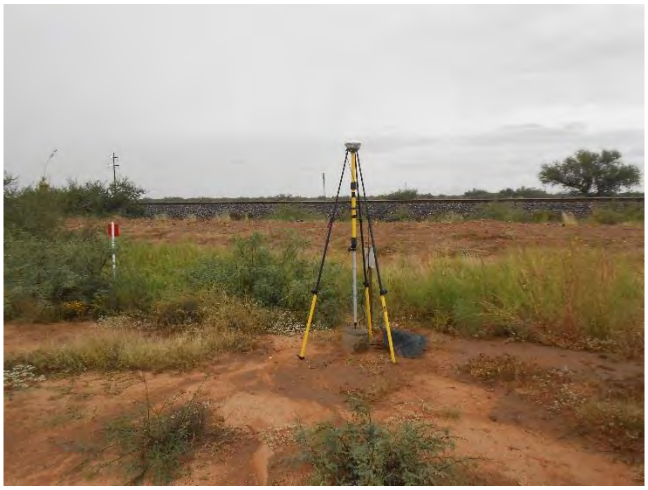
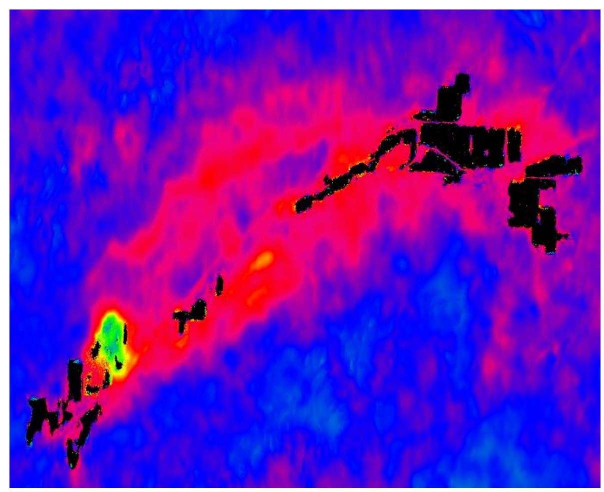
Arizona Department of Water Resources

Land Subsidence Monitoring Report No. 3



January 2017

PROTECTING ARIZONA'S
WATER SUPPLIES
for ITS NEXT CENTURY

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Acknowledgements

This Land Subsidence Monitoring Report was completed with the help of many individuals who collected and/or contributed data, helped with data analysis, or provided editorial help and suggestions. Contributors include, but are not limited to Frank Corkhill, Teri Davis, Paul Ivanich, Brian Mihlfeith, Jeff Trembly, Michelle Moreno, and Douglas MacEachern of the Arizona Department of Water Resources (ADWR) who offered editorial suggestions. Brian Mihlfeith, Jason Mitchell, Nick Valverde, Bryan Dixon, Brian Conway, and Paul Ivanich of ADWR assisted with survey-grade GNSS data and transducer groundwater level data collection.

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, what is known as the Hawk Rock Area, using survey-grade Global Navigation Satellite System (GNSS) 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 GNSS surveying to support the program. With the InSAR data, ADWR has identified more than 26 individual land subsidence features in Arizona, collectively covering more than 3,400 square miles of the state. In addition, the program now cooperates with 14 entities whose financial assistance allows the ADWR to fund the InSAR data collection. ADWR provides land subsidence maps for download from ADWR's website. As of November 2016, 366 land subsidence maps are available for download and are used daily by geologists, hydrologists, engineers, planners, surveyors, floodplain managers, GIS analysts, water resources managers and others.

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 are known 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 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 GNSS 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 GNSS 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 1,500 SAR scenes used to process InSAR data, covering an area greater than 150,000 square miles at a cost of more than $1.4 million, predominantly purchased through grants and cooperators (Figure 1). ADWR has compiled a statewide 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 depending on the satellite used. Using these data, ADWR has identified more than 26 individual land subsidence features in Arizona, collectively covering more than 3,400 square miles (Figure 2). ADWR provides land subsidence maps for download from ADWR's website. As of November 2016, 366 land subsidence maps are available for download and are used daily by geologists, hydrologists, engineers, planners, surveyors, floodplain managers, GIS analysts, water resources managers, and other interested parties. 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 and monitoring floodplains.

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 collecting during the fall and spring months to capture any seasonal deformation signals. At this time, ADWR primarily uses the Radarsat-2 satellite to fulfill its InSAR data needs and is starting to incorporate Sentinel-1A and ALOS-2 datasets. ADWR uses primarily conventional interferometry processing techniques, but has the ability 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 focused the InSAR data collection efforts on the Phoenix and Tucson Active Management Areas (AMAs), where there were well-documented land subsidence features. ADWR used archived InSAR data from the 1990s and 2000s to identify three land subsidence features in the Phoenix AMA and two land subsidence features in the Tucson AMA. The Phoenix AMA land subsidence features are: the West Valley (Figure 3), Northeast Phoenix/Scottsdale (Figure 4), and the Hawk Rock (Figure 5) land subsidence features. The Tucson AMA land subsidence features are: the Central Well-field and the Valencia (Figure 6) land subsidence features (both part of the Tucson land subsidence feature).

Through cooperation 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 with the necessary resources to identify a dynamic land subsidence feature south of Tucson called the Green Valley land subsidence feature (Figure 7) 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 Plain (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 and Graham County. The Cochise and Graham County features currently have the largest magnitude of land subsidence in the entire State between 2008 and 2016, greater than 11 centimeters/year (4.3 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 six years, cumulative land subsidence of 0.62 meters (2.03 feet) has occurred in both the Fort Grant Rd and Kansas Settlement land subsidence features.

InSAR data for the Holbrook Basin helped ADWR identify five 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.

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.

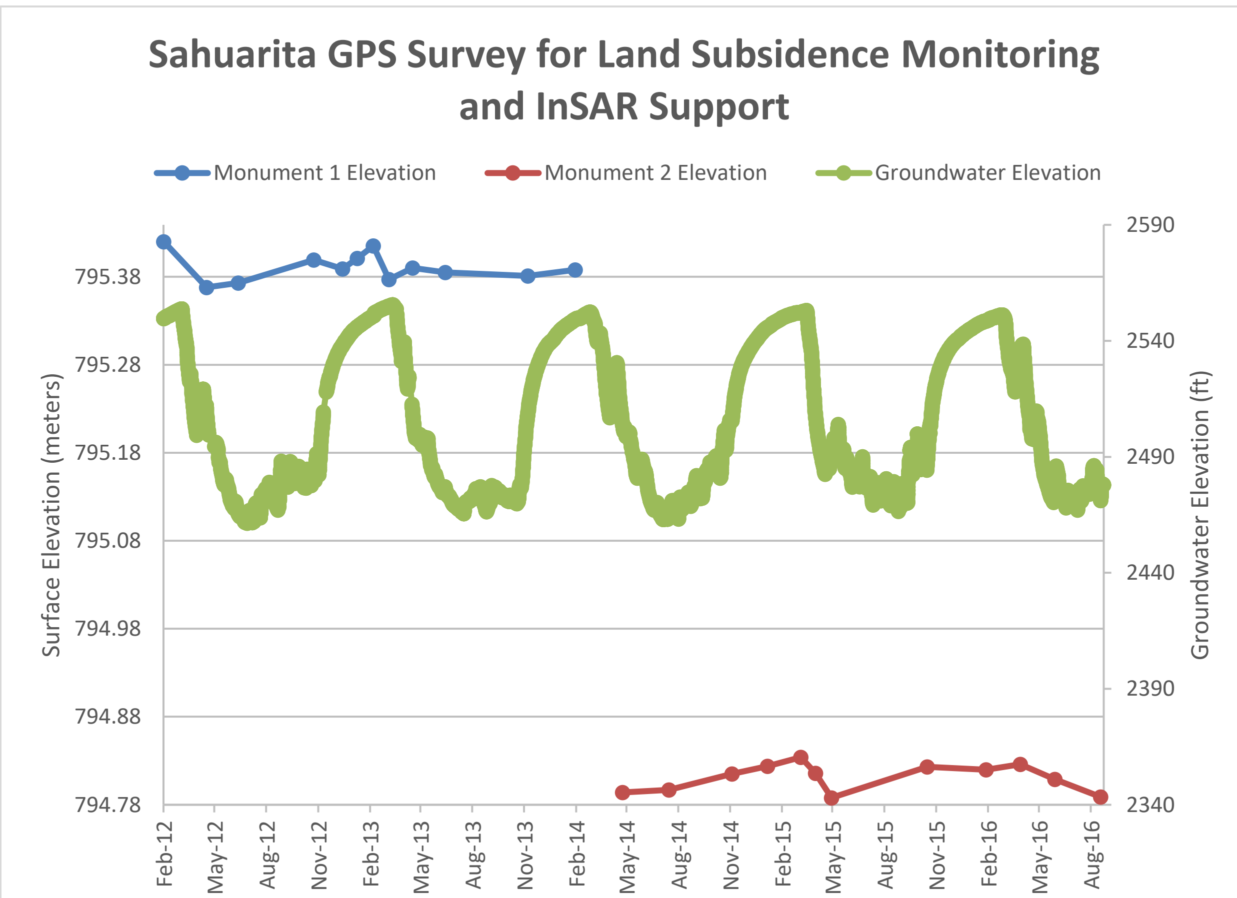
Results of Global Navigation Satellite System Surveying
ADWR collects survey-grade Global Navigation Satellite System (GNSS) data for validating ("ground-truthing") the InSAR data and for continued surveying on existing survey monuments. The GNSS data is

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 Eloy Area (Figure 9), the McMullen Valley Area (Figure 10), the Harquahala Valley Area (Figure 11), the Ranegras Area (Figure 12), the Willcox Groundwater Basin (Figures 13 and 14), the Elfrida Area (Figure 15), the Bowie/San Simon Areas (Figure 16), the Chimney Canyon land subsidence feature in the Holbrook Basin (Figure 17), and the East Valley land subsidence feature (Figure 18).

Land subsidence rates within the Phoenix and Tucson Active Management Areas have decreased between 25% and 90% compared to the 1990s InSAR data and more recent InSAR data. This is a result of decreased groundwater pumping, increased groundwater recharge, and recovering groundwater levels in the AMAs.

Green Valley/Sahuarita Results

Comparison of recent GNSS surveying data (Photo 1) with ADWR groundwater elevation data (Photo 2) from the Sahuarita/Green Valley Area (Figure 7) 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). The existing survey monument (monument 1) was destroyed due to road construction and was replaced with another survey monument (monument 2).



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

Photo 1 - GNSS Surveying along Sahuarita Rd in Green Valley

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

Willcox Groundwater Basin

ADWR started collecting InSAR data over the Willcox Groundwater Basin in 2010 and has documented land subsidence of as much as 11 centimeters (4.3 inches) in 2016. A comparison of InSAR data between the historical 1996 dataset and the recently acquired 2016 dataset, document that land subsidence rates have tripled in some areas.

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

ADWR also collects survey-grade GNSS 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. Since 2011, ADWR has been measuring 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 (2015) ADWR GNSS data with the historical 1945 data, ADWR determined that a total of 1.32 meters (4.31 feet) of land subsidence has occurred at this location since 1945, and 44 centimeters (1.5 feet) of land subsidence has occurred between 2011 and 2015 (Graph 2).

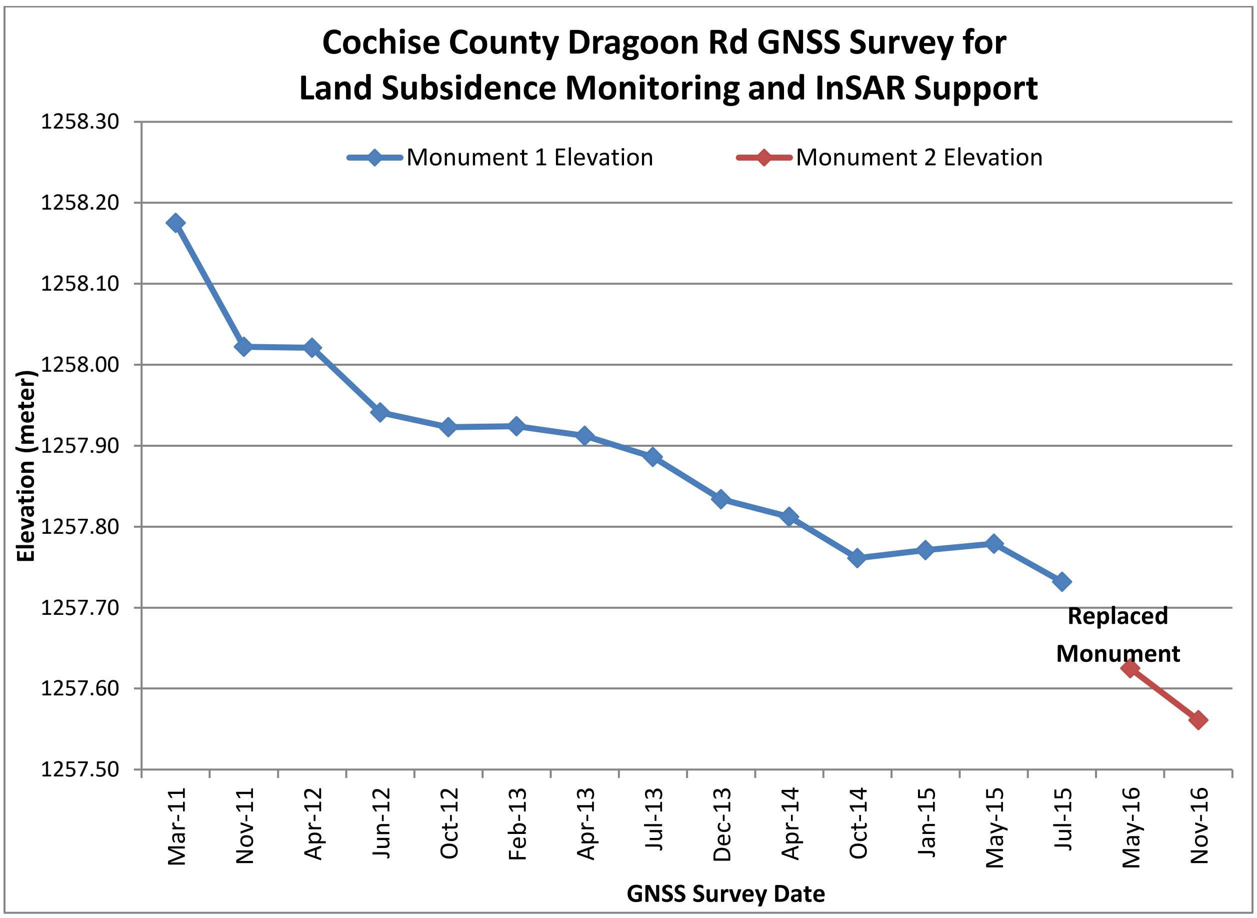
The existing survey monument, V261, (monument 1) was destroyed due to nearby construction and was replaced with a newly-constructed monument in the same location, Dragoon (monument 2).

In the spring of 2016, ADWR conducted a basin-wide GNSS survey of twenty-five survey monuments that were last measured between 1986 and 2008 (Figure 17). Land subsidence of more than 1 meter (3.28 feet) was measured at 4 locations and 1.203 meters (3.95 feet) was the largest magnitude of land subsidence measured in the basin (Table 1).

Earth fissures (http://www.azgs.az.gov/efmaps.shtml) have been an ongoing problem in the Willcox Groundwater Basin and have impacted a natural gas pipeline, roads, and powerlines. The Arizona Geological Survey (AZGS) has mapped 42 miles of earth fissures in the Basin. A protruding well casing (Photo 4) two miles north of Parker Ranch Rd on Robison Rd, and numerous earth fissures located in the Willcox Groundwater 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 GNSS surveying for land subsidence in the Basin.

Photo 4 - Protruding well casing in Cochise County (Photo credit AZGS)

Photo 5 - Sulfur Hills earth fissure in Cochise County



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

Photo 6 – GNSS Surveying in Elfrida

Elfrida

ADWR first discovered land subsidence in the Elfrida Area within the Douglas Irrigation Non-Expansion Area in 2008 with InSAR data. Before 2008, land subsidence had never been documented in the area. InSAR data documented land subsidence of as much as 8.1 centimeters (2.0 inches) in a twelve-month period in the Elfrida Area. In 2014 and 2016, ADWR collected survey-grade GNSS data at five survey monuments (Photo 6) within the Elfrida land subsidence feature (Figure 15) that were last measured between 1980 and 2008. Land subsidence as high as 0.887 meters (2.910 feet) was measured in the area (Figure 15). Earth fissures have also been identified by the AZGS. 1.3 miles of earth fissures have been mapped in the area.

Bowie/San Simon

InSAR data have documented land subsidence of as much as 4.2 centimeters (1.6 inches) in a twelve-month period in the Bowie/San Simon Area within the San Simon Valley Groundwater Sub-basin. In 2014 and 2016, ADWR collected survey-grade GNSS data at two survey monuments (Figure 16) within the Bowie/San Simon land subsidence feature that were last measured in 1970 and 1991. Land subsidence as high as 1.327 meters (4.35 feet) was measured in the area (Figure 16).

Photo 7 – Earth fissure in the Bowie/San Simon feature (Photo Credit AZGS)

Earth fissures (Photo 7) have developed in the San Simon and Bowie area over many years and have crossed I-10 and a natural gas pipeline. The AZGS has mapped 19.9 miles of earth fissures in this area.

McMullen Valley Groundwater Basin

ADWR first delineated land subsidence in the McMullen Valley Groundwater Basin 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 that will be used for on-going ground-truthing of the InSAR data and for land subsidence monitoring in the McMullen Valley Basin.

Photo 8 - Centennial Wash flooding the Town of Wenden in 2010 (Photo credit La Paz County)

Photo 9 - GNSS Surveying in the McMullen Valley

Comparing recent ADWR GNSS survey data collected during February 2013 and April 2016 at monument X 479, indicated that there was 18.7 centimeters (7.3 inches) of land subsidence. ADWR will continue to survey all three survey monuments for monitoring land subsidence in the McMullen Valley (Figure 10).

ADWR also conducted GNSS surveys (Photo 9) at two other survey monuments (H 25, L 25) that were last measured in 1991, to better understand historical and on-going land subsidence in the McMullen Valley (Figure 10). Between 1991 and 2016, H 25 subsided 0.744 meters (2.44 feet) and L 25 subsided 0.965 meters (3.17 feet). In 2014, the AZGS identified and mapped earth fissures in the McMullen Valley near the Town of Aguila.

Photo 10 – Rogers Earth Fissure

Harquahala Valley Groundwater Basin

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 has been collecting survey-grade GNSS data on a survey monument, 4BR1, within the Harquahala Valley since 2014 (Figure 11). Between 2014 and 2016, GNSS data measured 1.4 cm (0.55 in) of land subsidence. Comparing 2016 ADWR GNSS data with the historical 2000 data for 4BR1, a total of 10.1 centimeters (3.98 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 Roger's earth fissure (Photo10) continues to be active, extending at the eastern end. Since 2014, the earth fissure has extended 500 feet.

Ranegras Plain Groundwater Basin

ADWR first discovered land subsidence in the Ranegras Plain Groundwater Basin in 2008 with InSAR data. Before 2008, land subsidence had never been documented in the basin. In 2016, ADWR began collecting survey grade GNSS data on a survey monument, H 478 (Photo 11), within the Ranegras Plain area. The monument was last surveyed in 1991 and between 1991 and 2016, ADWR GNSS data measured 11.5 cm (4.53 in) of land subsidence. ADWR will continue to survey H 478 for land subsidence. A comparison of InSAR data between the historical 1992 - 1997 dataset and the recently acquired 2016 dataset, show that land subsidence rates have tripled in some areas.

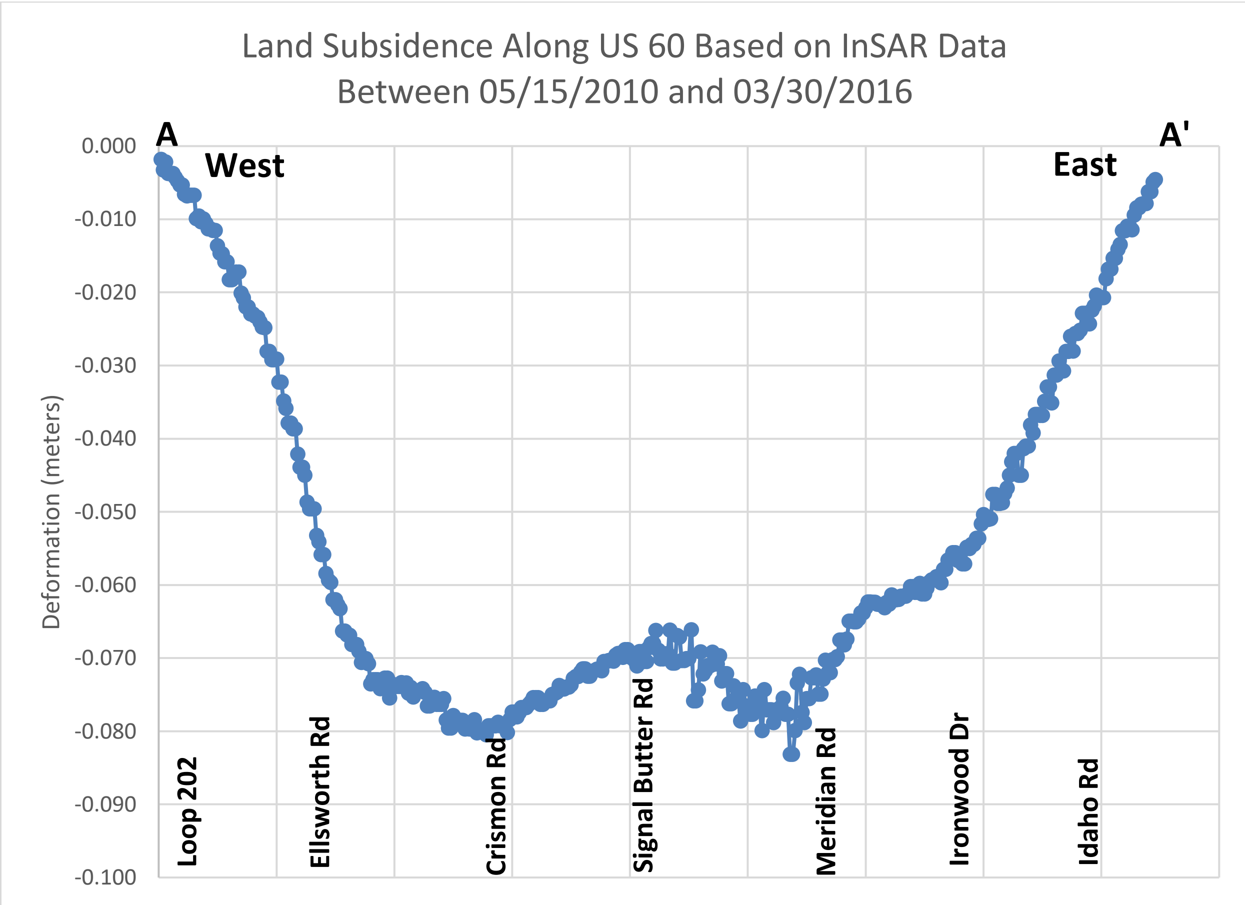
Photo 11 – GNSS Surveying in the Ranegras Plain

Hawk Rock

ADWR has conducted several GNSS surveys in the Hawk Rock Area since 1997. During the fall of 2016, a comprehensive GNSS survey was completed on most monuments in the Hawk Rock Area. Several monuments had been destroyed since the last GNSS survey, but 22 monuments were re-surveyed. Between the 1999 and 2016 surveys, land subsidence as high as 0.436 m (1.43 feet) had been measured (Figure 5) at US 60 and Crismon Rd. The US60 has been significantly impacted by land subsidence (Graph 3).

Photo 12 - Earth Fissure located at Baseline Rd and Meridian Rd in the Hawk Rock feature

The monument, SGC 17, located at US 60 and Meridian Rd, has subsided more than 5 feet since it was first installed and measured in 1973. Numerous earth fissures (Photo 12) have also been identified and mapped by the AZGS in the Hawk Rock area (Figure 5).



Graph 3 – InSAR Profile of US 60 for the Hawk Rock Land Subsidence Feature

Picacho

The Picacho land subsidence feature has been greatly affected by land subsidence. Land subsidence of as much as 19 feet has occurred in the Eloy Area since the 1940s. In 2016, ADWR started collecting GNSS data at a survey monument, W 363, about one-mile north of SR 87 along the Union Pacific railroad in Eloy (Figure 9). W 363 was last surveyed in 1991 and between 1991 and 2016, the monument has subsided 0.531 meters (1.74 feet).

Photo 13 – Earth Fissures in the Picacho Feature

The Picacho land subsidence feature has had earth fissures since the 1950s. The AZGS has mapped 70.2 miles of earth fissures (Photo 13) in the area. Several new earth fissures recently formed during the winter of 2015. Land subsidence and earth fissures have affected the Santa Cruz floodplain and many types of infrastructure in the area (roads, pipelines, canals, and railroads).

Photo 14 - GNSS Surveying in the East Valley

East Salt River Valley

ADWR has been monitoring the East Valley land subsidence feature since it was first detected with InSAR data in 2012. The land subsidence was a result of declining groundwater levels which were caused by increased groundwater pumping. ADWR started collecting GNSS data (Figure 14) at a survey monument, 1BJ1 (Photo 14), in 2013 to monitor the feature.

Automated groundwater monitoring sites in the area (Figure 19) reveal that groundwater levels have started to recover, resulting in an elastic response, with subsequent uplift and a slowing in land subsidence in the area. GNSS data between 2013 and 2014 measured subsidence of 1.9 cm (0.75 in) and between 2014 and 2016 measured uplift of 1.7 cm (0.67 in). Between 2013 and 2016, there is 0.2 cm (0.08 in) of land subsidence.

Continuous Operating Reference Station

Over the past seven years, ADWR has played an important role in site-selection and installation of several GNSS 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 GNSS 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.

Photo 15 - Usery Mountain Bedrock CORS

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 15). 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 129 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.

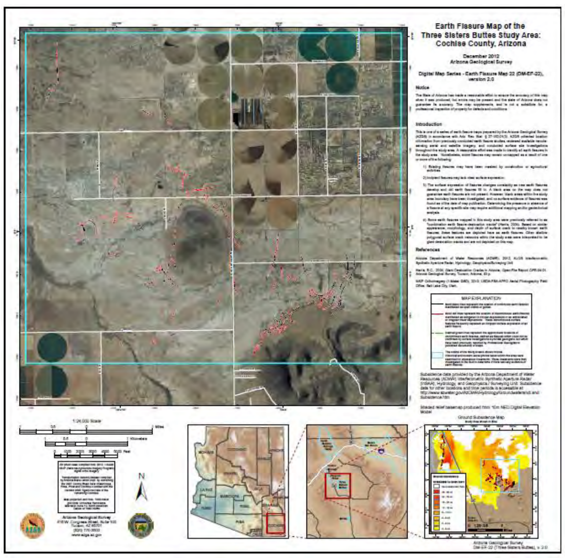


Photo 16 – AZGS Earth Fissure Map

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, buildings, 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 167 miles of earth fissures throughout Arizona. The AZGS provides earth fissure maps (Photo 16) for each earth fissure study area that is available for download through their website. The AZGS currently has 27 earth fissure study area maps and has mapped a total of 167 miles of earth fissures in the State. 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 GNSS-surveying program plays a vital role in supporting the statewide InSAR land subsidence monitoring program. Additionally, the GNSS 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 GNSS 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 educating groups about the InSAR data and how the data can be used to meet their monitoring needs, and further enhance 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 ADWR's website.

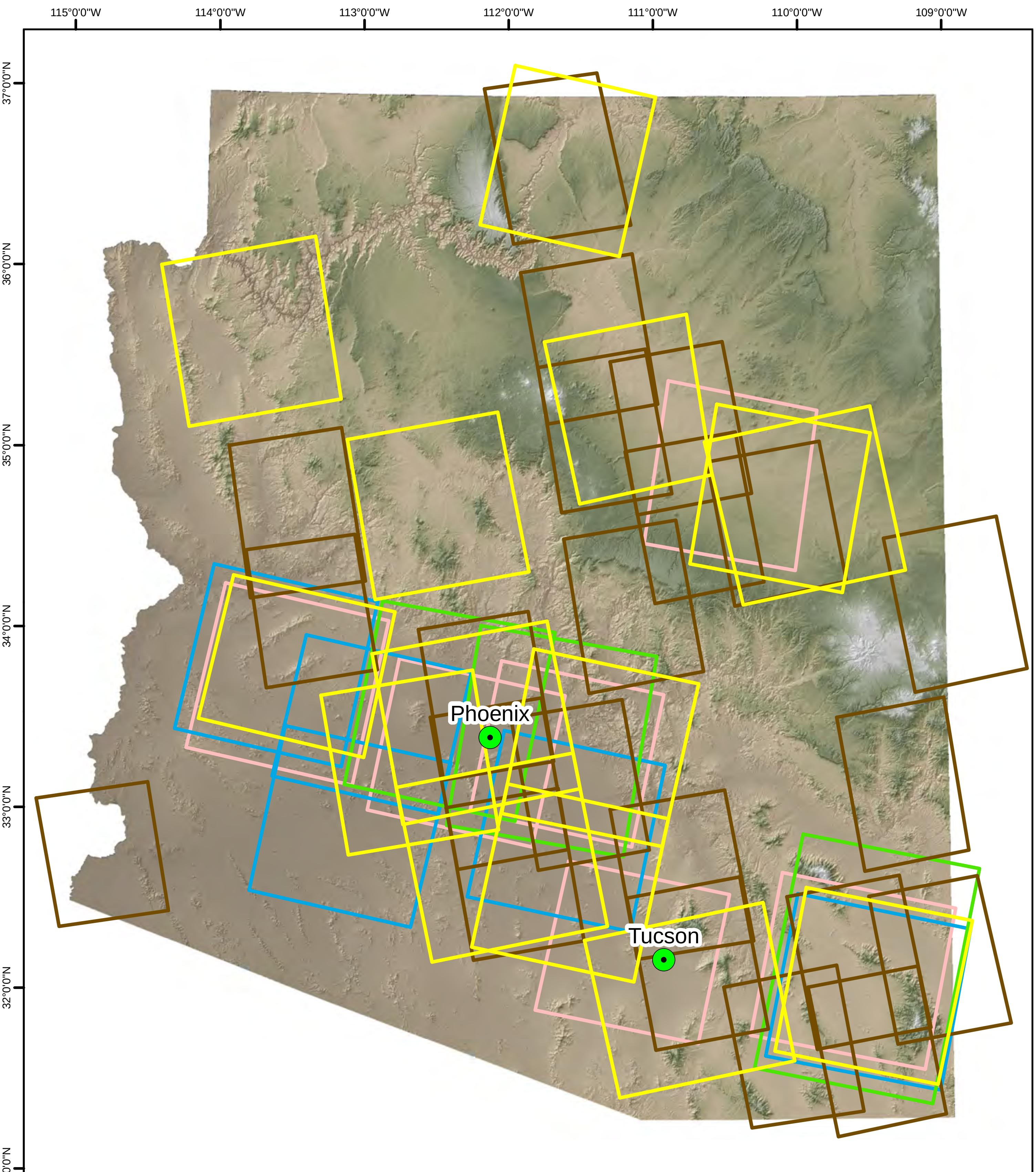


Figure 1 - All Satellite Frames Used to Collect InSAR Data in Arizona
InSAR Data is Collected, Processed, and Analyzed
by the Geophysics/Surveying Unit of the ADWR Hydrology Division

Explanation

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

1:3,200,000

0 15 30 60 90 120 Miles

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 1/3/2017

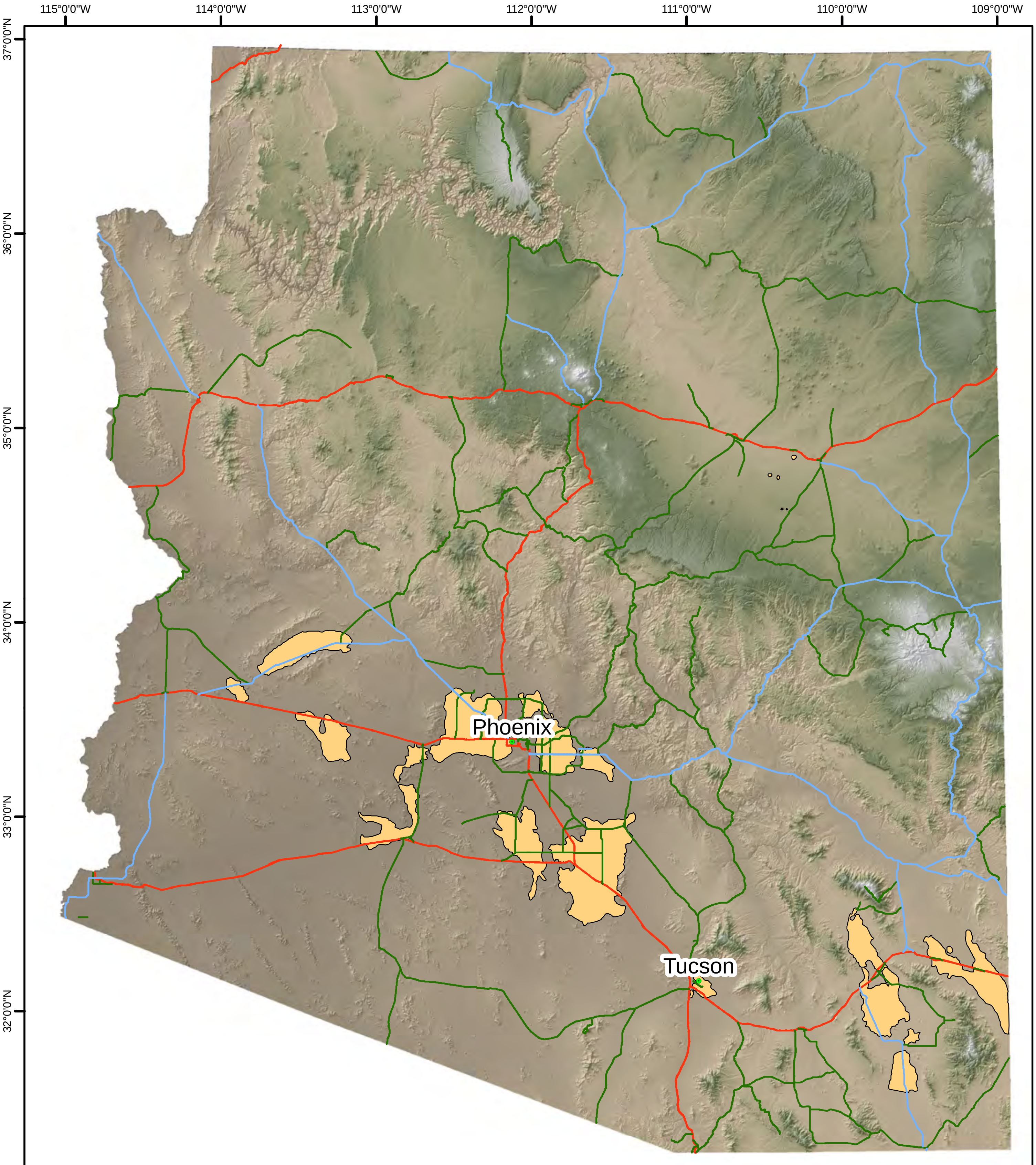


Figure 2 - Active Land Subsidence Areas in Arizona Based on InSAR Data
InSAR Data is Collected, Processed, and Analyzed
by the Geophysics/Surveying Unit of the ADWR Hydrology Division

Explanation

Active Land Subsidence Area

Highways and Interstates

Interstate

US

State

1:2,972,224

0 15 30 60 90 120 Miles

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

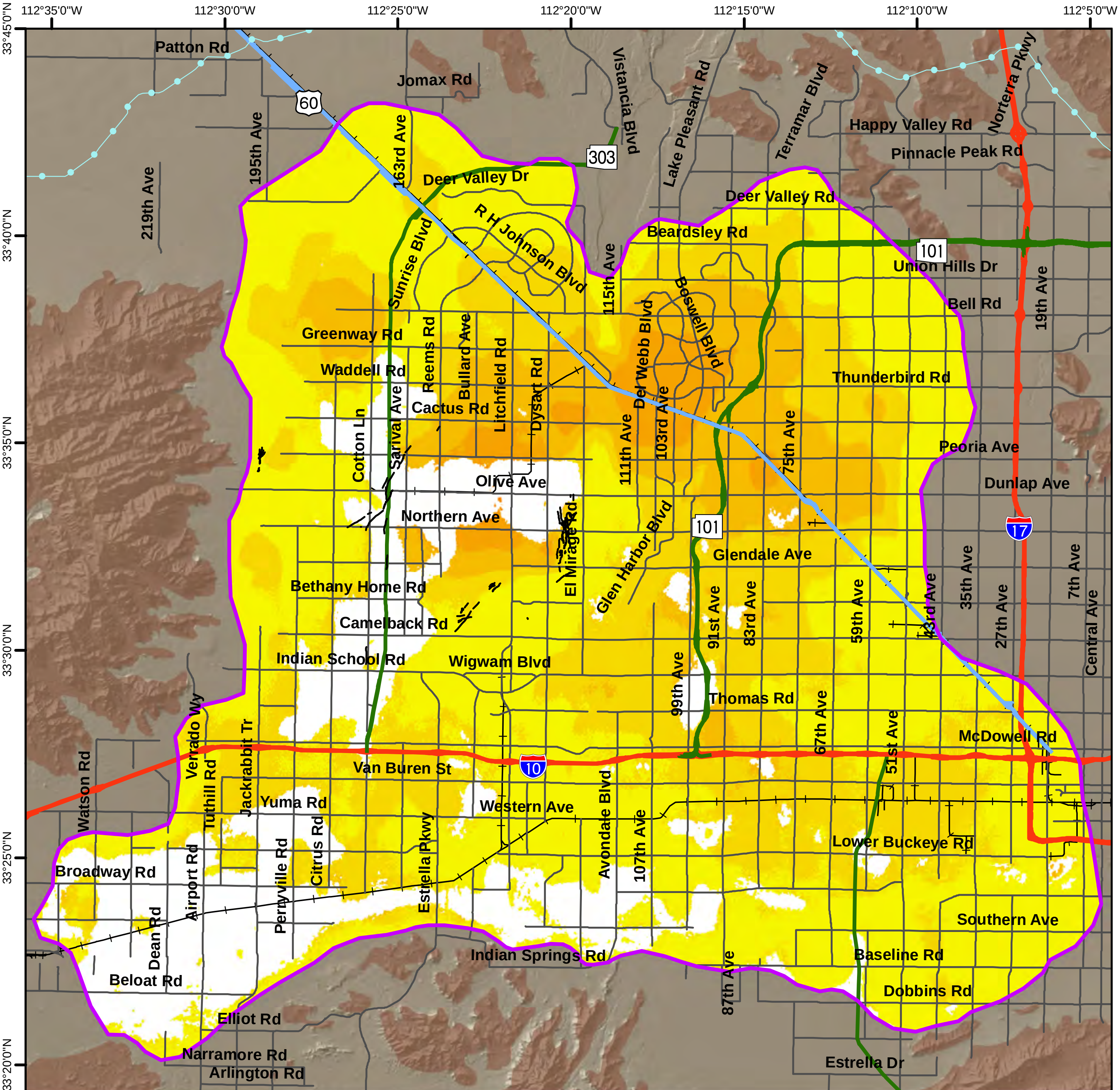


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Figure 3 - Total Land Subsidence in Western Metropolitan Phoenix
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data
Time Period of Analysis: 6.0 Years 05/08/2010 To 04/06/2016

Explanation

05/08/2010 To 04/06/2016
Total Land Subsidence
- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Hardrock
- CAP Canal
- Earth Fissures

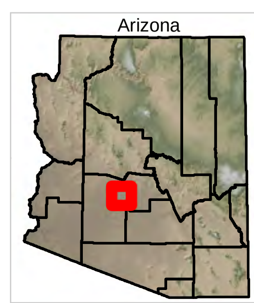
Highways and Interstates
- Interstate
- US
- State
- Roads
- Railway

1:250,000

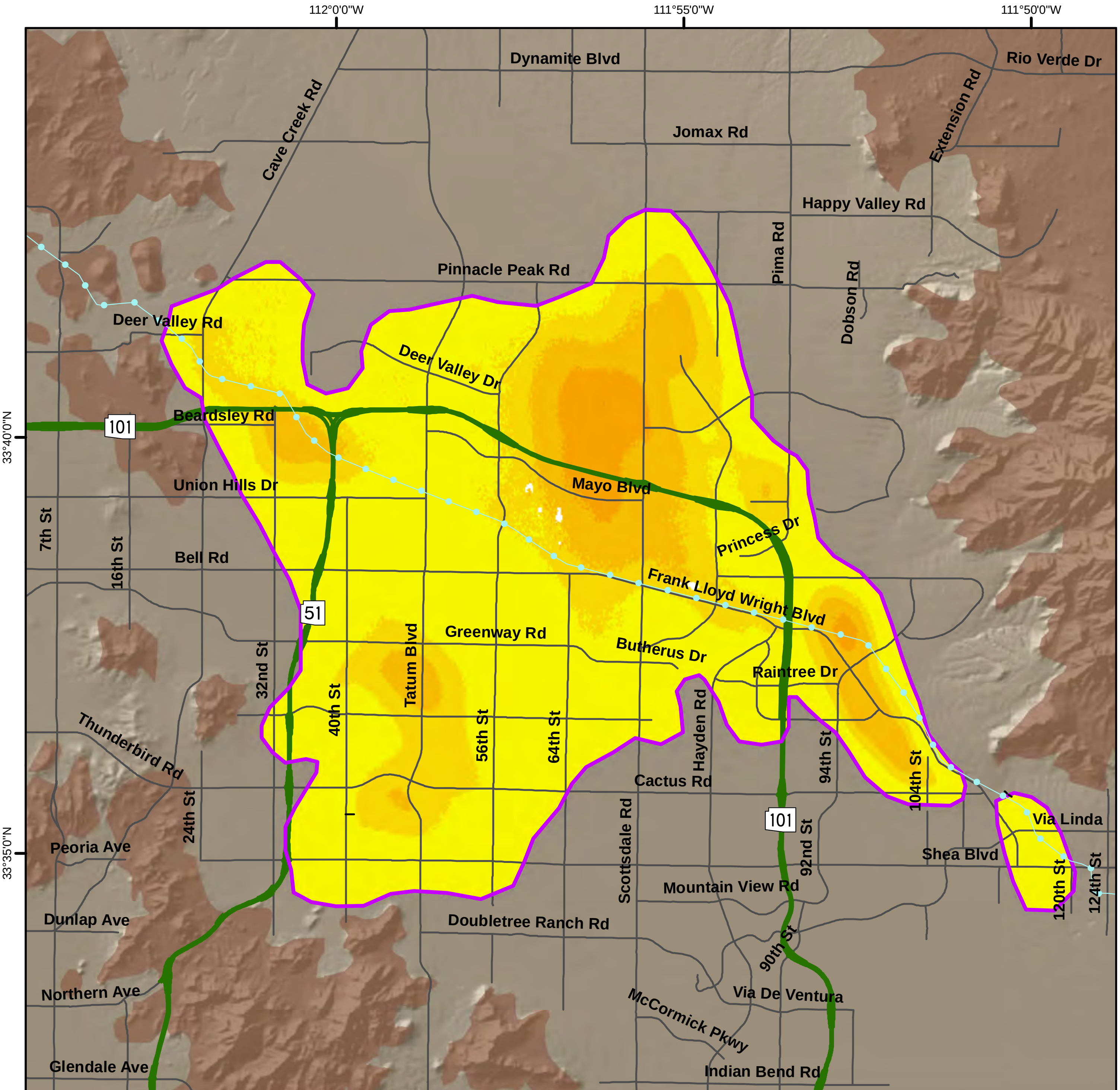
Miles: 0 1.5 3 6 9 12

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.az.gov/EFC



Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016



© MDA 2010 - 2016

Figure 4 - Total Land Subsidence in Northeast Phoenix and Scottsdale Areas
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 6.0 Years 05/08/2010 To 04/06/2016

Explanation

05/08/2010 To 04/06/2016
Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Hardrock
- CAP Canal
- Earth Fissures

Highways and Interstates

- Interstate
- US
- State
- Roads

1:125,000

Miles: 0, 0.75, 1.5, 3, 4.5, 6

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.az.gov/EFC

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

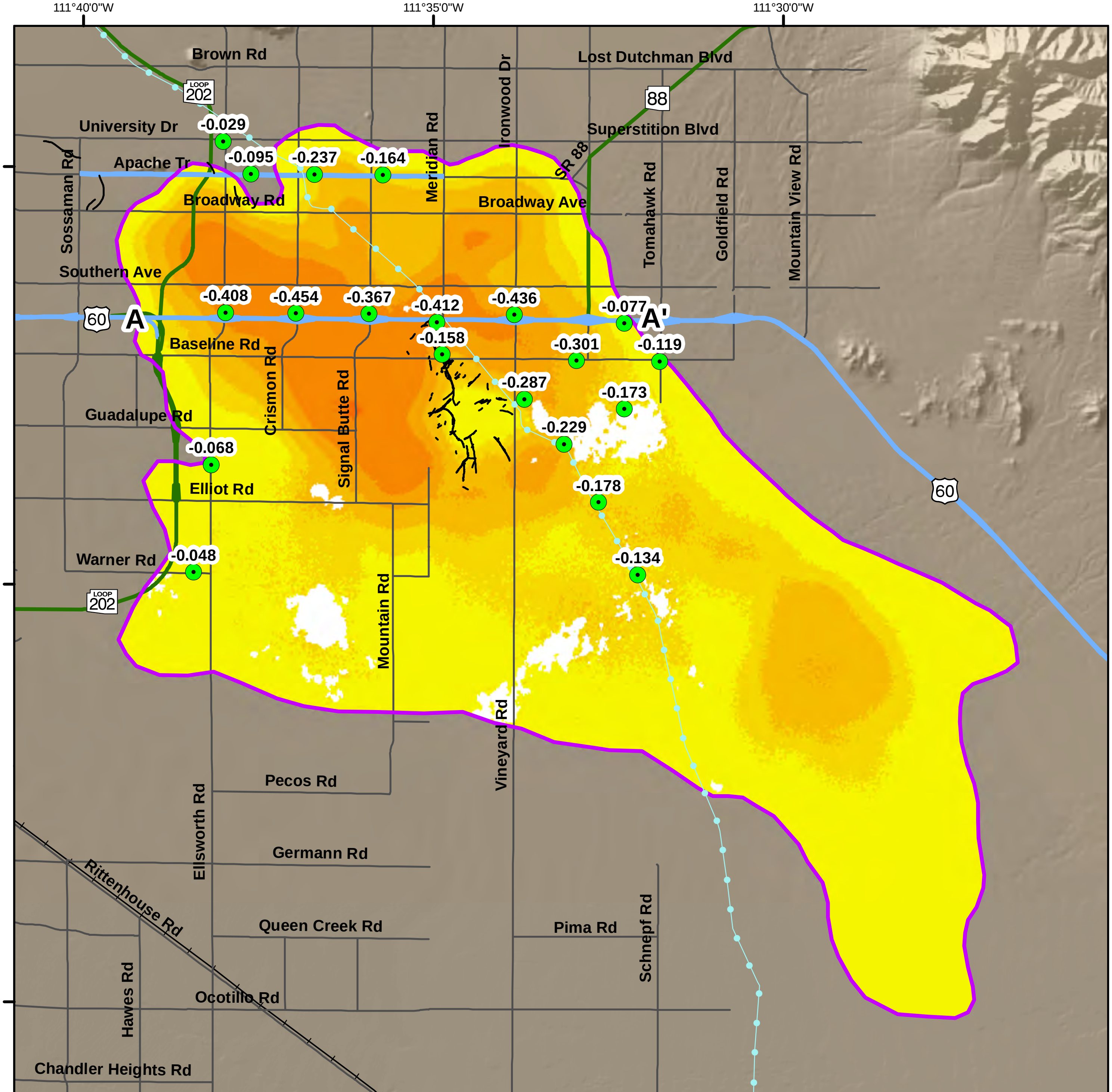


Figure 5 - Total Land Subsidence in the Hawk Rock Area of East Mesa and Apache Junction Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 5.9 Years 05/15/2010 To 03/30/2016

Explanation

05/15/2010 To 03/30/2016

Total Land Subsidence

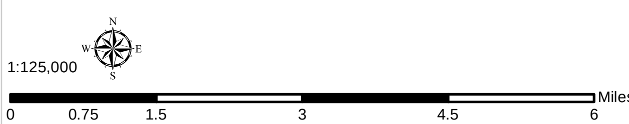
- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- CAP Canal
- Earth Fissures

Highways and Interstates

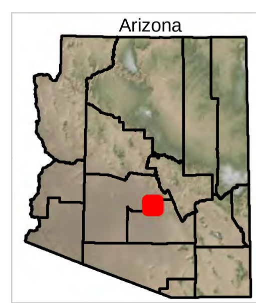
- Interstate
- US
- State
- Roads
- Railway
- Survey Monument

-0.408 subsidece in meters between 1999 and 2016



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.az.gov/EFC



Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

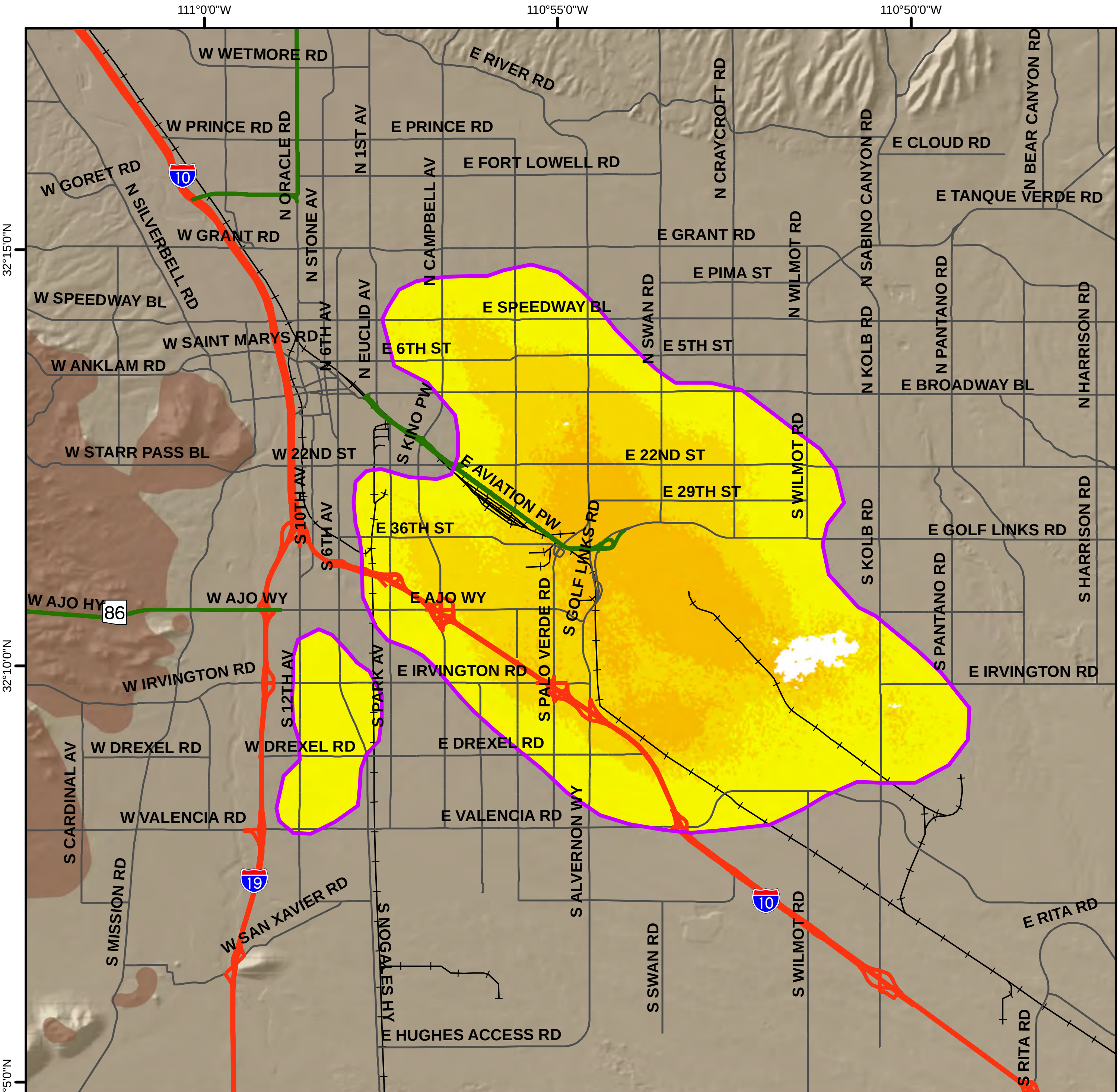


Figure 6 - Total Land Subsidence in the Tucson Metropolitan Area
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data
Time Period of Analysis: 5.8 Years 05/15/2010 To 02/01/2016

Explanation

05/15/2010 To 02/01/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

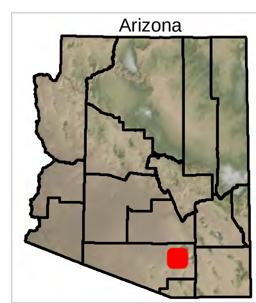
- Subsidence Feature
- Hardrock

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

1:125,000

Miles 0 0.5 1 2 3 4



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: 11/22/2016

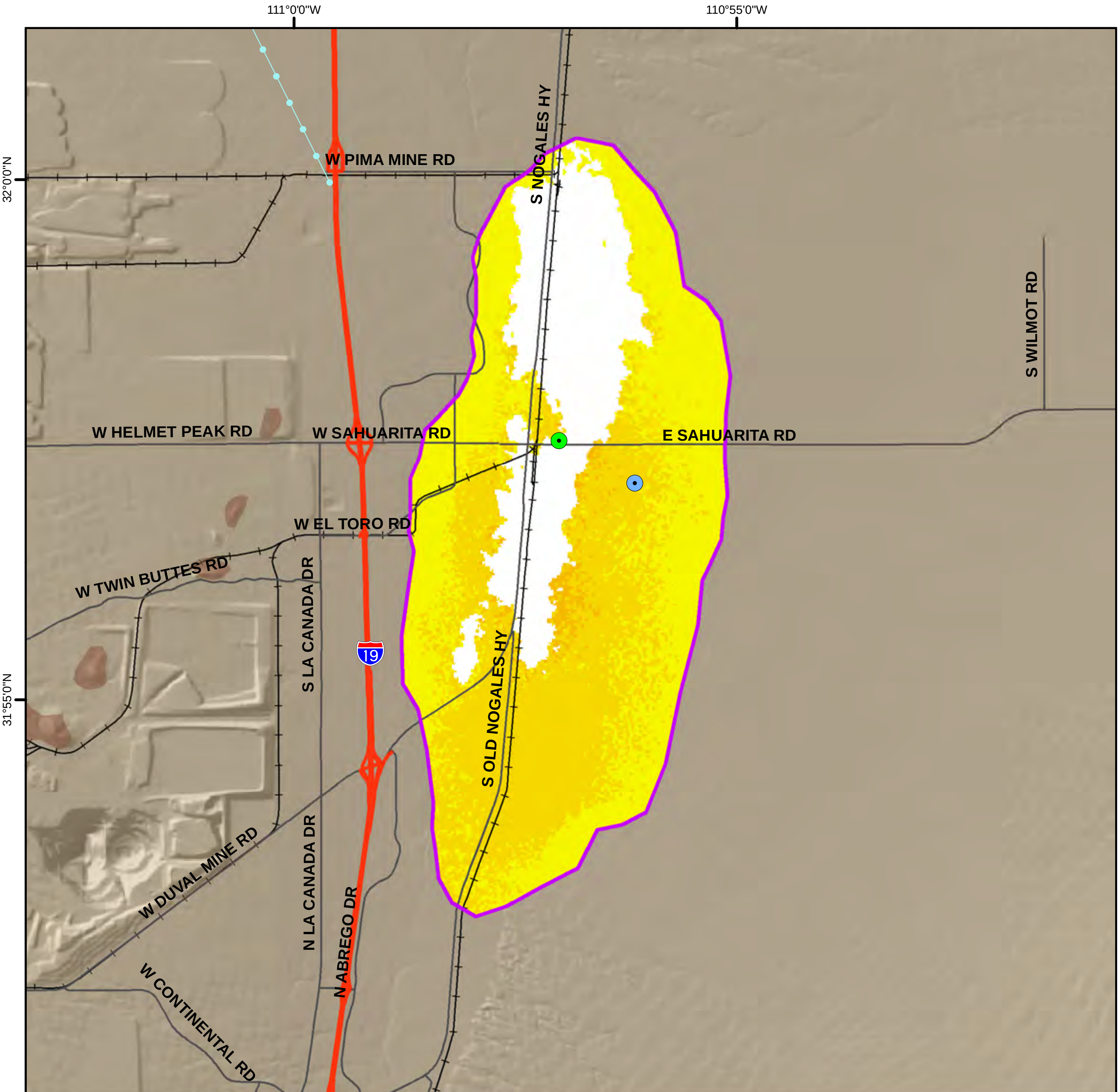


Figure 7 - Total Land Subsidence in the Sahuarita and Green Valley Areas, Pima County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 1.2 Years 02/06/2015 To 04/19/2016

Explanation

02/06/2015 To 04/19/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Groundwater Level Transducer
- Survey Monument
- Hardrock
- CAP Canal

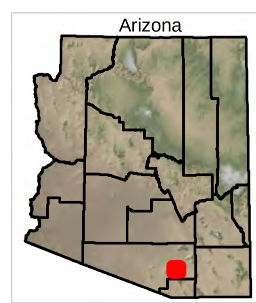
Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

1:100,000

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: 11/22/2016

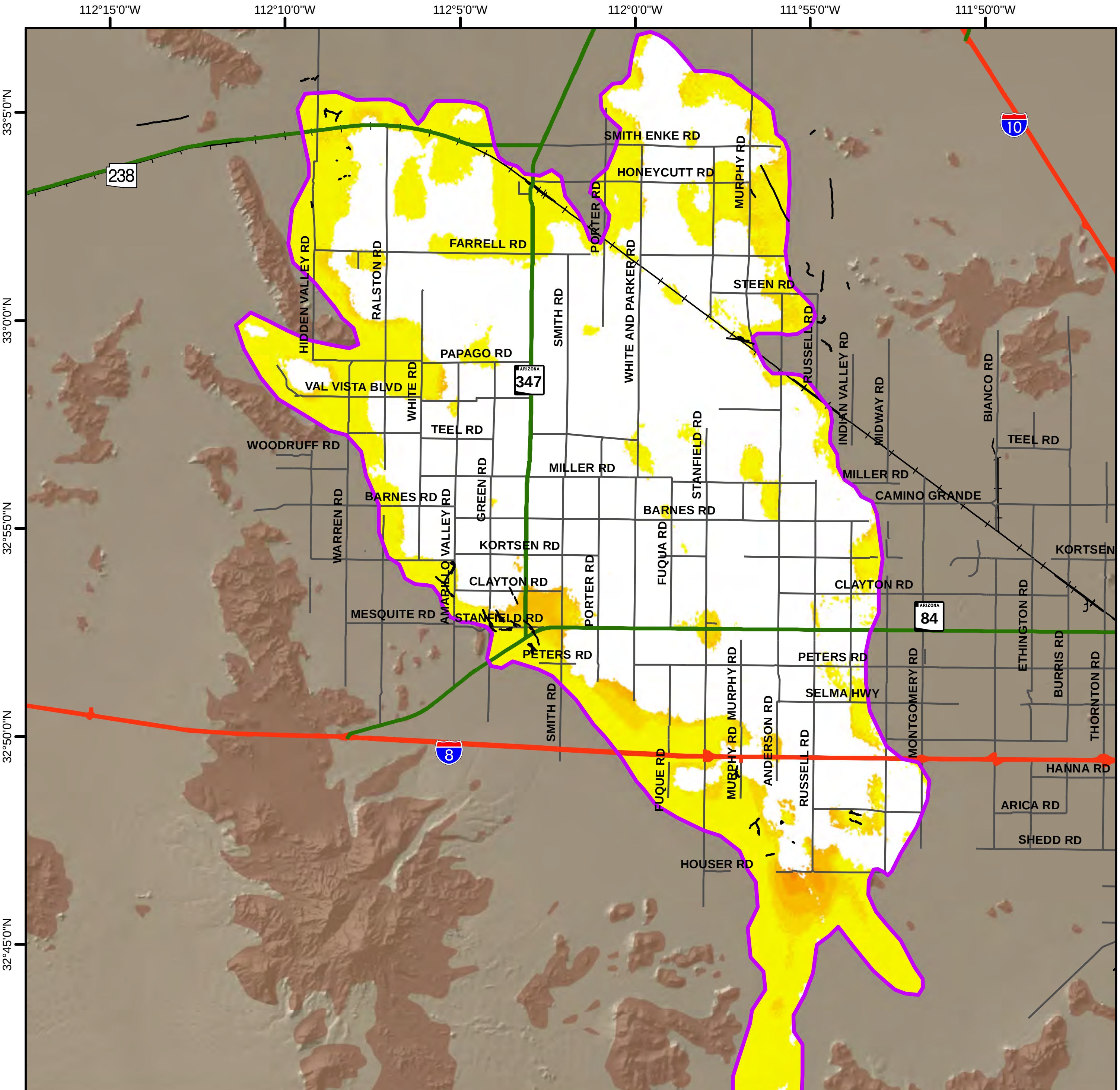


Figure 8 -Total Land Subsidence in the Maricopa-Stanfield Sub-Basin, Pinal County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 6.0 Years 05/08/2010 To 03/13/2016

Explanation

05/08/2010 To 03/13/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

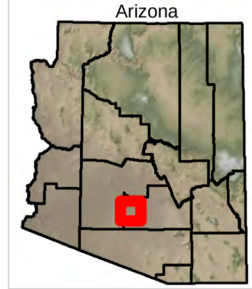
- Subsidence Feature
- Hardrock
- Earth Fissures

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

1:250,000

0 1.25 2.5 5 7.5 10 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).

Earth fissures were mapped by the Arizona Geological Survey.
For information on earth fissures visit: www.azgs.az.gov/EFC

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

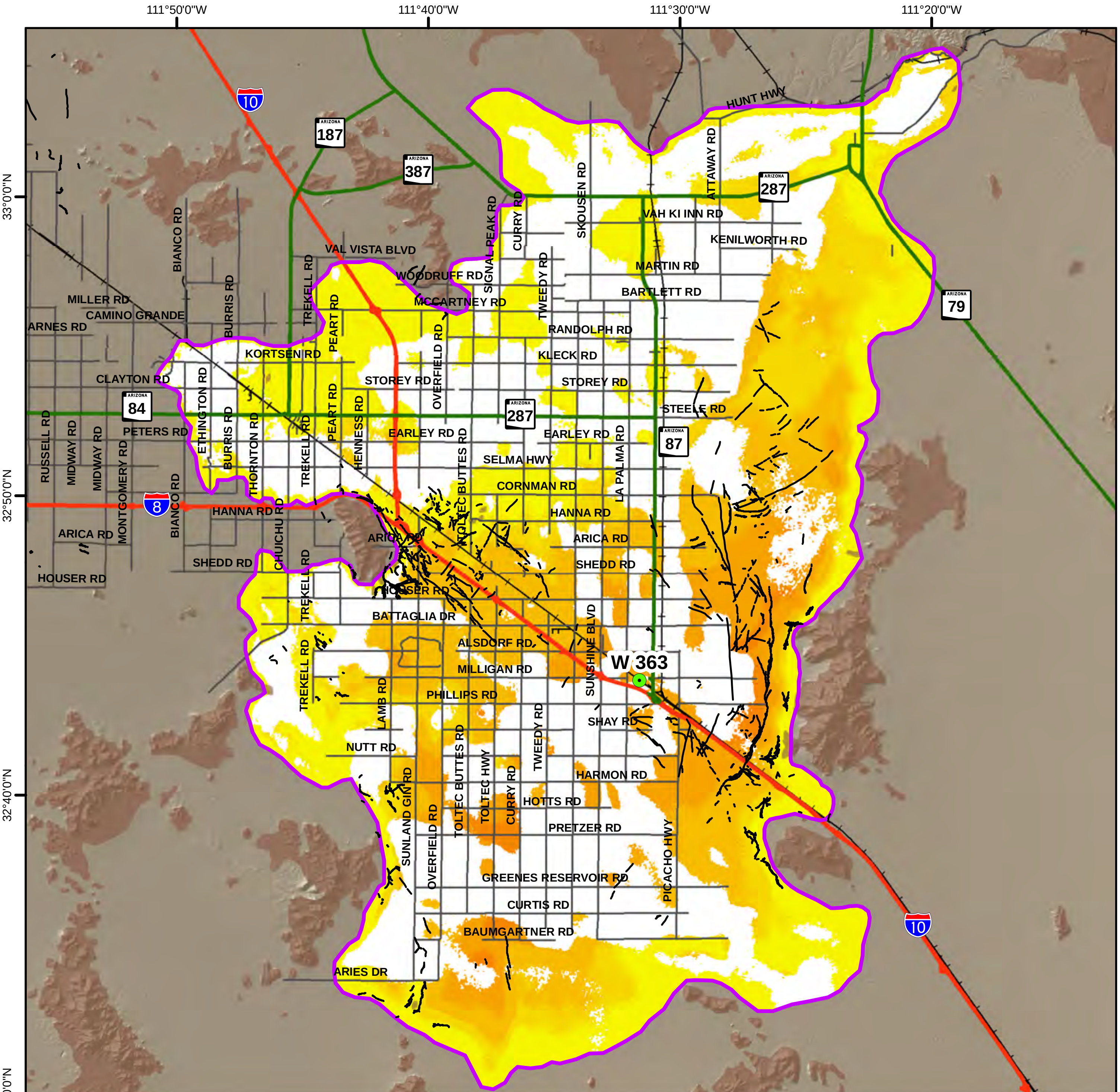


Figure 9 - Total Land Subsidence in the Eloy Sub-Basin, Pinal County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 5.9 Years 05/15/2010 To 03/30/2016

Explanation

05/15/2010 To 03/30/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Survey Monument
- Hardrock
- Earth Fissures

Highways and Interstates

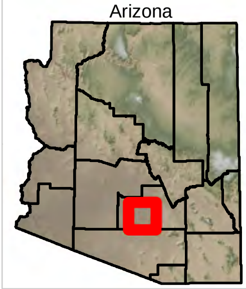
- Interstate
- US
- State
- Roads
- Railway

1:347,876

0 1.75 3.5 7 10.5 14 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).

Earth fissures were mapped by the Arizona Geological Survey. For information on earth fissures visit: www.azgs.az.gov/EFC



Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

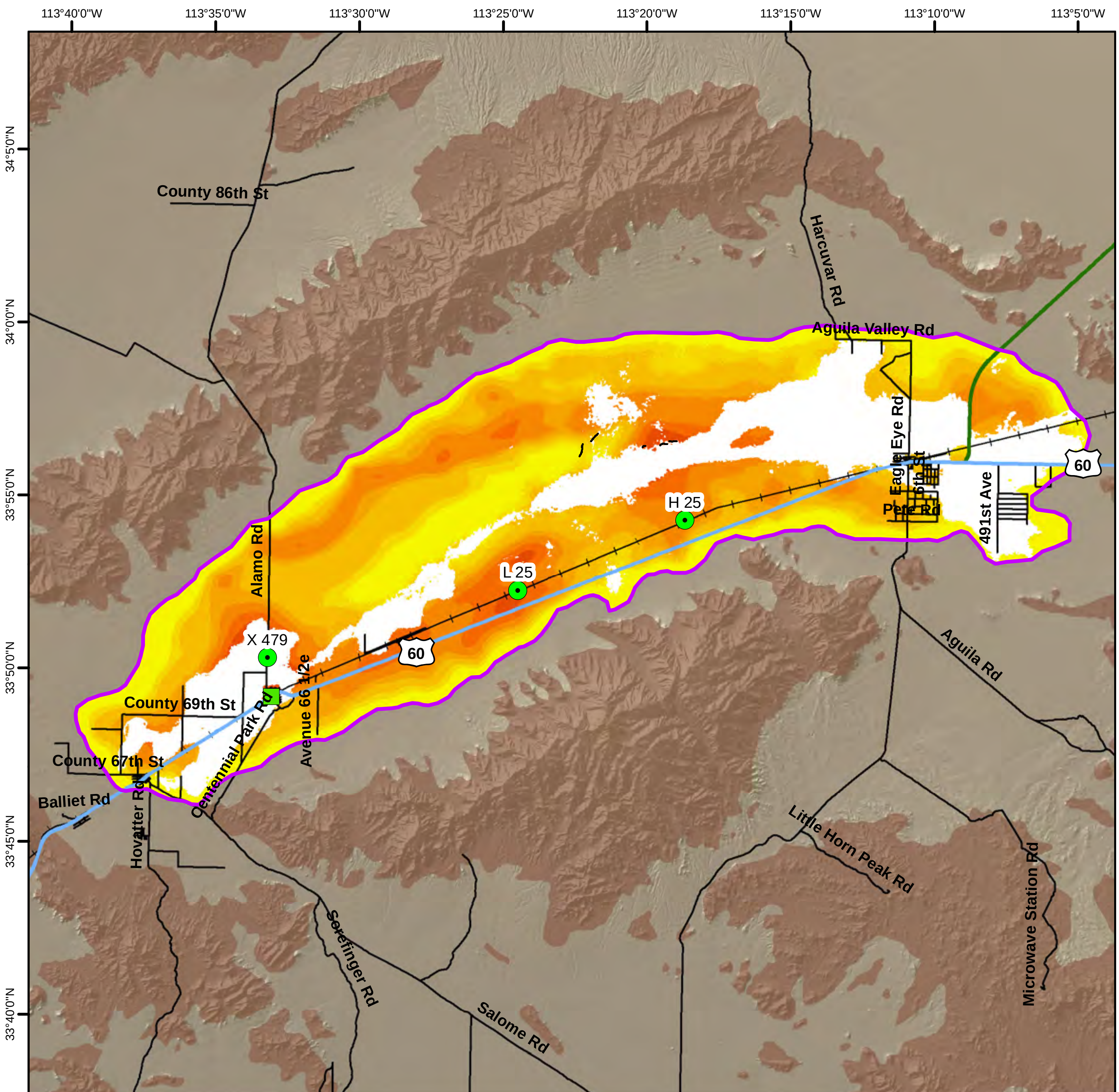


Figure 10 - Total Land Subsidence in the McMullen Valley, Maricopa and La Paz Counties
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data
Time Period of Analysis: 6.0 Years: 05/01/2010 To 03/30/2016

Explanation

05/01/2010 To 03/30/2016
Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Survey Monument
- Hardrock
- Town of Wenden
- Earth Fissures

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

1:300,000

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).

Earth fissures were mapped by the Arizona Geological Survey.
For information on earth fissures visit: www.azgs.az.gov/EFC

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

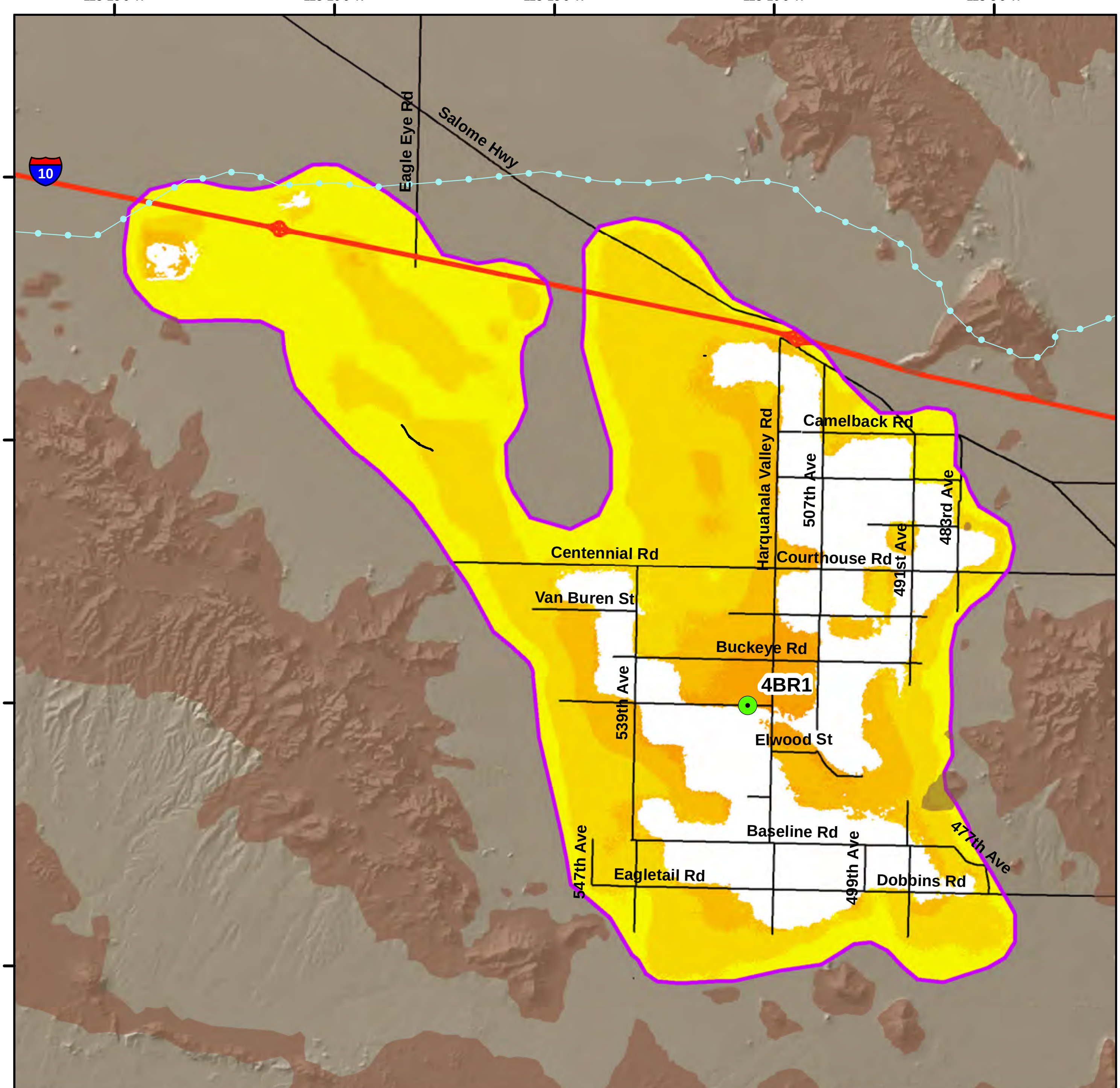


Figure 11 - Total Land Subsidence in the Harquahala Valley, Maricopa County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 6.0 Years: 05/01/2010 To 03/30/2016

Explanation

05/01/2010 To 03/30/2016
Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Hardrock
- Survey Monument
- CAP Canal
- Earth Fissures

Highways and Interstates

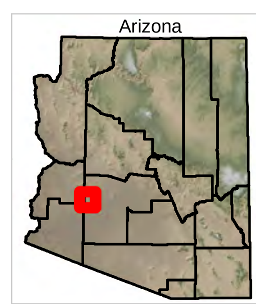
- Interstate
- US
- State
- Roads

1:200,000

0 1 2 4 6 8 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).

Earth fissures were mapped by the Arizona Geological Survey. For information on earth fissures visit: www.azgs.az.gov/EFC



Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

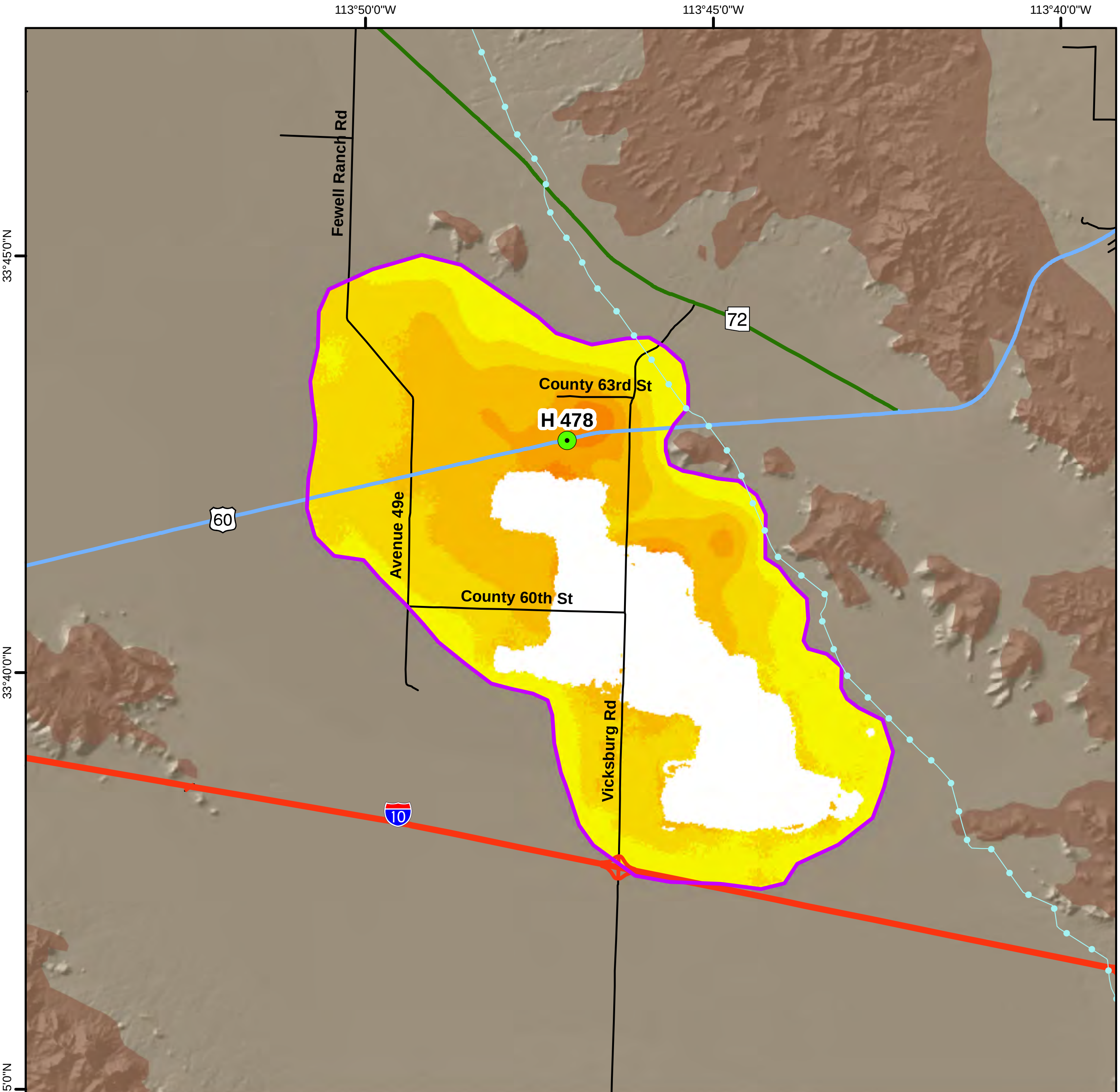


Figure 12 - Total Land Subsidence in the Ranegras Plain, La Paz County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data
Time Period of Analysis: 6.0 Years: 05/01/2010 To 03/30/2016

Explanation

05/01/2010 To 03/30/2016
Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

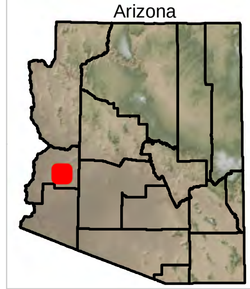
- Subsidence Feature
- Survey Monument
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads

1:125,000

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: 1/3/2017

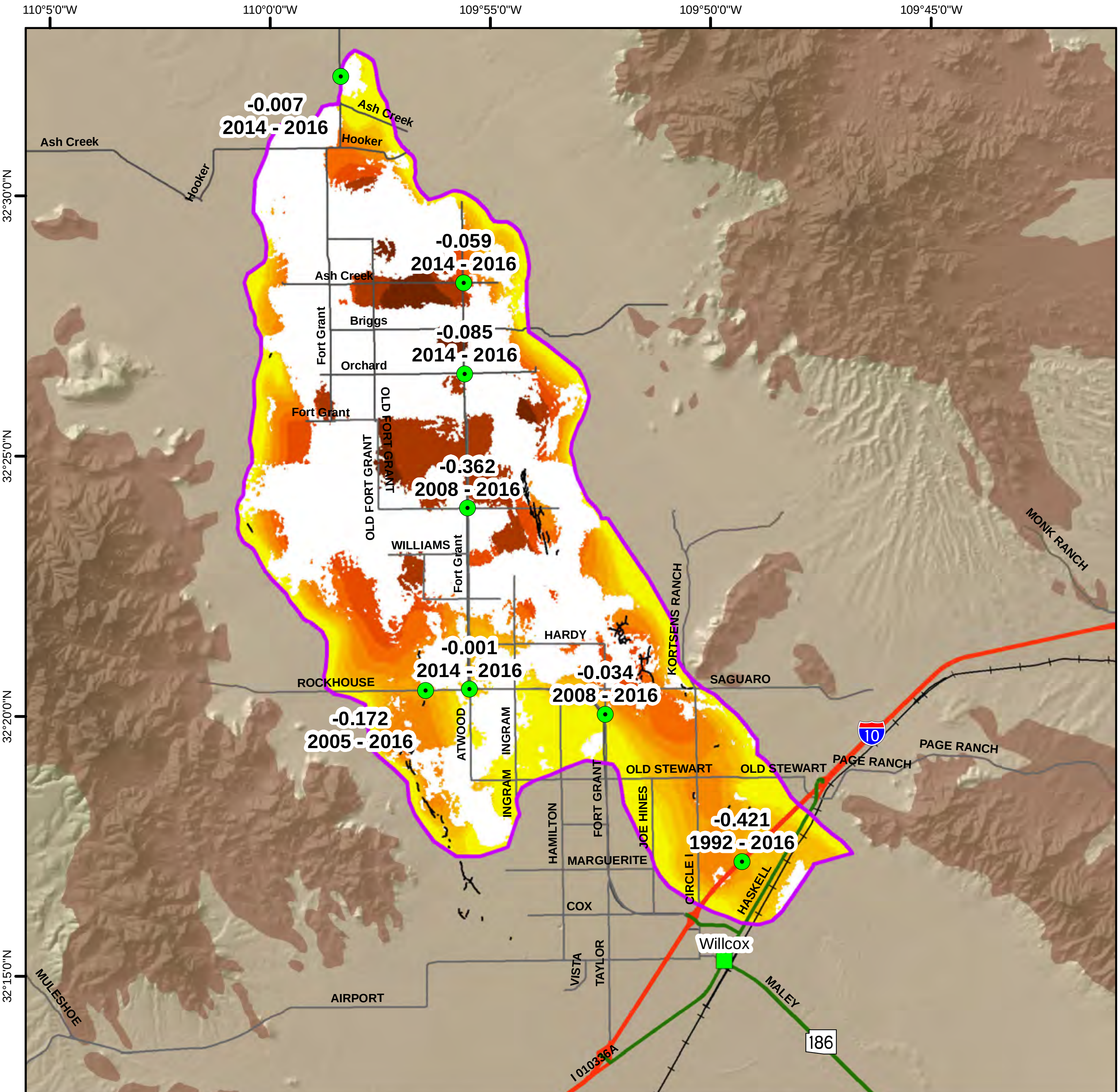


Figure 13 - Total Land Subsidence in the Fort Grant Rd and Willcox Areas, Cochise County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 6.0 Years 05/05/2010 To 04/03/2016

Explanation

05/05/2010 To 04/03/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Hardrock
- Earth Fissures
- Cities/Towns

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway
- Survey Monument
- -0.172 subsidece in meters

1:200,000

0 1 2 4 6 8 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).

Earth fissures were mapped by the Arizona Geological Survey.
For information on earth fissures visit: www.azgs.az.gov/EFC

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

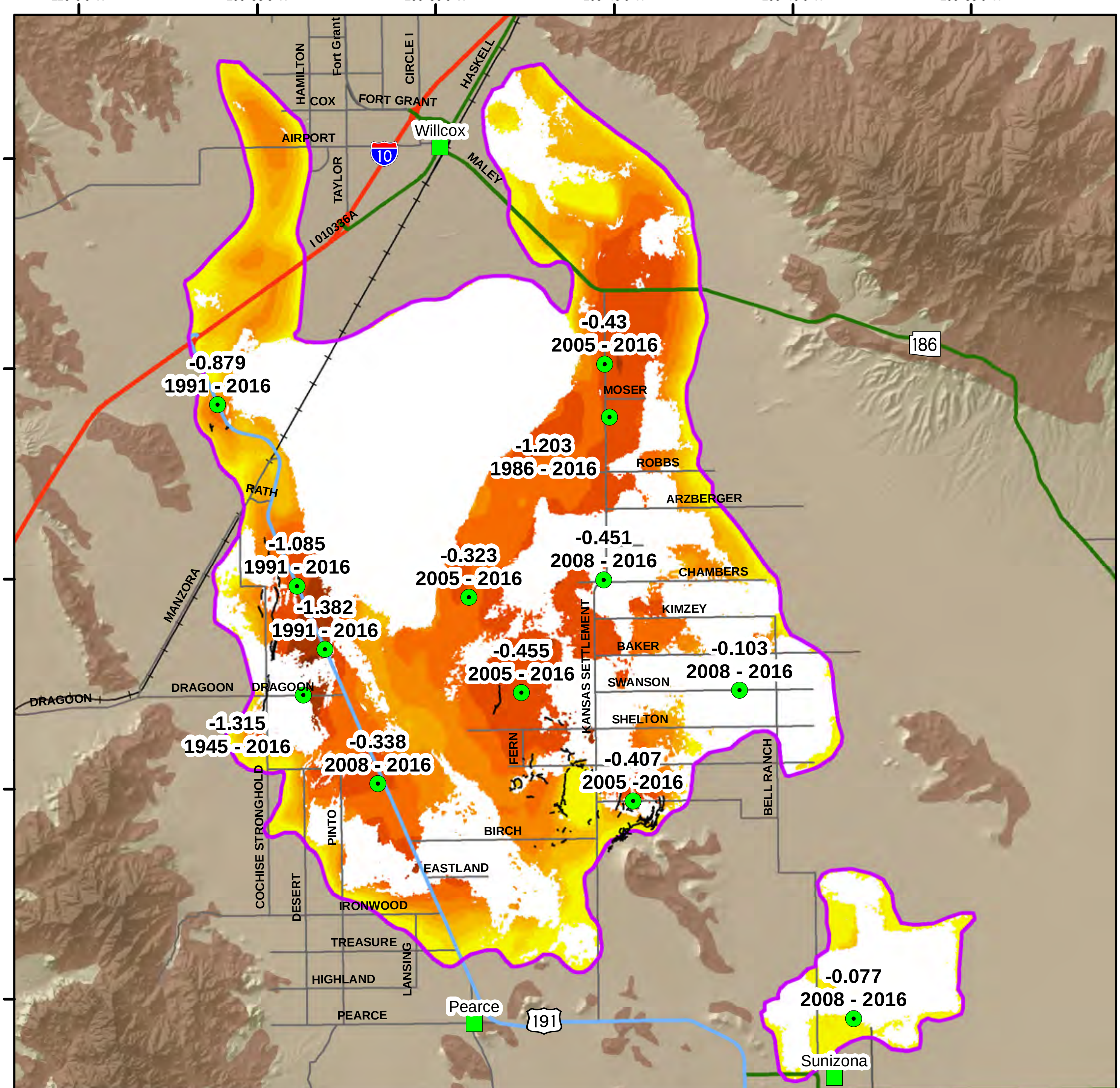


Figure 14 - Total Land Subsidence in the Willcox and Kansas Settlement Areas, Cochise County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 6.0 Years 05/05/2010 To 04/03/2016

Explanation

05/05/2010 To 04/03/2016
Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Hardrock
- Earth Fissures
- Cities/Towns

Highways and Interstates

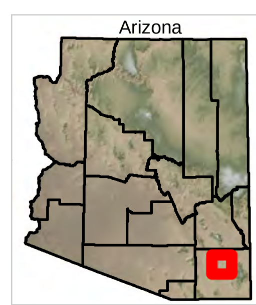
- Interstate
- US
- State
- Roads
- Railway
- Survey Monument
- -0.172 subsidece in meters

1:250,000

0 1.25 2.5 5 7.5 10 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).

Earth fissures were mapped by the Arizona Geological Survey.
For information on earth fissures visit: www.azgs.az.gov/EFC



Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 12/14/2016

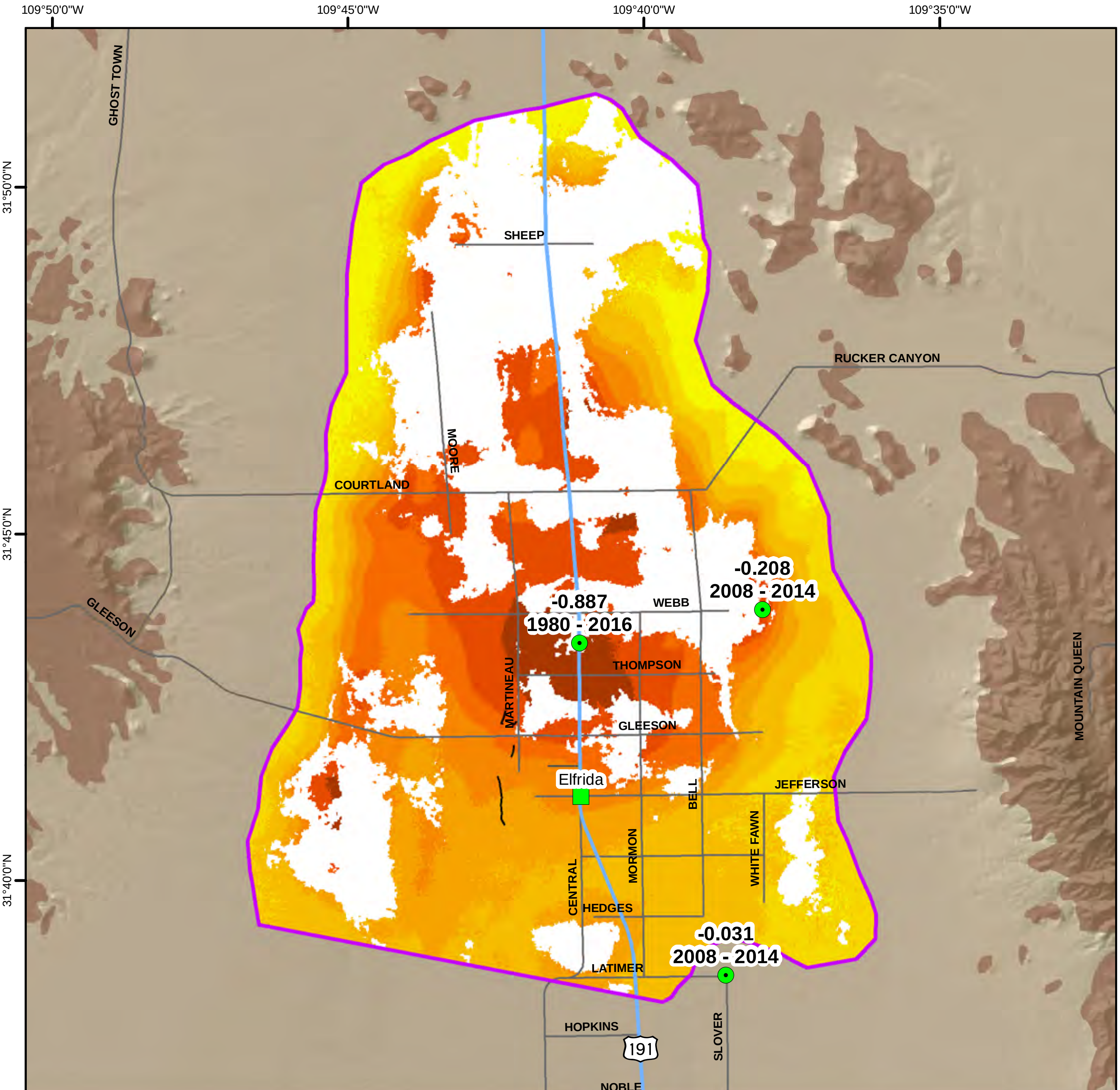


Figure 15 - Total Land Subsidence in the Elfrida Area, Cochise County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data
Time Period of Analysis: 6.0 Years 05/05/2010 To 04/03/2016

Explanation

05/05/2010 To 04/03/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Hardrock
- Earth Fissures
- Cities/Towns

Highways and Interstates

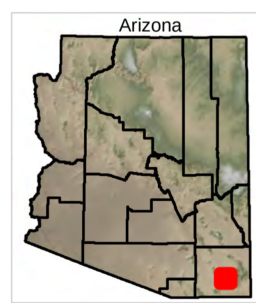
- Interstate
- US
- State
- Roads
- Railway
- Survey Monument
- -0.172 subsidece in meters

1:150,000

0 0.75 1.5 3 4.5 6 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).

Earth fissures were mapped by the Arizona Geological Survey. For information on earth fissures visit: www.azgs.az.gov/EFC



Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

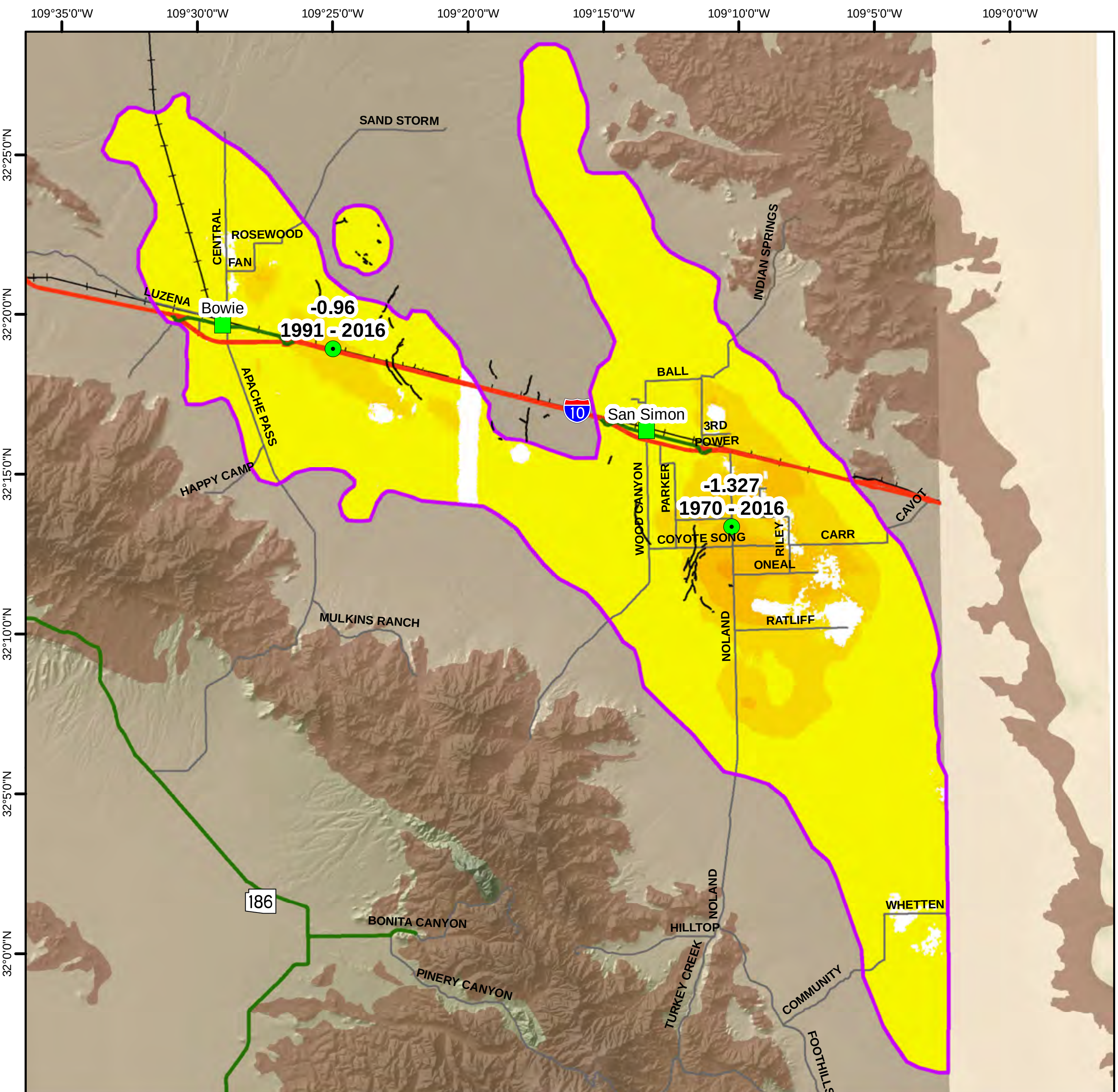


Figure 16 - Total Land Subsidence in the Bowie and San Simon Areas, Cochise County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 6.0 Years 05/05/2010 To 04/03/2016

Explanation

05/05/2010 To 04/03/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

- Subsidence Feature
- Hardrock
- Earth Fissures
- Cities/Towns

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway
- Survey Monument

-0.172 subsidece in meters

1:325,000

0 1.75 3.5 7 10.5 14 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).

Earth fissures were mapped by the Arizona Geological Survey. For information on earth fissures visit: www.azgs.az.gov/EFC

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

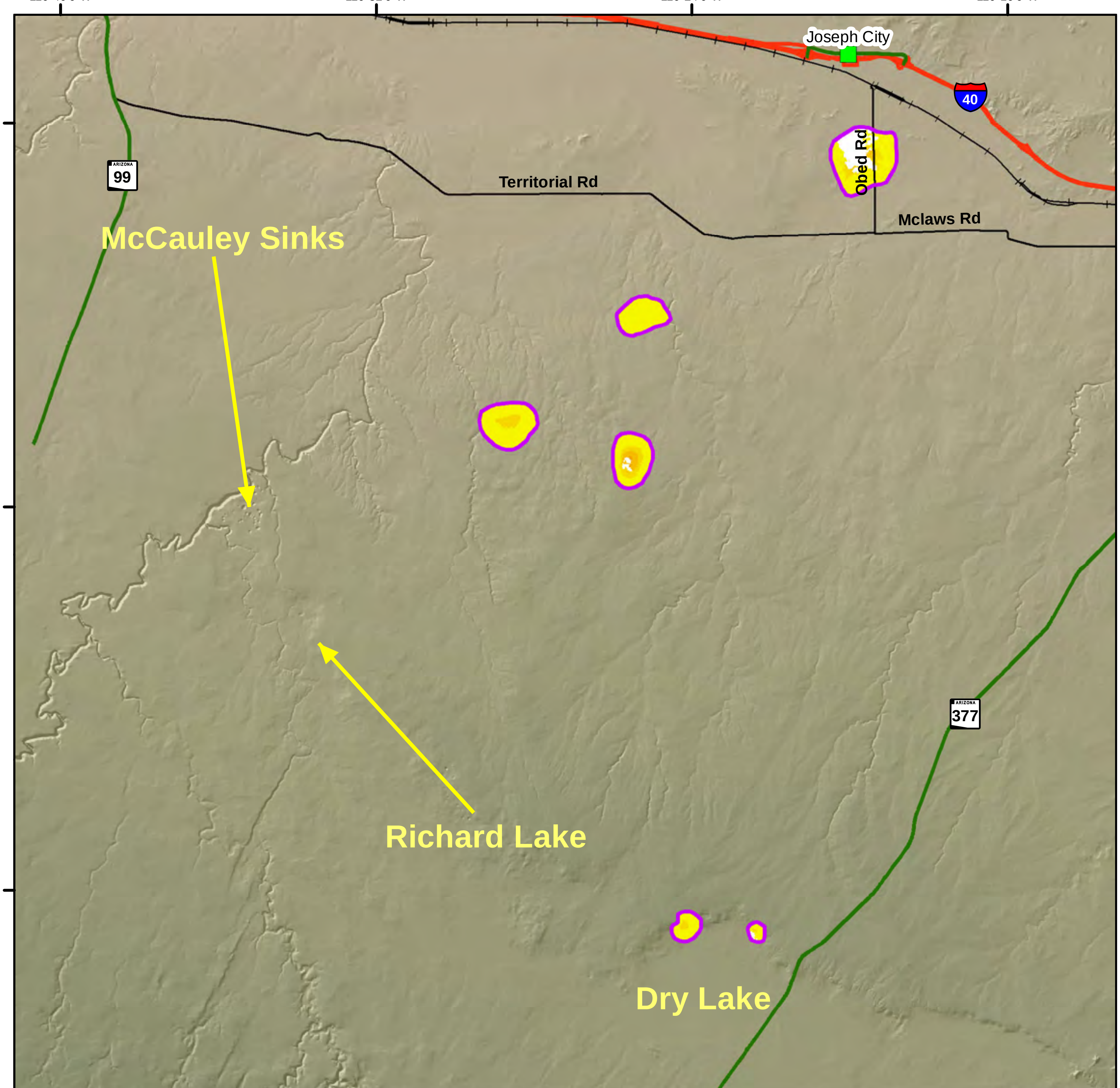


Figure 17 - Total Land Subsidence in the Holbrook Basin, Navajo County
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data
Time Period of Analysis: 3.5 Years 09/22/2012 To 03/17/2016

Explanation

09/22/2012 To 03/17/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

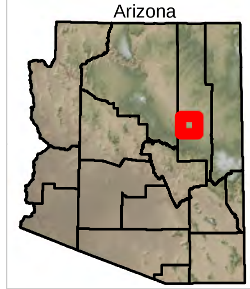
- Subsidence Feature
- Hardrock
- Cities/Towns

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

1:218,947

0 1 2 4 6 8 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: 11/22/2016

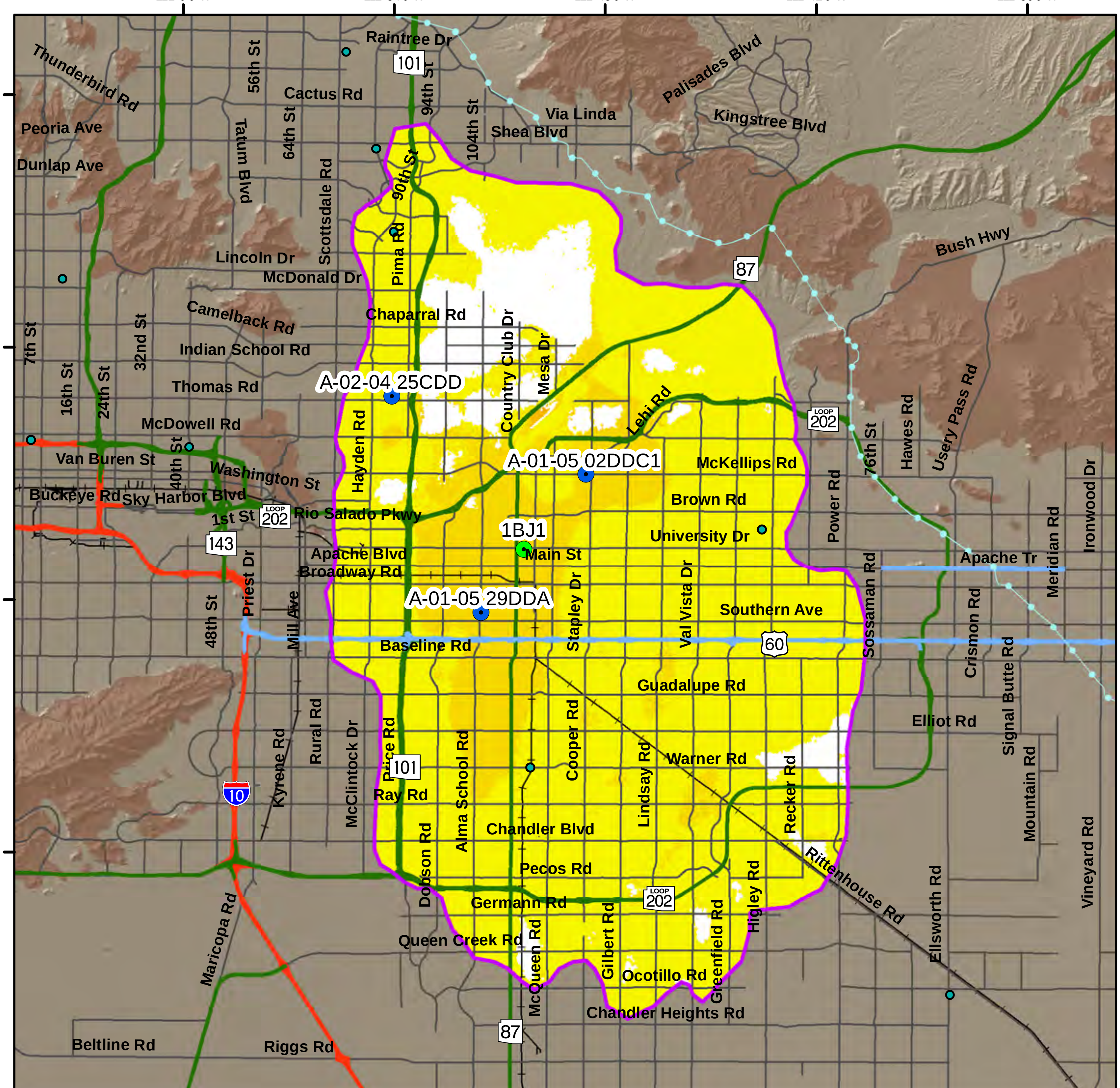
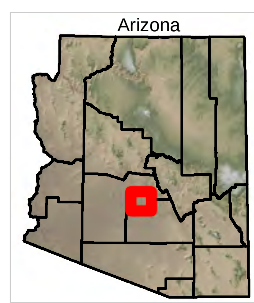


Figure 18 - Total Land Subsidence in the East Valley Area of Tempe, Chandler, Gilbert, and Mesa
Based on Radarsat-2 Satellite Interferometric Synthetic Aperture Radar (InSAR) Data

Time Period of Analysis: 4.5 Years 11/11/2011 To 04/06/2016



Explanation

11/11/2011 To 04/06/2016

Total Land Subsidence

- Decorrelation/No Data
- Greater 40 cm (15.7 in)
- 25 - 40 cm (9.8 - 15.7 in)
- 15 - 25 cm (5.9 - 9.8 in)
- 10 - 15 cm (3.9 - 5.9 in)
- 6 - 10 cm (2.4 - 3.9 in)
- 4 - 6 cm (1.6 - 2.4 in)
- 2 - 4 cm (0.8 - 1.6 in)
- 1 - 2 cm (0.4 - 0.8 in)
- 0 - 1 cm (0 - 0.4 in)

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

Highways and Interstates

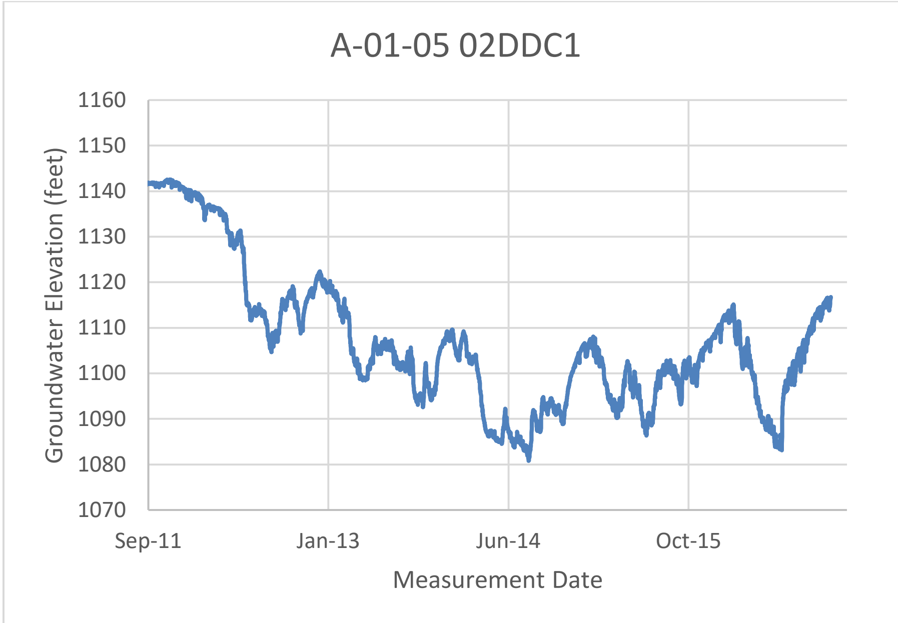
- Interstate
- US
- State
- Roads
- Railway

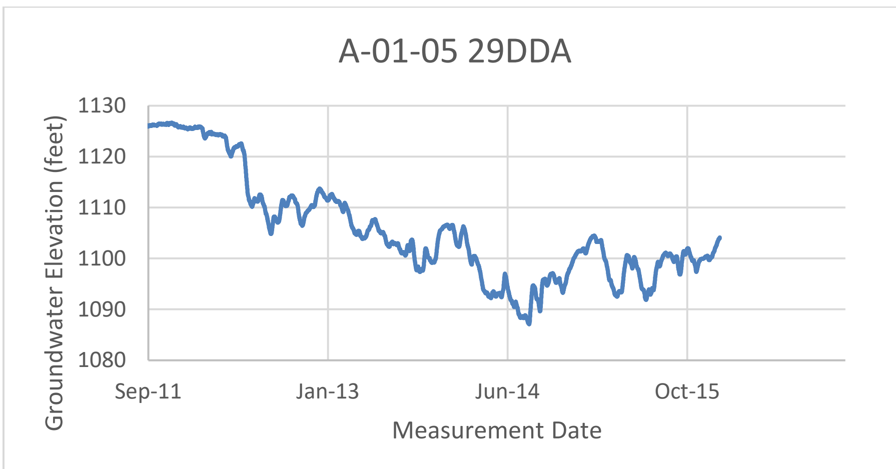
1:250,000

0 1.25 2.5 5 7.5 10 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: 12/14/2016





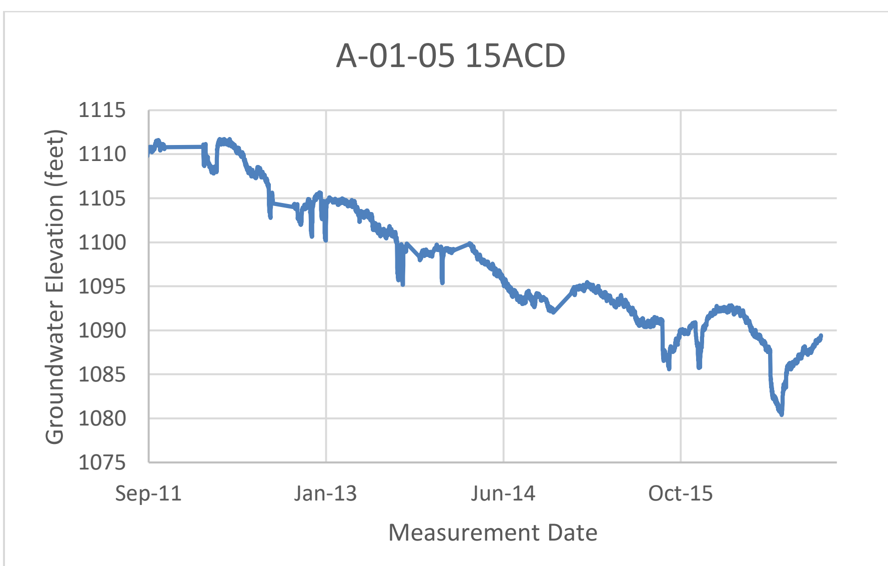


Figure 19 – Hydrographs documenting groundwater declines in the East Valley Land Subsidence Feature

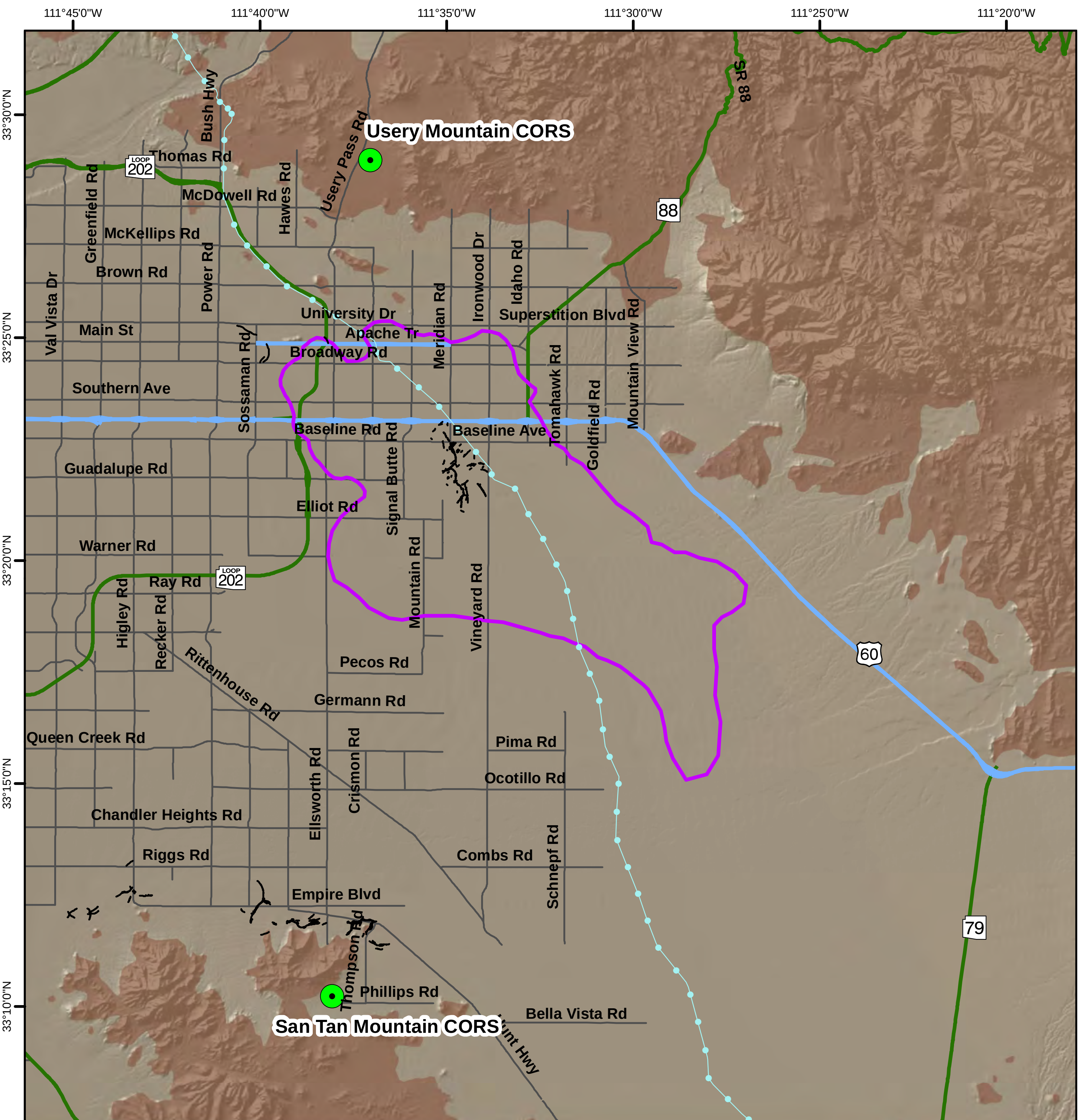
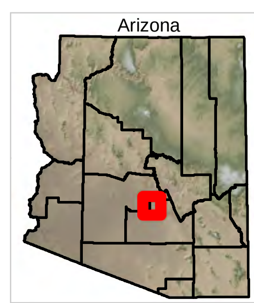


Figure 20 - Bedrock CORS Sites



Explanation

- Bedrock CORS
- Hardrock
- Hawk Rock Subsidence Feature
- CAP Canal
- Earth Fissures

Highways and Interstates

- Interstate
- US
- State
- Roads

1:225,000

0 1.25 2.5 5 7.5 10 Miles

Earth fissures were mapped by the Arizona Geological Survey.
For information on earth fissures visit: www.azgs.az.gov/EFC

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

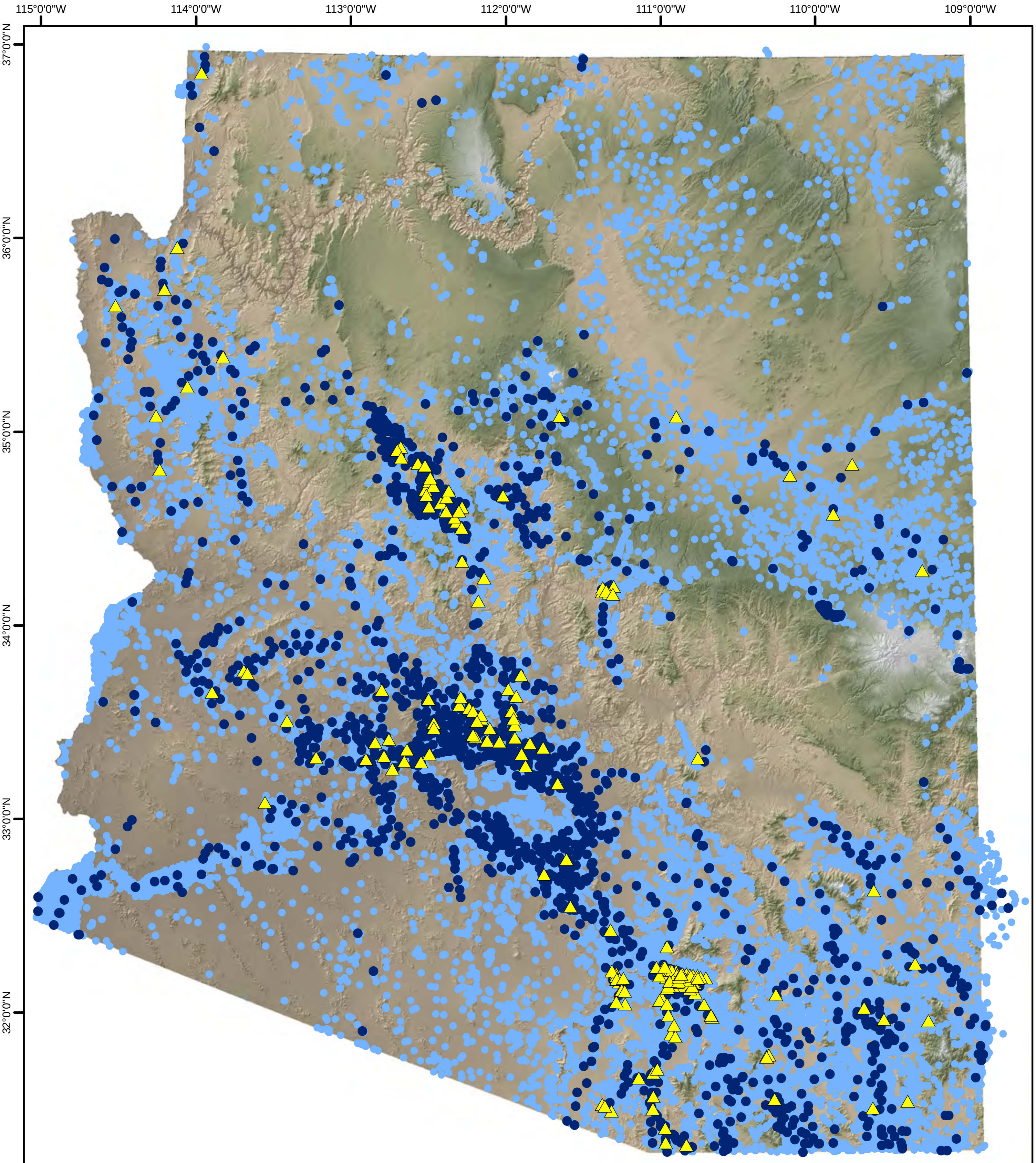


Figure 21 - Groundwater Wells Used to Monitor Annual Changes in Groundwater Levels
Groundwater Data is Collected by the Basic Data and Transducer Units of the ADWR Hydrology Division

Explanation

- Automated Wells (129)
- Index Wells (1,783)
- All GWSI Wells (44,340)

1:2,985,650

0 15 30 60 90 120 Miles

Coordinate System: NAD 1983 UTM Zone 12N
Projection: Transverse Mercator
Datum: North American 1983
Units: Meter
Created: 11/22/2016

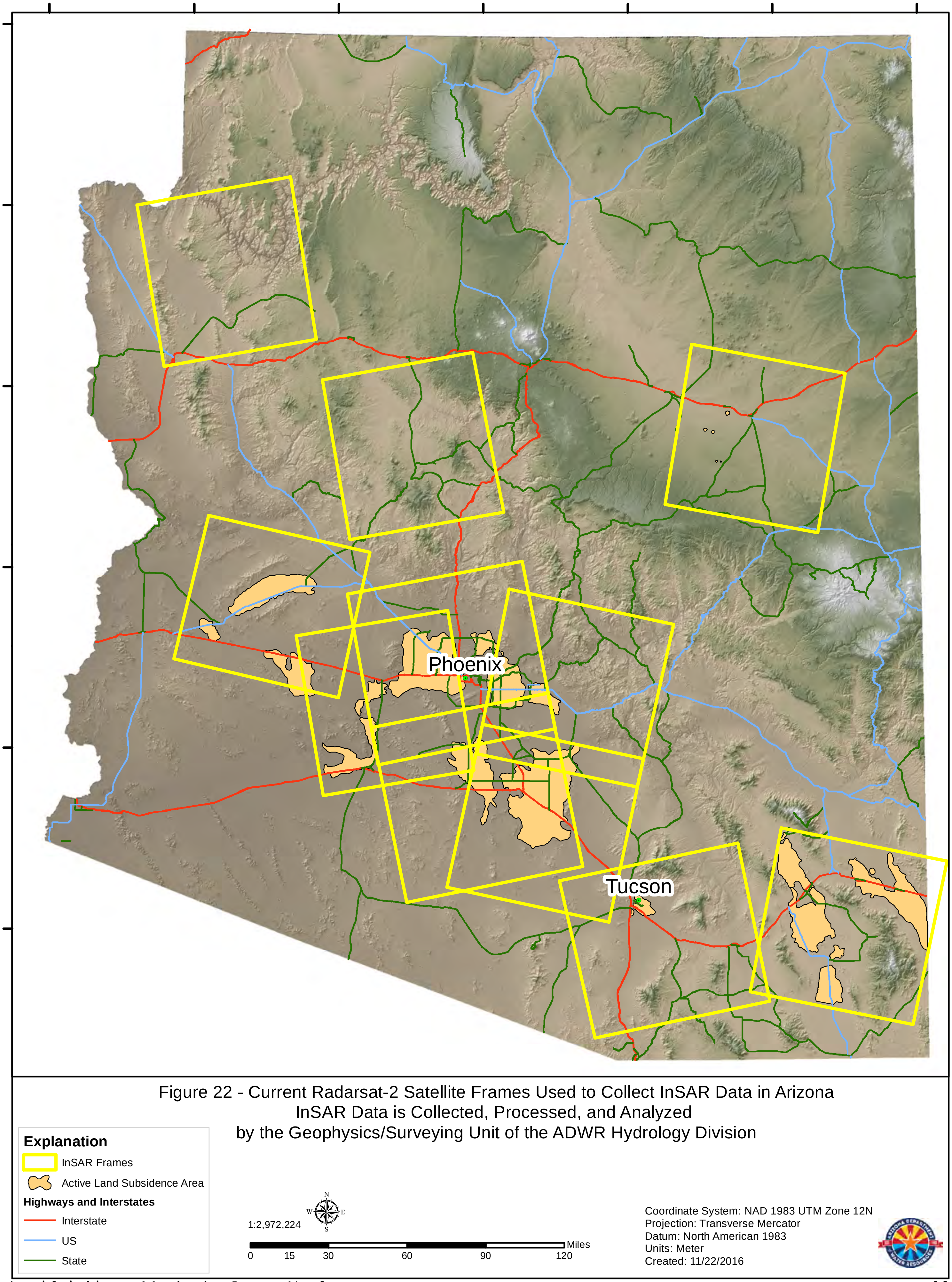


Figure 22 - Current Radarsat-2 Satellite Frames Used to Collect InSAR Data in Arizona
InSAR Data is Collected, Processed, and Analyzed
by the Geophysics/Surveying Unit of the ADWR Hydrology Division

Name	Latitude (NAD83)	Longitude (NAD83)	Deformation (ft)	Duration
Apple	32 26 30.16171	109 55 40.04761	-0.279	2014 - 2016
Arabian	32 00 02.43365	109 51 51.34884	-1.110	2008 - 2016
Ash Creek	32 32 14.41904	109 58 24.88593	-0.023	2014 - 2016
Attwood	32 20 26.31159	109 55 37.83407	-0.003	2014 - 2016
B 420	32 04 45.60571	109 54 03.40502	-3.560	1991 - 2016
Bell Ranch	32 02 09.98024	109 41 42.85163	-0.338	2008 - 2016
Bonita	32 35 54.89652	109 58 54.69132	-0.010	2008 - 2014
D 420	32 03 14.77250	109 53 17.78865	-4.534	1991 - 2016
Domann	32 02 09.87018	109 47 48.92815	-1.493	2005 - 2016
Ellis	32 20 24.96289	109 56 37.63949	-0.564	2005 - 2016
Fresh	32 28 15.03060	109 55 40.28468	-0.194	2014 - 2016
Hedrick	32 04 27.06099	109 49 14.72608	-1.060	2005 - 2016
Ike	32 09 57.73006	109 45 23.21819	-1.411	2005 - 2016
Kansas	32 04 49.93624	109 45 28.57135	-1.480	2008 - 2016
L 358	32 17 04.01809	109 49 29.62692	-1.381	1992 - 2016
Nickels	32 19 55.63377	109 52 33.43652	-0.111	2008 - 2016
Playa	32 08 42.06343	109 45 15.46185	-3.947	1986 - 2016
Ranch	32 23 55.29891	109 55 37.87510	-1.188	2008 - 2016
Soles	31 59 33.65401	109 44 43.73817	-1.335	2005 -2016
Turkey	31 54 19.39427	109 38 38.96737	-0.253	2008 - 2016
V 261	32 02 09.79085	109 53 54.84023	-4.314	1991 - 2016
Willcox CA	32 14 56.24736	109 50 07.68377	-0.356	2008 - 2016
Y 418	32 09 05.78612	109 56 13.79757	-2.884	1991 - 2016

Table 1 – 2016 GNSS Survey Results for the Willcox Groundwater Basin