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2020/21 Annual Report of the Ground-Level Monitoring Committee

PREPARED FOR

Ground-Level Monitoring Committee

PREPARED BY

23152610.1

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Project No. 941-80-21-61

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LIST OF ACRONYMS, ABBREVIATIONS, AND INITIALISMS

af	Acre-feet
Ayala Park	Rubin S. Ayala Park
Ayala Park Extensometer	Extensometer at Ayala Park
BMA	Baseline Management Alternative
CCX	Chino Creek Extensometer Facility
DHX	Daniels Horizontal Extensometer
EDM	Electronic distance measurement
ft	Feet
ft-amsl	Feet above mean sea level
ft-btoc	Feet below top of casing
ft-bgs	Feet below ground surface
ft/yr	Feet per year
FY	Fiscal Year
GLMC	Ground-Level Monitoring Committee
GLMP	Ground-Level Monitoring Program
IMP	Management Zone 1 Interim Monitoring Program
InSAR	Interferometric synthetic aperture radar
ISMA	Initial Subsidence Management Alternative
MVWD	Monte Vista Water District
MZ-1	Chino Basin Optimum Basin Management Plan Management Zone 1
MZ-1 Plan	Management Zone 1 Subsidence Management Plan
OBMP	Optimum Basin Management Plan
PA	Piezometer A (Ayala Park extensometer facility)
PC	Piezometer C (Ayala Park extensometer facility)
PFAS	Per – and polyfluoroalkyl substances
PX	Pomona Extensometer Facility
SAR	Synthetic Aperture Radar
SCADA	Supervisory Control and Data Acquisition
SMA-2	Second Subsidence-Management Alternative
Subsidence Management Plan	2015 Chino Basin Subsidence Management Plan
TCP	1,2,3-trichloropropane
USGS	United States Geological Survey
Watermaster	Chino Basin Watermaster
WEI	Wildermuth Environmental, Inc.
Work Plan	Work Plan to Develop a Subsidence Management Plan for the Northwest MZ-1

1.0 INTRODUCTION

This section describes background information on the history of land subsidence and ground fissuring in the Chino Basin, information on the formation of the Ground-Level Monitoring Committee (GLMC) and its responsibilities, and a description of the development and implementation of the Management Zone 1 Subsidence Management Plan (MZ-1 Plan) and the 2015 Chino Basin Subsidence Management Plan (Subsidence Management Plan).

1.1 Background

In general, land subsidence is the sinking or settlement of the Earth's surface due to the rearrangement of subsurface materials. In the United States, over 17,000 square miles in 45 states have experienced land subsidence (United States Geologic Survey [USGS], 1999). In many instances, land subsidence is accompanied by adverse impacts at the ground surface, such as sinkholes, earth fissures, encroachment of adjacent water bodies, modified drainage patterns, and others. In populated regions, these subsidence-related impacts can result in severe damage to man-made infrastructure and costly remediation measures. Over 80 percent of the documented cases of land subsidence in the United States have been caused by groundwater extractions from the underlying aquifer-system (USGS, 1999).

For purposes of clarification in this document, subsidence refers to the inelastic deformation (i.e., sinking) of the land surface. The term inelastic typically refers to the permanent, non-recoverable deformation of the land surface or the aquifer-system. The term elastic typically refers to fully reversible deformation of the land surface or the aquifer-system. A glossary of terms and definitions discussed in this report, as well as other terms related to basic hydrogeology and land subsidence is included in Section 5.0.

1.1.1 Subsidence and Fissuring in the Chino Basin

One of the earliest indications of land subsidence in the Chino Basin was the appearance of ground fissures within the City of Chino. These fissures appeared as early as 1973, but an accelerated occurrence of ground fissuring ensued after 1991 and resulted in damage to existing infrastructure. Figures 1-1 and 1-2 show the locations of these fissures. Scientific studies of the area have attributed the fissuring phenomenon to differential land subsidence caused by pumping of the underlying aquifer-system and the consequent drainage and compaction of aquitard sediments (Fife et al., 1976; Kleinfelder, 1993, 1996; Geomatrix, 1994; GEOSCIENCE, 2002).

1.1.2 The Optimum Basin Management Program

In 1999, the *Optimum Basin Management Program Phase I Report* (OBMP Phase I Report) identified the pumping-induced decline of hydraulic heads and subsequent aquifer-system compaction as the most likely cause of the land subsidence and ground fissuring observed in the Chino Basin OBMP Management Zone 1 (MZ-1; Wildermuth Environmental Inc. [WEI], 1999). Program Element 4 of the OBMP Implementation Plan, *Develop and Implement a Comprehensive Groundwater Management Plan for Management Zone 1*, called for the development and implementation of an interim management plan for MZ-1 that would:

- Minimize subsidence and fissuring in the short-term
- Collect the information necessary to understand the extent, rate, and mechanisms of subsidence and fissuring
- Abate future subsidence and fissuring or reduce it to tolerable levels

The OBMP called for an aquifer-system and land subsidence investigation in the southwestern region of MZ-1 to support the development of a management plan for MZ-1 (items 2 and 3 above). This investigation was titled the *MZ-1 Interim Monitoring Program* (WEI, 2003) and is described below.

The OBMP Phase I Report also identified that land subsidence was occurring in other parts of the basin besides in the City of Chino. Program Element 1 of the OBMP Implementation Plan, *Develop and Implement a Comprehensive Monitoring Program*, called for the initial collection of basin-wide data to characterize land subsidence, including ground-level surveys and remote-sensing (specifically, interferometric synthetic aperture radar or InSAR), and for the development of an ongoing monitoring program based on the analysis of the collected data.

1.1.3 Interim Management Plan and the MZ-1 Summary Report

From 2001 to 2005, the Chino Basin Watermaster (Watermaster) developed, coordinated, and conducted the Interim Management Plan (IMP) under the guidance of the MZ-1 Technical Committee. The MZ-1 Technical Committee was comprised of representatives from all major MZ-1 producers and their technical consultants, including the Agricultural Pool; the Cities of Chino, Chino Hills, Ontario, Pomona, and Upland; the Monte Vista Water District (MVWD); the Golden State Water Company; and the California Institution for Men.

The IMP consisted of three main monitoring elements for use in analyzing subsidence: ground-level surveys, InSAR, and aquifer-system monitoring. The ground-level surveys and InSAR analyses were used to characterize vertical ground motion. Aquifer-system monitoring of hydraulic and mechanical changes within the aquifer-system was used to characterize the causes of aquifer-system deformation.

The monitoring program was implemented in two phases: the Reconnaissance Phase and the Comprehensive Phase. The Reconnaissance Phase consisted of constructing 11 piezometers screened at various depths at Rubin S. Ayala Park (Ayala Park) in the City of Chino and installing pressure-transducers with integrated data loggers (transducers) in nearby pumping and monitoring wells to measure hydraulic head. Following installation of the monitoring network, several months of aquifer-system monitoring and testing were conducted. Testing included aquifer-system stress tests conducted at pumping wells in the area.

The Comprehensive Phase consisted of constructing a dual-borehole pipe extensometer at Ayala Park (Ayala Park Extensometer), near the area of historical fissuring. Following installation of the Ayala Park Extensometer, two aquifer-system stress tests were conducted, followed by passive aquifer-system monitoring.

During implementation of the IMP, Watermaster's Engineer made the data available to the MZ-1 Technical Committee and prepared quarterly progress reports for the MZ-1 Technical Committee, the Watermaster Pools and Board, and the Court.[1] The progress reports contained data and analyses from the IMP and summarized the MZ-1 Technical Committee meetings.

The main conclusions derived from the IMP were:

- Groundwater pumping from the deep and confined aquifer-system in the southwestern region of MZ-1 causes the greatest stress to the aquifer-system. In other words, pumping of the deep aquifer-system causes a hydraulic head decline that is much greater in magnitude

[1] San Bernardino County Superior Court, which retains continuing jurisdiction over the Chino Basin Judgment.

and lateral extent than the hydraulic head decline caused by pumping of the shallow aquifer-system.

- Hydraulic head decline due to pumping from the deep aquifer-system can cause inelastic compaction of the aquifer-system sediments, which results in land subsidence. The initiation of inelastic compaction within the aquifer-system was identified during the investigation when hydraulic heads in the deep aquifer-system at the Ayala Park PA-7 piezometer fell below a depth of about 250 feet (ft).
- The state of aquifer-system deformation in southern MZ-1 was essentially elastic during the Reconnaissance Phase of the IMP. Very little inelastic compaction was occurring in this area, which contrasted with the recent past when about 2.2 ft of land subsidence occurred from about 1987 to 1995 and resulted in ground fissuring. Figure 1-1 shows the land surface deformation that was measured in the western Chino Basin and the wells that pumped during that period.
- During the development of the IMP, a previously unknown barrier to groundwater flow was identified, shown in Figures 1-1 and 1-2. The barrier was named the “Riley Barrier” after Francis S. Riley, a retired USGS geologist who first detected the barrier during the IMP. This barrier is located within the deep aquifer-system and is aligned with the historical zone of ground fissuring. Pumping from the deep aquifer-system was limited to the area west of the barrier, and the resulting hydraulic head decline did not propagate eastward across the barrier. Thus, compaction occurred within the deep aquifer-system on the west side of the barrier but not on the east side, which caused concentrated differential subsidence across the barrier and created the potential for ground fissuring.
- The InSAR and ground-level surveys indicated that subsidence in Central MZ-1 had occurred in the past and was continuing to occur. InSAR also suggested that the groundwater barrier (Riley Barrier) extends northward into Central MZ-1, as shown in Figure 1-1. These observations suggested that the conditions that very likely caused ground fissuring near Ayala Park in the 1990s were also present in Central MZ-1. However, there was not enough historical hydraulic head data in this area to confirm this relationship. The IMP recommended that, if subsidence continued or increased in Central MZ-1, the mechanisms causing land subsidence should be studied in more detail.

The IMP provided enough information for Watermaster to develop Guidance Criteria for the Parties that pump from the southwestern region of MZ-1, that if followed, would minimize the potential for subsidence and fissuring in the investigation area. The methods, results, and conclusions of the IMP, including the Guidance Criteria, were described in detail in the *MZ-1 Summary Report* (WEI, 2006).

The Guidance Criteria were:

- The Managed Wells subject to the Guidance Criteria. Table 1-1 shows the list of Managed Wells with screens completed into the deep aquifer-system that are subject to the Guidance Criteria.

Table 1-1. Managed Wells Screened in the Deep Aquifer and Subject to the Guidance Criteria[a]				
Well Name	CBWM ID	Owner	2021 Status	Well Screen Interval(s) ft-bgs
CIM-11A[b]	3602461	California Institution for Men	Active[c]	174-187; 240-283; 405-465
C-7	3600461	City of Chino	Abandoned[d]	180-780
C-15	600670		Inactive[e]	270-400; 626-820
CH-1B	600487	City of Chino Hills	Inactive	440-470; 490-610; 720-900; 940-1,180
CH-7C	600687		Abandoned	550-950
CH-7D	600498		Destroyed	320-400; 410-450; 490-810; 850-930
CH-15B	600488		Inactive	360-440; 480-900
CH-16	600489		Inactive	430-940
CH-17	600499		Active	300-460; 500-680
CH-19	600500		Abandoned	300-460; 460-760; 800-1,000

(a) The MZ-1 Subsidence Management Plan identified the Managed Wells that are subject to the Guidance Criteria for the Managed Area that, if followed, would minimize the potential for subsidence and fissuring.

(b) The original casing was perforated from 135-148, 174-187, 240-283, 405-465, 484-512, and 518-540 feet below ground surface (ft-bgs). This casing collapsed below 471 ft-bgs in 2011. A liner was installed to 470 ft-bgs with a screen interval from 155 to 470 ft-bgs.

(c) Active = Well is currently being used for water supply.

(d) Abandoned = Unable to pump the well without major modifications.

(e) Inactive = Well can pump groundwater with little or no modifications.

- The spatial extent of the Managed Area. Figures 1-1 and 1-2 show the boundary of the Managed Area where the Guidance Criteria apply. Within the boundaries of the Managed Area, both existing (Table 1-1) and newly constructed wells are subject to being classified as Managed Wells. This area was delineated based on the observed and/or predicted effects of pumping on hydraulic heads and aquifer-system deformation. The Managed Well designations were based on the effects measured at the Ayala Park Extensometer during the IMP or well construction and borehole lithology.
- A piezometric Guidance Level. The Guidance Level is a specified depth to water, as measured in feet below the top of casing (ft-btoc) at the Ayala Park PA-7 piezometer. The initial Guidance Level was established as 245 ft-btoc. It was defined as the threshold hydraulic head level at the onset of inelastic compaction of the aquifer-system as recorded by the extensometer minus five feet. The five-foot reduction was meant to be a safety factor to ensure that inelastic compaction does not occur. The Guidance Level can be updated by Watermaster based on the periodic review of monitoring data.
- Criteria for recommending pumping curtailment. If the hydraulic head level in PA-7 falls below the Guidance Level, Watermaster recommends that the MZ-1 Parties curtail their pumping from designated Managed Wells as required.
- Real-time monitoring/reporting of head levels in PA-7. Watermaster was to provide the MZ-1 Parties with real-time hydraulic head level data from PA-7.

- Reporting of pumping operations at Managed Wells. The MZ-1 Parties were requested to maintain and provide Watermaster with accurate records of operations at the Managed Wells, including pumping rates and on-off dates and times. The MZ-1 Parties were requested to promptly notify Watermaster of all operational changes made to maintain the hydraulic head level in PA-7 above the Guidance Level.
- Request for ongoing monitoring at other monitoring wells. Watermaster recommended that the MZ-1 Parties allow it to continue to monitor hydraulic head levels at the Managed Wells.
- Process for adapting the Guidance Criteria. Watermaster and Watermaster's Engineer were to evaluate the data collected as part of the MZ-1 Monitoring Program (now called the Ground-Level Monitoring Program or GLMP) after each fiscal year and determine if modifications, additions, and/or deletions to the Guidance Criteria were necessary. Changes to the Guidance Criteria could include additions or deletions to the list of Managed Wells, re-delineation of the Managed Area, raising or lowering of the Guidance Level, or additions and/or deletions to the Guidance Criteria, including the need to have periods of hydraulic head level recovery.
- Acknowledgement of uncertainty. Watermaster cautioned that some subsidence and fissuring could occur in the future, even if the Guidance Criteria were followed. Watermaster made no warranties that faithful adherence to the Guidance Criteria would eliminate subsidence or fissuring.

1.1.4 MZ-1 Subsidence Management Plan

The Guidance Criteria formed the basis for the *MZ-1 Subsidence Management Plan* ([MZ-1 Plan]; WEI, 2007), which was developed by the MZ-1 Technical Committee and approved by the Watermaster Board in October 2007. In November 2007, the Court approved the MZ-1 Plan and ordered its implementation.

To minimize the potential for future subsidence and fissuring in the Managed Area, the MZ-1 Plan codified the Guidance Level and recommended that the MZ-1 Parties manage their groundwater pumping such that the hydraulic head level in PA-7 remains above the Guidance Level.

The MZ-1 Plan called for ongoing monitoring, data analysis, annual reporting, and adjustments to the MZ-1 Plan, as warranted by the data. Implementation of the MZ-1 Plan began in 2008. The MZ-1 Plan called for the continued scope and frequency of monitoring implemented during the IMP within the Managed Area and expanded monitoring of the aquifer-system and land subsidence in other areas of the Chino Basin where the IMP indicated concern for future subsidence and ground fissuring. Figure 1-1 shows the location of these so-called Areas of Subsidence Concern: Central MZ-1, Northwest MZ-1, Northeast Area, and Southeast Area. The expanded monitoring efforts outside the Managed Area are consistent with the requirements of the OBMP Program Element 1 and its implementation plan contained in the Peace Agreement.[2]

Potential future efforts listed in the MZ-1 Plan included: 1) more intensive monitoring of horizontal strain across the zone of historical ground fissuring to assist in developing management strategies related to fissuring, 2) injection feasibility studies within the Managed Area, 3) additional pumping tests to refine the Guidance Criteria, 4) computer-simulation modeling of groundwater flow and subsidence, and 5) the development of alternative pumping plans for the MZ-1 Parties affected by the MZ-1 Plan. The MZ-1

[2] Source: http://www.cbwm.org/rep_legal.htm.

Technical Committee (now called the Ground-Level Monitoring Committee or GLMC) discusses these potential future efforts, and if deemed prudent and necessary, they are recommended to Watermaster for implementation in future fiscal years.

1.1.5 2015 Chino Basin Subsidence Management Plan

The MZ-1 Plan stated that if data from existing monitoring efforts in the Areas of Subsidence Concern indicate the potential for adverse impacts due to subsidence, Watermaster would revise it to avoid those adverse impacts. The 2014 Annual Report of the GLMC recommended that the MZ-1 Plan be updated to better describe Watermaster's land subsidence efforts and obligations, including areas outside of MZ-1. As such, the update included a name change to the 2015 Chino Basin Subsidence Management Plan ([Subsidence Management Plan]; WEI 2015a) and a recommendation to develop a subsidence management plan for Northwest MZ-1.

Watermaster had been monitoring vertical ground motion in Northwest MZ-1 via InSAR during the development of the MZ-1 Plan. Land subsidence in Northwest MZ-1 was first identified as a concern in 2006 in the MZ-1 Summary Report and again in 2007 in the MZ-1 Plan. Of particular concern, the subsidence across the San Jose Fault in Northwest MZ-1 has occurred in a pattern of concentrated differential subsidence—the same pattern of differential subsidence that occurred in the Managed Area during the time of ground fissuring. Ground fissuring is the main subsidence-related threat to infrastructure. The issue of differential subsidence, and the potential for ground fissuring in Northwest MZ-1, has been discussed at prior GLMC meetings, and the subsidence has been documented and described as a concern in Watermaster's State of the Basin Reports, the annual reports of the GLMC, and in the *Initial Hydrologic Conceptual Model and Monitoring and Testing Program for the Northwest MZ-1 Area* (WEI, 2017). Watermaster increased monitoring efforts in Northwest MZ-1 beginning in Fiscal Year (FY) 2012/13 to include ground elevation surveys and electronic distance measurements (EDM) to monitor ground motion and the potential for fissuring.

In 2015, Watermaster's Engineer developed the *Work Plan to Develop a Subsidence Management Plan for the Northwest MZ-1 Area* ([Work Plan]; WEI 2015b). The Work Plan is characterized as an ongoing Watermaster effort and includes a description of a multi-year scope-of-work, a cost estimate, and an implementation schedule. The Work Plan was included in the Subsidence Management Plan as Appendix B. Implementation of the Work Plan began in July 2015.

The updated Subsidence Management Plan also addressed the need for hydraulic head "recovery periods" in the Managed Area by recommending that all deep aquifer-system pumping cease for a continuous six-month period between October 1 and March 31 of each year within the Managed Area. And, the Subsidence Management Plan recommends that every fifth year, all deep aquifer-system pumping cease for a continuous period until the hydraulic head at PA-7 reaches "full recovery" of 90 ft-btoc. These periodic cessations of pumping are intended to allow for sufficient hydraulic head recovery at PA-7 to recognize inelastic compaction, if any, at the Ayala Park Extensometer.

1.1.6 Annual Report of the Ground-Level Monitoring Committee

Pursuant to the Subsidence Management Plan, Watermaster will produce an annual report, containing the results of ongoing monitoring efforts, interpretations of the data, and recommended adjustments to the Subsidence Management Plan, if any. This annual report of the GLMC includes the results and interpretations for the data collected between March 2020 through March 2021, as well as recommendations for Watermaster's GLMP for FY 2021/22.

1.2 Report Organization

This report is organized into the following six sections:

- **Section 1.0 – Introduction**. This section provides background information on the history of land subsidence and ground fissuring in Chino Basin, information on the formation of the GLMC and its responsibilities, and a description of the development and implementation of the Subsidence Management Plan, which calls for annual reporting.
- **Section 2.0 – Ground-Level Monitoring Program.** This section describes the monitoring and testing activities performed by Watermaster for its GLMP between March 2020 and March 2021.
- **Section 3.0 – Results and Interpretations.** This section discusses and interprets the monitoring data collected between March 2020 and March 2021, including basin stresses (groundwater pumping and recharge) and responses (changes in hydraulic heads, aquifer-system deformation, and ground motion).
- **Section 4.0 – Conclusions and Recommendations.** This section summarizes the main conclusions derived from the monitoring program between March 2020 and March 2021 and describes recommended activities for the GLMP for FY 2021/22.
- **Section 5.0 – Glossary.** This section is a glossary of the terms and definitions utilized within this report and in discussions at GLMC meetings.
- **Section 6.0 – References.** This section lists the publications and reports cited in this report.

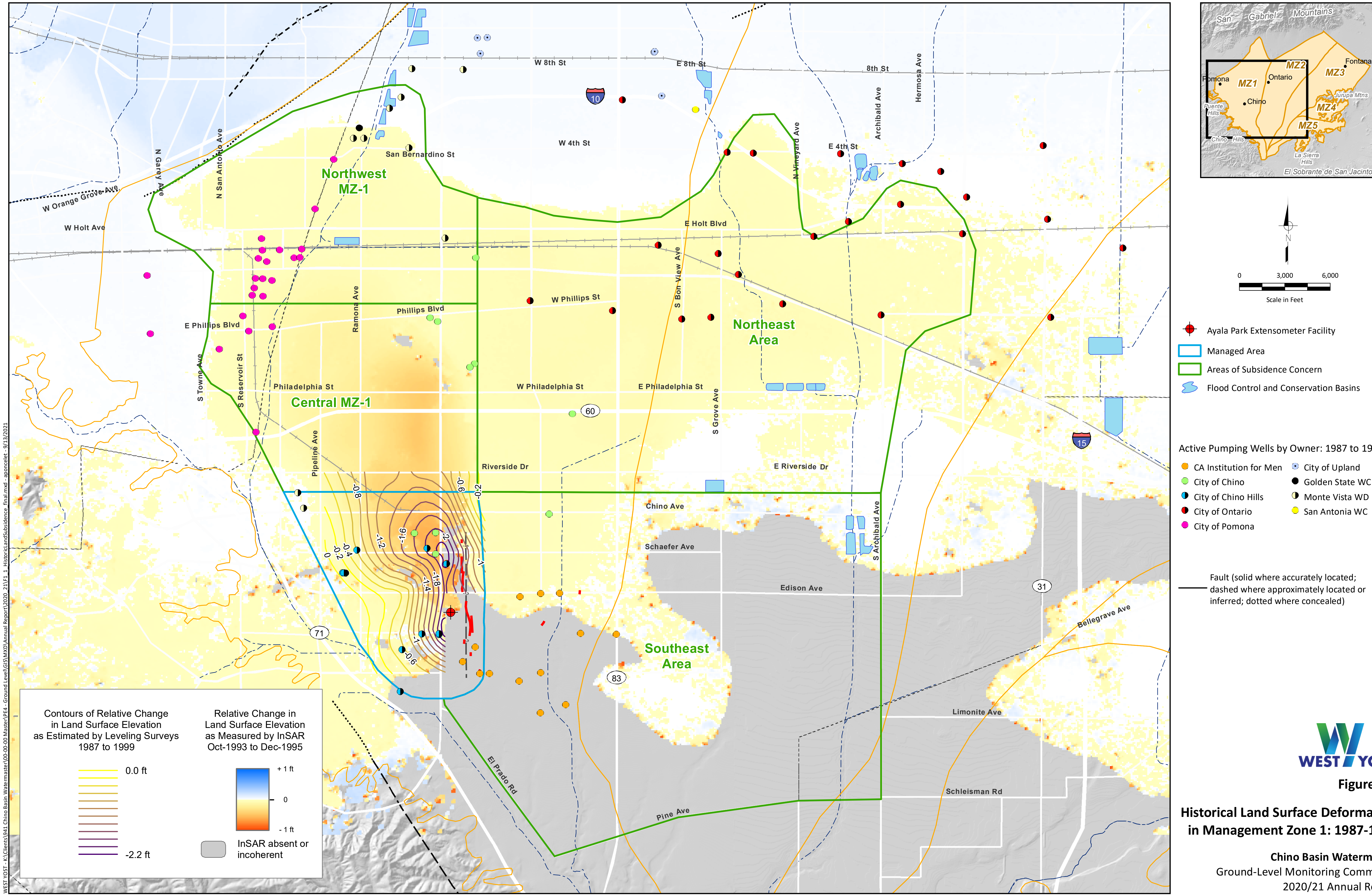

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Figure 1-1

Historical Land Surface Deformation in Management Zone 1: 1987-1999

Chino Basin Watermaster

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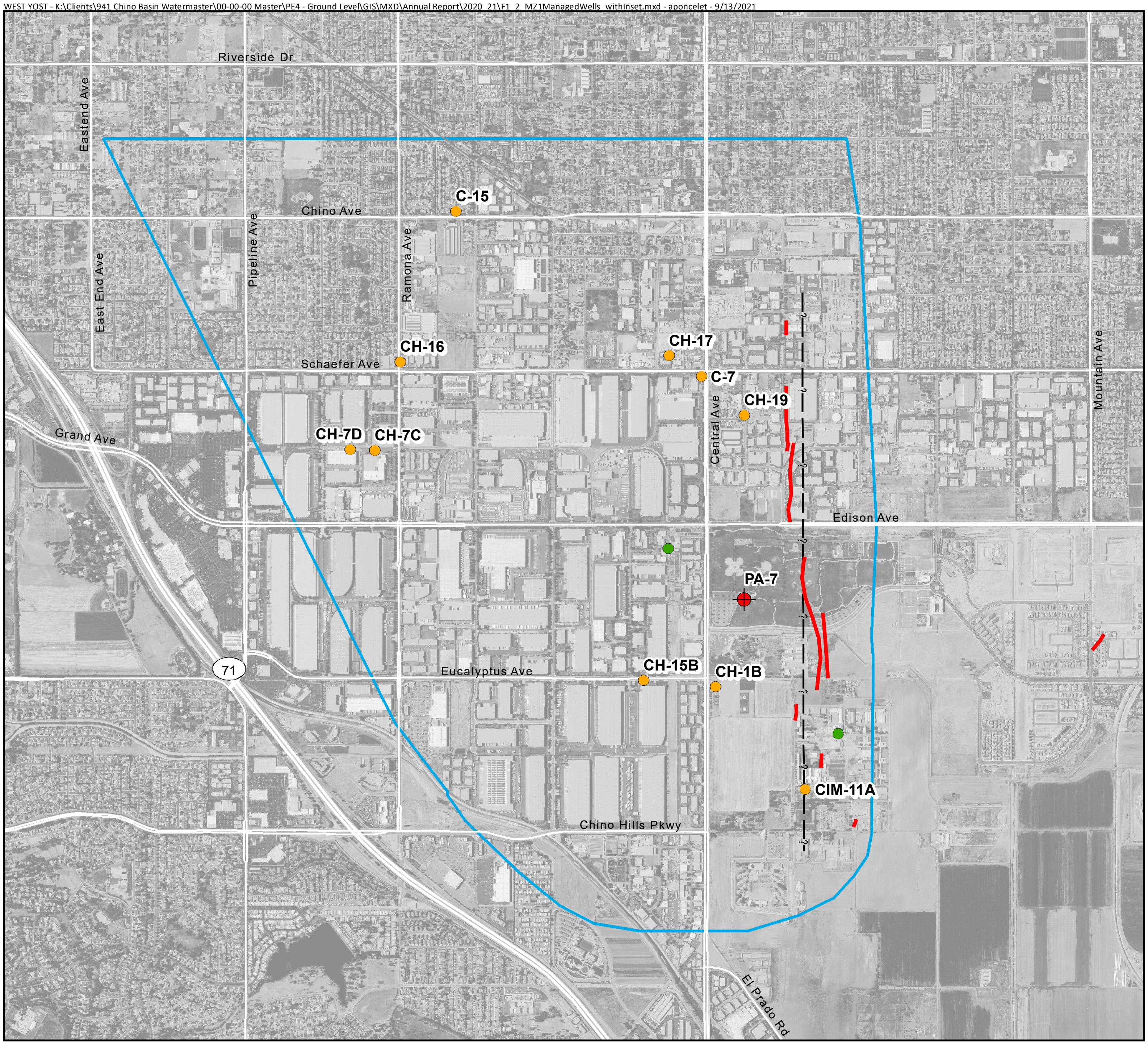

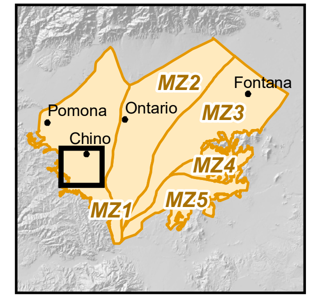

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Figure 1-2

MZ-1 Managed Area and the Managed Wells

Chino Basin Watermaster

Ground-Level Monitoring Committee

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2.0 GROUND-LEVEL MONITORING PROGRAM

This section describes the activities performed by Watermaster for the GLMP between March 2020 and March 2021.

Figure 2-1 shows the groundwater pumping and recharge facilities in the western Chino Basin that impart pumping and recharge stresses to the aquifer-system. Figure 2-2 shows the locations of the monitoring facilities in Watermaster's ground-level monitoring network, including: wells equipped with a transducer; extensometers that measure vertical aquifer-system deformation; and benchmark monuments that are used to perform ground elevation and EDM surveys to measure vertical and horizontal deformation of the ground surface.

2.1 Ground-Level Monitoring Program

Watermaster conducts its GLMP in the Managed Area and other Areas of Subsidence Concern pursuant to the Subsidence Management Plan and the recommendations of the GLMC. The GLMP activities performed between March 2020 and March 2021 are described below.

2.1.1 Setup and Maintenance of the Monitoring Facilities Network

The Chino Basin extensometer facilities are key monitoring facilities for the GLMP. They require regular and as needed maintenance and calibration to remain in good working order and to ensure the recording of accurate measurements. During the reporting period, the following activities were performed at the Chino Basin extensometer facilities:

- Performed routine monthly maintenance at the Ayala Park, Chino Creek, and Pomona Extensometer (PX) Facilities.
- Purchased and installed a new sump pump for the Piezometer A (PA) vault (Ayala Park Extensometer Facility). The sump pump automatically pumps water from the vault when water (rain or sprinklers) enters and accumulates in the vault.
- Replaced the 12 volt deep-cycle battery at the Piezometer C (PC) vault at the Ayala Park Extensometer Facility to ensure power to the datalogger and continuous data collection.
- Replaced the PA-7 dedicated transducer at the Ayala Park Extensometer Facility.
- Adjusted the deep extensometer rocker arm at the Ayala Park Extensometer Facility.
- At the PX Facility, all devices used to monitor piezometric (transducers) and aquifer-system deformation (linear potentiometers and vibrating wireline transducers) and data loggers were installed between April and September 2020. Data collection from the PX Facility commenced in December 2020.
- At the PX Facility, dead-band testing at each cable extensometer was conducted on July 1, 2020 to quantify the frictional properties of the extensometers, characterize performance and accuracy, and to refine the ideal counter-weight balance (Riley, 1986).
- Installed a new 12-volt deep-cycle batteries at the PX Facility to ensure continuous power to the dataloggers and continuous data collection.

2.1.2 Monitoring Activities

Changes in hydraulic heads are caused by the stresses of groundwater pumping and recharge. Changes in hydraulic head is the mechanism behind aquifer-system deformation, which in turn causes vertical and horizontal ground motion. Because of this cause-and-effect relationship, the Watermaster monitors groundwater pumping, recharge, hydraulic heads, aquifer-system deformation, and vertical and horizontal ground motion across the western portion of the Chino Basin. The following sub-sections (2.1.2.1 through 2.1.2.4) describe Watermaster's monitoring activities between March 2020 and March 2021, as called for by the Subsidence Management Plan and in accordance with the recommendations of the GLMC.

2.1.2.1 Monitoring of Pumping, Recharge, and Piezometric Levels

The Watermaster collects and compiles groundwater pumping data on a quarterly basis from well owners in the Managed Area and Areas of Subsidence Concern. The well locations that pumped groundwater between March 2020 and March 2021 are shown in Figure 2-1.

The Watermaster collects data from the Inland Empire Utilities Agency on the volumes of imported water, stormwater, and recycled water that are artificially recharged at spreading basins, and the volumes of recycled water for direct use within the Chino Basin.

Hydraulic heads were measured and recorded once every 15 minutes using transducers maintained by the Watermaster at 77 wells across the Managed Area and Areas of Subsidence Concern. Figure 2-2 shows the locations of these wells. Also, Watermaster staff and well owners typically measure hydraulic heads at other wells in western Chino Basin monthly.

2.1.2.2 Monitoring Vertical Aquifer-System Deformation

The Watermaster measured and recorded the vertical component of aquifer-system deformation at the Ayala Park and the Chino Creek Extensometer Facilities once every 15 minutes.

2.1.2.3 Monitoring Vertical Ground Motion

The Watermaster monitored vertical ground motion via ground-level surveys using InSAR and traditional leveling techniques.

For InSAR, the Watermaster retained General Atomics (formerly Neva Ridge Technologies, Inc.) to acquire and post-process land-surface displacement data from the TerraSAR-X satellite operated by the German Aerospace Center. The width of the TerraSAR-X data frame covers the western half of the Chino Basin only.[3] Six synthetic aperture radar (SAR) scenes were collected between March 2020 and March 2021. The

[3] All historical InSAR data that were collected and analyzed by Watermaster from 1993 to 2010 indicate that very little vertical ground motion occurred in the eastern half of the Chino Basin. In 2012, the GLMC decided to acquire and analyze InSAR only in the western portion of the Chino Basin as a cost-saving strategy.

scenes were used to create 10 interferograms[4] to estimate short- and long-term vertical ground motion[5] over the following periods (Table 2-1):

Table 2-1. 2020/21 Interferograms Short- and Long-Term Time-Periods

2020/21 Interferograms	Long-Term Interferograms
March 2020 to June 2020	March 2011 to March 2021
June 2020 to August 2020	March 2020 to March 2021
August 2020 to October 2020	March 2020 August 2020
October 2020 to December 2020	March 2020 October 2020
December 2020 to March 2021	March 2020 December 2020

This year's InSAR results were again generated using General Atomics new processing method to allow for estimates of vertical ground motion in areas that were previously incoherent. These areas include portions of the Southeast Area and the southeastern portions of the Northeast Area. A brief description of the processing techniques and the impact the processing techniques have on estimates of vertical ground motion across the western Chino Basin between 2011 and 2021 has been provided by General Atomics and is summarized below (Sean Yarborough, personal communication, September 3, 2020):

1. Tight filters[6] were applied to portions of the interferograms with higher overall coherence to preserve the shape and depth of smaller ground motion signals. Broad filters were used to retain and enhance ground motion trends in less coherent interferograms.
2. Intermittent coherence within agricultural and/or wildland (or open space) areas often result in a widespread loss of ground motion estimates, despite visible trends. Intermittently coherent points were interpolated in each interferogram.

The primary areas where the filters were applied (see No. 1 above) were agriculture and/or open-space areas in portions of the Southeast Area and the southeastern portions of the Northeast Area. The trade-off with using tight or broad filter sizes is that tight filters preserve the fine spatial detail of the ground motion in an area but creates noise in low coherence areas; and broad filters preserve overall ground motion trends but obscure the fine spatial details in the shape and displacement of the ground motion. Prior processing methods heavily favored one or the other approach. This year's InSAR delivery is an evolution,

[4] Two or more SAR scenes are used to generate grids of surface deformation (interferograms) over a given period. Typically, surfaces within a pixel will move up or down together as would be expected in recovery/subsidence scenarios. However, surfaces within the area of a pixel can move randomly and cause decorrelation in the radar signal. Examples of random motion within a pixel area are vegetation growing, urbanization, erosion of the ground surface, harvesting crops, plowing fields, and others. The magnitude of this decorrelation in the signal is measured mathematically and called incoherence. Based on the magnitude of decorrelation in an area, pixels will be rejected as "incoherent."

[5] Several factors can influence the accuracy of ground motion results as estimated by InSAR, such as satellite orbital uncertainties and atmospheric interference. On average, accuracy of ground motion results as estimated by InSAR are +/- 0.02 ft.

[6] Filters are used to smooth the ground motion measurements by reducing the standard deviation of the pixels in a given area. Filters can differ in overall size (areal extent), smoothing shape (flat, triangle, Gaussian, etc.) and strength (enforcement).

selecting an appropriate filter based on the coherence of specific agricultural and/or open-space areas in each frame.

The intermittent coherence described in No. 2 above appeared in certain areas in western Chino Basin with coherent points that had a clear spatial trend and a small handful of randomly incoherent points. With previous processing methods, once a point becomes incoherent and if no further spatial processing is performed, ground motion estimates at that location are lost moving forward in time, even if the point becomes coherent in the next interferogram and remains coherent indefinitely thereafter. A region with widespread intermittent coherence becomes completely masked over time as each point experiences a brief period of incoherence, even if its neighbors continue showing a clear trend. With the new processing techniques, these neighboring points are used to interpolate across intermittently incoherent points in order to preserve the overall ground motion estimate through time.

For the ground level surveys, Watermaster retained Guida Surveying, Inc. to conduct traditional leveling surveys at selected benchmark monuments in the western part of the Chino Basin. Table 2-2 below shows the number of benchmark monuments that were surveyed within each ground-level survey area. The locations of the ground-level survey areas are shown in Figure 2-2.

Table 2-2. Benchmark Monuments Surveyed in Ground-Level Survey Areas

Ground-Level Survey Area	Date of Most Recent Survey	Number of Benchmarks Surveyed
Managed Area[(a)]	January 2018	22
Central Area[a]	January 2018	14
Northwest Area	May 2021	25
San Jose Fault Zone Area	May 2021	10
Southeast Area[a]	January 2018	77
Northeast Area	April 2020	68

(a) The entire benchmark monument survey network for the ground-level survey area was not surveyed in 2021 based on the GLMC scope and budget recommendations for FY 2020/21.

2.1.2.4 Monitoring of Horizontal Ground Motion

Watermaster measures horizontal ground motion between benchmarks across areas that are susceptible to ground fissuring via EDMs. The EDMs were performed between the benchmarks located within the San Jose Fault Zone Area (Figure 2-2). The number of benchmarks surveyed are shown in Table 2-3.

Table 2-3. Number of Benchmark Surveyed

Ground-Level Survey Area	Date of Most Recent Survey	Number of Benchmarks Surveyed
Fissure Zone Area[(a)]	February 2018	66
San Jose Fault Zone Area	May 2021	9

(a) EDMs across the Fissure Zone Area were not conducted in 2021 based on GLMC scope and budget recommendations for FY 2020/21.

2.2 Land-Subsidence Investigations

The Watermaster performs land subsidence investigations pursuant to the Subsidence Management Plan, the recommendations of the GLMC for the GLMP, and the annually approved Watermaster budget. Investigations can include aquifer-stress tests (e.g. pumping and injection) and the simultaneous monitoring of hydraulic heads, aquifer-system deformation, and deformation of the ground surface. The goals of these investigations are to refine the Guidance Criteria and assist in the development of subsidence management plans to minimize or abate land subsidence and maximize the prudent extraction of groundwater.

This section describes the land subsidence investigations conducted between March 2020 and March 2021 that are called for in the Subsidence Management Plan.

2.2.1 Long-Term Pumping Test in the Managed Area

The GLMC developed the Long-Term Pumping Test in the Managed Area in response to the directives in the Subsidence Management Plan. The goal of the Long-Term Pumping Test is to develop a strategy for the prudent extraction of groundwater from the Managed Area. In this case, “prudent” is defined as extracting the maximum volume of groundwater possible without causing damage to the ground surface or the area’s infrastructure. As of February 2021, the City of Chino Hills (M. Wiley, personal communication, February 1, 2021) reported the Long-Term Pumping test will not be completed in FY 2020/21 due to mechanical issues at CH-15B and 1,2,3-trichloropropane (TCP) and per- and polyfluoroalkyl substances (PFAS) contamination in CH-15B and CH-17. Injection at CH-16 will also likely not occur in FY 2020/21.

2.2.2 Analysis of EDM Measurements Across the Fissure Zone and San Jose Fault Zone

The Subsidence Management Plan calls for the Watermaster to monitor horizontal ground motion across areas that are susceptible to ground fissuring. Historically, this monitoring has occurred via EDMs and with the Daniels Horizontal Extensometer (DHX). The DHX was decommissioned and removed in 2015 because the site was developed. The GLMC annually recommends the scope and frequency of EDM surveys. The 2016 Annual Report of the GLMC included an in-depth review of horizontal strain that had occurred over time and measured from EDM data across the Fissure Zone to assess if the EDM data can be used in-lieu of the horizontal extensometer data collected at the DHX. Based on the review of EDM data between closely spaced benchmarks in the Fissure Zone Area, the EDM method appears to be a suitable monitoring technique to detect the occurrence of tensile strain within shallow soils and the potential threat of ground fissuring. Additionally, the 2016 Annual Report recommended that if permanent subsidence is absent in the Managed Area, the GLMC should consider performing EDM surveys across the Fissure Zone at a frequency greater than annual and performing EDM surveys in coordination with the Long-Term Pumping Test in the Managed Area. In 2021, the EDM survey across the Fissure Zone in the Managed Area was not conducted based on the GLMC scope and budget recommendations for FY 2020/21.

Like the benchmark network in the Fissure Zone in the Managed Area, a series of closely spaced benchmarks were installed across the San Jose Fault Zone in Northwest MZ-1. These benchmarks were installed along San Bernardino and San Antonio Avenues to measure horizontal strain across the fault zone. EDM surveys have been performed in this area each year since 2014.

2.2.3 Subsidence Management Plan for Northwest MZ-1

In 2015, the GLMC developed the final Work Plan to develop a subsidence-management plan for Northwest MZ-1, which describes a multi-year effort with cost estimates to execute the Work Plan. The Work Plan was included in the Subsidence Management Plan as Appendix B.[7] The background and objectives of the Work Plan are described in Section 1.1.5. The Watermaster began implementation of the Work Plan in July 2015. The Work Plan has evolved over time as new data and information has been collected and evaluated by the GLMC. The following describes the Work Plan tasks and status of each task:

Task 1. Describe Initial Hydrogeologic Conceptual Model and Monitoring and Testing Program – A final report was submitted to the GLMC and Watermaster in December 2017 that summarized the current state of knowledge of the hydrogeology of Northwest MZ-1, the data gaps needed to be filled to fully describe the occurrence and mechanisms of aquifer-system deformation and the pre-consolidation stress, and a strategy to fill the data gaps.

Task 2. Implement the Initial Monitoring and Testing Program – The Watermaster's Engineer worked with the Watermaster, MVWD, City of Pomona, and SCADA Integrations, Inc. to identify and equip a set of wells with supervisory control and data acquisition (SCADA) monitoring capabilities and/or transducers. Through several field visits and technical meetings with the well owners, a protocol was developed to install monitoring equipment and collect pumping and piezometric data. For the City of Pomona, nine wells were equipped with transducers. For MVWD, seven wells were equipped with transducers, two wells with sonar units, and two wells with air-line units. Hydraulic heads are recorded once every 15 minutes. Nine of the 11 MVWD wells were connected to the MVWD's existing SCADA system. The hydraulic head data from these wells are currently being collected and analyzed as part of the Northwest MZ-1 monitoring and testing program.

Task 3. Develop and Evaluate the Baseline Management Alternative (BMA) and Task 4. Develop and Evaluate the Initial Subsidence-Management Alternative – A final technical memorandum was submitted to the GLMC and Watermaster in December 2017 that described the construction, calibration, and use of a numerical one-dimensional aquifer-system compaction model at MVWD-28. The objective of this memo was also to explore the future occurrence of subsidence in Northwest MZ-1 under various basin-operation scenarios of groundwater pumping and artificial recharge and to identify potential subsidence mitigation strategies.

Task 5. Design and Install the Pomona Extensometer Facility – The Watermaster's Engineer completed construction of two dual-nested piezometers located in Montvue Park, Pomona, CA in August 2019. Each PX piezometer was equipped with transducers and cable extensometers in June and July 2020 and has been collecting preliminary depth-specific hydraulic head and aquifer-system deformation since December 2020.

Task 6. Design and Conduct Aquifer-System Stress Tests (if necessary) – The objective of this task is to perform controlled aquifer-system stress tests at pumping wells in Northwest MZ-1 and to monitor the depth-specific hydraulic head and aquifer-system deformation response at PX. This information, along with hydraulic head data collected as part of Task 2 will be used to help identify the subsidence mechanisms and the pre-consolidation stress(es) in Northwest MZ-1. The Watermaster's Engineer has not yet identified specific questions that need to be answered with the controlled aquifer-system stress tests.

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[7] Source: http://www.cbwm.org/rep_engineering.htm

It is recommended a period of "passive" data collection and assessment of the data over time to determine if a controlled aquifer-system stress test is recommended in the future.

Task 7. Update the Hydrogeologic Conceptual Model – The objective of this task is to update the hydrogeologic conceptual model of Northwest MZ-1 based on new lithologic information from PX and an improved understanding of hydraulic head data across Northwest MZ-1. A numerical one-dimensional aquifer-system compaction model at PX was constructed and calibrated to refine the hydraulic and mechanical property estimates of the aquifer-system and the pre-consolidation stress. This task was completed in FY 2020/21.

Task 8. Document the One-Dimensional Compaction Models at the MVWD-28 and PX Locations – This task will help answer the question: What are the pre-consolidation stresses within the compacting intervals of the aquifer-system? The pre-consolidation stress is a piezometric "threshold." When piezometric levels are above the threshold, subsidence is abated. When piezometric levels are below the threshold, subsidence is caused. The determination of pre-consolidation stress by aquifer-system layer can provide "guidance" for the Chino Basin parties to manage pumping and recharge to avoid the future occurrence of land subsidence in Northwest MZ-1.

The model calibration results for two 1D compaction models located within the area of maximum subsidence in Northwest MZ-1 (at the MVWD-28 and PX locations) will be used, in combination with other monitoring data, to estimate the current (2018) pre-consolidation stresses by aquifer-system layer for Northwest MZ-1. The 1D compaction models, calibration results, and preliminary estimates of the pre-consolidation stress by aquifer-system layer will be presented by the Watermaster Engineer at a GLMC meeting. The Watermaster Engineer will accept verbal feedback and written comments from the GLMC, and then prepare a draft technical memorandum to document the 1D compaction models, the calibration results, and the preliminary estimates of the pre-consolidation stress. Another GLMC meeting will be held to review the draft technical memorandum. The GLMC will submit written comments and suggested revisions to the Watermaster Engineer. A final technical memorandum will be prepared that incorporates the feedback and comments from the GLMC. This task is anticipated to be completed in FY 2021/22.

Task 9. Refine and Evaluate Subsidence-Management Alternatives – This task will help answer the question: What are potential methods to manage the land subsidence in Northwest MZ-1?

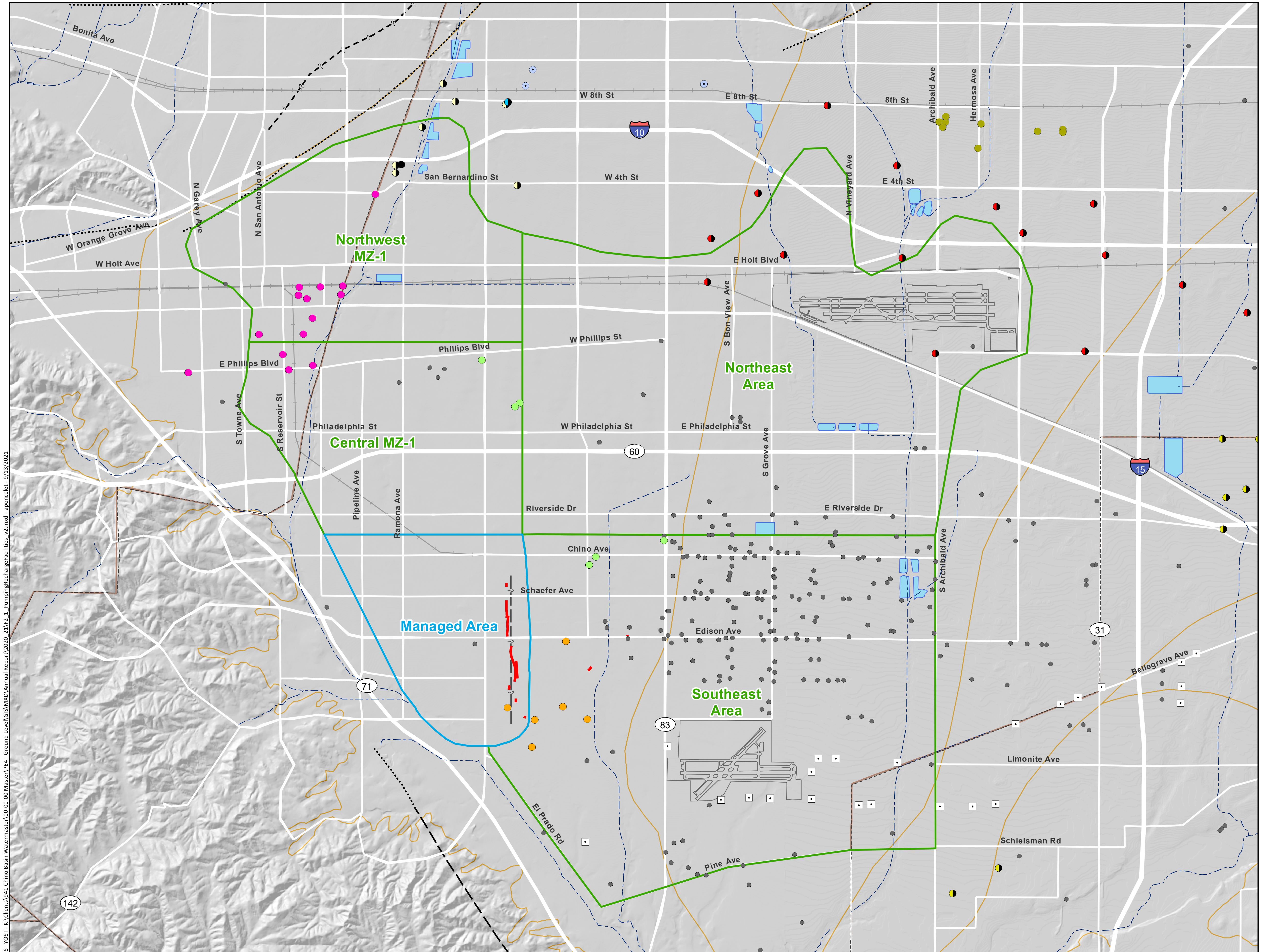
The 1D compaction models at MVWD-28 and PX will be used to characterize the mechanical response of the aquifer-system to a BMA. A draft technical memorandum will be prepared that summarizes the evaluation of the BMA, particularly, the ability of the BMA to raise and hold piezometric levels above the estimated pre-consolidation stresses. The draft technical memorandum may also include a recommendation for the Initial Subsidence Management Alternative (ISMA) if the BMA is not successful at raising and holding hydraulic heads above the estimated pre-consolidation stresses. The assumptions of the ISMA, including the groundwater production and replenishment plans of the Chino Basin parties, will be described, and must be agreed upon by the GLMC. A GLMC meeting will be held to review the model results and evaluation of the BMA, review the recommended ISMA, and to receive feedback on the draft technical memorandum.

After the recommended ISMA is agreed upon by the GLMC, the Watermaster's MODFLOW model will be updated to run the ISMA and will be used to estimate the hydraulic head response to the ISMA at the MVWD-28 and PX locations. The projected hydraulic heads generated from the MODFLOW model using the ISMA will be extracted from the MODFLOW model results at the MVWD-28 and PX locations and will be used as input files for both 1D compaction models. The 1D compaction models will then be run to characterize the mechanical response of the aquifer-system to the ISMA at both the MVWD-28 and PX locations.

A draft technical memorandum will be prepared that summarizes the evaluation of the ISMA, particularly, the ability of the ISMA to raise and hold piezometric levels above the estimated pre-consolidation stresses. The draft technical memorandum may also include a recommendation for a second Subsidence-Management Alternative (SMA-2), if the ISMA is not successful at raising and holding hydraulic heads above the estimated pre-consolidation stresses. The assumptions of the SMA-2, including the groundwater production and replenishment plans of the Chino Basin parties, will be described, and must be agreed upon by the GLMC. A GLMC meeting will be held to review the model results and evaluation of the ISMA, review the recommended SMA-2, and to receive feedback on the technical memorandum. This task is anticipated to be completed in FY 2021/22.

If necessary and recommended by the GLMC, additional subsidence management alternative scenarios may be run in FY 2022/23. It is currently envisioned by the GLMC that, based on the results of the 1D compaction model results, the GLMC may recommend an update to the Watermaster's Subsidence Management Plan in FY 2022/23 to minimize or abate the future occurrence of land subsidence in Northwest MZ-1.

Task 10. Update the Chino Basin Subsidence Management Plan – The objective of this task is to incorporate the preferred subsidence-management alternative for Northwest MZ-1 into the Chino Basin Subsidence Management Plan. An implementation plan will be prepared as part of this effort. The implementation plan will require review and approval by the GLMC and the Watermaster Pools, Advisory Committee, and Board. The Watermaster will apprise the Court of revisions to the plan as part of its OBMP implementation status reporting. The updated Chino Basin Subsidence Management Plan is anticipated to be completed by the end of FY 2023/24.



Active Groundwater Pumping Wells
April 1, 2020 to March 31, 2021

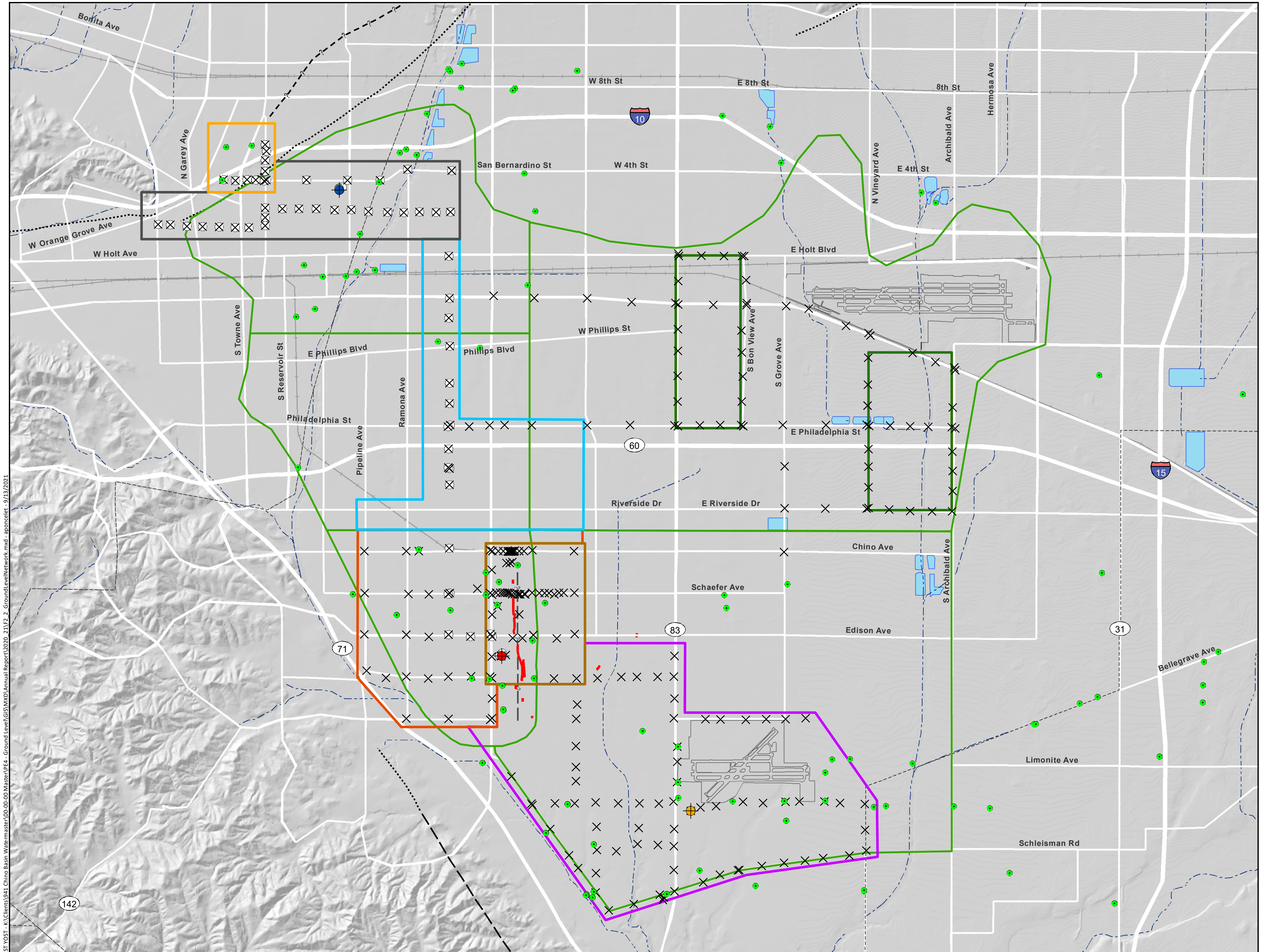
- Private
- California Institution for Men
- Chino Basin Desalter Authority
- City of Chino
- City of Chino HIlls
- Cucamonga Valley Water District
- Jurupa Community Services District
- City of Ontario
- City of Pomona
- City of Upland
- Golden State Water Company
- Monte Vista Water District
- Managed Area
- Areas of Subsidence Concern

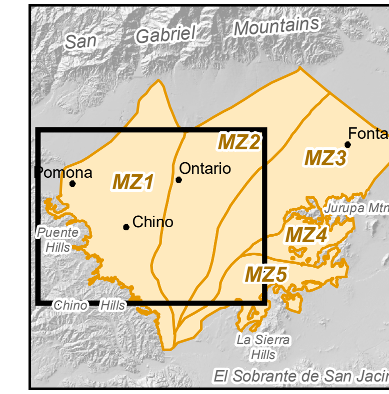
WEST YOST

Figure 2-1

Pumping and Recharge Facilities
Western Chino Basin: 2020/21

Chino Basin Watermaster
Ground-Level Monitoring Committee
2020/21 Annual Report





N

0 3,000 6,000

Scale in Feet

Ground-Level Monitoring Network Facilities

- Pomona Extensometer
- Ayala Park Extensometer
- Chino Creek Extensometer
- All Program Transducer Wells
- Ground-Level Survey Benchmark
- Ground-Level Survey Benchmark (Measured May 4, 2021)

Ground-Level Survey Areas

- Managed Area
- Fissure Zone Area
- Central Area
- Northwest Area
- San Jose Fault Zone Area
- Northeast Area
- Southeast Area

- Areas of Subsidence Concern

WEST YOST

Figure 2-2

Ground-Level Monitoring Network Western Chino Basin

Chino Basin Watermaster

Ground-Level Monitoring Committee

2020/21 Annual Report

3.0 RESULTS AND INTERPRETATIONS

This section describes the results and interpretations derived from the GLMP for the Managed Area and Areas of Subsidence Concern in the Chino Basin for the March 2020 and March 2021 reporting period. Figures 3-1a and 3-1b display vertical ground motion as measured by InSAR across the western portion of the Chino Basin between the periods of March 2011 and March 2021 and between March 2020 and March 2021, respectively. The maps also show the locations and magnitude of pumping and artificial recharge—the stresses to the aquifer-system that can cause ground motion. The data shown in these and subsequent figures are described and interpreted in this section.

3.1 Managed Area

The Managed Area is the primary focus of the Subsidence Management Plan. The discussion below describes the results and interpretations of the monitoring program in the Managed Area and, where appropriate, relative to the Guidance Criteria in the Subsidence Management Plan.

3.1.1 History of Stress and Strain in the Aquifer-System

Figure 3-2 illustrates the long-term history of groundwater pumping, hydraulic heads, and vertical ground motion in the Managed Area. Also shown is the volume of the direct use of recycled water in the Managed Area, which is an alternative water supply that can result in decreased groundwater pumping from the area. Recycled water is often used for irrigation purposes and can contribute to groundwater recharge to the shallow aquifer-system as well. General observations and interpretations from this chart are:

- Pumping from the shallow aquifer-system between the 1930s and about 1977 caused hydraulic heads to decline by about 150 ft. From 1978 to 1990, hydraulic heads recovered by about 50 ft.
- Pumping from the confined, deep aquifer-system during the 1990s caused the hydraulic heads to a decline, coinciding with high rates of land subsidence. About 2.5 ft of subsidence occurred from 1987 to 1999, and ground fissures opened within the City of Chino in the early 1990s.
- Since the early 2000s, groundwater pumping decreased, hydraulic heads in the deep aquifer-system recovered, and the rate of land subsidence declined significantly across the Managed Area.
- The direct use of recycled water, which began in 1997, may have contributed to decreased groundwater pumping from the area, which in turn, may have contributed to the observed increases in hydraulic heads in the Managed Area.
- Since 2005, hydraulic heads at PA-7 have not declined below the Guidance Level, and very little inelastic compaction was recorded in the Managed Area. These observations demonstrate the effectiveness of the Subsidence Management Plan in the management of land subsidence in the Managed Area.

3.1.2 Recent Stress and Strain in the Aquifer-System

This section discusses the last nine years of groundwater pumping, changes in hydraulic heads, and vertical ground motion in the Managed Area under the Subsidence Management Plan.

3.1.2.1 Groundwater Pumping and Hydraulic Heads

Table 3-1 summarizes groundwater pumping by well within the Managed Area for fiscal year 2012 through March 2021. A total of about 25 acre-feet (af) of groundwater pumping occurred in the Managed Area from July 1, 2020 to March 31, 2021—88 percent of the groundwater pumping was from wells screened in the shallow aquifer-system. Groundwater pumping in the Managed Area has declined from about 5,680 af in fiscal year 2012 to almost negligible volumes in 2021.

Figure 3-3 displays the hydraulic stresses and mechanical strains that have occurred within the shallow and deep aquifer-systems in the Managed Area over the period January 2011 through March 2021. The figure includes three time-series charts: quarterly groundwater pumping (hydraulic stress to the aquifer-systems); the resultant head changes (hydraulic responses to pumping); and aquifer-system deformation as measured at the Ayala Park Extensometers (mechanical strain that occurred within the aquifer-system sediments in response to the head changes). The following are observations and interpretations regarding pumping and head changes:

- Historically, there has been a seasonal pattern of pumping in the Managed Area – increased pumping during the spring to fall and decreased pumping during the winter.
- Hydraulic heads respond differently to the pumping stresses in the shallow and deep aquifer-systems. Pumping from the deep confined aquifer-system causes a hydraulic head decline that is much greater in magnitude than the hydraulic head decline caused by pumping from the shallow aquifer-system despite that more groundwater pumping occurs from the shallow aquifer-system.
- The hydraulic head at PA-7 (deep aquifer-system) has fluctuated from a low of approximately 190 ft-btoc in August 2013 to a high of about 57 ft-btoc in January 2021 and has not declined below the Guidance Level of 245 ft-btoc.
- The recovery of the hydraulic head in the deep aquifer-system to above 90 ft-btoc in February 2019 and November 2019 represented "full recovery" of hydraulic head at PA-7 as defined in the Subsidence Management Plan, and the hydraulic head at PA-7 has remained above 90 ft-btoc.
- Since the first instance of full recovery in 2012, the hydraulic head at PA-7 recovered to 90 ft-btoc or greater in 2016, 2018 and 2019, which complies with the recommendation in the Subsidence Management Plan for full recovery within the deep aquifer-system at least once every five years.[8]
- As a result of very little to almost zero pumping from the shallow and deep aquifer-systems since April 2018, hydraulic heads at PA-10 and PA-7 have increased to their highest levels since implementation of the GLMP in 2003: about 56 ft-btoc in PA-10 (March 2021) and about 57 ft-btoc in PA-7 (March 2021).

[8] Page 2-2 in the Subsidence Management Plan, Section 2.1.1.3—Recovery Periods: "Every fifth year, Watermaster recommends that all deep aquifer-system pumping cease for a continuous period until water-level recovery reaches 90 ft-btoc at PA-7. The cessation of pumping is intended to allow for sufficient water level recovery at PA-7 to recognize inelastic compaction, if any, at the Ayala Park Extensometer and at other locations where groundwater-level and ground-level data are being collected."

Table 3-1. Groundwater Pumping in the Managed Area for Fiscal Year 2012 Through 2021, acre-ft

Well Name	Aquifer Layer	Fiscal Year									Fiscal Year 2021				
		2012	2013	2014	2015	2016	2017	2018	2019	2020	Qtr 1	Qtr 2	Qtr 3	Qtr 4[(a)]	By Layer
C-4	Shallow	524	0	0	0	0	0	0	0	0	0	0	0	-	22.2
C-6		1049	594	0	0	0	0	0	0	0	0	0	0	-	
CH-1A		1137	909	738	861	649	637	369	0	0	0	0	0	-	
CH-7A		530	380	170	286	156	66	0	0	0	0	0	0	-	
CH-7B		712	264	200	616	261	232	350	0	0	0	0	0	-	
CIM-1		724	1,109	1,127	878	911	908	586	0	0	0	0	0	-	
XRef 8730[(b)]		3	5	5	4	3	35	29	29	29	7.4	7.4	7.4	-	
	Subtotals	4,679	3,260	2,240	2,644	1,980	1,879	1,334	29	29	7.4	7.4	7.4	-	22.2
CH-17	Deep[(c)]	758	1,444	937	1,142	567	624	571	0	0	0	0	0	-	3
CH-15B		0	28	105	0	0	0	0	0	0	0	0	0	-	
CIM-11A		243	239	195	92	94	222	0	0	0	1	1	1.2	-	
	Subtotals	1,001	1,711	1,237	1,234	662	846	571	0	0	1	1	1	-	3
	Totals	**5,680**	**4,971**	**3,477**	**3,878**	**2,642**	**2,725**	**1,905**	**29**	**29**	**8.4**	**8.1**	**8.6**	**-**	**25.2**

"C" = City of Chino

"CH" = City of Chino Hills

"CIM" = California Institution for Men

"XRef" = Private

(a) Data only available through March 2021.

(b) Well screen interval is unknown but assumed to be shallow based on typical well construction for other private wells in the vicinity.

(c) These wells have screen intervals that extend into the shallow-aquifer system, so a portion of the production comes from the shallow aquifer-system.

3.1.2.2 Aquifer-System Deformation

Figure 3-3 also includes a time-series chart of vertical deformation of the aquifer-system as measured at the Ayala Park Extensometers for the period January 2011 through March 2021. The following are observations and interpretations regarding aquifer-system deformation in response to the pumping and head changes:

- There has been seasonal compression and expansion of the aquifer-system in response to the seasonal decline and recovery of hydraulic heads, which indicates that the vertical deformation of the aquifer-system was mainly elastic during this period.
- However, between April 6, 2011 and June 27, 2016 (dates of full recovery at PA-7 to 90 ft-btoc), the Ayala Park Deep Extensometer recorded about 0.029 ft of aquifer-system compression, which indicates that this compression is permanent compaction that occurred within the depth interval of 30-1,400 ft-bgs.[9]
- From June 27, 2016 to February 1, 2019 (dates of full recovery at PA-7), the Deep Extensometer recorded an extended cycle of aquifer-system compression and expansion in response to the extended decline and recovery cycle of hydraulic heads at PA-7. By February 1, 2019, the Deep Extensometer recorded a slight amount of expansion, indicating that the vertical deformation of the deep aquifer-system was mainly elastic during this period.
- Since February 2019, the Deep Extensometer has continued to record purely elastic aquifer-system deformation – a total of about 0.056 ft of aquifer-system expansion was recorded at the Deep Extensometer between February 1, 2019 and March 31, 2021.

Figure 3-4 is a stress-strain diagram of hydraulic heads measured at PA-7 (stress) versus vertical deformation of the aquifer-system sediments as measured at the Deep Extensometer (strain). This diagram provides additional information on the nature of the aquifer-system deformation (i.e., elastic versus inelastic deformation). The hysteresis loops on this figure represent cycles of hydraulic head decline-recovery and the resultant compression-expansion of the aquifer-system sediments. The diagram can be interpreted to understand the timing and magnitude of the occurrence of compaction within the depth interval of the aquifer-system that is penetrated by the Deep Extensometer. Hydraulic head decline is shown as increasing from bottom to top on the y-axis, and aquifer-system compression is shown as increasing from left to right on the x-axis. The following are observations and interpretations regarding aquifer-system deformation in response to the head changes:

- From May 2006 to May 2018, the hysteresis loops progressively shifted to the right on this chart, indicating that about 0.065 ft of inelastic compaction occurred during this time-period. However, the rate of inelastic compaction appeared to gradually decline over this 12-year period.
- From May 2018 to February 2019, the hydraulic heads at PA-7 fluctuated between 70-120 ft-btoc. During this period, the hysteresis loops started to overlap one another and then shifted to the left, indicating that the vertical deformation of the aquifer-system was mainly elastic expansion of the aquifer-system sediments.

[9] The analysis of full recovery and inelastic compaction at Ayala Park was included in the 2016 Annual Report (WEI, 2016).

- Since February 2019, the hydraulic heads at PA-7 have remained at or above 90 ft-btoc and by March 2021 increased to their highest levels since 2003. During this period, the hysteresis loops shifted to the left, indicating that the vertical deformation of the aquifer-system was purely elastic expansion of the aquifer-system sediments.

3.1.2.3 Vertical Ground Motion

Vertical ground motion is measured across the Managed Area via InSAR, traditional ground-level surveys, and the Deep Extensometer. For FY 2020/21, the benchmark monument network in the Managed Area was not surveyed per the GLMC's scope and budget recommendations. Figures 3-1a and 3-1b illustrate vertical ground motion[10] as estimated by InSAR for the period from March 2011 to March 2021 and from March 2020 to March 2021, respectively.

Where coherent, the InSAR estimates of vertical ground motion from 2011 to 2021 shown in Figure 3-1a range from about zero ft to -0.04 ft across the Managed Area. The greatest downward ground motion occurred in the northern portions of the Managed Area.

The InSAR estimates of vertical ground motion from 2020 to 2021 indicate very little vertical ground motion occurred across most of the Managed Area.

As described above, Figure 3-1a shows that maximum downward ground motion during 2011-2021 occurred in the northern portion of the Managed Area. The City of Chino Well 15 (C-15) is in the northern portion of the Managed Area, is screened across both the shallow and deep aquifers, and has been equipped with a transducer that measures and records hydraulic heads once every 15 minutes. These data provide information on the nature of the aquifer-system deformation that occurred in this area (i.e. elastic versus inelastic deformation). Figure 3-5 is a time-series chart that compares the hydraulic heads at C-15 to vertical ground motion as measured by InSAR at the same location between 2005 and 2021. The main observations from this chart are:

1. The InSAR record at C-15 is measuring seasonal elastic vertical ground motion which is caused by seasonal fluctuations in hydraulic head and the resultant seasonal elastic deformation in the aquifer-system(s). The seasonal fluctuations of hydraulic head at C-15 are coincident with the seasonal fluctuations of vertical ground motion measured by InSAR at the same location.
2. From 2007 to 2016, InSAR indicates a long-term trend of downward ground motion at C-15. However, hydraulic heads at C-15 during this same time-period increased, indicating that about 0.19 ft of subsidence was caused by inelastic compaction of the aquifer-system. The inelastic compaction that occurred during this period of increasing hydraulic head most likely represents the delayed drainage and compaction of aquitards due to historical head declines.
3. Since 2016, the long-term subsidence trend appears to have stopped, indicating that inelastic compaction of the aquitards has also stopped. This observation is supported by the Deep Extensometer record, which indicates mostly elastic deformation of the aquifer-system since 2016 (see Figure 3-4). The recent cessation of subsidence observed at C-15 is likely a result of increasing hydraulic heads in the aquifers, which has led to

[10] Upward vertical ground motion is indicated by positive values; downward vertical ground motion is indicated by negative values.

equilibration with hydraulic heads in the aquitards and the cessation of aquitard drainage and compaction. These monitoring data may be providing information on hydraulic head "thresholds" that could be used as management criteria to protect against the future occurrence of land subsidence. At C-15, when groundwater elevations remain above 580 ft-above mean sea level (amsl), InSAR indicates that no permanent land subsidence occurs.

3.2 Southeast Area

Vertical ground motion is measured across the Southeast Area via InSAR, traditional ground-level surveys, and the Chino Creek Extensometer Facility (CCX). The InSAR results (Figures 3-1a and 3-1b) are somewhat incoherent across much of this area because the overlying agricultural land uses are not hard, consistent reflectors of radar waves. Where InSAR results are incoherent, the history of subsidence is best characterized by ground-level surveys and the CCX.

Figure 3-6 is a time-series chart that displays and describes the history of groundwater pumping, the direct reuse of recycled water, hydraulic heads, and vertical ground motion in the Southeast Area from 1930 to 2021. The main observations and interpretations from these figures are:

- From the 1940s to about 1968, hydraulic heads declined by up to about 75 ft. There is a data gap from about 1968 to 1988; however, it is likely that hydraulic heads continued to decline from 1968 to 1978, as was the case in most portions of the Chino Basin during this period. In the western portion of the Southeast Area, hydraulic heads remained relatively stable from 1988 to 2010 and then gradually increased by about 10 to 20 ft from 2010 to 2021 (see wells CH-18A, C-13, CCPA-1, and CCPA-2). In the eastern portion of the Southeast Area, hydraulic heads have been gradually declining by about 5 to 12 ft between 2005 and March 2021 (see wells HCMP-1/1 and HCMP-1/2).
- For the current period March 2020 and March 2021, Figure 3-1b shows that the occurrence of downward vertical ground motion has been relatively minor – about -0.02 ft across most of the Southeast Area. Hydraulic heads remained relatively stable or increased across most of the area during this period, which indicates that the downward ground motion is, at least in part, permanent subsidence due to delayed aquitard drainage in response to the historical declines in hydraulic heads that occurred from the 1940s to about 1978.

Figure 3-7 displays the time series of hydraulic and vertical aquifer-system deformation recorded at the CCX, which began collecting data in July 2012. Groundwater pumping began at the Chino Creek Well Field in 2014, but appears to have had little, if any, effect on hydraulic heads or aquifer-system deformation at the CCX through March 2021. In general, hydraulic heads at the CCX vary seasonally and have gradually increased since 2012, and a small amount of expansion of the aquifer-system has been measured by the CCX extensometers. This observation is consistent with the ground-levels surveys at BM 157/71 near the CCX through 2018.

3.3 Central MZ-1

Vertical ground motion is measured across Central MZ-1 via InSAR and traditional ground-level surveys. Figures 3-1a and 3-1b illustrate vertical ground motion as estimated by InSAR across Central MZ-1 for 2011-2021 and 2020-2021, respectively. The InSAR results are generally coherent across this area because the overlying land uses are urban and serve as hard and consistent reflectors of radar waves. Ground-level surveys are performed periodically along the eastern portion of the area. Figure 3-8 is a time-series chart that displays and describes the long-term history of pumping, recharge, hydraulic heads, and vertical ground motion in Central MZ-1. The following observations and interpretations are derived from these figures:

- Hydraulic head data are absent in the southern portion of Central MZ-1. In the northern portion of Central MZ-1, hydraulic heads declined by about 200 ft from 1930 to about 1978. From 1978 to 1986, hydraulic heads increased by about 80 ft and remained relatively stable or have slightly increased from 1986 to 2021. Recent hydraulic heads (1986 to 2021) in the northern portion of Central MZ-1 are about 120 ft lower than the hydraulic heads in the 1930s.
- About 1.9 ft of subsidence occurred near Walnut and Monte Vista Avenue from 1988 to 2000, as measured by ground-level surveys at BM 125/49 (about 0.16 feet per year [ft/yr]). Since 2000, the rate of subsidence has slowed significantly—about 0.34 ft of subsidence occurred at a gradually declining rate from 2000 to 2021 (about 0.016 ft/yr). This time history and magnitude of vertical ground motion along the eastern side of Central MZ-1 is like the time history and magnitude of vertical ground motion in the Managed Area, which suggests a relationship to the causes of land subsidence in the Managed Area; however, there is not enough historical hydraulic head data in this area to confirm this relationship.
- Figure 3-1a shows that the areas that experienced the greatest magnitude of subsidence from March 2011 to March 2021 are in the western portion of Central MZ-1, where up to about -0.18 ft of vertical ground motion has occurred (about -0.03 ft/yr). Hydraulic heads remained relatively stable in this area from 2011 to 2021, which indicates that the downward vertical ground motion is, at least in part, permanent subsidence due to delayed aquitard drainage in response to the historical declines in hydraulic heads that occurred from 1930 to 1978.
- The ground motion measured by InSAR in Figure 3-1a also shows that the groundwater barrier (Riley Barrier) may extend from the Managed Area northward into Central MZ-1 to at least Mission Boulevard. This observation is evidenced by a steep subsidence gradient located just east of Central Avenue.
- Figure 3-1b shows that between March 2020 and 2021, vertical ground motion across most of Central MZ-1 was very minor.

3.4 Northwest MZ-1

3.4.1 Vertical Ground Motion

Vertical ground motion is measured across Northwest MZ-1 via InSAR and ground-level surveys. The InSAR results are generally coherent across this area because the overlying land uses are urban and serve as hard, consistent reflectors of radar waves. Ground-level surveys have been performed annually in the early spring across the area to complement and check the InSAR estimates of vertical ground motion.

Figure 3-1a illustrates vertical ground motion as estimated by InSAR across Northwest MZ-1 during 2011-2021. Figure 3-9 is a time-series chart that displays and describes the long-term history of pumping, recharge, hydraulic heads, and vertical ground motion in Northwest MZ-1. Figures 3-10a and 3-10b are maps of the most recent data and illustrate vertical ground motion as estimated by InSAR and ground-level surveys across Northwest MZ-1 from January 2014 to March 2021 and from March 2020 to March 2021, respectively. Spring 2021 was the first year that the PX was used as the starting benchmark for the

Northwest MZ-1 ground-level survey. Starting the ground-level survey from PX increases the accuracy of the ground-level surveys in this area.

The following observations and interpretations are derived from Figures 3-1a, 3-1b, 3-9, and 3-10:

- From about 1930 to 1978, hydraulic heads in Northwest MZ-1 declined by about 200 ft. From 1978 to 1985, hydraulic heads increased by about 100 ft. From 1985 to 2020 hydraulic heads fluctuated but remained relatively stable. Between March 2020 and 2021, hydraulic heads in some wells (MVWD-10, MVWD-28, and P-27) declined up to about 15 ft, where heads in the other wells [P-05 (old), P-18, P-30] remained fairly stable.
- A maximum of about 1.3 ft of subsidence occurred in this area from 1992 through March 2021—an average rate of about 0.04 ft/yr—while hydraulic heads remained relatively stable. The persistent subsidence that occurred from 1992 to 2021 cannot be entirely explained by the concurrent changes in hydraulic heads. A plausible explanation for this subsidence is that thick, slow-draining aquitards are permanently compacting in response to the historical declines in hydraulic heads that occurred between 1930 and 1978.
- From March 2011 to March 2021, the InSAR results indicate a maximum of about -0.35 ft (0.04 ft/yr) of vertical ground motion occurred in Northwest MZ-1 near the intersection of Indian Hill Boulevard and San Bernardino Avenue. From 2014 to 2021, the rate vertical ground motion slowed to about -0.03 ft/yr at this location.
- Figure 3-10 shows that the ground-level survey results from 2014 to 2021 indicate a similar spatial pattern of downward ground motion as estimated by InSAR but with slightly different magnitudes. Both methods indicate the maximum downward ground motion from December 2013 to March 2021 occurred near the intersection of Indian Hill Boulevard and San Bernardino Avenue. There is a minor difference in the magnitudes of vertical ground motion between InSAR and ground-level survey results, but these differences are most likely related to the different timing of the ground-level surveys and the SAR acquisition and/or relative errors associated with each monitoring technique.
- Figure 3-1b shows that most of Northwest MZ-1 experienced some downward ground motion between March 2020 and March 2021.

As described above, Figure 3-1a shows that maximum downward ground motion during 2011-2021 occurred near the intersection of Indian Hill Boulevard and San Bernardino Avenue. The City of Pomona Well 30 (P-30) is located just south of this area. P-30 is a non-pumping well, is screened across the shallow aquifer and upper portion of the deep aquifer and has been equipped with a transducer that measures and records hydraulic heads once every 15 minutes since September 2006. These data can provide information on the nature of the aquifer-system deformation that occurred in this area (i.e., elastic versus inelastic deformation). Figure 3-11 is a time-series chart that compares the hydraulic heads at P-30 to vertical ground motion as estimated by InSAR between 2006 and 2021. The main observations from this chart are:

- The InSAR record at P-30 is measuring seasonal elastic vertical ground motion that is caused by seasonal fluctuations in hydraulic head and the resultant seasonal elastic deformation in the aquifer-system(s). The seasonal fluctuations of hydraulic head at P-30 are coincident with the seasonal fluctuations of vertical ground motion measured by InSAR, but the long-term trend of subsidence remains persistent between 2005 and 2021 despite periods of hydraulic head recovery.

- InSAR indicates a long-term trend of downward ground motion at P-30 from 2005 to 2017. However, hydraulic heads at P-30 during this same time-period increased, indicating that at least about 0.35 ft of subsidence was caused by inelastic compaction of the aquifer-system. The inelastic compaction that occurred during this period of increasing hydraulic heads most likely represents the delayed drainage and compaction of aquitards due to historical head declines.
- Between mid-2017 and 2021, the long-term subsidence trend appeared to have slowed down, indicating that inelastic compaction of the aquitards had also slowed down. The recent slowing of subsidence observed at P-30 was likely a result of increasing hydraulic heads in the aquifers, which had led to equilibration with hydraulic heads in the aquitards and the slowing of aquitard drainage and compaction.
- Between late 2018 and early 2021, the hydraulic head at P-30 experienced two cycles of head decline and recovery. The head decline and recovery at P-30 is contemporaneous with the downward and upward vertical ground motion measured by InSAR at P-30 during this same time period. These observations suggest that in Northwest MZ-1: (i) changes in hydraulic heads, which are controlled by the pumping and recharge stresses in the area, have at least some control on the pattern and rate of subsidence and (ii) these monitoring data may be providing information on hydraulic head "thresholds" that could be used as management criteria to protect against the future occurrence of land subsidence.

3.4.2 Horizontal Ground Motion

Figure 3-1a shows a steep gradient of subsidence across the San Jose Fault in Northwest MZ-1—the same pattern of "differential subsidence" that occurred in the Managed Area during the time of ground fissuring. Differential subsidence can cause an accumulation of horizontal strain in the shallow sediments and the potential for ground fissuring.[11]

To identify potential areas of accumulation of tensile horizontal strain in the shallow soils in this area, annual EDM surveys between closely spaced benchmark monuments that cross the San Jose Fault have been performed annually since December 2013. Figure 3-12 displays the time series of east/west-oriented and north/south-oriented strain between the pairs of closely spaced benchmarks (see the inset map on Figure 3-12) between 2013 and 2021. For reference, the top left chart on Figure 3-12 shows the downward vertical ground motion in Northwest MZ-1 as estimated by InSAR at Point C on Figure 3-9. The horizontal strain between most pairs of benchmarks appears to behave elastically – alternating between compressive and tensile deformation between EDM surveys. Tensile strain has been calculated between benchmarks (B-409 to B-408). Future EDM surveys that cross the San Jose Fault will continue to be conducted at a frequency determined by the GLMC during the scope and budget planning process for FY 2022/23.

[11] Ground fissuring is the main subsidence-related threat to overlying infrastructure. Watermaster, consistent with the recommendation of the GLMC, has determined that the Subsidence Management Plan needs to be updated to include a *Subsidence Management Plan for the Northwest MZ-1* with the long-term objective to minimize or abate the occurrence of the differential land subsidence. Development of this subsidence management plan is an ongoing, multi-year effort of the Watermaster.

3.5 Northeast Area

Vertical ground motion is measured across the Northeast Area via InSAR and ground-level surveys. In December 2017, a new network of benchmarks was installed across the Northeast Area (see Figure 2-2) and surveyed for initial elevations in January 2018. The Northeast Area benchmark network was not surveyed in spring 2021.

Figures 3-1a and 3-1b illustrate vertical ground motion, as measured by InSAR, across the Northeast Area from March 2011 to March 2021 and from March 2020 to March 2021, respectively. Figure 3-13 is a time-series chart that displays and describes the long-term history of pumping, recharge, hydraulic, and vertical ground motion in the Northeast Area. The following observations and interpretations are derived from these figures:

- From about 1930 to 1978, hydraulic heads in the Northeast Area declined by about 125 ft. From 1978 to about 1985, hydraulic heads increased by about 25 ft. From 1985 to 2020 hydraulic heads fluctuated but generally remained relatively stable or show a recovery trend since 2011. Between March 2020 and 2021, hydraulic heads in some wells (O-25, O-34, and O-36) showed a declining trend. For example, hydraulic heads at City of Ontario well O-34 declined about 10 ft since March 2020.
- About one foot of subsidence occurred in the Northeast Area near the intersection of Euclid Avenue and Phillips Street (see Point D on the inset map on Figure 3-13) from 1992 to 2021. From 1992 to 2011, the subsidence occurred at a gradual and persistent rate of about 0.04 ft/yr. From 2011 to 2021, the subsidence rate declined to about 0.02 ft/yr. Hydraulic heads have remained relatively stable in this area from 1992-2021, which indicates that the downward vertical ground motion is, at least in part, permanent subsidence due to delayed aquitard drainage in response to the historical declines in hydraulic heads that occurred from 1930 to 1978. The recent decline in the rate of subsidence may be due to recent decreases in pumping, increases in recharge, and increases in hydraulic heads.
- The InSAR estimates in Figures 3-1a also indicate that downward ground motion has occurred in a concentrated area between Vineyard Avenue and Archibald Avenue south of the Ontario International Airport, where a maximum of about -0.24 ft of vertical ground motion occurred from March 2011 to March 2021. Between 2020 and 2021, the same area experienced about -0.02 ft of vertical ground motion. The western edge of this subsiding area exhibits a steep subsidence gradient, or “differential subsidence.” Differential subsidence is thought to have led to episodes of ground fissuring in the Managed Area during the early 1990s. The causes of the downward ground motion in the Northeast Area are not known at this time, but a probable mechanism may be aquifer-system compaction. The differential subsidence shown in Figure 3-1a is a feature now more visible in the current InSAR long-term map for the time-period between 2011 and 2021 compared to previous long-term InSAR maps. One reason this feature is now more visible is the result of better and new processing and interpolation techniques used by General Atomics in the post-processing the SAR data and preparation of interferograms (see Section 2.1.2.3).

3.6 Seismicity

Tectonic displacement of the land surface on either side of geologic faults can be horizontal, vertical, or a combination of both. During a large earthquake, the land surface can deform suddenly (Weischet, 1963; Myers and Hamilton, 1964; Plafker, 1965). Aseismic creep is a process where smaller, more frequent earthquakes cause the land surface to deform more gradually (Harris, 2017). Figure 3-14 displays the location and magnitude of earthquake epicenters relative to vertical ground motion from March 2011 to March 2021.

Tectonic movement along the San Jose Fault Zone, including aseismic creep, is a plausible mechanism for the differential land subsidence that has occurred in Northwest MZ-1. While the earthquake epicenters shown on Figure 3-14 do not show a spatial relationship to the differential subsidence in Northwest MZ-1, without direct measurement of aquifer-system deformation, as will be provided by PX, tectonic deformation cannot be ruled-out as a mechanism for the observed subsidence in Northwest MZ-1.

Between March 2011 and March 2021, several earthquake epicenters, varying in magnitude (local magnitude) from zero to four, occurred south of the Ontario International Airport. Figure 3-14 shows that the seismicity observed along the eastern edge of the Northeast Area extends northeast towards the San Jacinto Fault. The observed seismicity may reflect deep-seated convergence between the Perris Block that underlies the Chino Basin and the San Gabriel Mountains south of the Cucamonga Fault Zone (Morton and Yerkes, 1974; Morton et al., 1982; Morton and Matti, 1987).

Currently, there is not enough data and information to determine whether tectonic movement, aquifer-system deformation, or both are the mechanisms of the observed subsidence in the eastern portion of the Northeast Area. Additional monitoring and investigation are necessary to assist in this determination.

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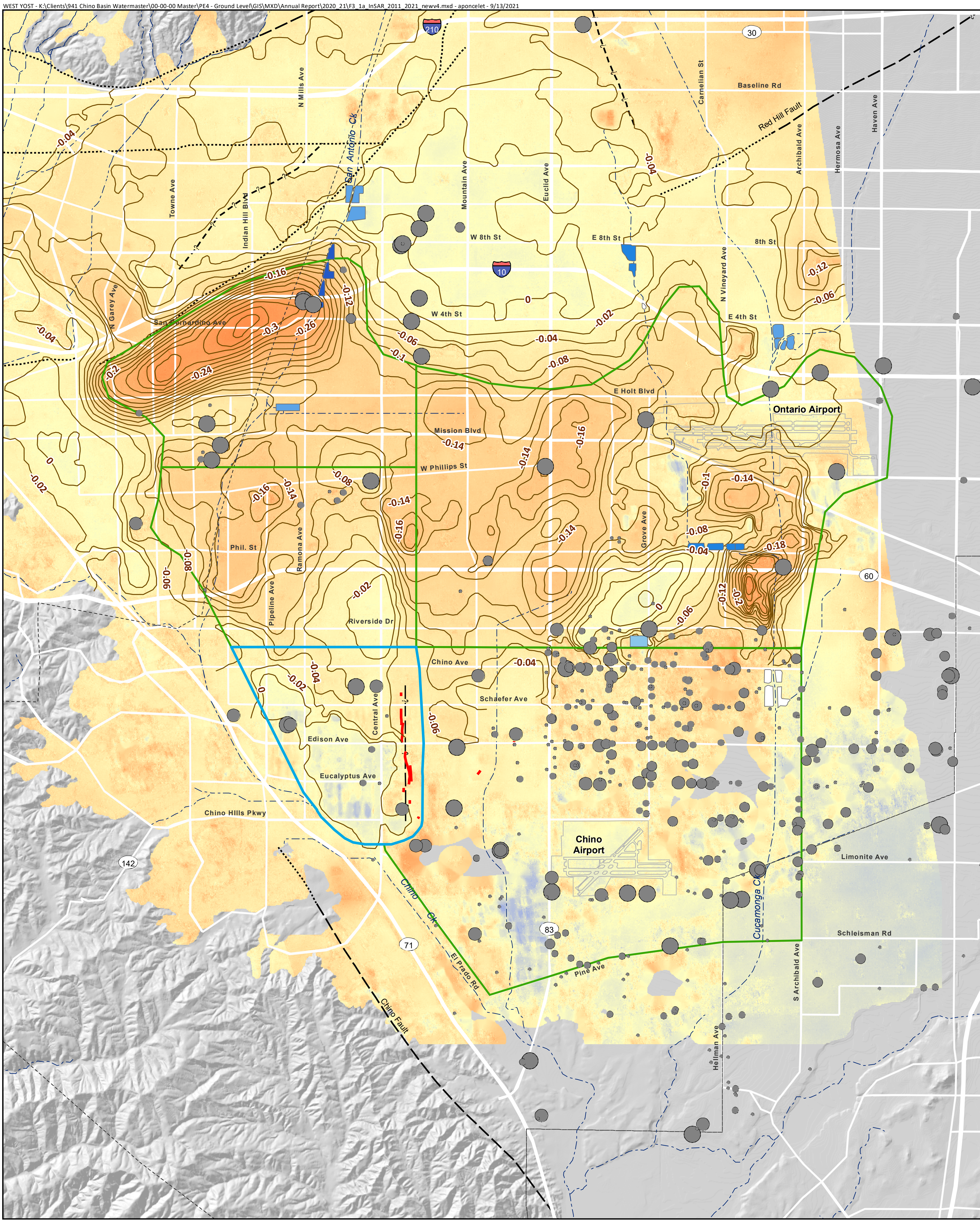


Relative Change in Land Surface Elevation as Estimated by InSAR (March 2011 to March 2021)

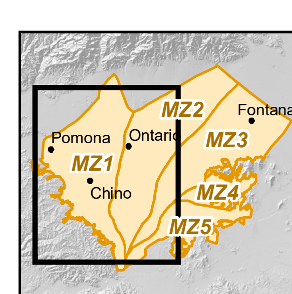
+0.45 ft
0 ft
-0.25 ft
-0.45 ft
InSAR absent or incoherent

Average Annual Groundwater Pumping April 1, 2011 to March 31, 2021 (afy)

0 - 100
101 - 500
501 - 1,000
1,001 - 2,000
> 2,000

Average Annual Basin Recharge FY 2011 to FY 2021 (afy)

0
1 - 1,000
1,000 - 2,000
2,000 - 3,000
> 3,000



Managed Area
Areas of Subsidence Concern
Historical Ground Fissures
Approximate Location of the Riley Barrier
Fault (solid where accurately located; dashed where approximately located or inferred; dotted where concealed)

N

0 1,500 3,000
Scale in Feet

Figure 3-1a

Vertical Ground Motion across the Western Chino Basin: 2011-2021

Chino Basin Watermaster
Ground-Level Monitoring Committee
2020/21 Annual Report

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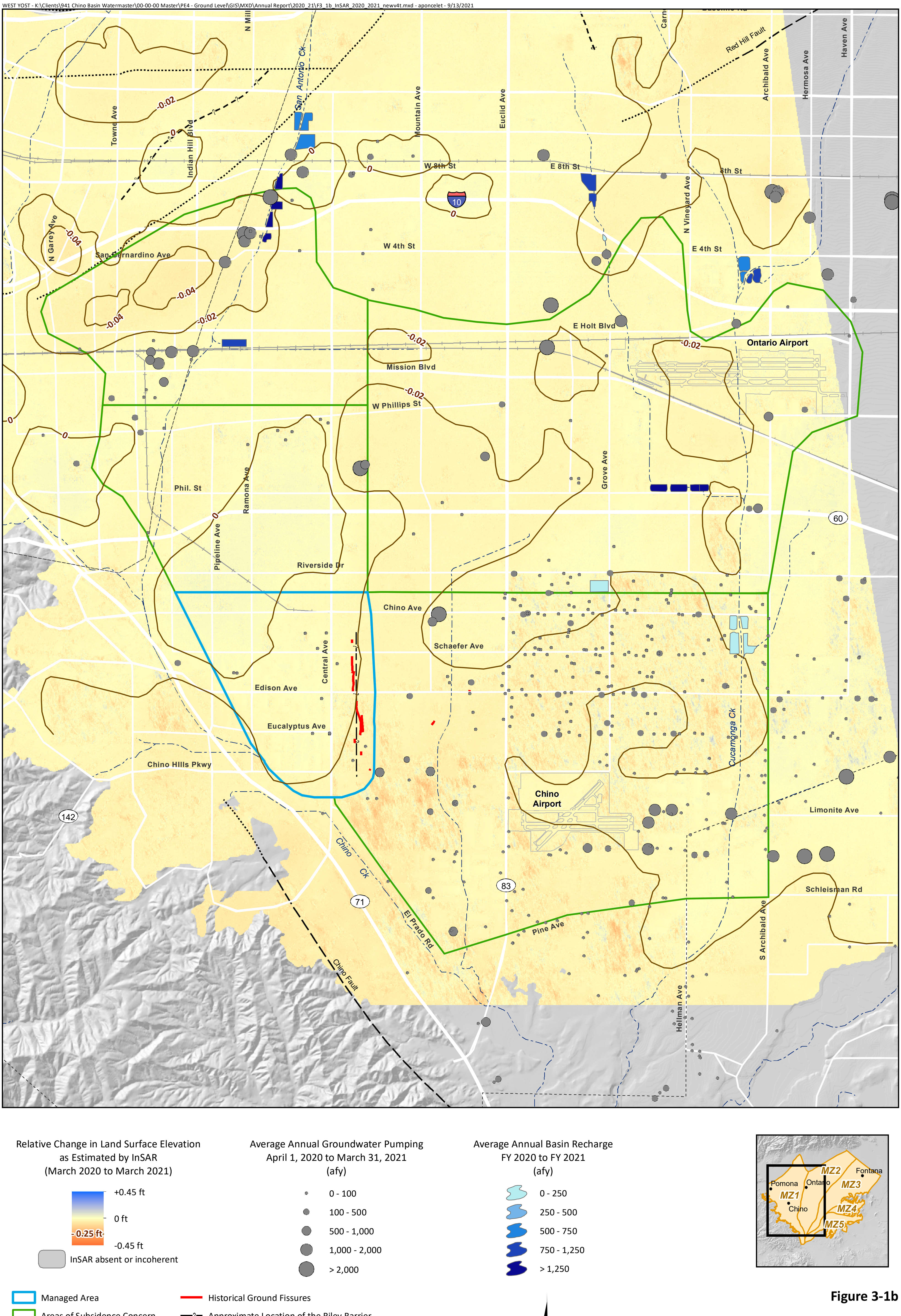

Figure 3-1b

Vertical Ground Motion across the Western Chino Basin: 2020-2021

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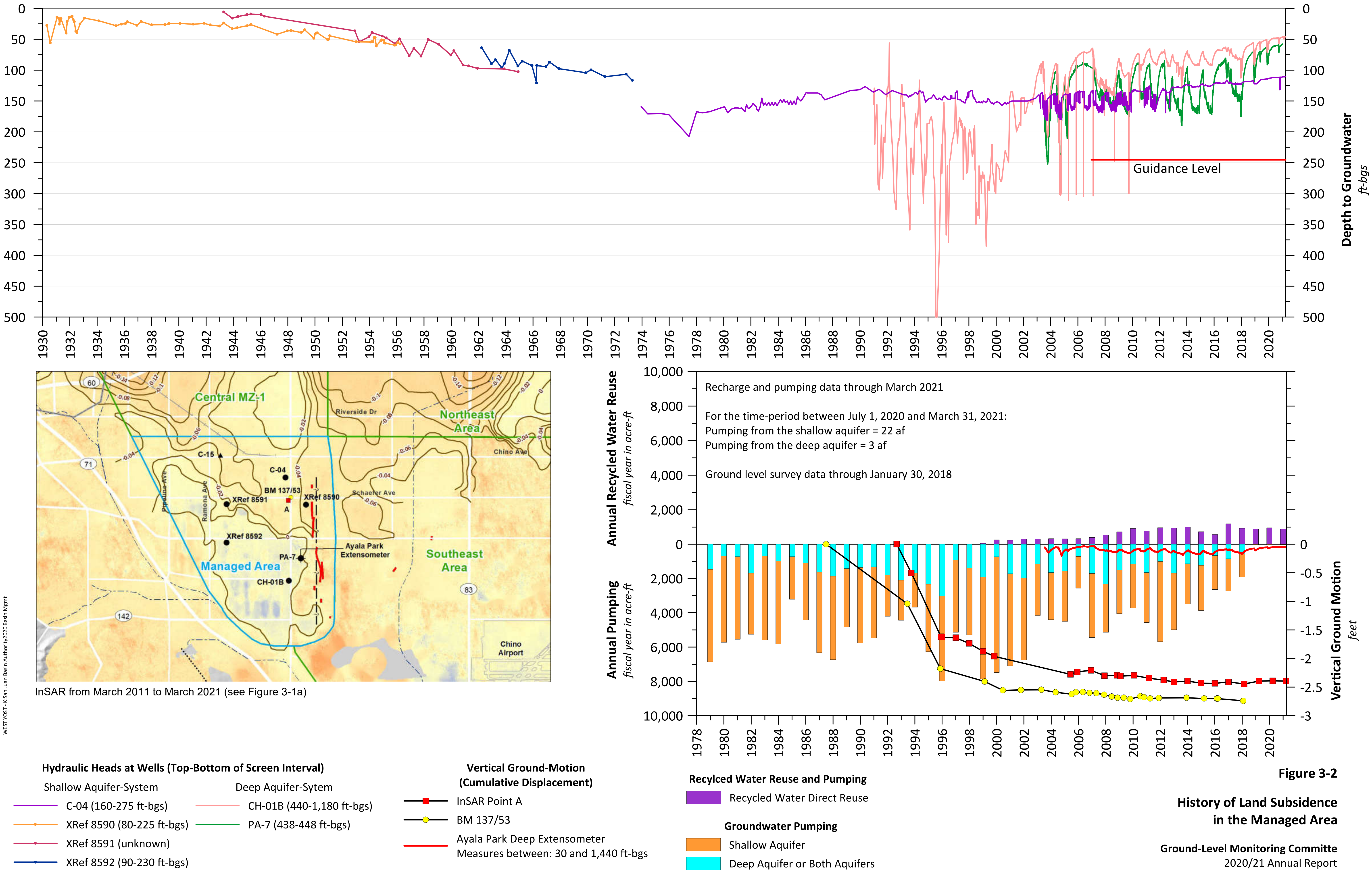

Figure 3-2

History of Land Subsidence in the Managed Area

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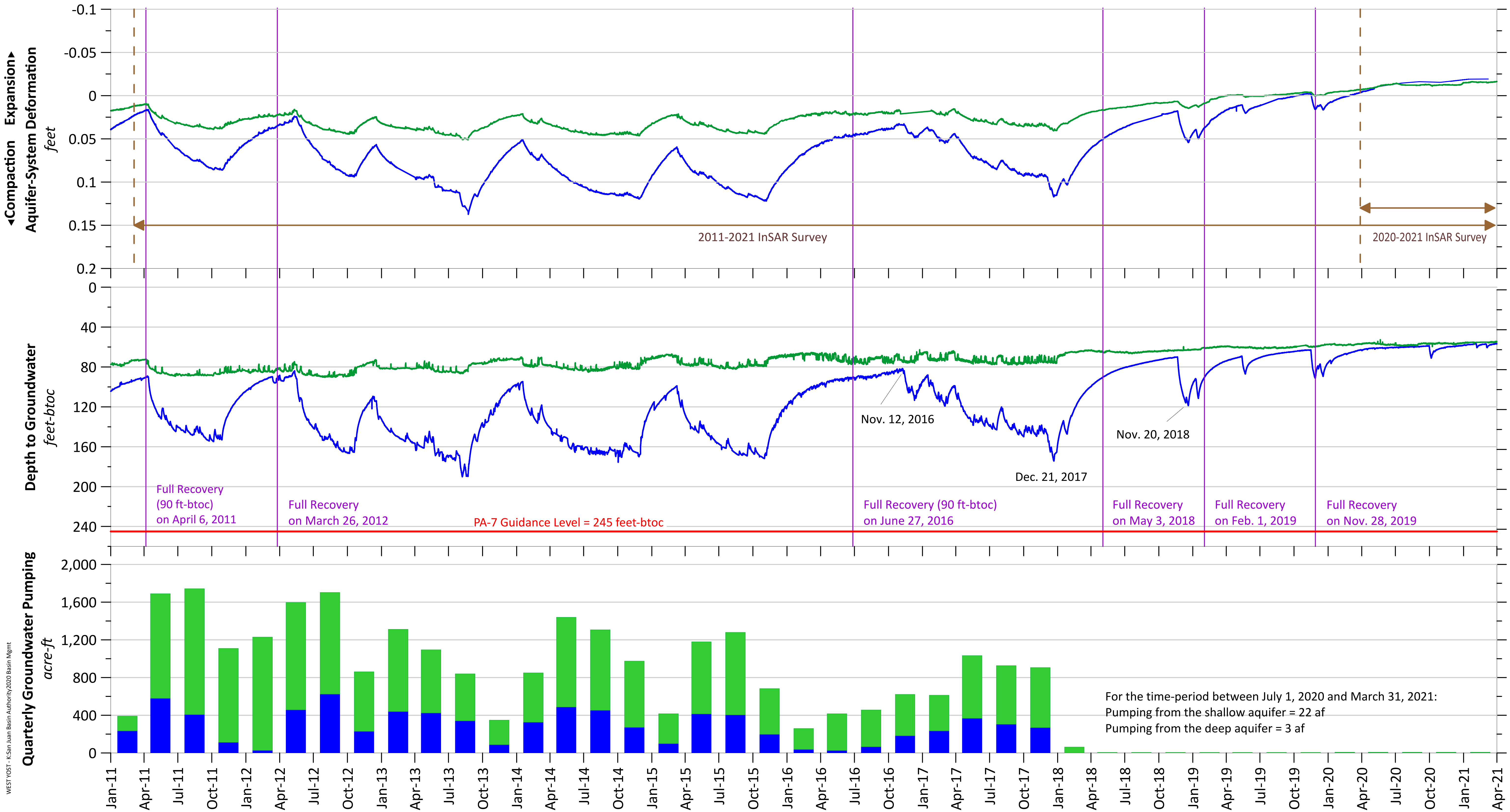
2020/21 Annual Report



Aquifer-System Deformation at Ayala Park (Extensometer Depth Interval)

- Shallow Extensometer (30-550 ft-bgs)
- Deep Extensometer (30-1,400 ft-bgs)

Hydraulic Heads at Ayala Park (Screened Interval)

- Shallow Piezometer PA-10 (213-233 ft-bgs)
- Deep Piezometer PA-7 (438-448 ft-bgs)

Quarterly Groundwater Pumping (see Table 3-1 for groundwater pumping by well)

- Shallow Aquifer
- Deep Aquifer

Figure 3-3

Stress and Strain within the Managed Area

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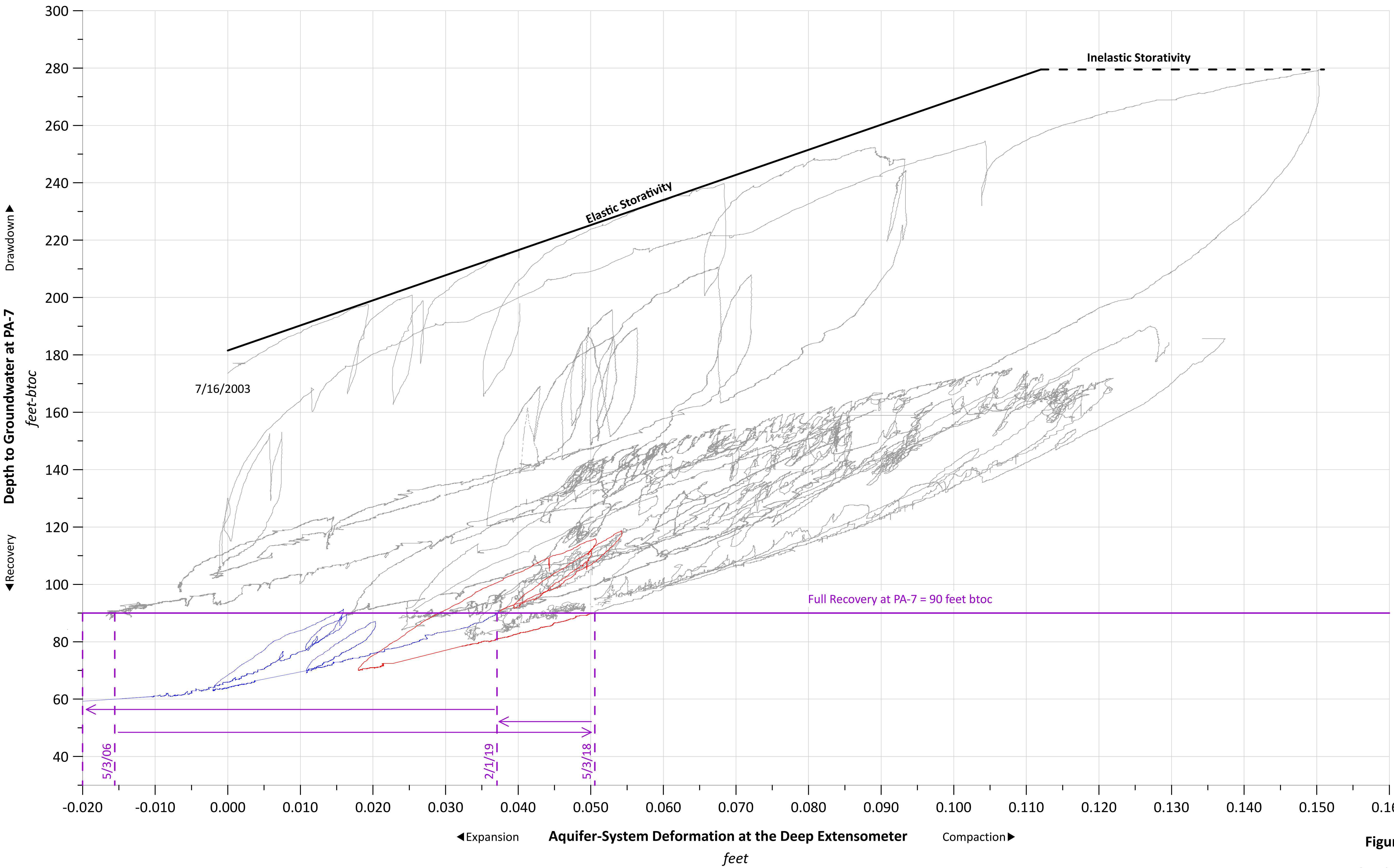

Stress - Strain Hysteresis Loops of Drawdown

- Drawdown and recovery between July 16, 2003 and May 3, 2018
- Drawdown and recovery between May 4, 2018 and January 31, 2019
- Drawdown and recovery between February 1, 2019 and April 1, 2021

*PA-7 well-screen interval: 438-448 ft-bgs

Depth interval of the Deep Extensometer: 30-1,400 feet-bgs

Figure 3-4

Stress-Strain Diagram
Ayala Park Extensometer

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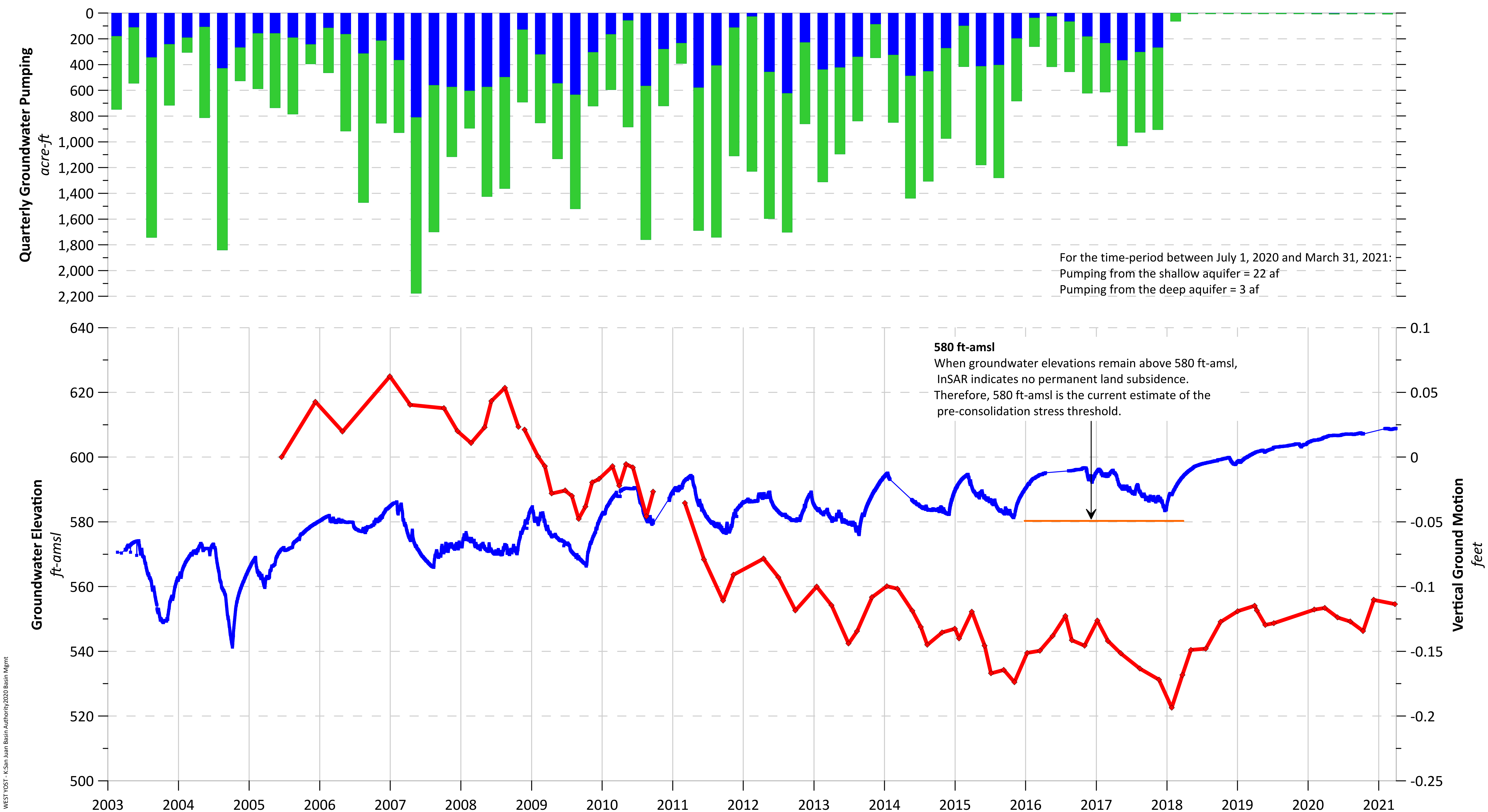

Quarterly Groundwater Pumping
Managed Area
Shallow Aquifer
Deep Aquifer

Groundwater Elevation at Wells (Screen Interval)
C-15 (270 - 820 ft-bgs)

Vertical Ground Motion
Cumulative Displacment (C-15)

Figure 3-5

Hydraulic Heads at C-15 Versus Groundwater Pumping and Vertical Ground Motion

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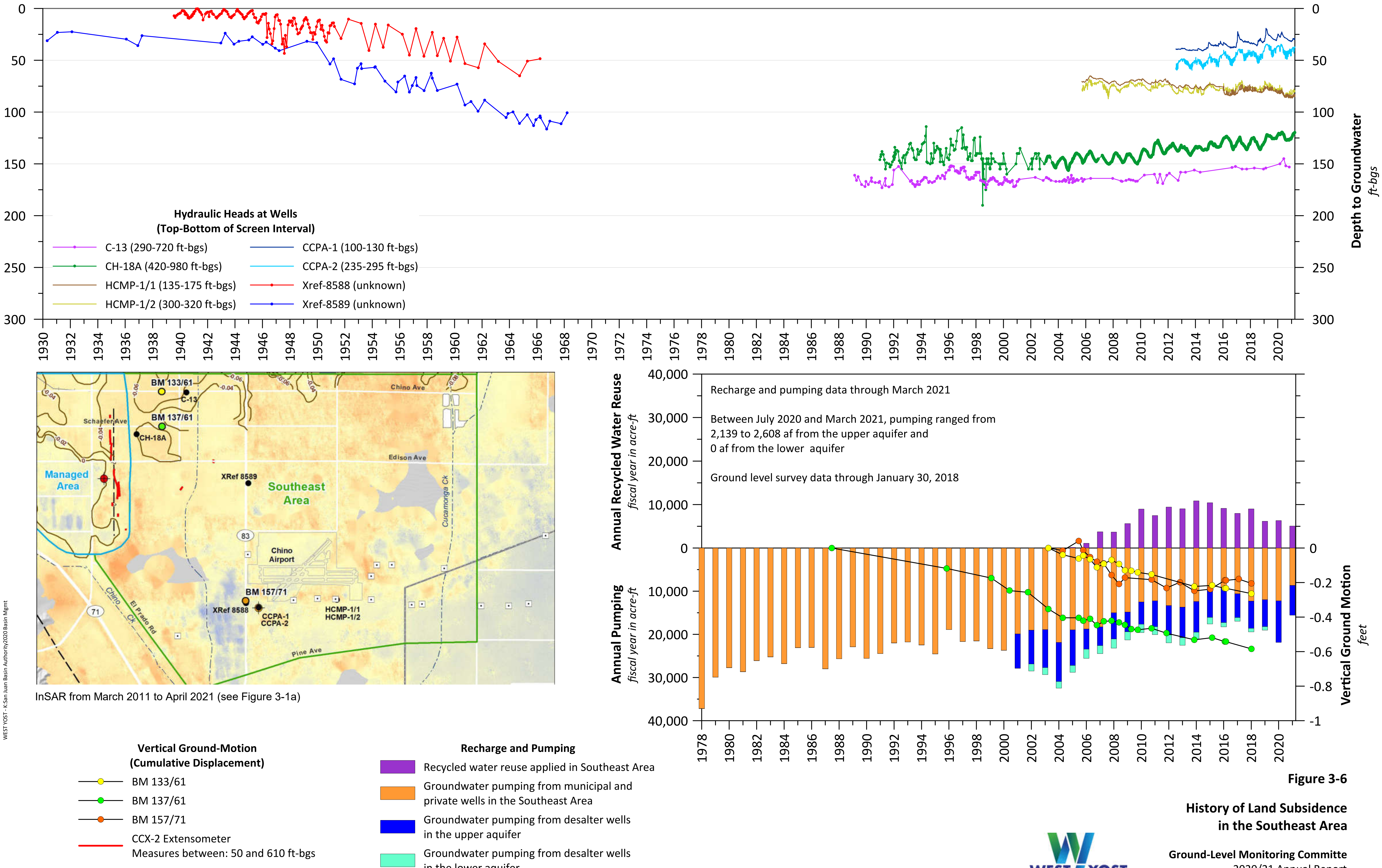

Figure 3-6

History of Land Subsidence in the Southeast Area

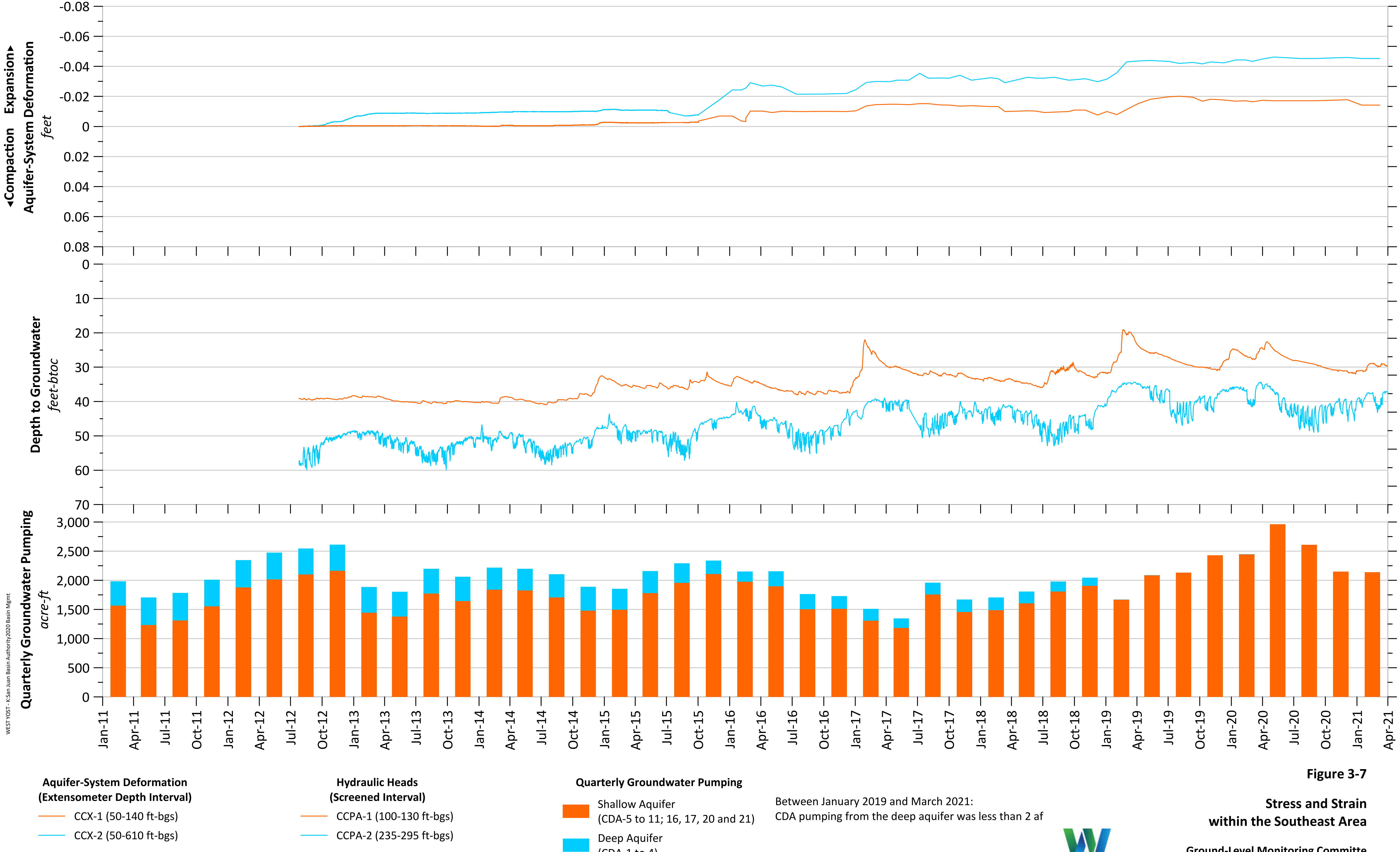

Figure 3-7

Stress and Strain within the Southeast Area

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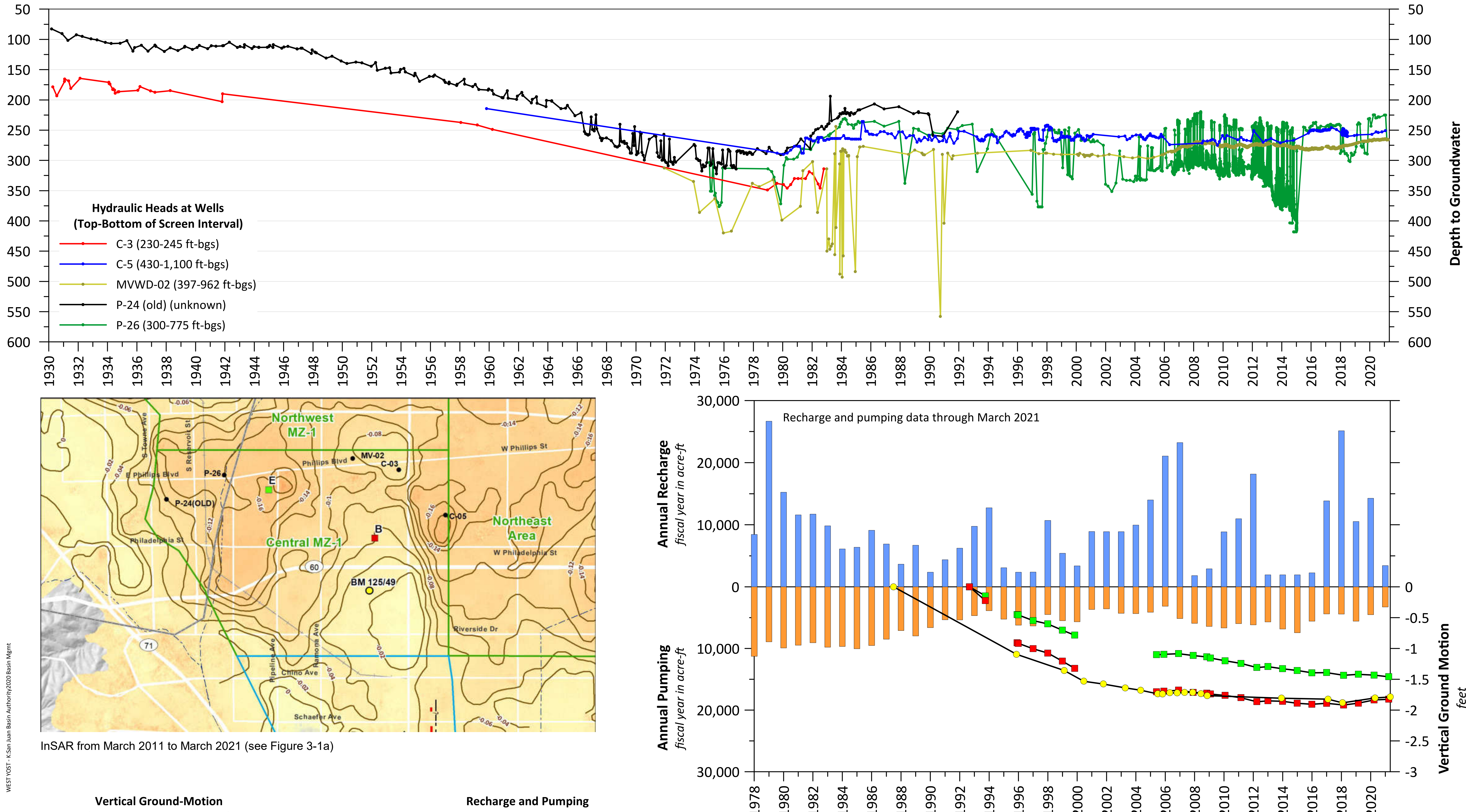

InSAR from March 2011 to March 2021 (see Figure 3-1a)

Vertical Ground-Motion (Cumulative Displacement)

- InSAR Point B
- InSAR Point E
- BM 125/49

Recharge and Pumping

- Recharge of Recycled Water, Storm-water,* and Imported Water at the College Heights, Upland, Montclair, and Brooks Recharge Basins; and, at MVWD ASR Wells
  *Storm-water is an estimated amount prior to fiscal year 2004/05
- Groundwater Pumping from Wells in Central MZ-1

Figure 3-8

History of Land Subsidence in Central MZ-1

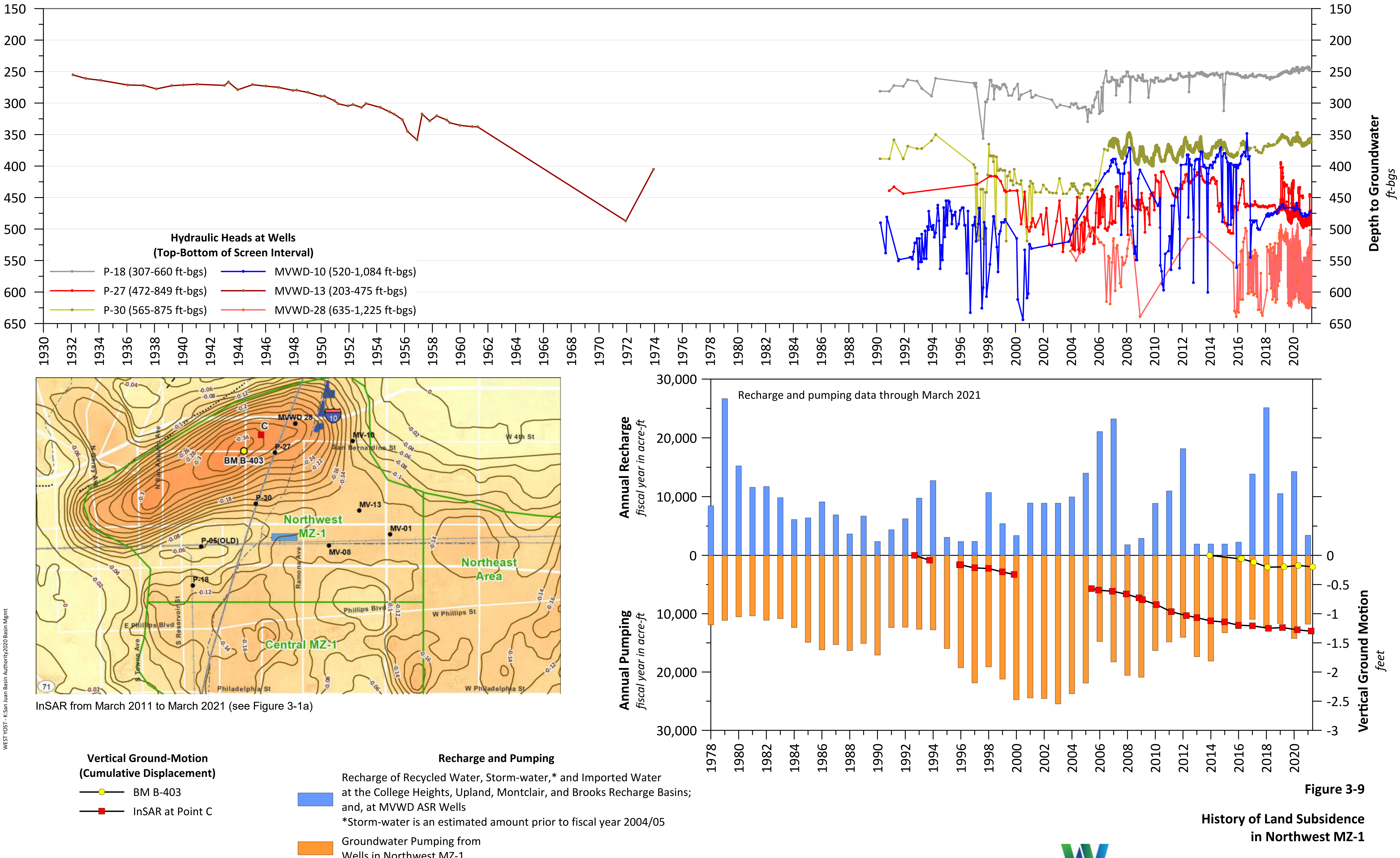

Figure 3-9

History of Land Subsidence in Northwest MZ-1

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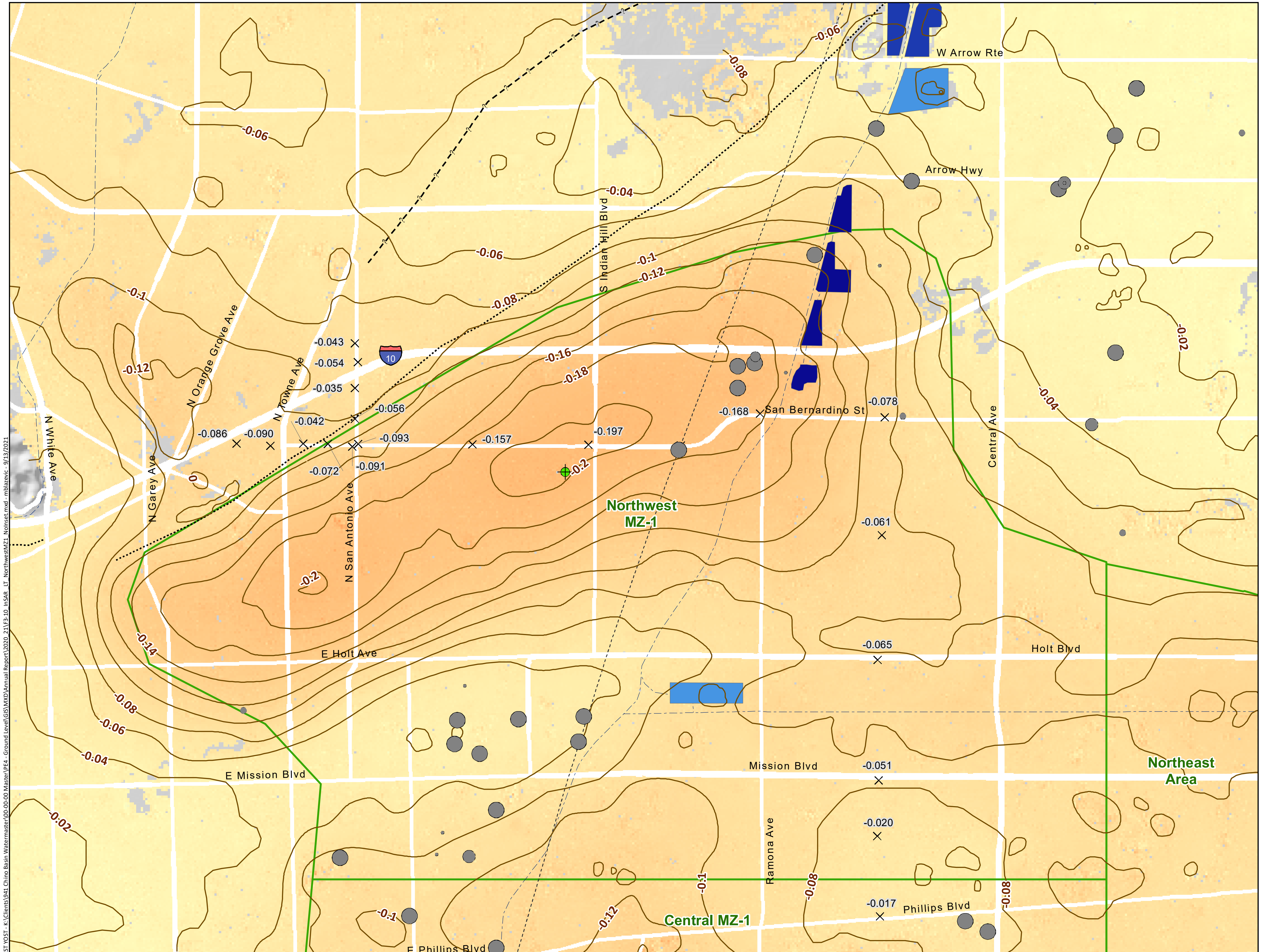

0 2,000 4,000
Scale in Feet

Active Groundwater Pumping Wells
April 1, 2014 to March 31, 2021
(afy)

- 0 - 100
- 101 - 500
- 500 - 1,000
- 1,000 - 2,000
- > 2,000

Average Annual Basin Recharge
April 1, 2014 to March 31, 2021
(afy)

- 0 - 500
- 500 - 1,000
- 1,000 - 1,500
- 1,500 - 2,000
- 2,000 - 3,000
- > 3,000

Relative Change in Land Surface Elevation as Estimated by InSAR
(April 2014 to March 2021)

+0.45 ft
0 ft
-0.25 ft
-0.45 ft

InSAR absent or incoherent

Pomona Extensometer Facility

Ground-Level Survey Benchmark (Measured May 4, 2021) Labeled by Vertical Ground Motion (in feet from December 2013 to May 2021)

Areas of Subsidence Concern

Fault (solid where accurately located; dashed where approximately located or inferred; dotted where concealed)

WEST YOST

Figure 3-10

Vertical Ground Motion across Northwest MZ-1: 2014-2021

Chino Basin Watermaster
Ground-Level Monitoring Committee
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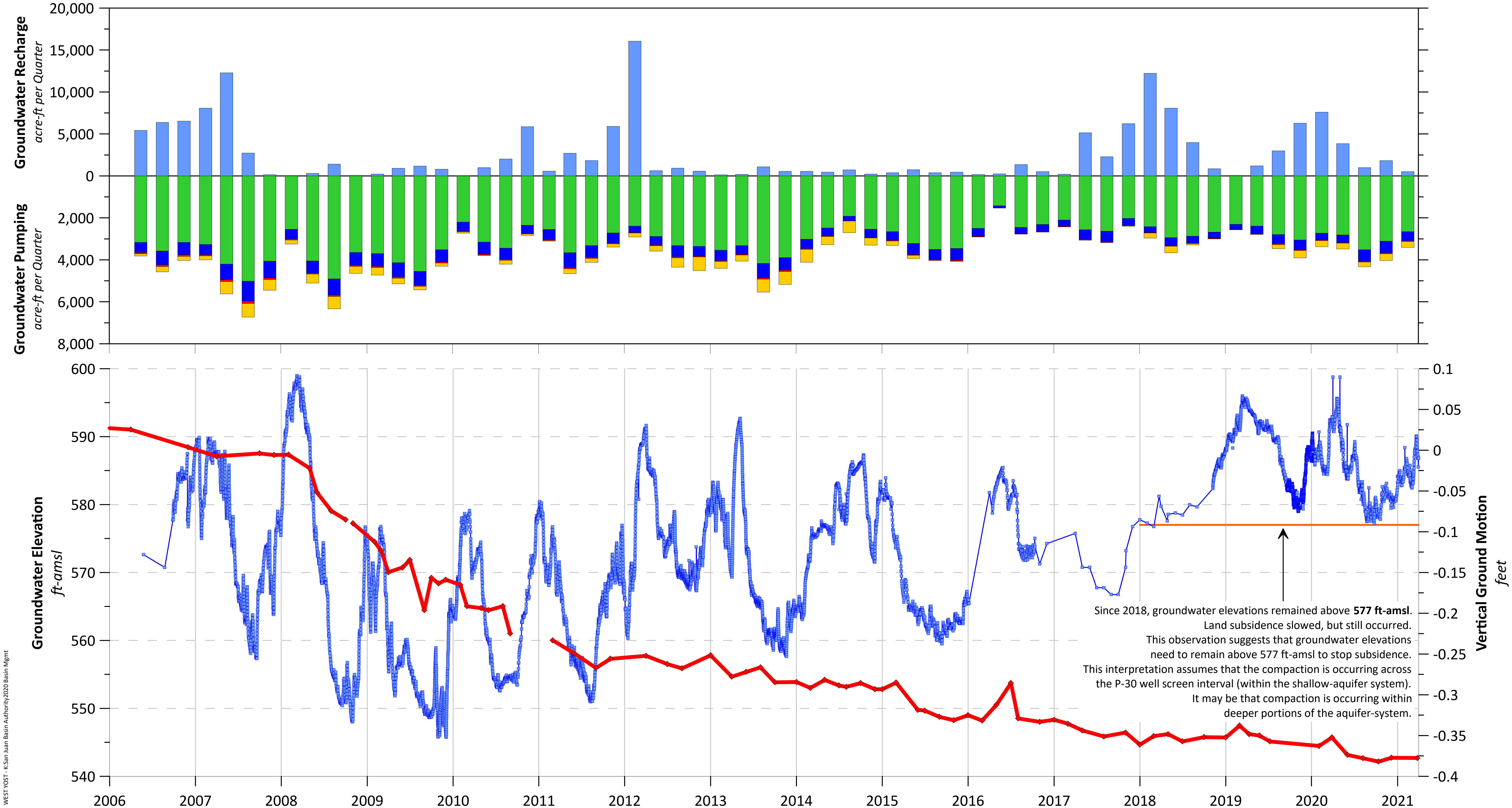

Quarterly Groundwater Pumping from Northwest MZ-1

- Aquifer Layer 1
- Aquifer Layer 3
- Aquifer Layer 5
- Unknown Aquifer(s)

Quarterly Recharge Northwest MZ-1*

*Brooks Basin
Upland Basin
Montclair Basins 1-4
College Heights Basins 1-2
MVWD Injection Wells

Groundwater Elevation at Wells (Screen Interval)

P-30 (565-875 ft-bgs)
Well screen across aquifer (model) layers 1 and 3

Vertical Ground Motion

Cumulative Displacement (at the P-30 location)

Figure 3-11

Hydraulic Heads at P-30 Versus Vertical Ground Motion

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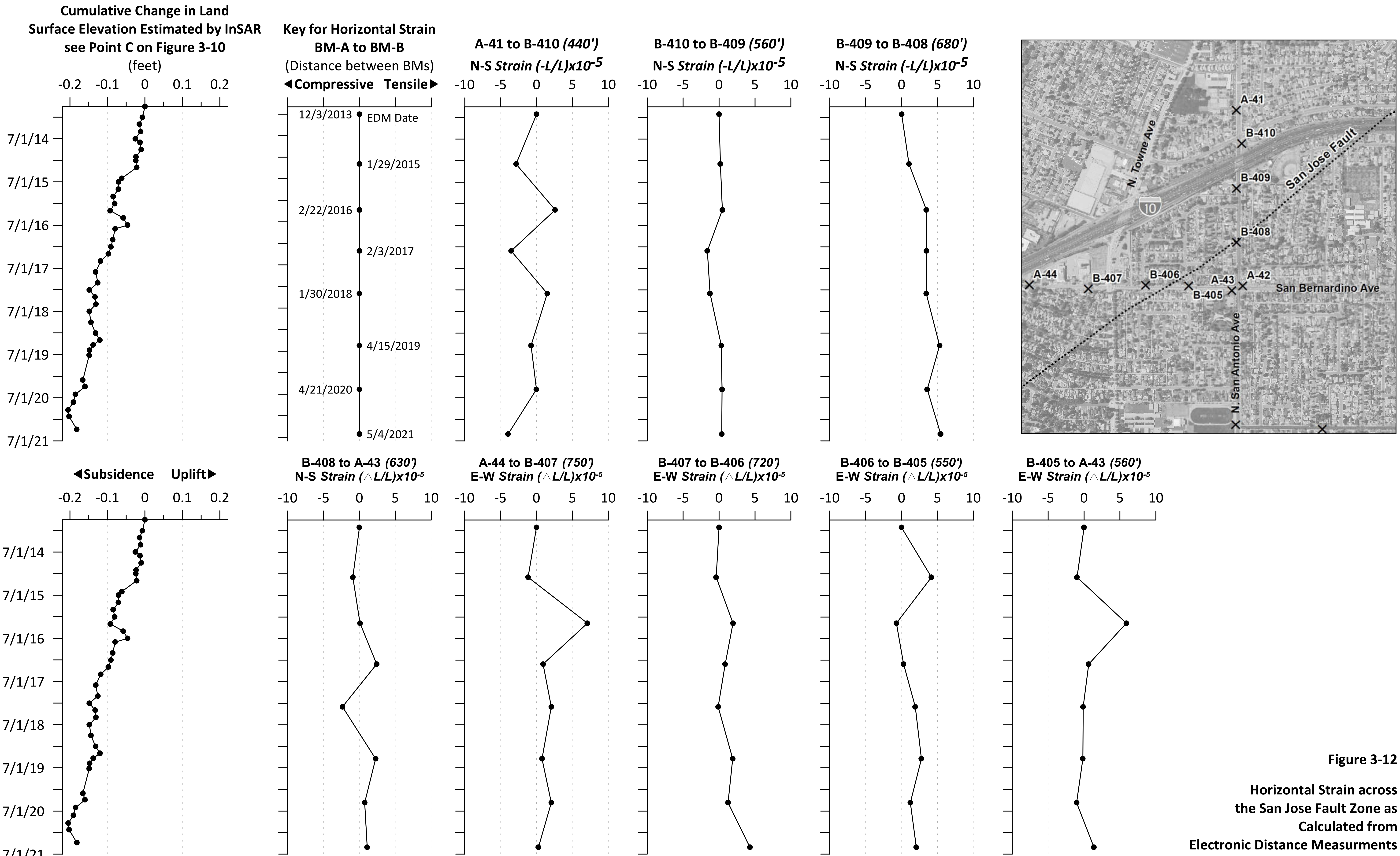

Figure 3-12

Horizontal Strain across the San Jose Fault Zone as Calculated from Electronic Distance Measurments 2013-2021

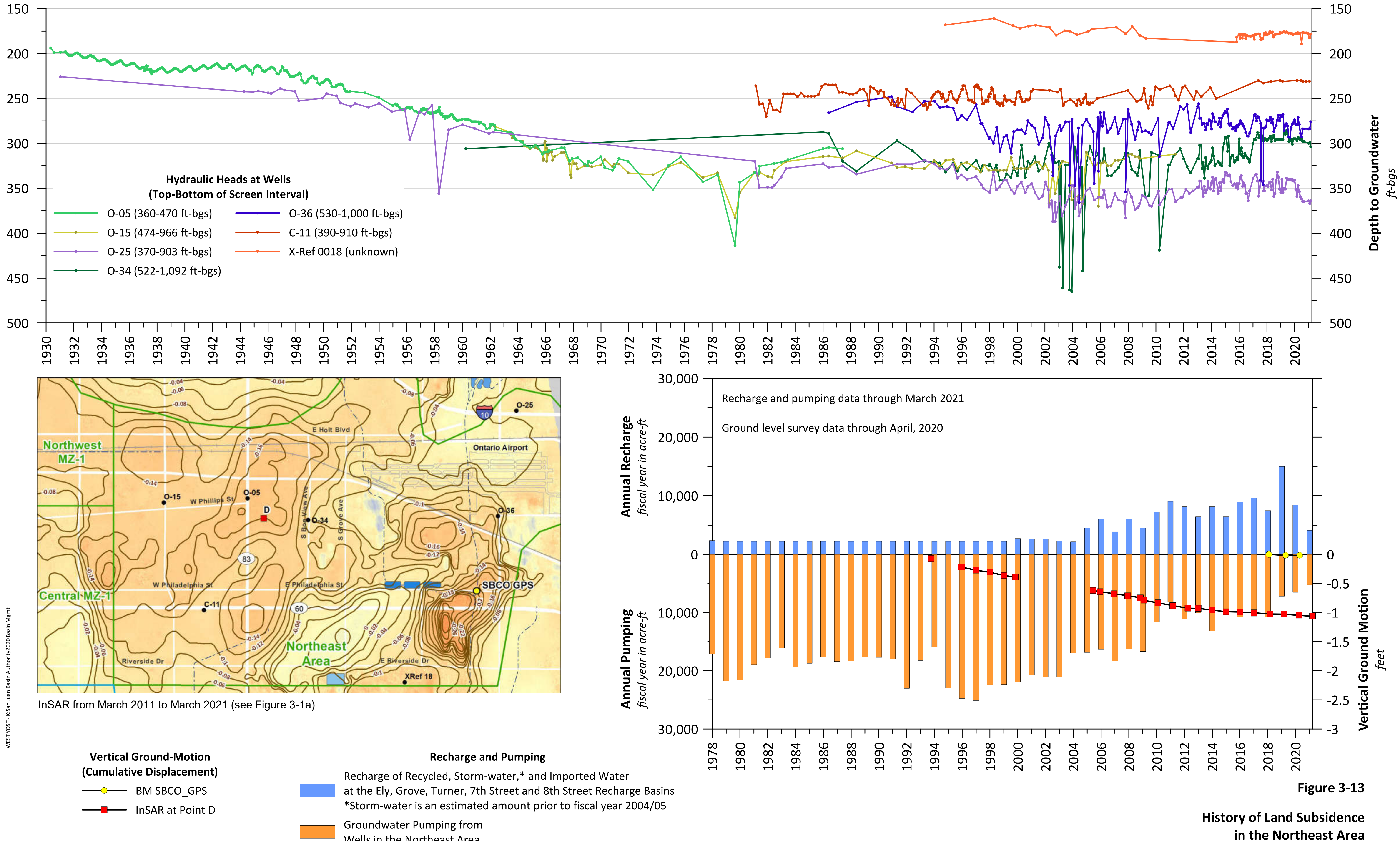

Figure 3-13

History of Land Subsidence in the Northeast Area

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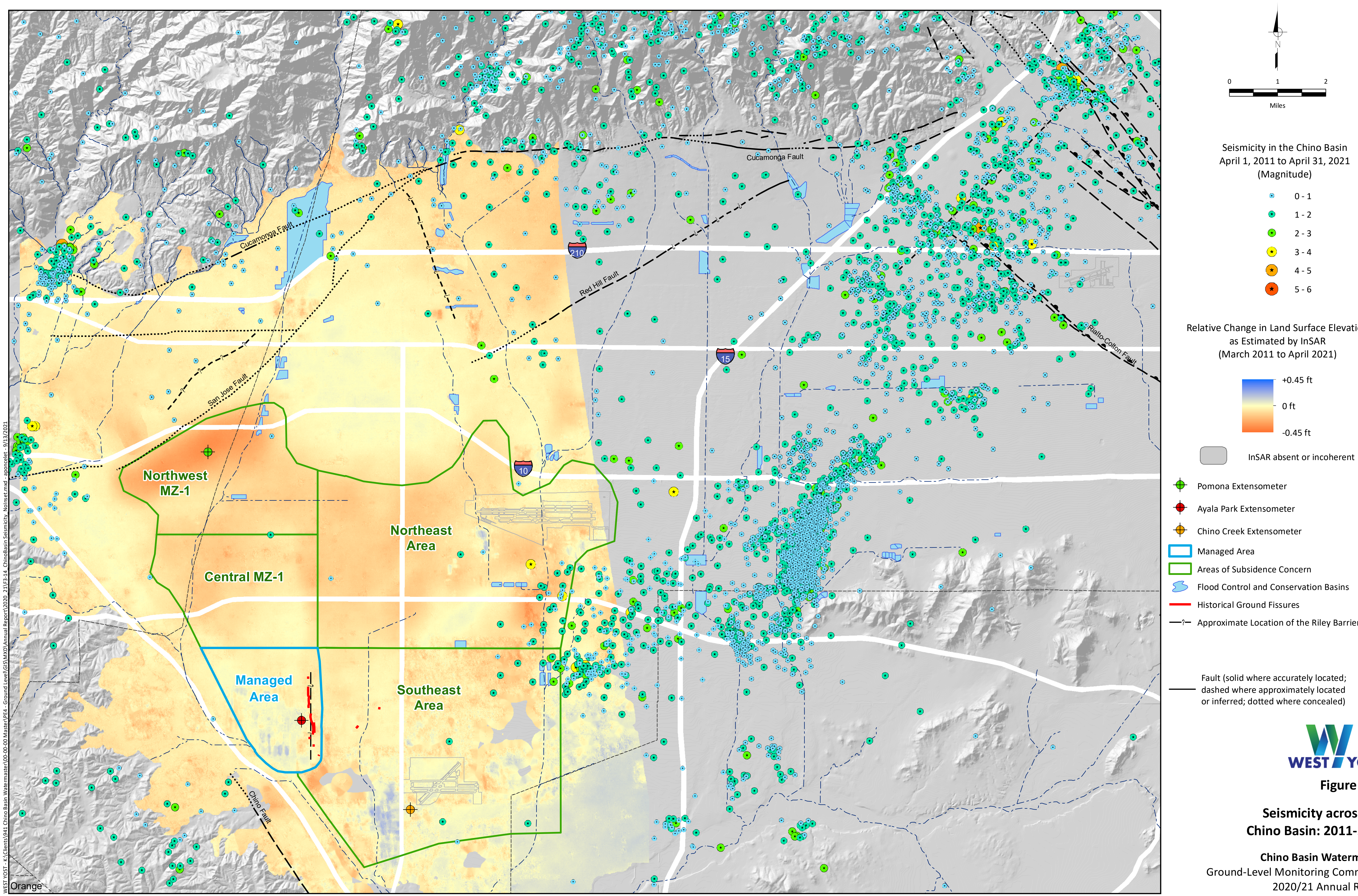
2020/21 Annual Report



WEST YOST

Figure 3-14

Seismicity across the Chino Basin: 2011-2021

Chino Basin Watermaster
Ground-Level Monitoring Committee
2020/21 Annual Report

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions and Recommendations

The major conclusions and recommendations of this 2020/21 Annual Report of the GLMC are:

- At the Ayala Park Extensometer in the Managed Area, hydraulic heads within the shallow and deep aquifer-systems increased to their highest levels since the inception of the GLMP in 2003, and the Ayala Park Extensometers recorded elastic expansion of the aquifer-system during the current reporting period of March 2020 to March 2021. The increases in hydraulic head were due to the virtual cessation of pumping in the Managed Area during the reporting period. The reduced pumping is largely due to the presence of water-quality contaminants in groundwater that constrain its use as drinking water. Hydraulic heads in the deep aquifer-system remain well above the Guidance Level, and the Ayala Park Extensometers recorded no inelastic compaction of the aquifer-system during the current reporting period.
- Across most of the other Areas of Subsidence Concern, prior annual reports have noted long-term trends of gradual land subsidence since 1992, even during periods of stable or increasing heads. The long-term trends in downward vertical ground motion have been of particular concern in Northwest MZ-1, where subsidence occurs differentially across the San Jose Fault and differential subsidence poses a threat for ground fissuring. The long-term trends of land subsidence have been attributed to the delayed drainage and compaction of aquitards as they slowly equilibrate with lower heads in the aquifers that were caused by historical pumping. Over the past several years, pumping has decreased across much of the western Chino Basin due to the presence of contaminants in groundwater that constrain its use as drinking water. Also, artificial recharge of imported water in Northwest MZ-1 (Upland, College Heights, Montclair, and Brooks basins) has increased mainly due to a "put" cycle in the Dry-Year Yield Program. The decreases in pumping and increases in recharge have caused heads to stabilize or increase, and InSAR estimates of ground motion across most of the Areas of Subsidence Concern have shown that the long-term trends of land subsidence have slowed. These observations suggest:
  - The reductions in pumping, increases in recharge, and increases in hydraulic head may be causing equilibration of hydraulic heads in the aquitards and aquifers, which is slowing the drainage and compaction of the aquitards.
  - Hydraulic heads may be nearing "threshold levels" that, if achieved and maintained, could abate the future occurrence of permanent land subsidence. These hydraulic head thresholds, and various pumping and recharge strategies to maintain heads above these thresholds, were explored by the GLMC in 2017 using a numerical, one-dimensional aquifer-system compaction model in Northwest MZ-1 (WEI, 2017b). The past few years of reduced pumping and increased recharge in Northwest MZ-1 functioned as an empirical test of the model simulations performed in 2017 and generally confirmed the model results that decreased pumping and increased recharge could elevate hydraulic heads and minimize or abate ongoing subsidence.
- The recent reduction in the rates of land subsidence across the Areas of Subsidence Concern does not mean that the future occurrence of subsidence and ground fissuring is no longer a threat. Future declines in hydraulic heads, which may be caused by increases in pumping or

decreases in recharge, among other causes, may cause aquitard compaction and rates of land subsidence to increase. For example, the pumpers in Northwest MZ-1 will likely increase pumping in the future by implementing strategies to remove groundwater contaminants through treatment, and the "put" cycles for the Dry-Year Yield Program will occur only periodically, if at all. The future occurrence of subsidence remains possible in the event of future head declines.

RECOMMENDATION: The GLMC should continue implementation of the *Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area* to develop management strategies to avoid future occurrences of subsidence. In FY 2021/22, this will include:

- Continuing aquifer-system monitoring and data analysis in Northwest MZ-1, including hydraulic head data and aquifer-system deformation data from the PX and hydraulic head data from Pomona and MVWD wells equipped with transducers.
- Updating the Northwest MZ-1 hydrogeologic conceptual model by constructing, calibrating, and documenting the one-dimensional compaction models at the MVWD-28 and PX locations.
- Using the one-dimensional compaction models at the MVWD-28 and PX locations to characterize the effectiveness of the BMA and the ISMA to minimize or abate the future occurrence of subsidence in Northwest MZ-1.[12,13]
- Developing additional subsidence-management alternatives for evaluation in FY 2022/23 if the prior alternatives are unsuccessful at minimizing or abating the future occurrence of subsidence in Northwest MZ-1.

- Since the inception of the GLMP, Watermaster has employed various methods to monitor ground motion via extensometers, InSAR, and traditional ground-level surveys. Analysis of these data over time has shown that InSAR has become an increasingly reliable and accurate method for monitoring of vertical ground motion across most of the Areas of Subsidence Concern for the following reasons:
  - Improvements in satellite technology over time have increased the spatial resolution, temporal resolution, and accuracy of InSAR. InSAR provides higher spatial and temporal resolution compared to traditional leveling surveys.
  - General Atomics (formerly Neva Ridge Technologies, Inc.), a long-time subconsultant to the Watermaster, has been able to stay abreast of the newest InSAR products and processing techniques which in turn provides InSAR deliverables to the GLMC with high accuracy, resolution, and coherence.
  - Where and when the extensometer, InSAR, and traditional ground-leveling datasets overlap, InSAR shows a similar spatial pattern and magnitude of ground motion compared to the ground-level surveys. Research performed by the GLMC has shown that the errors inherent in InSAR and traditional ground-level methods are similar.

[12] The development and evaluation of the BMA and ISMA were reported on here:

https://cbwm.syncedtool.com/shares/folder/e83081106c3072/?folder_id=1126

[13] Characterizing the Baseline Management Alternative, Initial Subsidence Management Alternative, and developing and evaluating additional subsidence-management alternatives is contingent on the successful completion, calibration, and GLMC review of the updated Watermaster's MODFLOW model that simulates subsidence across the Chino Basin. The completion dates for these tasks may need to be adjusted.

- Land-use changes from agricultural to urban uses have added hard, consistent radar wave reflectors to the ground surface over time. InSAR results are now coherent and useful across most of the Areas of Subsidence Concern.

RECOMMENDATION: The GLMC should preferentially rely on InSAR over traditional ground-leveling techniques to monitor ground motion as a cost-saving strategy. However, the GLMC should consider employing methods to verify the InSAR estimates of vertical ground motions via techniques such as GPS, extensometers, and less-frequent ground-leveling surveys.

- In the Northeast Area, the long- and short-term InSAR estimates indicate that persistent downward ground motion has occurred in a concentrated area south of the Ontario Airport between Vineyard Avenue and Archibald Avenue. The western edge of this subsiding area exhibits a steep subsidence gradient, or "differential subsidence." Subsidence may have occurred in this area in response to declining hydraulic heads, but there is not enough historical hydraulic head data in this area to confirm this relationship. In FY 2021/22, the GLMC will conduct a reconnaissance-level subsidence investigation of the Northeast Area. As part of the investigation, available borehole and lithologic data, pumping and recharge data, and high-frequency hydraulic head data will be collected, reviewed, analyzed and compared against InSAR estimates of vertical ground motion in the southeast part of the Northeast Area. Figures and charts will be prepared to support the data analysis and interpretations, and recommendations will be developed for future investigations and monitoring.

4.2 Recommended Scope and Budget for Fiscal Year 2021/22

The scope-of-work for the GLMP for FY 2021/22 was recommended by the GLMC in April 2021 and approved by Watermaster on July 22, 2021. Appendix A is the technical memorandum prepared by the GLMC, titled *Recommended Scope and Budget of the Ground-Level Monitoring Committee for FY 2021/22*.

In March 2022, Watermaster staff and the Watermaster Engineer will present the preliminary results of the GLMP through 2021 and a recommended FY 2022/23 scope and budget to the GLMC for consideration. As is typically done, the GLMC will recommend changes to the then-current scope of work for the GLMP.

4.3 Changes to the Subsidence Management Plan

The Subsidence Management Plan calls for ongoing monitoring, data analysis, annual reporting, and adjustments to the MZ-1 Plan, as warranted by the data. The Subsidence Management Plan states that if data from existing monitoring efforts in the Areas of Subsidence Concern indicate the potential for adverse impacts due to subsidence, Watermaster will revise the Subsidence Management Plan pursuant to the process outlined in Section 4 of the Subsidence Management Plan. The recommendations described above to continue implementation of the *Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area* and to conduct a reconnaissance-level subsidence investigation of the Northeast Area are consistent with the requirements of the OBMP Program Elements 1 and 4 and its implementation plan contained in the Peace Agreement.

5.0 GLOSSARY

The following glossary contains the terms and definitions used in this report and generally in the discussions at GLMC meetings.

Aquifer – A saturated, permeable, geologic unit that can transmit significant quantities of groundwater under ordinary hydraulic gradients and is permeable enough to yield economic quantities of water to wells.

Aquifer-system – A heterogeneous body of interbedded permeable and poorly permeable geologic units that function as a water-yielding hydraulic unit at a regional scale. The aquifer-system may comprise one or more aquifers within which aquitards are interspersed. Confining units may separate the aquifers and impede the vertical exchange of groundwater between aquifers within the aquifer-system.

Aquitard – A saturated, but poorly permeable geologic unit that impedes groundwater movement and does not yield water freely to wells but may transmit appreciable water to and from adjacent aquifers and, where sufficiently thick, may constitute an important groundwater storage unit. Areally, extensive aquitards may function regionally as confining units within aquifer-systems.

Artesian – An adjective referring to confined aquifers. Sometimes the term artesian is used to denote a portion of a confined aquifer where the altitudes of the potentiometric surface are above land surface (flowing wells and artesian wells are synonymous in this usage). But, more generally, the term indicates that the altitudes of the potentiometric surface are above the altitude of the base of the confining unit (artesian wells and flowing wells are not synonymous in this case).

Compaction – Compaction of the aquifer-system reflects the rearrangement of the mineral grain pore structure and largely non-recoverable reduction of the porosity under stresses greater than the pre-consolidation stress. Compaction, as used here, is synonymous with the term “virgin consolidation” used by soils engineers. The term refers to both the process and the measured change in thickness. As a practical matter, a very small amount (1 to 5 percent) of compaction is recoverable as a slight elastic rebound of the compacted material if stresses are reduced.

Compression – A reversible compression of sediments under increasing effective stress; it is recovered by an equal expansion when aquifer-system heads recover to their initial higher values.

Consolidation – In soil mechanics, consolidation is the adjustment of a saturated soil in response to increased load, involving the squeezing of water from the pores and a decrease in the void ratio or porosity of the soil. For the purposes of this report, the term “compaction” is used in preference to consolidation when referring to subsidence due to groundwater extraction.

Confined Aquifer-system – A system capped by a regional aquitard that strongly inhibits the vertical propagation of head changes to or from an overlying aquifer. The heads in a confined aquifer-system may be intermittently or consistently different than in the overlying aquifer.

Deformation, Elastic – A fully reversible deformation of a material. In this report, the term “elastic” typically refers to the reversible (recoverable) deformation of the aquifer-system sediments or the land surface.

Deformation, Inelastic – A non-reversible deformation of a material. In this report, the term "inelastic" typically refers to the permanent (non-recoverable) deformation of the aquifer-system sediments or the land surface.

Differential Land Subsidence – Markedly different magnitudes of subsidence over a short horizontal distance, which can be the cause of ground fissuring.

Drawdown – Decline in aquifer-system head typically due to pumping by a well.

Expansion – In this report, expansion refers to the expansion of sediments. A reversible expansion of sediments under decreasing effective stress.

Extensometer – A monitoring well housing a free-standing pipe or cable that can measure vertical deformation of the aquifer-system sediments between the bottom of the pipe and the land surface datum.

Ground Fissures – Elongated vertical cracks in the ground surface that can extend several tens of feet in depth.

Hydraulic Conductivity – A measure of the medium's capacity to transmit a particular fluid. The volume of water at the existing kinematic viscosity that will move in a porous medium in unit time under a unit hydraulic gradient through a unit area. In contrast to permeability, it is a function of the properties of the liquid, as well as the porous medium.

Hydraulic Gradient – Change in head over a distance along a flow line within an aquifer-system.

Hydraulic Head – A measure of the potential for fluid flow. The height of the free surface of a body of water above a given subsurface point.

InSAR (Synthetic Aperture Radar Interferometry) – A remote-sensing method (radar data collected from satellites) that measures ground-surface displacement over time.

Linear Potentiometer – A highly sensitive electronic device that can generate continuous measurements of displacement between two objects. Used to measure movement of the land-surface datum with respect to the top of the extensometer measuring point.

Nested Piezometer – A single borehole containing more than one piezometer.

Overburden – The weight of overlying sediments, including their contained water.

Piezometer – A monitoring well that measures groundwater levels, or piezometric level, at a point, or in a very limited depth interval, within an aquifer-system.

Piezometric (Potentiometric) Surface – An imaginary surface representing the total head of groundwater within a confined aquifer-system, defined by the level to which the water will rise in wells or piezometers that are screened within the confined aquifer-system.

Pore pressure – Water pressure within the pore space of a saturated sediment.

Rebound – Elastic rising of the land surface.

Stress, Effective – The difference between the geostatic stress and fluid pressure at a given depth in a saturated deposit, representing the portion of the applied stress that becomes effective as intergranular stress.

Stress, Pre-consolidation – The maximum antecedent effective stress to which a deposit has been subjected and can withstand without undergoing additional permanent deformation. Stress changes in the range less than the pre-consolidation stress produce elastic deformations of small magnitude. In fine-grained materials, stress increases beyond the pre-consolidation stress produce much larger deformations that are principally inelastic (non-recoverable). Synonymous with "virgin stress."

Stress – Stress (pressure) that is borne by and transmitted through the grain-to-grain contacts of a deposit, thus affecting its porosity and other physical properties. In one-dimensional compression, effective stress is the average grain-to-grain load per unit area in a plane normal to the applied stress. At any given depth, the effective stress is the weight (per unit area) of sediments and moisture above the water table plus the submerged weight (per unit area) of sediments between the water table and a specified depth plus or minus the seepage stress (hydrodynamic drag) produced by downward or upward components, respectively, of water movement through the saturated sediments above the specified depth. Effective stress may also be defined as the difference between the geostatic stress and fluid pressure at a given depth in a saturated deposit and represents the portion of the applied stress that becomes effective as intergranular stress.

Subsidence – Permanent or non-recoverable sinking or settlement of the land surface due to any of several processes.

Transducer – An electronic device that can measure piezometric levels by converting water pressure to a recordable electrical signal. Typically, the transducer is connected to a data logger, which records the measurements.

Water Table – The surface of a body of unconfined groundwater at which the pressure is equal to atmospheric pressure and is defined by the level to which the water will rise in wells or piezometers that are screened within the unconfined aquifer-system.

6.0 REFERENCES

Fife, D.L., Rodgers, D.A., Chase, G.W., Chapman, R.H., and E.C. Sprotte. (1976). *Geologic Hazards in Southwestern San Bernardino County, California*: California Division of Mines and Geology Special Report 113, 40 p.

Geomatrix Consultants, Inc. (1994). *Final Report Ground Fissuring Study, California Department of Corrections, California Institution for Men, Chino, California*. Project No. 2360. San Francisco, CA.

GEOSCIENCE, Support Services, Inc. (2002). *Preliminary Geohydrologic Analysis of Subsidence in the Western Portion of the Chino Basin*. Prepared for the City of Chino Hills. August 29, 2002.

Harris, R. A. (2017). *Large earthquakes and creeping faults*, Rev. Geophys., 55, 169-198, doi:10.1002/2016RG000539.

Kleinfelder, Inc. (1993). *Geotechnical Investigation, Regional Subsidence and Related Ground Fissuring, City of Chino, California*. Project No. 58-3101-01. Diamond Bar, CA.

Kleinfelder, Inc. (1996). *Chino Basin Subsidence and Fissuring Study, Chino, California*. Project No. 58-5264-02. Diamond Bar, CA.

Morton, D.M., and Yerkes, R.F. (1974). *Spectacular scarps of the frontal fault system, eastern San Gabriel Mountains.* Geological Society of America Abstracts with Programs, v. 6, no. 3, p. 223-224.

Morton, D.M., Matti, J.C., and Tinsley, J.C. (1982). *Quaternary history of the Cucamonga fault zone, southern California.* Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 218.

Morton, D.M., and Matti, J.C. (1987). *The Cucamonga fault zone: Geologic setting and Quaternary history, in Morton, D.M., and Yerkes R.F., eds., Recent reverse faulting in the Transverse Ranges, California.* U.S. Geological Survey Professional Paper 1339, p. 179-203.

Myers, W.B. and Hamiliton, W. (1964). *Deformation Accompanying the Hebgen Lake Earthquake of August 17. 1959*. U.S. Geological Survey Professional Paper 435-1, p. 55-98.

Plafker, G.G. (1965). *Tectonic Deformation Associated with the 1964 Alaska Earthquake of March 27, 1964.* Science, v. 148, no. 3678, p. 1675-1687.

Riley, F.S. (1986). *Developments in borehole extensometry,* in Johnson, A.I., Carbognin, L., and Ubertini, L., eds., Proceedings, Land Subsidence – Third International Symposium on Land Subsidence, Venice, Italy, March 1984: International Association of Hydrological Sciences Publication, p. 343-355.

United States Geological Survey (USGS). (1999). *Land subsidence in the United States* (Devin Galloway, David R. Jones, S.E). Ingebritsen. USGS Circular 1182. 175 p.

Weischet, W. (1963). *Further Observations of Geologic and Geomorphic Changes Resulting from the Catastrophic Earthquakes of May 1960, in Chile* (translated by R. Von Huene). Seismology Society America Bulletin, v. 53, no. 6, p. 1237-1257.

Wildermuth Environmental, Inc. (WEI). (1999). *Optimum Basin Management Program. Phase I Report*. Prepared for the Chino Basin Watermaster. August 19, 1999.

Wildermuth Environmental, Inc. (WEI). (2003). *Management Zone 1 (MZ-1) Interim Monitoring Program*. Prepared for the Chino Basin Watermaster. January 2003.

Wildermuth Environmental, Inc. (WEI). (2006). *Optimum Basin Management Program. Management Zone 1 Interim Monitoring Program. MZ-1 Summary Report*. Prepared for the Chino Basin Watermaster. February 2006.

Wildermuth Environmental, Inc. (WEI). (2007). *Chino Basin Optimum Basin Management Program. Management Zone 1 Subsidence Management Plan*. Prepared for the Chino Basin Watermaster. October 2007.

Wildermuth Environmental, Inc. (WEI). (2013). *2012 State of the Basin Atlas*. Prepared for the Chino Basin Watermaster. June 2013.

Wildermuth Environmental, Inc. (WEI). (2015a). *Chino Basin Subsidence Management Plan*. Prepared for the Chino Basin Watermaster. July 23, 2015.

Wildermuth Environmental, Inc. (WEI). (2015b). *Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area*. Prepared for the Chino Basin Watermaster. July 23, 2015.

Wildermuth Environmental, Inc. (WEI). (2016). *2016 Annual Report of the Ground-Level Monitoring Committee*. Prepared for the Chino Basin Watermaster. September 2017.

Wildermuth Environmental, Inc. (WEI). (2017a). *Initial Hydrologic Conceptual Model and Monitoring and Testing Program for the Northwest MZ-1 Area.* Prepared for the Chino Basin Watermaster. December 2017.

Wildermuth Environmental, Inc. (WEI). (2017b). *Task 3 and Task 4 of the Work Plan to Develop a Subsidence Management Plan for the Northwest MZ-1 Area: Development and Evaluation of Baseline and Initial Subsidence-Management Alternatives*. Prepared for the Ground-Level Monitoring Committee of the Chino Basin Watermaster. December 13, 2017.

Appendix A

Recommended Scope and Budget of the Ground-Level Monitoring Committee for FY 2021/22

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TECHNICAL MEMORANDUM

DATE: July 8, 2021

Project No.: 941-80-20-22
SENT VIA: EMAIL

TO: Ground-Level Monitoring Committee

FROM: Michael Blazevic

REVIEWED BY: Andy Malone

SUBJECT: Recommended Scope of Services and Budget of the Ground-Level Monitoring Committee for Fiscal Year 2021/22 (Final)

BACKGROUND AND PURPOSE

Pursuant to the Optimum Basin Management Program Implementation Plan and the Peace Agreement, the Chino Basin Watermaster (Watermaster) implements a Subsidence Management Plan (SMP) for the Chino Basin to minimize or stop the occurrence of land subsidence and ground fissuring. The Court approved the SMP and ordered its implementation in November 2007 (2007 SMP). The 2007 SMP was updated in 2015 (2015 SMP) and can be downloaded from the Watermaster website. The SMP outlines a program of monitoring, data analysis, and annual reporting. A key element of the SMP is its adaptive nature—Watermaster can adjust the SMP as warranted by the data.

The Watermaster Engineer, with the guidance of the Ground-Level Monitoring Committee (GLMC), prepares the annual reports which include the results of the monitoring program, interpretations of the data, recommendations for the Ground-Level Monitoring Program (GLMP) for the following fiscal year (FY), and recommendations for adjustments to the SMP, if any.

This Technical Memorandum (TM) describes the Watermaster Engineer's recommended activities for the GLMP for FY 2021/22 in the form of a proposed scope of services and budget.

Members of the GLMC are asked to:

- Review this TM prior to March 4, 2021
- Attend a meeting of the GLMC at 9:00 am on March 4, 2021 to discuss the proposed scope of services and budget for FY 2021/22
- Submit comments and suggested revisions on the proposed scope of services and budget for FY 2021/22 to the Watermaster by March 19, 2021
- Attend a meeting of the GLMC at 9:00 am on April 1, 2021 to discuss comments and revisions to the proposed scope of services and budget for FY 2021/22

- Submit additional comments and suggested revisions on the proposed scope of services and budget for FY 2021/22 to the Watermaster by May 21, 2020.

The final scope of services and budget that is recommended by the GLMC will be included in the Watermaster's FY 2021/22 budget. The final scope of services, budget, and schedule for FY 2021/22 will be included in Section 4 of the *2020/21 Annual Report of the GLMC*.

RECOMMENDED SCOPE OF SERVICES AND BUDGET – FY 2021/22

A proposed scope of services for the GLMP for FY 2021/22 is shown in Table 1 as a line-item cost estimate. The proposed scope of services is summarized below.

Task 1. Setup and Maintenance of the Monitoring Network

The Chino Basin extensometer facilities are key monitoring facilities for the GLMP. They require regular and as-needed maintenance and calibration to remain in good working order and to ensure the recording of accurate measurements.

Task 1.1. Maintain Extensometer Facilities

This subtask includes performing monthly visits to the Ayala Park, Chino Creek, and Pomona extensometer facilities to ensure functionality and calibration of the monitoring equipment and data loggers.

Task 1.2. Annual Lease Fees for the Chino Creek Extensometer Site

The County of San Bernardino (County) owns the land the Chino Creek extensometer facility is located on. As such, the Watermaster entered into a lease agreement with the County in 2012 and pays the County and annual rental payment of $1,596.

Task 2. Aquifer-System Monitoring and Testing

This task involves the collection and compilation of hydraulic head and aquifer-system deformation data from the Ayala Park, Chino Creek, and Pomona extensometer facilities.

Task 2.1. Conduct Quarterly Data Collection from Extensometers; Data Checking and Management

This subtask involves the routine quarterly collection and checking of data from the extensometer facilities. Quarterly data collection is necessary to ensure that the monitoring equipment is in good working order and to minimize the risk of losing data because of equipment malfunction. For this subtask, the complete extensometer records from the Ayala Park, Chino Creek, and Pomona extensometer facilities will be loaded to HydroDaVE^{SM} (Hydrologic Database and Visual Explanations) and checked. Both hydraulic head and aquifer-system data from the extensometer facilities will be loaded and checked to HydroDaVE on a quarterly basis.

Table 1. Work Breakdown Structure and Cost Estimates Ground-Level Monitoring Program: FY 2021/22

	Task Description	Notes	Labor (days) Person Days	Labor Total	Other Direct Costs Travel	New Equip.	Equip. Rental	Outside Pro	Misc.	Total	Totals by Task	Recommended Budget FY 2021/22 *a*	Approved Budget FY 2020/21 *b*	Net Change FY 2020/21 to 2021/22 *a - b*	Potential Carry-Over FY 2021/22 *c*	Budget with Carry-Over FY 2021/22 *a - c*
Task 1.	**Setup and Maintenance of the Monitoring Network**			**$26,208**						**$7,388**	**$33,596**	**$33,596**	**$32,988**	**$608**	**$0**	**$33,596**
1.1	Maintain Extensometer Facilities															
1.1.1	Routine maintenance of Ayala Park, Chino Creek, and Pomona extensometer facilities		14	$19,824	$1,056	$250	$152			$1,458	$21,282	$21,282	$20,818	$464	$0	$21,282
1.1.2	Replacement/repair of equipment at extensometer facilities		4	$6,384	$264	$2,000	$70	$2,000		$4,334	$10,718	$10,718	$10,574	$144	$0	$10,718
1.2	Annual Lease Fees for the Chino Creek extensometer site		0	$0					$1,596	$1,596	$1,596	$1,596	$1,596	$0	$0	$1,596
Task 2.	**MZ-1: Aquifer-System Monitoring and Testing**			**$30,736**						**$680**	**$31,416**	**$31,416**	**$27,392**	**$4,024**	**$0**	**$31,416**
2.1	Conduct Quarterly Data Collection from Extensometers; Data Checking and Management															
2.1.1	Download data from the Ayala Park extensometer facility		2	$2,687	$230		$76			$306	$2,993	$2,993	$2,930	$63	$0	$2,993
2.1.2	Download data from the Chino Creek extensometer facility		2	$2,687	$26					$26	$2,713	$2,713	$2,650	$63	$0	$2,713
2.1.3	Download data from Pomona extensometer facility		4	$5,374	$272		$76			$348	$5,722	$5,722	$5,596	$126	$0	$5,722
2.1.4	Process, check, and upload data to database		13	$19,988						$0	$19,988	$19,988	$16,216	$3,772	$0	$19,988
Task 3.	**Basin Wide Ground-Level Monitoring Program (InSAR)**			**$5,116**						**$85,000**	**$90,116**	**$90,116**	**$90,002**	**$114**	**$0**	**$90,116**
3.1	Acquire TerraSAR-X Data and Prepare Interferograms for 2021/22		1	$1,845				$85,000		$85,000	$86,845	$86,845	$86,808	$37	$0	$86,845
3.2	Check and Review InSAR Results		2	$3,271						$0	$3,271	$3,271	$3,194	$77	$0	$3,271
Task 4.	**Perform Ground-Level Surveys**			**$7,728**						**$192,203**	**$199,931**	**$93,982**	**$51,828**	**$42,154**	**$0**	**$93,982**
4.1	Conduct Spring-2022 Elevation surveys in Northwest MZ-1		0.5	$926				$25,157		$25,157	$26,083	$26,083	$34,784	-$8,701	$0	$26,083
4.2	Conduct Spring-2022 Elevation Survey in the Northeast Area		0	$0				$47,069		$47,069	$47,069	$0	$0	$0	$0	$0
4.3	Conduct Spring-2022 Elevation Survey in the Southeast Area		0.5	$926				$49,797		$49,797	$50,723	$50,723	$0	$50,723	$0	$50,723
4.4	Conduct Spring-2022 Elevation and EDM Surveys in the Managed Area/Fissure Zone Area		0	$0				$52,270		$52,270	$52,270	$0	$0	$0	$0	$0
4.5	Replace Destroyed Benchmarks (if needed)		0	$0				$17,910		$17,910	$17,910	$11,300	$11,300	$0	$0	$11,300
4.6	Process, Check, and Update Database		4	$5,877						$0	$5,877	$5,877	$5,744	$133	$0	$5,877
Task 5.	**Data Analysis and Reporting**			**$85,586**						**$0**	**$85,586**	**$85,586**	**$74,932**	**$10,654**	**$0**	**$85,586**
5.1	Prepare Draft 2020/21 Annual Report of the Ground-Level Monitoring Committee		20.5	$33,286						$0	$33,286	$33,286	$35,196	-$1,910	$0	$33,286
5.2	Prepare Final 2020/21 Annual Report of the Ground-Level Monitoring Committee		10.5	$19,546						$0	$19,546	$19,546	$19,088	$458	$0	$19,546
5.3	Compile and Analyze Data from the 2021/22 Ground-Level Monitoring Program		14	$21,144						$0	$21,144	$21,144	$20,648	$496	$0	$21,144
5.4	Conduct Reconnaissance-Level Subsidence Investigation of the Northeast Area (southeast part)															
5.4.1	Collect and compile available InSAR, ground-level survey, lithologic, piezometric level, and pumping and recharge data		2.75	$4,442						$0	$4,442	$4,442	$0	$4,442	$0	$4,442
5.4.2	Prepare lithologic cross-sections and data graphics of pumping, piezometric levels, and InSAR time-histories; share with the GLMC		4.25	$7,168						$0	$7,168	$7,168	$0	$7,168	$0	$7,168
Task 6.	**Develop a Subsidence-Management Plan for Northwest MZ-1**			**$238,164**						**$480**	**$238,644**	**$238,644**	**$99,189**	**$139,455**	**$91,691**	**$146,953**
6.1	Aquifer-System Monitoring															
6.1.1	Collect pumping and piezometric level data from agencies every two months; check and upload data to HDX		9.75	$12,669						$0	$12,669	$12,669	$10,599	$2,070	$0	$12,669
6.1.2	Prepare and analyze charts and data graphics of pumping and recharge (Northwest MZ-1), piezometric levels, and aquifer-system deformation from PX		8.25	$11,913						$0	$11,913	$11,913	$11,634	$279	$0	$11,913
6.2	Update the One-Dimensional (1D) Compaction Models at the MVWD-28 and PX Locations															
6.2.1	Construct a 1D compaction model at the PX location		0	$0						$0	$0	$0				
6.2.2	Calibrate 1D compaction model to derive hydraulic and mechanical properties of aquifers/aquitards and estimate the pre-consolidation stress(es)		0	$0						$0	$0	$0	$0	$0	$0	$0
6.2.3	Update the 1D compaction model at the MVWD-28 location from a three to a five layer model and re-calibrate		0	$0						$0	$0	$0				
6.3	Document the One-Dimensional (1D) Compaction Models at the MVWD-28 and PX Locations															
6.3.1	Prepare for and conduct a meeting to review the results of the 1D compaction models	a	4.25	$8,722	$120					$120	$8,842	$8,842	$0	$8,842	$0	$8,842
6.3.2	Review and respond to the GLMC comments on the 1D compaction models		3	$6,140						$0	$6,140	$6,140	$0	$6,140	$0	$6,140
6.3.3	Prepare a draft TM summarizing the construction and calibration of the PX 1D compaction model and updates to the MVWD-28 1D compaction model and distribute to the GLMC		25.5	$46,664						$0	$46,664	$46,664				
6.3.4	Prepare for and conduct a GLMC meeting to receive feedback and comments on the draft TM	a	4.75	$9,299						$0	$9,299	$9,299	$0	$61,813	$14,735	$47,078
6.3.5	Incorporate the GLMC comments and prepare a final technical memorandum		3.0	$5,730	$120					$120	$5,850	$5,850				
6.4	Refine and Evaluate Subsidence-Management Alternatives															
6.4.1	Run the Baseline Management Alternative (BMA)		19	$33,176						$0	$33,176	$33,176				
6.4.2	Prepare a TM that summarizes the evaluation of the BMA and a recommended ISMA		10.75	$19,425						$0	$19,425	$19,425				
6.4.4	Meet with the GLMC to receive feedback on the TM		4.5	$8,757	$120					$120	$8,877	$8,877				
6.4.5	Run the Initial Subsidence Management Alternative (ISMA)		25.75	$46,945						$0	$46,945	$46,945	$76,956	$60,311	$76,956	$60,311
6.4.6	Prepare a technical memorandum that summarizes the evaluation of the ISMA and a recommended Subsidence Management Alternative (SMA-2)		10.75	$19,425						$0	$19,425	$19,425				
6.4.7	Prepare for and conduct a meeting to receive feedback and comments on the draft technical memorandum		4.75	$9,299	$120					$120	$9,419	$9,419				
Task 7.	**Meetings and Administration**			**$53,813**						**$407**	**$54,220**	**$54,220**	**$51,250**	**$2,971**	**$0**	**$54,220**
7.1	Prepare for and Conduct Four Meetings of the Ground-Level Monitoring Committee	a	14	$27,877	$240					$240	$28,117	$28,117	$25,838	$2,279	$0	$28,117
7.2	Prepare for and Conduct One As-Requested Ad-Hoc Meeting	a	3	$5,857	$167					$167	$6,024	$6,024	$5,804	$221	$0	$6,024
7.3	Perform Monthly Project Management		6	$11,108						$0	$11,108	$11,108	$10,848	$260	$0	$11,108
7.4	Prepare a Recommended Scope and Budget for the GLMC for FY 2022/23		4.75	$8,970						$0	$8,970	$8,970	$8,760	$210	$0	$8,970
Totals												**$627,560**	**$427,581**	**$199,979**	**$91,691**	**$535,869**

Task 3. Basin-Wide Ground-Level Monitoring Program (InSAR)

This task involves the annual collection and analysis of Synthetic Aperture Radar (SAR) scenes to estimate the vertical ground motion across the western portion of Chino Basin from March 2021 to March 2022.

As part of the approved scope of services and budget of the GLMC for FY 2020/21, the GLMC directed the Watermaster Engineer to perform a pilot study of the Sentinel-1A InSAR data. The TM documenting the objectives, methods, results, and conclusions and recommendations of the pilot study is included in Attachment A. The conclusions from the pilot study were relied upon in recommending Tasks 3.1 and 3.2 for FY 2021/22.

Task 3.1. Acquire TerraSAR-X SAR Data and Prepare Interferograms for 2021/22

In this subtask, five SAR scenes that will be acquired by the TerraSAR-X satellite from March 2021 to March 2022 are purchased from the German Aerospace Center. General Atomics (formerly Neva Ridge Technologies) will use the SAR scenes to prepare 12 interferograms that describe the incremental and cumulative vertical ground motion that occurred from March 2021 to March 2022 and since 2011. The associated costs for General Atomics to task, acquire, purchase, and process the InSAR data is as follows:

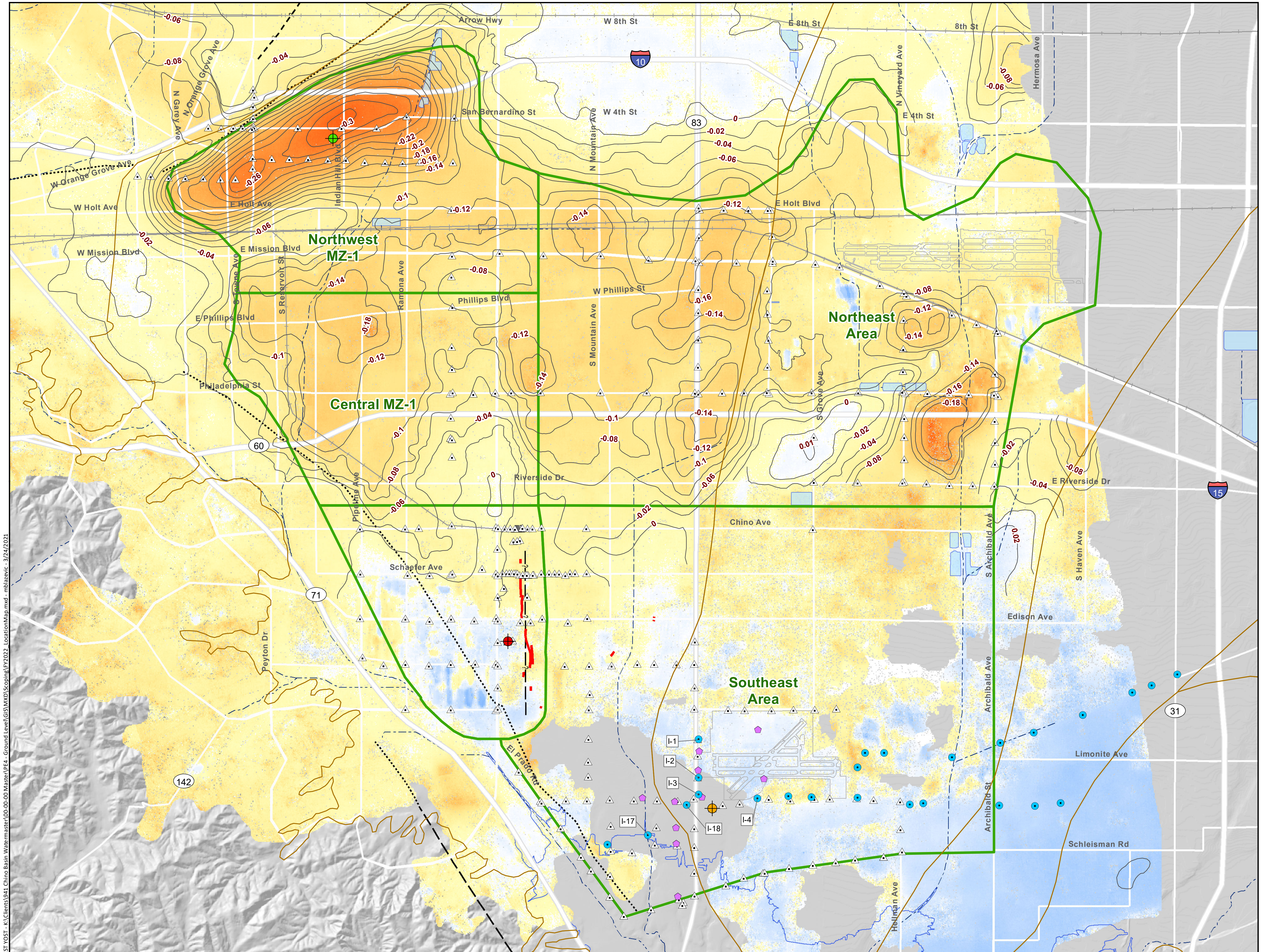
- Task TerraSAR-X for five acquisitions for the western Chino Basin ($12,000)
- Purchase all TerraSAR-X data ($17,000)
- Process the purchased TerraSAR-X data ($56,000)

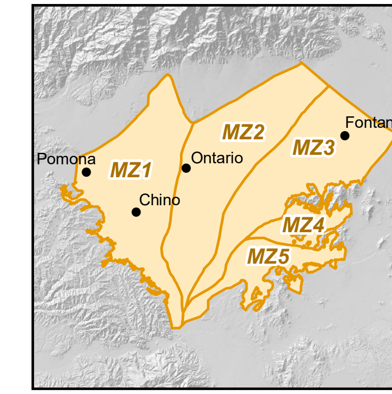
Task 3.2. Check and Review InSAR Results

In this subtask, the Watermaster Engineer reviews the InSAR results with General Atomics and performs checks for reasonableness and accuracy of the InSAR estimates of vertical ground motion across the western Chino Basin.

Task 4. Perform Ground-Level Surveys

This task involves conducting elevation surveys at benchmark monuments across defined areas of western Chino Basin to estimate the vertical ground motion that occurred since the prior survey. Figure 1 shows the location of the benchmark monuments surveyed across the western Chino Basin. Electronic distance measurements (EDM surveys) are also performed between benchmark monuments to estimate horizontal ground motion in areas where ground fissuring due to differential land subsidence is a concern.





0 1 2
Miles

Relative Change in Land Surface Altitude as Estimated by InSAR (March 2011 to March 2020)

+ 0.35 ft
0 ft
-0.20
- 0.35 ft

InSAR absent or incoherent

Areas of Subsidence Concern
Pomona Extensometer Facility
Ayala Park Extensometer Facility
Chino Creek Extensometer Facility
Chino Desalter Authority Well
SB County Proposed Extraction Well
Ground-Level Survey Benchmark
Ground Fissures
Approximate Location of the Riley Barrier

Figure 1

Ground-Level Monitoring Program
Fiscal Year 2021/22

Chino Basin Watermaster
Ground-Level Monitoring Committee

Table 2 documents the areas surveyed over the last five years as part of the GLMP.

Table 2. Ground Level Monitoring Program Ground-Level Survey History Over the Last Six Years

Ground-Level Survey Area	Ground-Level Survey Completed (Y/N)?					
	2016	2017	2018	2019	2020	2021[b]
Managed Area	Y	N	Y	N	N	N
Fissure Zone Area[a]	Y	N	Y	N	N	N
Central Area	N	N	N	N	N	N
Northwest Area	Y	Y	Y	Y	Y	Y
San Jose Fault Zone Area[a]	Y	Y	Y	Y	Y	Y
Southeast Area	Y	Y	Y	N	N	N
Northeast Area	N	N	Y	Y	Y	N

(a) Denotes EDM survey area.
(b) The 2021 ground-level surveys are scheduled to begin in early March 2021.

The ground-level survey efforts recommended for FY 2021/22 include the following Tasks.

Task 4.1. Conduct Spring-2022 Elevation surveys in Northwest MZ-1

In this subtask, the surveyor conducts elevation and EDM surveys at the established benchmarks in Northwest MZ-1 in Spring 2022. The elevation survey will begin at the Pomona Extensometer Facility and includes benchmarks across Northwest MZ-1. The elevation survey will be referenced to a newly established elevation datum at the Pomona Extensometer.

The vertical elevation survey is recommended in FY 2021/22 because of the recent subsidence that has occurred in Northwest MZ-1 and will support the development of a subsidence management plan in Northwest MZ-1. The EDM survey is ***not*** *recommended to be performed across the San Jose fault zone because the surveys have demonstrated since 2013 that the horizontal strain measured between benchmark pairs appears to behave elastically.*

Task 4.3. Conduct Spring-2022 Elevation in the Southeast Area

In this subtask, the surveyor conducts elevation surveys at the established benchmarks in the Southeast Area in Spring 2022. The elevation survey will begin at the Ayala Park Extensometer Facility and will include benchmarks throughout the Southeast Area.

The elevation survey in the Southeast Area is recommended because six Chino Creek Desalter wells (I-1 to I-4, I-17, and I-18) are expected to begin pumping in Summer/Fall 2023 and the InSAR data is largely incoherent across this area (see Figure 1).

Task 4.5. Replace Destroyed Benchmarks (if needed)

In this subtask, the surveyor replaces benchmark monuments that have been destroyed since the last survey, if any.

Task 4.6. Process, Check, and Update Database

In this subtask, the Watermaster Engineer receives and catalogs the survey results provided by the surveyor, prepares the data for display as a GIS layer, and performs checks against InSAR and extensometer data for reasonableness and accuracy.

The ground-level surveys efforts **not** recommended for FY 2021/22 include the following Tasks.

Task 4.2. Conduct Spring-2021 Elevation Survey in the Northeast Area

This survey is not recommended for FY 2021/22 because heads have been relatively stable or increasing across most of this area and recent ground motion as measured by InSAR and ground-level surveys has been minor in this area.

Task 4.4. Conduct Spring-2021 Elevation and EDM Surveys in the Managed Area/Fissure Zone Area

This survey is not recommended for FY 2021/22 because over the past several years hydraulic heads at PA-10 and PA-7 have increased to their highest levels since implementation of the GLMP in 2003; and, recent ground motion as measured by InSAR, ground-level surveys, and the Ayala Park Extensometer has been minor in this area.

Task 5. Data Analysis and Reporting

Task 5.1. Prepare Draft 2020/21 Annual Report of the Ground-Level Monitoring Committee

Prepare the text, tables, and figures for a draft 2020/21 Annual Report of the GLMC and submit the report to the GLMC by September 24, 2021 for review and comment.

Task 5.2. Prepare Final 2020/21 Annual Report of the Ground-Level Monitoring Committee

Update the text, tables, and figures based on the comments received from the GLMC and prepare a final *2020/21* Annual Report of the GLMC by October 29, 2021. Responses to comments will be included as an appendix to the final report. The report will be included in the agenda packet for the November 2021 Watermaster meetings for approval.

Also, as part of Task 5, Watermaster's Engineer will work with the GLMC to develop concepts for streamlining the Annual Report of the Ground-Level Monitoring Committee and the reporting process for future years. Watermaster's Engineer will present a recommended approach to streamline the report and reporting process to the GLMC, Watermaster's staff, and Watermaster's legal counsel during the scheduled meetings of the GLMC in FY 2021/22.

Task 5.3. Compile and Analyze Data from the 2021/22 Ground-Level Monitoring Program

In this subtask, monitoring data generated from the GLMP during 2021/22 is checked, mapped, charted, and analyzed as the first step in the preparation of the subsequent annual report. Some of the maps, charts, and tables are shared with the GLMC at its meetings in early 2022 during the development of a recommended scope of services and budget for FY 2022/23.

Task 5.4. Conduct Reconnaissance-Level Subsidence Investigation of the Northeast Area

In the Northeast Area, the long- and short-term InSAR estimates indicate that persistent downward ground motion has occurred in a concentrated area south of the Ontario International Airport between Vineyard Avenue and Archibald Avenue. The western edge of this subsiding area exhibits a steep subsidence gradient or "differential subsidence." Subsidence may have occurred in this area in response to declining hydraulic heads, but there is not enough historical hydraulic head data in this area to confirm this relationship. This task will include data collection, review, and analysis of available borehole and lithologic data, pumping and recharge data, high-frequency hydraulic head measurements, and InSAR estimates of vertical ground motion at up to four locations in the southeast part of the Northeast Area. Figures and charts will be prepared to support the data analysis, interpretations, and any recommendations for future investigations and monitoring.

Task 6. Develop a Subsidence-Management Plan for Northwest MZ-1

The 2007 SMP called for ongoing monitoring and data analysis of the Managed Area; including annual reporting and adjustments to the SMP, as warranted by the data. The 2007 SMP also called for expanded monitoring of the aquifer-system and land subsidence in other areas of subsidence and ground fissuring concern. Figure 1 shows the location of these so-called Areas of Subsidence Concern: Central MZ-1, Northwest MZ-1, Northeast Area, and Southeast Area. The expanded monitoring efforts outside of the Managed Area are consistent with the requirements of OBMP Program Element 1 and its implementation plan contained in the Peace Agreement.[1]

The 2007 SMP stated that if data from existing monitoring efforts in the Areas of Subsidence Concern indicate the potential for adverse impacts due to subsidence, the Watermaster would revise the SMP to avoid those adverse impacts. The 2014 Annual Report of the GLMC recommended that the 2007 SMP be updated to better describe the Watermaster's land subsidence efforts and obligations, including areas outside of MZ-1. As such, the update included a name change to the 2015 Chino Basin Subsidence Management Plan (2015 SMP) and a recommendation to develop a subsidence management plan for Northwest MZ 1.

The Watermaster had been monitoring vertical ground motion in Northwest MZ-1 via InSAR during the development of the 2007 SMP. Land subsidence in Northwest MZ-1 was first identified as a concern in 2006 in the MZ-1 Summary Report and again in 2007 in the 2007 SMP. Of particular concern was the occurrence of concentrated differential subsidence across the San Jose Fault in Northwest MZ-1—the same pattern of differential subsidence that occurred in the Managed Area during the time of ground fissuring. Ground fissuring is the main subsidence-related threat to infrastructure. The issue of differential subsidence, and the potential for ground fissuring in Northwest MZ-1, has been discussed at prior GLMC meetings, and the subsidence has been documented and described as a concern in the Watermaster's State of the Basin Reports, the annual reports of the GLMC, and in the *Initial Hydrologic Conceptual Model and Monitoring and Testing Program for the Northwest MZ-1 Area* (WEI, 2017). The Watermaster increased monitoring efforts in Northwest MZ-1 beginning in FY 2012/13 to include ground elevation surveys and electronic distance measurements (EDM) to monitor ground motion and the potential for fissuring.

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[1] http://www.cbwm.org/rep_legal.htm.

In 2015, the Watermaster's Engineer developed the *Work Plan to Develop a Subsidence Management Plan for the Northwest MZ-1 Area* (Work Plan; WEI 2015b).[2] The Work Plan is characterized as an ongoing Watermaster effort and includes a description of a multi-year scope-of-work, a cost estimate, and an implementation schedule. The Work Plan was included in the 2015 SMP as Appendix B. Implementation of the Work Plan began in July 2015. On an annual basis, the GLMC analyzes the data and information generated by the implementation of the Work Plan. The results and interpretations generated from the analysis are documented in the annual report of the GLMC and used to prepare recommendations for future activities.

The following tasks are recommended for in FY 2021/22 to implement the Work Plan:

Task 6.1. Aquifer-System Monitoring

The established monitoring program of piezometric levels and pumping at wells in Northwest MZ-1 will continue through various techniques, including: 1) SCADA-based monitoring by the Monte Vista Water District; 2) monitoring of piezometric levels via sonar[3]; 3) monitoring of piezometric levels via pressure transducers at City of Pomona production wells; and 4) manual measurements of piezometric levels. These data, along with data collected from the PX in Task 2.1, will improve the understanding of the hydrogeology in Northwest MZ-1, will be used to develop the Subsidence Management Plan for Northwest MZ-1, and in the future, will be used to adapt the Subsidence Management Plan, as appropriate.

In this subtask, all data is collected, compiled, checked, and analyzed every three months. Charts and data graphics of pumping, piezometric levels, and aquifer-system deformation will be updated to support the data collection and analysis.

Task 6.3. Document the One-Dimensional (1D) Compaction Models at the MVWD-28 and PX Locations

This task will help answer the question: What are the *pre-consolidation stresses* within the compacting intervals of the aquifer-system?

The *pre-consolidation stress* is a piezometric "threshold." When piezometric levels are above the threshold, subsidence is abated. When piezometric levels are below the threshold, subsidence is caused. The determination of *pre-consolidation stress* by aquifer-system layer can provide "guidance" for the Chino Basin parties to manage pumping and recharge to avoid the future occurrence of land subsidence in Northwest MZ-1.

The model calibration results for two 1D compaction models located within the area of maximum subsidence in Northwest MZ-1 (at the MVWD-28 and PX sites) will be used, in combination with other monitoring data, to estimate the current (2018) pre-consolidation stresses by aquifer-system layer for Northwest MZ-1. The 1D compaction models, the calibration results, and the preliminary estimates of the pre-consolidation stress by aquifer-system layer will be presented by the Watermaster Engineer at a GLMC meeting. The Watermaster Engineer will accept verbal feedback and written comments from the GLMC, and then prepare a draft technical memorandum (TM) to document 1D compaction models, the calibration results, and the preliminary estimates of the pre-consolidation stress. Another GLMC meeting will be held to review the draft TM. The GLMC will submit written comments and suggested revisions to the

[2] Work Plan to Develop a Subsidence-Management Plan for Northwest MZ-1

[3] The use of sonar technology to measure piezometric levels in wells in currently being used in Monte Vista Water District wells 28 and 31.

Watermaster Engineer. A final TM will be prepared that incorporates the feedback and comments from the GLMC.

Task 6.4. Refine and Evaluate the Subsidence-Management Alternatives

This task will help answer the question: What are potential methods to manage the land subsidence in Northwest MZ-1?

The 1D compaction models at MVWD-28 and PX will be used to characterize the mechanical response of the aquifer-system to a Baseline Management Alternative (BMA). A draft TM will be prepared that summarizes the evaluation of the BMA, particularly, the ability of the BMA to raise and hold piezometric levels above the estimated pre-consolidation stresses. The draft TM may also include a recommendation for the Initial Subsidence Management Alternative (ISMA) if the BMA is not successful at raising and holding hydraulic heads above the estimated pre-consolidation stresses. The assumptions of the ISMA, including the groundwater production and replenishment plans of the Chino Basin parties, will be described and must be agreed upon by the GLMC. A GLMC meeting will be held to review the model results and evaluation of the BMA, review the recommended ISMA, and to receive feedback on the draft TM.

After the recommended ISMA is agreed upon by the GLMC, the Watermaster's MODFLOW model will be updated to run the ISMA and will be used to estimate the hydraulic head response to the ISMA at the MVWD-28 and PX locations. The projected hydraulic heads generated from the MODFLOW model using the ISMA will be extracted from the MODFLOW model results at the MVWD-28 and PX locations and will be used as input files for both 1D compaction models. The 1D compaction models will then be run to characterize the mechanical response of the aquifer-system to the ISMA at both the MVWD-28 and PX locations.

A draft TM will be prepared that summarizes the evaluation of the ISMA, particularly, the ability of the ISMA to raise and hold piezometric levels above the estimated pre-consolidation stresses. The draft TM may also include a recommendation for a second Subsidence-Management Alternative (SMA-2), if the ISMA is not successful at raising and holding hydraulic heads above the estimated pre-consolidation stresses. The assumptions of the SMA-2, including the groundwater production and replenishment plans of the Chino Basin parties, will be described, and must be agreed upon by the GLMC. A GLMC meeting will be held to review the model results and evaluation of the ISMA, review the recommended SMA-2, and to receive feedback on the TM.

If necessary and recommended by the GLMC, additional subsidence management alternative scenarios may be run in FY 2022/23. It is currently envisioned by the GLMC that, based on the results of the 1D compaction model results, the GLMC may recommend an update to the Watermaster's Subsidence Management Plan in FY 2022/23 to minimize or abate the future occurrence of land subsidence in Northwest MZ-1.

Task 7. Meetings and Administration

Task 7.1. Prepare for and Conduct Four Meetings of the Ground-Level Monitoring Committee

This subtask includes preparing for and conducting four meetings of the GLMC:

- July 2021 – Implementation of the GLMP for FY 2021/22
- September 2021 – Review the draft 2020/21 Annual Report of the Ground-Level Monitoring Committee

- February 2022 – Review the draft recommended scope and budget for FY 2022/23
- March 2022 – Review the final recommended scope and budget for FY 2022/23 (if needed)

Task 7.2. Prepare for and Conduct One As-Requested Ad-Hoc Meeting

This subtask includes preparing for and conducting one ad-hoc meeting of the GLMC, as requested by the GLMC or Watermaster staff.

Task 7.3. Perform Monthly Project Management

This subtask includes monthly project administration and management, including staffing, financial and schedule reporting to Watermaster and subcontractor coordination.

Task 7.4. Prepare a Recommended Scope and Budget for the GLMC for FY 2022/23

This subtask includes preparing a draft and final recommended scope of services and budget for FY 2022/23 for the GLMC to support the Watermaster's budgeting process.

Response to GLMC Comments

The comments received from the GLMC as of April 19, 2021 on the, "Recommended Scope of Services and Budget of the Ground-Level Monitoring Committee for Fiscal Year 2021/22" and the Watermaster Engineer's response to comments is documented below.

City of Ontario by Christopher T. Quach

Comment 1 – Scope and Services and Budget (Task 5, Sub-task 5.4)

Ontario is in support of Task 5.4 to begin the subsidence investigation. We agree this seems like the correct initial approach to get ahead of it in relation to the proposed cost and nature of the investigatory work.

Response:

No change has been made to the scope of services or budget.

Comment 2 – Overall Scope and Services and Budget

We currently don't have any other comments on the rest of the proposed budget.

Response:

No change has been made to the scope of services or budget.

City of Chino by Dave Crosley

Comment 1 – Scope and Services and Budget (Tasks 1 through 5 and Task 7)

Chino concurs with recommendations in the GLMP scope and budget for items identified as Tasks 1 through 5 and Task 7. For Task 3, Chino supports acquiring and processing the TerraSAR-X data to continue with the higher level of accuracy these data provide. As Watermaster continues to prove the value of InSAR data for evaluating ground movements, we recommend further evaluation of potential cost savings as certain ground level surveys can be reliably replaced in the future by InSAR. The accuracy of InSAR compared to ground level surveys and the offset in costs should be documented to further support the use of InSAR.

Response:

No change has been made to the scope of services or budget.

Comment 2 –Scope and Services and Budget (Task 6, Sub-task 6.3)

For Task 6, Subtask 6.3, Chino recommends proceeding with use of 1D compaction models at the PX facility and MVWD-28 along with the Chino Basin MODFLOW model for use in developing the subsidence management plan for Northwest MZ-1. It is our opinion that the higher vertical resolution that can be simulated by the 1D compaction models will provide added benefit in the hydrogeologic understanding between aquifer and aquitard responses to changes in groundwater levels within the various aquifers compared to a 3D model where these zones would be averaged over greater aquifer thicknesses. The 1D model simulating the PX facility location will be the most reliable for subsidence management based on the detailed hydrogeologic data that has been collected at this location along with the facility's ongoing ground level monitoring. Establishing a guidance level at this location, where greatest subsidence has been measured by InSAR, should be representative for Northwest MZ-1 just as the guidance level that was developed for the Ayala Park extensometer facility has proven successful for the Managed Area. The extrapolation of hydrogeologic data and associated uncertainties that would be associated with the construction and use of a 3D model has the potential to lose the accuracy needed to successfully simulate aquitard compaction across the entire soil column for groundwater level management planning. It is our opinion that the added cost to develop a 3D subsidence model for Northwest MZ-1 is not warranted at this time.

Response:

The recommended scope of services and budget for sub-task 6.3 has been updated based on the City of Chino's comments and feedback received from the April 1, 2021 meeting GLMC.

Comment 3 – Overall Scope and Services and Budget (Task 6, Sub-task 6.4)

We understand that the scope of Subtask 6.4 is to refine and evaluate possible subsidence management alternatives. There are 20 identified tasks for this scope. While it is not clear how many of these 20 identified tasks can be completed or will be necessary in the next fiscal year, Chino recommends only budgeting through Subtask 6.4.10 at this time. This will bring the evaluation through the development of Subsidence Management Alternative 2 (SMA-2). Evaluation of additional alternatives may be pre-mature at this time as the PX continues to operate and our knowledge of the ground response to groundwater levels continues to improve. Following completion of SMA-2 activities and evaluation by the GLMC, future possible alternatives could be devised for modeling and implementation for future fiscal years.

Response:

The recommended scope of services and budget for sub-task 6.4 has been updated based on the City of Chino's comments.

City of Pomona and Monte Vista Water District by Christopher Coppinger

Comment 1 – Task 1.1. Maintain Extensometer Facilities

Geoscience agrees that site visits for downloads and maintenance should be performed monthly. However, future reports should include fieldnotes or "run sheets" as an appendix to the annual report. It is not clear what maintenance is expected or has been performed in the past. Maintenance requirements may provide data on inherent error in the method and instruments.

Response:

Section 2.1.1 in the Annual Reports of the GLMC list specific maintenance activities performed at the Ayala Park, Chino Creek, and Pomona Extensometer facilities for the reporting year.

Inclusion of field notes as an appendix to the Annual Report should be discussed and recommended by the GLMC.

Comment 2 – Task 2.1. Conduct Quarterly Data Collection from Extensometers; Data Checking and Management

The data download task should overlap with monthly maintenance. Downloads should be occurring with planned site visits.

The cost for task 2.1.4 has increased from the previous year. During the GLMC meetings, WY indicated these increases represented the effort to import extensometer data into the WM database. Access to raw data would allow full review of cost and allow determination of inherent error. Stakeholders should be provided access to the database if they are funding collection of the data and construction of the database.

Response:

Site visits for data download and routine maintenance are performed together. Every effort is made to make field work efficient.

Consistent with the long-standing policy of the Watermaster and the GLMC, all data collected for the GLMP are available to any Party via a Request for Information to the Watermaster.[4]

Comment 3 – Task 3. Basin-Wide Ground-Level Monitoring Program (InSAR)

During the GLMC meetings, Geoscience indicated the review of TerraSAR-X and Sentinel-1A datasets did not support the additional cost of TerraSAR-X data collection. The free TRE Altamira data set showed similar trends as the TerraSAR-X, had better spatial coverage of the Chino Basin than TerraSAR-X, and includes monthly data collection. Additionally, DWR processing and review of the Tre Altamira data set provides additional quality control for the InSAR data.

Since the March GLMC meetings, DWR has modified the SGMA data portal. These modifications have made the Sentinel-1A dataset less accessible. If the Sentinel-1A dataset cannot be reliably obtained, Geoscience recommends continuing InSAR collection as proposed by WY. General Atomic's deliverables should be included in the annual reports as appendices.

Data accessibility should be reviewed next fiscal year and the Sentinel-1A/Tre Altamira dataset adopted once DWR has finalized the data distribution platform.

Response:

Comments noted. The recommendation in this memorandum for the GLMP in FY 2021/22 is to acquire and utilize the TerraSAR-X InSAR estimates of vertical ground motion as provided by General Atomics. The

[4] http://www.cbwm.org/docs/forms/20120229%20Request%20For%20Information%20Form--PDF%20Form%20Version.pdf

acquisition and use of alternative InSAR datasets in the future can be discussed and recommended by the GLMC in FY 2021/22.

Inclusion of General Atomic's InSAR deliverables as an appendix to the Annual Report should be discussed and recommended by the GLMC. Consistent with the long-standing policy of the Watermaster and the GLMC, all data collected for the GLMP are available to any Party via a Request for Information to the Watermaster.

Comment 4 – Task 4. Perform Ground-Level Surveys

Geoscience recommends that all survey deliverables are included as attachments to provide measurement errors and access to data that stakeholders are paying for.

Geoscience agrees with the recommendations in Tasks 4.1 through 4.5. Task 4.6 includes data processing of the survey deliverables.

Response:

Inclusion of survey deliverables as an appendix to the Annual Report should be discussed and recommended by the GLMC. Consistent with the long-standing policy of the Watermaster and the GLMC, all data collected for the GLMP are available to any Party via a Request for Information to the Watermaster.

Comment 5 – Task 4.6. Process, Check, and Update Database

The person days and subsequent cost seem high for this task. Are surveyors able to provide deliverables in a format that would reduce the level of effort? What data processing is required once the survey deliverables are received?

Response:

The level of effort to conduct the GLMP and the associated cost estimates for time and materials are based on several years of experience in conducting the GLMP. The cost estimates represent conservative, best estimates for time and materials to complete each task.

The surveyors provide the survey deliverables in industry-standard electronic formats.

Once the survey deliverables are received, the following activities are executed to process, check, and update the database:

- Reviewing the surveyor's summary report and results.
- Updating and reviewing the time-series of ground-level elevations by benchmark.
- Corresponding with the surveyor to discuss the results, questions, and other information related to the ground-level survey results.
- Preparing GIS shapefiles showing the benchmark location and ground-level elevation change for various time-periods.
- Comparing the benchmark ground-level elevation change for various time-periods against the InSAR results for the same time-periods to check for reasonableness.

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Comment 6 – Task 5.3. Compile and Analyze Data from the 2021/22 Ground-Level Monitoring Program

Data compilation is included in each of the data collection tasks. What additional effort is included with this task?

Response:

In this task, the data is exported from the databases and is mapped, charted, reviewed, and analyzed. The information is used to prepare the figures and tables included in the Annual Report. The level of effort and the associated costs are based on several years of experience. The cost estimates represent conservative, best estimates for time and materials to complete the task.

Comment 7 – Task 5.4. Conduct Reconnaissance-Level Subsidence Investigation of the Northeast Area

The data presented does not yet rise to the level of requiring an additional investigation. In prior years, InSAR was incoherent in large parts of the eastern half of the basin. We recommend an additional year of monitoring InSAR data to confirm the trend before committing to further investigation.

Response:

Comment noted. Please see the comments received from the City of Ontario and City of Chino and the responses regarding Task 5.4.

This task has been approved by the Watermaster Board for completion in FY 2021/22.

Comment 8 – Task 6.1. Aquifer System Monitoring

Task 6.1 appears to overlap with data collection efforts in Task 5. The prior year budget should cover data collection and analysis in FY 2020/21, the current proposal should cover FY 2021/22. What additional scope would be included in Task 6.1? Data collection from PX has been included in new maintenance and download tasks.

Response:

There are no "data collection" efforts in Task 5. The data collection efforts proposed in Task 6.1 are specific to wells in the Northwest MZ-1 area. In addition, the data collection efforts proposed in Task 6.1 do not include data collection at the PX, which is included in Task 2.1.

We have revised the text for Task 6.1 for clarity.

Comment 9 – Task 6.3. Document the One-Dimensional (1D) Compaction Models at the MVWD-28 and PX Locations

Geoscience has previously expressed concern with use of 1D models to simulate delayed subsidence (See November 2017 TM entitled *Review of "Task 3 and Task 4 of the Work Plan to Develop a Subsidence Management Plan for the Northwest MZ-1 Area: Development and Evaluation of Baseline and Initial Subsidence – Management Alternatives" Draft Technical Memorandum by Wildermuth Environmental,* *Inc., Dated October 19, 2017).* The 1D model of PX utilizes groundwater elevations exported from the five-layer Chino Basin model and subsidence estimated from InSAR data.

Based on the data provided in the March and April meetings, Geoscience recommends limiting the scope of Task 6.3 to documenting the 1D models that have been already prepared. The 1D models should not be utilized for further efforts until documentation has been provided to stakeholders.

Response:

The intent of Task 6.3 is to document the construction and calibration of the 1D compaction models in a technical memorandum. The model calibration results also include estimates of the *pre-consolidation stress* for each model cell. It is appropriate and efficient to describe these model calibration results, in their entirety, to facilitate understanding and discussion within the GLMC on the pre-consolidation stresses in Northwest MZ-1. The technical memorandum for Task 6.3 will go through the standard review and comment process of the GLMC before starting Task 6.4.

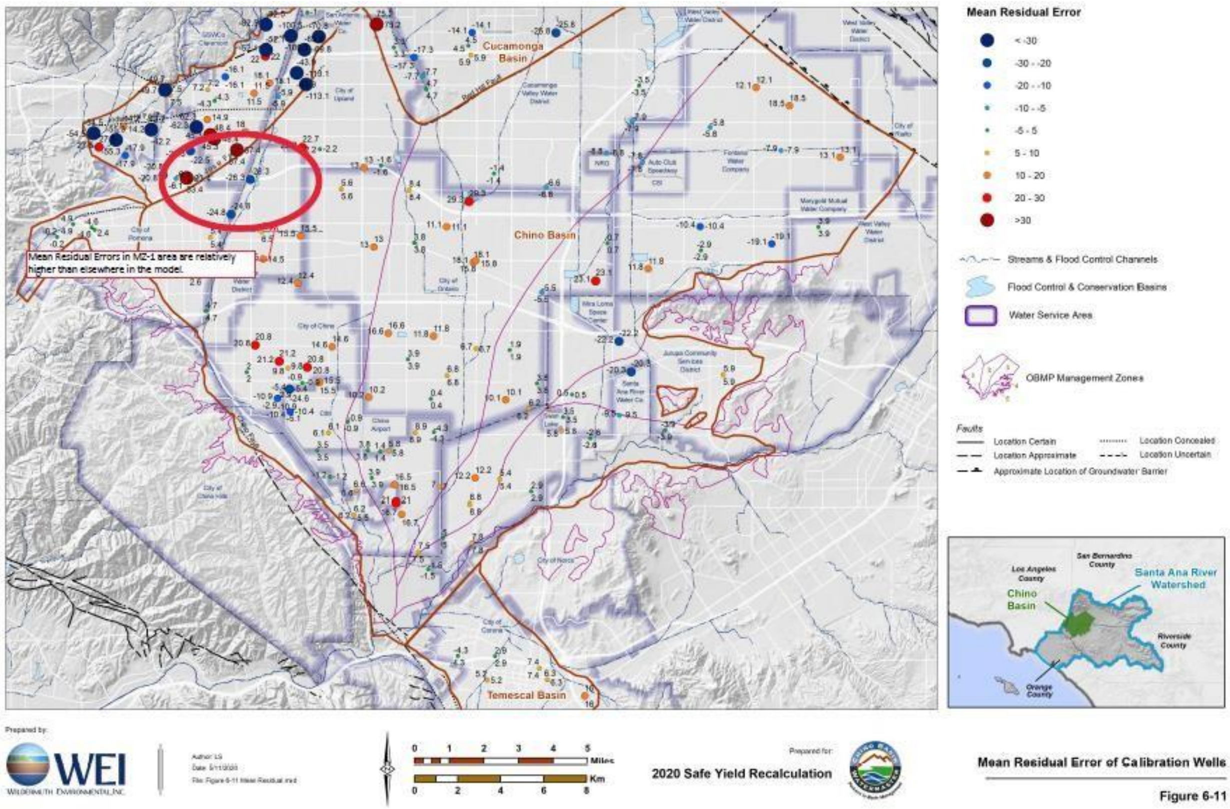
Comment 10 – Groundwater Elevation

Comments to the 2020 Safe Yield update identified a spatial bias in calibration at the Six Basins/Chino Basin Boundary. At the time, WEI indicated that wells in the area are perforated across multiple layers and that estimated water level would be influenced by head in all layers.

Figure 6-11 “Mean Residual Error of Calibration Wells” from the 2020 Safe Yield Recalculation is reproduced below. The Northwest MZ-1 area shows a high mean residual error relative to other parts of the basin.

The PX facility and the planned extended pumping test will provide layer specific groundwater elevation data. Additional calibration efforts or updates to the conceptual model may be required if predicted water levels in the deep PX completions are not consistent with MODFLOW model predicted water level and model predicted changes in water level.

The TM should provide data on the sensitivity of estimated pre-consolidation stress and other model based subsidence estimates to variation in layer specific model-simulated heads.



Response:

In our professional opinion, the Chino Valley Model (CVM) is sufficiently calibrated to be used as input data for the calibration of the 1D models. The CVM exhibits “very good” calibration across the Chino Basin and reproduces the behavior of historical groundwater levels. In Northwest MZ-1, the mean residual errors at wells are higher compared to some other areas of the basin, but are the same as in other areas, and have been deemed acceptable in model calibration and for the use of the model in the Safe Yield Reset. We recently performed an exercise of model validation in Northwest MZ-1 by comparing recently measured heads at the depth-specific PX piezometers (2019-2020) versus model-generated heads by model layer at the PX site at the end of the calibration period (2018).

The head data that is being collected at the PX piezometers will be valuable data for the future recalibrations of the CVM and the 1D model. However, we advise that those recalibration efforts and expenses are best planned for 5-10 years from now, when the data set is long enough to justify the recalibrations.

Sensitivity analyses for the 1D compaction models should be discussed by the GLMC and added to the scope of work if agreed upon by the GLMC.

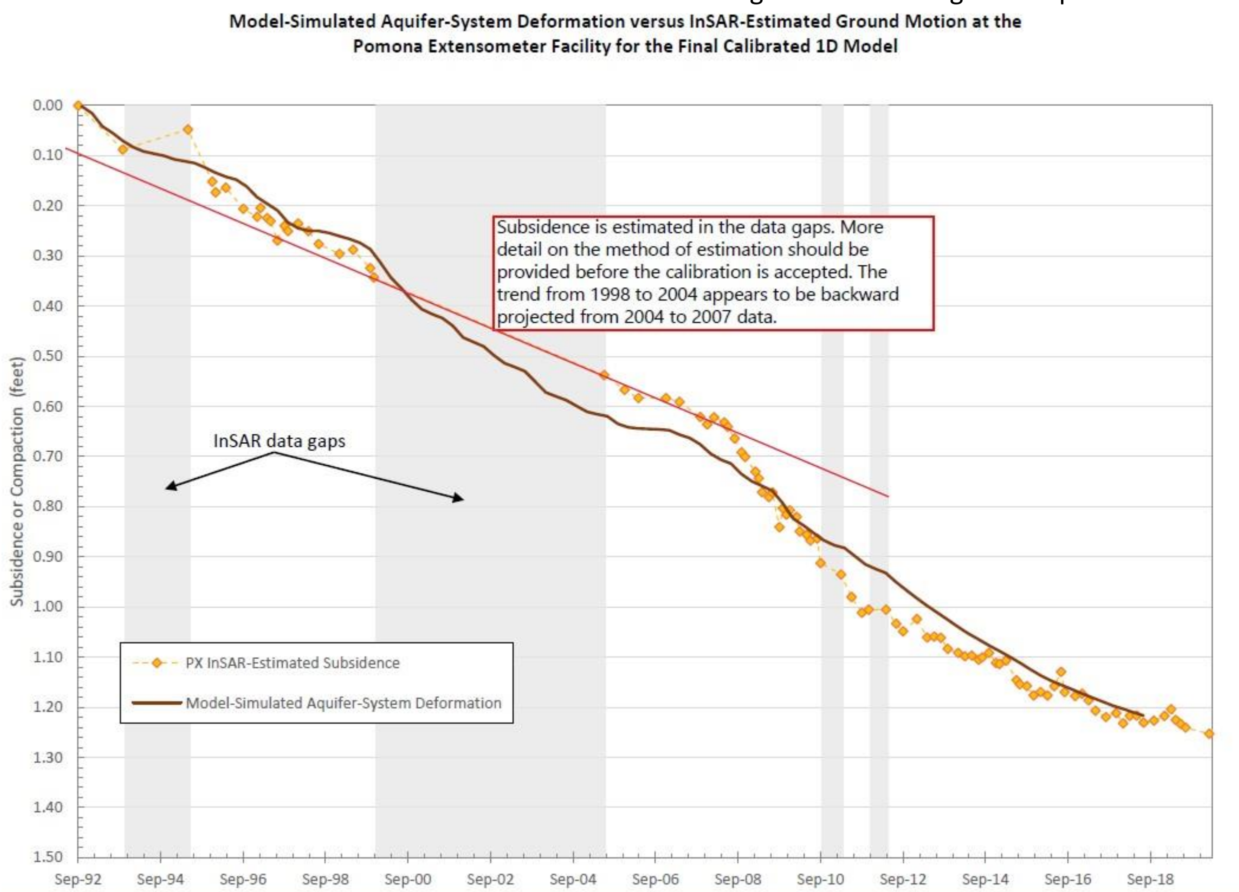
Comment 11 – InSAR-Estimated subsidence and Model-Simulated Aquifer System Deformation

During the March 4 meeting, WY presented InSAR-Estimated subsidence and Model-Simulated Aquifer System Deformation for the PX 1D model. InSAR data gaps were shown, with the InSAR-Estimated Subsidence projected through the data gaps. WY did not provide the method used to estimate subsidence in the data gap. Additional detail on the method should be provided before the calibration is accepted. The prediction trend appears to be backward projected from September 2004 to late 2007 levels.

If possible, the InSAR data should be compared to land level survey data. GLMC was not conducting ground level surveys in Northwest MZ-1 throughout the 1992 through 2018 period. However, there are Los Angeles County Department of Public Works Survey Division (LADPW) leveling circuits near the PX facility, with the closest benchmark approximately 700 ft away. The LADPW surveys are not conducted to the same accuracy as the GLMC leveling surveys, but the historical data may provide an additional check to InSAR estimated subsidence.

The Model-Simulated deformation vs InSAR-Estimated ground motion figure is reproduced below.

The Model-Simulated deformation vs InSAR-Estimated ground motion figure is reproduced



Response:

The GSSI comments and questions are not related to the recommended scope of work, but are intended for consideration in constructing, calibrating, and documenting the 1D compaction models at the MVWD-28 and PX locations. The comments are noted.

A description of the methods used to account for gaps in the InSAR record will be included in the technical memorandum for Task 6.3.

The *Task 3 and Task 4 of the Work Plan to Develop a Subsidence Management Plan for the Northwest MZ-1 Area: Development and Evaluation of Baseline and Initial Subsidence – Management Alternatives,* describes the effort by WSP USA (former surveyor for the GLMP) to validate the InSAR-derived estimates of vertical ground motion in Northwest MZ-1 using historical ground-elevation data from repeated leveling surveys performed by the National Geodetic Survey (NGS) and the Metropolitan Water District of Southern California (MWD). At the time of the investigation, the NGS and MWD survey data were the most accurate and best available historical estimates of vertical ground motion in Northwest MZ-1. These estimates were also used to check the reasonableness of the 1D compaction model at MVWD-28, which utilized the InSAR-derived estimates of vertical ground motion at one specific location as calibration targets.

The use of the LADPW survey data referenced by Geoscience should be discussed by the GLMC and added to the scope of work if agreed upon by the GLMC.

Comment 12 – Task 6.4. Refine and Evaluate the Subsidence-Management Alternatives

WY proposes using the 1D compaction models to update the Baseline Management Alternative (BMA) and Initial Subsidence Management Alternatives developed in Task 3 and Task 4 of the 2015 work plan.

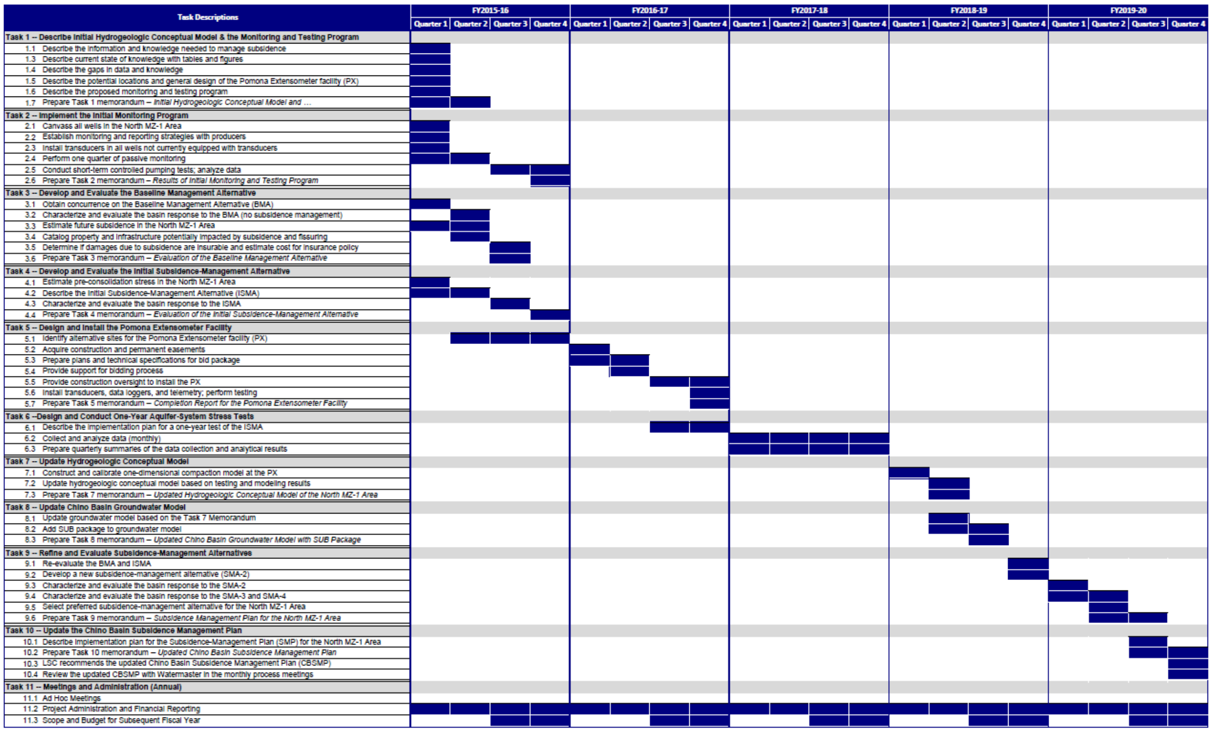
The 2015 workplan anticipated construction of the PX-1 Facility in FY 2016-17, updates to the conceptual model, and updates to the groundwater model before BMA is revaluated.

Construction of PX-1 was significantly delayed. Development of the deep completions took place in February and March of 2019 according to the Draft Well Completion report (WEI 2020). At the time of this memo, details of the installation of instruments and final completion of the extensometer facility are not available on Watermaster's website. Data presented during the March 4 meeting suggests transducer data has been loaded into Watermaster's database since at least December 2020.

Geoscience recommends that the committee consider the planned data collection and long-term pumping test before the conceptual model is revisited. Significant effort was expended to install a monitoring system in Northwest MZ-1. Data should be collected from the monitoring system to inform the modeling effort.

The 2015 schedule is reproduced below.

Table 4-1
Schedule
Work Plan to Develop a Subsidence-Management Plan for the North MZ-1 Area



Schedule.xlsx --NorthMZ-1WorkPlan_Schedule
5/5/2015

Land Subsidence Committee

Response:

The 2015 workplan is a planning document that described a step-wise plan to develop subsidence management criteria for Northwest MZ-1. However, the workplan and the Subsidence Management Plan also envisioned that the GLMC would analyze the data generated by the monitoring program each year and recommend the logical next steps for the subsequent year(s). For example, the GLMC is now recommending the use of 1D compaction models instead of the SUB package in MODFLOW to develop and test subsidence management strategies.

In our opinion, the CVM and the 1D compaction models are calibrated and ready to be used to estimate the pre-consolidation stress and provide guidance to the Stakeholders on pumping and recharge strategies to avoid the future occurrence of land subsidence in Northwest MZ-1. Continued data collection is also recommended to support future updates and improvements to the CVM and 1D compaction models.

The most prudent path forward is to:

1. Utilize the 1D models to develop estimates of the pre-consolidation stress in Northwest MZ-1.
2. Utilize the 1D models to test the future pumping and recharge plans of the Parties and estimate the potential for the future occurrence of land subsidence.
3. Develop Guidance Criteria to assist all Stakeholders in their groundwater management and water-supply planning efforts, basin-wide.
4. Update the Chino Basin Subsidence Management Plan based on the above.
5. Continue the monitoring program, including the collection of head and extensometer data at the PX.

6. Utilize the monitoring data in 5-10 years to update the CVM and the 1D models and, potentially, adapt the Guidance Criteria and the Subsidence Management Plan if appropriate.

Comment 13 – Task 7. Meetings and Administration

Geoscience recommends documentation in Task 6.3 be released to allow one of the scheduled meetings to include discussion of the 1D model.

Response:

A draft of the TM for Task 6.3 will be released for review and comment by the GLMC. A GLMC meeting will be held to review the draft TM. A final TM will be prepared that addresses the comments received by the GLMC members. Please see Task 6.3.2 in Table 1 – Work Breakdown Structure and Cost Estimates Ground-Level Monitoring Program: FY 2021/22 (Draft 3).

Comment 14 – Comparison of the Sentinel-1A and TerraSAR-X InSAR datasets across the Chino Basin

WY's review of the Sentinel-1A and TerraSAR-X datasets was provided as an attachment to the FY2021/22 budget. Geoscience has the following comments:

1) In prior versions of the SGMA Data Viewer, it appeared that monthly ground motion displacement was provided by DWR. Was WY able to download these data? Are they consistent with WY calculations?
2) It appears Sentinel-1A data is collected at twice the frequency as TerraSAR-X data. Is this the case? If so, is there benefit to the more frequent data collection? In 2017 communication regarding other basins, NevaRidge staff indicated more frequent data collection reduced error caused by crop growth and other seasonal activity. Is this still the case?
3) The Sentinel-1A data undergoes QC and calibration review by DWR. These efforts are documented and available to stakeholders through the DWR web portal. Is the TerraSAR data subject to the same reviews? Are the reviews available to stakeholders?
4) Sentinel-1A data has significantly higher coherence. Is there benefit to InSAR data at the Chino Creek facility?
5) Direct subtraction of the displacement rasters would allow a more precise comparison than the side-by-side graphic comparisons.
6) Without specifying the accuracies of other sources of data used in this analysis, it is unclear that increased accuracy is necessary. More information is needed to define what accuracy is acceptable and determine if the higher resolution/accuracy of the TerraSAR-X dataset is imperative to identifying risk to infrastructure and calculating better calibration targets for a model.

Geoscience's initial recommendation was to utilize the DWR provided Sentinel-1A data. However, recent changes to the SGMA Data Viewer made the data inaccessible. DWR indicates that the functionality will return shortly. Due to these changes, Geoscience now recommends proceeding with TerraSAR-X data as proposed by WY and reviewing the SGMA data viewer platform in fiscal year 2022/23.

Response:

These comments are noted and can be re-evaluated during the preparation of the *Recommended Scope of Services and Budget of the Ground-Level Monitoring Committee for Fiscal Year 2022/23,* at future GLMC meetings, or at requested ad-hoc meetings with the technical members of the GLMC.

No change has been made to the scope of services or budget (Task 3).

Attachment A

Comparison of the Sentinel-1A and TerraSAR-X InSAR Datasets Across the Chino Basin

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TECHNICAL MEMORANDUM

DATE: February 26, 2021

Project No.: 941-80-20-21
SENT VIA: EMAIL

TO: Ground-Level Monitoring Committee

FROM: Michael Blazevic, PG, CHG

REVIEWED BY: Andy Malone, PG

SUBJECT: Comparison of the Sentinel-1A and TerraSAR-X InSAR Datasets Across the Chino Basin

BACKGROUND AND OBJECTIVES

Since the inception of the Ground Level Monitoring Program (GLMP), the Chino Basin Watermaster (Watermaster) has employed various methods to monitor vertical ground motion via extensometers, traditional ground-level surveys, and the remote-sensing technique of Interferometric Synthetic Aperture Radar (InSAR). Analysis of these data over time has shown that InSAR is increasingly a reliable and accurate method for monitoring vertical ground motion across most of the areas of subsidence concern in the Chino Basin for the following reasons:

- Improvements in satellite technology over time have increased the spatial resolution, temporal resolution, and accuracy of InSAR; and
- Land-use changes from agricultural to urban have added hard, consistent radar wave reflectors to the ground surface over time. As such, InSAR results are now coherent and useful across most of the areas of subsidence concern.

For the GLMP, the InSAR-derived estimates of vertical ground motion across the areas of subsidence concern are used by the GLMC to:

- Provide an aerially continuous estimation of the occurrence and magnitude of vertical ground motion across the western Chino Basin over time. Monitoring of vertical ground motion via InSAR since 2006 across the Chino Basin helped identify land subsidence and the pattern of concentrated differential subsidence across the San Jose Fault in Northwest MZ-1.
- Identify areas of differential subsidence. Differential subsidence is sometimes indicative of the existence of groundwater barriers (i.e., the Riley Barrier in the Managed Area and the San Jose Fault in Northwest MZ-1); hence, the information derived from InSAR has improved the hydrogeologic understanding of the groundwater basin.
- Provide calibration data for the computer-simulation modeling of aquifer-system deformation and land subsidence across the Chino Basin. Specifically, Watermaster's Engineer is updating the Chino Valley Model (CVM) by adding a subsidence package (SUB) to

the MODFLOW model so that it can be used to simulate historical and potential future land subsidence across Northwest MZ-1. The SUB package will be calibrated across Northwest MZ-1 using the InSAR estimates of historical vertical ground motion.

Since 2011, the GLMC has chosen to acquire and use a single Synthetic Aperture Radar (SAR) scene from the TerraSAR-X satellite that covers only the western portion of the Chino Basin. This decision was based on:

- Observations that InSAR-derived estimates of ground motion from 1992-2005 indicated that little if any subsidence had occurred within the eastern portion of the basin; and
- The desire to manage costs for the GLMP. However, it has been shown in the Watermaster's State of the Basin Reports (WEI, 2019)[1] that hydraulic heads have decreased across the central and eastern portions of the Chino Basin since about 2005. Subsidence may have occurred in these areas in response to the declining heads, yet these areas have not been monitored for vertical ground motion since 2009.

There is a new satellite that was launched in 2014 by the European Space Agency, Sentinel-1A, that provides InSAR estimates of vertical ground motion across the state of California, including the entire Chino Basin. InSAR estimates of vertical ground motion from Sentinel-1A are freely available from the California's Department of Water Resources (DWR).[2] As part of the approved scope and budget of the GLMC for FY 2020/21, the GLMC directed the Watermaster Engineer to perform a study comparing the Sentinel-1A and TerraSAR-X InSAR datasets across the Chino Basin. The questions to be answered by the study are:

- Has land subsidence occurred in the eastern portion of Chino Basin during the period 2015 to 2018 as hydraulic heads have declined over this period? If so, what is its magnitude and spatial distribution? Does the GLMC see a concern for land subsidence that would warrant ongoing monitoring of eastern Chino Basin via InSAR?
- Across the western portion of the Chino Basin, how do the estimates of vertical ground motion derived from Sentinel-1A compare with those derived from TerraSAR-X in terms of spatial distribution, magnitude, coherence, and accuracy?
- If the GLMC were to switch to using Sentinel-1A, would the monitoring program be compromised? If so, how?

The purpose of this technical memorandum is to answer these questions and develop recommendations for the GLMC on the potential future uses of the Sentinel-1A and TerraSAR-X InSAR datasets for the GLMP.

METHODS

To answer the questions above, the following methods were used:

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[1] West Yost, formerly Wildermuth Environmental, Inc. (2019). Chino Basin Optimum Basin Management Program, 2018 State of the Basin Report.

[2] SGMA Data Viewer (ca.gov)

- Identify, download, and compile the Sentinel-1A moving annual cumulative displacement InSAR rasters for the entire Chino Basin from the DWR over a three-year period between 2015 and 2018.
- Utilize ArcMap's Spatial Analyst extension to extract monthly vertical ground motion displacements from the moving annual cumulative displacement InSAR rasters.
- Compare various aspects of the Sentinel-1A and TerraSAR-X[3] estimates of vertical ground motion – namely the magnitude of vertical ground motion, coherence, and the spatial resolution of ground motion across the Chino Basin.

RESULTS

Sentinel-1A and TerraSAR-X InSAR Processing Procedures

A brief summary of the InSAR processing procedures used by TRE ALTAMIRA and General Atomics (GA) for the Sentinel-1A and TerraSAR-X InSAR data, respectively, was provided by GA (S. Yarborough, personal communication, January 19, 2021):

Sentinel-1A

- SAR data is processed in large polygons across California. One processing polygon covers the entire Chino Basin.
- Ascending and descending satellite track data are combined to estimate differential vertical ground motion from radar line-of-sight (RLoS) measurements for a given time period.
- Differential vertical ground motion estimates are compared with observations from GPS stations located across California using 100 m radius of motion estimates around each station to derive absolute vertical measurements. For reference, one station is located in the Chino Basin near Rancho Cucamonga.
- Absolute vertical ground motion measurements are projected to 100 m x 100 m grids across each processing polygon and interpolated to regular time intervals (1st day of each month). Any voids are filled by spatial interpolation in each processing polygon. Each grid is an average of all measurements within a single 100 m x 100 m grid, located at the grid center.

For a more detailed description of these processes, see TRE ALTAMIRA (2020).[4]

TerraSAR-X

- The approximate InSAR processing footprint extends from Falling Springs (north) to Villa Park (south) and from La Puente (west) to the Ontario International Airport (east).
- Differential vertical ground motion is measured along the RLoS between each radar collection.
- Vertical ground motion offsets resulting from RLoS errors are removed with a combination of interferometric processing, and a reference patch in an observed stable location in the Chino Basin. The current reference patch is a 750 m x 750 m area, centered approximately

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[3] The TerraSAR-X InSAR rasters between the time-period 2015 and 2018 were readily available for this study as part of the long-term ground motion monitoring conducted for the GLMP.
[4] TRE ALTAMIRA (2020). *InSAR land surveying and mapping services in support of the DWR SGMA program.*

at the intersection of W. Phillips Blvd and S. White Avenue in Pomona, CA. Any vertical motion in the reference patch is assumed to show the constant offset resulting from RLoS errors, and the average value measured across the patch in each differential vertical motion height map is then removed from the vertical motion height map. The normalized differential height maps are then summed to provide a total displacement over the desired time-period.

- Small voids are filled by spatial interpolation in each InSAR frame, providing continuous high-resolution measurements over areas with intermittent signal loss.
- Sequential measurements are summed, providing a normalized total vertical ground motion estimate for a given time period.
- Normalized RLoS measurements are projected to 15 m x 15 m grids. Each grid is an average of all measurements within a single 15 m x 15 m grid, located at the grid center.

Sentinel-1A and TerraSAR-X InSAR Dataset Information

Table 1 lists the basic dataset description and information for the Sentinel-1A and TerraSAR-X InSAR datasets.

Table 1. Sentinel-1A and TerraSAR-X InSAR Dataset Information

Dataset Description	Sentinel-1A	TerraSAR-X
Processor	TRE ALTAMIRA	General Atomics
Current Availability	June 2015 – September 2019	March 2011 – March 2020
Current Coverage	Entire Chino Basin	Western Chino Basin
Current Acquisition Frequency	Monthly	Every Two Months
Spatial Resolution	100 m	15 m
Accuracy	+/- 1.6 cm	+/- 0.8 cm
Cost	Free	$87,000

Sentinel-1A and TerraSAR-X InSAR Observations

It has been shown in the Watermaster’s State of the Basin Reports (WEI, 2019) that hydraulic heads have decreased across the central and eastern portions of the Chino Basin since about 2005. Subsidence may have occurred in these areas in response to the declining heads, yet these areas have not been monitored for vertical ground motion since 2009. For reference, Figure 1 shows the change in groundwater levels for the two-year period between spring 2016 and spring 2018 across the Chino Basin. Groundwater levels have generally remained stable across most of the areas of subsidence concern but have declined up to 10 ft across parts of Northwest MZ-1. East of the areas of subsidence concern, groundwater levels have decreased in the central and northern portions of the basin by about 10 ft.

Figure 2 shows the total vertical ground motion estimated by the Sentinel-1A between June 2015 and May 2018 across the entire Chino Basin. The main observations from Figure 2 are:

- The InSAR coherence is good across the entire Chino Basin.

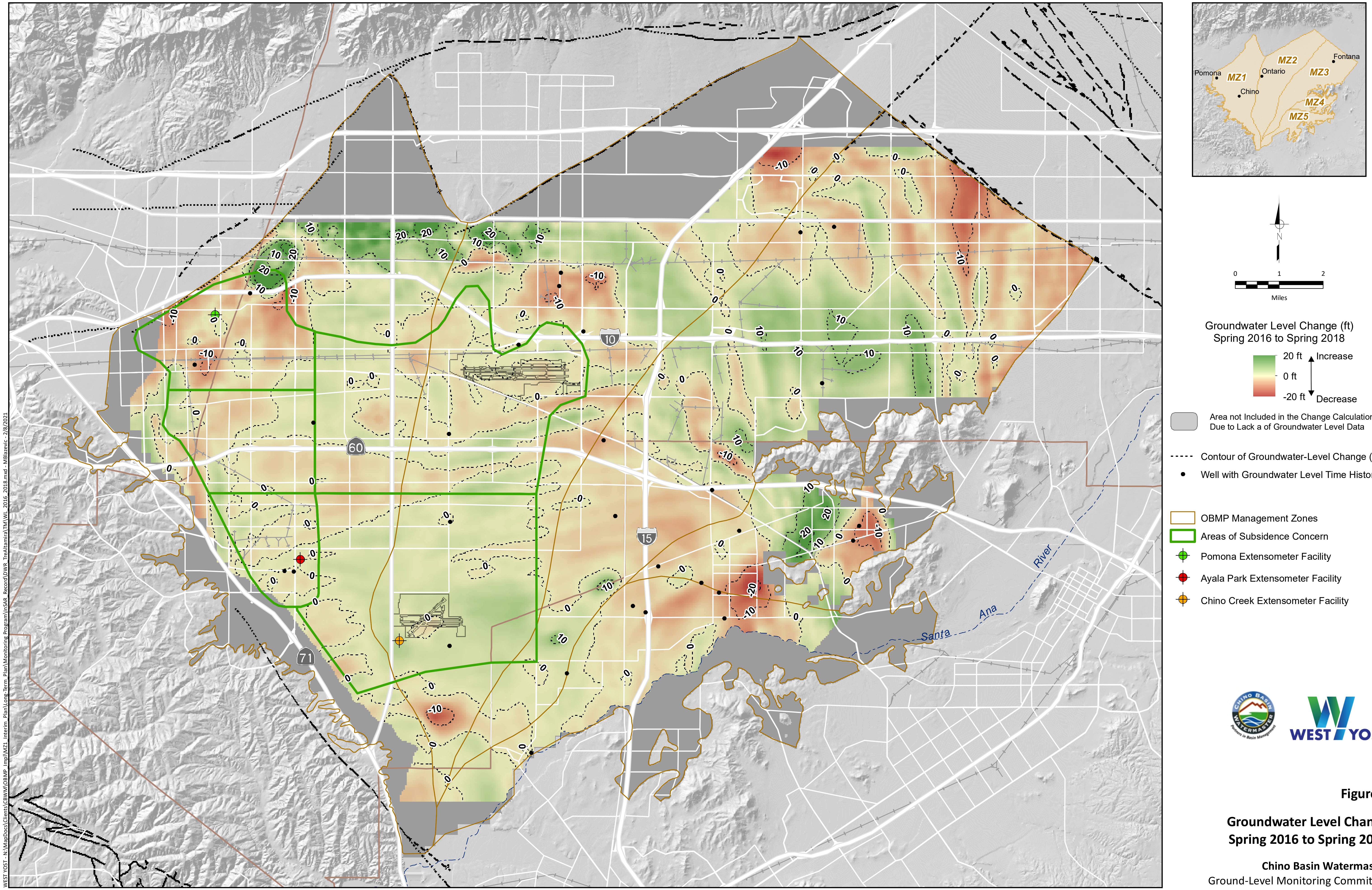

Figure 1

Groundwater Level Change
Spring 2016 to Spring 2018

Chino Basin Watermaster
Ground-Level Monitoring Committee

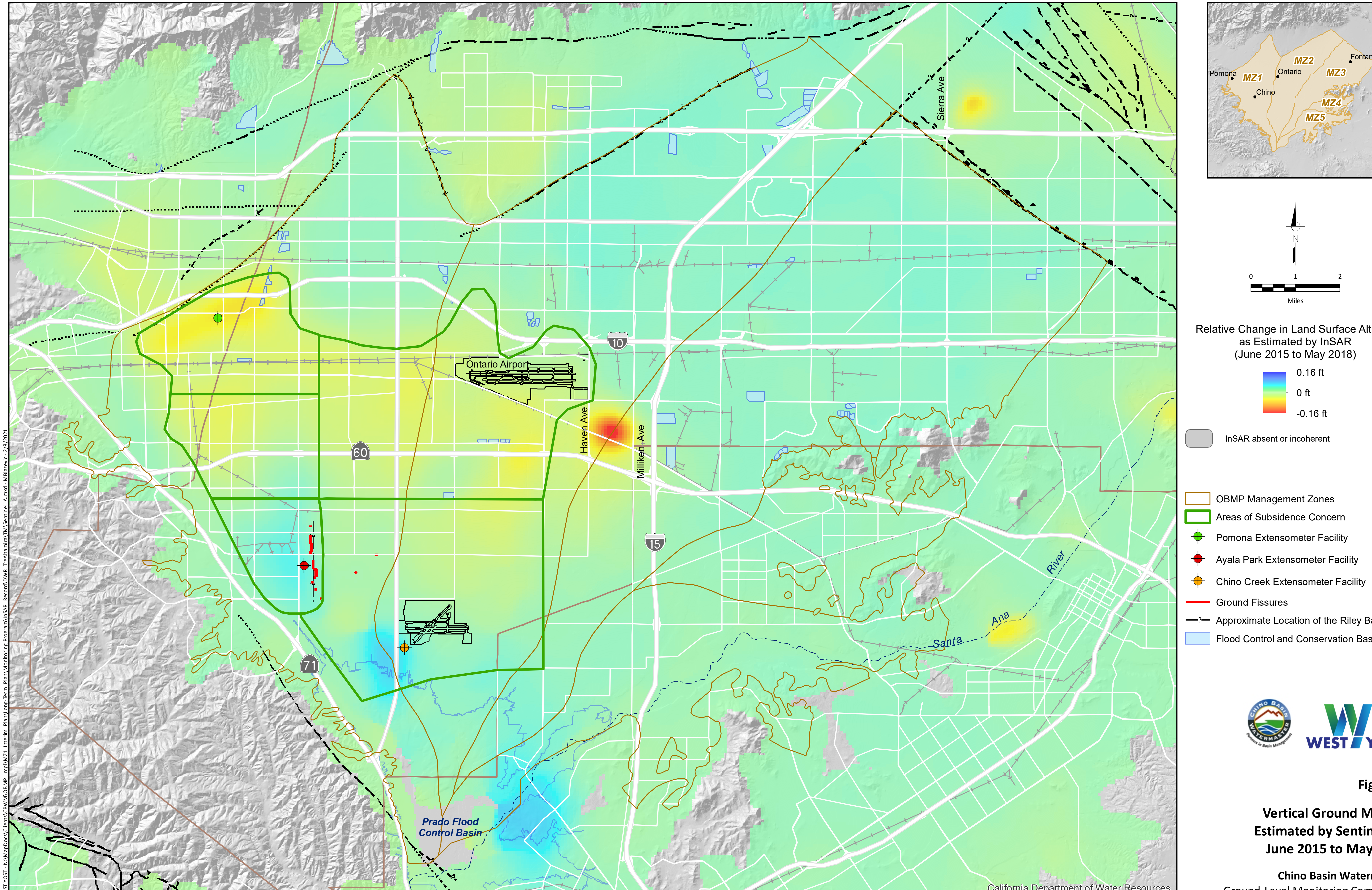

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Figure 2

Vertical Ground Motion
Estimated by Sentinel-1A
June 2015 to May 2018

Chino Basin Watermaster
Ground-Level Monitoring Committee

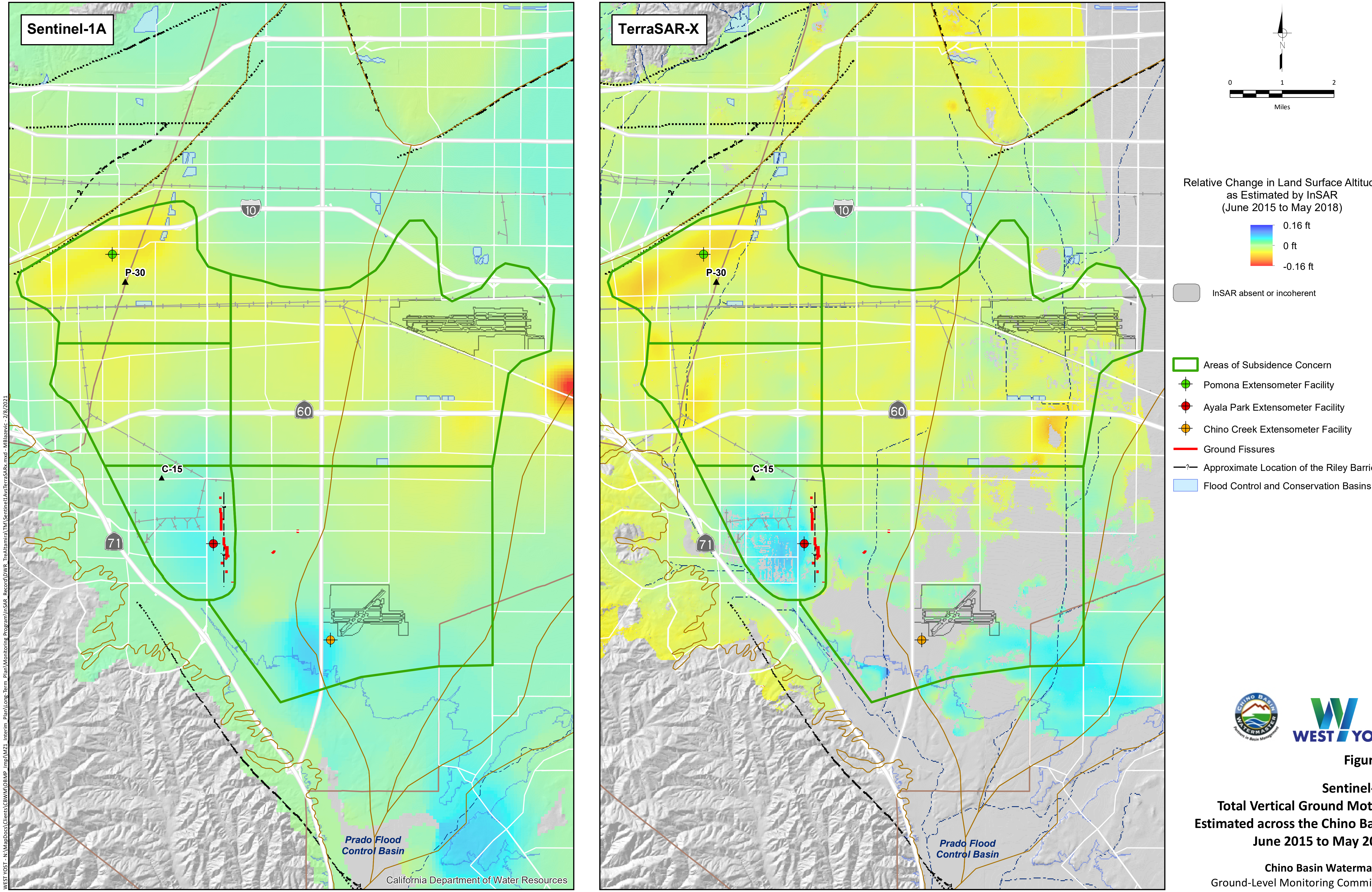
- Estimates of vertical ground motion are mostly downward across the areas of subsidence concern. The spatial pattern of vertical ground motion estimated by the Sentinel-1A is consistent with the long-term ground motion trends measured by the TerraSAR-X and is consistent with the spatial pattern and groundwater level change shown in Figure 1 between 2016 and 2018.
- Estimates of vertical ground motion are mostly upward across the eastern portion of the basin. The spatial pattern of vertical ground motion estimated by Sentinel-1A is not consistent with the spatial pattern and groundwater level change shown in Figure 1 between 2016 and 2018.
- There are focused patterns of vertical ground motion that are not explained by changes in groundwater levels shown in Figure 1. These areas are located just southeast of the Ontario Airport between Haven Avenue and Milliken Avenue, along the Santa Ana River, and just northeast of the intersection of the 210 Fwy and Sierra Avenue. Examination of these areas in Google Earth shows they correspond to recent earthwork construction activities and/or excavation activities.

Figures 3 and 4 show total vertical ground motion estimated across the western Chino Basin between June 2015 and May 2018 from Sentinel-1A and TerraSAR-X. Across the areas of subsidence concern, the main observations are:

- The spatial pattern of vertical ground motion is generally consistent between the two InSAR datasets.
- Between the two InSAR data sets, the spatial resolution of TerraSAR-X is noticeably better and the spatial details of subsidence are better delineated with TerraSAR-X.
- The magnitudes and directions of ground motion are not always consistent between the Sentinel-1A and TerraSAR-X InSAR datasets. InSAR data from TerraSAR-X across the western portion of Central MZ-1, Northwest MZ-1, and Northeast Area show greater magnitudes of downward vertical ground motion compared to the Sentinel-1A InSAR data. Where TerraSAR-X InSAR data is coherent across the southern part of the Managed Area (near Ayala Park), it shows slightly greater upward ground motion compared to the Sentinel-1A InSAR data. Across other parts of the western Chino Basin, the vertical ground motion magnitude and direction estimated by the two satellites is variable and not consistent.

Figures 5 and 6 are time-series charts that compare the hydraulic heads at C-15 and P-30 to vertical ground motion as measured by Sentinel-1A and TerraSAR-X between 2015 and 2018. For reference, the point locations are shown on Figure 3. The main observations and interpretations from Figures 5 and 6 are:

- The Sentinel-1A InSAR data are plotted on a monthly time-step, whereas the TerraSAR-X InSAR data are plotted on a two-month time-step. Because of this, Sentinel-1A InSAR data shows slightly more variability month to month compared to TerraSAR-X InSAR data. Both Sentinel-1A and TerraSAR-X InSAR data generally show a similar pattern of vertical ground motion annually.
- Both Sentinel-1A and TerraSAR-X InSAR data show a persistent downward vertical ground motion trend between 2015 and 2018.
- Sentinel-1A InSAR data shows a consistent pattern of upward ground motion in the fall of each year. This pattern of upward ground motion in the fall of each year is not observed in the TerraSAR-X InSAR data.

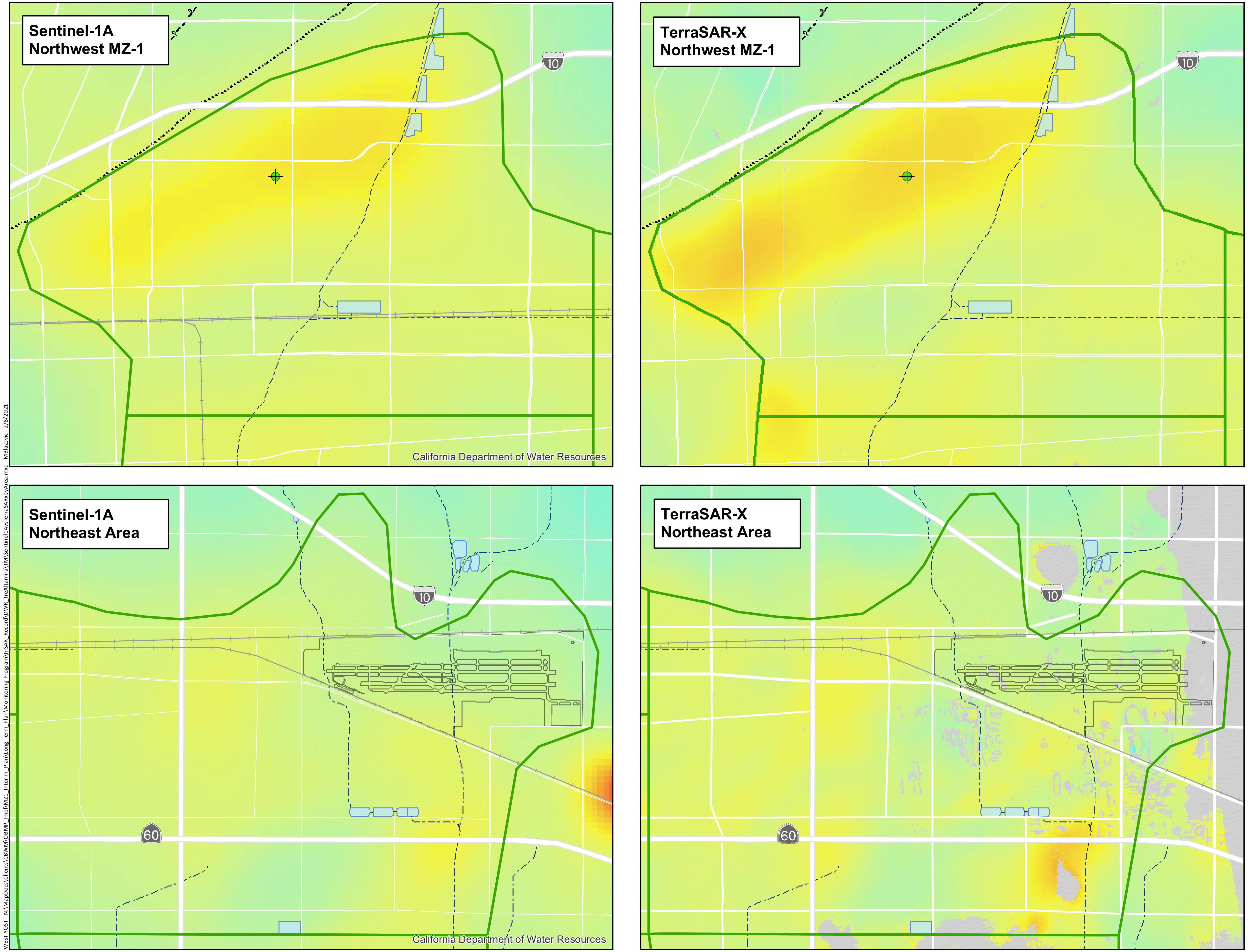


WEST YOST

Figure 3

Sentinel-1A
Total Vertical Ground Motion
Estimated across the Chino Basin
June 2015 to May 2018

Chino Basin Watermaster
Ground-Level Monitoring Committee



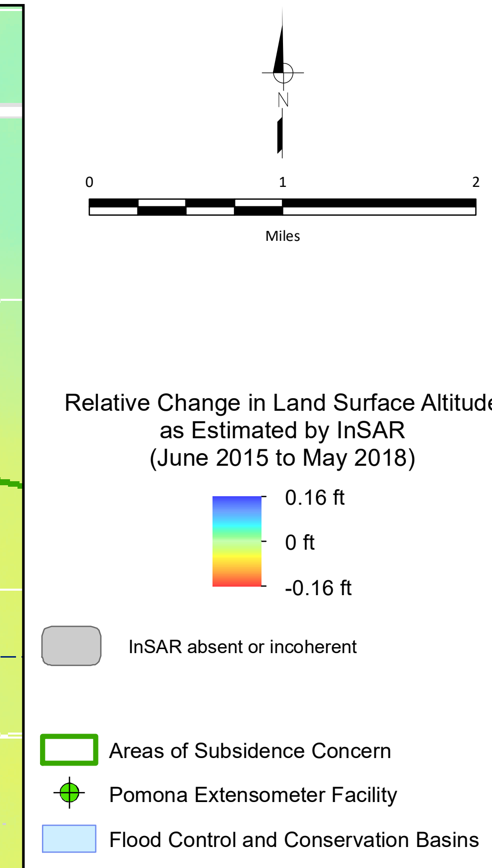


Figure 4

Sentinel-1A Versus TerraSAR-X Total Vertical Ground Motion Estimated across Northwest MZ-1 and Northeast Area June 2015 to May 2018

Chino Basin Watermaster
Ground-Level Monitoring Committee

Figure 5. Cumulative Vertical Ground Motion Displacement Measured by the Sentinel-1A and TerraSAR-X Satellites at City of Chino 15

August 2015 to May 2018

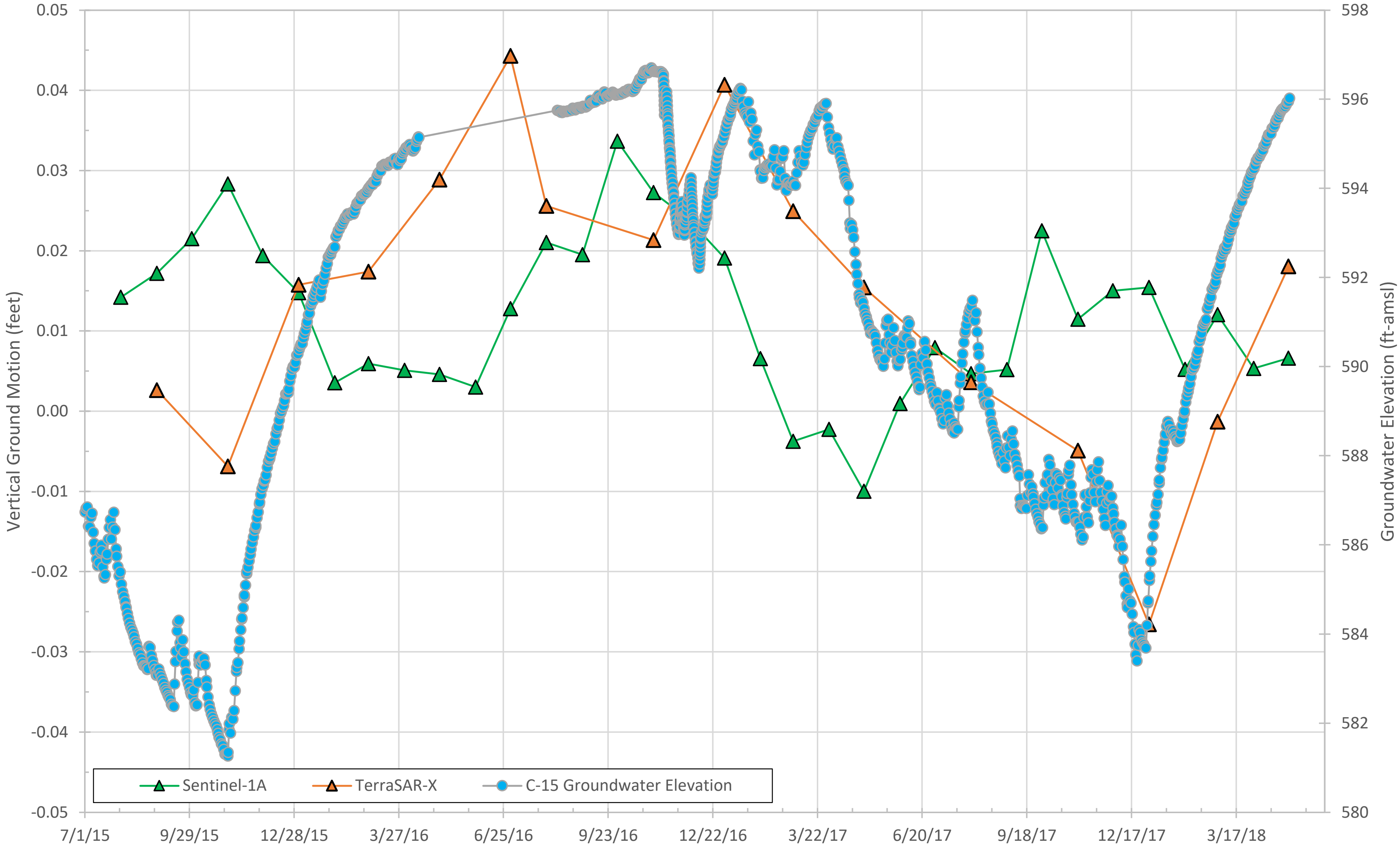
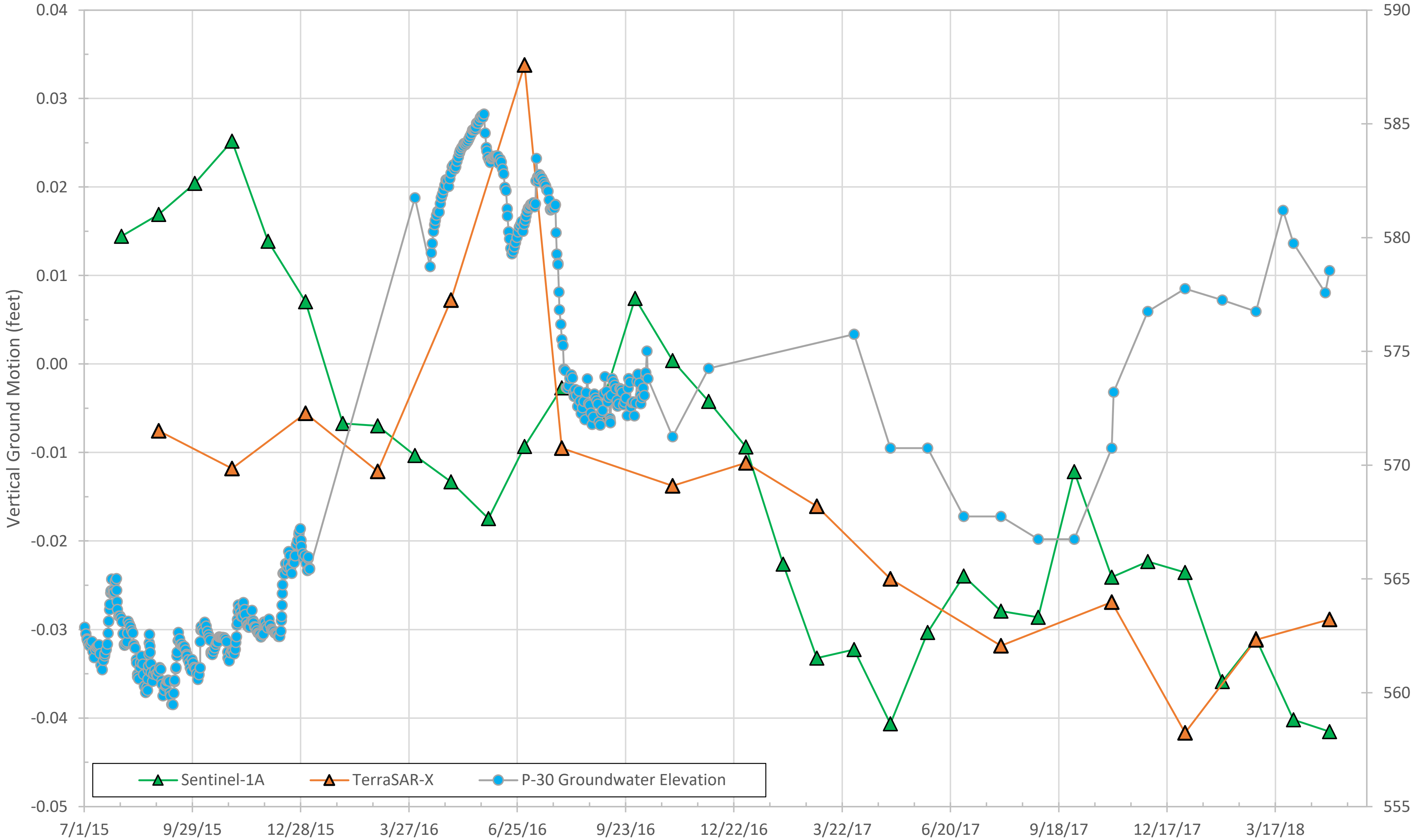


Figure 6. Cumulative Vertical Ground Motion Displacement Measured by the Sentinel-1A and TerraSAR-X Satellites at City of Pomona 30

August 2015 to May 2018



- The vertical ground motion magnitudes measured by the two InSAR data sets at each point location is inconsistent.
- The seasonal fluctuations of hydraulic head at C-15 and P-30 are coincident with the seasonal fluctuations of vertical ground motion measured by the TerraSAR-X InSAR data.
- The seasonal fluctuations of hydraulic head at C-15 and P-30 are not coincident with the seasonal fluctuations of vertical ground motion measured by the Sentinel-1A InSAR data. For example, in Figure 5, there are instances where Sentinel-1A estimates upward vertical ground motion but hydraulic head at C-15 is declining or stable.

One explanation for the limited relationship between the hydraulic head at C-15 and P-30 and the vertical ground motion observed with the Sentinel-1A InSAR data is that the Sentinel-1A grid size (100 m) is much larger compared to the TerraSAR-X grid size (15 m). Likewise, the TerraSAR-X accuracy (+/- 8 mm) is twice that of the Sentinel-1A accuracy (+/- 16 mm). A larger grid size and decreased accuracy will smooth-out the ground displacement magnitude over a larger area and produce less accurate ground motion results at specific point locations.

CONCLUSIONS AND RECOMMENDATIONS

Based on the figures, information, and observations discussed above, we summarize the advantages and limitations of both the Sentinel-1A and TerraSAR-X InSAR data sets in Table 2.

The recommendations from this study are:

- The GLMC should continue using TerraSAR-X for the following reasons:
  - TerraSAR-X InSAR data is available at a higher spatial resolution compared to the freely available Sentinel-1A InSAR data. Higher spatial resolution InSAR can better delineate areas of subsidence and better identify areas of differential subsidence. High-resolution InSAR is more appropriate over urban areas, such as the Chino Basin, where the finer detail can identify risk to infrastructure, characterize rapidly developing small features which may lead to ground fissures, and more accurately depict the depth and spatial extent of broad subsidence features.
  - TerraSAR-X InSAR data is purchased at higher vertical accuracy compared to the feely available Sentinel-1A InSAR data. For subsidence model calibration purposes, the TerraSAR-X InSAR data will provide more accurate calibration targets for vertical ground motion compared to the Sentinel-1A InSAR data. The vertical ground motion estimated by TerraSAR-X has shown to be coincidental with changes to hydraulic heads (see Figures 5 and 6). For the areas of subsidence concern, this relationship indicates hydraulic heads, which are controlled by the pumping and recharge stresses in the area, have at least some control on the pattern and rate of subsidence and that the information could be used as management criteria to protect against the future occurrence of land subsidence.
  - TerraSAR-X InSAR data has been collected for the GLMP since 2011. The GLMC is also in the process of developing a Subsidence Management Plan for Northwest MZ-1. To maintain continuity of the InSAR record during development and completion of the Northwest MZ-1 Subsidence Management Plan, it is recommended the GLMC continue

to use TerraSAR-X InSAR data, at least until the Northwest MZ-1 Subsidence Management Plan is completed.

- Based on the spatial pattern of vertical ground motion estimated by Sentinel-1A between 2015 and 2018 across the eastern Chino Basin, there is no immediate need to monitor vertical ground motion across the eastern Chino Basin. The GLMC could evaluate using the freely available Sentinel-1A InSAR data about once every five years to check for vertical ground motion trends across the eastern Chino Basin.

Table 2. Sentinel-1A and TerraSAR-X Advantages and Limitations

Criteria	Sentinel-1A	TerraSAR-X
Spatial Coverage	Coverage for the entire Chino Basin.	The GLMP only purchases InSAR for the western Chino Basin.
Spatial Resolution	Published to the DWR SGMA Data Viewer at a spatial resolution of 100 m.	Processed by GA at a spatial resolution of 15 m.
Vertical Accuracy	Published to the DWR SGMA Data Viewer at an accuracy of +/- 16 mm.	Processed by GA at an accuracy of +/- 8 mm.
Acquisition Frequency	Monthly.	Bimonthly (every two months).
Period of Record	As of December 2020, the InSAR is available for the time-period between June 2015 and September 2020.	The InSAR has been used by the GLMP since 2011 and is currently available through March 2020.
Continuity	The frequency at which new InSAR scenes will be available through the DWR SGMA Data Viewer is unknown.	The GLMP collects InSAR on a year-round basis in order to maintain continuity in the InSAR record from year-to-year.
Cost	The InSAR is freely available through the DWR SGMA Data Viewer website. There would be associated costs to download, re-project, and load the rasters to ArcMap for viewing and analysis.	The InSAR is ordered, purchased, and processed by GA each fiscal year. The cost is $87,000 and includes time by the Watermaster Engineer to review the InSAR deliverables with GA and load the InSAR rasters to ArcMap for viewing and analysis.

Appendix B

Response to GLMC Comments

STATE OF CALIFORNIA DEPARTMENT/JOHN WOOD GROUP PLC (RICHARD REES, PG, CHG)

Comment 1 – Northeast Area and InSAR

Regarding the InSAR estimated persistent downward ground motion concentrated area south of the Ontario Airport between Vineyard Avenue and Archibald Avenue, this area appears to be in the general vicinity of the Whispering Lakes Golf Course. We suggest reviewing historical aerial photographs of this area for borrow pits that may have been filled in the last five to seven years. Settlement of backfill materials could be interpreted as subsidence.

Response:

Thank you for your comment. In FY 2021/22, we plan to conduct a reconnaissance-level subsidence investigation of the Northeast Area (see Task 5.4 in the technical memorandum, *Recommended Scope of Services and Budget of the Ground-Level Monitoring Committee for Fiscal Year 2021/22)*. As part of the investigation, we will include a review of historical aerial photographs and land use changes for the area south of the Ontario Airport between Vineyard Avenue and Archibald Avenue.

CITY OF CHINO/GEOPENTECH (ERIC FORDHAM, PG, CEG, CHG)

Comment 1 – Section 3.1 Managed Area and Figure 3-2

The influence of recycled water use in the Managed area is referenced several times in this section and on the associated figure as it relates to the possible contribution to observed increases in groundwater levels. Though, it is not clear if the influence of recycled water use on increasing groundwater levels is being attributed to its in-lieu use of pumping from the shallow and deep aquifer or due to actual infiltration recharge to the aquifer. Actual wet water recharge would only directly influence groundwater levels in the shallow aquifer. Some additional discussion should be added to clarify this observation.

Response:

Thank you for your comments and suggestions. The text was updated, where appropriate, to address this comment.

Comment 2 – Section 3.4.2 Horizontal Ground Motion

The charts for B-409 to B-408 (N-S Strain), B-407 to B-406 (E-W Strain) and B-406 to B-405 (E-W Strain) show a slight trend with deviations away from 0 of up to about 5x10-5 (L/L) that could be expressing horizontal movement over the monitored time period. While the text explains the deviations as tensile strain that are within the range observed between other benchmarks, some additional explanation for the apparent recorded trends suggesting ongoing movement should be provided.

Response:

Thank you for your comments and suggestions. As stated in the report and comment, tensile strain has been calculated between benchmarks (B-409 to B-408). Its recognized the observed tensile strain may be real or may be the result of EDM survey noise. Future EDM surveys that cross the San Jose Fault will continue to be conducted at a frequency determined by the GLMC during the scope and budget planning process for FY 2022/23.

Recognize its real tensile strain, or noise.

Comment 3 – Section 4.0 Conclusions and Recommendations

This section should include concluding statements on the adequacy of the current monitoring program to address Program Elements 1 and 4 of the OBMP Implementation Plan that have been implemented within the different management zones. This should be followed with the recommendations for additional studies and planning to further characterize, monitor and plan land subsidence in the various management zones of the Chino Basin.

Response:

Thank you for your comments and suggestions. The text was updated, where appropriate, to address this comment.

MONTE VISTA WATER DISTRICT (JUSTIN SCOTT-COE, GENERAL MANAGER)

Comment 1 – Figure 3-11

During the September 30, 2021 meeting of the GLMC to discuss the draft 2020/21 Annual Report, Mr. Scott-Coe verbally recommended revisions to Figure 3-11. The recommended revisions included adding clarification to the figure's legend items and adding quarterly recharge from Northwest MZ-1 to the figure.

Response:

Figure 3-11 was updated in the final report.

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