FINAL REPORT | NOVEMBER 2022

2021/22 Annual Report of the Ground-Level Monitoring Committee

PREPARED FOR

Ground-Level Monitoring Committee

PREPARED BY

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Ground-Level Monitoring Committee

Project No. 941-80-22-26

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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 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. Figure 1-1 shows the locations of these fissures and the land subsidence that contemporaneously occurred in this area. Several scientific studies of the area 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 collection of basin-wide data to characterize land subsidence, including ground-level surveys and remote-sensing (specifically, interferometric synthetic aperture radar [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 to analyze land 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 the ground motion.

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. Figure 1-2 shows the location of the Ayala Park Extensometer. 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.
- During the development of the IMP, a previously unknown barrier to groundwater flow was identified, shown on Figures 1-1. 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 consisted of:

- A list of “Managed Wells” subject to the Guidance Criteria. Table 1-1 is a list of the Managed Wells that are subject to the Guidance Criteria. Figure 1-2 is a map that shows the locations of the Managed Wells. These wells have well screens that cross the deep aquifer-system.

Table 1-1. Managed Wells Screened in the Deep Aquifer and Subject to the Guidance Criteria[a]				
Well Name	CBWM ID	Owner	2022 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		Abandoned	270-400; 626-820
CH-1B	600487	City of Chino Hills	Inactive[e]	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		Active	360-440; 480-900
CH-16	600489		Inactive	430-940
CH-17	600499		Inactive	300-460; 500-680
CH-19	600500		Inactive	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 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 in PA-7 falls below the Guidance Level, Watermaster recommends that the MZ-1 Parties curtail their pumping from designated Managed Wells as required to maintain hydraulic heads above the Guidance Level.
- Monitoring/reporting of hydraulic heads at PA-7. Watermaster was to provide the MZ-1 Parties with real-time hydraulic head 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 at 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 heads 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 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 heads at PA-7 remain 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/docs/legaldocs/Peace_Agreement.pdf.

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.

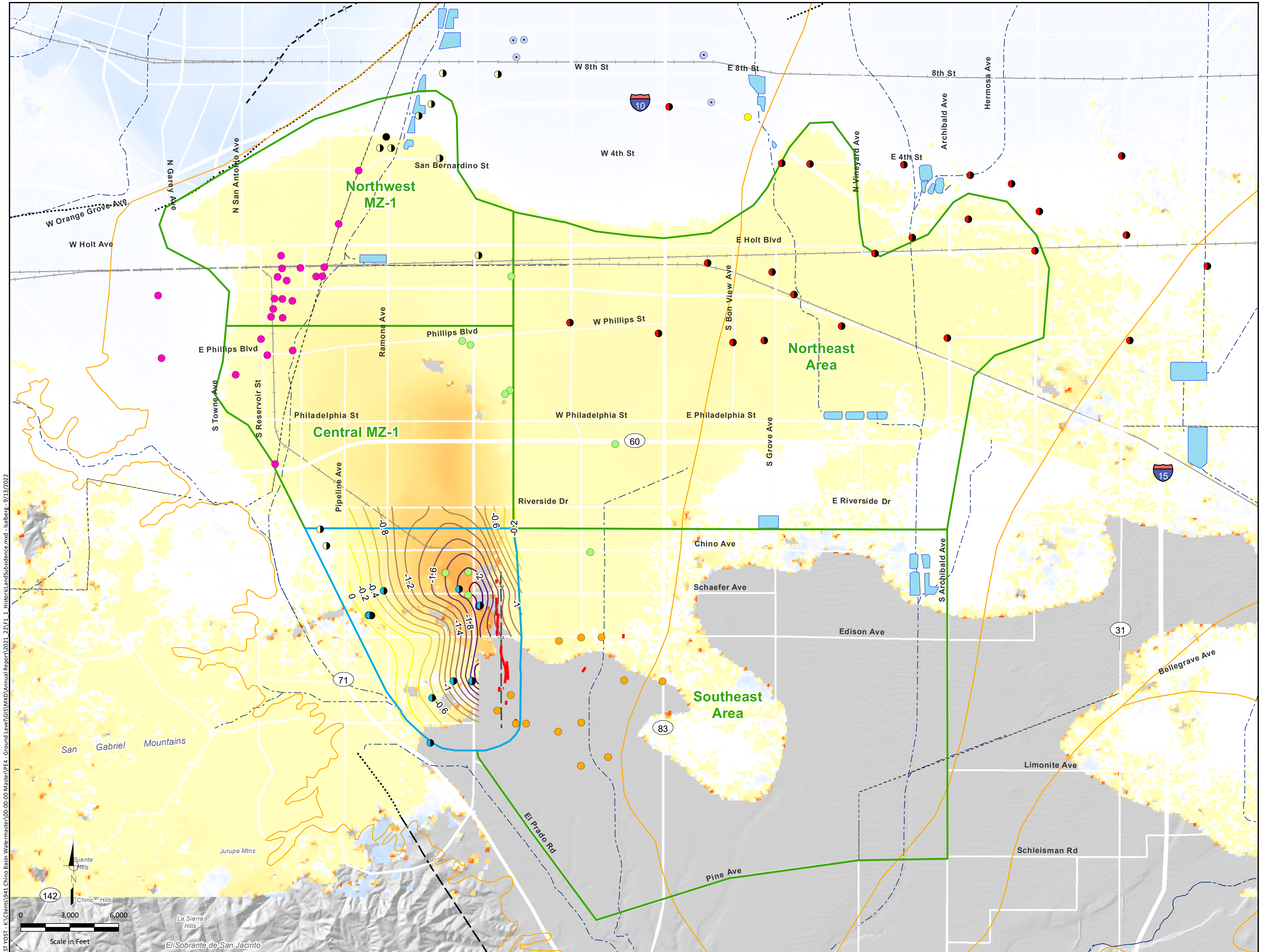
1.1.6 Annual Report of the Ground-Level Monitoring Committee

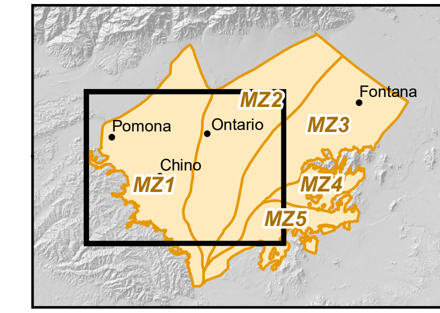
Pursuant to the Subsidence Management Plan, Watermaster prepares an annual report containing the results of ongoing monitoring efforts, interpretations of the data, and recommended adjustments to the Subsidence Management Plan, if any. This Annual Report of the GLMC includes the results and interpretations for the data collected between March 2021 through March 2022, as well as recommendations for Watermaster's GLMP for FY 2022/23.

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 2021 and March 2022.
- **Section 3.0 – Results and Interpretations.** This section discusses and interprets the monitoring data collected between March 2021 and March 2022, 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 2021 and March 2022 and describes recommended activities for the GLMP for FY 2022/23.
- **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.





Contours of Relative Change in Land Surface Elevation as Measured by Leveling Surveys 1987 to 1999

0.0 ft

-2.2 ft

Relative Change in Land Surface Elevation as Measured by InSAR Oct-1993 to Dec-1995

+1 ft

0

-1 ft

InSAR absent or incoherent

Active Pumping Wells by Owner: 1987 to 1999

- CA Institution for Men
- City of Chino
- City of Chino Hills
- City of Ontario
- City of Pomona
- City of Upland
- Golden State WC
- Monte Vista WD
- San Antonia WC

Managed Areas

- Managed Area
- Areas of Subsidence Concern

Other Features

- Flood Control and Conservation Basins
- Fault (solid where accurately located; dashed where approximately located or inferred; dotted where concealed)

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Figure 1-1

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

Chino Basin Watermaster
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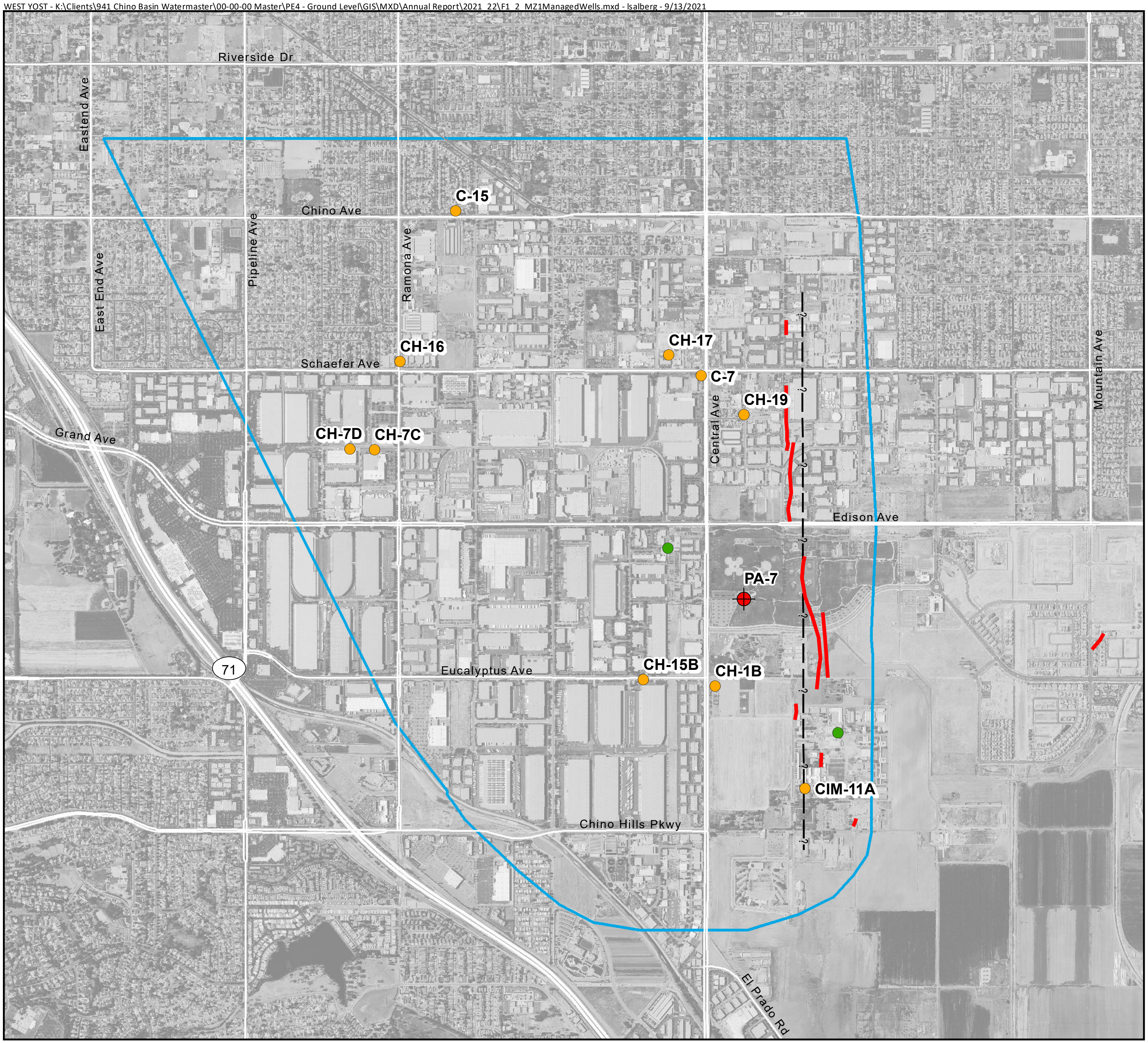

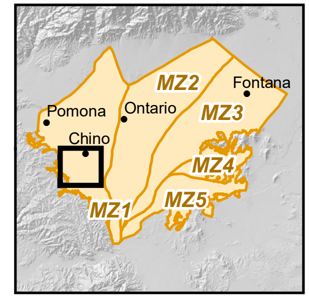

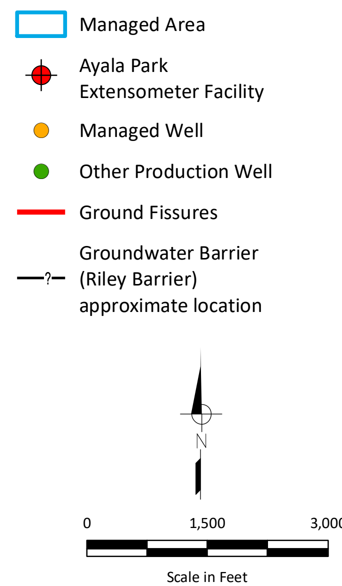

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Figure 1-2

MZ-1 Managed Area and the Managed Wells

Chino Basin Watermaster
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2.0 GROUND-LEVEL MONITORING PROGRAM

This section describes the activities performed by Watermaster for the GLMP between March 2021 and March 2022.

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 2021 and March 2022 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. Noteworthy activities performed during the reporting period included:
  - Replaced the 12 volt deep-cycle battery for the Piezometer C (PC) vault at the Ayala Park Extensometer Facility.
  - Replaced the 12 volt deep-cycle battery for both PX Facility vaults to ensure power to the datalogger and continuous data collection.
  - Checked and maintained the sump pump in the PA vault at Ayala Park to ensure that infiltrating irrigation or storm waters that periodically flood the vault are evacuated.
- The following activities were performed in attempts to improve the reliability of aquifer-system deformation monitoring data collected at the PX Facility:
  - Installed a dial gauge to measure aquifer compression at PX 2-4.
  - Updated the Loggernet code for the extensometer data at the PX facility.

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 sections (2.1.2.1 through 2.1.2.4) describe Watermaster's monitoring activities between March 2021 and March 2022, 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 2021 and March 2022 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. Preliminary depth-specific hydraulic head and aquifer-system deformation data continues to be collected at the Pomona Extensometer Facility. The facility does not appear to be measuring and/or recording reliable data for aquifer-system deformation. An investigation is ongoing into understanding the data and improving the reliability of the measurements.

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] Seven synthetic aperture radar (SAR) scenes were collected between March 2021 and March 2022.

[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.

The scenes were used to create 12 interferograms[4] to estimate short- and long-term vertical ground motion[5] over the following periods (Table 2-1):

Table 2-1. 2021/22 Interferograms

Interferograms Showing Short-Term Ground Motion	Interferograms Showing Cumulative Ground Motion
March 2021 to May 2021	March 2011 to March 2022
May 2021 to July 2021	March 2021 to July 2021
July 2021 to September 2021	March 2021 to September 2021
September 2021 to November 2021	March 2021 to November 2021
November 2021 to February 2022	March 2021 to February 2022
February 2022 to March 2022	March 2021 to March 2022

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 2022 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

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[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).

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, 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 date of the most recent benchmark monument survey within the 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
Managed Area[(a)]	January 2018
Central Area[a]	January 2018
Northwest Area	May 2022
San Jose Fault Zone Area	May 2022
Southeast Area	May 2022
Northeast Area[a]	April 2020

(a) The entire benchmark monument survey network for the ground-level survey area was not surveyed in 2022 based on the GLMC scope and budget recommendations for FY 2021/22.

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 date of the most recent horizontal benchmark survey within the ground-level survey area are shown in Table 2-3. Horizontal benchmark surveys were not performed in 2022 and are not planned for 2023.

Table 2-3. Horizontal Benchmark Survey

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

(a) EDMs across the Fissure Zone Area and San Jose Fault Zone Area were not conducted in 2022 based on GLMC scope and budget recommendations for FY 2021/22.

2.2 Land-Subsidence Investigations

The Watermaster performs land subsidence investigations pursuant to the Subsidence Management Plan, and/or recommendations from the GLMC that are approved in the annual Watermaster budget. The goals of these investigations are to refine the Guidance Criteria or 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 2021 and March 2022 that are called for in the Subsidence Management Plan.

2.2.1 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

[7] Source: http://www.cbwm.org/pages/reports/engineering/

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. 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 7/8. Update the Hydrogeologic Conceptual Model/Construct and Calibrate Subsidence Modeling Tools – The objectives of these tasks are: (i) 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; (ii) describe the subsidence mechanisms and the pre-consolidation head by aquifer-system layer in Northwest MZ-1; and (iii) develop modeling tools that can be used to explore the future occurrence of subsidence in Northwest MZ-1 under various basin-operation scenarios of groundwater production and artificial recharge and to identify potential subsidence mitigation strategies. This work was completed in FY 2021/22 and been reviewed by the GLMC. The GLMC has recommended additional model calibration refinements and sensitivity analyses. This additional work is currently being performed. The GLMC will perform final review and approval of an updated report on the model calibration before using the 1D models to develop subsidence management strategies (see Task 9 below).

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.

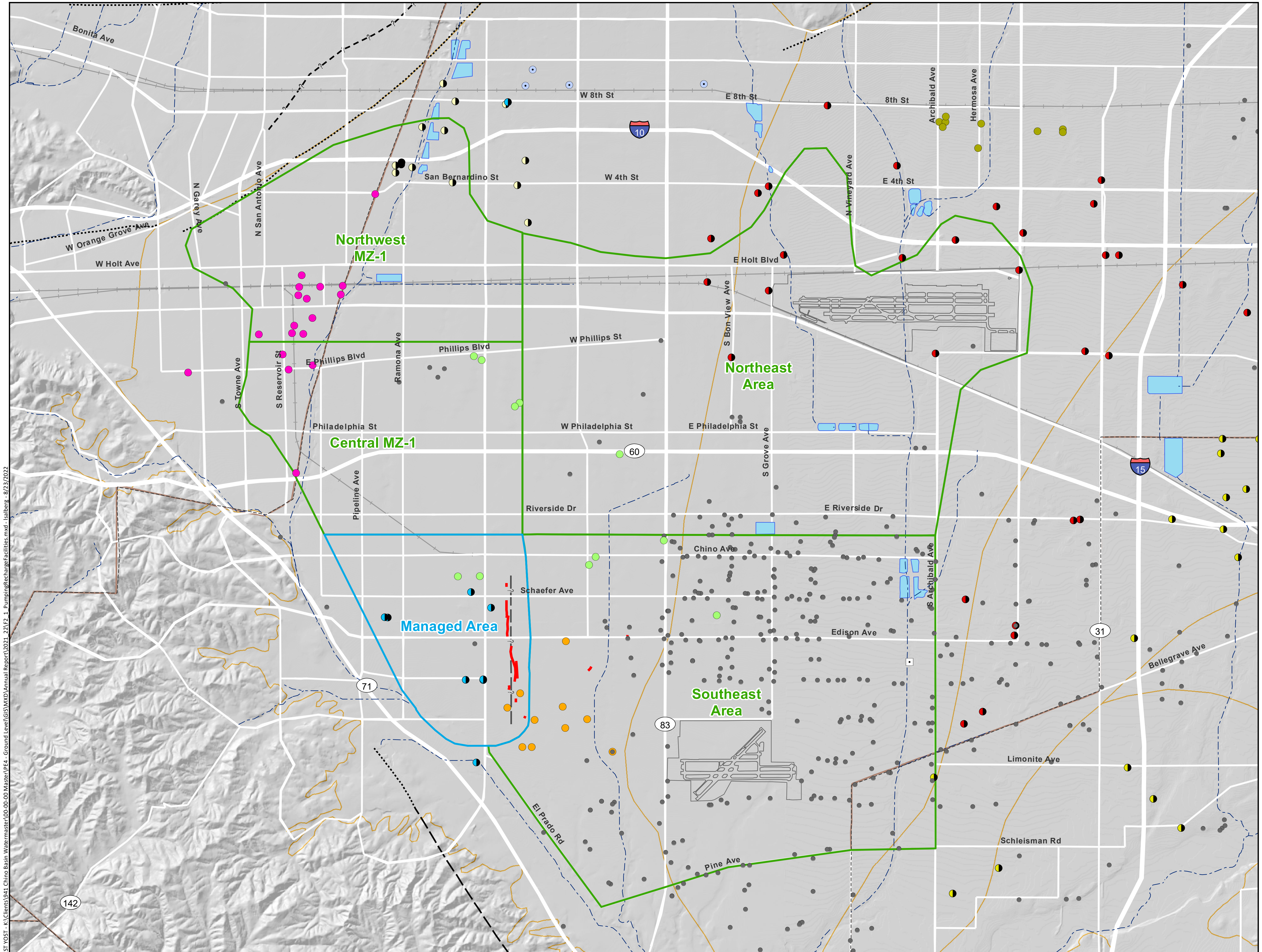
A draft technical memorandum will be prepared that summarizes the evaluation of the ISMA, particularly, the ability of the ISMA to raise and hold piezometric levels above the estimated pre-consolidation stresses. The draft technical memorandum may also include a recommendation for a second Subsidence-Management 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 2022/23. If necessary and recommended by the GLMC, additional subsidence management alternative scenarios may be run in FY 2023/24.

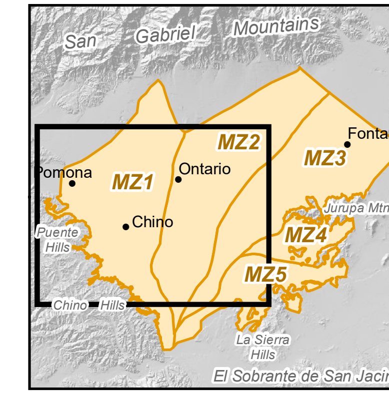
Task 10. Update the Chino Basin Subsidence Management Plan – The objective of this task is to incorporate the preferred subsidence-management alternative for Northwest MZ-1 into the Chino Basin Subsidence Management Plan. An implementation plan will be prepared as part of this effort. The implementation 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.

2.2.2 Northeast Area Subsidence Investigation

In the Northeast Area, the long- and short-term InSAR estimates indicate that persistent downward ground motion has occurred in a concentrated area in the vicinity of Whispering Lakes Golf Course, south of the Ontario Airport between Vineyard Avenue and Archibald Avenue. The western and eastern edges of this subsiding area exhibit steep subsidence gradients (i.e., differential subsidence”).

In FY 2021/22, the GLMC conducted a reconnaissance-level subsidence investigation of the Northeast Area focusing on the Whispering Lakes Subsidence Feature. This investigation included collection, review, and analysis of available borehole and lithologic data, pumping and recharge data, hydraulic head measurements, and InSAR estimates of vertical ground motion. Figures and charts were prepared to support the data analysis, interpretations, and recommendations for future investigations and monitoring.





N

0 3,000 6,000
Scale in Feet

Active Groundwater Pumping Wells
April 1, 2021 to March 31, 2022

- Private
- California Institution for Men
- Chino Basin Desalter Authority
- City of Chino
- City of Chino Hills
- City of Ontario
- City of Pomona
- City of Upland
- Cucamonga Valley Water District
- Golden State Water Company
- Jurupa Community Services District
- Monte Vista Water District

- Managed Area
- Areas of Subsidence Concern

WEST YOST

Figure 2-1

Pumping and Recharge Facilities
Western Chino Basin: 2021/22

Chino Basin Watermaster
Ground-Level Monitoring Committee
2021/22 Annual Report

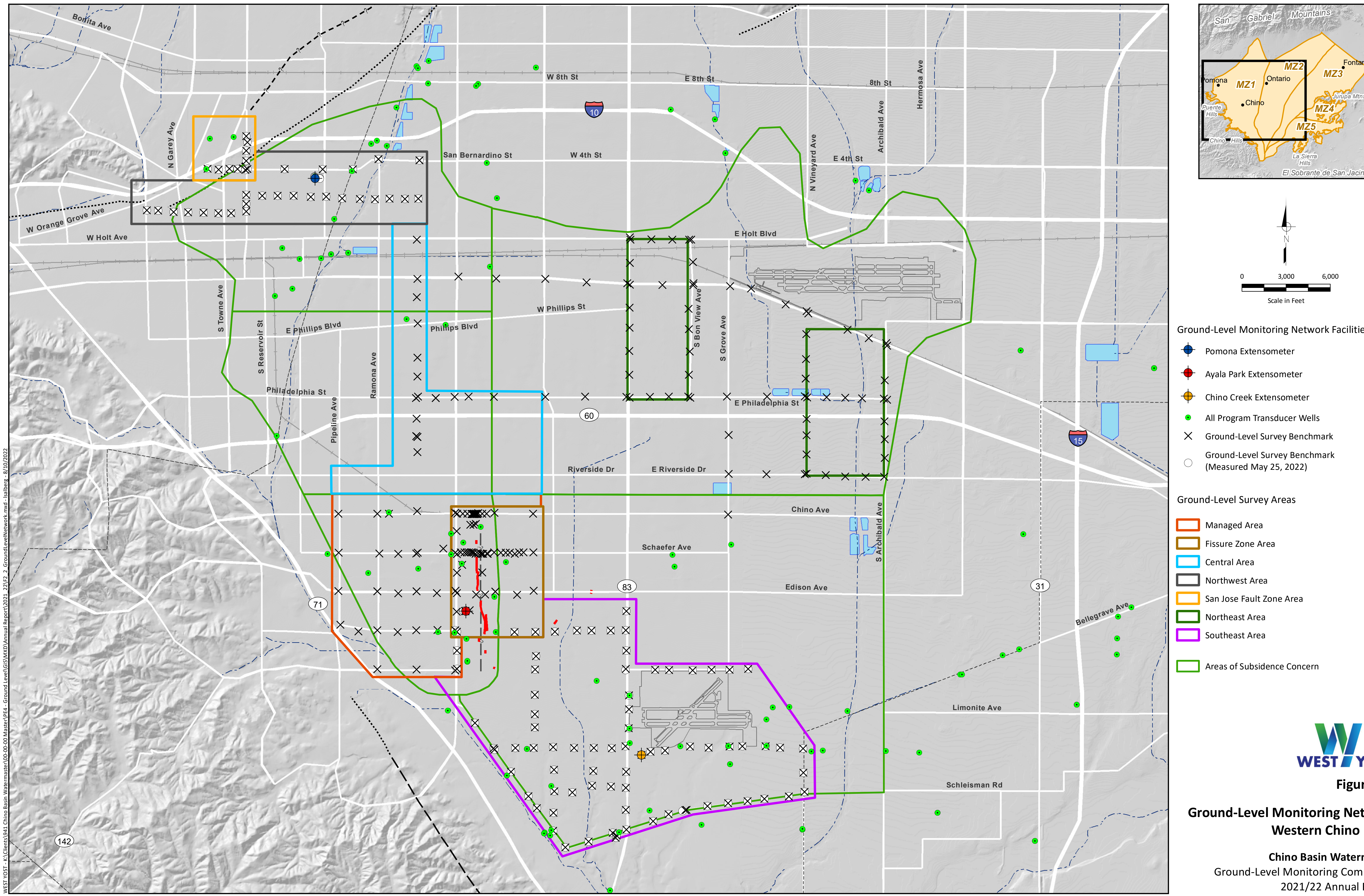


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Figure 2-2

Ground-Level Monitoring Network
Western Chino Basin

Chino Basin Watermaster
Ground-Level Monitoring Committee
2021/22 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 2021 to March 2022 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 2022 and between March 2021 and March 2022, 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. Data shown on 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 10 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 2022. Groundwater pumping in the Managed Area has declined from about 5,680 acre-feet (af) in fiscal year 2012 to almost negligible volumes in 2022. A total of about 51 af of groundwater pumping occurred in the Managed Area from July 1, 2021 to March 31, 2022—80 percent of the groundwater pumping was from wells screened in the deep aquifer-system.

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 2022. 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 has occurred 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 55 ft-btoc in January and May 2021 and has not declined below the Guidance Level of 245 ft-btoc.
- The recovery of hydraulic heads in the deep aquifer-system to above 90 ft-btoc in February 2019 and November 2020 represented "full recovery" of hydraulic head at PA-7 as defined in the Subsidence Management Plan. Ever since November 2020, hydraulic heads at PA-7 have 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, 2019, and 2020 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 53 ft-btoc in PA-10 (March 2021 and January 2022) and about 55 ft-btoc in PA-7 (May 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 2022, acre-ft

Well Name	Aquifer Layer	Fiscal Year										Fiscal Year 2022				
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	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	0	-	
C-6		1049	594	0	0	0	0	0	0	0	0	0	0	0	-	
CH-1A		1137	909	738	861	649	637	369	0	0	0	0	0	0	-	
CH-7A		530	380	170	286	156	66	0	0	0	0	0	0	0	-	
CH-7B		712	264	200	616	261	232	350	0	0	0	0	0	0	-	
CIM-1		724	1,109	1,127	878	911	908	586	0	0	0	0	0	0	-	
XRef 8730[b]		3	5	5	4	3	35	29	29	29	30	0	5	5	-	
	Sub-Totals	4,679	3,260	2,240	2,644	1,980	1,879	1,334	29	29	30	0	5	5	-	10
CH-17	Deep[c]	758	1,444	937	1,142	567	624	571	0	0	0	0	0	0	-	
CH-15B		0	28	105	0	0	0	0	0	0	0	0	0	0	-	
CIM-11A		243	239	195	92	94	222	0	0	3	3	35	5	1	-	
	Sub-Totals	1,001	1,711	1,237	1,234	662	846	571	0	3	3	35	5	1	-	41
	Totals	**5,680**	**4,971**	**3,477**	**3,878**	**2,642**	**2,725**	**1,905**	**29**	**32**	**33**	**35**	**10**	**6**	**-**	**51**

"C" = City of Chino

"CH" = City of Chino Hills

"CIM" = California Institution for Men

"XRef" = Private

(a) Data only available through March 2022.

(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 2022. 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 an extended cycle of decline and recovery of hydraulic heads at PA-7. Over this period, the Deep Extensometer recorded a slight amount of expansion, indicating that the vertical deformation of the deep aquifer-system was mainly elastic.
- Since February 2019, hydraulic heads at PA-7 have remained above the full recovery threshold and increased to their highest recorded levels. By February 2022, the Deep Extensometer recorded about 0.058 ft of aquifer-system expansion, indicating that the vertical deformation of the deep aquifer-system was mainly elastic.

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 inelastic compaction within the depth interval of the aquifer-system that is penetrated by the Deep Extensometer. Hydraulic head decline (drawdown) is shown as increasing from bottom to top on the y-axis, and aquifer-system compression (compaction) 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 February 2022 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 2021/22, the benchmark monument network in the Managed Area was not surveyed per the GLMC 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 2022 and from March 2021 to March 2022, respectively.

Where coherent, the InSAR estimates of vertical ground motion from 2011 to 2022 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 and southeastern portions of the Managed Area. The InSAR estimates of vertical ground motion from 2021 to 2022 shown in Figure 3-1b indicate very little recent vertical ground motion across the Managed Area.

As described above, Figure 3-1a shows that maximum downward ground motion during 2011-2022 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 2022. 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 that occurred prior to 2007.
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.

4. 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 3-6a 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 2022. Figure 3-6b is a map that illustrates vertical ground motion as estimated by InSAR and ground-level surveys across the Southeast Area from March 2011 to March 2022. 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 2022 (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 2 to 17 ft between 2005 and March 2022 (see wells HCMP-1/1 and HCMP-1/2) likely in response to pumping at the Chino Basin Desalter Authority (CDA) wells.

- Figure 3-6b displays vertical ground motion as estimated by InSAR and ground-level surveys from 2011 to 2022. Both methods indicate relatively minor ground motion over the period and similar, but not exact, spatial patterns and magnitudes of ground motion across the Southeast Area. These differences are likely related to the relative incoherence of the InSAR results, differences in the timing of the ground-level surveys and the SAR acquisition, and/or the relative errors associated with each monitoring technique. Maximum downward ground motion of about -0.12 ft as estimated by InSAR occurred in the northeastern portion of the area, which most likely represents the delayed drainage and compaction of aquitards due to historical head declines that occurred prior to the Judgment.

- For the current period March 2021 and March 2022, hydraulic heads remained relatively stable or increased across most of the area, and Figure 3-1b indicates very little, if any, downward ground motion across most of the Southeast Area.

Figure 3-7 displays the time series of hydraulic heads 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 2022. 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. The expansion of the aquifer-system is consistent with the estimates of vertical ground motion from InSAR and ground-level surveys shown on Figure 3-6a.

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 2011-2022 and 2021-2022, 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 2022. Recent hydraulic heads (1986 to 2022) 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 2022 are in the western portion of Central MZ-1, where up to about -0.24 ft of vertical ground motion has occurred—an average rate of about -0.02 ft/yr. Hydraulic heads remained relatively stable in this area from 2011 to 2022, 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 2021 and 2022, vertical ground motion across most of Central MZ-1 was minor.

3.4 Northwest MZ-1

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 2011-2022. 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. Figure 3-10 is a map of the most recent data and illustrates vertical ground motion as estimated by InSAR and ground-level surveys across Northwest MZ-1 from January 2014 to March 2022. 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 2022 hydraulic heads fluctuated but remained relatively stable but still well below the levels of 1930.
- A maximum of about 1.3 ft of subsidence occurred in this area from 1992 through March 2022—an average rate of about 0.04 ft/yr—while hydraulic heads remained relatively stable. The persistent subsidence that occurred from 1992 to 2022 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 2022, the InSAR results indicate that the maximum rate of downward ground motion in Northwest MZ-1 slowed to about -0.03 ft/yr. This resulted in a maximum of about -0.36 ft of downward ground motion near the intersection of Indian Hill Boulevard and San Bernardino Avenue.
- Figure 3-10 shows that the ground-level survey results from 2014 to 2022 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 2022 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 downward ground motion continued to occur in Northwest MZ-1 during 2021-22 at a maximum rate of about 0.03 ft/yr.

As described above, Figure 3-1a shows that maximum downward ground motion during 2011-2022 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 2022. 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 2022 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 0.37 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 2022, 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 2022, the hydraulic head at P-30 experienced four cycles of head decline and recovery. The head decline and recovery at P-30 appears to be contemporaneous with the downward and upward vertical ground motion measured by InSAR at P-30 during this same 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.

3.5 Northeast Area

3.5.1 Vertical Ground Motion

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 last surveyed April 2020 and was not surveyed in spring 2022.

Figures 3-1a and 3-1b illustrate vertical ground motion, as measured by InSAR, across the Northeast Area from March 2011 to March 2022 and from March 2021 to March 2022, respectively. Figure 3-12 is a time-series chart that displays and describes the long-term history of pumping, recharge, hydraulic heads, and vertical ground motion in the Northeast Area. The following observations and interpretations are derived from these figures:

- From 1930 to 1978, hydraulic heads in the Northeast Area declined by about 125 ft. From 1978 to 1985, hydraulic heads increased by about 25 ft. From 1985 to 2022, hydraulic heads fluctuated but have generally remained relatively stable.
- From 1992 to 2022, about 1.1 ft of subsidence occurred in the Northeast Area near the intersection of Euclid Avenue and Phillips Street (Point D on the inset map on Figure 3-12). From 1992 to 2011, the subsidence occurred at a gradual and persistent rate of about -0.04

ft/yr. From 2011 to 2022, the subsidence rate declined to about -0.02 ft/yr. Hydraulic heads have remained relatively stable in this area from 1992-2022, 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 1930 to 1978. The recent decline in the rate of subsidence at Point D may be due to recent decreases in pumping, recent increases in recharge, recent increases in hydraulic heads, or the gradual equilibration of heads between aquifers and aquitards.

3.5.2 Whispering Lakes Subsidence Investigation

Figure 3-1a shows that downward ground motion has occurred in a concentrated area between Vineyard Avenue and Archibald Avenue south of the Ontario International Airport in the vicinity of Whispering Lakes Golf Course in the City of Ontario (referred to herein as the Whispering Lakes Subsidence Feature). The map indicates that from March 2011 to March 2022 a maximum of about -0.4 ft of downward ground motion occurred in this area. The Whispering Lakes Subsidence Feature was only recently observed via InSAR due to enhanced processing and interpolation techniques used by General Atomics in post-processing the InSAR data and preparing interferograms (see Section 2.1.2.3).

Figure 3-13 is a map that displays a focused view of the Whispering Lakes Subsidence Feature. The western and eastern edges of the subsiding area exhibit steep subsidence gradients or “differential subsidence.” Differential subsidence is thought to have led to episodes of ground fissuring in the Managed Area during the early 1990s and is a threat for damage to overlying infrastructure.

At the time of the recognition of the Whispering Lakes Subsidence Feature, there was not enough information to describe the history of the subsidence feature or its causes, such as: aquitard drainage, shallow soil consolidation, land use changes, or tectonics. As an initial exploratory step to enhance the hydrogeologic understanding of the subsidence feature, the GLMC proposed a desktop investigation utilizing readily available data and information. The specific objectives of the desktop investigation are to:

- Describe the history of the Whispering Lakes Subsidence Feature, including the extent and rate of subsidence.
- Attempt to identify the most plausible mechanism(s) causing the differential subsidence.
- Identify data gaps, if any, that need to be filled to characterize the extent, rate, and mechanisms of the differential subsidence.

The following sub-sections describe the investigation results, conclusions, and recommendations.

3.5.2.1 History of Land Subsidence

Figure 3-13 displays the extent of a defined Study Area that surrounds the Whispering Lakes Subsidence Feature (black rectangle) and the spatial distribution and magnitude of land subsidence as measured by InSAR from March 2011 to March 2022. Figure 3-14 includes a time-series chart that describes the history of vertical ground motion from 1992 to 2022 at the three locations within and surrounding the Study Area (Points B, D and E in Figure 3-13). Point B is located directly within the Whispering Lakes Subsidence Feature. Points D and E are located northwest and north of the Study Area, respectively.

At all three Points, the total subsidence that occurred from 1992 to 2022 is similar at approximately one ft. However, the rates of downward ground motion at Point B within the subsidence feature appear to be different compared to Points D and E at different times. These spatial differences in the rates of downward ground motion may indicate that there is a different mechanism(s) driving the downward ground motion at the Whispering Lakes Subsidence Feature.

3.5.2.2 Potential Subsidence Mechanisms

This section describes the main potential mechanisms that could be responsible for the Whispering Lakes Subsidence Feature, which include:

- Aquitard Drainage
- Shallow Soil Consolidation due to Historical Land Use and/or Land Use Changes
- Differential Tectonic Movements

Each sub-section below describes the current understanding of each potential subsidence mechanism, the likelihood that the mechanism is the primary cause of the Whispering Lakes Subsidence Feature, and a description of the data gaps (where they exist) that need to be filled to better understand the potential subsidence mechanisms.

3.5.2.2.1 Aquitard Drainage

The drainage and compaction of aquitards due to pumping-induced drawdown of hydraulic heads within aquifers is a well-documented phenomenon that is responsible for much of the regional land subsidence that has been observed in the Chino Basin. To determine if aquitard drainage is a mechanism causing the Whispering Lakes Subsidence Feature, the following questions must be addressed:

- Do aquitards exist beneath the Whispering Lakes Subsidence Feature? If so, does the spatial distribution of the aquitard align with the extent of subsidence?
- Have there been pumping stresses within the Study Area that could have resulted in the drawdown of hydraulic heads and aquitard compaction?
- Are there groundwater barriers that exist within the aquifer system that may be responsible for the differential nature of the subsidence?

Do aquitards exist beneath the Whispering Lakes Subsidence Feature? Figure 3-13 includes the plan-view location of a hydrogeologic cross-section (A-A') aligned southwest to northeast across the Study Area. Figure 3-15 is the cross-section in profile view that includes selected well and borehole data, including borehole lithology, short-normal resistivity logs, well screen depth intervals, and groundwater elevation. The five layers of the Chino Basin aquifer-system are also shown on cross-section, which were derived from the Chino Valley Model (CVM). CVM layers 1, 3, and 5 are the primary aquifer layers, whereas layers 2 and 4 are the primary aquitards. The main observations and interpretations from the review of the cross-section are:

- All boreholes in the Study Area penetrate a similar sequence of sediments, which include interbedded layers of gravels, sands, silts, and clays.
- There are numerous layers of fine-grained sediments of varying thickness throughout the entire aquifer system underlying the Study Area. Additionally, the CVM aquitard layers (Layers 2 and 4) underlie the entire Study Area, thinning to the northwest. These fine-grained sediments and

aquitard layers are compressible and could be compacting under reduced heads in the aquifer layers, which would result in land subsidence.

- There is not enough site-specific hydrogeologic data to determine if the underlying hydrostratigraphy is responsible for the spatial distribution of the land subsidence across the Study Area and specifically within the Whispering Lakes Subsidence Feature.

Have there been pumping stresses within the Study Area that could have resulted in the drawdown of hydraulic heads and aquitard compaction? Figure 3-14 includes a time series of groundwater production for wells within the Study Area for fiscal year (FY) 1978 to 2022, and depth to groundwater measurements taken from wells within and surrounding the Study Area from 1930 to 2022. The location of these wells in proximity to the Study Area is shown on Figure 3-13 and the inset map on Figure 3-14.

Production wells within the Study Area are also displayed on Figures 3-13 as grey and 3-16 as yellow graduated symbols with the symbol size proportionate to the volume of groundwater pumped during the corresponding FY. There are 26 wells in the Study Area that have pumped groundwater since FY 1978.[11] As shown in Figure 3-14, groundwater production in the Study Area has nearly tripled since FY 1993: total production in FY 1993 was 545 af and increased to about 1,690 af in FY 2021. Of particular interest are three active pumping wells that produce groundwater directly adjacent to the Whispering Lakes Golf Course shown on Figures 3-13 and 3-16. Pumping from these three wells (Philadelphia #1, Philadelphia #2, 20960-DOM) account for up to 75% of total groundwater production in the Study Area. These three wells are described in more detail below:

- Most of the groundwater production in the Study Area occurs at the Philadelphia #1 and #2 wells, located adjacent to the northeast corner of the Whispering Lakes Golf Course, as shown in Figure 3-16. Philadelphia #1 and Philadelphia #2 are operated by Niagara Bottling, LLC and came online in 2005 and 2009, respectively. Both wells are screened within the deep aquifer (Layers 3 and 5 of the CVM). Since 2009, the wells have produced a maximum of 1,250 afy, which represents up to 73% of the total groundwater production in the Study Area.

- 20960-DOM is also located adjacent to the Whispering Lakes Golf Course and has been pumping groundwater since at least FY 1978. Maximum production from this well was 279 af in FY 2005.

There are no wells with long-term depth-to-groundwater measurements within the observed extent of the Whispering Lakes Subsidence Feature. However, Figure 3-14 shows the time series of hydraulic heads at wells located within and surrounding the Study Area that may be responding to groundwater production stresses within the Study Area. Some wells are screened across the shallow aquifer (Layer 1 of the CVM) and some wells are screened across the deep aquifer (Layers 3 and 5 of the CVM). The main observations from Figure 3-14 include:

- From 1985 to 2022, hydraulic heads fluctuated but have generally remained relatively stable. This seems especially true for the shallower wells (OW-5 and OW-13) located to the north and northwest of the Study Area.

- Hydraulic heads in some deeper wells (O-34 and O-36) near the Whispering Lakes Subsidence Feature show a declining trend since 2019. Hydraulic heads in wells O-34 and O-36 are likely

[11] Groundwater production data does not exist prior to the 1978 Stipulated Judgement.

representative of heads in the deep confined to semi-confined aquifer system in the vicinity of the Study Area as both wells are screened from approximately 500 to 1,000 ft-bgs. If hydraulic heads are declining within the deep aquifer system underlying the Whispering Lakes Subsidence Feature, these declines could be driving, at least in part, aquifer-system compaction and the resulting land subsidence feature.

Are there groundwater barriers that exist within the aquifer system that may be responsible for the differential nature of the subsidence? Currently, there is not enough spatial and depth-specific hydrogeologic and hydraulic heads data/information within the Study Area to determine if local groundwater barriers are responsible for the observed differential subsidence.

Main Interpretations: Based on the analysis of the readily available data on the local hydrogeology and the history of groundwater production and hydraulic heads within the Study Area, the mechanism(s) behind the Whispering Lakes Subsidence Feature could be: (i) delayed aquitard drainage in response to the historical declines in hydraulic heads that occurred from 1930 to 1978; (ii) recent declines in hydraulic head caused by recent pumping at the nearby Philadelphia Wells; or (iii) both. However, there is not enough spatial and depth-specific hydrogeologic and hydraulic head data within the Whispering Lakes Subsidence Feature to definitively conclude these interpretations.

3.5.2.2.2 Shallow Soil Consolidation due to Historical Land Use and/or Land Use Changes

Land uses and land-use changes can result in downward ground motion. Examples include: soil consolidation due to increased surface loads (e.g., construction of buildings on unconsolidated sediments); physical removal of soils; or, spreading of unconsolidated materials that subsequently consolidate. To determine if overlying land uses or land-use changes are potential mechanisms behind the Whispering Lakes Subsidence Feature, the following questions must be addressed:

- What is the history of land use within the Study Area?
- Do the spatial and temporal distribution of the land use or land-use changes align with the spatial and temporal occurrence of the Whispering Lakes Subsidence Feature?

To answer these questions, aerial images and literature regarding the history of land use in the Study Area were reviewed. Figure 3-16 shows a series of six aerial photos from 1953 to 2022 that show a time-series of the overlying land use in the vicinity of the Whispering Lakes Subsidence Feature. Total groundwater production for each FY is plotted on each image (pumping records unavailable prior to the 1978 Stipulated Judgment). The contours of change in ground-surface elevation from March 2011 to 2022 is shown on the 2022 image to show the location of the subsidence feature. The following is a summary of changes in land use that can be observed in Figure 3-16:

- **1953** – Land use is predominately agricultural. Although groundwater production was used to supply the agricultural land uses, groundwater production was not recorded and is, therefore, not shown on Figure 3-16. The Inland Empire Utilities Agency's (formerly Chino Basin Municipal Water District) Regional Water Recycling Plant No. 1 (RP-1) is in operation and labeled on the figure. Sewage disposal ponds are in operation (delineated by a red rectangle on Figure 3-16). The sewage disposal ponds first began operating in 1914 and were used to receive raw sewage from 1915 to 1934. From 1934 to the 1970s, the operational use of the sewage disposal ponds transitioned from receiving raw sewage to receiving treated sewage.

- **1965** – Whispering Lakes Golf Course was constructed around 1960. The RP-1 footprint has expanded and been reconfigured to include more lined ponds and infrastructure. The sewage disposal ponds are in operation receiving treated sewage. The surrounding land uses are still predominately agricultural. The Ely Basins have been constructed and are likely being used for flood control purposes (although this remains unconfirmed).
- **1994** – Whispering Lakes Golf Course and RP-1 are in operation. Approximately 60 percent of the surrounding land has been converted from agricultural to residential and commercial land uses. The sewage disposal ponds have been filled in (sometime between the 1970s and 1990s) and the City of Ontario's Westwind Park and the Westwind Community Center building now occupy the location of the historic sewage ponds.
- **2005** – Minor land use conversions have occurred from agricultural and dairy to residential and commercial, but overall, the land uses are similar to 1994. The Ely Basins were plumbed in 1997 to receive recycled water for groundwater recharge. The first of the Philadelphia Wells (Philadelphia Well #1) is online and pumped 38 acre-feet in FY 2005.
- **2011** – Additional land has been converted from agricultural and dairy to residential and commercial. A portion of the RP-1 footprint, north of California 60 Freeway, is converted to the Ontario Soccer Parks. Both Philadelphia Wells (#1 and #2) are online and pumped a total of 745 acre-feet in FY 2011.
- **2022**: Land uses are generally similar to the land uses in 2011. The Philadelphia Wells pumped 754 af in FY 2022.

The main observations from Figure 3-16 are:

- Land uses in the vicinity of the Whispering Lakes Subsidence Feature have been agricultural, sewage treatment and disposal, recreational (golf course and parks), and residential/commercial, with gradual conversions from agricultural to residential/commercial land uses.
- Significant new groundwater production from the Philadelphia Wells was contemporaneous with the development of the Whispering Lakes Subsidence Feature.
- The spatial extent of the Whispering Lakes Subsidence Feature (as defined by the contours of downward ground motion from 2011-2022) aligns closely with the spatial extent of the Whispering Lakes Golf Course.

Main Interpretations: The history of overlying land uses in the vicinity of the Whispering Lakes Subsidence Feature included agricultural, sewage disposal, and recreational (golf courses and parks). These overlying land uses could have involved disturbance, modifications, and additions to the shallow soils, which could have resulted in gradual consolidation of the shallow soils and downward ground motion. The observation that spatial extent of the subsidence feature closely aligns with the spatial extent of the Whispering Lakes Golf Course suggests that the golf course and/or its prior land uses are related to the subsidence feature. However, there is not enough site-specific monitoring data and information on the history of the overlying land uses (and the associated activities on the land uses) to definitively conclude these interpretations.

3.5.2.2.3 Tectonic Movement

Tectonic movement along fault zone(s) is a plausible mechanism for differential subsidence. To determine if tectonic movement is a mechanism causing the Whispering Lakes Subsidence Feature, the following questions must be addressed:

- Is seismicity occurring in the Study Area? If so, does the spatial and temporal distribution of the seismicity occur in a pattern that matches the spatial and temporal occurrence of the Whispering Lakes Subsidence Feature?

Figure 3-17 displays the location and magnitude of earthquake epicenters relative to vertical ground motion from April 2011 to March 2022 (this figure is discussed in more detail in Section 3.6). As shown on Figure 3-17, several earthquakes have occurred within the Study Area at magnitudes ranging from one to four. However, the earthquake epicenters in the Study Area do not appear to show a spatial relationship with the Whispering Lakes Subsidence Feature.

Main Interpretations: It does not appear from the existing seismicity data that tectonics is the cause of the Whispering Lakes Subsidence Feature. However, there is not enough currently available data to definitively conclude these interpretations.

3.5.2.3 Recommendations

The following are recommendations that the GLMC can consider to further identify the primary cause(s) of the differential subsidence at the Whispering Lakes Subsidence Feature:

- **Further investigate the historical land use practices in the vicinity of the Whispering Lakes Golf Course**. These land use practices could include agricultural disturbance and augmentation of soils; sewage disposal and spreading of solids; golf course construction and maintenance activities—all of which could result in downward ground motion. The GLMC should consider conducting additional research and documentation of the history of land uses (and the activities performed on the land uses) to better understand their potential as a contributing cause of the Whispering Lakes Subsidence Feature.

- **Perform field studies of shallow soil consolidation**. Currently, there is no known information or data on the shallow soil composition or rates of soil consolidation on the Whispering Lakes Golf Course. The GLMC should consider conducting such monitoring activities of shallow soil consolidation to develop a dataset that could be compared to the rates of land subsidence estimated by InSAR.

- **Expand aquifer-system monitoring**. As discussed above, the mechanism(s) behind the Whispering Lakes Subsidence Feature could be: (i) delayed aquitard drainage in response to the historical declines in hydraulic heads that occurred from 1930 to 1978; (ii) recent declines in hydraulic head caused by recent pumping at the nearby Philadelphia Wells; or (iii) both. Currently, there is not enough spatial and depth-specific hydrogeologic and hydraulic head data within the Whispering Lakes Subsidence Feature to definitively conclude these interpretations. The GLMC should consider additional aquifer-system monitoring and testing in the Study Area, which could include:

    - Installing transducers in wells within the Study Area to measure and record hydraulic heads at high temporal frequency. This form of monitoring can improve the understanding of how pumping affects the spatial and depth-specific distribution of hydraulic heads. This information can also reveal the presence of currently unknown groundwater barriers within the aquifer system that may be responsible for the differential nature of the subsidence feature.

  - Constructing an aquifer-system monitoring facility within the subsidence feature, such as a multi-depth piezometer. Such a monitoring facility could be used to reveal the depth-specific hydraulic head responses to nearby pumping underlying the subsidence feature. Cable extensometers could be installed to better understand the depth-specific occurrence of aquifer-system deformation and its causes.

3.6 Seismicity

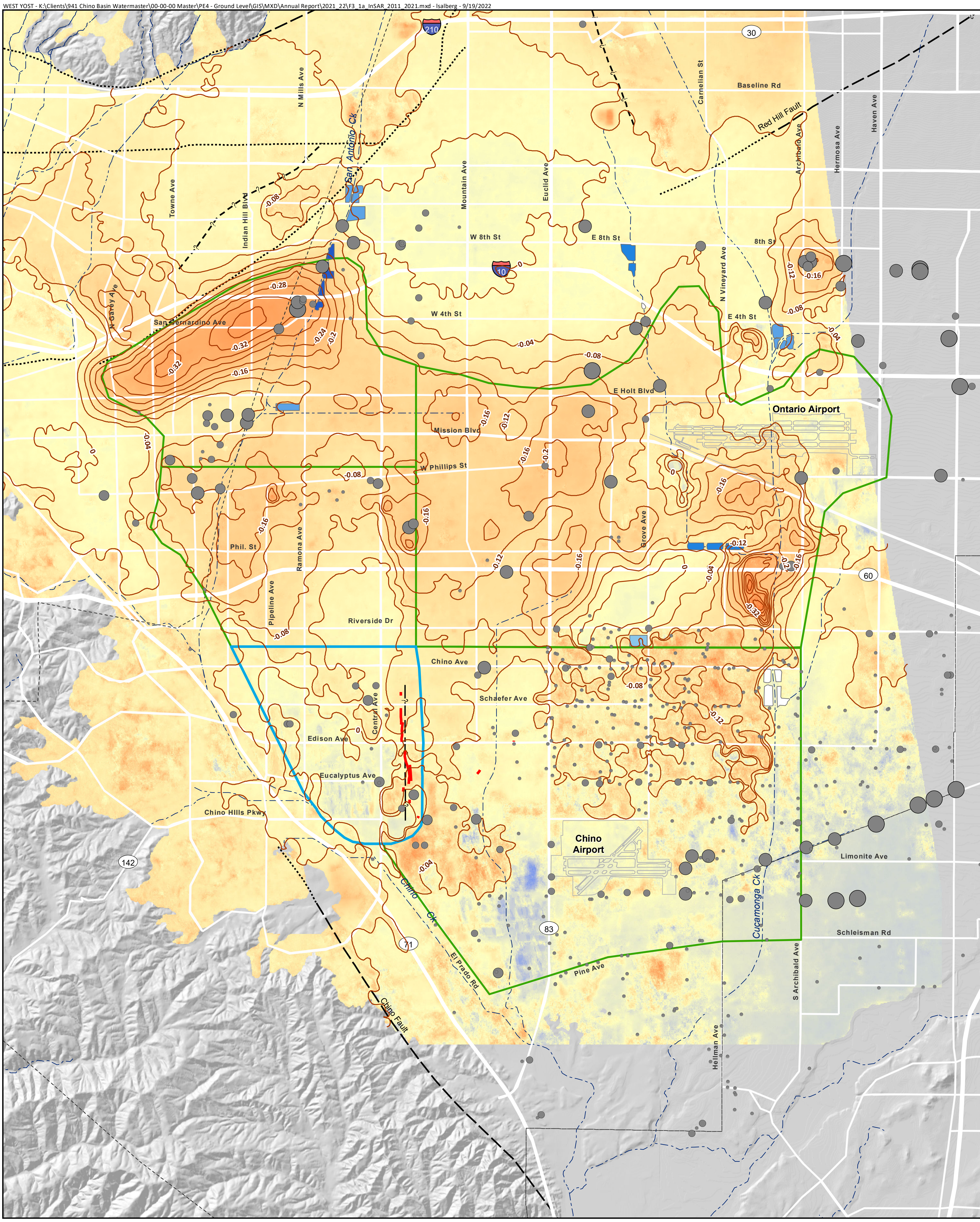
Tectonic displacement of the land surface on either side of geologic faults can be horizontal, vertical, or a combination of both. During a large earthquake, the land surface can deform suddenly (Weischet, 1963; Myers and Hamilton, 1964; Plafker, 1965). Aseismic creep is a process where smaller, more frequent earthquakes cause the land surface to deform more gradually (Harris, 2017).

Figure 3-17 is a map that displays the location and magnitude of earthquake epicenters relative to vertical ground motion as estimated by InSAR from March 2011 to March 2022. The main observations and interpretations derived from this figure are:

- 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. The earthquake epicenters on Figure 3-17 do not show a spatial relationship to the differential subsidence in Northwest MZ-1. However, without direct measurement of aquifer-system deformation, as will be measured by the PX, tectonic deformation cannot be ruled-out as a mechanism for the observed subsidence in Northwest MZ-1.

- Very little seismicity has occurred across the Areas of Subsidence Concern between March 2011 and March 2022. This observation indicates that the vertical ground motion that occurred in these areas is not related to tectonics.

- Figure 3-17 shows that most of the seismicity observed between March 2011 and March 2022 occurred in the eastern portion of the Chino Basin. 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).



Relative Change in Land Surface Elevation as Estimated by InSAR (March 2011 to March 2022)

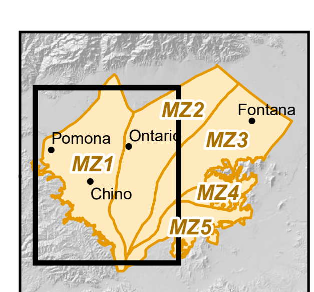
- High : 0.55
- 0 ft
- -0.25 ft
- Low : -0.55
- InSAR absent or incoherent

Average Annual Groundwater Pumping April 1, 2011 to March 31, 2022 (afy)

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

Average Annual Basin Recharge April 1, 2011 to March 31, 2022 (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

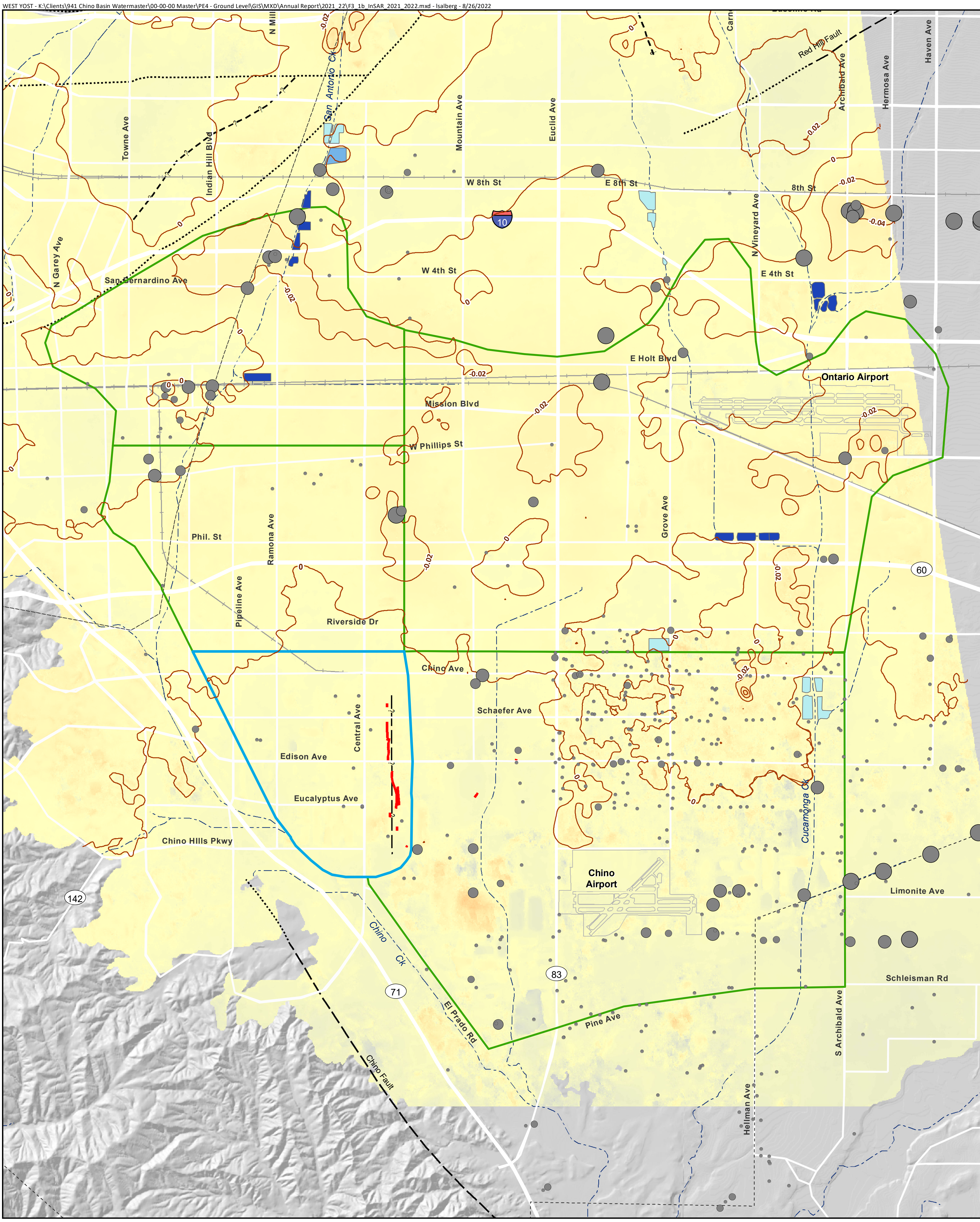
0 1,500 3,000
Scale in Feet

WEST YOST

Figure 3-1a

Vertical Ground Motion across the Western Chino Basin: 2011-2022

Chino Basin Watermaster
Ground-Level Monitoring Committee
2021/22 Annual Report



Relative Change in Land Surface Elevation as Estimated by InSAR (March 2021 to March 2022)

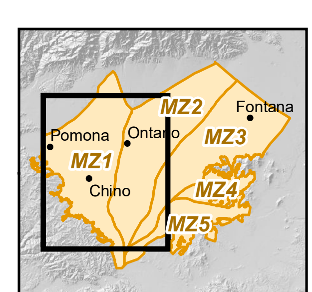
- +0.45 ft
- 0 ft
- -0.25 ft
- -0.45 ft
- InSAR absent or incoherent

Groundwater Pumping April 1, 2021 to March 31, 2022 (afy)

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

Basin Recharge April 1, 2021 to March 31, 2022 (afy)

- 0 - 250
- 250 - 500
- 500 - 750
- 750 - 1,250
- > 1,250



- 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 3-1b

Vertical Ground Motion across the Western Chino Basin: 2021-2022

Chino Basin Watermaster
Ground-Level Monitoring Committee
2021/22 Annual Report

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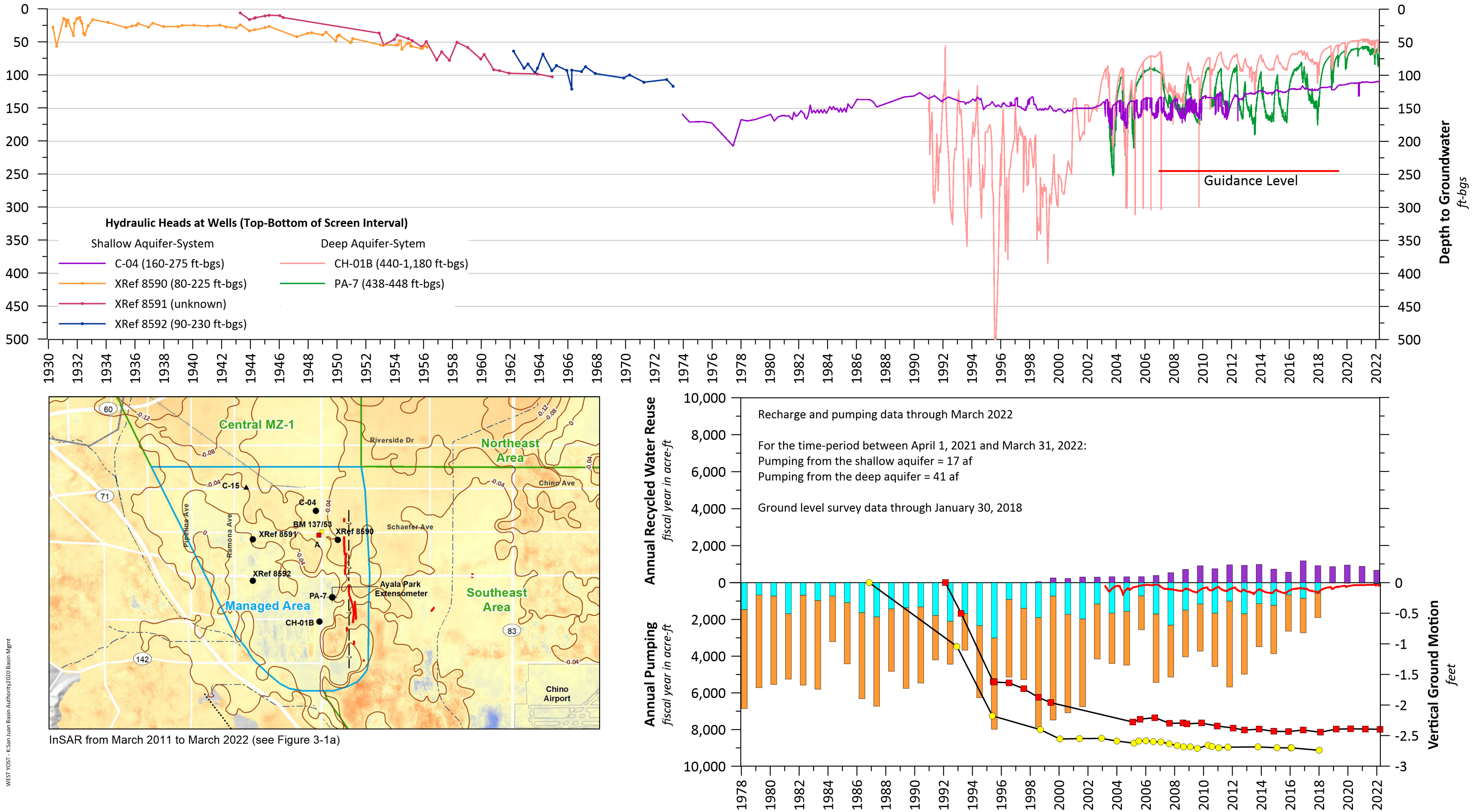

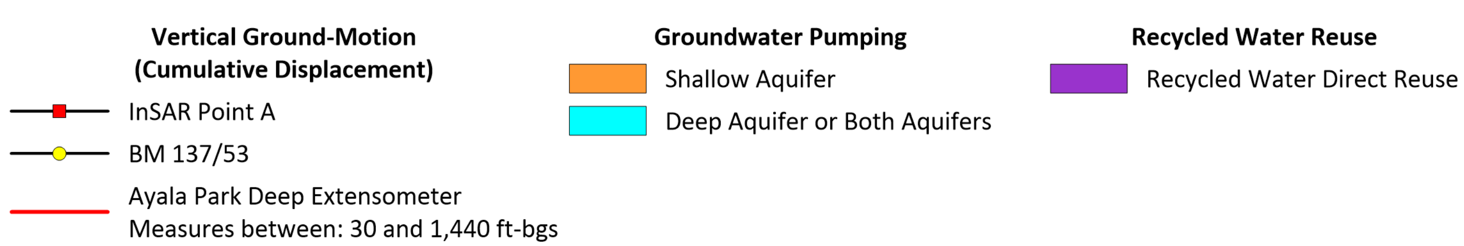

Figure 3-2

History of Land Subsidence in the Managed Area

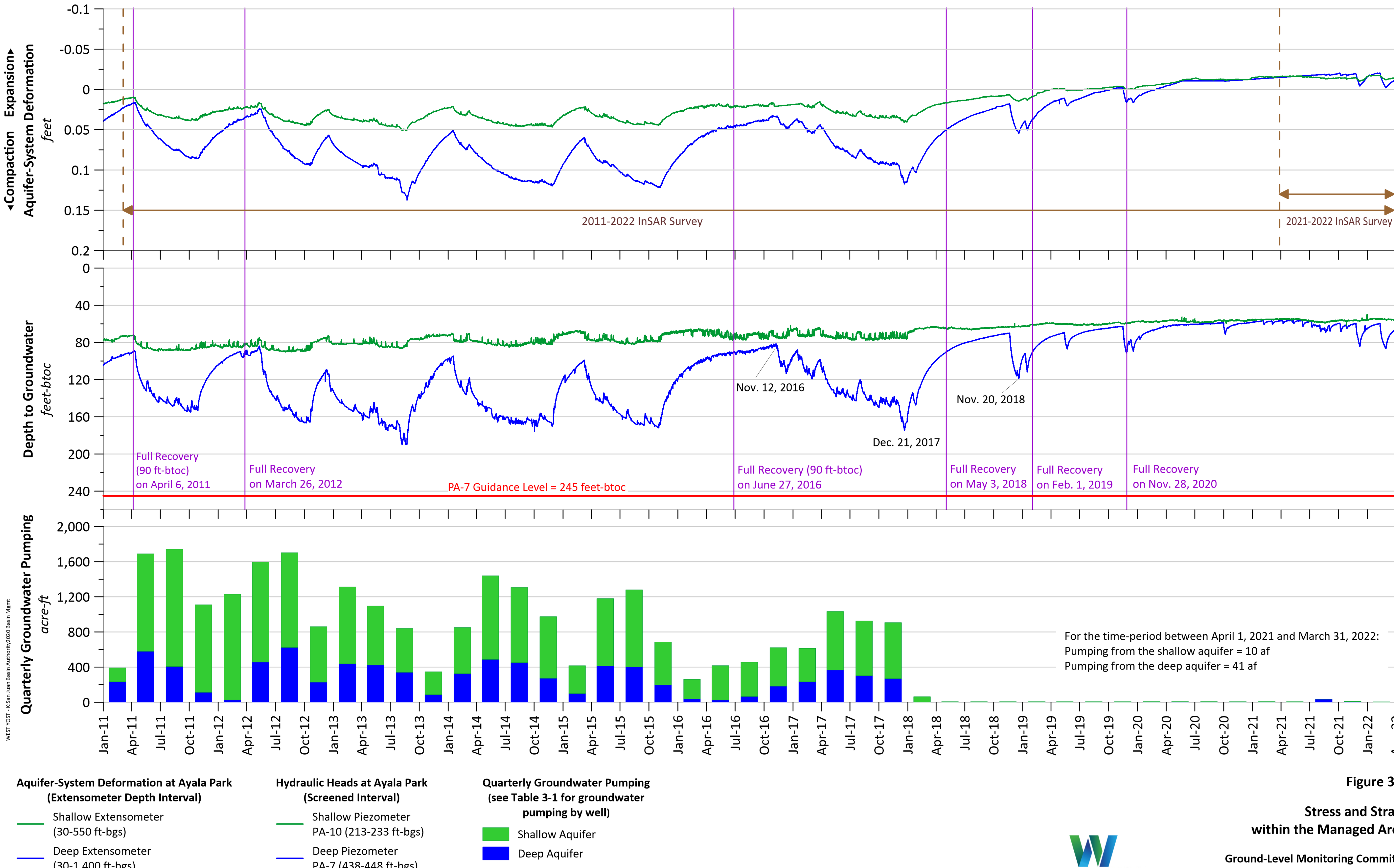

Figure 3-3

Stress and Strain within the Managed Area

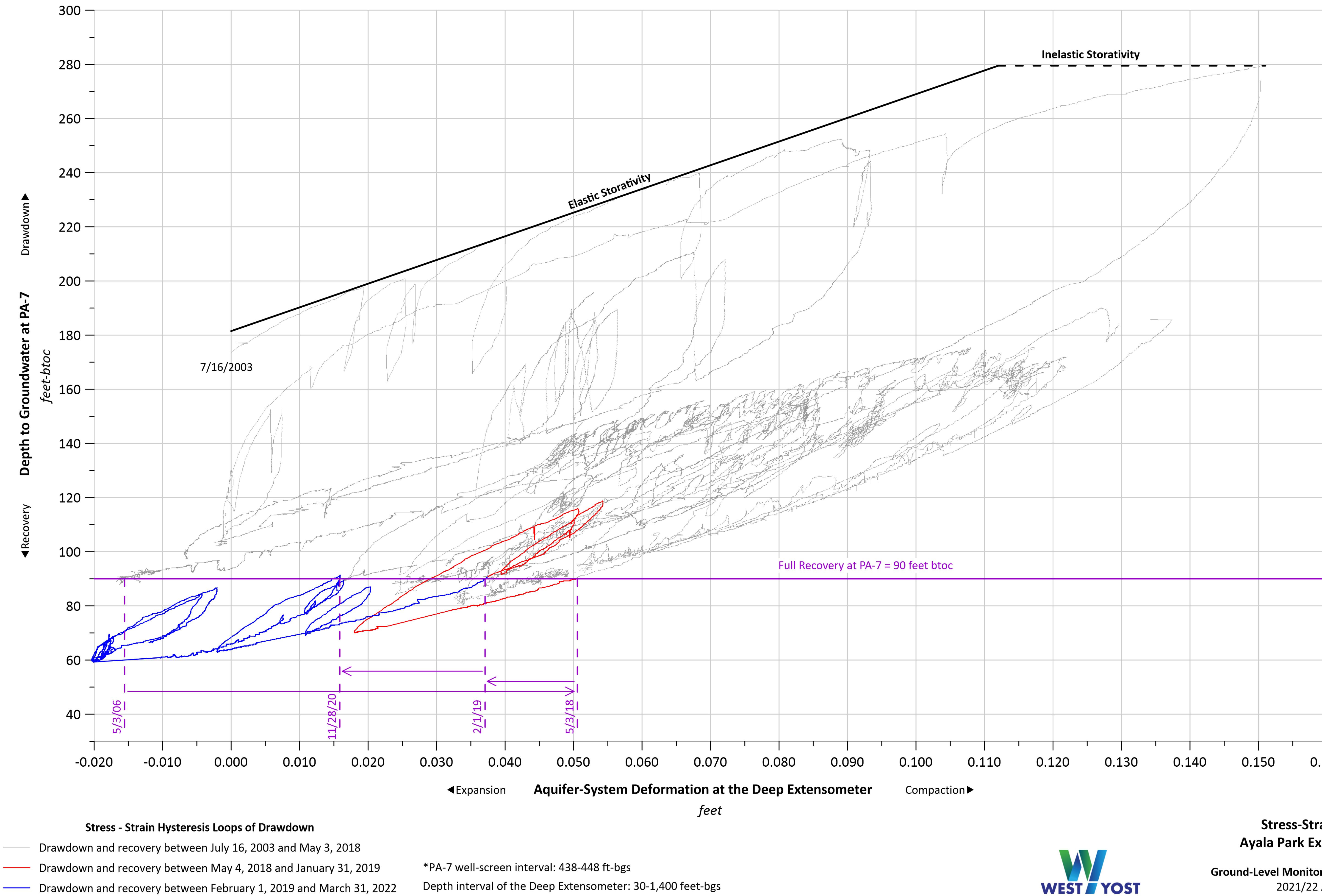

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Figure 3-4

Stress-Strain Diagram
Ayala Park Extensometer

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2021/22 Annual Report

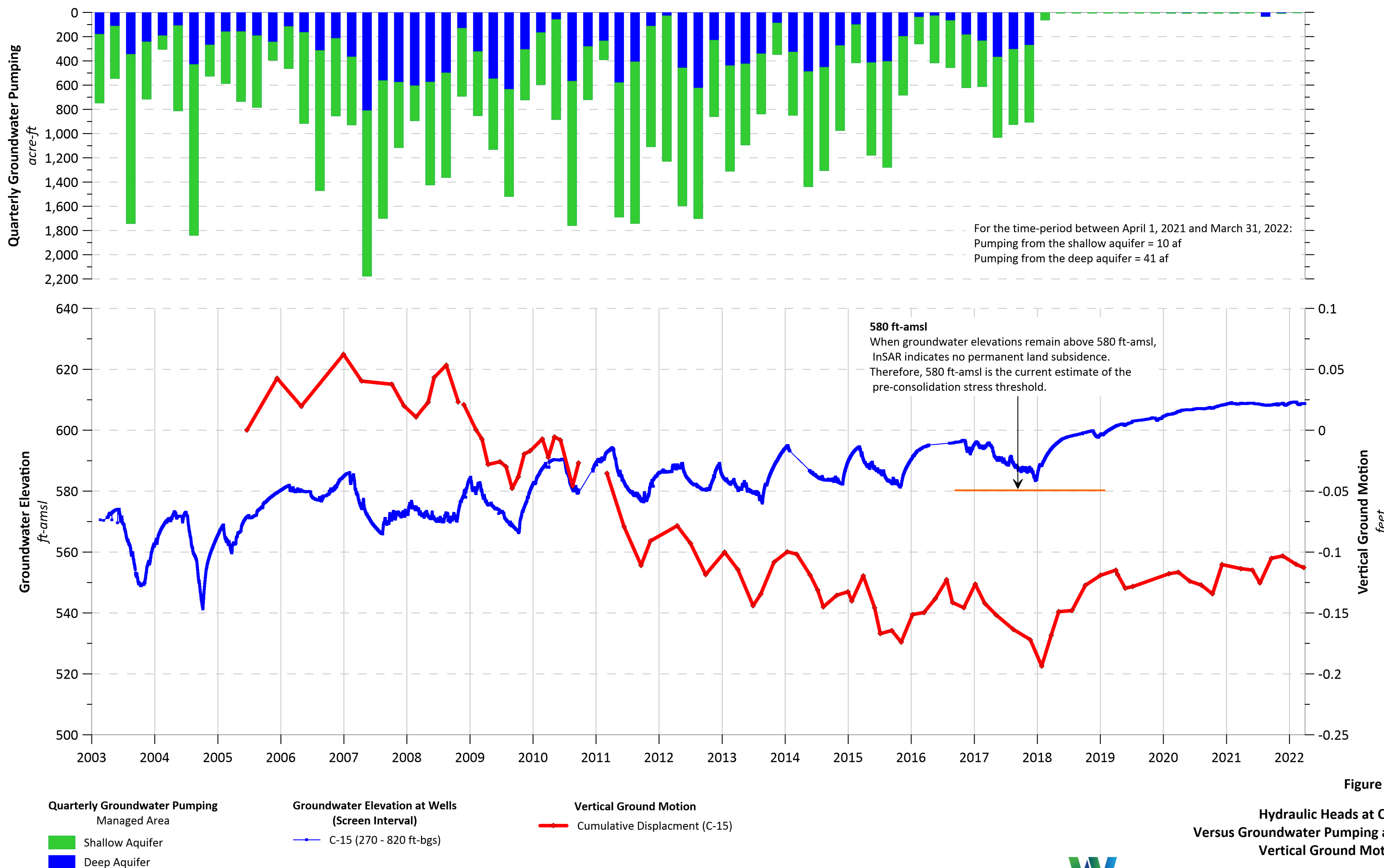

Figure 3-5

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

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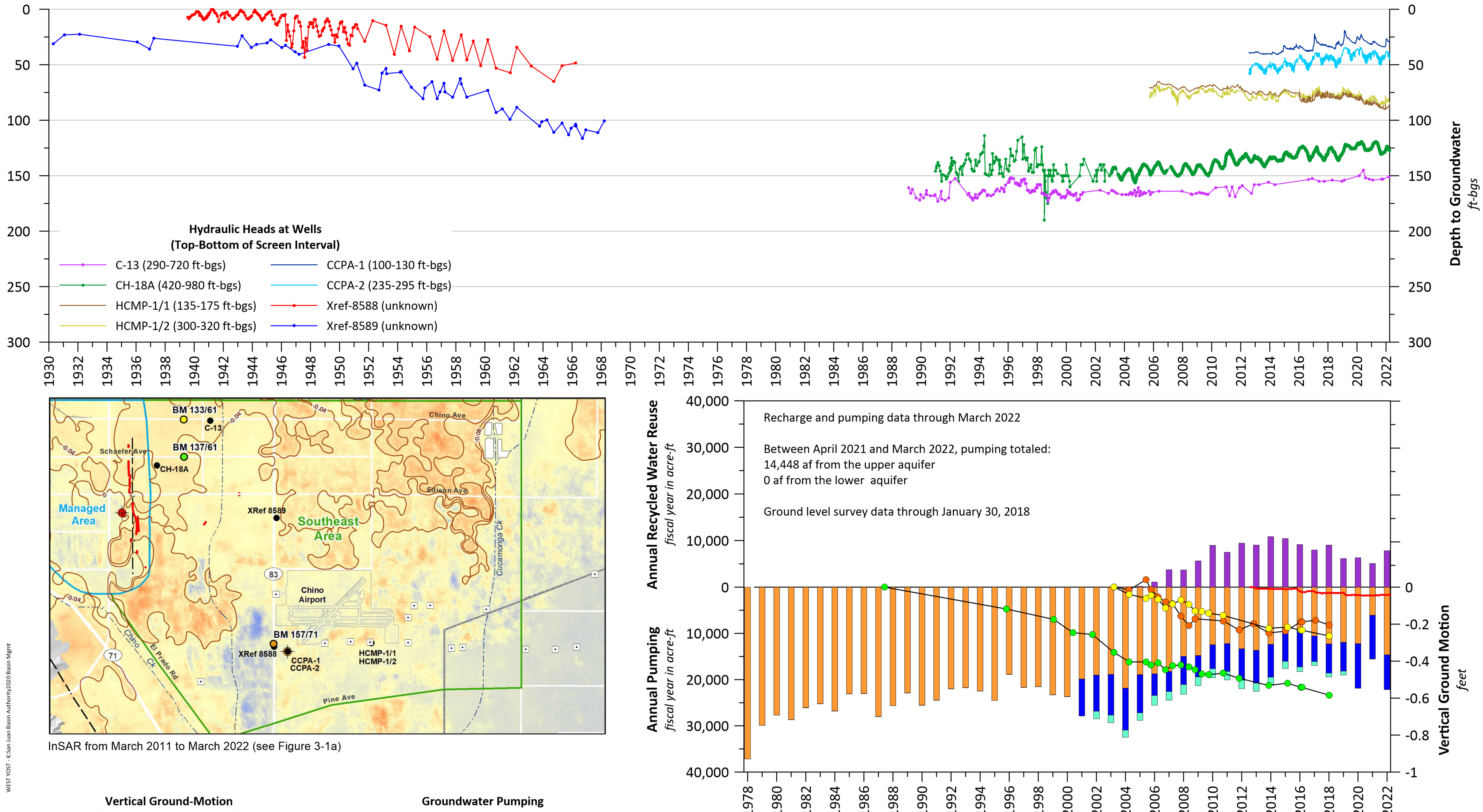

InSAR from March 2011 to March 2022 (see Figure 3-1a)

Vertical Ground-Motion (Cumulative Displacement)

- BM 133/61
- BM 137/61
- BM 157/71
- CCX-2 Extensometer Measures between: 50 and 610 ft-bgs

Groundwater Pumping

- Groundwater pumping from municipal and private wells in the Southeast Area
- Groundwater pumping from desalter wells in the upper aquifer
- Groundwater pumping from desalter wells in the lower aquifer

Recycled Water Reuse

- Recycled Water Direct Reuse

Figure 3-6a

History of Land Subsidence in the Southeast Area

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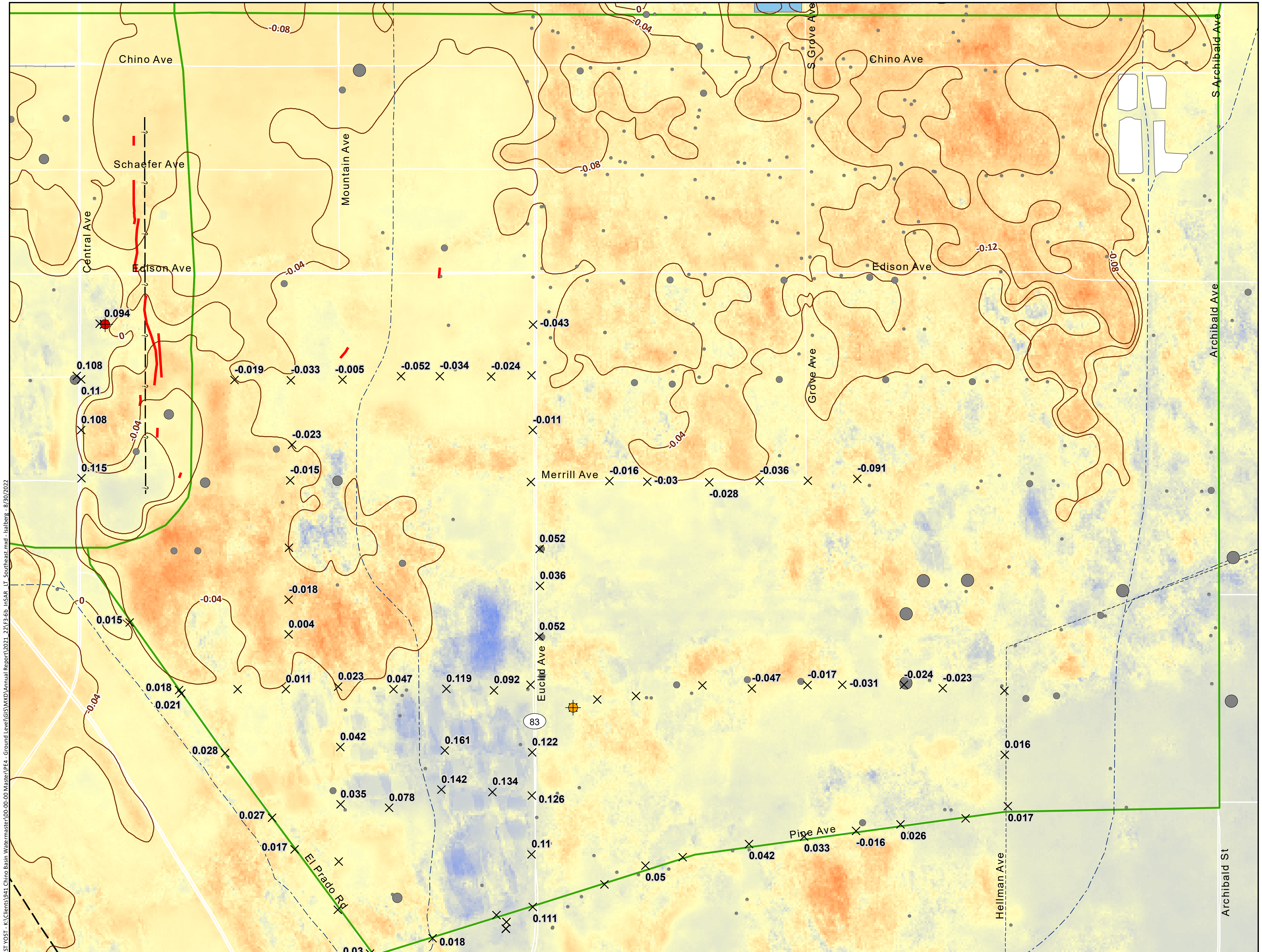

N

0 2,000 4,000
Scale in Feet

Average Annual Groundwater Pumping
April 1, 2011 to March 31, 2022
(afy)

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

Average Annual Basin Recharge
April 1, 2011 to March 31, 2022
(afy)

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

Relative Change in Land Surface Elevation
as Estimated by InSAR
(April 2011 to March 2022)

+0.55 ft
0 ft
-0.25 ft
-0.55 ft

InSAR absent or incoherent

Ayala Park Extensometer

Chino Creek Extensometer

Ground-Level Survey Benchmark (Measured May 25, 2022) Labeled by Vertical Ground Motion (in feet from November 2011 to May 2022)

Areas of Subsidence Concern

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

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Figure 3-6b

Vertical Ground Motion across Southeast MZ-1: 2011-2022

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Ground-Level Monitoring Committee
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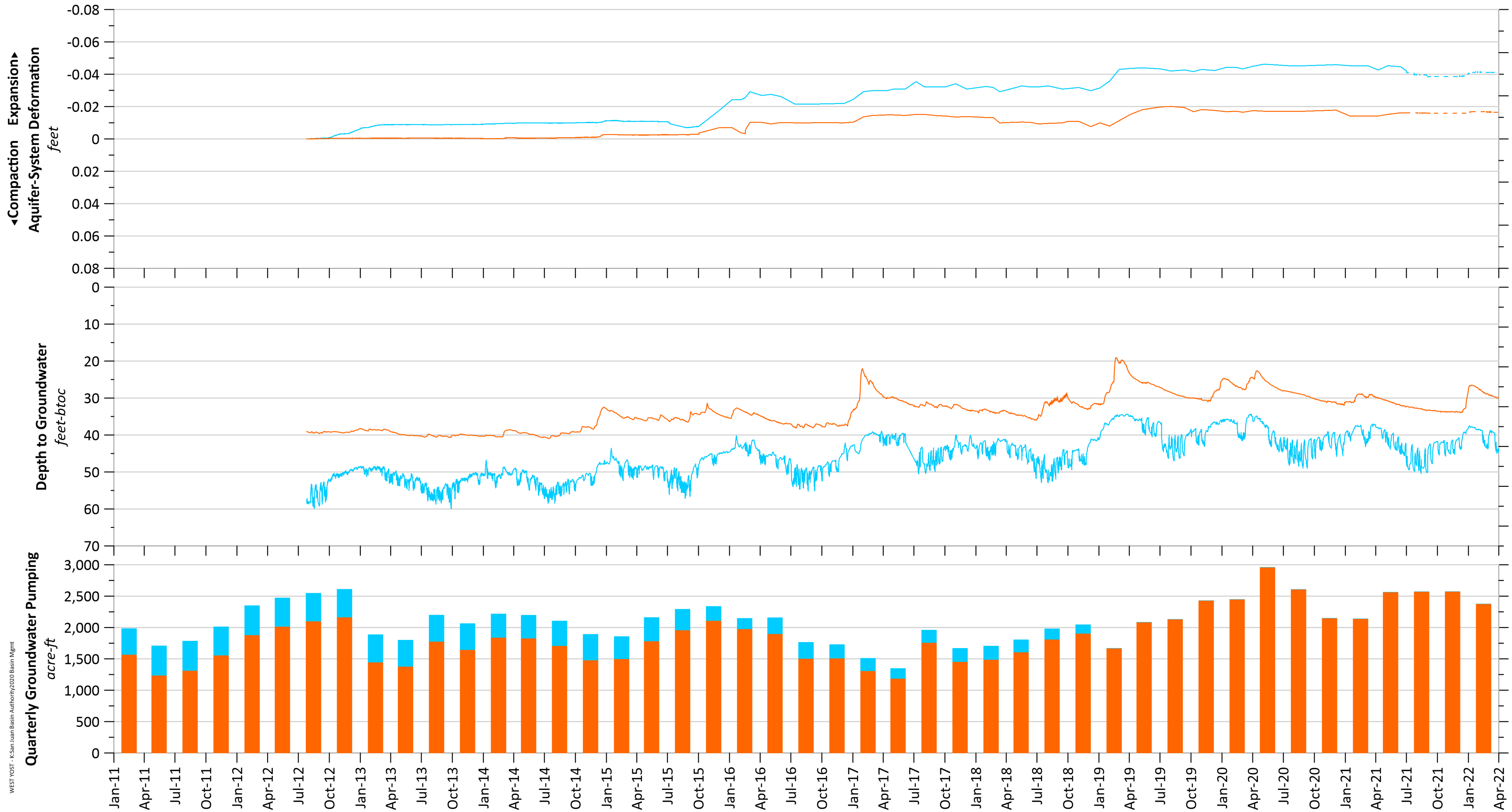
WEST YOST - K:\Clients\941 Chino Basin Watermaster\00-00-00 Master\PE4 - Ground Level\GIS\MXD\Annual Report\2021_22\F3-6b_InSAR_LT_Southeast.mxd - lsalberg - 8/30/2022



Aquifer-System Deformation (Extensometer Depth Interval)

- CCX-1 with manuals
- CCX-2 (50-610 ft-bgs)
- Preliminary Data

Hydraulic Heads (Screened Interval)

- CCPA-1 (100-130 ft-bgs)
- CCPA-2 (235-295 ft-bgs)

Quarterly Groundwater Pumping

- Shallow Aquifer (CDA-5 to 11; 16, 17, 20 and 21)
- Deep Aquifer (CDA-1 to 4)

Between April 2021 and March 2022:
There was no CDA pumping from the deep aquifer

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Figure 3-7

Stress and Strain within the Southeast Area

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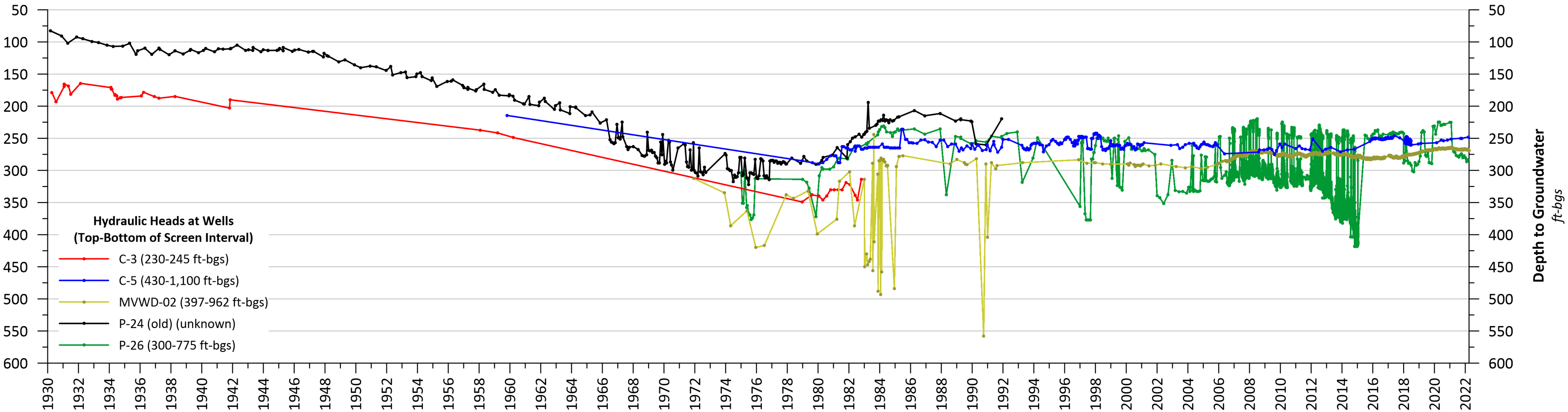
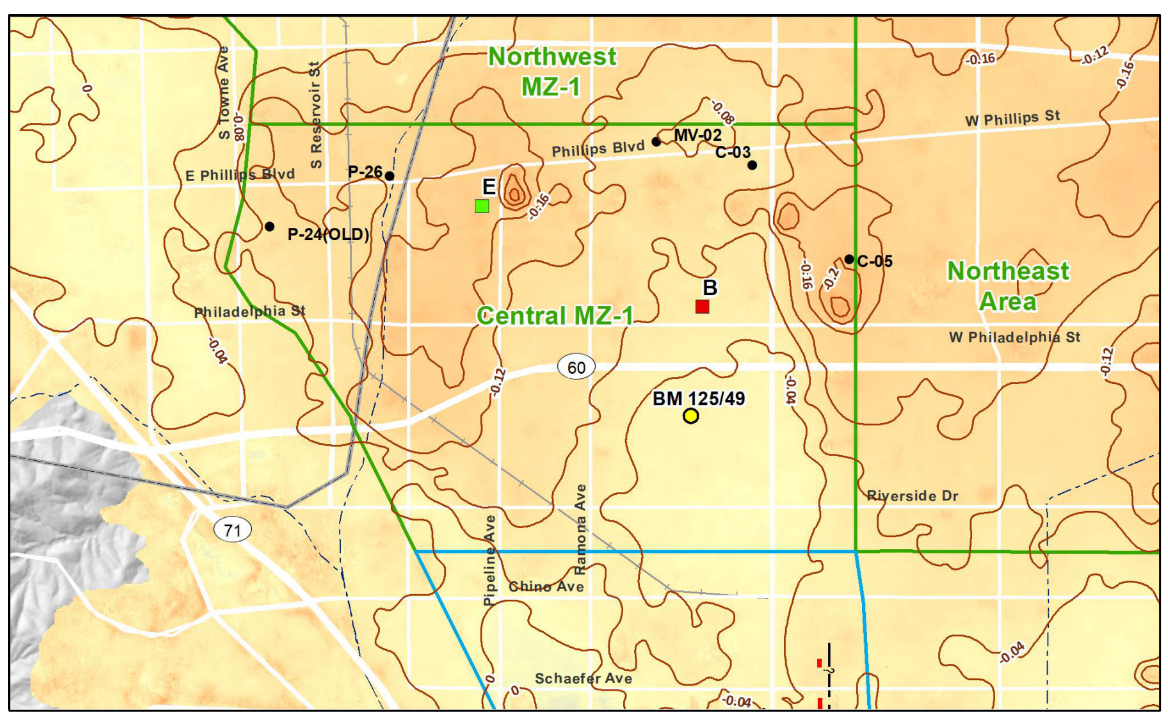
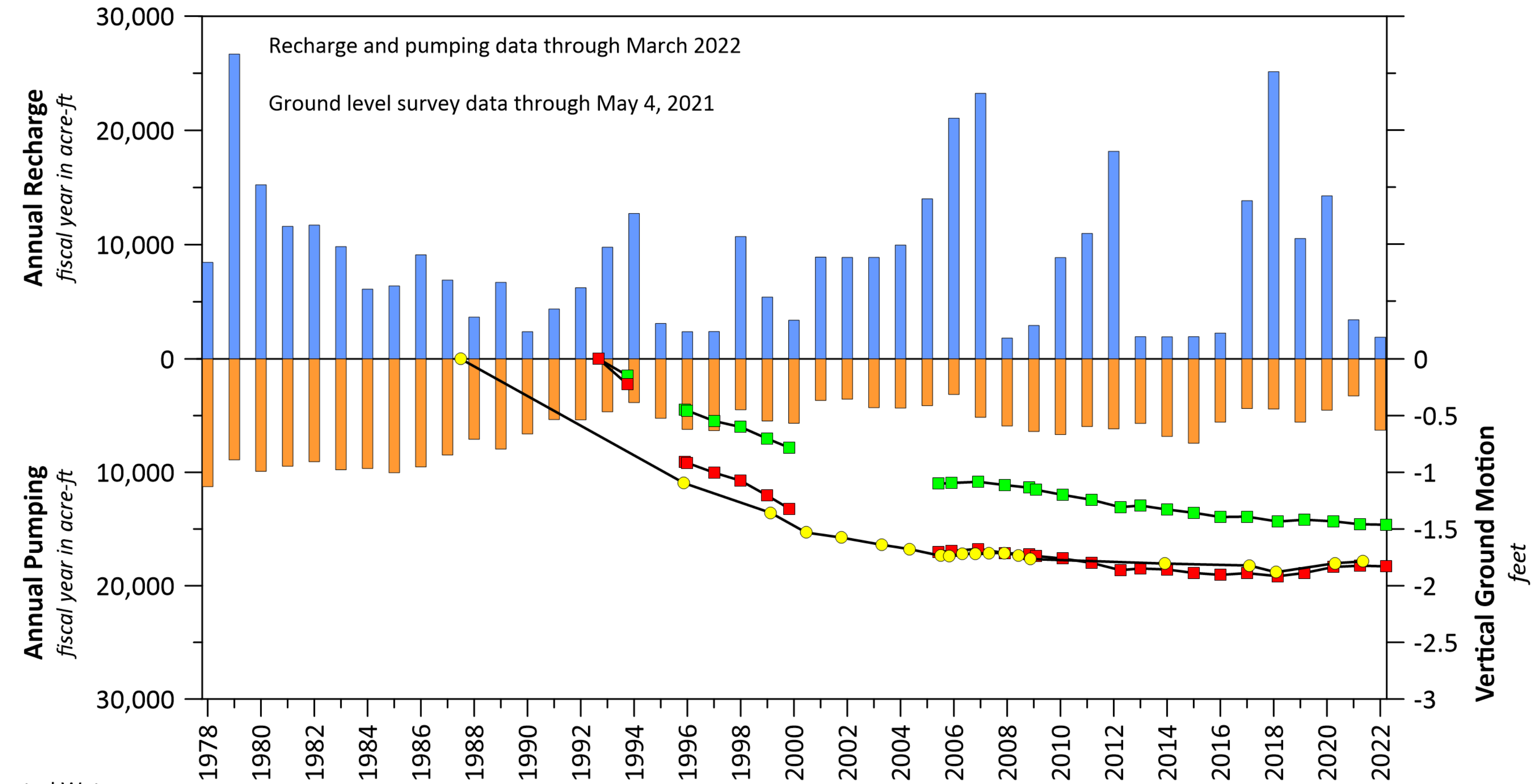




InSAR from March 2011 to March 2022 (see Figure 3-1a)



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

Ground-Level Monitoring Committe
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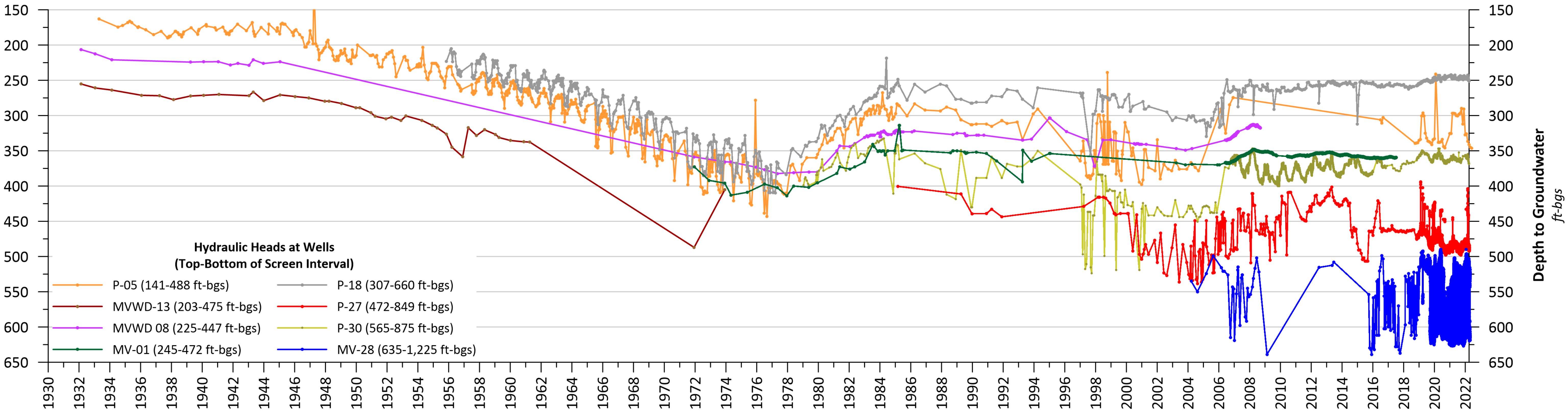
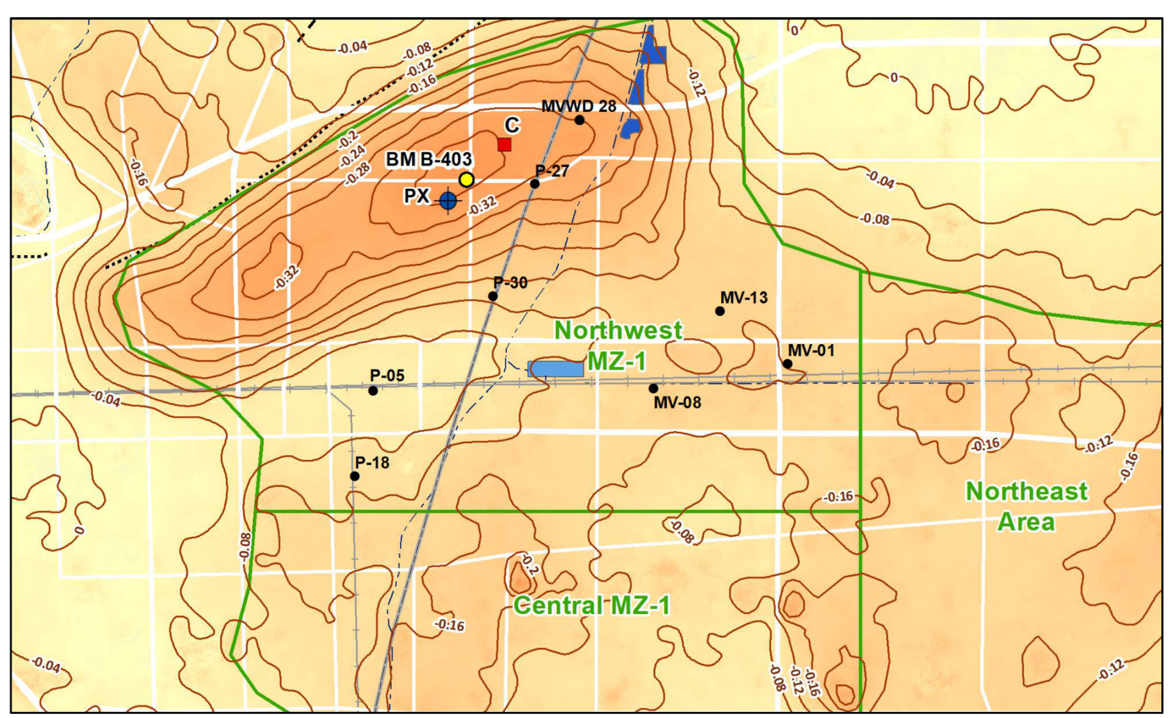
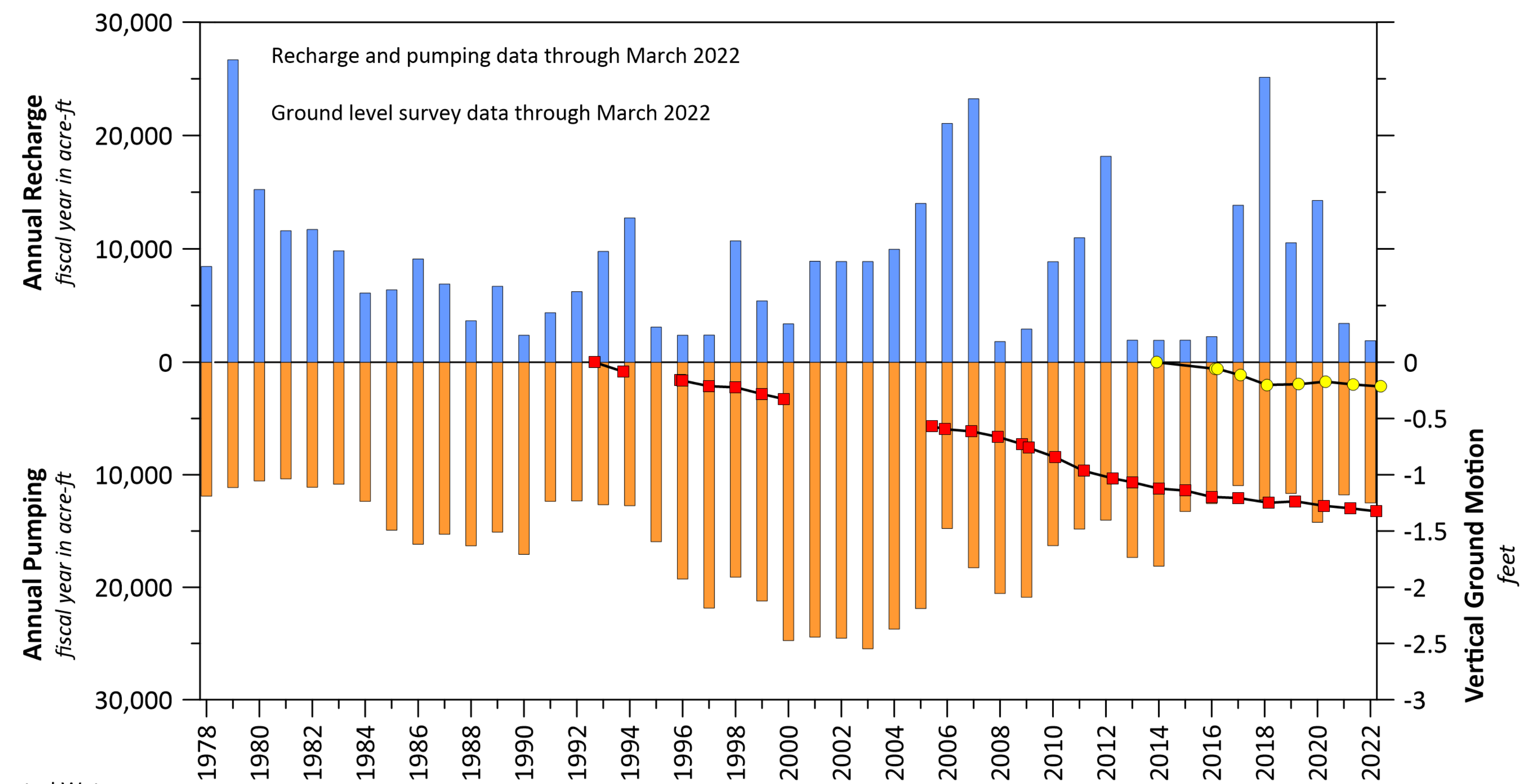




InSAR from March 2011 to March 2022 (see Figure 3-1a)



Vertical Ground-Motion (Cumulative Displacement)

- BM B-403
- InSAR at Point C

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 Northwest MZ-1

Figure 3-9

History of Land Subsidence in Northwest MZ-1

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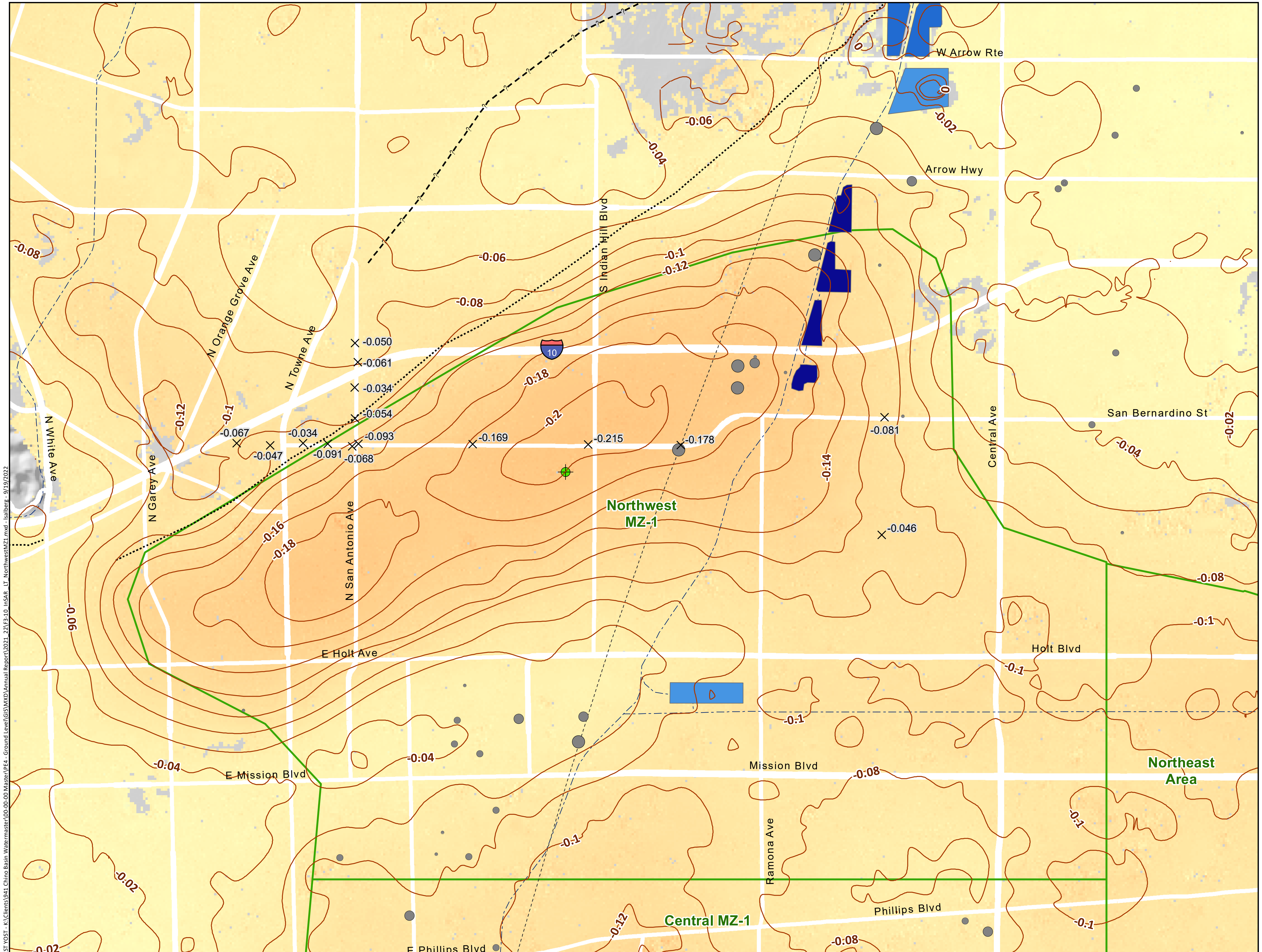

Scale in Feet: 0, 2,000, 4,000

Average Annual Groundwater Pumping
April 1, 2014 to March 31, 2022
(afy)

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

Average Annual Basin Recharge
April 1, 2014 to March 31, 2022
(afy)

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

Relative Change in Land Surface Elevation
as Estimated by InSAR
(April 2014 to March 2022)

+0.45 ft
0 ft
-0.25 ft
-0.45 ft

InSAR absent or incoherent

Pomona Extensometer Facility

Ground-Level Survey Benchmark (Measured May 25, 2022) Labeled by Vertical Ground Motion (in feet from December 2013 to May 2022)

Areas of Subsidence Concern

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

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Figure 3-10

Vertical Ground Motion across Northwest MZ-1: 2014-2022

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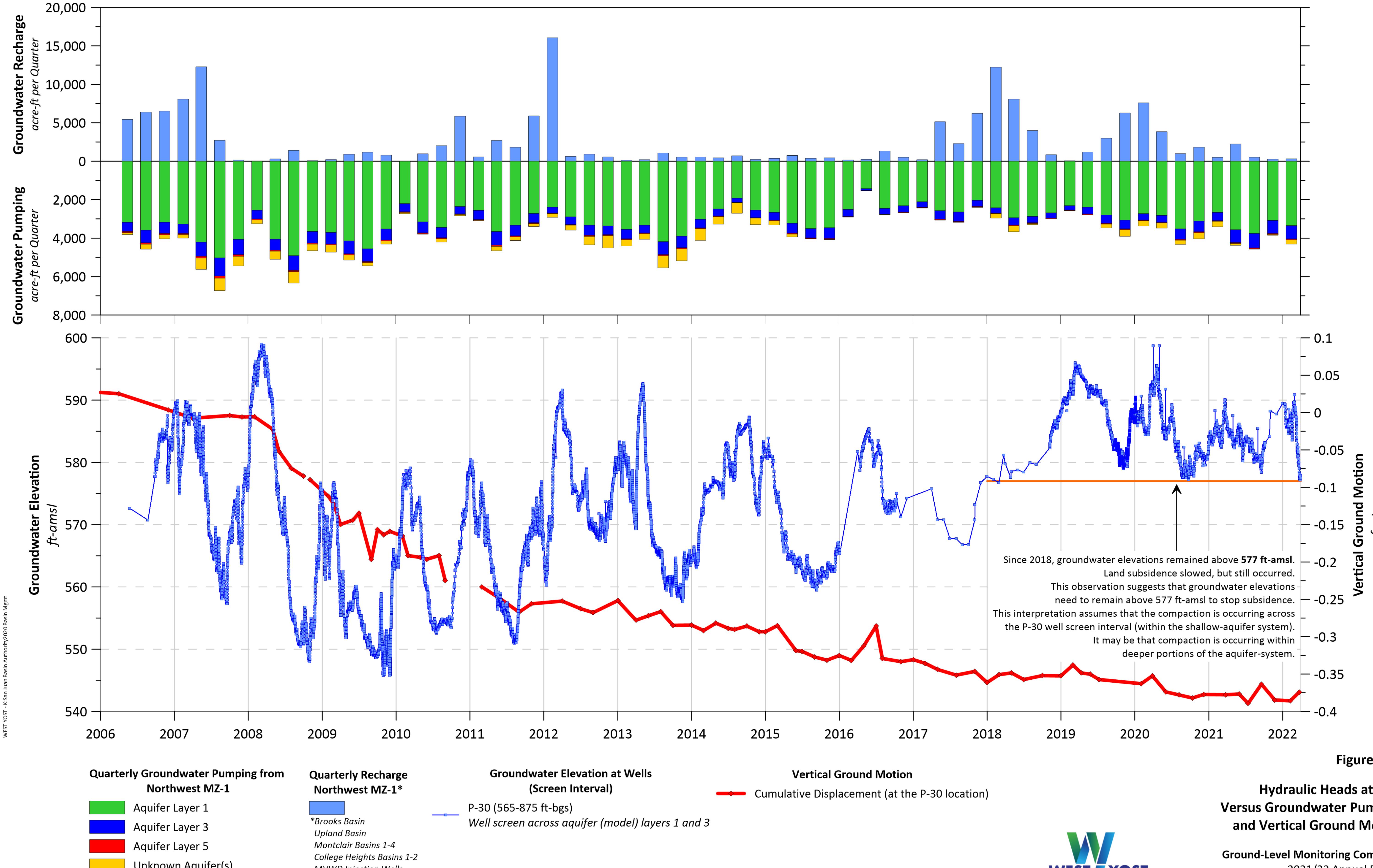
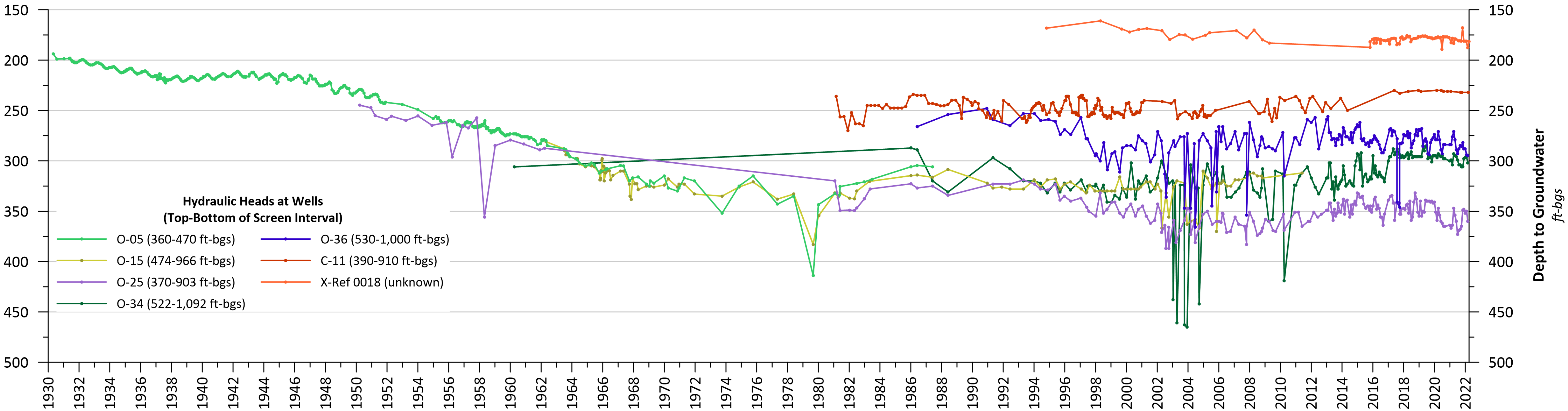
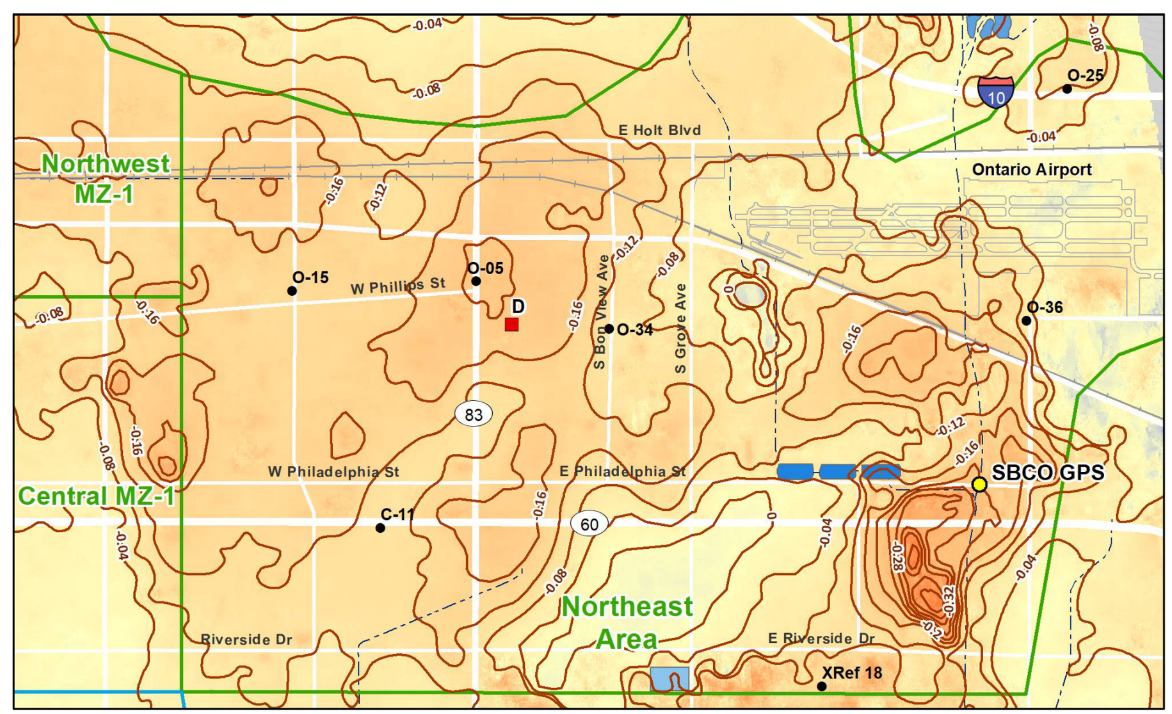


Figure 3-11

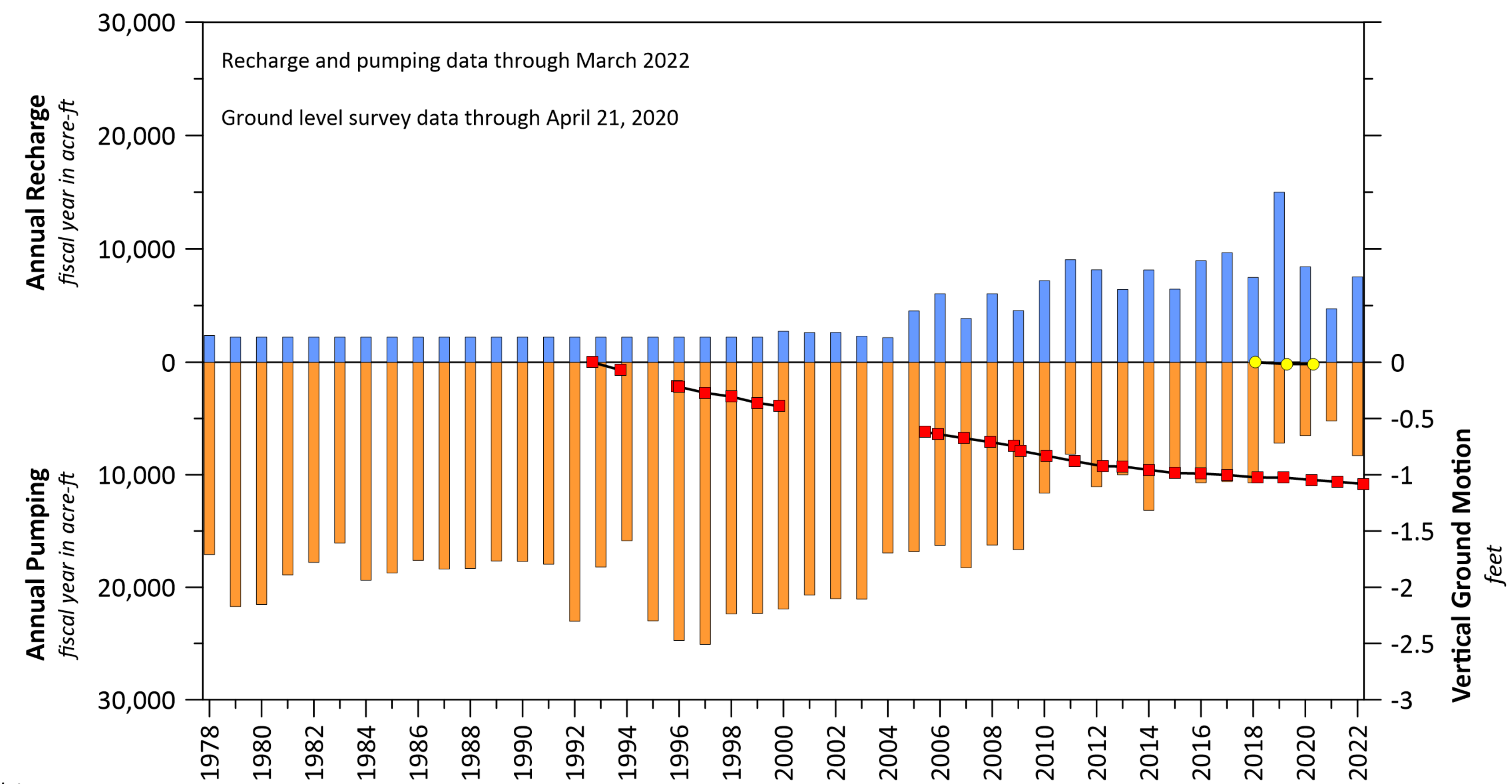
Hydraulic Heads at P-30 Versus Groundwater Pumping and Vertical Ground Motion

Ground-Level Monitoring Committe
2021/22 Annual Report





InSAR from March 2011 to March 2022 (see Figure 3-1a)



Vertical Ground-Motion (Cumulative Displacement)

- BM SBCO GPS
- InSAR at Point D

Recharge and Pumping

- Recharge of Recycled, Storm-water,* and Imported Water at the Ely, Grove, Turner, 7th Street and 8th Street Recharge Basins
  *Storm-water is an estimated amount prior to fiscal year 2004/05
- Groundwater Pumping from Wells in the Northeast Area

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Figure 3-12

History of Land Subsidence in the Northeast Area

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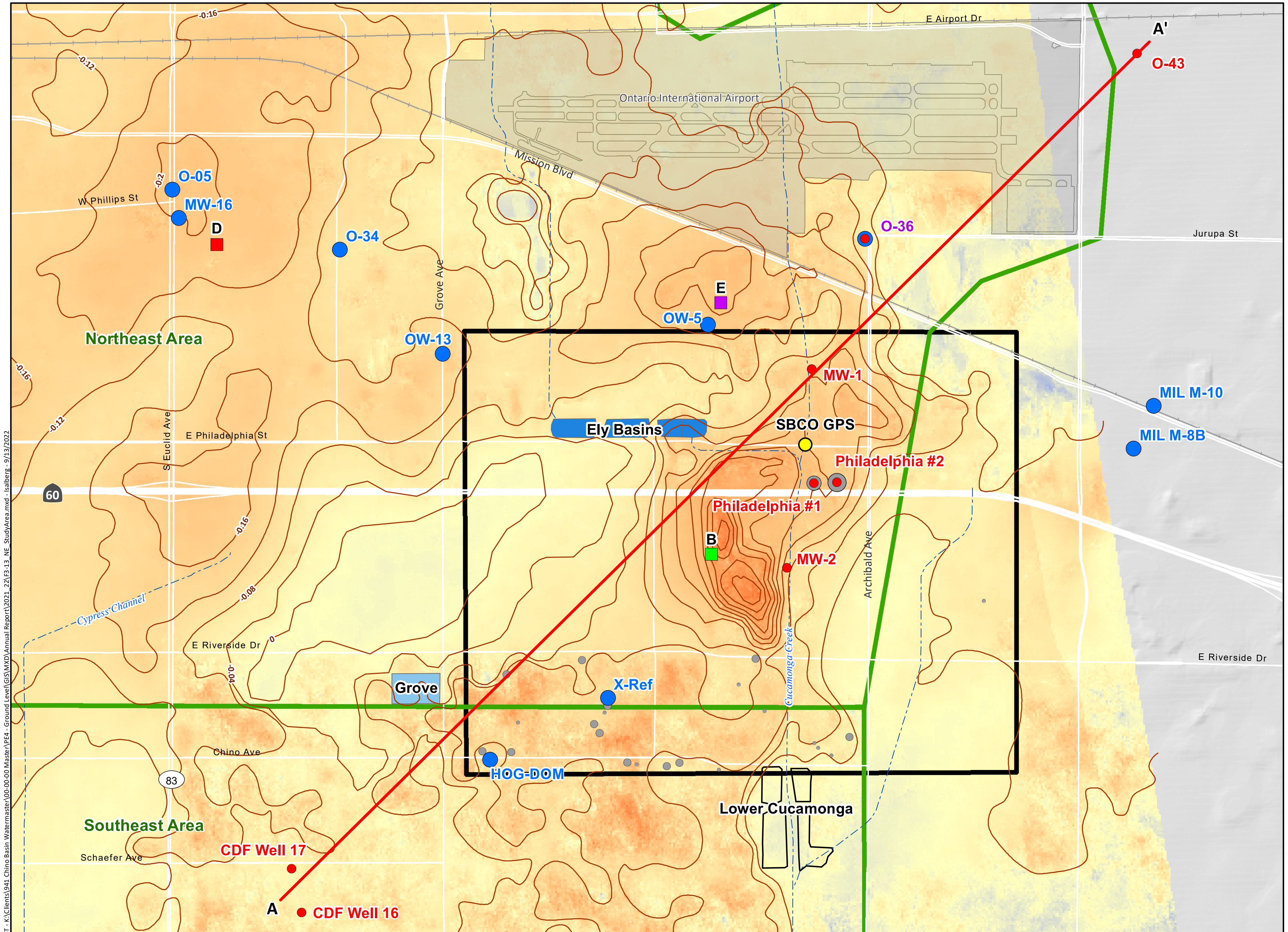


Areas of Subsidence Concern

Areas of Subsidence Concern

Whispering Lakes Subsidence Feature Study Area

Wells used in the Whispering Lakes Subsidence Investigation

Well with Long-Term Groundwater Elevation Data

Well used in Cross Section

Wells with Groundwater Production Data

Symbol Size indicates Average Annual Groundwater Production (FY 2011 - 2022)

0 - 10

11 - 100

101 - 250

251 - 500

501 - 700

Subsidence Features

Locations of InSAR Displacement Calculations

Contours of the Change in Ground Surface Elevation (Relative Change from March 2011 to March 2022)

Relative Change in Land Surface Elevation as Estimated by InSAR *(March 2011 to March 2022)*

+0.55 ft

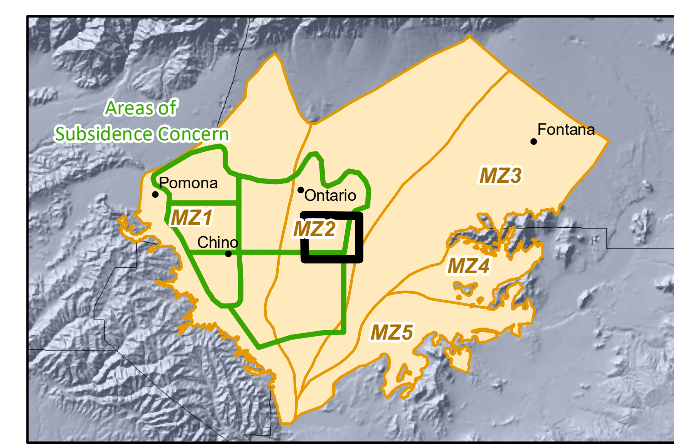
0 ft

-0.55 ft

Other Features

Cross Section Extent

Rivers and Streams



Prepared by:

WEST YOST Water. Engineered.

0 1 2 Miles

0 2 4 Km

Figure 3-13

Whispering Lakes Golf Course Subsidence Feature Study Area

Chino Basin Watermaster

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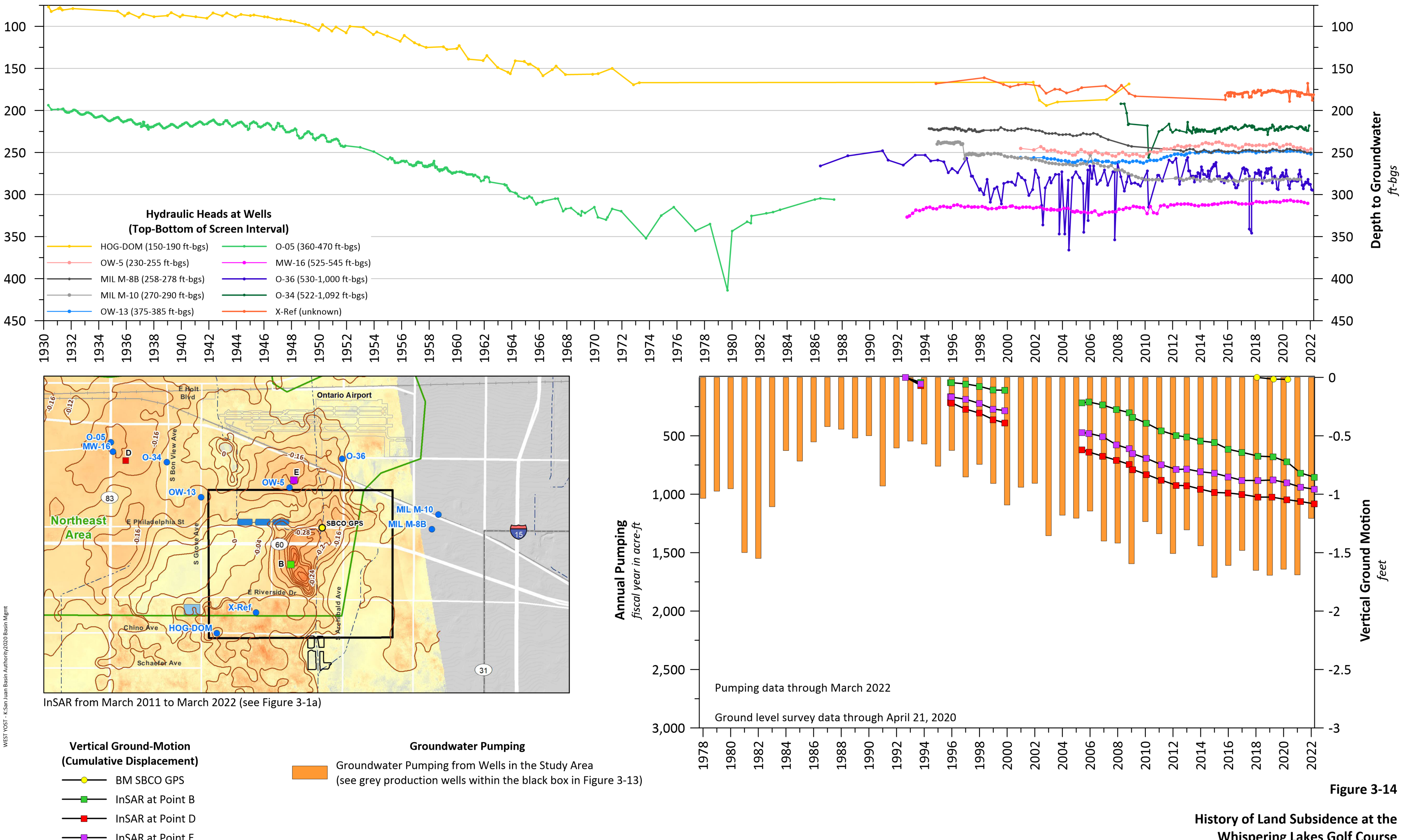

Figure 3-14

History of Land Subsidence at the Whispering Lakes Golf Course

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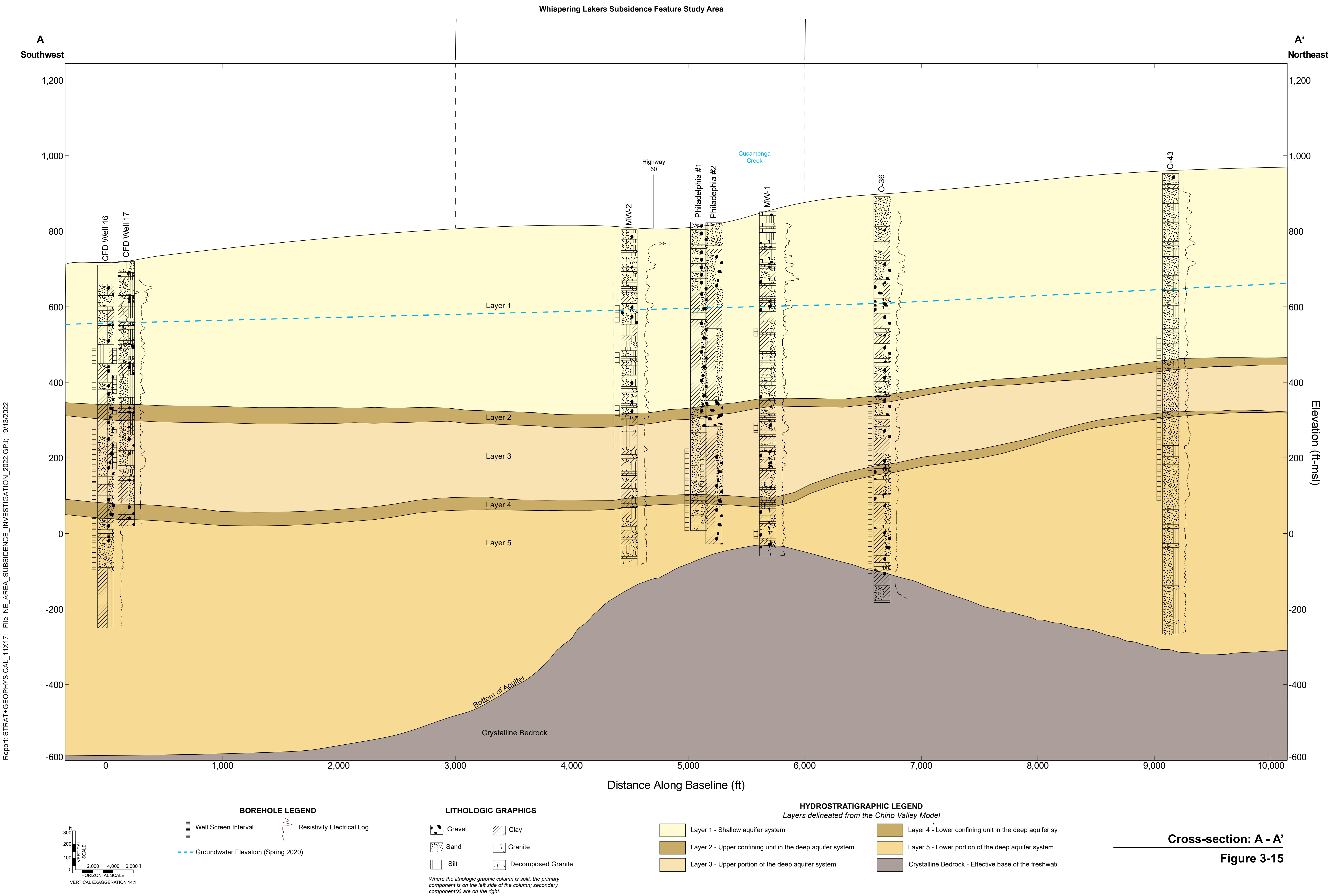
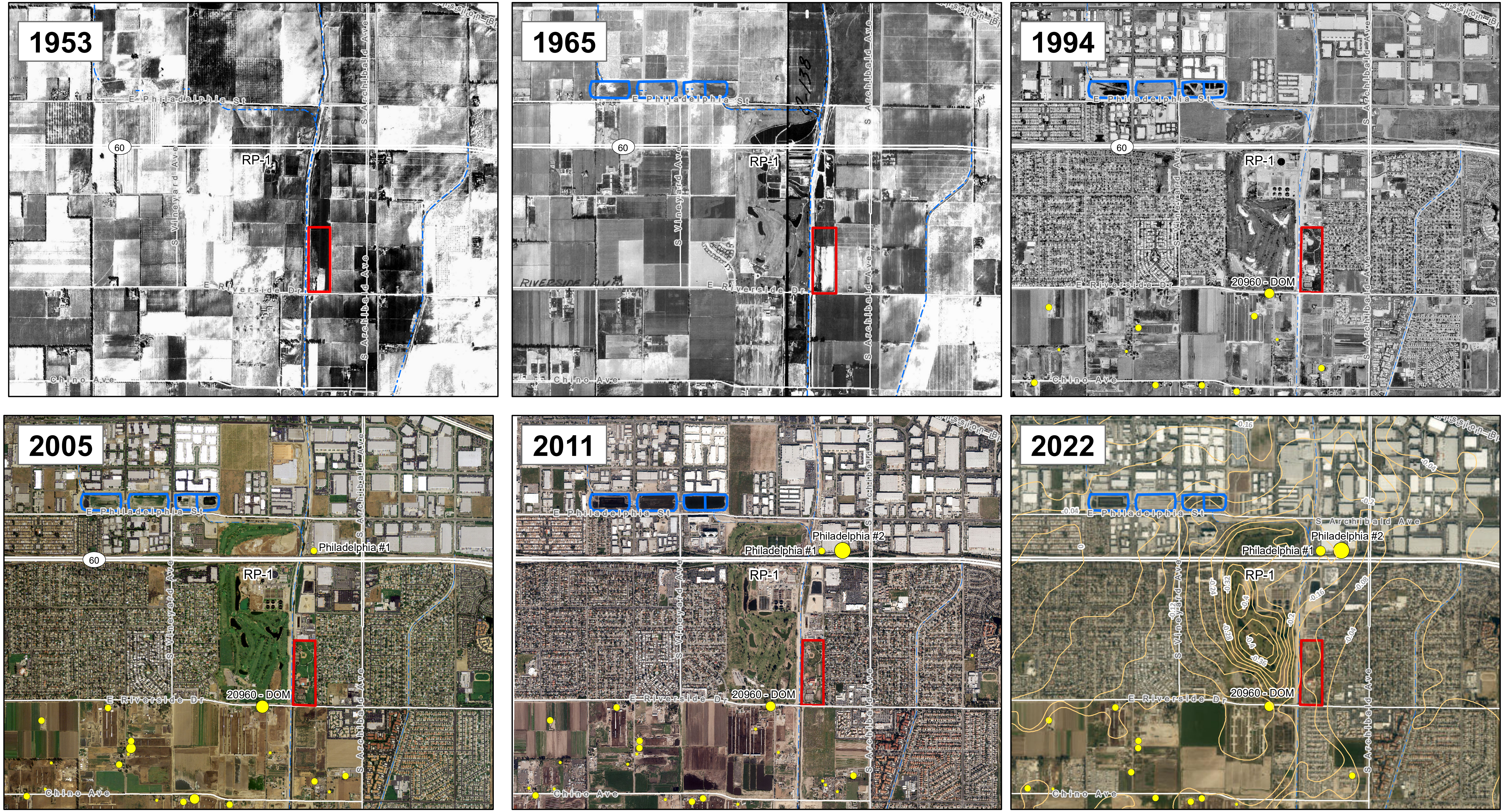


Cross-section: A - A'

Figure 3-15



0 0.5 1 Miles
0 1 2 Km

Annual Groundwater Production (af)
(reported by fiscal year)

- < 10
- 10 - 100
- 101 - 250
- 250 - 500
- 500 - 730

*Pumping records unavailable prior 1978 and the Stipulated Judgement
**Pumping for FY 2022 is limited to data from Q1 through Q3

Contours of the Change in Land Surface Elevation (Relative Change from March 2011 to March 2022)

Other Features

- Location of Historic Sewage Disposal Ponds
- Ely Recharge Basins
- Rivers and Streams

Figure 3-16

History of Land Use and Groundwater Pumping near the Whispering Lakes Subsidence Feature
1953 - 2022

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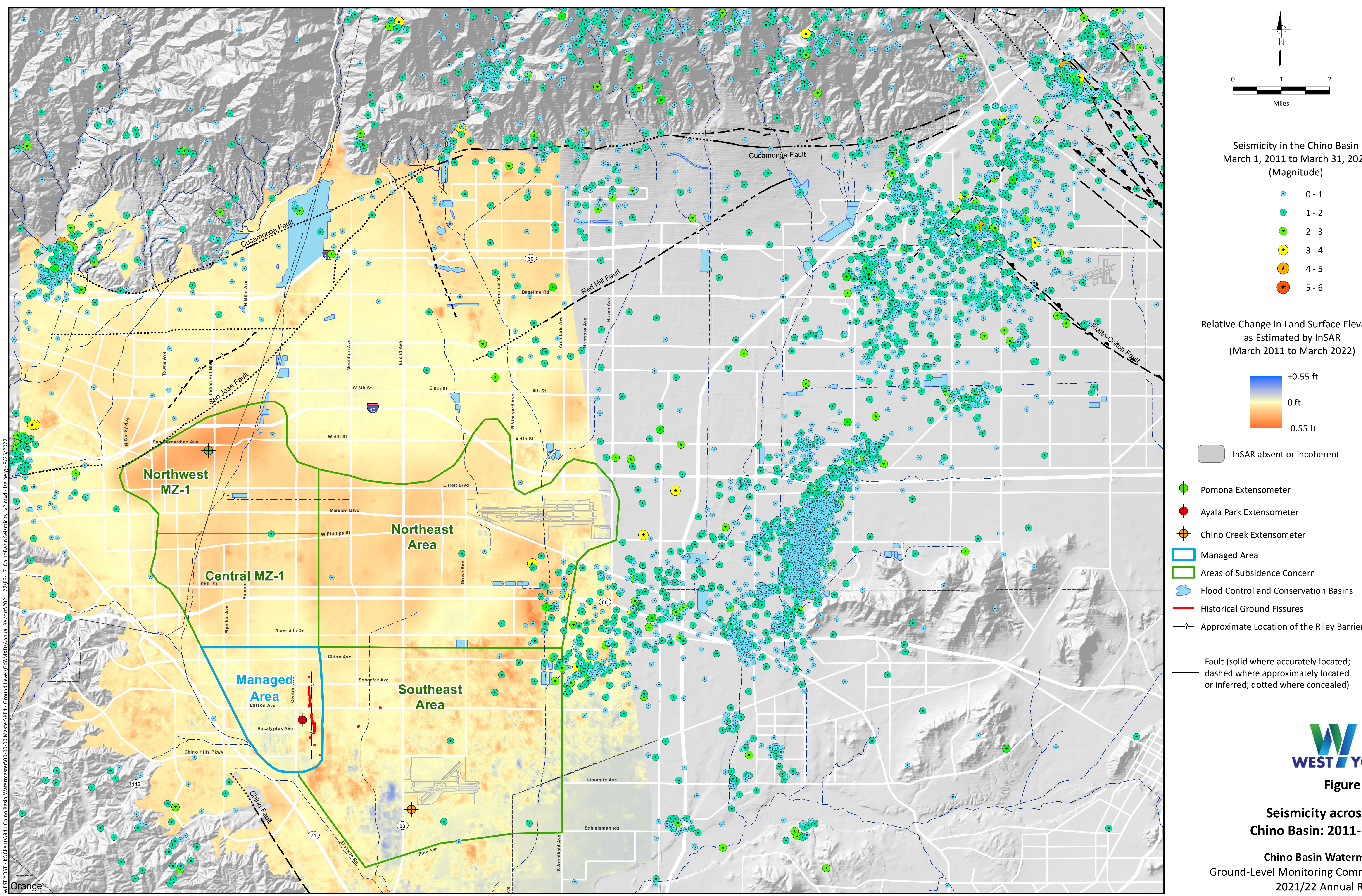

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Figure 3-17

Seismicity across the Chino Basin: 2011-2022

Chino Basin Watermaster
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4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions and Recommendations

The major conclusions and recommendations of this 2021/22 Annual Report of the GLMC are:

- At the Ayala Park Extensometer in the Managed Area, hydraulic heads within the shallow and deep aquifer-systems are at or near their highest levels since the inception of the GLMP in 2003, and the Ayala Park Extensometers recorded elastic compaction and expansion of the aquifer-system during the current reporting period of March 2021 to March 2022. 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 2022/23, 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.
- General Atomics has indicated that they may choose not to renew the 2022/23 contract for the InSAR processing work due to it not fitting well into the group's preferred scope of work.

RECOMMENDATION: The GLMC should continue to work with their consultant to find a solution that may include identifying alternative subconsultants for high-quality InSAR deliverables for 2022/23 should General Atomics choose not to perform this work in the ensuing year.

- **RECOMMENDATION**: The investigation of the Whispering Lakes Subsidence Feature in Section 3.5 identified several potential mechanisms that could be responsible for the recent land subsidence, including aquitard drainage, activities on overlying land uses, soil consolidation, and tectonics. The GLMC can consider the recommendations in Section 3.5 to further identify the primary cause(s) of the differential subsidence at the Whispering Lakes Subsidence Feature, including:
  - Further investigate the historical land use practices in the vicinity of the Whispering Lakes Golf Course.
  - Perform field studies of shallow soil consolidation.
  - Expand aquifer-system monitoring.

4.2 Recommended Scope and Budget for Fiscal Year 2022/23

The scope-of-work for the GLMP for FY 2022/23 was recommended by the GLMC in April 2022 and approved by Watermaster on May 26, 2022. Appendix A is the technical memorandum prepared by the GLMC, titled *Recommended Scope and Budget of the Ground-Level Monitoring Committee for FY 2022/23*.

In March 2023, Watermaster staff and the Watermaster Engineer will present the preliminary results of the GLMP through 2022 and a recommended FY 2023/24 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* 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. A really, 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.

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Appendix A

Recommended Scope and Budget of the Ground-Level Monitoring Committee for FY 2022/23

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TECHNICAL MEMORANDUM

DATE: March 31, 2022

Project No.: 941-80-21-63
SENT VIA: EMAIL

TO: Ground-Level Monitoring Committee

FROM: Andy Malone and Austin Poncelet

REVIEWED BY: Andy Malone

SUBJECT: Recommended Scope of Work and Budget of the Ground-Level Monitoring Committee for Fiscal Year 2022/23

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 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 2022/23 in the form of a proposed scope of services and budget.

Members of the GLMC are asked to:

- Review this TM prior to March 3, 2022.
- Attend a meeting of the GLMC at 9:00 am on March 3, 2022 to discuss the proposed scope of services and budget for FY 2022/23.
- Submit comments and suggested revisions on the proposed scope of services and budget for FY 2022/23 to the Watermaster by March 25, 2022.
- Attend a meeting of the GLMC at 9:00 am on March 31, 2022 to discuss comments and revisions to the proposed scope of services and budget for FY 2022/23 (if necessary).

- Submit additional comments and suggested revisions on the proposed scope of services and budget for FY 2022/23 to the Watermaster by April 8, 2022.

The final scope of services and budget that is recommended by the GLMC will be included in the Watermaster's FY 2022/23 budget. The final scope of services, budget, and schedule for FY 2022/23 will be included in Section 4 of the *2021/22 Annual Report of the GLMC*.

RECOMMENDED SCOPE OF SERVICES AND BUDGET – FY 2022/23

A proposed scope of services for the GLMP for FY 2022/23 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 for the Ground-Level Monitoring Program: FY 2022/23

Task Description			Labor (days)		Other Direct Costs						Totals					
			Person Days	Total	Travel	New Equip.	Equip. Rental	Outside Pro	Misc.	Total	Totals by Task	Recommended Budget *2022/23*	Approved Budget *2021/22*	Net Change *from 2021/22*	Potential Carry-Over *2022/23*	Budget with Carry-Over *2022/23*
												a	*b*	*a - b*	*c*	*a - c*
Task 1. Setup and Maintenance of the Monitoring Network				**$28,082**						**$7,388**	**$35,470**	**$35,470**	**$33,596**	**$1,874**	**$0**	**$35,470**
1.1		Maintain Extensometer Facilities														
	1.1.1	Routine maintenance of Ayala Park, Chino Creek, and Pomona extensometer facilities	14	$20,922	$1,056	$250	$152			$1,458	$22,380	$22,380	$21,282	$1,098	$0	$22,380
	1.1.2	Replacement/repair of equipment at extensometer facilities	4	$7,160	$264	$2,000	$70	$2,000		$4,334	$11,494	$11,494	$10,718	$776	$0	$11,494
1.2		Annual Lease Fees for the Chino Creek extensometer facility	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				**$30,007**						**$680**	**$30,687**	**$30,687**	**$31,416**	**-$729**	**$0**	**$30,687**
2.1		Conduct Quarterly Data Collection from Extensometers; Data Checking and Management														
	2.1.1	Download data from the Ayala Park Extensometer facility	2	$2,753	$230		$76			$306	$3,059	$3,059	$2,993	$66	$0	$3,059
	2.1.2	Download data from the Chino Creek Extensometer facility	2	$2,753	$26					$26	$2,778	$2,778	$2,713	$66	$0	$2,778
	2.1.3	Download data from Pomona Extensometer facility	4	$5,505	$272		$76			$348	$5,853	$5,853	$5,722	$131	$0	$5,853
	2.1.4	Process, check, and upload data to database	12	$18,997						$0	$18,997	$18,997	$19,988	-$991	$0	$18,997
Task 3. Basin Wide Ground-Level Monitoring Program (InSAR)				**$5,472**						**$85,000**	**$90,472**	**$90,472**	**$90,116**	**$356**	**$0**	**$90,472**
3.1		Acquire TerraSAR-X data and prepare interferograms for 2022/23	1	$1,892				$85,000		$85,000	$86,892	$86,892	$86,845	$47	$0	$86,892
3.2		Check and review InSAR results	2	$3,580						$0	$3,580	$3,580	$3,271	$309	$0	$3,580
Task 4. Perform Ground-Level Surveys				**$7,434**						**$30,807**	**$38,241**	**$38,241**	**$93,982**	**-$55,741**	**$0**	**$38,241**
4.1		Conduct Spring-2023 Elevation surveys in Northwest MZ-1	0.5	$1,102				$25,157		$25,157	$26,259	$26,259	$26,083	$176	$0	$26,259
4.2		Conduct Spring-2023 Elevation Survey in the Northeast Area	0	$0				$47,069		$0	$0	$0	$0	$0	$0	$0
4.3		Conduct Spring-2023 Elevation Survey in the Southeast Area	0	$0				$49,797		$0	$0	$0	$50,723	-$50,723	$0	$0
4.4		Conduct Spring-2023 Elevation and EDM Surveys in the Managed Area/Fissure Zone	0	$0				$54,410		$0	$0	$0	$0	$0	$0	$0
4.5		Replace Destroyed Benchmarks (if needed)	0	$0				$5,650		$5,650	$5,650	$5,650	$11,300	-$5,650	$0	$5,650
4.6		Process, Check, and Update Database	4	$6,332						$0	$6,332	$6,332	$5,877	$456	$0	$6,332
Task 5. Data Analysis and Reporting				**$85,760**						**$2,129**	**$87,888**	**$87,888**	**$85,586**	**$2,303**	**$0**	**$87,888**
5.1		Prepare Draft 2021/22 Annual Report of the Ground-Level Monitoring Committee	20.5	$34,124						$0	$34,124	$34,124	$33,286	$838	$0	$34,124
5.2		Prepare Final 2021/22 Annual Report of the Ground-Level Monitoring Committee	10.5	$19,993						$0	$19,993	$19,993	$19,546	$446	$0	$19,993
5.3		Compile and Analyze Data from the 2022/23 Ground-Level Monitoring Program	14	$21,643						$0	$21,643	$21,643	$21,144	$500	$0	$21,643
5.4		Conduct Reconnaissance-Level Subsidence Investigation of the Northeast Area (southeast part)	0	$10,000	$129	$2,000				$2,129	$12,129	$12,129	$11,610	$519	$0	$12,129
Task 6. Develop a Subsidence-Management Plan for Northwest MZ-1				**$165,404**						**$138**	**$165,541**	**$165,541**	**$238,644**	**-$73,102**	**$97,267**	**$68,275**
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	$12,995						$0	$12,995	$12,995	$12,669	$326	$0	$12,995
	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	$12,208						$0	$12,208	$12,208	$11,913	$295	$0	$12,208
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	0	$0						$0	$0	$0	$8,842	-$8,842	$0	$0
	6.3.2	Review and respond to the GLMC comments on the 1D compaction models	0	$0						$0	$0	$0	$6,140	-$6,140	$0	$0
	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	0	$0						$0	$0	$0	$61,813	-$61,813	$0	$0
	6.3.4	Prepare for and conduct a GLMC meeting to receive feedback and comments on the draft TM	0	$0						$0	$0	$0				
	6.3.5	Incorporate the GLMC comments and prepare a final technical memorandum	0.0	$0						$0	$0	$0				
6.4		Refine and Evaluate Subsidence-Management Alternatives														
	6.4.1	Run the Baseline Management Alternative (BMA)	19	$33,946						$0	$33,946	$33,946				
	6.4.2	Prepare a TM that summarizes the evaluation of the BMA and a recommended ISMA	10.75	$19,871						$0	$19,871	$19,871				
	6.4.4	Meet with the GLMC to receive feedback on the TM	4.5	$8,962	$69					$69	$9,031	$9,031				
	6.4.5	Run the Initial Subsidence Management Alternative (ISMA)	25.75	$48,047						$0	$48,047	$48,047	$137,267	$3,072	$97,267	$43,072
	6.4.6	Prepare a technical memorandum that summarizes the evaluation of the ISMA and a recommended Subsidence Management Alternative (SMA-2)	10.75	$19,871						$0	$19,871	$19,871				
	6.4.7	Prepare for and conduct a meeting to receive feedback and comments on the draft technical memorandum	4.75	$9,504	$69					$69	$9,573	$9,573				
Task 7. Meetings and Administration				**$54,241**						**$318**	**$54,559**	**$54,559**	**$54,220**	**$339**	**$0**	**$54,559**
7.1		Prepare for and Conduct Four Meetings of the Ground-Level Monitoring Committee	18	$29,737	$249					$249	$29,986	$29,986	$28,117	$1,869	$0	$29,986
7.2		Prepare for and Conduct One As-Requested Ad-Hoc Meeting	3	$4,956	$69					$69	$5,025	$5,025	$6,024	-$999	$0	$5,025
7.3		Perform Monthly Project Management	6	$10,740						$0	$10,740	$10,740	$11,108	-$369	$0	$10,740
7.4		Prepare a Recommended Scope and Budget for the GLMC for FY 2023/24	5.25	$8,808						$0	$8,808	$8,808	$8,970	-$162	$0	$8,808
Totals				**$376,401**						**$126,459**		**$502,860**	**$627,560**	**-$124,700**	**$97,267**	**$405,593**

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 2022 to March 2023.

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 2022 to March 2023 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 2022 to March 2023 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 periodically between monuments to estimate horizontal ground motion in areas where ground fissuring due to differential land subsidence is a concern. Table 2 documents the areas surveyed over the last six years as part of the GLMP.

Table 2. History of Ground-Level Surveys

Ground-Level Survey Area	Ground-Level Survey Completed (Y/N)?					
	2017	2018	2019	2020	2021	2022[b]
Managed Area	N	Y	N	N	N	N
Fissure Zone Area[a]	N	Y	N	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	N
Southeast Area	Y	Y	N	N	N	Y
Northeast Area	N	Y	Y	Y	N	N

(a) Denotes EDM survey area (measurements of horizontal strain).
(b) The 2022 ground-level surveys are scheduled to begin in early March 2022.

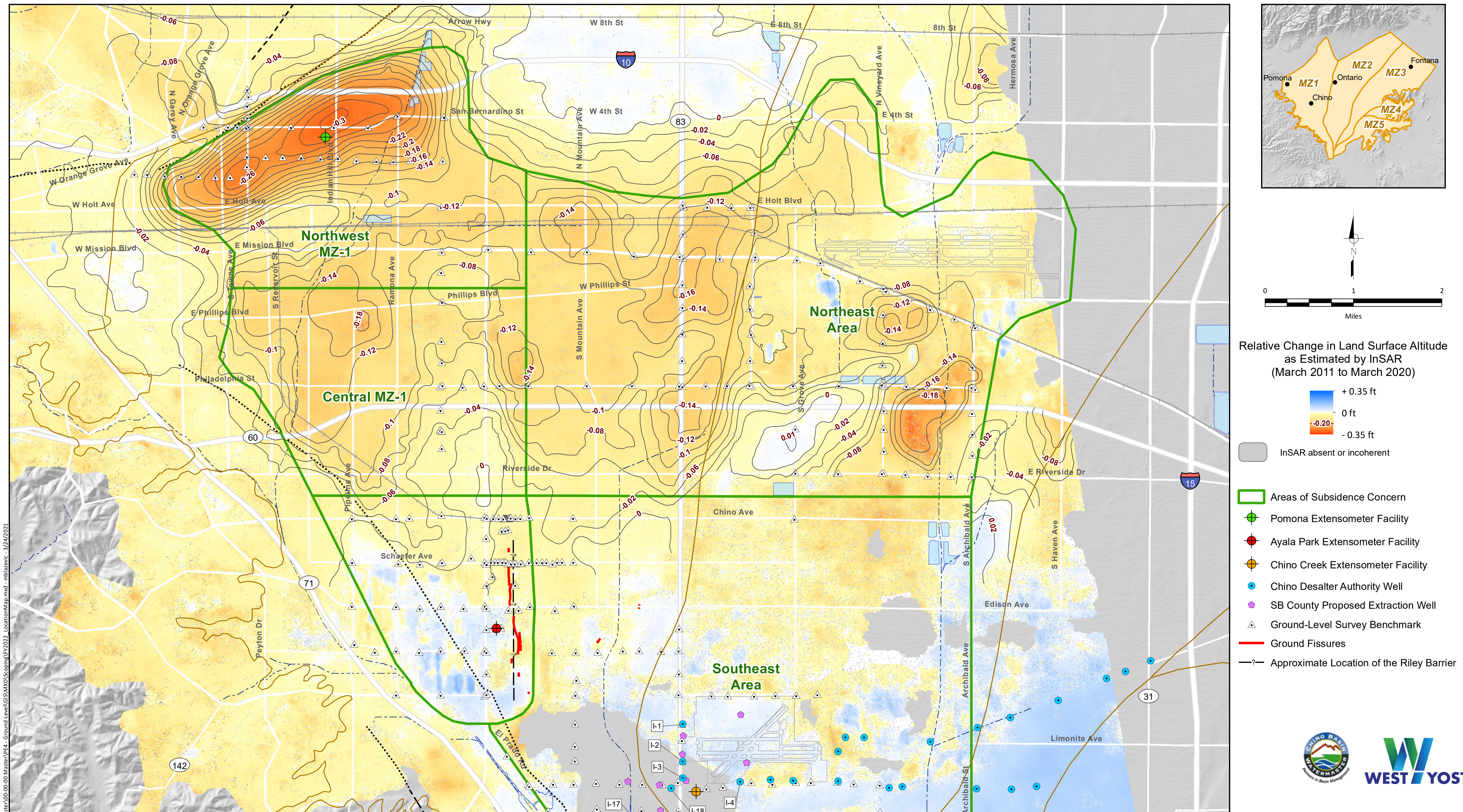

Figure 1

Ground-Level Monitoring Program Fiscal Year 2021/22

Chino Basin Watermaster

Ground-Level Monitoring Committee

The ground-level surveys recommended for FY 2022/23 include the following Tasks:

Task 4.1. Conduct Spring-2023 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 2022/23 because of the recent subsidence that has occurred in Northwest MZ-1 and because the survey 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 past surveys (2013-2021) have demonstrated that the horizontal strain measured between benchmark pairs appears to behave elastically. The EDM surveys should be conducted less frequently than annual (e.g., once every five years).*

Ground-Level Surveys Not Recommended for FY 2022/23

Ground-level surveys are **not** recommended for FY 2022/23 include all other Areas of Subsidence Concern. This recommendation is justified because:

- InSAR is proving to be an accurate, more efficient, higher-resolution method to monitor vertical ground motion across the western Chino Basin.
- Hydraulic heads and vertical ground motion in some of these areas are stable or increasing.

Ground-level surveys should be conducted in these areas less frequently than annual (*e.g.,* once every five years).

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.

Task 5. Data Analysis and Reporting

Task 5.1. Prepare Draft 2021/22 Annual Report of the Ground-Level Monitoring Committee

Prepare the text, tables, and figures for a draft *2021/22 Annual Report of the GLMC* and submit the report to the GLMC by September 23, 2022 for review and comment.

Task 5.2. Prepare Final 2021/22 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 *2021/22 Annual Report of the GLMC* by November 4, 2022. 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 2022 Watermaster meetings for approval.

Task 5.3. Compile and Analyze Data from the 2022/23 Ground-Level Monitoring Program

In this subtask, monitoring data generated from the GLMP during 2022/23 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 2023 during the development of a recommended scope of services and budget for FY 2023/24.

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

In the Northeast Area, the long-term 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 due to aquifer-system compaction, but there is not enough historical data in this area to confirm this relationship. In FY 2021/22, the Watermaster Engineer is conducting a *Reconnaissance-Level Subsidence Investigation of the Northeast Area* that includes the review and analysis of readily-available borehole and lithologic data, historical air photos, pumping and recharge data, hydraulic head data, and InSAR estimates of vertical ground motion at up to four locations in this area of concern. Figures and charts are being prepared and analyzed to derive interpretations and recommendations for future investigations and monitoring, if appropriate. This investigation is not yet complete. The GLMC should consider dedicating contingency budget for FY 2022/23 to implement the recommendations derived the investigation ($10,000).

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.

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

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.

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.

Progress to Implement Work Plan thru FY 2021/22

The progress that has been made to implement the Work Plan (through FY 2021/22) includes the following:

- An initial hydrogeologic conceptual model of the Northwest MZ-1 Area was developed, and a report was published in 2017.[3] This report described the hydrogeology of the area, speculated on the causes of the observed land subsidence, and included a recommended monitoring program.
- A preliminary one-dimensional (1D) compaction model, based on hydrogeologic information from the MVWD-28 well site, was constructed, calibrated, and used to explore the future occurrence of subsidence in Northwest MZ-1 under various basin-operation scenarios of groundwater production and artificial recharge and to identify potential subsidence mitigation strategies. A report[4] was published to document the results of the modeling and included a recommendation to construct the Pomona Extensometer.
- The initial monitoring program was implemented to closely track groundwater-levels, groundwater production, recharge, and ground motion across Northwest MZ-1. This monitoring program included the construction of the Pomona Extensometer to measure and record depth-

[2] Work Plan to Develop a Subsidence-Management Plan for Northwest MZ-1
[3] https://cbwm.syncedtool.com/shares/folder/PaauzoQapiZ/?folder_id=5150940
[4] https://cbwm.syncedtool.com/shares/folder/PaauzoQapiZ/?folder_id=5150942v

specific heads and aquifer-system deformation. Implementation of the monitoring program is ongoing.

- A new 1D model was constructed and calibrated using the hydrogeologic information collected at the Pomona Extensometer. The 1D model at MVWD-28 was also updated and recalibrated using current information. The objectives of this exercise were to: (i) describe the subsidence mechanisms and the pre-consolidation head by aquifer-system layer in Northwest MZ-1 and (ii) develop modeling tools that will be used to explore the future occurrence of subsidence in Northwest MZ-1 under various basin-operation scenarios of groundwater production and artificial recharge and to identify potential subsidence mitigation strategies. This work has been reviewed by the GLMC. The GLMC has recommended additional model calibration refinements and sensitivity analyses. This additional work is currently being performed. The GLMC will perform final review and approval of an updated TM on the model calibration before using the 1D models to develop subsidence management strategies (see Task 6.4 below). This work is expected to be completed by the beginning of FY 2022/23.

Based on the expected progress through FY 2021/22, the following work is recommended for FY 2022/23 to develop the Subsidence Management Plan for Northwest MZ-1:

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: (i) SCADA-based monitoring by the Monte Vista Water District; (ii) monitoring of piezometric levels via sonar[5]; (iii) monitoring of piezometric levels via pressure transducers at City of Pomona production wells; and (iv) 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 6.4. 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 over the planning horizon?

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 minimizing or abating land subsidence over the planning horizon. The assumptions of the ISMA, including the groundwater production and replenishment plans of the Chino Basin parties, will be described and must

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

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 2023/24. 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 2023/24 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 2022 – Implementation of the GLMP for FY 2022/23
- September 2022 – Review the draft 2021/22 Annual Report of the Ground-Level Monitoring Committee
- February 2023 – Review the draft recommended scope and budget for FY 2023/24
- March 2023 – Review the final recommended scope and budget for FY 2023/24 (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 2023/24

This subtask includes preparing a draft and final recommended scope of services and budget for FY 2023/24 for the GLMC to support the Watermaster's budgeting process.

Comments and Responses to Comments

The comments received from the GLMC as of March 31, 2022 on the "Recommended Scope of Services and Budget of the Ground-Level Monitoring Committee for Fiscal Year 2022/23 (Draft)" and the Watermaster Engineer's response to comments are documented below.

City of Pomona and Monte Vista Water District by Christopher Coppinger

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

Are there costs included to present the sensitivity analysis and calibration refinements before moving into Task 6.4? I'd like to make sure we have a chance to understand the results before the 1D model gets utilized. I thought there would be enough changes to warrant a line item, but I'm not sure that I see it.

Response:

The costs are not included in next year's budget because we hope to be complete with the additional calibration analyses this fiscal year before moving to Task 6.4 next fiscal year. You can find this statement in the last bullet on Page 8:

- A new 1D model was constructed and calibrated using the hydrogeologic information collected at the Pomona Extensometer. The 1D model at MVWD-28 was also updated and recalibrated using current information. The objectives of this exercise were to: (i) describe the subsidence mechanisms and the pre-consolidation head by aquifer-system layer in Northwest MZ-1 and (ii) develop modeling tools that will be used to explore the future occurrence of subsidence in Northwest MZ-1 under various basin-operation scenarios of groundwater production and artificial recharge and to identify potential subsidence mitigation strategies. This work has been reviewed by the GLMC. The GLMC has recommended additional model calibration refinements and sensitivity analyses. This additional work is currently being performed and should be completed by the beginning of FY 2022/23.

Comment 2 – Task 6. Develop a Subsidence Management Plan for Northwest MZ 1

Could we add a sentence to the end of the section - "A revised TM including the results of the sensitivity analyses and calibration refinements will be submitted to the committee for review prior to proceeding with the work described in section 6.4." or similar clarifying statement?

Response:

The last bullet on Page 9 was modified to read (changes in red):

- A new 1D model was constructed and calibrated using the hydrogeologic information collected at the Pomona Extensometer. The 1D model at MVWD-28 was also updated and recalibrated using current information. The objectives of this exercise were to: (i) describe the subsidence mechanisms and the pre-consolidation head by aquifer-system layer in Northwest MZ-1 and (ii) develop modeling tools that will be used to explore the future occurrence of subsidence in

Northwest MZ-1 under various basin-operation scenarios of groundwater production and artificial recharge and to identify potential subsidence mitigation strategies. This work has been reviewed by the GLMC. The GLMC has recommended additional model calibration refinements and sensitivity analyses. This additional work is currently being performed. The GLMC will perform final review and approval of an updated TM on the model calibration before using the 1D models to develop subsidence management strategies (see Task 6.4 below). This work is expected to be completed by the beginning of FY 2022/23.

Appendix B

Response to GLMC Comments

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

Comment 1 – General Comment

We reviewed the report entitled “2021/2022 Annual Report of the Ground-Level Monitoring Committee,” dated September 2022, on behalf of the State of California/California Department of Corrections and Rehabilitation, a member of the Agricultural Pool. We have no comments on the report.

Response:

Thank you for your review.

CITY OF ONTARIO (CHRISTOPHER QUACH, PE)

Comment 1 – Section 3.5.2 Whispering Lakes Subsidence Investigation (Northeast Area)

The City agrees with the recommendation for further research of historical land uses and water levels. The City may be able to share additional relevant documentation and it is recommended that Watermaster’s consultant include this effort in their research.

Response:

Thank you for your comment. We welcome any additional relevant documentation you are able to share that may aid in further investigation of the Whispering Lakes Subsidence Feature.

Comment 2 – Section 3.5.2 Whispering Lakes Subsidence Investigation

The City recommends a cost balanced approach and to exhaust all academic investigative efforts first.

Response:

Thank you for your comment. We agree with this approach fiscally conscious approach.

Comment 3 – Section 3.5.2 Whispering Lakes Subsidence Investigation

If initial investigations and historical research are inconclusive, the City would support gradually taking more expensive steps, such as performing field studies.

Response:

Thank you for your comment. We agree with this approach.

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

Comment 1 – Section 3.5.2 Whispering Lakes Subsidence Investigation

For future Annual Reports of the GLMC, we recommend including regional InSAR interferograms of the Chino basin (not just the Western Chino Basin) to better understand the relationship of observed changes in land surface elevation that have recently been identified near the eastern edge of the area currently mapped. Observations of trends in land surface elevation changes over a larger area extending to the northeast may provide additional insight as to the geologic relevance of the subsidence that has been identified at the Whispering Lakes Study Area.

Response:

Thank you for your comment and suggestion for expanding the InSAR interferograms coverage area for future GLMC Annual Reports. The GLMC should discuss this as a task to include in the FY 2024 budget.

Comment 2 – 4.1 Conclusions and Recommendations

We find that the report appropriately describes the work of the GLMC for the 2021-2022 fiscal Year and concur with the conclusions and recommendations presented in Section 4.1.

Response:

Thank you for your comment.

CITY OF POMONA AND MONTE VISTA WATER DISTRICT/GEOSCIENCE (CHRISTOFER COPPINGER, PG, CHG)

Comment 1 – Section 2.1.2.2 Monitoring Vertical Aquifer-System Deformation

Preliminary depth-specific hydraulic head and aquifer-system deformation data continues to be collected at the Pomona Extensometer Facility. The facility does not appear to be measuring and/or recording reliable data for aquifer-system deformation. An investigation is ongoing into understanding the data and improving the reliability of the measurements. Please provide more detail. Are the measurements of concern or the recording equipment? What steps are being taken to understand the data and improve measurement reliability?

Response:

It is currently unknown the exact reasons why the PX facility is not functioning as expected. Initial steps that have been taken to improve monitoring and recording at the PX facility are described in Annual Report sub-section 2.1.1. At the next GLMC meeting we will be presenting the available data from PX, identifying potential discrepancies in the monitoring and recording, and discussing potential next steps to improve monitoring and recording.

Comment 2 – Section 3.4 Northwest MZ-1

Generally – Please provide an update on PX. Why are water level data not presented? 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. An XY scatter plot of Surveyed motion vs InSAR motion would be more informative than this visual comparison. Additionally, contouring the survey data and subtracting the surfaces could provide information on lateral variation in the correlation between data sources.

Response:

These suggestions for additional data analysis should be discussed and agreed upon by the GLMC. To date, the groundwater level measurements at PX do not have a long enough record to contribute meaningful information and interpretation on Figure 3-9 in the Annual Report.

Comment 3 – Figure 3-9 History of Land Subsidence in Northwest MZ-1

Can MV-28 be plotted as points rather than connected lines? The rapid oscillation of water levels does not lend itself to connect lines? InSAR data at point C shows significant data gaps at 1995 and from 1999 to 2005. A reference indicating the method of interpolation between these InSAR captures and the appropriateness of the application of this method would be appreciated. What is considered best practice maximum time to compare InSAR interferograms?

Response:

These suggestions for changes to Figure 3-9 should be discussed and agreed upon by the GLMC.

The assumptions for subsidence that occurred during InSAR data gaps were based on the rates of subsidence as measured by InSAR during periods prior to and after the data gap.

Comment 4 – Figure 3-10 Vertical Ground Motion across Northwest MZ-1: 2014-2022

Can PX and the wells discussed in the section be shown and labeled in the body of figure?

Response:

The wells shown on Figure 3-9 are also plotted on the inset map included on Figure 3-9. The purpose of Figure 3-10 is to show a comparison of InSAR data with leveling survey data.

Comment 5 – Figure 3-11 Hydraulic Heads at P-30 versus Groundwater Pumping and Vertical Ground Motion

Please provide PX water level data. Is the interpretation that aquifer compaction is occurring in shallow aquifer system at P-30 consistent with the 1D Model Results?

Response:

The note on Figure 3-11 describes the limitations of this analysis and the derived interpretations (Figure 3-11 note):

…"This interpretation assumes that the compaction is occurring across the P-30 well screen interval (whin the shallow-aquifer system). It may be that the compaction is occurring within deeper portions of the aquifer-system."

Comment 6 – Section 3.5.2 Whispering Lakes Subsidence Investigation

If differential subsidence is occurring, is there some amount that could be acceptable? How does the General Atomics data compare to the TreAltimira data in this area? The largest mapped ground motion is some distance from the Philadelphia Wells. The changes in head should be centered on the pumping wells. Any thoughts on why the subsidence center would be occurring away from the pumping center?

Response:

These are all good questions that deserve consideration and discussion by the GLMC.

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

Some of the investigation should consider if there is an acceptable level of subsidence is in the area. What utilities underlie the site, etc.

Response:

We agree with your suggestion and this deserves consideration and discussion by the GLMC.

Comment 8 – Budget Memo Task 6.4 Refine and Evaluate the Subsidence-Management Alternatives

Please clarify the sequence between BMA, GLMC meeting, and ISMA scenario assumption development.

Response:

The sequence of events is well described in Task 6.4 of the Budget Memo. The GLMC will be consulted and will meet at every significant step and milestone.

Comment 9 – Budget Memo Attachment A Comments and Responses to Comments

Not to nitpick, but my name is spelled Christofer.

Response:

We will spell your name correctly in the future.

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