2016 Annual Report of the Ground-Level Monitoring Committee

Final Report
September 2017

Prepared for:

Prepared by:

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Acronyms, Abbreviations, and Initialisms

CCX	Chino Creek Extensometer Facility
DHX	Daniels Horizontal Extensometer
EDM	Electronic Distance Measurement
ft-btoc	feet below top of casing
GLMC	Ground-Level Monitoring Committee
GLMP	Ground-Level Monitoring Program
IMP	Interim Monitoring Program
InSAR	Interferometric Synthetic Aperture Radar
MZ-1	Chino Basin OBMP Management Zone 1
OBMP	Optimum Basin Management Plan
SMP	Chino Basin Subsidence Management Plan
USGS	United States Geological Survey

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 alone, over 17,000 square miles in 45 states have experienced land subsidence (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 all documented cases of land subsidence in the United States have been caused by groundwater extractions from the underlying aquifer system (USGS, 1999).

For purposes of clarification in this document, subsidence refers to permanent (non-recoverable) sinking of the land surface. The term inelastic (i.e. non-recoverable) typically refers to permanent 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.

1.1.1 Subsidence and Fissuring in Chino Basin

One of the earliest indications of land subsidence in the Chino Basin was the appearance of ground fissures within Management Zone 1 (MZ-1) in 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 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 Plan (OBMP) Phase I Report (WEI, 1999) 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 MZ-1. Program Element 4 of the OBMP, *Develop and Implement a Comprehensive Groundwater Management Plan for Management Zone 1*, called for the development and implementation of an interim management plan for MZ-1 that would:

- Minimize subsidence and fissuring in the short-term.
- Collect the information necessary to understand the extent, rate, and mechanisms of subsidence and fissuring.
- Formulate a management plan to 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 (second and third bullets above). This investigation was titled the *MZ-1 Interim Monitoring Program* (IMP; WEI, 2003) and is described below.

The OBMP Phase I Report also noted 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 a basin-wide analysis of land subsidence via ground-level surveys and remote-sensing (specifically, interferometric synthetic aperture radar or InSAR) and for ongoing monitoring 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 (now called the Ground-Level Monitoring Committee or GLMC). 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; the Golden State Water Company; and the State of California, California Institution for Men.

The IMP consisted of three main monitoring elements: ground-level surveys, InSAR, and aquifer-system monitoring. The ground-level surveys and InSAR analyses were used to monitor deformation of the ground surface. Aquifer-system monitoring measured the hydraulic and mechanical changes within the aquifer system that cause ground-surface deformation. Groundwater-production and groundwater-level data were collected from wells surrounding the areas of observed subsidence and ground fissuring.

The monitoring program was implemented in two phases: a Reconnaissance Phase and a Comprehensive Phase. The Reconnaissance Phase consisted of constructing multi-depth piezometers (11 piezometers screened at various depths) at Rubin S. Ayala Park (Ayala Park) in Chino and installing pressure transducers in nearby production wells and monitoring wells to measure piezometric levels. Following the installation of the monitoring network, several months of aquifer-system monitoring and testing were conducted. Testing included aquifer-system stress tests conducted at production wells in the area.

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

During implementation of the IMP, Watermaster's Engineer made the data available to the MZ-1 Technical Committee and prepared quarterly progress reports for submission to 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 a summary of the content of any Technical Committee meetings.

The main conclusions derived from the IMP were:

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

- 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 piezometric-level decline that is much greater in magnitude and lateral extent than the piezometric-level decline caused by pumping the shallow aquifer system.
- Piezometric-level decline due to pumping of 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 piezometric levels in the deep aquifer system fell below a depth of about 250 feet in Watermaster's PA-7 piezometer at Ayala Park.
- 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 feet of land subsidence occurred from about 1987 to 1995 and was accompanied by ground fissuring. Figure 1-1 shows the land subsidence 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, and its location is shown on Figures1-1. The barrier was named the "Riley Barrier" after Francis S. Riley, the 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 piezometric level 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 the central region of MZ-1 had occurred in the past and was continuing to occur. InSAR also suggested that the groundwater barrier extends northward into the central MZ-1 as shown on 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 the central MZ-1; however, there was not enough historical piezometric data in this area to confirm this relationship. The IMP recommended that, if subsidence continued or increased, the mechanisms causing the land subsidence should be studied in more detail.

The methods, results, and conclusions of the IMP were described in detail in the *MZ-1 Summary Report* (WEI, 2006). The IMP provided enough information for Watermaster to develop Guidance Criteria for MZ-1 producers in the investigation area that, if followed, would minimize the potential for subsidence and fissuring during the completion of the *MZ-1 Subsidence Management Plan* (MZ-1 Plan; WEI, 2007).

The Guidance Criteria were:

1. A list of existing wells shown on Table 1-1 with screens completed into the deep aquifer system (hereafter the Managed Wells) and their owners (hereafter the Parties) that are the subject of these Guidance Criteria.
2. A defined spatial area that is shown on Figure 1-1 and 1-2 where the Guidance Criteria applies (hereafter the Managed Area). Within the boundaries of the Managed Area, both existing and newly constructed wells are subject to being classified as Managed Wells. This area was based on the observed and/or predicted effects of pumping on piezometric levels and aquifer-system deformation. Initial Managed Well designations for wells that pumped during the IMP were based on effects measured at the Ayala Park Extensometer. Future Managed Well designations were to be based on analyses of well construction and borehole lithology.
3. The Guidance Level was a specified depth to water measured in Watermaster's PA-7 piezometer at Ayala Park. It was defined as the threshold piezometric level at the onset of inelastic compaction of the aquifer system as recorded by the extensometer minus 5 feet. The 5-foot reduction was meant to be a safety factor to ensure that inelastic compaction does not occur. The Guidance Level is to be established by Watermaster based on the periodic review of monitoring data collected by Watermaster. The initial Guidance Level was established as 245 feet below the top of the PA-7 well casing.
4. If the piezometric level in PA-7 falls below the Guidance Level, Watermaster recommends that the Parties curtail their pumping from designated Managed Wells as required to maintain the piezometric level in PA-7 above the Guidance Level.
5. Watermaster was to provide the Parties with real-time piezometric level data from PA-7.
6. The 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 Parties were requested to promptly notify Watermaster of all operational changes made to maintain the piezometric level in PA-7 above the Guidance Level.
7. Watermaster recommends that the Parties allow Watermaster to continue monitoring piezometric levels at their wells.
8. 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. These changes to the Guidance Criteria could include: (1) additions or deletions to the list of Managed Wells, (2) re-delineation of the Managed Area, (3) raising or lowering of the Guidance Level, or (4) additions and/or deletions to the Guidance Criteria, including the need to have periods of piezometric level recovery.
9. 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 Plan, which was developed by the MZ-1 Technical Committee and approved by 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 Parties manage their groundwater production such that the piezometric level in PA-7 remains above the Guidance Level.

The MZ-1 Plan called for ongoing monitoring, data analysis, annual reporting, and adjustments to the MZ-1 Plan, as warranted by the data. Implementation of the MZ-1 Plan began in 2008. The MZ-1 Plan called for the continued scope and frequency of monitoring implemented during the IMP within the Managed Area and expanded monitoring of the aquifer system and land subsidence in other areas of the Chino Basin where the IMP indicated concern for future subsidence and ground fissuring. Figure 1-1 shows the location of these so-called Areas of Subsidence Concern: Central MZ-1, Northwest MZ-1, Northeast, 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 those Parties affected by the MZ-1 Plan. The 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 will 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 efforts and obligations about land subsidence that included areas outside of MZ-1. As such, the update included a name change to the 2015 Chino Basin Subsidence Management Plan (SMP; WEI 2015a) and a recommendation to develop a subsidence management plan for the Northwest MZ-1 Area. 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 in Northwest MZ-1 across the San Jose Fault 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

[2] In July 2000, the Parties to the Judgement signed the Peace Agreement. The Peace Agreement outlined the Parties' intent to implement the OBMP as well as other related responsibilities for Watermaster and the Parties.

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 past State of the Basin Reports (WEI, 2013) and annual reports of the GLMC. Watermaster increased monitoring efforts in Northwest MZ-1 beginning in winter 2012-2013 to include elevation surveys and electronic distance measurements (EDMs) to monitor the 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, cost estimate, and a schedule. The Work Plan was included in the SMP as Appendix B. Implementation of the Work Plan began in July 2015.

The updated SMP also addressed the need for piezometric-level "recovery periods" in the Managed Area by recommending that all deep aquifer-system pumping cease for a continuous 3-month period between October 1 and March 31 of each year within the Managed Area. 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. These cessations of pumping are 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.

1.1.6 Annual Report of the Ground-Level Monitoring Committee

The SMP states that Watermaster will produce an annual report, containing the results of ongoing monitoring efforts, interpretations of the data, and recommended adjustments to the SMP, if any. This annual report of the GLMC includes results and interpretations for the data collected through calendar year 2016 as well as recommendations for Watermaster's GLMP for FY 2017-18.

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 SMP, which calls for annual reporting.

Section 2 – Ground-Level Monitoring Program (2016). This section describes the monitoring and testing activities that were performed by Watermaster for its GLMP during 2016.

Section 3 – Results and Interpretations. This section discusses and interprets the monitoring data collected through 2016, including basin stresses (i.e. groundwater pumping and recharge) and responses, which include changes in piezometric levels, aquifer-system deformation, and ground motion.

Section 4 – Conclusions and Recommendations. This section summarizes the main conclusions derived from the monitoring program as of December 2016 and describes recommended activities for the GLMP during fiscal year 2017-18 in the form of a proposed scope-of-work, schedule, and budget.

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 cited in this report.

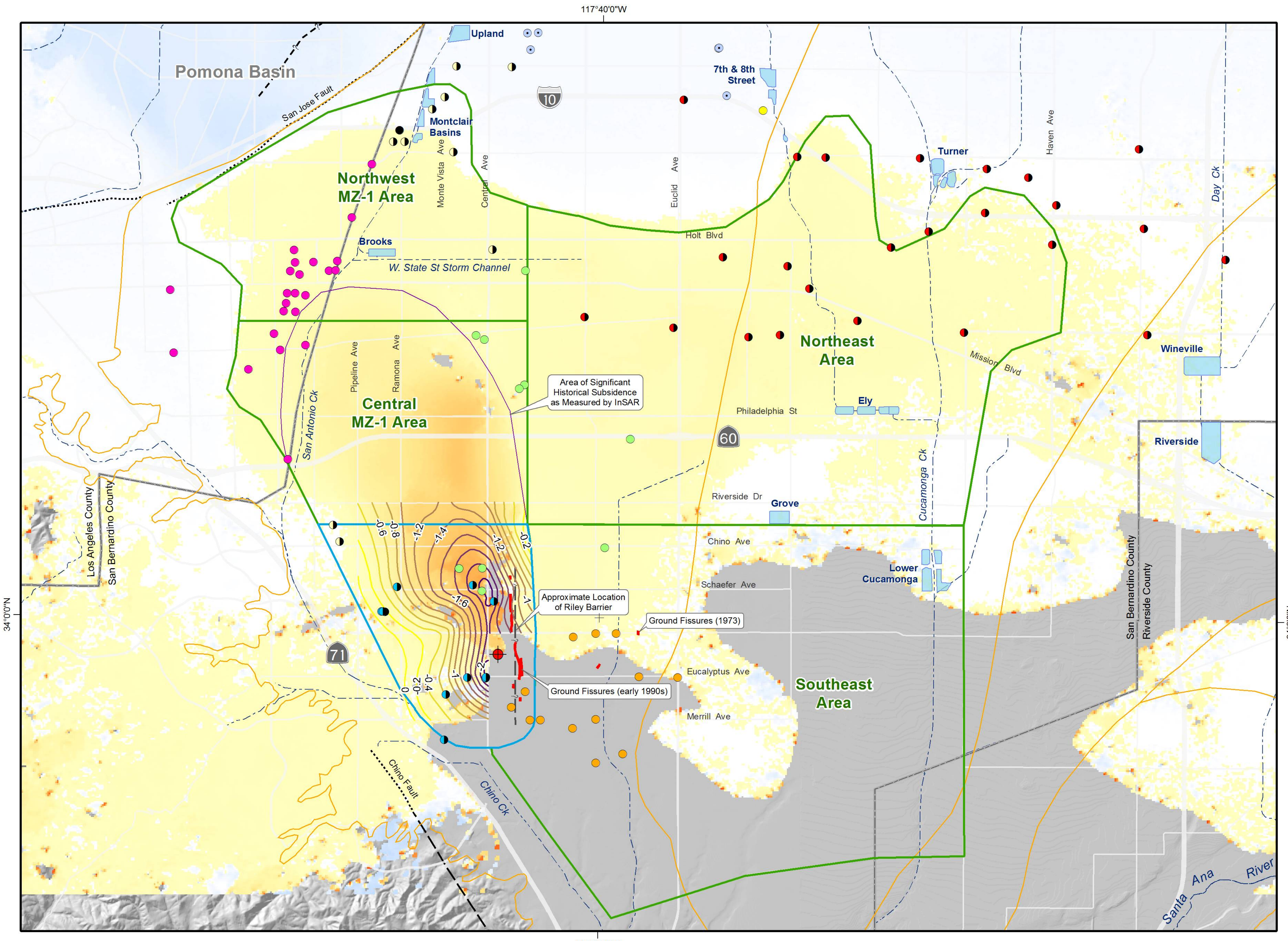
Table 1-1
Managed Wells Screened in the Deep Aquifer and Subject to the Guidance Criteria*

Well Name	CBWM ID	Owner	2016 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	City of Chino	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	City of Chino Hills	Abandoned	550-950
CH-7D	600498	City of Chino Hills	Destroyed	320-400; 410-450; 490-810; 850-930
CH-15B	600488	City of Chino Hills	Inactive	360-440; 480-900
CH-16	600489	City of Chino Hills	Inactive	430-940
CH-17	600499	City of Chino Hills	Active	300-460; 500-680
CH-19	600500	City of Chino Hills	Abandoned	300-460; 460-760; 800-1,000

*The The MZ-1 Subsidence Management Plan identified the Managed Wells that are the subject of 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 470.5 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



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

0.0 ft

-2.2 ft

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

+ 1 ft

0

- 1 ft

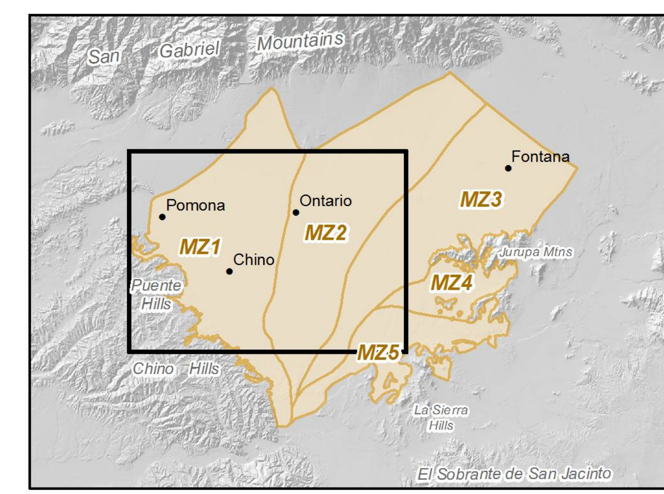
InSAR absent or incoherent

- Ayala Park Extensometer
- Managed Area
- Areas of Subsidence Concern
- Flood Control and Conservation Basins

Active Production Wells by Owner - 1987 to 1999

- City of Chino
- City of Chino Hills
- City of Ontario
- City of Pomona
- City of Upland
- Golden State Water Company
- Monte Vista Water District
- San Antonio Water Company
- California Institution for Men

- Fault (solid where accurately located; dashed where approximately located or inferred; dotted where concealed)
- Ground Fissures
- Approximate Location of the Riley Barrier



Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: AEM
Date: 7/17/2017
Document Name: Figure1_1_20170613

0 1 2 3 Miles

0 1 2 3 Kilometers

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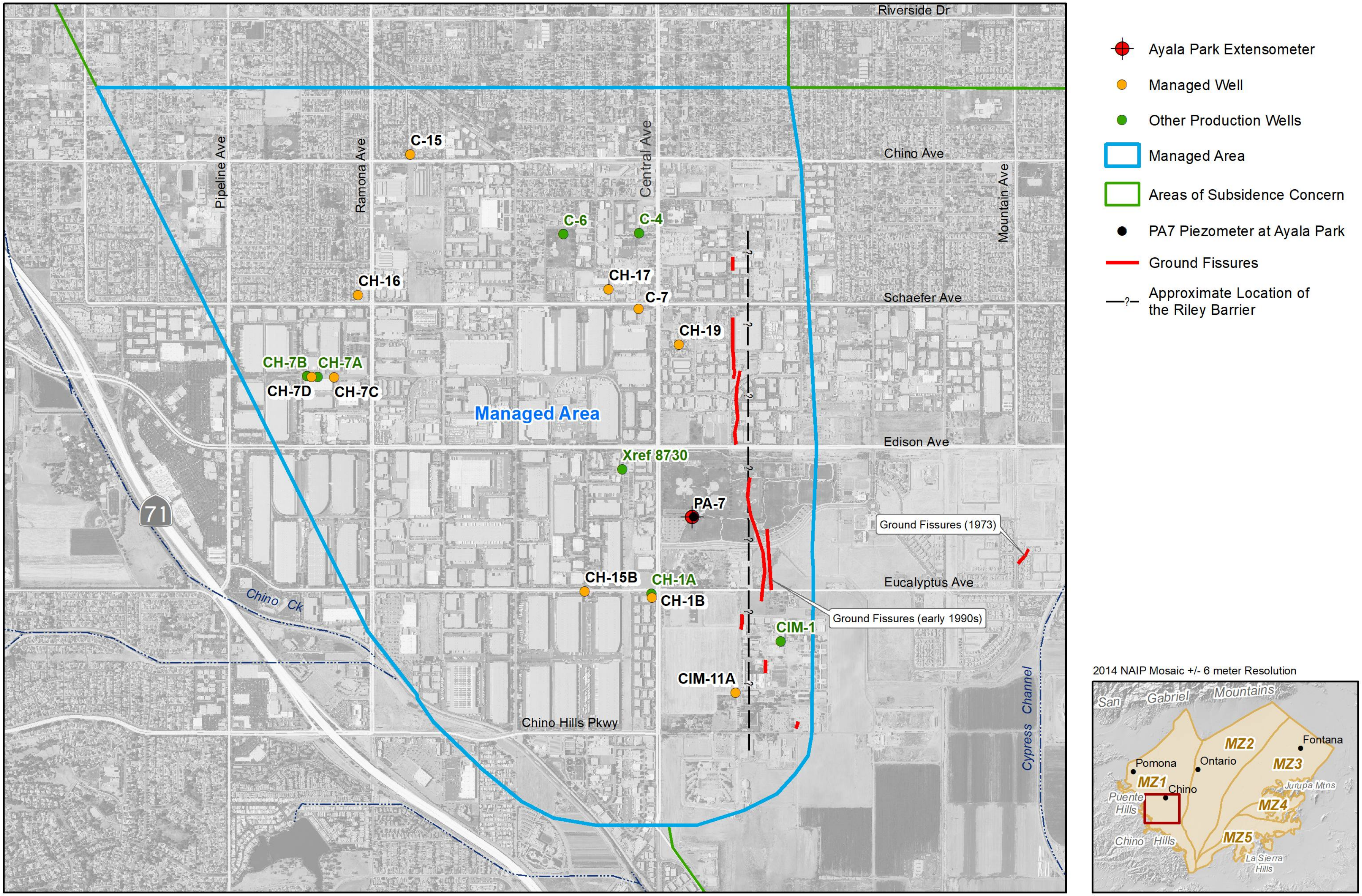
Historical Land Surface Deformation in Management Zone 1
1987-1999

Figure 1-1



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Author: AEM
Date: 7/18/2017
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MZ1 Managed Area and the Managed Wells

Figure 1-2

Section 2 – 2016 Ground-Level Monitoring Program

This section describes the activities performed by Watermaster for the GLMP during calendar year 2016.

Figures 2-1 and 2-2 are reference figures for this section. Figure 2-1 shows the groundwater production 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 transducers that measure piezometric levels, extensometers that measure vertical aquifer-system deformation, and benchmark monuments that are used to perform 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 SMP and the recommendations of the GLMC.

The GLMP activities performed in 2016 are described below.

2.1.1 Setup and Maintenance of the Monitoring Facilities Network

- Performed routine maintenance at the Ayala Park and Chino Creek Extensometers. Additional maintenance activities included:
    - Trouble-shooting the internet connection at the Ayala Park Extensometer to maintain electronic data delivery to the Watermaster's Ayala Park website.[3]
    - Installing additional counter-weights at the Chino Creek Extensometer to increase tension on the extensometer cables. The objective here was to reduce friction between the cables and the well casings to provide higher resolution and higher accuracy for the measured data.
    - Updating the software for the Chino Creek Extensometer telemetry modem to comply with a security advisory issued by the manufacturer and cellular service provider.
- Decommissioned and completely removed the Daniel's Horizontal Extensometer Facility (DHX) formerly located at 5500 Daniels St., Chino, CA in April 2016. Removal was necessary because the property is being developed.
- Installed pressure transducers in two wells owned by the Golden State Water Company. The wells are located within Northwest MZ-1.
- Coordinated and worked with staff from the Monte Vista Water District, City of Pomona, and SCADA Integrations to identify a set of wells and the costs associated

[3] http://ayala.wildermuthenvironmental.com:8888/AyalaPark/default.aspx

with equipping the wells with Supervisory Control and Data Acquisition (SCADA) monitoring capabilities. The SCADA-collected production and piezometric-level data will be incorporated into the monitoring program.

2.1.2 Monitoring Activities during 2016

Changes in piezometric levels are caused by the stresses of groundwater pumping and recharge. Changes in piezometric levels 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 production, recharge, piezometric levels, aquifer-system deformation, and vertical and horizontal ground motion across the western portion of the Chino Basin.

The following were Watermaster's monitoring activities in 2016, as called for by the SMP and in accordance with the recommendations of the GLMC.

2.1.2.1 Monitoring of Production, Recharge, and Piezometric Levels

Watermaster collects and compiles groundwater production data on a quarterly time-step from well owners in the Managed Area and the Areas of Subsidence Concern. The locations of wells that produced groundwater during 2016 are shown in Figure 2-1.

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

During 2016, piezometric levels were measured and recorded once every 15 minutes using pressure transducers maintained by Watermaster at approximately 70 wells in the Managed Area and the Central MZ-1, Northwest MZ-1, and the Southeast areas. Figure 2-2 shows the locations of these wells. Piezometric levels at other wells in western Chino Basin are also measured by manual methods by Watermaster staff and the well owners, typically on a monthly time-step.

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 Extensometers 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 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.[4] Seven synthetic aperture radar scenes were collected between January 2016 and January

[4] 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.

2017. The scenes were used to create twelve interferograms[5] to estimate short-term and long-term vertical ground motion over the following periods:

January 2016 to March 2016	March 2016 to May 2016
January 2016 to May 2016	May 2016 to July 2016
January 2016 to July 2016	July 2016 to August 2016
January 2016 to August 2016	August 2016 to November 2016
January 2016 to November 2016	November 2016 to January 2017
January 2016 to January 2017	March 2011 to January 2017

For the traditional leveling surveys, Watermaster retained Parsons Brinkerhoff to conduct the surveys at selected benchmark monuments in the western part of the Chino Basin. Elevation surveys were conducted at benchmark monuments within the following areas (Figure 2-2):

Ground-Level Survey Area	Date of Most Recent Survey	Number of Benchmarks Surveyed
Managed Area*	Mar-2016	22
Southeast Area	Feb-2017	66
Central MZ-1 Area	Feb-2017	12
Northwest MZ-1 Area	Feb-2017	25

*The Managed Area was not surveyed in 2017 based on the GLMC scope and budget recommendations for FY 2016-17.

2.1.2.4 Monitoring of Horizontal Ground Motion

Watermaster measured horizontal ground motion between benchmark locations across areas that are susceptible to ground fissuring via EDMs. EDMs were performed between the benchmarks shown in Figure 2-2 within the following areas:

Ground-Level Survey Area	Date of Most Recent Survey	Number of Benchmarks Surveyed
Fissure Zone Area*	Mar-2016	66
San Jose Fault Zone Area	Feb-2017	10

*The Fissure Zone Area was not surveyed in 2017 based on GLMC scope and budget recommendations for FY 2016-17.

[5] 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 uplift/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."

2.2 Land-Subsidence Investigations

Watermaster performs land subsidence investigations pursuant to the SMP, the recommendations of the GLMC, and approval of scope-of-work and budget by the Watermaster Pools, Advisory Committee, and Board. 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 during 2016 that are called for by the SMP.

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 SMP. 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. Specific questions that the test is designed to answer are:

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 piezometric levels 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 piezometric level at PA-7 to fall below the Guidance Level and may cause a small amount of subsidence.[6] The test will

[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 than the >2 ft of subsidence that occurred from 1987

be closely monitored at the Ayala Park Extensometer and will be stopped at the first indication of inelastic compaction. Piezometric levels recorded at 15-minute intervals at PA-7 will be updated every three-hours on Watermaster's website. When the piezometric levels decline to within 20 feet of the Guidance Level, data from the Ayala Park Extensometer 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 CIM 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 piezometric levels.

3. Conduct two cycles of injections at CH-16 to see how injection accelerates the recovery of the regional piezometric levels that were lowered by pumping at CH-17 and CH-15B.[7] After the injection tests, allow for full recovery of piezometric levels 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 once every 15 minutes throughout the test.

5. Check stress-strain diagrams from the Ayala Park Extensometer 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.

During 2016, the following activities were performed related to the Long-Term Pumping Test:

- The City of Chino Hills connected CH-16 to a potable source-water pipeline to facilitate the injection phase of the Long-Term Pumping Test.

- The City of Chino Hills performed wellhead-treatment rehabilitation at CH-15B. No production occurred at CH-15B during 2016.

- The Long-Term Pumping Test was not completed. Groundwater was produced from CH-17 during November and December 2016. Production from CH-17 did not cause

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to 1995 when ground fissures opened in the City of Chino and is much less 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 (ASR) well and pilot testing well. Watermaster assisted the City of Chino Hills in applying for and acquiring a Local Groundwater Assistance (LGA) 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.

piezometric levels to decline below the Guidance Level at the PA-7 piezometer (245 ft-btoc). The maximum depth-to-groundwater at the PA-7 piezometer was about 108 ft-btoc before pumping ceased at CH-17 in December 2016.

2.2.2 Analysis of EDM Measurements Across Fissure Zone

The SMP 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.

In the Managed Area, there is a network of closely-spaced benchmark monuments along Eucalyptus, Edison, Schaefer, and Chino Avenues that are used to perform the EDM surveys. EDM surveys in the Managed Area have been performed periodically since 2003. In Northwest MZ-1, a similar network of benchmark monuments is installed along San Bernardino and San Antonio Avenues across the San Jose Fault. EDM surveys have been performed in the Northwest MZ-1 Area annually since 2014.

In 2016, the EDM datasets were analyzed and evaluated. The objectives of this exercise were to: (i) describe and document the monitoring equipment, field methods, and accuracies associated with EDMs; (ii) describe the horizontal strain that has occurred between benchmark monuments over time; (iii) identify potential locations, if any, for the re-installation of a horizontal extensometer; and (iv) provide information to support recommendations for future monitoring via EDMs.

2.2.3 Develop a Subsidence Management Plan for Northwest MZ-1

In 2015, Watermaster's Engineer developed the Work Plan, which includes a description of a multi-year effort with cost estimates and a schedule to develop a subsidence management plan for the Northwest MZ-1 Area. The Work Plan was included in the SMP as Appendix B. The background and objectives of the Work Plan are described in Section 1.1.5 herein.

Watermaster began implementation of the Work Plan in July 2015. The following work was completed during 2016:

Task 1 Describe Initial Hydrogeologic Conceptual Model and Monitoring and Testing Program – A draft report was prepared that summarizes the current state of knowledge of the hydrogeology of the Northwest MZ-1 Area, 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.

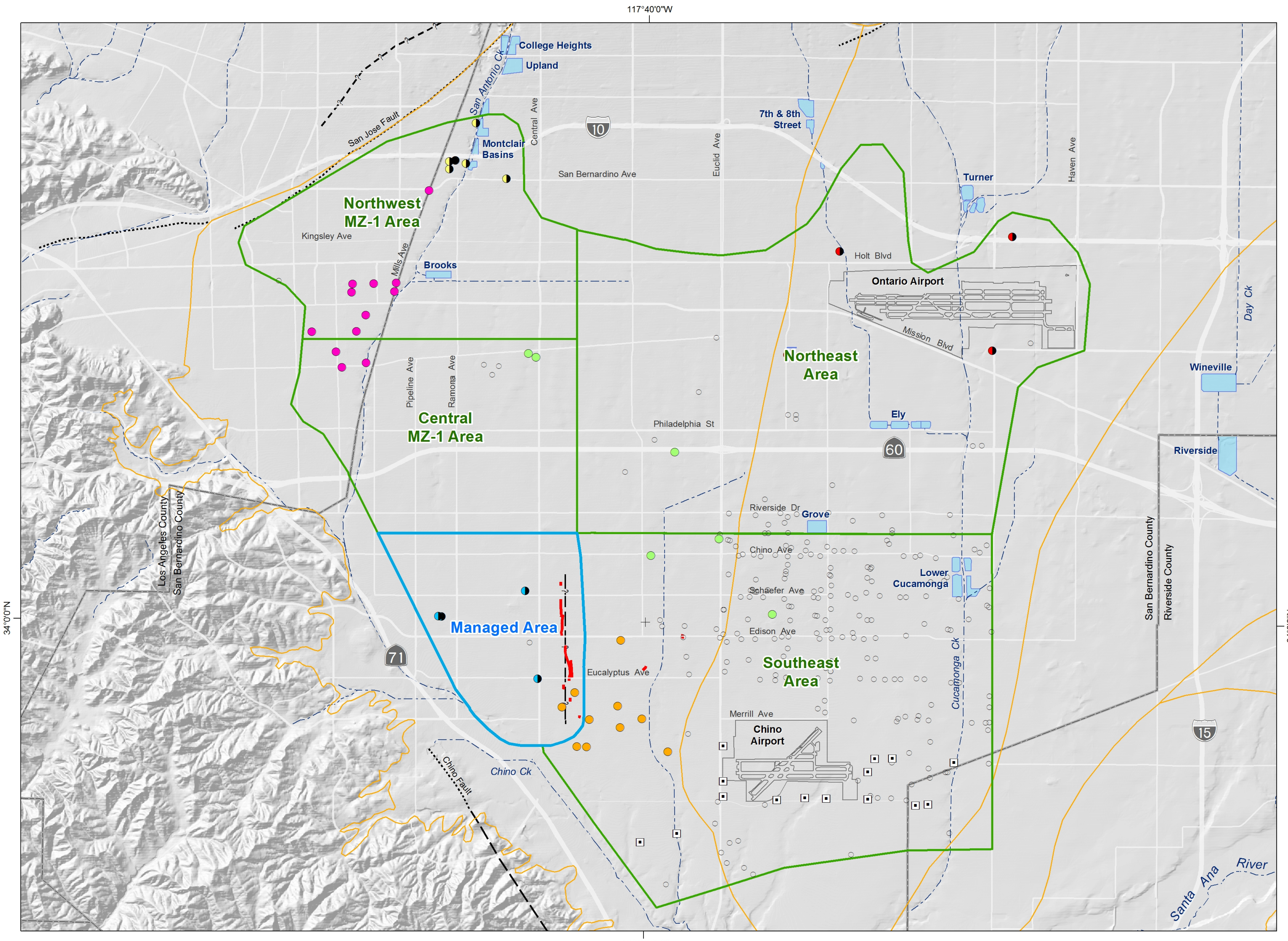
Task 2 Implement the Initial Monitoring and Testing Program – As of December 2016, 20 pressure transducers have been installed in public agency wells, and Watermaster is currently monitoring piezometric levels within the Northwest MZ-1 Study Area. Well owners include the Cities of Chino, Pomona, and Upland; the Golden State Water Company; and the Monte Vista Water District. In addition to the wells with pressure transducers installed by Watermaster's Engineer, the Golden State Water Company records piezometric levels and production rates (15-min intervals) via SCADA for five wells located in the Northwest MZ-1 Study Area.

In 2016, Watermaster's Engineer worked with staff from the Monte Vista Water District, City of Pomona, and SCADA Integrations to identify a set of wells and the costs associated with equipping additional wells with SCADA monitoring capabilities. The SCADA-collected piezometric level data will be incorporated into the Northwest MZ-1 Area monitoring and testing program.

Task 3 Develop and Evaluate the Baseline Management Alternative – Watermaster's Engineer developed and calibrated a one-dimensional aquifer-system compaction model to estimate future subsidence in the Northwest MZ-1 Area. A draft technical memorandum was prepared that summarizes the development of the Baseline Management Alternative.

Task 4 Develop and Evaluate the Initial Subsidence-Management Alternative – Watermaster's Engineer developed multiple groundwater production and wet-water recharge scenarios for Northwest MZ-1 to explore an Initial Subsidence-Management Alternative. These scenarios were simulated using the Chino Basin Groundwater Model and evaluated to assess the piezometric response to each scenario.

Task 5 Design and Install the Pomona Extensometer Facility – Watermaster's Engineer finalized the technical memorandum *Siting Study for the Pomona Extensometer Facility* and began drafting the technical specifications for the Pomona Extensometer facility.

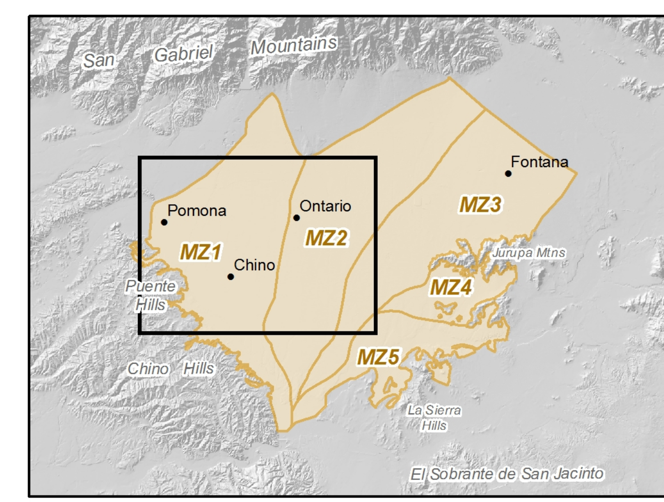


Active Groundwater Production Wells Within the Managed Area and Areas of Subsidence Concern Calendar Year 2016

- Chino Basin Desalter Authority
- City of Chino
- City of Chino Hills
- City of Ontario
- City of Pomona
- Golden State Water Company
- Monte Vista Water District
- California Institution for Men
- Private

- 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)
- Ground Fissures
- Approximate Location of the Riley Barrier



Prepared by:

WEI
Wildermuth Environmental, Inc.

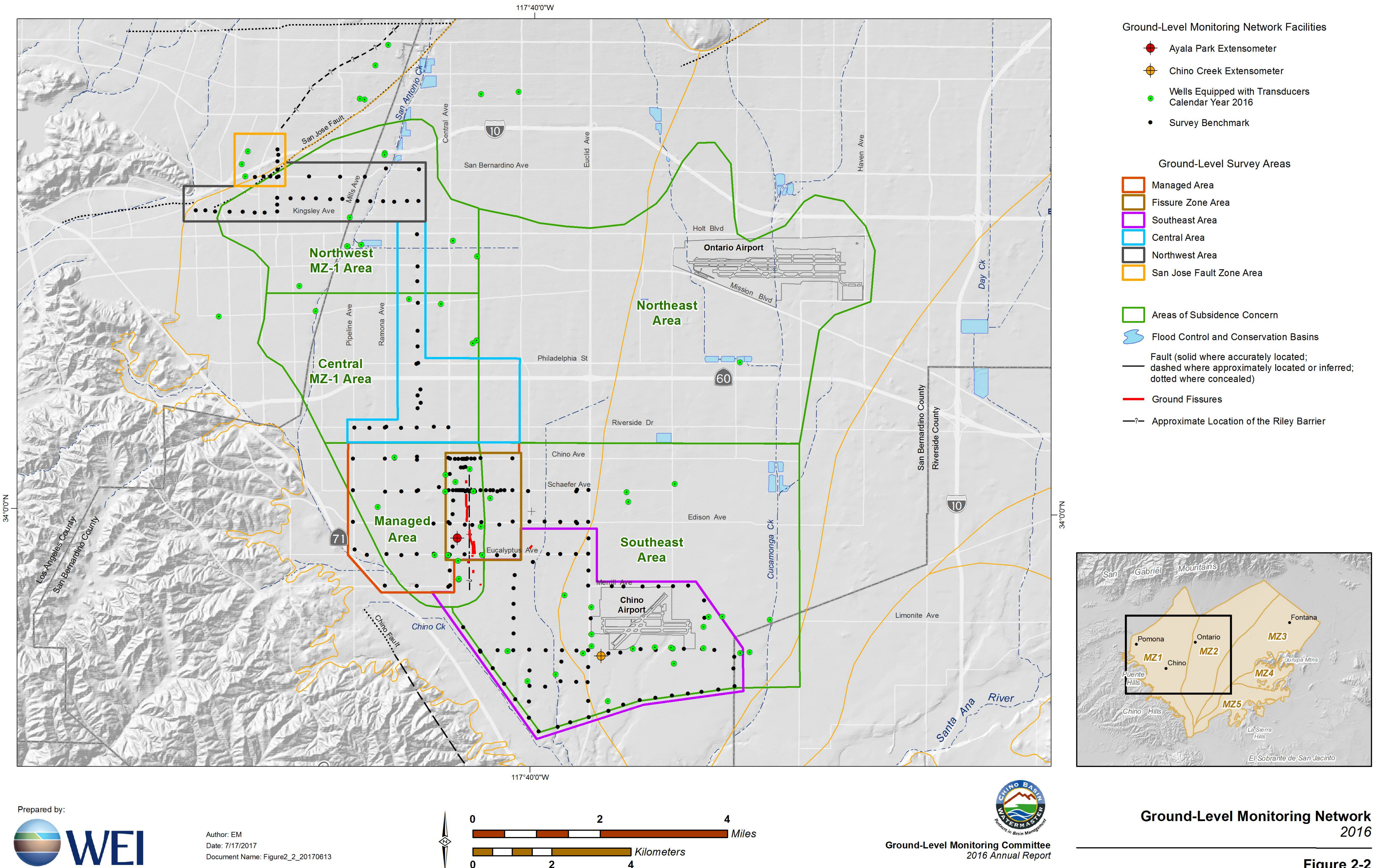
Author: EM
Date: 9/1/2017
Document Name: Figure_2-1_20170613

0 2 4 Miles
0 2 4 Kilometers

Ground-Level Monitoring Committee
2016 Annual Report

Pumping and Recharge Facilities
Western Chino Basin (2016)

Figure 2-1



Prepared by:

WEI
WILDERMUTH ENVIRONMENTAL, INC.

Author: EM
Date: 7/17/2017
Document Name: Figure2_2_20170613

Ground-Level Monitoring Committee
2016 Annual Report

Ground-Level Monitoring Network
2016

Figure 2-2

This section describes the results and interpretations derived from the GLMP for the Managed Area and all other Areas of Subsidence Concern in the Chino Basin through calendar year 2016. Figures 3-1a and 3-1b display vertical ground-motion as measured by InSAR across the western portion of the Chino Basin over the period of 2011 to 2016 and during calendar year 2016, respectively. Included on the figures are the locations of the specific monitoring sites and facilities referred to in this section. The data shown on the figures are described and interpreted in this section.

3.1 MZ-1 Managed Area

The Managed Area is the primary focus of the SMP. The discussion below describes the results and interpretations of the monitoring program in the Managed Area and relative to the Guidance Criteria.

3.1.1 History of Stress and Strain in the Aquifer-System

Figure 3-2 is a chart that illustrates the long-term history of groundwater production, piezometric levels, 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 a recently available alternative water supply that can result in decreased groundwater production from the area. The main observations from this chart are:

- Pumping from the deep aquifer-system during the 1990s caused a decline of piezometric levels that coincided 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 production decreased, piezometric levels in the deep aquifer-system recovered, and the rate of land subsidence declined significantly across the Managed Area.
- Recent increases in piezometric levels in the Managed Area may also be related in part to the increase in the direct use of recycled water, which began during FY 1998/1999 and has generally increased since.
- Since 2005, piezometric levels at PA-7 did not decline below the Guidance Level, and very little, if any, inelastic compaction was recorded in the Managed Area. These observations demonstrate the effectiveness of the SMP 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 six years of groundwater production, piezometric levels, and vertical ground motion in the Managed Area under the SMP.

3.1.2.1 Groundwater Production and Piezometric Levels

Table 3-1 summarizes groundwater production by well within the Managed Area for calendar years 2011-2016. A total of about 1,760 acre-feet of groundwater production occurred in the Managed Area during 2016—82 percent of the groundwater production was from wells screened in the shallow aquifer-system and 18 percent was from wells screened in both the shallow and deep aquifer-systems. Groundwater production in the Managed Area has declined over the past five years from about 5,400 acre-ft/yr in 2012 to about 1,750 acre-ft/yr in 2016. Well CH-17 did not produce groundwater during most calendar year 2016 due to problems with the pump motor. Historical production from CH-17 was typically about 1,080 acre-ft/yr.

Figure 3-3 is a time-series chart that displays groundwater production and the resultant piezometric change (stress) and aquifer-system deformation (strain) in the Managed Area for the period of 2011 and 2016. The chart illustrates the seasonal pattern of production in the Managed Area: increased production during the spring and summer months and decreased production during the fall and winter months.

Figure 3-3 also displays the time-series of piezometric levels at two piezometers at Ayala Park, PA-7 (deep aquifer-system) and PA-10 (shallow aquifer-system), illustrating the deep and shallow piezometric responses to seasonal groundwater production stresses. These data are consistent with the conclusions of the IMP and show that pumping from the deep, confined aquifer-system causes a piezometric decline that is much greater in magnitude than the piezometric decline caused by pumping of the shallow aquifer-system—even though more groundwater production occurs from the shallow aquifer-system. The chart shows that piezometric levels at PA-7 have fluctuated from a low of approximately 190 ft-btoc in August 2013 to a high of about 80 ft-btoc in November 2016 and have not declined below the Guidance Level of 245 ft-btoc. The recovery of piezometric levels at PA-7 to above 90 ft-btoc in 2016 represented a "full recovery" of piezometric levels at PA-7 as defined in the SMP. This is the first instance of full recovery since 2012, which complies with the recommendation in the SMP for full piezometric recovery within the deep aquifer system at least once every five years.[8]

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 Extensometer during 2011-2016. These data show that the seasonal vertical compression and expansion of the aquifer system is responding to the seasonal decline and recovery of piezometric levels and indicate that the vertical deformation of the aquifer-system was mainly elastic during this period. However, between April 6, 2011 to August 3, 2016 (dates of full recovery of piezometric levels at PA-7 to 90 ft-btoc), the Deep Extensometer recorded about 0.028 ft of compression within the aquifer-system, which indicates that this compression is permanent compaction that occurred within the depth interval of 30-1,400 ft-bgs. Over this

[8] Page 2-2 in the SMP; 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. The last time the water level at PA-7 was at or above 90 ft-btoc was in spring 2012. Therefore, the next recommended occurrence of water-level recovery to 90 ft-btoc will be spring 2017."

same period, the Shallow Extensometer recorded about 0.013 ft of compaction within the depth interval of 30-550 ft-bgs. Subtracting the permanent compaction recorded at the Shallow Extensometer from the permanent compaction recorded at the Deep Extensometer indicates that about 0.015 ft of compaction occurred within the depth interval of 550-1,400 ft-bgs between April 2011 to August 2016 (about 54% of the total compaction as estimated from the Deep Extensometer record).

Figure 3-4 is a stress-strain diagram of piezometric levels measured at PA-7 (stress) versus vertical deformation of the aquifer-system sediments as measured at the Deep Extensometer (strain). The hysteresis loops on this figure represent piezometric decline-recovery cycles 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 aquifer-system that is penetrated by the Deep Extensometer. Piezometric 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 April 2011 to January 2014, the hysteresis loops progressively shift to the right on this chart, indicating that about 0.028 ft of inelastic compaction occurred during this period within the depth interval of 30-1,400 ft-bgs. The overlapping hysteresis loops from 2014 to 2016 indicate that inelastic compaction at Ayala Park had ceased by about 2014 and that the seasonal vertical deformation of the aquifer-system sediments since 2014 has been virtually entirely elastic.

3.1.2.3 Vertical Ground Motion

Vertical ground motion[9] is measured across the Managed Area via InSAR and ground-level surveys. Figures 3-5a and 3-5b are maps that illustrate vertical ground motion as measured by InSAR and ground-level surveys[10] for the period 2011-2016 and during 2016, respectively.

The InSAR data shown in Figure 3-5a indicate the occurrence of up to about -0.08 ft of vertical ground motion across the Managed Area over the period of March 2011 to January 2017. Figure 3-3 shows that piezometric levels in the deep aquifer system were near full recovery (93 ft-btoc at PA-7) in both March 2011 and January 2017, suggesting that the downward vertical ground motion shown by InSAR in the Managed Area is at least in part inelastic and represents permanent land subsidence that occurred during this period. The greatest amount of subsidence shown on Figure 3-5a is in the northern portion of the Managed Area in the vicinity of well CH-17—the main deep production well in the Managed Area that was pumped on a seasonal basis during this period.

The InSAR data shown in Figure 3-5b indicate up to about +0.04 ft of vertical ground motion across most of the Managed Area during the period of January 2016 to January 2017. The area of upward vertical ground motion is confined to areas west of the Riley Barrier, and the greatest upward vertical ground motion is in the vicinity of CH-17. The upward vertical ground motion is explained by decreased production from CH-17 during 2016, which resulted in recovery of piezometric levels and elastic vertical expansion of the aquifer system (see Figure 3-3: the

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

[10] The most recent ground-level survey conducted in the Managed Area was in March 2016. Ground-level surveys in the Managed Area were not conducted in FY 2016/17 at the recommendation of the GLMC.

recovery of piezometric levels at PA-7 and the expansion of the aquifer-system as measured by the Deep Extensometer).

Figure 3-1b shows that upward vertical ground motion in the Managed Area during 2016 also occurred to the north across most of Central MZ-1, which suggests a hydrogeologic connection between these two areas within the deep aquifer system; however, there is not enough piezometric data in Central MZ-1 to verify this connection.

The InSAR data shown in Figure 3-5a are consistent with Deep Extensometer record at Ayala Park:

- Figure 3-3 shows that during the period of March 2011 to January 2017, the Deep Extensometer at Ayala Park recorded about -0.017 ft of vertical compression of the aquifer system, which causes the same magnitude of downward vertical ground motion at this site. The InSAR data in Figure 3-5a during the same period indicate about -0.024 ft of vertical ground motion—a similar direction and magnitude of ground motion.

- Figure 3-3 shows that during the period of January 2016 to January 2017, the Deep Extensometer at Ayala Park recorded about +0.042 ft of vertical expansion of the aquifer system, which causes the same magnitude of upward vertical ground motion at this site. The InSAR data in Figure 3-5b during the same period indicate about +0.02 ft of vertical ground motion—a similar direction and magnitude of ground motion.

3.1.2.4 Horizontal Ground Motion

EDM surveys have been performed periodically since 2003 in the Managed Area between the benchmark monuments located along Eucalyptus, Edison, Schaefer, and Chino Avenues to monitor for horizontal ground motion across the historical Fissure Zone.

The EDM data sets were analyzed in 2016/17 for the following specific purposes: (i) to describe and document the monitoring equipment, field methods, and accuracies associated with EDMs; (ii) to describe the horizontal strain that has occurred between benchmark monuments over time; (iii) to identify potential locations, if any, for the installation of a horizontal extensometer; and (iv) to support recommendations for the future of monitoring via EDMs.

Parsons Brinckerhoff (PB) is the engineering sub-consultant that has conducted elevation and EDM surveys in the Chino Basin since 2003. PB staff conducts EDM surveys using Geodimeter Series 600 Total Stations. These instruments can resolve horizontal angles to within three seconds of arc and have distance accuracies of ±0.01 feet plus 3 parts per million (ppm). The total stations are calibrated annually and are operated consistent with the instrument's user manual. PB staff follows standard surveying practices to reduce sighting error and ensure the integrity of measurements. All measurements are computed and adjusted using MicroSurvey STAR*NET least squares survey network adjustment software. This has produced a standard error for distances between points less than 1,000 feet apart of about ±0.015 feet and about ±0.02 feet at over 3,000 feet. PB has made efforts to ensure continuity of the technology, methods, and operating staff to minimize errors over the course of the monitoring period.

Since 2003, EDM surveys were performed by PB at benchmark monuments aligned along east-west transects shown on the following map figures:

- Figure 3-6a: widely-spaced benchmarks along Schaefer, Edison, and Eucalyptus Avenues from Spring 2003 to Fall 2009.
- Figure 3-7a: closely-spaced benchmarks along Schaefer Avenue east of Central Avenue from Summer 2010 to Spring 2016.
- Figure 3-8a: closely-spaced benchmarks along Chino Avenue east of Central Avenue from Spring 2011 to Spring 2016.

The EDM data were reviewed with PB staff to ensure that they were correctly compiled and interpreted. To quantify and compare the magnitude and type of horizontal strain (compressive or tensile) in the shallow soils over time, horizontal strain in the east-west direction[11] was calculated from the EDM data-sets between pairs of adjacent monuments. Strain is a dimensionless value that was calculated using the following formula:

$$\varepsilon = \frac{\Delta L}{L_0}, \text{ where } \Delta L = L_i - L_0$$

L is the east-west distance between two adjacent monuments.

L_0 is the initial east-west distance between two adjacent monuments.

L_i is a subsequent east-west distance between two adjacent monuments.

Calculating strain based on the initial survey length (L_0) can reveal the occurrence of both elastic and inelastic strain over time. Negative strain values indicate compression between monuments (compressive strain). Positive strain values indicate extension between monuments (tensile strain).

Several figures were prepared to display the time series of east/west-oriented strain between pairs of adjacent monuments shown in the transects on Figures 3-6a, 3-7a, and 3-8a. To understand the effects of vertical ground motion in the Managed Area on the occurrence of horizontal strain between monuments, the time-series of the Deep Extensometer record at Ayala Park (located to the west of the historical Fissure Zone) was plotted on each figure alongside the time series charts of horizontal strain. Each figure was analyzed for the indication of inelastic tensile strain between monuments to identify zones that are most susceptible to ground fissuring that could be caused by subsidence in the Managed Area. If identified, such zones may be appropriate for more intensive monitoring for horizontal strain, such as the installation of a horizontal extensometer and/or addition of closely-spaced monuments and future EDM surveys.

- **Figure 3-6b**. This figure displays the time series of east/west-oriented strain between pairs of widely-spaced monuments shown on Figure 3-6a along Eucalyptus Avenue during 2003-2009. This period included the controlled deep aquifer-system stress testing in the Managed Area west of the Fissure Zone that occurred as part of the IMP in 2003-

[11] Because the historical Fissure Zone was aligned in a north-south direction, the horizontal deformation in the east-west direction is of primary concern for the threat of future ground fissuring.

2005. The Deep Extensometer at Ayala Park recorded up to about 0.15 feet of elastic compression and expansion of the aquifer system during these tests. Analysis of the stress-strain diagram in Figure 3-4 indicates that about 0.01 ft of inelastic compaction occurred at Ayala Park during the 2004-2005 stress test, and a total of about 0.04 ft of inelastic compaction occurred during 2003-2009. The analysis of horizontal strain on Figure 3-6b indicates no obvious areas of inelastic tensile strain that accumulated along Eucalyptus Avenue during 2003-2009. Tensile strain between monuments 145/55.1 and A-18 increased as the Deep Extensometer recorded vertical compression and decreased as the Deep Extensometer recorded vertical expansion, particularly during the 2003-2005 stress testing. Over the entire period of 2003-2009, the tensile strain appeared to be mainly elastic. These two monuments span the historical Fissure Zone and, based on this analysis, appear to be the most logical location along Eucalyptus Avenue for more intensive monitoring of horizontal strain if necessary in the future.

- **Figure 3-6c**. This figure displays the time series of east/west-oriented strain between pairs of widely-spaced monuments, shown on Figure 3-6a along Edison Avenue during 2003-2009. This period included the controlled deep aquifer-system stress testing in the Managed Area west of the Fissure Zone that occurred as part of the IMP in 2003-2005. The Deep Extensometer at Ayala Park recorded up to about 0.15 feet of elastic compression and expansion of the aquifer system during these tests. Analysis of the stress-strain diagram in Figure 3-4 indicates that about 0.01 ft of inelastic compaction occurred at Ayala Park during the 2004-2005 stress test, and a total of about 0.04 ft of inelastic compaction occurred during 2003-2009. The analysis of horizontal strain on Figure 3-6c indicates no obvious areas of inelastic tensile strain that accumulated along Edison Avenue during 2003-2009. Tensile strain between monuments A-12 and A-13 increased as the Deep Extensometer recorded vertical compression and decreased as the Deep Extensometer recorded vertical expansion, particularly during the 2003-2005 stress testing. During the entire period of 2003-2009, the tensile strain appeared to be mainly elastic. These two monuments span the historical Fissure Zone and, based on this analysis, appear to be the most logical location along Edison Avenue for more intensive monitoring of horizontal strain if necessary in the future.

- **Figure 3-6d**. This figure displays the time series of east/west-oriented strain between pairs of widely-spaced monuments, shown on Figure 3-6a along Schaefer Avenue during 2005-2009. This period was subsequent to the controlled deep aquifer-system stress testing in the Managed Area west of the Fissure Zone that occurred as part of the IMP in 2003-2005. The analysis of horizontal strain on Figure 3-6d indicates no obvious areas of inelastic tensile strain that accumulated along Schaefer Avenue during 2005-2009.

- **Figure 3-7b**. This figure displays the time series of east/west-oriented strain between pairs of closely-spaced monuments, shown on Figure 3-7a along Schaefer Avenue during 2011-2016. During this period, the Deep Extensometer at Ayala Park recorded several cycles of seasonal elastic compression and expansion of the aquifer system up to about 0.08 feet. Analysis of the stress-strain diagram in Figure 3-4 indicates that about 0.028 ft of inelastic compaction occurred during 2011-2016 at Ayala Park but that most of this compaction occurred during 2011-2013. The analysis of horizontal strain on

Figure 3-7b indicates one specific area where inelastic tensile strain accumulated along Schaefer Avenue during 2011-2016. Tensile strain between monuments B-75 and B-76 increased during 2011-2013, and then remained relatively stable during 2014-2016. This occurrence of inelastic tensile strain between monuments during 2011-2013 was contemporaneous with the 0.028 ft of inelastic compaction recorded at the Ayala Park Extensometer. These monuments span the historical Fissure Zone and, based on this analysis, appear to be the most logical location along Schaefer Avenue for more intensive monitoring of horizontal strain if necessary in the future.

- **Figures 3-8b and 3-8c**. These figures display the time series of east/west-oriented strain between pairs of closely-spaced monuments, shown on Figure 3-8a along Chino Avenue during 2011-2016. During this period, the Deep Extensometer at Ayala Park recorded several cycles of seasonal elastic compression and expansion of the aquifer system up to about 0.08 feet. Analysis of the stress-strain diagram in Figure 3-4 indicates that about 0.028 ft of inelastic compaction occurred during 2011-2016 at Ayala Park but that most of this compaction occurred during 2011-2013. The analysis of horizontal strain in Figures 3-8b and 3-8c indicates specific areas where inelastic tensile strain accumulated along Chino Avenue during 2011-2016. Tensile strain between monuments [B-238 and B-237], [B-230 and B229], [B-229 and B228], [B-227 and B226], and [B-226 and B225] increased during 2011-2013 and then remained relatively stable during 2014-2016. This occurrence of inelastic tensile strain between monuments during 2011-2013 was contemporaneous with the 0.028 ft of inelastic compaction recorded at the Ayala Park Extensometer. These monuments span an approximate northward extension of the historical Fissure Zone and, based on this analysis, appear to be the most logical locations along Chino Avenue for more intensive monitoring of horizontal strain if necessary in the future.

The following are the conclusions and recommendations from this analysis:

- Tensile and compressive horizontal strains within the shallow soils across the Fissure Zone, as calculated from EDMs, have occurred in a logical and contemporaneous manner relative to the vertical compression and expansion of the aquifer system in the Managed Area west of the Fissure Zone. This observation is especially true for strain between those monuments that directly span the Fissure Zone.

- The analysis above indicates that repeated EDM surveys are suitable as a monitoring technique for detecting the occurrence of tensile strain within shallow soils and determining their elastic and/or inelastic nature.

- During 2003-2009, the EDM surveys indicated that horizontal strain between the widely-spaced monuments across the Fissure Zone was primarily elastic.

- During 2011-2013, the EDM surveys indicated that the tensile strain between the closely-spaced monuments that span the Fissure Zone was in part inelastic and coincided with a small amount of permanent land subsidence that occurred to the west in the Managed Area. During 2014-2016, the land subsidence that was occurring in the

Managed Area during 2011-2013 ceased, and the tensile strain ceased but did not fully recover.

- The areas within the Managed Area that should be monitored by EDMs in the future are the transects of monuments that span the Fissure Zone along Chino, Schaefer, Edison, and Eucalyptus Avenues; EDMs have indicated that inelastic tensile strain can accumulate across the Fissure Zone when permanent land subsidence occurs to the west of the Fissure Zone.

- If the Long-Term Pumping Test will include groundwater production at CH-15B, which is located west on Eucalyptus Avenue, the GLMC should consider adding a series of closely-spaced monuments along Edison and Eucalyptus avenues across the Fissure Zone to perform EDM surveys as part of the test.

- It appears that very little, if any, inelastic tensile strain has accumulated across the Fissure Zone since 2014, when permanent land subsidence in the Managed Area appears to have ceased. Therefore, as long as permanent subsidence is absent in the Managed Area, the GLMC should consider performing EDM surveys across the Fissure Zone once every two to three years. The EDM surveys should be performed in conjunction with elevation surveys at monuments across the Managed Area at full recovery (or near full recovery) of piezometric levels at PA-7.

- If and when the Long-Term Pumping Test in the Managed Area is performed, EDM surveys across the Fissure Zone should be conducted in coordination with the test. These surveys should occur just prior to the test at full recovery of piezometric levels at PA-7, at maximum drawdown of piezometric levels below the Guidance Level at PA-7, and at the subsequent full recovery of piezometric levels at PA-7. The purpose of these EDM surveys will be to monitor for the occurrence and magnitude of inelastic tensile strain across the Fissure Zone associated with the drawdown of piezometric levels below the Guidance Level at PA-7.

- The installation of a new horizontal extensometer is not recommended at this time for the following reasons: (i) EDM surveys are a suitable monitoring technique to monitor for the occurrence and magnitude of inelastic tensile strain in shallow soils across the Fissure Zone; (ii) currently, very little, if any, permanent land subsidence in the Managed Area and tensile strain across the Fissure Zone is occurring; (iii) based on the monitoring results from the IMP, very little, if any, permanent land subsidence in the Managed Area and tensile strain across the Fissure Zone is expected to occur as a result of the Long-Term Pumping Test; and (iv) very little, if any, additional management-grade information would be provided by a horizontal extensometer (that would not be provided by EDMs), and therefore the cost is not justified.

3.2 Southeast Area

Vertical ground motion is measured across the Southeast Area via InSAR, traditional ground-level surveys, and the CCX. Figure 3-9 is a time-series chart that displays and describes the long-term history of land subsidence in the Southeast Area. InSAR data are generally incoherent across much of this area because the overlying agricultural land uses are not hard, consistent reflectors of radar waves. Therefore, the history of subsidence is best characterized by ground-level surveys and the CCX. The main observations from this chart are that a total of about 0.5 ft of subsidence occurred in the Southeast Area since 1987, but since about 2010, subsidence has virtually ceased, coinciding with the increased direct reuse of recycled water, decreased groundwater production, and stable or increasing piezometric levels.

Figures 3-10a and 3-10b illustrate the vertical ground motion that has occurred in the Southeast Area during 2011-2016 and 2016 respectively, as measured by InSAR and ground-level surveys. Both maps show that little recent subsidence has occurred across the Southeast Area and that some of the area experienced upward vertical ground motion.

Figure 3-11 displays the time series of piezometric levels and vertical aquifer-system deformation recorded at the CCX, which began collecting data in July 2012. In general, piezometric levels have changed very little and have generally recovered from 2012 through 2016. A small amount of expansion of the aquifer-system sediments has been measured by the CCX extensometers, coincident with the piezometric-level recovery. These observations are consistent with the ground-level surveys shown in Figures 3-10a and 3-10b, which indicate minor upward vertical ground motion near the CCX. Groundwater production began at the Chino Creek Well Field in 2014, but appears to have had little, if any, effect on piezometric levels or aquifer-system deformation at the CCX through 2016.

The InSAR and traditional ground-level survey datasets do not always corroborate each other in the pattern and/or magnitude of vertical ground motion in the Southeast Area where both data-sets overlap. Therefore, ground-level surveys should continue to be the primary method of measurement of vertical ground motion across the Southeast Area.

3.3 Central MZ-1 Area

Vertical ground-motion is measured across the Central MZ-1 Area via InSAR and traditional ground-level surveys. Figures 3-1a and 3-1b illustrate vertical ground motion as measured by InSAR across Central MZ-1 during 2011-2016 and 2016, respectively. Figure 3-12 is a time-series chart that displays and describes the long-term history of land subsidence in Central MZ-1. These maps and charts show that the time history and magnitude of vertical ground motion in Central MZ-1 is similar to 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 piezometric level data in this area to confirm this relationship.

About 1.2 feet of subsidence occurred near Walnut and Monte Vista Avenue (BM 125/49) from 1993 to 2000. Since 2000, about 0.3 feet of subsidence has occurred at a gradually declining rate. Figure 3-1b shows that during 2016, upward vertical ground motion occurred across most of Central MZ-1—similar to the upward vertical ground motion that occurred across most of the Managed Area during 2016. Figure 3-13 shows that up to about +0.03 ft of vertical ground motion occurred across Central MZ-1 during 2016 as measured by InSAR, and that the ground-level survey data showed a similar spatial pattern and magnitude of vertical ground motion.

3.4 Northwest MZ-1 Area

3.4.1 Vertical Ground Motion

Vertical ground motion is measured across the Northwest MZ-1 Area via InSAR and traditional ground-level surveys. Figures 3-1a and 3-1b illustrate vertical ground motion as measured by InSAR across Northwest MZ-1 during 2011-2016 and 2016, respectively. A maximum of about -0.25 ft of vertical ground motion occurred in Northwest MZ-1 during 2011-2016—an average rate of about -0.04 ft/yr. A maximum of about -0.03 ft of vertical ground motion occurred during 2016.

Figure 3-14 is a time-series chart that displays and describes the long-term history of land subsidence in Northwest MZ-1. The main observations from this chart are that about 1.3 ft of subsidence occurred in this area from 1992 through 2016—an average rate of about 0.05 ft/yr. The chart also shows piezometric levels at wells in the area from 1930-2016. From about 1930 to 1978, piezometric levels in Northwest MZ-1 declined by about 175 feet. Since then, piezometric levels have recovered, but have remained below the 1930 levels. The observed and continuous subsidence that occurred between the 1992 and 2016 period cannot be entirely explained by the concurrent changes in piezometric levels. A plausible explanation for the subsidence is that thick, slow-draining aquitards are compacting in response to the historical declines in piezometric levels that occurred from 1930 to 1978.

Figure 3-15 illustrates the recent vertical ground motion that occurred in Northwest MZ-1 from 2014-2016, as measured by both ground-level surveys and InSAR: a maximum of about -0.1 ft of vertical ground motion occurred in Northwest MZ-1 over this period as measured by InSAR. The ground-level survey data showed a similar spatial pattern and magnitude of vertical ground motion across Northwest MZ-1 as measured by InSAR.

The subsidence shown on these maps and charts has been gradually and persistently occurring in Northwest MZ-1, and is ongoing. Although the downward vertical ground motion that occurred in Northwest MZ-1 during 2016 was less than historical rates, groundwater levels at many wells in the area were recovering during 2016, which may have resulted in elastic expansion of the aquifer system that offset a portion of the permanent compaction that is likely occurring in other portions of the aquifer system (*i.e.* other areas and/or depths). The planned Pomona Extensometer facility (see location on Figures 3-15a and 3-15b) will potentially elucidate these hydro-mechanical processes and identify the compacting depth interval(s) within the aquifer system.

3.4.2 Horizontal Ground Motion

Figure 3-1a shows that the subsidence that occurred in Northwest MZ-1 over the period 2011-2016 created a steep subsidence gradient across the San Jose Fault—the same pattern of "differential subsidence" that occurred in the MZ-1 Managed Area during the time of ground fissuring. Differential subsidence can cause an accumulation of horizontal strain in the shallow sediments and the potential for ground fissuring.[12]

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[12] Ground fissuring is the main subsidence-related threat to overlying infrastructure. Watermaster, consistent with the recommendation of the GLMC, has determined that the SMP needs to be updated to include a

To identify the potential areas of accumulation of tensile horizontal strain in the shallow soils in this area, annual EDM surveys between benchmark monuments that cross the San Jose Fault have been performed since 2014. Figure 3-16 displays: (i) the vertical ground motion that occurred in Northwest MZ-1 from 2014-2016 as measured by InSAR and (ii) the closely-spaced benchmark monuments where EDM surveys were performed across the San Jose Fault during 2014-2016. Figure 3-17 displays the time series of east/west-oriented and north/south-oriented strain between the pairs of closely-spaced monuments, shown on Figure 3-16, during 2014-2016. Although tensile strain has been calculated from the EDMs between some monuments (e.g. B-409 to B-408), it is pre-mature to draw conclusions at this point. The GLMC should recommend the continuance of annual elevation and EDM surveys across the San Jose Fault Zone during the development of 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. Figure 3-18 is a time-series chart that displays and describes the long-term history of land subsidence in the Northeast Area. The main observations from this chart are that about 1.0 ft of subsidence occurred in the Northeast Area from 1992 to 2016 at a gradual and persistent rate of about 0.04 ft/yr. Since about 2011, the rate has declined to about 0.03 ft/yr. This decline coincides with relatively stable or increasing piezometric levels in the Northeast Area. These observations indicate that the gradual and persistent subsidence that has occurred is likely inelastic and permanent.

Figure 3-19a is a map of vertical ground motion as measured by InSAR for the Northeast Area over the period 2011 to 2016. The predominant area of downward vertical ground motion is near State Highway 60 between Vineyard and Archibald Avenues, where a maximum of about -0.25 ft of vertical ground motion occurred between March 2011 and January 2017.

Figure 3-19b is a map of vertical ground motion as measured by InSAR across the Northeast Area during 2016. The predominant areas of downward vertical ground motion are similar to the areas shown in Figure 3-19a. Maximum downward vertical ground motion of about -0.06 ft occurred just east of the intersection of Mission Boulevard and Archibald Avenue.

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 an earthquake, the land surface can subside suddenly. Subsidence associated with large magnitude earthquakes has been documented across North America and elsewhere (Weischet, 1963; Myers and Hamilton, 1964; Plafker, 1965). Tectonic movement along the San Jose Fault Zone, including aseismic creep, is also a plausible mechanism for the occurrence of the differential land subsidence that has occurred in Northwest MZ-1. Figures 3-1a and 3-1b include earthquake epicenters and associated magnitudes for the period between 2011 to 2017 and 2016, respectively. The earthquake epicenters do not show a clear spatial relationship between the seismicity and the differential subsidence in Northwest MZ-1 nor do the data show a spatial correlation between earthquakes

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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.

and other areas of subsidence concern. With respect to the Northwest MZ-1 Area, without direct evidence of compaction within the aquifer system, as will potentially be provided by the Pomona Extensometer, tectonic deformation cannot be ruled out as a mechanism for the observed differential subsidence.

Table 3-1
Groundwater Production in the Managed Area for Calendar Years 2011-2016
acre-ft

Well Name	Aquifer Layer	2011	2012	2013	2014	2015	Calendar Year 2016					
							Qtr 1	Qtr 2	Qtr 3	Qtr 4	Total	By Layer
C-4	Shallow	709	85	0	0	0	0	0	0	0	0	1,447
C-6		892	1,203	0	0	0	0	0	0	0	0	
CH-1A		910	873	726	1,048	793	39	185	110	170	503	
CH-7A		398	390	283	289	283	2	0	0	41	43	
CH-7B		510	438	236	599	476	2	0	0	56	58	
CIM-1		185	1,064	1,122	1,096	896	180	206	281	173	840	
XRef 8730*		-	-	5	5	3	0.75	0.75	0.75	0.75	3	
CH-17	Deep**	897	867	1,025	1,379	1,060	0	0	0	110	110	310
CH-15B		-	-	140	0	0	0	0	0	0	0	
CIM-11A		433	466	128	156	51	37	25	65	72	200	
	Totals	**4,934**	**5,386**	**3,665**	**4,572**	**3,560**	**261**	**417**	**456**	**622**	**1,756**	

"C" = City of Chino

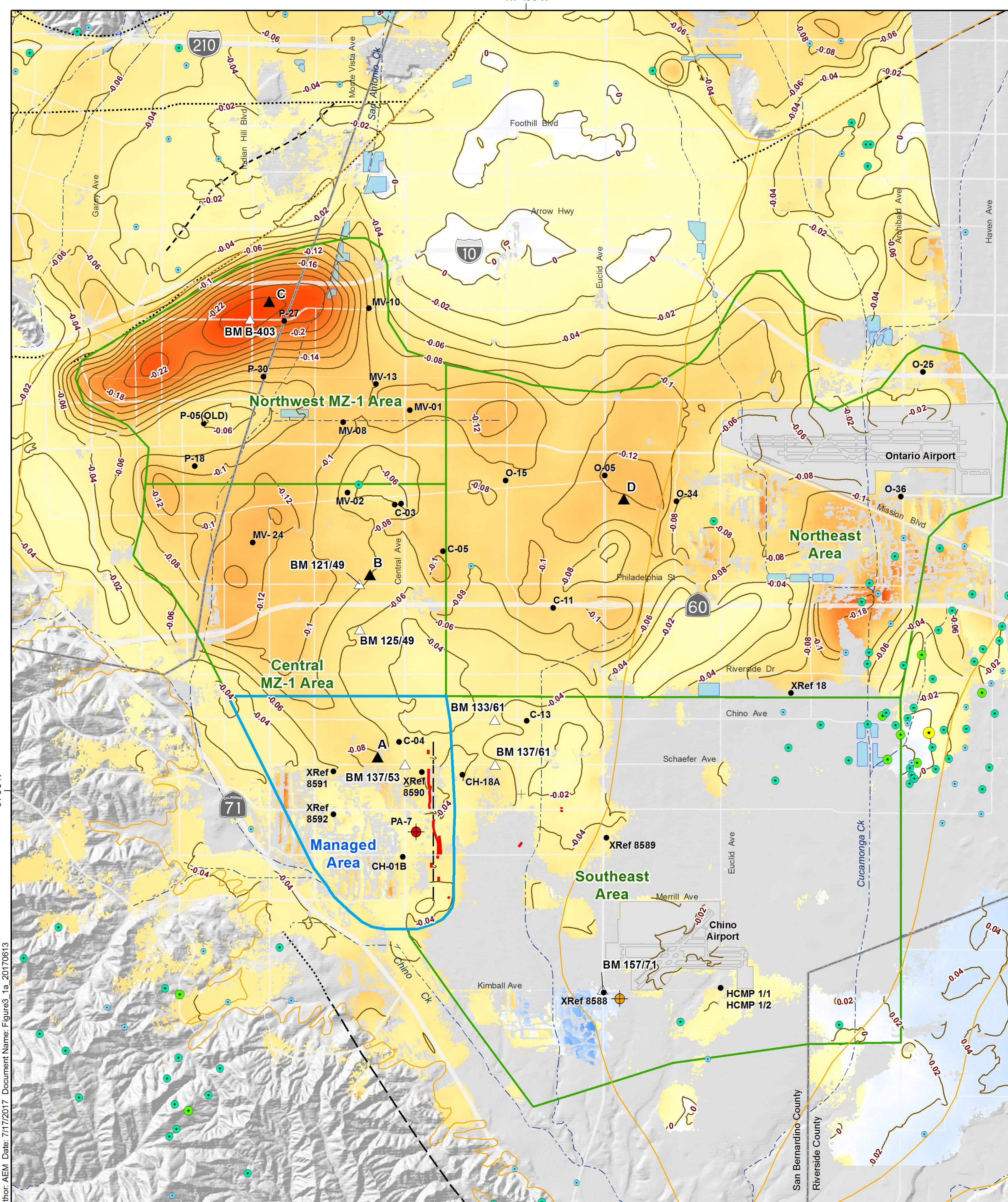
"CH" = City of Chino Hills

"CIM" = California Institution for Men

"XRef" = Private

*Well screen interval is unknown, but assumed to be shallow based on typical well construction for other private well 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 Altitude as Measured by InSAR (March 2011 to January 2017)

+ 0.5 ft
0
-0.25
- 0.5 ft

InSAR absent or incoherent

Ayala Park Extensometer

Chino Creek Extensometer

Ground Fissures

Approximate Location of the Riley Barrier

Earthquake Epicenters March 2011 to January 2017 (Local Magnitude)

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

Wells with Long-Term Time Series of Depth-to-Groundwater

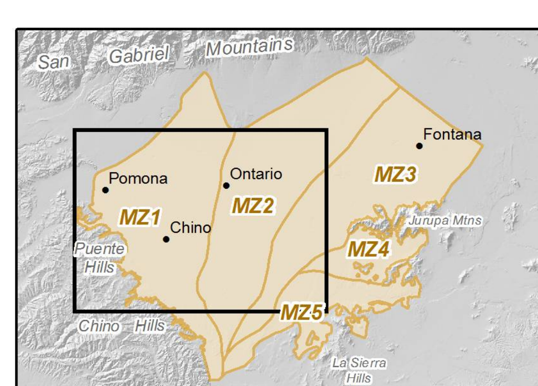
Location of INSAR Time Series of Change in Ground-Surface Elevation

Location of Benchmark with Time Series of Ground-Surface Elevation

Flood Control and Conservation Basins

Managed Area

Areas of Subsidence Concern



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0 1 2 Miles

0 1 2 Kilometers

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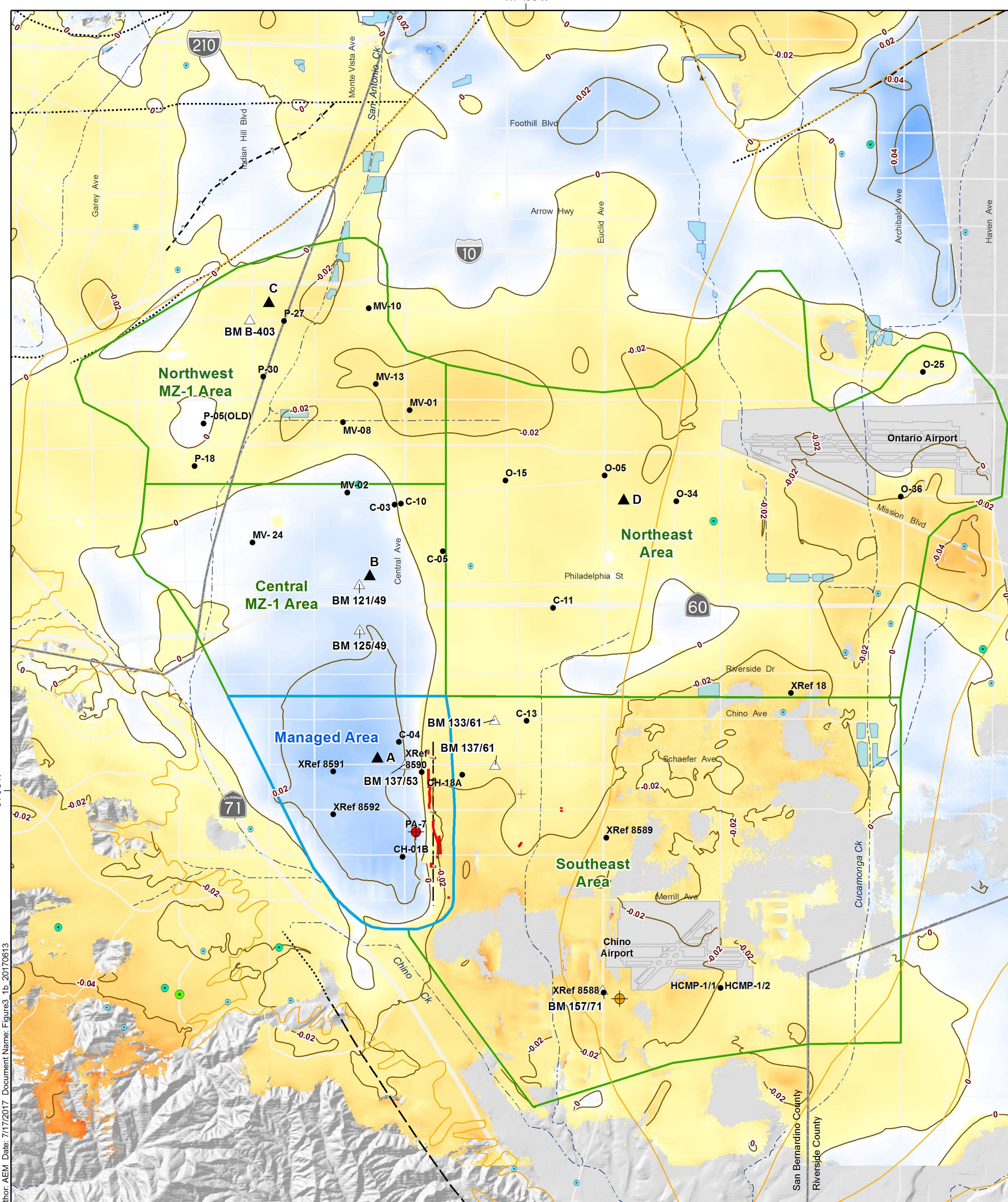
Vertical Ground-Motion Across Western Chino Basin
2011-2016

Figure 3-1a



117°40'0"W

Relative Change in Land Surface Altitude as Measured by InSAR (January 2016 to January 2017)

+ 0.1 ft
0
-0.05
- 0.1 ft

InSAR absent or incoherent

Ayala Park Extensometer

Chino Creek Extensometer

Ground Fissures

Approximate Location of the Riley Barrier

Earthquake Epicenters January 2016 to 2017 (Local Magnitude)

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

Wells with Long-Term Time Series of Depth-to-Groundwater

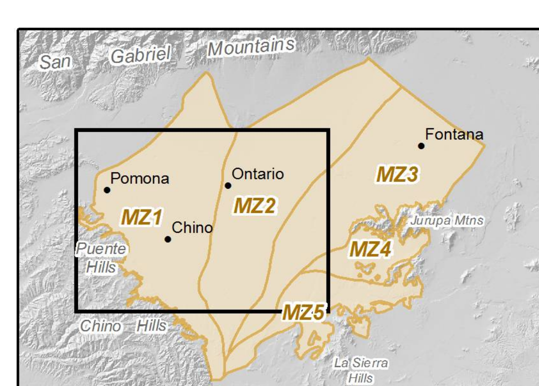
Location of Benchmark with Time Series of Ground-Surface Elevation

Location of INSAR Time Series of Change in Ground-Surface Elevation

Flood Control and Conservation Basins

Managed Area

Areas of Subsidence Concern



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0 1 2 Miles

0 1 2 Kilometers

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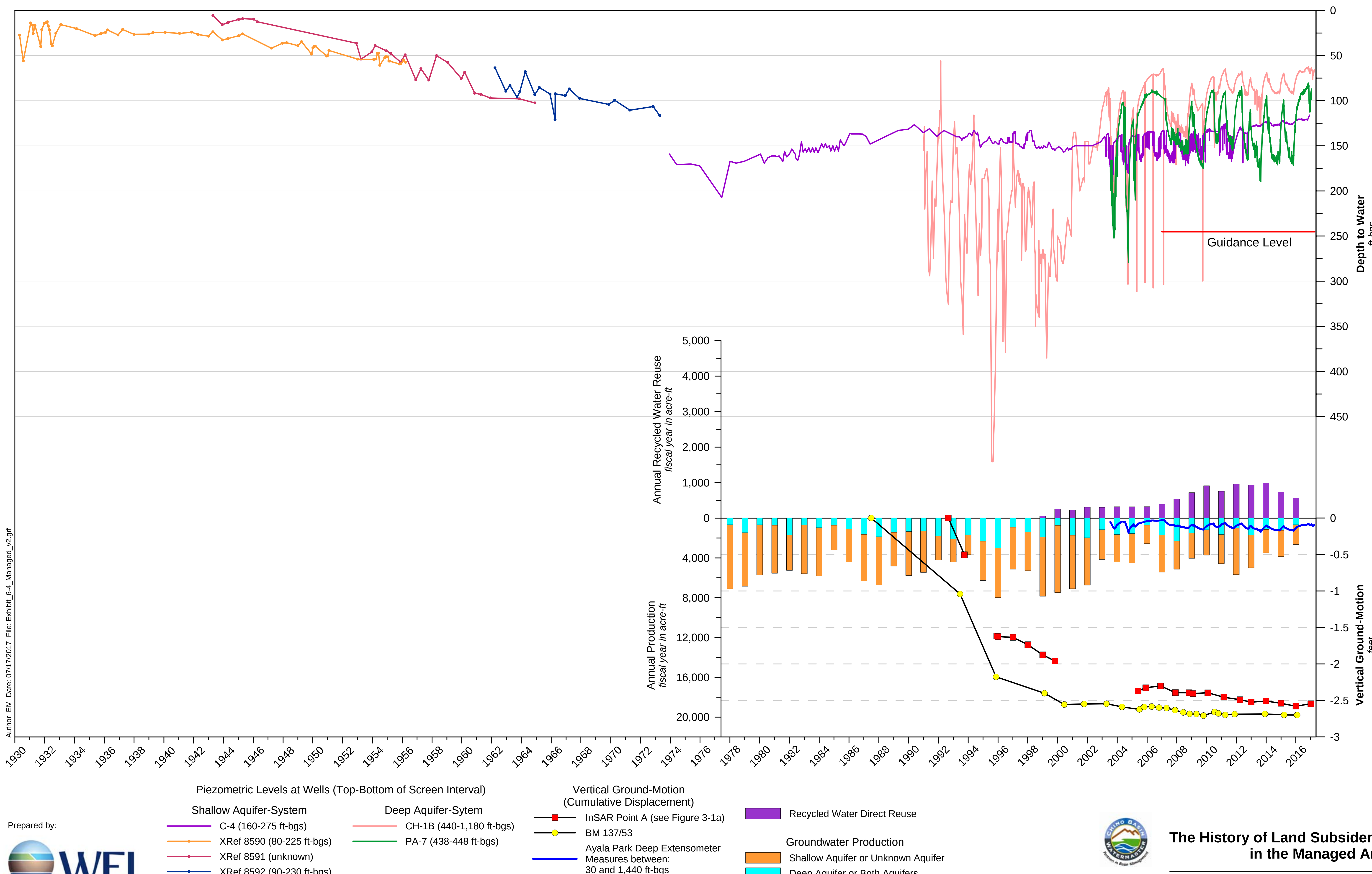
Vertical Ground-Motion Across Western Chino Basin
2016

Figure 3-1b

Author: AEM Date: 7/17/2017 Document Name: Figure3_1b_20170613



*See Figures 3-1a, b for locations of wells, benchmarks, and extensometers

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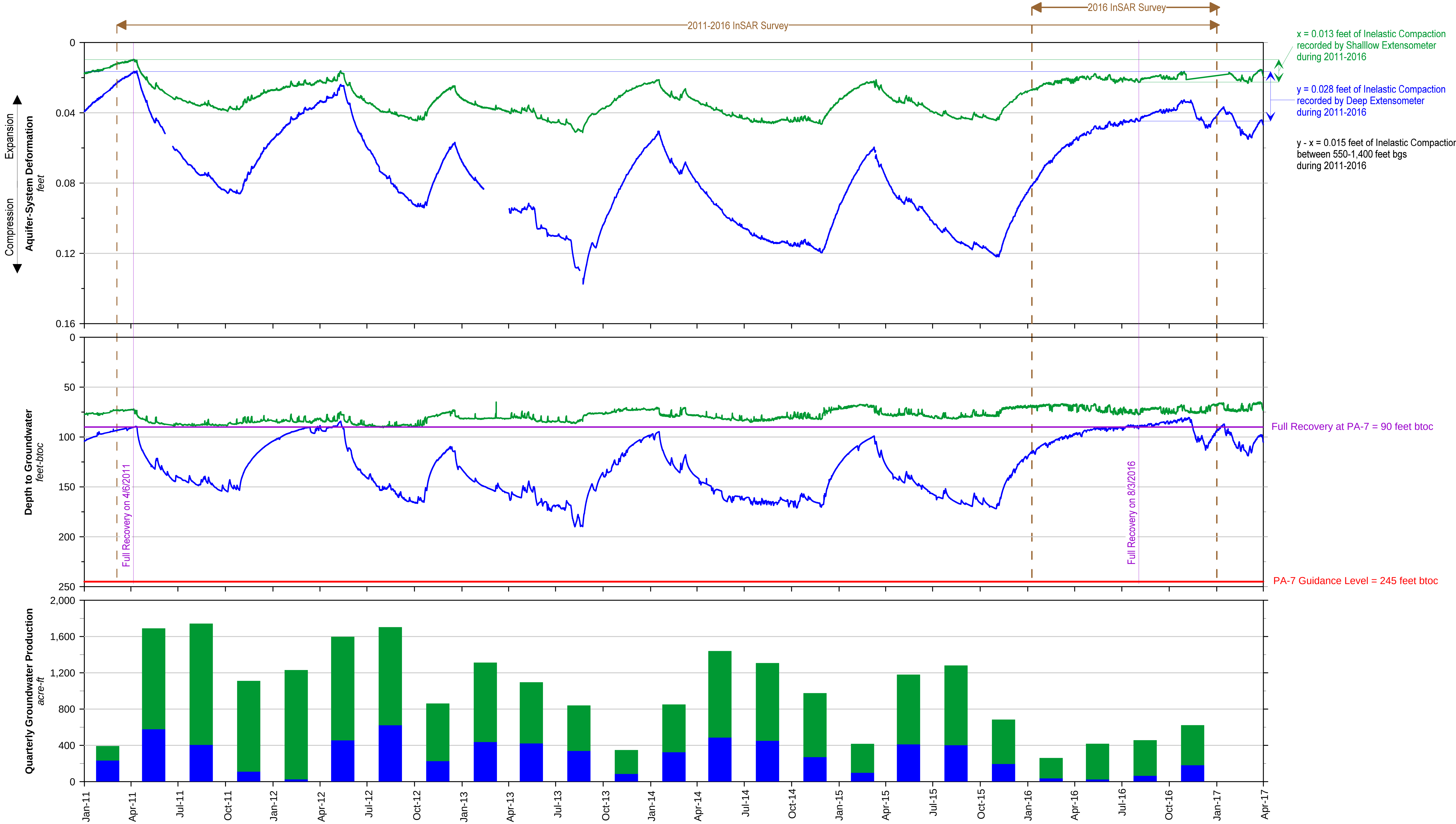
The History of Land Subsidence in the Managed Area

Figure 3-2



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Aquifer-System Deformation at Ayala Park
(Extensometer Depth Interval)
Shallow Extensometer
(30-550 ft-bgs)
Deep Extensometer
(30-1,400 ft-bgs)

Piezometric Levels at Ayala Park
(Perforated Depth Interval)
Shallow Piezometer
PA-10 (213-233 ft-bgs)
Deep Piezometer
PA-7 (438-448 ft-bgs)

Groundwater Production
(see Table 3-1 for well details)
Shallow Aquifer
Deep Aquifer

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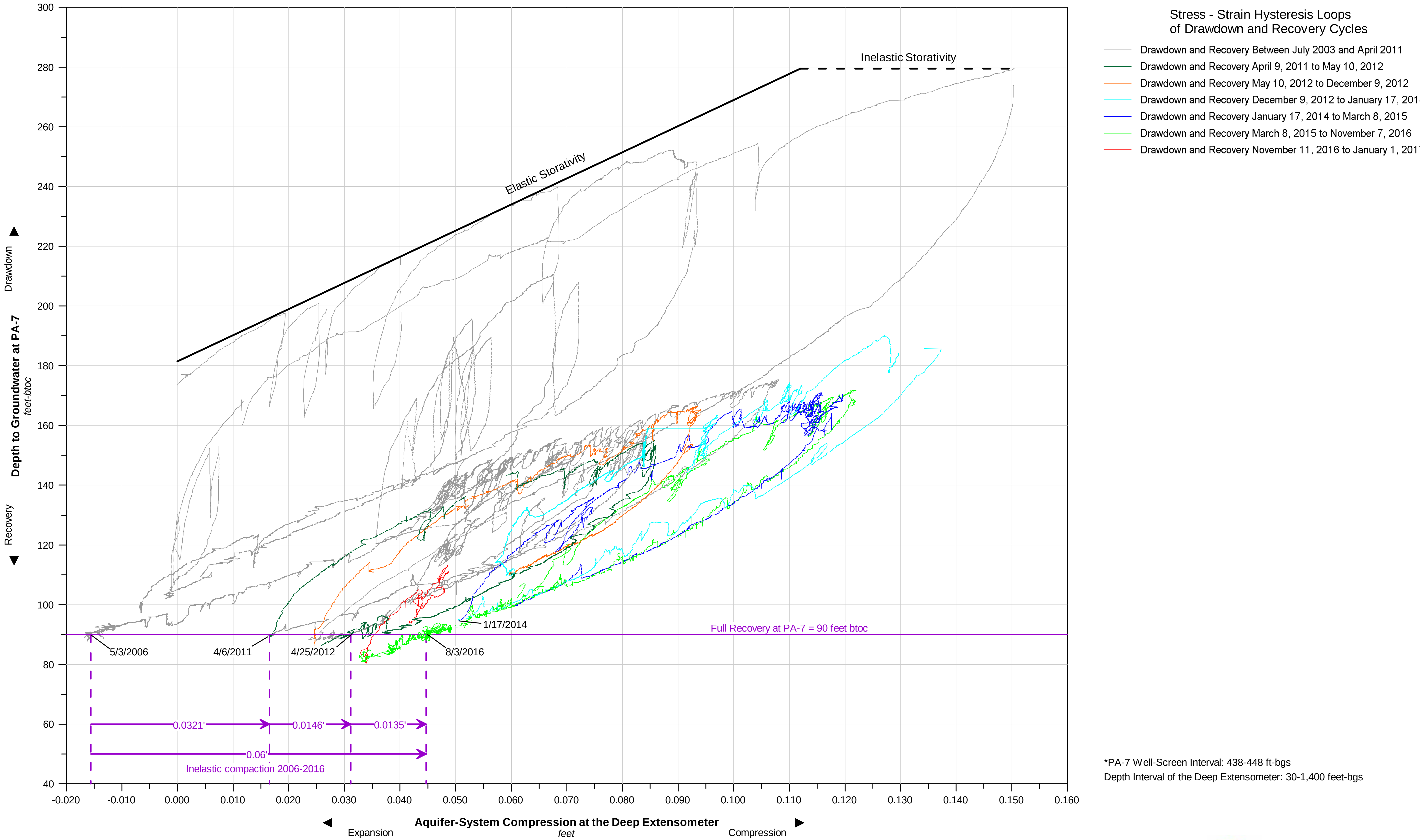
Stress and Strain within the Managed Area

Figure 3-3



*PA-7 Well-Screen Interval: 438-448 ft-bgs
Depth Interval of the Deep Extensometer: 30-1,400 feet-bgs

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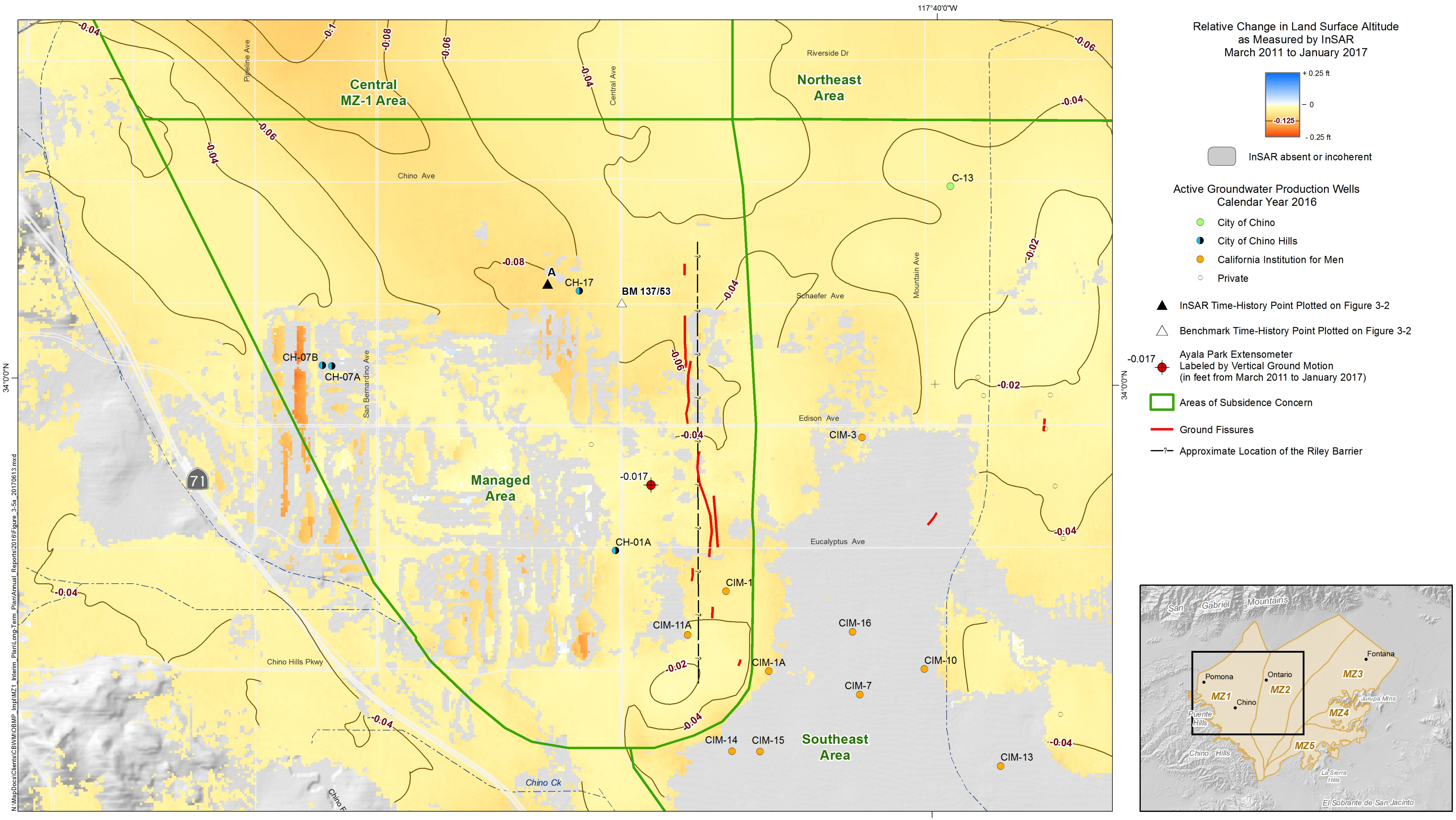
Stress-Strain Diagram
Ayala Park Extensometer

Figure 3-4



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Author: EM
Date: 9/1/2017
Document Name: Figure_3-5a_20170613

0 0.5 1 Miles
0 0.5 1 Kilometers

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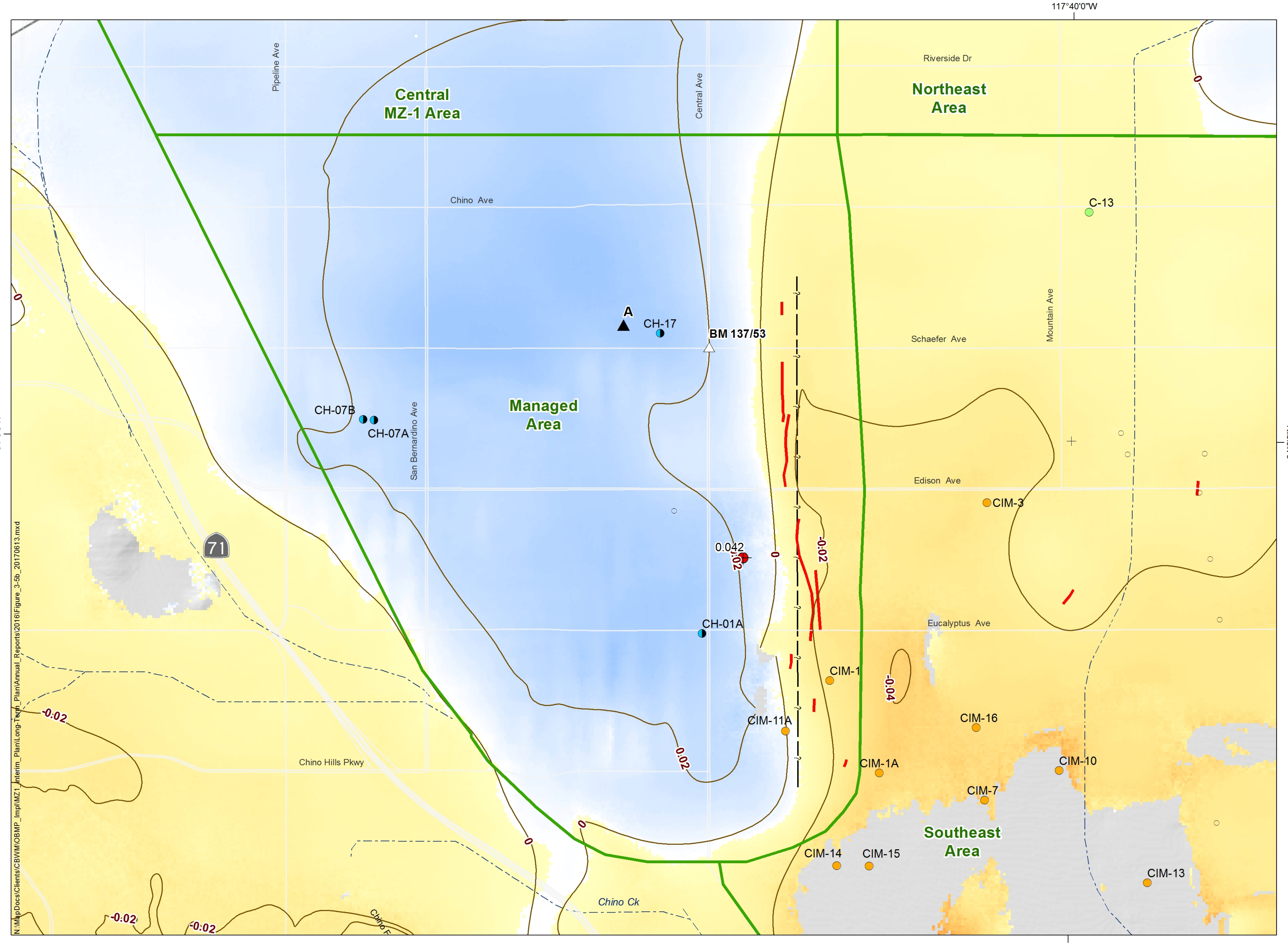
Vertical Ground-Motion in the Managed Area
2011-2016

Figure 3-5a



Relative Change in Land Surface Altitude as Measured by InSAR January 2016 to January 2017

+ 0.15 ft
0
-0.075
- 0.15 ft

InSAR absent or incoherent

Active Groundwater Production Wells Calendar Year 2016

- City of Chino
- City of Chino Hills
- California Institution for Men
- Private

InSAR Time-History Point Plotted on Figure 3-2

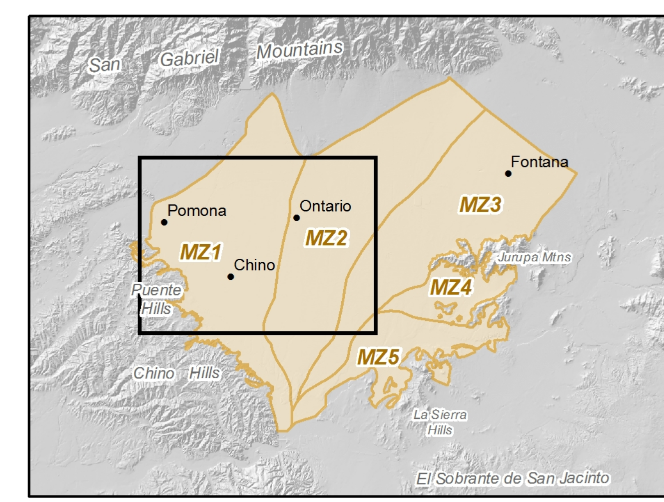
Benchmark Time-History Point Plotted on Figure 3-2

0.042 Ayala Park Extensometer Labeled by Vertical Ground Motion (in feet from January 2016 to January 2017)

Areas of Subsidence Concern

Ground Fissures

Approximate Location of the Riley Barrier



N:\MapDocs\Clients\CBWM\OBMP_Impl\MZ1_Interim_Plan\Long-Term_Plan\Annual_Reports\2016\Figure_3-5b_20170613.mxd

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Document Name: Figure_3-5b_20170613

0 0.5 1 Miles

0 0.5 1 Kilometers

Chino Basin Watermaster

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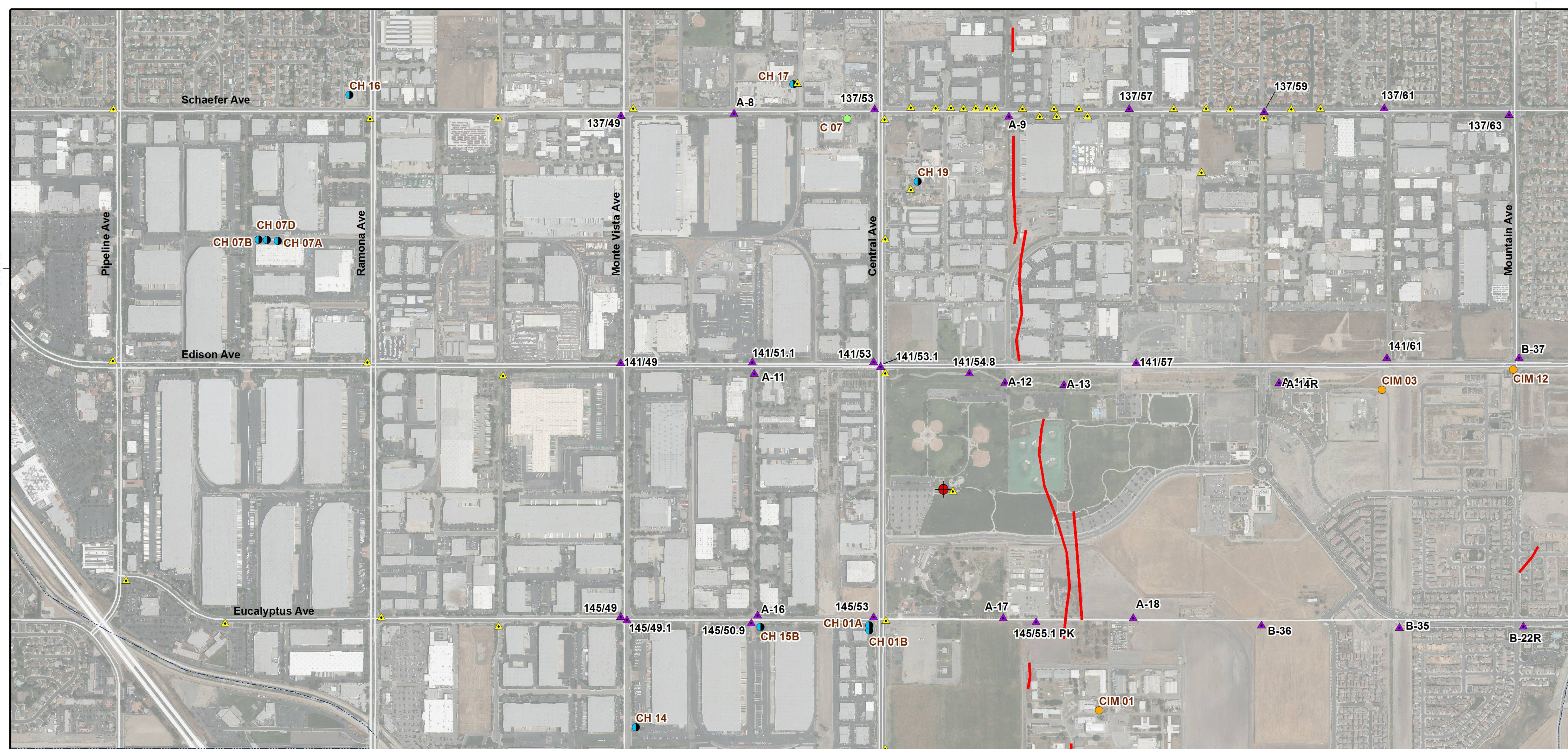
2016 Annual Report

Vertical Ground-Motion in the Managed Area
2016

Figure 3-5b



Survey Benchmarks

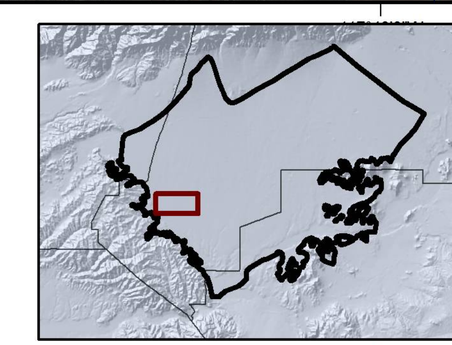
- Existing Benchmark Monument
- Existing Benchmark Monument with Survey Data shown in Figures 3-6b through 3-6d

Ground Fissures

Deep Extensometer at Ayala Park

Active Production Wells by Owner

- City of Chino
- City of Chino Hills
- California Institution for Men



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Author: GAR
Date: 20170712
File: Figure_3-6a.mxd

N

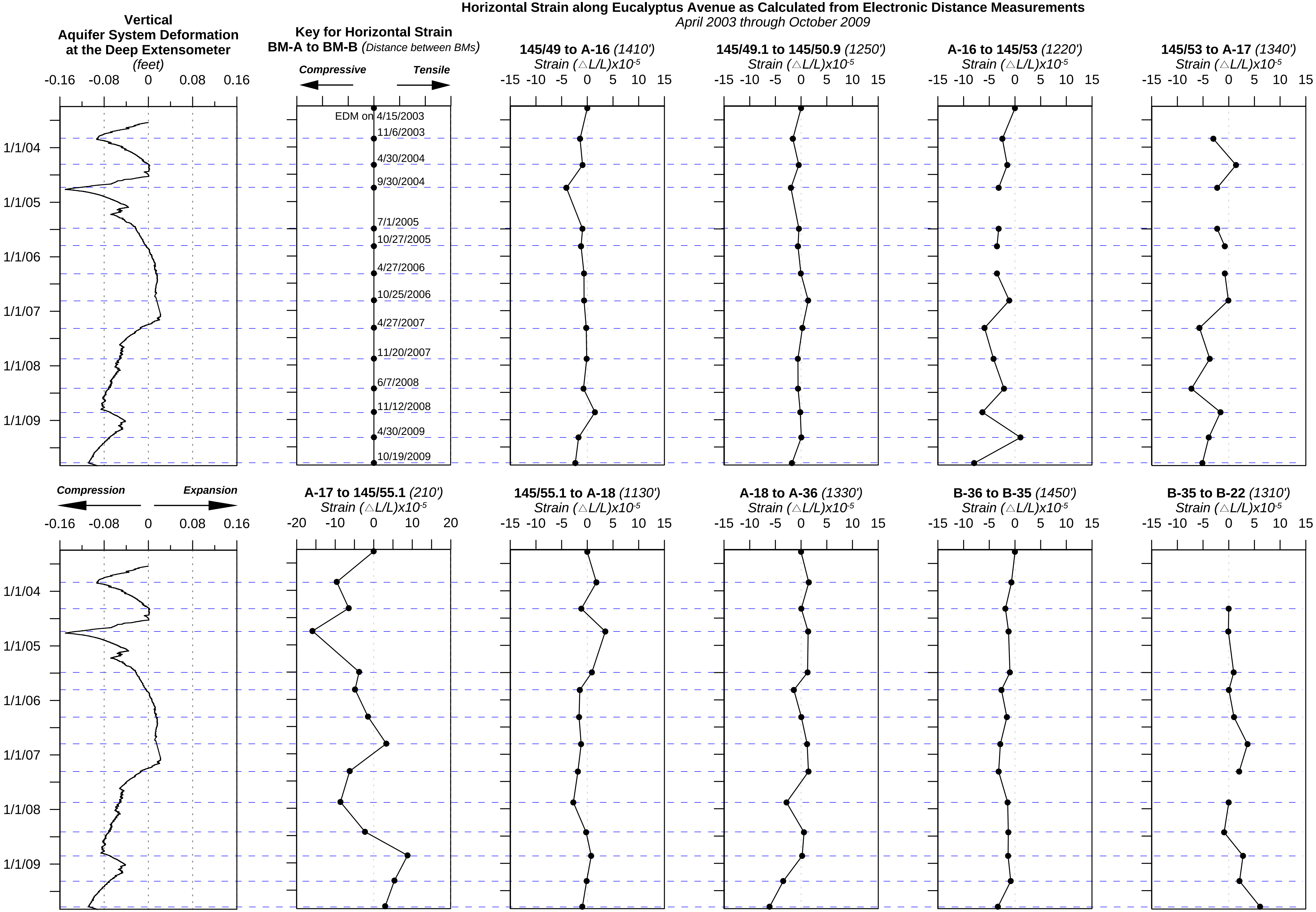
0 1,000 2,000 Feet

0 500 Meters

Map of Widely-Spaced Benchmark Monuments
Managed Area: 2003-2009

Figure 3-6a

Figure 3-6b
Horizontal Strain along Eucalyptus Avenue as Calculated from Electronic Distance Measurements
April 2003 through October 2009

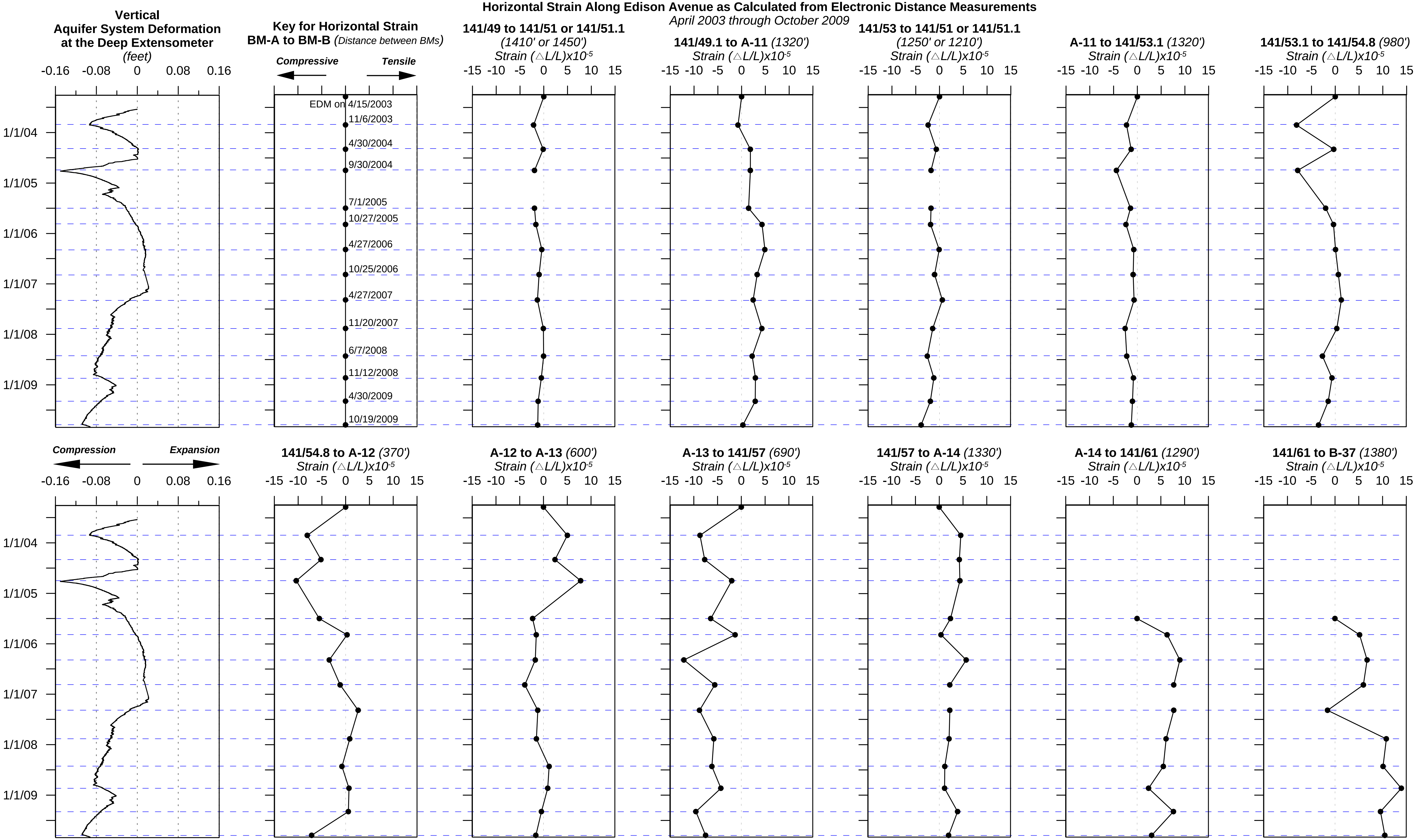


Strain_GWL_Schaefer_05-09_v2.grf
Printed on 3/14/2017

Figure 3-6c

Horizontal Strain Along Edison Avenue as Calculated from Electronic Distance Measurements

April 2003 through October 2009



Strain_GWL_Schaefer_05-09_v2.grf
Printed on 3/14/2017

Figure 3-6d
Horizontal Strain Along Schaefer Avenue as Calculated from Electronic Distance Measurements
October 2005 through October 2009

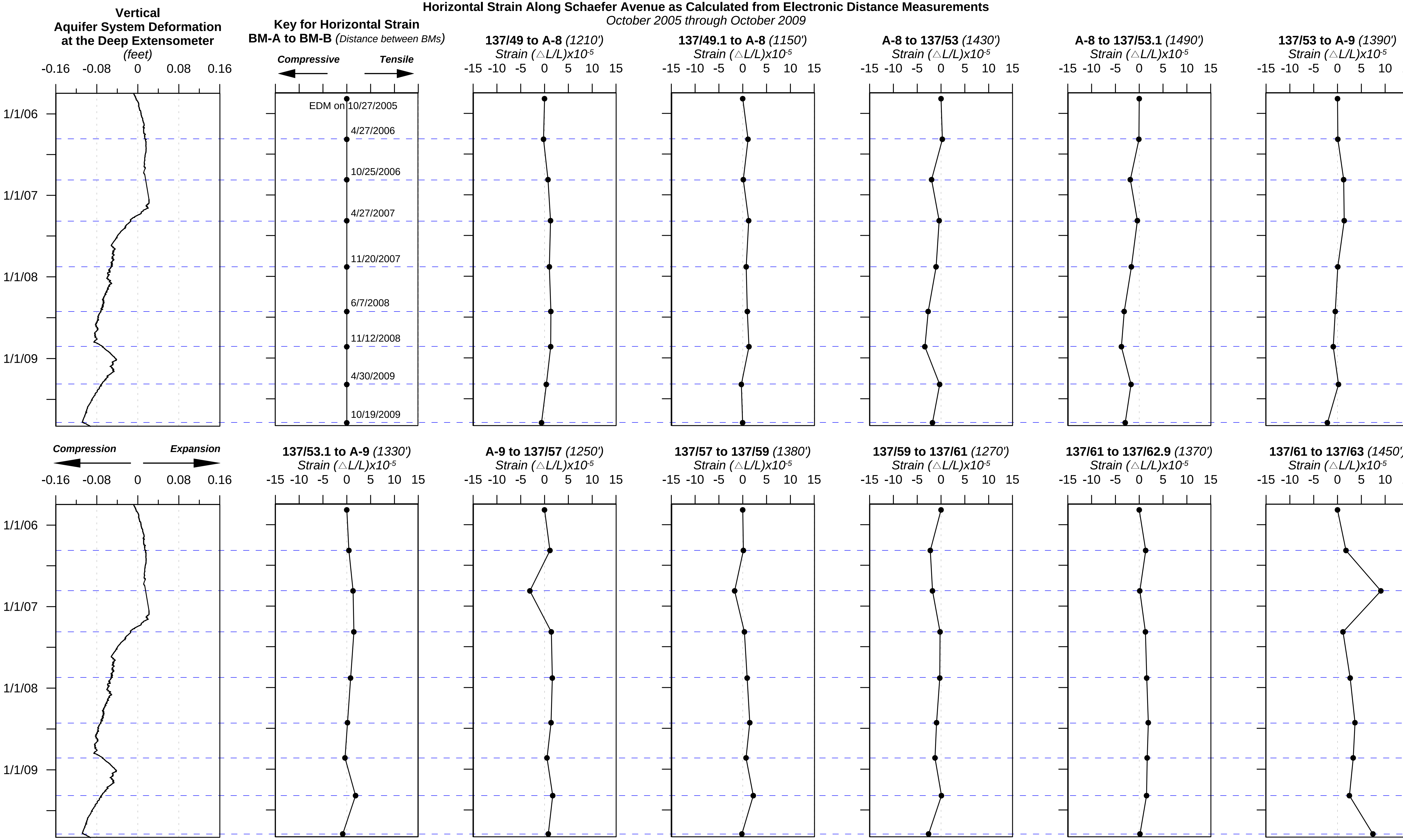
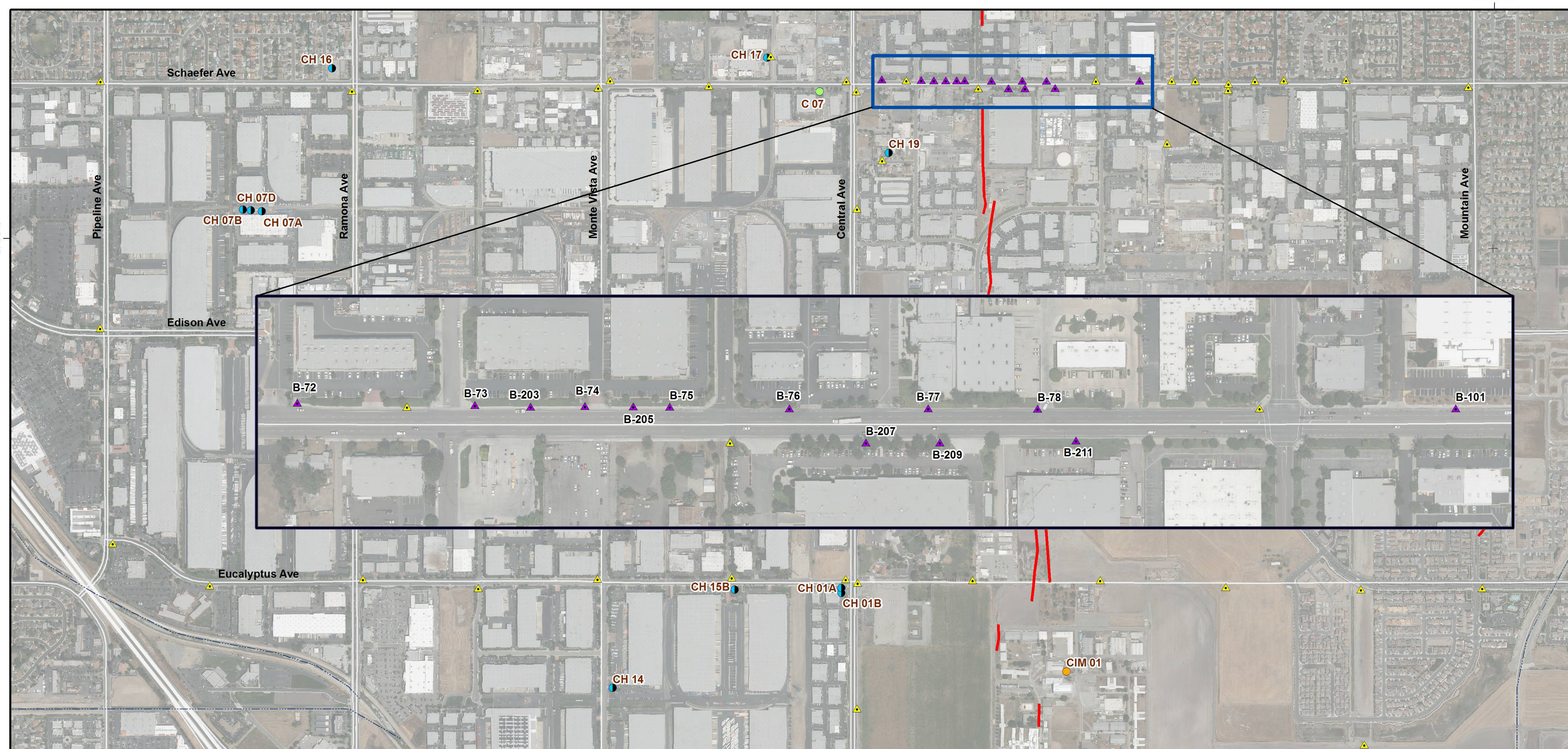


Fig_2a_Schaefer_05-09.grf
Printed on 4/6/2017



Survey Benchmarks

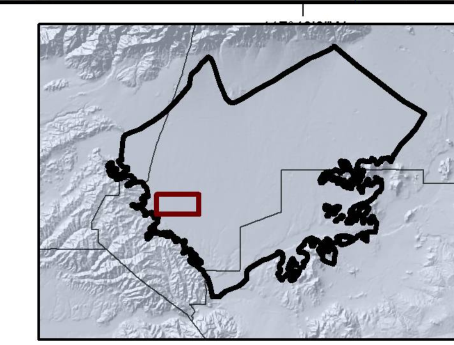
- Existing Benchmark Monument
- Existing Benchmark Monument with Survey Data shown in Figure 3-7b

Ground Fissures

Deep Extensometer at Ayala Park

Active Production Wells by Owner

- City of Chino
- City of Chino Hills
- California Institution for Men



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Author: GAR
Date: 20170712
File: Figure_3-7a.mxd

Map of Closely-Spaced Benchmark Monuments Across the Fissure Zone Along Schaefer Avenue

Figure 3-7a

Figure 3-7b
Horizontal Strain Along Schaefer Avenue as Calculated from Electronic Distance Measurements
April 2011 through March 2016

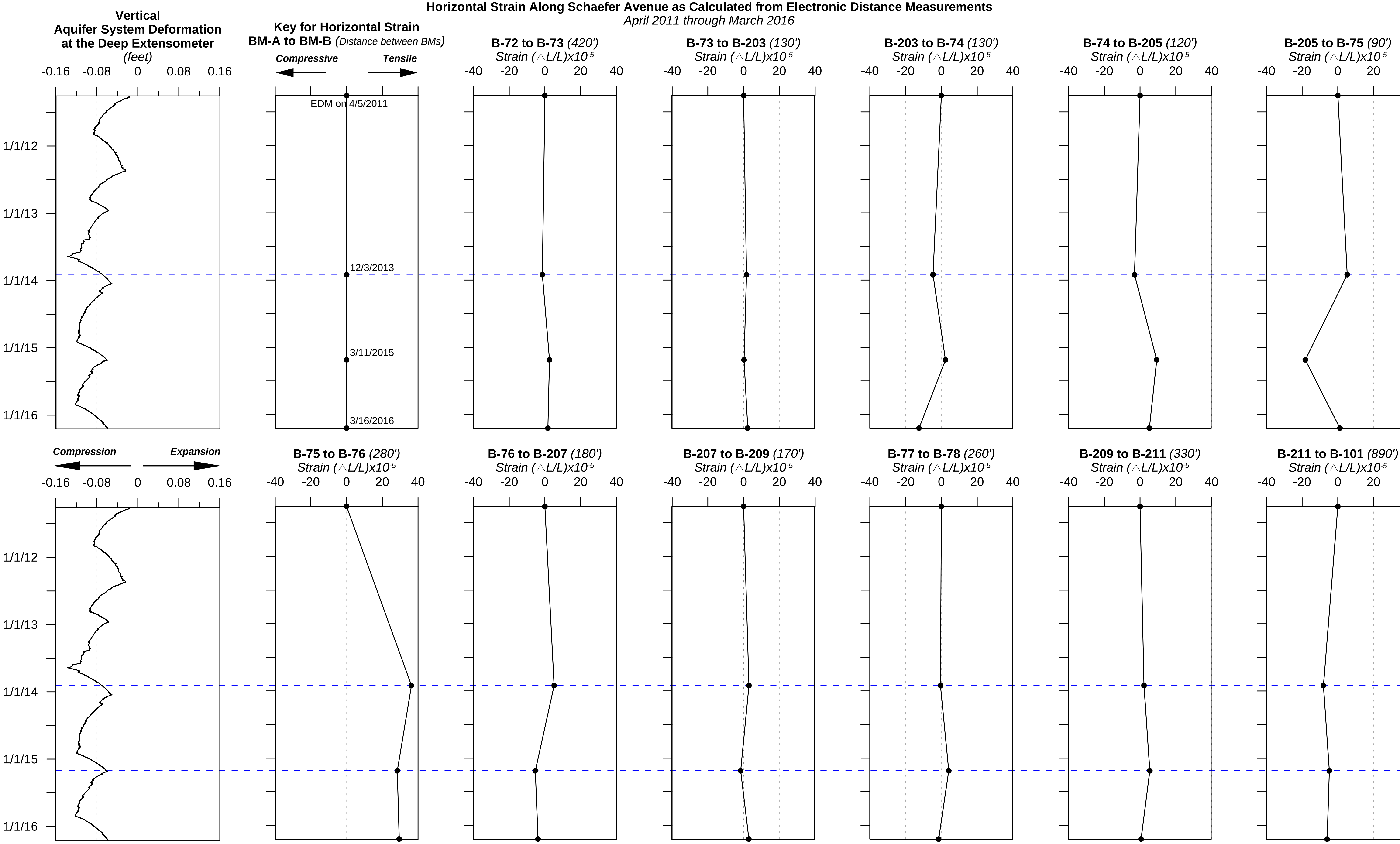
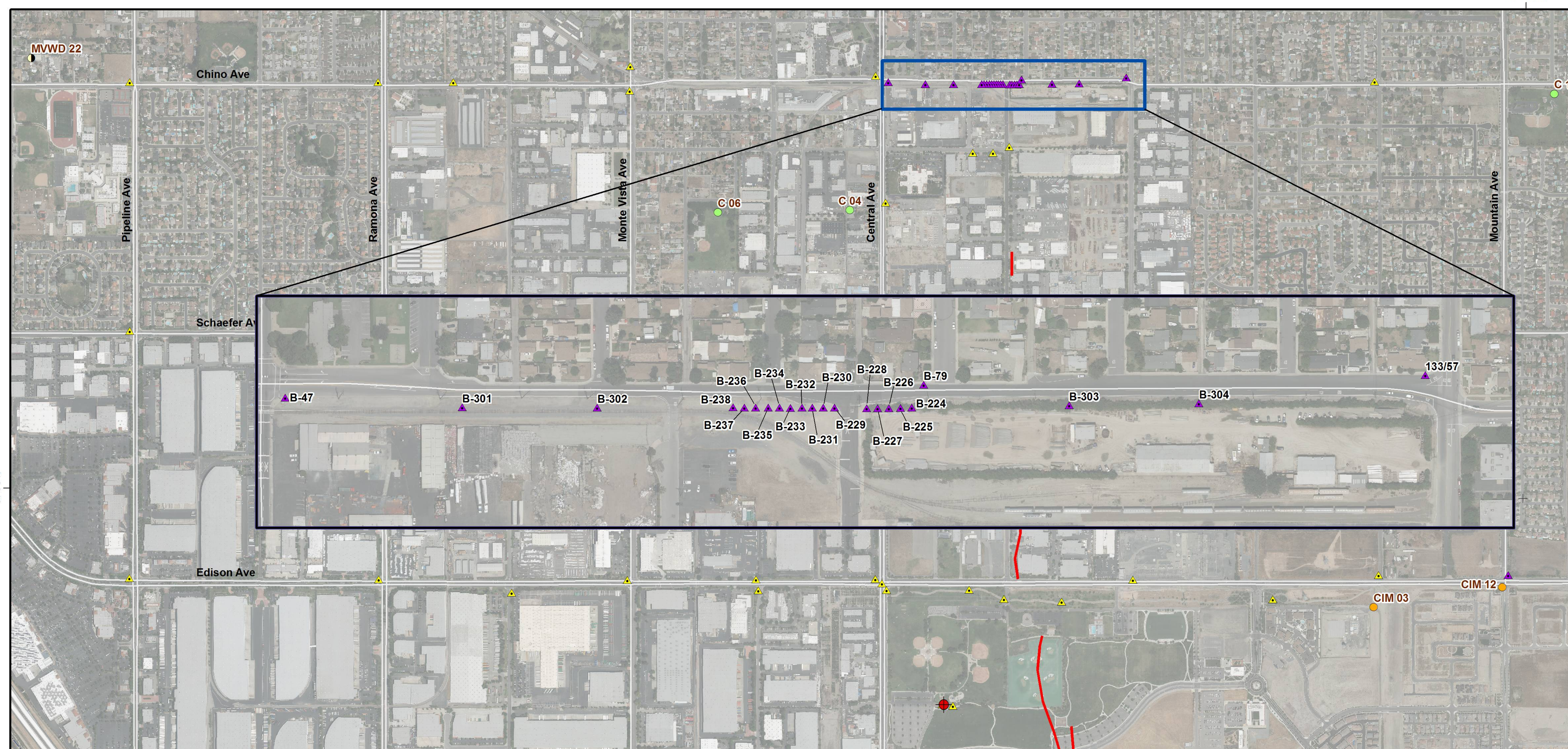


Fig_6_Schaefer_11-16.grf
Printed on 4/6/2017



Survey Benchmarks

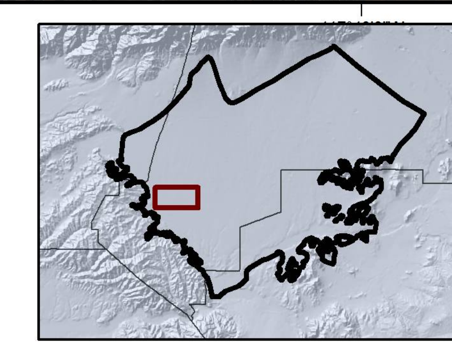
- Existing Benchmark Monument
- Existing Benchmark Monument with Survey Data shown in Figures 3-8b and 3-8c

Ground Fissures

Deep Extensometer at Ayala Park

Active Production Wells by Owner

- City of Chino
- City of Chino Hills
- California Institution for Men
- Monte Vista Water District



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Author: GAR
Date: 20170712
File: Figure_3-8a.mxd

N

0 1,000 2,000 Feet

0 500 Meters

Map of Closely-Spaced Benchmark Monuments Across the Fissure Zone Along Chino Avenue

Figure 3-8a

Figure 3-8b
Horizontal Strain Along Western Chino Avenue as Calculated from Electronic Distance Measurements
April 2011 through March 2016

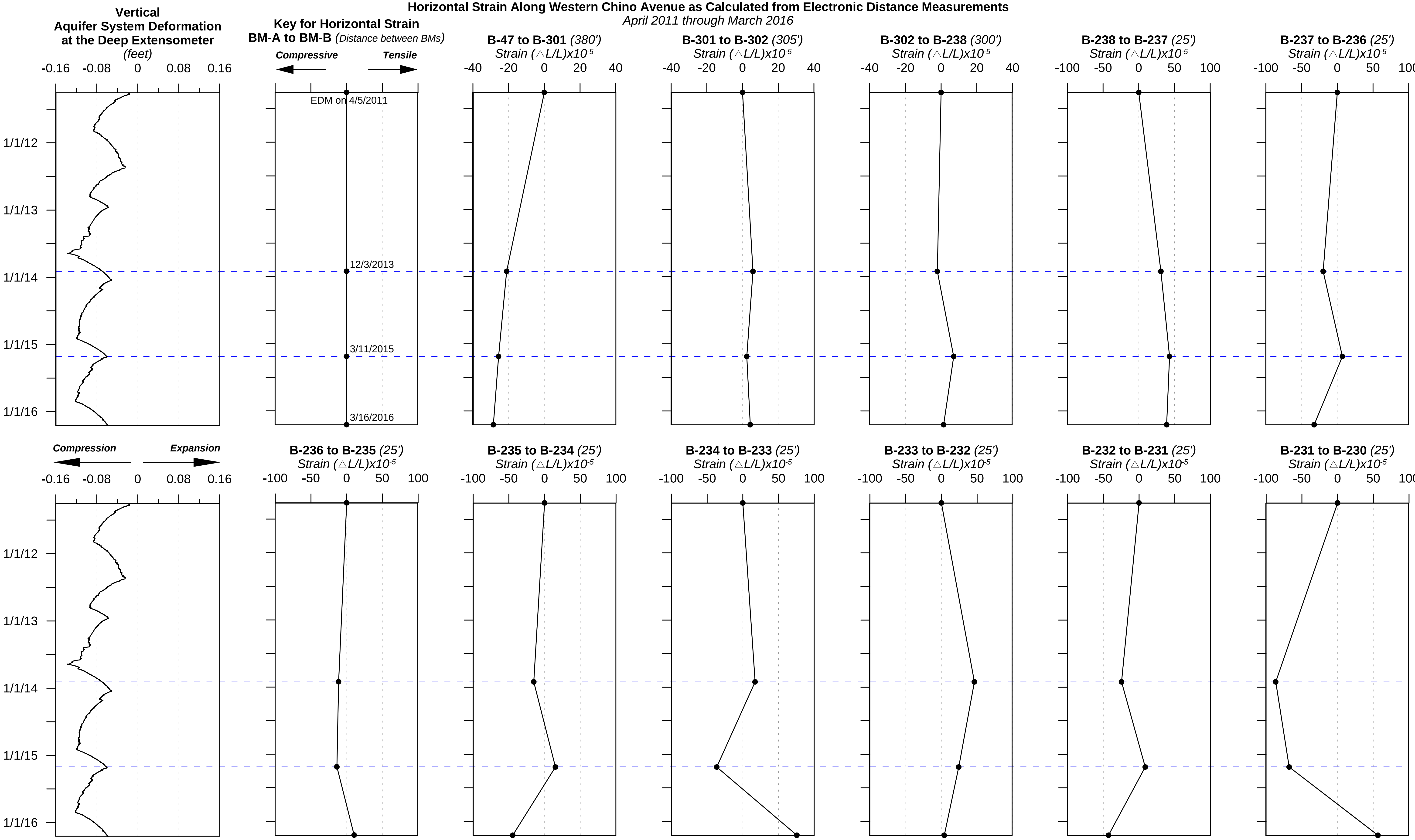


Fig_4a_Chino_10-16_p1.grf
Printed on 4/6/2017

Figure 3-8c
Horizontal Strain Along Eastern Chino Avenue as Calculated from Electronic Distance Measurements
April 2011 through March 2016

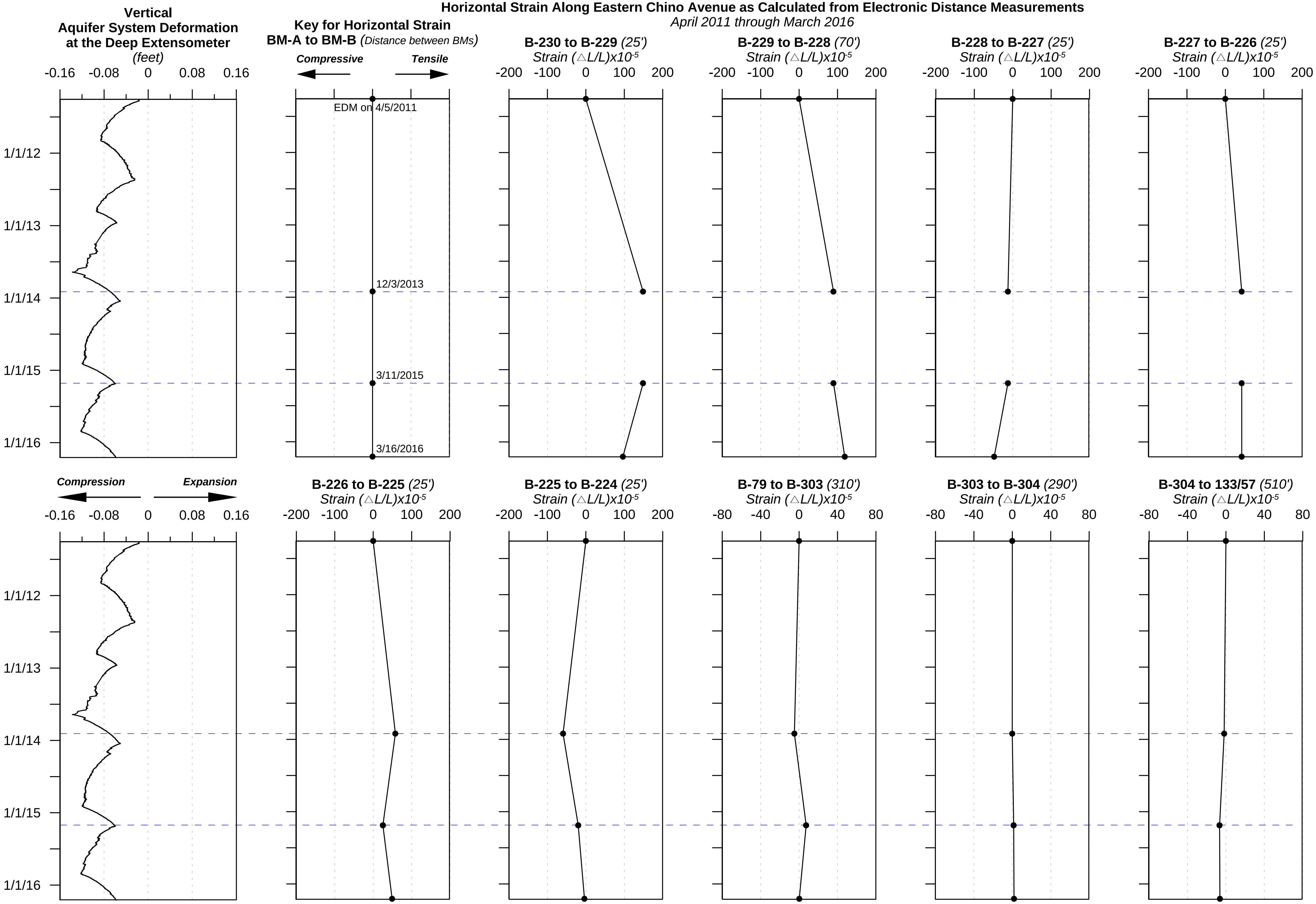
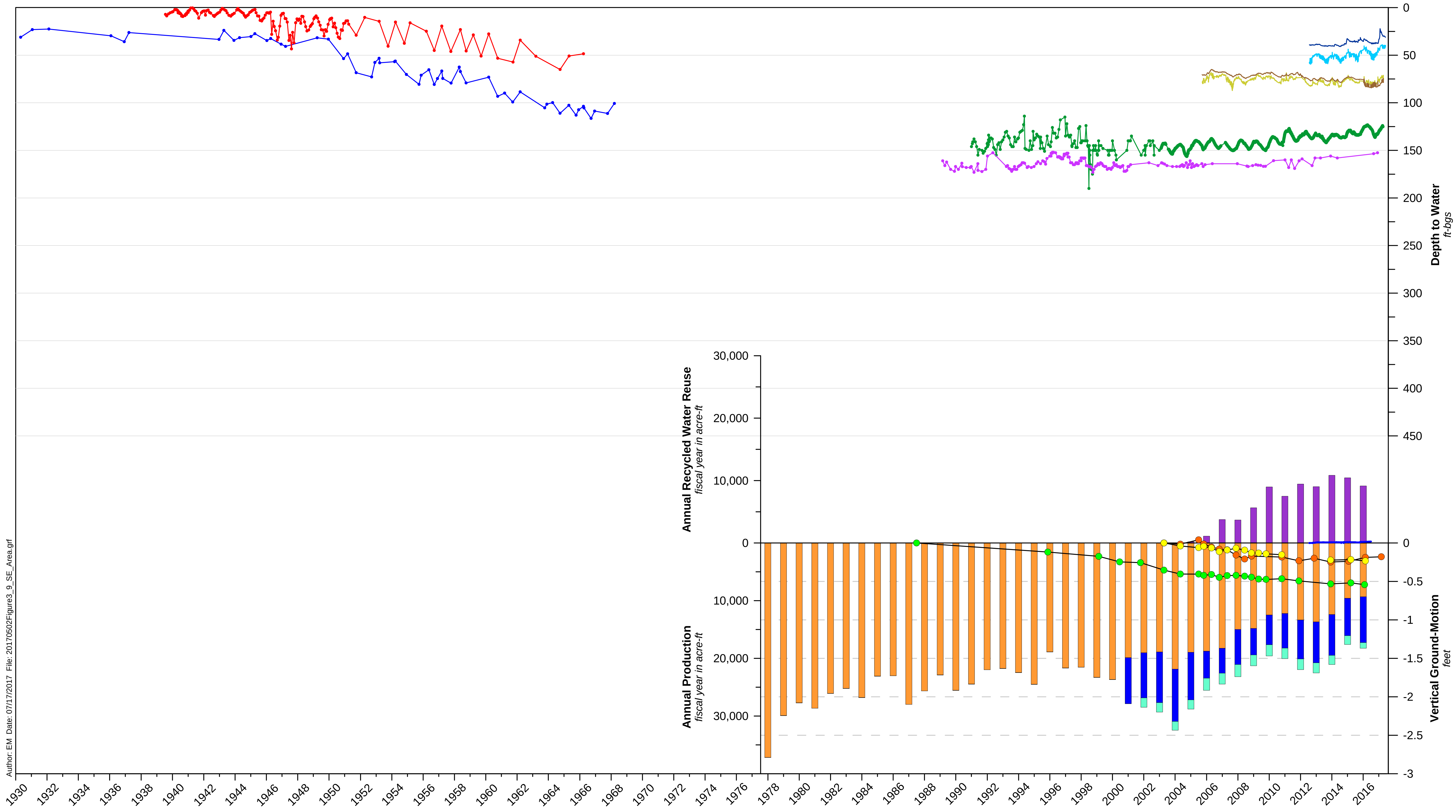


Fig_4b_Chino_11-16_p1.grf
Printed on 4/6/2017



*See Figures 3-1a, b for locations of wells, benchmarks, and extensometers

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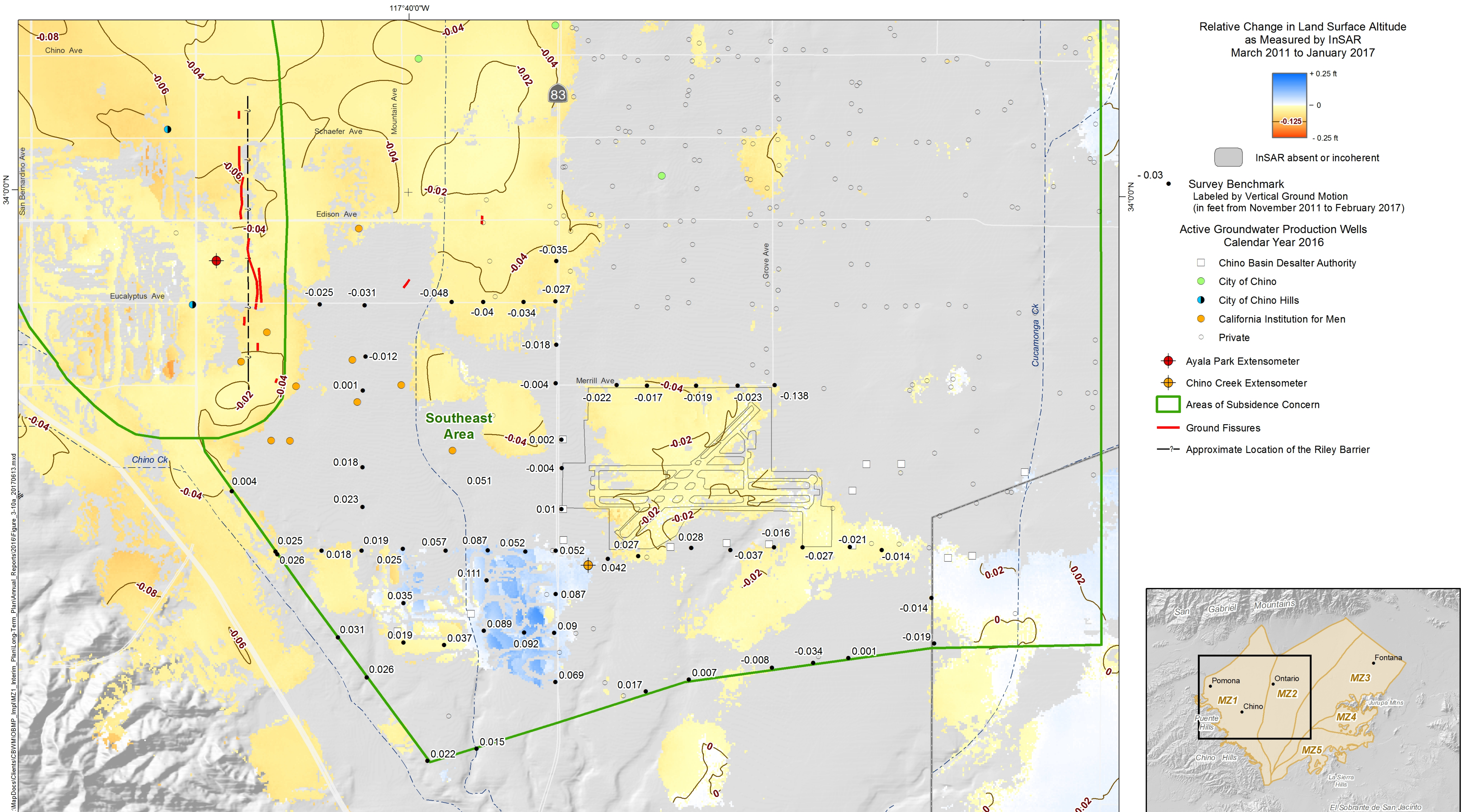
2016 Annual Report

The History of Land Subsidence in the Southeast Area

Figure 3-9



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Author: EM
Date: 9/1/2017
Document Name: Figure_3-10a_20170613

0 0.5 1 Miles
0 0.5 1 Kilometers

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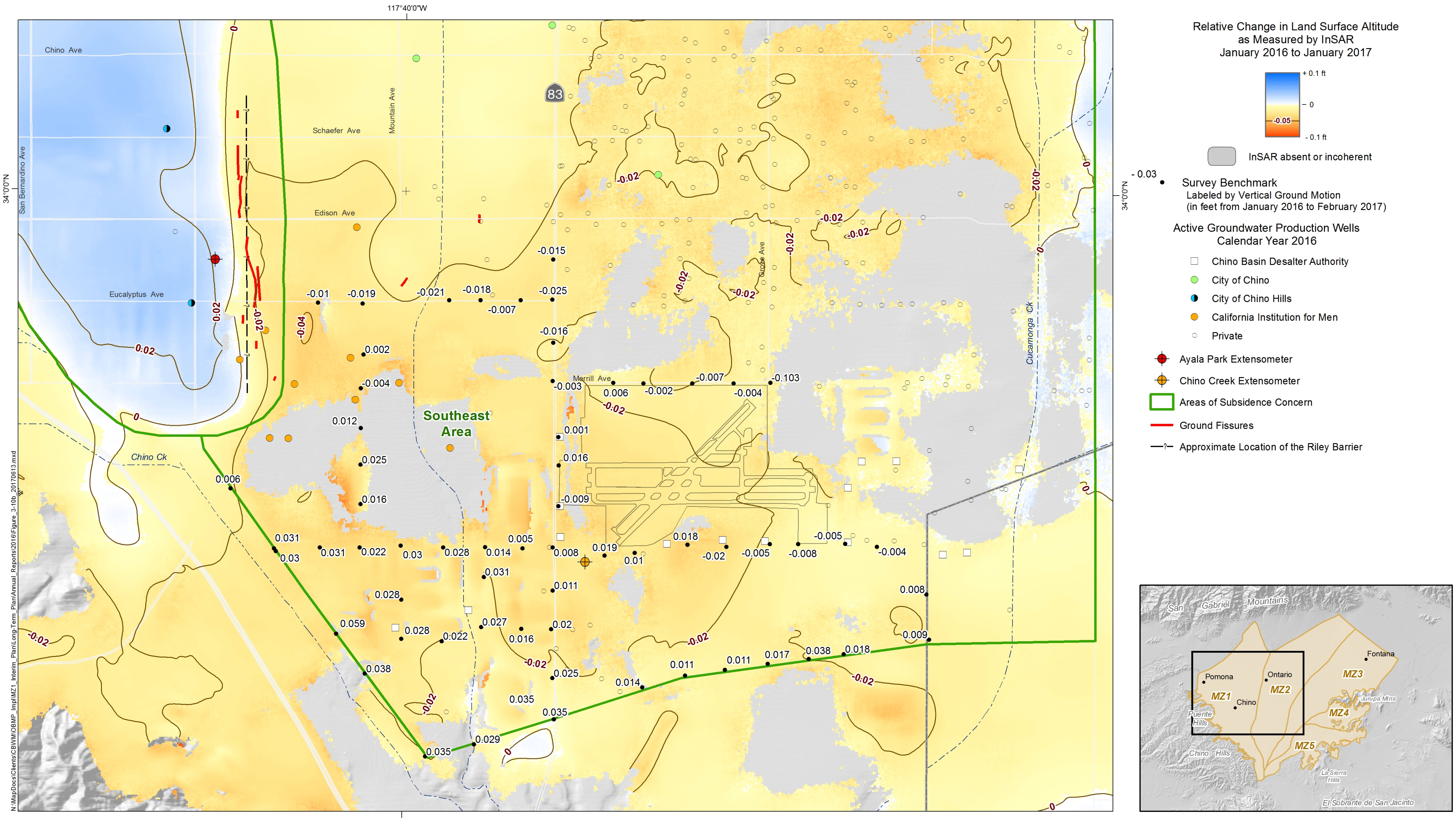
2016 Annual Report

Vertical Ground-Motion in the Southeast Area
2011- 2016

Figure 3-10a



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Author: EM
Date: 9/1/2017
Document Name: Figure_3-10b_20170613

0 0.5 1 Miles
0 0.5 1 Kilometers

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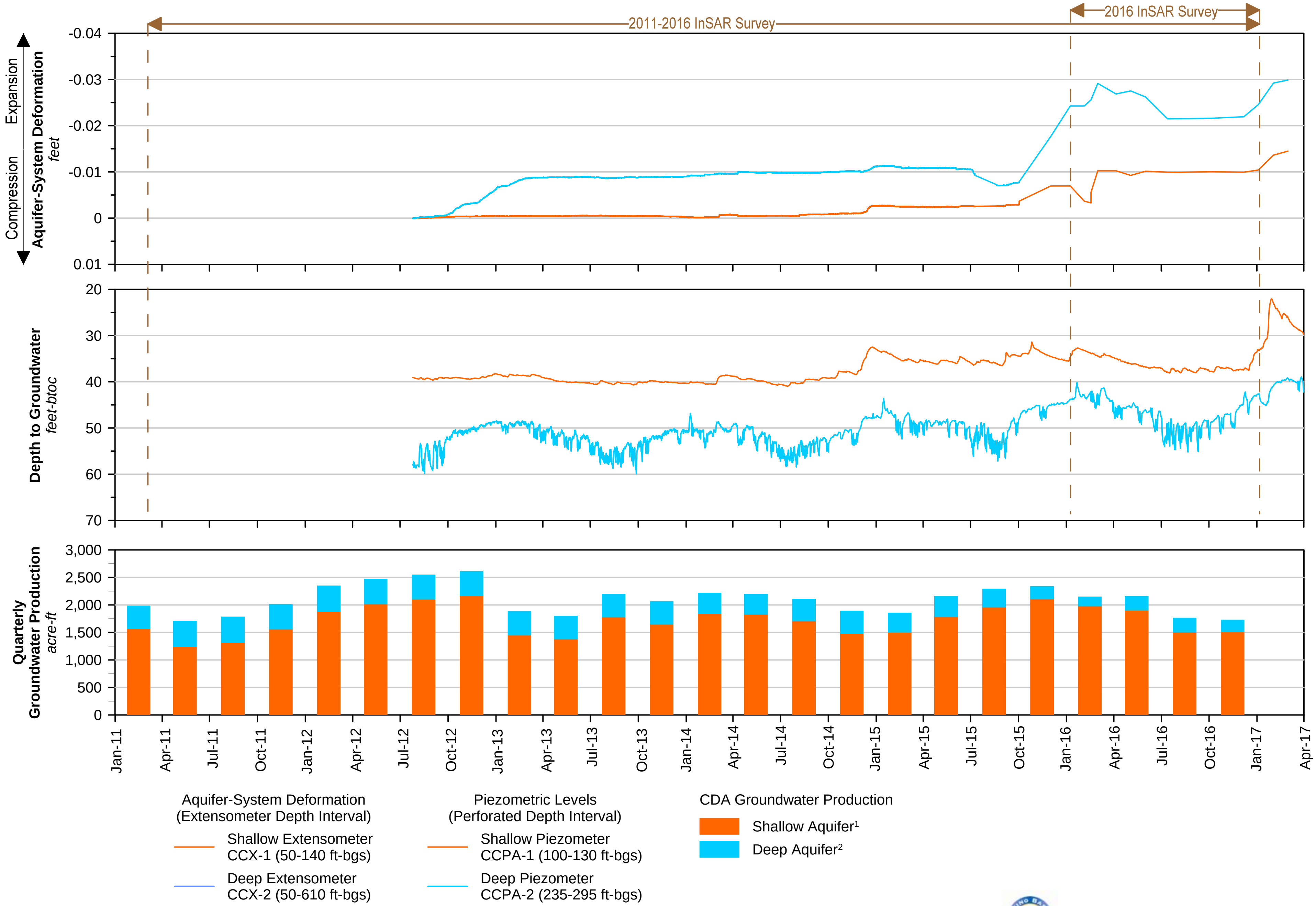
Vertical Ground-Motion in the Southeast Area
2016

Figure 3-10b



1 = CDA-5 through 11, 16, 17, 20 and 21
2 = CDA-1 through 4

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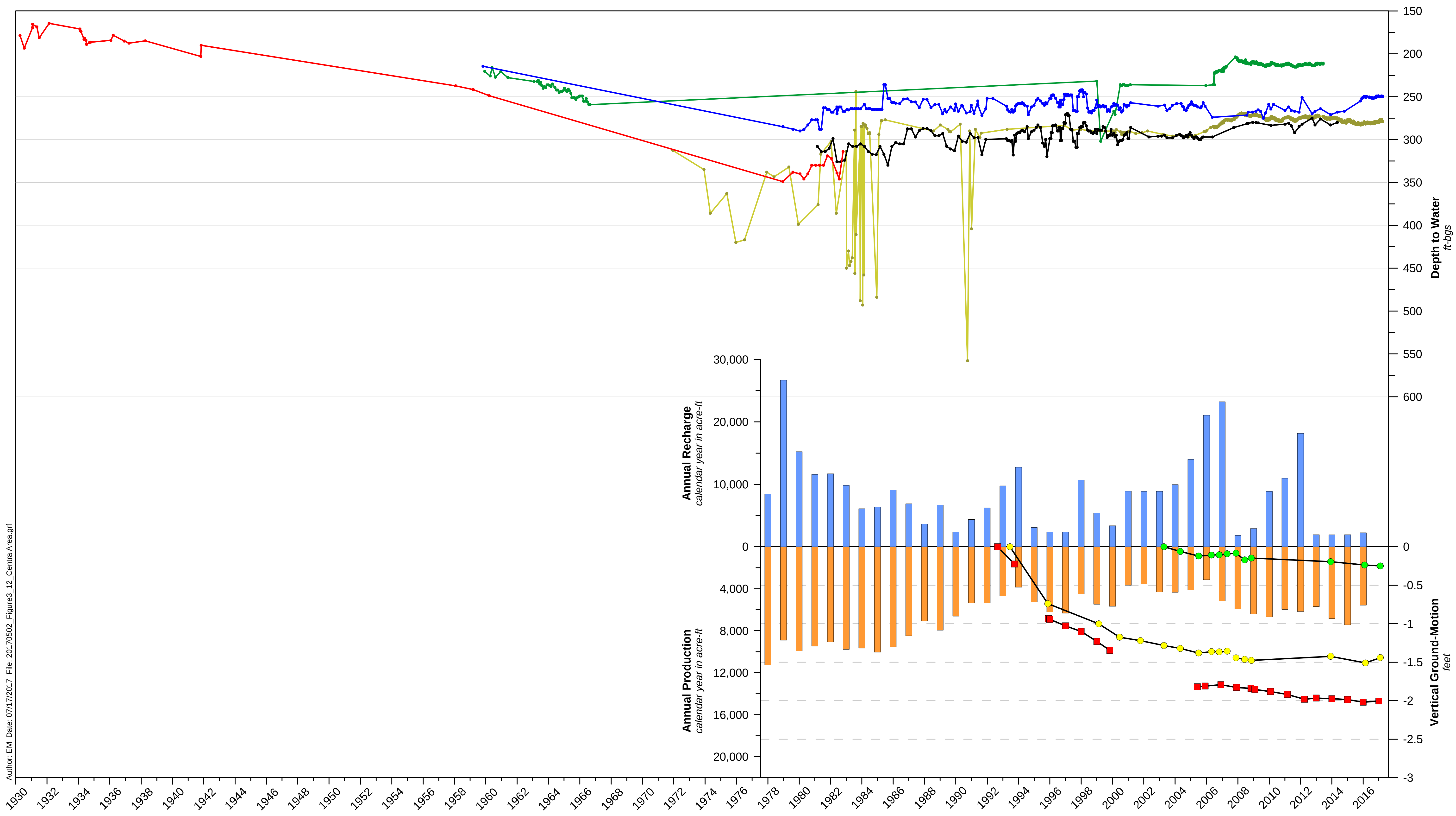
Stress and Strain Within the Southeast Area

Figure 3-11



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*See Figures 3-1a, b for locations of wells, benchmarks, and extensometers

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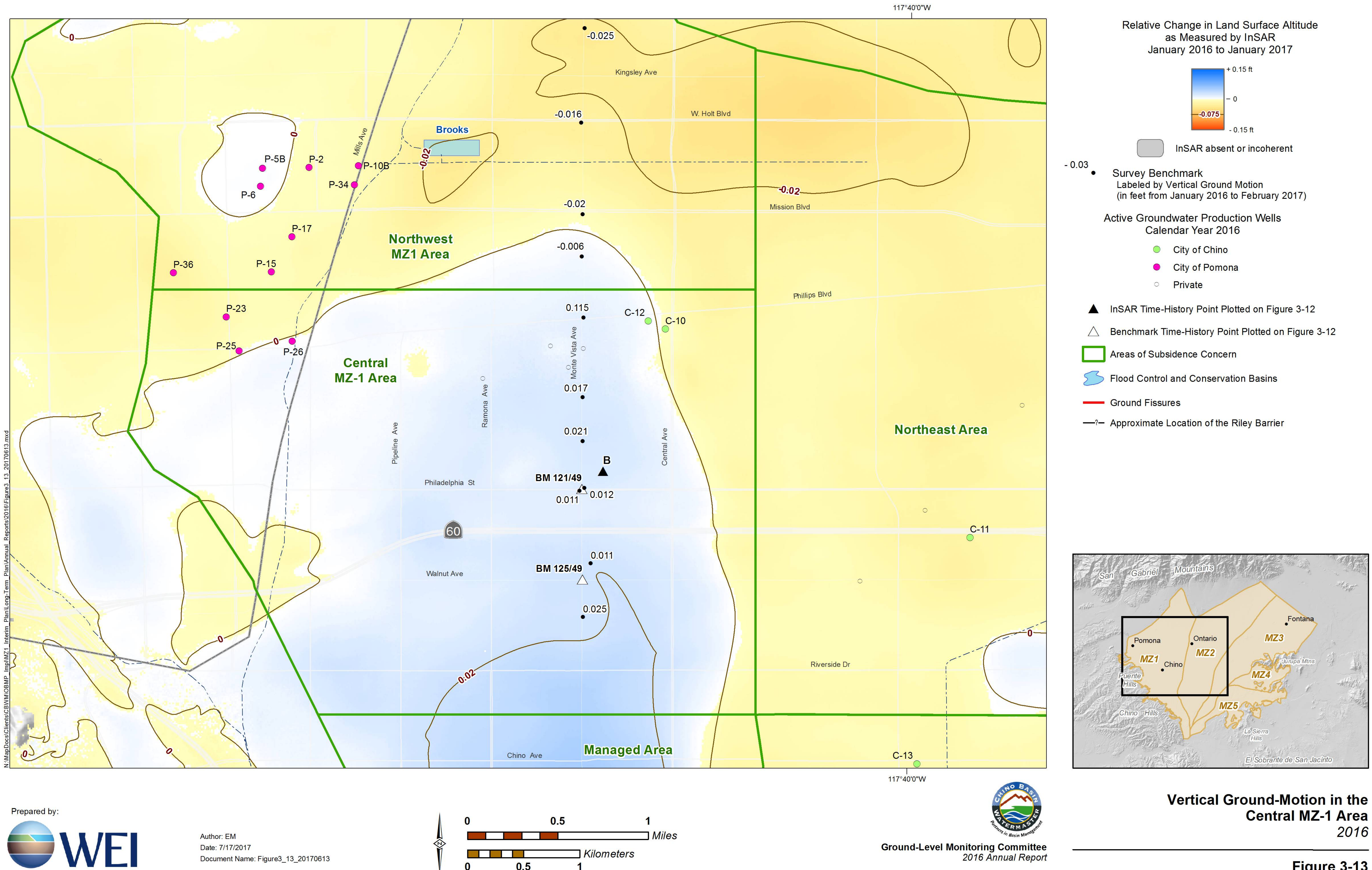
The History of Land Subsidence in the Central MZ-1 Area

Figure 3-12



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Author: EM
Date: 7/17/2017
Document Name: Figure3_13_20170613

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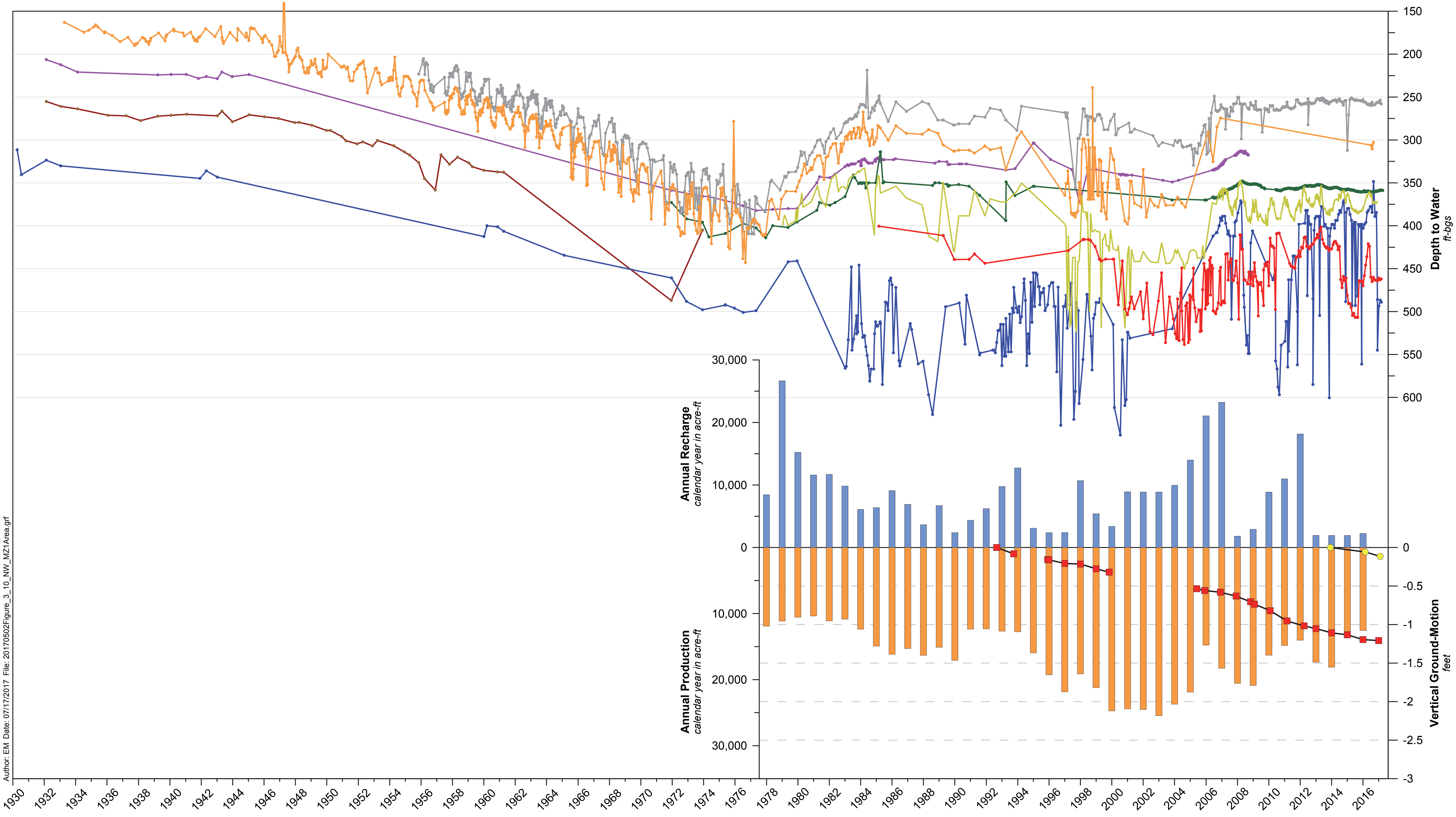
Vertical Ground-Motion in the Central MZ-1 Area
2016

Figure 3-13



*See Figures 3-1a, b for locations of wells, benchmarks, and extensometers

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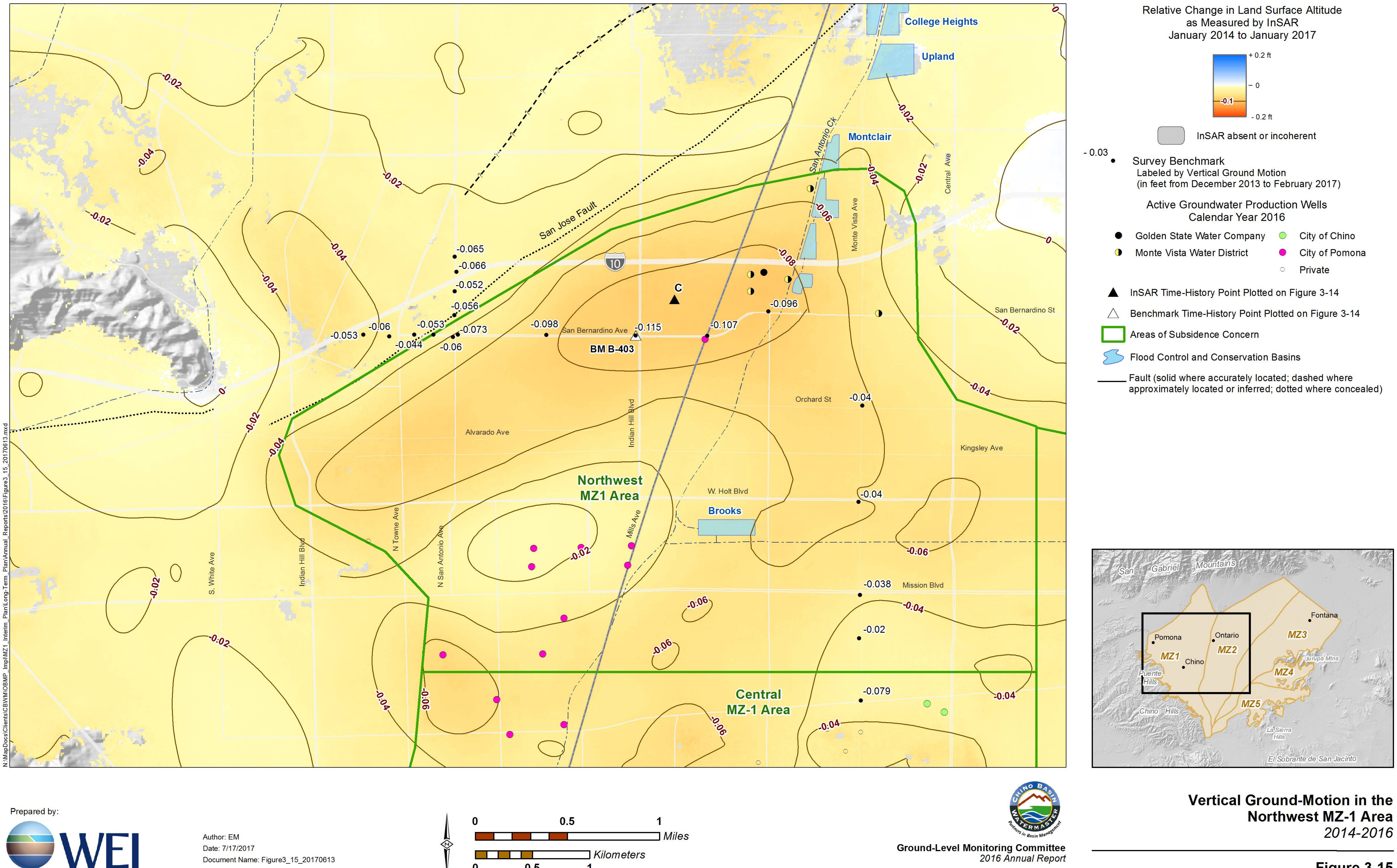
The History of Land Subsidence in the Northwest MZ1 Area

Ground-Level Monitoring Committee
2016 Annual Report

Figure 3-14



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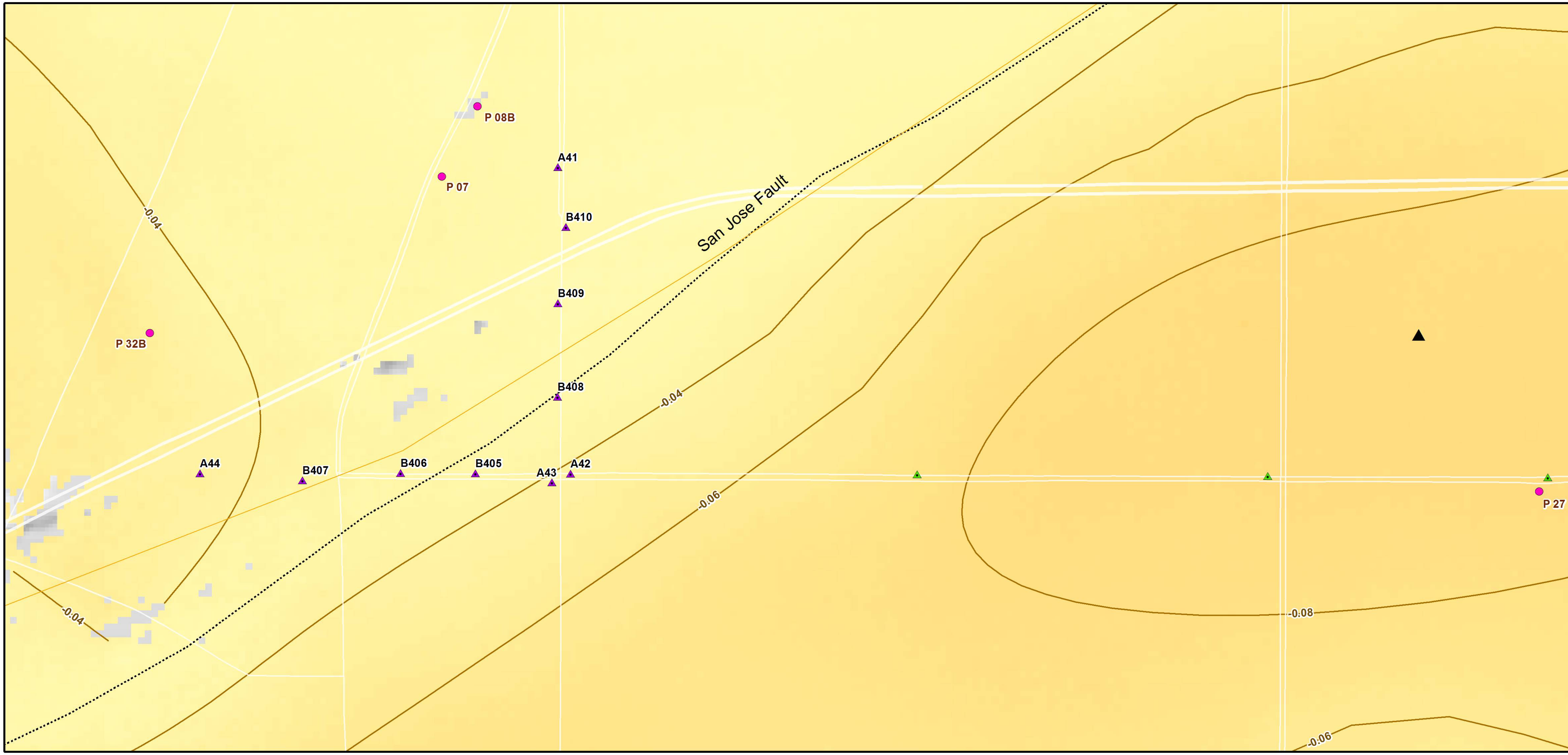
Date: 7/17/2017
Document Name: Figure3_15_20170613

Ground-Level Monitoring Committee
2016 Annual Report

Vertical Ground-Motion in the Northwest MZ-1 Area
2014-2016

Figure 3-15



+ 0.25 ft
0
-0.1
- 0.25

Relative Change in Land Surface Altitude as Measured by InSAR Jan-2014 to Jan-2017

InSAR data incoherent

Survey Benchmarks

Existing Benchmark Monument

Existing Benchmark Monument with Survey Data shown in Figure 3-17

InSAR Time-History Point Plotted on Figure 3-17

Active Production Wells by Owner

City of Pomona

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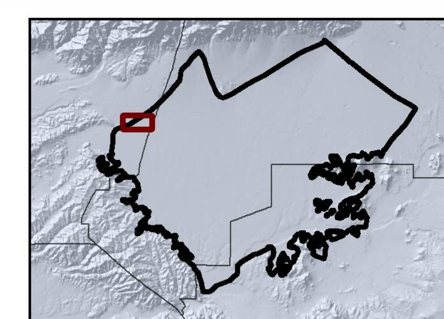
WEI
WILDERMUTH ENVIRONMENTAL, INC.

Author: GAR
Date: 20170712
File: Figure_3-16.mxd

N

0 1,000 2,000 Feet

0 500 Meters



Benchmark Monuments Accross the San Jose Fault

Figure 3-16

Figure 3-17

Horizontal Strain Across the San Jose Fault as Calculated from Electronic Distance Measurements

December 2013 through February 2017

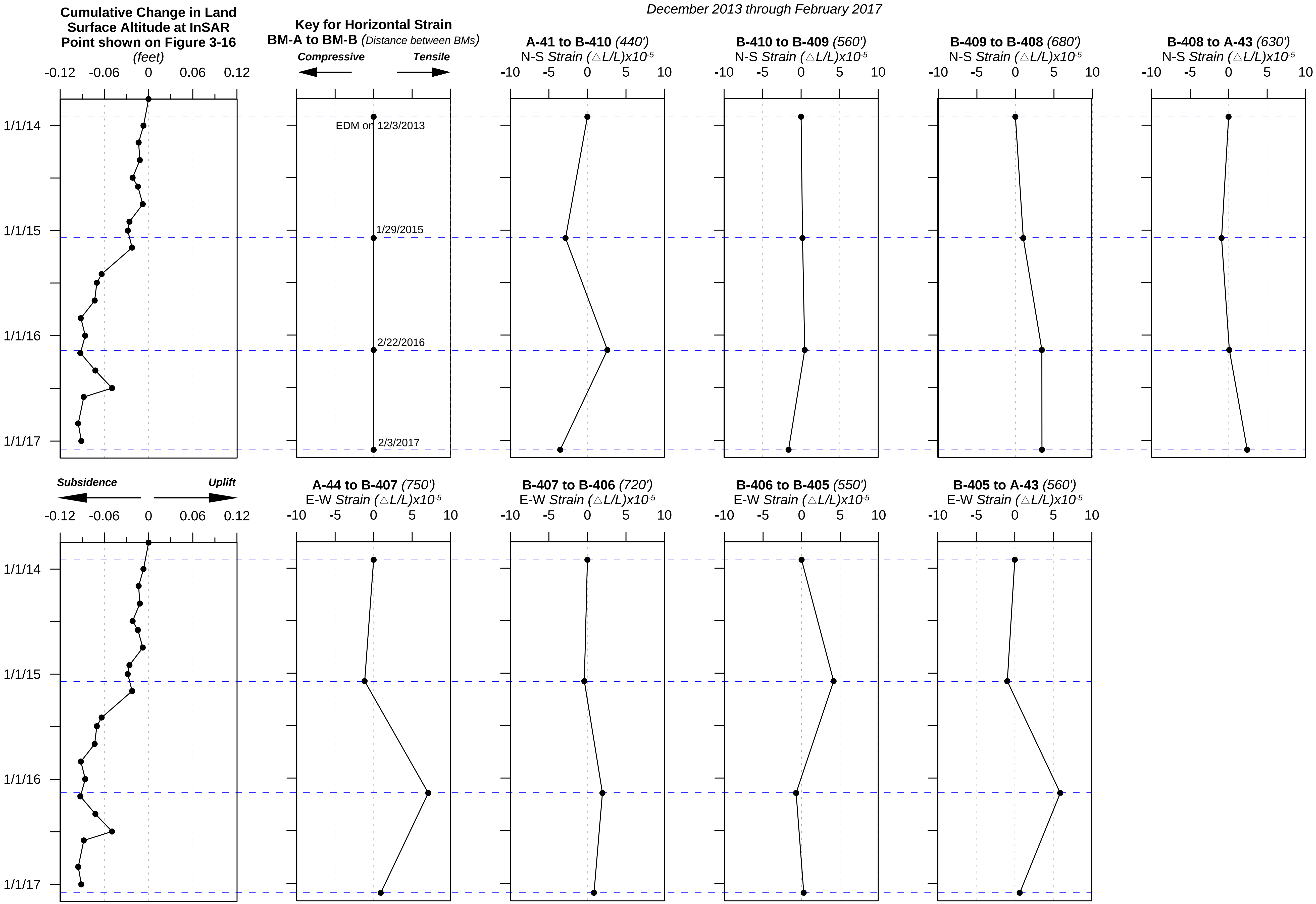
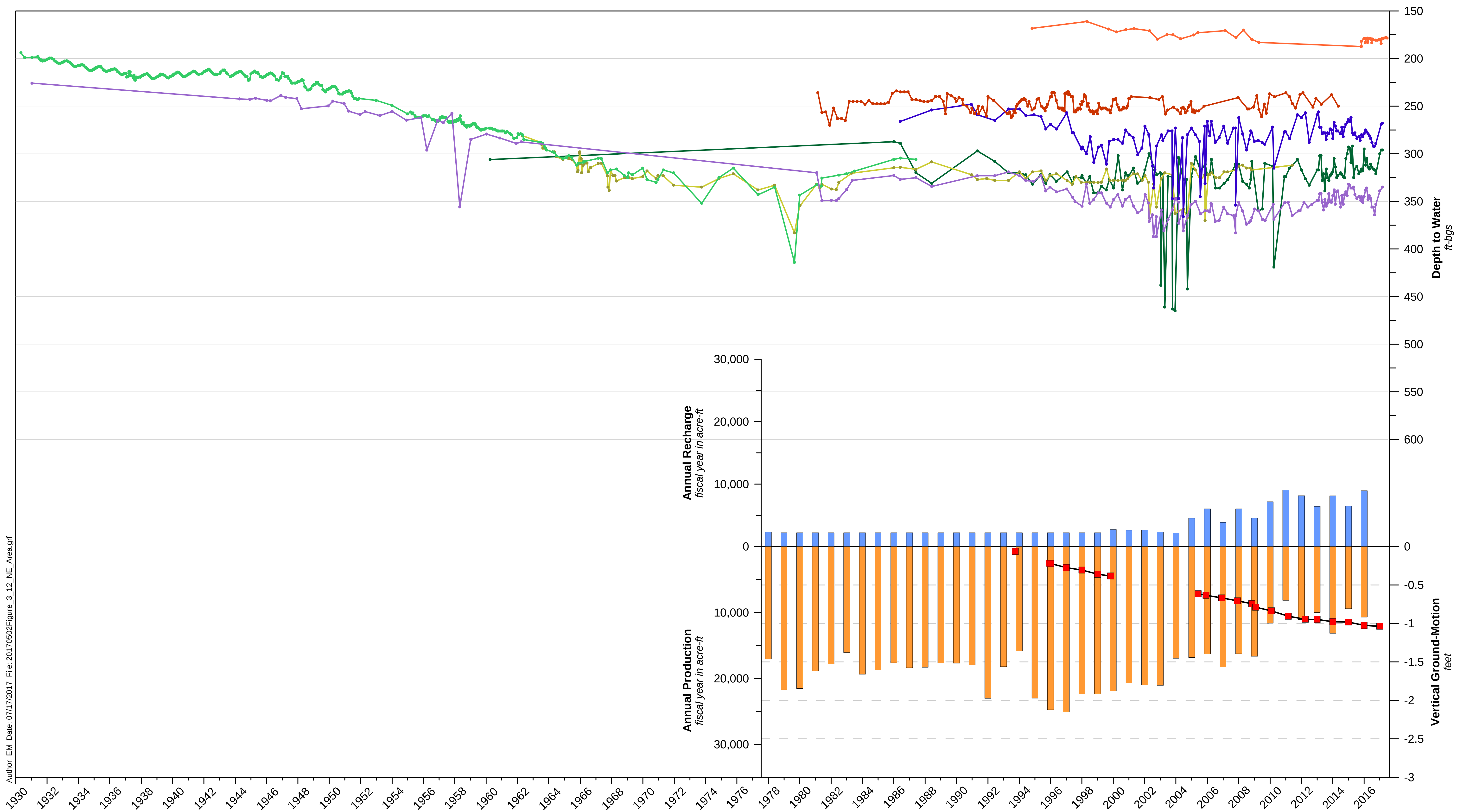


Fig_4a_Chino_10-16_p1.grf
Printed on 4/6/2017



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

O-05 (360-470 ft-bgs)
O-15 (474-966 ft-bgs)
O-25 (370-903 ft-bgs)
O-34 (522-1,092 ft-bgs)
O-36 (530-1,000 ft-bgs)
C-11 (390-910 ft-bgs)
XRef 18 (unknown)

Vertical Ground-Motion
(Cumulative Displacement)

InSAR Point D
(see Figure 3-1a)

Recharge and Production

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 Production from
Wells in the Northeast Area

Prepared by:

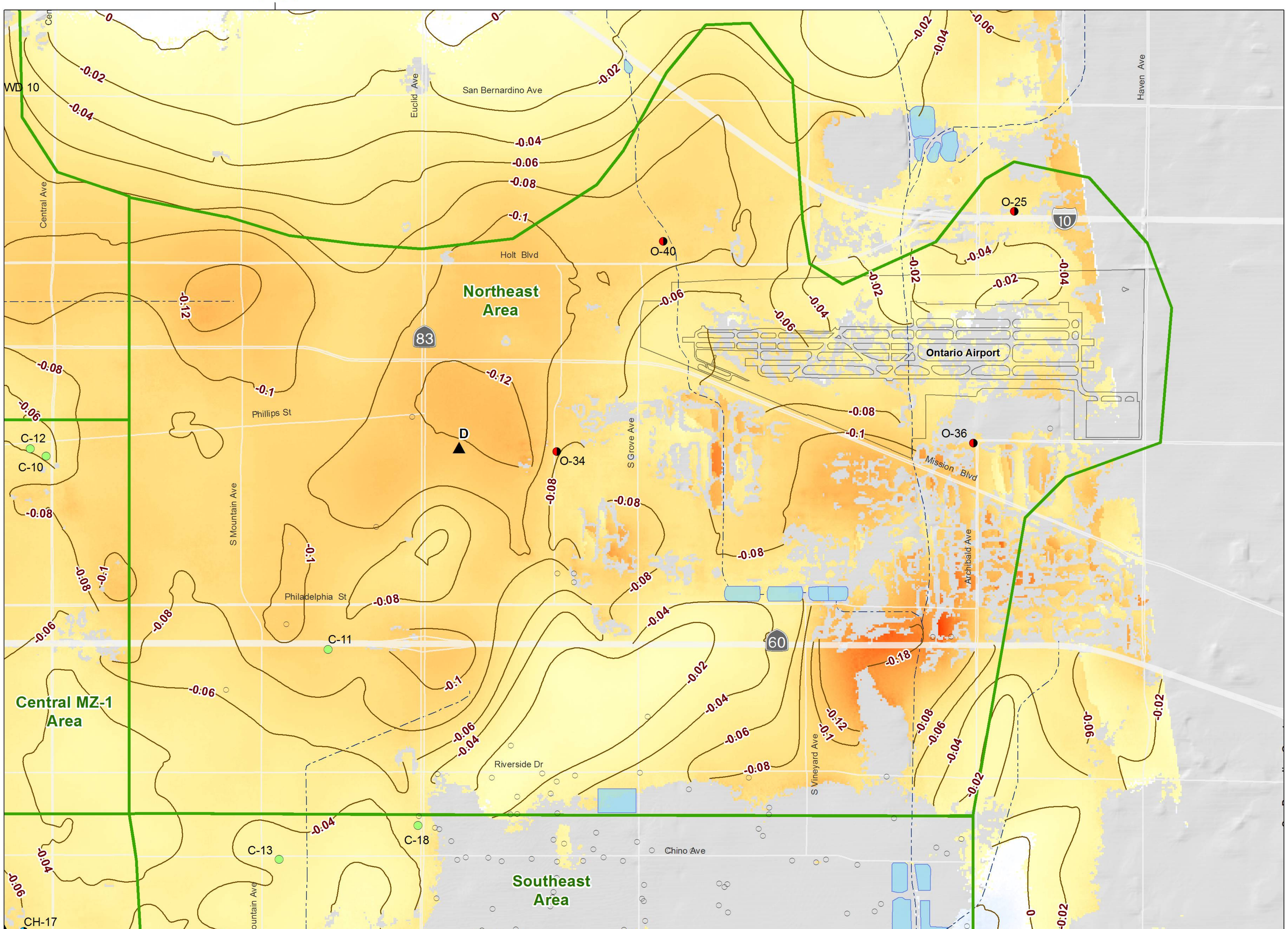
WEI
Wildermuth Environmental, Inc.

*See Figures 3-1a, b for locations of wells, benchmarks, and extensometers

Ground-Level Monitoring Committee
2016 Annual Report

The History of Land Subsidence in the Northeast Area

Figure 3-18



Relative Change in Land Surface Altitude as Measured by InSAR March 2011 to January 2017

+ 0.25 ft
0
-0.125
- 0.25 ft

InSAR absent or incoherent

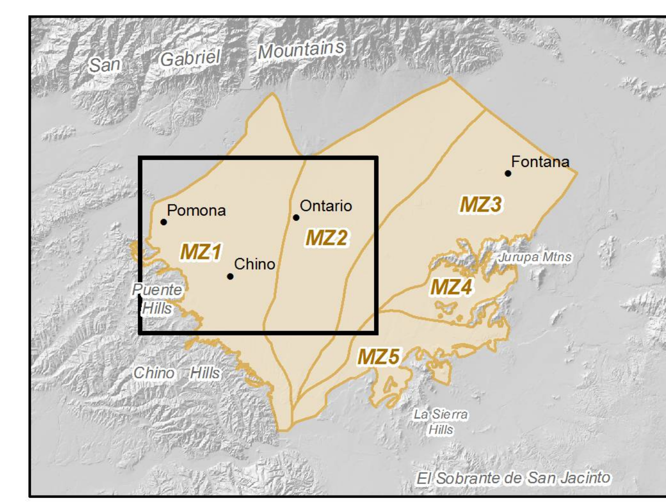
Active Groundwater Production Calendar Year 2016

- City of Chino
- City of Chino Hills
- City of Ontario
- Private

InSAR Time-History Point Plotted on Figure 3-18

Areas of Subsidence Concern

Flood Control and Conservation Basins



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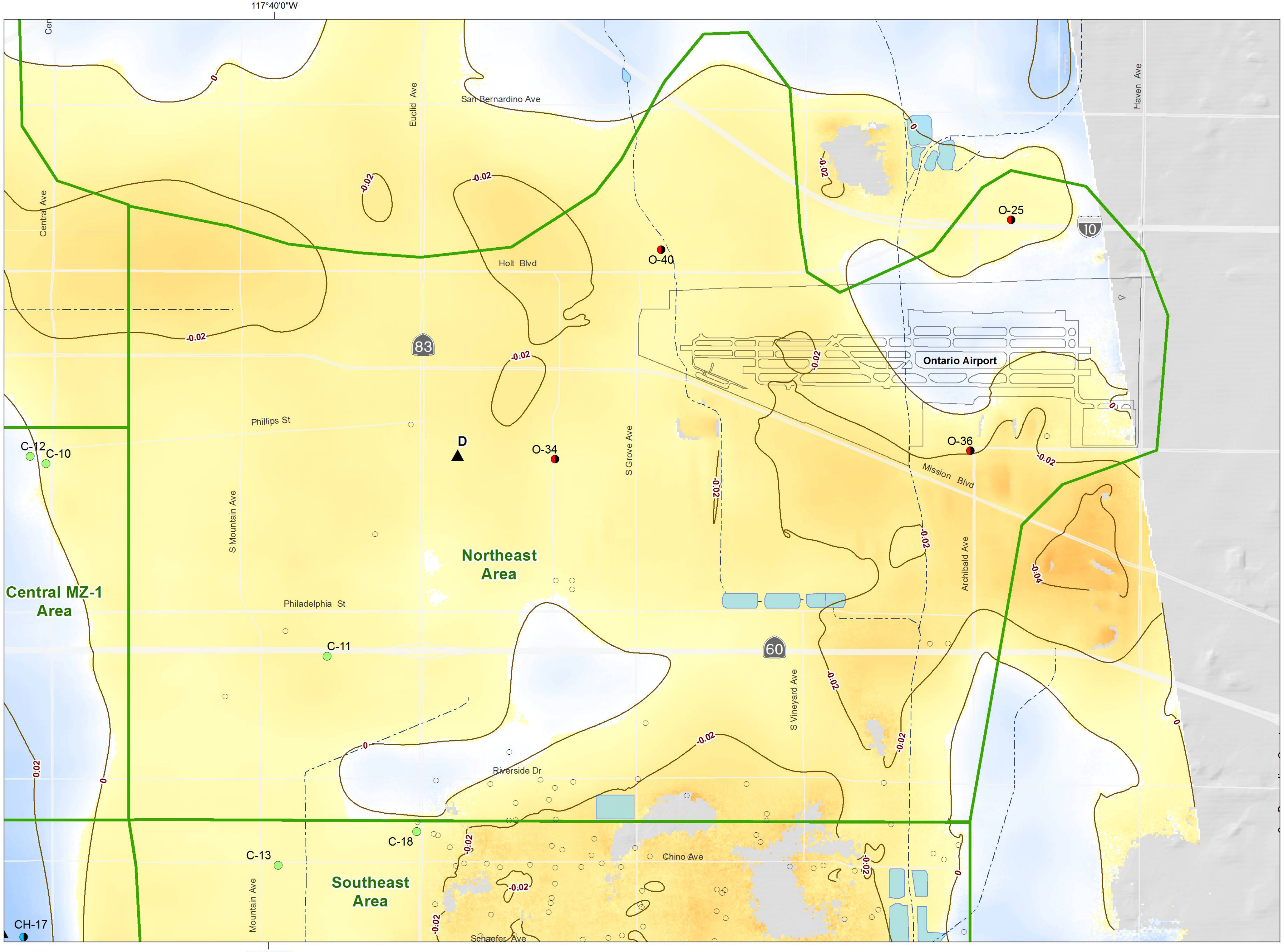
Author: EM
Date: 7/17/2017
Document Name: Figure3_19a_20170613

0 1 2 Miles
0 1 2 Kilometers

Ground-Level Monitoring Committee
2016 Annual Report

Vertical Ground-Motion in the Northeast Area
2011-2016

Figure 3-19a



Relative Change in Land Surface Altitude as Measured by InSAR January 2016 to January 2017

+ 0.1 ft

0

-0.05

- 0.1 ft

InSAR absent or incoherent

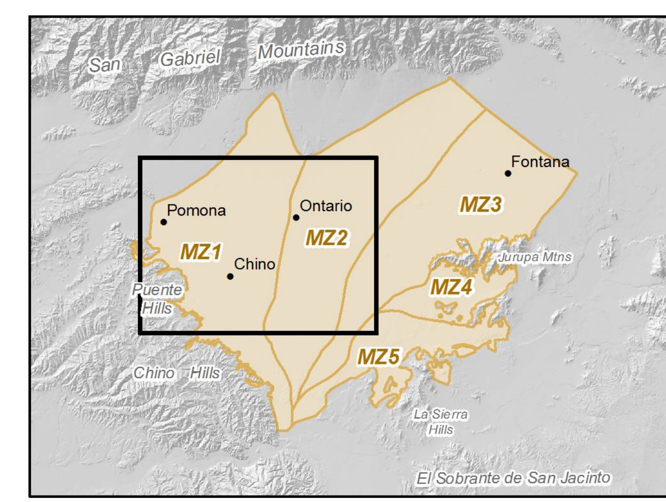
Active Groundwater Production Wells Calendar Year 2016

- City of Chino
- City of Chino Hills
- City of Ontario
- Private

InSAR Time-History Point Plotted on Figure 3-18

Areas of Subsidence Concern

Flood Control and Conservation Basins



Prepared by:

WEI
WILDERMUTH ENVIRONMENTAL, INC.

Author: EM
Date: 7/17/2017
Document Name: Figure3_19b_20170613

0 1 2 Miles

0 1 2 Kilometers

Ground-Level Monitoring Committee
2016 Annual Report

Vertical Ground-Motion in the Northeast Area
2016

Figure 3-19b

Section 4 – Conclusions and Recommendations

4.1 Conclusions and Recommendations

The main conclusions and recommendations of this annual report are:

- During 2016, piezometric-levels measured at the PA-7 piezometer at the Ayala Park Extensometer did not decline below the Guidance Level of 245 ft-btoc, and the aquifer-system deformation as measured at the Deep Extensometer was elastic. This indicates that the Guidance Criteria have been protective in this portion of the Managed Area.

- The recovery of piezometric levels at PA-7 to above 90 ft-btoc in 2016 represented a "full recovery" of piezometric levels at PA-7 as defined in the SMP. This is the first instance of full recovery since 2012, which complies with the recommendation in the SMP for full piezometric recovery within the deep aquifer system at least once every five years.

- The full recovery of piezometric levels coincided with a rebound of the ground surface across most of the Managed Area and Central MZ-1. This observation: (i) indicates that the aquifer-system expanded in response to the full recovery and (ii) suggests a hydrogeologic relationship between these two areas within the deep aquifer system. There is not enough piezometric data in Central MZ-1 to verify this apparent hydrogeologic relationship.

- The in-depth review of horizontal strain calculations from EDM data across the Fissure Zone in the Managed Area indicates the following conclusions and recommendations:

    - EDMs between closely-spaced benchmark monuments appear to be a suitable monitoring technique to detect the occurrence of tensile strain within shallow soils and the potential threat of ground fissuring.

    - The Fissure Zone in the Managed Area and the San Jose Fault Zone in Northwest MZ-1 should be monitored by EDMs in the future; EDMs have indicated that inelastic tensile strain can accumulate across areas of differential land subsidence.

    - As long as permanent subsidence is absent in the Managed Area, the GLMC should consider performing EDM surveys across the Fissure Zone at a frequency longer than annual. The EDM surveys should be performed in conjunction with elevation surveys at monuments across the Managed Area at times of full recovery (or near full recovery) of piezometric levels at PA-7.

    - If and when the Long-Term Pumping Test in the Managed Area is performed, EDM surveys across the Fissure Zone should be conducted in coordination with the test. These surveys should occur just prior to the test at full recovery of piezometric levels at PA-7, at maximum drawdown of piezometric levels (potentially below the Guidance Level at PA-7), and at the subsequent full recovery of piezometric levels at PA-7. These EDM surveys will be used to monitor for the occurrence and magnitude of inelastic tensile strain across the Fissure Zone associated with the drawdown of piezometric levels below the Guidance Level at PA-7.

  - If the Long-Term Pumping Test will include groundwater production at CH-15B, which is located west on Eucalyptus Avenue, the GLMC should consider adding a series of closely-spaced monuments along Edison and Eucalyptus Avenues across the Fissure Zone to perform EDM surveys as part of the test.

  - The installation of a new horizontal extensometer is not recommended at this time for the following reasons: (i) EDM surveys are a suitable technique to monitor for the occurrence and magnitude of inelastic tensile strain in shallow soils across the Fissure Zone; (ii) currently very little, if any, permanent land subsidence in the Managed Area and tensile strain across the Fissure Zone is occurring;, (iii) based on the monitoring results from the IMP, very little, if any, permanent land subsidence in the Managed Area and tensile strain across the Fissure Zone is expected to occur as a result of the Long-Term Pumping Test; and (iv) very little, if any, additional management-grade information would be provided by a horizontal extensometer (that would not be provided by EDMs), and therefore the cost is not justified.

- Ground-level surveys and the CCX data indicate very little, if any, ongoing subsidence in the Southeast Area even though groundwater production at the Chino Creek Well Field began in the second quarter of 2014 and increased through 2016. The InSAR and ground-level survey datasets do not always corroborate each other in the pattern and/or magnitude of vertical ground motion in the Southeast Area where both datasets overlap—likely due to InSAR incoherence associated with the agricultural land uses in this area. As such, ground-level surveys should continue to be the primary method of measurement of vertical ground motion across the Southeast Area. An elevation survey at the existing benchmark monuments in the Southeast Area should be performed during winter 2017/18 as two additional Chino Creek Desalter wells (I-20 and I-21) commenced production in February 2016.

- During 2016, concentrated differential land subsidence continued to occur in Northwest MZ-1 across the San Jose Fault. The GLMC should pursue the following in 2017/18:

  - Continue monitoring vertical and horizontal ground-motion via InSAR and elevation/EDM surveys at benchmarks.

  - Continue implementation of the *Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area*, which includes investigations into the cause(s) of the observed land subsidence and the development and evaluation of subsidence-management alternatives to minimize or abate future subsidence.

- About one-foot of gradual and persistent land subsidence has occurred in the Northeast Area since 1992 and appears to be ongoing. An array of benchmark monuments should be established across the subsiding portions of the Northeast Area to perform elevation surveys; InSAR data are largely incoherent in some areas that are experiencing subsidence, such as south and southwest of the Ontario Airport.

4.2 Recommended Scope and Budget for Fiscal Year 2017-18

The scope-of-work for the GLMP for FY 2017-18 is a recommendation of the GLMC, and is shown in Table 4-1 as a work breakdown structure with cost estimates:

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 recalibration to remain in good working order. Task 1.1 includes conducting monthly visits to the Ayala Park and Chino Creek Extensometer Facilities to ensure functionality and calibration of the monitoring equipment and data loggers.

Task 1.3 involves siting a new horizontal extensometer in the Managed Area to replace the Daniels Horizontal Extensometer, performing CEQA, and procuring permits and easements. This work was originally budgeted for FY 2016-17 but was not completed. This budget is shown as carry-over under Task 1.3. Since this annual report is not recommending the installation of a new horizontal extensometer, this budget can be conserved or used to install additional closely-spaced EDM monuments along Edison and Eucalyptus Avenues as recommended in Section 4.1.

Task 2—Aquifer-System Monitoring and Testing. This task involves the quarterly collection of piezometric levels and aquifer-system deformation data at the Ayala Park, Chino Creek, and Pomona Extensometer facilities. The collection of piezometric level and aquifer-system deformation data at the new Pomona Extensometer is anticipated for the final two quarters of FY 2017-18. Quarterly collection and checking of data is necessary to (i) ensure that the monitoring equipment is in good working order and (ii) minimize the risk of losing data because of equipment malfunction.

Task 3—Basin Wide Ground-Level Monitoring Program. This task involves the annual data collection and analysis of InSAR data during 2017. InSAR data are collected by the TerraSAR-X satellite, operated by the German Aerospace Center. Five interferograms will be prepared that will describe the vertical ground motion across the western portion of Chino Basin during 2017. Correlations between InSAR and ground-level surveys (Task 4) will be evaluated in Task 5 to validate the reliability of the InSAR data.

Task 4—Ground-Level Surveys. This task involves conducting elevation surveys at benchmark monuments across defined areas of the western Chino Basin. EDMs are performed between selected benchmark monuments to monitor for horizontal deformation of the ground surface in areas where ground fissuring due to differential land subsidence is a concern. The surveys proposed for FY 2017-18 include:

- *Southeast Area*. Conduct an elevation survey at benchmarks in the Southeast Area in early 2018. The elevation survey will begin at the Ayala Park extensometer and will include benchmarks throughout the Southeast Area shown in Figure 4-1. The elevation survey data will be referenced to the Ayala Park elevation datum. The elevation survey in the Southeast Area is recommended because the InSAR data is largely incoherent across most of the area and two additional Chino Creek Desalter wells (I-20 and I-21) commenced production in February 2016.

- *Northeast Area.* Establish a benchmark array and conduct an elevation survey of the benchmarks in the Northeast Area in early 2018. The elevation survey will begin at the Ayala Park extensometer and will include benchmarks for the areas in the Northeast Area shown on Figure 4-1. The elevation survey will be referenced to the Ayala Park elevation datum. The elevation survey in the Northeast Area was requested by the City of Ontario because the InSAR data show that up to approximately 0.2 feet of subsidence has occurred since 2011 (between Euclid Ave and Bon View Ave) and the InSAR data are largely incoherent south and southwest of Ontario Airport.

- *Northwest MZ-1 Area.* Conduct an elevation survey and an EDM survey at benchmarks in Northwest MZ-1 during early 2018. The elevation survey will begin at the Ayala Park extensometer and include the benchmarks along Monte Vista Avenue, San Bernardino Avenue, and Orchard Street/Lincoln Avenue/Alvarado Street, as shown on Figure 4-1. The elevation survey data will be referenced to the Ayala Park elevation datum. The surveys are recommended to verify the InSAR data and to measure horizontal deformation across the San Jose Fault where differential land subsidence is occurring.

- *Managed Area.* Conduct an elevation survey and EDM survey in the Managed Area at full recovery (or near full recovery) of piezometric levels at PA-7. Maximum recovery of piezometric levels in the Managed Area typically occurs during the spring months. The elevation survey will begin at the Ayala Park extensometer and include benchmarks within the Managed Area and Fissure Zone Area, as shown on Figure 4-1. The elevation survey data will be referenced to the Ayala Park elevation datum. The elevation and EDM surveys are recommended because the InSAR data are partly incoherent in the southern portions of the area and the last elevation and EDM surveys conducted in the Managed Area occurred in March 2016.

***Task 5—Data Analysis and Reporting*.** This task involves the analysis of the data generated by the GLMP through 2017. The results and interpretations generated from the data analysis will be documented in the *2017 Annual Report of the GLMC.*

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.[13] Several tasks outlined in the Work Plan are recommended for implementation in FY 2017-18:

- *Finalize Implementation of the Initial Monitoring Program.* The initial monitoring program will continue to be implemented. This subtask includes the initiation of SCADA-based monitoring of piezometric levels and production at selected wells owned by the Monte Vista Water District and City of Pomona; continuation of monitoring piezometric levels and production from wells owned by the Cities of Chino, Pomona, and Upland, the Monte Vista Water District, and the Golden State Water Company; analysis of the data

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

generated from the initial monitoring program; and preparation of a Task Memorandum that will document the improved understanding of the aquifer system in the Northwest MZ-1 Area and provide recommendations for designing short-term controlled pumping tests, if necessary.

- *Install the Pomona Extensometer Facility*. Early in FY 2017-18, an extensometer facility site, CEQA compliance, and all appropriate easements will have been secured. Within the first quarter of FY 2017-18, the bid package and contractor selection process to construct the Pomona Extensometer piezometers will be completed. It is anticipated that the drilling, construction, and installation of the Pomona Extensometer Facility piezometers will be completed at the end of the second quarter of FY 2017-18.

- *Install Monitoring Equipment for the Pomona Extensometer Facility*. Immediately following the completion of the Pomona Extensometer piezometers, each piezometer will be equipped with a cable extensometer, data loggers, and pressure transducers. It is anticipated the Pomona Extensometer Facility will be online early in the third quarter of FY 2017-18.

- *Completion Report for the Pomona Extensometer Facility*. A well completion summary report will be prepared to document the drilling and construction activities for the piezometers and the installation of the extensometers and monitoring equipment for the Pomona Extensometer Facility by the end of FY 2017-18.

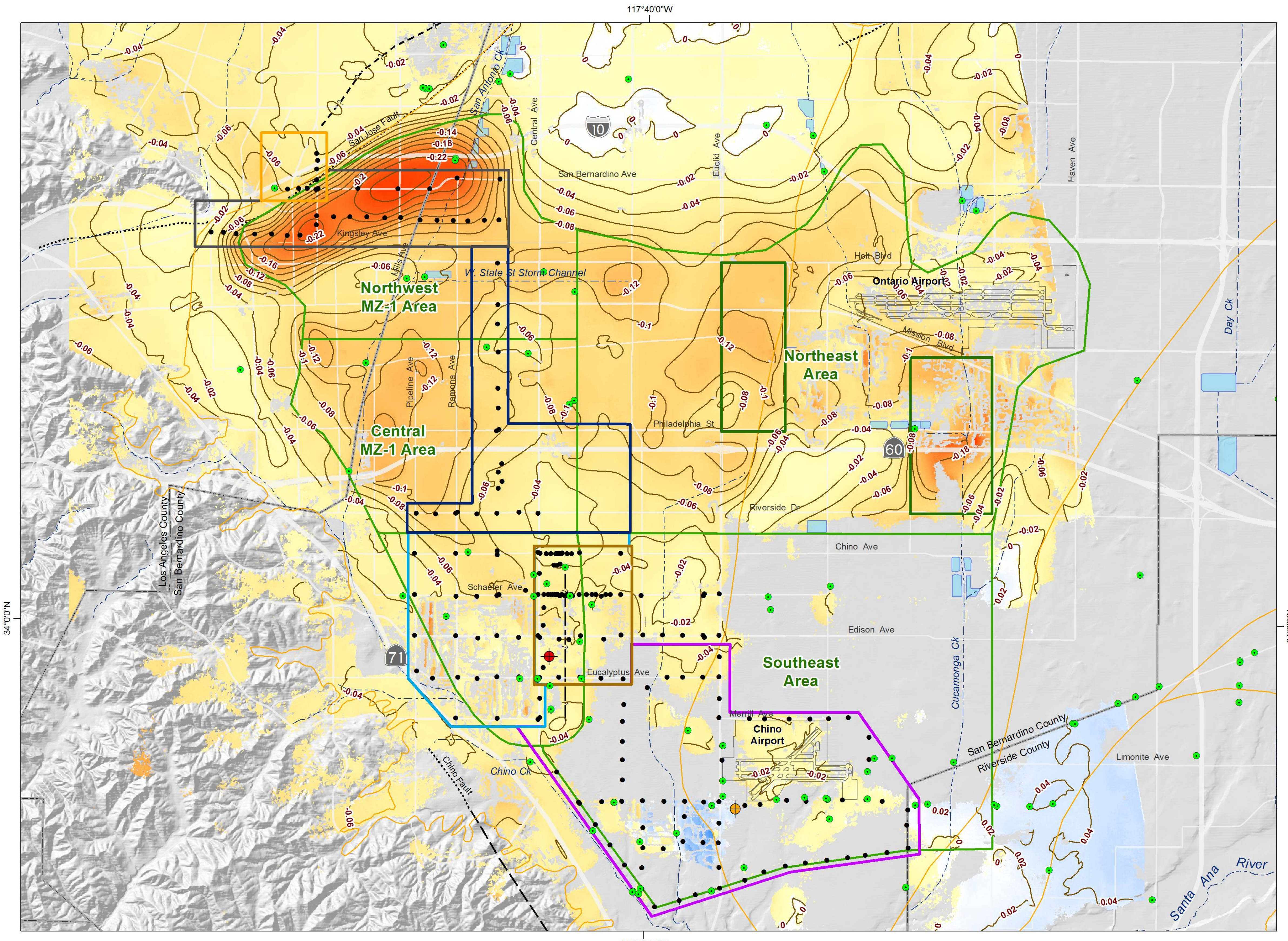
Task 7—Meetings and Administration. Four meetings of the GLMC are planned to oversee the GLMP: July 2017 – review of this annual report and kickoff for the GLMP for FY 2017-18; January 2018 – review of the Technical Memorandum documenting the initial monitoring program for Northwest MZ-1; March 2018 – review of the data collected from the monitoring program through calendar year 2017 and a recommended scope and budget for FY 2018-19; April 2018 – finalize the recommended scope and budget for FY 2018-19. Also, included in Task 7 is project administration, including staffing and financial/schedule reporting.

4.3 Changes to the Subsidence Management Plan

The SMP 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 SMP pursuant to the process outlined in Section 4 of the SMP. Currently, there are no recommended changes to the SMP.

Table 4-1
Work Breakdown Structure and Cost Estimates
Ground-Level Monitoring Program - FY 2017-18

Task Description	Labor		Other Direct Costs							Totals					
	Person Days	Total	Travel	New Equip.	Equip. Rental	Outside Pro	Repro	Misc.	Total	Totals by Task	Recommended Budget *2017-18*	Budget *2016-17*	Net Change *2016-17 to 2017-18*	Potential Carry-Over *2017-18*	Budget with Carry-Over *2017-18*
											a	*b*	*a - b*	*c*	*a - c*
Task 1 -- Setup and Maintenance of the Monitoring Network		**$36,092**							**$30,182**	**$66,274**	**$66,274**	**$64,714**	**$1,560**	**$41,268**	**$25,006**
1.1 Equipment maintenance															
Routine maintenance of Ayala Park and CCX extensometer facilities	9	$11,208	$583	$500	$152				$1,235	$12,443	$12,443	$12,227	$216	$0	$12,443
Replacement/repair of equipment at extensometer facilities	4	$5,616	$73	$3,000	$38	$2,000			$5,111	$10,727	$10,727	$10,407	$320	$0	$10,727
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
1.3 Identify a site and install a horizontal extensometer in the Managed Area															
Coordinate with the City of Chino	7	$10,760	$194						$194	$10,954	$10,954	$10,298	$656	$10,760	$194
Prepare for and attend a meeting of the GLMC to discuss and approve potential sites	2	$3,536	$46						$46	$3,582	$3,582	$3,398	$184	$3,536	$46
Perform CEQA for the potential new sites and procure permits and easements	4	$4,972				$22,000			$22,000	$26,972	$26,972	$26,788	$184	$26,972	$0
Task 2 -- MZ-1: Aquifer-System Monitoring and Testing		**$21,770**							**$1,004**	**$22,774**	**$22,774**	**$16,294**	**$6,480**	**$0**	**$22,774**
2.1 Groundwater-level and extensometer data collection and processing															
Download data from the Ayala Park facility	1.5	$2,004	$259		$76				$335	$2,339	$2,339	$2,255	$84	$0	$2,339
Download data from the CCX facility	0.5	$804	$259		$76				$335	$1,139	$1,139	$1,063	$76	$0	$1,139
Download data from PX facility	0.8	$1,002	$144		$190				$334	$1,336	$1,336	$0	$1,336	$0	$1,336
Process, check, and upload data to database	13	$17,960							$0	$17,960	$17,960	$12,976	$4,984	$0	$17,960
Task 3 -- Basin Wide: InSAR		**$4,292**							**$85,000**	**$89,292**	**$89,292**	**$89,082**	**$210**	**$0**	**$89,292**
3.1 InSAR data collection	1	$1,608				$85,000			$85,000	$86,608	$86,608	$86,456	$152	$0	$86,608
3.2 Process, check, and upload data to database/GIS	2	$2,684							$0	$2,684	$2,684	$2,626	$58	$0	$2,684
Task 4 -- Ground-Level Surveys		**$5,690**							**$142,356**	**$148,346**	**$148,346**	**$71,147**	**$77,199**	**$0**	**$148,346**
4.1 Conduct fall 2017 ground-level survey in Southeast Area	0.25	$300				$29,571			$29,571	$29,871	$29,871	$29,435	$436	$0	$29,871
4.2 Conduct fall 2017 ground-level and EDM survey in Northwest MZ-1 Area	0.5	$600				$21,907			$21,907	$22,507	$22,507	$15,441	$7,066	$0	$22,507
4.3 Install additional benchmarks and conduct fall 2017 ground-level and EDM survey in the NW MZ-1 Area	0	$0							$0	$0	$0	$16,456	-$16,456	$0	$0
4.4 Conduct ground-level-survey in Managed Area	0.25	$300				$20,988			$20,988	$21,288	$21,288	$0	$21,288	$0	$21,288
4.5 Replace destroyed benchmarks (if needed)	0	$0				$5,963			$5,963	$5,963	$5,963	$5,501	$462	$0	$5,963
4.6 Process, check, and update database	3.25	$4,490				$6,410			$6,410	$10,900	$10,900	$4,314	$6,586	$0	$10,900
4.7 Conduct fall 2017 ground-level survey in Northeast Area	0.25	$300				$57,518			$57,518	$57,818	$57,818	$0	$57,818	$0	$57,818
Task 5 -- Data Analysis and Reports		**$59,644**							**$20,000**	**$79,644**	**$79,644**	**$105,398**	**-$25,754**	**$0**	**$79,644**
5.1 Analysis of data from the areas of subsidence concern															
Production/recharge/piezometric/extensometer	4	$5,208				$20,000			$20,000	$25,208	$25,208	$25,032	$176	$0	$25,208
Ground-level survey and Northwest MZ-1 Area EDM data	4	$5,572							$0	$5,572	$5,572	$5,384	$188	$0	$5,572
Perform analysis of EDM and elevations surveys in the Fissure Zone	0	$0							$0	$0	$0	$28,352	-$28,352	$0	$0
InSAR data	4	$5,208							$0	$5,208	$5,208	$5,032	$176	$0	$5,208
Tectonic data	0.25	$300							$0	$300	$300	$298	$2	$0	$300
Recycled water reuse data	2	$2,400							$0	$2,400	$2,400	$2,384	$16	$0	$2,400
5.2 Prepare 2017 Annual Report of the Ground-Level Monitoring Committee										$0					
Prepare draft annual report	23	$32,920							$0	$32,920	$32,920	$31,240	$1,680	$0	$32,920
Prepare final annual report	5.5	$8,036							$0	$8,036	$8,036	$7,676	$360	$0	$8,036
Task 6 -- Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area		**$365,050**							**$1,217,526**	**$1,582,576**	**$1,582,576**	**$275,945**	**$1,306,631**	**$75,000**	**$1,507,576**
6.1 Finalize implementation of the initial monitoring program	62	$84,224	$644				$50		$694	$84,918	$84,918	$84,645	$273	$75,000	$9,918
6.2 Develop and evaluate the Initial Subsidence-Management Alternative (ISMA)	0	$0							$0	$0	$0	$112,014	-$112,014	$0	$0
6.3 Install the Pomona Extensometer Facility	93.75	$188,426	$12,500			$1,160,000			$1,172,500	$1,360,926	$1,360,926	$60,944	$1,299,982	$0	$1,360,926
6.4 Install monitoring equipment (transducers, data loggers, telemetry) in the Pomona Extensometer and test	48	$62,312	$1,920	$18,300		$24,000			$44,220	$106,532	$106,532	$0	$106,532	$0	$106,532
6.5 Prepare task memorandum - completion report for the Pomona Extensometer Facility	20	$30,088	$62				$50		$112	$30,200	$30,200	$0	$30,200	$0	$30,200
6.6 Meetings and administration	0	$0							$0	$0	$0	$18,342	-$18,342	$0	$0
Task 7 -- Meetings and Administration		**$43,404**							**$242**	**$43,646**	**$43,646**	**$35,814**	**$7,832**	**$0**	**$43,646**
7.1 Prepare for and attend three Ground-Level Monitoring Committee meetings	12	$20,576	$194						$194	$20,770	$20,770	$14,569	$6,200	$0	$20,770
7.2 Ad hoc meetings	3	$5,144	$48						$48	$5,192	$5,192	$4,856	$336	$0	$5,192
7.3 Project administration and financial reporting	7.5	$12,540							$0	$12,540	$12,540	$11,580	$960	$0	$12,540
7.4 Scope and budget for FY2018/19	3	$5,144							$0	$5,144	$5,144	$4,808	$336	$0	$5,144
Totals										**$2,032,552**	**$2,032,552**	**$658,394**	**$1,374,158**	**$116,268**	**$1,916,284**



Relative Change in Land Surface Altitude
as Measured by InSAR
March 2011 to January 2017

+ 0.25 ft
0
-0.125
- 0.25 ft

InSAR absent or incoherent

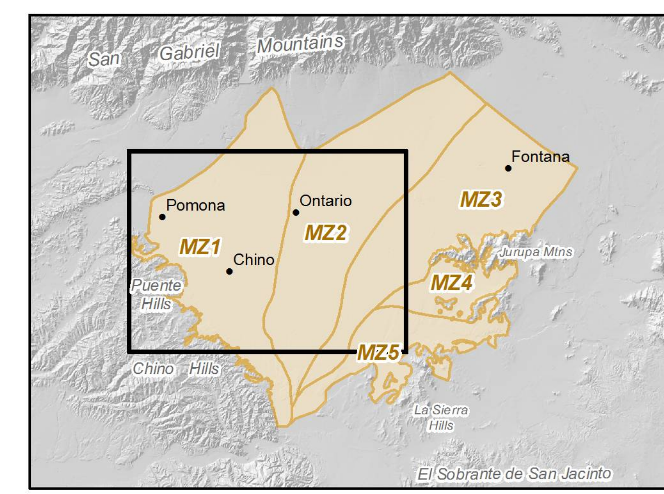
Ground-Level Monitoring Network Facilities

- Ayala Park Extensometer
- Chino Creek Extensometer
- Wells Equipped with Transducers Calendar Year 2016
- Survey Benchmark

Ground-Level Survey Areas

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

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



Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: AEM
Date: 7/17/2017
Document Name: Figure4_1_20170613

0 2 4 Miles
0 2 4 Kilometers

Ground-Level Monitoring Committee
2016 Annual Report

Ground-Level Monitoring Program
Fiscal Year 2017-18

Figure 4-1

The following glossary contains terms and definitions that are 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 which 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 the 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 void ratio or porosity of the soil. For 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 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.

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.

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.

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, and is 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, and represents that portion of the applied stress which becomes effective as intergranular stress.

Stress, Preconsolidation – The maximum antecedent effective stress to which a deposit has been subjected and which it 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, and thus affects 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 the 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 that portion of the applied stress which 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

Comments and Responses

A.1 Monte Vista Water District

Comment Number	Reference	Comment	Response
1	n/a	"Guidance level" is used throughout the report. What is the purpose and significance of this term?	The initial investigations that Watermaster performed to develop a subsidence management plan for the Managed Area in Chino showed that groundwater-level declines due to pumping from the deep aquifer system within the Managed Area can cause inelastic (non-recoverable) compaction of the aquifer-system sediments, which results in land subsidence. The initiation of inelastic compaction within the aquifer system was identified at the Ayala Park Extensometer when water levels fell below a depth of about 250 feet in the PA-7 piezometer. For more information on these investigations, see the MZ-1 Summary Report (2006): http://www.cbwm.org/docs/engdocs/Land%20Subsidence/20071017_MZ1_Plan%20--%20Appendix_A_MZ1_SummaryReport_20060226.pdf The "Guidance Level" is a specified depth-to-water measured in Watermaster's PA-7 piezometer at Ayala Park. It is defined as the threshold water level at the onset of inelastic compaction of the aquifer system as recorded by the extensometer minus five feet. The five-foot reduction serves as a safety factor to ensure that inelastic compaction does not occur in the future. The initial (and current) Guidance Level was set at 245 feet below the top of the well casing (ft-btoc) in PA-7. The Guidance Level is established by Watermaster and

			subject to change based on the periodic review of monitoring data collected by Watermaster. Watermaster recommends that the Parties manage their groundwater production such that the water level in PA-7 remains above the Guidance Level. If the water level in PA-7 falls below the Guidance Level, Watermaster recommends that the Parties curtail their production from the Managed Wells as required (1) to allow for water-level recovery and (2) to maintain the water level in PA-7 above the Guidance Level. The magnitude of groundwater-level decline at which aquifer compaction is initiated in areas other than at the Ayala Park Extensometer has not been directly evaluated. Therefore, caution is recommended when pumping from Managed Wells in order to minimize groundwater-level decline within the Managed Area. Guidance Levels for wells and/or piezometers in addition to PA-7 may be specified in the future as a result of ongoing monitoring and the evaluation of groundwater production, groundwater levels, and land subsidence. For further explanation, see the Chino Basin Subsidence Management Plan: http://www.cbwm.org/docs/engdocs/Land%20Subsidence/20150724%20-%20Chino%20Basin%20Subsidence%20Management%20Plan%202015/FINAL_2015_CBSMP.pdf
2	Page 1-1 (Sec. 1.1.2)	Has there been anything in writing by either Watermaster or WEI to describe what [a management plan to abate future subsidence and fissuring or reduce it to “tolerable levels” in MZ-1] looks like? If only verbal	Program Element 4 of the OBMP Implementation Plan states that the “occurrence of subsidence and fissuring in Management Zone 1 is not acceptable and should be reduced to tolerable levels or abated.” The OBMP

		discussion, what is the synopsis of these discussions to date?	Implementation Plan does not provide – and neither Watermaster nor WEI have developed to date – a definition of a "tolerable level" of subsidence. The OBMP Implementation Plan called for the development of an interim plan to minimize subsidence and fissuring, the collection of information to assess the causes of subsidence and fissuring, and the development of an effective long-term management plan. Watermaster, with WEI's assistance, has and continues to undertake these activities, which will result in the determination of whether and to what extent subsidence and fissuring can be abated or the levels to which it might be reduced.
3	Page 3-10 (Sec. 3.4.1)	To an engineer, a negative downward motion of 0.25-ft means the ground rose by 0.25-ft. To a hydrogeologist, does this mean the ground dropped by 0.25-ft? More importantly, which way is the reader supposed to understand it?	The report has been revised to describe "upward vertical ground motion" as positive values and "downward vertical ground motion" as negative values.
4	Page 4-5 (Sec. 4-2)	"Fiscal Year 2016-2017" Typo?	The text has been modified to address this comment.
5	Page 4-5 (Sec. 4-3)	[Referring to "no recommended changes to the SMP"] I thought, at the 7/27/17 GLMC meeting, WEI said the frequency of surveys in the Managed Area can be adjusted, no?	Correct. Section 2.1.3 of the Chino Basin Subsidence Management [*On-going Monitoring and Testing*] states: "The GLMC will annually recommend the scope and frequency of leveling surveys and InSAR measurements within the Managed Area."

A.2 City of Chino

Comment Number	Reference	Comment	Response
1	Page 1-5 (Sec. 1.1.4)	The discussion should be clarified to indicate the program recommends "full" groundwater level recovery at least once every 5 years to assess non-elastic compaction.	Section 1.1.5—2015 Chino Basin Subsidence Management Plan was revised to include the following text: The updated SMP also addressed the need for "recovery periods" for piezometric levels in the Managed Area by recommending that all deep aquifer-system pumping cease for a continuous 3-month period between October 1 and March 31 of each year within the Managed Area. 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. These cessations of pumping are 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.
2	Page 3-8 (Sec. 3.1.2.4)	We agree that baseline EDM should be established on Edison and Eucalyptus Avenues prior to any future groundwater level drawdown testing.	Comment noted.
3	(Sec. 3.4.1)	Can the differential subsidence across the San Jose Fault be quantified? That is, change in elevation/horizontal distance. How does differential subsidence in the NW	Differential subsidence can be quantified across the San Jose Fault in Northwest MZ-1 and the Riley Barrier in the Managed Area. Vertical ground motion has

City of Chino

Comment Number	Reference	Comment	Response
		compare to what was observed/measured in the Managed Area?	been measured by both InSAR and ground-level surveys. Horizontal deformation has been measured by EDMs. Analysis and comparison is possible depending the recommendations by the GLMC.