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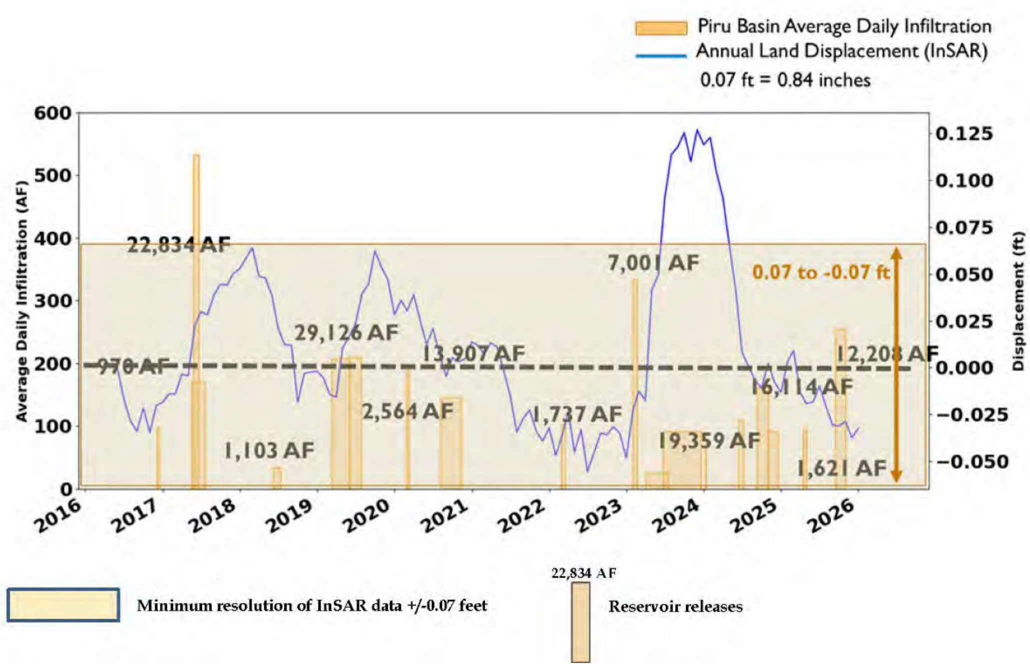
Subsidence Technical Memorandum
Fillmore and Piru Subbasins

Prepared for

Fillmore and Piru Basins
Groundwater Sustainability Agency



Prepared by

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a Geo-Logic Company

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September 4, 2026

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This document has been prepared under the direction of a professional geologist and certified hydrogeologist licensed in the State of California as required by the California Code of Regulations, Title 23 Section 354.12. The findings or professional opinions were prepared consistent with professional standards of practice.

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Date:	Date:

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Limitations of Investigation

This investigation was performed using the degree of care and skill ordinarily exercised, under similar circumstances, by experienced geologists and hydrogeologists practicing in this or similar locations. No warranty, expressed or implied, is made as to the conclusions and professional advice included within this report. The findings of this report are valid as of the present date. However, changes in the conditions of a property can and do occur with the passage of time, whether they are due to natural processes or the work of people on this or adjacent properties. Accordingly, the findings of this report may be invalidated wholly or partially by changes outside of our control. Therefore, this report is subject to review and revision as changed conditions are identified.

List of Acronyms and Abbreviations

AREMA	American Railway Engineering and Maintenance-of-Way Association
CalGEM	Geologic Energy Management Division (formerly DOGGR)
Caltrans	California Department of Transportation
CBC	California Building Code
CGPS	continuous global positioning system
DBS&A	Daniel B. Stephens & Associates, Inc.
DOGGR	Division of Oil, Gas, and Geothermal Resources (reorganized as CalGEM)
DWR	[California] Department of Water Resources
FPBGSA	Fillmore and Piru Basins Groundwater Sustainability Agency (also called GSA or Agency)
FRA	Federal Railroad Administration
ft/yr	feet per year
GPS	global positioning system
GSP	groundwater sustainability plan
IM	interim milestone
InSAR	interferometric synthetic aperture radar
mm/yr	millimeters per year
MO	measurable objective
MT	minimum threshold
NGS	National Geodetic Survey
OSHPD	Office of Statewide Health Planning and Development [California]
SGMA	Sustainable Groundwater Management Act
SMC	Sustainable Management Criteria
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UWCD	United Water Conservation District

Foreword

The Fillmore and Piru Basins Groundwater Sustainability Agency (FPBGSA or Agency) adopted Groundwater Sustainability Plans (GSPs) for both the Fillmore and Piru Basins in December 2021. The GSPs included a *Land Subsidence Evaluation Technical Memorandum* as Appendix F. Appendix F was not modified with the resubmittal of the GSPs in 2024.

Since the 2024 resubmittal of the GSPs, the Agency has consulted with the California Department of Water Resources (DWR) about incorporating the Recommended Corrective Actions (DWR, 2025a, 2025b) and the evaluation process described in DWR's Final Land Subsidence Best Management Practices (DWR, 2026) into an expanded treatment of subsidence. This consultation helped shape an evaluation approach for these subbasins with no documented history of significant subsidence.

This document is intended to completely replace the original Appendix F from the 2021 GSPs. Because this document is a total revision of the original technical memorandum, DWR concurred with the Agency's recommendation that a red-lined version of the original document was not necessary. ***This new technical memorandum supersedes the earlier version.***

1. Introduction

Daniel B. Stephens & Associates, Inc. (DBS&A) has prepared this updated Fillmore and Piru Groundwater Subbasins Land Subsidence Evaluation Technical Memorandum for the Fillmore and Piru Basins Groundwater Sustainability Agency (FPBGSA or Agency) and is under contract to assist with the preparation of their Periodic Evaluations and Amended GSPs for the two subbasins. Although the Sustainable Groundwater Management Act (SGMA) requires separate plans to be prepared for each subbasin, Fillmore and Piru subbasins are hydrogeologically connected and have historically been managed and monitored together. The FPBGSA Board of Directors has memorialized in Resolution 2021-05 their intent to continue this precedent and to manage these subbasins together. In keeping with this historical precedent, this technical memorandum has been prepared to cover both subbasins. This document includes references to appendices in the GSPs to provide supplemental information on several topics.

SGMA identifies land subsidence as one of six sustainability indicators. This technical memorandum summarizes the physical processes that cause inelastic subsidence, reviews previous investigations and current geodetic and interferometric synthetic aperture radar (InSAR) data, and evaluates the susceptibility of both subbasins to future subsidence. DBS&A (2021, 2023) provide the Agency's earlier analyses of the subsidence indicator.

Responses to the stakeholder comments on the draft updated Subsidence Technical Memorandum (insert date) are provided in Appendix A.

This evaluation addresses two primary questions: (1) Is subsidence currently occurring in the subbasins and (2) Is subsidence likely to occur in the future? The evaluation process is summarized in Figure 1-1.

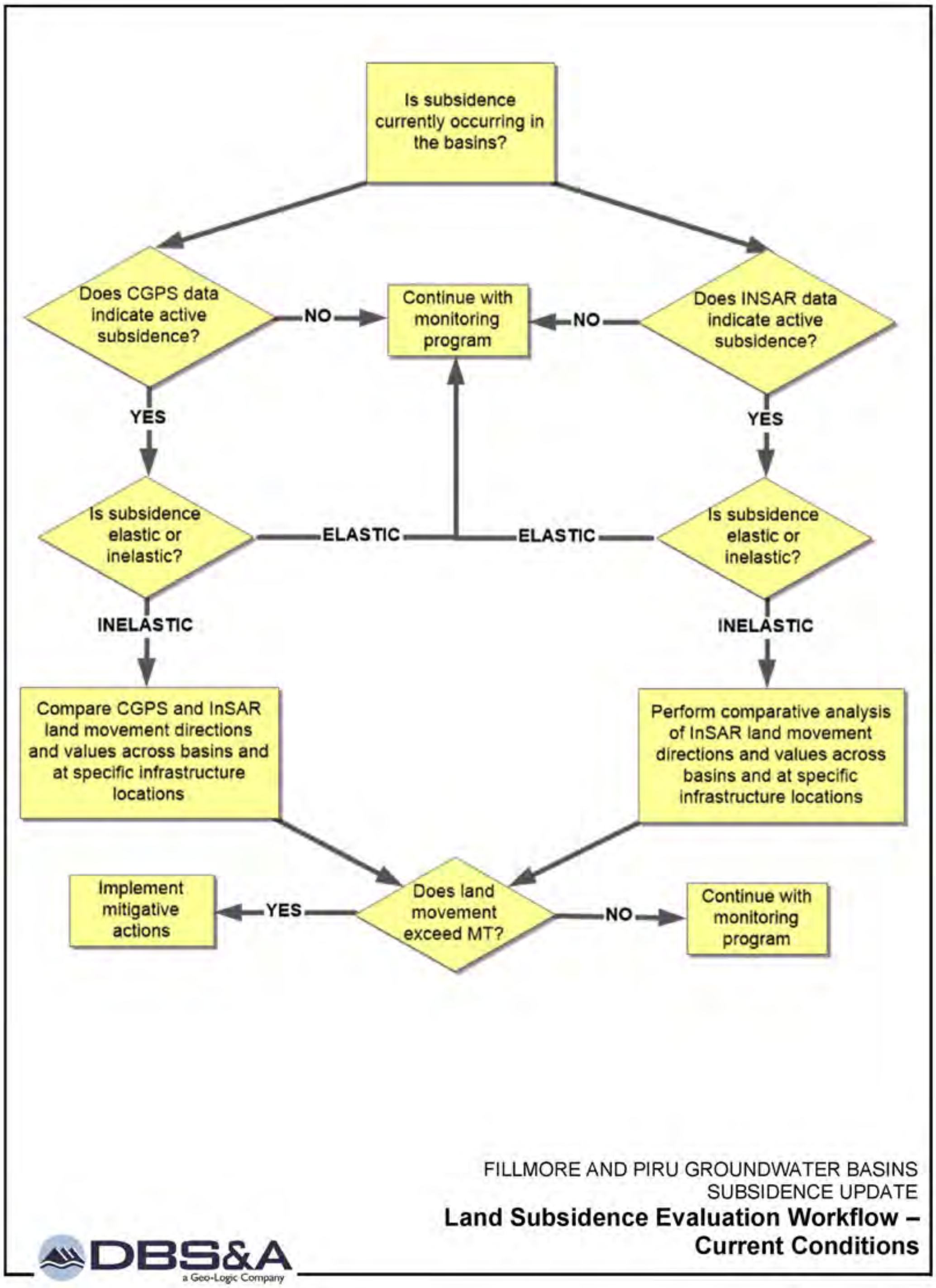

Figure 1-1. Land Subsidence Evaluation Workflow – Current Conditions

2. Background

Land subsidence caused by groundwater or hydrocarbon extraction has been documented in many parts of California. When fluid withdrawal lowers pore pressure, more of the overlying weight is transferred to the sediment framework. Fine-grained sediments can compact under this increased effective stress, reducing both land-surface elevation and aquifer storage. If the land surface recovers as groundwater levels rise, the movement is elastic. If it does not recover, the movement is inelastic and the lost storage is essentially permanent. Poland (1984), Poland and Davis (1969), and the U.S. Geological Survey (USGS) (1999, 2016) provide detailed discussions of these processes. SGMA focuses on inelastic subsidence because it can permanently reduce groundwater storage and damage infrastructure.

Hanson (1995) identified three potential causes of land-surface movement in Ventura County: groundwater extraction, hydrocarbon extraction, and tectonic movement. The GSPs describe the long-term increase in groundwater pumping from the late 1800s through the late 1980s. This section briefly addresses tectonic movement and nearby hydrocarbon production, but the remainder of the technical memorandum focuses on subsidence associated with groundwater-level decline.

2.1 Hydrocarbon Extraction

Hydrocarbon extraction has occurred in Ventura County for many decades; however, no extraction-related subsidence has been documented within the subbasins. Figure 2-1 shows oil and gas wells listed by the California Geologic Energy Management Division (CalGEM, formerly DOGGR). Most active production occurs outside the subbasins in surrounding mountain areas. A few active wells in the Bardsdale and Shiells Canyon Oil Fields are less than 0.25 mile inside the southeastern Fillmore subbasin boundary, and three active Holser Oil Field wells are just inside the Piru subbasin boundary in Holser Canyon. No subsidence has been reported in association with these wells or with nearby oil fields.

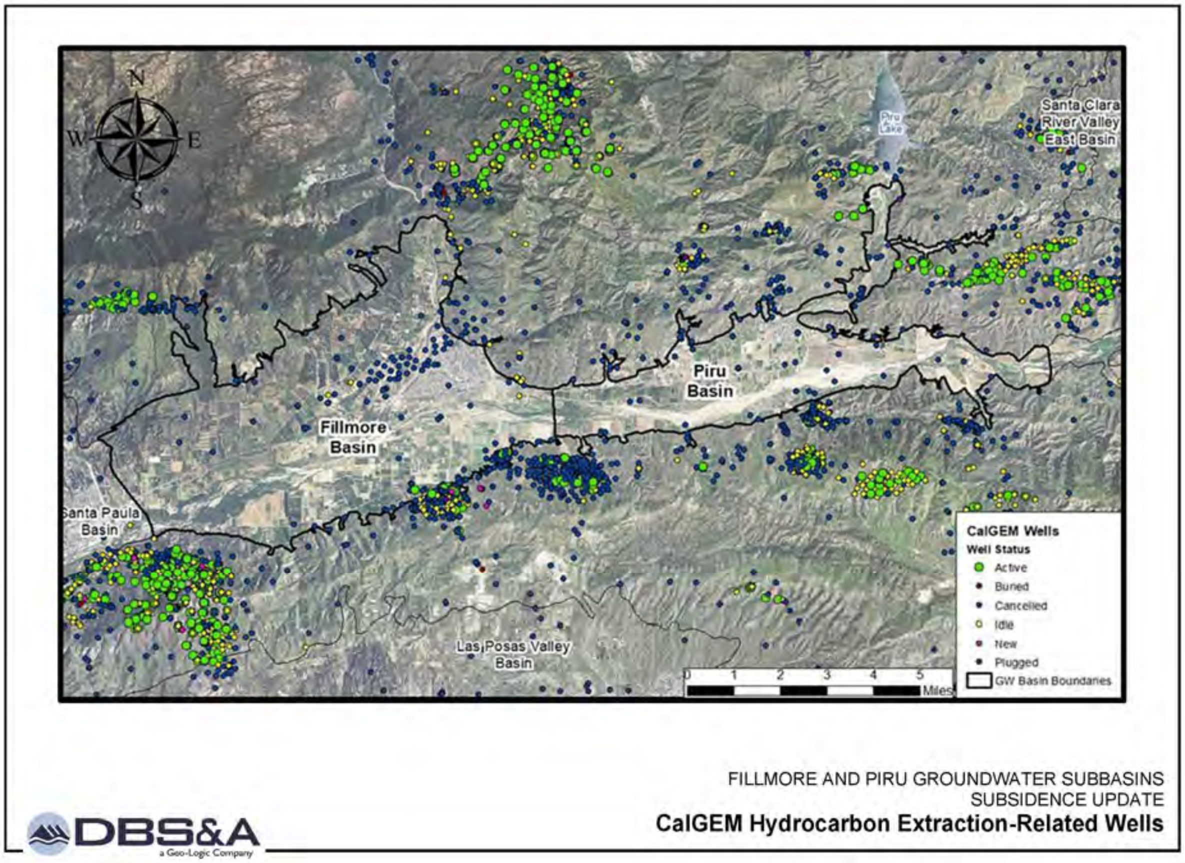

Figure 2-1. Fillmore and Piru subbasins area map showing CalGEM hydrocarbon extraction-related wells

2.2 Basin Tectonics

The subbasins are part of the tectonically active Transverse Ranges, where crustal shortening and rapid uplift rates have occurred for millions of years. Orme (1998) reports a broad range of 0.05 to 9 millimeters per year (mm/yr) of long-term uplift for the coastal Transverse Ranges region. The subbasins consist of varying thicknesses of alluvium underlain primarily by the San Pedro Formation synclinal fold. Studies have estimated maximum dip-displacement values for the north basin-bounding San Cayetano reverse fault and south basin-bounding Oak Ridge fault of 8.8 mm/yr (about 0.03 feet per year [ft/yr]) (Rockwell, 1988) and 12.5 mm/yr (about 0.04 ft/yr) (Yeats, 1988), respectively. Not only is the region's topography vertically affected by gradual long-term tectonic shifts, but the area is prone to earthquakes, which can cause sudden land movements.

2.3 Technical Approach

The evaluation of subsidence for the Fillmore and Piru subbasins in this document is based on a review of the following lines of evidence:

- Previous investigations and reports
- Geodetic surveys
- InSAR data
- Infrastructure vulnerability to differential subsidence

3. Previous Investigations

Previous investigations evaluated subsidence potential using groundwater models, leveling surveys, global positioning system (GPS), InSAR, and groundwater-level trends. Collectively, these studies indicate small modeled or measured vertical movement and no verified infrastructure impacts. The principal findings and limitations are summarized in Table 3-1.

Table 3-1. Previous Subsidence Evaluations

Study / Investigator	Fillmore Subbasin	Piru Subbasin	Comments
USGS, 1996	Maximum subsidence of 0.03 foot (8 mm, 0.6 mm/yr) near City of Fillmore	maximum subsidence zone up to 0.05 foot (15 mm, ~1 mm/yr) around the Town of Piru	1975-1989 study period; groundwater flow model simulations – no field verification
Hanson et al., 2003	Maximum value of just over 0.1 foot (0.00098 ft/yr) of subsidence	0.25 feet (0.0024 ft/yr) in the eastern portion of Piru Subbasin	1891 to 1993 study period; groundwater flow model simulations – no field verification
Ventura County, 2013 and 2020	Lies within subsidence hazard zone	Lies within subsidence hazard zone	No technical analyses conducted.
DWR, 2014	Low potential	Insufficient data	
DBS&A, 2023 - InSAR	Less than ±0.05 ft	Generally, less than ±0.05 foot except during periods of artificial recharge, then up to +0.14 foot of rebound in Piru subbasin	June 2015–Sept 2019 study period

Study / Investigator	Fillmore Subbasin	Piru Subbasin	Comments
2070 Climate Change Modeling by UWCD	No subsidence anticipated	No subsidence anticipated	1986 to 2096 model time frame

Subsidence susceptibility depends primarily on two factors:

- Hydrostratigraphy, particularly the presence and thickness of fine-grained sediments
- Whether groundwater levels fall, or are projected to fall, below historical lows (i.e., preconsolidation heads) in the future

Both conditions generally must be present before inelastic subsidence can occur. Site-specific subsidence monitoring data (e.g., extensometer or tiltmeter) can be used, if available, to augment the hydrostratigraphic setting and water level datasets and develop a subsidence susceptibility ranking for the subbasins, as summarized in Table 3-2.

Table 3-2. Inelastic Subsidence Potential

Subbasin	Hydro-stratigraphic Setting Susceptibility	Chronic Declines in Groundwater Levels	Geodetic/ Extensometer/ Tiltmeter Evidence of Subsidence	InSAR Evidence of Subsidence	Subsidence Susceptibility Ranking
Fillmore	Low to Moderate	No	No	No	Low
Piru	Low	No	No	No	Low

Source: DBS&A, 2021, Appendix F

The Fillmore subbasin has low to moderate hydrostratigraphic susceptibility because its western portion contains more fine-grained alluvial sediment than its eastern portion. The Piru subbasin has low hydrostratigraphic susceptibility because it is dominated by coarse-grained deposits. When these conditions are considered with groundwater-level, geodetic, and InSAR data, both subbasins receive an overall low subsidence-susceptibility ranking.

3.1 Groundwater Modeling

Hanson et al. (2003) used a numerical groundwater-flow and subsidence model to estimate historical subsidence in coastal Ventura County from 1891 through 1993. Model-derived subsidence is not a direct field measurement; it is calculated from simulated groundwater-level changes and assumed geomechanical properties, with selected benchmarks on the South Oxnard Plain used for calibration. The model attributed most regional subsidence to the late-1920s drought and increased agricultural pumping after the 1950s. The largest modeled values were approximately 3 feet on the South Oxnard Plain and 5 feet in Las Posas Valley. By comparison, modeled subsidence was just over 0.1 foot in the Fillmore subbasin and just over 0.25 foot in the eastern Piru subbasin over the 1891-1993 simulation period.

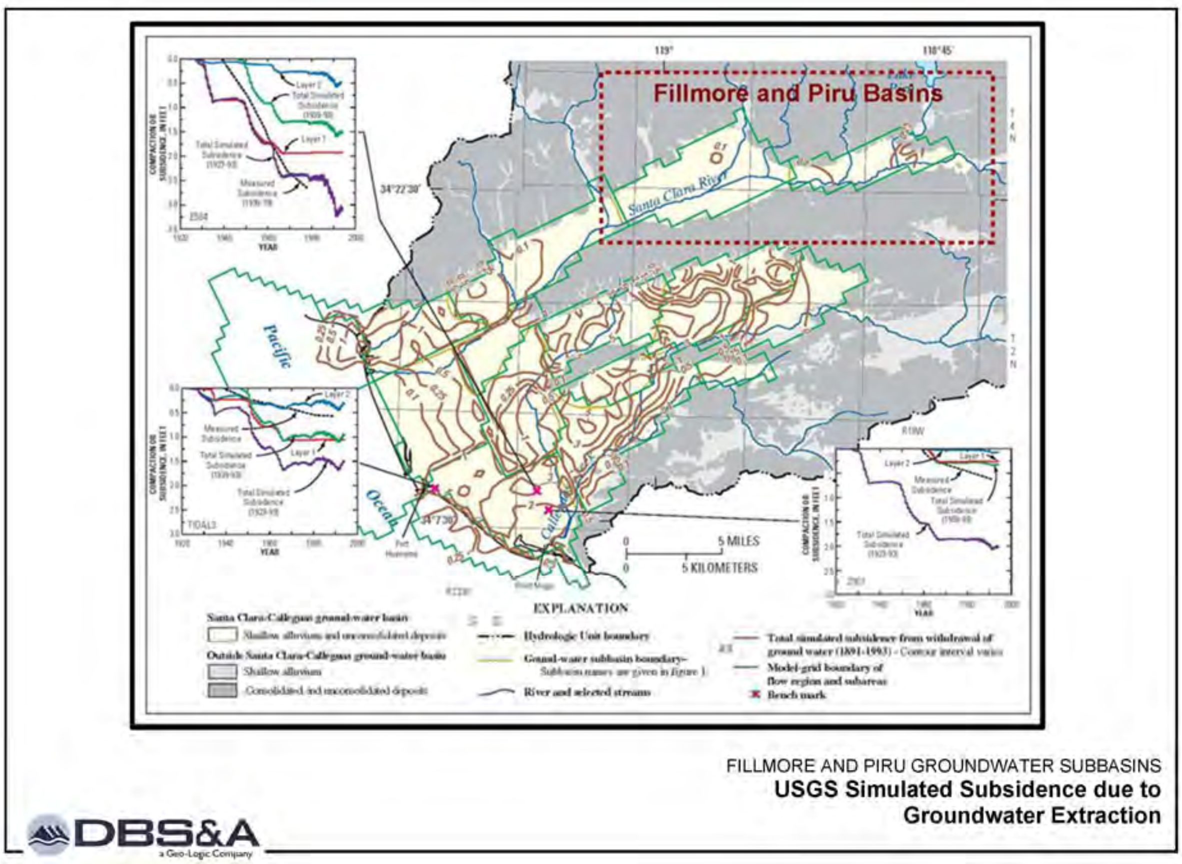

Figure 3-1. Simulated subsidence in the Santa Clara-Calleguas groundwater subbasin due to groundwater withdrawal from 1891 to 1993. Modified from Hanson et al. (2003)

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Borchers (2014) summarizes results from the Hanson et al. (2003) study, and focuses on areas of more significant subsidence (i.e., Oxnard Plain, Las Posas Valley, and South Pleasant Valley subbasins).

3.2 Geodetic Surveys

UNAVCO operates continuous global positioning system (CGPS) stations that measure three-dimensional ground position at frequent intervals. Four stations within 5 miles of the subbasins have records beginning in 1999 or 2000. Because all four stations are installed in bedrock outside the alluvial subbasins, their vertical movement primarily reflects regional tectonic or monument motion rather than compaction of the groundwater basin sediments.

Figure 3-2 shows locations of these CGPS stations, along with UNAVCO 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. Outliers with a standard deviation greater than 20 mm (about 0.8 inch) were removed by UNAVCO. Long-term general vertical movement rate trends were determined by applying a line of best fit to each station's entire measured time frame of data. Three of the four CGPS stations surrounding Fillmore subbasin (KBRC, SOMT, and FMVT) are all set in weathered or poorly lithified sedimentary bedrock (UNAVCO) and show a long-term trend of approximately 0.003 mm/yr (0.000009 ft/yr) of downward vertical movement since December 2000. Just south of Lake Piru, CGPS station SFDM set in bedrock (UNAVCO) indicates a linear trend of 0.001 mm/yr (0.000003 ft/yr) of upward vertical movement since 1999. Looking on a smaller timescale, the four stations show similar seasonal upward and downward movement trends.

Following the 1994 Northridge earthquake (magnitude 6.7), USGS (1996) conducted a study to assess and restore geodetic infrastructure affected or damaged by land elevation changes caused by the earthquake. A geophysical model of permanent ground deformation, based on the geodetic infrastructure movement, was developed and benchmarks that differed by ±1.2 inches (3 centimeters [cm]) from the model were considered anomalous (suggesting needed replacement). The model required non-tectonic deformation (i.e., subsidence due to groundwater withdrawal) to be removed from measured elevation changes to infer deformation solely due to tectonic activity. Therefore, at least three pre-seismic surveys made between 1971 and 1989 were used to subtract the elevation changes from the 1994 measurements. The

National Geodetic Survey (NGS) conducted leveling surveys along routes in areas affected by the earthquake, including routes cutting through the Fillmore and Piru subbasins (Figure 3-3).

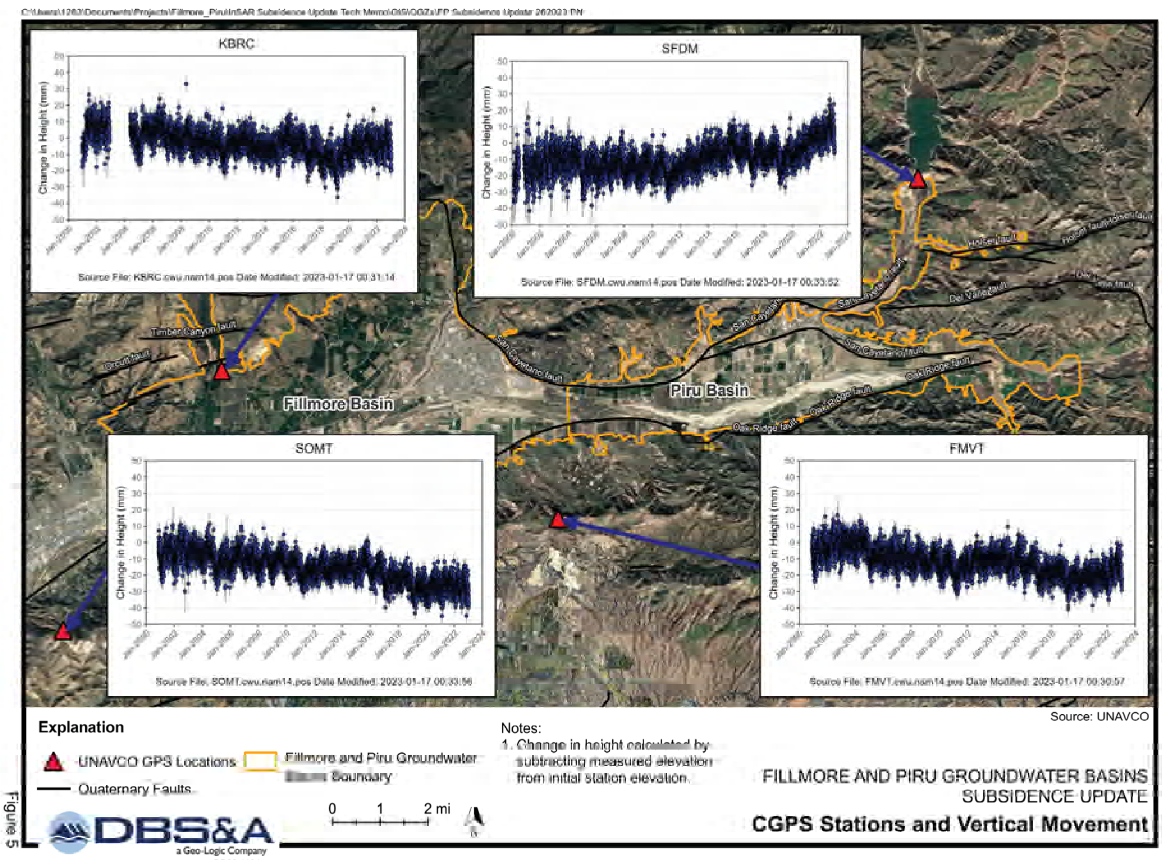

Figure 3-2. Map showing CGPS locations and vertical movement time-series data provided by UNAVCO (DBS&A, 2023)

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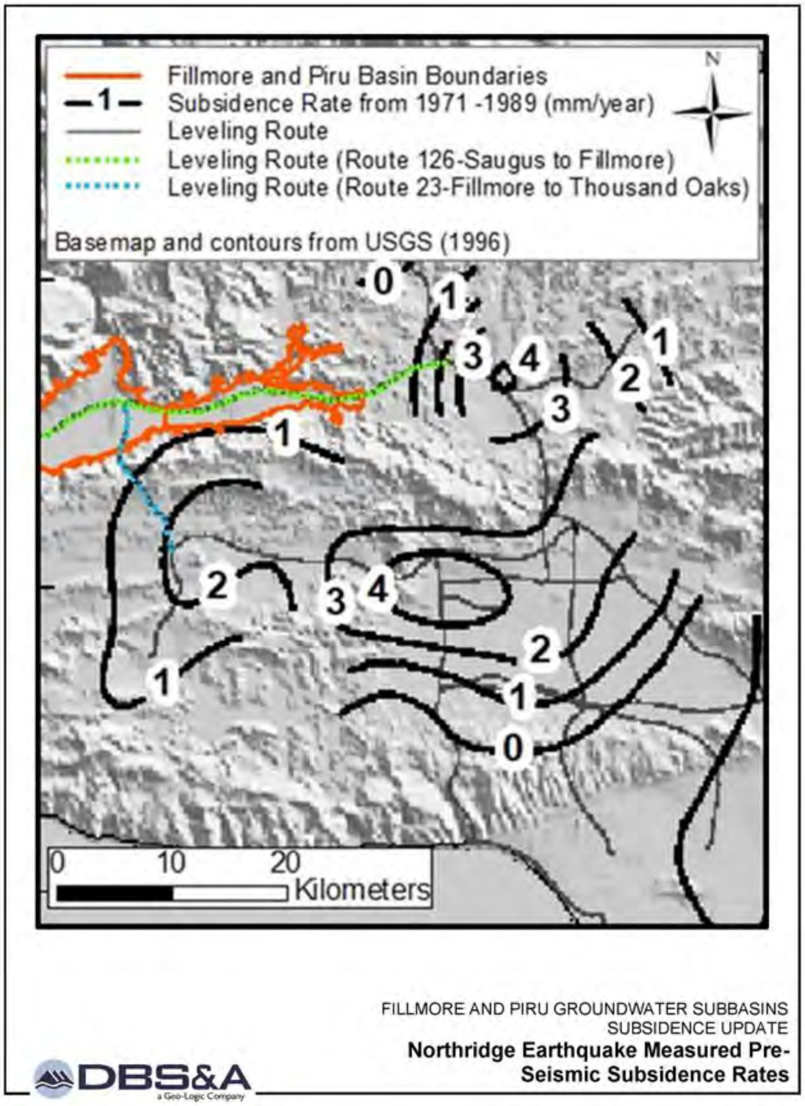

Figure 3-3. USGS (1996) 1994 Northridge Earthquake report NGS leveling routes and contours of measured pre-seismic subsidence rates (mm/yr) from 1971 to 1989

Figure 3-3 includes subsidence rate contours that USGS produced from the 1971 to 1989 pre-seismic surveys covering the Los Angeles Basin. Based on these contours, average subsidence rates in the Fillmore and Piru Subbasins were under 1 mm/yr (0.003 ft/yr) from 1971 to 1989. A comparison of 1975 and 1989 leveling surveys (pre-1994 Northridge earthquake) taken along Route 126 (Los Angeles Avenue) from Saugus to Fillmore determined 15 mm (0.05 foot) of cumulative subsidence over the 14-year period, with maximum subsidence of 60 mm (0.2 foot) occurring between the 1975 and 1978 surveys. The area of maximum subsidence was 20 km (12.4 miles) wide and centered around the Town of Piru. The rebound in ground elevation following 1978 could have been due to groundwater recharge or a systematic error in the 1978 survey. A survey along Route 23 (Moorpark Freeway) from Fillmore to Thousand Oaks determined a maximum subsidence of 8 mm (0.03 foot) at Fillmore between 1975 and 1989.

The final modeled coseismic uplift extent related to the 1994 Northridge earthquake is shown in Figure 3-4. Within the subbasins, only the very eastern portion of the Piru subbasin showed tectonic deformation related to the earthquake and fell within the 0 to 10 cm (less than 0.3 foot) zone of the coseismic uplift contours modeled by USGS.

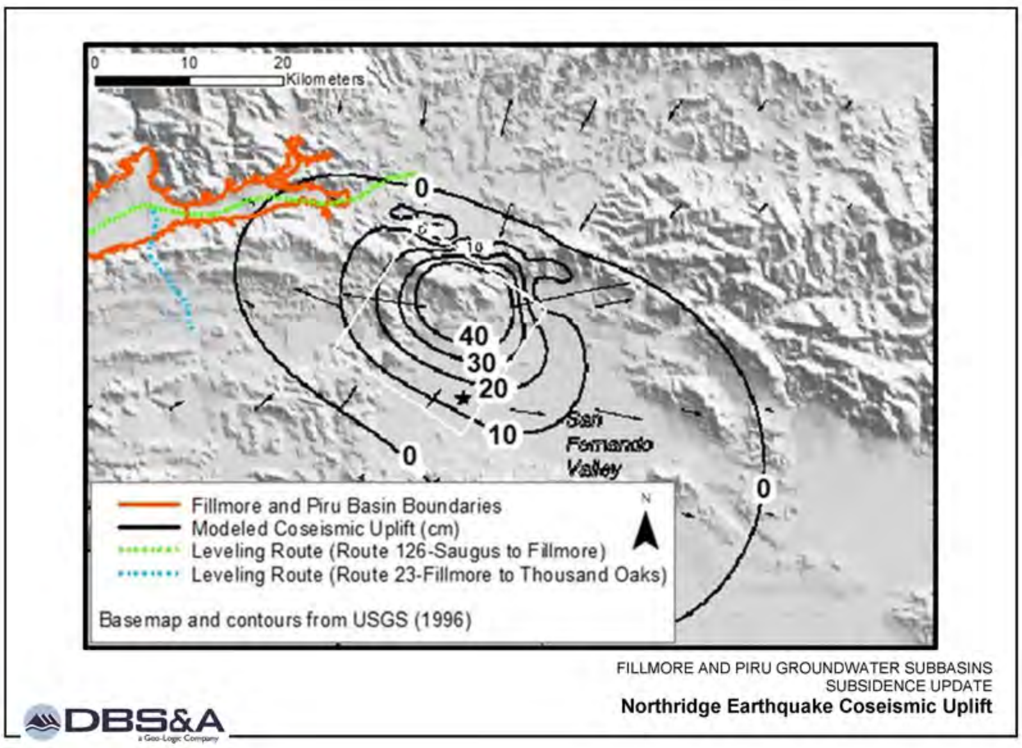

Figure 3-4. USGS (1996) 1994 Northridge Earthquake report modeled coseismic uplift

3.3 Extensometers

There are no known extensometers located in either subbasin (SGMA Data Viewer – Land Subsidence – accessed August 13, 2025).

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3.4 InSAR Data

DBS&A's 2023 evaluation used DWR-provided InSAR data to assess land-surface movement in the Fillmore and Piru subbasins. InSAR measures total surface displacement, including both elastic and inelastic movement. The method does not, by itself, distinguish among groundwater extraction, hydrocarbon production, tectonic activity, or other causes of movement.

Eight points within the subbasins 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 3-5 and described as follows:

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

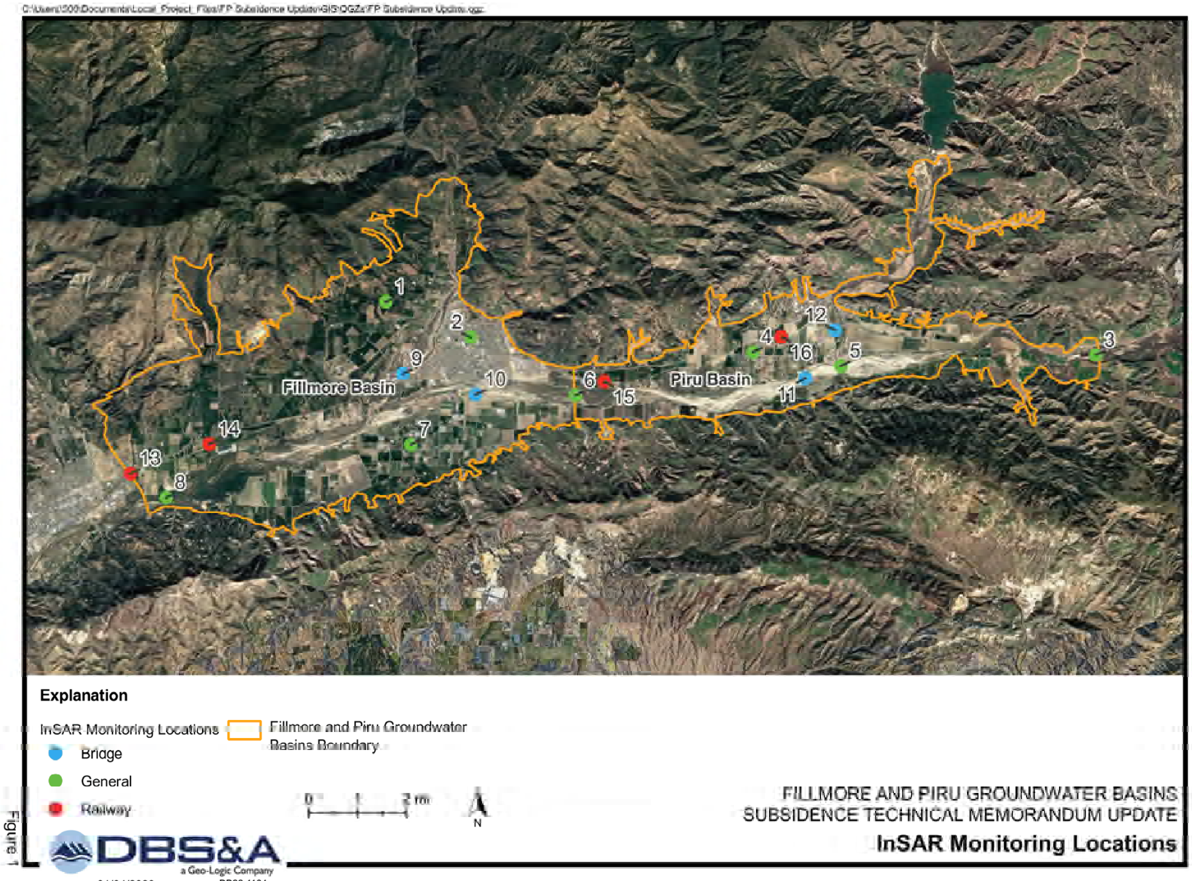

Figure 3-5. InSAR monitoring locations (DBS&A, 2023)

Eight additional points within the subbasin 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 3-5 and described below:

1. Hwy 126 Crossing Sespe Creek
2. Hwy 23 Crossing Santa Clara River
3. Torrey Road Crossing Santa Clara River
4. Hwy 126 Crossing Piru Creek
5. Hwy 126 and Railway Intersection Near Santa Paula

6. Railway - Fillmore Subbasin
7. Railway - Near Fillmore-Piru Subbasin Boundary
8. Railway - Piru Subbasin

DWR provided monthly InSAR results as cumulative displacement since June 13, 2015 and as moving 12-month displacement. At the selected monitoring locations, most measurements were within the reported ±0.07-foot uncertainty range and did not show sustained downward movement. Locations 6, 11, and 16 in central Piru instead showed upward movement during 2020 and 2021, consistent with elastic rebound. No related infrastructure impacts were reported at these locations.

Total observed cumulative subsidence for the Fillmore and Piru subbasins from June 13, 2015 to October 1, 2022 is shown in Figure 3-6. All cumulative subsidence values fell within the InSAR measurement error of ±0.07 foot; therefore, no significant changes in land-surface elevation have been observed. This is consistent with the interpretation of the InSAR time-series data.

The upward movement in the Piru subbasin was temporally associated with releases from Santa Felicia and Castaic Dams. Locations 6 and 16 reached maximum cumulative upward displacements of approximately 1.5 inches and 1.2 inches, respectively, following large releases in 2019 and 2020. Locations 6, 11, and 16 show similar annual and cumulative displacement patterns.

Because most measurements fall within the reported uncertainty range, the apparent short-term response should be interpreted cautiously. Nevertheless, annual displacement at several Piru locations increases soon after reservoir releases and begins to decline within approximately 2 to 3 months after the releases end.

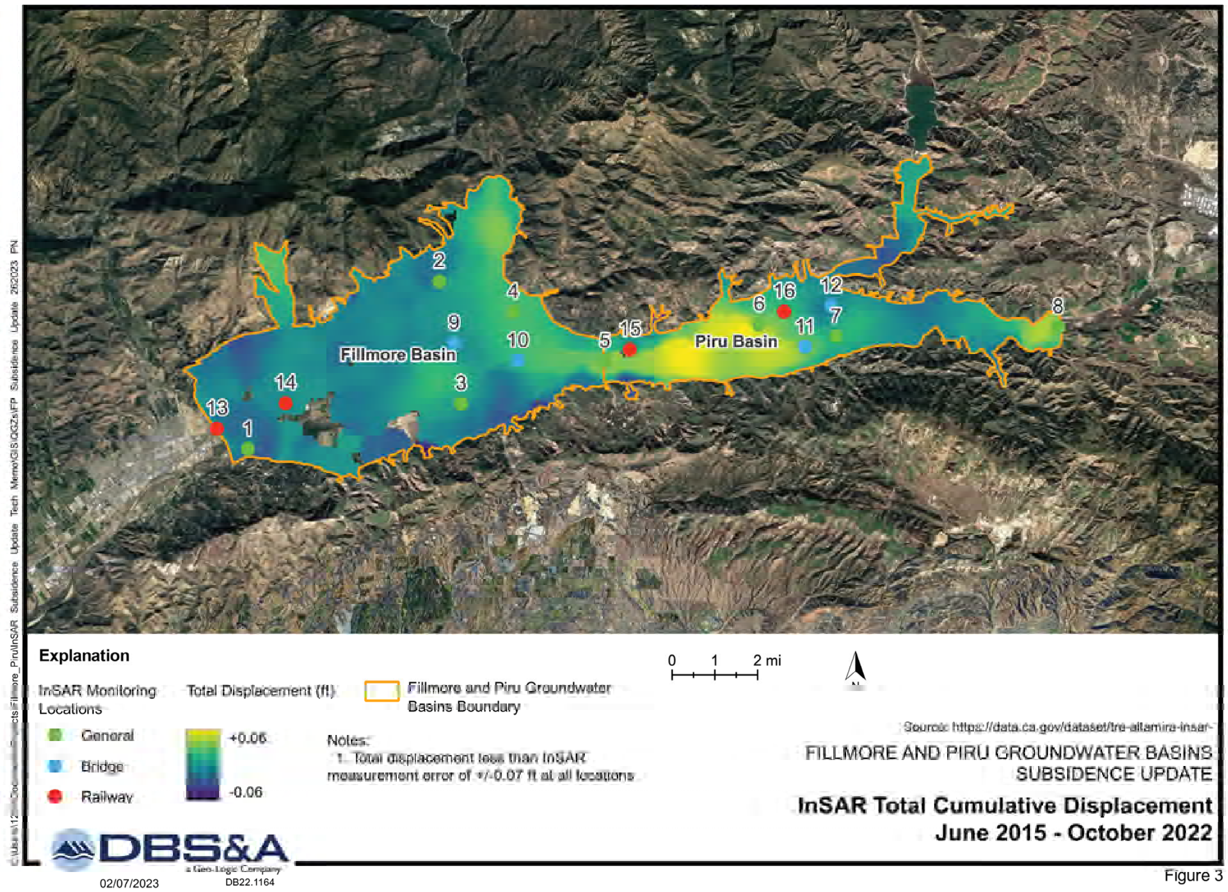

Figure 3-6. InSAR total cumulative displacement (DBS&A, 2023)

3.5 Critical Groundwater Levels (from DBS&A, 2021, Appendix F)

Historical studies describe past conditions but do not, by themselves, establish future risk. This evaluation therefore uses simulated future groundwater levels as a screening tool. Subsidence potential depends on the distribution, thickness, and compressibility of fine-grained sediments, the magnitude and duration of groundwater-level decline, and whether groundwater levels fall below the preconsolidation head. Because the preconsolidation head has not been measured directly, estimated historical low groundwater levels are used as a screening proxy. The United Water Conservation District (UWCD) groundwater-flow model (UWCD, 2021) simulated conditions from 1986 through 2096 under the central-tendency 2070 climate-change scenario.

Simulated groundwater elevations at selected wells were then compared with estimated historical lows (Figure 3-7).

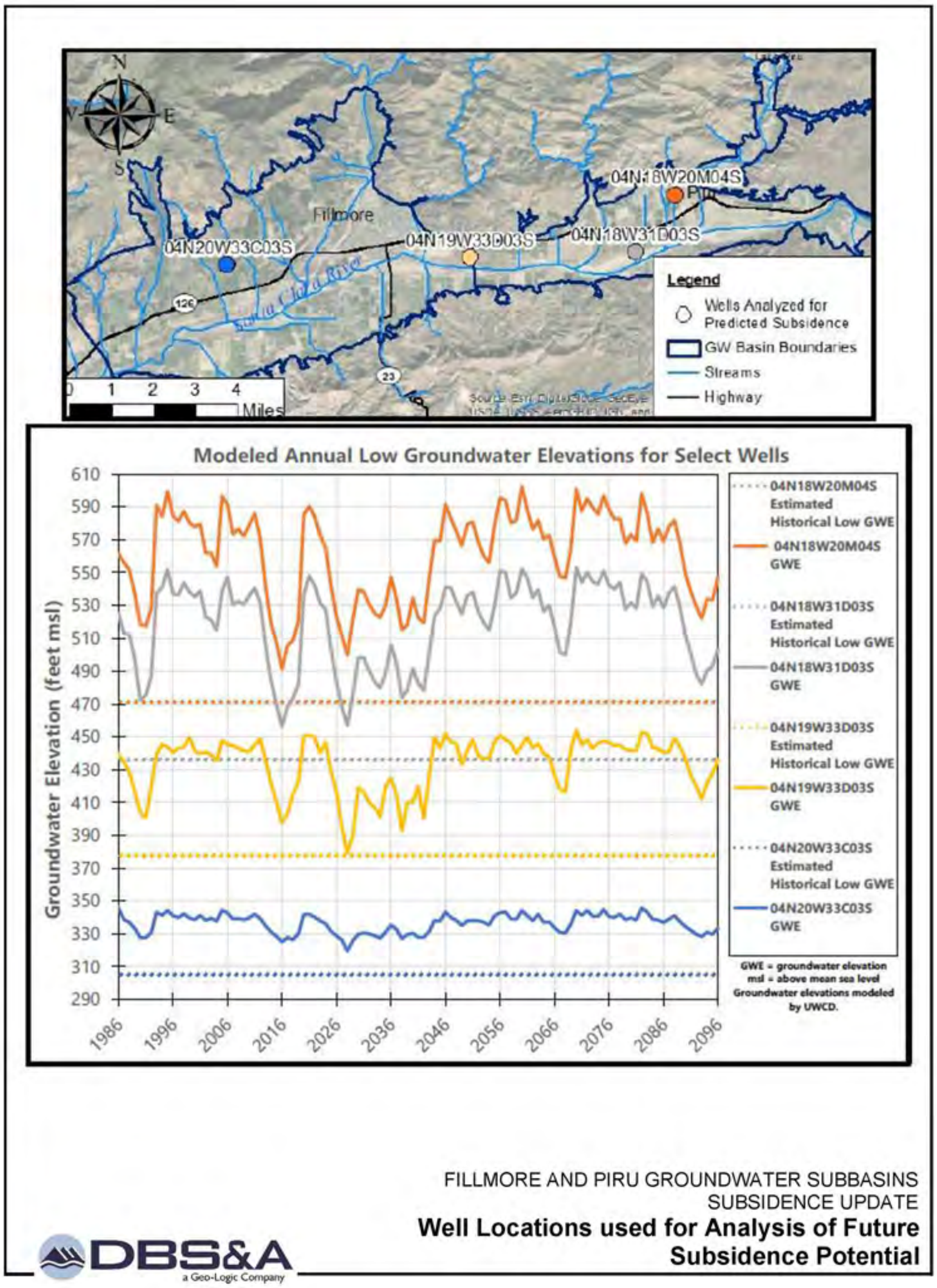

Figure 3-7. Well locations used for analysis of future subsidence potential (DBS&A, 2023)

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Simulated annual low water levels for the four example wells for the available model time frame were used for the evaluation. To account for maximum historical lows anticipated prior to the modeled time frame, the historical low water level was estimated to be 20 feet lower than the modeled 2016 drought water level. This historical low estimate was based on review of wells with long-term water level records (e.g., back to the 1940s), which showed that early drought levels generally measured about 20 feet lower than the measured 2016 drought low water levels.

Comparing the 2070 climate-change simulation with estimated historical lows identifies where future groundwater levels could approach conditions associated with subsidence. At nearly all wells with known construction details, projected future groundwater elevations remain above the estimated historical lows. This result indicates that inelastic subsidence is unlikely in either subbasin under the modeled climate and pumping scenario.

The water levels near the boundary between the Fillmore and Piru subbasins are typically some of the shallowest in the subbasins and the 2070CF modeled water levels are predicted to be less than 10 feet above the estimated historical low in this area. In general, the differences between the estimated historical low water level and the 2070CF modeled low water levels increase to the east and west away from the Fillmore-Piru subbasin boundary.

3.6 Ventura County General Plan

The 2013 Ventura County General Plan Hazards Appendix (Ventura County, 2013) maps a subsidence-hazard zone along the Santa Clara River Valley that includes both subbasins. The zone is based on figures from the 1973 Hazards Appendix and has not been updated with newer geodetic data. The General Plan states that sediment loading and groundwater-level decline could contribute to hydrocompaction and increase flooding potential on lower lands, including the Oxnard Plain. Hydrocompaction and groundwater-extraction subsidence are related but distinct processes. The 2040 General Plan Environmental Impact Report (Ventura County, 2020) similarly identifies the Santa Clara River Valley, Oxnard Plain, and Las Posas Valley as areas with potential subsidence risk.

3.7 California Department of Water Resources

In 2014, California Department of Water Resources (DWR) prepared a document summarizing recent, historical, and estimated future subsidence potential for groundwater subbasins included in DWR Bulletin 118 (DWR, 2014). The purpose of the document was to provide screening-level information with respect to subsidence. DWR lists the Fillmore subbasin with *low* potential for future subsidence. The ranking was determined from less than 10 percent of wells with long-term water-level trends (well records longer than 10 years) with current water levels (2008-2014) at or below historical low spring levels and one active continuous GPS monitoring station (see Geodetic Surveys) that showed 0.03 foot of maximum decrease in ground elevation. The Piru subbasin had insufficient data to establish a subsidence ranking.

4. Currently Active Subsidence Evaluation

No active groundwater-related subsidence has been documented in either the Fillmore or Piru subbasin. The GSA and other governmental entities also have not received anecdotal reports of land movement associated with groundwater or other resource extraction.

The Agency monitors the readily available datasets for any indications that subsidence may be occurring or conducive conditions exist within the subbasins. Those datasets include the following:

- Geodetic data: Limited datasets in bedrock areas outside of the basin alluvial fill
- InSAR data: As provided by DWR
- Reservoir releases: Effect of reservoir releases on land surface movement

Additional discussion of the ongoing subsidence monitoring program is presented in Section 6.

4.1 Geodetic Data

Figure 4-1 shows locations of CGPS stations near the Fillmore and Piru subbasins, along with the updated time-series graphs displaying measured land displacement relative to the first measurement of each station. This figure is an updated version from DBS&A (2023). Data displayed in the time-series graphs are referenced to the North American tectonic plate (NAM14) reference frame. Long-term general vertical movement rate trends were determined by applying a line of best fit to each station's entire measured time frame of data.

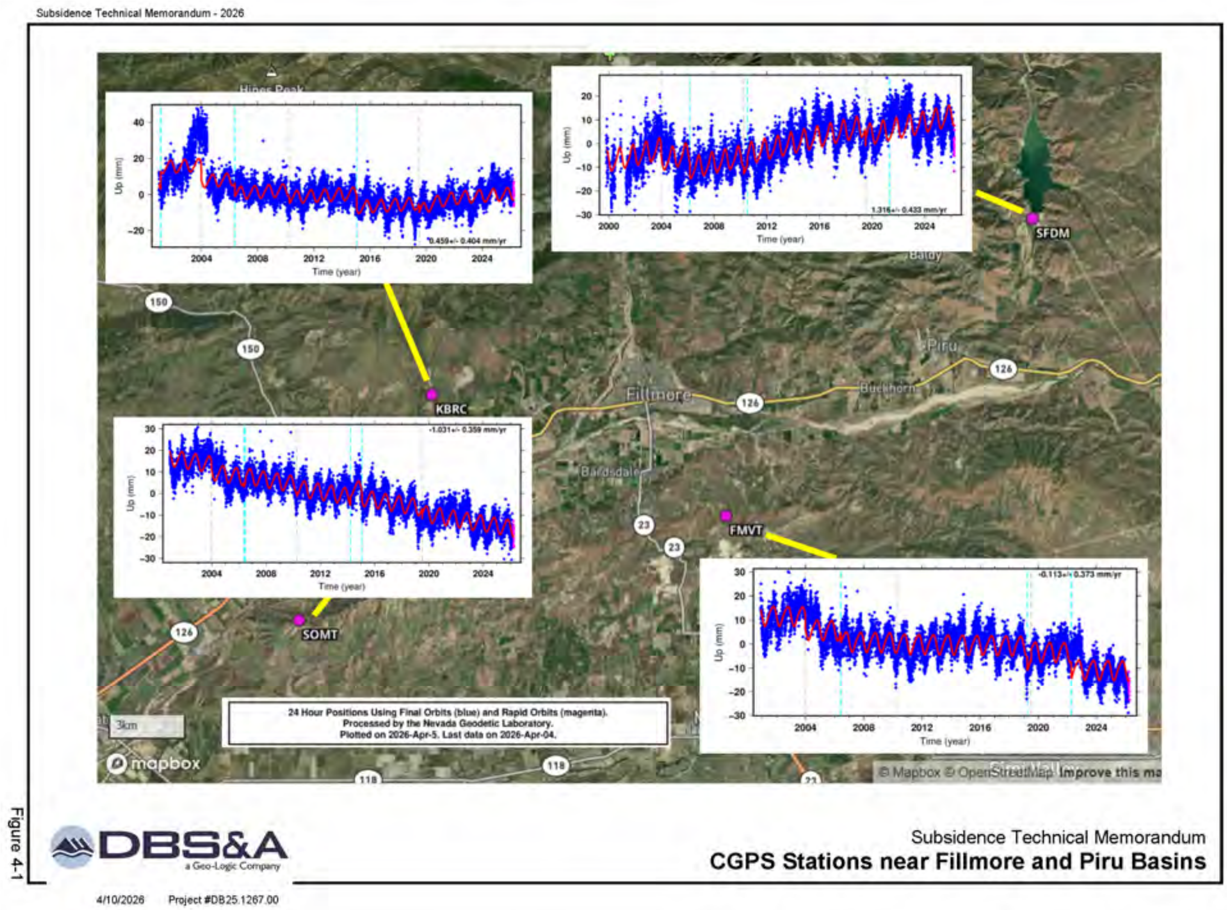

Figure 4-1. CGPS stations near Fillmore and Piru subbasins

Three of the four CGPS stations surrounding Fillmore subbasin (KBRC, SOMT, and FMVT) are all set in weathered or poorly lithified sedimentary bedrock (UNAVCO) with CGPS station SFDM set in bedrock (UNAVCO).

Table 4-1. CGPS Long-Term Vertical Movement

CGPS Station	Vertical Movement Trend
KBRC	0.459 ± 0.404 mm/yr
SOMT	-1.031 ± 0.359 mm/yr
FMVT	-0.113 ± 0.373 mm/yr
SFDM	1.313 ± 0.433 mm/yr

None of the four trend estimates demonstrates a clear subsidence signal at the monitored bedrock sites.

4.2 InSAR Data

The State of California has sponsored the collection and processing of InSAR data across many basins in California including the Fillmore and Piru subbasins. DWR makes these data available on the California Natural Resources Agency Open Data Portal and the SGMA Data Viewer.

The DBS&A (2023) technical memorandum established the InSAR evaluation approach summarized in Section 3. This section applies the same approach to the updated dataset.

Eight points within the subbasins 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 4-2 and described below:

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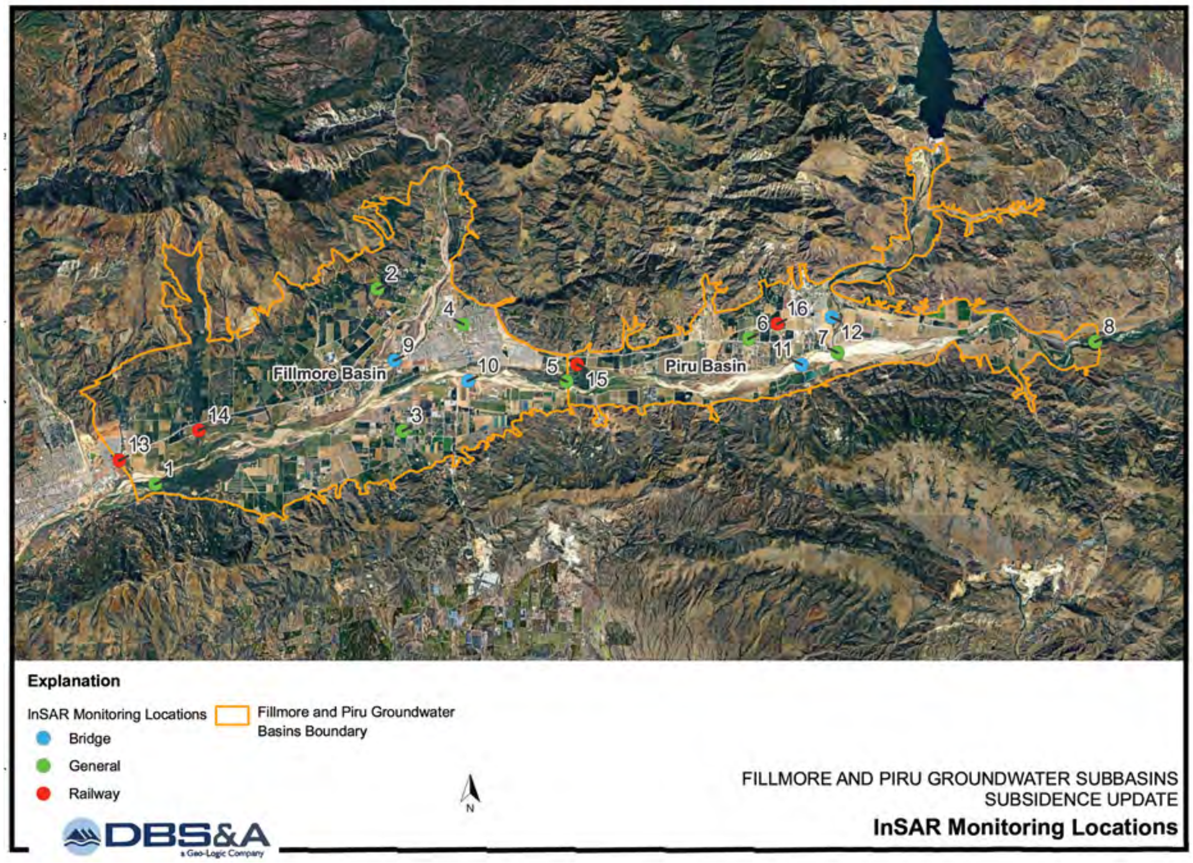

Figure 4-2. InSAR monitoring locations

Eight additional points within the subbasin 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 4-2 and described below:

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6. Railway - Fillmore Subbasin
7. Railway - Near Fillmore-Piru Subbasin Boundary
8. Railway - Piru Subbasin

DWR provides monthly InSAR results as cumulative displacement since June 13, 2015 and as moving 12-month displacement. Figures 4-3 and 4-4 show the selected monitoring locations. Most measured displacement remains within the reported ±0.07-foot uncertainty range and does not show sustained downward movement. Locations 6, 11, and 16 in central Piru instead show periods of upward movement consistent with elastic rebound. No related infrastructure impacts have been reported at these locations.

Figure 4-5 shows cumulative vertical displacement in the Fillmore and Piru subbasins from June 13, 2015 through January 2026. The data do not show sustained downward movement beyond 0.07 foot. Several Piru locations show upward movement associated with periods of higher groundwater levels. The record therefore does not indicate ongoing inelastic subsidence.

Upward movement in the Piru subbasin is temporally associated with releases from Santa Felicia and Castaic Dams (Figure 4-6). Locations 6 and 16 reached maximum cumulative upward displacements of approximately 1.5 inches and 1.2 inches, respectively, after large releases in 2019 and 2020. Locations 6, 11, and 16 show similar annual and cumulative displacement patterns.

Because most measurements fall within the reported uncertainty range, the apparent short-term response should be interpreted cautiously. Nevertheless, annual displacement at several Piru locations increases soon after reservoir releases and begins to decline within approximately 2 to 3 months after the releases end (Figure 4-6).

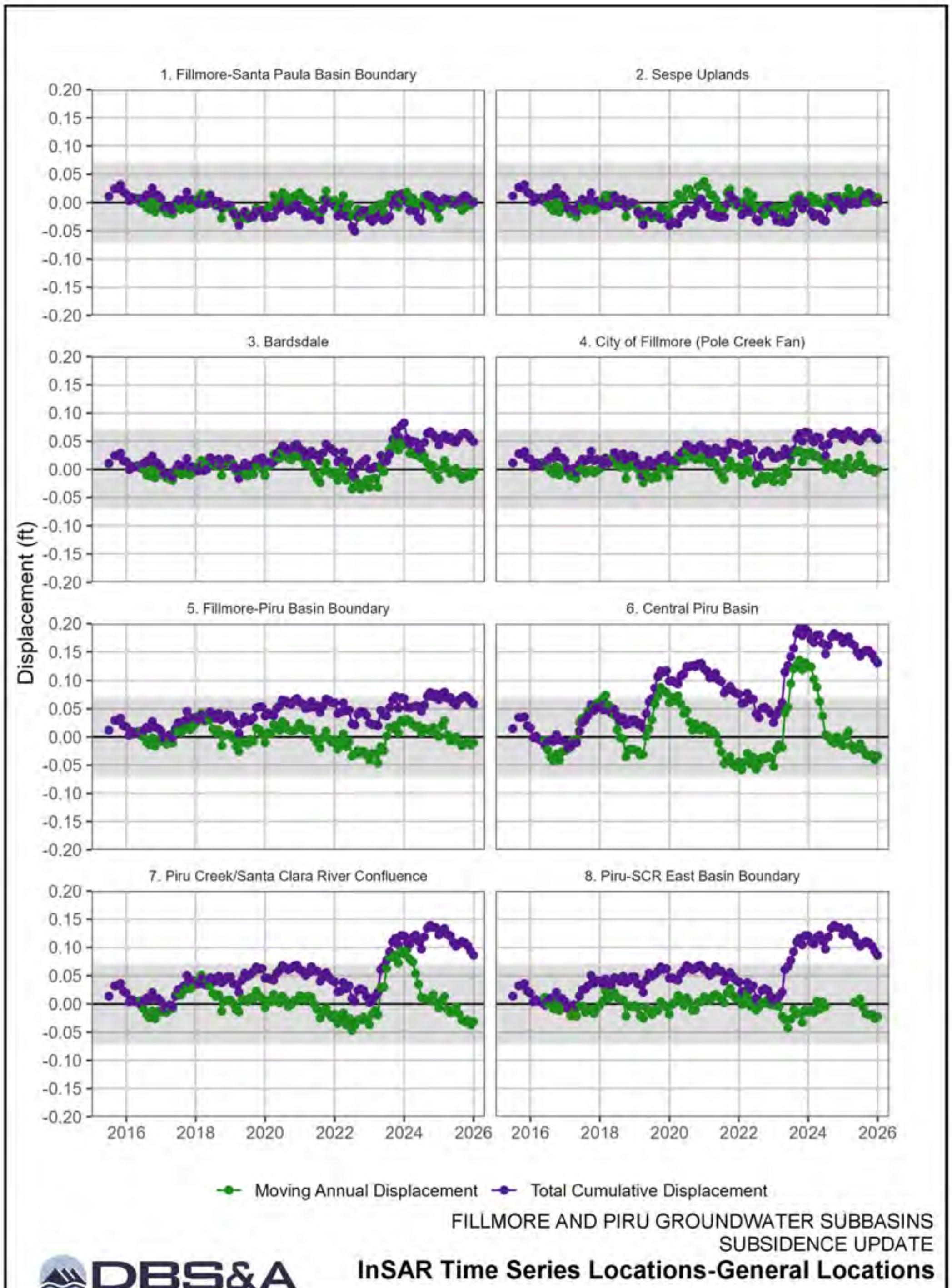

Figure 4-3. InSAR time-series locations, general locations

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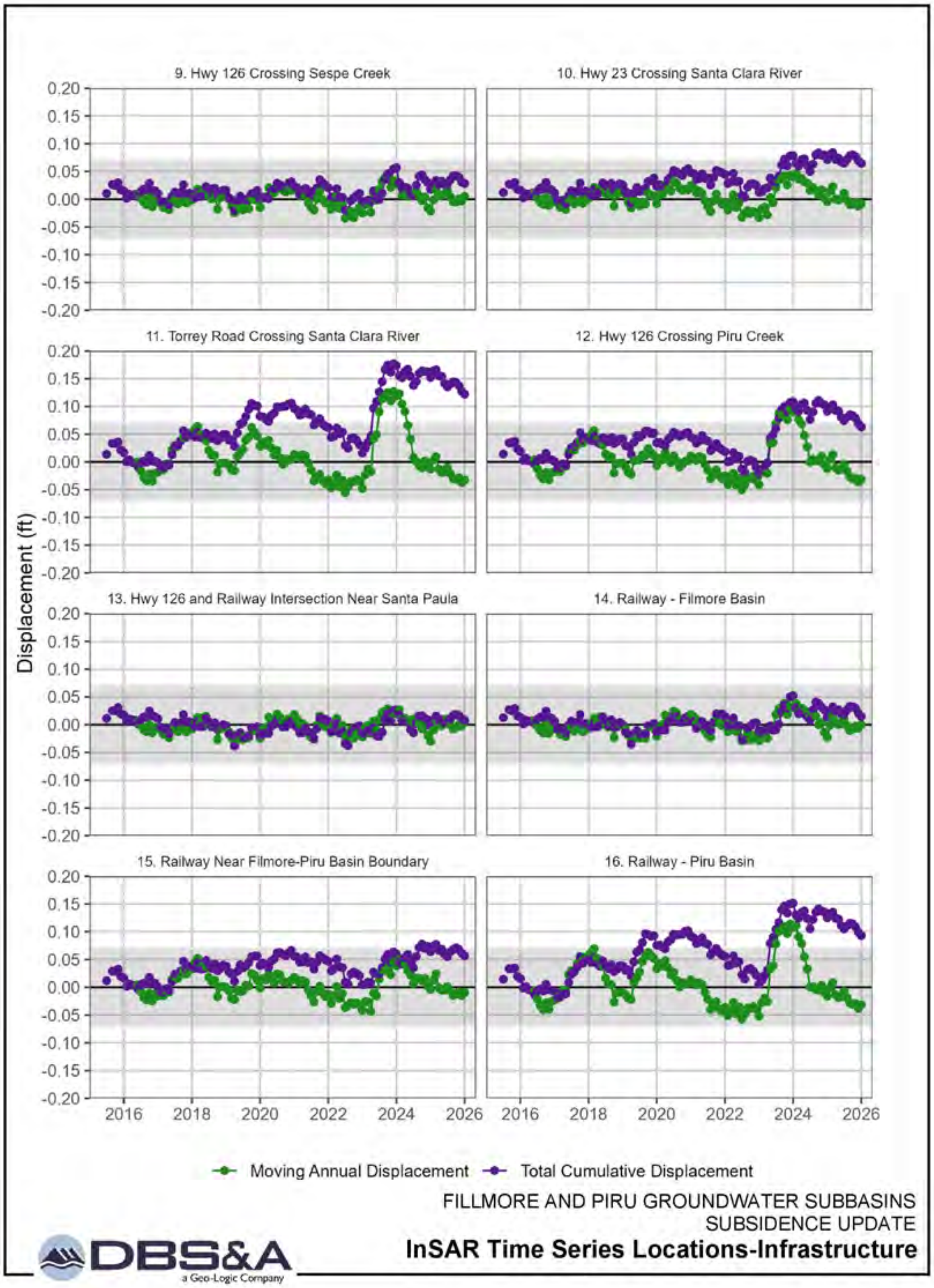

Figure 4-4. InSAR time-series locations, infrastructure

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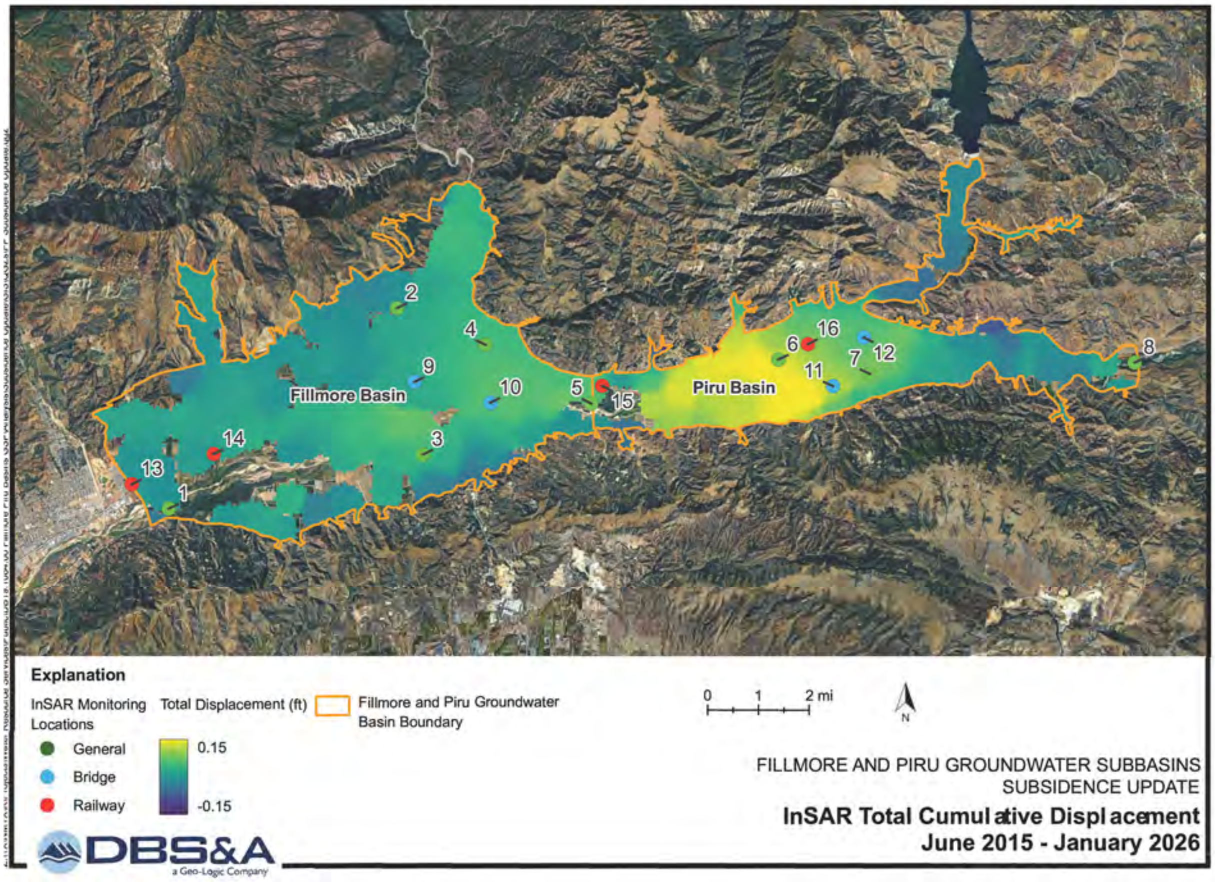

Figure 4-5. InSAR total cumulative displacement

Figures 4-3 and 4-4 show cyclic land-surface movement, with most annual displacement remaining within the ±0.07-foot measurement range. The clearest exception is upward movement in the Piru subbasin during periods of elevated groundwater levels, where annual displacement approaches 0.15 foot. The subsequent decline remains above the –0.07-foot screening level and is consistent with elastic, rather than permanent, deformation.

Reservoir releases from Santa Felicia and Castaic Dams (Table 4-2) produce rapid, observable groundwater-level responses, particularly in the Piru subbasin. Figure 4-6 shows a similar timing in the InSAR record. Land-surface elevation rises during and shortly after the releases, then declines over the following weeks or months as groundwater levels recede. This pattern is consistent with an elastic aquifer response.

Table 4-2. Reservoir Releases Upstream of Fillmore and Piru Subbasins

					Estimated Infiltration, AF			Estimated Infiltration, AF			Average Daily Infiltration, AF		
Release Origin	startDate	endDate	Release duration, days	Reservoir Volume Released, AF	Castaic Lagoon	Castaic Creek	Castaic Basin	Fillmore	Piru	Other	Fillmore	Piru	Other
Santa Felicia Dam	12/6/2016	12/16/2016	10	970	0	0	0	0	970	0	0.00	97.00	0.00
Castaic Dam	5/17/2017	7/21/2017	65	14,917	0	0	3783	0	11134	0	0.00	171.29	0.00
Santa Felicia Dam	5/29/2017	6/20/2017	22	15,300	0	0	0	2000	11700	1600	90.91	531.82	72.73
Santa Felicia Dam	6/8/2018	7/11/2018	33	1,103	0	0	0	0	1103	0	0.00	33.42	0.00
Castaic Dam	3/12/2019	6/4/2019	84	18,972	495	1127	0	0	17350	0	0.00	206.55	0.00
Santa Felicia Dam	6/3/2019	7/29/2019	56	39,444	0	0	0	5800	11776	21868	103.57	210.29	390.50
Santa Felicia Dam	2/26/2020	3/10/2020	13	7,516	0	0	0	2701	2564	2251	207.77	197.23	173.15
Castaic Dam	4/16/2020	5/22/2020	36	6,800	0	0	0	0	0	6800	0.00	0.00	188.89
Santa Felicia Dam	8/7/2020	11/11/2020	96	33,421	0	0	0	6902	13907	12612	71.90	144.86	131.38
Castaic Dam	3/2/2022	3/19/2022	17	2,711	751	223	0	0	1737	0	0.00	102.18	0.00
Castaic Dam	2/1/2023	2/22/2023	21	10,545	0	0	2,995	0	7001	0	0.00	333.36	0.00
Castaic Dam	4/3/2023	7/19/2023	107	52,483	0	0	0	0	2639	0	0.00	24.67	0.00
Santa Felicia Dam	6/23/2023	12/19/2023	179	61,858	0	0	0	0	16323	0	0.00	91.19	0.00
Castaic Dam	1/10/2024	1/15/2024	5	974	0	0	577	0	397	0	0.00	79.40	0.00
Castaic Dam	3/22/2024	3/28/2024	6	397	0	0	0	0	0	0	0.00	0.00	0.00
Castaic Dam	4/3/2024	4/30/2024	27	1,141	0	0	555	0	0	0	0.00	0.00	0.00
Santa Felicia Dam	6/12/2024	7/8/2024	26	6,754	0	0	0	536	2822	0	20.62	108.54	0.00
Santa Felicia Dam	9/10/2024	11/4/2024	55	33,903	0	0	0	1111	8919	0	20.20	162.16	0.00
Castaic Dam	11/1/2024	12/19/2024	48	6,359	0	0	1643	368	4373	0	7.67	91.10	0.00
Castaic Dam	4/15/2025	5/2/2025	17	2,025	0	0	404	0	1621	0	0.00	95.35	0.00
Santa Felicia Dam	9/15/2025	11/2/2025	48	27,450	0	0	0	1361	12208	0	28.35	254.34	0.00

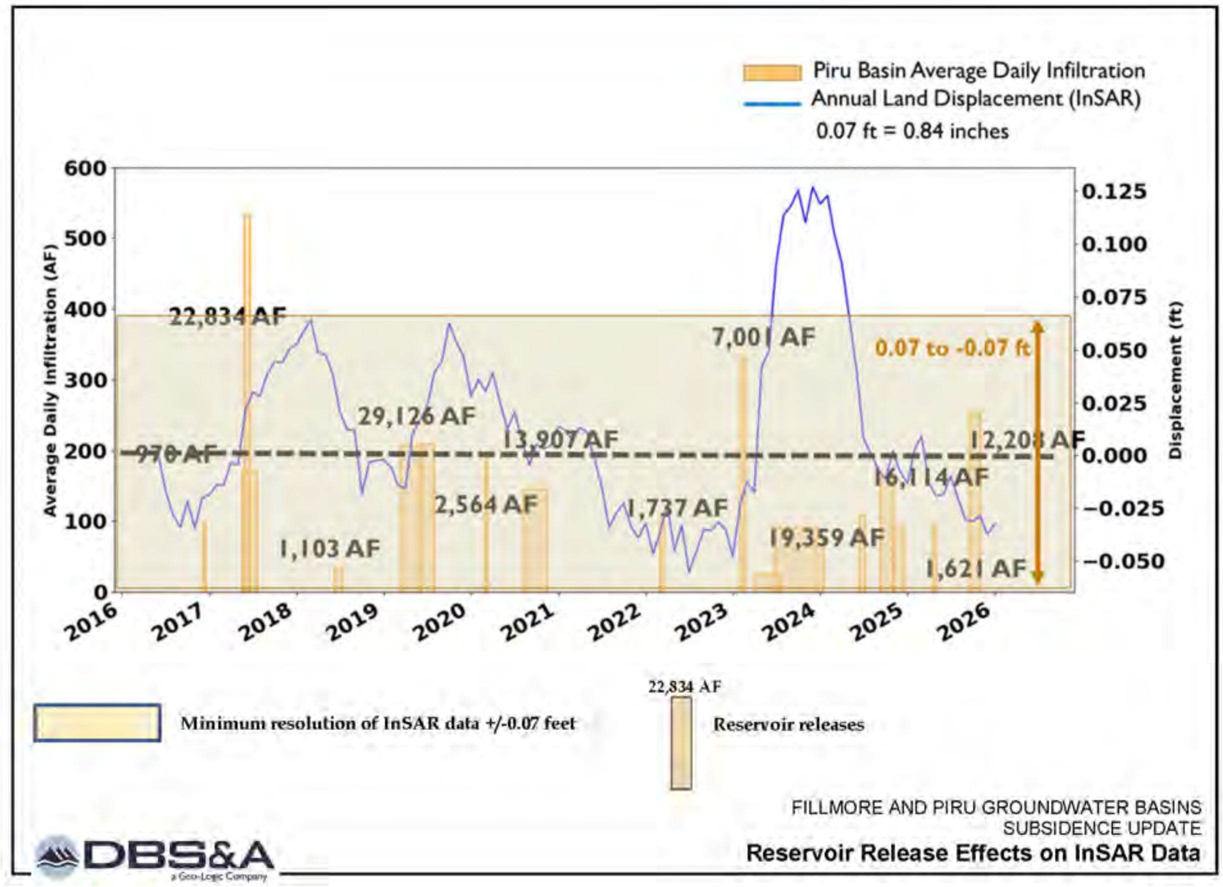

Figure 4-6. InSAR vertical displacement and reservoir releases

5. Sustainable Management Criteria

The revised Sustainable Management Criteria (SMC) framework translates the technical evidence into three SGMA management tools. The measurable objective (MO) describes the desired condition. The minimum threshold (MT) identifies conditions considered significant and unreasonable. Interim milestones (IMs) measure progress. Development of this framework was guided by the following:

- DWR's (2026) final guidance on this topic

- Explicit recommendations from DWR (2025a [page 42], 2025b [page 40-41]) that ". . . the GSA establish conservative minimum thresholds (e.g., close to InSAR measurement error) to avoid future land subsidence. . ."
- DWR staff's recommendation to set the MT at the InSAR value equivalent to the minimum negative land displacement
- DWR's (2025a and 2025b) recognition that, for both the Fillmore and Piru subbasins, the 2024 GSPs provide sufficient information to show that groundwater pumping has not historically caused land subsidence and that relatively stable groundwater levels make near-term subsidence unlikely

5.1 Significant and Unreasonable Impacts

For these subbasins, significant and unreasonable impacts are evaluated by considering whether differential land movement could damage infrastructure and impair its beneficial use. Agricultural land generally is less sensitive to small vertical movements than roads, bridges, railways, pipelines, wells, and buildings. The MT is therefore designed to identify persistent inelastic movement where vulnerable infrastructure is present.

5.1.1 Potentially Impacted Infrastructure

There are several categories of infrastructure present in the Fillmore and Piru subbasins. Table 5-1 summarizes those types of infrastructure, potential impacts of subsidence, and whether evidence of historical or ongoing subsidence is found in the subbasins. No evidence of impacts due to subsidence has been reported for any infrastructure category.

Table 5-1. List of Infrastructure Types and Potential Impacts of Subsidence (modified from DWR, 2025)

Infrastructure or Land Use Type	Infrastructure	Infrastructure Type Present in Fillmore or Piru Subbasin	Evidence of Subsidence	Example Potential Impacts of Subsidence
Cities and Communities	▪ Property drainage ▪ Power systems ▪ Municipal water systems ▪ Sewer systems	Yes	No	▪ Physical damage ▪ Reduced service reliability ▪ Increased maintenance
Pipelines and Other Utilities	▪ Natural gas ▪ Water ▪ Underground cables and overhead powerline utilities	Yes	No	▪ Cracking or joint failure ▪ Overpressurization ▪ Reduced capacity ▪ Pinch-points and un-alignment of transmission poles, towers, and lines
Railroads	▪ Private rail ▪ High-speed rail	Yes	No	▪ Track deformation, instability, or loss of use during flooding ▪ Safety hazards
Roads	▪ Drainage systems ▪ Highways ▪ Bridges	Yes	No	▪ Surface cracking ▪ Drainage failure ▪ Structural instability ▪ Loss of use due to flooding
Canals	▪ State canals ▪ Federal canals ▪ Local canals	No	No	▪ Reduced conveyance, freeboard ▪ Lining damage ▪ Altered slope ▪ Erosion and sedimentation of unlined channels
Flood Control & Drainage	Federal, state, and local flood facilities (e.g., levees, bypasses, and dams)	No	No	▪ Loss of grade ▪ Structural failure ▪ Reduced flood capacity ▪ Levee overtopping or breach
Pumping Facilities	Domestic, agricultural, and public supply wells	Yes	No	▪ Casing collapse ▪ Reduced capacity ▪ Operational inefficiencies ▪ Sand and gravel damaging pump bowls

5.1.2 Undesirable Results

Table 5-1 lists the potential infrastructure impacts of vertical land movement. Their severity can be evaluated using engineering codes, design guidance, and project-specific differential-settlement tolerances. No current or historical subsidence impacts have been documented in either subbasin.

5.1.2.1 California Building Code

The California Building Code (CBC, Title 24, Part 2) does not prescribe specific "inch-per-foot" limits for different structure types. Instead it requires geotechnical and structural design teams to:

- Evaluate expected total and differential settlements in the geotechnical investigation report
- Include those expected settlement values on the construction documents
- Design foundations so that differential settlement is "minimized"
- Note certain very light or non-structural elements that are exempt

The CBC makes the project-specific geotechnical investigation and structural design teams responsible for:

- Quantifying what total and differential settlement they expect
- Calling out those values in the construction documents
- Designing foundations so that "differential settlement is minimized" in a way that is appropriate to the risk category and occupancy

In the absence of general CBC guidance, industry-specific guidelines or standard practice documents are the likely sources of information on subsidence tolerances.

5.1.2.2 Differential Subsidence Tolerances

Infrastructure built on compressible sediments must accommodate some differential settlement. The following sections summarize reported guidance values, in millimeters and inches, for several major infrastructure types:

- Railroads
  - ◇ *Track differential settlement:* California high-speed rail guidelines limit *residual* differential settlement after track installation to ≤⅜ inch (≈9.5 mm) over a 62-foot chord for non-ballasted (slab) track, and ≤¾ inch (≈19 mm) for ballasted track (Caltrans, 2011).

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Residual uniform settlement should be <1.125 inches (ballasted track) and <0.625 inch for non-ballasted track (Caltrans, 2011). If expected settlement exceeds these limits, ground improvement or changing to a viaduct is recommended (Caltrans, 2011). For high-speed Classes 6 through 9, the corresponding 62-foot-chord limit is 1 inch for Classes 6 through 8 and 0.75 inch for Class 9 (FRA, 2026a and 2026b). Additional limits apply over 31- and 124-foot chords. The important qualification is that these are regulatory defect limits, not recommended design or subsidence-monitoring thresholds. The Federal Railroad Administration (FRA) specifically expects railroads to correct developing geometry conditions before they reach the applicable limit.

FRA (2026a and 2026b) permits a maximum vertical-profile deviation ranging from 1.25 to 3 inches for conventional Class 1 through Class 5 track, measured at the midpoint of a 62-foot chord. Because these values represent regulatory defect limits, a lower project-specific monitoring or action threshold should be established in consultation with the railroad owner. A value of 1 inch of measured profile deviation should be used as a conservative investigation trigger, not as the definition of track failure.

- ◇ *Track vertical deflection (stiffness):* The American Railway Engineering and Maintenance-of-Way Association (AREMA) (as cited by FRA) recommends that track support deflection under load be between ⅛ inch and ¼ inch (≈3 to 6 mm) (AREMA, 2011). Excessive subsidence that softens the track support (deflection >¼ inch) or stiffens it (<⅛ inch) can increase stresses and is undesirable.

- Highway Bridges
  - ◇ *Differential settlement between supports:* Caltrans geotechnical practice limits differential footing settlement on bridges to ½ inch (12.7 mm) between adjacent supports for multi-span or diaphragm-abutment bridges, and up to 2 inches (50.8 mm) for single-span bridges with seat abutments (Caltrans, 2021). These are essentially the maximum tolerable differences; beyond ~0.5 inch, bridges are evaluated for additional stresses.
  - ◇ *Grade separation design limits:* State standards often express tolerable settlement per span. For example, Washington State guidance limits total settlement to 1 inch over 100 feet and differential to 0.75 inch (19 mm) per 100 feet within a bridge structure (AASHTO, 2018). The Arizona Department of Transportation similarly advises limiting foundation settlement to 0.75 inch (~19 mm) per 100 feet of span, with any settlement >4 inches requiring special approval (AASHTO, 2018). (Equivalently, this is ~0.0025 of span length.) In practice, Caltrans/AASHTO design includes a settlement allowance (e.g.,

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if an overpass is predicted to settle >1.0 inch, the vertical clearance is increased accordingly) (Caltrans, 2011 and 2019).

- Freeways
  - ◇ *Pavement and approach slabs:* For freeway embankments and approach slabs, designers use criteria similar to short-span bridges. Caltrans practice for approach slabs (seat abutment) is the same 2-inch (50-mm) limit noted above (Caltrans, 2011 and 2019). More generally, highway agencies aim to keep roadway grade changes very small. For example, Arizona's guidelines (used for interstate/freeway approaches) repeat the 0.75 inch per 100 feet limit from bridge guidance (AASHTO, 2018). Settlements on the order of a few centimeters (tens of mm) over a highway span are considered the threshold of concern; above this, smoothing or repair is needed.
  - ◇ *Ride quality:* Although not a formal "tolerance," AASHTO/Caltrans design standards require smooth vertical alignment. In practice, any differential settlement that produces a bump exceeding about 1 inch over a short distance is usually deemed unacceptable for freeway ride quality (requiring grinding or milling). (By comparison, highway design vertical curves typically accommodate grade changes up to a few percent over tens of meters; subsidence beyond those limits will violate design).
- Hospitals (Essential Facilities)
  - ◇ *Building foundations:* Hospitals (Risk Category IV) must tolerate very small differential settlement. U.S. Army Corps of Engineers (USACE) guidance (applicable to buildings) states that differential settlement should not usually exceed ½ inch (12.7 mm) in buildings, otherwise cracking and structural damage may occur (USACE, 1990). Essential facilities often assume even tighter performance (essentially near-zero differential movement). In California, hospital design follows Office of Statewide Health Planning and Development (OSHPD) standards, which in turn reference USASCE/CBC settlement criteria (see below). In effect, hospitals are designed so that long-term subsidence induces negligible stress.
- Schools (Occupancy Category II)
  - ◇ *Building foundations:* Schools and normal buildings are generally allowed slightly more movement than hospitals, but still small. The same USACE guideline applies to typical buildings: keep differential settlement <0.5 inch (12.7 mm) (USACE, 1990). Although not necessarily interchangeable, CBC relies on USASCE 7 seismic provisions for deformation

limits; for example, USASCE 7 Table 12.13-3 implies differential thresholds on the order of 1 percent of span (e.g., ≈3 inches for a 25-foot span). In practice, designers aim for differential settlement of a few tens of millimeters at most. (By contrast, total settlement of an entire school may be somewhat larger if uniform and well supported.)

5.2 Minimum Threshold

DWR (2026) recommends setting the subsidence MT as close as reasonably practicable to the measurable limit of the InSAR monitoring method. During basin-specific consultation, DWR staff advised using more than 0.07 foot of downward land-surface movement, the stated InSAR measurement limit, as the MT for both subbasins.

An MT is the quantified condition at which effects become significant and unreasonable. InSAR is useful for screening basin-scale movement, but a decline greater than the stated measurement limit does not, by itself, establish an infrastructure impact. The movement also must be persistent and inelastic and must occur where vulnerable infrastructure is present.

The minimum displacement reliably resolved by InSAR is larger than the differential-settlement tolerance of several infrastructure types (Table 5-2). InSAR therefore cannot serve as the sole predictor of potential damage to those facilities. The proposed minimum threshold combines the InSAR screening value with persistence, cumulative movement, and infrastructure exposure, while recognizing the cyclic elastic movement described in Section 4.2. The MT is defined using the following tiered evaluation process:

1. InSAR data show annual land surface declines greater than the resolution of the technology (-0.07 foot/-0.84 inch) continuing through the next winter
2. InSAR data show cumulative land surface declines that exceed the differential subsidence tolerances for more than one infrastructure category (Table 5-2) for three consecutive winters
3. Infrastructure (Table 5-2) is located within the land parcels experiencing conditions 1 and 2 above
4. If conditions 1 through 3 are satisfied, then the MT is considered exceeded and impacts are considered significant and unreasonable.

Table 5-2. InSAR Resolution Compared to Infrastructure Differential Subsidence Tolerances

	± feet	± inches	± millimeters
InSAR resolution	0.07	0.84	21.336
Railroads			
Track differential		0.375	9.525
Ballasted track		0.75	19.05
Vertical deflection		0.25	6.35
Highway Bridges			
Differential settlement- multispan		0.5	12.7
Differential settlement- single span		2	50.8
Grade separation		1	25.4
Freeways			
Approach slabs		2	50.8
Ride quality		1	25.4
Hospitals			
Building foundations		0.5	12.7
Schools			
Building foundations		0.5	12.7
Differential span settlement		3	76.2

5.3 Measurable Objectives

The MO is to maintain the subbasin-wide average long-term vertical land-surface movement within the ±0.07-foot InSAR measurement range. This represents no reliably detectable downward movement at the basin scale. Upward movement greater than 0.07 foot that is associated with reservoir releases and subsequent elastic rebound also satisfies the MO.

5.4 Interim Milestones

IMs are used to assess the progress of the GSA in reaching the MO for each subbasin. At this time, the GSA has not established IMs for the following reasons:

- The subbasins currently meet the MO and are expected to continue meeting it.
- The MT has not been exceeded.

- There is no detectable trend in land surface movement suggesting that MT exceedances are imminent.

6. Subsidence Monitoring Program

The GSA's subsidence monitoring program uses the available InSAR and groundwater-level datasets for each subbasin.

6.1 InSAR Data

The GSA will review the InSAR dataset annually as part of each Annual Report preparation analysis. The report will state whether each subbasin meets the MO and whether the MT has been approached or exceeded.

6.2 Groundwater Levels

If annual InSAR data show more than 0.07 foot of downward land-surface movement, the GSA will review groundwater levels and other potential causes in the affected area. Groundwater levels below the estimated historical lows used as proxies for preconsolidation heads would provide supporting evidence that conditions are conducive to inelastic compaction.

If declining water levels become pronounced in the subbasins and are approaching the historical lows, the Agency will explore the causal factors for the water-level declines. These factors fall into two major categories: groundwater extractions or drought, or a combination of the two. The findings will be documented in the Annual Report.

6.3 Mitigative Actions

MT exceedances will trigger further investigation by the GSA, including coordination with entities that operate infrastructure within the affected area and evaluation of appropriate site-specific monitoring or mitigation measures.

7. Conclusions

Current evidence does not indicate significant and unreasonable inelastic subsidence caused by groundwater pumping in either subbasin. Historical groundwater model estimates were small and unverified. Pre-1989 leveling averaged less than 1 mm/yr and nearby bedrock CGPS stations show no clear long-term signal of land surface decline. DWR InSAR data for June 2015 through January 2026 show no sustained downward movement beyond 0.07 foot. Alternatively, the InSAR data suggest a cyclic pattern of rising and declining land surface that occurs within the measurement resolution of this technology. After reservoir releases or heavy, prolonged precipitation periods, the upward cyclic movement in central Piru is consistent with elastic reservoir-release response. No related infrastructure damage has been reported.

Future susceptibility also is low. Neither subbasin shows chronic groundwater-level decline, and projected lows under the 2070 climate-change scenario generally remain above estimated historical lows used as proxies for preconsolidation heads. The smallest margin occurs near the subbasin boundary, where some projected lows are less than 10 feet above the proxy.

The proposed SMC provide a conservative detection and response framework. The MO is movement within the effective InSAR range, and the MT adds persistence and infrastructure exposure. Available data indicate that the MO is being achieved, so interim milestones are not warranted. Because InSAR resolution is coarser than some infrastructure tolerances, its appropriate use is as a basin-scale trigger, not as sole evidence of significant and unreasonable impacts.

DBS&A recommends the following next steps:

- Continue annual review of basin-wide and point displacement and comparisons of groundwater levels with estimated historical lows. More than 0.07 foot of annual downward movement should trigger data-quality review and cause assessment, confirmation of persistent inelastic movement, and coordination with infrastructure operators.
- If movement persists or infrastructure may be affected, work with infrastructure operators to add field inspection and site-specific monitoring.
- Document the MO, MT, investigations, and management responses in the Annual Reports.

References Reviewed

American Association of State Highway and Transportation Officials (AASHTO). 2018. *Incorporation of Foundation Movements in AASHTO LRFD Bridge Design Process* (2nd ed.). <https://shrp2.transportation.org/Documents/Renewal/R19B_Incorporation%20of%20Foundation%20Movements%20in%20AASHTO%20LRFD%20Bridge%20Design%20Process%20V2.pdf>.

American Railway Engineering and Maintenance-of-Way Association (AREMA). 2011. *Manual for Railway Engineering*, Vol. 4, Chapter 16, Part 10, "Economics of Railway Engineering and Operations - Construction and Maintenance Operations."

Borchers, J.W., Grabert, V.K, Carpenter, M., Dalgish, B., and Cannon, D., 2014, Land Subsidence from Groundwater Use in California, Prepared by Luhdorff & Scalmanni Consulting Engineers. http://californiawaterfoundation.org/wp-content/uploads/PDF/1397858037-SubsidenceShortReportFINAL%2800248030xA1C15%29.pdf.

California Department of Transportation (Caltrans). 2011. California High-Speed Train Project. *Technical Memorandum: Geotechnical Analysis and Design Guidelines* (TM 2.9.10, Rev. 01). <https://hsr.ca.gov/wp-content/uploads/docs/programs/eir_memos/Proj_Guidelines_TM2_9_10R01.pdf>.

Caltrans. 2019. *California Amendments to the AASHTO LRFD Bridge Design Specifications* (8th ed.). <https://dot.ca.gov/programs/engineering-services/manuals/aashto-lrfd-ca-amendments>.

Caltrans. 2021. *Caltrans Geotechnical Manual: Shallow Foundations for Bridges*. <https://dot.ca.gov/-/media/dot-media/programs/engineering/documents/geotechnical-services/202102-gm-shallowfoundations-a11y.pdf>.

Daniel B. Stephens & Associates, Inc. (DBS&A) 2021. *Fillmore and Piru Basins Land Subsidence Evaluation Technical Memorandum.* Appendix F to the Fillmore and Piru Basins Groundwater Sustainability Plans. Prepared for the Fillmore and Piru Basins Groundwater Sustainability Agency. December 16, 2021.

DBS&A. 2023. *Fillmore and Piru Basins 2022 Land Subsidence Update*. Prepared for the Fillmore and Piru Basins Groundwater Sustainability Agency. February 10, 2023.

California Department of Water Resources (DWR), 2014, Summary of Recent, Historical, and Estimated Future Land Subsidence in California. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Data-and-Tools/Files/Statewide-Reports/California-Groundwater-Update-2013/California-Groundwater-Update-2013---Appendix-F.pdf.

Department of Water Resources [California] (DWR). 2025. *Draft Land Subsidence: Best Management Practices of the Sustainable Management of Groundwater.* July 2025.

DWR. 2025a. Approved Determination of the 2024 Groundwater Sustainability Plan Submitted for the Santa Clara River Valley - Fillmore Subbasin. February 27, 2025.

DWR. 2025b. Approved Determination of the 2024 Groundwater Sustainability Plan Submitted for the Santa Clara River Valley - Piru Subbasin. February 27, 2025.

DWR. 2026. *Final Land Subsidence: Best Management Practices of the Sustainable Management of Groundwater*.

Federal Railroad Administration (FRA). 2016. FAST Act Report on Vertical Track Deflection. <https://railroads.dot.gov/sites/fra.dot.gov/files/2022-08/FAST%20Act%20Report%20on%20Vertical%20Track%20Deflection.pdf>.

FRA. 2026a. Track and Structures Compliance Manual, Vol. II, Chapter 1. <https://railroads.dot.gov/sites/fra.dot.gov/files/2026-03/Track_Structures_CM_2026_Vol_II_Ch1_Track_Safety_Standards_Subparts_A-F.pdf>.

FRA. 2026b. Repealing a Track Surface Requirement, 49 CFR Part 213. Final Rule. <https://www.govinfo.gov/content/pkg/FR-2026-04-28/pdf/2026-08245.pdf>.

Hanson, R.T., Martin, P. and Koczot, K.M., 2003, Simulation of Ground-Water/Surface-Water Flow in the Santa Clara-Calleguas Ground-Water Basin, Ventura County, California; U.S. Geological Survey Water-Resources Investigations Report 02-4136. 2003. https://pubs.usgs.gov/wri/wri024136/wrir024136.pdf

Hanson, R.T., 1995, Simulation of Ground-Water/Surface-Water Flow in the Santa Clara-Calleguas Ground-Water Basin, Ventura County *in* Prince, K.R., Galloway, D.L., and Leake, S.A., eds., U.S. Geological Survey Subsidence Interest Group conference, Edwards Air Force Base, Antelope Valley, California, November 18–19, 1992: Abstracts and summary: California; U.S.

Geological Survey Open-File Report 94-532. https://pubs.usgs.gov/of/1994/ofr94-532/pdf/OFR94-532.pdf.

NOAA National Geodetic Survey. 2025. Sentinel-1 SqueeSAR Coastal Deformation Dataset Metadata. National Oceanic and Atmospheric Administration. Accessed July 2025.

Orme, A. R. 1998. Late Quaternary tectonism along the Pacific coast of the Californias: a contrast in style. Pages 179–197 in R. L. Stewart and C. Vita-Finzi, editors. Coastal tectonics, special publication 146. Geological Society, London.

Poland, J.F. 1984. Guidebook to studies of land subsidence due to ground-water withdrawal. Prepared for the International Hydrological Programme, Working Group 8.4.

Poland, J.F. and Davis, G.H.1969. Land Subsidence Due to Withdrawal of Fluids. Reviews in Engineering Geology, 2, 187-269.

Rockwell, T. 1988. Neotectonics of the San Cayetano fault, Transverse Ranges, California. Geological Society of America Bulletin 100: 500–513.

United State Army Corps of Engineers. 1990. Engineering Manual No. 1110-1-1904, Engineering Design-Settlement Analysis, https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-1904.pdf#:~:text=match%20at%20L789%20application,not%20usually%20exceed%202%20inches

United Water Conservation District. 2021. Groundwater Model Documentation

U.S. Geological Survey (USGS),.1996. Open-File Report 96-517: Damage and Restoration of Geodetic Infrastructure Caused by the 1994 Northridge, California, Earthquake. https://pubs.usgs.gov/of/1996/0517/fema/html/FEMA-1.2.html.

Ventura County, 2013, Ventura County General Plan: Hazards Appendix. https://docs.vcrma.org/images/pdf/planning/plans/General_Plan_Hazards_Appendix.pdf.

Ventura County, 2020, Final Environmental Impact Report (FEIR) for the Ventura County 2040 General Plan. https://docs.vcrma.org/images/pdf/planning/plans/Final_2040_General_Plan_docs/Ventura_County_2040_General_Plan_web_link.pdf

Yeats, R.S., 1988, Oak Ridge fault, Ventura basin, California: slip rates and late Quaternary history; U.S. Geological Survey Open-File Report 89-343. https://pubs.er.usgs.gov/publication/ofr89343.

Appendix A

Response to Comments

DBS&A
a Geo-Logic Company