Chino Basin
Subsidence Management Plan

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F I N A L

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1.1 Historical Land Subsidence and Ground Fissuring

One of the earliest indications of land subsidence in the Chino Basin was the appearance of ground fissures in the City of Chino. While fissures appeared as early as 1973, an accelerated occurrence of ground fissuring ensued after 1991, resulting in damage to existing infrastructure. Figure 1-1 shows fissure locations within Chino Basin Management Zone 1 (MZ-1). The scientific studies that followed attributed the fissuring phenomenon to differential land subsidence caused by pumping of the underlying aquifer system and the consequent drainage and compaction of aquitard sediments (see Appendix A for a thorough discussion).

1.2 Chino Basin Judgment, OBMP, and Peace Agreements

A 1978 Judgment entered in the Superior Court of the State of California for the County of San Bernardino (Chino Basin Municipal Water District *v.* City of Chino et al.) established pumping and storage rights in the Chino Basin. The Judgment established the Chino Basin Watermaster (Watermaster) to oversee the implementation of the Judgment and provided Watermaster with the discretionary authority to develop an optimum basin management program (OBMP) to maximize the beneficial use of the Basin.

The OBMP Phase I Report was developed by Watermaster and the Parties to the Judgment in the late 1990s (WEI, 1999); it identified pumping-induced groundwater-level decline and subsequent aquifer-system compaction as the most likely cause of the land subsidence and ground fissuring observed in MZ-1. Program Element 4 of the OBMP – *Develop and Implement a Comprehensive Groundwater Management Plan for Management Zone 1* called for the development and implementation of an interim management plan for MZ-1 that would:

- Minimize subsidence and fissuring in the short-term.
- Collect information necessary to understand the extent, rate, and mechanisms of subsidence and fissuring.
- Formulate a management plan to reduce to tolerable levels or abate future subsidence and fissuring.

In 2000, the Chino Basin parties executed the so-called Peace Agreement (Watermaster, 2000), which memorialized the Parties' intent to implement the OBMP. The Peace Agreement included an OBMP Implementation Plan (Watermaster, 2007) that outlined the time frames for implementing tasks and projects in accordance with the Peace Agreement and the OBMP. The OBMP Implementation Plan is a comprehensive, long-range water-management plan for the Chino Basin that, in part, 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).

1.3 MZ-1 Interim Monitoring Program

From 2001-2005, Watermaster developed, coordinated, and conducted the IMP under the guidance of the MZ-1 Technical Committee, which was composed of representatives from all major MZ-1 producers and their technical consultants. Specifically, the producers represented on the MZ-1 Technical Committee included: the Agricultural Pool; the Cities of Chino, Chino Hills, Ontario, Pomona, and Upland; the Monte Vista Water District; the Golden State Water Company; and the State of California, California Institution for Men (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.[1]

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, the "Riley Barrier," was identified. The Riley Barrier is located within the deep aquifer system and aligned with the historical zone of ground fissuring. Pumping from the deep aquifer system was limited to the area west of the barrier; the resulting groundwater-level decline did not propagate eastward across the barrier. Based on this observation, it was evident that compaction had occurred within the deep system on the west side of the barrier but not on the east side, causing concentrated differential subsidence across the barrier and creating the potential for ground fissuring.

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

5. InSAR and ground-level survey data indicated that subsidence had occurred in the central region of MZ-1 in the past and was continuing to occur. The InSAR data also suggested that the groundwater barrier extends northward into central MZ-1. These observations suggested that the conditions that very likely caused ground fissuring near Ayala Park in the 1990s are also present in central MZ-1 and should be studied in more detail.

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 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).

1.4 Initial MZ-1 Subsidence Management Plan

The Guidance Criteria formed the basis for the MZ-1 Plan, which was developed by the MZ-1 Technical Committee and approved by Watermaster 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 lists the Managed Wells that are subject to the plan; these wells are listed in Table 1-1. The MZ-1 Plan also includes a map of the Managed Area in southern MZ-1 that is subject to the plan. Figure 1-2 is the map that shows the Managed Area and Managed Wells.

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 was 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 was 245 feet below the top of the well casing (ft-btoc) in PA-7. The MZ-1 Plan recommended that the Parties manage their groundwater production such that the water level in PA-7 remains above the Guidance Level.

The initial MZ-1 Plan called 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 Areas of Subsidence Concern: Central MZ-1, Northwest MZ-1, the Northeast Area, and the Southeast Area. The expanded monitoring efforts outside of the Managed Area are consistent with the requirements of Program Element 1 of the OBMP – *Develop and Implement Comprehensive Monitoring Program*.

The initial MZ-1 Plan contemplated the following programs to refine the Guidance Criteria and develop alternative groundwater management plans that would minimize or abate land subsidence.

- *An injection feasibility study at a production well within the Managed Area.* This test would 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 proposed project would construct improvements to an existing well to allow the injection of water from the City of Chino Hills distribution system into the aquifer during off peak demand periods and the recovery of stored water through the same well for municipal use during peak periods.
- *Further evaluation of the potential contribution of pumping in the central and northern portions of MZ-1 on groundwater conditions in the central and southern portions of MZ-1.* Watermaster, in consultation with the MZ-1 Technical Committee, will specifically design an investigation to address whether production in the northern and central areas have a material impact on subsidence. This investigation may include additional testing, monitoring, constructing new monitoring facilities (e.g. extensometers and piezometers), and developing and using a three-dimensional, computer-simulation model of groundwater flow and subsidence.
- *Additional testing and monitoring to refine Guidance Criteria.* Watermaster, in consultation with the MZ-1 Technical Committee, will assist the Parties in designing pumping plans within the Managed Area for the purpose of further refining the Guidance Criteria and improving the prudent extraction of groundwater. Computer-simulation models of groundwater flow and subsidence will assist in the development of these pumping plans. Watermaster has recently developed an analytical drawdown model of the deep aquifer system within the Managed Area and a numerical, one-dimensional compaction model at Ayala Park. Watermaster also recently updated its regional MODFLOW model of Chino Basin. And, the City of Chino Hills recently developed a MODFLOW model of MZ-1. These models are useful tools for developing and refining the pumping plans.
- *Development of alternative pumping plans.* Watermaster, in consultation with the MZ-1 Technical Committee, will cooperate with the City of Chino Hills to evaluate the best available options for the City to produce a reasonable quantity of groundwater from MZ-1, taking into account any new information derived from the bulleted activities described above, the City's relative share of Operating Safe Yield, its historical investments in water supply development, its water supply requirements, and the physical limitations within MZ-1. The pumping plans will not be designed such that they purposefully cause groundwater levels to decline below the Guidance Level.

A key element of the MZ-1 Plan is its *adaptive* nature. As new data are collected, they are analyzed to evaluate the on-going effectiveness of the plan. The initial MZ-1 Plan called for ongoing monitoring, data analysis, annual reporting, and adjustment to the MZ-1 Plan as warranted by the data. Adjustments to the plan are proposed by the MZ-1 Technical Committee and must be approved through the Watermaster process.

1.5 Ground-Level Monitoring Program (2008-2014)

Implementation of the MZ-1 Plan began in 2008. The following are the major activities and accomplishments of the program from 2008 through 2014:

- *Cable extensometer at Ayala Park*. A cable extensometer facility was installed in 2008 at Ayala Park. The facility consists of dual-nested piezometers completed to 727 and 1,120 feet-bgs with a cable extensometer installed within each piezometer. The purposes of the cable extensometers were to test the cable-extensometer technology and to measure vertical deformation of the aquifer system at depths between the depths of the shallow and deep pipe extensometers installed during the IMP.

- *Formation of the Land Subsidence Committee*. The MZ-1 Technical Committee was renamed the Land Subsidence Committee (LSC) in 2010 and was opened to include all Watermaster Parties. The LSC was renamed the Ground-Level Monitoring Committee (GLMC) in 2015.

- *Injection feasibility study*. The City of Chino Hills is conducting an injection feasibility study at a production well within the Managed Area. The study will help determine if aquifer injection is a viable tool to manage subsidence within the Managed Area while maximizing the use of existing infrastructure (i.e. wells). The study includes the conversion 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 assisted the City of Chino Hills in applying for and acquiring a Local Groundwater Assistance (LGA) grant from the DWR to partly fund the study. Watermaster also assisted with a cost-share contribution of $368,000 to execute the study. As of the end of 2014, Chino Hills has completed modifications to well CH-16 making it an ASR well, and will complete connections to an injection water supply in 2015. The cost-share funds were fully disbursed during fiscal year 2014-15.

- *Horizontal extensometer at Daniels site*. The Daniels Horizontal Extensometer (DHX) was constructed in October 2011 at 5500 Daniels Way in Chino to measure the horizontal strain across the historical fissure zone. The extensometer consists of nine quartz-tube extensometers that measure horizontal strain. The facility began collecting data in October 2011.

- *Pumping Test at CH-18A*. A three-day pumping test was performed in November 2011 at Chino Hills well CH-18 to verify the depth and extent of the Riley Barrier as a barrier to groundwater flow in the deep aquifer, to test the effects of pumping on groundwater levels and land subsidence on the east side of the Riley Barrier, and to test the feasibility of using CH-18A as a potable water-supply well with regard to water quality and production. The test showed that drawdown from pumping at CH-18A did not propagate west of the Riley Barrier in the shallow or deep aquifers and did not affect groundwater levels at deep or shallow wells east of the Riley Barrier that were about 1.5 to 2 miles away.

- *Expanded monitoring efforts in the Southeast Area*:
  - The benchmark network was expanded throughout the Southeast Area in 2011. Figure 1-3 shows the locations of these benchmarks. The purpose of the Southeast Area benchmark array is to measure vertical ground motion associated with pumping at the Chino Creek Well Field (CCWF). Leveling surveys were completed in the fall/winter of 2011, 2012, and 2013 to establish baseline ground motion prior to the initiation of pumping at the CCWF. An additional survey was completed in fall/winter 2014 following the initiation of pumping at three of the CCWF wells.
  - A cable extensometer was installed near the CCWF called the Chino Creek Extensometer (CCX). The CCX was installed pursuant to the monitoring and mitigation requirements of the Peace II SEIR (Dodson, 2010). The CCX consists of dual-nested piezometers completed to 140 and 610 feet-bgs with a cable extensometer installed within each piezometer. The CCX measures groundwater-level changes and the vertical deformation of the aquifer system.
- *Expanded monitoring efforts in the Northwest MZ-1 Area*:
  - In 2006, the groundwater-level monitoring network was expanded to include wells within the Northwest MZ-1 and Central MZ-1 areas. Transducers were installed in 12 wells that record groundwater levels at 15-minute intervals. The purpose of the expansion was to better characterize the relationships between pumping, recharge, and groundwater levels in these areas.
  - The benchmark network was expanded through the Northwest MZ-1 Area and across the San Jose Fault in 2013. Figure 1-3 shows the locations of these benchmarks. Two transects of closely-spaced benchmarks were constructed across the San Jose Fault (the San Jose Fault Array): one in the north-south direction and one in the east-west direction. The purpose of the San Jose Fault Array of benchmarks is to measure vertical and horizontal ground motion across the San Jose Fault. The horizontal motion is measured via electronic distance measurements between benchmarks (EDM). Two surveys were conducted across the San Jose Fault Array in the fall/winter of 2013 and 2014.
- *Annual reporting*. The GLMC has prepared annual reports that include the results of the monitoring program, interpretations of the data, recommendations for the monitoring program for the following fiscal year, and recommendations for adjustments to the MZ-1 Plan, if any.

1.6 2015 Update to the Chino Basin Subsidence Management Plan

By 2014, the content of the initial MZ-1 Plan was outdated and no longer an accurate description of Watermaster's current and future efforts to monitor and manage land subsidence in the Chino Basin. A general update of the entire plan was needed to better describe Watermaster's efforts and obligations with regard to land subsidence, which has grown to include areas outside MZ-1.

This document updates the initial MZ-1 Plan. Since areas outside of MZ-1 have been included, the plan has been renamed the Chino Basin Subsidence Management Plan (CBSMP).

The CBSMP is comprised of the following sections:

Section 1 – Background and Objectives. This section describes the historical context for the CBSMP and its objectives.

Section 2 – Subsidence-Management Program. This section describes the monitoring program for the CBSMP for the Managed Area and for all other Areas of Subsidence Concern within the Chino Basin.

Section 3 – Annual Reporting. This section describes the process for the annual review and analysis of monitoring data and for the annual reporting on results, interpretations, and recommendations.

Section 4 – Process to Revise the CBSMP. This section describes the process to revise the CBSMP based on the results of the monitoring program and the recommendations of the GLMC.

Section 5 – Glossary of Terms. This section provides a glossary of the terms and definitions used within the CBSMP and in discussions at GLMC meetings.

Section 6 – References. This section lists the publications referenced in the CBSMP.

Section 2 – Subsidence-Management Program

This section describes the current subsidence-management program in the Chino Basin for the MZ-1 Managed Area and the other Areas of Subsidence Concern.

2.1 Managed Area

Figure 2-1 shows the Area of Subsidence Management (hereafter, the Managed Area).

The Managed Area was delineated based on:

- Measurements of historical land subsidence
- Proximity to historical ground fissuring
- Areal extent of intensive investigation of the IMP

2.1.1 Management Criteria

The management criteria described below were developed by the MZ-1 Technical Committee following the IMP.

2.1.1.1 Managed Wells

A Managed Well is defined as any production well (regardless of current status) located within the Managed Area that has casing perforations deeper than 400 feet below the ground surface. Table 1-1 lists the existing Managed Wells and their owners that are currently subject to the CBSMP in the Managed Area. Well owners include the City of Chino, the City of Chino Hills, and CIM.

Managed Well designations were based upon the observed and/or predicted effects of their pumping on groundwater levels and aquifer-system deformation. Managed Well designations for wells that pumped during the IMP were based on effects measured at the Ayala Park Extensometer Facility. Managed Well designations for wells that were not pumped during the IMP were based on analyses of well construction, geology, and water-level responses to nearby pumping. Within the boundaries of the Managed Area, other existing wells and/or newly constructed wells are subject to Managed Well classification.

2.1.1.2 Guidance Level

The IMP showed that groundwater-level declines due to pumping from the deep aquifer system within the Managed Area can cause inelastic (non-recoverable) compaction of the aquifer-system sediments, which results in land subsidence. The initiation of inelastic compaction within the aquifer system was identified during the IMP at the Ayala Park Extensometer when water levels fell below a depth of about 250 feet in the PA-7 piezometer.

The Guidance Level is a specified depth-to-water measured in Watermaster's PA-7 piezometer at Ayala Park. It is defined as the threshold water level at the onset of inelastic compaction of the aquifer system as recorded by the extensometer minus 5 feet. As noted in Section 1, the 5-foot reduction serves as a safety factor to ensure that inelastic compaction does not occur in the future. The initial Guidance Level was set at 245 feet below the top of the well casing (ft-btoc) in PA-7. The Guidance Level is established by Watermaster and subject to change based on the periodic review of monitoring data collected by Watermaster.

Watermaster recommends that the Parties manage their groundwater production such that the water level in PA-7 remains above the Guidance Level. If the water level in PA-7 falls below the Guidance Level, Watermaster recommends that the Parties curtail their production from the Managed Wells as required (1) to allow for water-level recovery and (2) to maintain the water level in PA-7 above the Guidance Level.

The magnitude of groundwater-level decline at which aquifer compaction is initiated in areas other than at the Ayala Park Extensometer has not been directly evaluated. Therefore, caution is recommended when pumping from Managed Wells in order to minimize groundwater-level decline within the Managed Area. Guidance Levels for wells and/or piezometers in addition to PA-7 may be specified in the future as a result of ongoing monitoring and the evaluation of groundwater production, groundwater levels, and land subsidence.

2.1.1.3 Recovery Periods

Within the Managed Area, Watermaster recommends that all deep aquifer-system pumping cease for a continuous 3-month period between October 1 and March 31 of each year.[2] Every fifth year, Watermaster recommends that all deep aquifer-system pumping cease for a continuous period until water-level recovery reaches 90 ft-btoc at PA-7. The cessation of pumping is intended to allow for sufficient water level recovery at PA-7 to recognize inelastic compaction, if any, at the Ayala Park Extensometer and at other locations where groundwater-level and ground-level data are being collected. The last time the water level at PA-7 was at or above 90 ft-btoc was in spring 2012. Therefore, the next recommended occurrence of water-level recovery to 90 ft-btoc will be spring 2017.

2.1.2 Data Exchange between Watermaster and Owners of the Managed Wells

Watermaster will provide the owners of the Managed Wells with current water level data from PA-7 on its website (www.cbwm.org).

Owners of the Managed Wells are requested to maintain accurate well operations records, including production rates and on-off dates and times; to provide these records to Watermaster monthly; and to promptly notify Watermaster of all operational changes made to maintain the water level in PA-7 above the Guidance Level.

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[2] Well 11A will be exempt from this recommendation. This is based on the small amount of water pumped from the deep zone by this well and the impracticability to shut it down due to permitting requirements. This exemption shall be subject to continuous review by the GLMC to ensure that continued pumping from this well does not interfere with water level recovery.

2.1.3 On-going Monitoring and Testing Program

Watermaster will continue the scope and frequency of monitoring implemented during the IMP within the Managed Area. These monitoring efforts are necessary to:

- Supply the Parties with the requisite information to comply with the Management Criteria.
- Assess the Parties' compliance with the CBSMP.
- Evaluate the effectiveness of the CBSMP to reduce to tolerable levels or abate future land subsidence and ground fissuring.

Watermaster will continue to conduct the monitoring program as described below at the facilities shown in Figure 2-1:

- *Production* - Production data will be collected from the owners of wells in the Managed Area.
- *Recharge* - The volumes of imported, storm, and recycled waters that are artificially recharged at basins in MZ-1, and of recycled water that is used for direct use in the Managed Area will be collected from the Inland Empire Utilities Agency (IEUA) for each fiscal year.
- *Piezometric Levels* - Piezometric levels will be measured and recorded once every 15 minutes using pressure transducers at about 26 wells in the Managed Area. The wells used in the monitoring program will be periodically assessed, and transducers in wells will be removed or added as deemed necessary by the GLMC.
- *Vertical Aquifer-System Deformation* - Watermaster will measure and record the vertical component of aquifer-system deformation at the Ayala Park Extensometer once every 15 minutes. Watermaster will maintain the Ayala Park Extensometer in good working order.
- *Vertical Ground-Surface Deformation* - Watermaster will measure vertical ground motion via traditional leveling surveys and remote sensing techniques (InSAR), as established during the IMP. The GLMC will annually recommend the scope and frequency of leveling surveys and InSAR measurements within the Managed Area.
- *Horizontal Ground-Surface Deformation* - Watermaster will measure horizontal ground motion across areas that are susceptible to ground fissuring via EDMs and the horizontal extensometers at the DHX. In the Managed Area, closely-spaced benchmark monuments used for EDMs are installed along Schaefer Avenue, G Street, and Chino Avenue. The GLMC will annually recommend the scope and frequency of EDM surveys within the Managed Area. The purpose of the DHX is to measure horizontal strain across the zone of historical ground fissuring and to test the horizontal-extensometer technology as a subsidence management tool. Watermaster will maintain the DHX in good working order and continue monitoring horizontal strain until the GLMC recommends that the DHX is no longer necessary.

2.1.4 Future Efforts

The initial MZ-1 Plan contemplated the following programs to refine the Guidance Criteria and develop alternative groundwater management plans that would minimize or abate land subsidence and maximize the prudent extraction of groundwater: (1) more intensive monitoring of horizontal strain across the zone of historical ground fissuring to assist in developing management strategies related to fissuring, (2) injection feasibility studies within the Managed Area, (3) additional pumping tests to refine the Guidance Criteria, (4) computer-simulation modeling of groundwater flow and subsidence, and (5) the development of alternative pumping plans for the Parties affected by the MZ-1 Plan.

The GLMC developed the Long-Term Pumping Test in the Managed Area in response to these directives in the initial 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 possible without causing damage to the ground surface or the area's infrastructure. Specific questions that the test is designed to answer are:

1. Is the Guidance Level for the Managed Area, as currently defined, appropriate? If not, how should the Guidance Level be updated?
2. Does the Riley Barrier separate the Managed Area from the Southeast Area within the deep aquifer system? If not, should the eastern boundary of the Managed Area be revised?
3. How does the subsidence (elastic and inelastic) and rebound that occurs in the Managed Area affect the horizontal strain across the historical zone of ground fissuring and its northward extension into the heavily-urbanized portions of the City of Chino?
4. Is aquifer injection a viable tool for mitigating groundwater-level decline and preventing non-recoverable compaction in the deep aquifer system?
5. Is there an "acceptable" rate of land 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 decline below the Guidance Level, and may cause a small amount of subsidence.[3] The test will be closely monitored at the Ayala Park

[3] The aquifer-system stress testing in 2004-05 resulted in about 0.01 feet of permanent (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.

Extensometer and the horizontal monitoring facilities and will be stopped at the first clear indication of non-recoverable deformation. Groundwater levels recorded at 15-minute intervals at PA-7 will be updated every three-hours on Watermaster's website. As 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 a determination to stop the test when appropriate.

2. Stop the pumping test and allow for the partial recovery of groundwater levels.
3. Conduct two cycles of injection at CH-16 to see how injection may accelerate the recovery of the regional groundwater levels 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 DHX 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 permanent compaction of the aquifer system in the Managed Area. Check stress-strain diagrams from the DHX 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.

Chino Hills has completed modifications to well CH-16 making it an ASR well, and will complete connections to an injection water supply in 2015. The Long-Term Pumping Test is expected to occur during 2015 and 2016.

2.2 Areas of Subsidence Concern

2.2.1 Northwest MZ-1 Area

The Northwest MZ-1 Area of Subsidence Concern (hereafter, Northwest MZ-1) is located directly north of Central MZ-1. Figure 2-1 shows the extent of Northwest MZ-1, which was delineated based on:

- Measurements of historical land subsidence
- The location of the San Jose Fault

Subsidence in Northwest MZ-1 was first identified as a concern in the MZ-1 Summary Report (2006) and in the initial MZ-1 Plan (2007). Of particular concern is that subsidence in Northwest MZ-1 has occurred differentially across the San Jose Fault—the same pattern of differential subsidence that occurred in the MZ-1 Managed Area during the time of ground fissuring. The GLMC/Watermaster has since been monitoring subsidence via InSAR and groundwater-levels with transducers at selected wells. Over the past few years, the GLMC/Watermaster has increased monitoring efforts to include elevation surveys and EDMs due to the ongoing concern for potential ground fissuring near the San Jose Fault. This has been discussed at many prior GLMC meetings, and the subsidence has been documented and described as a concern in past State of the Basin Reports as well as past Annual Reports of the GLMC.

2.2.1.1 On-going Monitoring and Testing Program

Watermaster will continue to conduct the monitoring program as described below at the facilities shown in Figure 2-1:

- *Production* – Production data will be collected from the well owners in Northwest MZ-1.
- *Recharge* - The volumes of imported, storm, and recycled waters that are artificially recharged at basins in MZ-1, and of recycled water used for direct use in Northwest MZ-1, will be collected from the IEUA each fiscal year.
- *Piezometric Levels* - Piezometric levels will be measured and recorded once every 15 minutes using pressure transducers at about seven wells in Northwest MZ-1. The wells used in the monitoring program will be periodically assessed, and transducers will be removed or added as deemed necessary by the GLMC.
- *Vertical Ground-Surface Deformation* - Watermaster will measure vertical ground motion via traditional leveling surveys and remote sensing techniques (InSAR). The GLMC will annually recommend the scope and frequency of leveling surveys and InSAR measurements within Northwest MZ-1.
- *Horizontal Ground-Surface Deformation* - Watermaster will measure horizontal ground motion across areas that are susceptible to ground fissuring in Northwest MZ-1 via EDMs. In Northwest MZ-1, closely-spaced benchmark monuments used for EDMs are installed along San Antonito Avenue and San Bernardino Avenue (San Jose Fault Array). The GLMC will annually recommend the scope and frequency of EDM surveys at the San Jose Fault Array.

2.2.1.2 Future Efforts

Watermaster, consistent with the recommendation of the GLMC, has determined that the MZ-1 Plan needed 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.[4]

To develop a Subsidence Management Plan for the Northwest MZ-1 Area, a number of questions will need to be answered:

1. What are the mechanisms driving the observed subsidence?

[4] Chino Basin Watermaster. (2014). 2013 Annual Report of the Land Subsidence Committee. July, 2014.

Available evidence indicates that the most likely mechanism behind the observed subsidence is the compaction of fine-grained sediment layers within the aquifer-system. If so, the following questions need to be answered:

a. What are the depth intervals within the aquifer system that are compacting?

b. How does pumping from wells in the vicinity of Northwest MZ-1 influence piezometric levels within the aquifer system?

c. How does wet-water recharge via spreading and/or injection influence piezometric levels?

d. What is the pre-consolidation stress[5] within the compacting intervals of the aquifer system?

A hydrogeologic investigation of Northwest MZ-1 is necessary to definitively answer these questions. The investigation may include the installation of piezometers and extensometers and the design and implementation of controlled aquifer-stress tests. To identify pre-consolidation stress, aquifer-stress testing will require an increase in groundwater levels within Northwest MZ-1.

2. What is the appropriate method to manage land subsidence in Northwest MZ-1?

Depending on the answer to Question 1, there may be multiple methods to manage land subsidence, such as the modification of pumping patterns, in-lieu recharge, wet-water recharge via spreading or injection, or a combination of methods. These methods might necessitate the modification of water-supply plans for purveyors in the Chino Basin and/or the implementation of regional-scale storage or conjunctive-use programs. Alternative methods include accepting the occurrence of subsidence and its consequences and liabilities or insuring against potential future damages. The methods need to be described as management alternatives and evaluated in enough detail to choose a preferred alternative.

The development of the Subsidence Management Plan for the Northwest MZ-1 Area is a multi-year effort. The GLMC/Watermaster has prepared a work plan that describes a conceptual framework for this effort as tasks with cost estimates and a preliminary schedule. On an annual basis, the GLMC will analyze the data generated by the implementation of the work plan. The results and interpretations generated from the analysis will be documented in the annual report of the GLMC and used to prepare recommendations for future activities pursuant to Section 3 of this document. The work plan has been included herein as Appendix B.

2.2.2 Southeast Area

The Southeast Area is located east of the MZ-1 Managed Area, as shown in Figure 2-1.

[5] A technical definition of pre-consolidation stress is included in the Glossary of Terms. In lay terms, pre-consolidation stress is a groundwater-level "threshold." When groundwater levels are above the threshold, subsidence is abated. When groundwater levels are below the threshold, subsidence is caused.

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; agricultural land uses in the area are not good reflectors of radar waves. 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, ground-level survey data indicated land subsidence of about 0.25 feet from 2000 to 2006. The Chino-I Desalter wells began pumping in 2000 and have caused localized groundwater-level decline within the deep aquifer system, which may have caused the observed land subsidence. Another plausible cause of this observed subsidence is that thick, slowly-draining aquitards are compacting in response to the historical groundwater-level declines that occurred prior to 1990. Watermaster installed the CCX 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) record the effects of pumping at the CCWF on groundwater levels and land subsidence. The CCX began collecting data in July 2012 and thus far has not recorded any land subsidence. Pumping at the CCWF commenced in late 2014.

2.2.2.1 On-going Monitoring and Testing Program

Watermaster will continue to conduct the monitoring program as described below at the facilities shown in Figure 2-1:

- *Production* –Production data will be collected from the owners of wells in the Southeast Area.
- *Recharge* – The volumes of imported, storm, and recycled waters that are artificially recharged at basins in MZ-1 and MZ-2, and of recycled water used for direct use in the Southeast Area will be collected from the IEUA each fiscal year.
- *Piezometric Levels* – Piezometric levels will be measured and recorded once every 15 minutes using pressure transducers at about 20 wells in the Southeast Area. The wells used in the monitoring program will be periodically assessed, and transducers will be removed or added as deemed necessary by the GLMC.
- *Vertical Aquifer-System Deformation* – Watermaster will measure and record the vertical component of aquifer-system deformation at the CCX once every 15 minutes. Watermaster will maintain the CCX in good working order.
- *Vertical Ground-Surface Deformation* – Watermaster will measure vertical ground motion via traditional leveling surveys and remote sensing techniques (InSAR). The GLMC will annually recommend the scope and frequency of leveling surveys and InSAR measurements within the Southeast Area.

2.2.2.2 Future Efforts

Currently, no additional monitoring or testing efforts are planned for the Southeast Area. The GLMC will annually review the data collected in the Southeast Area and, if appropriate, recommend additional monitoring or testing efforts.

2.2.3 Northeast Area

The Northeast Area is located east of the Central MZ-1 and Northwest MZ-1 areas, as shown in Figure 2-1.

Over one-foot of inelastic subsidence occurred in the Northeast Area between 1993 and 2014, as measured by InSAR. In the Northeast Area, subsidence has generally occurred gradually and over a broad area. 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 during 1993-2014 cannot be explained entirely by concurrent changes in groundwater levels. A plausible explanation for the subsidence is that thick, slowly-draining aquitards are compacting in response to the historical groundwater-level declines that occurred from 1935 to 1978.

2.2.3.1 On-going Monitoring and Testing Program

Watermaster will continue the monitoring program described below at the facilities shown in Figure 2-1:

- *Production* – Production data will be collected from the owners of wells in the Northeast Area.
- *Recharge* – The volumes of imported, storm, and recycled waters that are artificially recharged at basins in MZ-1 and MZ-2, and of recycled water used for direct use in the Northeast Area will be collected from the IEUA each fiscal year.
- *Piezometric Levels* – Piezometric levels will be measured manually monthly by Watermaster and the well owners in the Northeast Area.
- *Vertical Ground-Surface Deformation* – Watermaster monitors vertical ground motion in the Northeast Area via remote sensing techniques (InSAR). The GLMC will annually recommend the frequency of InSAR measurements.

2.2.3.2 Future Efforts

Currently, no additional monitoring or testing efforts are planned for the Northeast Area. The GLMC will annually review the data collected in the Northeast Area and, if appropriate, recommend additional monitoring or testing efforts.

2.2.4 Central MZ-1 Area

The Central MZ-1 Area is located directly north of the MZ-1 Managed Area, as shown in Figure 2-1.

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

2.2.4.1 On-going Monitoring and Testing Program

Watermaster will continue the monitoring program described below at the facilities shown in Figure 2-1:

- *Production* – Production data will be collected from well owners in Central MZ-1.
- *Recharge* – The volumes of imported, storm, and recycled waters that are artificially recharged at basins in MZ-1, and of recycled water used for direct use in Central MZ-1 will be collected from the IEUA each fiscal year.
- *Piezometric Levels* – Piezometric levels will be measured manually monthly by Watermaster staff and well owners in Central MZ-1.
- *Vertical Ground-Surface Deformation* – Watermaster will measure vertical ground motion via traditional leveling surveys and remote sensing techniques (InSAR). The GLMC will annually recommend the scope and frequency of leveling surveys and InSAR measurements within Central MZ-1.

2.2.4.2 Future Efforts

Currently, no additional monitoring or testing efforts are planned for Central MZ-1. The GLMC will annually review the data collected in Central MZ-1 and, if appropriate, recommend additional monitoring or testing efforts.

2.3 Data Exchange between Watermaster Parties

The Parties are requested to maintain accurate well operations records, including production rates, injection rates, and on-off dates and times. The Parties are requested to provide these records to Watermaster. The Parties are requested to promptly notify Watermaster of all operational changes related to groundwater production.

At the beginning of each calendar year, Watermaster staff and the Watermaster engineer will analyze the data generated by the Ground-Level Monitoring Program during the prior calendar year. The results and interpretations generated from the analysis will be documented in an annual report and used to prepare recommendations for future activities. The GLMC will meet to review the draft annual report and recommend a scope and budget to the Watermaster for the Ground-Level Monitoring Program for the upcoming fiscal year. These activities are described in greater detail below.

3.1 Annual Report of the Ground-Level Monitoring Committee

During the first quarter of each calendar year, Watermaster staff and the Watermaster engineer will analyze the data generated by the Ground-Level Monitoring Program during the prior calendar year and prepare a draft *Annual Report of the Ground-Level Monitoring Committee*. The annual report will include the following 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 and its responsibilities, and the CBSMP.

Section 2 – Ground-Level Monitoring Program. This section describes the monitoring and testing activities performed by Watermaster for its Ground-Level Monitoring Program during the previous calendar year.

Section 3 – Results and Interpretations. This section discusses and interprets the monitoring and testing data collected and analyzed during the previous calendar year.

Section 4 – Conclusions and Recommendations. This section summarizes the main conclusions derived from the monitoring program through the previous calendar year and recommends activities for the program during the following fiscal year(s) in the form of a proposed scope-of-work, schedule, and budget. This section also includes recommendations for updates to the CBSMP, if any, as warranted by the data.

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

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

Annual reports will be prepared and approved through the Watermaster Pool process by the end of each fiscal year (June 30). Upon approval, the reports will be submitted to the Court.

3.2 Scope and Budget for Future Fiscal Years

Section 4 of the *Annual Report of the Ground-Level Monitoring Committee* describes recommended activities for the Ground-Level Monitoring Program for the future fiscal year(s) in the form of a proposed scope-of-work, schedule, and budget. The recommended scope-of-work, schedule, and budget will be run through Watermaster's budgeting process for revisions, if needed, and approval. The budgeting process typically occurs during the fourth quarter of each fiscal year. The final scope-of-work, schedule, and budget for the upcoming fiscal year will be included in the final *Annual Report of the Ground-Level Monitoring Committee*.

Section 4 – Process to Update the CBSMP

A key element of the CBSMP is the verification of its protective nature against land subsidence and ground fissuring in the Chino Basin. This verification is accomplished through continued monitoring, testing, and reporting by the GLMC (as described in Sections 2 and 3 above), and revision of the CBSMP when appropriate. In this sense, the CBSMP is adaptive.

The process of annual analysis and reporting of the data generated from the Ground-Level Monitoring Program (described in Section 3) includes the evaluation of the effectiveness of the CBSMP to minimize or abate land subsidence and ground fissuring and the recommendation to update the CBSMP if warranted by the data. The GLMC will make these recommendations within its annual reports and prepare a draft revised CBSMP. The draft revised CBSMP will be run through the Watermaster process for revisions and/or approval. Upon Watermaster Board approval, the revised CBSMP will be submitted to the Court.

The following glossary of terms and definitions are utilized within this report and generally in discussions at GLMC:

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

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

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

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

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

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

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

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

Deformation, Elastic – A fully reversible deformation of a material. In this report, the term “elastic” typically refers 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 the expansion of sediments: a reversible expansion of sediments under decreasing effective stress.

Extensometer – A monitoring well housing a free-standing pipe or cable that can measure the 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, 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, a transducer is connected to a data logger, which records 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.

Section 6 – References

Chino Basin Watermaster. (2000). Peace Agreement, Chino Basin. SB 240104 v 1:08350.0001. 29 June 2000.

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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.

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Appendix A

MZ-1 Summary Report

Appendix B

Work Plan to Develop the Subsidence Management Plan for the Northwest MZ-1 Area

Appendix C

Comments and Responses

Appendix C
Comments and Responses
on the Draft 2015 Chino Basin Subsidence Management Plan

C-1 State of California, California Institution for Men

Comment Number	Reference	Comment	Response
1	Page 1-2	Under header 1.3, second sentence – "…and the State of California (CIM)." Suggest "…State of California, California Institution for Men (CIM)."	The text has been changed as requested.
2	Page 2-1	Under header 2.1.1.1, third sentence – "… and the State of California." Suggest "…and CIM."	The text has been changed as requested.

C-2 City of Chino

Comment Number	Reference	Comment	Response
1	Page 2-4	Item No. 4. Insert "preventing" preceding "non-recoverable compaction".	The text has been changed as requested.
2	Page 2-5	Continuation of Bullet No. 1, third line. Why not use "subsidence" in place of "non-recoverable deformation?"	Comment noted. "Non-recoverable deformation" in this sentence refers to both horizontal strain in the shallow soils and permanent aquifer-system compaction, not just subsidence.
3	Page 2-5	Bullet No. 5, insert "horizontal and vertical" before "ground deformation" so it reads, "non-recoverable horizontal and vertical ground deformation…"	The text has been changed as requested.