2018/19 Annual Report of the Ground-Level Monitoring Committee

FINAL REPORT
OCTOBER 2019

Prepared for:
Ground-Level Monitoring Committee

Prepared by:

Table of Contents

List of Tables

List of Figures

Acronyms, Abbreviations, and Initialisms

af	Acre-ft
Ayala Park	Rubin S. Ayala Park
CCX	Chino Creek Extensometer Facility
DHX	Daniels Horizontal Extensometer
EDM	Electronic distance measurement
ft	Feet
ft-btoc	Feet below top of casing
GLMC	Ground-Level Monitoring Committee
GLMP	Ground-Level Monitoring Program
IMP	Management Zone 1 Interim Monitoring Program
InSAR	Interferometric synthetic aperture radar
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
PX	Pomona Extensometer Facility
SAR	Synthetic Aperture Radar
Subsidence Management Plan	2015 Chino Basin Subsidence Management Plan
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 Area

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 and its responsibilities, and a description of the development and implementation of the Management Zone 1 Subsidence Management Plan and the 2015 Chino Basin 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).

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. For purposes of clarification in this document, subsidence refers to the permanent (i.e. inelastic) sinking (deformation) of the land surface. 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.

1.1.1 Subsidence and Fissuring in the Chino Basin

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

1.1.2 The Optimum Basin Management Program

In 1999, the *Optimum Basin Management Program Phase I Report* (OBMP) identified the pumping-induced decline of piezometric levels 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:

1. minimize subsidence and fissuring in the short-term;
2. collect the information necessary to understand the extent, rate, and mechanisms of subsidence and fissuring; and
3. 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* (IMP; 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 the City of Chino. Program Element 1 of the OBMP Implementation Plan, *Develop and Implement a Comprehensive Monitoring Program*, called for the initial collection of basin-wide data to characterize land subsidence, including ground-level surveys and remote-sensing (specifically, interferometric synthetic aperture radar or InSAR), and for the development of an ongoing monitoring program based on the analysis of the subsidence 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 IMP under the guidance of the MZ-1 Technical Committee. The MZ-1 Technical Committee was comprised of representatives from all major MZ-1 producers and their technical consultants, including the Agricultural Pool; the Cities of Chino, Chino Hills, Ontario, Pomona, and Upland; the Monte Vista Water District (MVWD); the Golden State Water Company; and the California Institution for Men.

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

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

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

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

The IMP provided enough information for Watermaster to develop Guidance Criteria for the MZ-1 Parties that, if followed, would minimize the potential for subsidence and fissuring in the

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

investigation area. The methods, results, and conclusions of the IMP, including the Guidance Criteria, were described in detail in the *MZ-1 Summary Report* (WEI, 2006).

The Guidance Criteria were:

1. The Managed Wells subject to the Guidance Criteria. Table 1-1 shows the list of Managed Wells with screens completed into the deep aquifer-system that are subject to the Guidance Criteria.
2. 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.
3. A piezometric Guidance Level. The Guidance Level is a specified depth to water, as measured in feet below the top of the casing (ft-btoc) at the Ayala Park PA-7 piezometer. The initial Guidance Level was established as 245 ft-btoc. It was defined as the threshold hydraulic head level at the onset of inelastic compaction of the aquifer-system as recorded by the extensometer minus five feet. The five-foot reduction was meant to be a safety factor to ensure that inelastic compaction does not occur. The Guidance Level can be updated by Watermaster based on the periodic review of monitoring data.
4. Criteria for recommending pumping curtailment. If the hydraulic head level in PA-7 falls below the Guidance Level, Watermaster recommends that the MZ-1 Parties curtail their pumping from designated Managed Wells as required.
5. Real-time monitoring/reporting of head levels in PA-7. Watermaster was to provide the MZ-1 Parties with real-time hydraulic head level data from PA-7.
6. Reporting of pumping operations at Managed Wells. The MZ-1 Parties were requested to maintain and provide Watermaster with accurate records of operations at the Managed Wells, including pumping rates and on-off dates and times. The MZ-1 Parties were requested to promptly notify Watermaster of all operational changes made to maintain the hydraulic head level in PA-7 above the Guidance Level.
7. Request for ongoing monitoring at other monitoring wells. Watermaster recommended that the MZ-1 Parties allow it to continue to monitor hydraulic head levels at the Managed Wells.
8. Process for adapting the Guidance Criteria. Watermaster and Watermaster's Engineer were to evaluate the data collected as part of the MZ-1 Monitoring Program (now called the Ground-Level Monitoring Program or GLMP) after each fiscal year and determine if modifications, additions, and/or deletions to the Guidance Criteria were necessary. Changes to the Guidance Criteria could include: additions or deletions to the list of Managed Wells, re-delineation of the Managed Area, raising or lowering of the Guidance Level, or additions and/or deletions to

the Guidance Criteria, including the need to have periods of hydraulic head level recovery.

9. 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 level in PA-7 remains above the Guidance Level.

The MZ-1 Plan called for ongoing monitoring, data analysis, annual reporting, and adjustments to the MZ-1 Plan, as warranted by the data. Implementation of the MZ-1 Plan began in 2008. The MZ-1 Plan called for the continued scope and frequency of monitoring implemented during the IMP within the Managed Area and expanded monitoring of the aquifer-system and land subsidence in other areas of the Chino Basin where the IMP indicated concern for future subsidence and ground fissuring. Figure 1-1 shows the location of these so-called Areas of Subsidence Concern: Central MZ-1, Northwest MZ-1, and Northeast and Southeast Areas. 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.[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 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-

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

1. 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. Since then, Watermaster has been monitoring vertical ground motion in this area via InSAR and piezometric levels with pressure transducers at selected wells.

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 FY 2012/13 to include ground elevation surveys and electronic distance measurements (EDMs) to monitor ground motion and the potential for fissuring.

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

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

1.1.6 Annual Report of the Ground-Level Monitoring Committee

Pursuant to the Subsidence Management Plan , Watermaster will produce an annual report, containing the results of ongoing monitoring efforts, interpretations of the data, and recommended adjustments to the Subsidence Management Plan, if any. This annual report of the GLMC includes the results and interpretations for the data collected between March 2018 through March 2019 as well as recommendations for Watermaster's GLMP for FY 2019/20.

1.2 Report Organization

This report is organized into the following six sections:

Section 1 – 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 – Ground-Level Monitoring Program. This section describes the monitoring and testing activities performed by Watermaster for its GLMP between March 2018 and March 2019.

Section 3 – Results and Interpretations. This section discusses and interprets the monitoring data collected between March 2018 and March 2019, including basin stresses (i.e. groundwater pumping and recharge) and responses, which include changes in hydraulic heads, aquifer-system deformation, and ground motion.

Section 4 – Conclusions and Recommendations. This section summarizes the main conclusions derived from the monitoring program between March 2018 and March 2019 and describes recommended activities for the GLMP for FY 2019/20.

Section 5 – Glossary. This section is a glossary of the terms and definitions utilized within this report and in discussions at GLMC meetings.

Section 6 – References. This section lists the publications and reports cited in this report.

Table 1-1

Managed Wells Screened in the Deep Aquifer and Subject to the Guidance Criteria*

Well Name	CBWM ID	Owner	2017 Status	Well Screen Interval(s) *ft-bgs*
CIM-11A**	3602461	California Institution for Men	Active	174-187; 240-283; 405-465
C-7	3600461	City of Chino	Abandoned	180-780
C-15	600670		Inactive	270-400; 626-820
CH-1B	600487	City of Chino Hills	Inactive	440-470; 490-610; 720-900; 940-1,180
CH-7C	600687		Abandoned	550-950
CH-7D	600498		Destroyed	320-400; 410-450; 490-810; 850-930
CH-15B	600488		Inactive	360-440; 480-900
CH-16	600489		Inactive	430-940
CH-17	600499		Active	300-460; 500-680
CH-19	600500		Abandoned	300-460; 460-760; 800-1,000

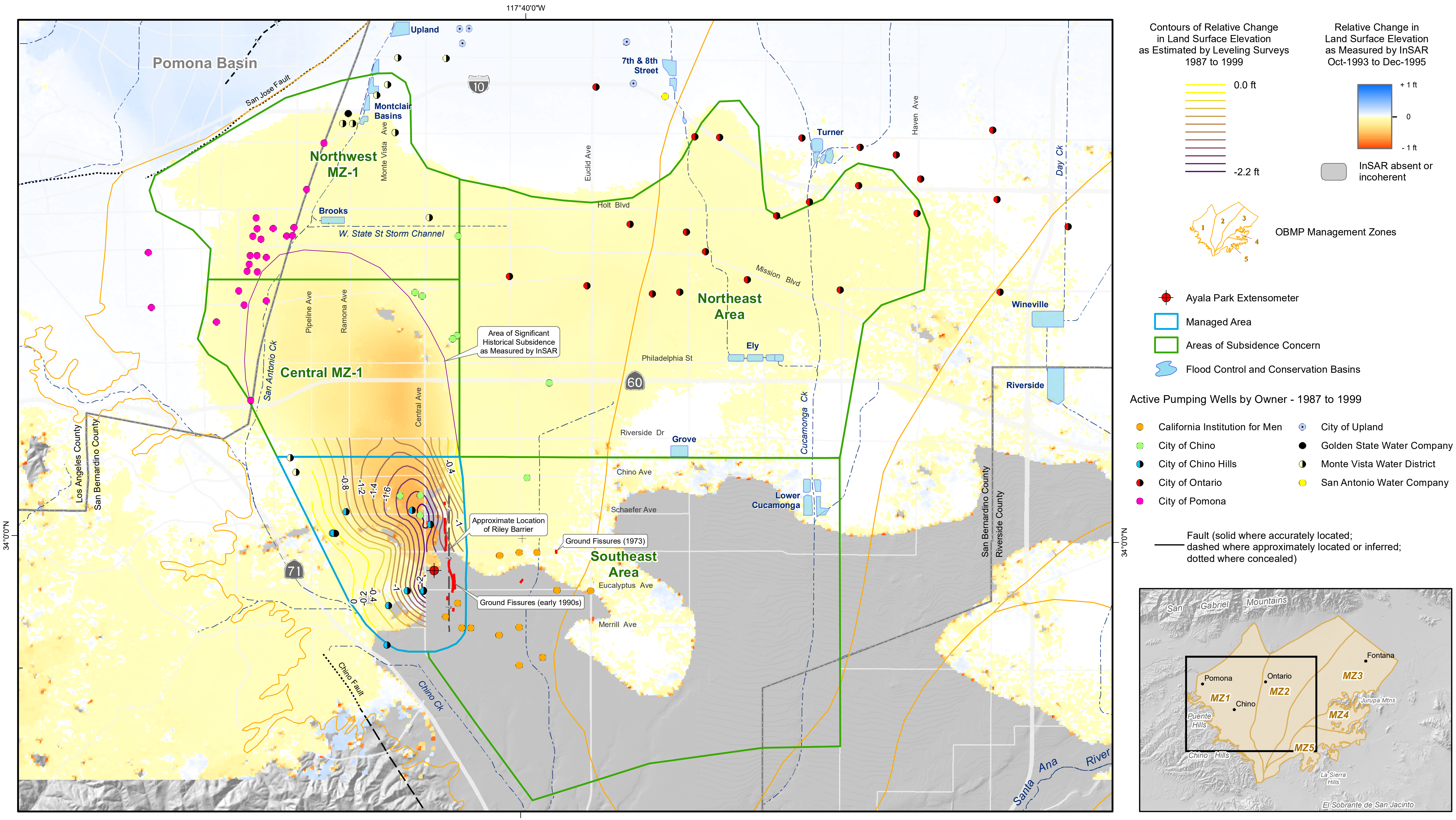
*The MZ-1 Subsidence Management Plan identified the Managed Wells that are subject to the Guidance Criteria for the Managed Area that, if followed, would minimize the potential for subsidence and fissuring.

**The original casing was perforated from 135-148, 174-187, 240-283, 405-465, 484-512, and 518-540 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.

Active = Well is currently being used for water supply

Inactive = Well can pump groundwater with little or no modifications

Abandoned = Unable to pump the well without major modifications



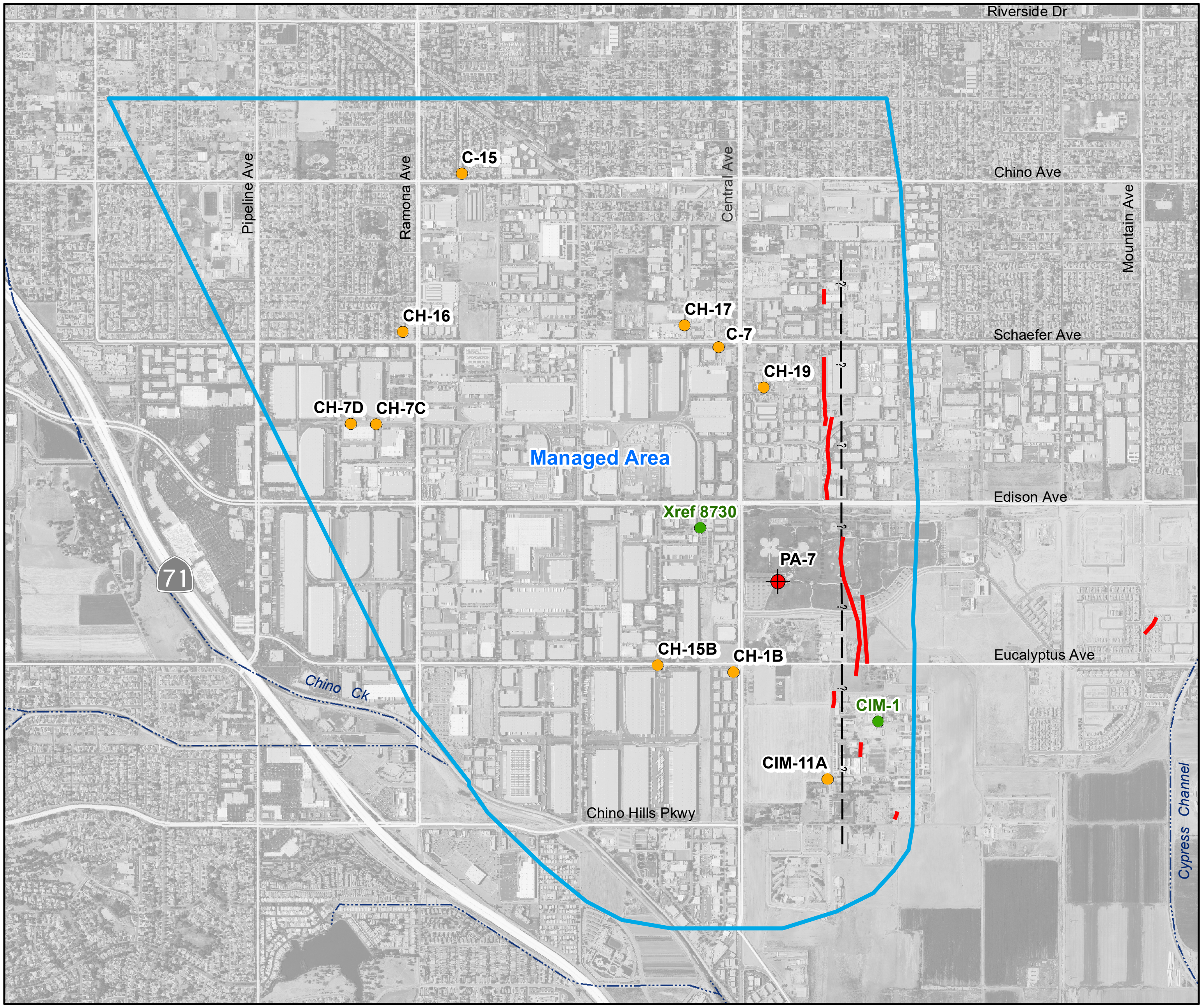
WEI
WILDERMUTH ENVIRONMENTAL, INC.

Author: NWS
Date: 8/30/2019
Document Name: Figure_1-1_2018_19

Ground-Level Monitoring Committee
2018/19 Annual Report

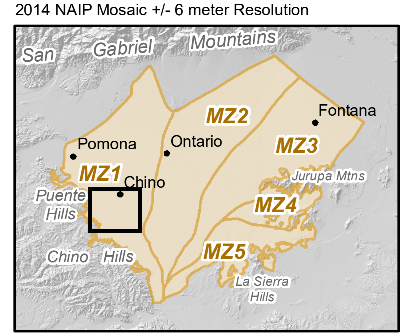
Historical Land Surface Deformation in Management Zone 1
1987-1999

Figure 1-1



Managed Area
Ayala Park Extensometer
Managed Well
Other Production Well
Ground Fissures
Groundwater Barrier (Riley Barrier) approximate location

2014 NAIP Mosaic +/- 6 meter Resolution



WEI
Wildermuth Environmental, Inc.

Author: NWS
Date: 8/30/2019
Document Name: Figure_1-2_2018_19

0 0.5 1 Miles
0 0.5 1 Kilometers

Ground-Level Monitoring Commitee
2018/19 Annual Report

MZ-1 Managed Area and the Managed Wells

Figure 1-2

Section 2 – Ground-Level Monitoring Program

This section describes the activities performed by Watermaster for the GLMP between March 2018 and March 2019.

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 pressure-transducer data loggers that measure hydraulic heads, 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 Ongoing 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 2018 and March 2019 are described below.

2.1.1 Setup and Maintenance of the Monitoring Facilities Network

- Performed routine maintenance at the Ayala Park and Chino Creek Extensometer Facilities. Additional maintenance activities included:
  - Troubleshot the CR1000 Datalogger, computer, and USB Serial Adapter at the Ayala Park Extensometer Facility after experiencing a connection malfunction. Replaced USB Serial Adapter with an FTP chip set to fix connection problem and ensure data is being continuously recorded.
  - Troubleshot the CR1000 Datalogger and computer at the Ayala Park Extensometer Facility when the internal clock malfunctioned.
  - Replaced the 12 volt deep-cycle batteries at the Ayala Park Extensometer Facility to ensure power to the datalogger and continuous data collection.
  - Troubleshot the backup and dedicated pressure transducer data loggers and associated installation hardware at the Ayala Park Extensometer Facility when the equipment failed or malfunctioned.
  - Installed replacement backup and dedicated pressure transducers at the Ayala Park and Chino Creek Extensometer Facilities when the pressure transducers began to drift or stopped recording data.
- Adjusted the deep extensometer's rocker arm at the Ayala Park Extensometer Facility to ensure it will record continued aquifer-system expansion through 2018 to 2019.

2.1.2 Monitoring Activities

Changes in hydraulic heads are caused by the stresses of groundwater pumping and recharge. Changes in hydraulic heads are the mechanism behind aquifer-system deformation, which in turn causes vertical and horizontal ground motion. Because of these cause-and-effect relationships, Watermaster monitors groundwater pumping, recharge, hydraulic heads, aquifer-system deformation, and vertical and horizontal ground motion across the western portion of the Chino Basin. The following sub-sections (2.1.2.1 through 2.1.2.4) describe Watermaster's monitoring activities between March 2018 and March 2019, 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

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 2018 and March 2019 are shown in Figure 2-1.

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 pressure transducer data loggers maintained by Watermaster at approximately 88 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 of Vertical Aquifer-System Deformation

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

2.1.2.3 Monitoring of Vertical Ground Motion

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

For InSAR, Watermaster retained 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] Five synthetic aperture radar (SAR) scenes were collected between March

[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.

2018 and March 2019. The scenes were used to create ten interferograms[4] to estimate short-term and long-term vertical ground motion[5] over the following periods:

March 2018 to May 2018	May 2018 to July 2018
March 2018 to July 2018	July 2018 to October 2018
March 2018 to October 2018	October 2018 to January 2019
March 2018 to January 2019	January 2019 to March 2019
March 2018 to March 2019	March 2011 to March 2019

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

Ground-Level Survey Area	Date of Most Recent Survey	Number of Benchmarks Surveyed
Managed Area*	January 2018	22
Central Area*	January 2018	14
Northwest Area	April 2019	27
San Jose Fault Zone Area	April 2019	10
Southeast Area*	January 2018	77
Northeast Area	April 2019	55

* The entire benchmark monument survey network for the ground-level survey area was not surveyed in 2019 based on the GLMC scope and budget recommendations for FY 2018/19.

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. EDMs were performed between the benchmarks with the San Jose Fault Zone Area shown in Figure 2-2. The number of benchmark monuments surveyed are shown in the table below.

[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.

Ground-Level Survey Area	Date of Most Recent Survey	Number of Benchmarks Surveyed
Fissure Zone Area*	February 2018	66
San Jose Fault Zone Area	April 2019	10

*EDMs across the Fissure Zone Area were not conducted in 2019 based on GLMC scope and budget recommendations for FY 2018/19.

2.2 Land-Subsidence Investigations

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

This section describes the land subsidence investigations conducted between March 2018 and March 2019 that are called for by the Subsidence Management Plan.

2.2.1 Long-Term Pumping Test in the Managed Area

The GLMC developed the Long-Term Pumping Test in the Managed Area in response to the directives in the Subsidence Management Plan. The goal of the Long-Term Pumping Test is to develop a strategy for the prudent extraction of groundwater from the Managed Area. In this case, "prudent" is defined as extracting the maximum volume of groundwater possible without causing damage to the ground surface or the area's infrastructure. The test was specifically designed to answer:

1. Is the Guidance Level for the Managed Area, as currently defined, appropriate? If not, how should the Guidance Level be updated?
2. Does the Riley Barrier separate the Managed Area from the Southeast Area within the deep aquifer-system? If not, should the eastern boundary of the Managed Area be revised?
3. How does the recoverable and inelastic aquifer-system deformation that occurs in the Managed Area affect the horizontal strain across the historical zone of ground fissuring and its northward extension into the heavily urbanized portions of the City of Chino?
4. Is aquifer injection a viable tool for mitigating the decline of hydraulic heads and preventing inelastic compaction in the deep aquifer-system?
5. Is there an "acceptable" rate of subsidence in the Managed Area? If so, what is the "acceptable" rate?

Figure 1-2 shows the locations of the wells included in the Long-Term Pumping Test. The GLMC envisioned the following scope and sequence for the Long-Term Pumping Test:

1. Conduct a controlled pumping test of the deep aquifer-system in the Managed Area at wells CH-17 and CH-15B. This test should cause the hydraulic head at PA-7 to fall below the Guidance Level and may cause a small amount of subsidence.[6] The test will be closely monitored at the Ayala Park Extensometer Facility and will be stopped at the first indication of inelastic compaction. Hydraulic heads recorded at 15-minute intervals at PA-7 will be updated every three hours on Watermaster's website. When the hydraulic heads decline to within 20 ft of the Guidance Level, data from the Ayala Park Extensometer Facility will be downloaded and used to prepare a stress-strain diagram. The stress-strain diagram will be distributed promptly to the GLMC by e-mail. Watermaster staff and the Watermaster Engineer will remain in close telephonic contact with staff at the City of Chino, the City of Chino Hills, and the California Institution for Men to review and interpret the stress-strain diagram, to plan for the preparation of the next stress-strain diagram, or to decide to stop the test when appropriate.

2. Stop the pumping test and allow for the partial recovery of hydraulic heads.

3. Conduct two cycles of injection at CH-16 to see how injection accelerates the recovery of the regional hydraulic heads that were lowered by pumping at CH-17 and CH-15B.[7] After the injection tests, allow for full recovery of hydraulic heads at PA-7 to pre-test conditions.

4. Conduct ground-level surveys, InSAR monitoring, and EDM surveys to measure vertical and horizontal ground motion across the Managed Area before, during, and after the test. Collect piezometric and aquifer-system deformation data at the Ayala Park Extensometer Facility once every 15 minutes throughout the test.

5. Check the stress-strain diagrams from the Ayala Park Extensometer Facility for inelastic compaction of the aquifer-system in the Managed Area. Analyze ground-level survey, InSAR, and EDM data for inelastic horizontal and vertical ground deformation within the Managed Area.

As of July 2019, the City of Chino Hills (M. Wiley, personal communication, July 5, 2019) reported the Long-Term Pumping test will not be completed during the first half of FY 2019/20 due to mechanical issues at CH-15 and 1,2,3-trichloropropane (TCP) contamination in CH-17. Injection at CH-16 may occur in FY 2019/20, but it is dependent on the City of Chino Hills to

[6] The aquifer-system stress testing in 2004-05 resulted in about 0.01 feet of non-recoverable compaction and associated land subsidence (WEI, 2006). The Long-Term Pumping Test may cause a similar small amount of subsidence. This small amount of subsidence is far less (three orders of magnitude) than the >2 ft of subsidence that occurred from 1987 to 1995 when ground fissures opened in the City of Chino and is much less (one order of magnitude) than the +/- 0.1 ft of elastic vertical ground motion that occurs seasonally in this area.

[7] The City of Chino Hills is conducting an injection feasibility study at CH-16 as part of the Long-Term Pumping Test. The study will help determine if aquifer injection is a viable tool to manage subsidence within the Managed Area while maximizing the use of existing infrastructure (i.e. wells). The study includes the conversion CH-16 to an aquifer storage and recovery well and pilot testing well. Watermaster assisted the City of Chino Hills in applying for and acquiring a Local Groundwater Assistance grant from the DWR to partially fund the study. Watermaster also assisted with a cost-share contribution of $368,000 to execute the study. As of the end of 2016, Chino Hills completed modifications to well CH-16 to convert it to an ASR well and completed connections to a potable water supply pipeline.

complete the permit process for CH-16 with the Division of Drinking Water and the City's readiness to perform the test.

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

The Subsidence Management Plan calls for Watermaster to monitor for horizontal ground motion across areas that are susceptible to ground fissuring. Historically, this monitoring has occurred via EDMs and with the Daniels Horizontal Extensometer (DHX). The GLMC annually recommends the scope and frequency of EDM surveys. The DHX was decommissioned and removed in 2015 because the site was developed. The 2016 Annual Report of the GLMC included an in-depth review of horizontal strain that had occurred over time and measured from EDM data across the Fissure Zone to assess if the EDM data can be used in-lieu of the horizontal extensometer data collected at the DHX. Based on the review of EDM data between closely spaced benchmark monuments in the Fissure Zone Area, the EDM method appears to be a suitable monitoring technique to detect the occurrence of tensile strain within shallow soils and the potential threat of ground fissuring. Additionally, the 2016 Annual Report recommended that if permanent subsidence is absent in the Managed Area, the GLMC should consider performing EDM surveys across the Fissure Zone at a frequency greater than annual and performing EDM surveys in coordination with the Long-Term Pumping Test in the Managed Area. In 2019, the EDM survey across the Fissure Zone in the Managed Area was not conducted based on the GLMC scope and budget recommendations for FY 2018/19.

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

2.2.3 Subsidence Management Plan for Northwest MZ-1

In 2015, the GLMC developed the final Work Plan to develop a subsidence-management plan for Northwest MZ-1, which describes a multi-year effort with cost estimates to execute the Work Plan. The Work Plan was included in the Subsidence Management Plan as Appendix B.[8] The background and objectives of the Work Plan are described in Section 1.1.5. Watermaster began implementation of the Work Plan in July 2015. The following describes the Work Plan tasks and current 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, summarizing the current state of knowledge of the hydrogeology of Northwest MZ-1, the data gaps that need 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 – Watermaster's Engineer worked with Watermaster, the MVWD, the City of Pomona, and SCADA Integrations, Inc. to identify and equip a set of wells with supervisory control and data acquisition monitoring

8 http://www.cbwm.org/rep_engineering.htm

capabilities and/or pressure 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 pressure transducers. For MVWD, seven wells were equipped with pressure 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 and pumping data are currently being collected and analyzed as part of the Northwest MZ-1 monitoring and testing program for FY 2019/20.

Tasks 3 Develop and Evaluate the Baseline Management Alternative 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 in Northwest MZ-1, an area that has experienced gradual and persistent subsidence for decades (WEI, 2017b). The objective of this memo was to explore the future occurrence of subsidence in Northwest MZ-1 under various basin-operation scenarios of groundwater pumping and artificial recharge and to identify potential subsidence mitigation strategies.

Task 5 Design and Install the Pomona Extensometer Facility (PX) – Watermaster began construction of two dual-nested piezometers located in Montvue Park, Pomona, CA in January 2019. As of March 2019, three of the four piezometers (PX1-2, PX2-3, and PX2-4) have been successfully developed. Development of PX1-1 is incomplete due to annular grout reported by the well developer to have entered the well screens in March 2019. Development of PX1-1 was halted in March 2019 to develop mitigation options. The GLMC recommended re-development at PX1-1, which was completed in August 2019. Each PX piezometer will be equipped with pressure transducer dataloggers and cable extensometers. PX is anticipated to be operational in late fall 2019.

Task 6 Design and Conduct Aquifer-System Stress Tests – 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 testing program will have a duration of one year and will start once the PX monitoring equipment (i.e. pressure transducers and cable extensometers) is installed. PX is anticipated to be operational in late fall 2019.

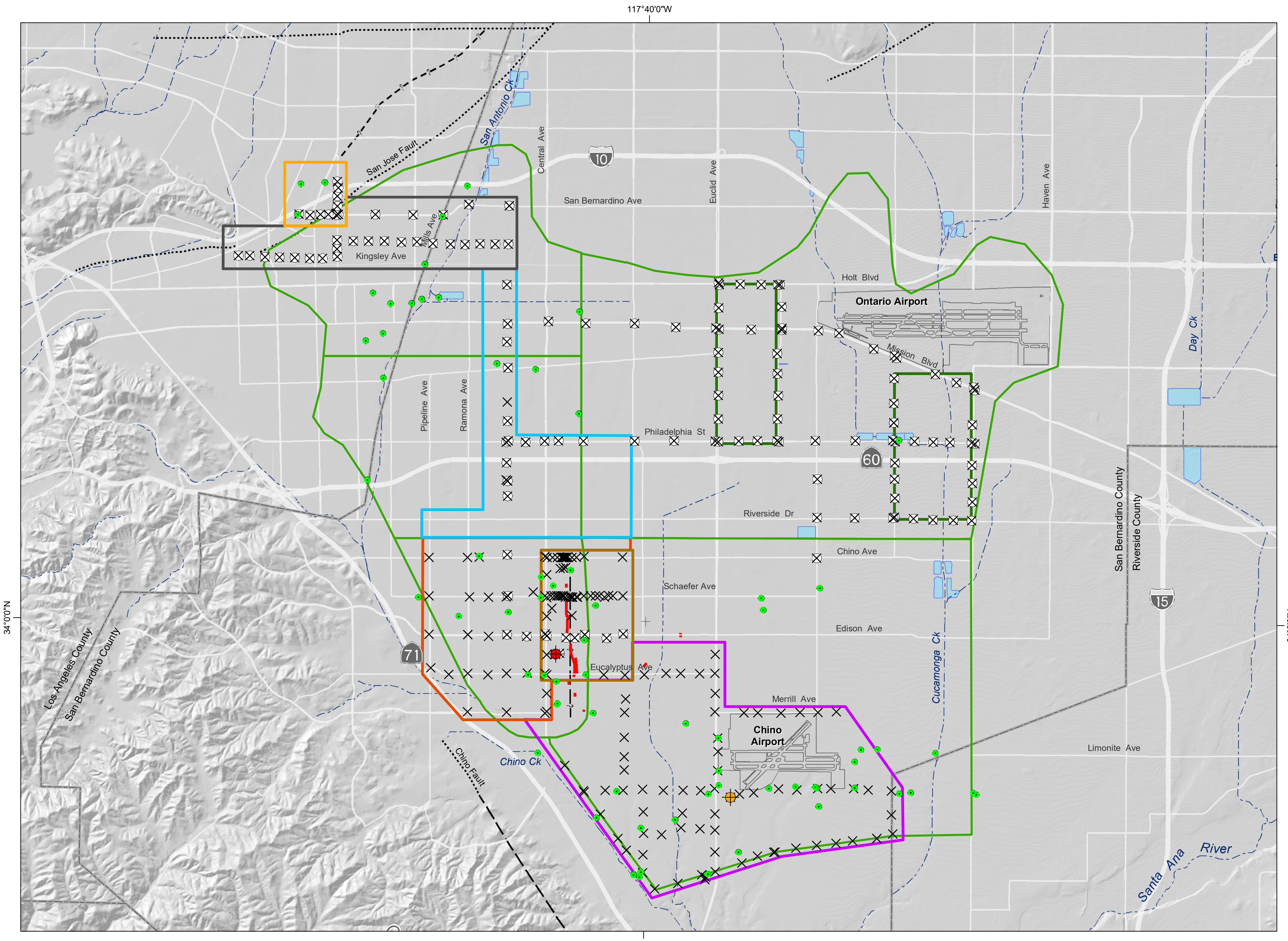
Task 7 Update the Hydrogeologic Conceptual Model and Prepare a Summary Report – The objective of this task is to update the hydrogeologic conceptual model of Northwest MZ-1 based on an improved understanding from monitoring at PX and in Northwest MZ-1. The numerical one-dimensional aquifer-system compaction constructed in Tasks 3 and 4 will be updated and calibrated to represent the aquifer-system at PX. The model will be used to refine the hydraulic and mechanical property estimates of the aquifer-system and the pre-consolidation stress. A technical memorandum will be prepared to document the updated hydrogeologic conceptual model, including a description of the subsidence mechanisms and the pre-consolidation stress(es). This task is estimated to be completed in FY 2020/21.

Task 8 Update the Chino Basin Groundwater Model – The objective of this task is to update Watermaster's groundwater modeling tools to support the development and evaluation of subsequent subsidence-management alternatives. The layering and aquifer properties in Watermaster's current groundwater model are currently being updated as part of the 2020 Chino Basin Safe Yield Recalculation. The 2020 groundwater model is being updated to include a subsidence package so it can be used to simulate subsidence across Northwest MZ-1 and the western Chino Basin under future basin management activities. New information and understanding derived in Task 7 will be used to update the 2020 groundwater model. This task is estimated to be complete in FY 2021/22.

Task 9 Refine and Evaluate Subsidence-Management Alternatives – The objective of this task is to develop up to three additional subsidence-management alternatives that will minimize or abate the ongoing subsidence in Northwest MZ-1. Using new information on the subsidence mechanisms and the pre-consolidation stress and the results of the Initial Subsidence-Management Alternative, a new method to increase and hold hydraulic heads at the estimated pre-consolidation stress will be described and called Subsidence-Management Alternative 2 (SMA-2).

The assumptions of SMA-2, including the groundwater pumping and replenishment plans of the Chino Basin parties, will be described and agreed upon by the GLMC. The updated Chino Basin groundwater model will be used to characterize the basin response to the SMA-2, its ability to raise and hold hydraulic heads above the pre-consolidation stress, and its ability to minimize or abate the ongoing subsidence in Northwest MZ-1. Up to two additional subsidence-management alternatives will be developed and evaluated in the same fashion as SMA-2. A technical memorandum will be prepared to document the development and evaluation of the subsidence-management alternatives and the recommendation of the preferred subsidence-management alternative. This task is estimated to be completed in FY 2021/22.

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. 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 2022.



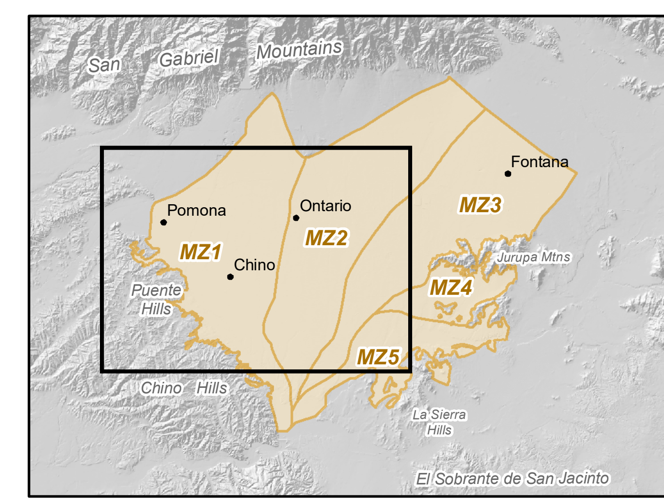
Ground-Level Monitoring Network Facilities

- Ayala Park Extensometer
- Chino Creek Extensometer
- Well Equipped with Pressure Transducer (2018/19)
- Ground-Level Survey Benchmark
- Ground-Level Survey Benchmark (Measured in April 15, 2019)

Ground-Level Survey Areas

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

- Areas of Subsidence Concern
- Flood Control and Conservation Basins
- Ground Fissures
- Approximate Location of the Riley Barrier
- Fault (solid where accurately located; dashed where approximately located or inferred; dotted where concealed)



WILDERMUTH ENVIRONMENTAL, INC.

Author: NWS
Date: 8/30/2019
Document Name: Figure_2-2_2018_19

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Ground-Level Monitoring Committee
2018/19 Annual Report

Ground-Level Monitoring Network
Western Chino Basin

Figure 2-2

Section 3 – 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 2018 and March 2019 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 2019 and between March 2018 and March 2019, respectively. These figures include the locations and magnitude of pumping and artificial recharge—stresses to the aquifer system that can cause ground motion. The data shown in these and subsequent figures are described and interpreted in this section.

3.1 MZ-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 as well. The main 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 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 seven 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 2019. A total of about 22 acre-feet (af) of groundwater pumping occurred in the Managed Area between July 2018 and March 2019 —100 percent of the groundwater pumping was from wells screened in the shallow aquifer-system. Groundwater pumping in the Managed Area has declined over the past seven years from about 5,680 af in fiscal year 2012 to about 20 af between July 2018 and March 2019.

Figure 3-3 is a time-series chart that displays stress and strain in the shallow and deep aquifer systems in the Managed Area. The chart includes: quarterly groundwater pumping, the resultant head change (stress), and aquifer-system deformation (strain) for the period January 2011 through March 2019. The chart illustrates the general seasonal pattern of pumping in the Managed Area – increased pumping during the spring to fall and decreased pumping during the winter.

Figure 3-3 displays the time-series of hydraulic heads at two Ayala Park piezometers: PA-7 (deep aquifer-system) and PA-10 (shallow aquifer-system); it illustrates the deep and shallow hydraulic head responses to seasonal groundwater pumping. These data are consistent with the conclusions of the IMP and show that pumping from the deep confined aquifer-system causes a hydraulic head decline that is much greater in magnitude than the hydraulic head decline caused by pumping from the shallow aquifer-system despite that more groundwater pumping occurs from the shallow aquifer-system. The hydraulic head at PA-7 has fluctuated from a low of approximately 190 ft-btoc in August 2013 to a high of about 70 ft-btoc in November 2018 and has not declined below the Guidance Level of 245 ft-btoc. The recovery of the hydraulic head in the deep aquifer-system to above 90 ft-btoc in May 2018 and February 2019 represented "full recovery" of hydraulic head at PA-7 as defined in the Subsidence Management Plan. Since the first instance of full recovery in 2012, the hydraulic head at PA-7 recovered to 90 ft-btoc or greater in 2016 and 2018, which complies with the recommendation in the Subsidence Management Plan for full recovery within the deep aquifer-system at least once every five years. [9]

From January 2018 to March 2019, there was very little pumping from the shallow aquifer-system and zero reported pumping from the deep aquifer-system. Piezometric levels at PA-10 and PA-7 have increased to their highest levels since implementation of the GLMP in 2003: about 60 ft-btoc in PA-10 and about 70 ft-btoc in PA-7.

Figure 3-3 illustrates an extended drawdown and recovery period between December 2017 and March 2019. The extended recovery period is supported by minimal to zero pumping reported

[9] 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."

from the shallow and deep aquifer-systems beginning in January 2018. Figure 3-3 also shows that between late 2018 and early 2019, there were some short episodes of head decline observed in the deep aquifer-system at PA-7. However, these short episodes of hydraulic head decline are not supported by Watermaster's pumping records for the Managed Area (Frank Yoo, personal communication, June 24, 2019) or e-mail correspondence with the City of Chino Hills (Mark Wiley, personal communication, July 29, 2019).

3.1.2.2 Aquifer-System Deformation

Figure 3-3 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 2019. These data show that the seasonal compression and expansion of the aquifer-system is 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.[10]

From June 27, 2016 to February 1, 2019 (dates of full recovery at PA-7), the Deep Extensometer recorded an extended cycle of aquifer-system compression and expansion in response to the extended decline and recovery cycle of hydraulic heads at PA-7. By February 1, 2019, the Deep Extensometer recorded a slight amount of expansion from June 27, 2016, indicating that the vertical deformation of the deep aquifer-system was mainly elastic during this period.

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 that occurred during the November 2016 to March 2019 period (i.e. elastic versus inelastic deformation). The hysteresis loops on this figure represent cycles of hydraulic head decline-recovery and the resultant compression-expansion of the aquifer-system sediments. The diagram can be interpreted to understand the timing and magnitude of the occurrence of compaction within the depth interval of the aquifer-system that is penetrated by the Deep Extensometer. Hydraulic head decline is shown as increasing from bottom to top on the y-axis, and aquifer-system compression is shown as increasing from left to right on the x-axis.

From May 2006 to June 2016, the hysteresis loops progressively shift to the right on this chart, indicating that about 0.060 ft of inelastic compaction occurred during this time-period. Beginning in 2016, the hysteresis loops overlap one another, indicating that the vertical deformation of the aquifer-system was mainly elastic during this period.

Figure 3-4 shows that the most recent hysteresis loop from November 20, 2018 to March 31, 2019 has shifted to the left, which may indicate the expansion of the shallow aquifer-system in response to historically high heads (see PA-10 on Figure 3-3).

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

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 2018/19, the benchmark monument network in the Managed Area was not surveyed per the GLMC's scope and budget recommendations. Figures 3-5a and 3-5b illustrate vertical ground motion[11] as estimated by InSAR for the period from March 2011 to March 2019 and from March 2018 to March 2019, respectively.

Where coherent, the InSAR estimates shown in Figure 3-5a indicate the occurrence of about zero to -0.07 ft of vertical ground motion across the Managed Area from 2011 to 2019. The greatest downward ground motion occurred in the northern and central portions of the Managed Area. The principal areas of InSAR incoherence in the Managed Area are located south of Schaefer Avenue.

The InSAR estimates shown in Figure 3-5b indicate the occurrence of about 0.01 to 0.06 ft of vertical ground motion across the Managed Area from March 2018 to March 2019. The vertical ground motion observed in the Managed Area was completely upward—with the central portion of the Managed Area experiencing the greatest uplift (0.06 ft). The InSAR estimates of ground motion are consistent with the Deep Extensometer record at Ayala Park from March 2018 to March 2019. Over this one-year period, the Deep Extensometer recorded about 0.052 ft of aquifer-system expansion compared to about 0.048 ft of upward ground motion estimated by InSAR at the Deep Extensometer location. The upward ground motion across the Managed Area during this period is likely due to two main factors:

1. Permanent compaction of the aquifer system is no longer occurring in the Managed Area. The discussion in the prior section on aquifer-system deformation, as indicated by the Ayala Park Extensometer, concluded that aquifer-system deformation at Ayala Park was elastic from June 27, 2016 to February 1, 2019.

2. Hydraulic heads in the shallow and deep aquifer systems experienced an extended period of recovery between December 2017 and March 2019 and are at or near historical highs since monitoring began for the GLMP.

As described above, Figure 3-5a shows that maximum downward ground motion during 2011-2019 occurred in the northern portions of the Managed Area. The InSAR estimates of vertical ground motion are coherent in this area. City of Chino Well 15 (C-15) is located in this area, is screened across both the shallow and deep aquifers, and has been equipped with a pressure transducer data logger 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 3-6 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 2019. Figure 3-6 also shows the Ayala Park Deep Extensometer record for comparison to the InSAR-derived estimates of vertical ground motion. The main observations from this chart are:

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

1. The InSAR record at C-15 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 C-15 are coincident with the seasonal fluctuations of vertical ground motion measured by InSAR at the same location. The seasonal elastic vertical ground motion measured by InSAR is verified by the timing and approximate magnitude of the seasonal elastic deformation of the aquifer-system as measured by the Ayala Park Deep Extensometer.
2. InSAR indicates a long-term trend of downward vertical ground motion at C-15 from 2007 to 2017. However, hydraulic heads at C-15 during this same time-period increased, indicating that about 0.188 ft of subsidence was caused by inelastic compaction of the aquifer-system. The Ayala Park Deep Extensometer measured about 0.068 ft of aquifer-system compaction over this same time-period. 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.
3. Since 2017, 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 Ayala Park 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 equilibration with hydraulic heads in the aquitards and the cessation of aquitard drainage and compaction. These monitoring data may be providing information on hydraulic head "thresholds" that could be used as management criteria to protect against the future occurrence of land subsidence.

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 are generally 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 3-7 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 2019. Figure 3-8 is a map that illustrates vertical ground motion as estimated by InSAR across the Southeast Area during 2018-19. 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 25 ft from 2010 to 2019 (see wells CH-18A, C-13, CCPA-1, and CCPA-2). In the eastern portion of the Southeast Area, hydraulic heads gradually declined by about 3 to 10 ft between 2005 and

November 2017 but show a recovery trend between December 2017 and March 2019 (see wells HCMP-1/1 and HCMP-1/2).

- In general, the occurrence of subsidence has been relatively minor across the Southeast Area, and some areas have recently experienced upward vertical ground motion. The recent upward vertical ground motion is evidenced in the InSAR data for the period between March 2018 and March 2019, which shows up to 0.06 ft of upward vertical ground motion across most of the Southeast Area.
- The magnitude and history of land subsidence differs in different portions of the Southeast Area:
    - In the northwest portion of the Southeast Area, a total of 0.58 ft of subsidence occurred at BM 137/61 from 1987 to 2018, and 0.26 ft of subsidence occurred at BM 133/61 from 2003 to 2018. Both benchmarks have subsided at similar rates of about 0.02 ft/yr. However, hydraulic heads remained relatively stable or increased during this period, which indicates that the downward ground motion is, at least in part, permanent subsidence due to delayed aquitard drainage in response to the historical declines in hydraulic heads that occurred from the 1940s to about 1978.
    - In the southern portion of the Southeast Area near the CCX, a total of 0.2 ft of subsidence occurred at BM 157/71 from 2003 to 2009 (about 0.03 ft/yr). However, from 2009-2019, subsidence virtually ceased.
    - In the 2017 Annual Report of the GLMC, Figure 3-7b showed an isolated area of downward vertical ground motion located southwest of the intersection of Highway 71 and Soquel Canyon Parkway. The area of downward ground motion was a new feature visible in the InSAR maps for the time-period of March 2017 to March 2018. Figure 3-8 of this report does not show this isolated area of downward vertical ground motion as it was likely a result of earthwork construction activities for a new hotel.

Figure 3-9 displays the time series of hydraulic and vertical aquifer-system deformation recorded at the CCX, which began collecting data in July 2012. Groundwater pumping began at the Chino Creek Well Field in 2014, but appears to have had little, if any, effect on hydraulic heads or aquifer-system deformation at the CCX through March 2019. In general, hydraulic heads at the CCX vary seasonally and have gradually increased since 2012. A small amount of expansion of the aquifer-system has been measured by the CCX extensometers, coincident with hydraulic head recovery beginning in 2012. This observation is consistent with the ground-levels surveys at BM 157/71 near the CCX and the general observation that the cessation of subsidence in the southern part of the Southeast Area is a result of increasing hydraulic heads and the equilibration of hydraulic heads within the aquifer and aquitards.

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 2011-2019 and 2018-2019, respectively. 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 are performed periodically along the eastern portion of the area. Figure 3-10 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 from 1986 to 2019. Recent hydraulic heads (1986 to 2019) 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 ft/yr). Since 2000, the rate of subsidence has slowed significantly—about 0.35 ft of subsidence occurred at a gradually declining rate from 2000 to 2018 (about 0.019 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 2019 are located in the western portion of Central MZ-1, where up to -0.15 ft of vertical ground motion had occurred (about -0.02 ft/yr). Hydraulic heads remained relatively stable in this area from 2011 to 2019, 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.

- Figure 3-1b shows that between March 2018 and 2019, most of Central MZ-1 experienced upward vertical ground motion. The upward vertical ground motion measured by InSAR is consistent with the observation that groundwater pumping has been decreasing since 2015, recharge significantly increased in 2017 and 2018, and hydraulic heads have been relatively stable. This has led to the equilibration of the hydraulic heads in the aquifer and aquitards and the cessation of aquifer-system compaction and subsidence across Central MZ-1.

3.4 Northwest MZ-1

3.4.1 Vertical Ground Motion

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

Figure 3-1a illustrates vertical ground motion as estimated by InSAR across Northwest MZ-1 during 2011-2019. Figure 3-11 is a time-series chart that displays and describes the long-term history of pumping, recharge, hydraulic heads, and vertical ground motion in Northwest MZ-1. Figures 3-12a and 3-12b are maps of the most recent data and illustrate vertical ground motion as estimated by InSAR and ground-level surveys across Northwest MZ-1 from January 2014 to

March 2019 and from March 2018 to March 2019, respectively. The following observations and interpretations are derived from these figures:

- 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 2019 hydraulic heads fluctuated but remained relatively stable. Hydraulic heads in 2018 and 2019 show a slight recovery trend but are at least 100 ft lower than hydraulic heads in the 1930s.

- A maximum of about 1.2 ft of subsidence occurred in this area from 1992 through March 2019—an average rate of about 0.05 ft/yr—while hydraulic heads remained relatively stable. The persistent subsidence that occurred from 1992 to 2019 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 2019, the InSAR results indicate a maximum of about -0.25 ft of vertical ground motion occurred in Northwest MZ-1 near the intersection of Indian Hill Boulevard and San Bernardino Avenue (see Point C on inset map of Figure 3-11). From 2014 to 2019, the rate vertical ground motion slowed to about -0.02 ft/yr at this location.

- Figure 3-12b shows that between March 2018 and 2019 most of Northwest MZ-1 experienced upward vertical ground motion. The upward vertical ground motion measured by InSAR is consistent with the observation that groundwater pumping has been decreasing since 2014, recharge significantly increased in 2017 and 2018, and hydraulic heads have been relatively stable or increasing. This has likely led to the equilibration of the hydraulic heads in the aquifer and aquitards and the cessation of aquifer-system compaction and subsidence across most of Northwest MZ-1.

- The ground-level survey results from 2014-2019 and 2018-19 indicate a similar spatial pattern of downward ground motion as estimated by InSAR but with slightly different magnitudes. Figure 3-12a shows that both methods indicate the maximum downward ground motion from January 2014 to March 2019 occurred near the intersection of Indian Hill Boulevard and San Bernardino Avenue, but the magnitudes between InSAR and ground-level surveys are slightly different. This discrepancy is likely related to the differences in timing of the ground-level surveys and the SAR acquisition and/or relative errors associated with each monitoring technique.[12]

3.4.2 Horizontal Ground Motion

Figure 3-1a shows a steep gradient of subsidence across the San Jose Fault in Northwest MZ-1—the same pattern of "differential subsidence" that occurred in the Managed Area during

[12] The general accuracy associated with both monitoring techniques is about +/- 0.02 ft. In addition, the farther away the surveyed benchmarks are from the starting benchmark (i.e. the Ayala Park Extensometer), the larger the potential error and uncertainty in the absolute position of the benchmark (Jim Elliot, personal communication, July 11, 2018). The future Pomona Extensometer Facility (see location on Figure 3-12a) is planned to be used as the starting benchmark for future ground-level surveys in Northwest MZ-1, which will increase the accuracy of future ground-level surveys.

the time of ground fissuring. Differential subsidence can cause an accumulation of horizontal strain in the shallow sediments and the potential for ground fissuring.[13]

To identify potential areas of accumulation of tensile horizontal strain in the shallow soils in this area, annual EDM surveys between closely spaced benchmark monuments that cross the San Jose Fault have been performed annually since December 2013. Figure 3-13 displays the time series of east/west-oriented and north/south-oriented strain between the pairs of closely spaced benchmarks (see the inset map on Figure 3-13) between 2013 and 2019. For reference, the top left chart on Figure 3-13 shows the downward vertical ground motion in Northwest MZ-1 as estimated by InSAR at Point C on Figure 3-11. The horizontal strain between most pairs of benchmarks appears to behave elastically—alternating between compressive and tensile deformation between EDM surveys. Tensile strain has been calculated between two pairs of benchmarks (B-409 to B-408 and B-406 to B-405); however, this magnitude of strain is within the range of elastic strain observed between other pairs of benchmarks. It is premature to draw conclusions at this point. Annual elevation and EDM surveys across the San Jose Fault Zone will be needed to develop the *Subsidence Management Plan for the Northwest MZ-1 Area*.

3.5 Northeast Area

Vertical ground motion is measured across the Northeast Area via InSAR and ground-level surveys. In December 2017, a new network of benchmark monuments was installed across the Northeast Area (see Figure 2-2) and surveyed for initial elevations in January 2018. The entire Northeast Area benchmark network was surveyed in April 2019. The ground-level surveys will complement and verify the vertical ground motion estimates derived by InSAR.

Figures 3-1a and 3-1b illustrate vertical ground motion, as measured by InSAR, across the Northeast Area from March 2011 to March 2019 and from March 2018 to March 2019, respectively. Figure 3-14 is a time-series chart that displays and describes the long-term history of pumping, recharge, hydraulic, and vertical ground motion in the Northeast Area. Figure 3-15 illustrates vertical ground motion as estimated by InSAR and ground-level surveys across the Northeast Area from January 2018 to April 2019. The following observations and interpretations are derived from these figures:

- From about 1930 to 1978, hydraulic heads in the Northeast Area declined by about 125 ft. From 1978 to about 1985, hydraulic heads increased by about 25 ft. From 1985 to 2019 hydraulic heads fluctuated but generally remained relatively stable or show a recovery trend since 2011. For example, City of Ontario well O-34 has increased about 10 ft since 2011. However, hydraulic heads across the Northeast Area are about 100 ft lower than the hydraulic heads in the 1930s.

- About one foot of subsidence occurred in the Northeast Area near the intersection of Euclid Avenue and Phillips Street ("Point D" on Figure 3-1a) from 1992 to 2019. From 1992 to 2011, the subsidence occurred at a gradual and persistent rate of about 0.04 ft/yr. From

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

2011 to 2019, the subsidence rate declined to about 0.018 ft/yr. Hydraulic heads remained relatively stable in this area from 1992-2019, which indicates that the downward vertical ground motion is, at least in part, permanent subsidence due to delayed aquitard drainage in response to the historical declines in hydraulic heads that occurred from 1930 to 1978. The recent decline in the rate of subsidence may be due to recent increases in hydraulic heads.

- The InSAR estimates in Figures 3-1a also indicate that downward ground motion has occurred in an area between Vineyard Avenue and Archibald Avenue south of the Ontario International Airport, where a maximum of about -0.18 ft of vertical ground motion occurred from March 2011 to March 2019. Between 2018 and 2019, the same area experienced about 0.02 ft of downward vertical ground motion. In comparison, Figure 3-1b shows that zero to 0.02 ft of upward vertical ground motion occurred across the rest of the Northeast Area from 2018-2019.

- Figure 3-1b shows that between March 2018 and 2019, most of the Northeast Area experienced upward vertical ground motion. The upward vertical ground motion measured by InSAR is consistent with the observation that groundwater pumping has been decreasing since 2014, recharge has been increasing since 2005, and hydraulic heads have been relatively stable or increasing. This has likely led to the equilibration of the hydraulic heads in the aquifer and aquitards and the cessation of aquifer-system compaction and subsidence across most of the Northeast Area. Figure 3-16 displays earthquake epicenters across the Chino Basin between 2011 and 2019, which may indicate an alternative mechanism for the subsidence observed in this portion of the Northeast Area. Section 3.6 below discusses the potential relationship between the seismicity and land subsidence.

- The ground-level survey results from 2018-2019 indicate a similar spatial pattern of downward and upward ground motion as estimated by InSAR but with slightly different magnitudes. Figure 3-15 shows that both methods indicate minor downward ground motion from 2018 to 2019 in the northwest portion of the Northeast Area and in the area between Vineyard Avenue and Archibald Avenue south of the Ontario International Airport, but the magnitudes between InSAR and ground-level surveys are slightly different. In general, very little ground-level motion was measured by both InSAR and ground-level surveys across the Northeast Area.

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 3-16 displays the location and magnitude of earthquake epicenters relative to vertical ground motion from March 2011 to March 2019.

Tectonic movement along the San Jose Fault, including aseismic creep, is a plausible mechanism for the differential land subsidence that has occurred in Northwest MZ-1. While the earthquake epicenters shown on Figure 3-16 do not show a spatial relationship to the differential subsidence in Northwest MZ-1, without direct measurement of aquifer-system deformation, as will be provided by PX, tectonic deformation cannot be ruled-out as a mechanism for the observed subsidence in Northwest MZ-1.

Between March 2011 and March 2019, several earthquake epicenters, varying in magnitude (local magnitude) from zero to four, occurred south of the Ontario International Airport. Figure 3-16 shows that the seismicity observed along the eastern edge of the Northeast Area extends northeast towards the San Jacinto Fault. The observed seismicity may reflect deep-seated convergence between the Perris Block that underlies the Chino Basin and the San Gabriel Mountains south of the Cucamonga Fault Zone (Morton and Yerkes, 1974; Morton et al., 1982; Morton and Matti, 1987).

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

Table 3-1
Groundwater Pumping in the Managed Area for Fiscal Year 2012 Through 2019
acre-ft

Well Name	Aquifer Layer	Fiscal Year							Fiscal Year 2019					
		2012	2013	2014	2015	2016	2017	2018	Qtr 1	Qtr 2	Qtr 3	Qtr 4*	Total	By Layer
C-4	Shallow	524	0	0	0	0	0	0	0	0	0	-	0	22
C-6		1049	594	0	0	0	0	0	0	0	0	-	0	
CH-1A		1137	909	738	861	649	637	369	0	0	0	-	0	
CH-7A		530	380	170	286	156	66	0	0	0	0	-	0	
CH-7B		712	264	200	616	261	232	350	0	0	0	-	0	
CIM-1		724	1,109	1,127	878	911	908	586	0	0	0	-	0	
XRef 8730**		3	5	5	4	3	35	29	7.35	7.35	7.35	-	22	
CH-17	Deep***	758	1,444	937	1,142	567	624	571	0	0	0	-	0	0
CH-15B		0	28	105	0	0	0	0	0	0	0	-	0	
CIM-11A		243	239	195	92	94	222	0	0	0	0	-	0	
	Totals	**5,680**	**4,971**	**3,477**	**3,878**	**2,642**	**2,725**	**1,905**	**7**	**7**	**7**	**-**	**22**	

"C" = City of Chino

"CH" = City of Chino Hills

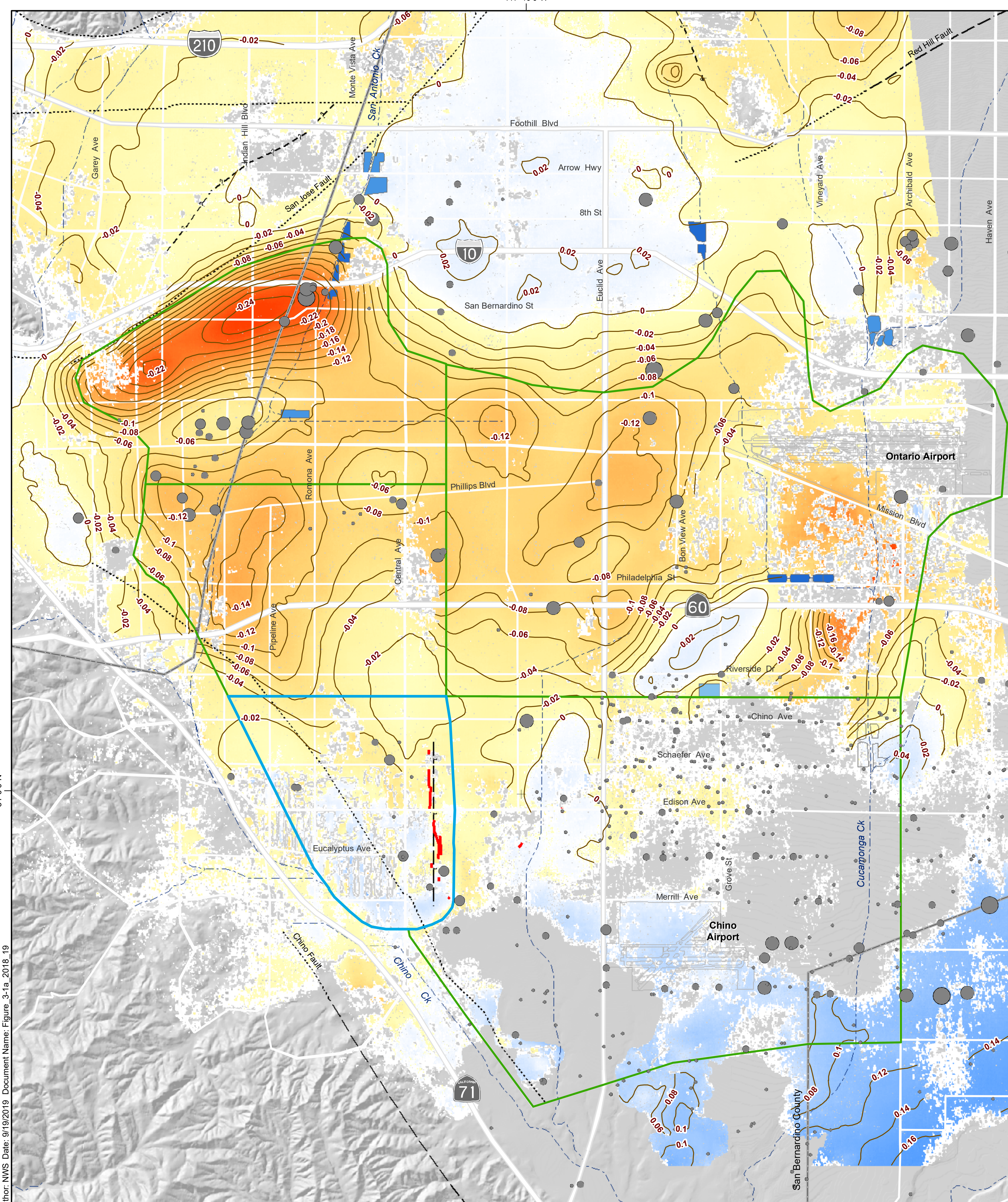
"CIM" = California Institution for Men

"XRef" = Private

*Data only available through March 2019

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

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



Relative Change in Land Surface Elevation as Estimated by InSAR (March 2011 to March 2019)

+ 0.25 ft
0 ft
- 0.25 ft

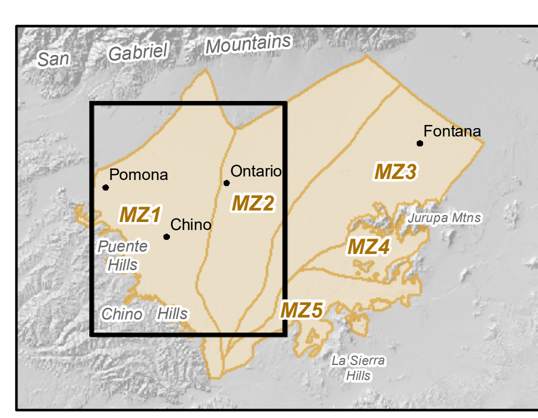
InSAR absent or incoherent

Average Annual Groundwater Pumping April 1, 2011 to March 31, 2019 (afy)

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

Average Annual Basin Recharge FY 2011 to FY 2018 (afy)

- 0
- <1,000
- 1,000 - 2,500
- 2,500 - 5,000



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)

0 1 2 Miles

0 1 2 Kilometers

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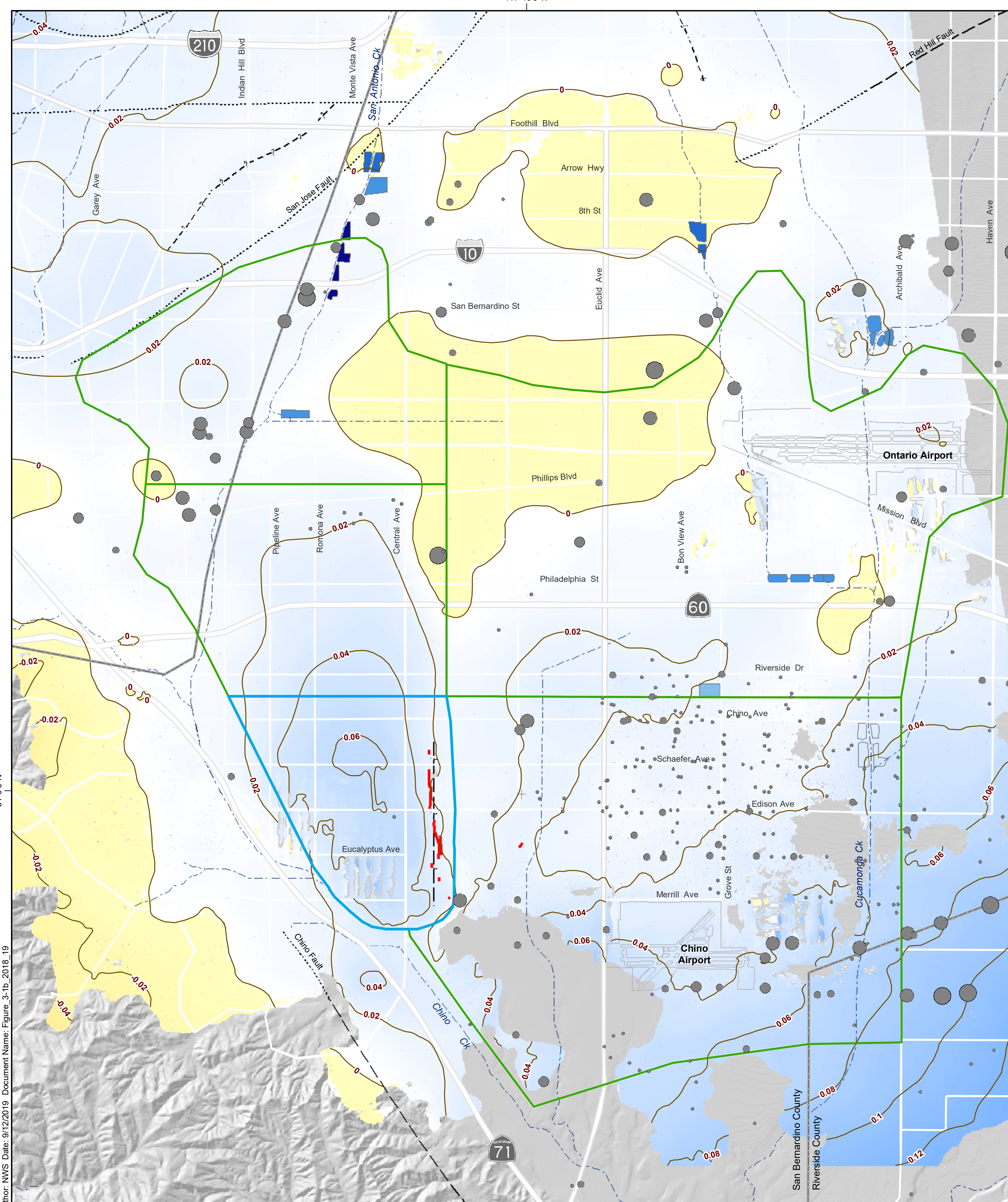
Vertical Ground Motion across the Western Chino Basin
2011/19

Figure 3-1a



Relative Change in Land Surface Elevation as Estimated by InSAR (March 2018 to March 2019)

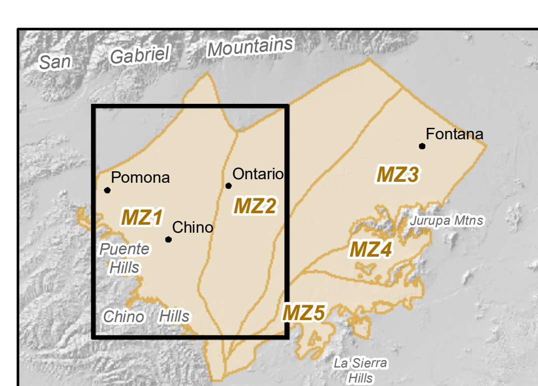
- + 0.25 ft
- 0 ft
- -0.20
- - 0.25 ft
- InSAR absent or incoherent

Groundwater Pumping April 1, 2018 to March 31, 2019 (afy)

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

Average Annual Basin Recharge FY 2017 to FY 2018 (afy)

- 0
- <1,000
- 1,000 - 2,500
- 2,500 - 5,000
- >7,500



- 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)

0 1 2 Miles

0 1 2 Kilometers

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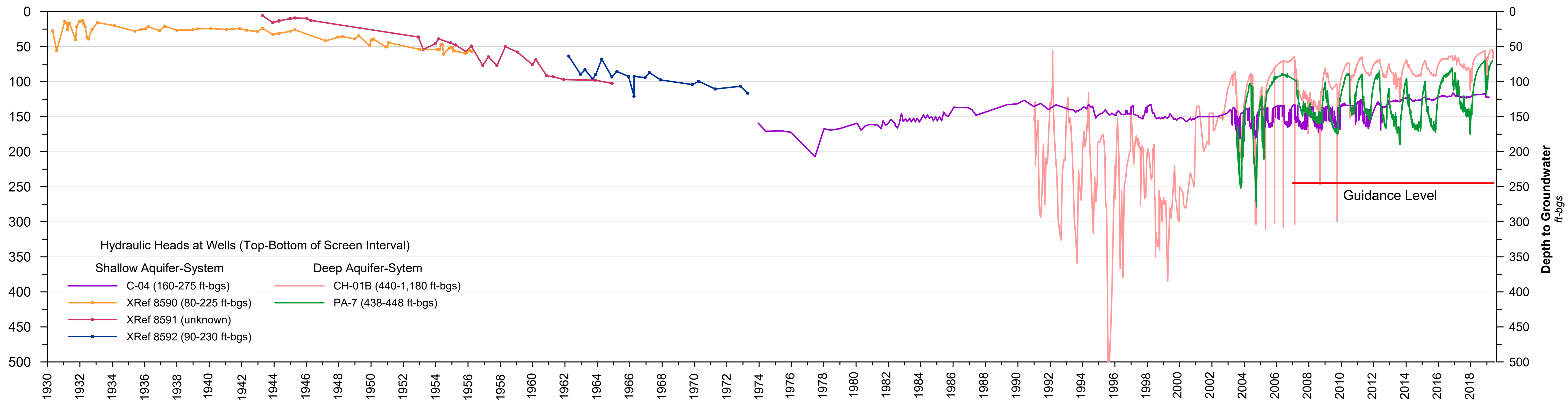
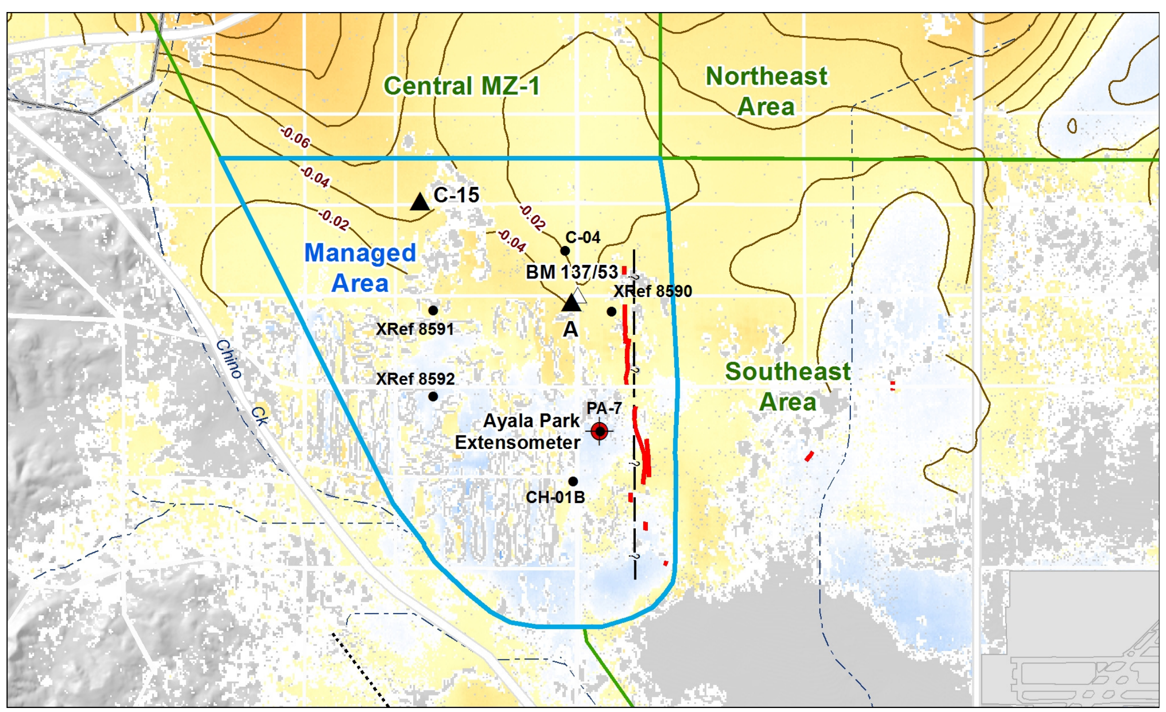
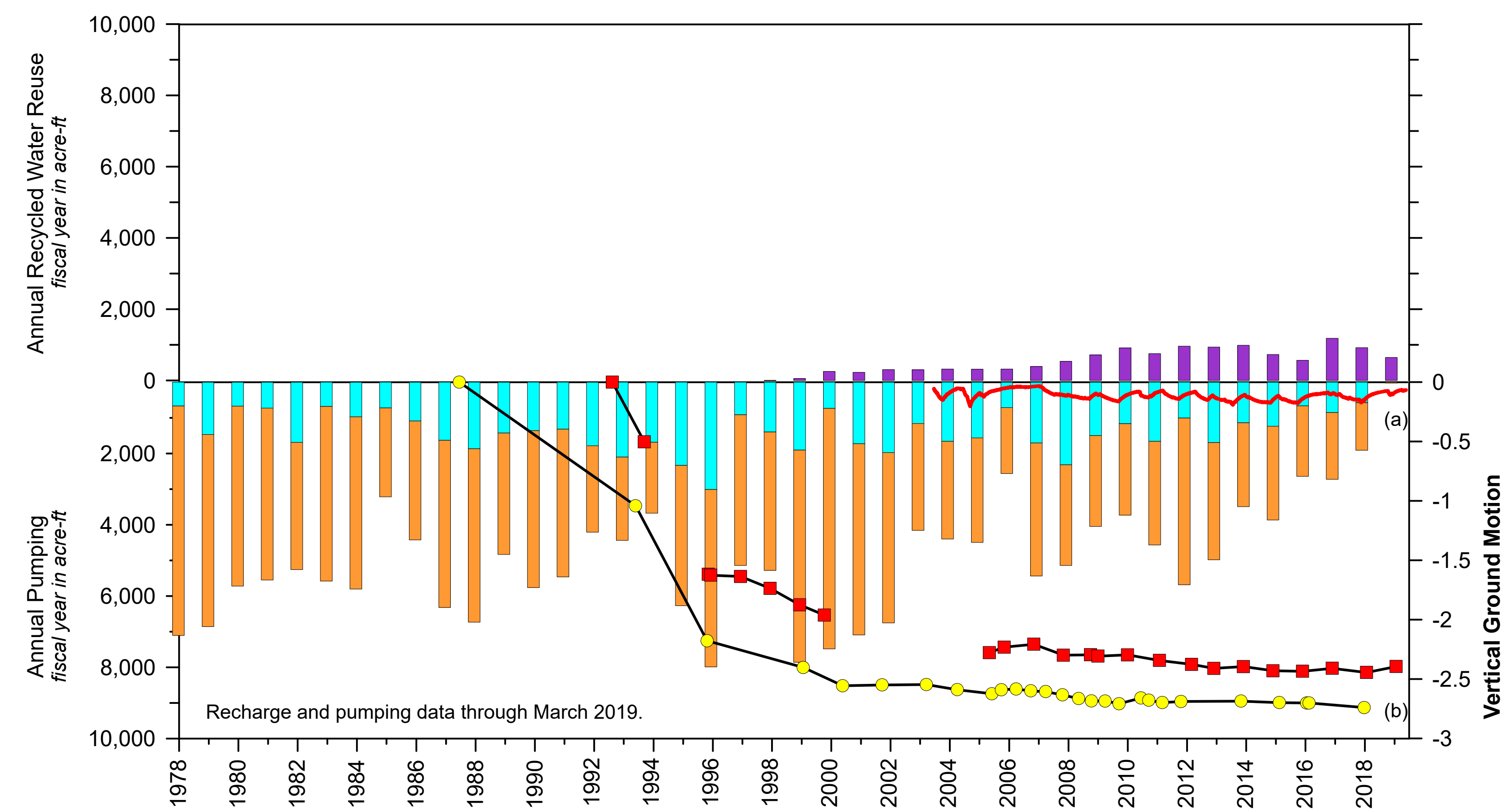
Vertical Ground Motion across the Western Chino Basin
2018/19

Figure 3-1b





InSAR from March 2011 to March 2019 (see Figure 3-1a)



Vertical Ground-Motion
(Cumulative Displacement)

- InSAR Point A
- BM 137/53
- Ayala Park Deep Extensometer Measures between: 30 and 1,440 ft-bgs

Recycled Water Reuse and Pumping

- Recycled Water Direct Reuse

Groundwater Pumping

- Shallow Aquifer
- Deep Aquifer or Both Aquifers

(a) Pumping from the shallow aquifer = 22 af
Pumping from the deep aquifer or both shallow and deep aquifers = 0 af

(b) The Managed Area was not surveyed per the recommended scope and budget of the GLMC for FY 2018/19.

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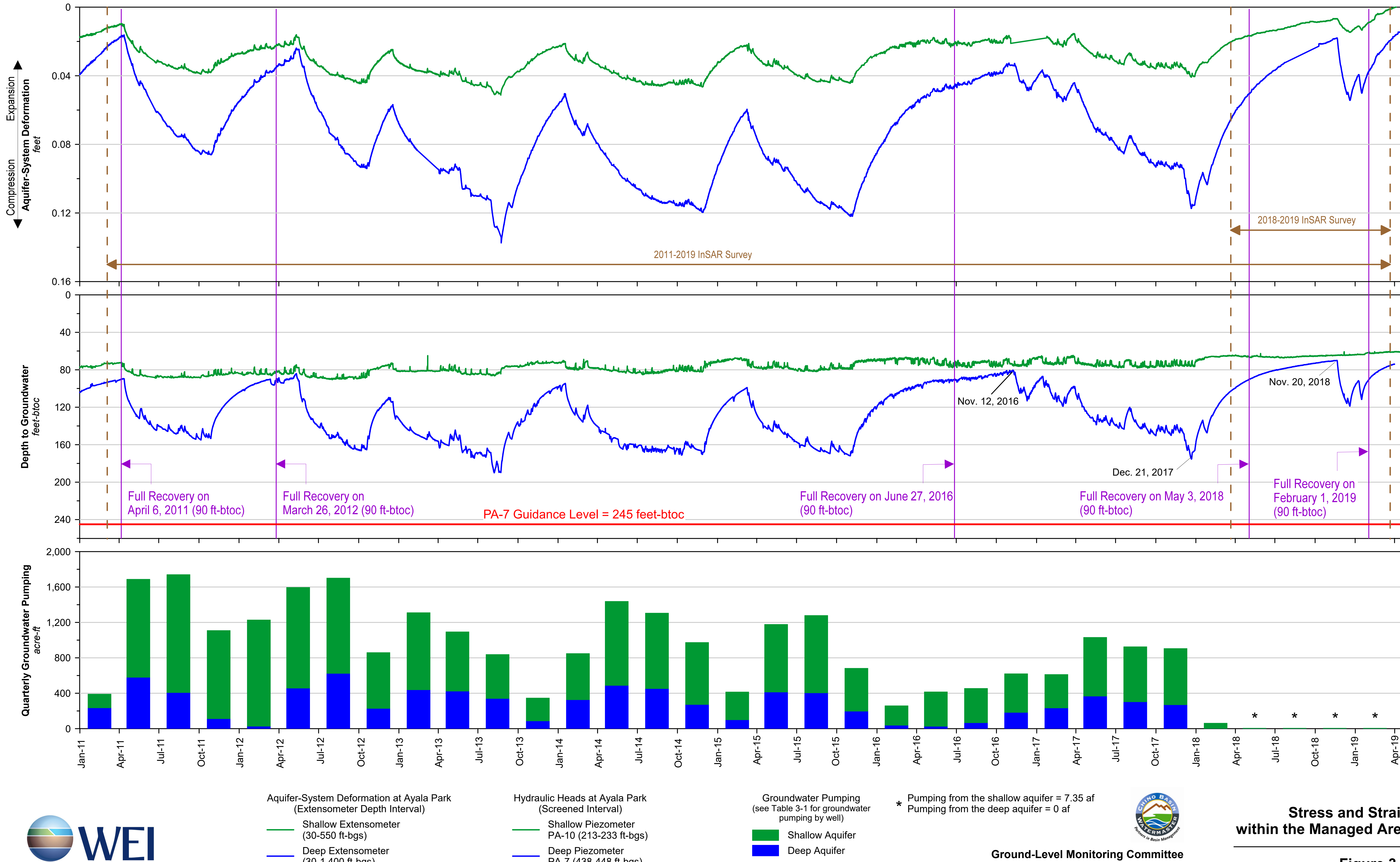
History of Land Subsidence in the Managed Area

Figure 3-2



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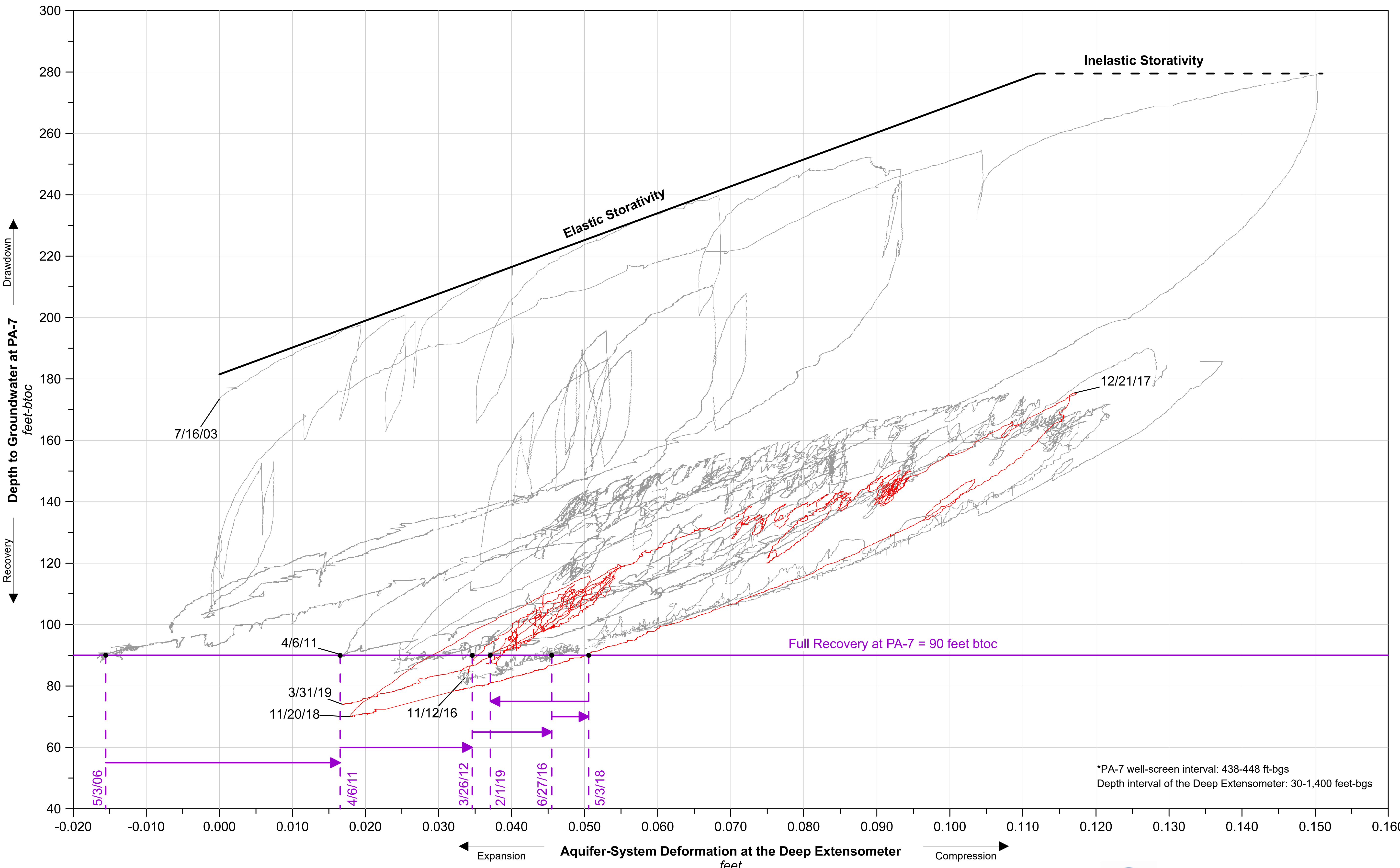
Stress and Strain within the Managed Area

Figure 3-3



Stress - Strain Hysteresis Loops of Drawdown and Recovery Cycles

Drawdown and recovery between July 16, 2003 and November 12, 2016

Drawdown and recovery between November 13, 2016 and March 31, 2019

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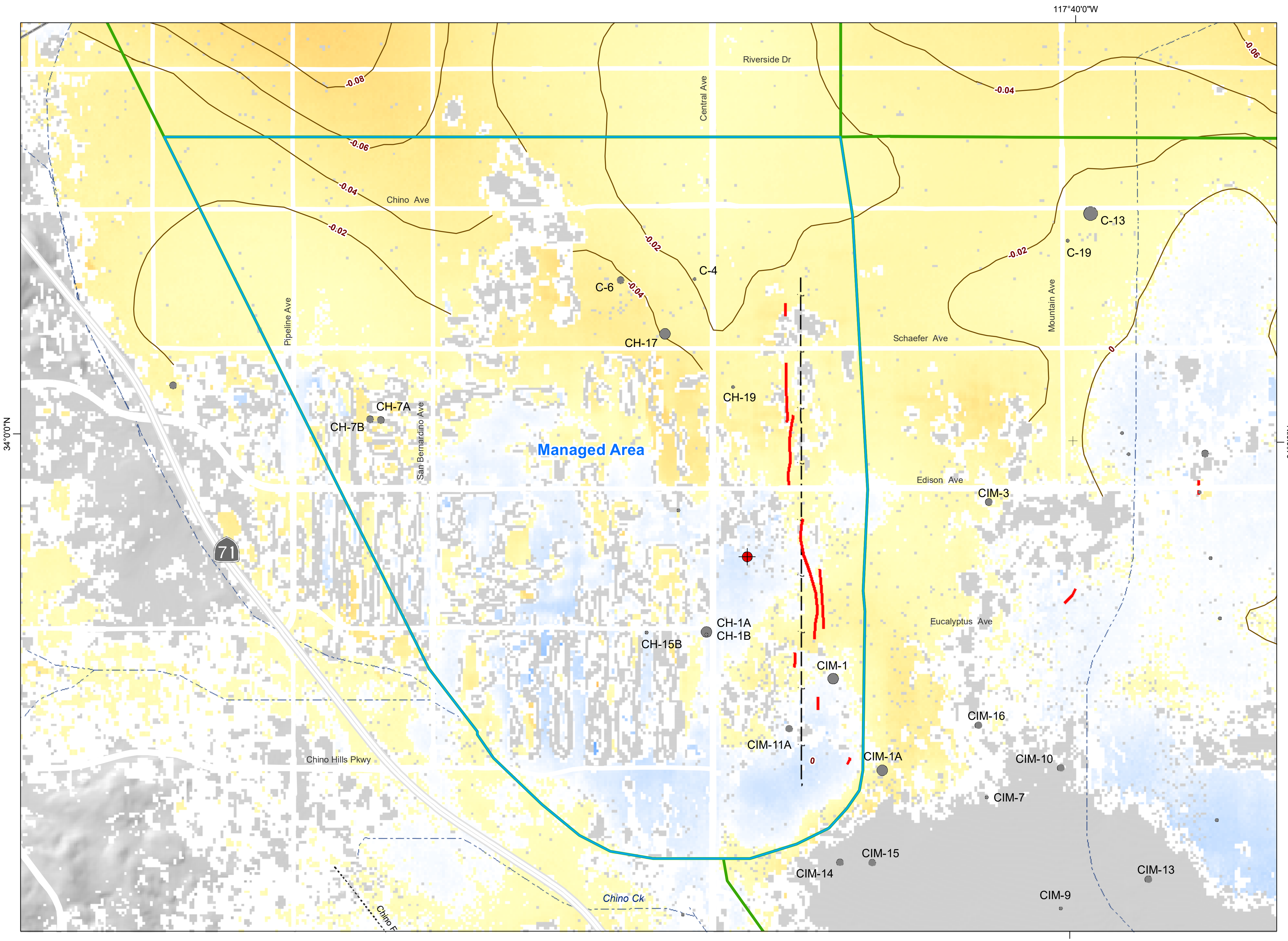
Stress-Strain Diagram
Ayala Park Extensometer

Figure 3-4



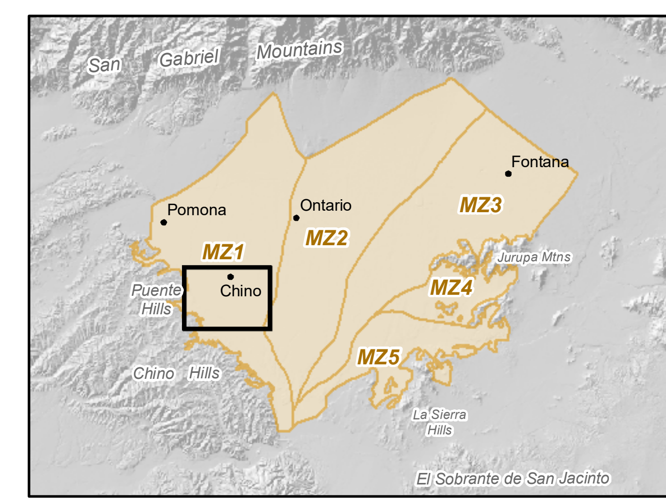
Relative Change in Land Surface Elevation
as Estimated by InSAR
March 2011 to March 2019

+ 0.25 ft
0 ft
-0.20
- 0.25 ft
InSAR absent or incoherent

Average Annual Groundwater Pumping
April 1, 2011 to March 31, 2019
(afy)

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

Ayala Park Extensometer Facility
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



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Document Name: Figure_3-5a_2018_19

0 0.5 1 Miles
0 0.5 1 Kilometers

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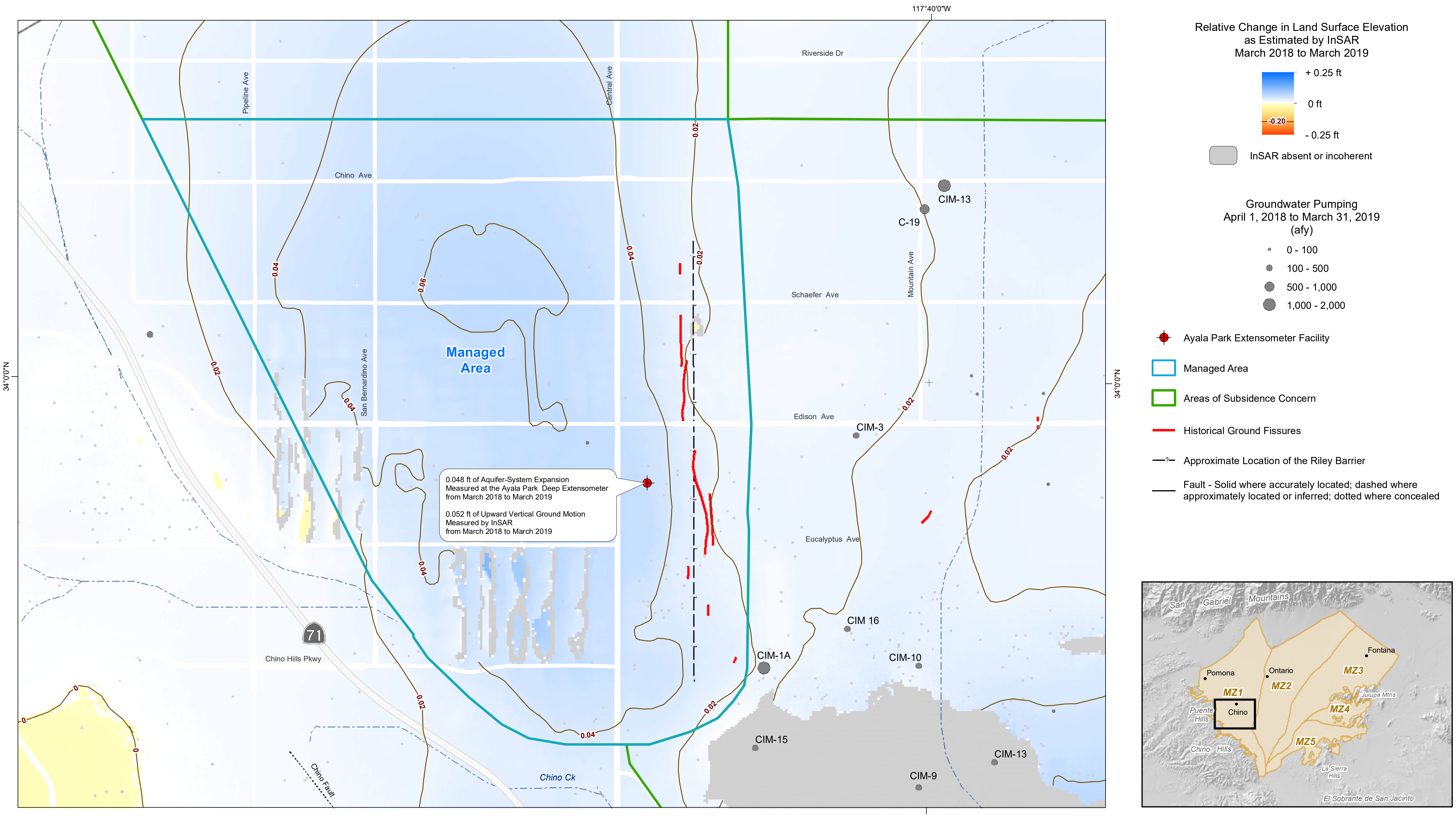
Vertical Ground Motion across the Managed Area
2011 - 2019

Figure 3-5a



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Date: 9/19/2019
Document Name: Figure_3-5b_2018_19

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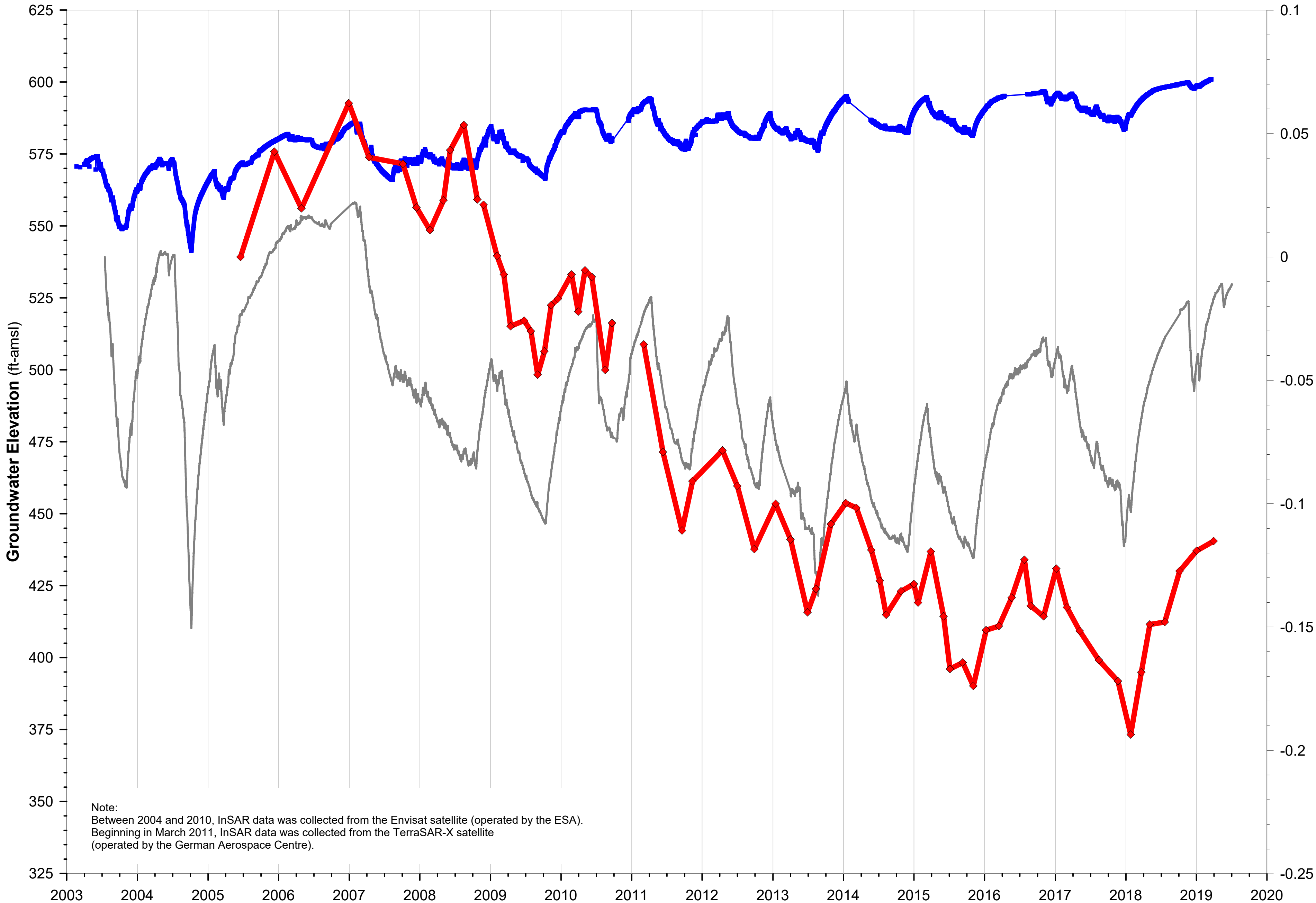
Vertical Ground Motion across the Managed Area
2018/19

Figure 3-5b



Vertical Ground Motion
(Cumulative Displacement)

InSAR Point measured at C-15

Estimated by the Ayala Park Deep Extensometer
(1,440 ft-bgs)

Piezometric Levels at Wells
(Top-Bottom of Screen Interval)

C-15 (270 - 820 ft-bgs)

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Hydraulic Heads at C-15 versus Vertical Ground Motion

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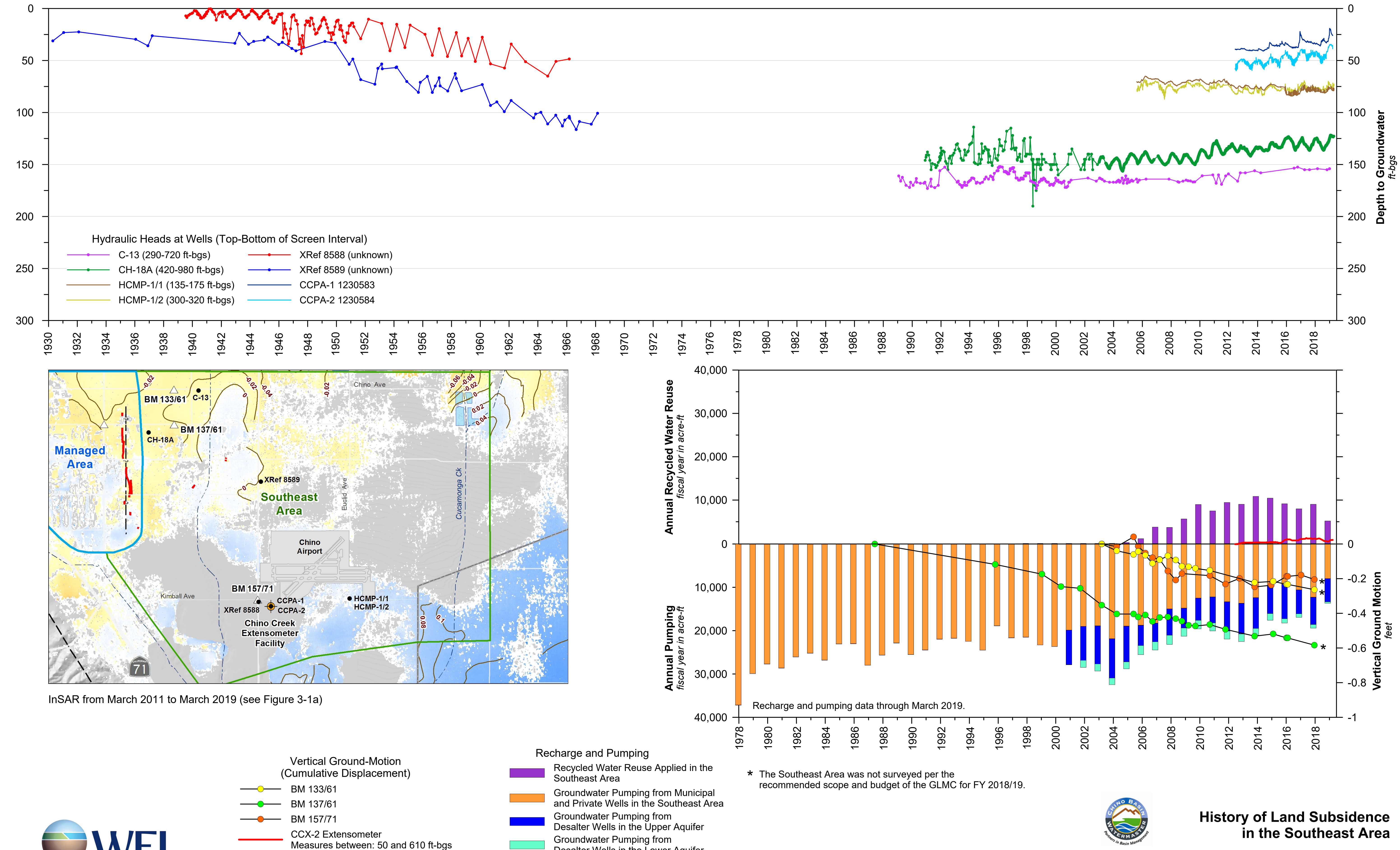
Figure 3-6



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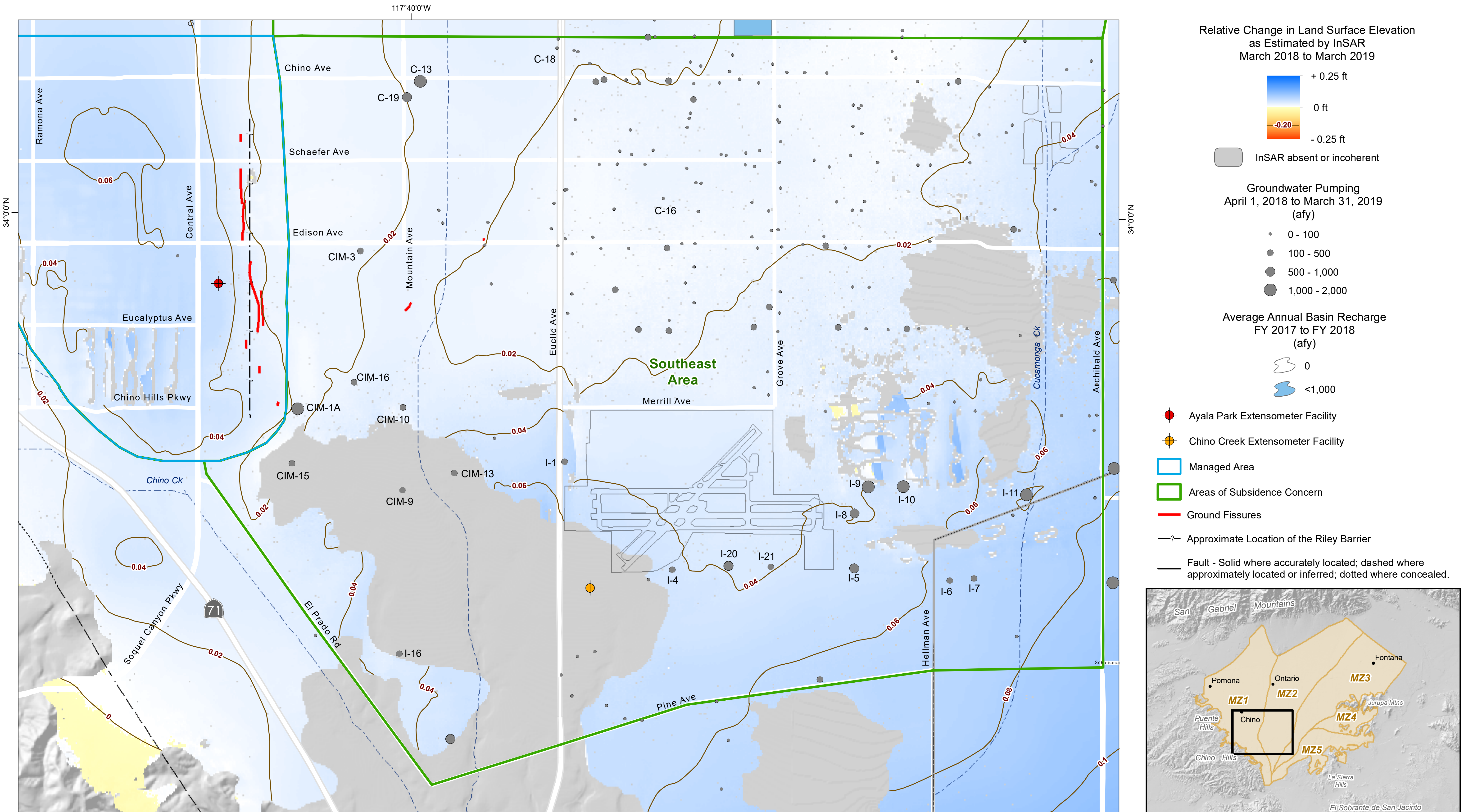
History of Land Subsidence in the Southeast Area

Figure 3-7



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Document Name: Figure_3-8_2018_19

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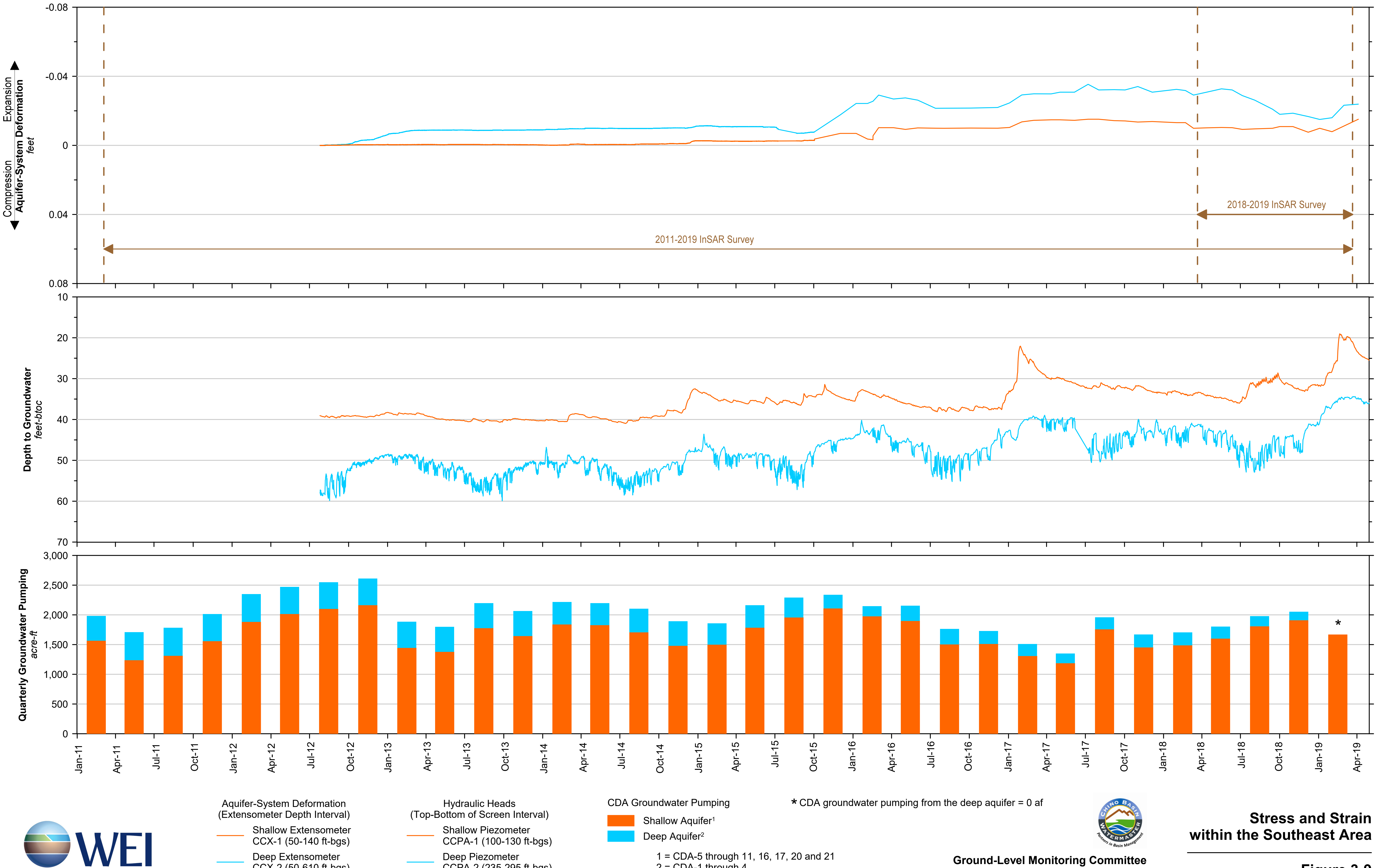
Vertical Ground Motion across the Southeast Area
2018/19

Figure 3-8



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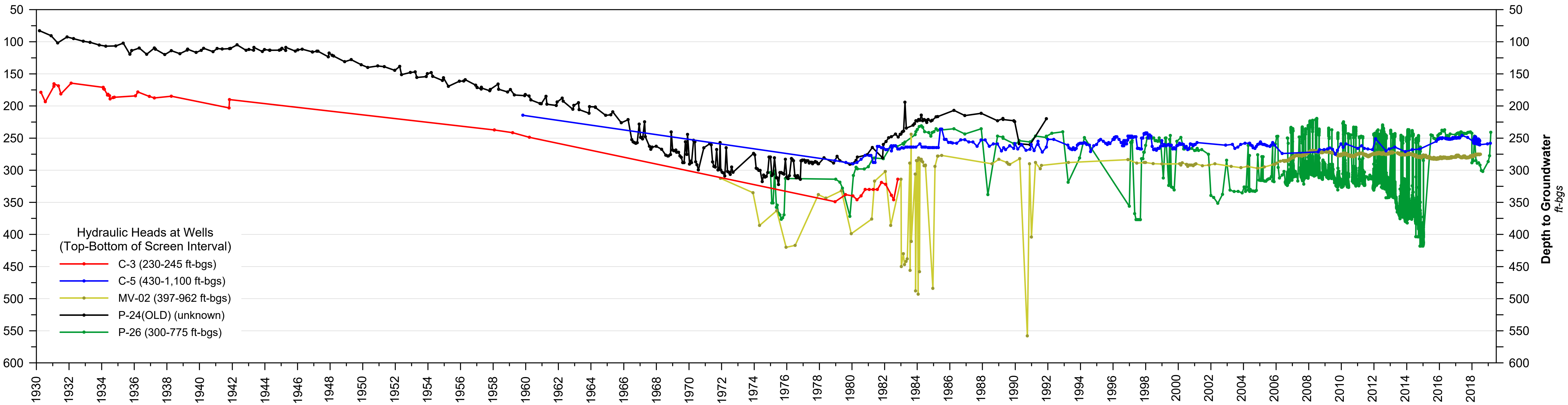
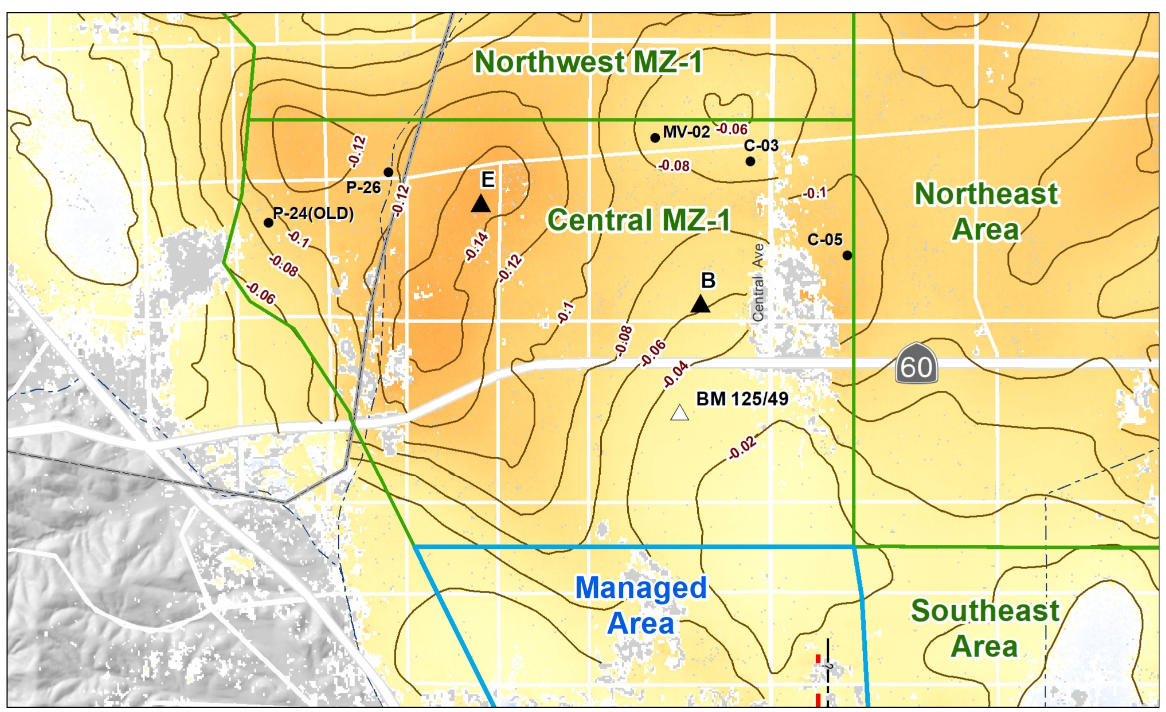
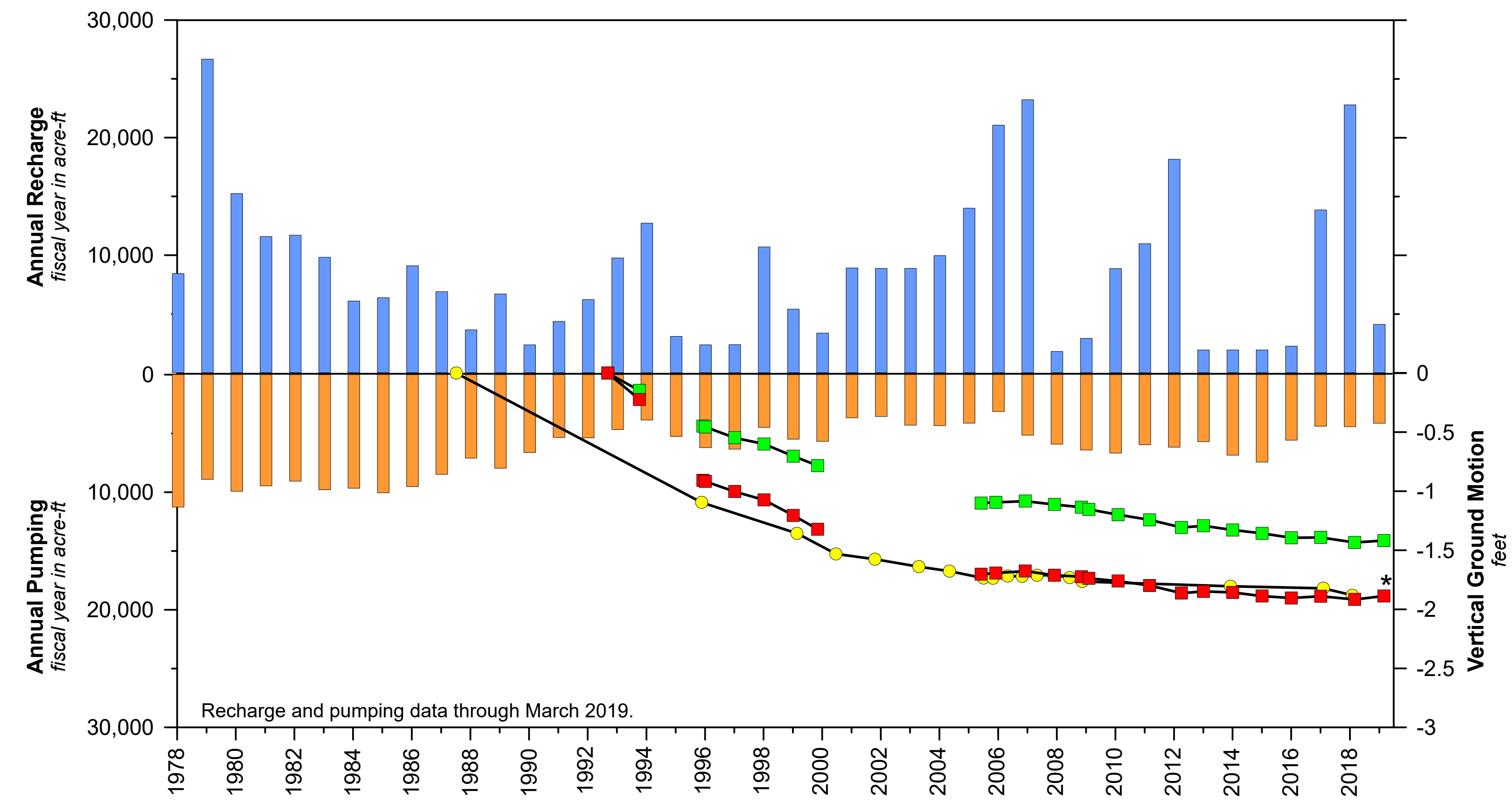
Stress and Strain within the Southeast Area

Figure 3-9





InSAR from March 2011 to March 2019 (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

* The Central MZ-1 was not surveyed per the recommended scope and budget of the GLMC for FY 2018/19.

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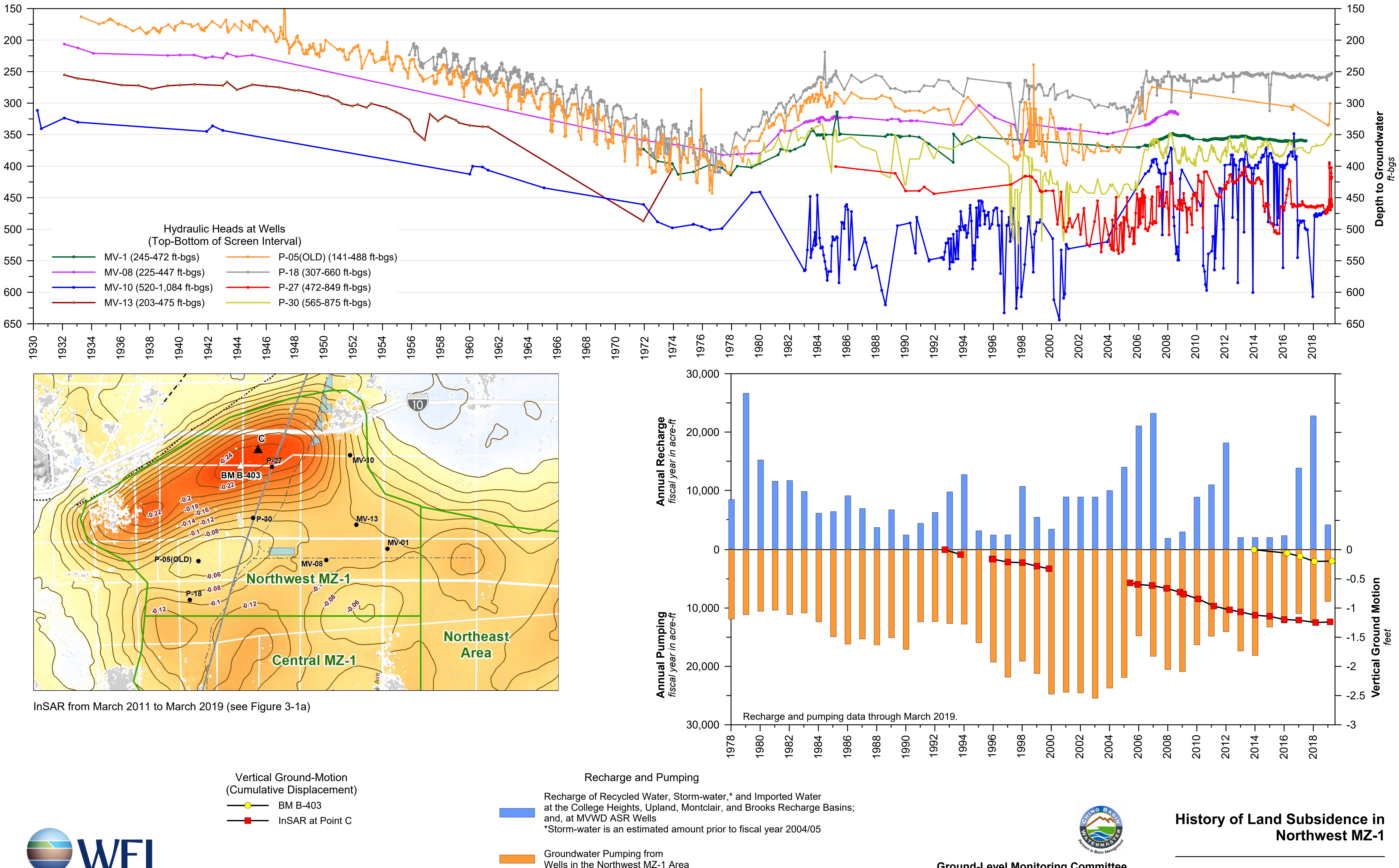
History of Land Subsidence in Central MZ-1

Figure 3-10



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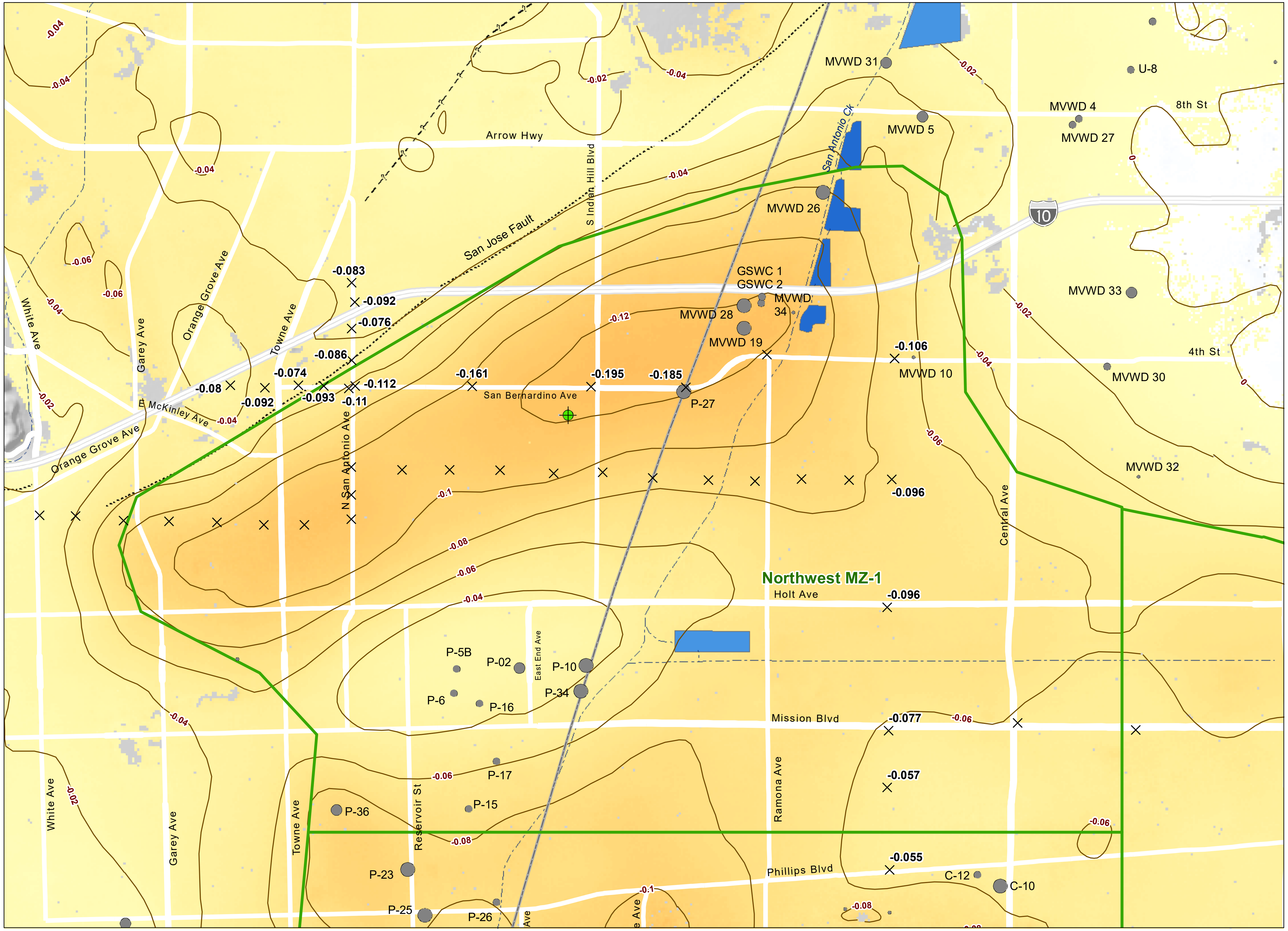
History of Land Subsidence in Northwest MZ-1

Figure 3-11



Relative Change in Land Surface Elevation as Estimated by InSAR January 2014 to March 2019

+ 0.25 ft
0 ft
-0.20
- 0.25 ft

InSAR absent or incoherent

Average Annual Groundwater Pumping April 1, 2014 to March 31, 2019 (afy)

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

Average Annual Basin Recharge FY 2014 to FY 2018 (afy)

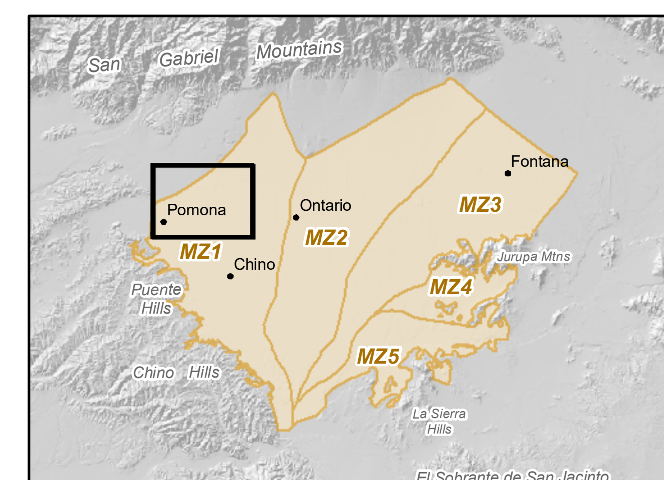
- 1,000 - 2,500
- 2,500 - 5,000

Ground-Level Survey Benchmark (Measured April 15, 2019) Labeled by Vertical Ground Motion (in feet from December 2013 to April 2019)

Pomona Extensometer Facility

Areas of Subsidence Concern

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



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Document Name: Figure_3-12a_2018_19

0 0.5 1 Miles
0 0.5 1 Kilometers

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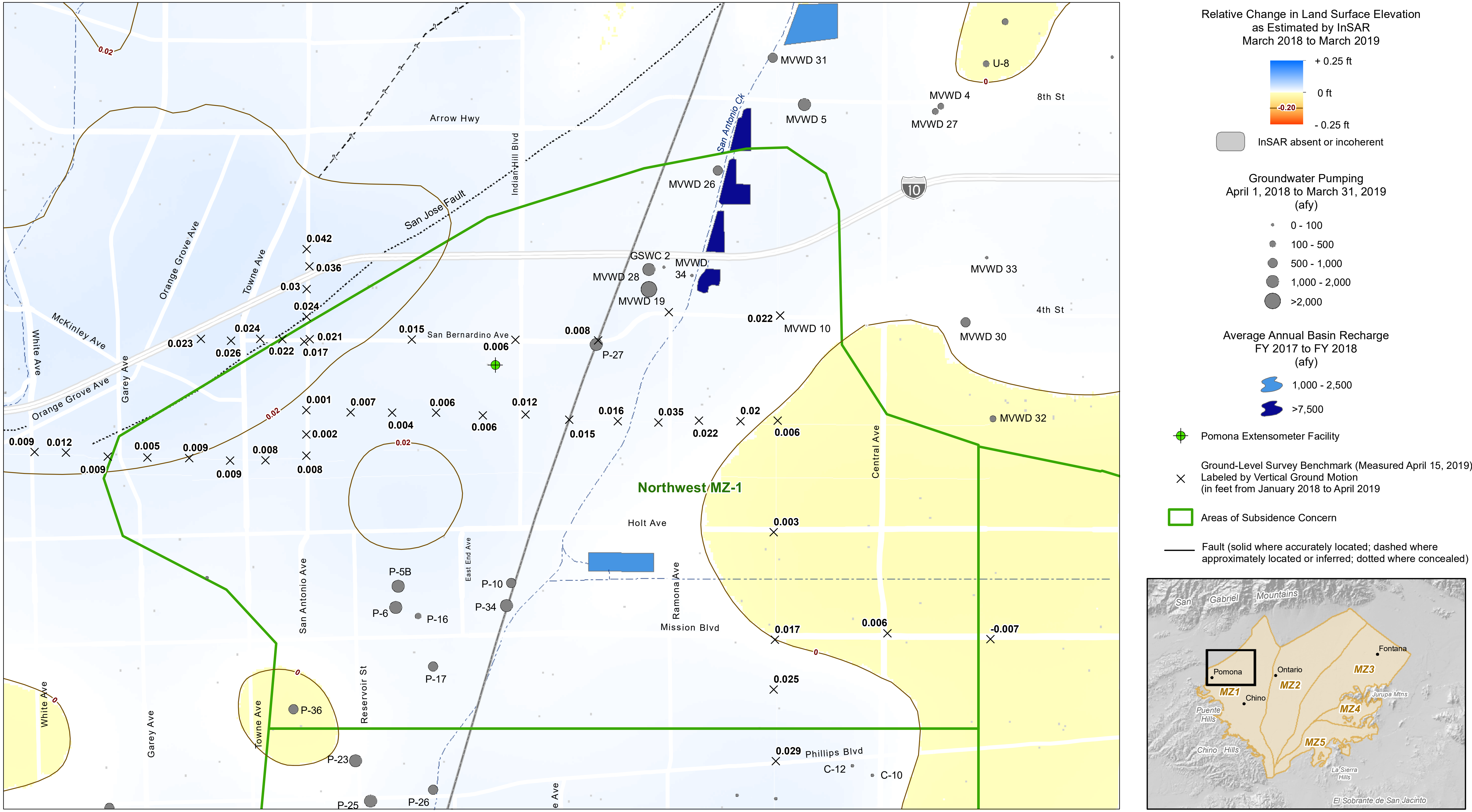
Vertical Ground Motion across Northwest MZ-1
2014 - 2019

Figure 3-12a



Author: NWS
Date: 9/19/2019
Document Name: Figure_3-12b_2018_19

0 0.5 1 Miles
0 0.5 1 Kilometers

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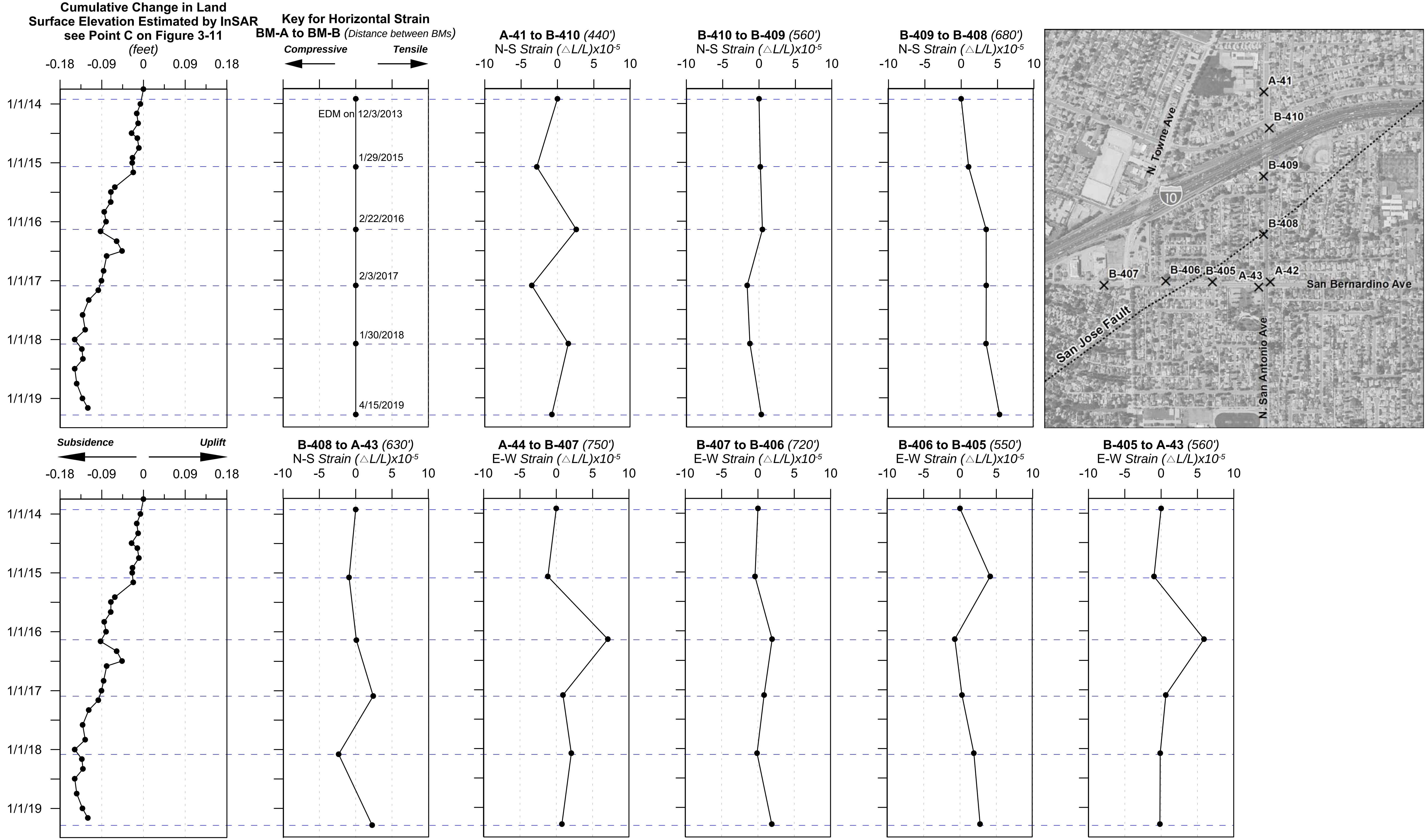
Vertical Ground Motion across Northwest MZ-1
2018/19

Figure 3-12b



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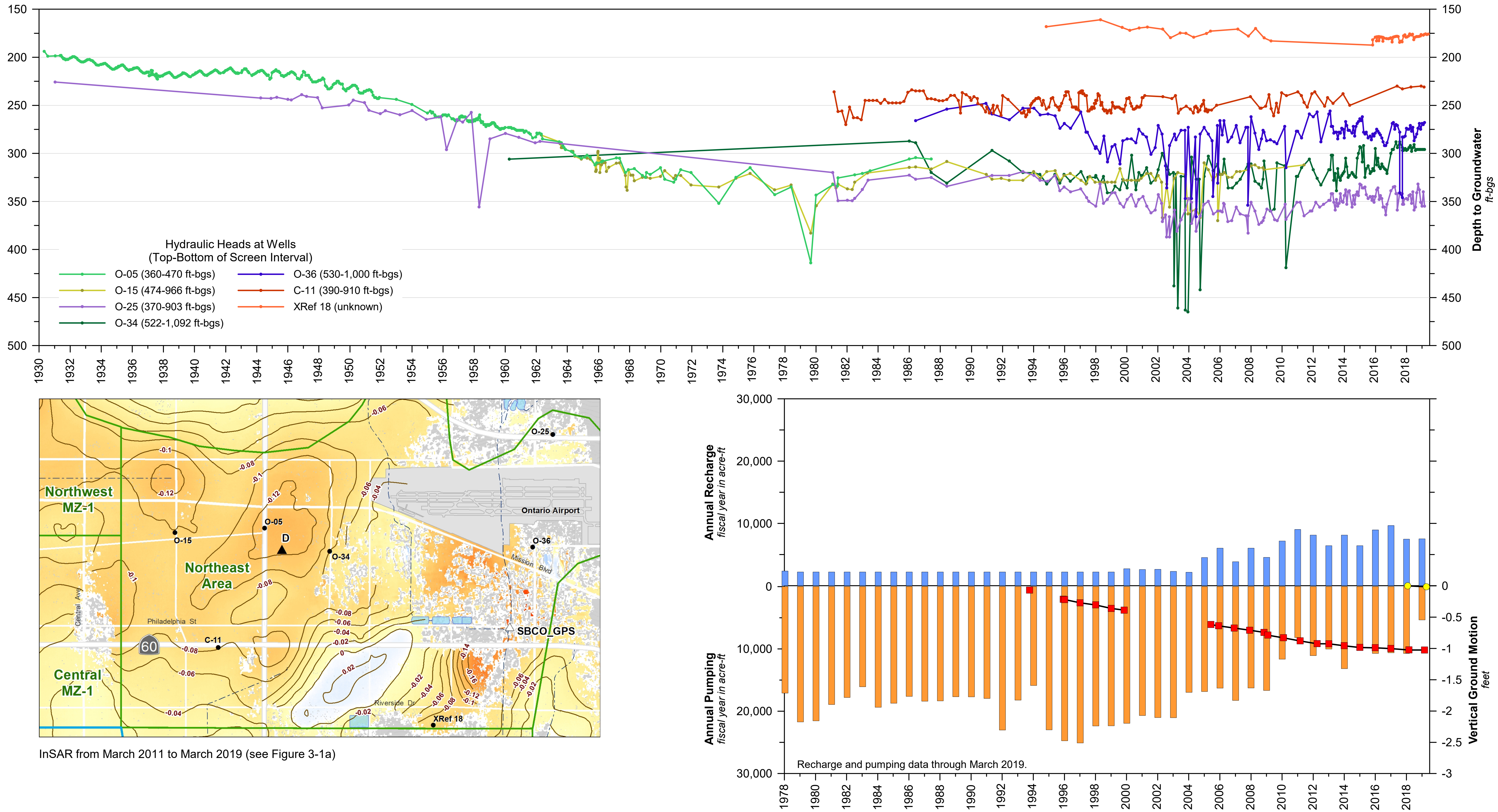
Horizontal Strain across the San Jose Fault as Calculated from Electronic Distance Measurements
2013 - 2019

Figure 3-13



InSAR from March 2011 to March 2019 (see Figure 3-1a)

Vertical Ground-Motion
(Cumulative Displacement)

- SBCO_GPS
- InSAR 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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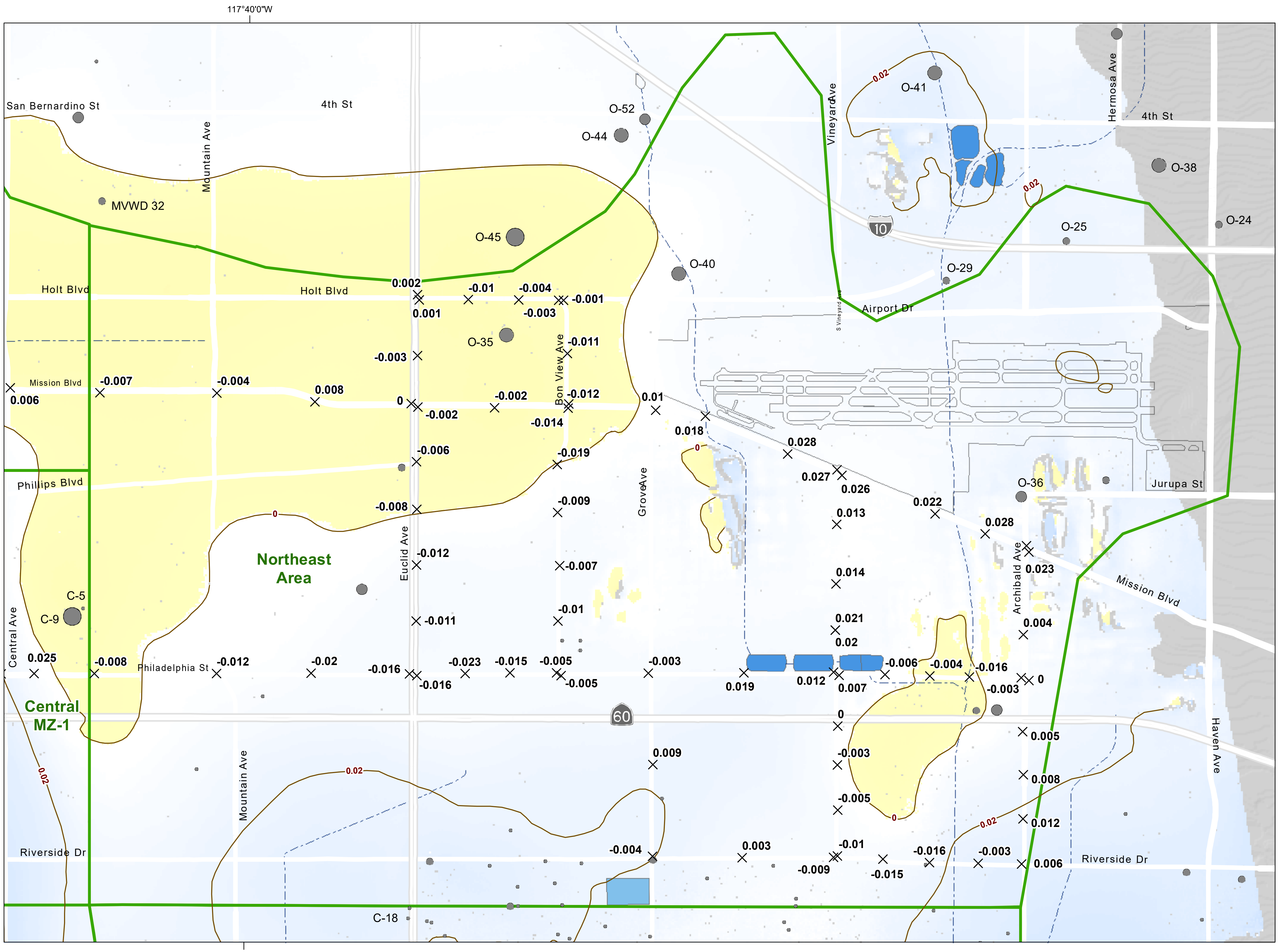
History of Land Subsidence in the Northeast Area

Figure 3-14



Relative Change in Land Surface Elevation as Estimated by InSAR March 2018 to March 2019

+ 0.25 ft
0 ft
-0.20
- 0.25 ft
InSAR absent or incoherent

Groundwater Pumping April 1, 2018 to March 31, 2019 (afy)

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

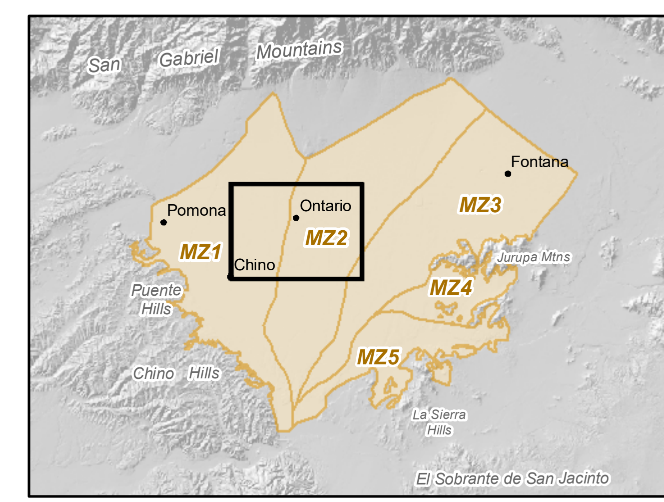
Average Annual Basin Recharge FY 2017 to FY 2018 (afy)

- 0
- <1,000
- 1,000 - 2,500

Ground-Level Survey Benchmark (Measured April 15, 2019) Labeled by Vertical Ground Motion (in feet from January 2018 to April 2019)

Areas of Subsidence Concern

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



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Author: NWS
Date: 9/19/2019
Document Name: Figure_3-15_2018_19

0 0.5 1 Miles
0 0.5 1 Kilometers

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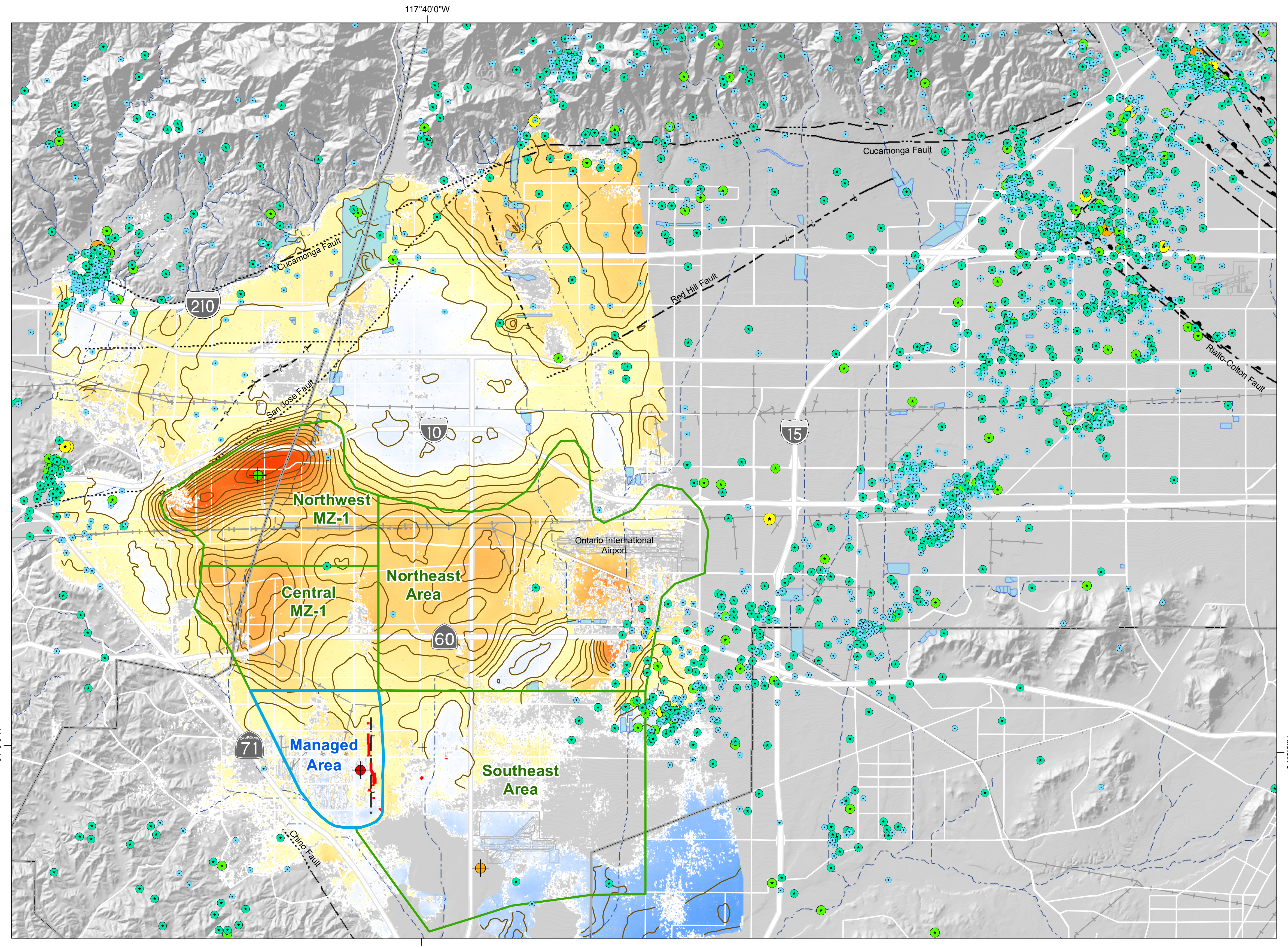
2018/19 Annual Report

Vertical Ground Motion across the Northeast Area
2018/19

Figure 3-15



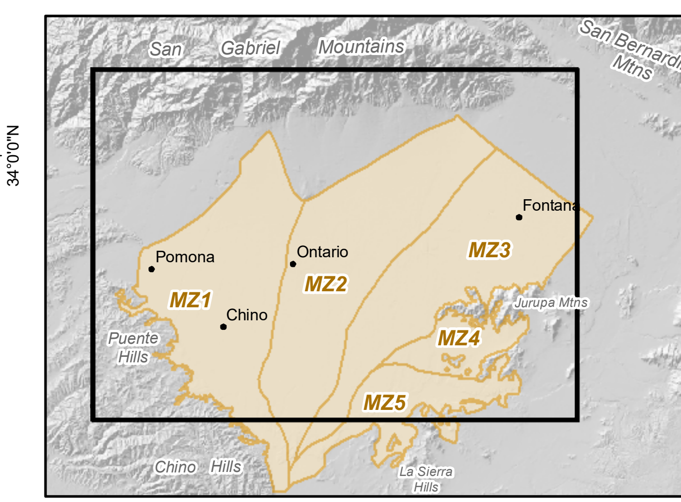
Relative Change in Land Surface Elevation as Estimated by InSAR (March 2011 to March 2019)

+ 0.25 ft
0 ft
-0.20
- 0.25 ft
InSAR absent or incoherent

Earthquake Epicenters March 2011 to March 2019 (Local Magnitude)

0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6

Pomona Extensometer Facility
Ayala Park Extensometer Facility
Chino Creek Extensometer Facility
Ground Fissures
Approximate Location of the Riley Barrier
Managed Area
Areas of Subsidence Concern
Flood Control and Conservation Basins
Fault - Solid where accurately located; dashed where approximately located or inferred; dotted where concealed



Author: NWS
Date: 9/19/2019
Document Name: Figure_3-16_EQ_ZoomOut

0 1 2 *Miles*
Kilometers 0 1 2

Ground-Level Monitoring Committee
2018/19 Annual Report

Seismicity across the Chino Basin
2011 - 2019

Figure 3-16

Section 4 – Conclusions and Recommendations

4.1 Conclusions and Recommendations

The major conclusions and recommendations of this 2018/19 Annual Report of the GLMC are:

- At the Ayala Park Extensometer in the Managed Area, hydraulic heads within the shallow and deep aquifer systems increased to their highest levels since the inception of the GLMP in 2003. 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. 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 of March 2018 to March 2019.

- In the Managed Area, prior annual reports have noted the occurrence of minor amounts of inelastic aquifer-system compaction and permanent land subsidence from 2006-2018 as measured at the Ayala Park Deep Extensometer and by InSAR, even during periods of increasing hydraulic heads. These observations 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. The extensometer and InSAR data collected during the current reporting period indicate that the reduced pumping and increases in hydraulic heads may have resulted in the equilibration of hydraulic heads in the aquitards and aquifers, which stopped the drainage and compaction of the aquitards.

- Across most of the other Areas of Subsidence Concern, prior annual reports have noted similar long-term trends of persistent, gradual land subsidence from 1992-2018, 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 the 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 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 over the current reporting period indicate upward ground motion across most of the Areas of Subsidence Concern. These observations suggest that the reductions in pumping, increases in recharge, and increases in hydraulic head may have caused equilibration of hydraulic heads in the aquitards and aquifers, which stopped the drainage and compaction of the aquitards.

- The cessation of land subsidence across the Areas of Subsidence Concern during the current reporting period 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 land subsidence to resume. However, these recent observations may be indicating hydraulic head "thresholds" that, if 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.

- It is unlikely that the reduced pumping and increased recharge that has occurred over the past few years in Northwest MZ-1 will persist into the future. The pumpers in this area will likely increase pumping and devise and implement strategies to remove groundwater contaminants through treatment, and the "put" cycles for the Dry-Year Yield Program occur only periodically. The future occurrence of subsidence remains a threat if increased pumping or decreased recharge cause future head declines. RECOMMENDATION: The Watermaster 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 2019/20, this will include: the completion of the Pomona Extensometer, analyzing hydraulic head data from Pomona and MVWD wells recently equipped with pressure transducers, estimating vertical ground motion via InSAR and elevation surveys at benchmarks, and estimating horizontal ground motion via EDM surveys at benchmarks across the San Jose Fault.

- 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.

    - Where and when the extensometer, InSAR, and traditional leveling datasets overlap, InSAR shows a similar spatial pattern and magnitude of ground motion compared to the extensometers and leveling surveys. Research performed by the GLMC has shown that the errors inherent in InSAR and traditional leveling methods are similar.

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

    RECOMMENDATION: The GLMC should preferentially rely on InSAR over traditional leveling techniques to monitor ground motion as a cost-saving strategy.

However, the GLMC should employ methods to verify the InSAR estimates of vertical ground motions via techniques, such as GPS, extensometers, and less-frequent leveling surveys.

- The comparison of InSAR estimates of vertical ground motion and high-frequency head measurements at Well C-15 (discussed in Section 3) demonstrates the usefulness and efficacy of this type of monitoring and data analysis to reveal the nature of aquifer-system deformation (i.e. elastic versus inelastic deformation) over short- and long-term time scales. This type of monitoring also can provide information on hydraulic head "thresholds" that could be used as management criteria to protect against the future occurrence of land subsidence. RECOMMENDATION: The GLMC should consider performing this type of monitoring and data analysis in other Areas of Subsidence Concern where such datasets exist. However, if depth-specific understanding of head and aquifer-system compaction are necessary to develop subsidence-management criteria, then depth-specific extensometers are the more appropriate monitoring strategy.

- Since 2011, the GLMC has been monitoring only the western portion of the Chino Basin via InSAR as a cost-saving strategy. This decision was based on: (i) observations that InSAR-derived estimates of ground motion from 1992-2005 indicated that little if any subsidence had occurred within the eastern portions of the basin and (ii) the desire to manage costs associated with the GLMP. Since 2005, hydraulic heads have decreased across the central and eastern portions of the Chino Basin (see Exhibit 4-5 in the 2018 State of the Basin Report[14]). Subsidence may have occurred in these areas in response to the declining heads, yet these areas have not been monitored for vertical ground motion. For example, the area south of the Ontario Airport within the Northeast Area has shown persistent land subsidence since about 2011, but the eastward extent of the subsiding area is not monitoring by the current InSAR monitoring technique.

  There is a new satellite in operation that can provide InSAR estimates of ground motion across the entire basin for approximately the same cost as the GLMC currently pays for InSAR across the west side only. However, the new satellite collects SAR data at a lower spatial resolution. RECOMMENDATION: The GLMC should consider the merit of performing a pilot study to compare its recent InSAR results to InSAR results provided by the new satellite. The purpose of the pilot study would be to answer the following:

  1) Are there areas of subsidence concern in the eastern Chino Basin that have resulted from recent declines in head?
  2) Will the larger spatial resolution of the new satellite impact the usefulness of the InSAR estimates of ground motion for the GLMP?
  3) Is the vertical accuracy of the InSAR estimates from the new satellite the same, better, or worse compared to the current InSAR estimates?
  4) Based on the answers to the three questions above, should the GLMC recommend using the new satellite for monitoring of vertical ground motion via InSAR across the entire basin.

[14] http://www.cbwm.org/rep_engineering.htm

4.2 Recommended Scope and Budget for Fiscal Year 2018/19

The scope-of-work for the GLMP for FY 2019/20 was recommended by the GLMC in April 2019 and approved by Watermaster on May 23, 2019. Appendix A is the technical memorandum prepared by the GLMC, titled *Recommended Scope and Budget of the Ground-Level Monitoring Committee for FY 2019/20*.

In March 2020, Watermaster staff and the Watermaster Engineer will present the preliminary results of the GLMP through 2019 and a recommended an FY 2020/21 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 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. Currently, there are no recommended changes to the Subsidence Management Plan.

The following glossary contains the terms and definitions used in this report and generally in the discussions at GLMC meetings (USGS, 1999).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Rebound – Elastic rising of the land surface.

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

Stress, Preconsolidation – 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 preconsolidation stress produce elastic deformations of small magnitude. In fine-grained materials, stress increases beyond the preconsolidation 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, Pressure – 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 2019/20

WILDERMUTH ENVIRONMENTAL, INC.

Technical Memorandum	
To:	Ground-Level Monitoring Committee
From:	Watermaster Engineer – Wildermuth Environmental Inc. (WEI)
Date:	April 9, 2019
Subject:	Recommended Scope and Budget of the Ground-Level Monitoring Committee for FY 2019/20 (FINAL)

Background and Purpose

Pursuant to the Optimum Basin Management Program (OBMP) Implementation Plan and the Peace Agreement, the Chino Basin Watermaster (Watermaster) implements a Subsidence Management Plan (SMP) for the Chino Basin to minimize or abate the occurrence of land subsidence and ground fissuring. 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.[1]

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

This memorandum describes the Watermaster Engineer's recommended activities for the GLMP for FY 2019/20 in the form of a proposed scope-of-work and budget.

Members of the GLMC are asked to:

1. Review this memorandum prior to February 28, 2019.
2. Attend a meeting of the GLMC at 9am on February 28, 2019 at Watermaster to discuss the proposed scope-of-work and budget for FY 2019/20.
3. Submit comments and suggested revisions on the proposed scope-of-work and budget for FY 2019/20 to the Watermaster by March 15, 2019.
4. Attend a meeting of the GLMC at 9am on March 28, 2019 at Watermaster to discuss comments and revisions to the proposed scope-of-work and budget for FY 2019/20 (if needed).

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[1] The Court approved the SMP and ordered its implementation in November 2007. The SMP was updated in 2015, and can be downloaded or viewed at this link.

The final scope-of-work and budget that is recommended by the GLMC will be included in the Watermaster's FY 2019/20 budget. The final scope-of-work, budget, and schedule for FY 2019/20 will be included in Section 4 of the *2018/19 Annual Report of the Ground-Level Monitoring Committee*.

Recommended Scope of Work and Budget – FY 2019/20

A proposed scope-of-work for the GLMP for FY 2019/20 is shown in Table 1 as a line-item cost estimate. The proposed scope-of-work is summarized below:

Task 1—Setup and Maintenance of the Monitoring Network

The extensometers are the 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 CCX Extensometer Site.

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 FY 2019/20, this task includes collection and checking of data from the newly-installed Pomona Extensometer facility.

Task 2.2—Conduct Long-Term Pumping Test in the Managed Area. This sub-task involves the work to implement the Long-Term Pumping Test in the Managed Area to test the appropriateness of the current Guidance Level. The work includes: (i) coordination with the City of Chino Hills on the start and duration of the pumping test; (ii) downloading and checking data from the Ayala Park Extensometer and uploading the data to the database; (iii) preparing stress-strain diagrams of the PA-7 piezometer and deep extensometer data and distributing the diagrams to the GLMC; and (iv) terminating the test once the stress-strain diagrams indicate the first occurrence of permanent compaction. The results of the test will be documented in a subsequent Annual Report of the GLMC.

This sub-task will not be implemented in FY 2019/20 due to water quality issues reported by the City of Chino Hills at well CH-17 (M. Wiley, personal communication, January 20, 2019).

Task 2.3—Conduct Pilot Injection Test in the Managed Area. This sub-task involves the work to implement a Pilot Injection Test in the Managed Area at City of Chino Hills well CH-16 to test the effectiveness of injection as a tool to manage hydraulic head and land subsidence in the Managed Area. The work involved in this task includes coordinating the injection test with the City of Chino Hills and collecting and compiling the injection/production data at CH-16 (e.g. timing of injection, injection rates, water levels at CH-16, etc.). The results of the test will be documented in a subsequent Annual Report of the GLMC.

This sub-task will be implemented only if the City of Chino Hills indicates that it wants to proceed with the test in FY 2019/20.

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 that occurred across the western portion of Chino Basin from March 2019 to March 2020.

Task 3.1—Acquire SAR Data from German Aerospace Center and Prepare Interferograms for 2019/20. In this sub-task, six SAR scenes that will be acquired by the TerraSAR-X satellite from March 2019 to March 2020 are purchased from the German Aerospace Center. Neva Ridge Technologies of Boulder, CO uses the SAR scenes to prepare 12 interferograms that describe the incremental and cumulative vertical ground motion that occurred from March 2019 to March 2020 and since 2011.

Task 3.2—Convert Interferograms to GIS Rasters and Check Results. In this sub-task, the Watermaster Engineer converts the interferograms into GIS rasters of vertical ground motion across western Chino Basin and performs checks for reasonableness and accuracy.

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. Electronic distance measurements (EDM surveys) are performed between benchmark monuments to estimate horizontal ground motion in areas where ground fissuring due to differential land subsidence is a concern. The surveys for consideration in FY 2019/20 include:

Task 4.1—Conduct Spring-2020 Elevation and EDM surveys in the Northwest MZ-1 Area. In this subtask, the surveyor conducts elevation and EDM surveys at the established benchmarks in Northwest MZ-1 in early 2020. The elevation survey begins at the new Pomona Extensometer Facility and includes benchmarks across Northwest MZ-1 shown on Figure 1. The elevation survey will be referenced to a newly-established elevation datum at the Pomona Extensometer. The EDM survey is performed across the San Jose Array of benchmark monuments shown on Figure 1.

These surveys are recommended in FY 2019/20 because of the ongoing subsidence that is occurring in Northwest MZ-1 and will support the development of a subsidence management plan in Northwest MZ-1.

Task 4.2—Conduct Spring-2020 Elevation Survey in the Northeast Area. In this subtask, the surveyor conducts an elevation survey at the established benchmarks in the Northeast Area in early 2020. The elevation survey will begin at the new Pomona Extensometer Facility and includes benchmarks across the Northeast Area shown on Figure 1.

This survey is recommended in FY 2019/20 budget because InSAR indicates ongoing subsidence is occurring in the Northeast Area; Spring-2018 was the initial elevation survey of newly-installed benchmarks in this area; and InSAR is largely incoherent south of the Ontario Airport.

Task 4.3—Conduct Spring-2020 Elevation in the Southeast Area. In this subtask, the surveyor conducts an elevation survey at the established benchmarks in the Southeast Area in early 2019. The elevation survey begins at the Ayala Park Extensometer and includes benchmarks across the Southeast Area shown on Figure 1. The elevation survey data is referenced to the Ayala Park elevation datum.

This survey is not recommended for FY 2019/20 because over the past several years hydraulic heads have been relatively stable in this area; recent ground motion as measured by InSAR, ground-level surveys, and the Chino Creek Extensometer has been minor in this area; hydraulic heads are not projected to significantly decline in this area over the next year.

Task 4.4—Install Closely-Spaced Benchmarks along Edison and Eucalyptus (for Long-Term Pumping Test). In this sub-task, closely-spaced benchmarks are installed by the surveyor across the historic fissure zone in the Managed Area along Edison and Eucalyptus Avenues to facilitate future the EDM surveys. This task was a recommendation in the 2016 Annual Report of the GLMC, if the Long-Term Pumping Test is conducted to test the Guidance Level.

This task is not recommended in FY 2019/20 unless the Long-Term Pumping Test is planned for execution in the near future.

Task 4.5—Conduct Spring-2020 Elevation and EDM Surveys in the Managed Area. In this sub-task, the surveyor conducts elevation and EDM surveys at the established benchmarks in the Managed Area and Fissure Zone Area in early 2020. The elevation survey begins at the Ayala Park Extensometer and includes benchmarks across the Managed Area shown on Figure 1. The elevation survey is referenced to the Ayala Park elevation datum. The EDM surveys are performed between closely-spaced benchmarks located across the historic fissure zone along Chino, Schaefer, Edison, and Eucalyptus Avenues.

This survey is not recommended for FY 2019/20 because over the past several years hydraulic heads have been relatively stable in this area; recent ground motion as measured by InSAR, ground-level surveys, and the Ayala Park Extensometer has been minor in this area.

Task 4.6—Establish the Pomona Extensometer Datum. The Pomona Extensometer is expected to be completed and operational by the end of FY 2018/19. In this subtask, the surveyor will install a new benchmark monument at the Pomona Extensometer in Summer-2019 (after the Pomona Extensometer is operational) and establish an initial elevation for the monument that is tied to the Ayala Park elevation datum. This task is necessary so that future elevation surveys that start at the Pomona Extensometer are consistent with elevation surveys that begin at the Ayala Park Extensometer.

Task 4.7—Replace Destroyed Benchmarks (if needed). In this sub-task, the surveyor replaces benchmark monuments that have been destroyed since the last survey, if any.

Task 4.8—Process, Check, and Update Database. In this sub-task, 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 4.9—New Surveyor Support. Guida Surveying, Inc. is replacing the long-time surveyor for the GLMP (Jim Elliott of WSP USA) in Spring-2019. In this sub-task, Jim Elliott is retained through FY 2019/20 to continue to assist Guida Surveying with locating all the existing benchmarks and ensuring the surveying methods, protocols for data processing, and the data deliverables are consistent with previous ground-level surveys.

Task 5—Data Analysis and Reporting

Task 5.1—Prepare Draft 2018/19 Annual Report of the Ground-Level Monitoring Committee. Prepare the text, tables, and figures for a draft *2018/19 Annual Report of the GLMC* and submit the report to the GLMC by September 20, 2019 for review and comment.

Task 5.2—Prepare Final 2018/19 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 *2018/19 Annual Report of the GLMC* by October 31, 2019. 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 2019 Watermaster meetings for approval.

Task 5.3—Compile and Analyze Data from the 2019/20 Ground-Level Monitoring Program. In this task, monitoring data generated from the GLMP during 2019/20 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 2020 during the development of a recommended scope and budget for FY 2020/21.

Task 6—Develop a Subsidence-Management Plan for the Northwest MZ-1 Area

The development of the subsidence management plan for the Northwest MZ-1 Area is a multi-year effort. The conceptual framework for this effort is described in the *Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area*.[2] Several tasks outlined in the Work Plan are recommended for implementation in FY 2019/20:

Task 6.1—Conduct One-Year of Passive Monitoring and Prepare Recommendations for Controlled Aquifer-System Stress Test(s). The monitoring of water levels and production at wells in Northwest MZ-1 will continue through various techniques, including: (i) SCADA-based monitoring by Monte Vista Water District; (ii) monitoring of water levels via sonar[3]; (iii) monitoring of water levels via pressure transducers; and (iv) manual measurements of water levels. It is anticipated that the Pomona Extensometer will be collecting water-level and aquifer-system-deformation data by the end of FY 2018/19. This subtask includes one-year of passive monitoring of water levels from existing wells in Northwest MZ-1 and water-level and aquifer-system-deformation data from the Pomona Extensometer Facility. Analysis of these data will improve the understanding of the hydrogeology in Northwest MZ-1 and provide the basis for designing controlled aquifer-system stress tests in FY 2020/21, if deemed necessary by the GLMC.

Task 7—Meetings and Administration

Task 7.1—Prepare for and Conduct Four Meetings of the Ground-Level Monitoring Committee. This sub-task includes preparing for and conducting four meetings of the GLMC:

- July 25, 2019 – Implementation of the GLMP for FY 2019/20.
- September 26, 2019 – Review the draft *2018/19 Annual Report of the Ground-Level Monitoring Committee.*
- February 28, 2020 – Review the draft recommended scope and budget for FY 2020/21.
- March 28, 2020 – Review the final recommended scope and budget for FY 2020/21 (if needed).

Task 7.2—Prepare for and Conduct One As-Requested Ad-Hoc Meeting. This sub-task includes preparing for and conducting one ad-hoc meeting of the GLMC, as requested by the GLMC or Watermaster staff.

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[2] http://www.cbwm.org/docs/engdocs/Land%20Subsidence/20150724%20-%20Chino%20Basin%20Subsidence%20Management%20Plan%202015/FINAL_CBSMP_Appendix_B.pdf

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

Task 7.3—Perform Monthly Project Management. This sub-task includes monthly project administration and management, including staffing, financial and schedule reporting to Watermaster and sub-contractor coordination.

Task 7.4—Prepare a Recommended Scope and Budget for the GLMC for FY 2020/21. This sub-task includes preparing a draft and final recommended scope and budget for FY 2020/21 for the GLMC to support the Watermaster's budgeting process.

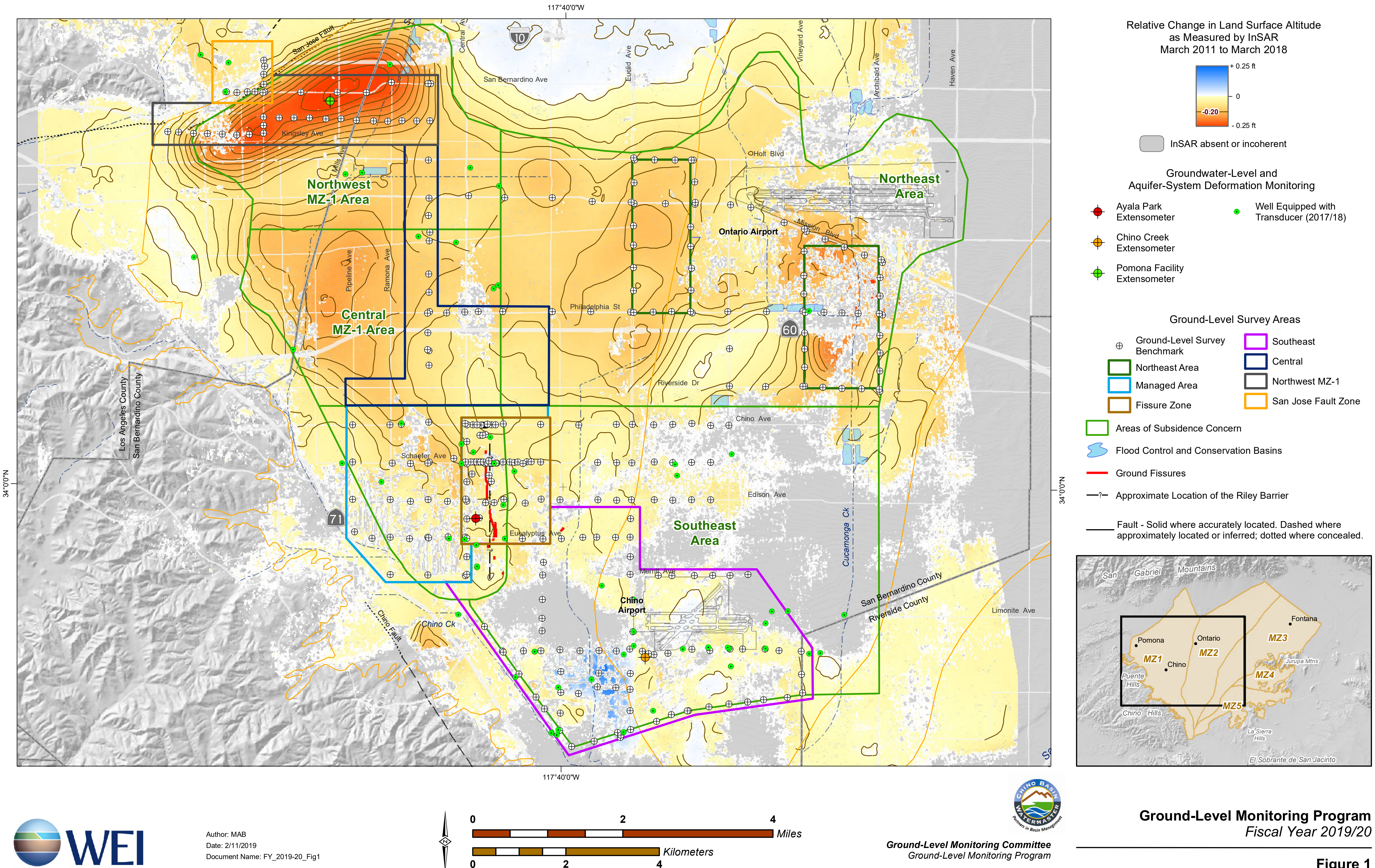
Encl.:

Table 1. Work Breakdown Structure and Cost Estimates – Ground-Level Monitoring Program: FY 2019/20

Figure 1. Ground-Level Monitoring Program – Fiscal Year 2019/20

Table 1
Work Breakdown Structure and Cost Estimates
Ground-Level Monitoring Program: FY 2019/20

Task Description	Labor		Other Direct Costs								Totals					
	Person Days	Total	Travel	New Equip.	Equip. Rental	Outside Pro	Lab	Repro	Misc.	Total	Totals by Task	Recommended Budget *FY 2019/20*	Approved Budget *FY 2018/19*	Net Change *FY 2018/19 to 2019/20*	Potential Carry-Over *FY 2019/20*	Budget with Carry-Over *FY 2019/20*
												a	*b*	*a - b*	*c*	*a - c*
Task 1 -- Setup and Maintenance of the Monitoring Network		**$28,320**								**$8,537**	**$36,857**	**$36,857**	**$35,353**	**$1,504**	**$0**	**$36,857**
1.1 Maintain Extensometer Facilities																
Routine maintenance of Ayala Park, Chino Creek, and Pomona extensometer facilities	16	$22,272	$1,139	$250	$152					$1,541	$23,813	$23,813	$22,661	$1,152	$0	$23,813
Replacement/repair of equipment at extensometer facilities	4	$6,048	$362	$3,000	$38	$2,000				$5,400	$11,448	$11,448	$11,096	$352	$0	$11,448
1.2 Annual Lease Fees for CCX Extensometer Site	0	$0							$1,596	$1,596	$1,596	$1,596	$1,596	$0	$0	$1,596
Task 2 -- MZ-1: Aquifer-System Monitoring and Testing		**$31,696**								**$2,990**	**$34,686**	**$34,686**	**$33,150**	**$1,536**	**$0**	**$34,686**
2.1 Conduct Quarterly Data Collection from Extensometers; Data Checking and Management																
Download data from the Ayala Park Extensometer facility	2	$2,544	$275		$76					$351	$2,895	$2,895	$2,783	$112	$0	$2,895
Download data from the Chino Creek Extensometer facility	2	$2,544	$42		$76					$118	$2,662	$2,662	$2,550	$112	$0	$2,662
Download data from Pomona Extensometer facility	4	$5,088	$269		$76					$345	$5,433	$5,433	$5,209	$224	$0	$5,433
Process, check, and upload data to database	11	$15,712								$0	$15,712	$15,712	$14,944	$768	$0	$15,712
2.2 Conduct Long-Term Pumping Test in the Managed Area																
Coordinate testing with pumpers	0	$0								$0	$0	$0	$0	$0	$0	$0
Equip CH-15B and CH-17 with high-frequency water-level monitoring devices	0	$0	$0	$0	$0					$0	$0	$0	$0	$0	$0	$0
Collect data; process, check, and upload to database	0	$0								$0	$0	$0	$0	$0	$0	$0
Prepare, analyze, and distribute stress-strain diagrams to GLMC; terminate test	0	$0								$0	$0	$0	$0	$0	$0	$0
Adjust extensometer hardware, as necessary	0	$0	$0							$0	$0	$0	$0	$0	$0	$0
2.3 Conduct Pilot Injection Test in the Managed Area																
Coordinate testing with pumpers	1	$1,512								$0	$1,512	$1,512	$1,424	$88	$0	$1,512
Equip CH-15B and CH-17 with high-frequency water-level monitoring devices	3	$4,296	$138	$2,000	$38					$2,176	$6,472	$6,472	$6,240	$232	$0	$6,472
Task 3 -- Basin Wide Ground-Level Monitoring Program (InSAR)		**$5,362**								**$85,000**	**$90,362**	**$90,362**	**$90,064**	**$298**	**$0**	**$90,362**
3.1 Acquire SAR Data from German Aerospace Center and Prepare Interferograms for 2019/20	1	$1,752				$85,000				$85,000	$86,752	$86,752	$86,632	$120	$0	$86,752
3.2 Convert Interferograms to GIS Raster Surfaces and Check Results	2.5	$3,610								$0	$3,610	$3,610	$3,432	$178	$0	$3,610
Task 4 -- Perform Ground-Level Surveys		**$7,828**								**$209,030**	**$216,858**	**$124,878**	**$84,046**	**$40,832**	**$0**	**$124,878**
4.1 Conduct Spring-2020 Elevation and EDM surveys in the Northwest MZ-1 Area	0.5	$876				$28,600				$28,600	$29,476	$29,476	$23,816	$5,660	$0	$29,476
4.2 Conduct Spring-2020 Elevation Survey in the Northeast Area	0.5	$876				$37,180				$37,180	$38,056	$38,056	$33,316	$4,740	$0	$38,056
4.3 Conduct Spring-2020 Elevation Survey in the Southeast Area	0	$0				$37,180				$37,180	$37,180	$0	$0	$0	$0	$0
4.4 Install Closely-Spaced Benchmarks along Edison and Eucalyptus (for Long-Term Pumping Test)	0	$0				$12,300				$12,300	$12,300	$0	$0	$0	$0	$0
4.5 Conduct Spring 2020-Elevation and EDM Surveys in the Managed Area/Fissure Zone Area	0	$0				$42,500				$42,500	$42,500	$0	$0	$0	$0	$0
4.6 Conduct Summer-2019 Survey to Establish PX Datum and Connect to Existing Survey Network	0	$0				$31,570				$31,570	$31,570	$31,570	$0	$31,570	$0	$31,570
4.7 Replace Destroyed Benchmarks (if needed)	0	$0				$9,700				$9,700	$9,700	$9,700	$6,000	$3,700	$0	$9,700
4.8 Process, Check, and Update Database	4.25	$6,076								$0	$6,076	$6,076	$5,768	$308	$0	$6,076
4.9 New Surveyor Support	0	$0				$10,000				$10,000	$10,000	$10,000	$15,146	-$5,146	$0	$10,000
Task 5 -- Data Analysis and Reporting		**$63,842**								**$0**	**$63,842**	**$63,842**	**$70,476**	**-$6,634**	**$0**	**$63,842**
5.1 Prepare Draft 2018/19 Annual Report of the Ground-Level Monitoring Committee	23	$35,312								$0	$35,312	$35,312	$33,384	$1,928	$0	$35,312
5.2 Prepare Final 2018/19 Annual Report of the Ground-Level Monitoring Committee	5.5	$8,584								$0	$8,584	$8,584	$8,148	$436	$0	$8,584
5.3 Compile and Analyze Data from the 2019/20 Ground-Level Monitoring Program																
Production/recharge/piezometric/extensometer	4	$5,568								$0	$5,568	$5,568	$15,280	-$9,712	$0	$5,568
Ground-level survey and Northwest MZ-1 Area EDM data	4	$5,948								$0	$5,948	$5,948	$5,648	$300	$0	$5,948
InSAR data	4	$5,568								$0	$5,568	$5,568	$5,280	$288	$0	$5,568
Tectonic data	0.25	$318								$0	$318	$318	$304	$14	$0	$318
Recycled water reuse data	2	$2,544								$0	$2,544	$2,544	$2,432	$112	$0	$2,544
Task 6 -- Develop a Subsidence-Management Plan for the Northwest MZ-1 Area		**$0**								**$7,500**	**$7,500**	**$7,500**	**$36,406**	**-$28,906**	**$0**	**$7,500**
6.1 Conduct One-Year Passive Monitoring and Prepare Recommendations for Controlled Pumping Test(s)	0	$0	$0		$0	$7,500				$7,500	$7,500	$7,500	$35,220	-$27,720	$0	$7,500
6.2 Install the Pomona Extensometer Facility	0	$0	$0			$0				$0	$0	$0	$0	$0	$0	$0
6.3 Install and Test Monitoring Equipment at the Pomona Extensometer	0	$0	$0	$0		$0				$0	$0	$0	$820	-$820	$0	$0
6.4 Prepare Completion Report for the Pomona Extensometer Facility	0	$0						$0		$0	$0	$0	$366	-$366	$0	$0
Task 7 -- Meetings and Administration		**$46,776**								**$418**	**$47,194**	**$47,194**	**$44,434**	**$2,760**	**$0**	**$47,194**
7.1 Prepare for and Conduct Four Meetings of the Ground-Level Monitoring Committee	12	$22,144	$334							$334	$22,478	$22,478	$21,198	$1,280	$0	$22,478
7.2 Prepare for and Conduct One As-Requested Ad-Hoc Meeting	3	$5,536	$84							$84	$5,620	$5,620	$5,300	$320	$0	$5,620
7.3 Perform Monthly Project Management	7.5	$13,560								$0	$13,560	$13,560	$12,720	$840	$0	$13,560
7.4 Prepare a Recommended Scope and Budget for the GLMC for FY 2020/21	3	$5,536								$0	$5,536	$5,536	$5,216	$320	$0	$5,536
Totals												**$405,318**	**$393,928**	**$11,390**	**$0**	**$405,318**



WEI Wildermuth Environmental, Inc.

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Ground-Level Monitoring Committee
Ground-Level Monitoring Program

Ground-Level Monitoring Program
Fiscal Year 2019/20

Figure 1

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