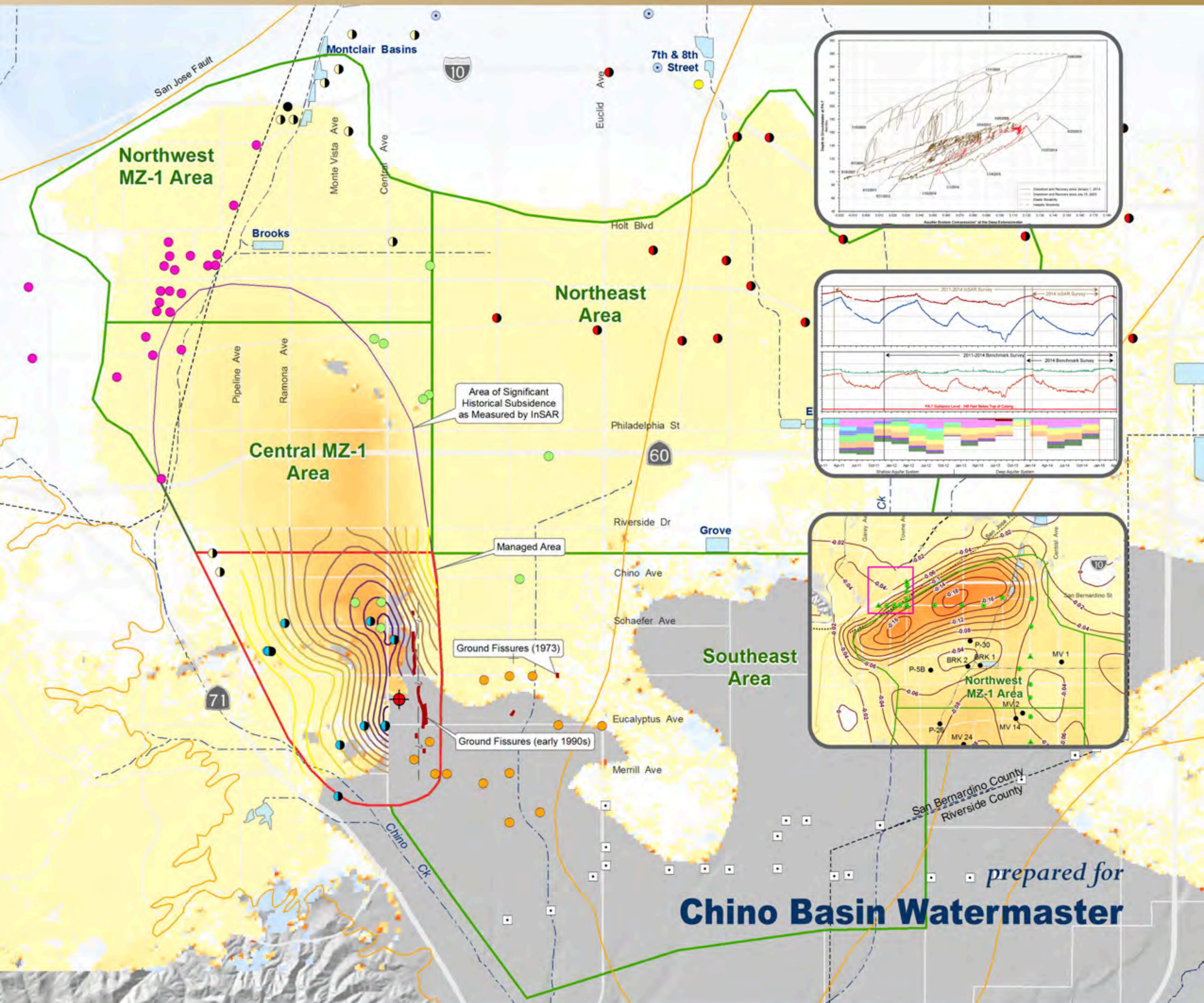
2014 Annual Report of the Ground-Level Monitoring Committee

Final



prepared for

Chino Basin Watermaster

July 2015

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
GLMC	Ground-Level Monitoring Committee
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

In general, land subsidence[1] is the sinking or settlement 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. Figures 1-1 and 1-2 show 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; Geoscience, 2002).

1.1.2 The Optimum Basin Management Program (OBMP)

In 1999, the OBMP Phase I Report (WEI, 1999) identified pumping-induced decline of groundwater levels 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.

[1] For purposes of clarification in this document, subsidence refers to permanent (non-recoverable) sinking of the ground surface. In previous Watermaster land-subsidence reports, subsidence referred to both permanent and elastic (recoverable) sinking of the ground surface.

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 Ground-Level Monitoring 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 decline that is much greater in magnitude and lateral extent than groundwater-level decline caused by pumping of the shallow aquifer system.[2]
2. Groundwater-level decline due to pumping of the deep aquifer system can cause non-recoverable compaction of the aquifer-system sediments, which results in land subsidence. The initiation of non-recoverable 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 non-recoverable 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 groundwater-level decline 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 subsidence in the central region of MZ-1 had occurred in the past and was continuing to occur. The InSAR data

[2] 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).

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.

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 non-recoverable 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 non-recoverable 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, Northwest MZ-1, Northeast, and Southeast Areas. 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 Ground-Level Monitoring Committee, and if deemed prudent and necessary, are recommended to Watermaster for implementation in future fiscal years.

1.1.5 Annual Report of the Ground-Level Monitoring 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 Ground-Level Monitoring Committee includes results and interpretations for data that were collected during calendar year 2014, and includes recommendations for Watermaster's Ground-Level Monitoring Program for fiscal year 2015-16.

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 Ground-Level Monitoring Committee (formerly the Land Subsidence Committee) and its responsibilities, and the MZ-1 Plan.

Section 2 – Ground-Level Monitoring Program (2014). This section describes the monitoring and testing activities that were performed by the Watermaster for its Ground-Level Monitoring Program during 2014.

Section 3 – Results and Interpretations. This section discusses and interprets the monitoring data collected through 2014, 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 2014, and describes recommended activities for the program during fiscal year 2015-16 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 Ground-Level Monitoring Committee.

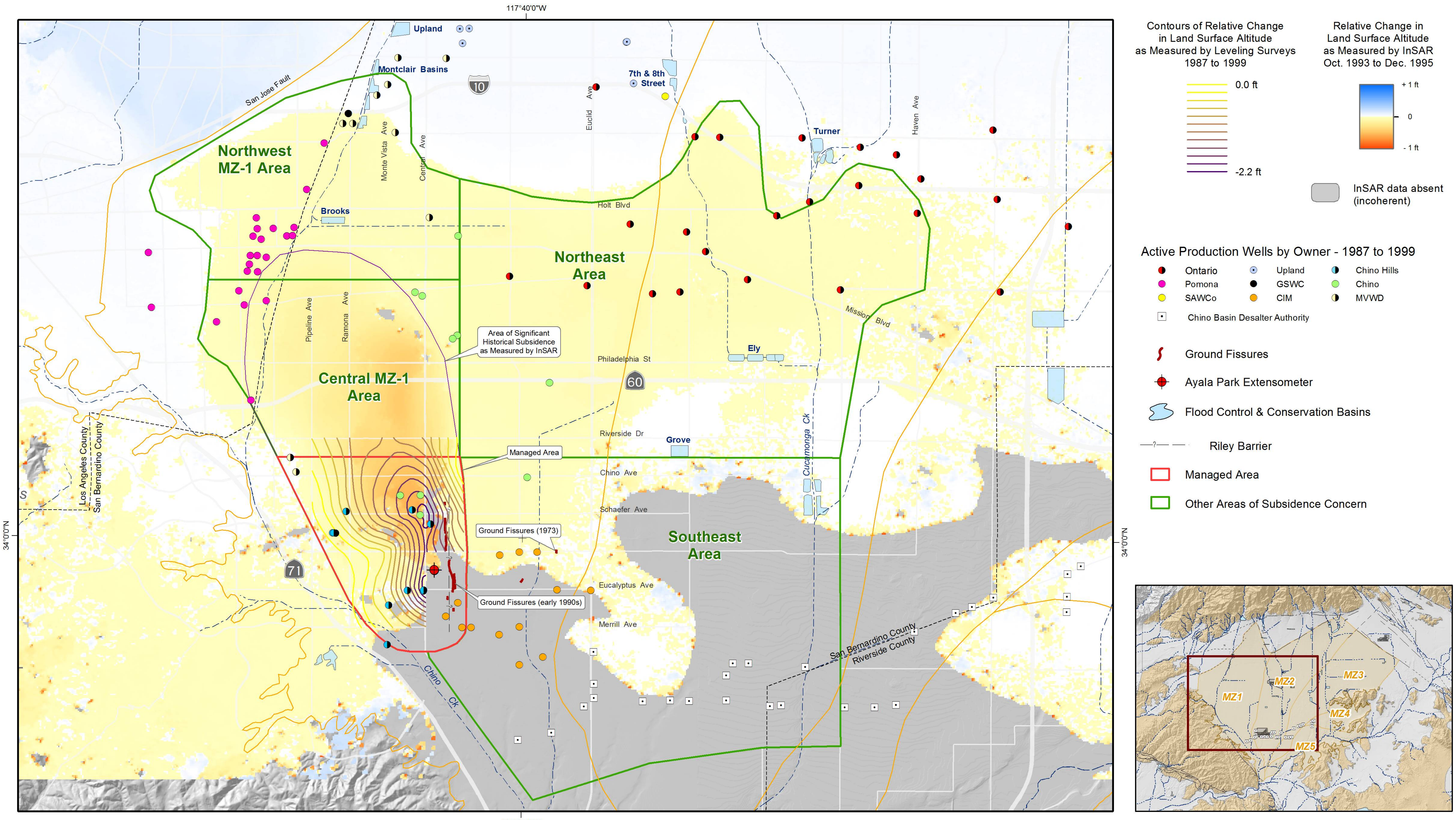
Section 6 – References. This section is a list of the publications cited in this report.

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	Active	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, and 518-540 ft-bgs. This casing collapsed below 470.5 ft- bgs in 2011. A liner was installed to 470 ft-bgs with a screen interval from 155 to 470 ft-bgs.



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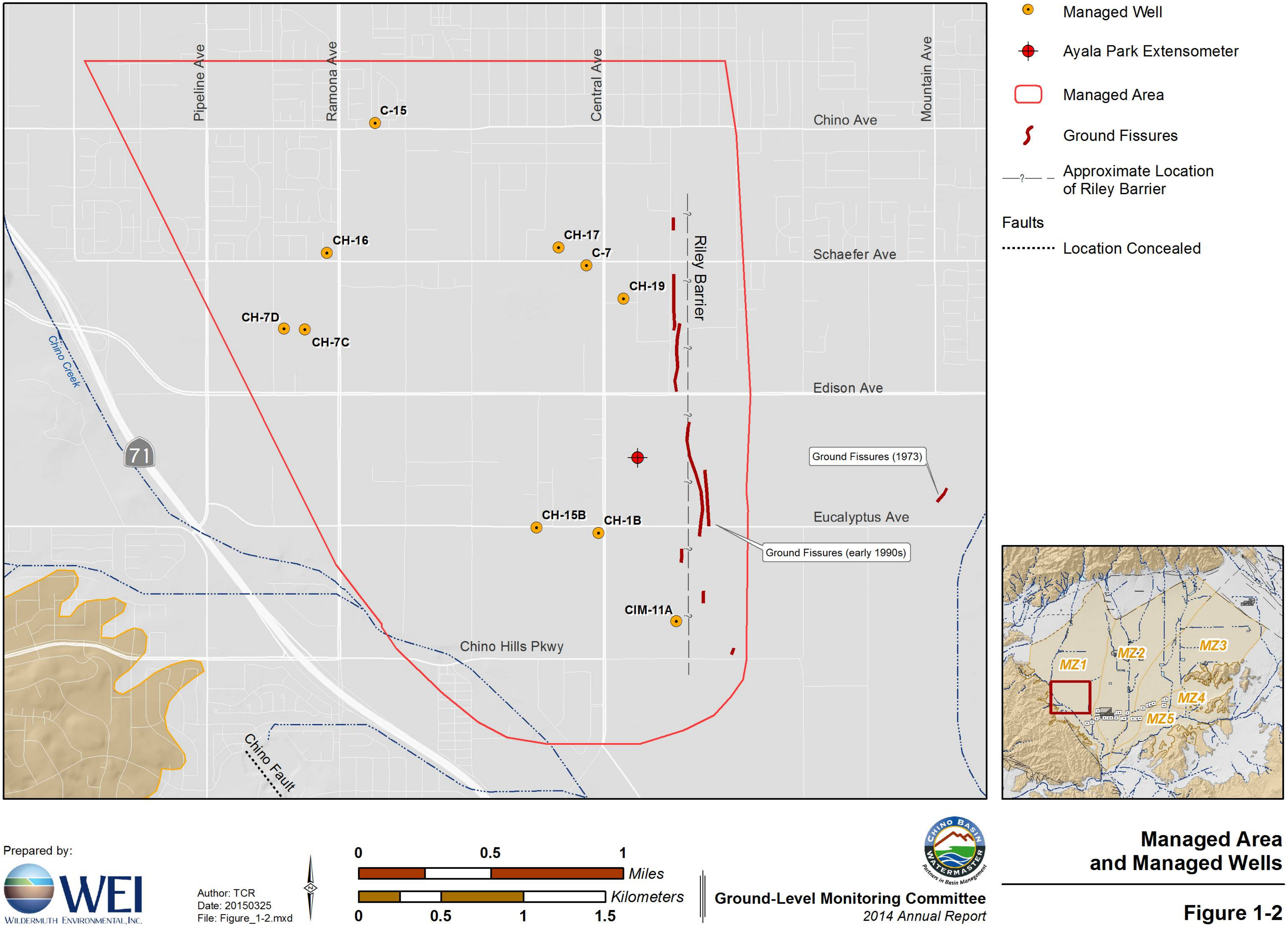
Ground-Level Monitoring Committee
2014 Annual Report

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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Ground-Level Monitoring Committee
2014 Annual Report

Managed Area and Managed Wells

Figure 1-2

Section 2 – Ground-Level Monitoring Program (2014)

This section describes the activities performed by the Watermaster for its Ground-Level Monitoring Program during 2014.

2.1 Setup and Maintenance of the Monitoring Network

The facilities that comprise Watermaster's ground-level monitoring network are shown on Figures 2-1 and 2-2, and include: pressure transducers and data loggers to measure and record water levels at wells, production wells, recharge to basins, 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 across the area shown in Figures 2-1 and 2-2 by remote-sensing techniques (InSAR).

Described below are the specific monitoring and testing activities performed by Watermaster in 2014.

2.1.1 Maintenance of Monitoring Equipment and Facilities

Watermaster replaced four pressure transducers at wells within the groundwater-level monitoring network that were malfunctioning. Watermaster also performed maintenance activities at the extensometer facilities, which included: protection of the PA piezometer vault at Ayala Park against surface-water intrusion during storm events; removal of down-hole equipment and protection of the wellheads at the PB piezometer against surface-water intrusion during storm events; maintenance of Watermaster's website that displays groundwater-levels at the PA-7 piezometer at Ayala Park; repair of the air conditioning unit at the Ayala Park Extensometer building; and repair and waterproofing of the quartz-tube extensometers at the Daniels Horizontal Extensometer.

2.2 Land-Subsidence Investigations

Watermaster performs land-subsidence investigations pursuant to the MZ-1 Plan and the recommendations of the GLMC. Past and current investigations typically include aquifer-stress tests (e.g. pumping, injection) and the simultaneous monitoring of groundwater levels, aquifer-system deformation, and deformation of the land surface. The goals of these investigations are to refine the Guidance Criteria and assist in the development groundwater management plans that will not cause damage to the land surface and overlying infrastructure.

2.2.1 Injection Test at CH-16

The MZ-1 Plan calls for an injection feasibility study at a production well within the Managed Area. The test will help determine if aquifer injection is a viable tool to manage subsidence within the Managed Area while maximizing the use of existing infrastructure (i.e. wells). The study includes the conversion of an existing production well (City of Chino Hills Well 16 [CH-16]) to an aquifer storage and recovery (ASR) well, and a pilot injection test.

Watermaster's assistance to Chino Hills in this study has included: assistance in applying for and acquiring a Local Groundwater Assistance (LGA) grant from the DWR, grant administration, and a cost-share contribution of $368,000 to execute the study.

During 2014, the following activities were performed by Chino Hills and Watermaster:

- prepared a Mitigated Negative Declaration document for CEQA compliance
- performed the bidding process and retained General Pump to rehabilitate Well CH-16
- performed a downhole video log investigation to evaluate the feasibility of the well for retrofit and to determine a rehabilitation strategy
- performed well rehabilitation utilizing mechanical, pumping, airburst, and chemical techniques
- performed aquifer pumping tests (step-drawdown and constant-rate tests)
- constructed improvements to convert CH-16 into an ASR well
- prepared and submitted four quarterly progress reports to the DWR grant administrators that described the work performed, the project schedule, and the costs associated with the project

In 2015, the well will be connected to a potable water pipeline, and the injection test is expected to be executed by Chino Hills in fall 2015 and winter 2016 in coordination with the Long-Term Pumping Test in the Managed Area (see below).

2.2.2 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." The GLMC developed the Long-Term Pumping Test in 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 elastic and non-recoverable vertical ground motion 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 decline of groundwater levels and preventing non-recoverable compaction in the deep aquifer system?

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

The GLMC envisioned the following scope and sequence for the Long-Term Pumping Test:

1. Conduct a controlled pumping test of the deep aquifer system in the Managed Area at wells CH-17 and CH-15B (with arsenic treatment). This test should cause the groundwater level at PA-7 to fall below the Guidance Level, and may cause a small amount of 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 non-recoverable compaction. Groundwater levels recorded at 15-minute intervals at PA-7 will be updated every three-hours on Watermaster's website. When the groundwater level declines 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 GLMC 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 groundwater levels that were lowered 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. Collect piezometric and deformation data at the Ayala Park Extensometer and the Daniels Horizontal Extensometer once every 15 minutes.

5. After injection tests, allow for full recovery of groundwater levels at PA-7 to pre-test conditions. Check stress-strain diagrams from the Ayala Park extensometer for non-recoverable compaction of the aquifer system in the Managed Area. Check stress-strain diagrams from the Daniels horizontal extensometer for non-recoverable horizontal deformation across the fissure zone. Analyze ground-level survey, InSAR, and EDM data for non-recoverable horizontal and vertical ground deformation within the Managed Area.

During 2014, pumping at CH-15B did not commence, and pumping at CH-17 alone failed to cause groundwater levels to decline below the Guidance Level at the PA-7 piezometer (245 ft-

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

btoc). Maximum depth-to-groundwater at the PA-7 piezometer was about 170 ft-btoc before pumping ceased at CH-17 in November 2014.

2.2.3 Subsidence Management Plan for the Northwest MZ-1 Area

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, then Watermaster will revise the MZ-1 Plan in an attempt to avoid the adverse impacts.

Land subsidence in the Northwest MZ-1 Area was first identified as a concern in 2006 in the MZ-1 Summary Report in 2006 and again in 2007 in the MZ-1 Plan. Since then, the Watermaster has been monitoring vertical ground motion in this area via InSAR and groundwater levels with transducers at selected wells.

The available InSAR data indicate that about 1.4 feet of subsidence has occurred in this area from 1993 through 2014—an average rate of about 0.06 feet per year. From about 1945 to 1978, groundwater levels in the Northwest MZ-1 Area declined by about 175 feet. Since 1978 groundwater levels have fluctuated, and have risen in some wells by more than 100 feet, but groundwater levels in 2014 are still below the 1935 levels. The observed, continuous land subsidence that occurred during 1993-2014 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 decline of groundwater levels that occurred from 1935 to 1978. If so, subsidence could have begun when the rate of groundwater-level decline increased around 1943. If subsidence has been occurring at a constant rate of 0.06 feet per year since 1943, then the Northwest MZ-1 Area has experienced approximately 4.2 feet of subsidence since the onset of increased groundwater-level decline.

Of particular concern is that the subsidence in the Northwest MZ-1 Area has occurred differentially across the San Jose Fault—the same pattern of differential subsidence that occurred in the MZ1 Managed Area during the time of ground fissuring. Ground fissuring is the main subsidence-related threat to infrastructure. Over the past few years, the Watermaster has increased monitoring efforts in the Northwest MZ-1 Area to include elevation surveys and electronic distance measurements (EDMs) because of the potential for ground fissuring.

The issue of differential subsidence and the potential for ground fissuring in the Northwest MZ-1 Area has been discussed at prior GLMC meetings, and the subsidence has been documented and described as a concern in past State of the Basin Reports (see WEI, 2013 for example) and annual reports of the GLMC.

In 2014, the Watermaster, consistent with the recommendation of the GLMC, determined that the MZ-1 Plan needs to be updated to include a Subsidence Management Plan for the Northwest MZ-1 Area with the long-term objective to minimize or abate the occurrence of the land subsidence. Watermaster's Engineer developed a draft work plan to develop the Subsidence Management Plan for the Northwest MZ-1 Area, which includes a description of a multi-year effort with cost estimates and a schedule. Upon recommendation by the GLMC and approval by the Watermaster, the work plan will be attached to the MZ-1 Plan as an appendix, and characterized as an ongoing effort of the Watermaster.

2.3 Monitoring Activities during 2014

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, 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 2014 that are either called for by the MZ-1 Plan or the Long-Term Pumping Test in the Managed Area (described above). Figures 2-1 and 2-2 show the locations of the facilities described below.

2.3.1 Monitoring of Production, Recharge, and Piezometric Levels

Quarterly production data were collected and compiled from the owners of wells in the Managed Area and the Areas of Subsidence Concern for calendar year 2014.

The volumes of imported water, storm 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 2013-14.

During 2014, piezometric levels were measured and recorded once every 15 minutes using pressure transducers at 67 wells in the Managed Area, Central MZ-1, Northwest MZ-1 Area, and Southeast Area.

2.3.2 Monitoring of Vertical Aquifer-System Deformation

Watermaster measured and recorded the vertical component of aquifer-system deformation at the Ayala Park Extensometer and at the Chino Creek Extensometer (CCX) 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 GLMC decides annually on the benchmarks to be surveyed. During winter 2014-15, Parsons conducted leveling surveys within the following areas shown on Figure 2-2:

- the Managed Area
- the Southeast Area (around the Chino Creek Well Field)
- the San Jose Fault Zone

Watermaster 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] Six InSAR data frames were collected in March 2014, May 2014, July 2014, August 2014, October 2014, and December 2014, and were used to create twelve interferograms to measure short-term and long-term vertical ground motion over the following periods:

- January 2014 to March 2014
- January 2014 to May 2014
- January 2014 to July 2014
- January 2014 to August 2014
- January 2014 to October 2014
- January 2014 to December 2014
- March 2014 to May 2014
- May 2014 to July 2014
- July 2014 to August 2014
- August 2014 to October 2014
- March 2011 to December 2014

2.3.4 Monitoring of Horizontal Ground-Surface Deformation

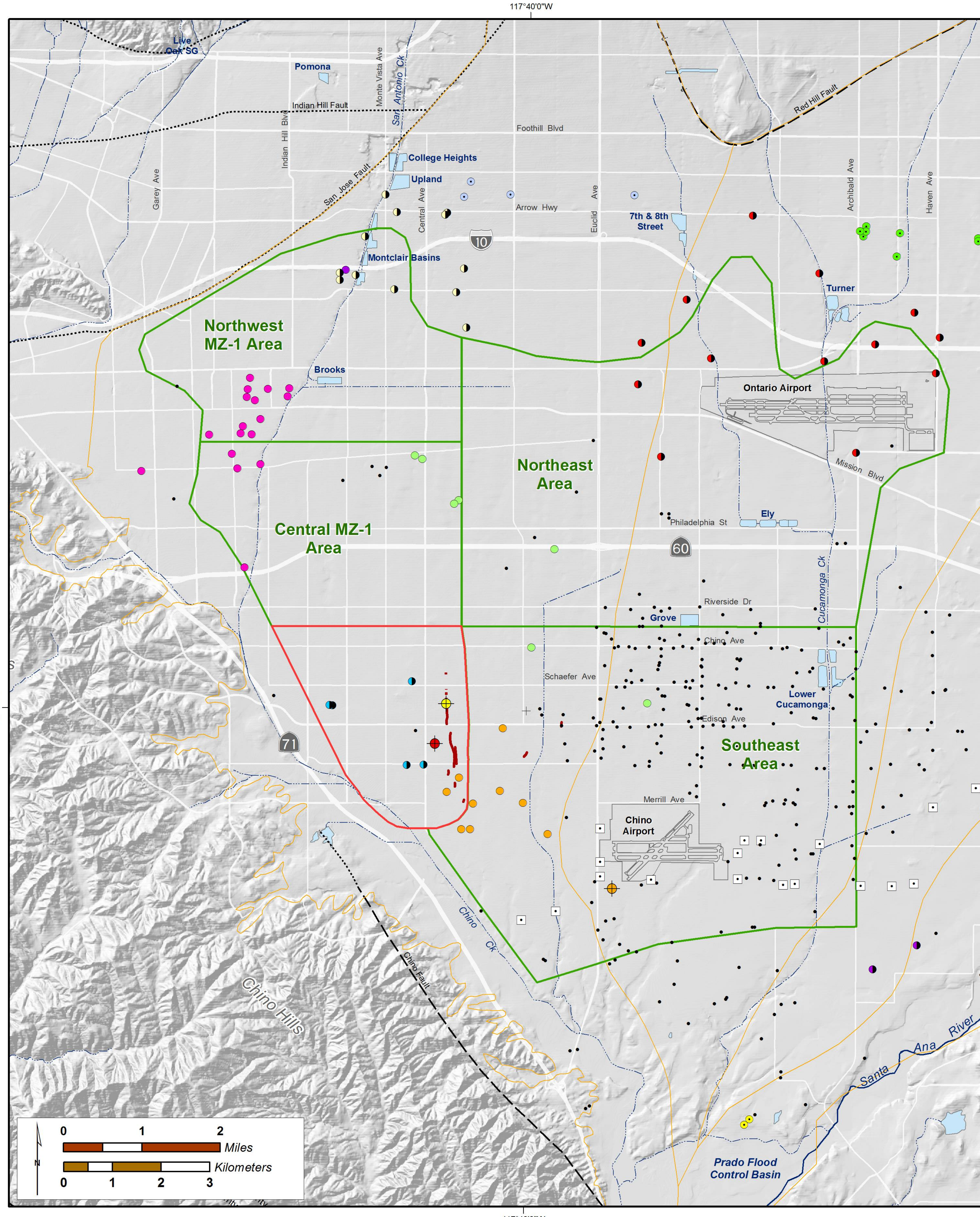
Watermaster measures horizontal ground motion across areas that are susceptible to ground fissuring via EDMs and horizontal extensometers.

EDMs were performed between benchmarks in the:

- *Managed Area* along Schaefer Avenue, G Street, and Chino Avenue in January 2014.
- *Northwest MZ-1 Area* along San Bernardino Avenue and North San Antonio Avenue in January 2014 and February 2015.

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. The facility was flooded in November 2013 and repaired during 2014. Repairs to the facility were completed in February 2015.

[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 GLMC decided to acquire and analyze InSAR data only in the western portion of Chino Basin as a cost-savings strategy.



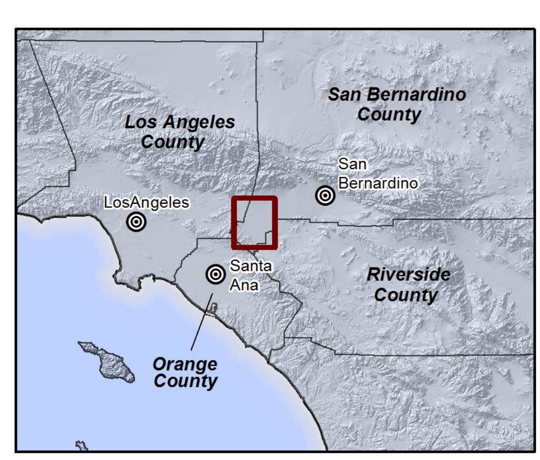
Active Production Wells by Owner 2014

- Ontario
- Pomona
- SAWCo
- CVWD
- Upland
- GSWC
- Private
- CIM
- JCSD
- Chino Hills
- Chino
- MVWD
- OCWD
- Chino Basin Desalter Authority

Extensometers

- Ayala Park Extensometer
- Chino Creek Extensometer
- Daniels Horizontal Extensometer

- Managed Area
- Areas of Subsidence Concern
- Ground Fissures
- Flood Control & Conservation Basins
- Chino Basin Management Zones



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Ground-Level Monitoring Committee
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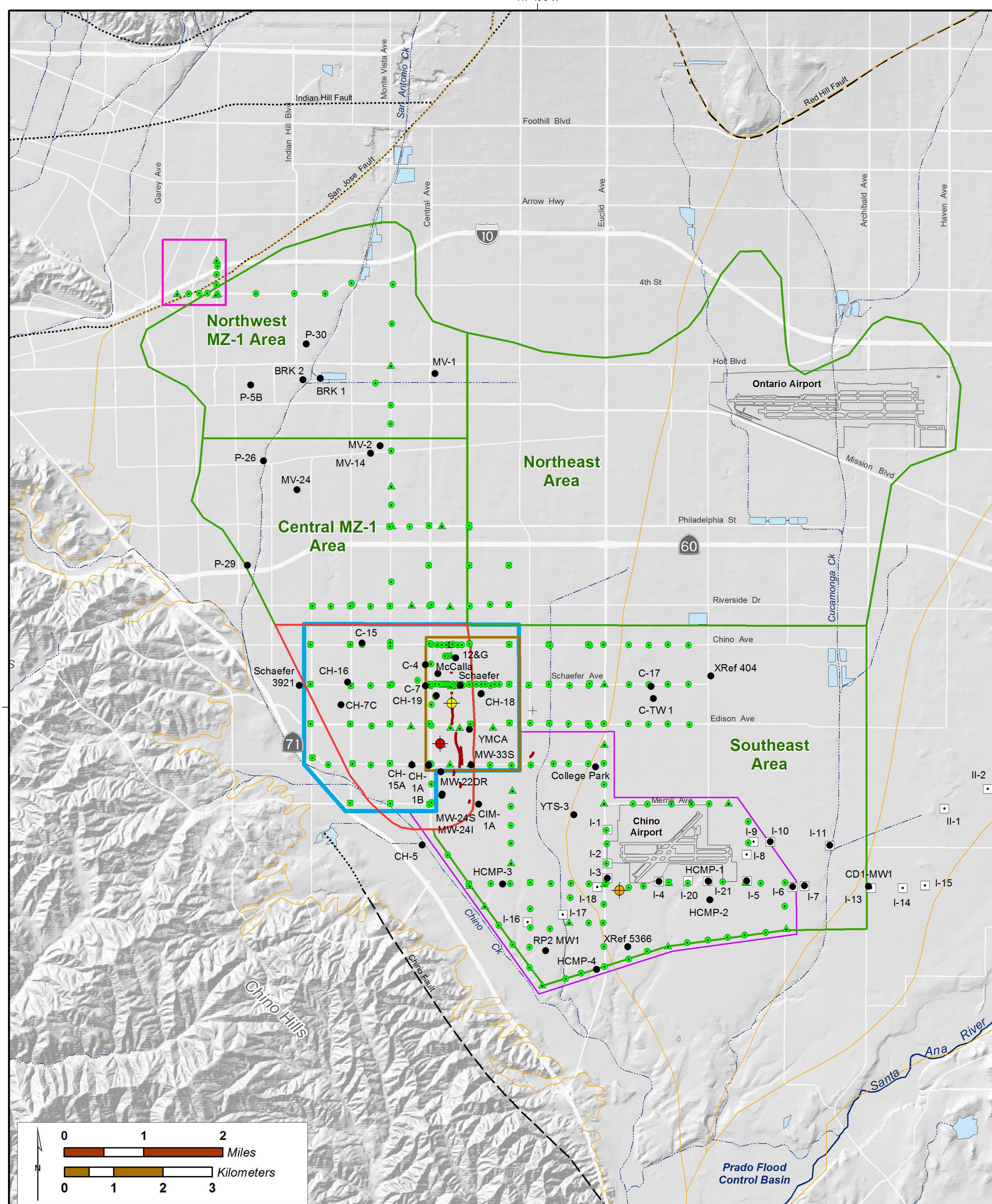
Production & Recharge Facilites

Western Chino Basin 2014

Figure 2-1



117°40'0"W

Survey Benchmarks

- Class A Monuments
- Class B Monuments

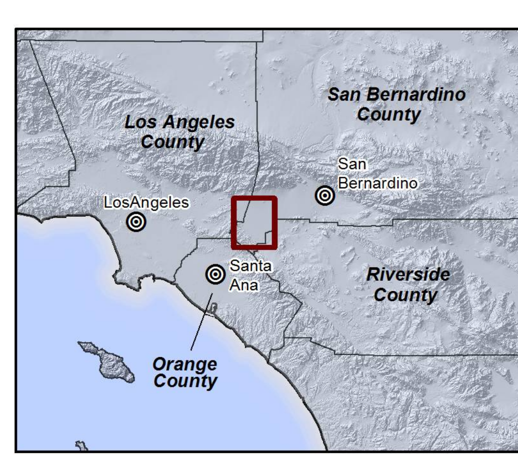
Survey Areas

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

Wells and Extensometers

- Desalter Well
- Ayala Park Extensometer
- Chino Creek Extensometer
- Daniels Horizontal Extensometer
- Well Monitored by Pressure Transducer during 2014

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



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Ground-Level Monitoring Committee
2014 Annual Report

Ground-Level Monitoring Program
as of 2014

Figure 2-2

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

Figures 3-1a and 3-1b display vertical ground motion as measured by InSAR across the western portion of the Chino Basin from April 2011 to December 2014 and January 2014 to December 2014, respectively. The maps also show the locations of specific monitoring facilities referenced in this section.

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 Stress and Strain in the Aquifer-System

Figure 3-2 is a chart that displays and describes 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 decline of piezometric levels that 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 about 0.01 ft/yr.

3.1.2 Recent Stress and Strain in the Aquifer-System

3.1.2.1 Groundwater Production and Groundwater Levels

Table 3-1 summarizes groundwater production by well within the Managed Area for 2014. Approximately 4,600 acre-feet of groundwater was pumped from the Managed Area in 2014—about 66 percent of the total production was from wells screened in the shallow aquifer system and 34 percent was from wells screened in both the shallow and deep aquifer systems.

Figure 3-3 is a time-series chart that displays groundwater production and the resultant piezometric change (stress) and aquifer-system deformation (strain) in the Managed Area for 2011-2014. The chart illustrates the seasonal pattern of production in the Managed Area of increased production during the spring/summer months, and decreased production during the fall/winter months.

Figure 3-3 includes the time-series of piezometric levels at two piezometers at Ayala Park: 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 groundwater-level decline that is much greater in magnitude than groundwater-level decline 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 four cycles of seasonal groundwater-level decline and recovery. Maximum groundwater-level decline occurred when piezometric levels declined to about 190 ft-btoc in August 2013, and returned to full recovery at about 95 ft-btoc in January 2014. The calendar year of 2014 was another typical year of seasonal groundwater-level decline and recovery. The piezometric levels at PA-7 did not decline below the Guidance Level of 245 ft-btoc.

3.1.2.2 Aquifer-System Deformation

Figure 3-3 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 decline and recovery of piezometric levels, was mainly elastic. However, the Deep Extensometer recorded about 0.035 ft of compression in the aquifer system from April-2011 to January-2014, which appears to be non-recoverable compaction.

Figure 3-4 is a stress-strain diagram of piezometric levels measured at PA-7 (stress) versus vertical deformation of the aquifer-system sediments as measured at the Deep Extensometer (strain). The hysteresis loops on this chart represent piezometric decline-recovery cycles and the resultant compression-expansion of the aquifer-system sediments. From April-2011 to January-2014, the hysteresis loops progressively shift to the right on this chart, which indicates about 0.035 ft of non-recoverable compaction of the aquifer-system sediments during this period. The overlapping hysteresis loop during 2014 (the red loop) indicates mostly elastic deformation of the aquifer-system sediments during this most recent decline-recovery cycle.

3.1.2.3 Vertical Ground Motion

Vertical ground motion is measured across the Managed Area via InSAR and via traditional leveling surveys. These data are mapped on:

- Figure 3-5a for the period 2011 to 2015
- Figure 3-5b for 2014

The InSAR data on Figure 3-5a indicate -0.02 to -0.12 ft of vertical ground motion across the Managed Area for the period March-2011 to December-2014. Figure 3-3 shows that groundwater levels at PA-7 were about 30 ft lower in December-2014 compared to March-2011, which suggests that the vertical ground motion shown by InSAR in the Managed Area is, in part, elastic, and may rebound when groundwater levels recover.

The InSAR data on Figure 3-5a are consistent with the Deep Extensometer record at Ayala Park during the period March-2011 to December-2014—the InSAR indicate about -0.05 ft of vertical ground motion; the Deep Extensometer measured -0.07 ft of vertical ground motion.

The leveling-survey data on Figure 3-5a indicate +0.02 to -0.06 ft of vertical ground motion across the Managed Area for the period November-2011 to March-2015. Figure 3-3 shows that groundwater levels at PA-7 were about the same in March-2015 compared to November-2011, which suggests very little, if any, subsidence occurred across the Managed Area over this period.

The InSAR data on Figure 3-5b indicate +0.01 to -0.04 ft of vertical ground motion across the Managed Area for the period January-2014 to December-2014. Figure 3-3 shows that groundwater levels at PA-7 were about 40 ft lower in December-2014 compared to January-

2014, which suggests that the vertical ground motion shown by InSAR in the Managed Area is, in part, elastic, and may rebound when groundwater levels recover.

The InSAR data on Figure 3-5b are consistent with the Deep Extensometer record at Ayala Park during the period January-2014 to December-2014—the InSAR indicate about -0.03 ft of vertical ground motion; the Deep Extensometer measured -0.05 ft of vertical ground motion.

The leveling-survey data on Figure 3-5b indicate +0.02 to -0.03 ft of vertical ground motion across the Managed Area for the period December-2013 to March-2015. Figure 3-3 shows that groundwater levels at PA-7 were about 15 ft lower in March-2015 compared to December-2013, which suggests very little, if any, subsidence occurred across the Managed Area over this period.

3.2 Central MZ-1 Area

Figures 3-1a and 3-1b are maps that show recent vertical ground motion in the Central MZ-1 Area. About -0.02 to -0.08 ft of vertical ground motion occurred across Central MZ-1 during the period March-2011 to December-2014. About 0 to -0.03 ft of vertical ground motion occurred across Central MZ-1 during the period January-2014 to December-2014.

Figure 3-6 is a time-series chart that displays and describes the long-term history of land subsidence in Central MZ-1. The time history and magnitudes of vertical ground motion in Central MZ-1 is similar to that of the Managed Area. Over two feet of subsidence occurred at the corner of Philadelphia Avenue and Monte Vista Avenue from 1993 to 2000, but only about 0.4 feet of 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.

3.3 Northwest MZ-1 Area

Figures 3-1a and 3-1b are maps that show recent vertical ground motion in the Northwest MZ-1 Area. About -0.04 to -0.2 ft of vertical ground motion occurred across Northwest MZ-1 Area during the period March-2011 to December-2014. About 0 to -0.03 ft of vertical ground motion occurred in the Northwest MZ-1 Area during the period January-2014 to December-2014.

The pattern of vertical ground motion on Figures 3-1a and 3-1b is a continuation of the historical time-series of subsidence in this area shown on Figure 3-7, which indicates a total of about 1.4 feet of subsidence since 1992 (about 0.06 ft/yr). Of particular concern in Northwest MZ-1 Area is that the historical and ongoing subsidence has been differential across 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 historical and ongoing subsidence in the Northwest MZ-1 Area, but it is likely related to recent and/or past decline of piezometric levels. If so, subsidence could have begun when the rate of groundwater-level decline increased around 1943. If subsidence has been occurring at a constant rate of 0.06 feet per year since 1943, then the Northwest MZ-1 Area has experienced about 4.2 feet of subsidence since the onset of increased groundwater-level decline.[5]

Figure 3-8 is a map that displays vertical ground motion across the San Jose Fault from January 2014 to December 2014 as measured by InSAR, and horizontal ground motion across the San Jose Fault as measured by EDM surveys from January 2014 to January 2015. These data indicate that horizontal extension occurred in the shallow soils across the San Jose Fault during 2014 in both the north-south direction and the east-west direction.

3.4 Southeast Area

Vertical ground motion is measured across the Southeast Area via InSAR and via traditional leveling surveys. The InSAR data is absent (incoherent) across much of this area, but is becoming increasingly coherent as the area's land uses have converted from agricultural to urban (i.e. better reflector of radar waves). These data are mapped on:

- Figure 3-5a for the period 2011 to 2014
- Figure 3-5b for 2014

These figures show little, if any, recent subsidence across the Southeast Area, and that some areas experienced rebound of the ground surface. Historically, ground fissuring has been documented in the Southeast Area which may have been caused by compaction of the aquifer system. There is not enough historical data to confirm the causes of the fissuring.

Figure 3-9 is a time-series chart that displays and describes the long-term history of land subsidence in the Southeast Area. This figure shows that a total of 0.5 ft of subsidence has occurred in the Southeast Area since 1987, but that recently subsidence has virtually ceased, which has coincided with increased reuse of recycled water, decreased groundwater production, and stable or increasing groundwater levels.

Figure 3-10 displays the time series of piezometric levels and vertical aquifer-system deformation recorded at the CCX, which began collecting data in mid-2012. In general, piezometric levels have changed very little, and only a small amount of expansion of the aquifer-system sediments has been measured by the CCX. These observations are consistent with the InSAR and leveling surveys shown on Figures 3-5a and 3-5b.

In the second half of 2014, pumping began at the Chino Creek Well Field, but this pumping had no discernable effect on piezometric levels or the extensometer records at the CCX.

3.5 Northeast Area

Figures 3-1a and 3-1b are maps that show recent vertical ground motion in the Northeast Area. About 0 to -0.1 ft of vertical ground motion occurred across the Northeast Area during

[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 groundwater-level declines compared to the rate of subsidence observed since 1992.

the period March-2011 to December-2014. Virtually no vertical ground motion occurred across the Northeast Area during the period January-2014 to December-2014.

Figure 3-11 is a time-series chart that displays and describes the long-term history of land subsidence in the Northeast Area. This figure shows that a total of 1.2 ft of subsidence has occurred in the Northeast Area since 1992, but that recent subsidence has virtually ceased, which has coincided with increased artificial recharge at spreading basins within or directly upgradient of the Northeast Area, decreased groundwater production, and stable or increasing groundwater levels.

3.6 Seismicity versus Ground Motion

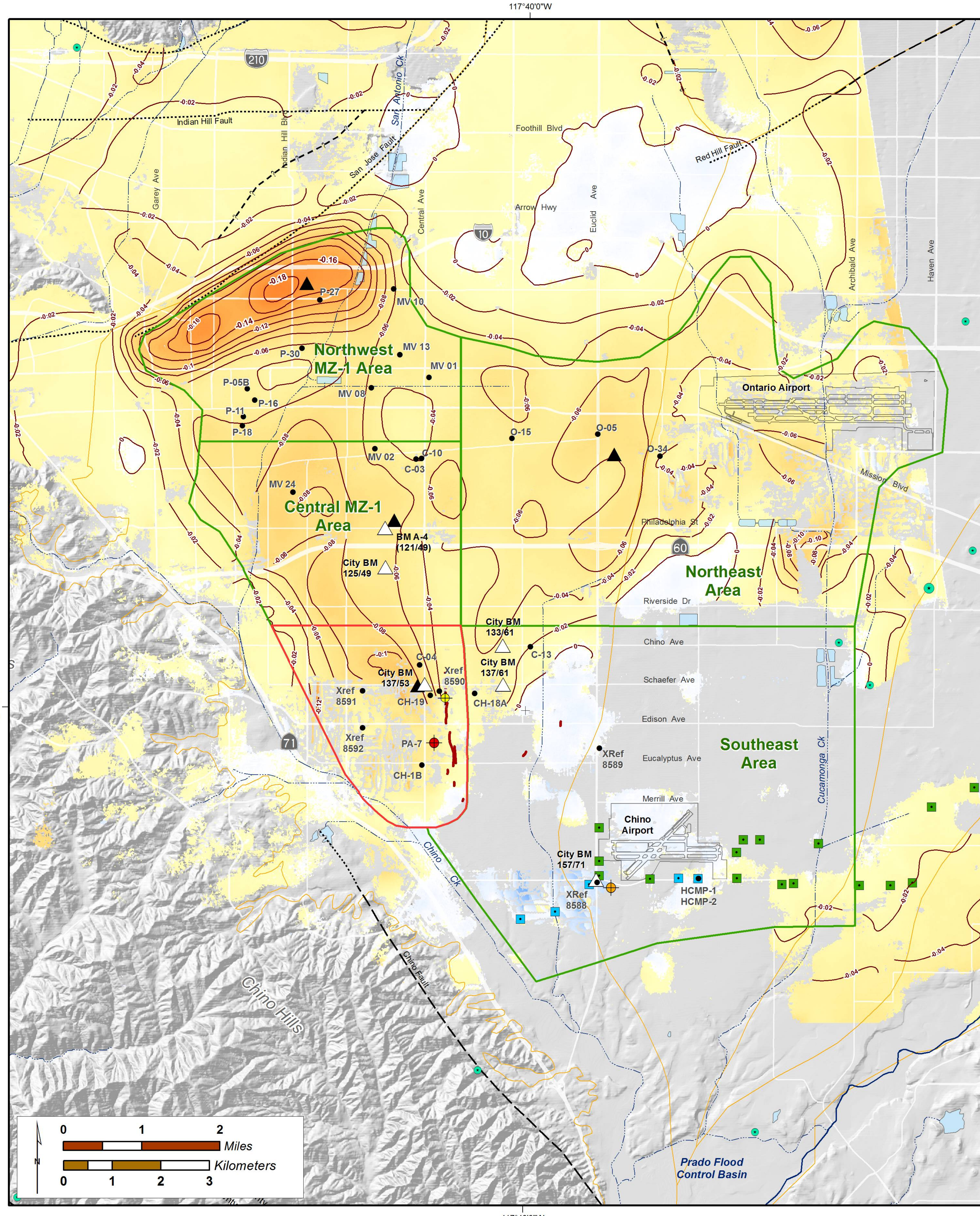
Epicenters of earthquakes that occurred from 2011 through 2014 are shown on Figure 3-1a and 3-1b. The maps show no correlation between earthquake events and vertical ground motion.

Table 3-1
Groundwater Production in the Managed Area for 2014
acre-feet

Well Name	Aquifer Layer	2014 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**	**3,037**
C-6		0	0	0	0	**0**	
CH-1A		237	318	323	171	**1,048**	
CH-7A		0	131	66	92	**289**	
CH-7B		0	200	233	166	**599**	
CIM-1		287	302	233	274	**1,096**	
Xref 8730[1]		1	1	1	1	**5**	
CH-17	Deep[2]	312	418	399	250	**1,379**	**1,535**
CH-15B		0	0	0	0	**0**	
CIM-11A		13	69	52	21	**156**	
Totals		**850**	**1,440**	**1,307**	**975**	**4,572**	**4,572**

[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.



+ 0.25 ft
0
-0.1
- 0.25
Relative Change in Land Surface Altitude as Measured by InSAR Mar-2011 to Dec-2014

InSAR data absent (incoherent)

2 - 3
3 - 4
4 - 5
< 5
Earthquake Epicenters Mar-2011 to Dec-2014 (Local Magnitude)

Wells and Extensometers

Wells with water-level data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11

Chino I & II Desalter Wells

Chino Creek Desalter Well Field

Ayala Park Extensometer

Chino Creek Extensometer

Daniels Horizontal Extensometer

Benchmark monument with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11

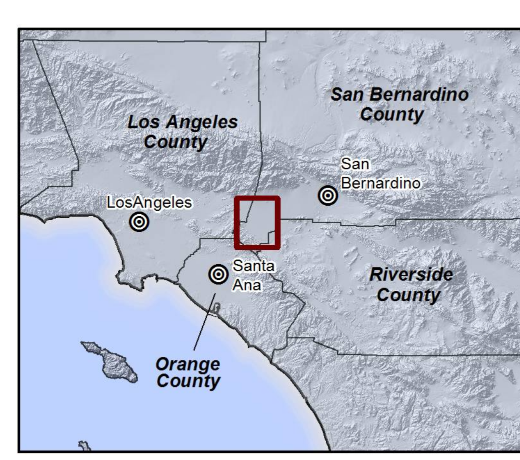
InSAR measurement point with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11

Managed Area

Areas of Subsidence Concern

Ground Fissures

Chino Basin Management Zones



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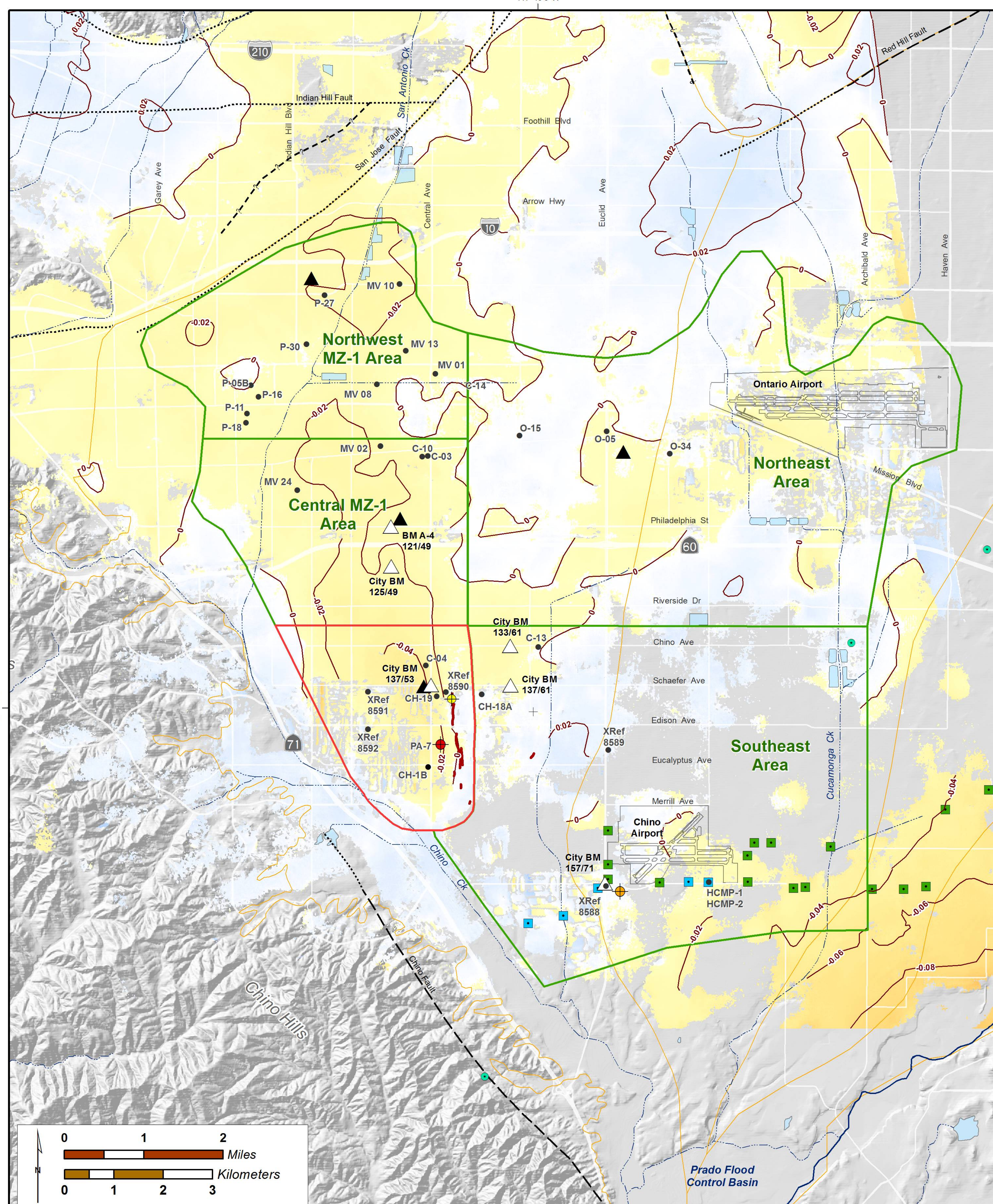
2014 Annual Report

Vertical Ground Motion across Western Chino Basin
2011-2014

Figure 3-1a

117°40'0"W



117°40'0"W

+ 0.25 ft
0
-0.1
- 0.25
Relative Change in Land Surface Altitude as Measured by InSAR Jan-2014 to Dec-2014

InSAR data absent (incoherent)

2 - 3
3 - 4
4 - 5
< 5
Earthquake Epicenters Jan-2014 to Dec-2014 (Local Magnitude)

Wells and Extensometers

Wells with water-level data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11

Chino I & II Desalter Wells

Chino Creek Desalter Well Field

Ayala Park Extensometer

Chino Creek Extensometer

Daniels Horizontal Extensometer

Benchmark Monument with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11

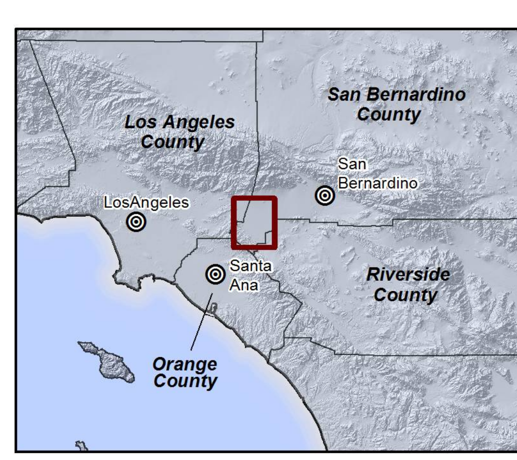
InSAR measurement point with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11

Managed Area

Areas of Subsidence Concern

Ground Fissures

Chino Basin Management Zones



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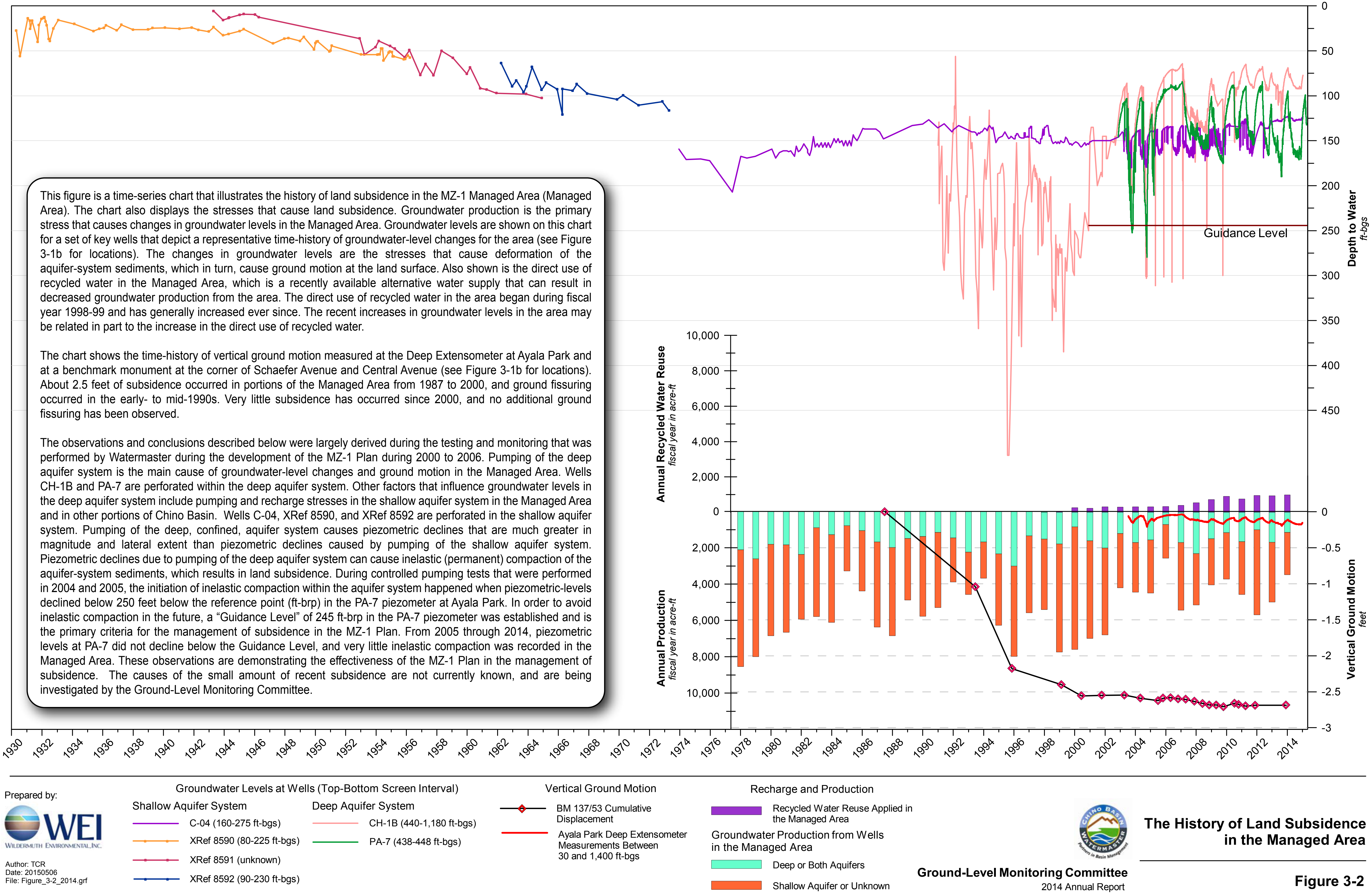
Ground-Level Monitoring Committee
2014 Annual Report

Vertical Ground Motion across Western Chino Basin

2014

Figure 3-1b



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 (see Figure 3-1b for locations). 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 1998-99 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 measured at the Deep Extensometer at Ayala Park and at a benchmark monument at the corner of Schaefer Avenue and Central Avenue (see Figure 3-1b 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 subsidence has occurred since 2000, and no additional ground fissuring has been observed.

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. Other factors that influence groundwater levels in the deep aquifer system include pumping and recharge stresses in the shallow aquifer system in the Managed Area and in other portions of Chino Basin. Wells C-04, XRef 8590, and XRef 8592 are perforated in the shallow aquifer system. Pumping of the deep, confined, aquifer system causes piezometric declines that are much greater in magnitude and lateral extent than piezometric declines caused by pumping of the shallow aquifer system. Piezometric declines due to pumping of the deep aquifer system can cause inelastic (permanent) compaction of the aquifer-system sediments, which results in 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 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 2014, 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 recent subsidence are not currently known, and are being investigated by the Ground-Level Monitoring Committee.

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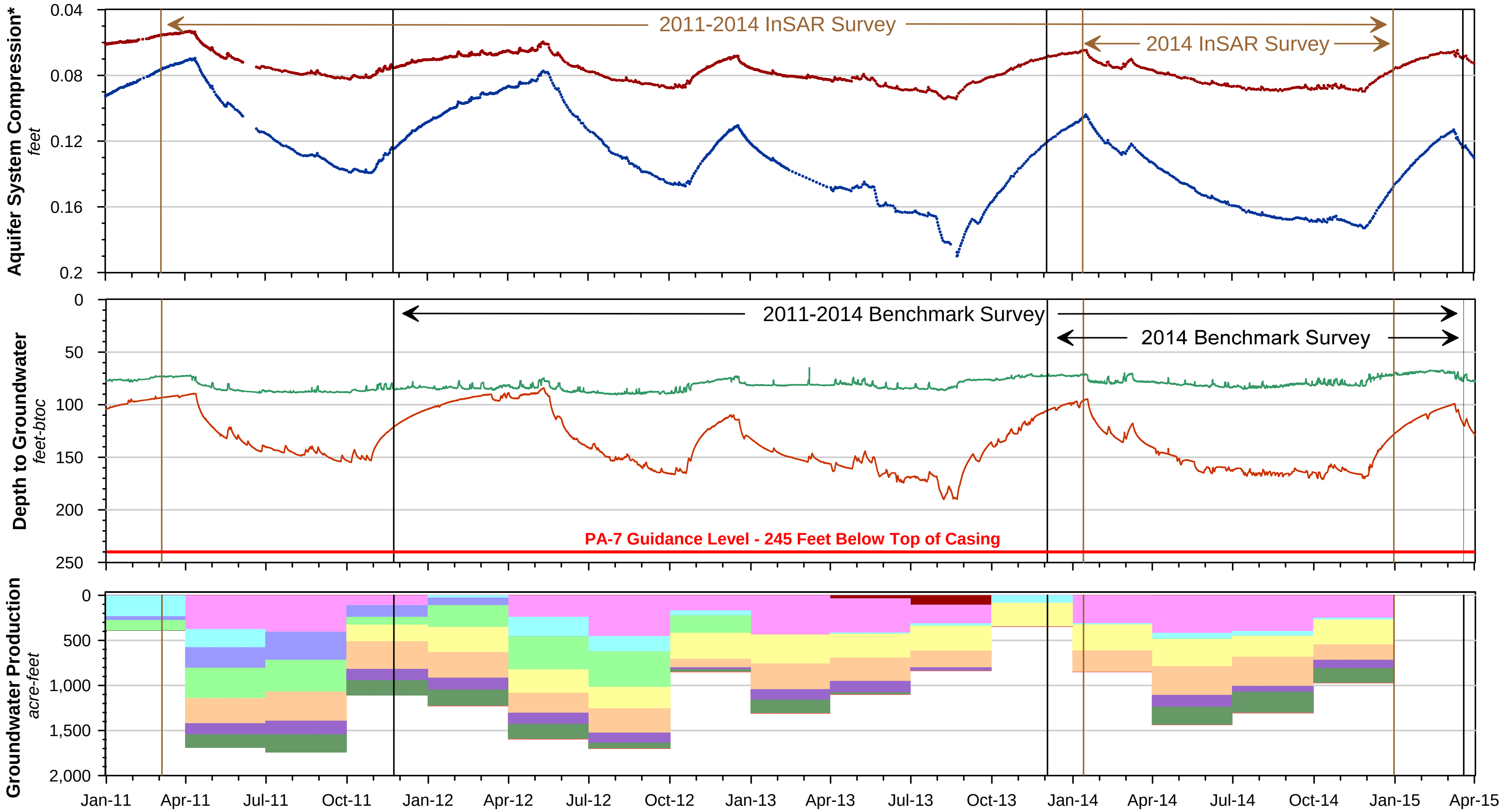
The History of Land Subsidence in the Managed Area

Figure 3-2



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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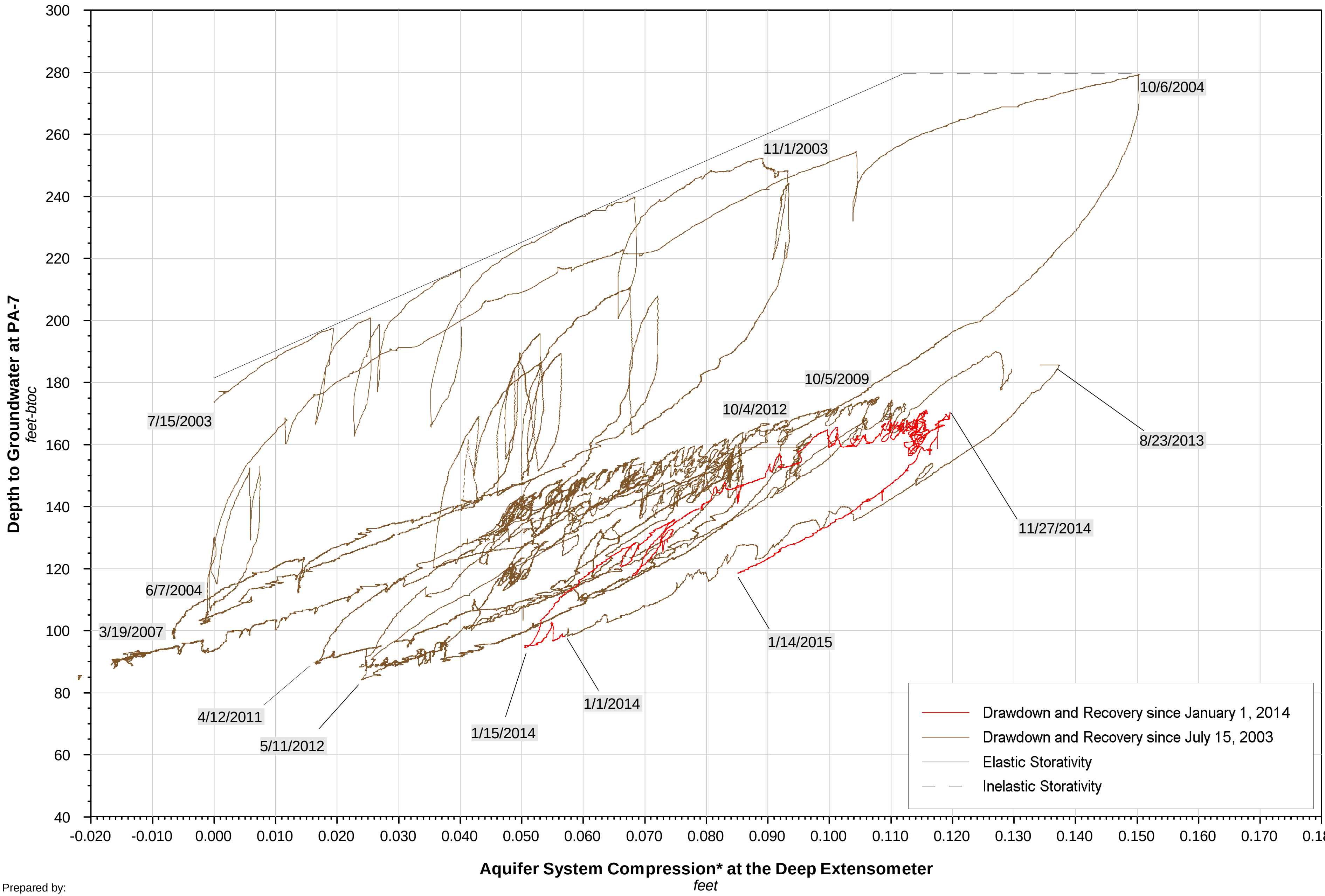
Stress and Strain within the Managed Area

Figure 3-3

*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

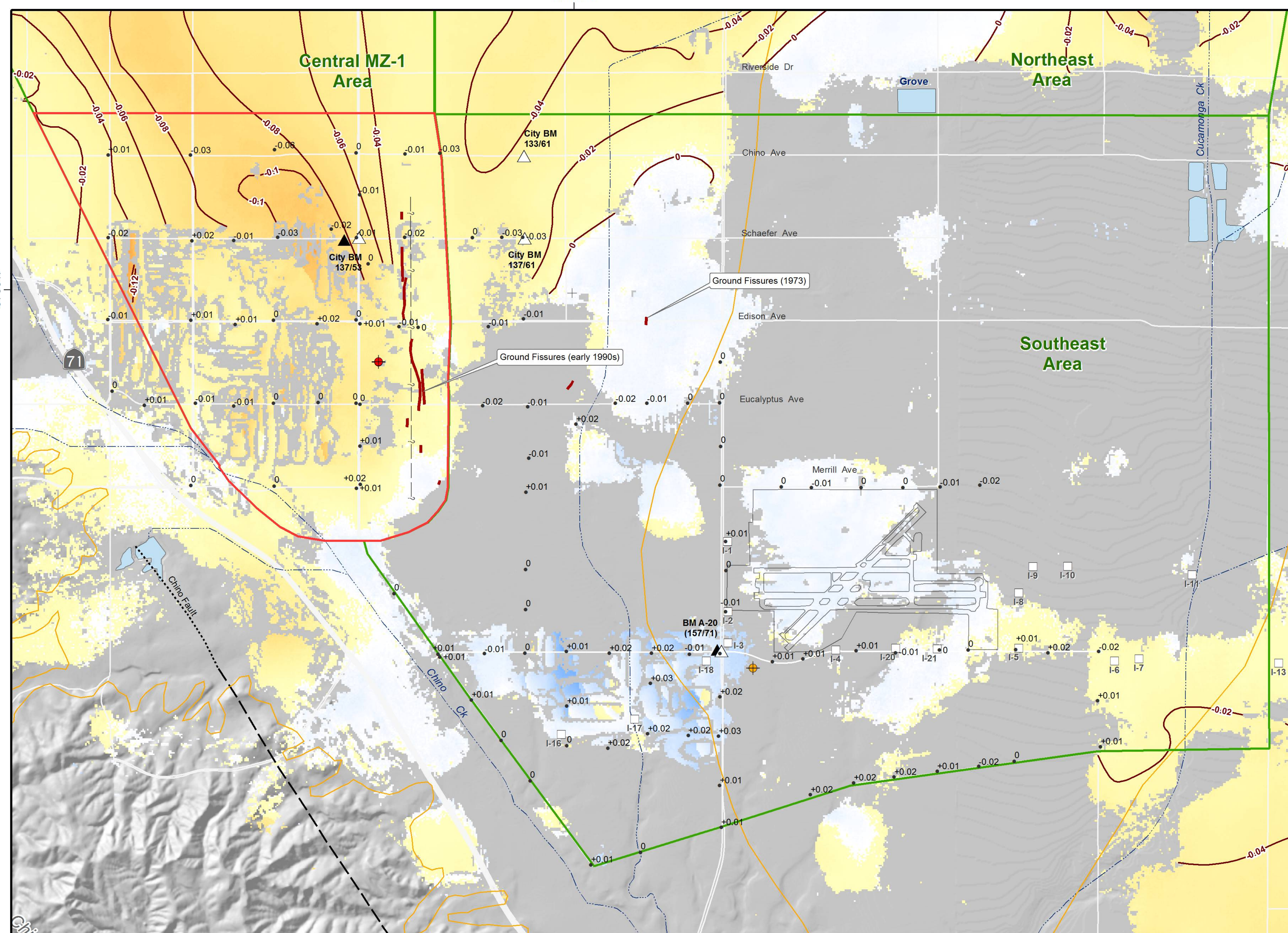
Depth Interval of the Deep Extensometer
= 30-1,400 feet-bgs

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

Ground-Level Monitoring Committee
2014 Annual Report

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

Figure 3-4



Vertical Ground Motion

- 0.01 Benchmark Monument labeled by feet of change in ground-surface altitude for the period:

Nov-2011 to Jan-2015 in the Southeast Area
Nov-2011 to Mar-2015 in the Managed Area

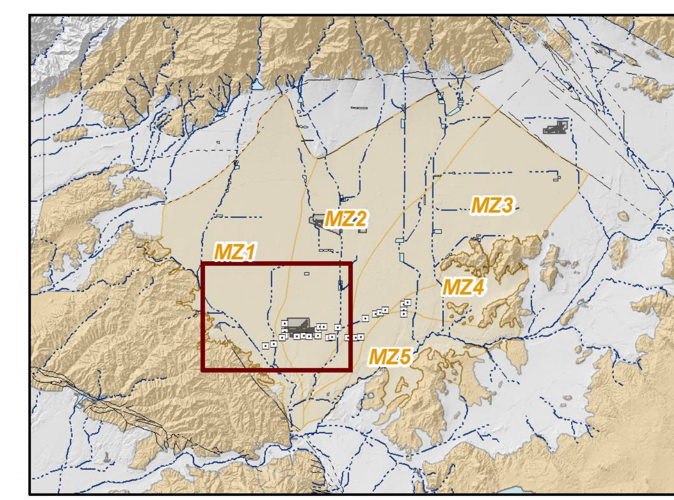
+ 0.25 ft / 0 / -0.1 / - 0.25 Relative change in ground-surface altitude as measured by InSAR for the period:

Mar-2011 to Dec-2014

InSAR data absent (incoherent)

Other Features

- Desalter Well
- Chino Creek Extensometer
- Ayala Park Extensometer
- Ground Fissures
- Benchmark monument with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11
- InSAR point with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11
- Riley Barrier
- Managed Area
- Other Areas of Subsidence Concern
- Flood Control & Conservation Basins



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0 1 2 Miles
0 1 2 3 Kilometers

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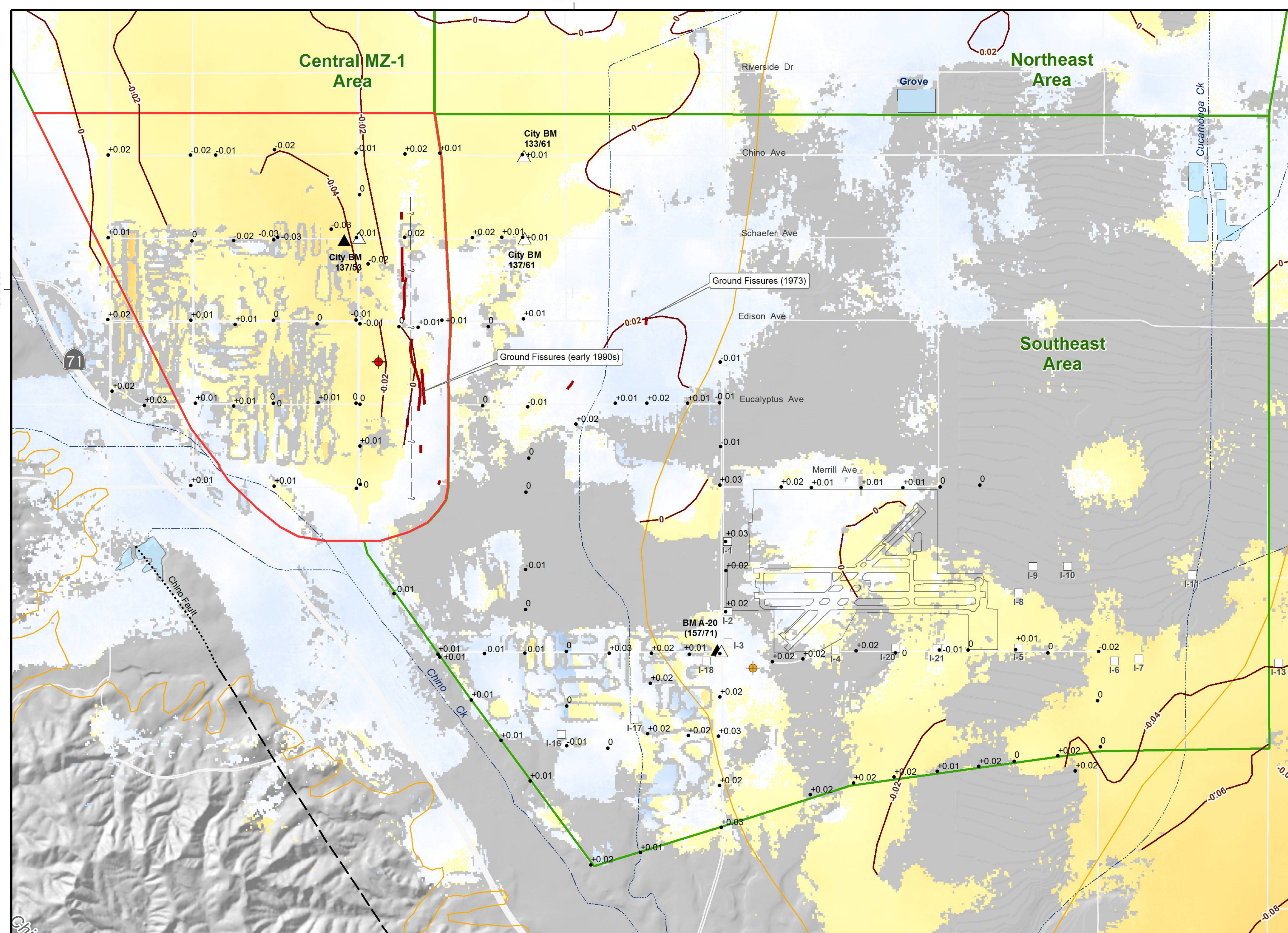
2014 Annual Report

Vertical Ground Motion in the Managed Area and Southeast Area
2011-2015

Figure 3-5a



Vertical Ground Motion

- 0.01 Benchmark Monument labeled by feet of change in ground-surface altitude for the period:

Dec-2013 to Jan-2015 in the Southeast Area
Dec-2013 to Mar-2015 in the Managed Area

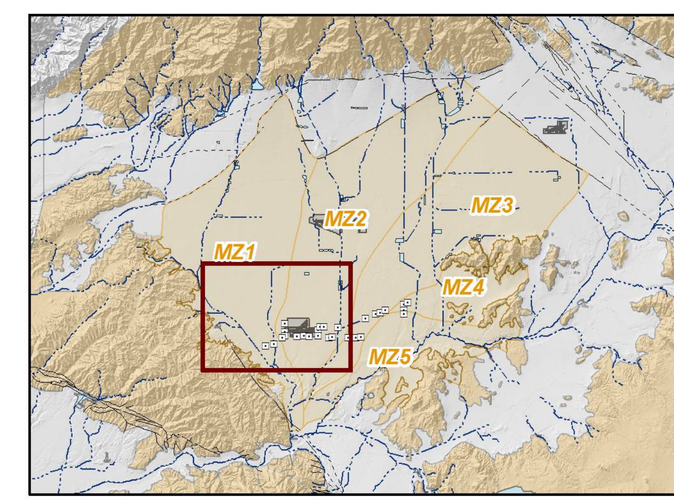
+ 0.25 ft / 0 / -0.1 / - 0.25 — Relative change in ground-surface altitude as measured by InSAR for the period:

Jan-2014 to Dec-2014

InSAR data absent (incoherent)

Other Features

- Desalter Well
- Chino Creek Extensometer
- Ayala Park Extensometer
- Ground Fissures
- Benchmark monument with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11
- InSAR point with vertical ground-motion data shown on Figures 3-2, 3-6, 3-7, 3-9, and 3-11
- Riley Barrier
- Managed Area
- Other Areas of Subsidence Concern
- Flood Control & Conservation Basins



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0 1 2 Miles
0 1 2 3 Kilometers

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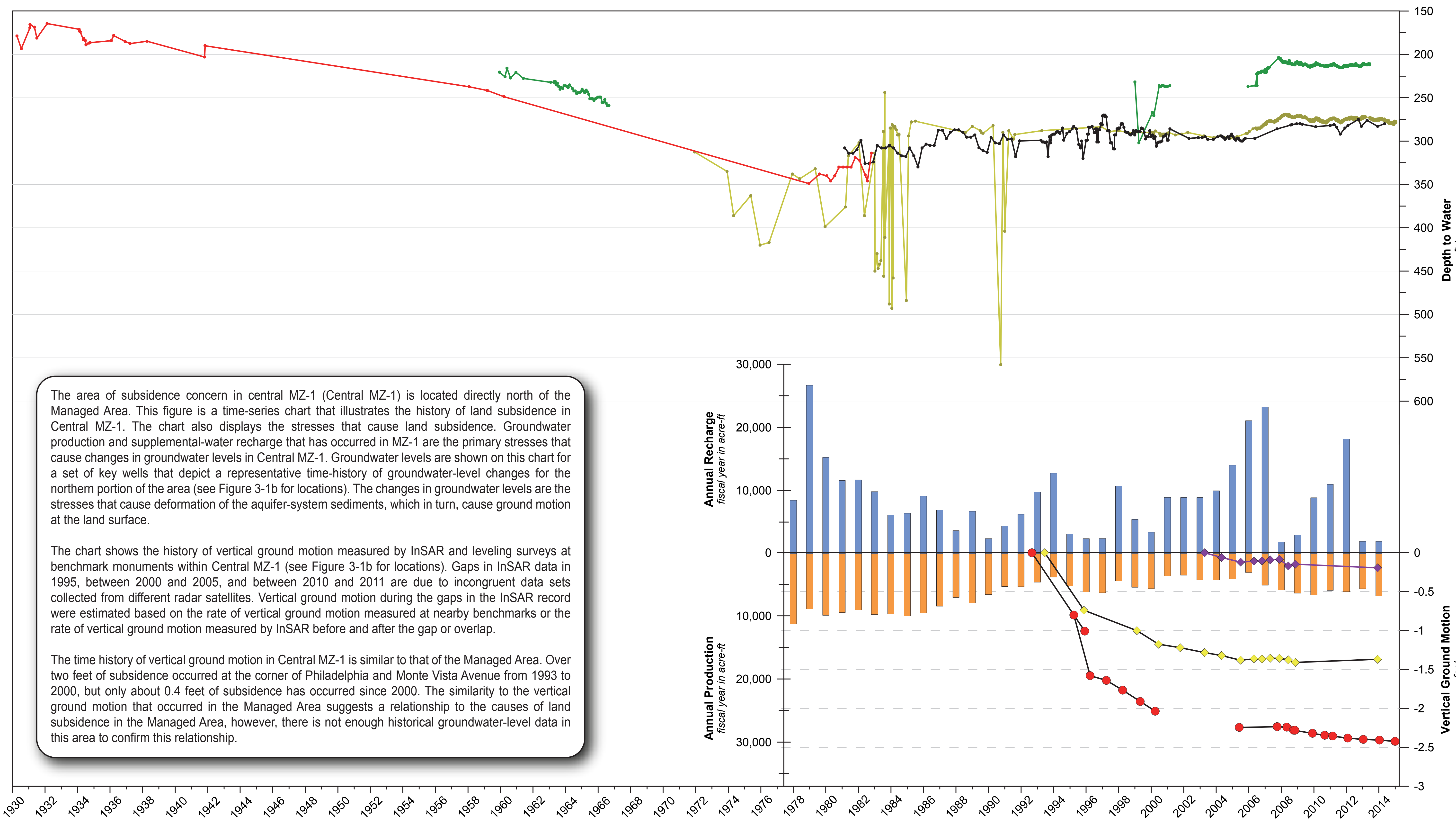
Vertical Ground Motion in the Managed Area and Southeast Area

2014-2015

Figure 3-5b



The area of subsidence concern in central MZ-1 (Central MZ-1) is located directly north of the Managed Area. 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 (see Figure 3-1b for locations). 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 3-1b 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 gaps in the InSAR record were estimated based on the rate of vertical ground motion measured at nearby benchmarks or the rate of vertical ground motion measured by InSAR before and after the gap or overlap.

The time history of vertical ground motion in Central MZ-1 is similar to that of the Managed Area. Over two feet of subsidence occurred at the corner of Philadelphia and Monte Vista Avenue from 1993 to 2000, but only about 0.4 feet of 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

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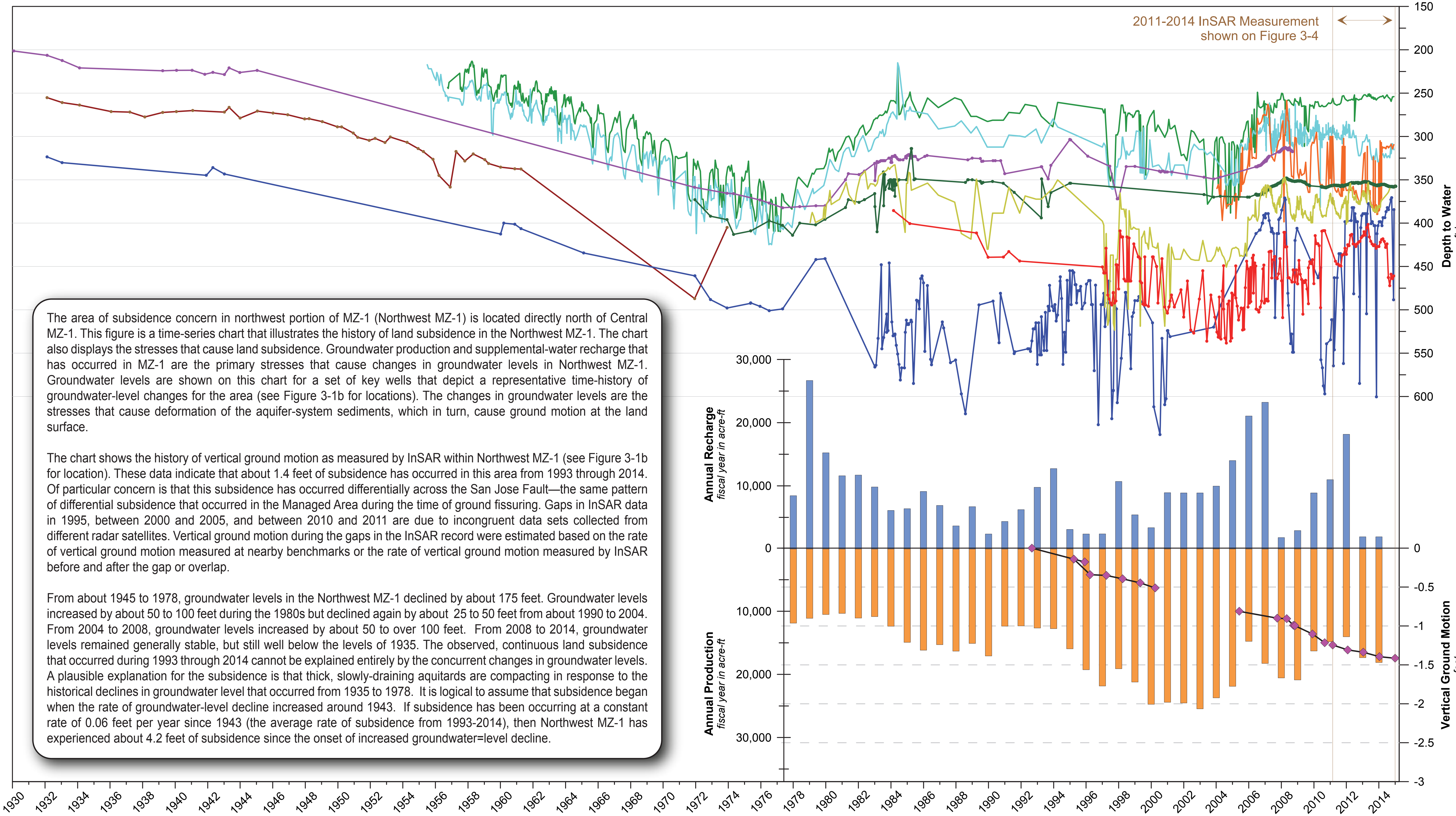
The History of Land Subsidence in the Central MZ-1 Area

Ground-Level Monitoring Committee
2014 Annual Report

Figure 3-6



The area of subsidence concern in northwest portion of MZ-1 (Northwest MZ-1) is located directly north of Central MZ-1. This figure is a time-series chart that illustrates the history of land subsidence in the Northwest 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 Northwest 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 area (see Figure 3-1b for locations). 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 Northwest MZ-1 (see Figure 3-1b for location). These data indicate that about 1.4 feet of subsidence has occurred in this area from 1993 through 2014. 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 gaps in the InSAR record were estimated based on the rate of vertical ground motion measured at nearby benchmarks or the rate of vertical ground motion measured by InSAR before and after the gap or overlap.

From about 1945 to 1978, groundwater levels in the Northwest MZ-1 declined by about 175 feet. Groundwater levels increased by about 50 to 100 feet during the 1980s but declined again by about 25 to 50 feet from about 1990 to 2004. From 2004 to 2008, groundwater levels increased by about 50 to over 100 feet. From 2008 to 2014, groundwater levels remained generally stable, but still well below the levels of 1935. The observed, continuous land subsidence that occurred during 1993 through 2014 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 declines in groundwater level that occurred from 1935 to 1978. It is logical to assume that subsidence began when the rate of groundwater-level decline increased around 1943. If subsidence has been occurring at a constant rate of 0.06 feet per year since 1943 (the average rate of subsidence from 1993-2014), then Northwest MZ-1 has experienced about 4.2 feet of subsidence since the onset of increased groundwater=level decline.

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Date: 20150421
File: Figure_3-7_2014_North.grf

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

- Northwest MZ-1 InSAR

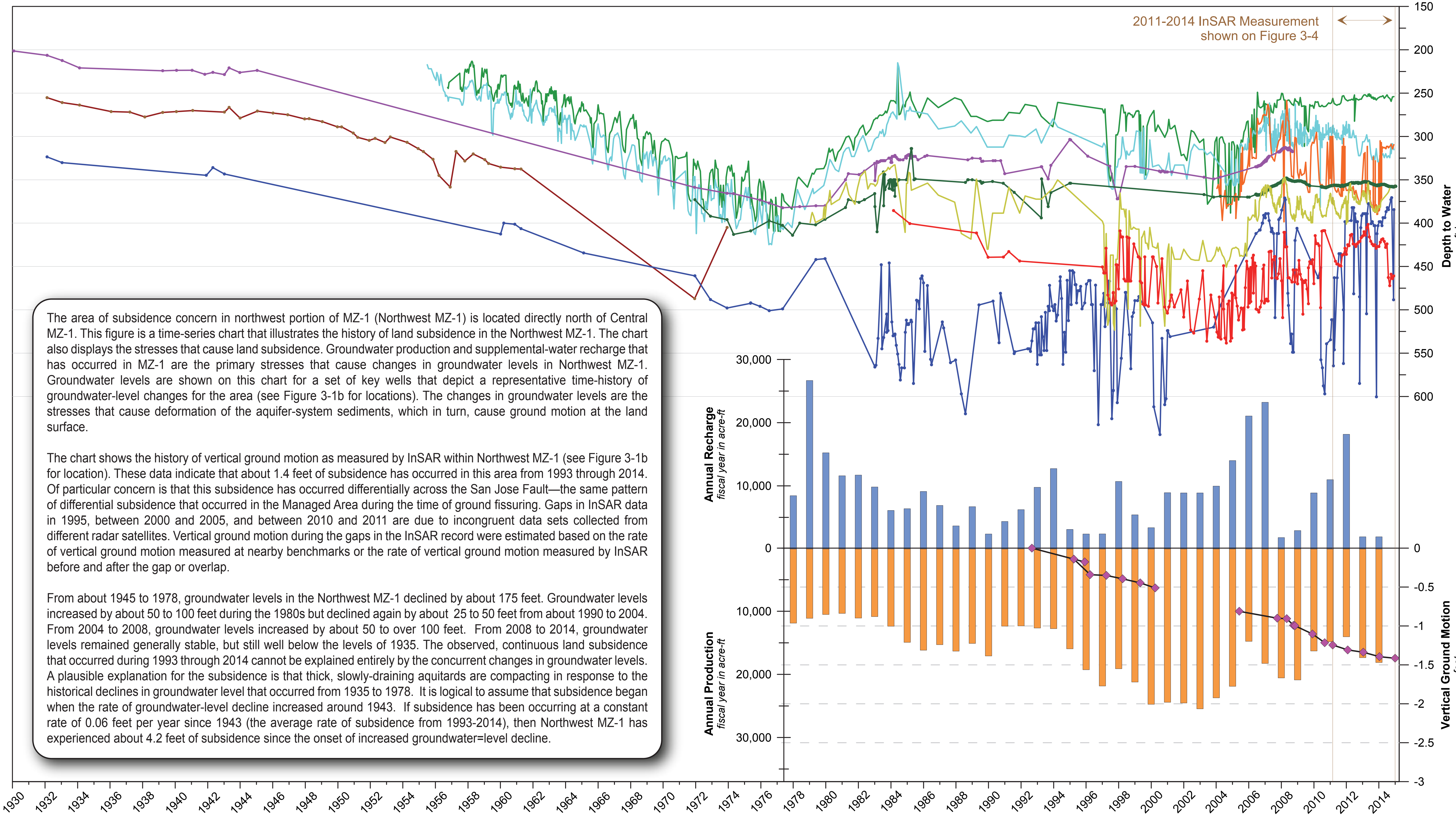
Recharge and Production

- 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 Northwest MZ-1

Ground-Level Monitoring Committee
2014 Annual Report

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

Figure 3-7



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From about 1945 to 1978, groundwater levels in the Northwest MZ-1 declined by about 175 feet. Groundwater levels increased by about 50 to 100 feet during the 1980s but declined again by about 25 to 50 feet from about 1990 to 2004. From 2004 to 2008, groundwater levels increased by about 50 to over 100 feet. From 2008 to 2014, groundwater levels remained generally stable, but still well below the levels of 1935. The observed, continuous land subsidence that occurred during 1993 through 2014 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 declines in groundwater level that occurred from 1935 to 1978. It is logical to assume that subsidence began when the rate of groundwater-level decline increased around 1943. If subsidence has been occurring at a constant rate of 0.06 feet per year since 1943 (the average rate of subsidence from 1993-2014), then Northwest MZ-1 has experienced about 4.2 feet of subsidence since the onset of increased groundwater=level decline.

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Groundwater Levels at Wells (Top-Bottom Screen Interval)

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- MV-08 (225-447 ft-bgs)
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- P-30 (565-875 ft-bgs)

Vertical Ground Motion

- Northwest MZ-1 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 Northwest MZ-1

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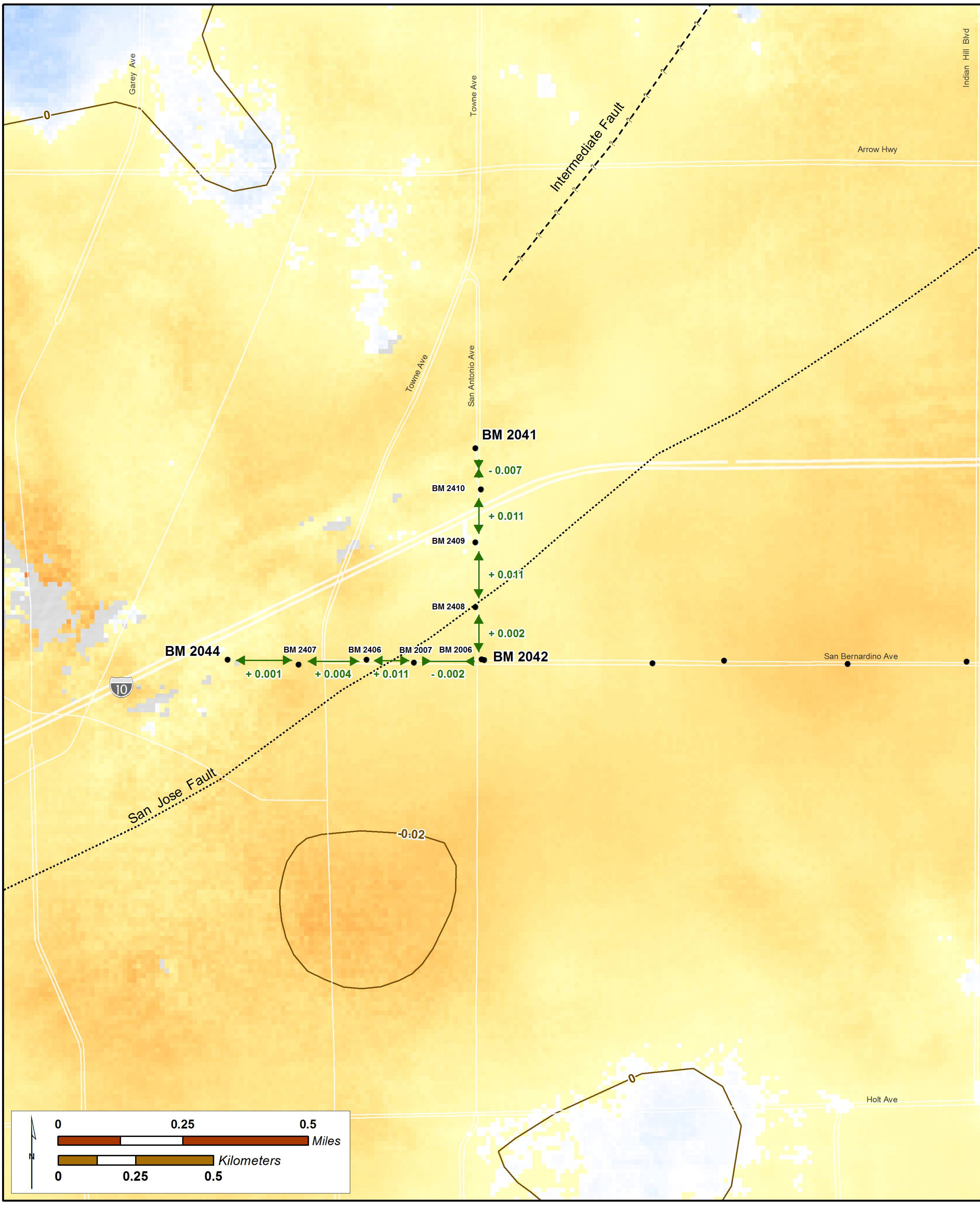
Ground-Level Monitoring Committee
2014 Annual Report

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

Figure 3-7



+ 0.05 / 0 / -0.02 / - 0.05 — Relative Change in Land Surface Altitude as Measured by InSAR Jan. 2014 to Dec. 2014 (feet)

InSAR data absent (incoherent)

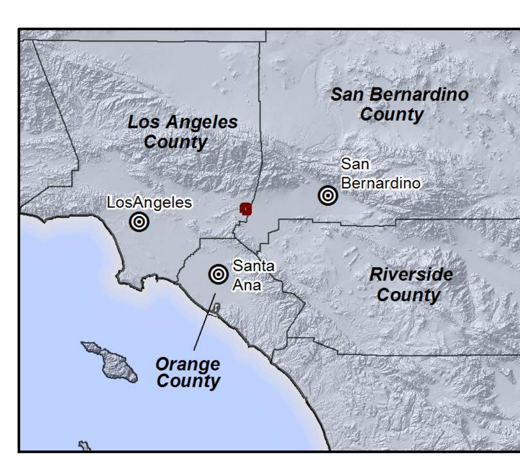
Benchmark Location

Horizontal Ground Motion Between Adjacent Benchmarks Jan. 2014 to Jan. 2015 (feet)

+ 0.010

Horizontal ground motion between adjacent benchmarks is shown as extension (+) or compression (-) in either the north-south direction for benchmarks along San Antonio Ave or the east-west direction for benchmarks along San Bernardino Ave.

Benchmark BM 2042 is assumed to be stable in the horizontal plane (i.e. no horizontal motion).



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2014 Annual Report

Ground Motion across the San Jose Fault

2014

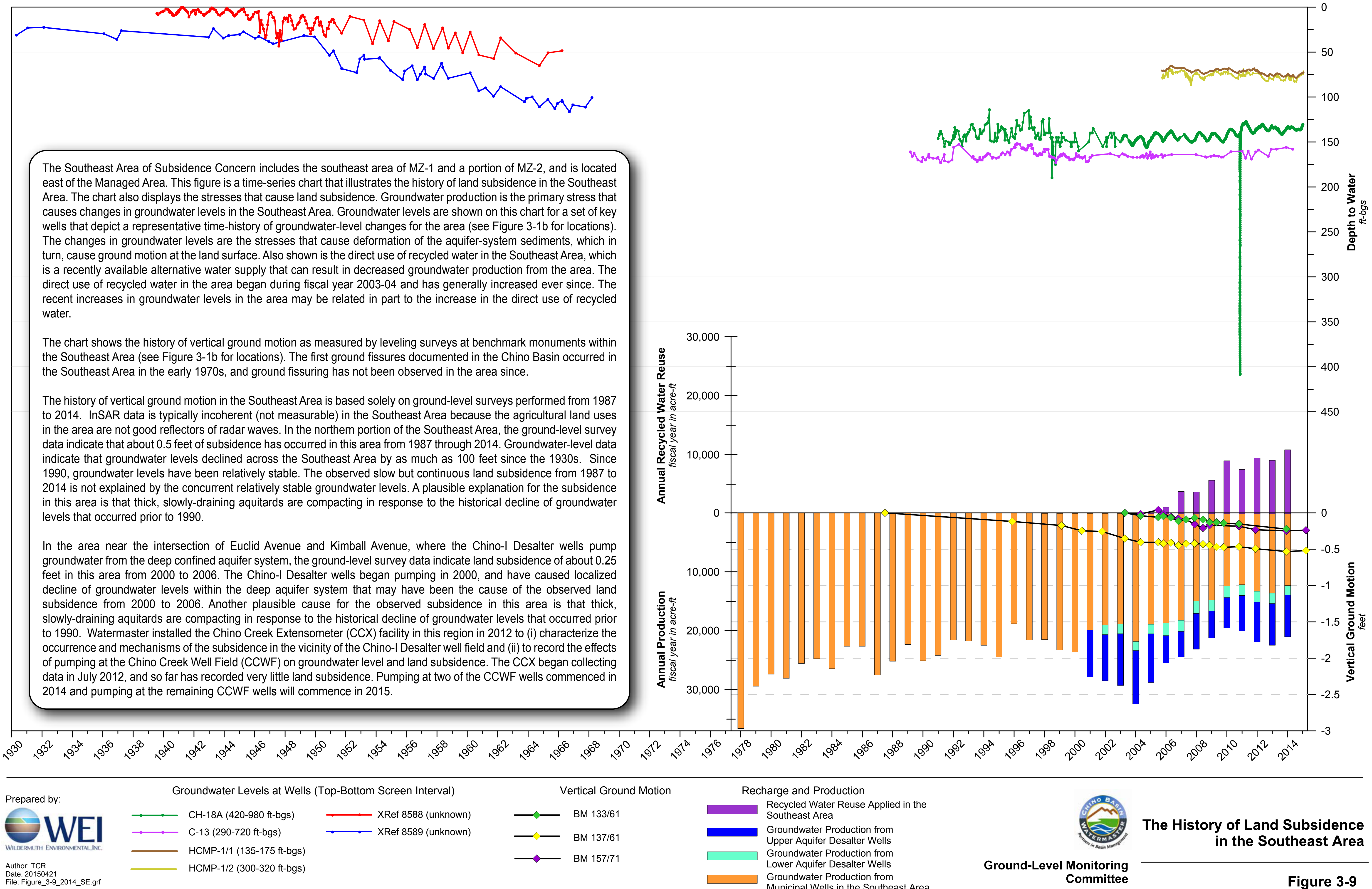
Figure 3-8

The Southeast Area of Subsidence Concern includes the southeast area of MZ-1 and a portion of MZ-2, and is located east of the Managed Area. 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 (see Figure 3-1b for locations). 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 2003-04 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 3-1b for 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 2014. 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 subsidence has occurred in this area from 1987 through 2014. Groundwater-level data indicate that groundwater levels declined across the Southeast Area by as much as 100 feet since the 1930s. Since 1990, groundwater levels have been relatively stable. The observed slow but continuous land subsidence from 1987 to 2014 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 decline of groundwater levels 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 2000 to 2006. The Chino-I Desalter wells began pumping in 2000, and have caused localized decline of groundwater levels within the deep aquifer system that may have been the cause of the observed land subsidence from 2000 to 2006. Another plausible cause for the observed subsidence in this area is that thick, slowly-draining aquitards are compacting in response to the historical decline of groundwater levels that occurred prior to 1990. Watermaster installed the Chino Creek Extensometer (CCX) 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 level and land subsidence. The CCX began collecting data in July 2012, and so far has recorded very little land subsidence. Pumping at two of the CCWF wells commenced in 2014 and pumping at the remaining CCWF wells will commence in 2015.



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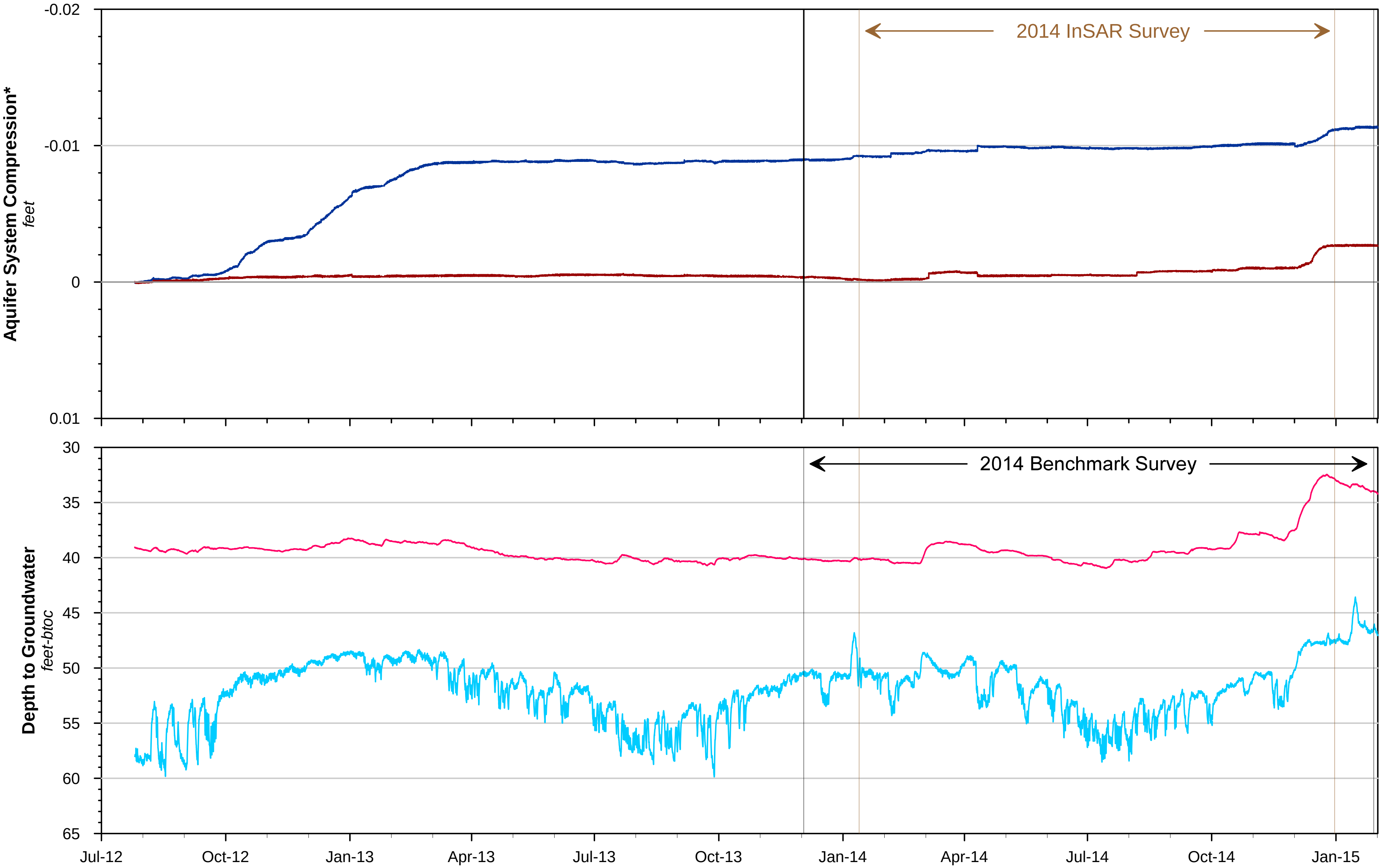
Ground-Level Monitoring Committee
2014 Annual Report

The History of Land Subsidence in the Southeast Area

Figure 3-9



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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Date: 20150421
Filename: Figure_3-10_CCX_S-S.grf

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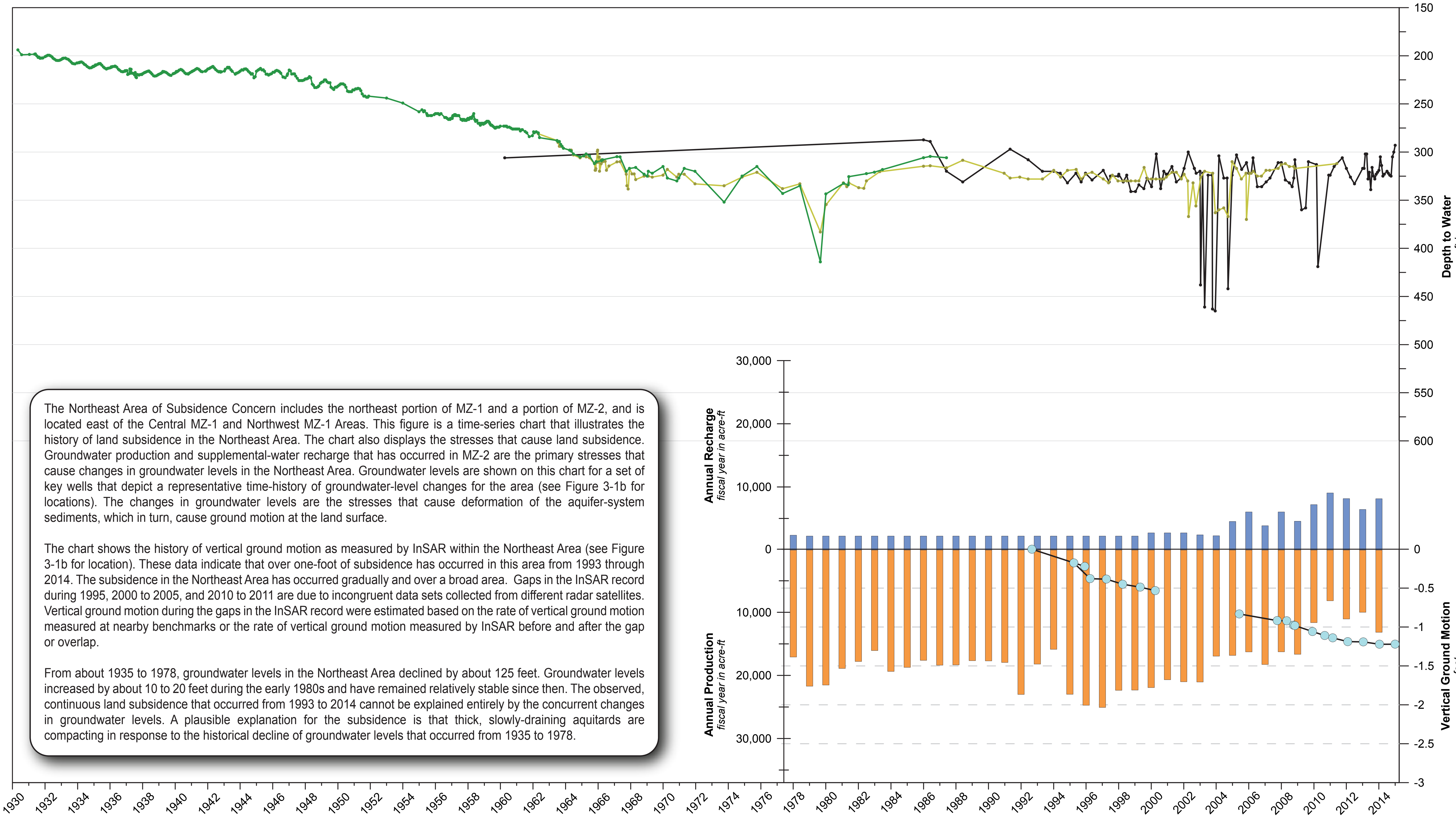
Stress and Strain
Chino Creek Extensometer

Figure 3-10

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



The Northeast Area of Subsidence Concern includes the northeast portion of MZ-1 and a portion of MZ-2, and is located east of the Central MZ-1 and Northwest MZ-1 Areas. This figure is a time-series chart that illustrates the history of land subsidence in the Northeast 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 Northeast 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 (see Figure 3-1b for locations). 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 Northeast Area (see Figure 3-1b for location). These data indicate that over one-foot of subsidence has occurred in this area from 1993 through 2014. The subsidence in the Northeast Area has occurred gradually and over a broad area. Gaps in the InSAR record during 1995, 2000 to 2005, and 2010 to 2011 are due to incongruent data sets collected from different radar satellites. Vertical ground motion during the gaps in the InSAR record were estimated based on the rate of vertical ground motion measured at nearby benchmarks or the rate of vertical ground motion measured by InSAR before and after the gap or overlap.

From about 1935 to 1978, groundwater levels in the Northeast 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 from 1993 to 2014 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 decline of groundwater levels that occurred from 1935 to 1978.

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Ground-Level Monitoring Committee
2014 Annual Report

The History of Land Subsidence in the Northeast Area

Figure 3-11

Section 4 – Conclusions and Recommendations

4.1 Conclusions

The following main conclusions of this annual report are based on the data collected and analyzed for the Ground-Level Monitoring Program through 2014:

- Groundwater-level decline at PA-7 has not exceeded the Guidance Level since 2004, and vertical ground motion in the Managed Area has been primarily elastic, which suggests that the Guidance Criteria have been protective. However, recent data also indicate that a small and gradual amount of non-recoverable compaction has been occurring in the aquifer-system, even though groundwater levels have not declined below the Guidance Level since 2004. The threat of future ground fissuring caused by this compaction is not well characterized. The Long-Term Pumping Test and the associated monitoring will provide additional information on the mechanisms that are causing the compaction in this area and the threat of future ground fissuring, and may result in a revision to the Guidance Level.

- During 2014, differential land subsidence continued to occur in the Northwest MZ-1 Area across the San Jose Fault, which is the type of deformation of the land surface that can lead to ground fissuring. At least 4.2 feet of differential subsidence may have occurred in this area since the onset of increased groundwater-level decline in the 1940s. Future surveys at benchmarks across the San Jose Fault will better characterize the threat of ground fissuring in this area. During 2014, the GLMC began preparation of a hydrogeologic conceptual model in the area to better characterize the aquifer system and the stresses that could be contributing to the observed land subsidence. The GLMC prepared a *Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area* which includes investigations into the cause(s) of the observed land subsidence and the development and evaluation of subsidence-management alternatives to minimize or abate future subsidence.

- Since July 2012, the CCX has recorded very little fluctuation of groundwater levels or vertical deformation of the aquifer system. In 2014, a small increase in water levels resulted in a small but measurable amount of aquifer-system expansion in the shallow aquifer system. This pattern is consistent with the conceptual model of decline of groundwater levels in the area causing vertical compression of the sediments of the aquifer-system (and visa versa). Pumping at the Chino Creek Well Field began in the second quarter of 2014 and continued through the end of 2014. The CCX did not record any decline of groundwater levels associated with pumping from the Chino Creek Well Field. 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 2015-16

The scope-of-work for the Ground-Level Monitoring Program for fiscal year 2015-16 is a recommendation of the GLMC, and is shown in Table 4-1 as a work breakdown structure with cost estimates:

- *Task 1—Setup and Maintenance of Monitoring Network*. The extensometers are sophisticated and key monitoring facilities for the Ground-Level Monitoring Program. They require regular and as-needed maintenance and recalibration to remain in good working order. Specifically for 2015-16, the CCX is experiencing friction between the extensometers cable and the piezometer casing that needs to be minimized. Testing will be conducted to determine the proper modifications, which may include adjustment to the counter weight and/or pulley system. If warranted by the testing, these modifications will be made during the fiscal year.

- *Task 2—Aquifer-System Monitoring and Testing.*

    - *Groundwater-level and extensometer data collection and processing.* Conduct 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.

    - *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.* The MZ-1 Plan calls for the Long-Term Pumping Test and the pilot injection test in the Managed Area. Pumping in the Managed Area began in March 2015 and is expected to continue through summer and fall 2015. Figure 4-2 shows piezometric levels at PA-7 recorded through early 2015 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 assisted the City of Chino Hills in preparation for its injection test at Well CH-16 through cost-share funding for a feasibility study for conversion of Well CH-16 to an aquifer storage and recovery (ASR) well, modification to Well CH-16, and administration of a Local Groundwater Assistance (LGA) grant from the DWR. The LGA grant was completed on February 28, 2015 and the cost-share funding was exhausted in March 2015.

- *Task 3—Basin Wide Ground-Level Monitoring Program: Collect and analyze InSAR data during 2015*. 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 ground motion across the western portion of Chino Basin. Correlation between InSAR and ground-level survey data (Task 4) will be evaluated in order to validate the reliability of the InSAR data and select a long-term approach to measure non-recoverable compaction.

- *Task 4—Ground-Level Surveys.*

    - *Conduct elevation and EDM surveys at benchmark monuments in the Managed Area to coincide with maximum decline 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 in the Northwest MZ-1 Area.* The elevation survey will begin at Ayala Park and include benchmarks along Monte Vista Avenue and San Bernardino Street to the San Jose Fault Array. Figure 4-1 shows the locations of the benchmark monuments in the San Jose Fault Array. The elevation survey data will be referenced to the Ayala Park datum. 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.

- *Conduct an elevation survey at benchmark monuments in the Southeast Area during the fall of 2015.* Three new Chino Creek desalter wells began producing groundwater during 2014. Additional Chino Creek desalter wells are expected to begin production in 2015. The monitoring and mitigation plan in the Peace II SEIR calls for subsidence monitoring in the vicinity of the Chino Creek Well Field.

- *Task 5—Data Analysis and Reporting.* During the first quarter of 2016, Watermaster staff and the Watermaster engineer will analyze the data generated by the Ground-Level Monitoring Program through 2015. The results and interpretations generated from the analysis will be documented in the *2015 Annual Report of the Ground-Level Monitoring Committee.*

- *Task 6—Implementation of the Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area.* Watermaster, consistent with the recommendation of the GLMC, has determined that the MZ-1 Plan needs to be updated to include a Subsidence Management Plan for the Northwest MZ-1 Area with the long-term objective to minimize or abate the occurrence of subsidence in this area. The development of the Subsidence Management Plan for the Northwest MZ-1 Area is a multi-year effort. The conceptual framework for this effort is described in the work plan.

- *Task 7—Meetings and Administration.* Three meetings of the GLMC will be held to oversee the Ground-Level Monitoring Program: the first will be held in fall 2015 to implement the Ground-Level Monitoring Program; the second will be held in March 2016 to review data collected from the monitoring program through 2015 and recommend a scope of work for fiscal year 2016-17; the third will be held in May 2016 to review the 2015 Annual Report of the Ground-Level Monitoring Committee. On-going management of project staffing and financial reporting will be conducted. A scope and budget will be prepared for fiscal year 2016-17 in the first quarter 2016 based on review data collected from the monitoring program through 2015.

4.3 Changes to the MZ-1 Plan

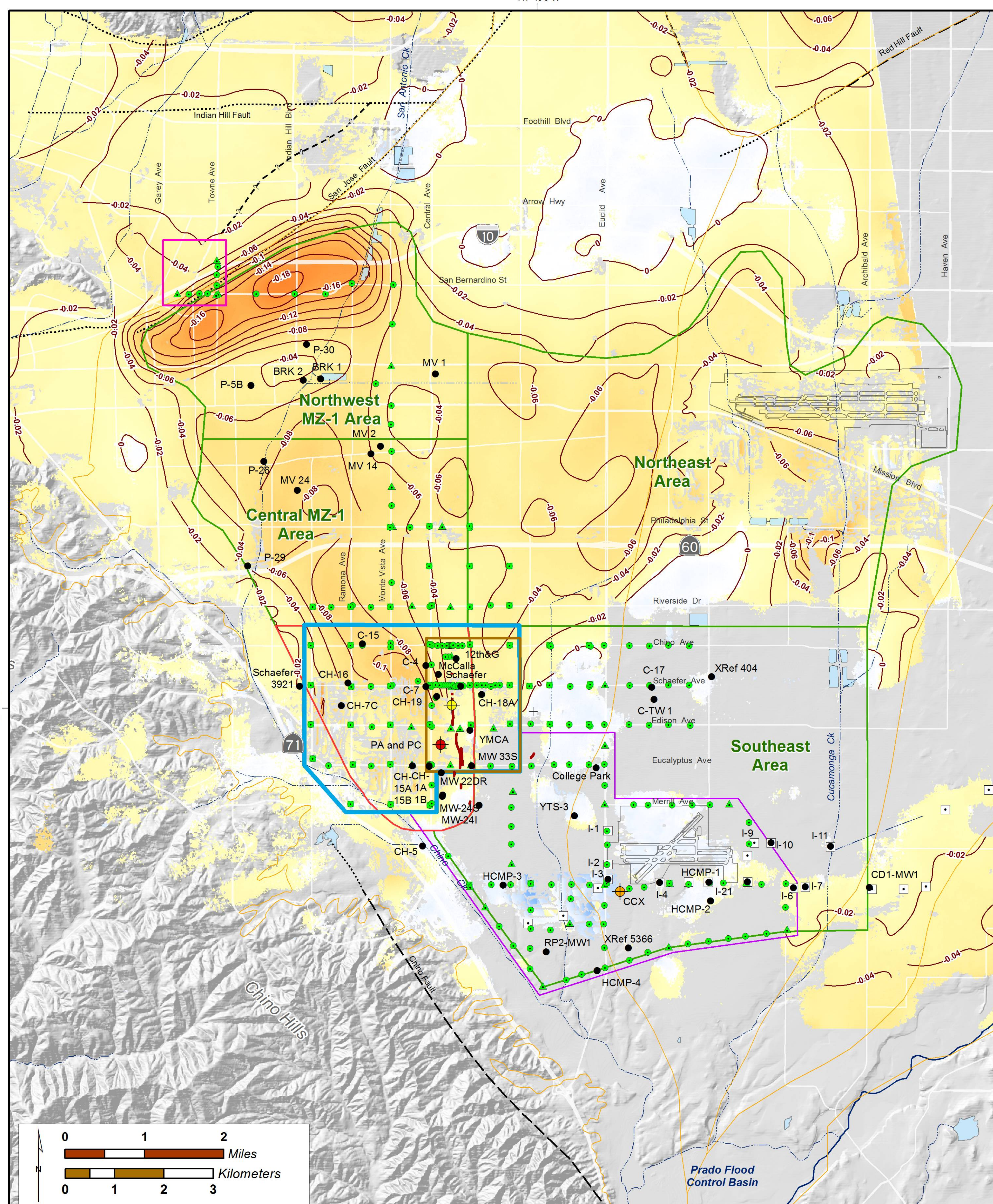
The MZ-1 Plan states that if data from existing monitoring efforts in the so-called Areas of Subsidence Concern indicate the potential for adverse impacts due to subsidence, Watermaster will revise the MZ-1 Plan pursuant to the process outlined in Section 3 of the MZ-1 Plan.

In 2014, the Watermaster, consistent with the recommendation of the GLMC, determined that the MZ-1 Plan needs to be updated to include a Subsidence Management Plan for the Northwest MZ-1 Area with the long-term objective to minimize or abate the occurrence of the differential land subsidence. Watermaster's Engineer developed a draft work plan to develop the *Subsidence Management Plan for the Northwest MZ-1 Area*, which includes a description of a multi-year effort with cost estimates and a schedule. Upon recommendation by the GLMC and approval by the Watermaster, the work plan will be attached to the MZ-1 Plan as an appendix, and characterized as an ongoing effort of the Watermaster.

The update to the MZ-1 Plan will include additional changes other than those related to the Northwest MZ-1 Area. The content of the current MZ-1 Plan is outdated and is not an accurate reflection of Watermaster's current and future efforts with regard to the monitoring and management of land subsidence in Chino Basin. A general update of the entire plan is needed to better describe Watermaster's efforts and obligations with regard to land subsidence, which now include areas outside of MZ-1. As such, the update of the plan will include a name change to the "Subsidence Management Plan for the Chino Basin."

Table 4-1
Work Breakdown Structure and Cost Estimates
Ground-Level Monitoring Program -- FY2015-16

Task Description	Labor		Other Direct Costs						Totals				
	Person Days	Total	Travel	Equip and Expend	Subs	Repro	Misc.	Total	Recommended Budget *2015-16*	Budget *2014-15*	Net Change *2014-15 to 2015-16*	Potential Carry-Over *2014-15*	Budget with Carry-Over *2015-16*
									a	*b*	*a - b*	*c*	*a - c*
Task 1 -- Setup/Maintenance of Monitoring Network		**$16,780**						**$29,811**	**$46,591**	**$109,151**	**-$62,560**	**$0**	**$46,591**
1.1 Equipment maintenance													
Routine maintenance of Ayala Park/CCWF/DHX extensometer facilities	11	$8,520	$256	$259				$515	$9,035	$9,992	-$957		$9,035
Maintenance at horizontal extensometer site	3	$2,620	$32		$23,600			$23,632	$26,252	$55,502	-$29,250		$26,252
Replacement/repair of equipment at extensometer facilities	5	$5,640	$68	$2,000	$2,000			$4,068	$9,708	$40,347	-$30,639		$9,708
1.2 Annual lease fees for CCWF extensometer site	0						$1,596	$1,596	$1,596	$1,596	$0		$1,596
1.3 Maintenance of PB facility													
Remove in situ equipment from the wells										$1,714	-$1,714		
Task 2 -- MZ-1: Aquifer-System Monitoring and Testing		**$30,240**						**$812**	**$31,052**	**$200,421**	**-$169,369**	**$9,813**	**$21,240**
2.1 Groundwater-level and extensometer data collection and processing													
Download data from the Ayala Park facility	2.5	$1,960	$128	$76				$204	$2,164	$2,136	$29		$2,164
Download data from the Daniels Horizontal Extensometer facility	2.5	$1,960	$128	$76				$204	$2,164	$1,100	$1,064		$2,164
Download data from the CCWF facility	2.5	$1,960	$128	$76				$204	$2,164	$2,136	$29		$2,164
Process, check, and upload data to database	10.5	$12,660						$0	$12,660	$12,660	$0		$12,660
2.2 Conduct Long-Term Pumping Test in the Managed Area													
Coordinate testing with pumpers	1	$1,320						$0	$1,320	$1,320	$0	$1,320	$0
Collect production data; process, check, and upload to database	2.3	$2,330						$0	$2,330	$2,823	-$493	$2,823	-$493
Prepare, analyze, and distribute stress-strain diagrams to GLMC	4	$6,080				$200		$200	$6,280	$3,700	$2,580	$3,700	$2,580
Adjust extensometer hardware	1	$1,970						$0	$1,970	$1,970	$0	$1,970	$0
2.3 Conduct Injection Test in Managed Area													
Well rehabilitation and retrofit										$142,950	-$142,950		
Quarterly reports - LGA Grant										$11,880	-$11,880		
Project administration - LGA Grant										$5,868	-$5,868		
Prepare final report for LGA Grant										$11,880	-$11,880		
Task 3 -- Basin Wide: InSAR		**$2,830**						**$85,000**	**$87,830**	**$92,830**	**-$5,000**	**$0**	**$87,830**
3.1 InSAR data collection	1	$1,320			$85,000			$85,000	$86,320	$91,320	-$5,000		$86,320
3.2 Process, check, and upload data to database/GIS	1.25	$1,510						$0	$1,510	$1,510	$0		$1,510
Task 4 -- Ground-Level Surveys		**$5,730**						**$168,980**	**$136,335**	**$123,955**	**$12,380**	**$34,770**	**$101,565**
4.1 Conduct Fall 2015 ground-level survey in Central MZ-1 Area	0.25	$330			$19,855			$19,855		$0	$0		
4.2 Conduct Fall 2015 ground-level survey in Southeast Area (CCWF)	0.25	$330			$26,315			$26,315	$26,645	$26,645	$0		$26,645
4.3 Conduct Fall 2015 ground-level and EDM survey in Northwest MZ-1 Area (Ayala Park start)	0.25	$330			$23,750			$23,750	$24,080	$0	$24,080		$24,080
4.4 Conduct Fall 2015 ground-level and EDM survey at the San Jose Fault Zone	0.25	$330			$17,860			$17,860		$18,190	-$18,190		
4.5 Conduct ground-level and EDM survey in Managed Area at maximum groundwater-level decline	0.25	$330			$36,600			$36,600	$36,930	$35,100	$1,830	$34,770	$2,160
4.6 Conduct ground-level and EDM survey in Managed Area at maximum groundwater-level recovery	0.25	$330			$36,600			$36,600	$36,930	$37,260	-$330		$36,930
4.7 Replace destroyed benchmarks	0	$0			$8,000			$8,000	$8,000	$5,000	$3,000		$8,000
4.8 Process, check, and upload data to database	3.25	$3,750						$0	$3,750	$1,760	$1,990		$3,750
Task 5 -- Data Analysis and Reports		**$52,180**						**$20,000**	**$72,180**	**$68,720**	**$3,460**	**$0**	**$72,180**
5.1 Analysis of Data from the Areas of Subsidence Concern													
Production/recharge/piezometric/extensometer	6	$7,360			$20,000			$20,000	$27,360	$27,360	$0		$27,360
EDM and ground-level survey data	5	$5,180						$0	$5,180	$5,180	$0		$5,180
InSAR data	1	$1,160						$0	$1,160	$1,160	$0		$1,160
Tectonic data	0.5	$500						$0	$500	$500	$0		$500
Recycled water reuse data	3.5	$3,660						$0	$3,660	$3,660	$0		$3,660
5.2 Prepare 2015 Annual Report of the Ground-Level Monitoring Committee													
Prepare draft annual report	23	$27,520						$0	$27,520	$23,760	$3,760		$27,520
Prepare final annual report	5.5	$6,800						$0	$6,800	$7,100	-$300		$6,800
Task 6 -- Work Plan to Develop a Subsidence-Management Plan for the Northwest MZ-1 Area		**$441,053**						**$65,202**	**$506,255**	**$0**	**$506,255**	**$0**	**$506,255**
6.1 Describe Initial Hydrogeologic Conceptual Model & the Monitoring and Testing Program	54.375	$77,713	$62			$50		$112	$77,825	$0	$77,825		$77,825
6.2 Implement the Initial Monitoring Program	127.75	$147,390	$1,368	$32,950	$10,000	$200		$44,518	$191,908	$0	$191,908		$191,908
6.3 Develop and Evaluate the Baseline Management Alternative	40.25	$52,920	$62		$15,000	$50		$15,112	$68,032	$0	$68,032		$68,032
6.4 Develop and Evaluate the Initial Subsidence-Management Alternative	79	$124,010	$186			$150		$336	$124,346	$0	$124,346		$124,346
6.5 Design and Install the Pomona Extensometer Facility													
6.5.1 Identify alternative sites for the Pomona Extensometer facility (PX)	16.75	$22,440	$62		$5,000			$5,062	$27,502	$0	$27,502		$27,502
6.6 Meetings and Administration (Annual)	11	$16,580	$62					$62	$16,642	$0	$16,642		$16,642
Task 7 -- Meetings and Administration		**$32,300**						**$187**	**$32,487**	**$28,077**	**$4,410**	**$0**	**$32,487**
7.1 Prepare for and attend Ground-Level Monitoring Committee meetings	9	$13,080	$141					$141	$13,221	$8,811	$4,410		$13,221
7.2 Ad hoc meetings	3	$4,360	$46					$46	$4,406	$4,406	$0		$4,406
7.3 Project Administration and Financial Reporting	7.5	$10,500						$0	$10,500	$10,500	$0		$10,500
7.4 Scope and Budget for FY2016/17	3	$4,360						$0	$4,360	$4,360	$0		$4,360
Totals									**$912,730**	**$623,154**	**$289,576**	**$44,583**	**$868,148**



Survey Benchmarks

- Class A Monuments
- Class B Monuments

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 Mar. 2011 to Decmeber 2014 (feet)

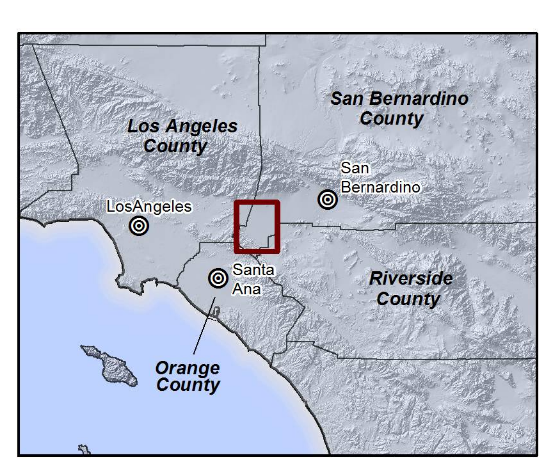
+ 0.25 / 0 / -0.1 / - 0.25

InSAR data absent (incoherent)

Wells and Extensometers

- Desalter Well
- Ayala Park Extensometer
- Chino Creek Extensometer
- Daniels Horizontal Extensometer
- Well Monitored by Pressure Transducer during 2014

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



Prepared by:

WEI WILDERMUTH ENVIRONMENTAL, INC.

Author: TCR

Date: 20150325

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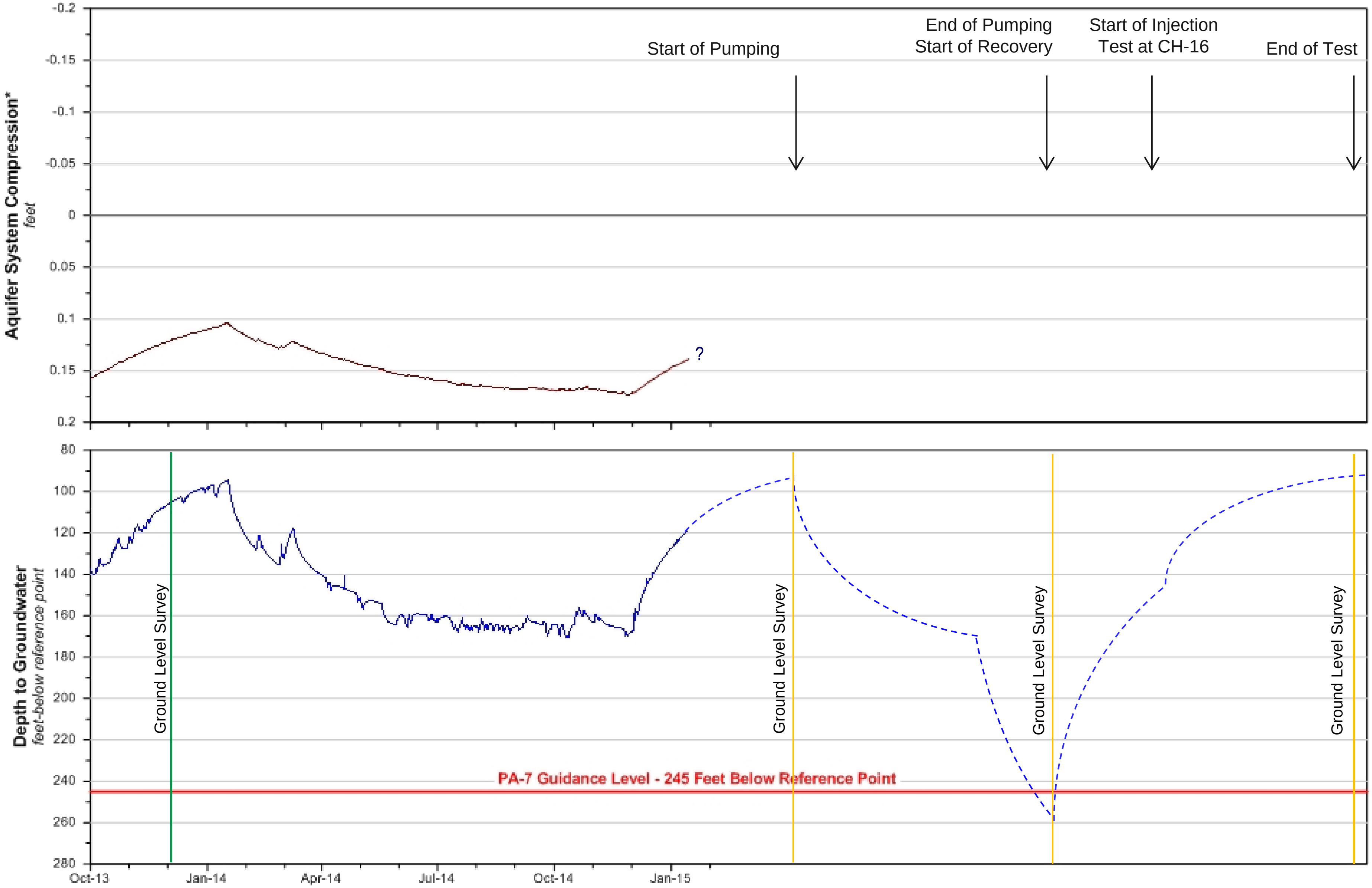
Ground-Level Monitoring Committee

2014 Annual Report

Ground-Level Monitoring

Fiscal Year 2015-16

Figure 4-1



Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: TCR
Date: 20150125
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

Existing Ground-Level Survey

Planned Ground-Level Survey

Ground-Level Monitoring Committee
2014 Annual Report

Long-Term Pumping Test
Managed Area

Figure 4-2

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

The following glossary of terms and definitions are utilized within this report and generally in the discussions at meetings of the Ground-Level Monitoring 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 of the aquifer system reflects the rearrangement of the mineral grain pore structure and largely non-recoverable reduction of the porosity under stresses greater than the 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. For purposes of this report, the term "compaction" is used in preference to consolidation when referring to subsidence due to groundwater extraction.

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

Deformation, Elastic – A fully reversible deformation of a material. In this report, the term "elastic" typically refers 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 – Permanent or non-recoverable sinking or settlement of the land surface, due to any of several processes.

Transducer, Pressure – An electronic device that can measure 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.

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

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

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

Appendix A

Monitoring Data through December 2014

Appendix B

Comments and Responses

Appendix B
Comments and Responses
on the Draft 2014 Annual Report of the Ground-Level Monitoring Committee

B-1 City of Chino Hills, Monte Vista Water district, and City of Pomona

Comment Number	Reference	Comment	Response
1	Page 1-1, Section 1.1	Insert “In general” at the beginning of the first sentence and add “or settlement” in the middle of the first sentence: “Land subsidence is the sinking of the Earth’s surface due to the rearrangement of subsurface Earth materials.”	Modified sentence to read: “In general, land subsidence is the sinking or settlement of the Earth’s surface due to the rearrangement of subsurface Earth materials.”
2	Page 1-1, Section 1.1	At the end of the first paragraph, add: “For purposes of clarification in this document, subsidence refers to non-recoverable compaction due to groundwater withdrawal.”	Added footnote: “For purposes of clarification in this document, subsidence refers to permanent (non-recoverable) sinking of the ground surface. In previous Watermaster land-subsidence reports, subsidence referred to both permanent and elastic (recoverable) sinking of the ground surface.”
3	Page 1-1, Section 1.1.1	Add reference to Geoscience, 2002 in list of references.	Added text: “[…], Geoscience, 2002)” to the last sentence.
4	Page 2-2	In the last sentence of Section 2.2.1, delete: “/winter”.	Replaced “in fall/winter 2015” with “in fall 2015 and winter 2016 “
5	Page 2-3	Add “(non-recoverable)” to the footnote in “[…] about 0.01 feet of permanent “(non-recoverable)” compaction […]”	Text has been changed as requested.

CITY OF CHINO HILLS, Monte Vista Water district, and City of Pomona COMMENTS AND RESPONSES

Comment Number	Reference	Comment	Response
6	Page 2-4	Modify the third paragraph of Section 2.2.3 to read: "[…] A plausible explanation for the subsidence is that thick, slowly-draining aquitards are compacting in response to ~~the~~ historical ~~drawdowns~~ lowering of groundwater levels that occurred from 1935 to 1978. If so, subsidence could have begun when the rate of groundwater-level drawdown lowering increased around 1943. ~~If~~ subsidence has been occurring at a constant rate of 0.06 feet per year since 1943, ~~then~~ the North MZ-1 Area ~~has~~ experiencing~~ed about~~ approximately 4.2 feet of permanent subsidence since the onset of increased ~~drawdown~~water level declines."	Modified paragraph to read: "[…] A plausible explanation for the subsidence is that thick, slowly-draining aquitards are compacting in response to the historical decline of groundwater levels that occurred from 1935 to 1978. If so, subsidence could have begun when the rate of groundwater-level decline increased around 1943. If subsidence has been occurring at a constant rate of 0.06 feet per year since 1943, then the North MZ-1 Area has experienced approximately 4.2 feet of subsidence since the onset of increased groundwater level decline."
7	Page 2-4	In the first sentence of the fourth paragraph, replace: "has" with "that appears to have"	Replaced "has" with "appears to have".
8	Page 2-4	At the end of the first sentence of the last paragraph, add: "(and land subsidence in general)".	Text has been changed to read: […] to minimize or abate the occurrence of the land subsidence.
9	Page 3-4	At the end of the second paragraph of Section 3.4, add: "Historical evidence has shown that ground fissures are present in the southeast area which may reflect non-recoverable compaction. However, more data is necessary to confirm the causes of the fissures."	Added text: "Historically, ground fissuring has been documented in the Southeast Area which may have been caused by compaction of the aquifer system. There is not enough historical data to confirm the causes of the fissuring."

CITY OF CHINO HILLS, Monte Vista Water district, and City of Pomona COMMENTS AND RESPONSES

Comment Number	Reference	Comment	Response
10	Page 3-4	At the end of the first paragraph of Section 3.5, add: "There is still some uncertainty why the InSAR data shows closed contours in the Northwest area of MZ-1 just south of the San Jose Fault as these data do not coincide with areas of greatest water level declines. This is one of the focus points of the LSC."	This comment is not relevant in Section 3.5 - Ontario Area. This comment appears to relate to the Work Plan to Develop a Subsidence Management Plan for the North MZ-1 Area. It is the intent of the Work Plan to better understand the causes of the observed subsidence.
11	Page 3-4	In the footnote, replace: "drawdown" with "water level declines"	Replaced "drawdown" with "groundwater-level declines" in the footnote and throughout the report.
12	Figure 3-2	In the second sentence of the third paragraph of the text-box, replace: "Pumping of the deep aquifer system" with: "One hypothesis is that deep aquifer pumping" […] "however, another hypothesis is that the long-term lowering of ground water levels (particularly in the northern MZ-1 area) may also be responsible, or have contributed to the subsidence observed in the southern area."	Added text after the second sentence of the third paragraph: "Other factors that influence groundwater levels in the deep aquifer system include pumping and recharge stresses in the shallow aquifer system in the Managed Area and in other portions of Chino Basin."
13	Page 4-1	In the beginning of the first bullet-point of Section 4-1, replace: "Drawdown" with "Water level lowering"	Replaced "Drawdown" with "Groundwater-level decline".

Comment Number	Reference	Comment	Response
14	Page 4-1	In the second sentence of the first bullet-point of Section 4-1, replace sentence with: "However, data also indicate that a small amount of non recoverable compaction is occurring gradually, […]"	Compaction is defined as largely non-recoverable and synonymous with "virgin consolidation". Therefore, adjectives used to describe "compaction" were removed throughout the report, and text in the referenced section was changed to: "However, recent data also indicate that a small and gradual amount of compaction has been occurring in the aquifer system, […]"
15	Page 4-1	At the end of the last sentence of the first bullet-point of Section 4-1, add: "which may help establish a "subsidence threshold" elevation."	Added text: "…and may result in a revision to the Guidance Level."
16	Page 4-3	At the end of the last bullet point for Task 4, add: "In conjunction with both the InSAR and land leveling surveys, better correlation will be evaluated in order to validate the reliability of the best long-term approach to measure non-recoverable compaction."	Added text to Page 4-2, at the end of bullet point for Task 3: "Correlation between InSAR and ground-level survey data will be evaluated in order to validate the reliability of the methods and select a long-term approach to measure vertical ground motion."
17	Page 4-4	"Andy: I don't know if this is the right place but I would like to see a 2-D subsidence model (e.g. Helm model) run in both the northern and southern MZ-1 area using the elastic and inelastic parameters from the extensometers. You could use reasonable "book ends" for the pre-consolidation stress and run the model as a first cut estimate of how long the residual subsidence	This comment is addressed in the Work Plan to Develop a Subsidence Management Plan for the North MZ-1 Area.

Comment Number	Reference	Comment	Response
		could occur given the historical decline in water levels. I think this is important and cost effective if you could work this in to your budget for next year."	
18	Page 5-1	Replace the first sentence of the definition for "Compaction" with: "Compaction of sediments in response to increase in applied stress is "elastic" if the applied stress increase is in the stress range less than preconsolidation stress, and is "virgin" if the applied stress increase is in the stress range greater than preconsolidation stress. Elastic compaction (expansion) is fully recoverable. Virgin compaction has an inelastic component that is not recoverable upon decrease in stress and a recoverable elastic component. Permanent subsidence of the land is the result of the non-recoverable portion of the virgin compaction (USGS WSP 2025, Poland, J.F. 1972)"	Comment noted. The first sentence of the definition of Compaction was deleted. The definition included in the report was excerpted from the 1999 USGS Circular 1182 on Land Subsidence. This circular is a more recent document than that suggested. And, its definition represents the use of the term "compaction" as it is used by the Ground-Level Monitoring Committee. In this report, "compaction" is defined as largely non-recoverable and synonymous with "virgin consolidation". Therefore, adjectives used to describe "compaction" were removed throughout the report,
19	Page 5-1	Replace the last sentence of the definition for "Consolidation" with: "For purposes of this report, the geologic term compaction is used in preference to consolidation when referring to subsidence due to groundwater withdrawal"	Modified text to read: "For purposes of this report, the term "compaction" is used in preference to consolidation when referring to subsidence due to groundwater extraction."
20	Page 5-3	In the last sentence of the definition for "Subsidence" replace "to any of the several processes" with: "to non-recoverable compaction such as lowering of	Modified text to read: "Permanent or non-recoverable sinking or settlement of

CITY OF CHINO HILLS, Monte Vista Water district, and City of Pomona COMMENTS AND RESPONSES

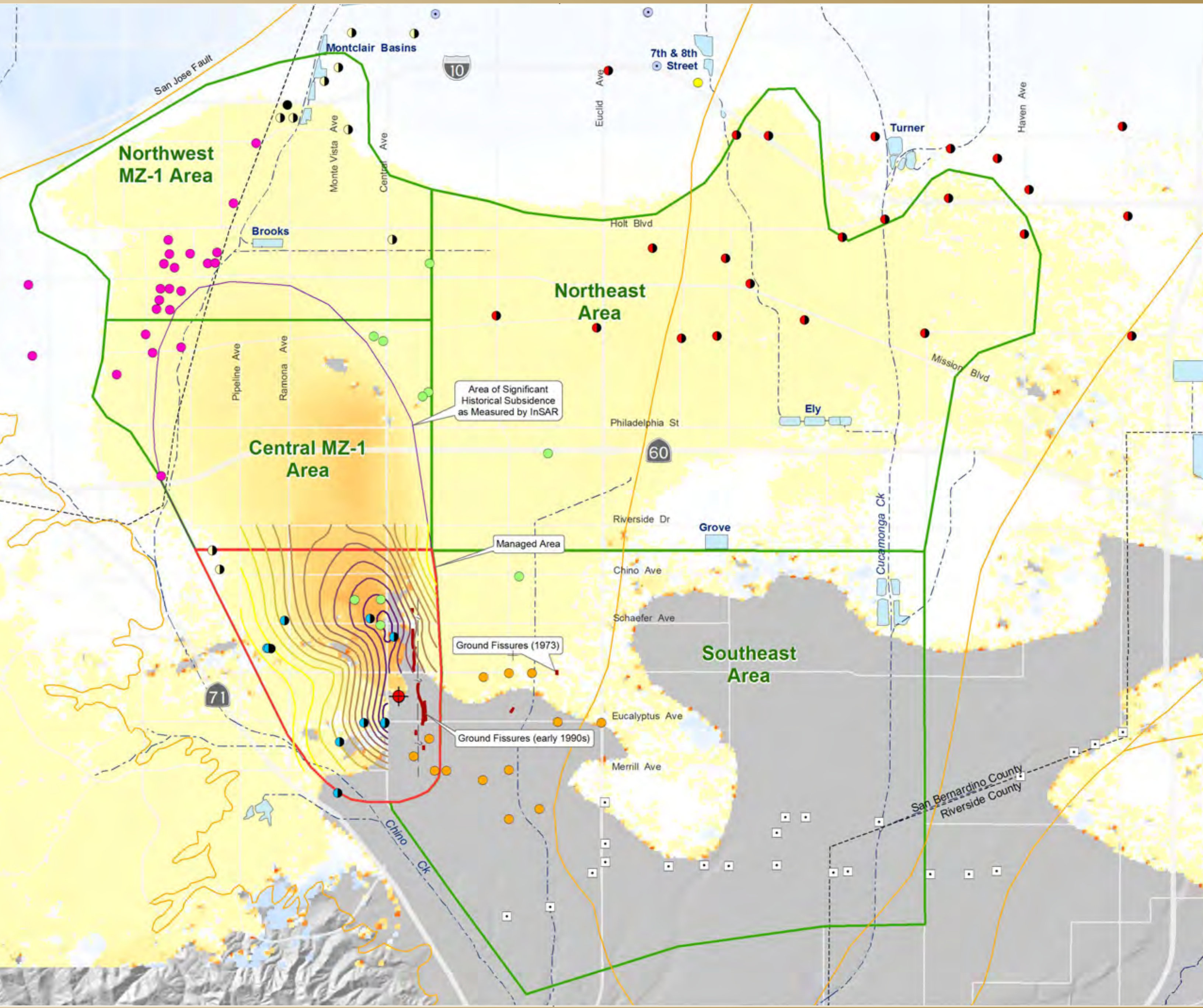
Comment Number	Reference	Comment	Response
		groundwater levels resulting in non-recoverable compaction."	the land surface, due to any of several processes" The use of "subsidence" was modified accordingly throughout.
21	Page 6-1	Add a reference from comment Number 3: "GEOSCIENCE, Support Services, Inc., (2002) Preliminary Geohydrologic Analysis of Subsidence in the Western Portion of the Chino Basin, prepared for the City of Chino Hills, 29-Aug-2002"	Text has been changed as requested.

Appendix B
Comments and Responses
on the Draft 2014 Annual Report of the Ground-Level Monitoring Committee

B-2 City of Chino

Comment Number	Reference	Comment	Response
1	Page 1-2, Items Nos. 2 and 3	Insert "non-recoverable" immediately preceding "compaction" in the instances where "permanent" has been struck.	Text has been changed as requested.
2	Page 1-3, Section 1.1.4	In the third 3rd paragraph. Insert "non-recoverable" immediately preceding "compaction" in the instances where "permanent" has been struck.	Text has been changed as requested.
3	Page 1-4, Section 1.2	Section 1 description. Add that the GLMC was "previously known as the Land Subsidence Committee."	Added text consistent with the text in the Work Plan: "…formerly the Land Subsidence Committee"
4	Page 2-2 Section 2.2.2 and Page 2-3, footnote 3	Bullet No. 3, suggest replacing "sinking and rebound of the ground surface" with "lowering." The term "sinking" is used to define "subsidence" and is used to describe subsidence in other parts of the report.	Replaced "sinking (elastic and inelastic) and rebound of the ground surface" with "elastic and non-recoverable vertical ground motion"
5	Page 2-3	1st Item No. 4. Insert "preventing non-recoverable" immediately preceding "compaction" in the instance where "permanent" has been struck.	Text has been changed as requested.
6	Page 2-4	At the end of Bullet No. 5, insert "horizontal and vertical" before "ground deformation" so it reads, "non-recoverable horizontal and vertical ground deformation…"	Text has been changed as requested.
7	Figure 3-2	Inset text, last sentence. Substitute "Ground Level Monitoring committee" for LSC.	Text has been changed as requested.

WILDERMUTH ENVIRONMENTAL, INC.



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