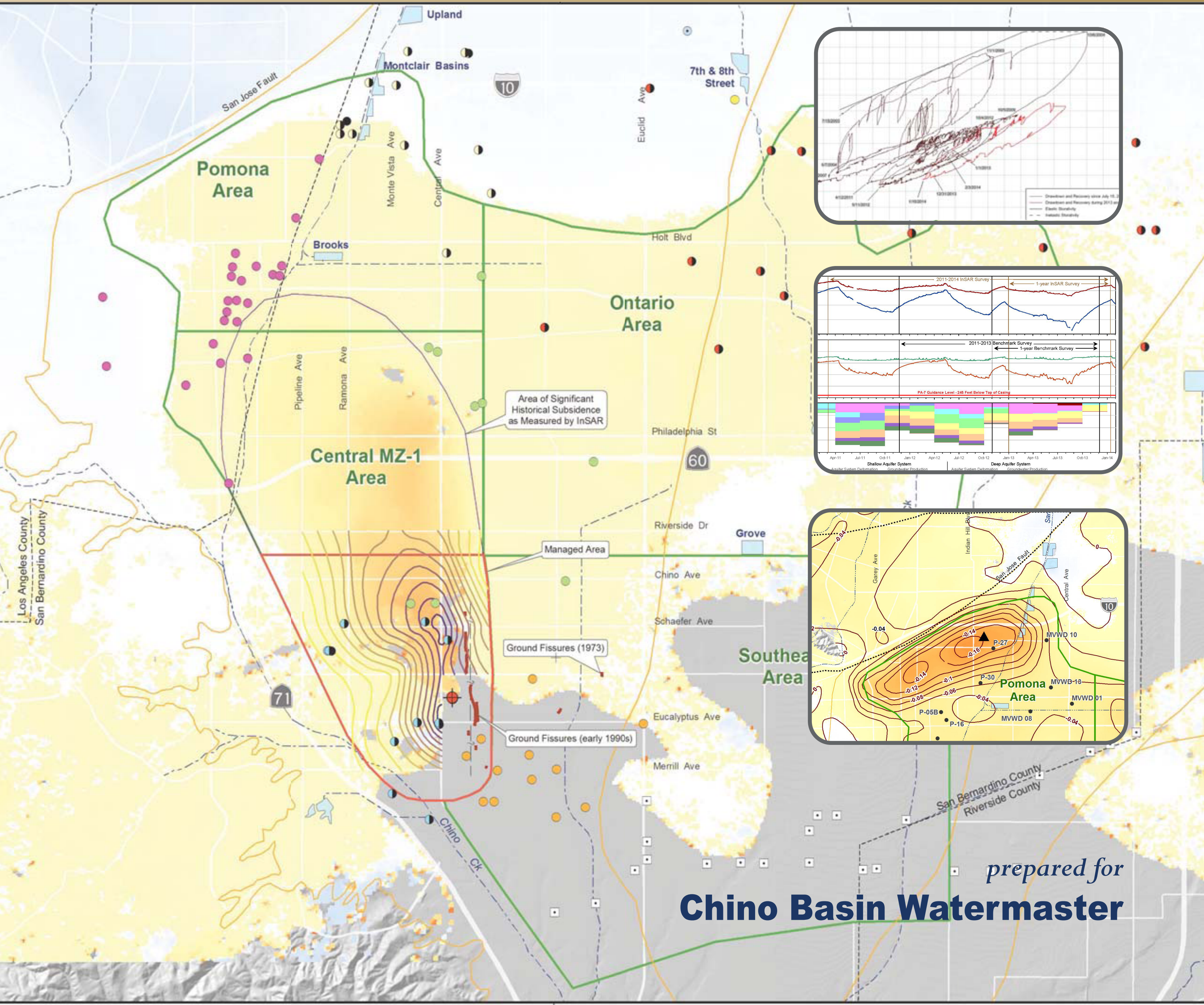
2013 Annual Report of the Land Subsidence Committee

Final



prepared for

Chino Basin Watermaster

July 10, 2014

WEI
Wildermuth Environmental, Inc.

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Acronyms, Abbreviations, and Initialisms

acre-ft/yr	acre-feet per year
CCX	Chino Creek Extensometer Facility
CIM	California Institution for Men
DHX	Daniels Horizontal Extensometer
EDM	Electronic Distance Measurement
ft-bgs	feet below ground surface
ft-btoc	feet below top of casing
GSWC	Golden State Water Company
IEUA	Inland Empire Utilities Agency
IMP	Interim Monitoring Program
InSAR	Interferometric Synthetic Aperture Radar
MVWD	Monte Vista Water District
MZ-1	Management Zone 1
OBMP	Optimum Basin Management Plan
PE1	Program Element 1
SAWCo	San Antonio Water Company
USGS	United States Geological Survey
WEI	Wildermuth Environmental Inc.

1.1 Background

Land subsidence is the sinking of the Earth's surface due to the rearrangement of subsurface Earth 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 land 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% of all documented cases of land subsidence in the United States have been caused by groundwater extractions from the underlying aquifer system (USGS, 1999).

1.1.1 Subsidence and Fissuring in Chino Basin

One of the earliest indications of land subsidence in Chino Basin was the appearance of ground fissures 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. Figure 1-1 shows the location of the fissures within Management Zone 1 (MZ-1) of the Chino Basin. The scientific studies of the area attributed the fissuring phenomenon to differential land subsidence that was 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).

1.1.2 The Optimum Basin Management Program (OBMP)

In 1999, the OBMP Phase I Report (WEI, 1999) identified pumping-induced drawdown and subsequent aquifer-system compaction as the most likely cause of 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.

In 2000, the Implementation Plan in the Peace Agreement 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), which 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 (PE1) of the OBMP Implementation Plan, *Develop and Implement a Comprehensive Monitoring Program*, called for the basin-wide analysis of land subsidence via ground-level surveys and remote-sensing (InSAR), and 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, Watermaster developed, coordinated, and conducted the IMP under the guidance of the MZ-1 Technical Committee (now called the Land Subsidence Committee). The MZ-1 Technical Committee was composed 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; Monte Vista Water District; Golden State Water Company; and the State of California, California Institution for Men (CIM).

The main conclusions derived from the IMP were:

1. Groundwater production from the deep, 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 groundwater-level drawdown that is much greater in magnitude and lateral extent than drawdown caused by pumping of the shallow aquifer system.[1]
2. Groundwater-level drawdown due to pumping of the deep aquifer system can cause inelastic (permanent) compaction of the aquifer-system sediments, which results in permanent land subsidence. The initiation of permanent compaction within the aquifer system was identified during the investigation when water levels fell below a depth of about 250 feet in the PA-7 piezometer at Ayala Park.
3. The then current state of aquifer-system deformation in southern MZ-1 (in the vicinity of Ayala Park) was essentially elastic. Very little permanent compaction was occurring in this area, which was in contrast to 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 active production wells during that period.
4. During this study, a previously undetected barrier to groundwater flow, called the Riley Barrier, was identified. 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 drawdown did not propagate eastward across the barrier. Thus, compaction occurred within the deep 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.
5. InSAR and ground-level-survey data indicated that permanent subsidence in the central region of MZ-1 had occurred in the past and was continuing to occur. The InSAR data also suggested that the groundwater barrier extends northward into central MZ-1. These observations suggested that the conditions that very likely caused ground fissuring near Ayala Park in the 1990s are also present in central MZ-1 and should be studied in more detail.

[1] Production from the deep aquifer system within the Managed Area generally occurs from wells that are screened deeper than 400 feet below the ground surface. (WEI, 2007)

The methods, results, and conclusions of the IMP are described in detail in the MZ-1 Summary Report (WEI, 2006). The IMP provided enough information for Watermaster to develop Guidance Criteria for the 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).

1.1.4 MZ-1 Subsidence Management Plan (MZ-1 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 in October 2007. In November 2007, the San Bernardino County Superior Court, which retains continuing jurisdiction over the Chino Basin Adjudication, approved the MZ-1 Plan and ordered its implementation.

The MZ-1 Plan includes a list of the Managed Wells that are subject to the plan. The Managed Wells are listed in Table 1-1. The MZ-1 Plan also includes a map of the so-called Managed Area in southern MZ-1 that is subject to the plan. The Managed Area and Managed Wells are shown on Figure 1-2.

To minimize the potential for future subsidence and fissuring in the Managed Area, the MZ-1 Plan established a Guidance Level, which 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 permanent compaction of the aquifer system as recorded by the extensometer, minus five feet. The five foot reduction is meant to be a safety factor to ensure that permanent compaction does not occur in the future. The Guidance Level is subject to change based on the periodic review of monitoring data collected by Watermaster. The initial Guidance Level is 245 feet below the top of the well casing (ft-btoc) in PA-7. The Plan recommended that the Parties manage their groundwater production so that the water level in PA-7 remains above the Guidance Level.

The MZ-1 Plan calls for ongoing monitoring, data analysis, annual reporting, and adjustment to the MZ-1 Plan as warranted by the data. Implementation of the MZ-1 Plan began in 2008. The MZ-1 Plan calls for (1) the continued scope and frequency of monitoring implemented during the IMP within the Managed Area and (2) 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, the Pomona Area, the Ontario Area, and the Southeast Area. The expanded monitoring efforts outside of the Managed Area are consistent with the requirements of PE1.

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) development of alternative pumping plans for those Parties affected by the MZ-1 Plan. These potential future efforts are discussed by the Land Subsidence Committee, and if deemed prudent and necessary, are recommended to Watermaster for implementation in future fiscal years.

1.1.5 Annual Report of the Land Subsidence Committee

The MZ-1 Plan states that Watermaster will produce an annual report that includes the results of ongoing monitoring efforts, interpretations of the data, and recommended adjustment to the MZ-1 Plan, if any. This Annual Report of the Land Subsidence Committee includes results and interpretations for data that were collected during calendar year 2013, and includes recommendations for Watermaster's Land-Subsidence Monitoring Program for fiscal year 2014-15.

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, the formation of the Land Subsidence Committee and its responsibilities, and the MZ-1 Plan.

Section 2 – Land-Subsidence Monitoring Program (2013). This section describes the monitoring and testing activities that were performed by the Watermaster for its Land-Subsidence Monitoring Program during 2013.

Section 3 – Results and Interpretations. This section discusses and interprets the monitoring data collected through 2013, including the basin stresses of groundwater pumping and recharge and the basin responses including changes in groundwater 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 2013, and describes recommended activities for the program during fiscal year 2014-15 in the form of a proposed scope-of-work, schedule, and budget.

Section 5 – Glossary. This section a glossary of terms and definitions that are utilized within this report and in the discussions at meetings of the Land Subsidence Committee.

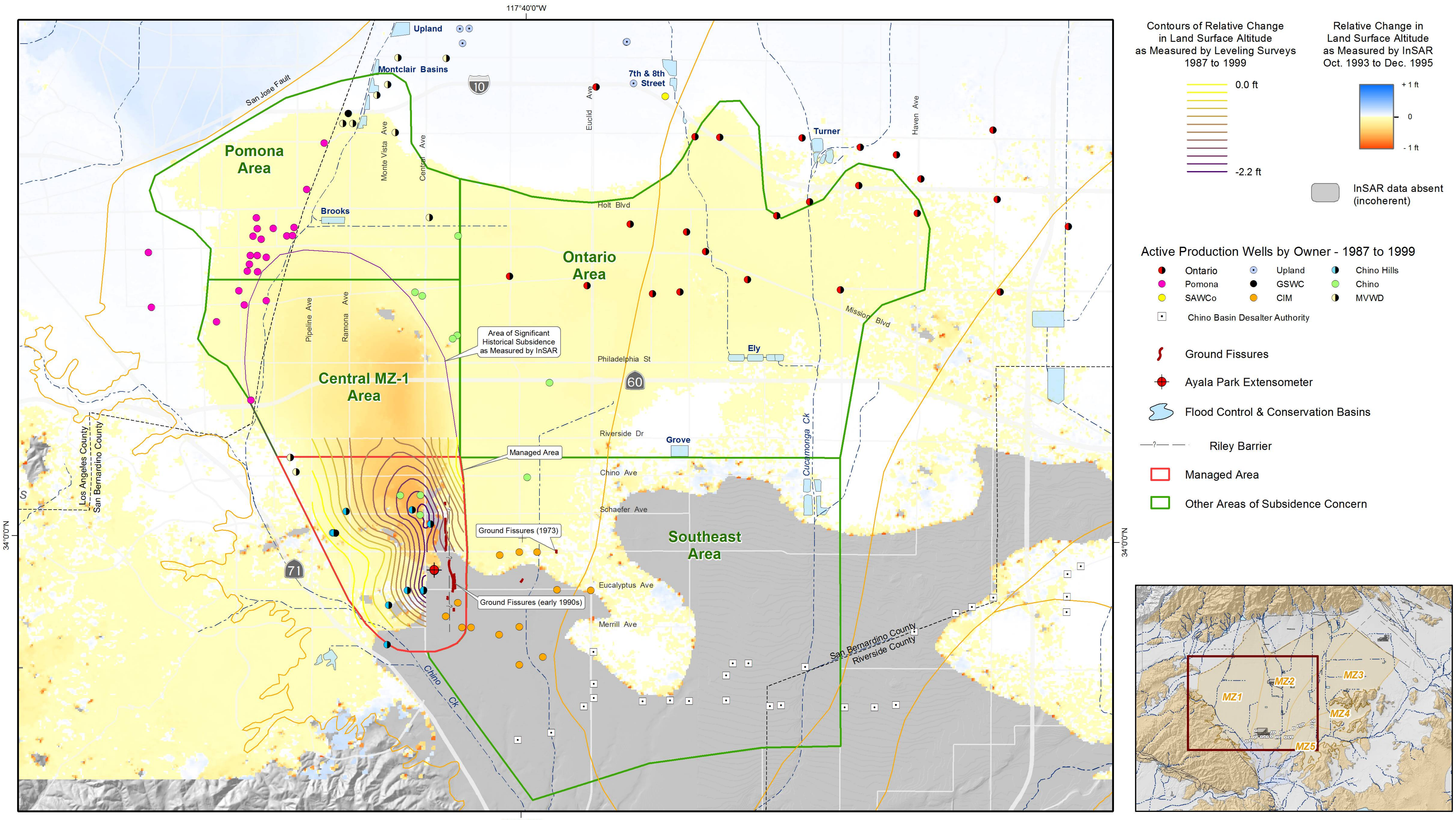
Section 6 – References. This section is a list of the publications cited in this report.

Table 1-1
Managed Wells

CBWM ID	Owner	Well Name	Status[1]	Well Screen Intervals *ft-bgs*
3600461	Chino	C-7	Not Equipped	180-780
600670	Chino	C-15	Not Equipped	270-400, 626-820
600487	Chino Hills	CH-1B	Inactive	440-470, 490-610, 720-900, 940-1180
600687	Chino Hills	CH-7C	Not Equipped	550-950
600498	Chino Hills	CH-7D	Inactive	320-400, 410-450, 490-810, 850-930
600488	Chino Hills	CH-15B	Active	360-440, 480-900
600489	Chino Hills	CH-16	Inactive	430-940
600499	Chino Hills	CH-17	Active	300-460, 500-980
600500	Chino Hills	CH-19	Not Equipped	340-420, 460-760, 800-1000
3602461	CIM	CIM-11A	Active	174-187, 240-283, 405-465 ft bgs[2]

[1] Active: Well is currently being used for water supply.
Inactive: Well can pump groundwater with little or no modifications, but no pumping is planned for the current year.
Not Equipped: Unable to pump the well without major modifications, and no pumping is planned for the current year.

[2] The original casing was perforated from 135-148, 174-187, 240-283, 405-465, 484-512, 518-540 ft-bgs. This casing collapsed below 470.5 ft-bgs in 2011. A liner was installed to 470 ft-bgs with screen interval from 155 to 470 ft-bgs.



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Land Subsidence Committee
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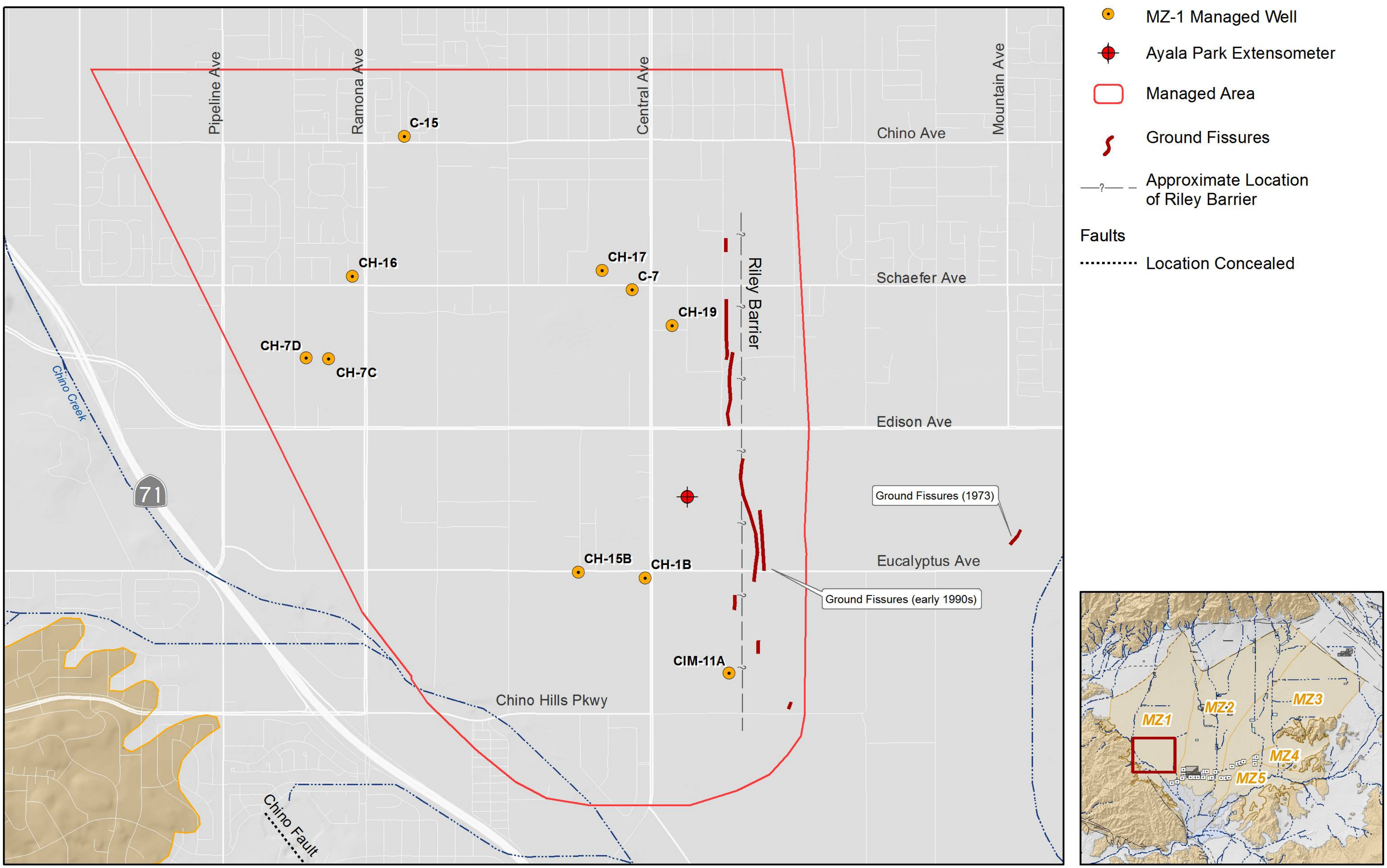
Historical Land Surface Deformation in Management Zone 1

Leveling Surveys (1987 to 1999) and InSAR (1993 to 1995)

Figure 1-1



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Land Subsidence Committee
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MZ-1 Managed Area and Managed Wells

Figure 1-2

Section 2 – Land-Subsidence Monitoring Program (2013)

This section describes the activities performed by the Watermaster for its Land-Subsidence Monitoring Program during 2013.

2.1 Setup and Maintenance of the Monitoring Network

The facilities that comprise Watermaster's land-subsidence monitoring network are shown on Figure 2-1, and include: pressure transducers and data loggers to measure and record water levels at wells, extensometers that measure aquifer-system deformation and ground motion, and benchmark monuments that are periodically surveyed to measure ground motion. Vertical ground motion is also measured by remote-sensing techniques (InSAR).

Described below are activities performed by Watermaster in 2013 to (i) setup new monitoring facilities and (ii) maintain the monitoring network:

2.1.1 Setup of the Pomona Benchmark Network

InSAR monitoring to date has shown persistent land subsidence that is differential across the San Jose Fault within the Pomona Area.[2] The differential subsidence may be causing an accumulation of extensional strain in the soils and the potential for ground fissuring in this heavily urbanized area of Pomona.

To measure the vertical and horizontal ground motion in this area, Watermaster installed a network of benchmark monuments for ground-motion surveys. The new monuments are shown on Figure 2-1. The new monuments were surveyed for initial elevations in January 2014. The closely-spaced monuments that span the San Jose Fault were also surveyed for horizontal distance between monuments using an electronic-distance-measurement (EDM) technique. The initial elevations were referenced to the datum at Ayala Park, and thereby tied into the entire network of benchmark elevations. Future elevation surveys and EDMs will provide information on vertical and horizontal ground motion in this area.

2.1.2 Maintenance of Monitoring Equipment and Facilities

During 2013, Watermaster replaced 10 pressure transducers within the groundwater-level monitoring network that were malfunctioning. Watermaster also performed maintenance activities at the extensometer facilities, which included: protection of the PA facility against surface-water intrusion during storm events; replacement of deployment hardware for backup transducers at Ayala Park; maintenance of Watermaster's Ayala Park website; adjustment of counter-weight arm of the Deep Extensometer at Ayala Park; recalibration of displacement sensors at the deep extensometer at the Chino Creek Extensometer facility (CCX-2); and service of liquid-level equipment and adjustment of solar cell voltage at the Daniels Horizontal Extensometer.

[2] See Figures 1-1, 3-4, 3-5, and 3-10. Figure 3-10 shows that at least 1.4 feet of differential subsidence occurred in Pomona during 1992-2013.

2.2 Land-Subsidence Investigations

Watermaster performs land-subsidence investigations pursuant to the requirements described in the MZ-1 Subsidence Management Plan. Past and current investigations typically include (i) aquifer-stress tests (pumping) and (ii) monitoring of groundwater levels, aquifer-system deformation, and deformation of the land surface. The primary goal of investigation is to develop pumping plans that will not cause damage to the land surface and overlying infrastructure.

The investigations that were conducted in 2013 are described below.

2.2.1 Long-Term Pumping Test in the Managed Area

The MZ-1 Plan states that Watermaster will assist the Parties with "additional testing and monitoring to refine the Guidance Criteria" and to "develop alternative pumping plans" to "produce a reasonable quantity of groundwater from MZ-1." Furthermore, the MZ-1 Plan states that Watermaster will assist the City of Chino Hills in an injection feasibility study to determine if injection is a viable tool for managing subsidence and maximizing the use of existing groundwater production infrastructure (see pages 2-5 and 2-6 of the MZ-1 Plan for reference).

The Land Subsidence Committee developed the Long-Term Pumping Test within the Managed Area in response to these directives in the MZ-1 Plan. The goal of the Long-Term Pumping Test is to develop a strategy for the prudent extraction of groundwater from the Managed Area. In this case, "prudent" is defined as extracting the maximum volume of groundwater without causing damage to the ground surface or the area's infrastructure. Specific questions that the program is designed to answer are:

1. Is the Guidance Level for the Managed Area, as currently defined, appropriate? If no, 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 subsidence (elastic and inelastic) and rebound 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 drawdown and permanent compaction in the deep aquifer system?

5. Is there an "acceptable" rate of permanent land subsidence in the Managed Area? If so, what is the "acceptable" rate?

The Land Subsidence Committee 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 (with arsenic treatment). This test should cause drawdown

at PA-7 to fall below the Guidance Level, and may cause a small amount of permanent subsidence[3]. The test will be closely monitored at the Ayala Park Extensometer and the horizontal monitoring facilities, and will be stopped at the first clear indication of permanent deformation. Groundwater levels recorded at 15-minute intervals at PA-7 will be updated every three-hours on Watermaster's website. As drawdown approaches 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 immediately to the Land Subsidence Committee by email. Watermaster staff and engineers will remain in close telephonic contact with staff at the City of Chino, 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 make the determination to stop the test when appropriate.

2. Stop the pumping test and allow for partial recovery of groundwater levels.

3. Conduct two cycles of injection at CH-16 to see how injection may accelerate recovery of regional drawdown caused by pumping at CH-17 and CH-15B.

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.

5. After injection tests, allow for full recovery of groundwater levels at PA-7 to pre-test conditions. Check stress-strain diagrams for permanent compaction of the aquifer system and/or horizontal deformation across the fissure zone. Analyze ground-level survey, InSAR, and EDM data for permanent ground deformation within the Managed Area.

Since May 2012, pumping at CH-17 and CH-15B has been intermittent, and has failed to cause drawdown below the Guidance Level at the PA-7 piezometer (245 ft-btoc). Maximum depth to water was 190 ft-btoc before pumping was ceased in August 2013. Groundwater levels recovered to about 96 ft-btoc in January 2014 and pumping resumed at CH-17. Ground-level surveys and InSAR data were collected in December 2013 and January 2014, and will serve as the initial ground-level elevation condition for the Long-Term Pumping Test if pumping by Chino Hills causes drawdown below the Guidance Level in 2014.

2.3 Monitoring Activities during 2013

Changes in piezometric levels are caused by the stresses of groundwater production 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,

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

piezometric levels at wells, aquifer-system deformation at vertical extensometers, and vertical and horizontal ground motion across the western portion of Chino Basin.

This section describes Watermaster's monitoring activities during 2013 that are either called for by the MZ-1 Plan or the Long-Term Pumping Test in the Managed Area (described above).

2.3.1 Monitoring of Production, Recharge, and Piezometric Levels

Monthly production data were collected and compiled from the owners of wells in the Managed Area for calendar year 2013.

The volumes of imported water and recycled water that were artificially recharged at basins in MZ-1 and MZ-2, and recycled water used for direct use within the Managed Area and the Southeast Area, were collected from the Inland Empire Utilities Agency (IEUA) for fiscal year 2012-13.

During 2013, piezometric levels were measured and recorded once every 15 minutes using pressure transducers at 70 wells in the Managed Area, Central MZ-1, Pomona Area, and Southeast Area.

2.3.2 Monitoring of Vertical Aquifer-System Deformation

Watermaster recorded aquifer-system deformation at the Ayala Park Extensometer and at the Chino Creek Extensometer (CCX) where the vertical component of aquifer-system deformation is measured once every 15 minutes.

2.3.3 Monitoring of Vertical Ground-Surface Deformation

Watermaster monitors vertical ground motion via traditional leveling surveys and remote sensing techniques (InSAR) established during the IMP.

Watermaster retained Parsons Brinkerhoff (Parsons) to conduct the leveling surveys at selected benchmark monuments in the western part of the Chino Basin. The Land Subsidence Committee decides annually on the benchmarks to be surveyed. During winter 2013, Parsons conducted leveling surveys within the following areas shown on Figure 2-1:

- the Managed Area
- the Southeast Area (around the Chino Creek Well Field)
- the new benchmark network in the Pomona Area

Watermaster has retained Neva Ridge Technologies to acquire InSAR 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] Five InSAR data frames were collected in April 2013, June 2013, August 2013, October 2013 and January 2014, and were used to create six interferograms to record short-term and long-term vertical ground motion over the following periods:

- January 2013 to April 2013
- January 2013 to June 2013
- January 2013 to August 2013
- January 2013 to October 2013
- January 2013 to January 2014
- March 2011 to January 2014

2.3.4 Monitoring of Horizontal Ground-Surface Deformation

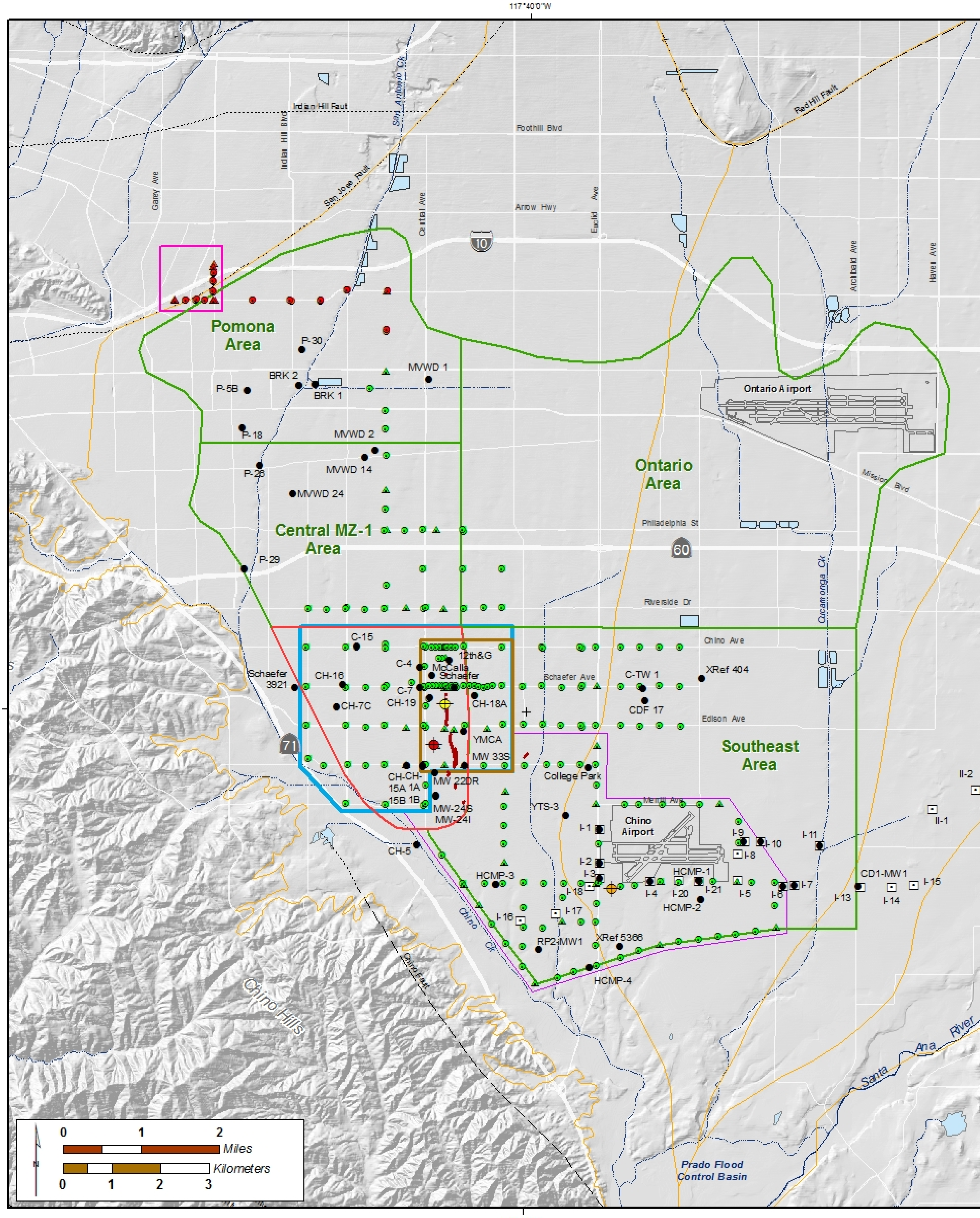
Watermaster measures horizontal ground motion across areas that are susceptible to ground fissuring via EDMs and horizontal extensometers.

In 2013, EDMs were performed between benchmarks in the:

- *Managed Area* along Schaefer Avenue, G Street, and Chino Avenue
- *Pomona Area* along San Bernardino Avenue and North San Antonio Avenue

Watermaster also measures horizontal ground motion within the shallow soils across the historic fissure zone in the Managed Area at the Daniels Horizontal Extensometer (DHX). The DHX is composed of an in-line series of nine quartz-tube horizontal extensometers that measure and record expansion and compression within the shallow soils once every 15 minutes.

[4] All historical InSAR data that was collected and analyzed by Watermaster from 1993-2010 indicates that very little vertical ground motion occurs in the eastern half of the Chino Basin. In 2012, the Land Subsidence Committee decided to acquire and analyze InSAR data only in the western portion of Chino Basin as a cost-savings strategy.



Survey Benchmarks

- Class A Monuments
- Class B Monuments
- Existing Monuments
- New Monuments installed in Pomona Area during 2013-14

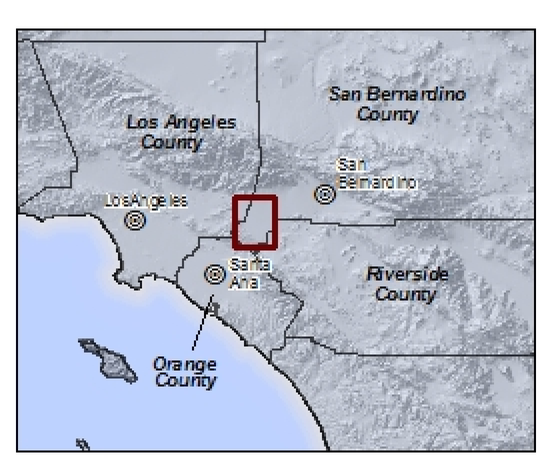
Survey Areas

- Southeast Area
- Fissure Zone
- Managed Area
- San Jose Fault Zone

Wells and Extensometers

- Well Monitored by Pressure Transducer during 2013
- Desalter Well
- Ayala Park Extensometer
- Chino Creek Extensometer
- Daniels Horizontal Extensometer

- Managed Area
- Areas of Subsidence Concern
- Ground Fissures
- Chino Basin Management Zones



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Land Subsidence Committee

2013 Annual Report

Land-Subsidence Monitoring Network

2013

Figure 2-1

Section 3 – Results and Interpretations

This section describes the results and interpretations derived from the Land-Subsidence Monitoring Program for the Managed Area and the other Areas of Subsidence Concern.

3.1 Managed Area

The Managed Area is the primary focus of the MZ-1 Plan. The discussion below describes the results of the monitoring program relative to the Guidance Criteria in the MZ-1 Plan.

3.1.1 History of Aquifer-System Stress and Strain

Figure 3-1 provides a description and explanation of the history of land subsidence in the Managed Area. The main observations from this chart are that pumping from the deep aquifer system during the 1990s caused large drawdown and coincided with high rates of land subsidence. About 2.5 ft of subsidence occurred from 1987-1999, and ground fissures opened within the City of Chino in the early 1990s. Since 2000, pumping has decreased, piezometric levels in the deep aquifer system have recovered, and the rate of land subsidence has declined significantly to a rate of about 0.01 ft/yr.

3.1.2 Recent Aquifer-System Stress and Strain

3.1.2.1 Groundwater Production

Table 3-1 summarizes groundwater production by well within the Managed Area for 2013. Approximately 3,700 acre-feet of groundwater was pumped from the Managed Area in 2013—about 65 percent of the production was from wells screened in the shallow aquifer system and 35 percent was from wells screened in both the shallow and deep aquifer systems.

Figure 3-2 is a time-series chart for 2011-2013 that shows groundwater production and piezometric change (stress), and the resultant aquifer-system deformation (strain). Figure 3-2 illustrates the seasonal pattern of production in the Managed Area. Production typically increases during the warmer spring/summer months, and decreases during the cooler fall/winter months.

3.1.2.2 Groundwater Levels and Aquifer-System Deformation

Figure 3-2 includes a time-series of piezometric levels at Ayala Park for PA-7 (deep aquifer system) and PA-10 (shallow aquifer system). These data are consistent with the conclusions of the IMP and show that pumping from the deep, confined, aquifer system causes drawdown that is much greater in magnitude than drawdown caused by pumping of the shallow aquifer system, even though more pumping occurs from the shallow aquifer system.

In April 2011, piezometric levels at PA-7 were at full seasonal recovery at about 89 ft-btoc. Since then, the Managed Area has experienced three cycles of seasonal drawdown and recovery. Piezometric levels declined to about 190 ft-btoc between May 2012 and August 2013, and returned to full recovery at about 95 ft-btoc by January 2014. While levels at PA-7 did not decline below the Guidance Level of 245 ft-btoc during 2011 to 2013, drawdown was greater than at any time since 2004 and of longer duration than at any time since 2008.

Figure 3-2 includes a time-series of vertical deformation of the aquifer system as measured at the Ayala Park Extensometer facility. These data illustrate that vertical deformation of the aquifer system in response to drawdown and recovery of piezometric levels is mainly elastic. However, the deep extensometer recorded about 0.035 ft of compaction in the aquifer system from April 2011 to January 2014, which appears to be permanent.

Figure 3-3 is a stress-strain diagram of piezometric levels measured at PA-7 (stress) versus vertical deformation of the aquifer system measured at the deep extensometer (strain). Overlapping hysteresis loops on this stress-strain diagram indicate purely elastic deformation of the aquifer system during drawdown-recovery cycles. However, the hysteresis loops appear to be shifting to the right over time, which indicates that the aquifer system is experiencing gradual permanent compaction. This compaction is small relative to the compaction that occurred in the 1990s but is significant from a management perspective, since drawdown at PA-7 has not exceeded the Guidance Level since 2004. A possible explanation for this compaction is that thick aquitard layers are still in the process of delayed drainage and compaction as they equilibrate with heads in the pumped aquifers that are lower than pre-consolidation heads.

3.1.2.3 Vertical Ground Motion

Figure 3-4 is a map of vertical ground motion across the western portion of Chino Basin as measured by InSAR and leveling surveys from 2011 through 2013. Generally, the data indicate less than 0.08 ft of subsidence across the Managed Area.

The InSAR data on Figure 3-4 are a measure of vertical ground motion from March 2011 to December 2013. Figure 3-2 shows that groundwater levels at PA-7 and PA-10 were about the same in March 2011 and December 2013, which suggests that the subsidence shown by InSAR on Figure 3-4 in the Managed Area is permanent.

The InSAR data on Figure 3-4 at the location of the Ayala Park Extensometer are consistent with the aquifer-system deformation on Figure 3-2 as measured at the deep extensometer—both indicate about 0.03 ft of subsidence during the period March 2011 to December 2013.

The ground-level survey data on Figure 3-4 show less than 0.02 feet of subsidence across the Managed Area over the period November 2011 to December 2013. This is less subsidence than indicated by InSAR on Figure 3-4, which is reasonable because piezometric levels increased over the period November 2011 to December 2013, as shown on Figure 3-2. Epicenters of earthquakes that occurred from 2011 to 2014 are included on Figure 3-4 and 3-5. The data show that the vertical ground motion shown on the maps is not associated with earthquake events.

Figure 3-5 is a map of vertical ground motion across the western portion of Chino Basin as measured by InSAR from January 2013 to January 2014. Figure 3-2 shows that piezometric levels at PA-7 and PA-10 increased over this period, which is consistent with the InSAR data Figure 3-5 that shows rebound of the land surface by up to 0.02 ft across much of the Managed Area.

The InSAR data on Figure 3-5 at the location of the Ayala Park Extensometer are consistent with the aquifer-system deformation on Figure 3-2 as measured at the deep extensometer—both indicate about 0.01 ft of rebound during the period January 2013 to January 2014.

Ground-level survey data collected during 2013 is still being processed and verified as of the date of this report.

3.1.2.4 Horizontal Ground Motion

Figure 3-6 is a map of the DHX which measures and records horizontal extension and compression within the shallow soils across the historical fissure zone where it passes north of 12th Street in Chino. The DHX is comprised of nine quartz-tube extensometers that were installed within a trench in an east/west series. The western extensometer is 10-feet long and the other eight extensometers are each 20-feet long. The total length of the DHX is about 170 feet. The Q11 extensometer spans the surface rupture of the historical ground fissure.

Figures 3-7 and 3-8 are time-series charts of horizontal deformation across the length of the DHX from west to east. Figure 3-7 charts cumulative horizontal deformation across the DHX from west to east. Figure 3-8 charts individual strain across the nine horizontal extensometers that comprise the DHX. The extension/compression data shown on Figures 3-7 and 3-8 were set to zero on May 12, 2012, prior to initiation of pumping at CH-17. Also shown on the charts are groundwater levels at PA-7 and vertical aquifer-system deformation as measured by the deep extensometer at Ayala Park. The groundwater levels are a measure of groundwater level changes in the deep aquifer, the mechanism that causes aquifer system deformation at the Ayala Park Extensometer. The vertical compression at the deep extensometer is a measure of the subsidence and rebound of the land surface that is occurring west of the fissure zone.

Figure 3-7 generally shows horizontal compression of the soils across the fissure zone during periods of water-level recovery and rebound of the land surface to the west, and horizontal extension during periods of drawdown and subsidence to the west. This pattern of horizontal strain is consistent with the conceptual model of drawdown and differential subsidence west of the fissure zone causing extensional stresses across the fissure zone (and visa versa). The majority of horizontal extensometers in the DHX show this same pattern, but with differing response time and magnitude of deformation. The response of the DHX to changes in piezometric levels and aquifer-system deformation recorded at Ayala Park was almost immediate (i.e. response times of less than an hour). These observations indicate the DHX functioning as planned, and is measuring and recording the horizontal strain in the shallow soils in response to hydraulic stresses (pumping and piezometric changes) that are occurring in the Managed Area.

Figure 3-7 indicates a net horizontal compression of the shallow soils from October 2011 to October 2012, though vertical subsidence and rebound of the aquifer system at Ayala Park was essentially elastic.

Figures 3-7 and 3-8 indicate that from January 2013 to December 2013 net horizontal compression also occurred at the horizontal extensometers west of and across the surface rupture of the historical ground fissure (Q1 through Q4) and at Q8, the eastern most extensometer. However, Q5 continued extension throughout the year even as vertical rebound of the aquifer system at Ayala Park was occurring between August 2013 and December 2013. And, there was a net extension at Q6 and Q7, though some compression occurred during rebound at Ayala Park. This pattern of deformation indicates that horizontal strain at the surface is mostly occurring along Q5, Q6, and Q7.

3.2 Areas of Subsidence Concern

Figures 3-4 and 3-5 display land subsidence data from InSAR and leveling surveys across the so-called Areas of Subsidence Concern in Chino Basin. Figures 3-9 through 3-12 are time-series charts that describe and explain the occurrence of land subsidence in each of these areas, which include: the *Central MZ-1, Pomona, Ontario,* and *Southeast* areas. The main observations and interpretations with regard to subsidence in these areas are:

- A maximum of about 0.17 feet of subsidence occurred in the *Pomona Area* during the period of March 2011 to January 2014. This pattern of subsidence is a continuation of the historical time-series of subsidence in this area shown on Figure 3-10, which indicates a total of about 1.4 feet of permanent subsidence since 1992. Of particular concern in the *Pomona Area* is that the historical and ongoing subsidence has been differential near the San Jose Fault. Differential subsidence can result in ground fissuring, as it did in the Managed Area during the 1990s. Currently, there are not enough data available to definitively explain the causes of the subsidence in this area, but it is likely related to recent and/or past drawdown of piezometric levels. It is logical to assume that subsidence began when the rate of groundwater level drawdown increased around 1943. If subsidence has been occurring at a constant rate of -0.06 feet per year since 1943, then the *Pomona Area* has experienced about 4.2 feet of permanent subsidence since the onset of increased drawdown.[5]

- A maximum of about 0.07 feet of subsidence occurred in the *Ontario Area* and the *Central MZ-1 Area* during the period of March 2011 to January 2014. The rate of subsidence is relatively slow, and is not occurring in a differential pattern anywhere that would indicate a threat of ground fissuring.

- Very little, if any, subsidence is occurring in the *Southeast Area* as measured by either InSAR and ground-level surveys (see Figure 3-4) or the CCX near the Chino Creak Week Field (see Figure 3-13).

[5] This calculation potentially understates the total subsidence that occurred in this area because it is likely that the rate of subsidence was higher during the earlier period of drawdown compared to the rate of subsidence observed since 1992.

Table 3-1
Groundwater Production in the Managed Area for 2013
acre-feet

Well Name	Aquifer Layer	2013 Calendar Year					
		Quarter 1	Quarter 2	Quarter 3	Quarter 4	Annual Total	Annual Total by Aquifer Layer
C-4	Shallow	0	0	0	0	**0**	**2,372**
C-6		0	0	0	0	**0**	
CH-1A		284	258	184	0	**726**	
CH-7A		117	128	39	0	**283**	
CH-7B		151	22	63	0	**236**	
CIM-1		321	264	276	261	**1,122**	
Xref 8730[1]		1.25	1.25	1.25	1.25	**5**	
CH-17	Deep[2]	437	381	207	0	**1,025**	**1,293**
CH-15B		0	35	105	0	**140**	
CIM-11A		1	14	27	86	**128**	
Totals		**1,312**	**1,102**	**902**	**348**	**3,665**	**3,665**

[1] Well screen interval is unknown, but assumed to be shallow based on typical well construction for other private wells in the general vicinity.

[2] These deep-aquifer wells have screen intervals that extend into the shallow aquifer system, so a portion of this production comes from the shallow aquifer system.

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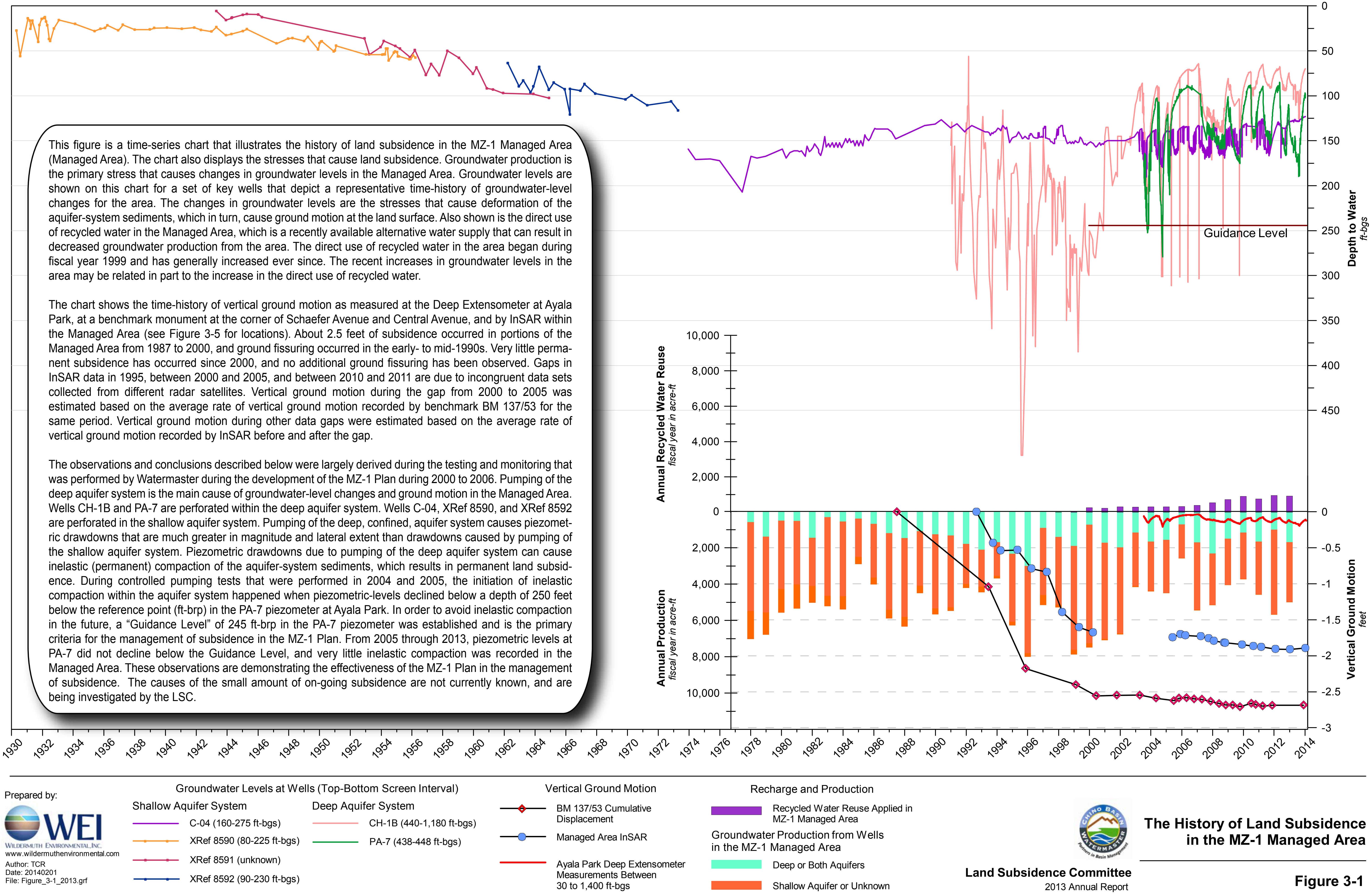
This figure is a time-series chart that illustrates the history of land subsidence in the MZ-1 Managed Area (Managed Area). The chart also displays the stresses that cause land subsidence. Groundwater production is the primary stress that causes changes in groundwater levels in the Managed Area. Groundwater levels are shown on this chart for a set of key wells that depict a representative time-history of groundwater-level changes for the area. The changes in groundwater levels are the stresses that cause deformation of the aquifer-system sediments, which in turn, cause ground motion at the land surface. Also shown is 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 direct use of recycled water in the area began during fiscal year 1999 and has generally increased ever since. The recent increases in groundwater levels in the area may be related in part to the increase in the direct use of recycled water.

The chart shows the time-history of vertical ground motion as measured at the Deep Extensometer at Ayala Park, at a benchmark monument at the corner of Schaefer Avenue and Central Avenue, and by InSAR within the Managed Area (see Figure 3-5 for locations). About 2.5 feet of subsidence occurred in portions of the Managed Area from 1987 to 2000, and ground fissuring occurred in the early- to mid-1990s. Very little permanent subsidence has occurred since 2000, and no additional ground fissuring has been observed. Gaps in InSAR data in 1995, between 2000 and 2005, and between 2010 and 2011 are due to incongruent data sets collected from different radar satellites. Vertical ground motion during the gap from 2000 to 2005 was estimated based on the average rate of vertical ground motion recorded by benchmark BM 137/53 for the same period. Vertical ground motion during other data gaps were estimated based on the average rate of vertical ground motion recorded by InSAR before and after the gap.

The observations and conclusions described below were largely derived during the testing and monitoring that was performed by Watermaster during the development of the MZ-1 Plan during 2000 to 2006. Pumping of the deep aquifer system is the main cause of groundwater-level changes and ground motion in the Managed Area. Wells CH-1B and PA-7 are perforated within the deep aquifer system. Wells C-04, XRef 8590, and XRef 8592 are perforated in the shallow aquifer system. Pumping of the deep, confined, aquifer system causes piezometric drawdowns that are much greater in magnitude and lateral extent than drawdowns caused by pumping of the shallow aquifer system. Piezometric drawdowns due to pumping of the deep aquifer system can cause inelastic (permanent) compaction of the aquifer-system sediments, which results in permanent land subsidence. During controlled pumping tests that were performed in 2004 and 2005, the initiation of inelastic compaction within the aquifer system happened when piezometric-levels declined below a depth of 250 feet below the reference point (ft-brp) in the PA-7 piezometer at Ayala Park. In order to avoid inelastic compaction in the future, a "Guidance Level" of 245 ft-brp in the PA-7 piezometer was established and is the primary criteria for the management of subsidence in the MZ-1 Plan. From 2005 through 2013, piezometric levels at PA-7 did not decline below the Guidance Level, and very little inelastic compaction was recorded in the Managed Area. These observations are demonstrating the effectiveness of the MZ-1 Plan in the management of subsidence. The causes of the small amount of on-going subsidence are not currently known, and are being investigated by the LSC.



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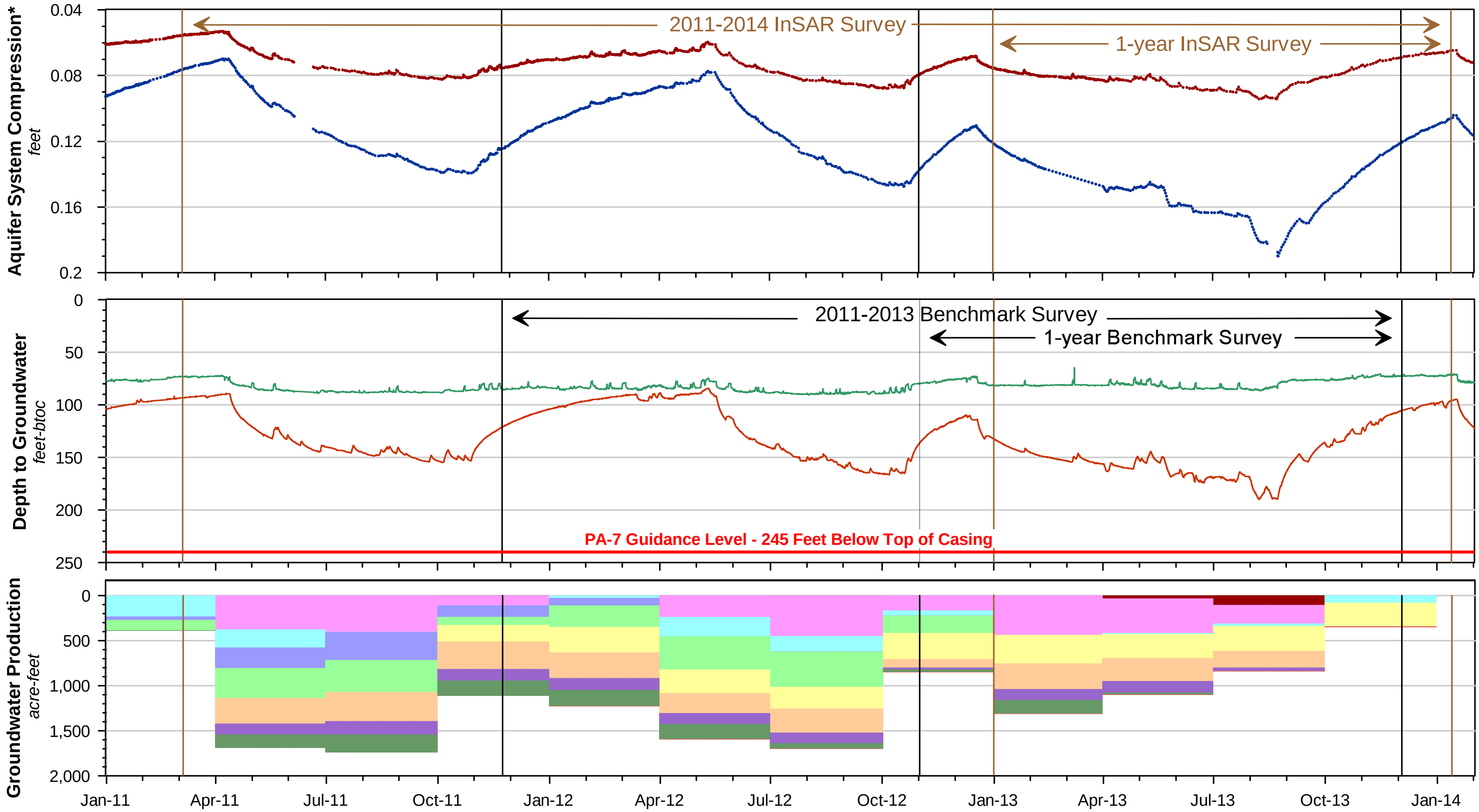
The History of Land Subsidence in the MZ-1 Managed Area

Figure 3-1



Shallow Aquifer System

Aquifer System Deformation (Extensometer Depth Interval)

- Shallow Extensometer (30-550 ft-bgs)

Depth to Groundwater (Perforated Depth Interval)

- PA-10 Piezometer (213-233 ft-bgs)

Groundwater Production (Top-Bottom Screen Interval)

- C-4 (160-275 ft-bgs)
- C-6 (200-375 ft-bgs)
- CIM-1 (118-357 ft-bgs)
- CH-1A (166-317 ft-bgs)
- CH-7A (135-290 ft-bgs)
- CH-7B (120-360 ft-bgs)
- XRef 8730 (unknown)

Deep Aquifer System

Aquifer System Deformation (Extensometer Depth Interval)

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

Depth to Groundwater (Perforated Depth Interval)

- PA-7 Piezometer (438-448 ft-bgs)

Groundwater Production (Top-Bottom Screen Interval)

- CH-15B (360-900 ft-bgs)
- CH-17 (300-980 ft-bgs)
- CIM-11A (174-465** ft-bgs)

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Chino Basin Watermaster

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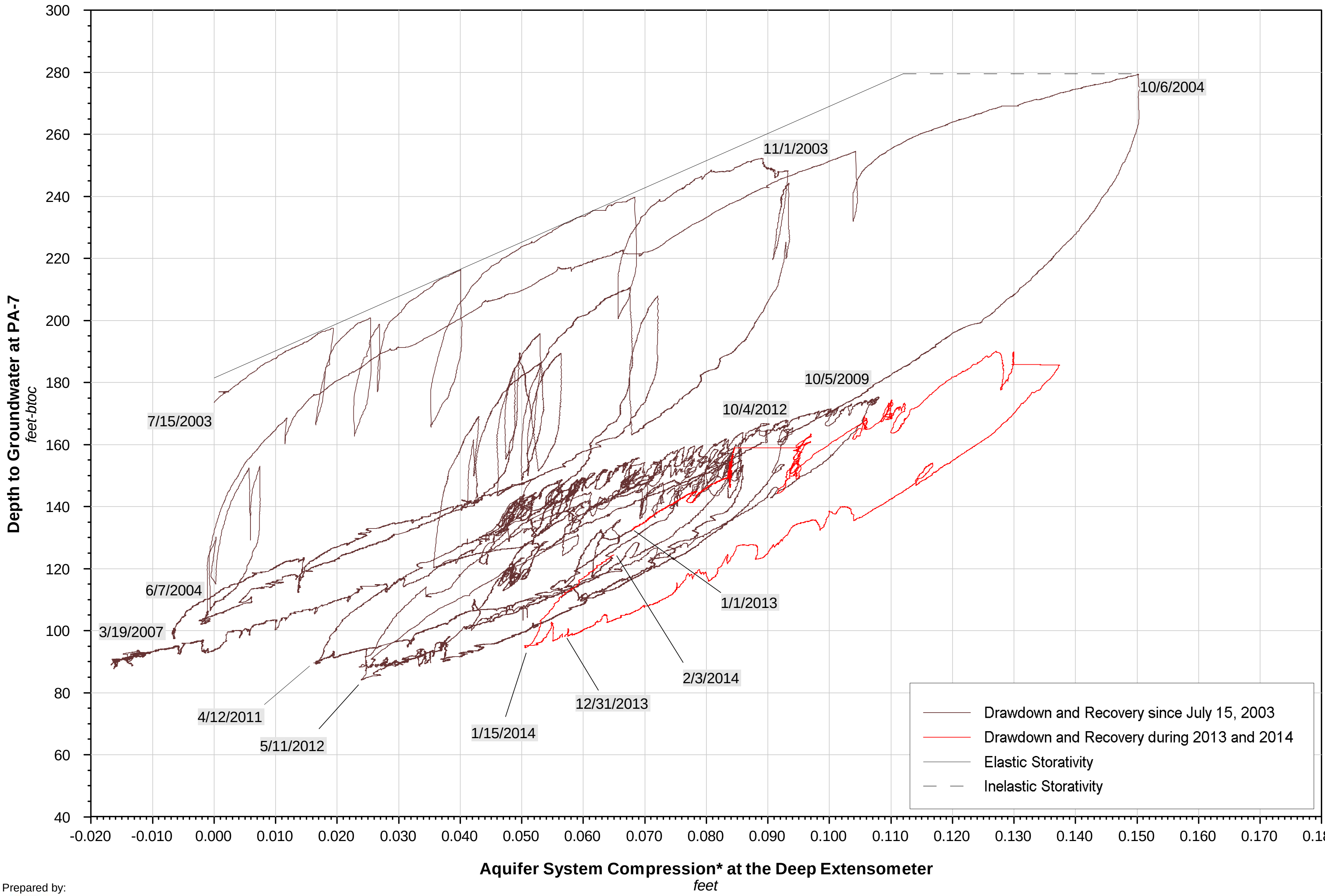
Stress and Strain within the Managed Area

Figure 3-2

*Positive compression values represent compression of soils, negative compression values represent expansion of soils

**The original casing was perforated from 135-148, 174-187, 240-283, 405-465, 484-512, 518-540 ft-bgs. This casing collapsed below 470 ft-bgs in 2011. A liner was installed to 470.5 ft-bgs with screen interval from 155 to 470 ft-bgs.



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PA-7 Well-Screen Interval
= 438-448 ft-bgs

Depth Interval of the Deep Extensometer
= 30-1,400 feet-bgs

*Positive compression values represent compression of soils, negative compression values represent expansion of soils

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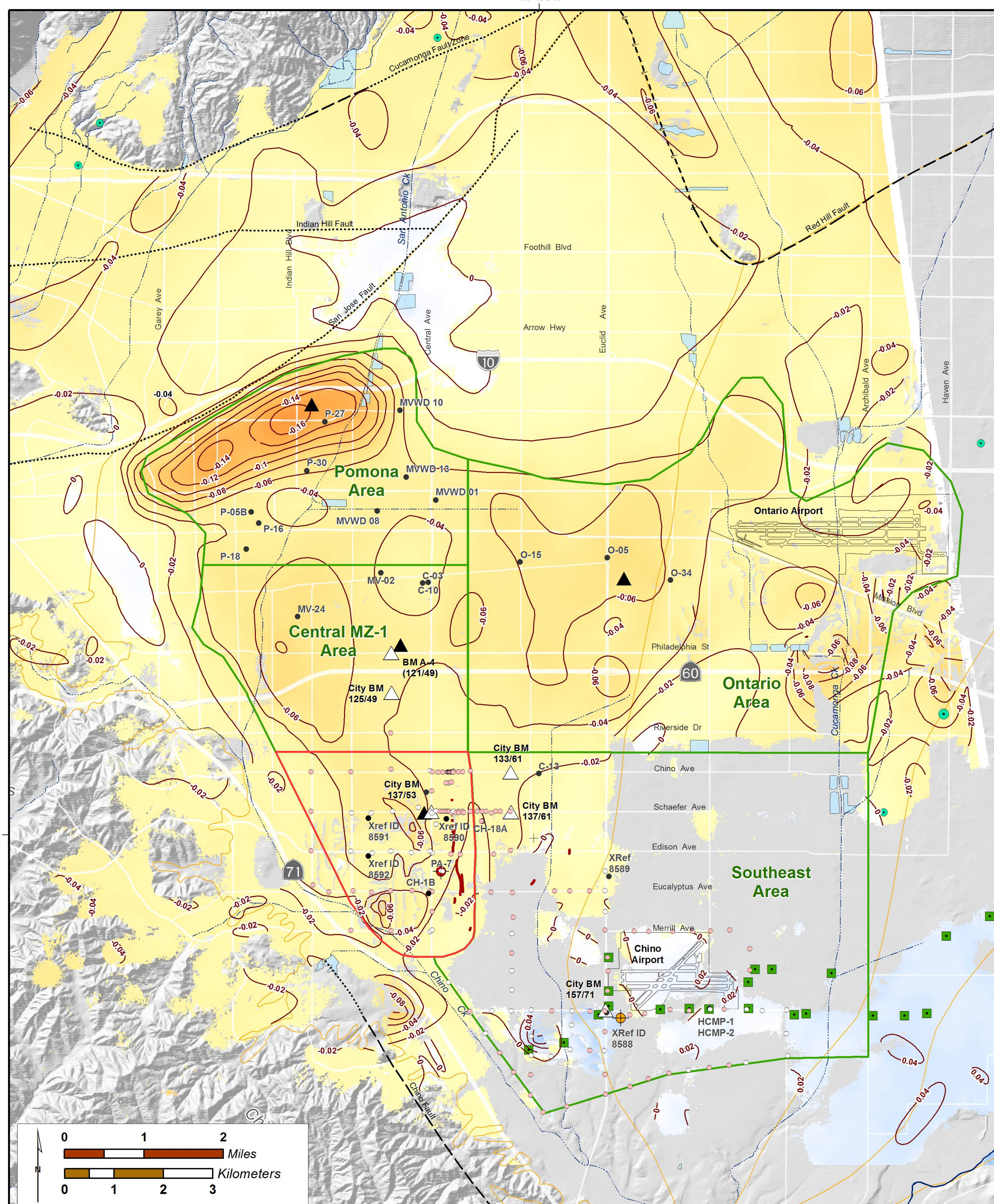
Stress-Strain Diagram
PA-7 Piezometer vs. Deep Extensometer

Figure 3-3



Relative Change in Land Surface Altitudes Measured by Leveling Surveys November 2011 to December 2013 (feet)

- 0.00 - +0.02
- 0.00 - -0.02
- -0.02 - -0.04
- -0.04 - -0.06
- -0.06 - -0.08
- -0.08 - -0.10
- -0.10 - -0.12

Relative Change in Land Surface Altitude as Measured by InSAR March 2011 to January 2014 (feet): + 0.25, 0, -0.1, - 0.25

InSAR data absent (incoherent)

Survey Measurement Stations (see Figures 3-1 and 3-9 to 3-12)

InSAR Measurement Point (see Figures 3-1 and 3-9 to 3-12)

Wells and Extensometers

- Wells with Water Level Data (see Figures 3-1 and 3-9 to 3-12)
- Desalter Well
- Ayala Park Extensometer
- Chino Creek Extensometer

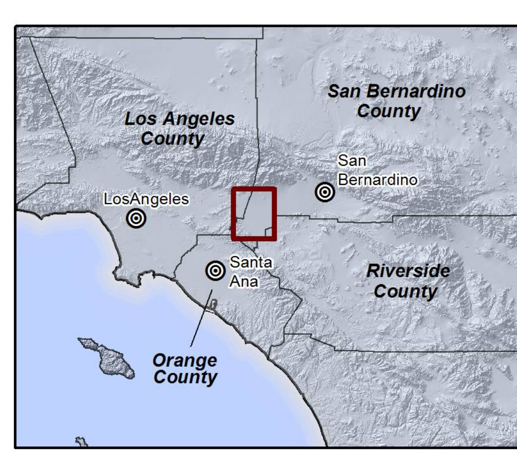
Earthquake Epicenters March 2011 to January 2014 (Local Magnitude): 2, 2 - 3, 3 - 4, 4 - 5, < 5

Managed Area

Areas of Subsidence Concern

Ground Fissures

Chino Basin Management Zones (1, 2, 3, 4, 5)



Vertical Ground Motion across Western Chino Basin

2011-2013

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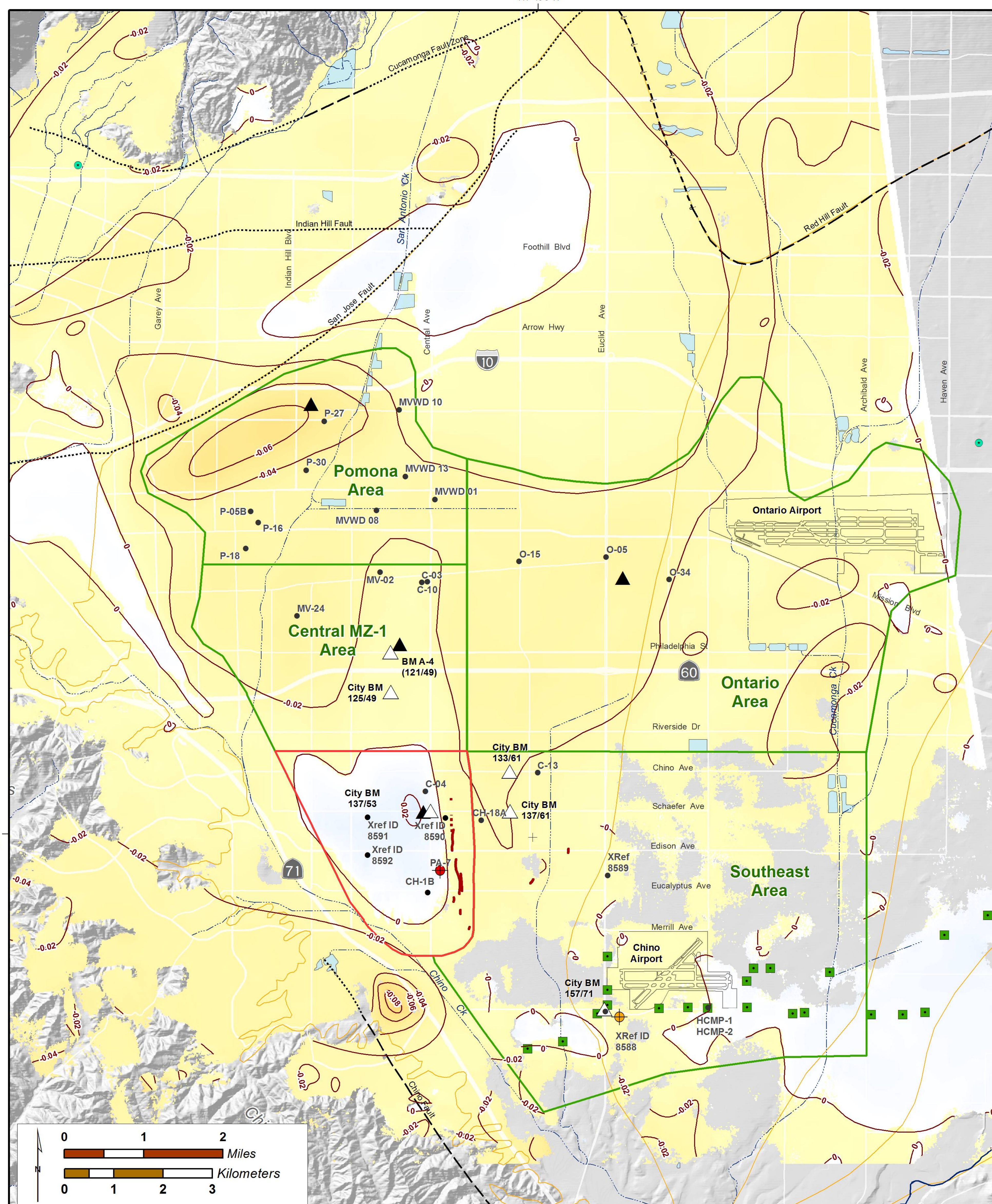
File: Figure_3-4.mxd



+ 0.25
0
-0.1
- 0.25
Relative Change in Land Surface Altitude as Measured by InSAR January 2013 to January 2014 (feet)

InSAR data absent (incoherent)

Prepared by:

Survey Measurement Stations (see Figures 3-1 and 3-9 to 3-12)

InSAR Measurement Point (see Figures 3-1 and 3-9 to 3-12)

Wells and Extensometers

Wells with Water Level Data (see Figures 3-1 and 3-9 to 3-12)

Desalter Well

Ayala Park Extensometer

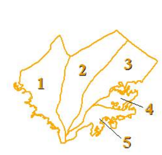
Chino Creek Extensometer

Earthquake Epicenters January 2013 to January 2014 (Local Magnitude)
- 2
- 2 - 3
- 3 - 4
- 4 - 5
- < 5

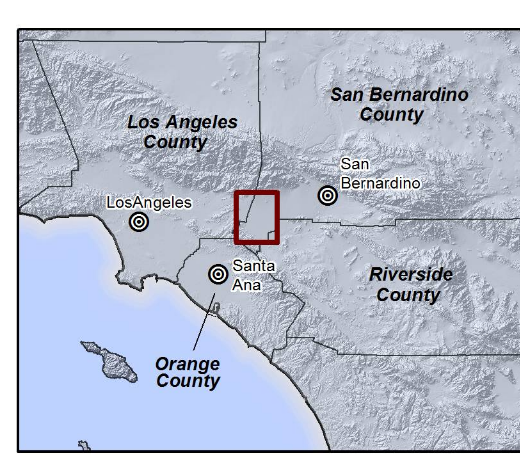
Managed Area

Areas of Subsidence Concern

Ground Fissures



Chino Basin Management Zones



Vertical Ground Motion across Western Chino Basin

2013

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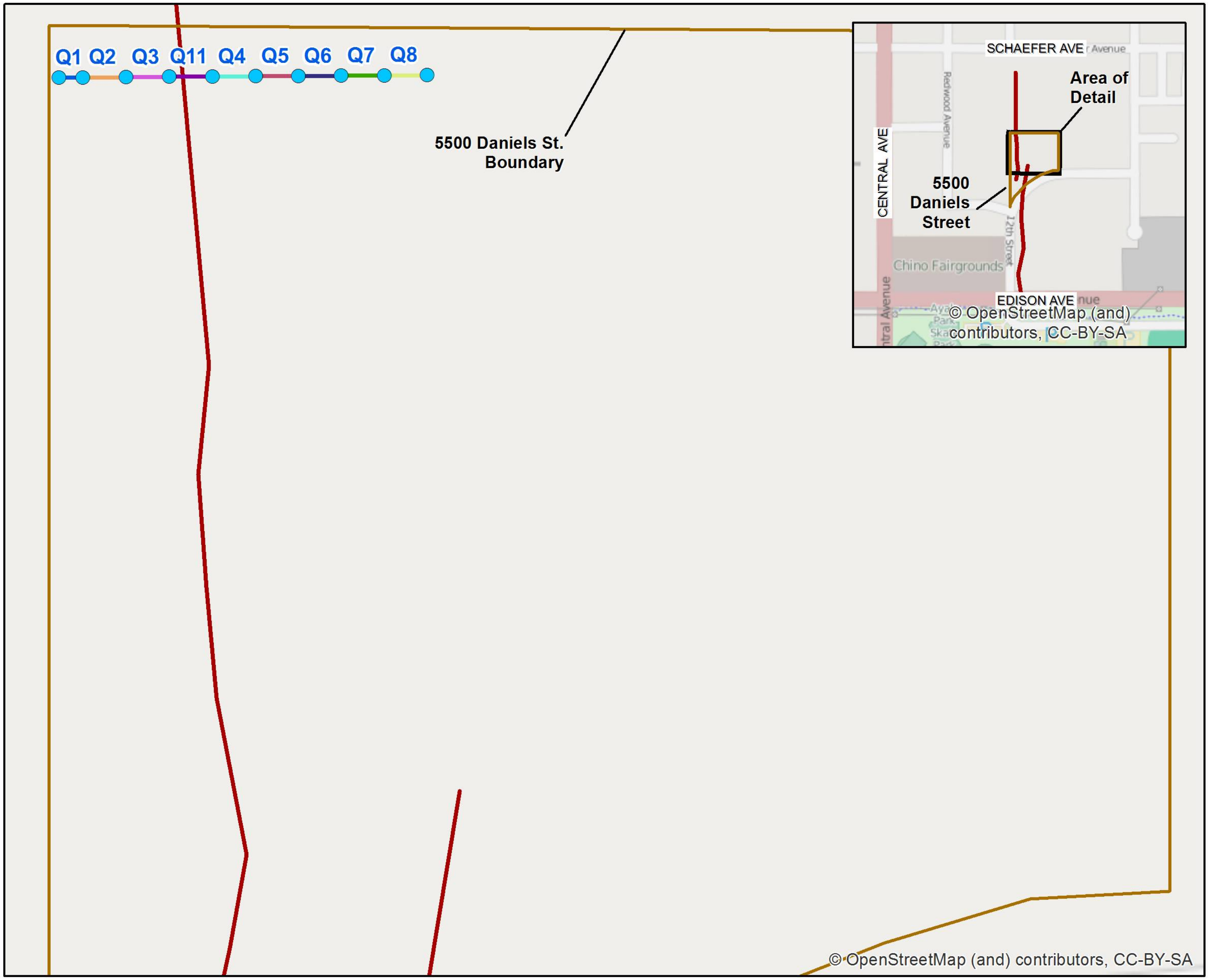
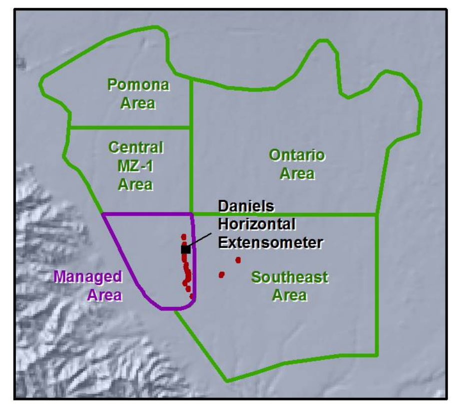
Figure 3-5



Horizontal Extensometer Benchmark

Quartz Tube Extensometer
color corresponds to recorded deforamtion shown on Figure 3-5

Historical Ground Fissures (1990s)



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Date: 20140516
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0 20 40 60 80 100 120 Feet

0 10 20 30 40 Meters

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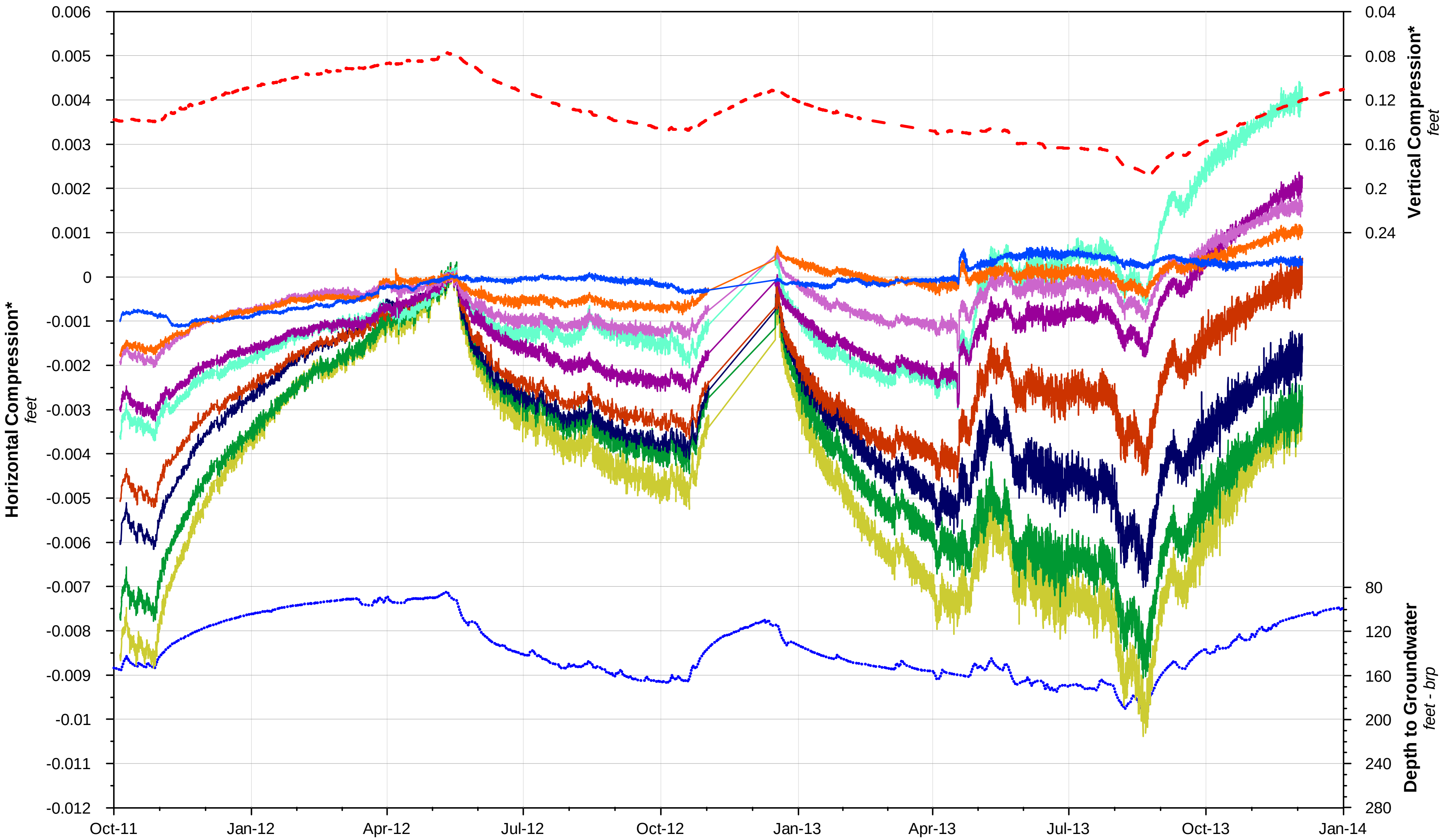
Location of the Daniels Horizontal Extensometer

Figure 3-6



Cumulative Displacement of Horizontal Extensometers
- Q1 (west)
- Q2
- Q3
- Q11 (historical fissure)
- Q4
- Q5
- Q6
- Q7
- Q8 (east)

Displacement is cumulative from west to east

Vertical Compression of the Aquifer System West of the Fissure Zone
- Ayala Park Deep Extensometer

Depth to Groundwater West of the Fissure Zone at Ayala Park
- DTW- PA-7

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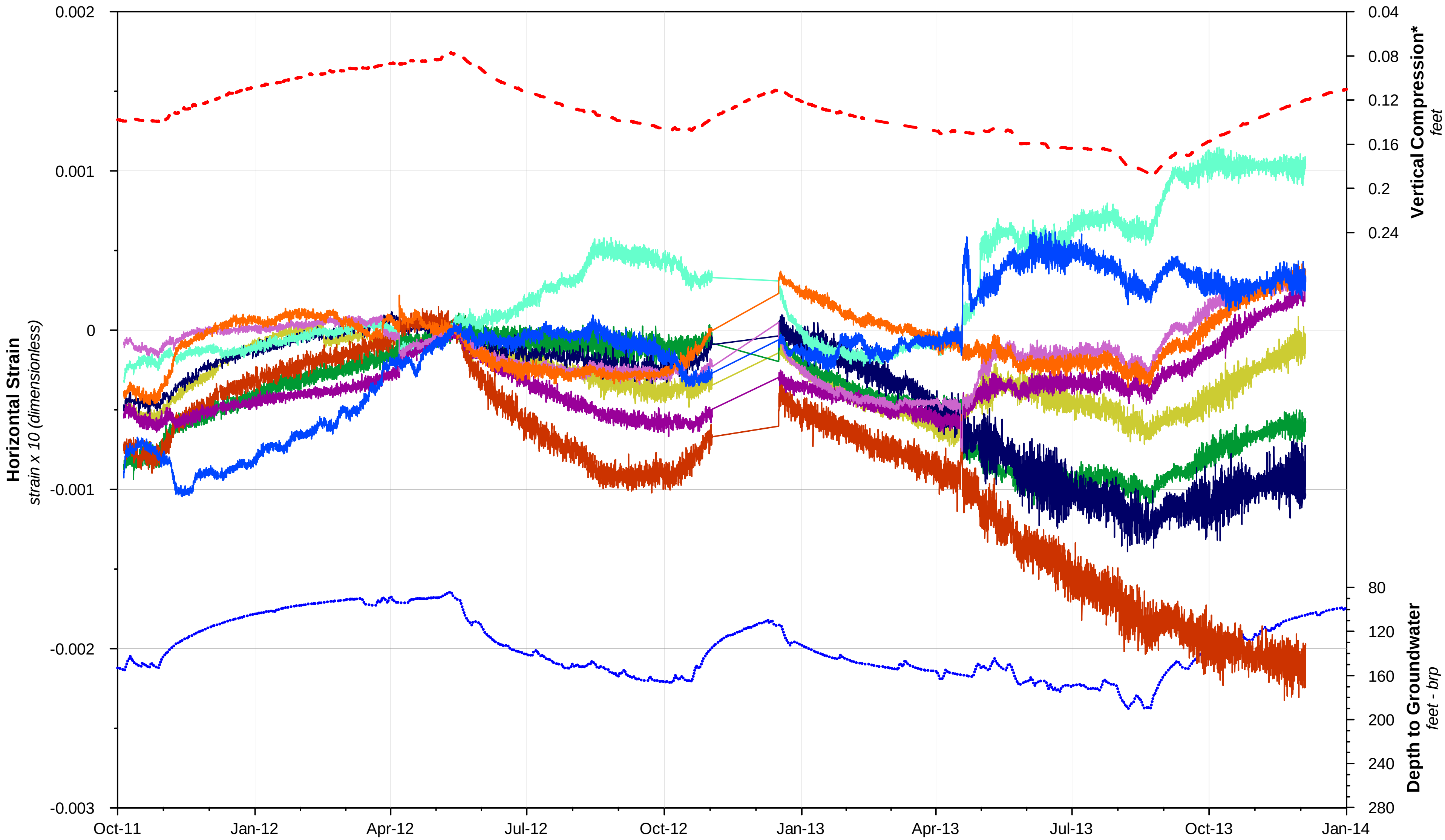
Cumulative Horizontal Deformation at the Daniels Horizontal Extensometer

Figure 3-7

*Positive compression values represent compression of soils, negative compression values represent expansion of soils.



Horizontal Extensometers
- Q1 (west)
- Q2
- Q3
- Q11 (historical fissure)
- Q4
- Q5
- Q6
- Q7
- Q8 (east)

Vertical Compression of the Aquifer System West of the Fissure Zone
- Ayala Park Deep Extensometer

Depth to Groundwater West of the Fissure Zone at Ayala Park
- DTW- PA-7

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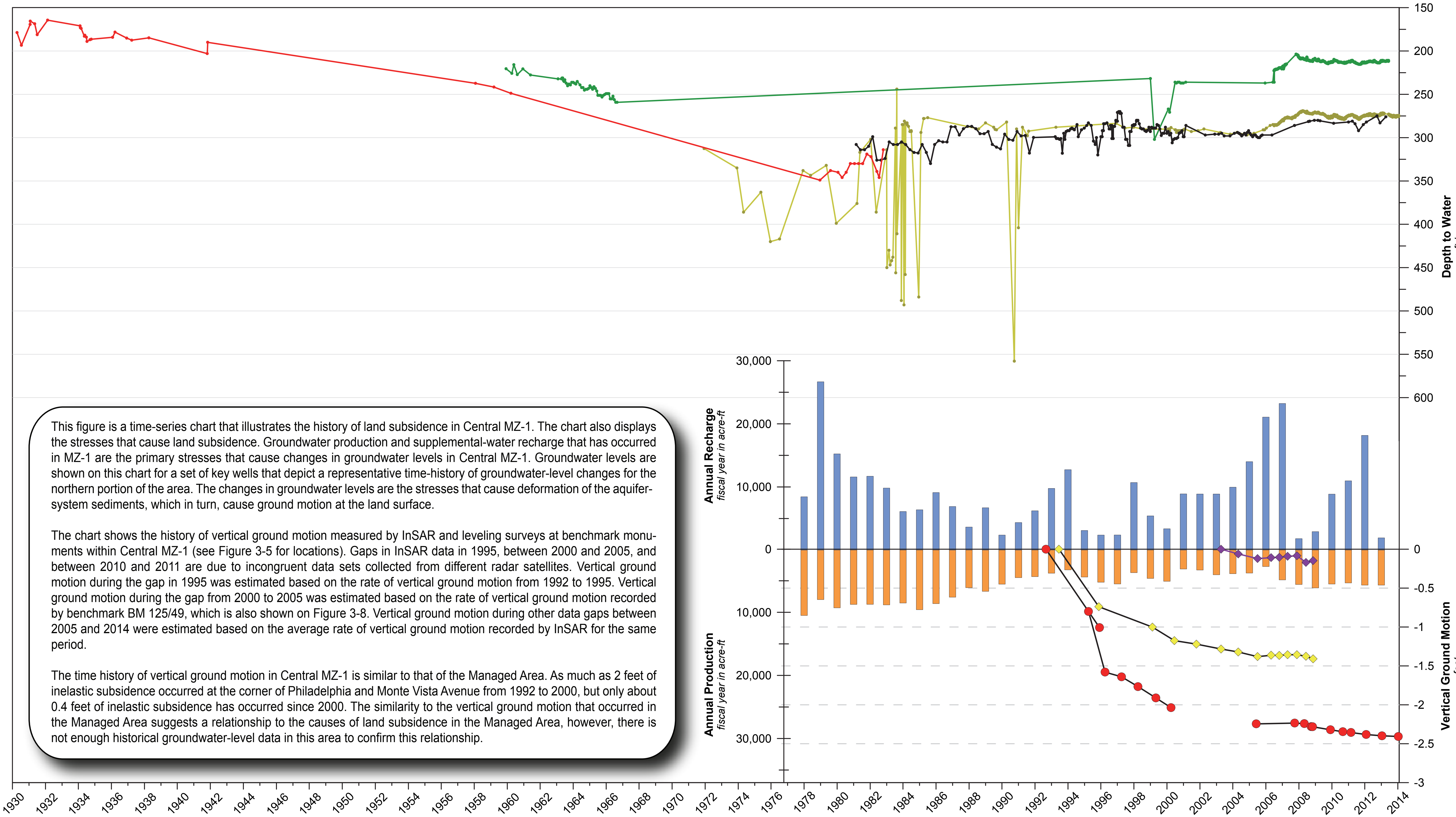
Horizontal Strain across Individual Extensometers at the Daniels Horizontal Extensometer

Figure 3-8

*Positive trends represent compressional strain, negative trends represent expansive strain.



This figure is a time-series chart that illustrates the history of land subsidence in Central MZ-1. The chart also displays the stresses that cause land subsidence. Groundwater production and supplemental-water recharge that has occurred in MZ-1 are the primary stresses that cause changes in groundwater levels in Central MZ-1. Groundwater levels are shown on this chart for a set of key wells that depict a representative time-history of groundwater-level changes for the northern portion of the area. The changes in groundwater levels are the stresses that cause deformation of the aquifer-system sediments, which in turn, cause ground motion at the land surface.

The chart shows the history of vertical ground motion measured by InSAR and leveling surveys at benchmark monuments within Central MZ-1 (see Figure 3-5 for locations). Gaps in InSAR data in 1995, between 2000 and 2005, and between 2010 and 2011 are due to incongruent data sets collected from different radar satellites. Vertical ground motion during the gap in 1995 was estimated based on the rate of vertical ground motion from 1992 to 1995. Vertical ground motion during the gap from 2000 to 2005 was estimated based on the rate of vertical ground motion recorded by benchmark BM 125/49, which is also shown on Figure 3-8. Vertical ground motion during other data gaps between 2005 and 2014 were estimated based on the average rate of vertical ground motion recorded by InSAR for the same period.

The time history of vertical ground motion in Central MZ-1 is similar to that of the Managed Area. As much as 2 feet of inelastic subsidence occurred at the corner of Philadelphia and Monte Vista Avenue from 1992 to 2000, but only about 0.4 feet of inelastic subsidence has occurred since 2000. The similarity to the vertical ground motion that occurred in the Managed Area suggests a relationship to the causes of land subsidence in the Managed Area, however, there is not enough historical groundwater-level data in this area to confirm this relationship.

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Groundwater Levels at Wells
(Top-Bottom Screen Interval)

- C-03 (230-450 ft-bgs)
- MV-24 (244-420 ft-bgs)
- MV-02 (397-962 ft-bgs)
- C-10 (355-1090 ft-bgs)

Vertical Ground Motion

- Central MZ-1 InSAR
- BM A-4
- BM 125/49

Recharge and Production

- Recharge of Recycled Water, Storm Water*, and Imported Water at the College Heights, Upland, Montclair, and Brooks Basins; and at MVWD ASR Wells
  *Storm Water is an estimated amount prior to Fiscal Year 04/05
- Groundwater Production from Wells in Central MZ-1 Area

The History of Land Subsidence in Central MZ-1

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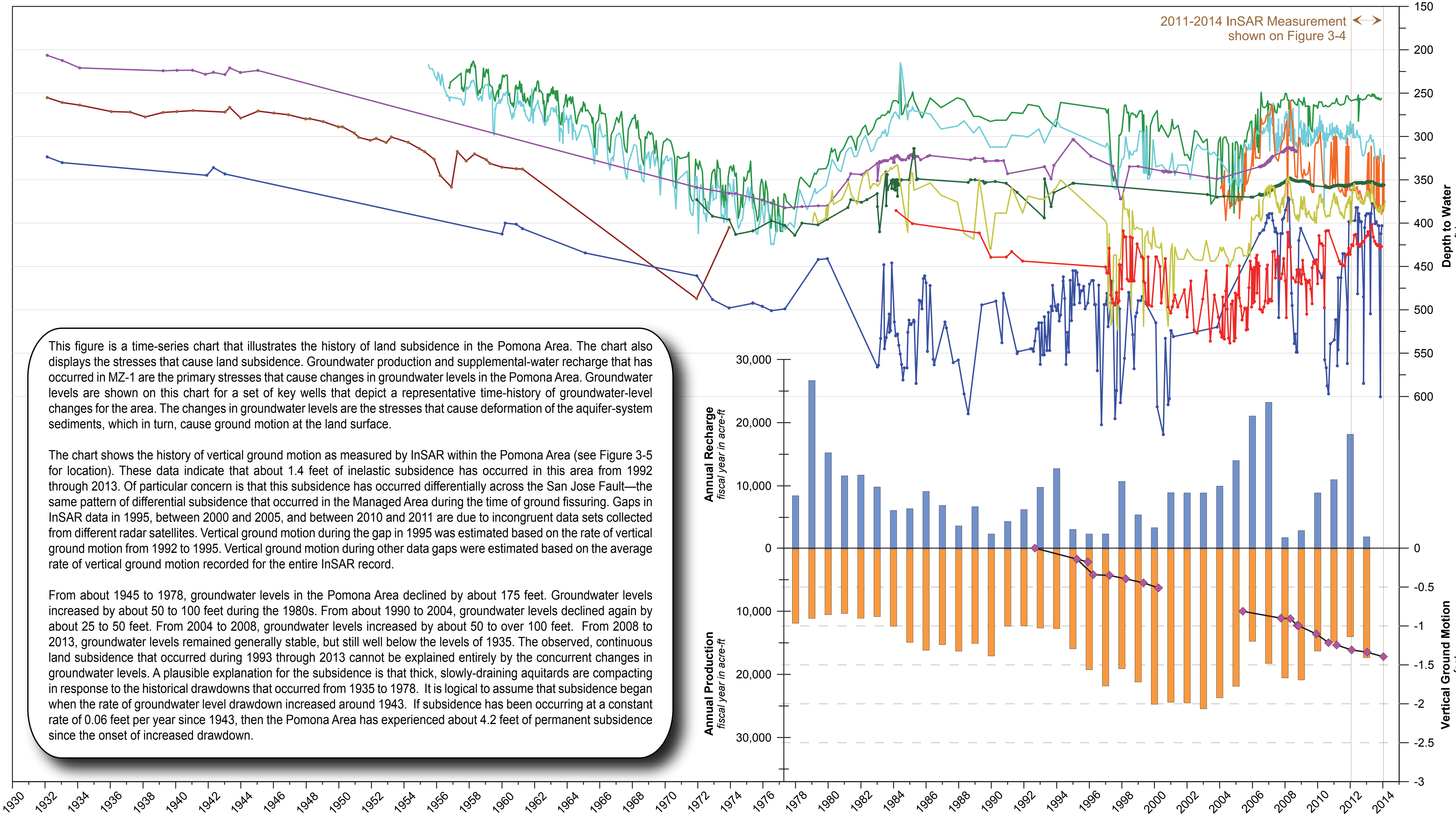
Figure 3-9



This figure is a time-series chart that illustrates the history of land subsidence in the Pomona Area. The chart also displays the stresses that cause land subsidence. Groundwater production and supplemental-water recharge that has occurred in MZ-1 are the primary stresses that cause changes in groundwater levels in the Pomona Area. Groundwater levels are shown on this chart for a set of key wells that depict a representative time-history of groundwater-level changes for the area. The changes in groundwater levels are the stresses that cause deformation of the aquifer-system sediments, which in turn, cause ground motion at the land surface.

The chart shows the history of vertical ground motion as measured by InSAR within the Pomona Area (see Figure 3-5 for location). These data indicate that about 1.4 feet of inelastic subsidence has occurred in this area from 1992 through 2013. Of particular concern is that this subsidence has occurred differentially across the San Jose Fault—the same pattern of differential subsidence that occurred in the Managed Area during the time of ground fissuring. Gaps in InSAR data in 1995, between 2000 and 2005, and between 2010 and 2011 are due to incongruent data sets collected from different radar satellites. Vertical ground motion during the gap in 1995 was estimated based on the rate of vertical ground motion from 1992 to 1995. Vertical ground motion during other data gaps were estimated based on the average rate of vertical ground motion recorded for the entire InSAR record.

From about 1945 to 1978, groundwater levels in the Pomona Area declined by about 175 feet. Groundwater levels increased by about 50 to 100 feet during the 1980s. From about 1990 to 2004, groundwater levels declined again by about 25 to 50 feet. From 2004 to 2008, groundwater levels increased by about 50 to over 100 feet. From 2008 to 2013, groundwater levels remained generally stable, but still well below the levels of 1935. The observed, continuous land subsidence that occurred during 1993 through 2013 cannot be explained entirely by the concurrent changes in groundwater levels. A plausible explanation for the subsidence is that thick, slowly-draining aquitards are compacting in response to the historical drawdowns that occurred from 1935 to 1978. It is logical to assume that subsidence began when the rate of groundwater level drawdown increased around 1943. If subsidence has been occurring at a constant rate of 0.06 feet per year since 1943, then the Pomona Area has experienced about 4.2 feet of permanent subsidence since the onset of increased drawdown.

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Groundwater Levels at Wells (Top-Bottom Screen Interval)

- MV-01 (245-472 ft-bgs)
- MV-08 (225-447 ft-bgs)
- MV-10 (520-1084 ft-bgs)
- MV-13 (203-475 ft-bgs)
- P-5B (457-615 ft-bgs)
- P-16 (270-328 ft-bgs)
- P-18 (307-660 ft-bgs)
- P-27 (472-849 ft-bgs)
- P-30 (565-875 ft-bgs)

Vertical Ground Motion

- Pomona Area InSAR

Recharge and Production

- Recharge of Recycled Water, Storm Water*, and Imported Water at the College Heights, Upland, Montclair, and Brooks Basins; and at MVWD ASR Wells
  *Storm Water is an estimated amount prior to Fiscal Year 04/05
- Groundwater Production from Wells in the Pomona Area

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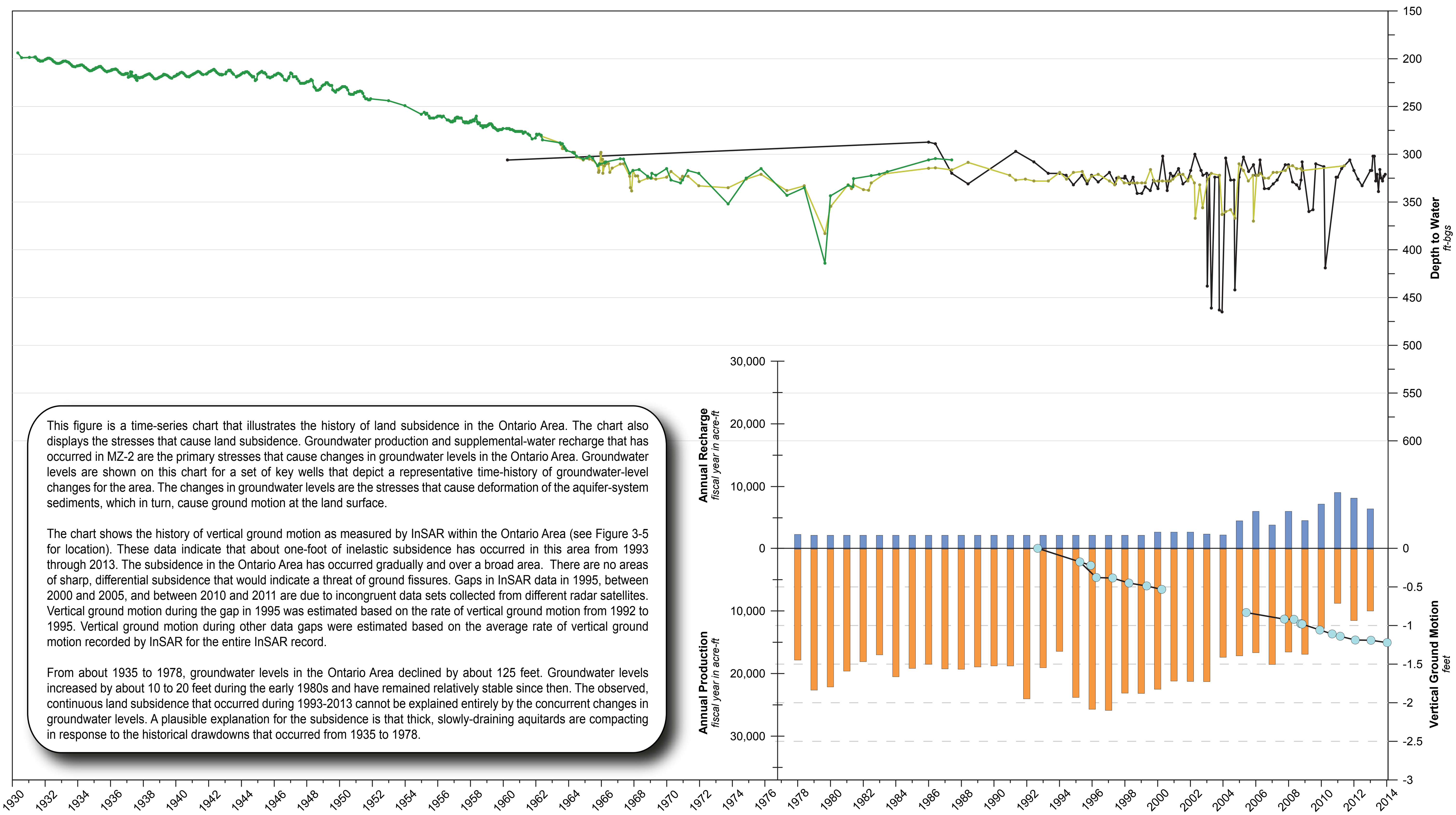
The History of Land Subsidence in the Pomona Area

Figure 3-10



This figure is a time-series chart that illustrates the history of land subsidence in the Ontario Area. The chart also displays the stresses that cause land subsidence. Groundwater production and supplemental-water recharge that has occurred in MZ-2 are the primary stresses that cause changes in groundwater levels in the Ontario Area. Groundwater levels are shown on this chart for a set of key wells that depict a representative time-history of groundwater-level changes for the area. The changes in groundwater levels are the stresses that cause deformation of the aquifer-system sediments, which in turn, cause ground motion at the land surface.

The chart shows the history of vertical ground motion as measured by InSAR within the Ontario Area (see Figure 3-5 for location). These data indicate that about one-foot of inelastic subsidence has occurred in this area from 1993 through 2013. The subsidence in the Ontario Area has occurred gradually and over a broad area. There are no areas of sharp, differential subsidence that would indicate a threat of ground fissures. Gaps in InSAR data in 1995, between 2000 and 2005, and between 2010 and 2011 are due to incongruent data sets collected from different radar satellites. Vertical ground motion during the gap in 1995 was estimated based on the rate of vertical ground motion from 1992 to 1995. Vertical ground motion during other data gaps were estimated based on the average rate of vertical ground motion recorded by InSAR for the entire InSAR record.

From about 1935 to 1978, groundwater levels in the Ontario Area declined by about 125 feet. Groundwater levels increased by about 10 to 20 feet during the early 1980s and have remained relatively stable since then. The observed, continuous land subsidence that occurred during 1993-2013 cannot be explained entirely by the concurrent changes in groundwater levels. A plausible explanation for the subsidence is that thick, slowly-draining aquitards are compacting in response to the historical drawdowns that occurred from 1935 to 1978.

Groundwater Levels at Wells (Top-Bottom Screen Interval)

- O-05 (360-470 ft-bgs)
- O-15 (474-966 ft-bgs)
- O-34 (522-1092 ft-bgs)

Vertical Ground Motion

- Ontario Area InSAR

Recharge and Production

- Recharge of Recycled, Storm Water*, and Imported Water at the Ely, Grove, Turner, 7th Street, 8th Street, and 15th Street Basins
  *Storm Water is an estimated amount prior to Fiscal Year 04/05
- Groundwater Production from Wells in the Ontario Area

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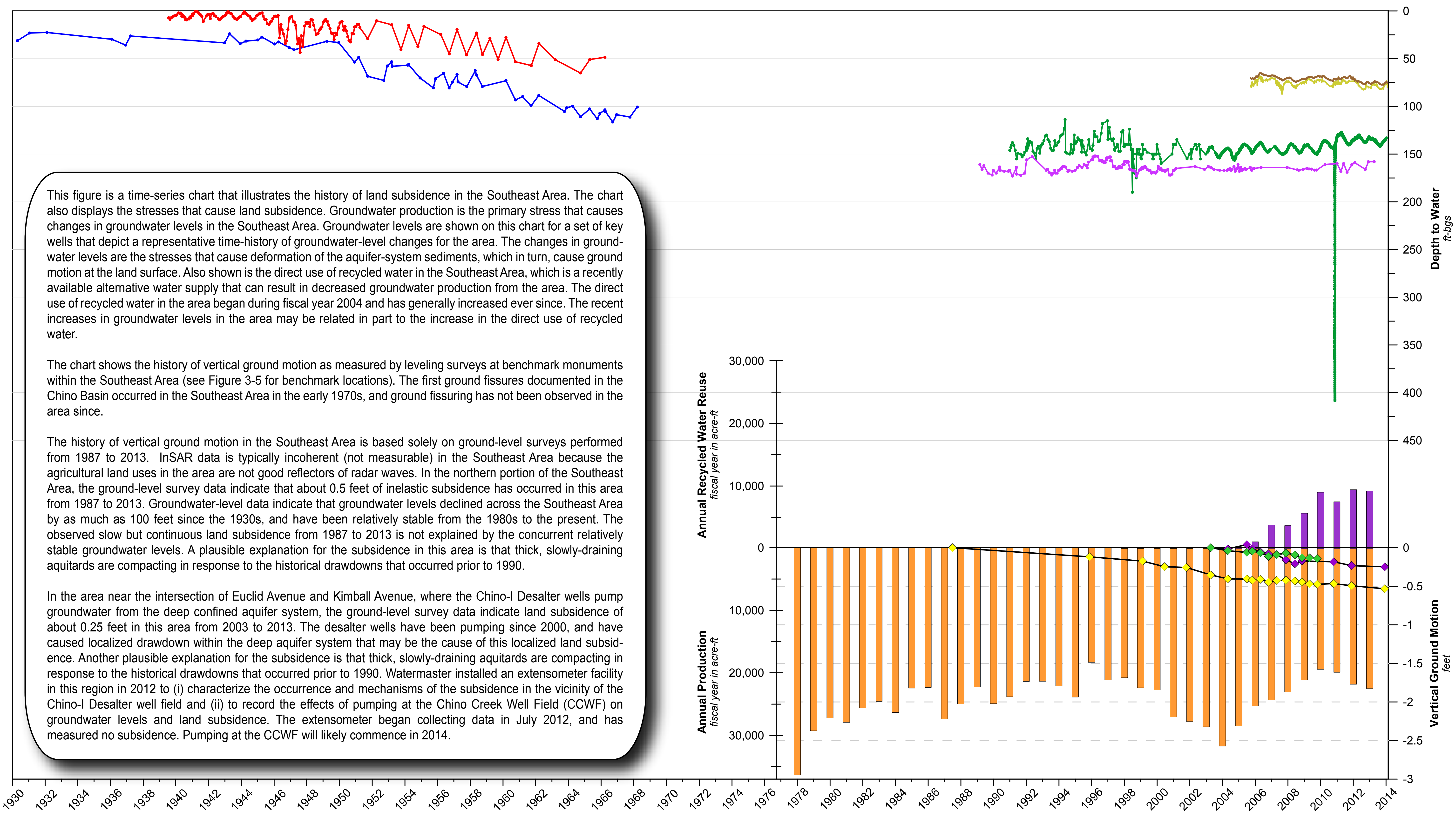
Land Subsidence Committee
2013 Annual Report

The History of Land Subsidence in the Ontario Area

Figure 3-11



This figure is a time-series chart that illustrates the history of land subsidence in the Southeast Area. The chart also displays the stresses that cause land subsidence. Groundwater production is the primary stress that causes changes in groundwater levels in the Southeast Area. Groundwater levels are shown on this chart for a set of key wells that depict a representative time-history of groundwater-level changes for the area. The changes in groundwater levels are the stresses that cause deformation of the aquifer-system sediments, which in turn, cause ground motion at the land surface. Also shown is the direct use of recycled water in the Southeast Area, which is a recently available alternative water supply that can result in decreased groundwater production from the area. The direct use of recycled water in the area began during fiscal year 2004 and has generally increased ever since. The recent increases in groundwater levels in the area may be related in part to the increase in the direct use of recycled water.

The chart shows the history of vertical ground motion as measured by leveling surveys at benchmark monuments within the Southeast Area (see Figure 3-5 for benchmark locations). The first ground fissures documented in the Chino Basin occurred in the Southeast Area in the early 1970s, and ground fissuring has not been observed in the area since.

The history of vertical ground motion in the Southeast Area is based solely on ground-level surveys performed from 1987 to 2013. InSAR data is typically incoherent (not measurable) in the Southeast Area because the agricultural land uses in the area are not good reflectors of radar waves. In the northern portion of the Southeast Area, the ground-level survey data indicate that about 0.5 feet of inelastic subsidence has occurred in this area from 1987 to 2013. Groundwater-level data indicate that groundwater levels declined across the Southeast Area by as much as 100 feet since the 1930s, and have been relatively stable from the 1980s to the present. The observed slow but continuous land subsidence from 1987 to 2013 is not explained by the concurrent relatively stable groundwater levels. A plausible explanation for the subsidence in this area is that thick, slowly-draining aquitards are compacting in response to the historical drawdowns that occurred prior to 1990.

In the area near the intersection of Euclid Avenue and Kimball Avenue, where the Chino-I Desalter wells pump groundwater from the deep confined aquifer system, the ground-level survey data indicate land subsidence of about 0.25 feet in this area from 2003 to 2013. The desalter wells have been pumping since 2000, and have caused localized drawdown within the deep aquifer system that may be the cause of this localized land subsidence. Another plausible explanation for the subsidence is that thick, slowly-draining aquitards are compacting in response to the historical drawdowns that occurred prior to 1990. Watermaster installed an extensometer facility in this region in 2012 to (i) characterize the occurrence and mechanisms of the subsidence in the vicinity of the Chino-I Desalter well field and (ii) to record the effects of pumping at the Chino Creek Well Field (CCWF) on groundwater levels and land subsidence. The extensometer began collecting data in July 2012, and has measured no subsidence. Pumping at the CCWF will likely commence in 2014.

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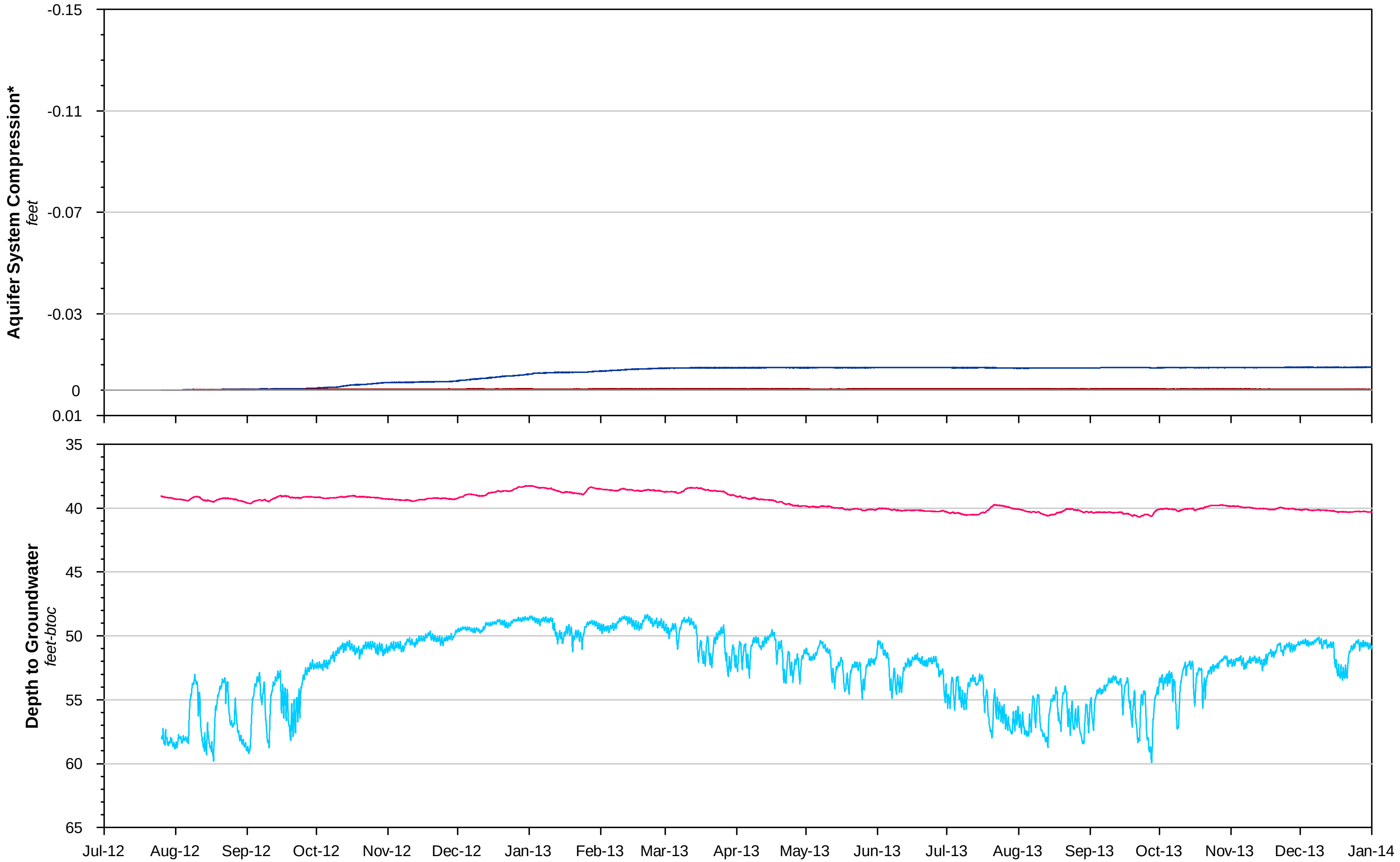
The History of Land Subsidence in the Southeast Area

Land Subsidence Committee
2013 Annual Report

Figure 3-12



Shallow Aquifer System

Aquifer System Deformation
(Extensometer Depth Interval)

CCX-1 Extensometer
(50-140 ft-bgs)

Depth to Groundwater
(Well-Screen Interval)

CCPA-1 Piezometer
(100-130 ft-bgs)

Deep Aquifer System

Aquifer System Deformation
(Extensometer Depth Interval)

CCX-2 Extensometer
(50-610 ft-bgs)

Depth to Groundwater
(Well-Screen Interval)

CCPA-2 Piezometer
(235-295 ft-bgs)

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Land Subsidence Committee
2013 Annual Report

Stress and Strain
Chino Creek Extensometer

Figure 3-13

*Positive compression values represent compression of soils, negative compression values represent expansion of soils

Section 4 – Conclusions and Recommendations

4.1 Conclusions

The following conclusions are based on the data collected and analyzed for the Land-Subsidence Monitoring Program through 2013:

- Drawdown at PA-7 has not exceeded the Guidance Level since 2004, and subsidence and rebound in the Managed Area has been primarily elastic, which indicates that the Guidance Criteria has been largely protective. However, the data also indicate that a small amount of permanent compaction is occurring gradually, even though drawdown has not exceeded the Guidance Level since 2004. The threat of future ground fissuring caused by this permanent subsidence is not well characterized. The Long-Term Pumping Test will provide additional information on the mechanisms that are causing the subsidence in this area and the threat of future ground fissuring.

- The horizontal-strain data collected to date at the DHX demonstrate a logical response to stresses in the Managed Area:

  - Horizontal extension across the fissure zone occurs during subsidence of the ground surface in the Managed Area.

  - Horizontal compression across the fissure zone occurs during rebound of the land surface in the Managed Area.

  In 2013, the extensional strain mostly occurred to the east of the historical fissure zone. The data collected and analyzed from the DHX during the Long-Term Pumping Test in the Managed Area may provide information on the threat of future ground fissuring in this area, and is needed to determine if the DHX is capable of producing "management-grade" information.

- During 2013, differential land subsidence continued to occur in the Pomona Area near the San Jose Fault, which is the type of vertical deformation of the land surface that can lead to ground fissuring. It is logical to assume that at least 4.2 feet of permanent, differential subsidence has occurred in this area since the onset of increased drawdown in the 1940s. Future surveys at new benchmarks installed across the San Jose Fault zone during fiscal year 2013-14 will contribute to a better characterization of the threat of ground fissuring in this area. A hydrogeologic investigation in the area is needed if the Watermaster intends to better characterize the causes of the observed land subsidence in this area, and to develop management criteria to minimize or abate its occurrence.

- Since July 2012, the CCX has recorded very little fluctuation of groundwater levels or vertical deformation of the aquifer system. There appears to be very little, if any, ongoing subsidence in the vicinity of the CCX and the Chino Creek Well Field.

4.2 Recommended Scope and Budget for Fiscal Year 2014-15

The recommended scope-of-work for the Land-Subsidence Monitoring Program for fiscal year 2014-15 is shown in Table 4-1 as a work breakdown structure with cost estimates. The following summarizes the recommended scope and associated reasoning and justification:

- *Continued regular and as-needed maintenance at the Ayala Park Extensometer, Chino Creek Extensometer, and Daniels Horizontal Extensometer.* The extensometers are sophisticated monitoring facilities that record deformation of the aquifer system and the shallow soils across the historical fissure zone. The extensometers require periodic maintenance. The MZ-1 Plan requires that the extensometers be maintained in good working order.

- *Refurbishing of the Ayala Park Extensometer and replacement of electronic equipment.* This facility is more than 10 years old. Recent data recorded at the facility suggests that the electronic and/or mechanical components at the facility are degrading and require replacement or refurbishing. The MZ-1 Plan requires that the Ayala Park Extensometer be maintained in good working order.

- *Repair of the Daniels Horizontal Extensometer.* In March 2014, a portion of the DHX was flooded which damaged parts of the facility. The DHX must be repaired if it is to monitor the fissure zone during the Long-Term Pumping Test.

- *Capping of the PB nested piezometers at the PB vault at Ayala Park.* Watermaster is not currently using the PB nested piezometers for monitoring and desires to secure the PB nested piezometers from surface water infiltration. Equipment from the PB nested piezometers at Ayala Park will be removed from the casings and vault and the casings will be fitted with watertight covers. This is a discretionary but prudent maintenance activity.

- *Continued quarterly collection of groundwater-elevation and aquifer-system-deformation data at wells and extensometers within the monitoring network.* Quarterly collection and checking of data is necessary to (i) ensure that the monitoring network is in good working order and (ii) minimize the risk of losing data because of equipment malfunction. The MZ-1 Plan requires the same monitoring frequency as implemented during the Interim Monitoring Program.

- *Conduct the Long-Term Pumping Test in the Managed Area to verify the Guidance Criteria, and assist the City of Chino Hills with a pilot injection test at Well CH-16.* Pumping in the Managed Area began in January 2014 and is expected to continue through 2014. Figure 4-2 shows piezometric levels at PA-7 recorded through early 2014 and the conceptual piezometric levels for the remainder of the Long-Term Pumping Test. Also shown is the conceptual timing of ground-level surveys in the Managed Area as described below. An injection test is planned at CH-16 to coincide with the recovery phase and to evaluate injection as a tool for subsidence management. Watermaster is assisting the City of Chino Hills in its injection test at CH-16 through cost-share funding for subsidence monitoring, modification to Well CH-16, administration of a Local Groundwater Assistance grant from the DWR, and reporting on results and conclusions. The MZ-1 Plan called for the Long-Term Pumping Test and the pilot injection test in the Managed Area.

- *Collect and analyze InSAR data during 2014.* The data for InSAR is collected by the TerraSAR-X satellite operated by the German Aerospace Center. Five interferograms will be prepared that will describe the vertical motion of the ground surface across the western portion of Chino Basin. The MZ-1 Plan requires the same scope and frequency of monitoring by InSAR as was implemented during the Interim Monitoring Program.

- *Conduct elevation and EDM surveys at benchmark monuments in the Managed Area during fall 2014 and spring 2015 to coincide with maximum drawdown and maximum recovery of groundwater levels during the Long-Term Pumping Test.* The conceptual timing of these surveys is shown on Figure 4-2. The MZ-1 Plan called for Long-Term Pumping Test and associated monitoring to verify the Guidance Criteria.

- *Conduct ground-surface elevation and EDM surveys at the San Jose Fault Array of benchmark monuments in the Pomona Area.* Figure 4-1 shows the locations of the new benchmark monuments in the San Jose Fault Array. These surveys will measure relative motion across the San Jose Fault to detect extensional strain and will be used to assess the potential for ground fissuring. This is a discretionary monitoring activity that was contemplated in the MZ-1 Plan.

- *Conduct an elevation survey at benchmark monuments in the Southeast Area during the fall of 2014.* Several new Chino Creek desalter wells are expected to begin producing groundwater during 2014. The monitoring and mitigation plan in the Peace II SEIR requires subsidence monitoring in the vicinity of the Chino Creek Well Field.

- *Preparation of the 2014 Annual Report of the Land Subsidence Committee.* The MZ-1 Plan requires the preparation of the annual report.

4.3 Recommendations for Changes to the MZ-1 Plan

The MZ-1 Plan states that if data from existing monitoring efforts in the so-called Areas of Subsidence Concern indicate the potential for adverse impacts due to subsidence, Watermaster will revise the MZ-1 Plan pursuant to the process outlined in Section 3 of the MZ-1 Plan.

As reported herein, differential land subsidence has continued to occur through 2013 in the Pomona Area near the San Jose Fault, which is the type of vertical deformation of the land surface that can lead to ground fissuring. The Pomona subsidence issue was first identified as a concern in the MZ-1 Summary Report (2006) and in the MZ-1 Plan (2007). The Land Subsidence Committee/Watermaster has since been monitoring subsidence via InSAR and groundwater-levels with transducers at selected wells. Over the past few years, the Land Subsidence Committee/Watermaster has increased monitoring efforts to include elevation surveys and EDMs because of the ongoing concern for the potential of ground fissuring near the San Jose Fault. The issue has been discussed at many prior Land Subsidence Committee meetings, and the subsidence has been documented and described as a concern in past State of the Basin Reports/Atlas and in the 2012 Annual Report of the Land Subsidence Committee.

The MZ-1 Plan should be updated to include a process to develop a subsidence management plan for the Pomona Area with the long-term objective to minimize or abate the occurrence of the differential land subsidence in the Pomona Area. In 2014/15, the Land Subsidence Committee should develop a scope of work (with schedule and budget estimates) to develop the subsidence management plan for the Pomona Area. The scope may need to include a hydrogeologic investigation to (i) definitively characterize the mechanisms driving the observed subsidence and (ii) develop subsidence-management criteria.

Table 4-1
Work Breakdown Structure
Land Subsidence Monitoring Program -- FY2014-15

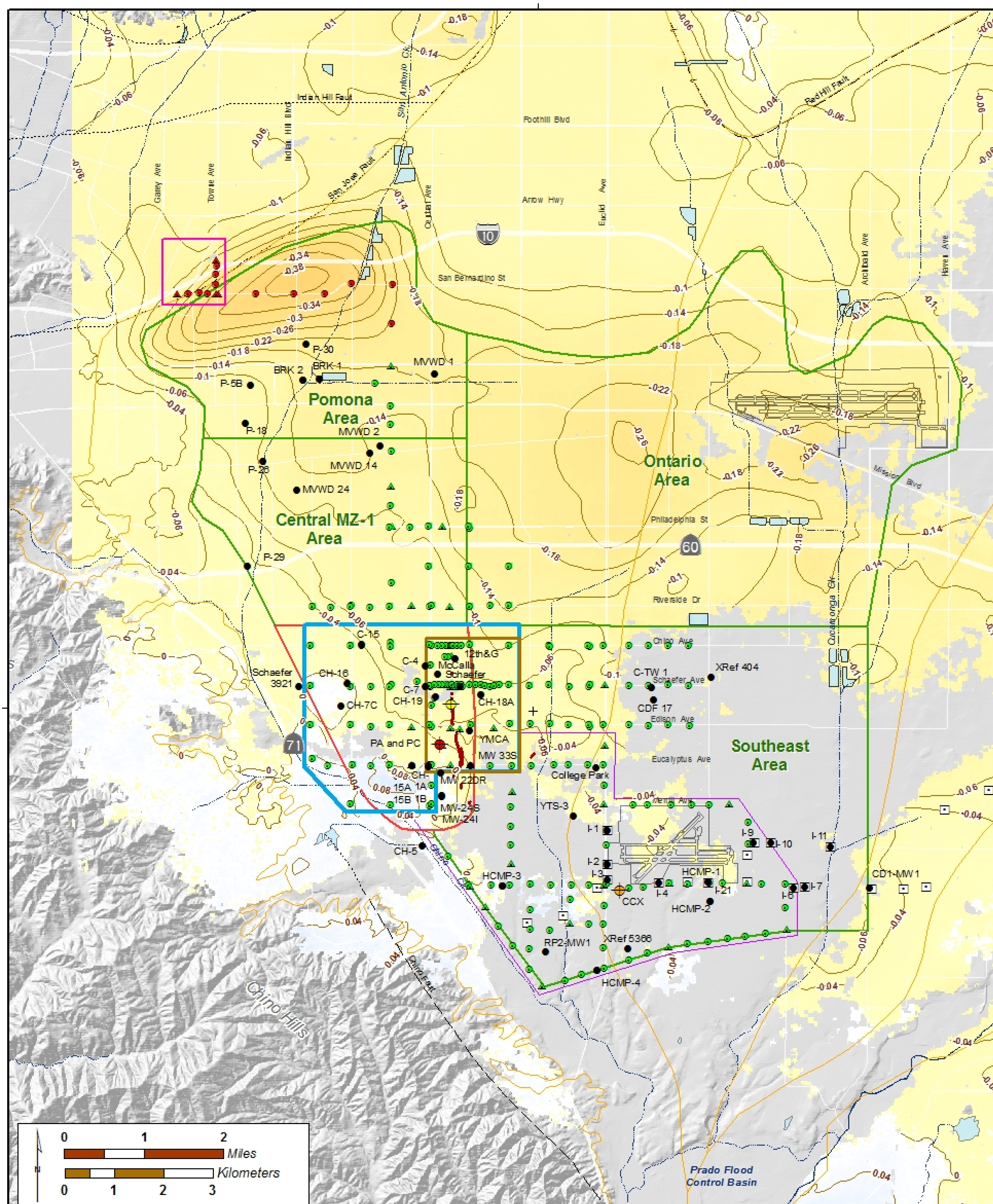
Task/Subtask/Description	Notes	Labor		Total Labor	Other Direct Costs					Total ODC	Totals					2014-15 Budget Compared to 2013-14 Budget		
		Task Repetition Multiplier	Person Days		Travel	Equip and Expend	Subs	Repro	Misc.		Recommended Tasks *2014-15*	Potential Carryover from 2013-14	Budget *2014-15*	Estimated Future O & M	Potential Future Tasks	Approved Budget *2013-14*	Variance with Carryover	Variance without Carryover
																$112,428		**-$112,428**
Task 1 -- Setup/Maintenance of Monitoring Network											**$109,151**	**$0**	**$109,151**	**$77,090**	**$57,192**	**$56,214**	**$52,937**	**$52,937**
1.1 Equipment maintenance	(1)																	
Routine maintenance of Ayala Park/CCWF extensometer facilities		12	12	$9,330	$384	$278				$662	$9,992		$9,992	$9,992		$9,942	$50	$50
Maintenance at horizontal extensometer site		1	8	$6,550	$32	$4,200	$44,720			$48,952	$55,502		$55,502	$55,502		$17,264	$38,238	$38,238
Replacement/repair of equipment at extensometer facilities		1	20	$22,380	$32	$11,935	$6,000			$17,967	$40,347		$40,347	$10,000		$27,412	$12,935	$12,935
1.2 Annual lease fees for CCWF extensometer site	(1)	1	0	$0					$1,596	$1,596	$1,596		$1,596	$1,596		$1,596	$0	$0
1.3 Maintenance of PB facility	(3)																	
Write specification, subcontract, etc.		1	0	$0				$200		$200			$0				$0	$0
Coordinate with the City of Chino on schedule, permits, and landscaping		1	0	$0				$50		$50			$0				$0	$0
Remove in situ equipment from the wells		1	2	$1,650	$64					$64	$1,714		$1,714		$57,192	$0	$1,714	$1,714
Task 2 -- MZ-1: Aquifer-System Monitoring and Testing											**$200,421**	**$191,608**	**$8,813**	**$18,031**	**$19,030**	**$83,841**	**-$75,028**	**$116,580**
2.1 Groundwater-level and extensometer data collection and organization	(1)																	
Download data from the Ayala Park facility		4	2.5	$1,960	$128	$48				$176	$2,136		$2,136	$2,136		$2,948	-$813	-$813
Download data from the Daniels Horizontal Extensometer facility		3	1.125	$983	$96	$21				$117	$1,100		$1,100	$1,100		$2,898	-$1,798	-$1,798
Download data from the CCWF facility		4	2.5	$1,960	$128	$48				$176	$2,136		$2,136	$2,136		$2,298	-$163	-$163
Process, check, and upload data to database		4	10.5	$12,660						$0	$12,660		$12,660	$12,660		$5,320	$7,340	$7,340
2.2 Conduct Long-Term Pumping Test in the Managed Area	(1)																	
Coordinate testing with pumpers		1	1	$1,320						$0	$1,320		$1,320			$1,320	$0	$0
Collect field data; process and upload to database		1	2.8	$2,823						$0	$2,823		$2,823			$7,290	-$4,468	-$4,468
Prepare, analyze, and distribute stress-strain diagrams to LSC		4	2.5	$3,500				$200		$200	$3,700		$3,700			$4,760	-$1,060	-$1,060
Adjust Extensometer Hardware		2	1	$1,970						$0	$1,970		$1,970				$1,970	$1,970
2.3 Conduct Injection Test in Managed Area	(1)																	
Well rehabilitation and retrofit		2	1.5	$1,310			$141,640			$141,640	$142,950	$142,950	$0			$41,655	-$41,655	$101,295
Quarterly reports - LGA Grant		3	9	$11,880						$0	$11,880	$11,880	$0			$10,340	-$10,340	$1,540
Project administration - LGA Grant		1	4.4	$5,868						$0	$5,868	$5,868	$0				$0	$5,868
Prepare final report for LGA Grant		1	8.9	$11,880						$0	$11,880	$11,880	$0				$0	$11,880
Injection pilot testing - collect and process data from transducer network 1 time during cycle testing and contribute the analysis of data.		1	7.9	$8,987	$44					$44		$9,031	-$9,031		$9,031	$5,012	-$14,043	-$5,012
Analyze data collected during cycle tests and contribute interpretation to LSC Annual Report		1	7.8	$9,999						$0		$9,999	-$9,999		$9,999		-$9,999	$0
Task 3 -- Basin Wide: InSAR											**$92,830**	**$0**	**$92,830**	**$92,830**	**$0**	**$92,830**	**$0**	**$0**
3.1 InSAR data collection	(1)	1	1	$1,320			$90,000			$90,000	$91,320		$91,320	$91,320		$91,320	$0	$0
3.2 Process and upload data to database/GIS	(1)	1	1.25	$1,510						$0	$1,510		$1,510	$1,510		$1,510	$0	$0
Task 4 -- Ground-Level Surveys											**$123,955**	**$28,560**	**$95,395**	**$86,695**	**$43,605**	**$121,880**	**-$26,485**	**$2,075**
4.1 Replace destroyed benchmarks	(2)	1	0	$0			$5,000			$5,000	$5,000		$5,000	$5,000		$5,400	-$400	-$400
4.2 Conduct Fall 2014 ground-level and EDM survey in Managed Area	(1)	1	0.25	$330			$34,770			$34,770	$35,100		$35,100	$35,100		$28,560	$6,540	$6,540
4.3 Conduct Fall 2014 ground-level survey in Central MZ-1 Area	(3)	1	0	$0			$19,855			$19,855					$19,855			
4.4 Conduct Fall 2014 ground-level survey in Southeast Area (CCWF)	(3)	1	0.25	$330			$26,315			$26,315	$26,645		$26,645	$26,645		$27,700	-$1,055	-$1,055
4.5 Conduct Fall 2014 ground-level and EDM survey in Pomona Area (Ayala Park start)	(3)	1	0	$0			$23,750			$23,750					$23,750	$29,480	-$29,480	-$29,480
4.6 Conduct Fall 2014 ground-level and EDM survey at the Pomona Fault Zone	(3)	1	0.25	$330			$17,860			$17,860	$18,190		$18,190	$18,190			$18,190	$18,190
4.7 Conduct Spring 2015 ground-level and EDM survey in Managed Area	(1)	1	0.5	$660			$36,600			$36,600	$37,260	$28,560	$8,700			$28,560	-$19,860	$8,700
4.8 Process and upload data to database	(1)	1	1.5	$1,760						$0	$1,760		$1,760	$1,760		$2,180	-$420	-$420
Task 5 -- Data Analysis and Reporting											**$68,720**	**$0**	**$68,720**	**$68,720**	**$100,000**	**$68,770**	**-$50**	**-$50**
5.1 Data analysis in Managed Area	(1)																	
Production/piezometric/extensometer		1	6	$7,360			$20,000			$20,000	$27,360		$27,360	$27,360		$27,590	-$230	-$230
EDM and ground-level survey data		1	5	$5,180						$0	$5,180		$5,180	$5,180		$8,000	-$2,820	-$2,820
InSAR data		1	1	$1,160						$0	$1,160		$1,160	$1,160		$1,160	$0	$0
Tectonic data		1	0.5	$500						$0	$500		$500	$500		$500	$0	$0
Recycled water reuse data		1	3.5	$3,660						$0	$3,660		$3,660	$3,660		$660	$3,000	$3,000
5.2 Prepare MZ-1 Annual Report	(1)																	
Prepare draft technical memorandum		1	20	$23,560				$200		$200	$23,760		$23,760	$23,760		$23,760	$0	$0
Prepare final technical memorandum		1	5.5	$6,800				$300		$300	$7,100		$7,100	$7,100		$7,100	$0	$0
5.3 Update MZ-1 Plan (if necessary)	(1)			$100,000											$100,000			
Task 6 -- Meetings and Administration											**$28,077**	**$0**	**$28,077**	**$28,077**	**$0**	**$27,675**	**$402**	**$402**
6.1 Prepare for and attend Land Subsidence Committee meetings	(1)	2	6	$8,720	$91					$91	$8,811		$8,811	$8,811		$9,630	-$819	-$819
6.2 Ad hoc meetings	(1)	1	3	$4,360	$46					$46	$4,406		$4,406	$4,406		$3,186	$1,220	$1,220
6.3 Project Administration and Financial Reporting	(1)	12	7.5	$10,500						$0	$10,500		$10,500	$10,500		$10,500	$0	$0
6.4 Scope and Budget for FY2015/16	(1)	1	3	$4,360						$0	$4,360		$4,360	$4,360		$4,360	$0	$0
Totals											**$623,154**	**$220,168**	**$402,986**	**$371,442**	**$219,827**	**$451,210**	**-$48,224**	**$171,944**

Notes:

(1) Required by MZ-1 Plan and/or Peace Agreement

(2) Contingency budget. Spent only if necessary.

(3) Discretionary task. Performed if recommended by the Land Subsidence Committee



Survey Benchmarks

- Class A Monuments
- Class B Monuments
- Exisiting Monuments
- New Monuments installed in Pomona Area during 2013-14

Survey Areas

- Southeast Area Surveys
- Fissure Zone Surveys
- Managed Area Surveys
- San Jose Fault Zone Surveys

Relative Change in Land Surface Altitude as Measured by InSAR June 2005 to September 2010 (feet)

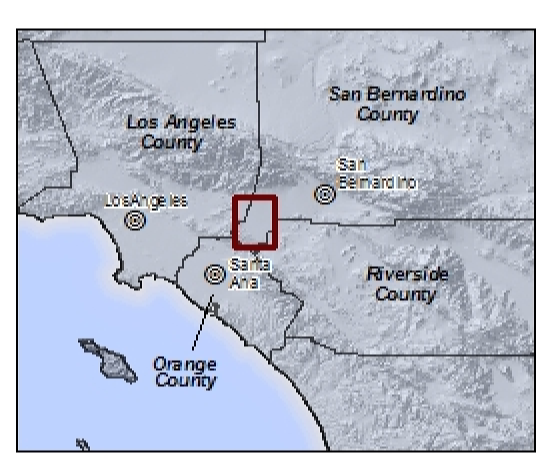
+1
0
-0.5
-1

InSAR data absent (incoherent)

Wells and Extensometers

- Desalter Well
- Ayala Park Extensometer
- Chino Creek Extensometer
- Daniels Horizontal Extensometer
- Well Monitored by Pressure Transducer during 2013

- Managed Area
- Areas of Subsidence Concern
- Ground Fissures
- Chino Basin Management Zones



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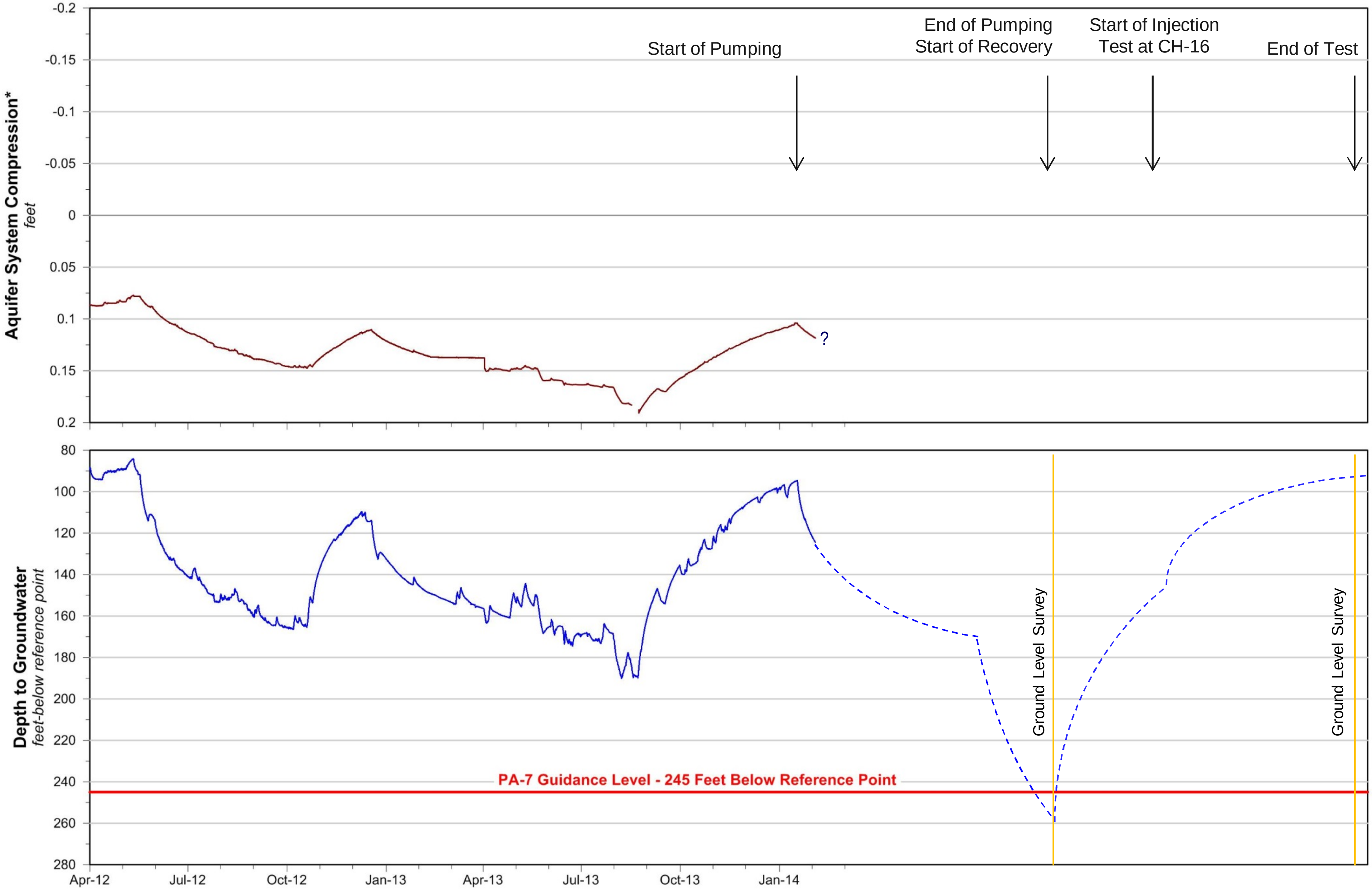
Land Subsidence Committee
2013 Annual Report

Land Subsidence Monitoring
Fiscal Year 2014-15

Figure 4-1



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Filename: Figure_4-2_report.grf

Aquifer System Compression (Aquifer System Depth Interval)

Ayala Park Deep Extensometer (30-1,400 feet-bgs)

Groundwater Levels at Wells (Well-Screen Interval)

PA-7 (438-448 feet-bgs)

Predicted Record for PA-7 During Test

*Positive compression values represent compression of soils, negative compression values represent expansion of soils.

Land Subsidence Committee
2013 Annual Report

Long-Term Pumping Test
Managed Area

Figure 4-2

The following glossary of terms and definitions are utilized within this report and generally in the discussions at meetings of the Land Subsidence Committee (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 in the geologic sense refers to the inelastic compression of the aquifer system. Compaction of the aquifer system reflects the rearrangement of the mineral grain pore structure and largely nonrecoverable reduction of the porosity under stresses greater than the preconsolidation 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. The term "compaction" is sometimes used in preference to consolidation.

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 the 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 the permanent 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 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 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 (nonrecoverable). 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 – Sinking or settlement of the land surface, due to any of several processes.

Transducer, Pressure – An electronic device that can measure groundwater 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

Monitoring Data through December 2013

Appendix B

Comments and Responses

B-1 CITY OF CHINO COMMENTS AND WATERMASTER RESPONSES

Comment Number	Reference	Comment	Response
1	Page 2-2	Item 5 "Is there an "acceptable rate of ***permanent*** land subsidence in the Managed Area?" Permanent should be inserted into the sentence as indicated.	Comment addressed in report, on page 2-2: "permanent" was added.
2	Page 3-1	At the end of Section 3.1.1 the meaning of "a rate of about - 0.01 ft/yr" should be clarified.	Comment addressed in report, on page 3-1: "- 0.01 ft/yr" was changed to "0.01 ft/yr"
3	Page 3-2	Last sentence of the second paragraph suggest using "pre-consolidation" in place of "virgin", that is …they equilibrate with heads in the pumped aquifers that are lower than **pre-consolidation** heads."	Comment addressed in report, on page 3-2: "virgin" was replaced with "pre-consolidation"
4	Figure 3-1	Last sentence in text box "The causes of the small amount of ***recent*** subsidence are not currently known…"; suggest using "on-going" in place of "recent". On-going more correctly suggests the process causing inelastic subsidence is continuing.	Comment addressed in report, on Figure 3-1: "recent" was replaced with "on-going"
5	Figure 3-7	The horizontal strain is accumulated for each segment of the extensometer from west to east, though it seems like the strain for each segment should be plotted individually normalized such as foot of strain/length of rod (ft/ft) times some fixed scalar to better show the zones where strain is greatest/least.	Figure 3-8 was added to show individual strain across each segment of the Daniels Horizontal Extensometer.

Comment Number	Reference	Comment	Response
6	No reference	Please add a discussion describing the protocol and process that is recommended for maintaining efficient communication between Watermaster and the parties participating in, and affected by, the planned pumping test, including review and analysis of the data as it is collected in order to ensure that the timing and duration of the test activities achieves the test objectives.	Comment addressed in report, in Section 2.2.1: “This test should cause drawdown at PA-7 to fall below the Guidance Level. The test will be closely monitored at the Ayala Park Extensometer and the horizontal monitoring facilities, and will be stopped at the first clear indication of permanent subsidence. Groundwater levels recorded at 15-minute intervals at PA-7 will be updated every three-hours on Watermaster’s website. As drawdown approaches 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 immediately to the Land Subsidence Committee by email. Watermaster staff and engineers will remain in close telephonic contact with staff at the City of Chino, 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 make the determination to stop the test when appropriate.”
7	No reference	Please add a description of the anticipated magnitude of permanent compression (subsidence) that is expected to occur as a result of the planned pumping test, and relate this amount of subsidence to historical subsidence that occurred in the affected area.	Comment addressed in report in footnote on Page 2-3: “The aquifer-system stress testing in 2004-05 resulted in about 0.01 feet of permanent compaction and associated land subsidence (WEI, 2006). The Long-Term Pumping Test may cause a similar small amount of permanent subsidence. This small amount of permanent subsidence is far less than the >2 ft of permanent subsidence that occurred from 1987-1995

Comment Number	Reference	Comment	Response
			when ground fissures opened in the City of Chino, and is much less than the +/- 0.1 ft of elastic subsidence and rebound that occurs seasonally in this area.”

B-2 STATE OF CALIFORNIA, CALIFORNIA INSTITUTION FOR MEN COMMENTS AND WATERMASTER RESPONSES

Comment Number	Reference	Comment	Response
1	Page 1-1, section 1.1.1	Refers to an accelerated occurrence of ground fissuring after 1991 and later refers to the scientific studies that followed but references Fife (1976) as one of the studies. Consider minor re-wording (perhaps "scientific studies of the area….") to avoid this apparent inconsistency in timing.	Comment addressed in report, on page 1-1: "The scientific studies of the area attributed the fissuring phenomenon to differential land subsidence that was 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)."
2	Table 1-1 and Figure 3-2	Reference to perforated interval of CIM Well 11A. Should note somewhere in the tables and figure that the lower part of the casing of CIM Well 11A collapsed circa 2011. The well was video logged on July 20, 2011 and it was documented that the well was obstructed below a depth of 470.5 feet. A copy of the Layne Christenson Co. Well Inspection Report is attached for reference. A 12-inch liner was subsequently placed In the well with a screen interval from 155 to 470 feet (see attached email from Layne Christenson).	Comment addressed in report, on Table 1-1 and Figure 3-2: Table 1-1 shows the screened interval as "174-187, 240-283, 405-445 ft bgs[2]" And a footnote was added: "[2] The casing in CIM-11A collapsed below 470 ft-bgs in 2011. A liner was installed to 470 ft-bgs with screen intervals from 155 to 470 ft-bgs." Figure 3-2 shows the screen interval as "155-445 ft-bgs"
3	Figure 2-1 and 4-1	Transducer instrumented well Xref 5767 is shown on these figures at a location west of Euclid and south of the projected east-west line of Merrill Ave. If this location is accurate, the well would be located on property belonging to the State of California (State). If the well belongs to the State, then it should be identified by its common name.	Comment addressed in the report, on Figures 2-1 and 4-1: The well is owned by the State. Its local name is YTS-3. References to the well have been updated.
4	Page 2-3	First non-enumerated paragraph, first sentence. "CH-17 and CH-15…" Should this be CH-15B?	Comment addressed in report, on page 2-3: The well should be CH-15B. The text was changed to "CH-17 and CH-15B"

CIM COMMENTS AND WATERMASTER RESPONSES

Comment Number	Reference	Comment	Response
5	Page 3-4 and figure 3-9	An estimate of a potential for 4.2 feet of permanent subsidence in the Pomona/San Jose fault area is given but is explained as being based on an extrapolated rate of -0.06 feet/year. The text on page 4-1 states, "It is likely that about 4.2 feet of permanent, differential subsidence has occurred in this area since the onset of increased drawdown in the 1940s." This latter statement may suggest a greater degree of certainty in the estimate than indicated by the previous statements and by the available data.	Comment addressed in report on Page 4-1: The identified sentence was replaced with: "It is logical to assume that at least 4.2 feet of permanent, differential subsidence has occurred in this area since the onset of increased drawdown in the 1940s."
6	Table 3-1	Well Xref8730. This well is located in the Managed Area but does not appear on any of the figures. Note 1 in the table indicates that the well screen interval for this well is unknown but it is placed in the category of wells screened in the Shallow aquifer layer for the purpose of tabulation. Suggest expanding on note 1. Example - Perforated interval of well is unknown but assumed to be shallow based on typical well construction for other wells in the general vicinity.	This well is not on any figures because the wells that produced groundwater during 2013 are not displayed on any figures. Text was added to Note 1 of Table 3-1 to address this comment.
7	Figure 3-1	Last paragraph of narrative, 7th sentence, "…when piezometric-levels declined below 250 feet below…). Delete first "below" in sentence.	Comment addressed in report, on Figure 3-1: Text was changed to "piezometric-levels declined below a depth of 250 feet below the reference point (ft-brp)"

CIM COMMENTS AND WATERMASTER RESPONSES

Comment Number	Reference	Comment	Response
8	Figure 3-4 and Figure 3-5	Earthquake epicenters are posted on both maps. The text in the report does not have an explanation as to why these data are relevant to subsidence.	Comment addressed in report, on Page 3-2: "Epicenters of earthquakes that occurred from 2011 to 2014 are included on Figure 3-4 and 3-5. The data show that the vertical ground motion shown on the maps is not associated with earthquake events."

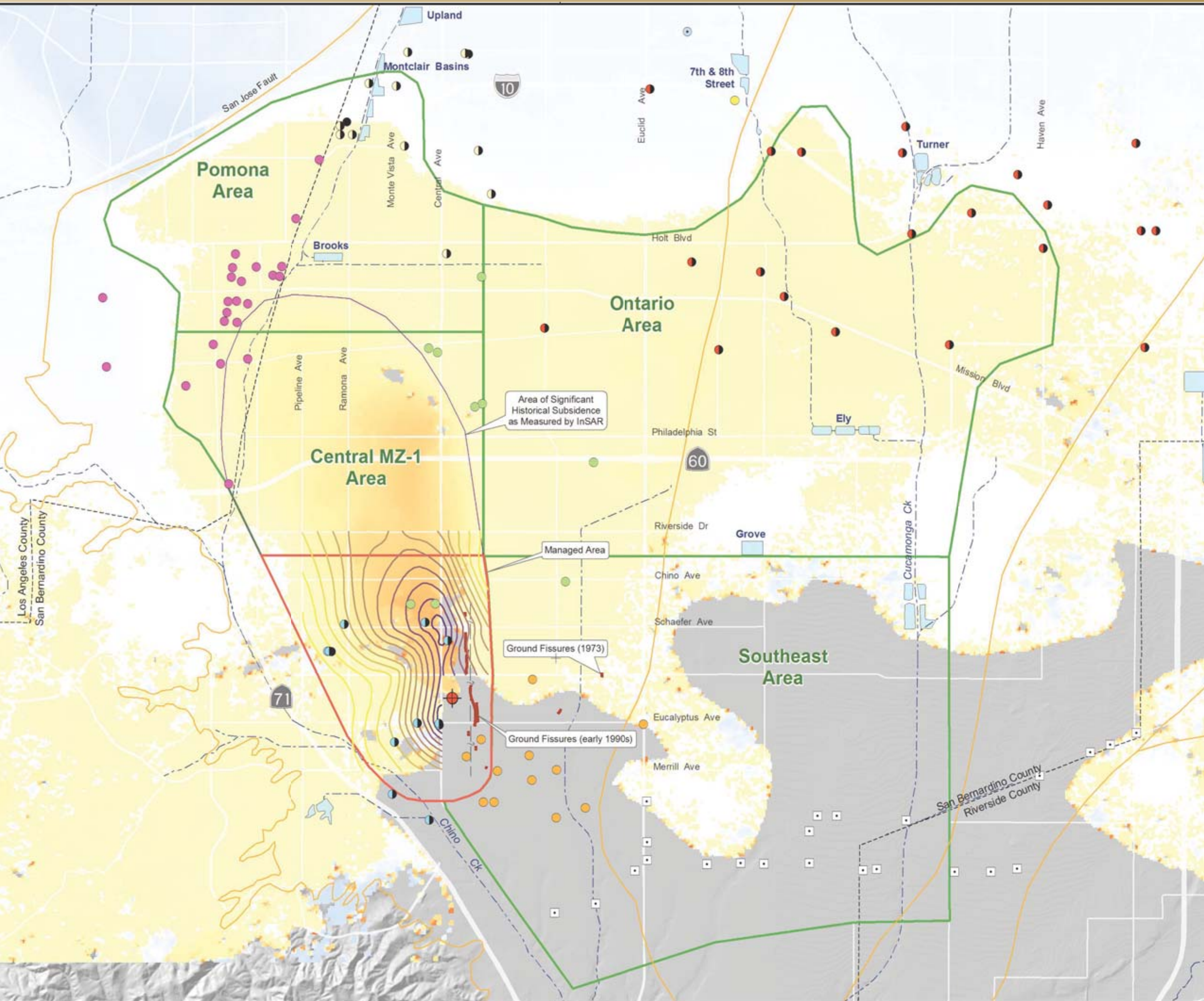
B-3 MONTE VISTA WATER DISTRICT COMMENTS AND WATERMASTER RESPONSES

Comment Number	Reference	Comment	Response
1	Figure 1-1	Three wells are not currently active (see figure from MVWD)	This figure was updated to show wells that were active during the period specified in the figure. Text was added to the figure to clarify.
2	Section 4.1	Is this goal too ambitious for now? Shouldn't the first big thing we do is to assess and monitor the Pomona area. Do we have guidance criteria for the other unmanaged areas? If not, why not?	The recommendation in the annual report is to "develop a subsidence management plan for the Pomona Area with the long-term objective to minimize or abate the occurrence of the differential land subsidence" in the area. This is a long-term recommendation. The recommendation for 2014-15 is to begin the process with a scoping effort by the Land Subsidence Committee. This will likely entail multiple meetings over the year to develop scope, schedule, and budget estimates. The scope may need to include a hydrogeologic investigation to (i) definitively characterize the mechanisms driving the observed subsidence and (ii) develop subsidence-management criteria.
3	Section 4.2	When is the benchmark surveys for the areas due? Or said another way, what is the target interval for benchmark surveys?	The intervals for ground-level surveys are decided by the Land Subsidence Committee annually.
4	Page 4-4, Table 4-1	The page right after this one, Task 5.3, shows a budget of $15k to update MZ-1 plan. However, if the scoping hasn't begun yet, the $15k may grossly under- (or-over) state the budgeting requirement? Subsidence Management-Pomona: though this is eventually the goal, is this too ambitious for now?	See Response to Comment 2. The $15,000 was a general place-holder for updating the MZ-1 Plan, and was not intended to represent costs associated with developing a new subsidence management plan for the Pomona Area. The LSC did

MVWD COMMENTS AND WATERMASTER RESPONSES

Comment Number	Reference	Comment	Response
		Meaning, I thought we have very limited understanding of the Pomona area, so the first big step is really to investigate/assess in the near-term?	not recommend this line item for FY 2014/15, so it is not included in the Watermaster's approved budget for FY 2014/15. In 2014/15, the scope of work to update the MZ-1 Plan is generally this: 1. Developing a draft scope(s) and cost estimate(s) for the development of a subsidence management plan for the Pomona Area. 2. Conducting ad hoc technical meetings, as necessary, to assist in the development of scope and cost estimates. 3. Conducting additional meetings of the LSC to discuss/revise the draft scope and cost estimates. 4. Prepare a draft revision of the MZ-1 Plan, and conduct meetings with LSC to review and revise. 5. Prepare final MZ-1 Plan. The approximate engineering costs for this effort are $100,000 for 2014/15. Again, Watermaster has no approved budget for this effort, so it would require a budget transfer or budget amendment to perform this effort in 2014/15.

WEI
WILDERMUTH ENVIRONMENTAL, INC.



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