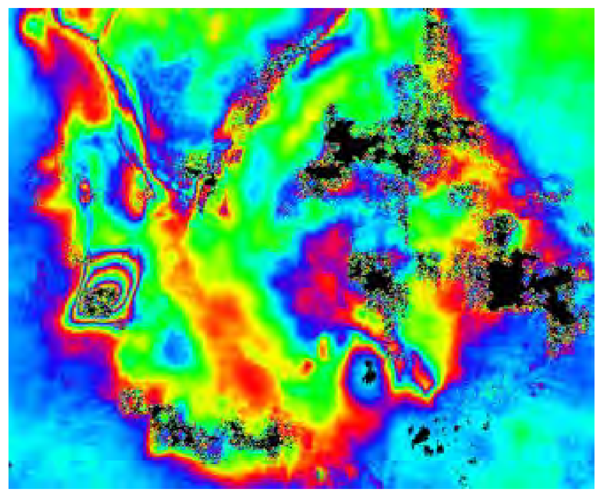
Land Subsidence Monitoring Report



Number 1

July 2013

By Brian D. Conway

ARIZONA DEPARTMENT of WATER RESOURCES EST. 1980

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, and Tracey Carpenter of ADWR who offered editorial suggestions. Paul Ivanich, Brian Mihlfeith, and Michael Winn (retired) of ADWR and Rob Carruth of the USGS assisted with survey-grade GPS data, transducer groundwater level data, and gravity 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 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 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 land subsidence features in Arizona, collectively covering more than 2,800 square miles of the state (Figure 1). In addition, the program now cooperates with 12 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 2013, 163 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's Land Subsidence Monitoring Program

In 1997 numerous non-exempt wells were 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 which led to a Directorate level decision to begin a land subsidence monitoring program. As a result, 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 that processes satellite-based synthetic aperture radar (SAR) data using interferometry (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.

ADWR's InSAR Program

Synthetic Aperture Radar 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 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 motion along active faults, on volcanoes, landslides, sinkholes, and other geologic hazards.

ADWR has developed an extensive library of over 1,200 SAR scenes used to process InSAR data, covering an area greater than 150,000 square miles at a cost of more than $750,000, mostly paid for by grants and cooperators. 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 land subsidence features in Arizona, collectively covering more than 2,800 square miles (Figure 1). ADWR provides land subsidence maps for download from ADWR's website. As of May 2013, 163 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 and 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:

http://maps.google.com/maps?q=http%3A//www.azwater.gov/AzDWR/Hydrology/Geophysics/ArizonaLandSubsidenceArea04-2013.kmz

ADWR uses InSAR data not only for monitoring land subsidence, but also seasonal deformation (uplift and subsidence), natural and artificial recharge events, as a tool for geological mapping and investigations, locating earth fissures, identifying areas where conditions may exist for future earth fissure formation, and 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, Community Water Company of Green Valley, City of Scottsdale, Cochise County, Salt River Project, and Petrified Forest National Park.

ADWR InSAR Results

ADWR initially started focusing the InSAR data collection efforts on the Phoenix and Tucson Active Management Areas (AMA), 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 2), Northeast Phoenix/Scottsdale (Figure 3), and the Hawk Rock (Figure 4) land subsidence features, and also three land subsidence features in the Tucson AMA known as the Central Well-field and the Valencia features (Figure 5), and the Green Valley feature (Figure 6) 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 confirm two well-documented land subsidence areas in the Pinal AMA known as the Maricopa-Stanfield (Figure 7) and the Picacho-Eloy (Figure 8) 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 9), Harquahala Valley (Figure 10), and the Ranegras Valley (Figure 11) land subsidence features. ADWR also identified two more land subsidence features in southwestern Maricopa County known as the Buckeye and Gila Bend features. The most recent land subsidence features identified with ADWR InSAR data are located in Cochise and Apache Counties. 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 12), Kansas Settlement (Figure 13), Elfrida (Figure 14), and the Bowie/San Simon (Figure 15) land subsidence features. The Apache County features were identified while investigating possible land subsidence related to the existing Holbrook sinks and to also establish a baseline for any existing land subsidence around the Petrified Forest National Park before planned potash mining activity begins in the area. These features are known as the Holbrook Basin (Figure 16) land subsidence features.

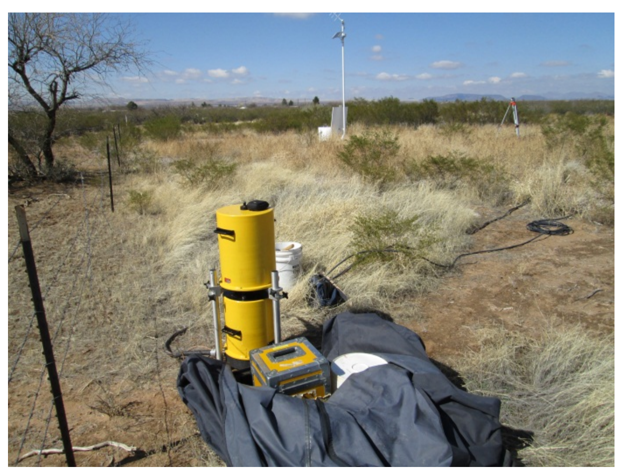
GPS Surveying

ADWR also collects survey-grade GPS data for ground-truthing of the InSAR data and for land subsidence monitoring in Hawk Rock Area in East Mesa and Apache Junction (Figure 4), Sahuarita/Green Valley Area (Figure 6), the McMullen Valley/Wenden Area (Figure 9), the Dragoon Rd Area in Cochise County (Figure 13) and the Chimney Canyon land subsidence feature in the Holbrook Basin (Figure 16).

Green Valley/Sahuarita Results

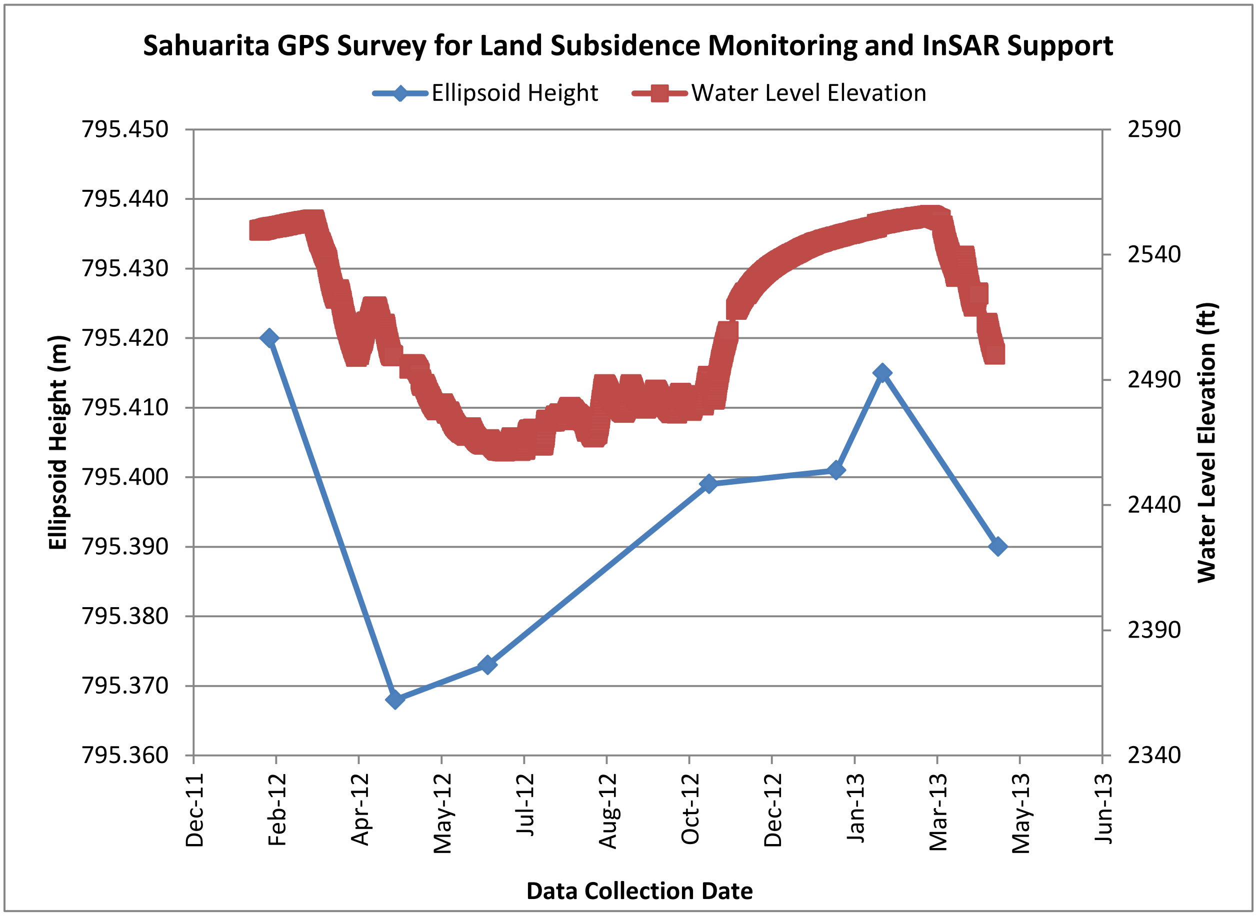
Comparison of recent GPS surveying (Picture 1) and ADWR groundwater data (Picture 2) from the Sahuarita/Green Valley Area has shown a striking correlation.

Picture 1 - GPS Surveying along Sahuarita Rd in Green Valley



Picture 2 - Collecting gravity and groundwater level data at the Rosemont East transducer, Green Valley

Seasonal groundwater pumping demands have resulted in both seasonal groundwater declines and recovery of 110 feet, causing both seasonal uplift and land subsidence that reflect the groundwater changes (Graph 1).



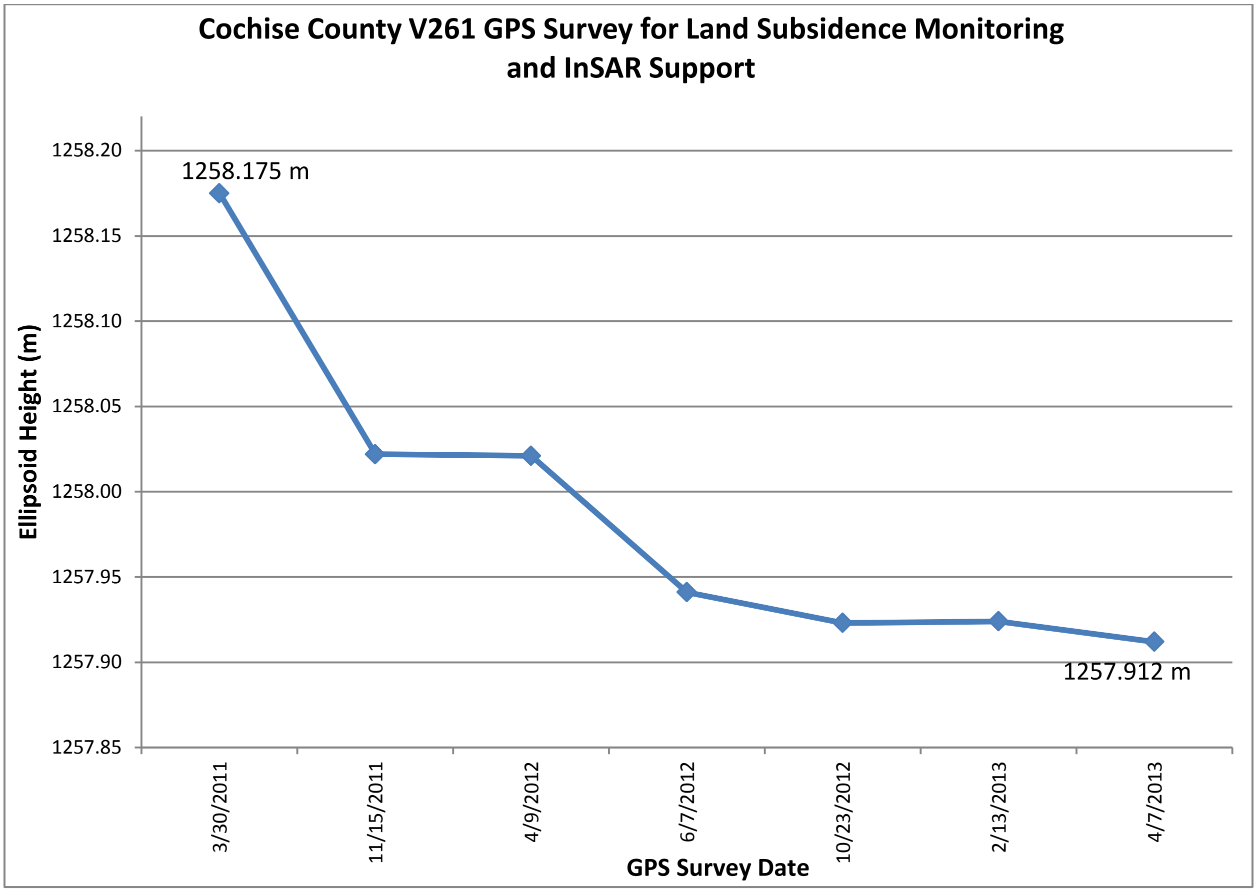
Graph 1 – GPS Survey and transducer groundwater data for the Green Valley Land Subsidence Feature

Cochise County/Willcox Basin Results

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

Picture 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 which is located between the towns of Dragoon and Willcox along Dragoon Rd within the Kansas Settlement land subsidence feature. ADWR was able to recover 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. Comparing recent (2013) ADWR GPS data with the historical 1945 data, ADWR was able to determine that a total of 1.2 meters (3.9 feet) of land subsidence has occurred at this location since 1945, and 26 centimeters (10.2 inches) of land subsidence has occurred between 2011 and 2013 (Graph 2).



Graph 2 – GPS Survey data for land subsidence along Dragoon Rd in Cochise County

There is also an exposed well casing (Picture 4) about a mile northwest of the V 261 survey monument, and numerous earth fissures located in the Willcox Basin (Picture 5). These features further document the amount of historical land subsidence that has occurred in the immediate area as well as the need for ADWR to continue to surveying V 261 for land subsidence in this area.

Picture 4 - Exposed well casing in Cochise County

Picture 5 - Sulfur Hills earth fissure in Cochise County

McMulley Valley Basin Results

ADWR first detected 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 a second time in ten years (2000) by Centennial Wash. The Town of Wenden is located within a land subsidence bowl which has contributed to the recent flooding. ADWR recently recovered three historical NGS monuments (A 480, Y 479, X 479) in the Wenden Area (Picture 7) that will be used for on-going ground-truthing of the InSAR data and for land subsidence monitoring in the McMullen Valley.

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

Picture 7 - GPS Surveying in the McMullen Valley

Comparing recent ADWR GPS data with the historical 1991 data for the three survey monuments, a total of 0.28 meters (0.92 feet), 0.43 meters (1.4 feet), and 0.81 meters (2.7 feet) of land subsidence has occurred at these three locations since 1991. ADWR will continue to survey (Figure 3) all three survey monuments for monitoring land subsidence in the McMullen Valley.

Holbrook Basin Results

ADWR recently discovered three new land subsidence features in the Holbrook Basin (Figure 16) while investigating potential land subsidence related to the well-documented geologic sink features that exist in the basin.

While the two southern-most land subsidence features seem to be directly related to the more than 400 existing sinks located throughout the basin, these two sinks are much larger in size but not as deep. Staff from the AZGS and ADWR visited the Chimney Canyon sink (Picture 9) and collected baseline GPS survey data in October 2012 (Picture 9). Repeat survey data will be collected in the near future to monitor

Picture 8 - One of the many expansion cracks located in the Chimney Canyon Area of the Holbrook Basin

Picture 9 - GPS Surveying in the Chimney Canyon Area of the Holbrook Basin

any changes in these features, as part of the ongoing cooperative land subsidence monitoring efforts between the AZGS and ADWR.

Hawk Rock Results

Picture 10 - Earth Fissure located at Baseline Rd and Meridian Rd in the Hawk Rock feature

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 2013, SGC 17 has subsided just over 1.55 meters (5.1 feet) in 40 years. Recently ADWR recovered three historical monuments, Y 477, SS-C, and SS-D (Figure 4). The SS-C and SS-D monuments were first established in 1978 during the first land subsidence studies in preparation and design of the CAP canal and the Y 477 monument was established later in 1991. Recent ADWR survey results (2013) showed that Y 477 has subsided 0.46 meters (1.52 feet) since 1991, and SS-C has subsided 0.37 meters (1.21 feet) and SS-D has subsidence 0.35 meters (1.13 feet) since 1978. The SS-C and SS-D monuments are located 50 feet across from each other, situated on different sides of an active earth fissure (Picture 10), further documenting the vertical offset on either side of the earth fissure.

Continuous Operating Reference Station

Picture 11 –Usery Mountain Bedrock CORS

Over the past three 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 State Cartographer's Office (SCO) with the Arizona State Land Department 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 for where stable sites may be located away from land subsidence areas to not only the SCO, but to other entities.

ADWR has worked with the SCO, 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 (Figure 17). These sites will provide stable vertical control around the Hawk Rock land subsidence feature to the surveying community.

Future Land Subsidence Data Collection

ADWR's GPS-surveying program plays a vital role in supporting the State-wide InSAR land subsidence monitoring program. 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 (Figure 18). ADWR will also continue to update land subsidence maps on an annual basis, making the maps available on the Department's website.

Figures

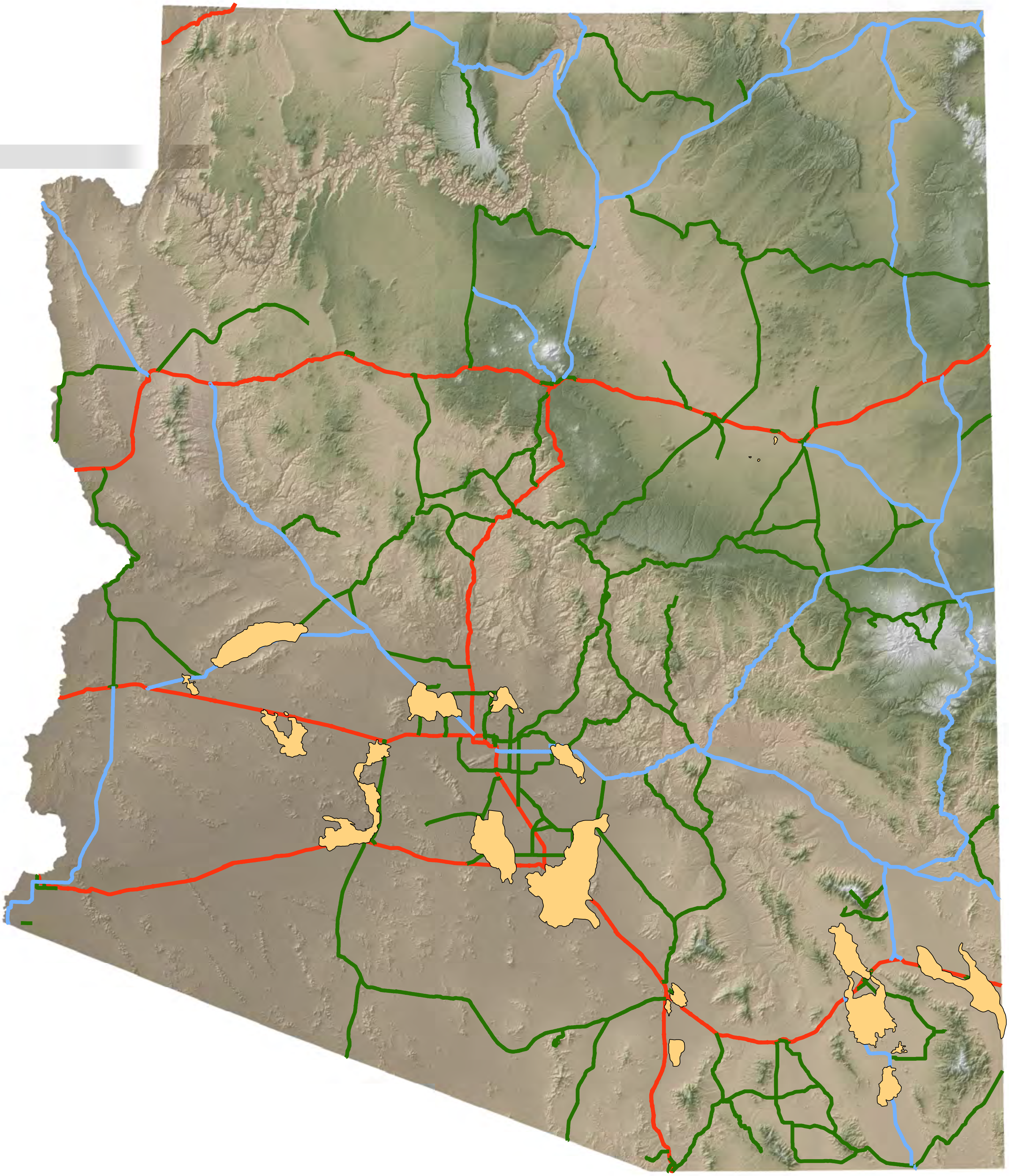


Figure 1 - Active Land Subsidence Areas in Arizona Based on ADWR InSAR Data
InSAR Data is Collected, Processed, and Analyzed
By the Geophysics/Surveying Unit of the Hydrology Division

Active Land Subsidence Area

Highways and Interstates

- Interstate
- US
- State

1:2,832,259

0 12.5 25 50 75 100 Miles

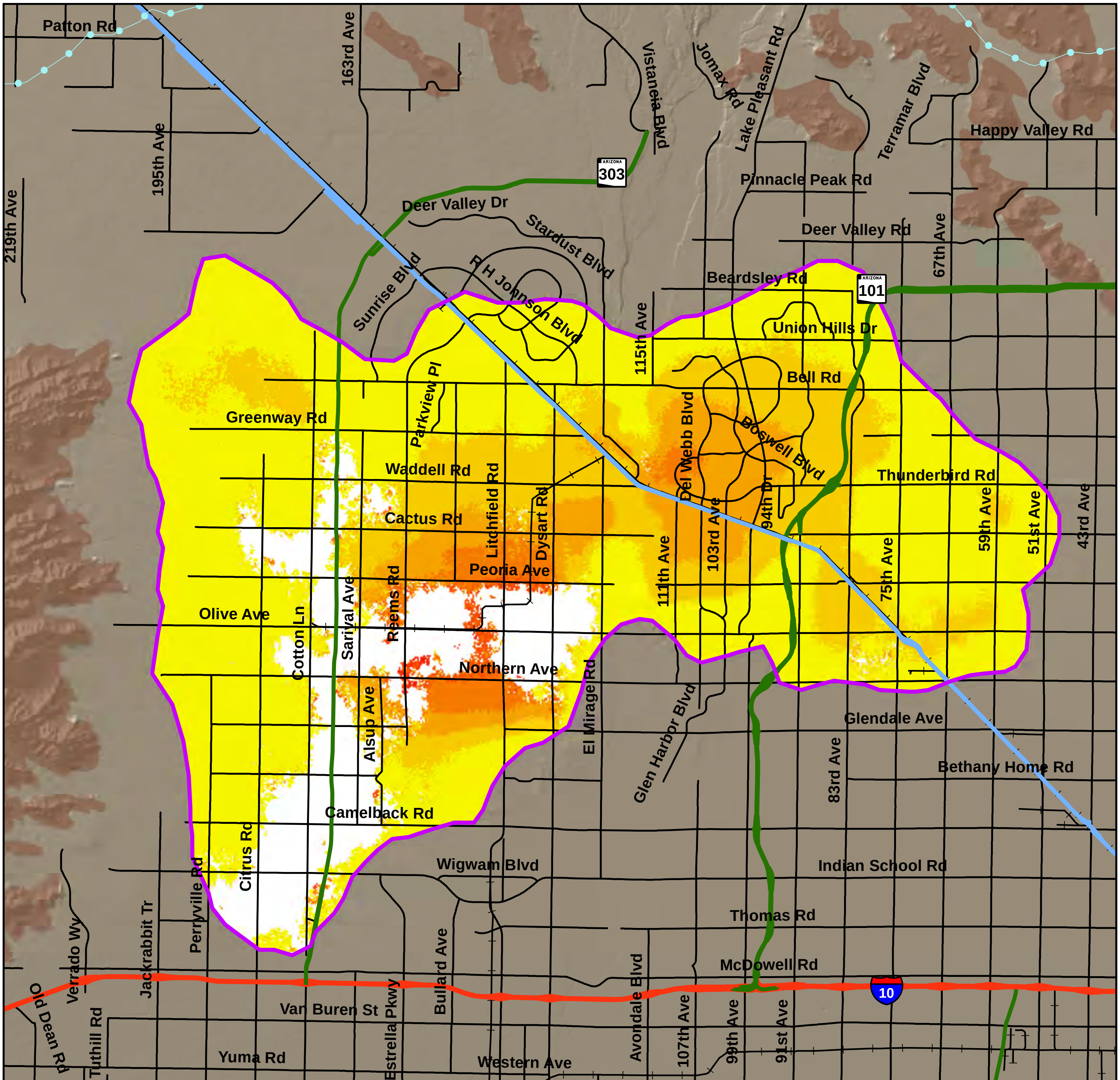


Figure 2 - Land Subsidence in Western Metropolitan Phoenix
Based on ADWR Radarsat-2 InSAR Data
Time Period of Analysis: 3.0 Years 05/08/2010 To 04/22/2013

05/08/2010 To 04/22/2013

Subsidence

- Decorrelation/No Data
- 6 To 8 cm
- 4 To 6 cm
- 3 To 4 cm
- 2 To 3 cm
- 1 To 2 cm
- 0 To 1 cm

- Subsidence Feature
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:183,029

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).

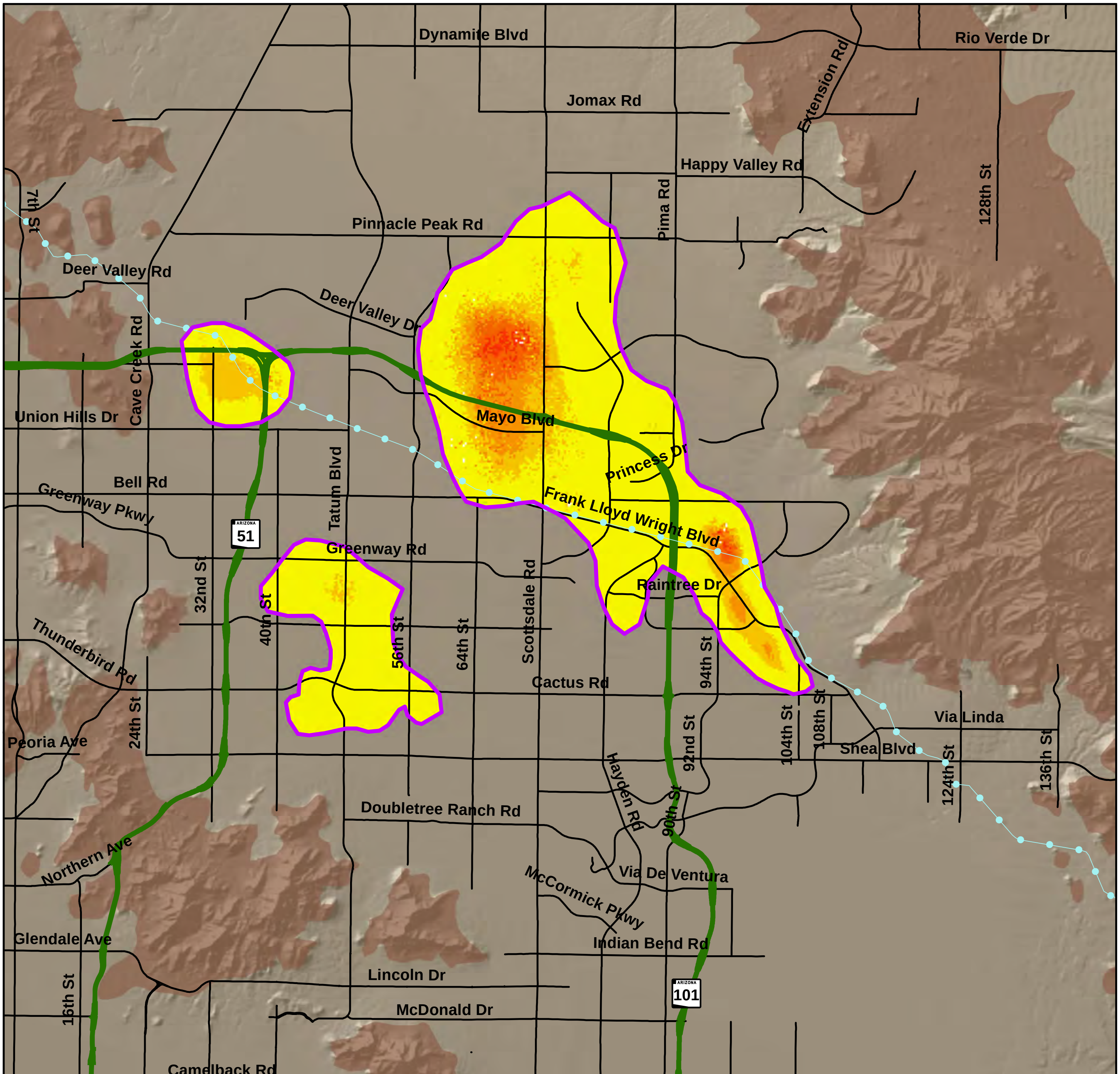


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Figure 3 - Land Subsidence in Northeast Phoenix and Scottsdale Areas
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 3.0 Years 05/08/2010 To 04/22/2013

05/08/2010 To 04/22/2013

Subsidence

- Decorrelation/No Data
- 2.0 To 2.5 cm
- 1.5 To 2.0 cm
- 1.0 To 1.5 cm
- 0.5 To 1.0 cm
- 0 To 0.5 cm

- Subsidence Feature
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

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).

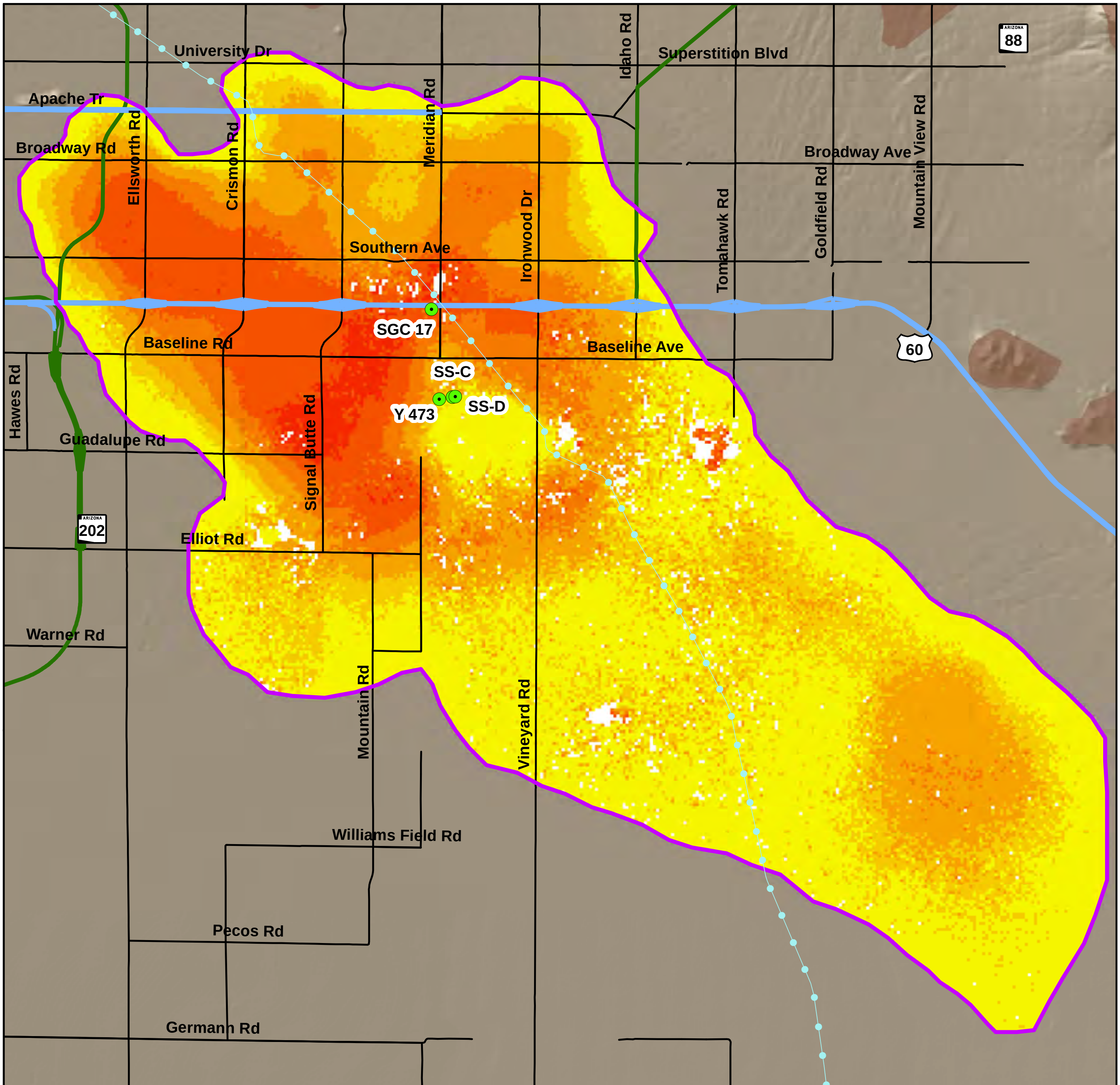

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Figure 4 - Land Subsidence in the Hawk Rock Area of East Mesa and Apache Junction
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 3.0 Years 05/15/2010 To 04/29/2013

05/15/2010 To 04/29/2013

Subsidence

- Decorelation/No Data
- 4 To 5 cm
- 3 To 4 cm
- 2 To 3 cm
- 1 To 2 cm
- 0.5 To 1.0 cm
- 0 To 0.5 cm

- Subsidence Feature
- Survey Monument
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:91,309

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).

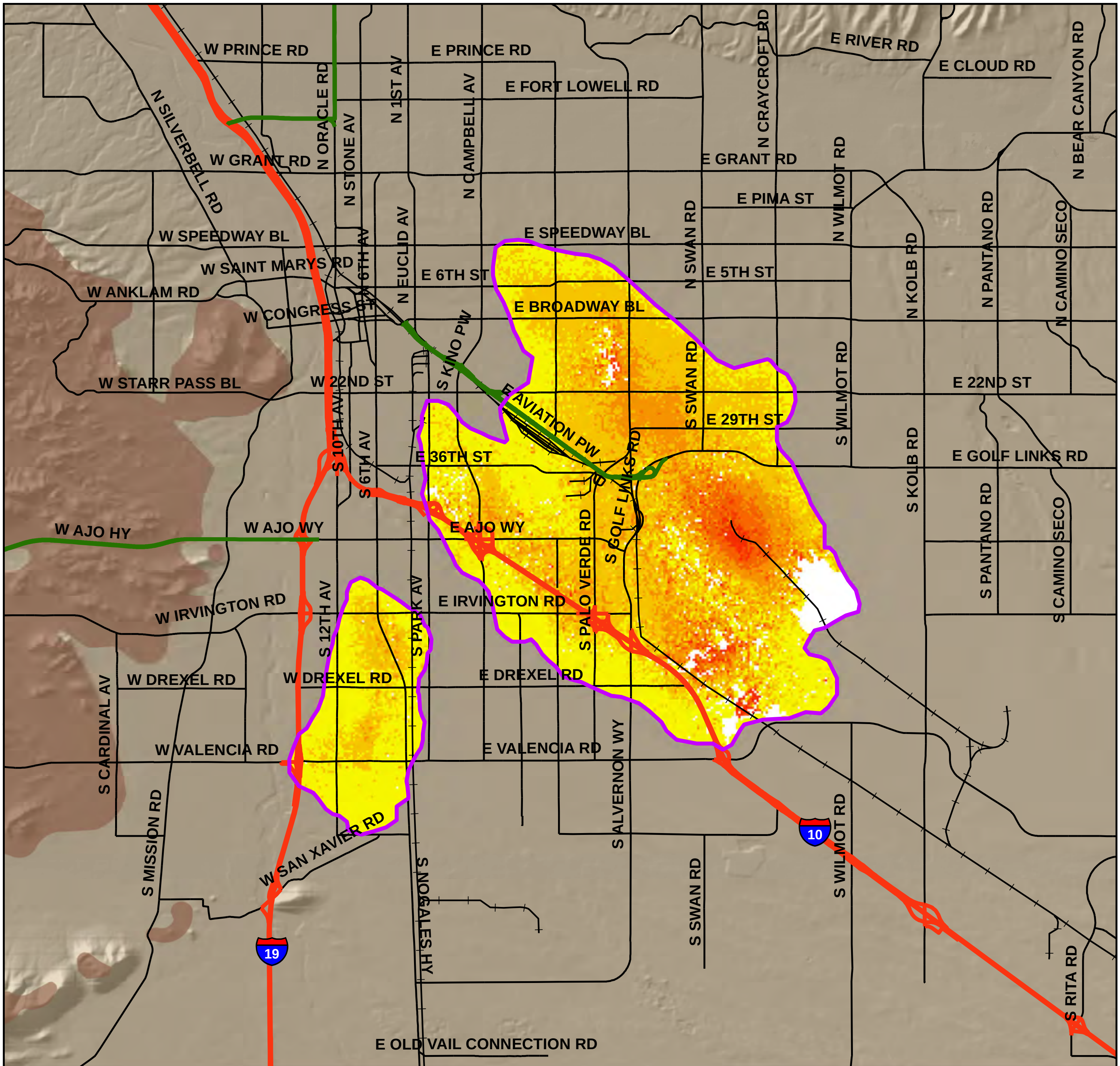

Figure 5 - Land Subsidence in the Tucson Metropolitan Area
Based on ADWR Radarsat-2 InSAR Data
Time Period of Analysis: 3.0 Years 05/15/2010 To 04/29/2013

05/15/2010 To 04/29/2013

Subsidence

- Decorrelation/No Data
- 2.0 To 3.0 cm
- 1.5 To 2.0 cm
- 1.0 To 1.5 cm
- 0.5 To 1.0 cm
- 0 To 0.5 cm

- Subsidence Feature
- Hardrock

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:121,136

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).

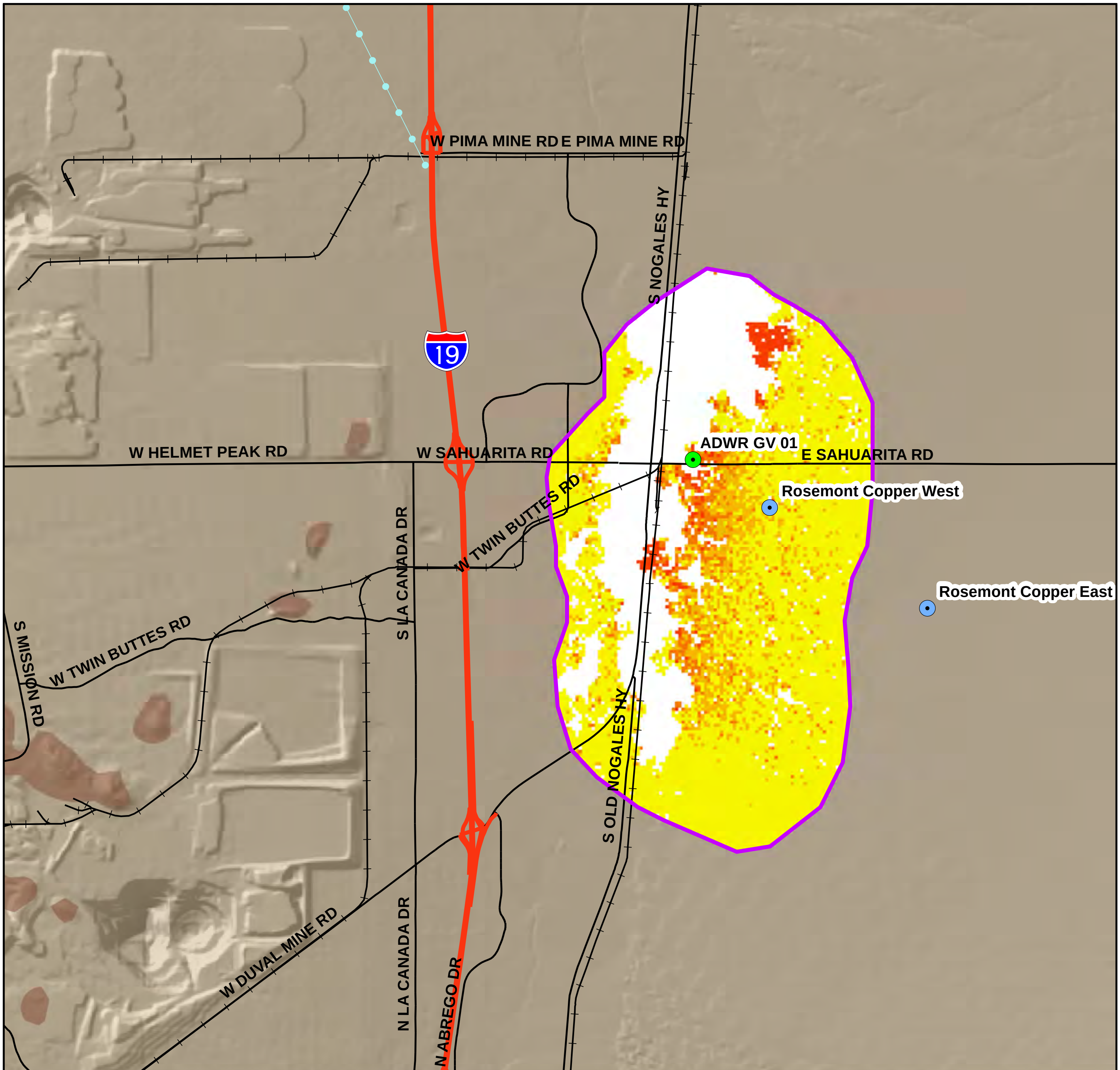

Figure 6 - Land Subsidence in the Sahuarita and Green Valley Areas, Pima County
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 1.1 Years 02/22/2012 To 04/29/2013

02/22/2012 To 04/29/2013

Subsidence

- Decorrelation/No Data
- 2.0 To 4.0 cm
- 1.0 To 2.0 cm
- 0.5 To 1.0 cm
- 0 To 0.5 cm

- Subsidence Feature
- Survey Monument
- ADWR Transducer
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:86,569

0 0.325 0.65 1.3 1.95 2.6 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).

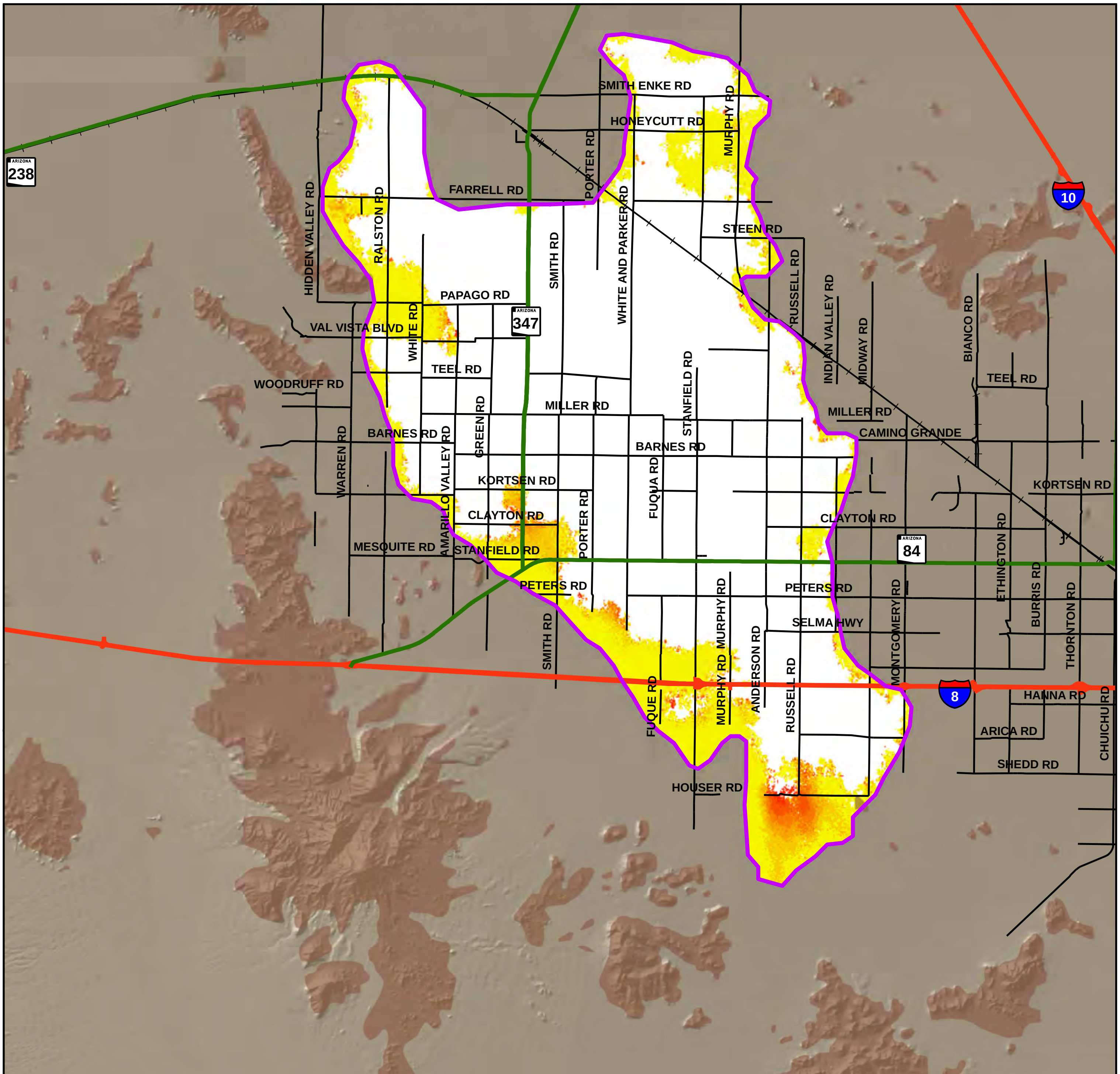

Figure 7 - Land Subsidence in the Maricopa-Stanfield Sub-Basin, Pinal County Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 3.0 Years 05/08/2010 To 04/22/2013

05/08/2010 To 04/22/2013

Subsidence

- Decorrelation/No Data
- 3.0 To 4.0 cm
- 2.0 To 3.0 cm
- 1.5 To 2.0 cm
- 1.0 To 1.5 cm
- 0.5 To 1.0 cm
- 0 To 0.5 cm

- Subsidence Feature
- Hardrock
- CAP Canal

Arizona Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:257,110

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).

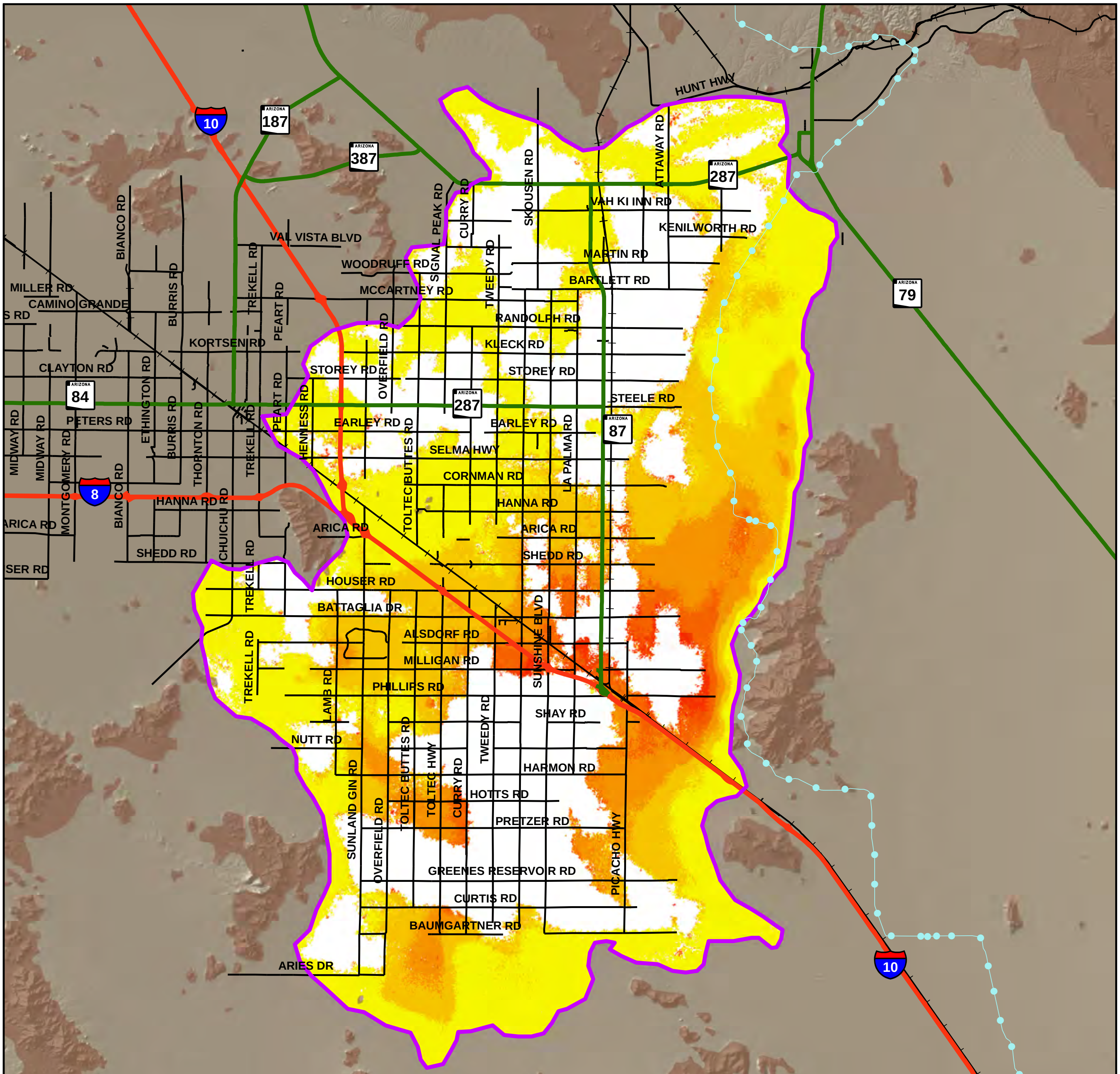

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Figure 8 - Land Subsidence in the Picacho Sub-Basin, Pinal County
Based on ADWR Radarsat-2 InSAR Data
Time Period of Analysis: 3.0 Years 05/15/2010 To 04/29/2013

05/15/2010 To 04/29/2013

Subsidence

- Decorelation/No Data
- 4 To 5 cm
- 3 To 4 cm
- 2 To 3 cm
- 1 To 2 cm
- 0 To 1 cm

- Subsidence Feature
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

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).

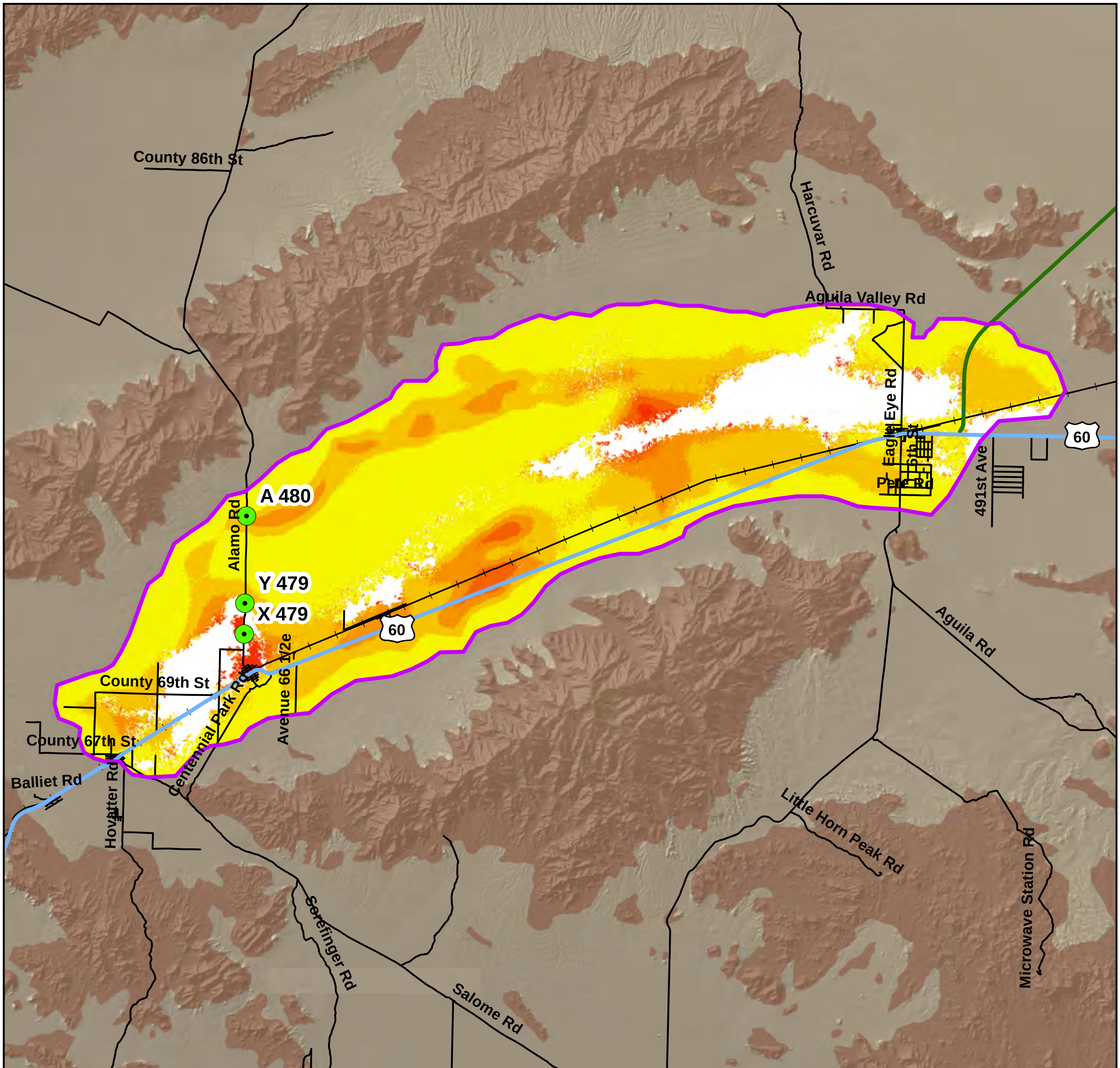

Figure 9 - Land Subsidence in the McMullen Valley, Maricopa and La Paz Counties
Based on ADWR Radarsat-2 Single Pair InSAR Data

Time Period of Analysis: 2.9 Years: 05/01/2010 To 03/22/2013

05/01/2010 To 03/22/2013

Subsidence

- Decorrelation/No Data
- 6.0 To 8.0 cm
- 4.5 To 6.0 cm
- 3.0 To 4.5 cm
- 1.5 To 3.0 cm
- 0 To 1.5 cm

- Subsidence Feature
- Survey Monument
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

1:287,039

0 1.5 3 6 9 12 Miles

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

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).

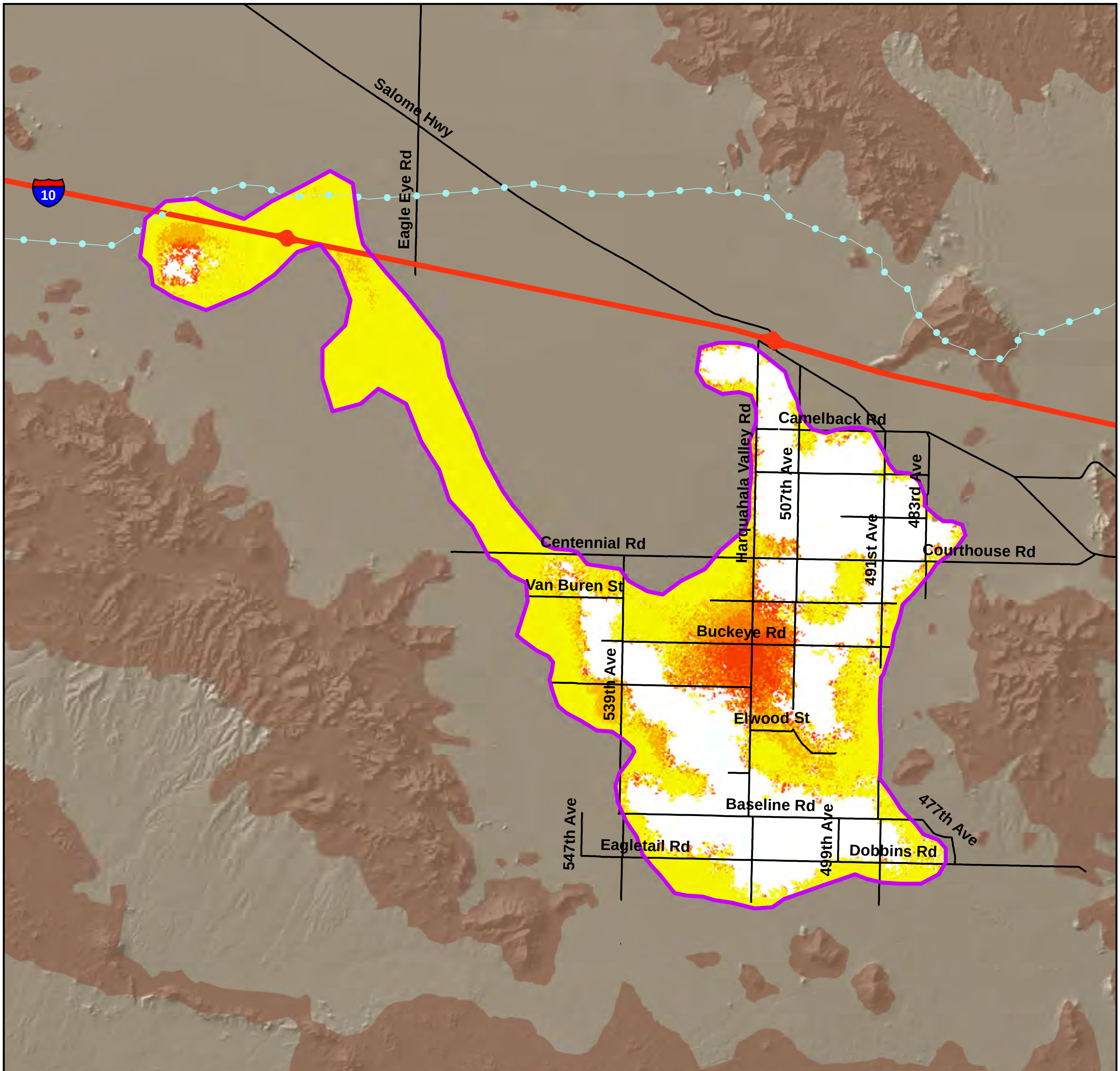

Figure 10 - Land Subsidence in the Harquahala Valley, Maricopa County
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 2.9 Years 05/01/2010 To 03/22/2013

05/01/2010 To 03/22/2013

Subsidence

- Decorrelation/No Data
- 1.5 To 2.0 cm
- 1.0 To 1.5 cm
- 0.5 To 1.0 cm
- 0 To 0.5 cm

- Subsidence Feature
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:207,806

0 1 2 4 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).

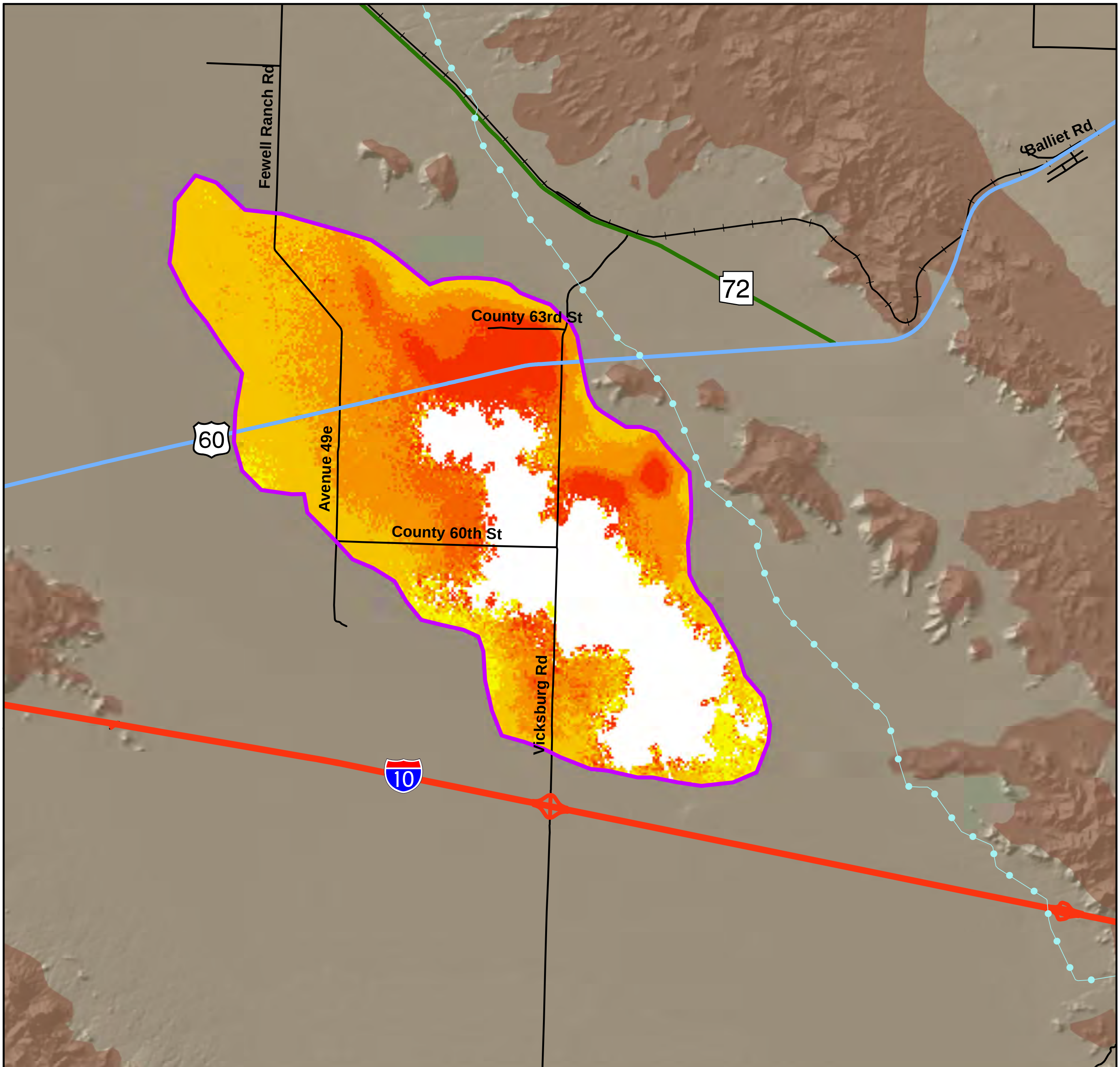

Figure 11 - Land Subsidence in the Ranegras Valley, La Paz County
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 2.9 Years 05/01/2010 To 03/22/2013

05/01/2010 To 03/22/2013

Subsidence

- Decorrelation/No Data
- 2.0 To 3.0 cm
- 1.5 To 2.0 cm
- 1.0 To 1.5 cm
- 0.5 To 1.0 cm
- 0 To 0.5 cm

- Subsidence Feature
- Hardrock
- CAP Canal

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:121,130

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).

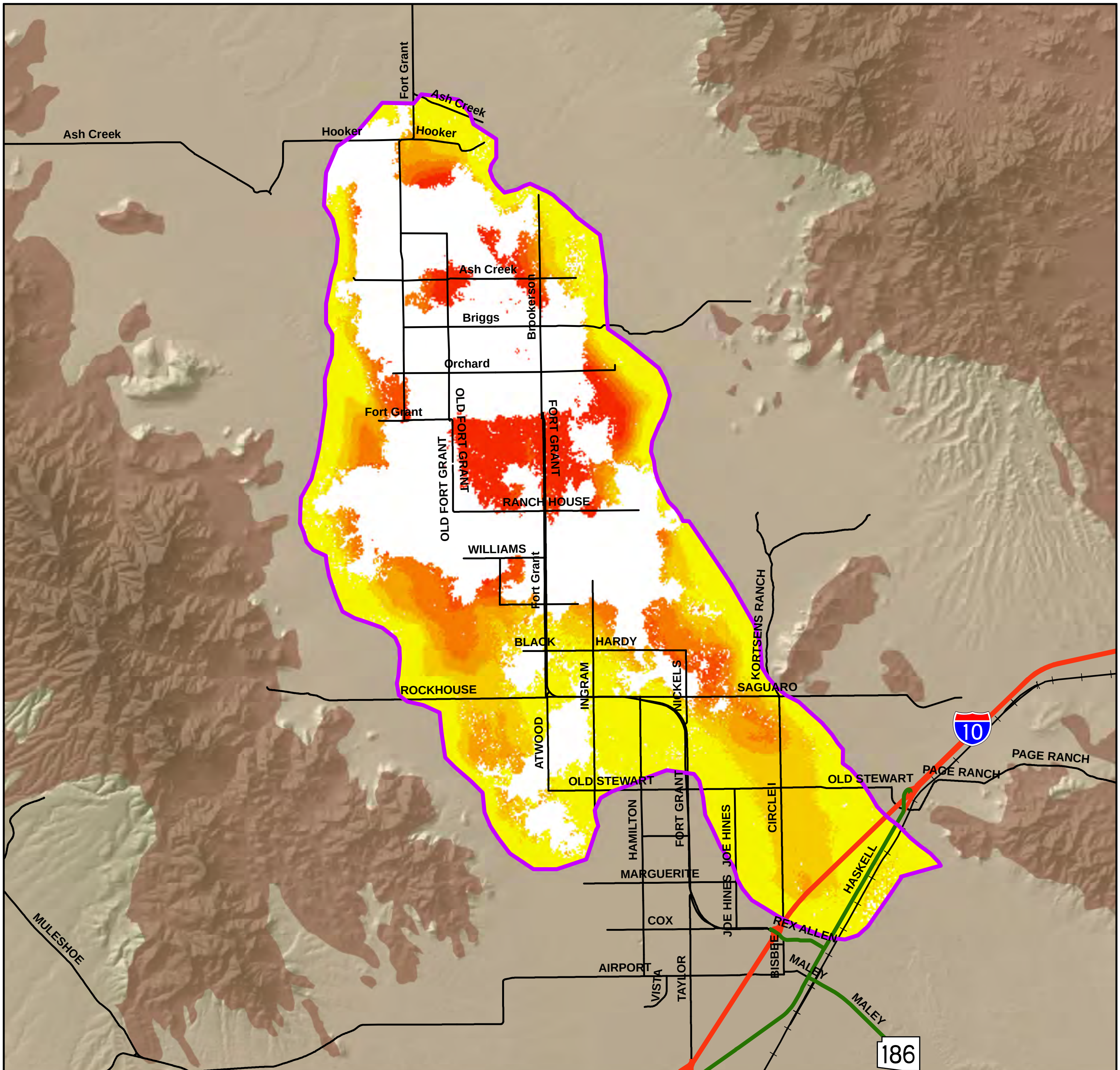

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Figure 12 - Land Subsidence in the Fort Grant Road and Willcox Areas, Cochise County
Based on ADWR Radarsat-2 Time-Series InSAR Data

Time Period of Analysis: 2.9 Years 05/05/2010 To 03/26/2013

05/05/2010 To 03/26/2013

Subsidence

- Decorrelation/No Data
- 12 To 15 cm
- 9 To 12 cm
- 6 To 9 cm
- 4 To 6 cm
- 2 To 4 cm
- 0 To 2 cm

- Subsidence Feature
- Hardrock

Highways and Interstates

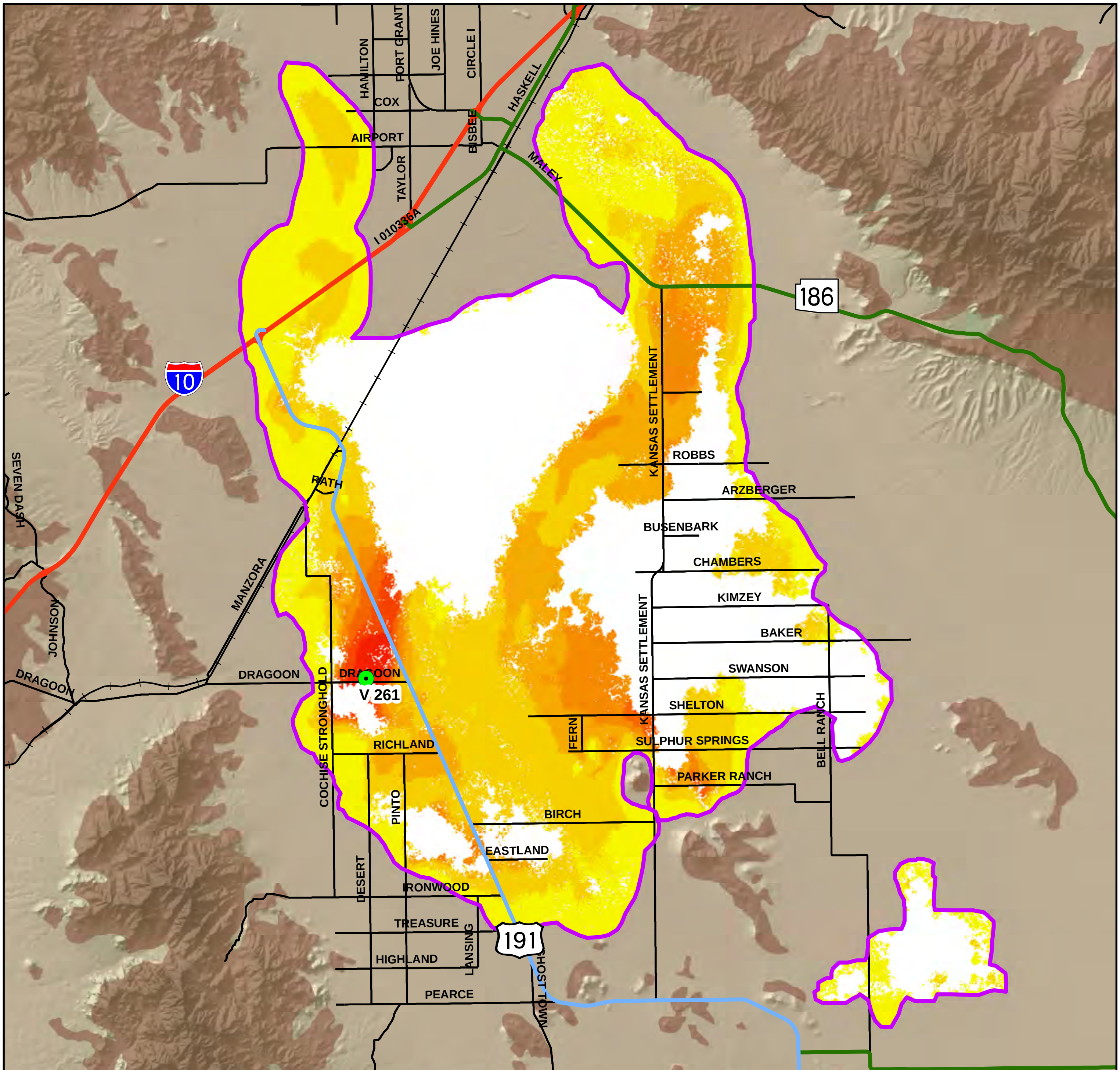
- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:191,637

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).



© MDA 2010 - 2013

Figure 13 - Land Subsidence in the Willcox and Kansas Settlement Areas, Cochise County
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 2.9 Years 05/05/2010 To 03/26/2013

05/05/2010 To 03/26/2013

Subsidence

- Decorrelation/No Data
- 19 To 23 cm
- 15 To 19 cm
- 12 To 15 cm
- 9 To 12 cm
- 6 To 9 cm
- 2 To 6 cm
- 0 To 2 cm

- Subsidence Feature
- Survey Monument
- Hardrock

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:250,000

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).

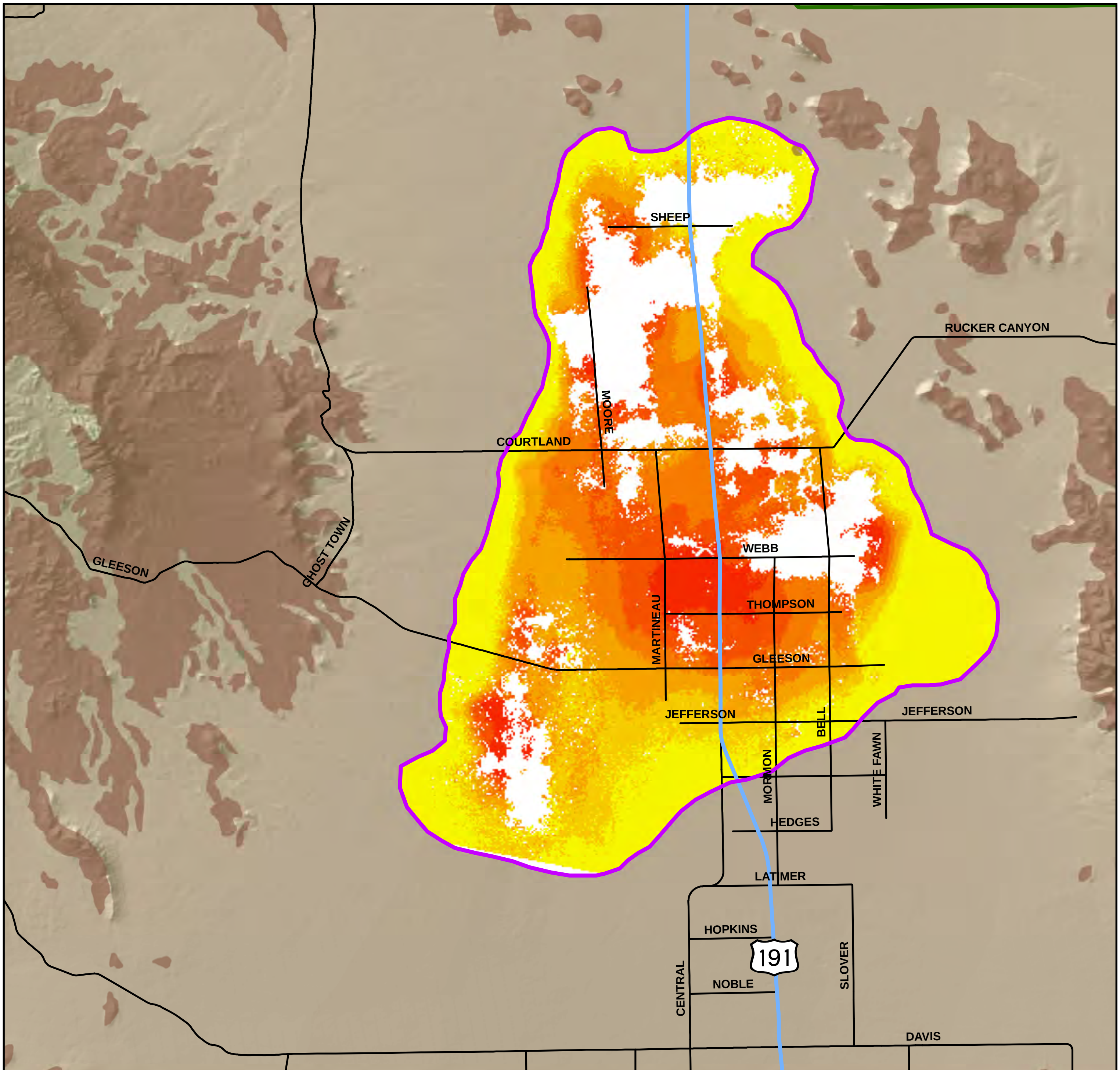


Figure 14 - Land Subsidence in the Elfrida Area, Cochise County
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 2.9 Years 05/05/2010 To 03/26/2013

05/05/2010 To 03/26/2013

Subsidence

- Decorrelation/No Data
- 9 To 12 cm
- 6 To 9 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Subsidence Feature

Hardrock

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

1:164,624

0 1 2 4 6 8 Miles

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

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).

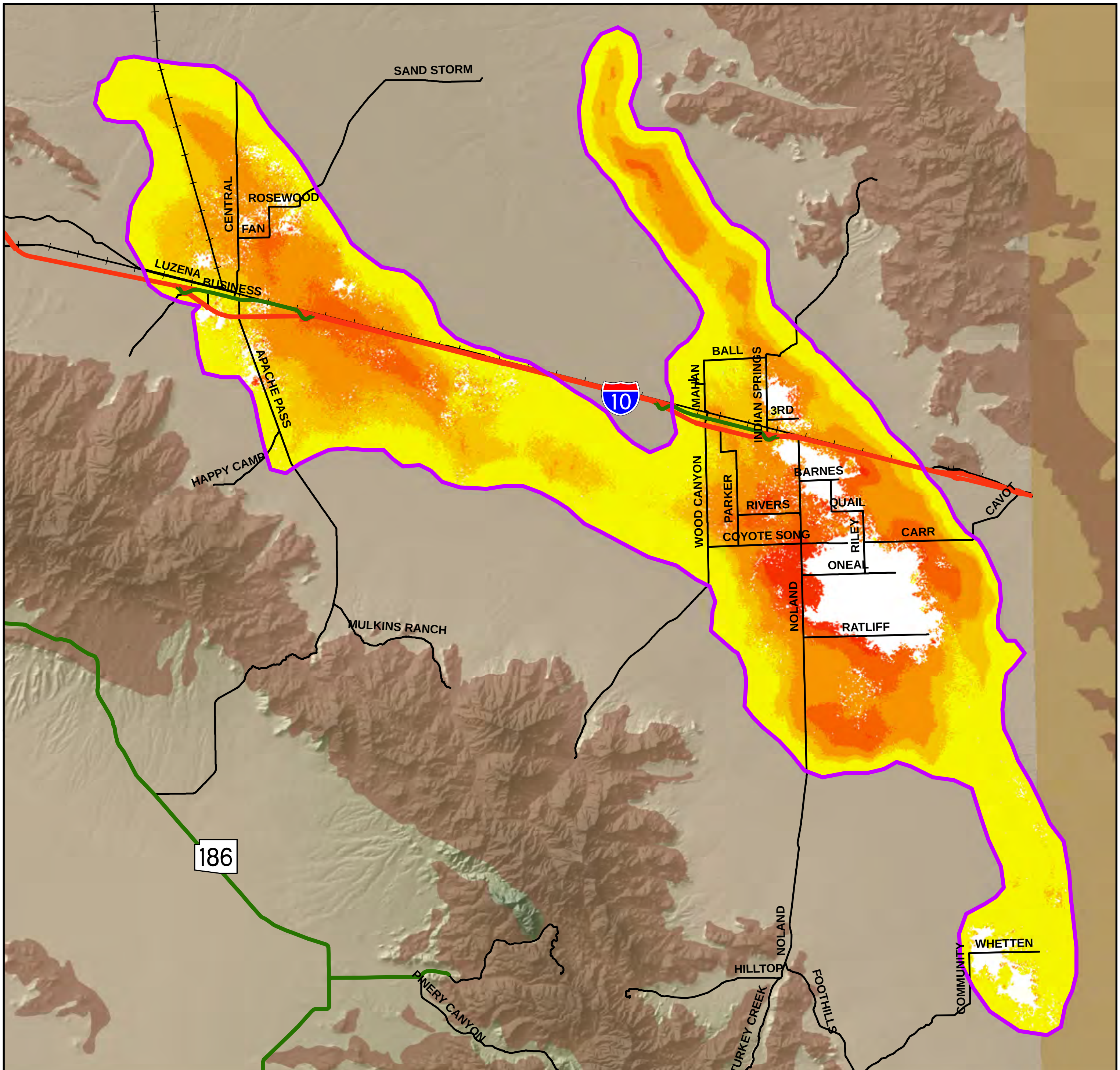


Figure 15 - Land Subsidence in the Bowie and San Simon Areas, Cochise County
Based on ADWR Radarsat-2 InSAR Data

Time Period of Analysis: 2.9 Years 05/05/2010 To 03/26/2013

05/05/2010 To 03/26/2013

Subsidence

- Decorrelation/No Data
- 6 To 9 cm
- 4 To 6 cm
- 2 To 4 cm
- 1 To 2 cm
- 0 To 1 cm

Subsidence Feature

Hardrock

Highways and Interstates

- Interstate
- US
- State
- Roads
- Railway

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:288,798

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).

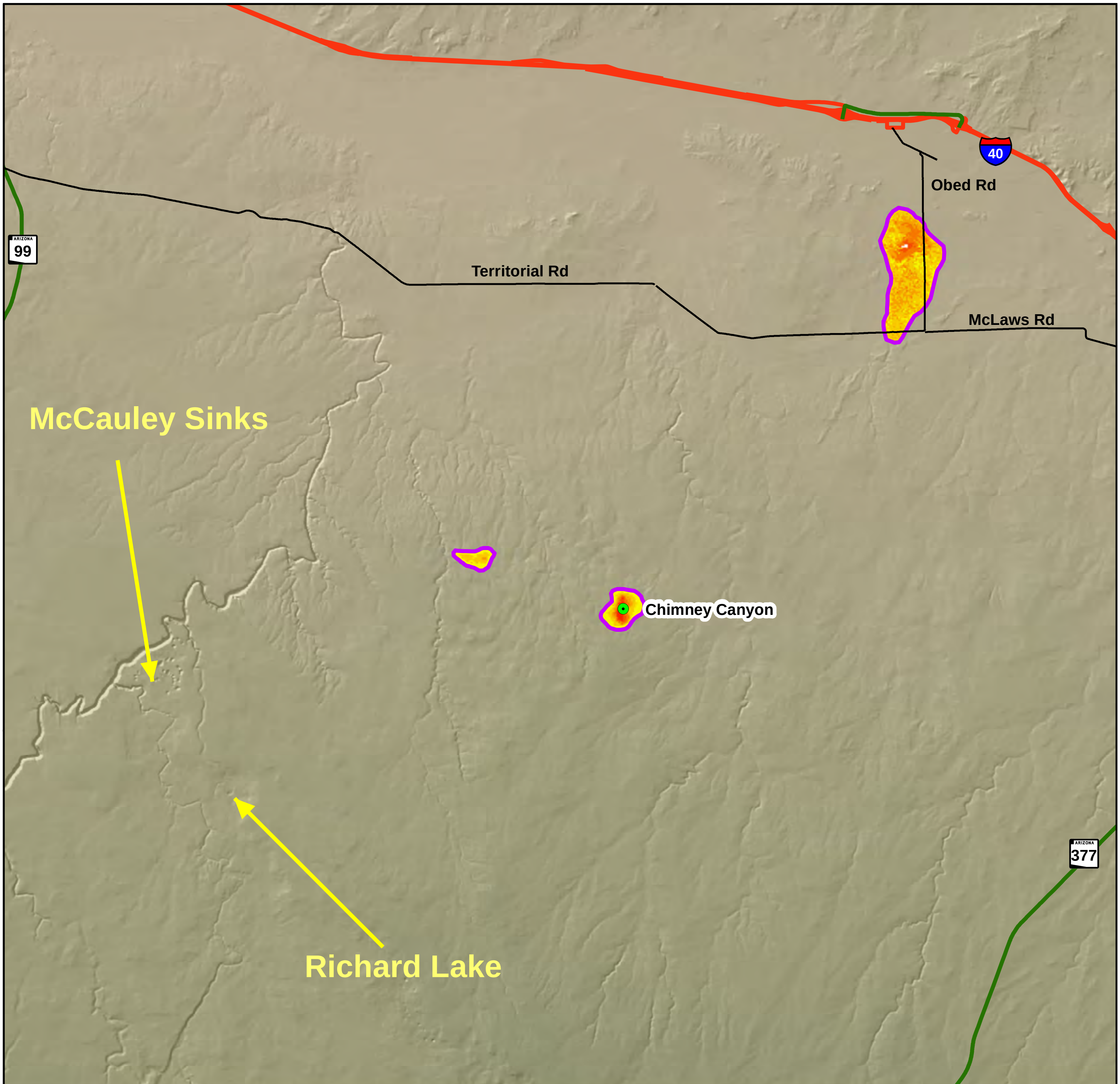


Figure 16 - Land Subsidence in the Holbrook Sinks Area, Navaho County
Based on ADWR ALOS InSAR Data
Time Period of Analysis: 4.1 Years 12/06/2006 To 02/01/2011

12/06/2006 To 02/01/2011

Subsidence

- Decorrelation/No Data
- 18 To 26 cm
- 12 To 18 cm
- 6 To 12 cm
- 4 To 6 cm
- 2 To 4 cm
- 0 To 2 cm

- Subsidence Feature
- Survey Monument
- Hardrock

Highways and Interstates

- Interstate
- US
- State
- Roads

Note! Colors assigned representing differing amounts of subsidence apply to this map only. Color codes may vary for other maps

1:177,022

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).

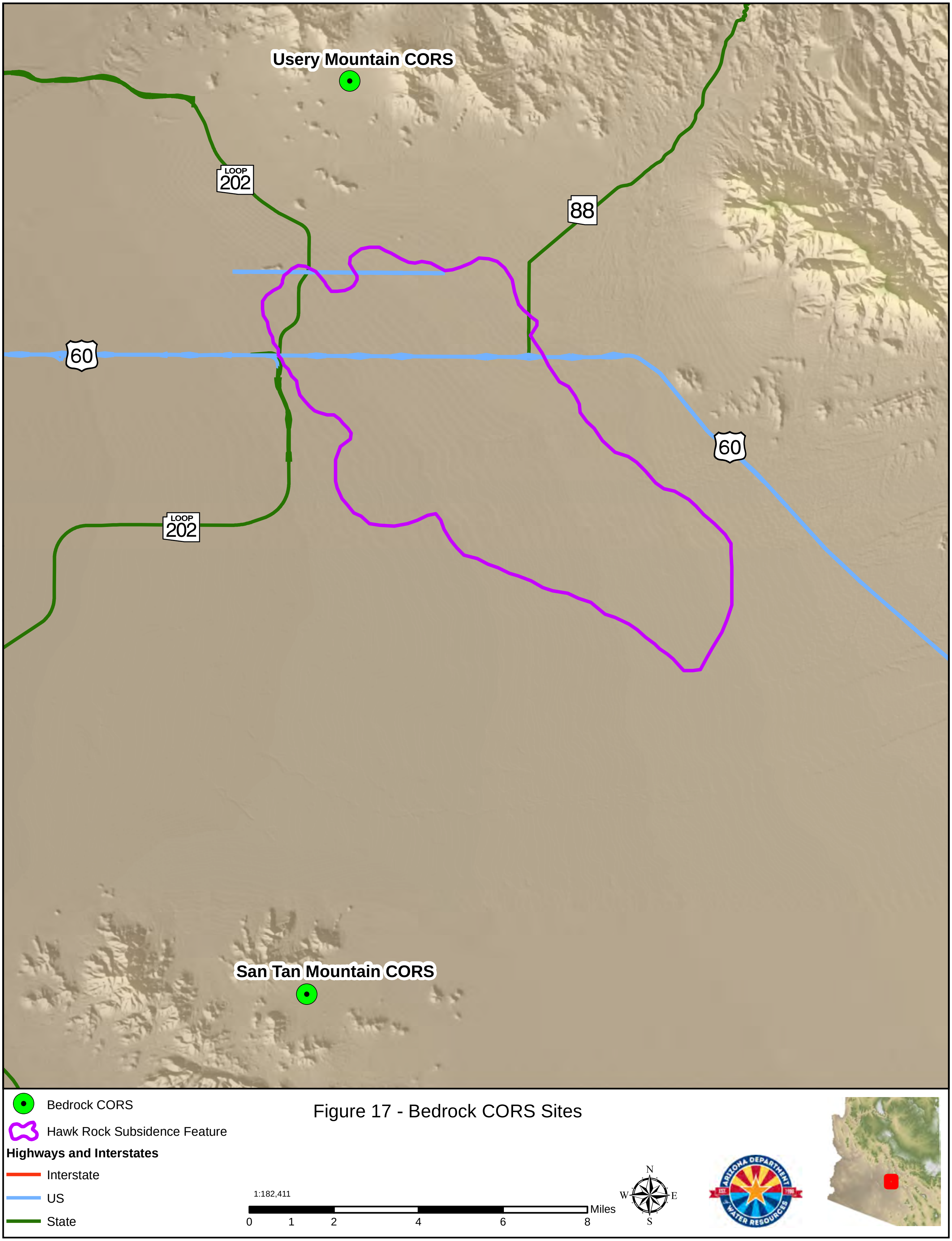


Figure 17 - Bedrock CORS Sites

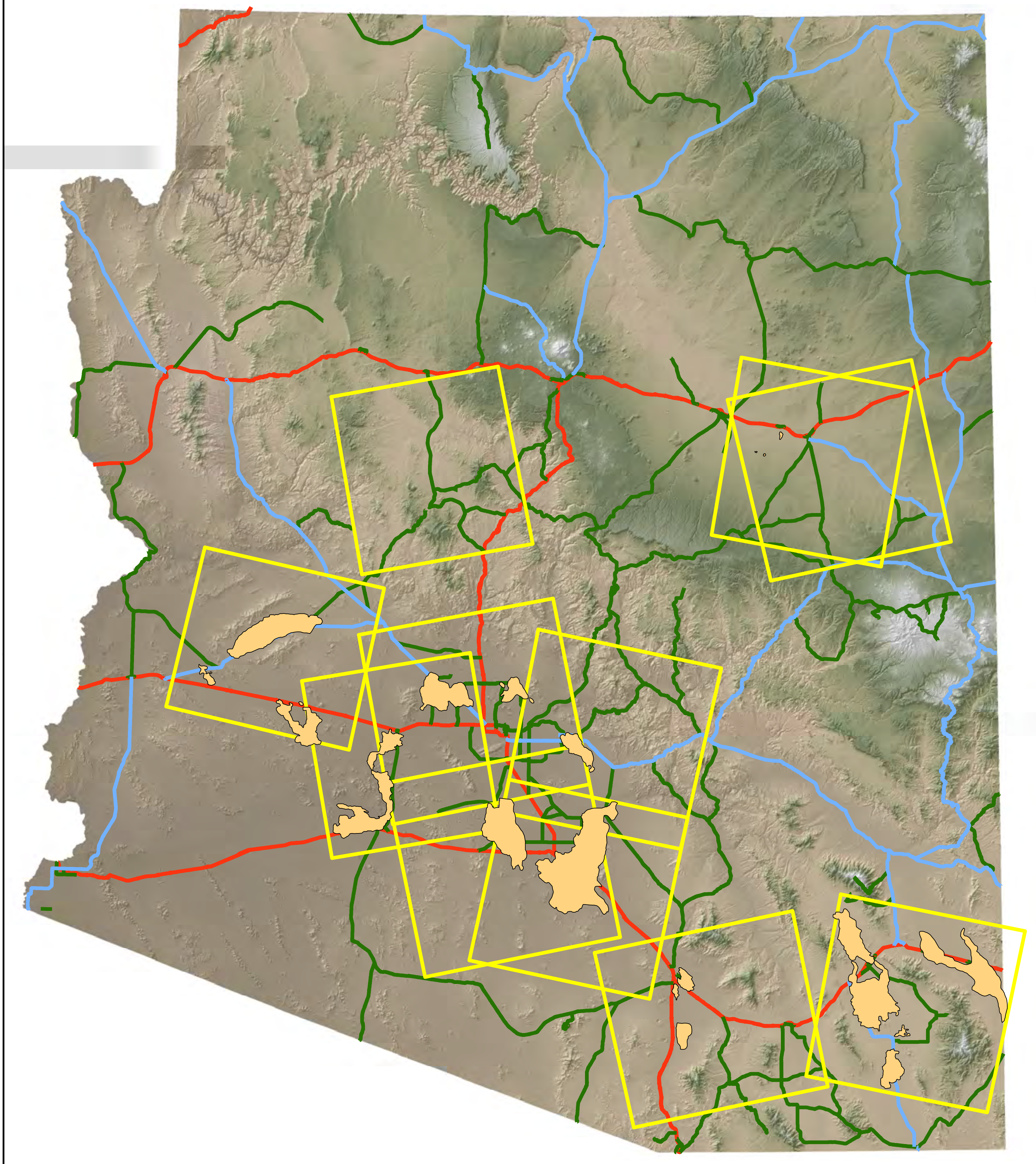


Figure 18 - Current Satellite Frames Used by ADWR to Collect InSAR Data in Arizona
InSAR Data is Collected, Processed, and Analyzed
By the Geophysics/Surveying Unit of the Hydrology Division

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 Area) are showing active land subsidence at this time