Technical Memorandum

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Transmitted via email

Subject: **Fillmore and Piru Groundwater Basins 2022 Subsidence Update, prepared for Fillmore and Piru Basins Groundwater Sustainability Agency, DB22.1164.00**

Findings

A review and analysis of recently collected satellite (InSAR) data strongly indicates that net land subsidence due to groundwater pumping has not occurred in the Fillmore and Piru Groundwater Basins since June 2015, when direct measurements became available. On the contrary, portions of the Piru Basin showed a period of increasing land surface elevations believed to be caused by elastic rebound of the aquifer. In addition, groundwater elevations and geodetic survey (CGPS) stations, which provide indirect measures of land subsidence, support the conclusions reached using the remotely sensed InSAR data. Therefore, the Fillmore and Piru basins are currently being managed sustainably in the context of undesirable results caused by land subsidence due to groundwater extractions.

Introduction

Daniel B. Stephens & Associates, Inc. (DBS&A) has prepared this Fillmore and Piru Groundwater Basins Land Subsidence Update Technical Memorandum (Tech Memo) for the Fillmore and Piru Basins Groundwater Sustainability Agency (FPBGSA or Agency) pursuant to Task Order No. 2022-02 issued under Professional Services Agreement No. 2022-04-21-DBSA. This Tech Memo provides an update to the Fillmore and Piru Basins Land Subsidence Evaluation Technical Memorandum (DBS&A, 2021), which was prepared during the development of the Fillmore and Piru basins Groundwater Sustainability Plans (GSP or Plan) as required the Sustainable Groundwater Management Act (SGMA) of 2014.

The Land Subsidence Evaluation Technical Memorandum describes the Minimum Threshold (MT) for land subsidence at any location in either basin as an annual rate of 1 foot/year or 1 foot of cumulative [net] subsidence over a period of five years. Land subsidence is one of six sustainability indicators defined in the SGMA legislation. This document provides a review of current data sets (e.g., geodetic monitoring, interferometric synthetic radar) and an evaluation of subsidence susceptibility for both Fillmore and Piru basins.

Interferometric Synthetic Aperture (InSAR) Data

Interferometric Synthetic Aperture (InSAR) is a satellite-based remote sensing method used to map ground surface elevation change over large areas with high accuracy. Satellites emit electromagnetic pulses that produce measurements upon their return. These measurements are processed to create synthetic aperture radar images. The InSAR method calculates the change in elevation from one measurement to the next and presents the changes as raster images (gridded data with coordinates). To assist with quantitative subsidence evaluations for GSP development, the California Department of Water Resources (DWR) contracted TRE Altamira Inc. (TRE) to process InSAR data collected by the European Space Agency (ESA) Sentinel-1A satellite covering Bulletin 118 groundwater basins. The processed TRE InSAR datasets are available on DWR's SGMA Data Viewer application, DWR's image service directory, and the Filmore and Piru basins database management system (DMS).

Eight points within the basins were chosen for vertical displacement time-series analysis based on special geographical characteristics and/or hydrogeological setting (e.g., likelihood of the area having significant thicknesses of fine-grained sediment, presence or absence of rising groundwater elevations, and general depths-to-groundwater). Locations of these points are shown in Figure 1 and described below:

1. Fillmore-Santa Paula Basin Boundary
2. Sespe Uplands
3. Bardsdale
4. City of Fillmore (Pole Creek Fan)
5. Fillmore-Piru Basin Boundary
6. Central Piru Basin
7. Piru Creek/Santa Clara River Confluence
8. Piru-SCR East Basin Boundary

Eight additional points within the basin were chosen for vertical displacement time-series analysis at specific infrastructure locations (e.g., railways and bridges), as these locations would be most impacted by subsidence. In addition, these new locations were generally selected to be in close proximity to pumping centers. Infrastructure monitoring locations are shown in Figure 1 and described below:

9. Hwy 126 Crossing Sespe Creek
10. Hwy 23 Crossing Santa Clara River
11. Torrey Road Crossing Santa Clara River
12. Hwy 126 Crossing Piru Creek
13. Hwy 126 and Railway Intersection Near Santa Paula
14. Railway - Fillmore Basin
15. Railway - Near Fillmore-Piru Basin Boundary
16. Railway - Piru Basin

InSAR data from DWR are available on a monthly basis as both total subsidence observed since June 13th, 2015 and annual rates (moving 12-month window). Timeseries of these data for the monitoring locations described above are shown in Figures 2a and 2b. The majority of the measured displacement falls within the InSAR measurement error range of ±0.07 ft (gray band on time series), and indicates there is no observed subsidence in Fillmore and Piru basins. In fact, land surface elevations in the central portion of the Piru basin (locations 6, 11, and 16) increased in 2020 and 2021 above the InSAR measurement error. This indicates that the aquifer in that portion of the basin was experiencing elastic rebound effects. However, no adverse impacts to the infrastructure at these three locations have been reported.

Total observed cumulative subsidence for the Fillmore and Piru basins from June 13th, 2015 to October 1st, 2022 is shown in Figure 3. All cumulative subsidence values fall within the InSAR measurement error of ±0.07 ft, and therefore no significant changes in land surface elevation have been observed. This is consistent with the interpretation of the InSAR time series data.

Elastic rebound within the Piru basin can be attributed to water releases from the Santa Felicia and Castaic dams, which can be seen in Figure 4. The annual and total cumulative displacement time series increases above the +0.07 InSAR measurement error range at the Pole Creek Fan site (6) and the Piru Basin Railway (16) in response to the release of water from the reservoirs. Location 6 had a maximum total cumulative land displacement of 1.5 inches and location 16 had a maximum total cumulative land displacement of 1.2 inches as a result of two large reservoir releases from the Santa Felicia and Castaic dams in 2019 and 2020. Locations 6, 11, and 16 display very similar annual and total land displacement time series.

While the time series data fall largely within the measurement error bars and it is speculative to rely upon these data, it is interesting to note that the annual displacement values respond quickly to reservoir releases but begin to decline within 2-3 months of the termination of reservoir releases (Figure 4).

Lastly, the InSAR timeseries data and total observed subsidence shows that the annual displacement and the total cumulative displacement over the last five years has not reached the MT described in the Land Subsidence Evaluation Technical Memorandum. As previously stated, the MT for land subsidence at any location in either basin is an annual rate of 1 foot/year or 1 foot of cumulative subsidence over a period of five years. Recent InSAR data shows that subsidence data from this year fall within the InSAR measurement error, which is almost two orders of magnitude lower than the annual MT rate. InSAR data also shows that cumulative displacement over the last five years does not approach 1 foot of subsidence, and has stayed within the InSAR measurement error, except for areas exhibiting elastic rebound.

Geodetic Surveys

UNAVCO monitors continuously operating geodetic instrument networks, including Continuous Global Positioning Systems (CGPS) stations, that measure three-dimensional positions (generally every 15 or 30 seconds) of a point near the earth's surface. Four CGPS stations are located within

5 miles of the basins that have been operational for over 20 years. All four stations are installed outside of the alluvial basins on bedrock, so any vertical displacement is likely caused by tectonic movement rather than compaction of fine-grained materials due to groundwater withdrawal. CGPS datasets are available at: (https://www.unavco.org/data/web-services/documentation/documentation.html#!/GNSS47GPS/getPositionByStationId)

Figure 5 shows the location of nearby CGPS stations, along with time series graphs displaying measured land displacement relative to the first measurement of each station. Data displayed in the time-series graphs are referenced to the North American tectonic plate (NAM14) reference frame. Measurements with a standard deviation greater than 20 mm (about 0.8 inches) were considered to be outliers and removed from analysis.

Data from the two CGPS stations within the basin shows either no significant elevation change or a slightly increased elevation of approximately 20mm over the last 20 years. The two CGPS stations to the south of the Fillmore and Piru basins show a slight decrease in elevation over the last 20 years (10-20mm or 0.4-0.8 in), which is considered to be minor and related to natural tectonic motion as opposed to land subsidence due to groundwater pumping.

Groundwater Hydrographs

The susceptibility of each basin to subsidence is rooted in a few key factors:

- The hydrostratigraphic setting (i.e., do the geologic units contain fine-grained sediments); and
- If the water level is below the historic lows.

In general, both of these factors must be present to initiate subsidence. The Fillmore Basin contains greater amounts of fine-grained alluvial sediments in the western portion compared to the eastern portion, resulting in a moderate to low subsidence susceptibility ranking, with respect to its hydrostratigraphic setting (DBS&A, 2021). The Piru Basin contains greater amounts of coarse-grained materials which results in a low subsidence susceptibility ranking. Both basins are characterized as having a low subsidence susceptibility ranking (DBS&A, 2021).

Figure 6 shows selected groundwater elevation hydrographs in the Fillmore and Piru basins. Although groundwater elevations have decreased recently due to consecutive dry years, they have not reached their respective historic lows which is typically the threshold at which aquifer subsidence processes begin. Hydrographs for all monitoring wells in the basin are available on the Fillmore and Piru Basins DMS. DBS&A (2021; Figure 8) developed estimated historical low water levels for four groundwater wells distributed across the basins and compared those low water levels to the future simulated water levels for the period from 1986-2096. In each well, the modeled low water levels were at or above the historical low water levels thereby removing this potential subsidence triggering condition. The most recent water level measurements for these wells or wells nearby record water levels above the historical low water levels.

Conclusions

Analyses of remotely sensed vertical movement (InSAR), geodetic survey (CGPS), and groundwater elevation data show that there has not been any measurable net subsidence in the basin since measurements started in June 2015. In fact, some areas in the Piru Basin showed increased land surface elevations that are believed to be caused by elastic rebound of the aquifer. Water levels in the basins remain above the potential subsidence triggering estimated historical low water levels. None of the subsidence data sets include ground movement that exceeds the Minimum Threshold set in the GSP for each of the basins. Therefore, the Fillmore and Piru basins are currently being managed sustainably in the context of undesirable results caused by land subsidence due to groundwater extractions.

References

California Department of Water Resources SGMA Data Viewer, Accessed January 2023. https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer#landsub)

DBS&A, 2021. Fillmore and Piru Basins Land Subsidence Evaluation. Technical Memo. https://s29420.pcdn.co/wp-content/uploads/2022/02/Appendix-F_Subsidence-Tech-Memo.pdf

Fillmore and Piru Basins SGMA DMS, Accessed January 2023. https://Fillmore-Piru.GLAData.com/

UNAVCO, Accessed January 2023. https://www.unavco.org/data/gps-gnss/gps-gnss.html

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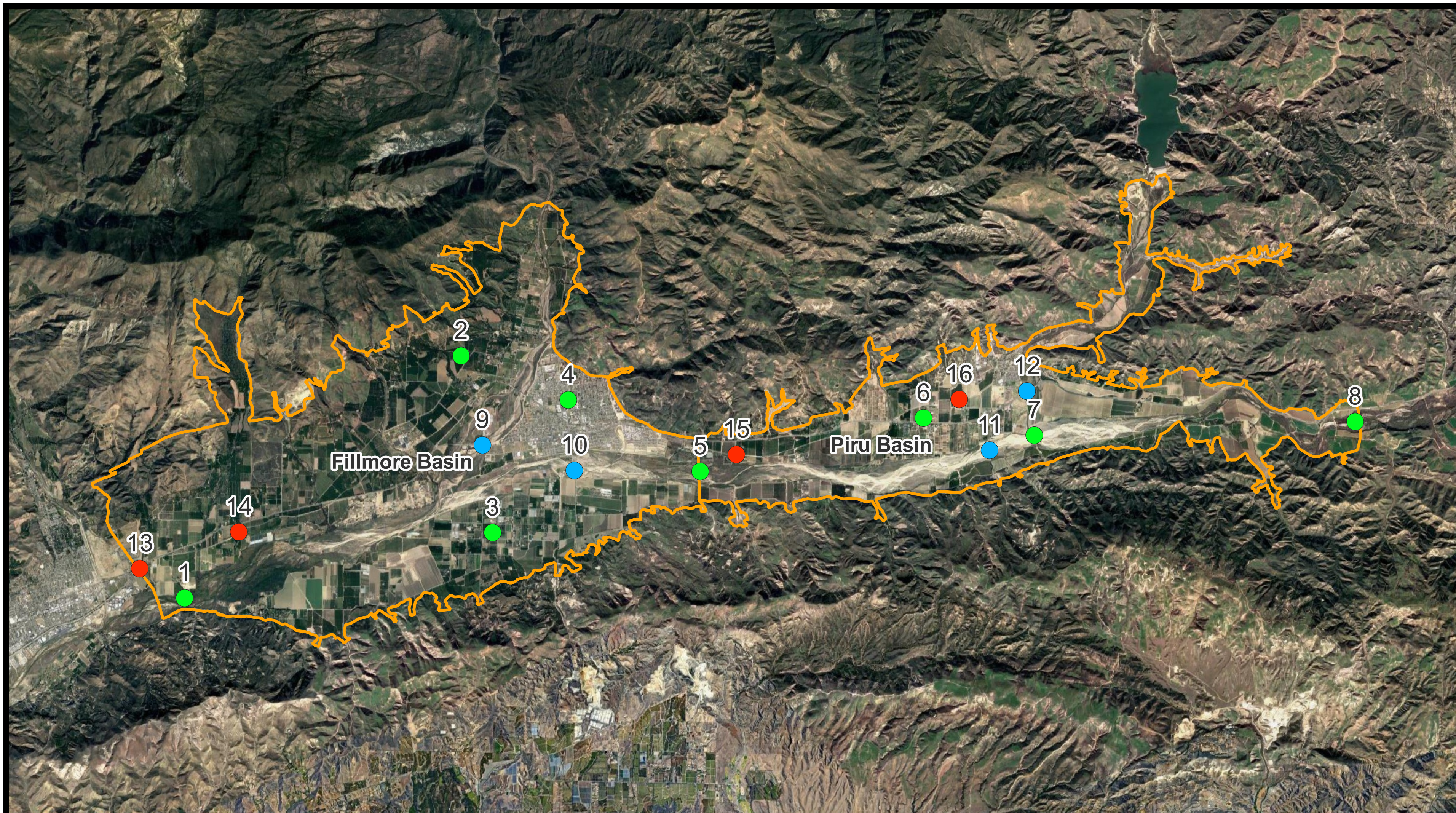

Explanation

InSAR Monitoring Locations
- Bridge
- General
- Railway

Fillmore and Piru Groundwater Basins Boundary

0 1 2 mi

N

FILLMORE AND PIRU GROUNDWATER BASINS
SUBSIDENCE UPDATE
InSAR Monitoring Locations

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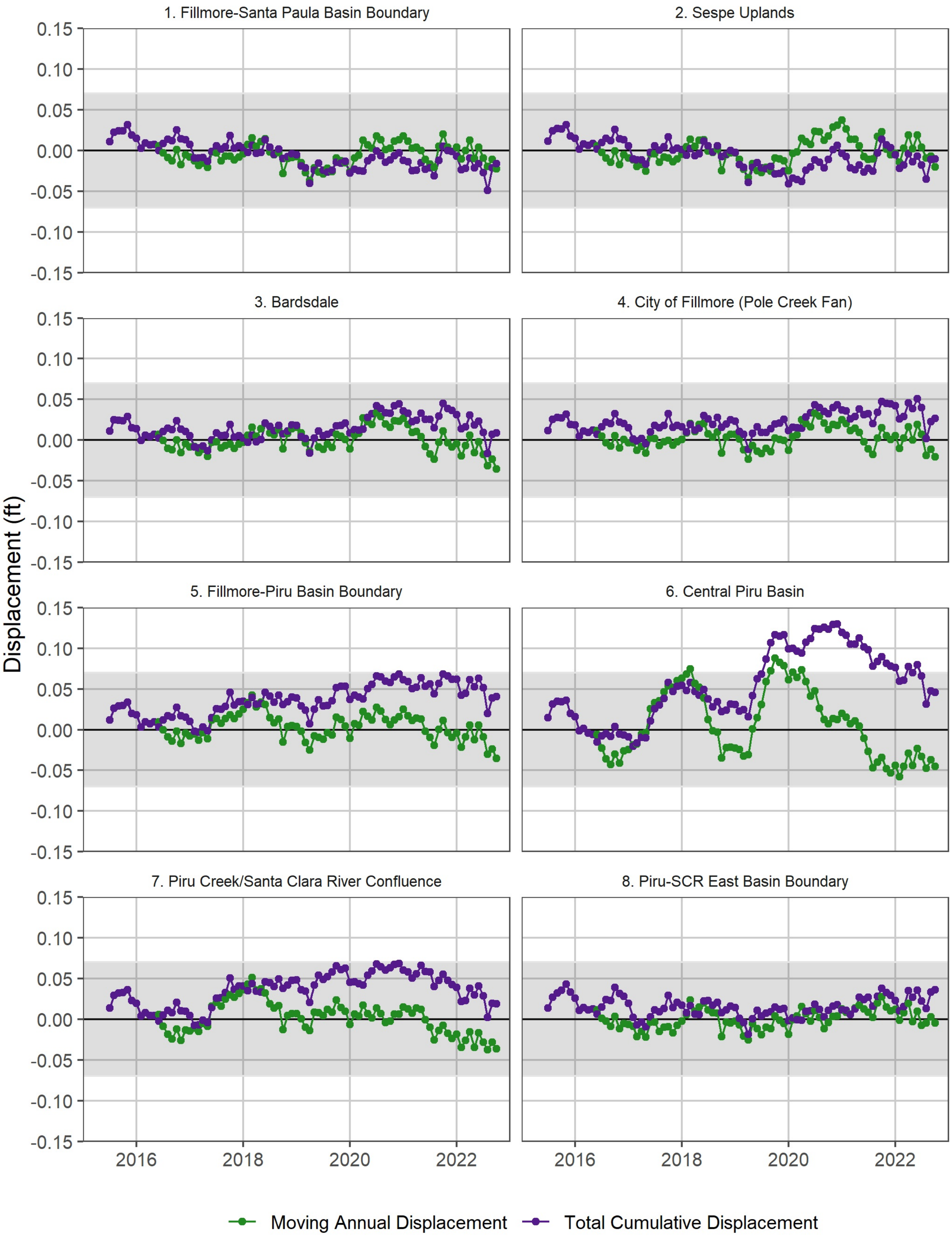
Figure 1



Source: https://data.ca.gov/dataset/tre-altamira-insar-subsidence-data

Notes:
1. Gray shading indicates InSAR measurement accuracy of +/- 0.07 ft

FILLMORE AND PIRU GROUNDWATER BASINS
SUBSIDENCE UPDATE

InSAR Monitoring Location Time Series
Annual Rates & Total Cumulative Displacement

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Figure 2a

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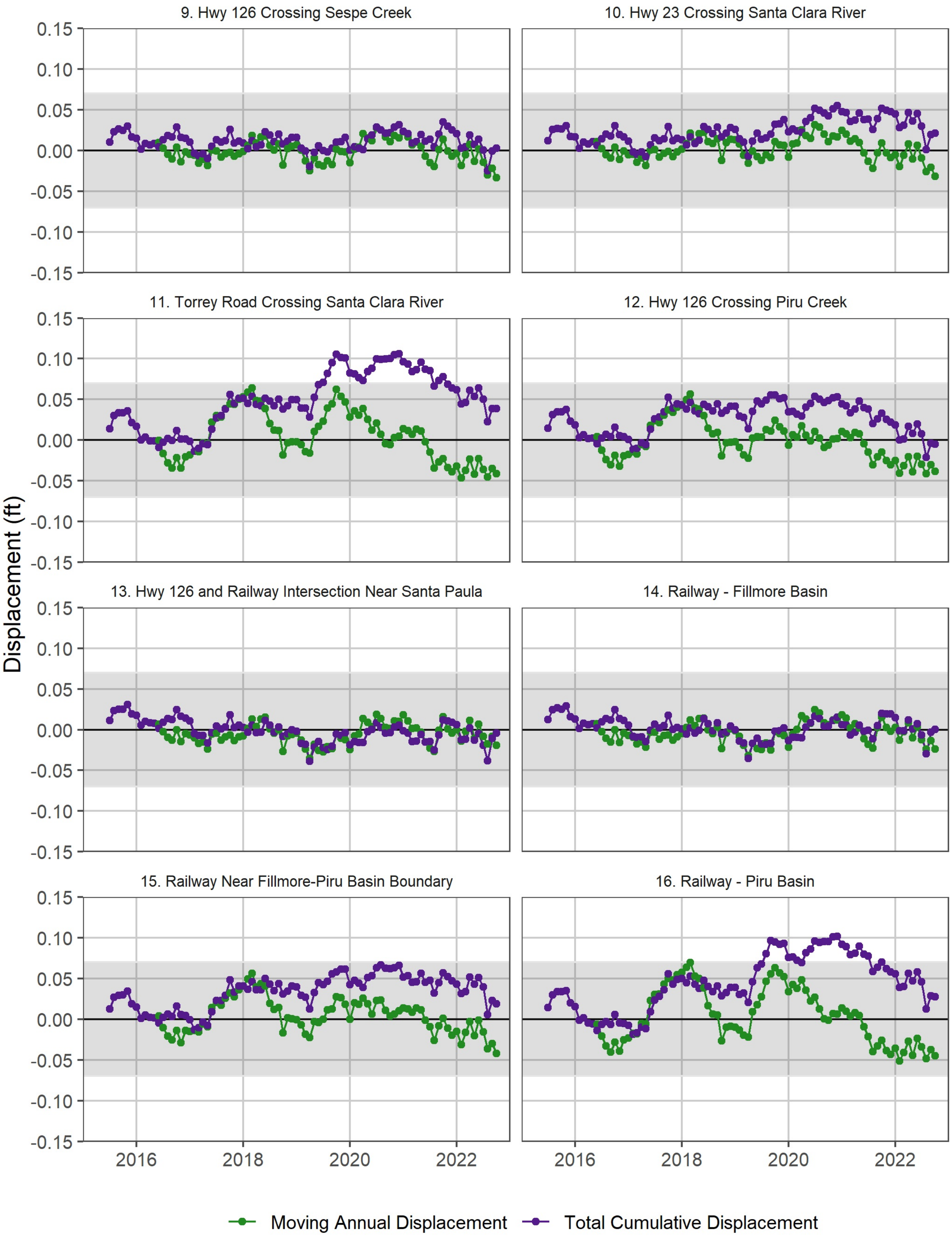

Source: https://data.ca.gov/dataset/tre-altamira-insar-subsidence-data

Notes:
1. Gray shading indicates InSAR measurement accuracy of +/- 0.07 ft

FILLMORE AND PIRU GROUNDWATER BASINS
SUBSIDENCE UPDATE

InSAR Monitoring Location Time Series
Annual Rates & Total Cumulative Displacement

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Figure 2b

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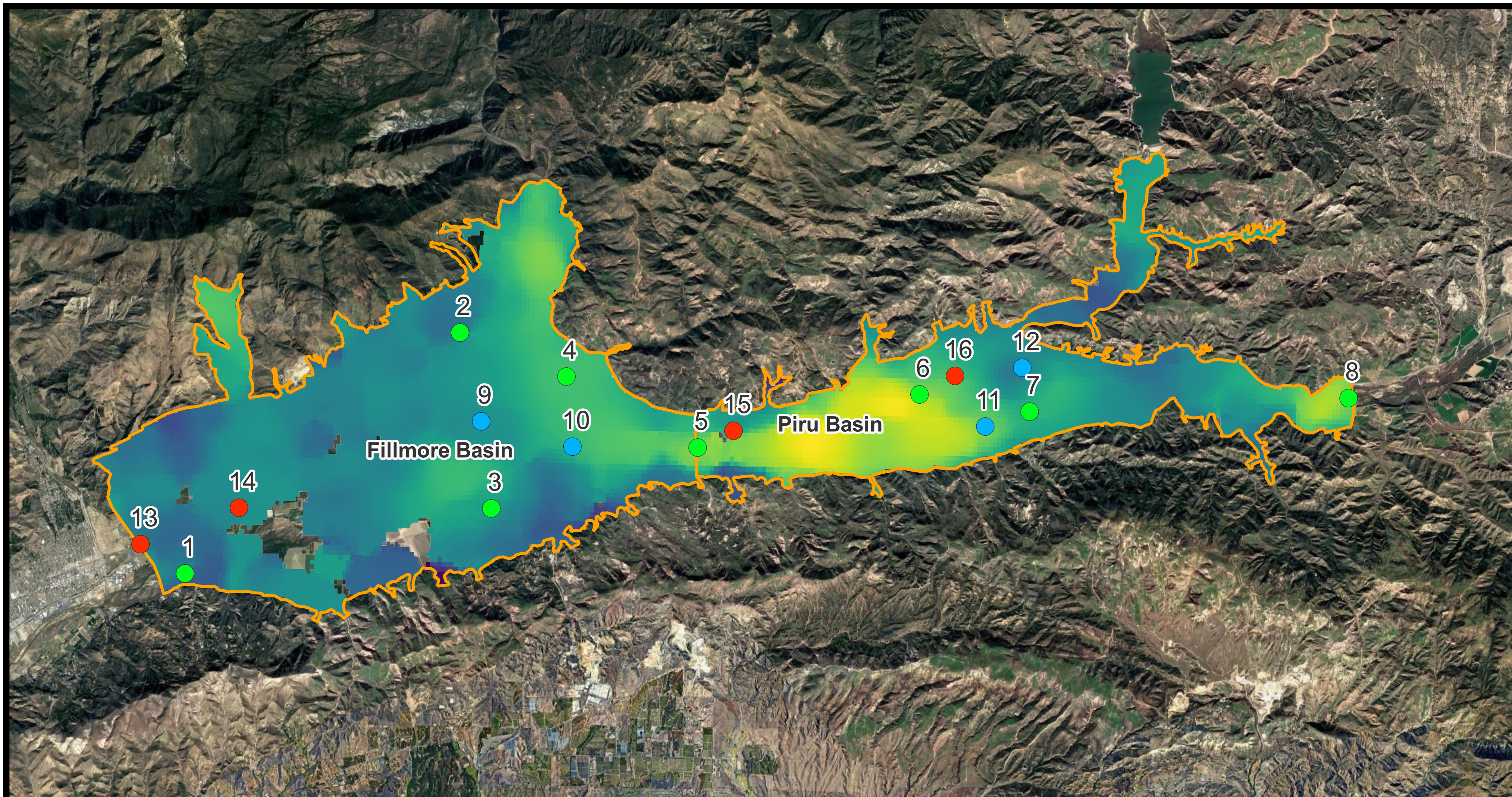

Explanation

InSAR Monitoring Locations
- General
- Bridge
- Railway

Total Displacement (ft)
+0.06
-0.06

Fillmore & Piru Basins Boundary

Notes:
1. Total displacement less than InSAR measurement error of +/-0.07 ft at all locations

0 1 2 mi

N

Source: https://data.ca.gov/dataset/tre-altamira-insar-

FILLMORE AND PIRU GROUNDWATER BASINS
SUBSIDENCE UPDATE

InSAR Total Cumulative Displacement
June 2015 - October 2022

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Figure 3

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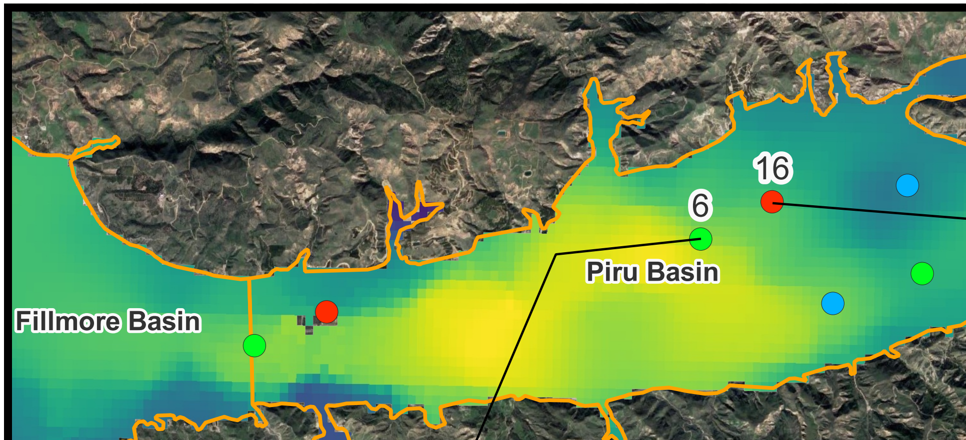

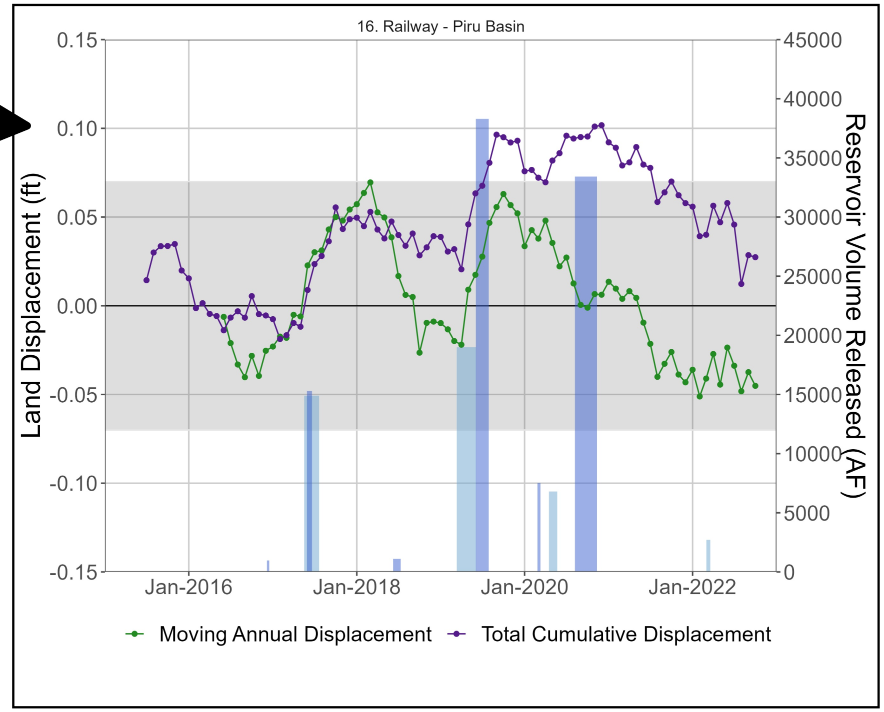

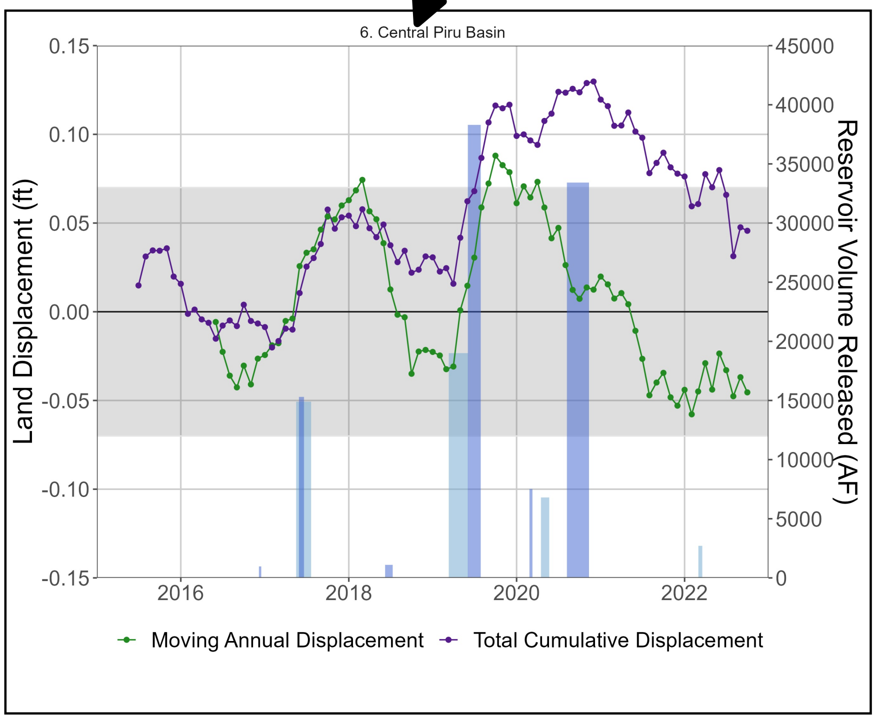

Explanation

InSAR Monitoring Points
- General
- Bridge
- Railway

Total Displacement (ft)
+0.06
-0.06

Fillmore & Piru Basin Boundaries

Castaic Dam
Santa Felicia Dam

Notes:
1. Data shows two sites selected which have exhibited evidence of elastic rebound.
2. Reservoir release data has been included to show correlation between elastic rebound and dam releases.

Source: https://data.ca.gov/dataset/tre-altamira-insar-subsidence-data

FILLMORE AND PIRU GROUNDWATER BASINS
SUBSIDENCE UPDATE

InSAR Vertical Displacement and Reservoir Releases
June 2015 - October 2022

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Figure 4

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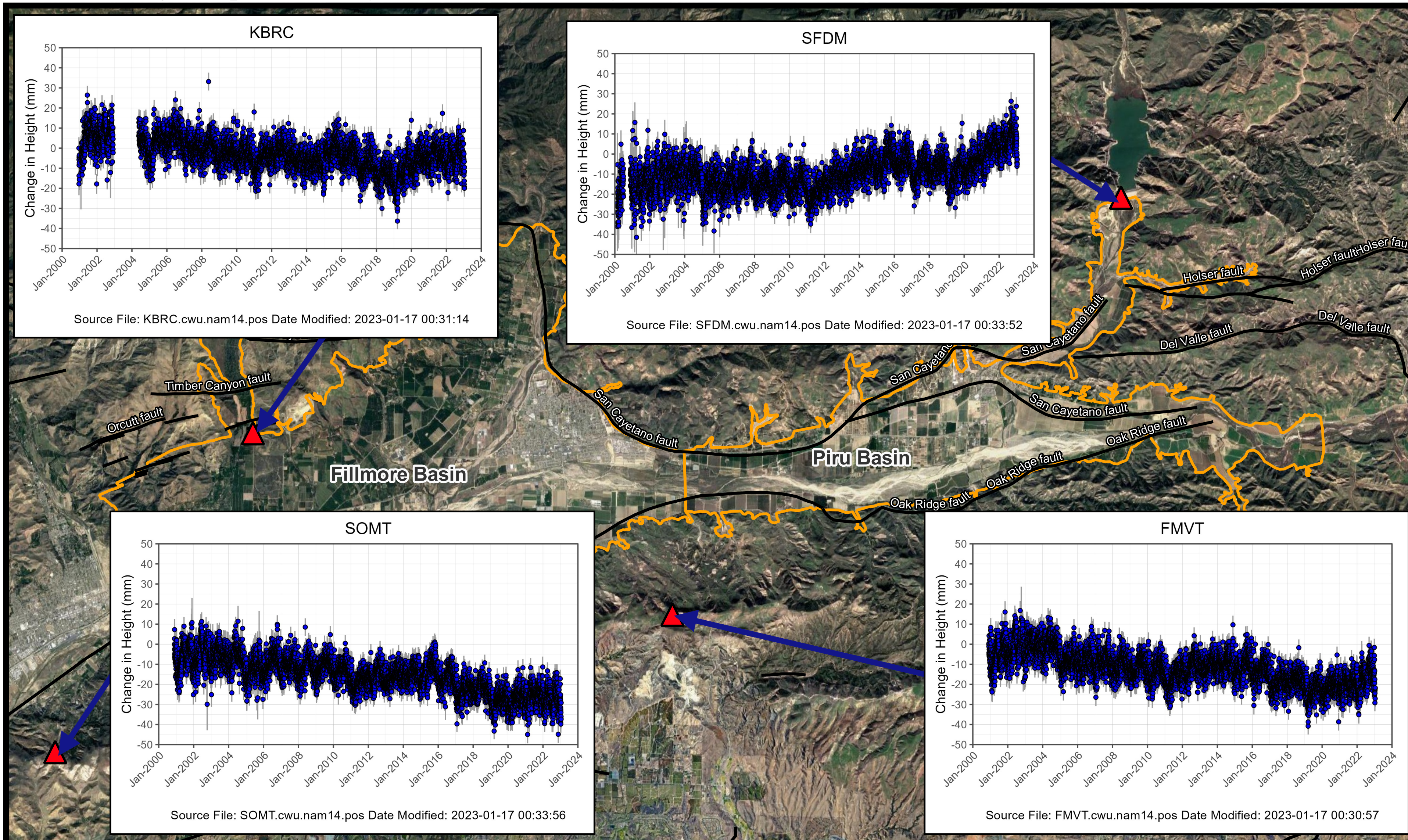

Source: UNAVCO

Explanation

UNAVCO GPS Locations

Quaternary Faults

Fillmore and Piru Groundwater Basins Boundary

0 1 2 mi

N

Notes:
1. Change in height calculated by subtracting measured elevation from initial station elevation.

FILLMORE AND PIRU GROUNDWATER BASINS SUBSIDENCE UPDATE

CGPS Stations and Vertical Movement

Figure 5

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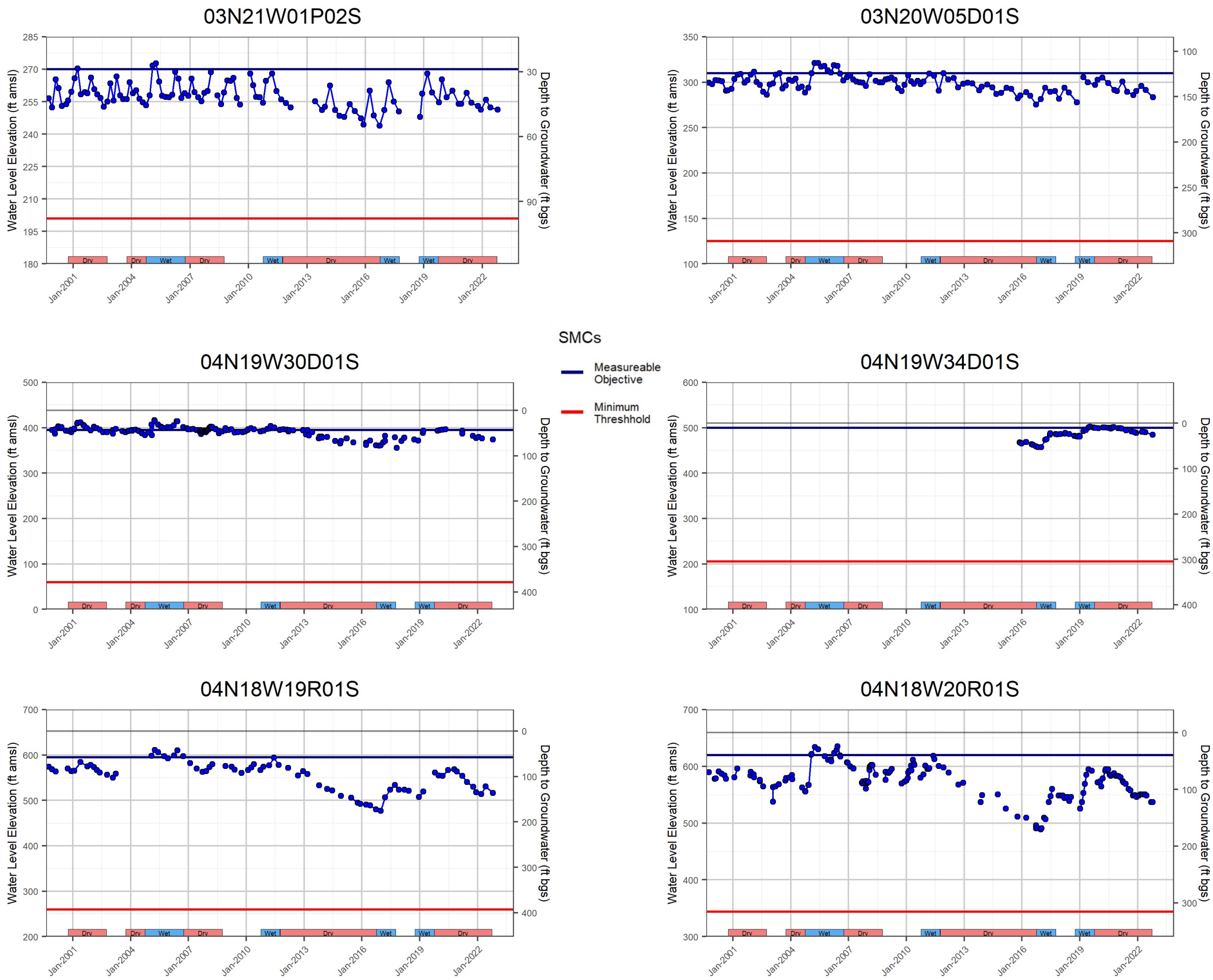
Explanation

InSAR Monitoring Point | Fillmore and Piru Basins Boundary

N

0 1 2 mi



Notes:
1. All hydrographs for both basins can be found at https://fillmore-piru.gladata.com/
2. Colors along the bottom of the plot indicate dry/critical (red) and wet (blue) water year types according to the San Joaquin Valley water year hydrologic classification from DWR.

Source: https://fillmore-piru.gladata.com/

FILLMORE AND PIRU GROUNDWATER BASINS
SUBSIDENCE UPDATE

Selected Groundwater Hydrographs

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Figure 6