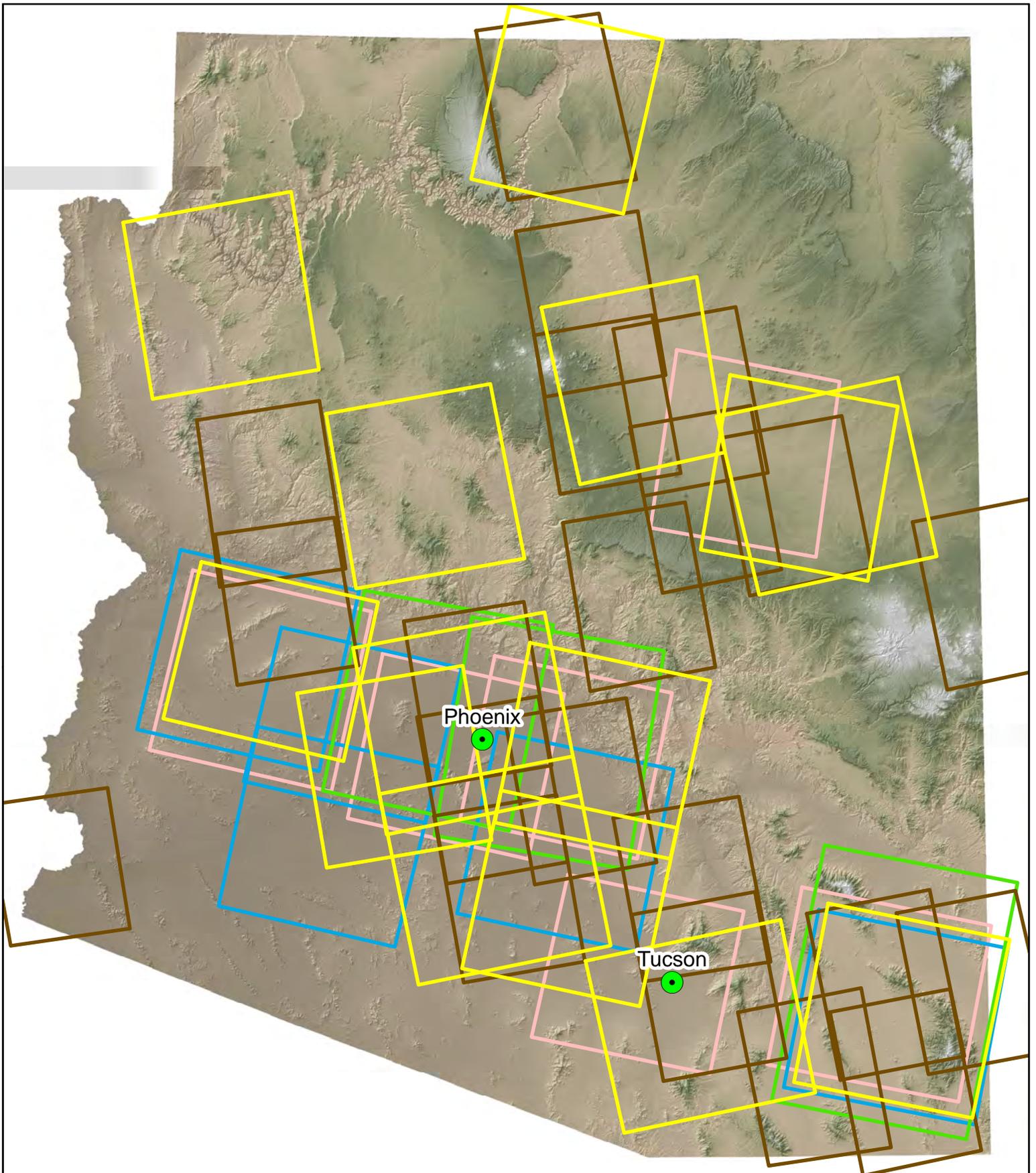
website. The AZGS currently has 24 earth fissure study area maps. ADWR and AZGS work closely together to monitor earth fissures by using InSAR data to identify areas of differential land subsidence which may result in future earth fissuring.

Future Land Subsidence Data Collection

ADWR's GPS-surveying program plays a vital role in supporting the State-wide InSAR land subsidence monitoring program. Additionally the GPS surveying is also used for ongoing aquifer storage change monitoring conducted by ADWR and the United States Geological Survey (USGS) in several groundwater basins in south-central Arizona. Routine survey data will continue to be collected in existing areas and other subsidence areas will be examined to determine if additional surveying locations should be added for enhanced monitoring using GPS surveying techniques.

ADWR continues to provide land subsidence products for its own hydrologic studies and for cooperators, consultants, other government and private entities, and the public. At the same time, ADWR is continually searching for additional InSAR cooperators, educating groups about the InSAR data and how the data can be used to meet their monitoring needs, and further enhancing the InSAR program through investments in software and hardware upgrades.

ADWR will continue to collect InSAR data around the State at the existing data collection frequency and spatial distribution of more than 50,000 square miles (Figure 22). If needed, ADWR will begin to collect InSAR data in areas where increasing groundwater demands and declining groundwater level may be occurring or starting to occur. ADWR will also continue to update land subsidence maps on an annual basis, making the maps available on the Department's website.



- Cities
- Radarsat-2
- ALOS-1
- Radarsat-1
- Envisat
- ERS-1 & 2

Figure 1 -All Satellite Frames Used to Collect InSAR Data in Arizona
 InSAR Data is Collected, Processed, and Analyzed
 by the Geophysics/Surveying Unit of the ADWR Hydrology Division



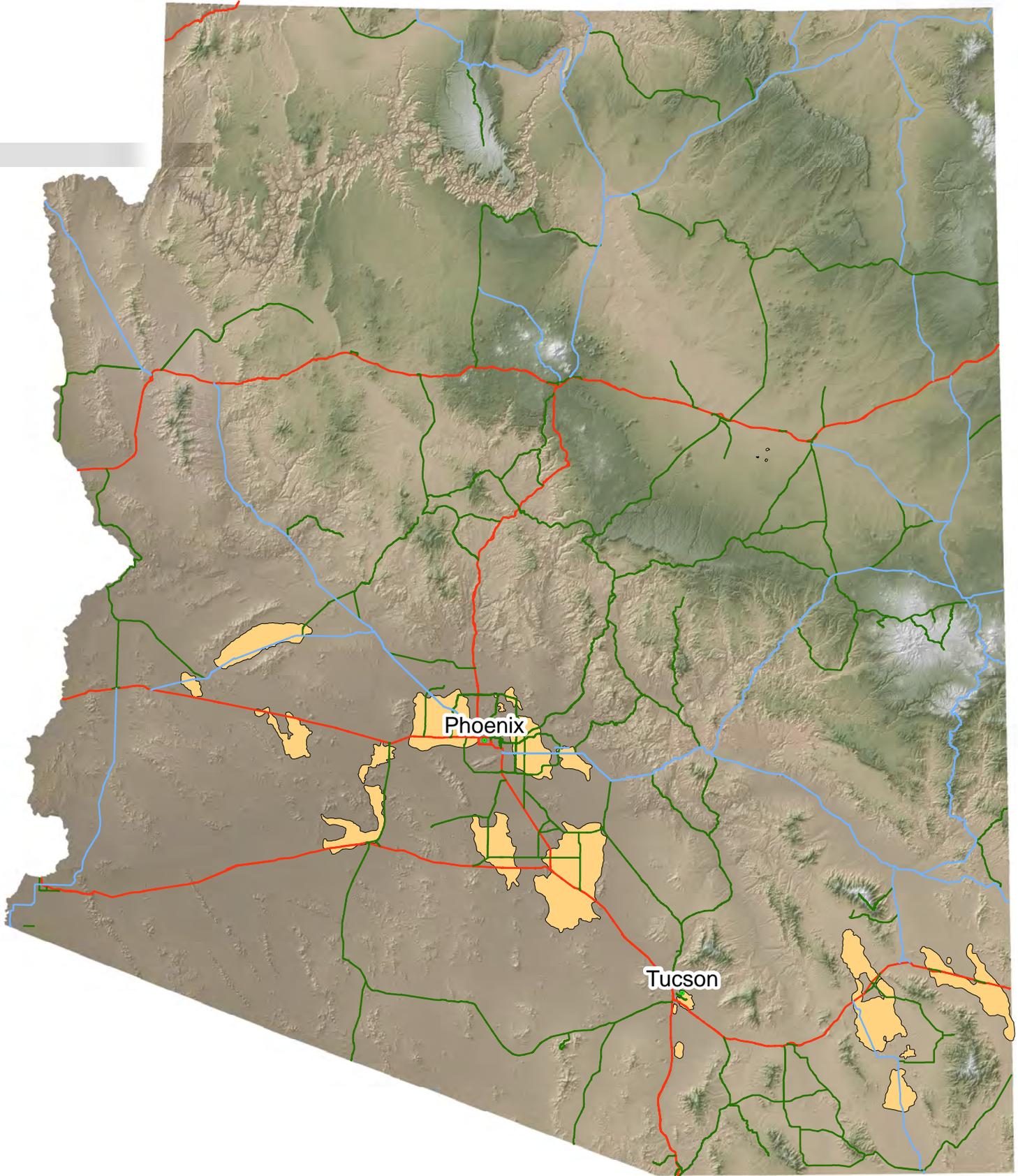
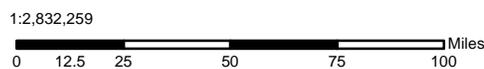


Figure 2 - Active Land Subsidence Areas in Arizona Based on InSAR Data
 InSAR Data is Collected, Processed, and Analyzed
 by the Geophysics/Surveying Unit of the ADWR Hydrology Division

- Cities
- Active Land Subsidence Area
- Highways and Interstates**
- Interstate
- US
- State



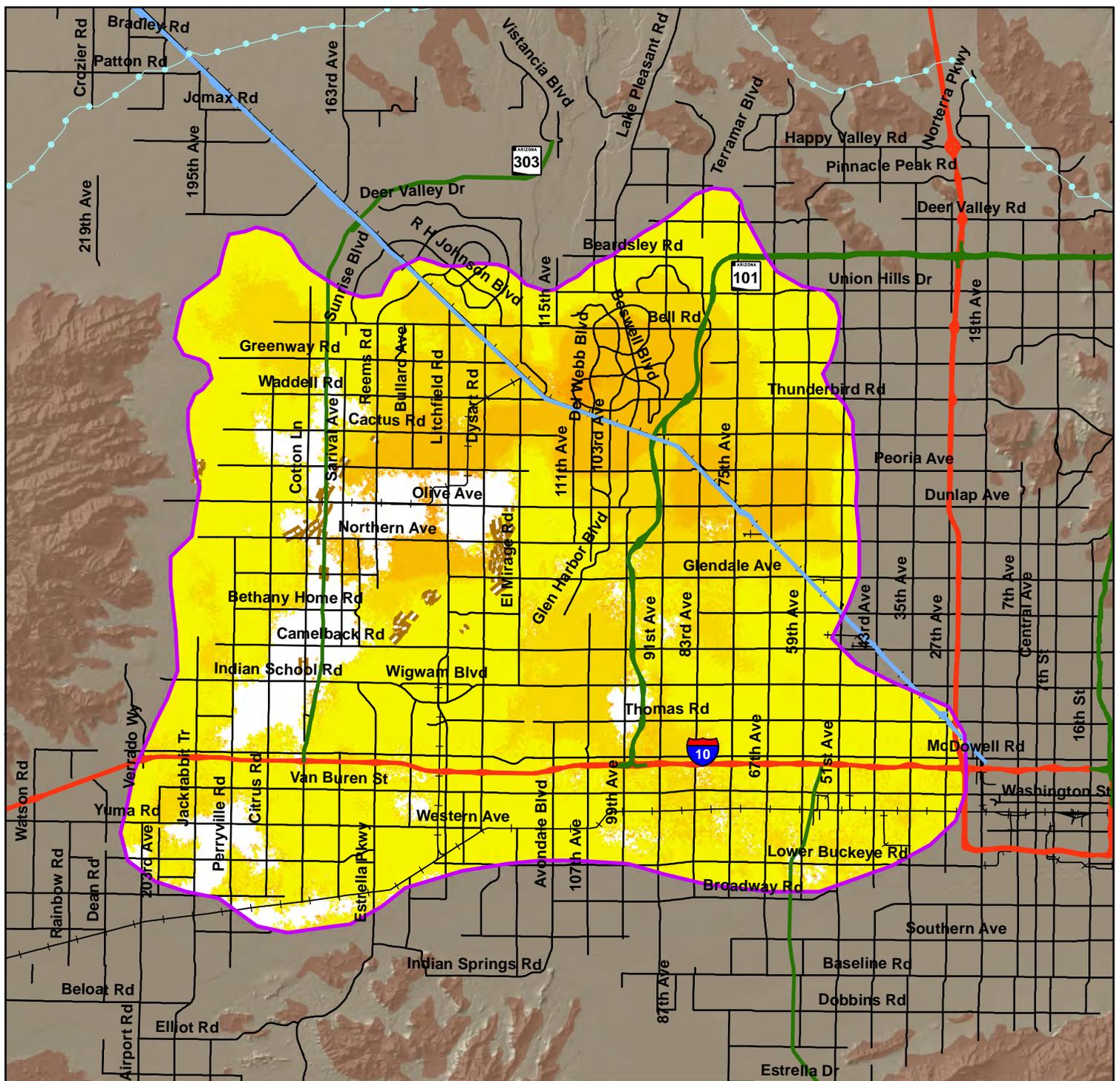


Figure 3 - Total Land Subsidence (cm) in Western Metropolitan Phoenix
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 4.0 Years 05/08/2010 To 04/17/2014

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05/08/2010 To 04/17/2014

Total Land Subsidence (cm)

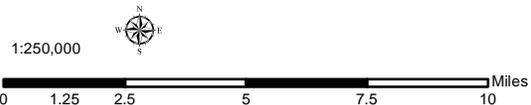
- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Subsidence Feature

- Hardrock
- Earth Fissures
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



Arizona



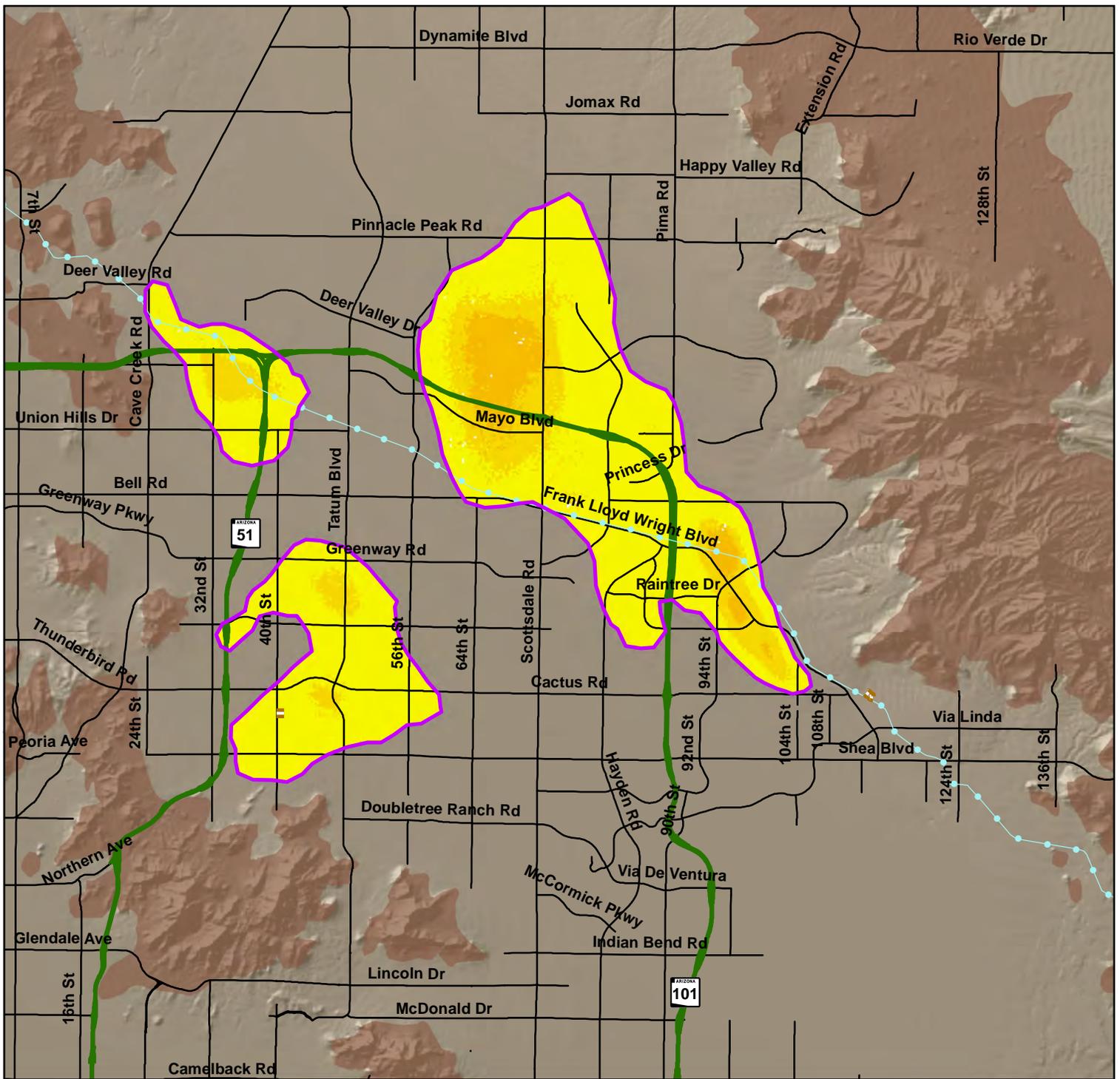


Figure 4 - Total Land Subsidence (cm) in Northeast Phoenix and Scottsdale Areas
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 4.0 Years 05/08/2010 To 04/17/2014

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Explanation

05/08/2010 To 04/17/2014

Total Land Subsidence (cm)

- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

- Subsidence Feature
- Earth Fissures
- Hardrock
- CAP Canal
- Highways and Interstates**
- Interstate
- US
- State
- Roads

1:138,037



0 0.5 1 2 3 4 Miles

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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



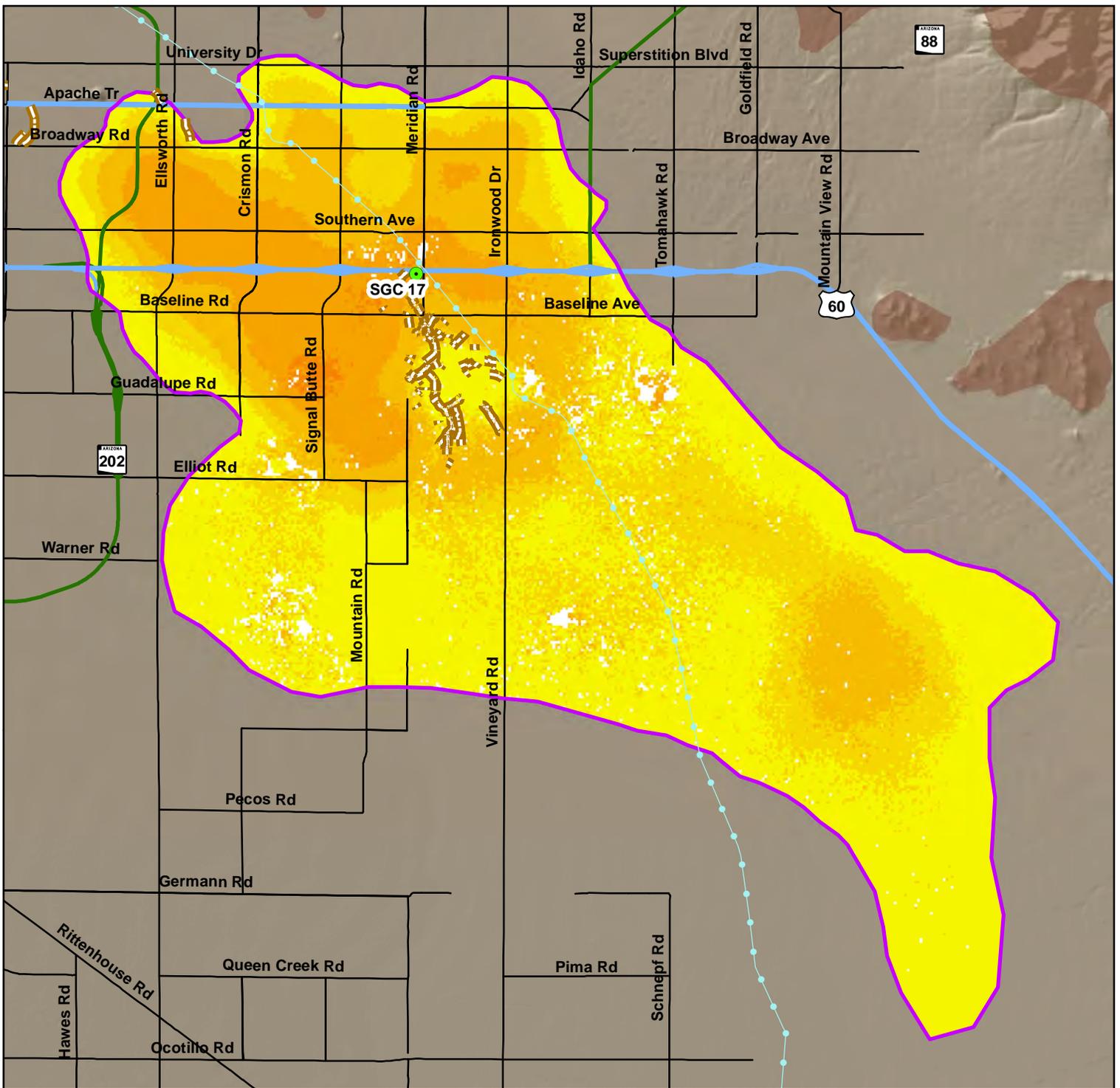
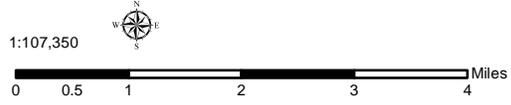


Figure 5 - Total Land Subsidence (cm) in the Hawk Rock Area of East Mesa and Apache Junction
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 3.9 Years 05/15/2010 To 03/31/2014

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Explanation
 05/15/2010 To 03/31/2014

Decorrelation/No Data	Subsidence Feature
Greater Than 40 cm	Earth Fissures
25 to 40 cm	Survey Monument
15 to 25 cm	Hardrock
10 to 15 cm	CAP Canal
6 To 10 cm	Highways and Interstates
4 To 6 cm	Interstate
2 To 4 cm	US
1 To 2 cm	State
0 To 1 cm	Roads



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



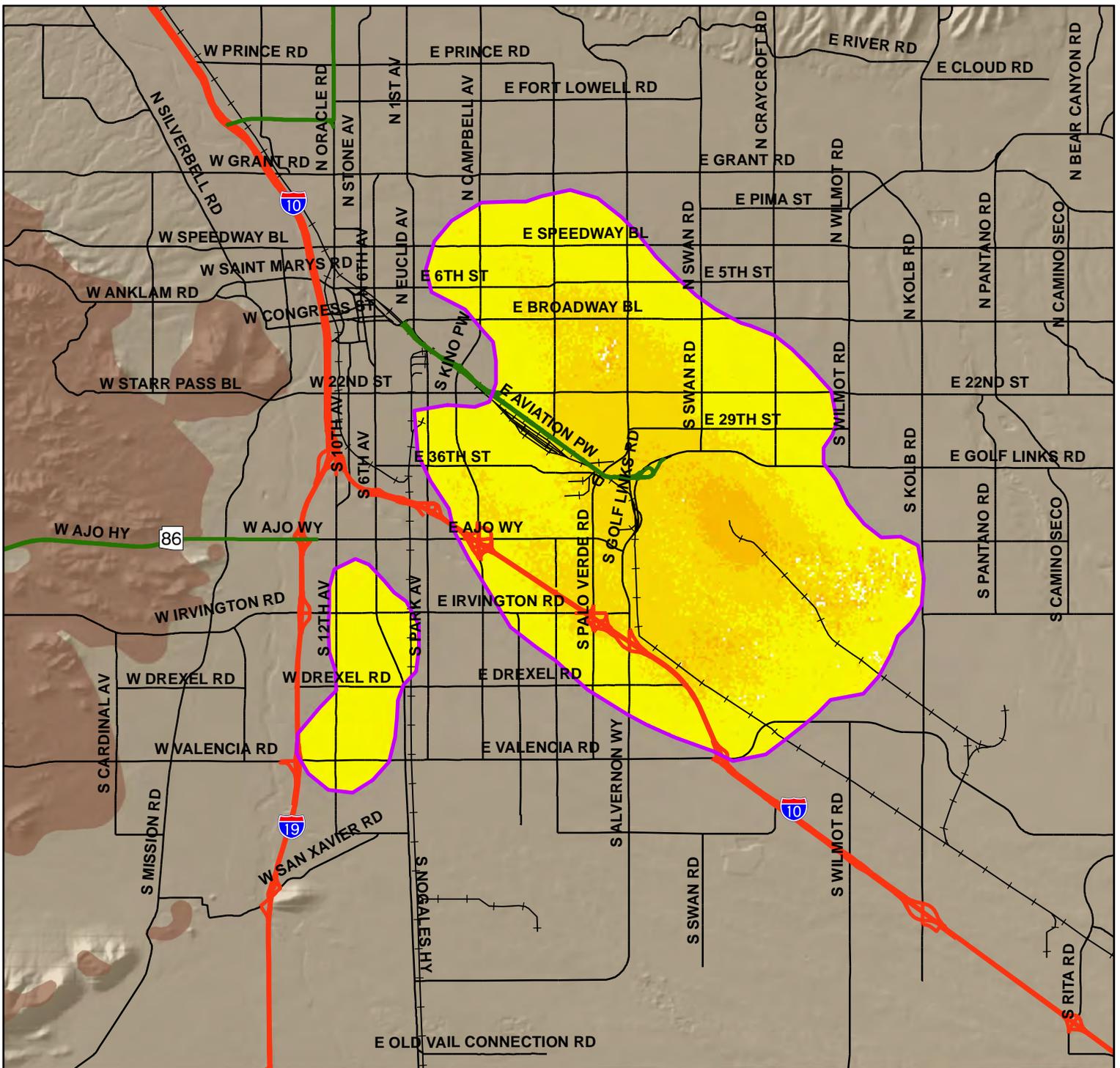


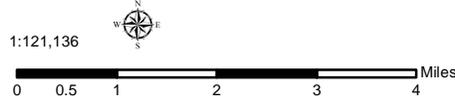
Figure 6 - Total Land Subsidence (cm) in the Tucson Metropolitan Area
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 4.0 Years 05/15/2010 To 05/18/2014

© MDA 2010 - 2014

Explanation

05/15/2010 To 05/18/2014

- | | | |
|--|--|--|
| <ul style="list-style-type: none"> Decorrelation/No Data Greater Than 40 cm 25 to 40 cm 15 to 25 cm 10 to 15 cm 6 To 10 cm 4 To 6 cm 2 To 4 cm 1 To 2 cm 0 To 1 cm | <ul style="list-style-type: none"> Subsidence Feature Hardrock | <ul style="list-style-type: none"> Highways and Interstates Interstate US State Roads Railway |
|--|--|--|



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



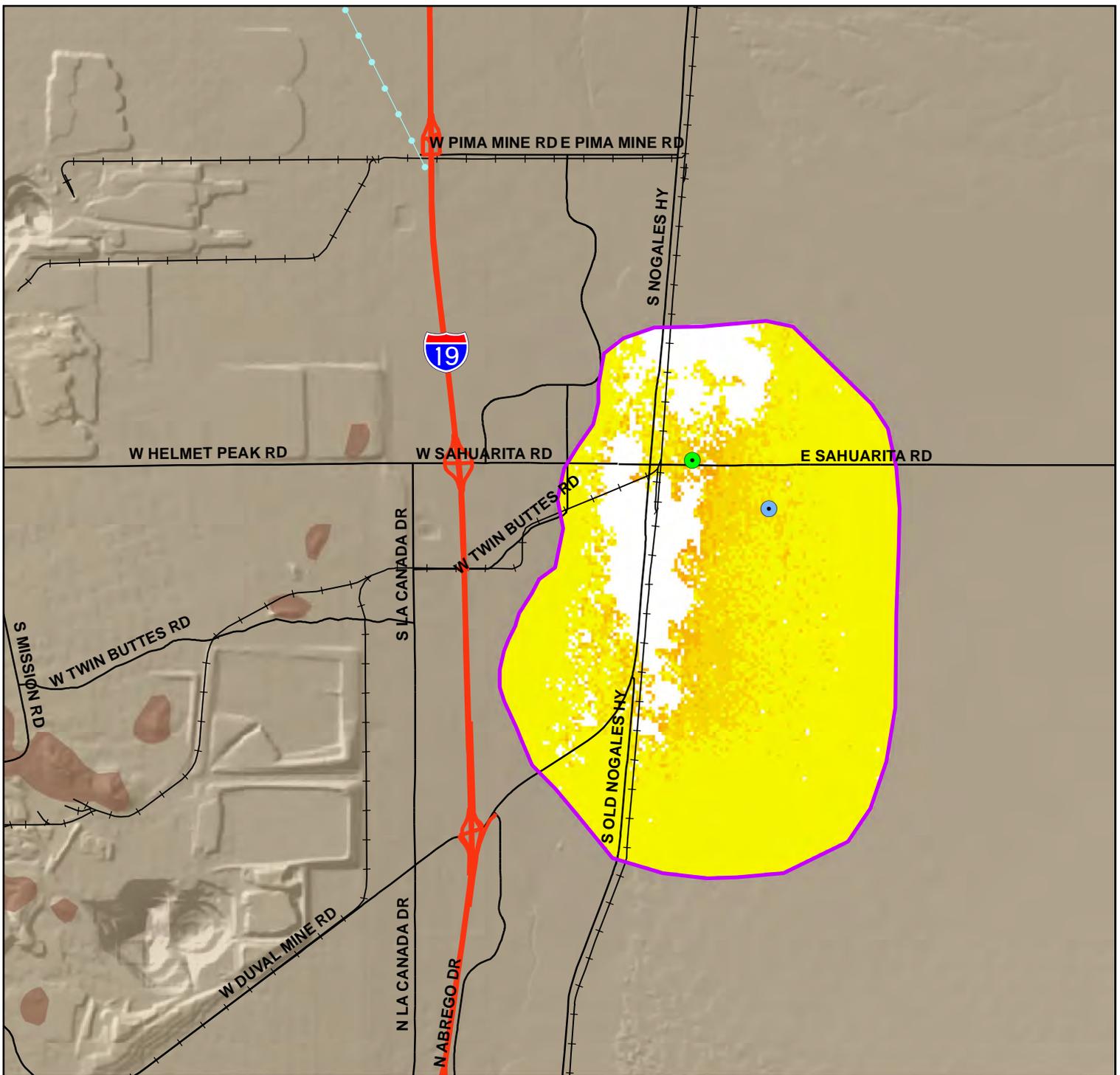


Figure 7 - Total Land Subsidence (cm) in the Sahuarita and Green Valley Areas, Pima County
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 2.2 Years 02/22/2012 To 05/18/2014

© MDA 2012 - 2014

Explanation
 02/22/2012 To 05/18/2014

Total Land Subsidence (cm)

- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Subsidence Feature
 Subsidence Feature

Survey Monument
 Survey Monument

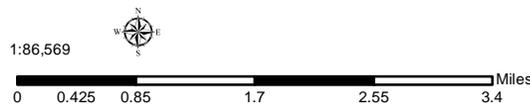
Groundwater Level Transducer
 Groundwater Level Transducer

Hardrock
 Hardrock

CAP Canal
 CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



Arizona



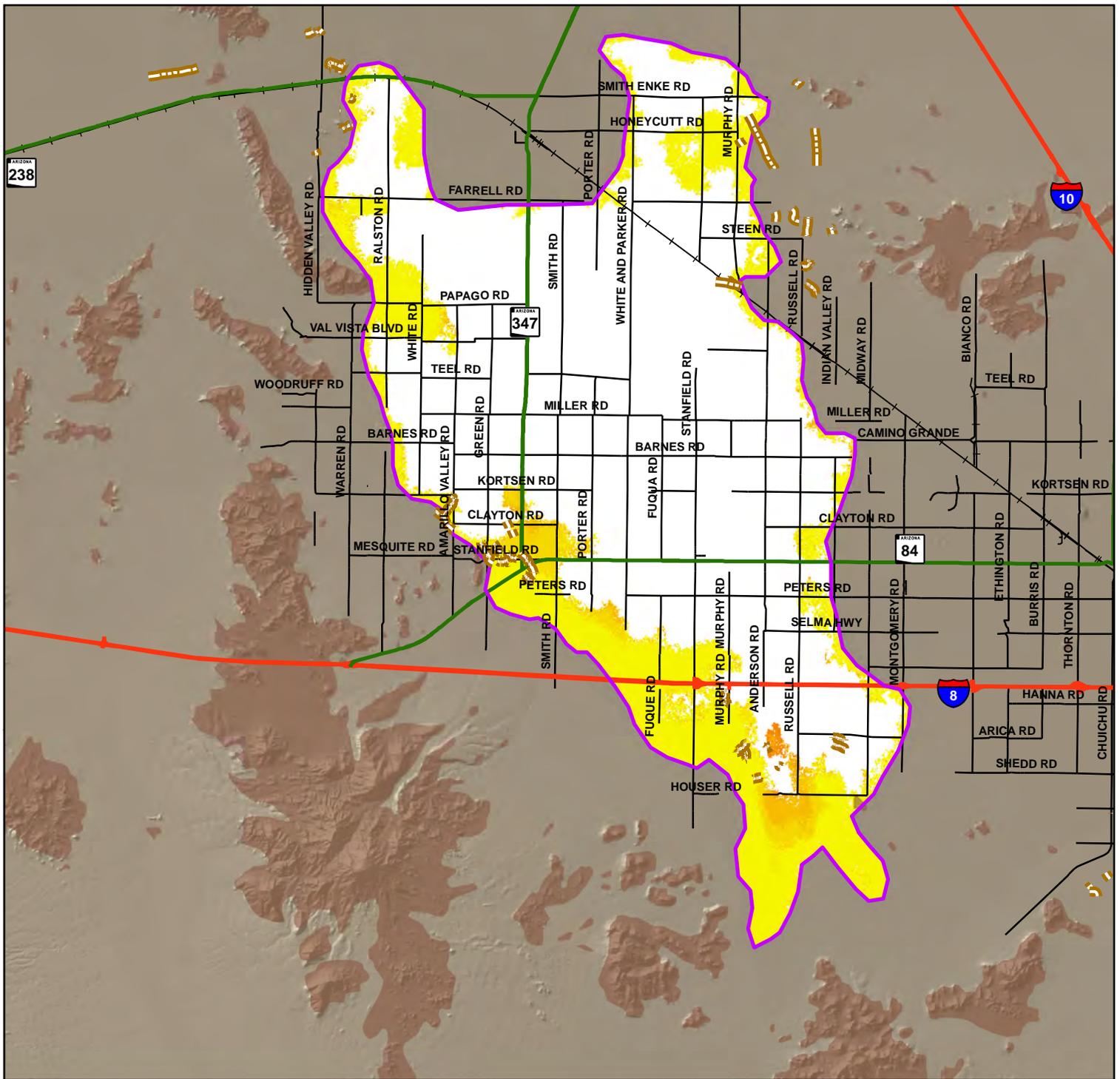


Figure 8 -Total Land Subsidence (cm) in the Maricopa-Stanfield Sub-Basin, Pinal County
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 4.0 Years 05/08/2010 To 04/17/2014

© MDA 2010 - 2014

Explanation

05/08/2010 To 04/17/2014

Total Land Subsidence (cm)

- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Subsidence Feature

Earth Fissures

Hardrock

CAP Canal

Highways and Interstates

Interstate

US

State

Roads

Railway

1:257,110



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



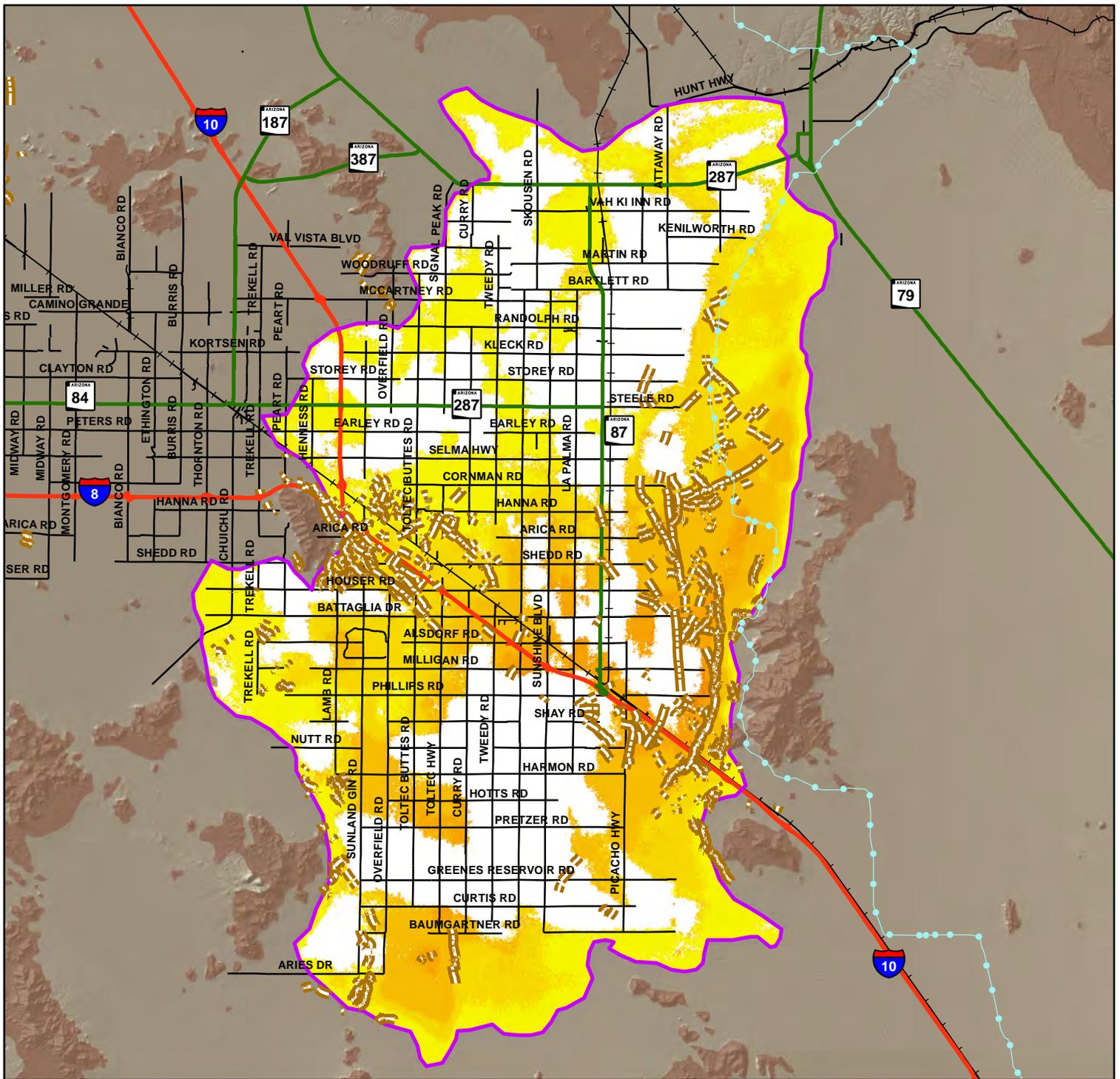


Figure 9 - Total Land Subsidence (cm) in the Picacho Sub-Basin, Pinal County Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
Time Period of Analysis: 3.9 Years 05/15/2010 To 03/31/2014

© MDA 2010 - 2014

Explanation

- 05/15/2010 To 03/31/2014
- Subsidence Feature
 - Earth Fissures
 - Hardrock
 - CAP Canal
 - Highways and Interstates**
 - Interstate
 - US
 - State
 - Roads
 - Railway
 - Total Land Subsidence (cm)**
 - Decorrelation/No Data
 - Greater Than 40 cm
 - 25 to 40 cm
 - 15 to 25 cm
 - 10 to 15 cm
 - 6 To 10 cm
 - 4 To 6 cm
 - 2 To 4 cm
 - 1 To 2 cm
 - 0 To 1 cm

1:341,495



0 1.5 3 6 9 12 Miles

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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



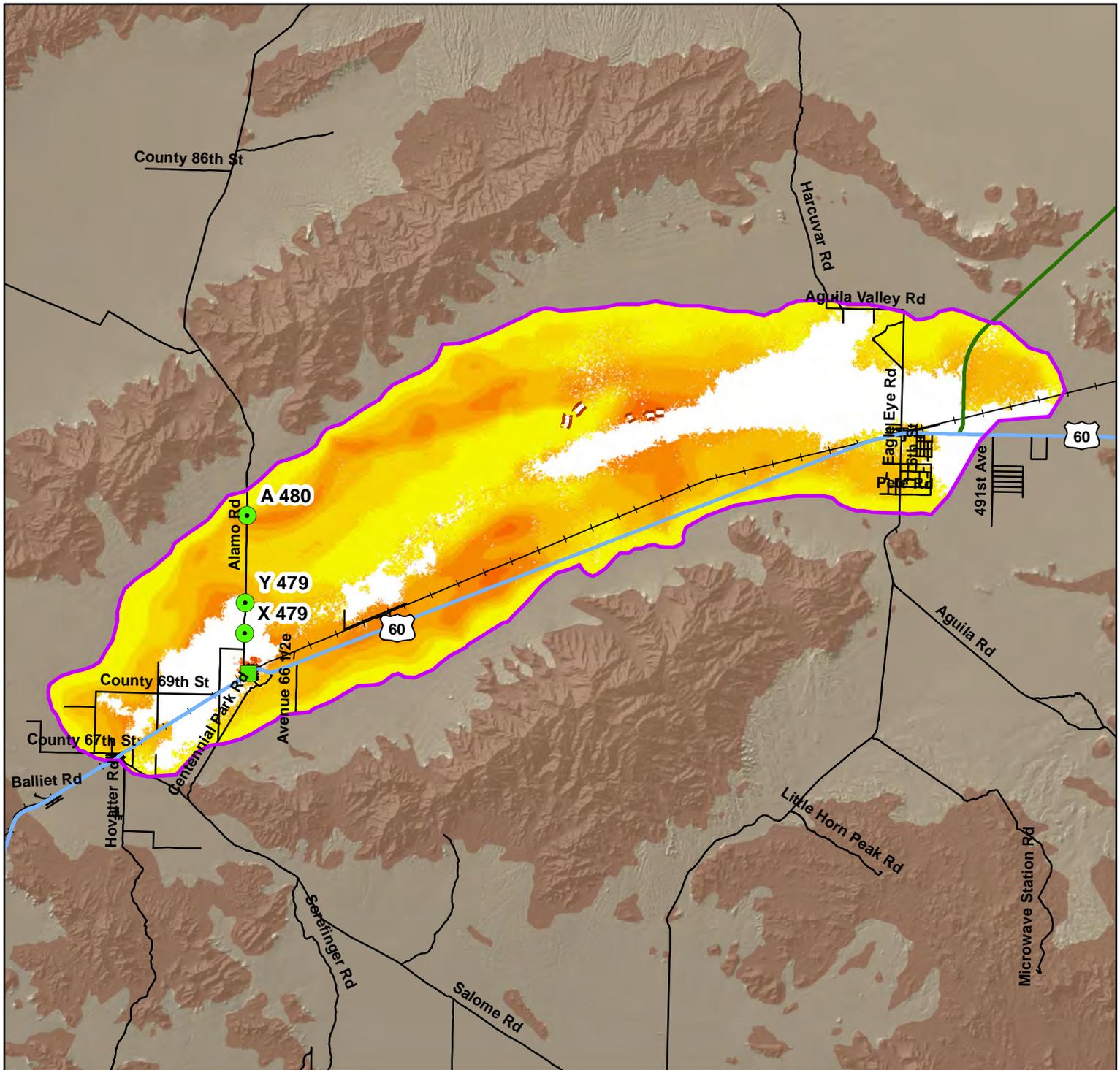


Figure 10 - Total Land Subsidence in the McMullen Valley, Maricopa and La Paz Counties
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 3.9 Years: 05/01/2010 To 03/17/2014

© MDA 2010 - 2014

Explanation

05/01/2010 To 03/17/2014

Total Land Subsidence (cm)

- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

- Subsidence Feature
- Hardrock
- Earth Fissures
- Town of Wenden
- Survey Monument
- CAP Canal
- Highways and Interstates**
- Interstate
- US
- State
- Roads
- Railway

1:287,039



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



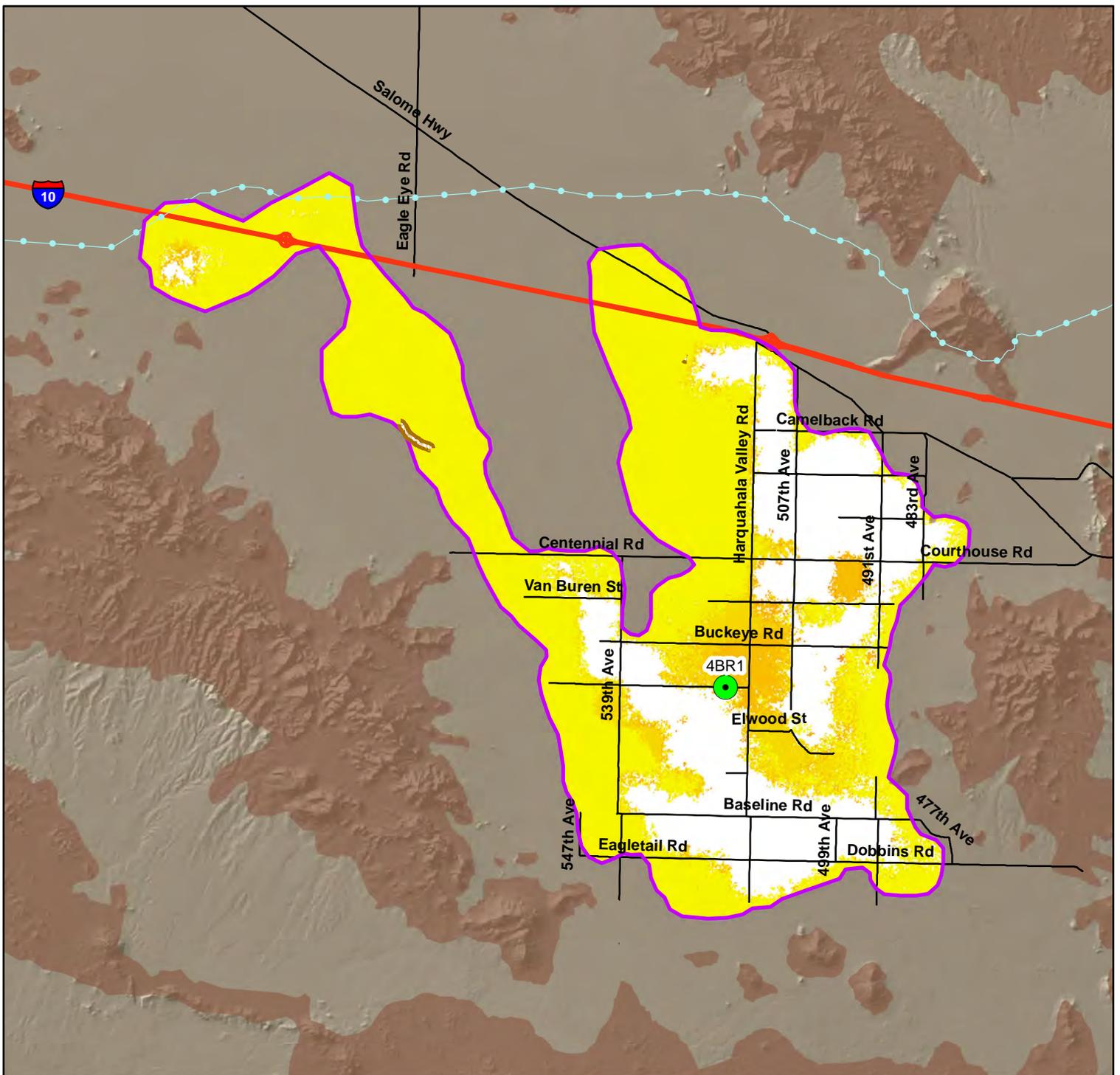


Figure 11 - Total Land Subsidence (cm) in the Harquahala Valley, Maricopa County
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 3.9 Years 05/01/2010 To 03/17/2014

© MDA 2010 - 2014

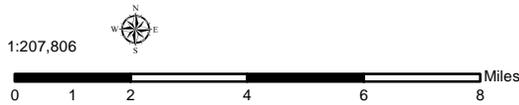
Explanation

05/01/2010 To 03/17/2014

Total Land Subsidence (cm)

- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

- Subsidence Feature
- Earth Fissures
- Survey Monument
- Hardrock
- CAP Canal
- Highways and Interstates**
- Interstate
- US
- State
- Roads



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



Arizona



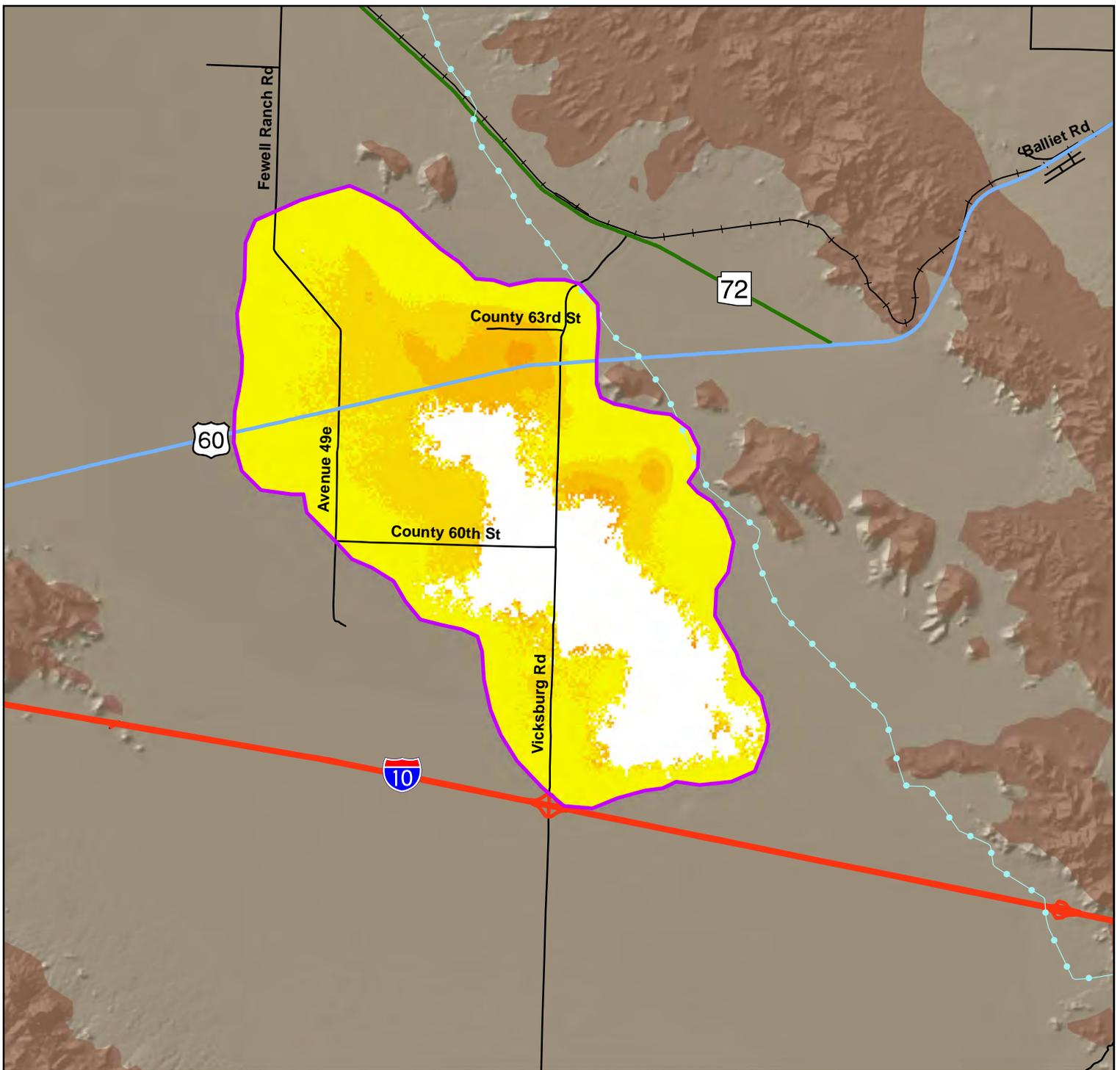


Figure 12 - Total Land Subsidence (cm) in the Ranegras Valley, La Paz County
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 3.9 Years 05/01/2010 To 03/17/2014

©MDA 2010 - 2014

Explanation

05/01/2010 To 03/17/2014

Total Land Subsidence (cm)

- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Subsidence Feature

- Subsidence Feature

Hardrock

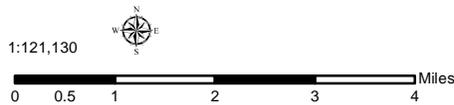
- Hardrock

CAP Canal

- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



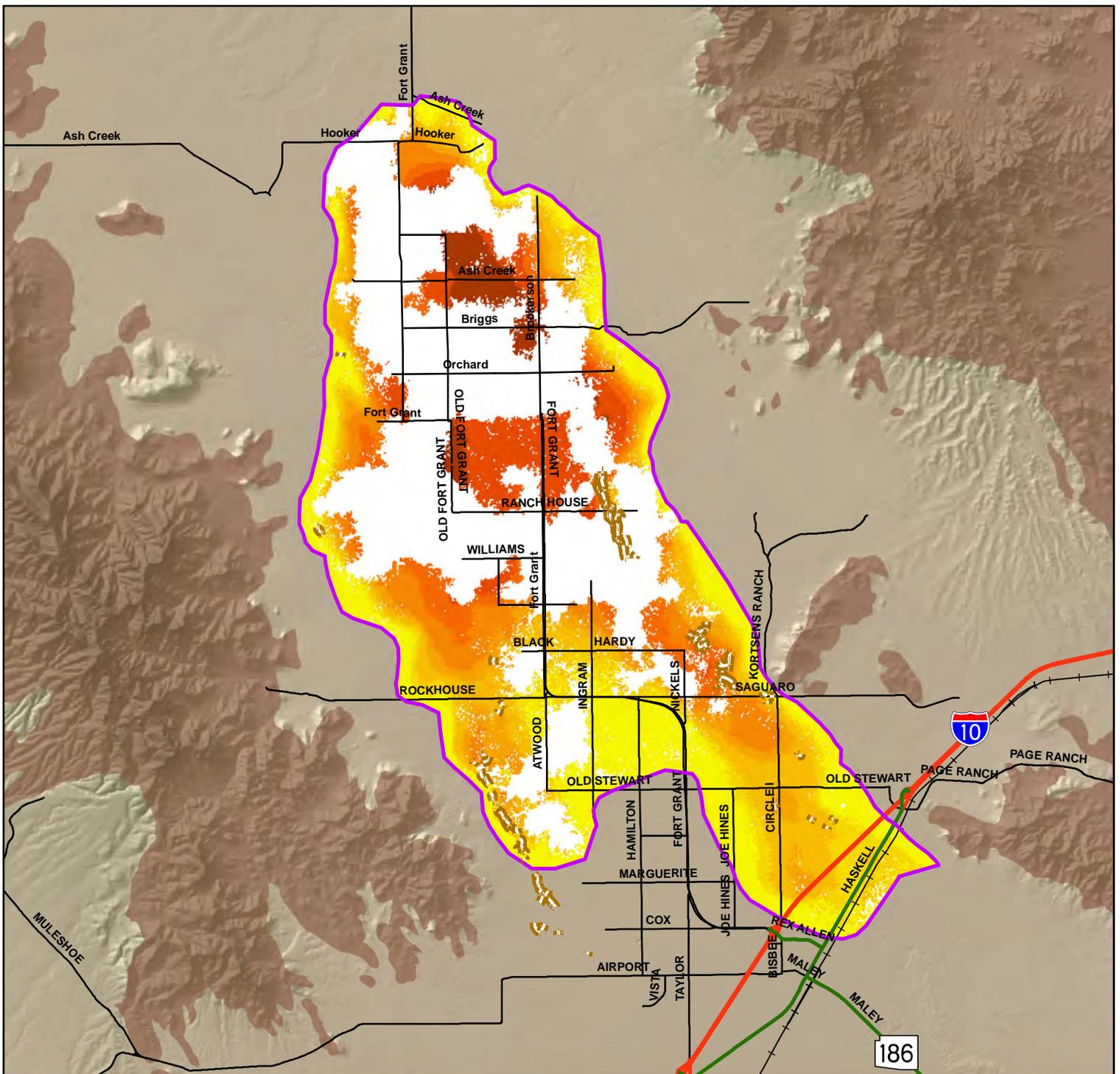


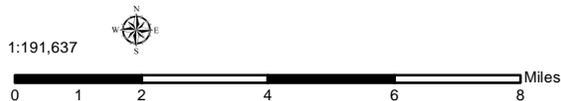
Figure 13 - Total Land Subsidence (cm) in the Fort Grant Road and Willcox Areas, Cochise County
Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data

© MDA 2010 - 2014

Time Period of Analysis: 3.9 Years 05/05/2010 To 03/21/2014

Explanation

- 05/05/2010 To 03/21/2014
- Subsidence Feature
 - Earth Fissures
 - Hardrock
 - Decorrelation/No Data
 - Interstate
 - US
 - State
 - Roads
 - Railway
- Total Land Subsidence (cm)**
- Greater Than 40 cm
 - 25 to 40 cm
 - 15 to 25 cm
 - 10 to 15 cm
 - 6 To 10 cm
 - 4 To 6 cm
 - 2 To 4 cm
 - 1 To 2 cm
 - 0 To 1 cm



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).

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 9/19/2014



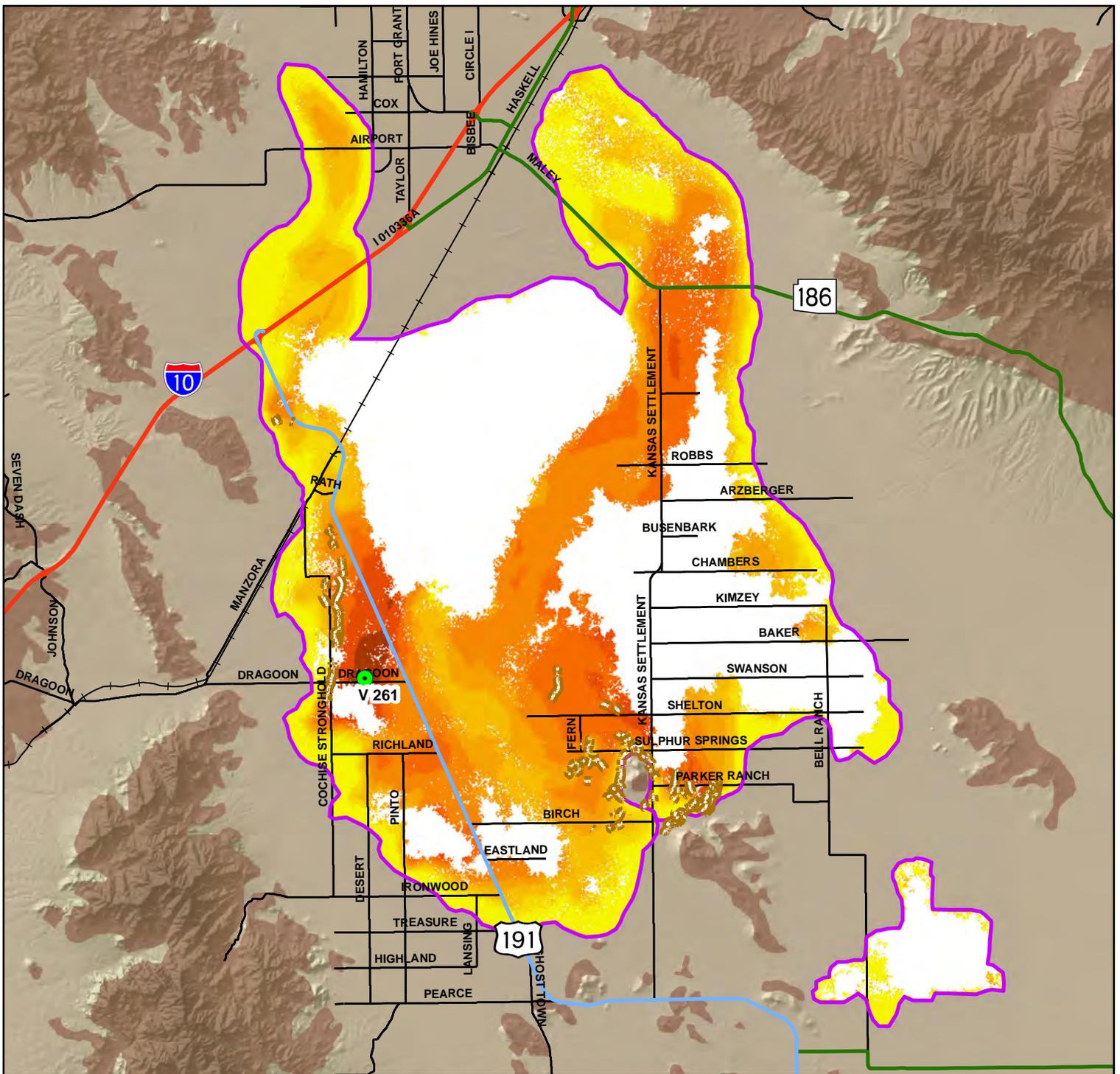
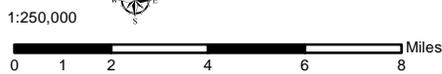


Figure 14 - Total Land Subsidence (cm) in the Willcox and Kansas Settlement Areas, Cochise County © MDA 2010 - 2014
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 3.9 Years 05/20/2010 To 03/21/2014

Explanation

- 05/05/2010 To 03/21/2014
- Subsidence Feature
 - Earth Fissures
 - Survey Monument
 - Hardrock
 - Highways and Interstates**
 - Interstate
 - US
 - State
 - Roads
 - Railway
- Total Land Subsidence (cm)**
- Decorrelation/No Data
 - Greater Than 40 cm
 - 25 to 40 cm
 - 15 to 25 cm
 - 10 to 15 cm
 - 6 To 10 cm
 - 4 To 6 cm
 - 2 To 4 cm
 - 1 To 2 cm
 - 0 To 1 cm



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



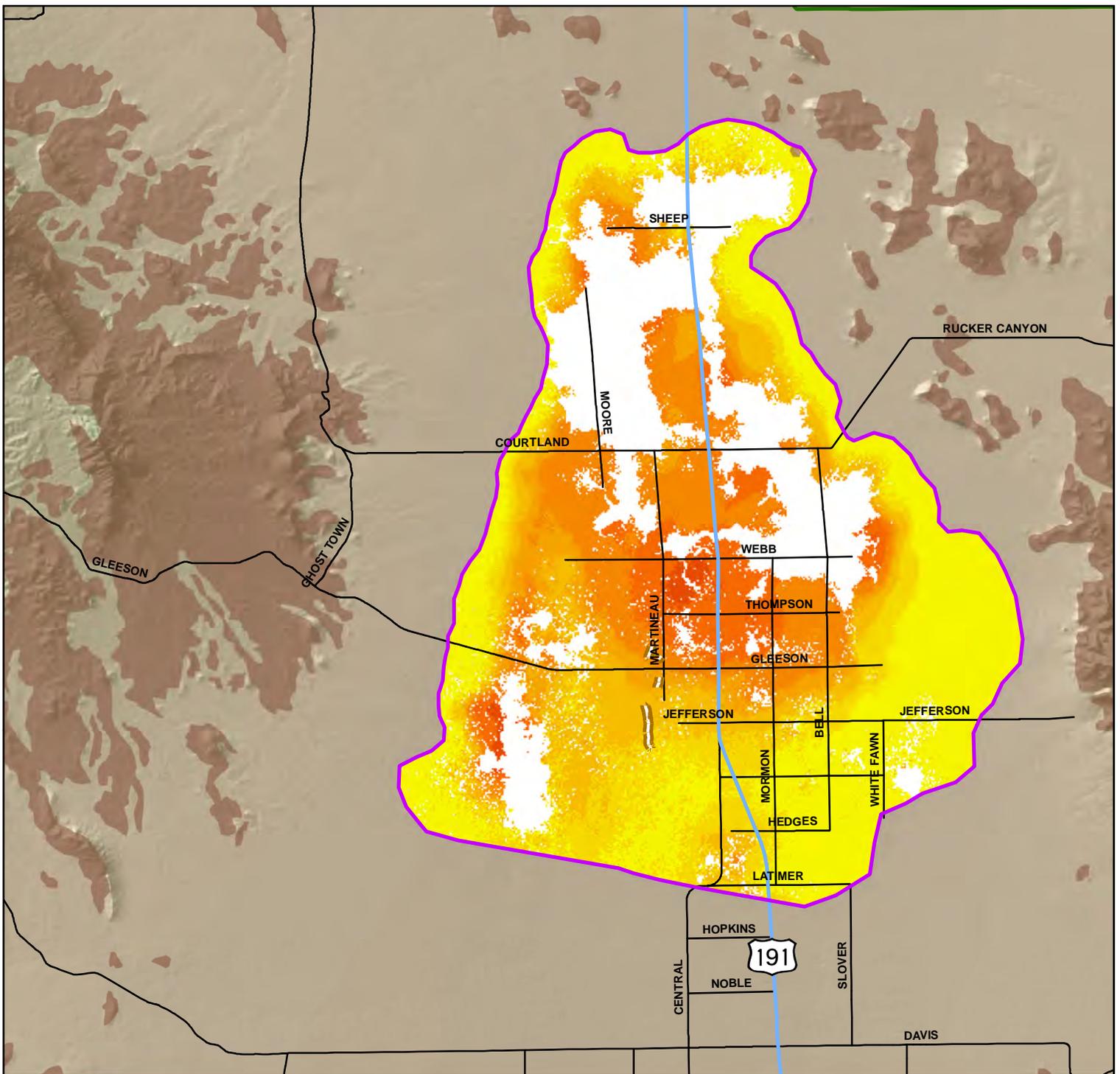


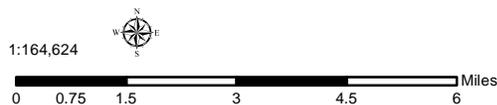
Figure 15 - Total Land Subsidence (cm) in the Elfrida Area, Cochise County
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 3.9 Years 05/05/2010 To 03/21/2014

© MDA 2010 - 2014

Explanation

05/05/2010 To 03/21/2014

<ul style="list-style-type: none"> Decorrelation/No Data Greater Than 40 cm 25 to 40 cm 15 to 25 cm 10 to 15 cm 6 To 10 cm 4 To 6 cm 2 To 4 cm 1 To 2 cm 0 To 1 cm 	<ul style="list-style-type: none"> Subsidence Feature Earth Fissures Hardrock Highways and Interstates Interstate US State Roads Railway
--	--



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



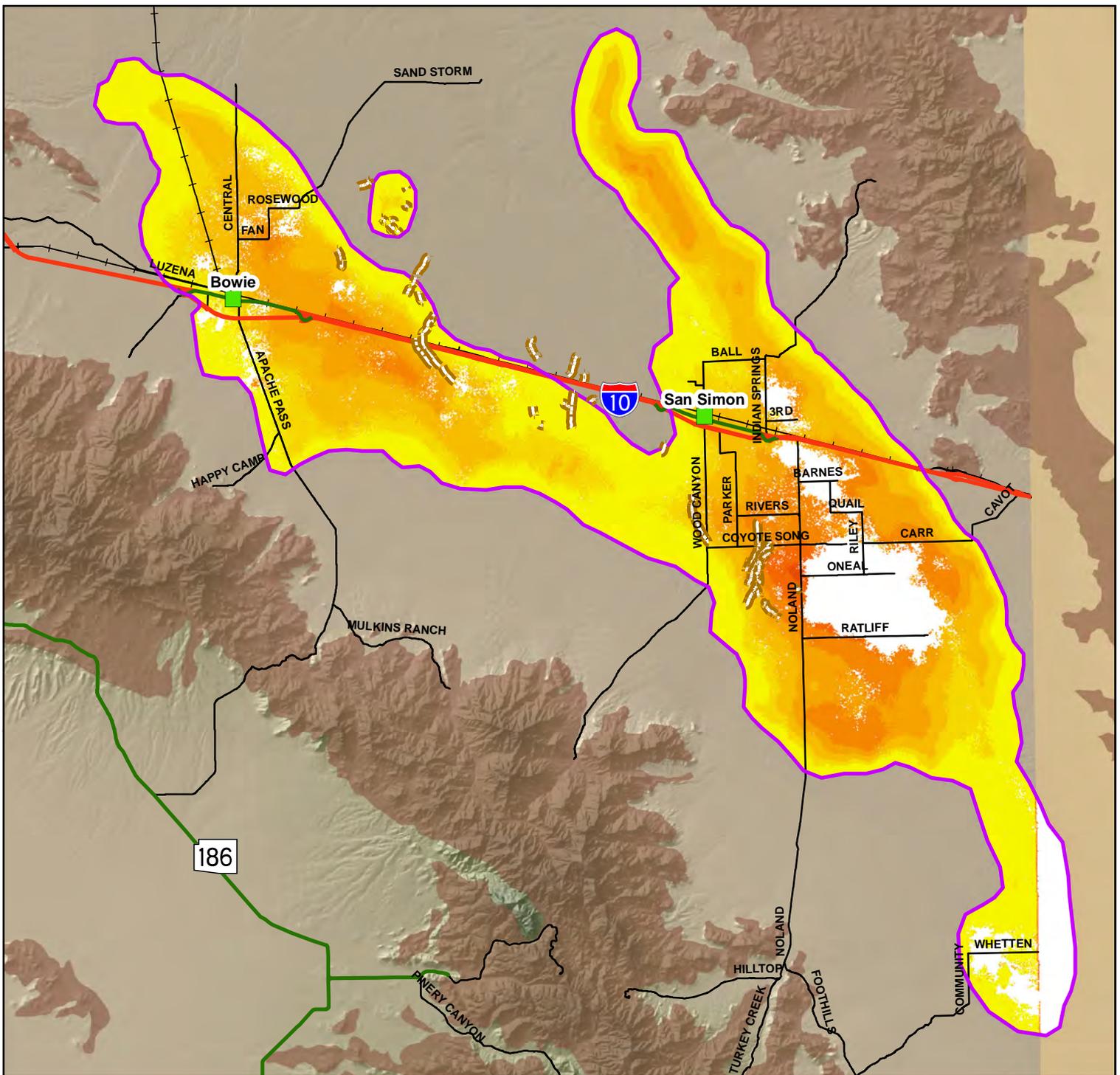


Figure 16 - Total Land Subsidence (cm) in the Bowie and San Simon Areas, Cochise County
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 3.9 Years 05/05/2010 To 03/21/2014

© MDA 2010 - 2014

Explanation

- 05/05/2010 To 03/21/2014
- Subsidence Feature
 - Hardrock
 - Earth Fissures
 - Towns
 - Highways and Interstates**
 - Interstate
 - US
 - State
 - Roads
 - Railway
- Total Land Subsidence (cm)**
- Decorrelation/No Data
 - Greater Than 40 cm
 - 25 to 40 cm
 - 15 to 25 cm
 - 10 to 15 cm
 - 6 To 10 cm
 - 4 To 6 cm
 - 2 To 4 cm
 - 1 To 2 cm
 - 0 To 1 cm

1:288,798



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



Arizona



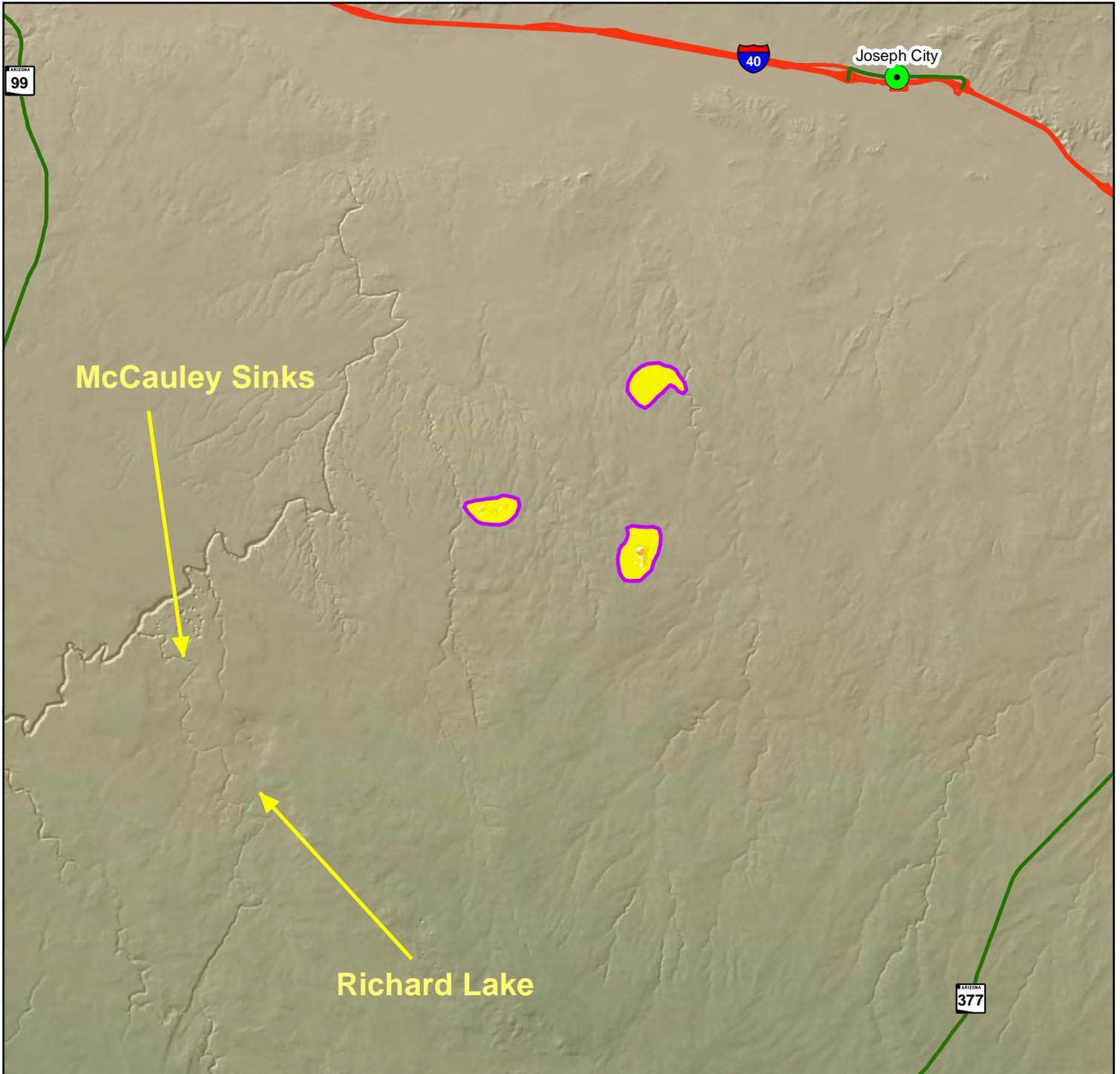


Figure 17 -- Total Land Subsidence (cm) in the Holbrook Basin, Navajo County
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 1.6 Years 10/16/2012 To 05/15/2014

© MDA 2012 - 2014

Explanation
 10/16/2012 To 05/15/2014

Total Land Subsidence (cm)

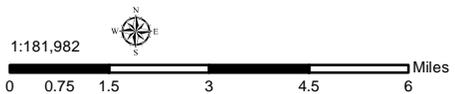
- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Highways and Interstates

- Interstate
- US
- State

Other Symbols

- Subsidence Feature
- City



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



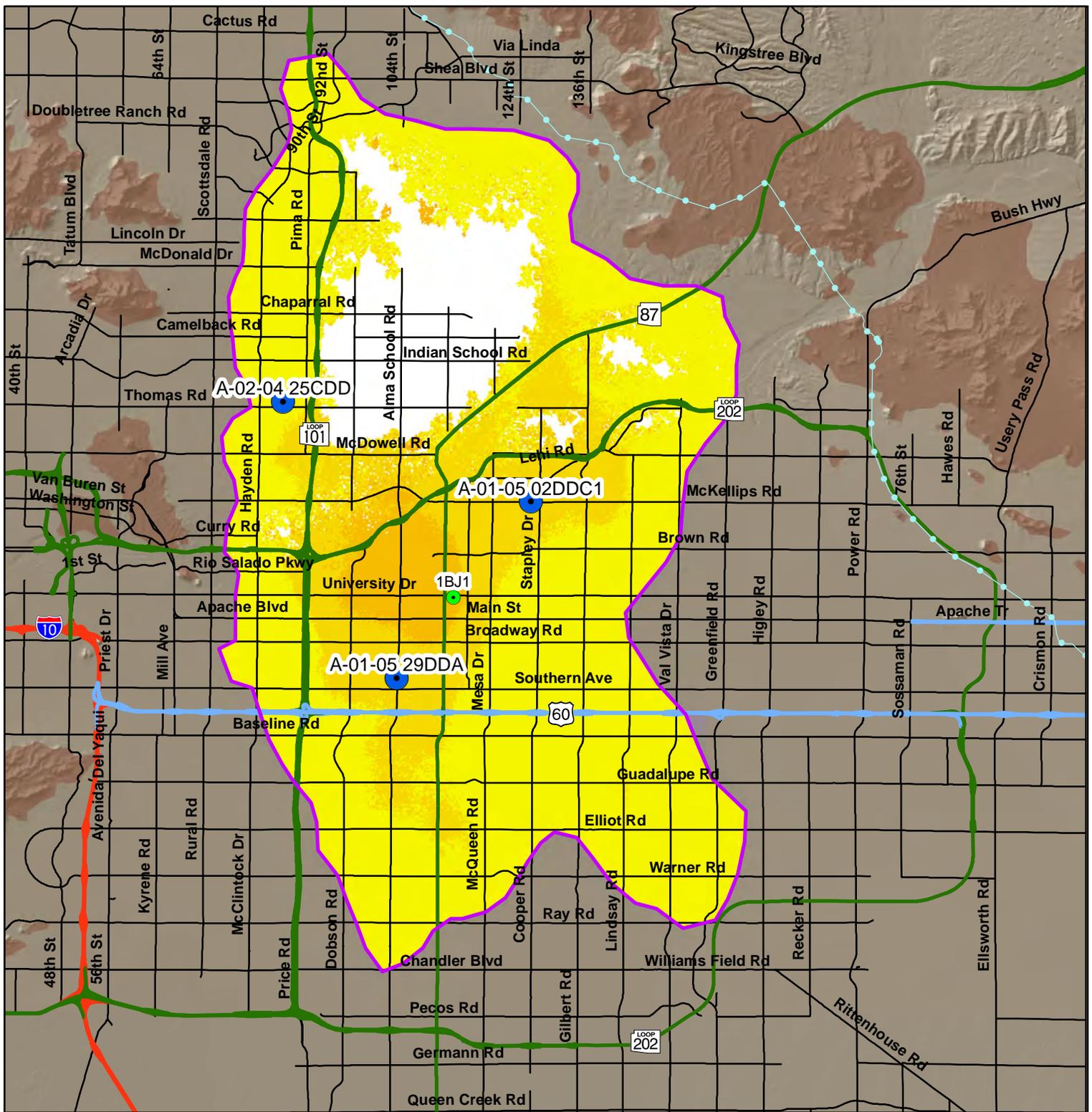


Figure 18 -- Total Land Subsidence (cm) in the Eastern Metropolitan Phoenix Area
 Based on Radarsat-2 Interferometric Synthetic Aperture Radar (InSAR) Data
 Time Period of Analysis: 2.5 Years 11/11/2011 To 04/17/2014

© MDA 2011 - 2014

Explanation

11/11/2011 To 04/17/2014

Total Land Subsidence (cm)

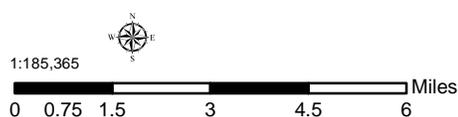
- Decorrelation/No Data
- Greater Than 40 cm
- 25 to 40 cm
- 15 to 25 cm
- 10 to 15 cm
- 6 To 10 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Subsidence Feature

- Hardrock
- Groundwater Level Transducers
- Survey Monument
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads



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).

Coordinate System: NAD 1983 UTM Zone 12N
 Projection: Transverse Mercator
 Datum: North American 1983
 Units: Meter
 Created: 9/19/2014



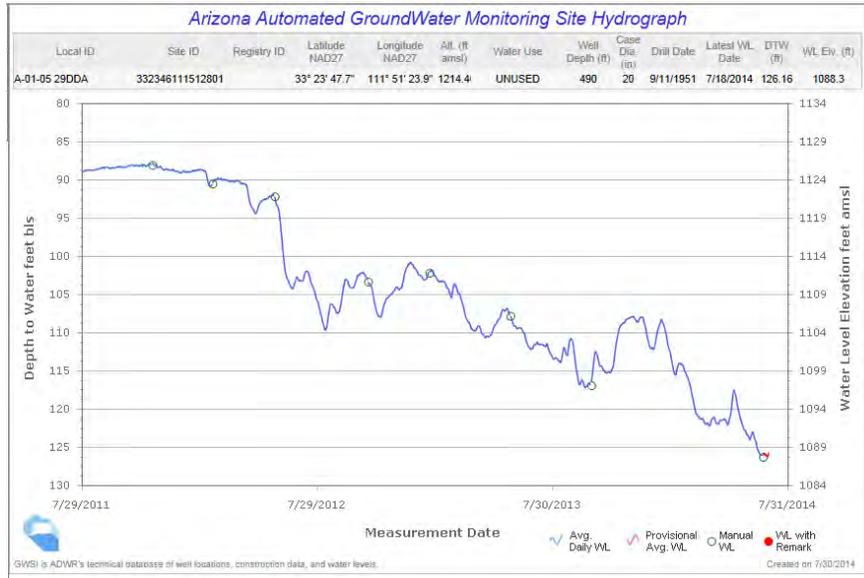
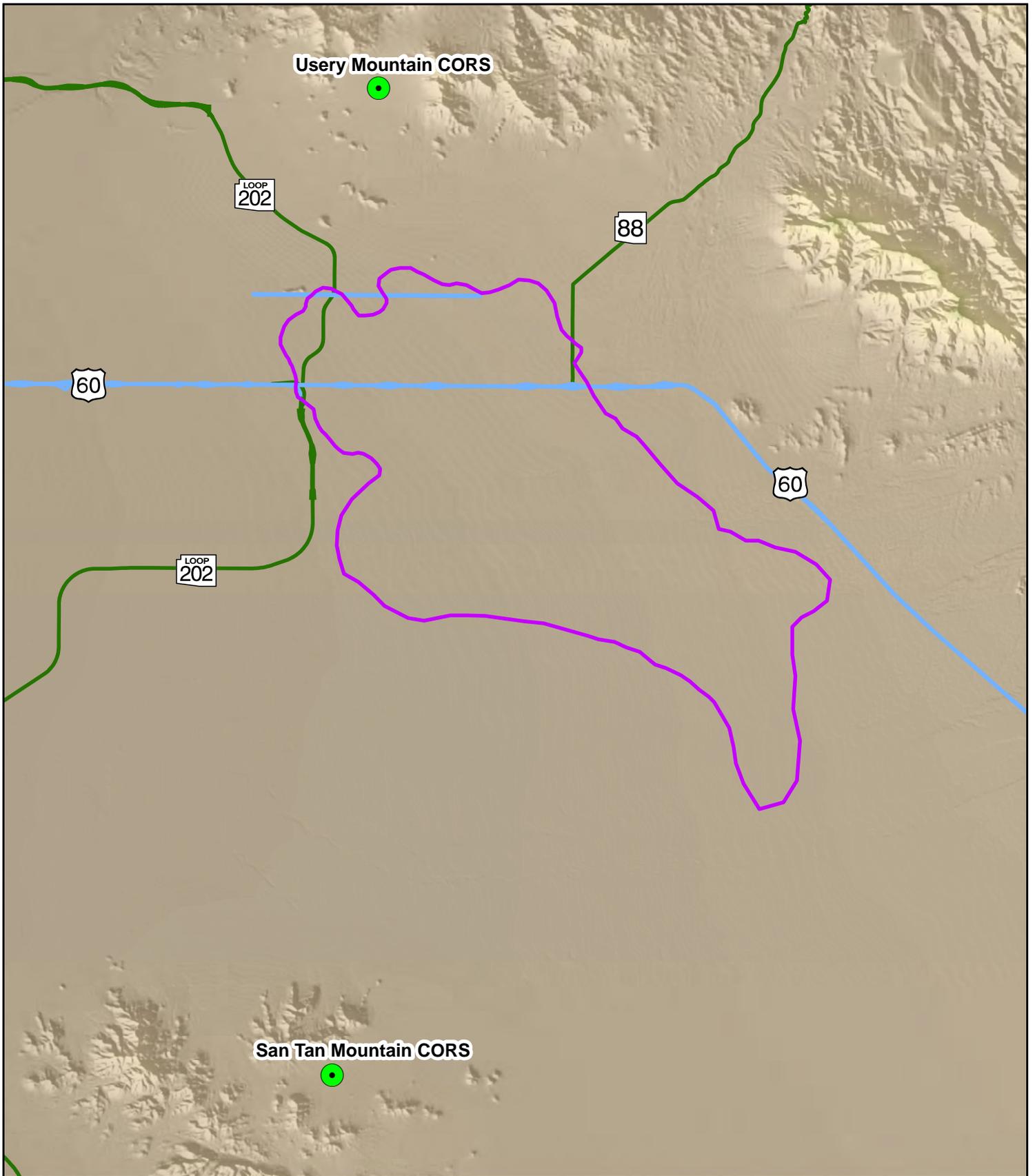


Figure 19 – Hydrographs documenting groundwater declines in the East Valley Land Subsidence Feature



Usery Mountain CORS

LOOP 202

88

60

60

LOOP 202

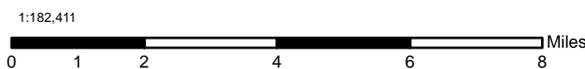
San Tan Mountain CORS

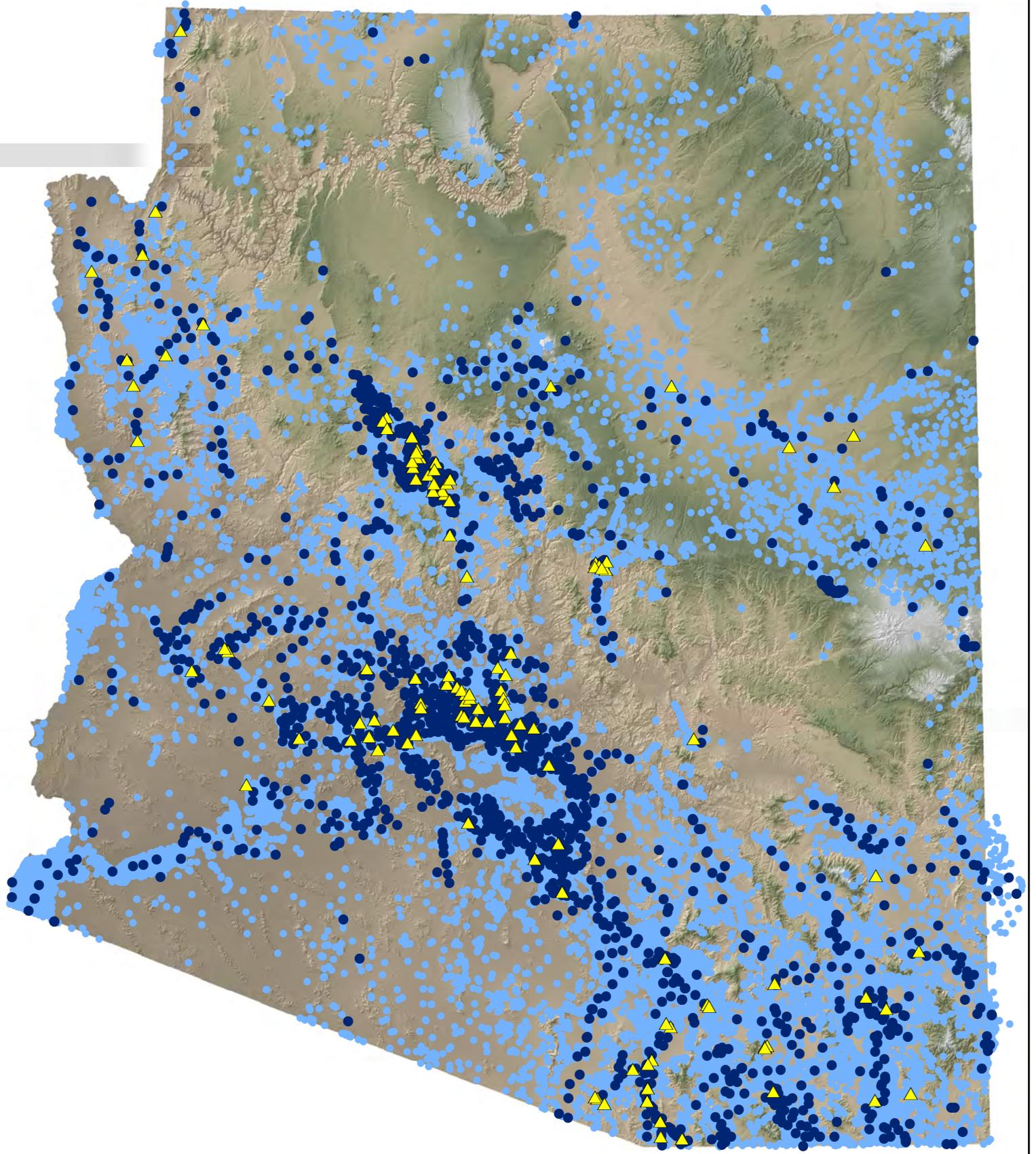
-  Bedrock CORS
-  Hawk Rock Subsidence Feature

Highways and Interstates

-  Interstate
-  US
-  State

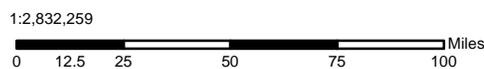
Figure 20 - Two New Bedrock CORS Sites





Groundwater Wells Used to Monitor Annual Changes in Groundwater Levels
 Groundwater Data is Collected by the Basic Data and Transducer Units of the ADWR Hydrology Division

- ▲ Automated Wells (126)
- Index Wells (1,783)
- All GWSI Wells (44,340)



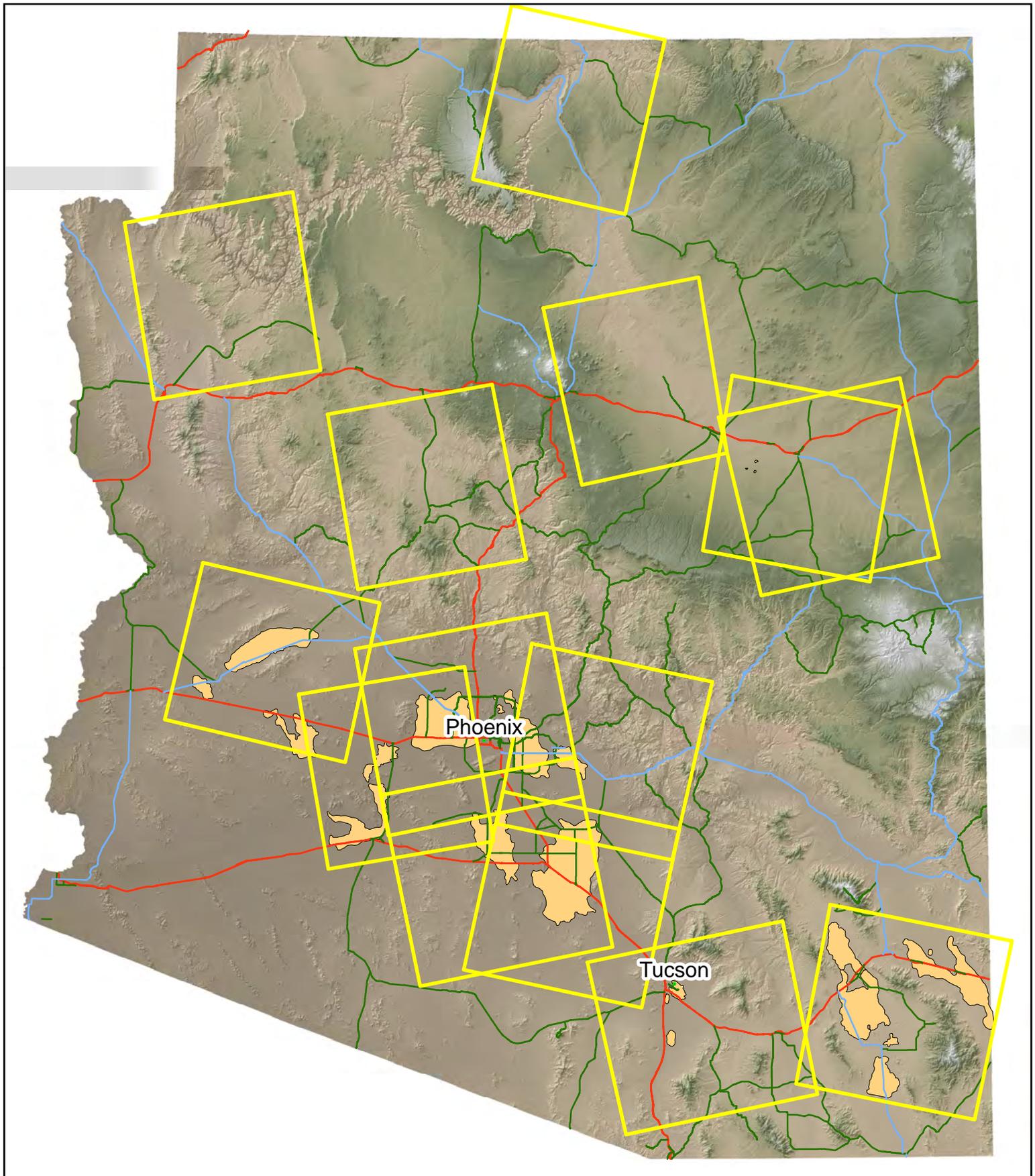


Figure 22 - Current Radarsat-2 Satellite Frames Used to Collect InSAR Data in Arizona
 InSAR Data is Collected, Processed, and Analyzed
 by the Geophysics/Surveying Unit of the ADWR Hydrology Division

- Cities
- Active Land Subsidence Area
- InSAR Frames
- Highways and Interstates**
- Interstate
- US
- State

1:2,832,259

0 12.5 25 50 75 100 Miles



Note: Not all InSAR Frames (Big Chino/Prescott and Mohave County Areas) are showing active land subsidence at this time

