Initial Hydrologic Conceptual Model and Monitoring and Testing Program for the Northwest MZ-1 Area

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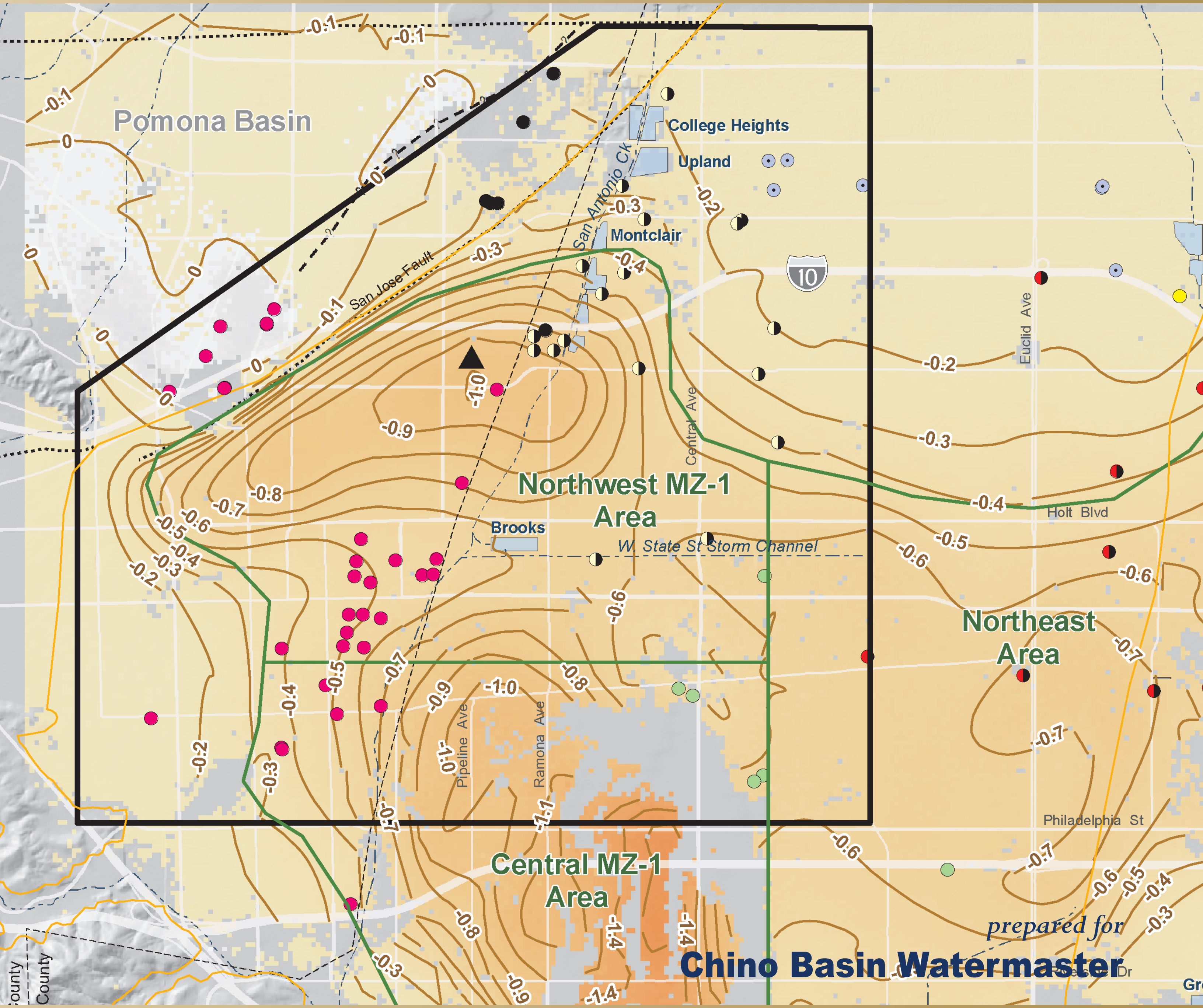

prepared for

Chino Basin Watermaster

December 2017

WEI
Wildermuth Environmental, Inc.

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Acronyms, Abbreviations, and Initialisms

CBWM	Chino Basin Watermaster
EDM	Electronic Distance Measurement
GLMC	Ground-Level Monitoring Committee
InSAR	Interferometric Synthetic Aperture Radar
MZ-1	Management Zone 1
WEI	Wildermuth Environmental, Inc.

1.1 Background

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

In 2000, the Chino Basin Watermaster (Watermaster) approved the Implementation Plan for the Peace Agreement (CBWM, 2000), which called for an aquifer-system and land subsidence investigation in the southwestern region of MZ-1 to support the development of a subsidence management plan. From 2001-2005, the Watermaster developed, coordinated, and conducted the investigation under the guidance of the MZ-1 Technical Committee, which was composed of representatives from all major MZ-1 producers and their technical consultants.[1] The investigation included collecting and analyzing the information necessary to understand the extent, rate, and mechanisms of subsidence and fissuring, and using that information to develop a management plan to abate future subsidence and fissuring or reduce it to tolerable levels.

The methods, results, conclusions, and recommendations of the investigation are described in detail in the *MZ-1 Summary Report* (WEI, 2006). The original subsidence management plan for MZ-1 is the *MZ-1 Subsidence Management Plan* (CBWM, 2007). Herein, the MZ-1 Subsidence Management Plan is referred to as the MZ-1 Plan. The focus of the MZ-1 Plan was the area around the historical fissuring in Chino—the so-called MZ-1 Managed Area (Managed Area).

The MZ-1 Plan identified other areas in the Chino Basin where subsidence and potential ground fissuring are a concern. Figure 1-1a shows the location of these "Areas of Subsidence Concern," which include: Central MZ-1, Northwest MZ-1, the Northeast Area, and the Southeast Area. The MZ-1 Plan states that if ongoing monitoring efforts in the Areas of Subsidence Concern indicate the potential for adverse impacts due to subsidence, Watermaster will revise the MZ-1 Plan in an attempt to avoid these adverse impacts.

Subsidence in Northwest MZ-1 was first identified as a concern in the MZ-1 Summary Report and the MZ-1 Plan. Since 2007, Watermaster has been monitoring vertical ground motion via InSAR and piezometric levels with transducers at selected wells in the area.

Figures 1-1a through 1-1d show vertical ground motion across the western Chino Basin for various time-periods between 1987 and 2016. Historically, the Managed Area shows the greatest amount of subsidence. Figure 1-1a shows that over two feet of subsidence occurred in the Managed Area from 1987 to 1999. Figures 1-1c and 1-1d show that from 2005 to 2016,

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[1] The MZ-1 Technical Committee is now called the Ground-Level Monitoring Committee, which now includes representatives from all Watermaster Parties.

less than about 0.2 ft of subsidence has occurred in the Managed Area, indicating that subsidence is successfully being managed here. Figures 1-1c and 1-1d also show that subsidence was greatest during 2005 to 2016 in Northwest MZ-1, where over 0.5 ft of subsidence was measured by InSAR.

Figure 1-2 is a time-series chart that shows the long-term history of vertical ground motion within Northwest MZ-1. These data indicate that about 1.2 ft of subsidence has occurred in this area from 1992 through 2016—an average rate of about 0.05 ft/yr. The chart also shows piezometric levels at wells in the area from 1930-2015. From about 1930 to 1978, piezometric levels in Northwest MZ-1 declined by about 175 feet. Since then, piezometric levels have recovered, but have remained below 1930 levels. The observed and continuous subsidence that occurred during the 1992-2015 period cannot be explained entirely by concurrent changes in piezometric levels. A plausible explanation for the subsidence is that thick, slow-draining aquitards are compacting in response to the historical declines in piezometric levels that occurred from 1930 to 1978. It is logical to assume that subsidence began when piezometric levels began to decline in 1930. If subsidence has been occurring at a constant rate of 0.05 ft/yr since 1930, then Northwest MZ-1 has experienced about 4.3 ft of permanent subsidence since 1930.

Of particular concern is that the subsidence in Northwest MZ-1 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. Figure 1-1d shows vertical ground motion for the western Chino Basin between 2011 and 2016, as measured by InSAR, and highlights not only the steep subsidence gradient across the San Jose Fault but also shows steep subsidence gradients across the southern boundary of the observed "bulls-eye" subsidence pattern in Northwest MZ-1. Differential subsidence can cause an accumulation of horizontal strain in the shallow sediments and the potential for ground fissuring.

To better understand the extent, rate, and causes of the subsidence, and the potential for ground fissuring in Northwest MZ-1, the Ground-Level Monitoring Committee (GLMC) and Watermaster have increased monitoring efforts in this area to include elevation surveys at benchmarks, electronic distance measurements (EDMs) between benchmarks across the San Jose Fault, and high-frequency measurements of piezometric levels at wells.

1.2 Northwest MZ-1 Study Area

Figure 1-3 shows the location of Northwest MZ-1 and the study area for this report (Study Area). The Study Area encompasses about 23 square miles around Northwest MZ-1 and includes the southeast corner of the Pomona Basin north of the San Jose Fault. The Study Area boundary is based on InSAR data (1992 to 2016), the locations of production wells, the locations of recharge basins, and the location of the San Jose Fault.

1.3 Objectives

Differential subsidence and the potential for ground fissuring in Northwest MZ-1 has been discussed at prior GLMC meetings, and the subsidence has been documented and described as a concern in past State of the Basin Reports and GLMC Annual Reports (WEI, 2012, 2013, 2014a, and 2015). The 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 Northwest MZ-1 with the long-term objective of minimizing or abating differential land subsidence.

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

1. What are the mechanisms driving the observed subsidence?

Available evidence indicates that the most likely mechanism behind observed subsidence in Northwest MZ-1 is the compaction of fine-grained sediment layers (aquitards) within the aquifer-system. Other mechanisms, such as tectonic forces, may also be plausible causes for the observed subsidence. If in fact, the cause of the observed subsidence in Northwest MZ-1 is the compaction of aquitards, the following must be answered:

2. What are the depth intervals within the aquifer system that are compacting?
3. How does pumping from wells in the vicinity of Northwest MZ-1 influence piezometric levels within the aquifer-system?
4. How does wet-water recharge via spreading and/or injection influence piezometric levels?
5. What is the pre-consolidation stress[2] within the compacting intervals of the aquifer system?

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

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

Depending on the answers to questions one to five, there may be multiple methods to manage the subsidence, such as modification of pumping patterns, in-lieu recharge, wet-water recharge via spreading, 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. An alternative method is to accept the occurrence of subsidence and insure against potential future damages. The methods need to be described as management alternatives and evaluated in enough detail to choose a preferred alternative.

The first step to answer the above questions and to develop a Subsidence Management Plan for Northwest MZ-1 is to describe the initial hydrogeologic conceptual model. The initial hydrogeologic conceptual model will:

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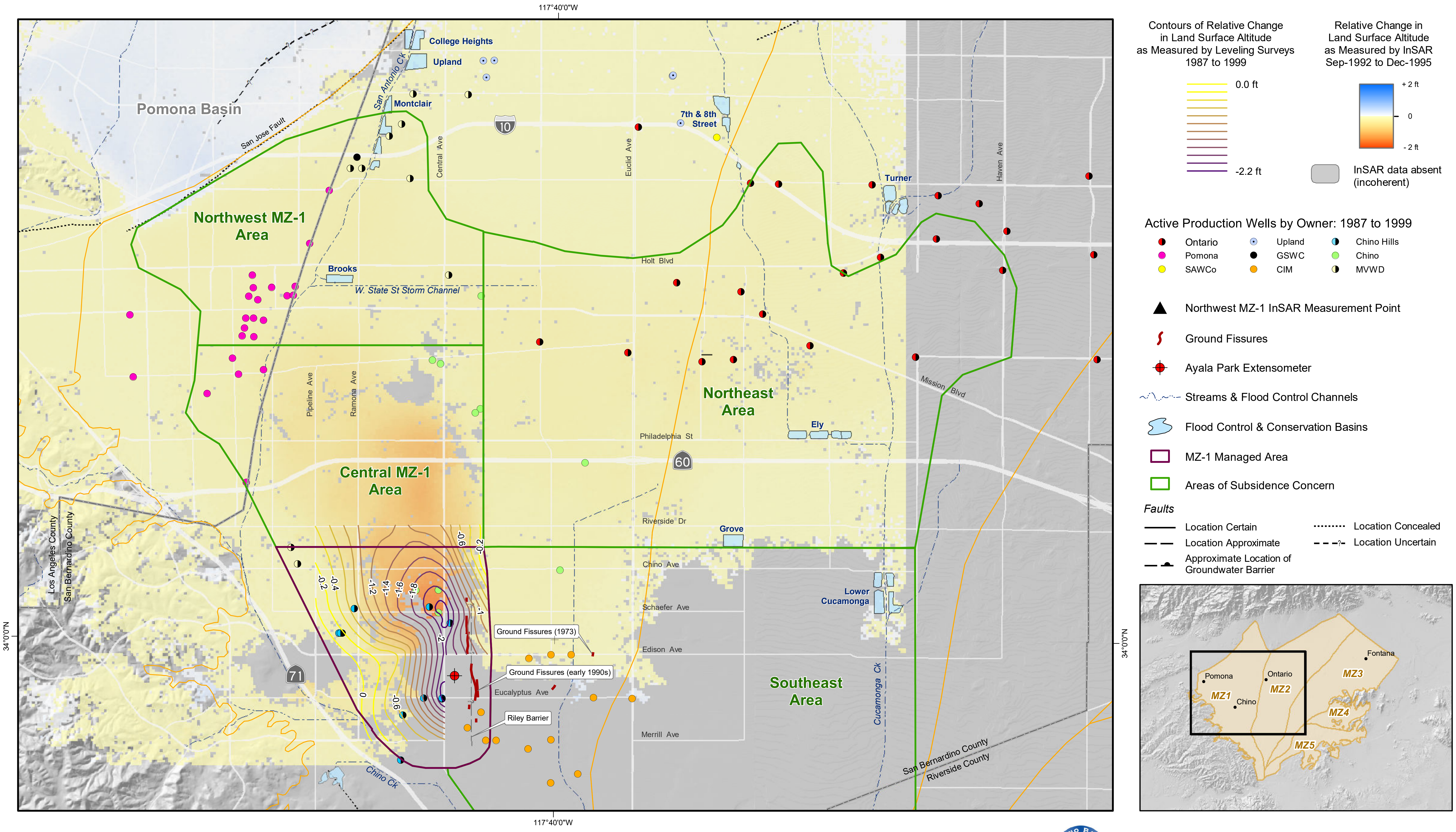
[2] A technical definition of pre-consolidation stress is included in the Glossary of Terms. In lay terms, the pre-consolidation stress is a groundwater level "threshold." When groundwater levels are above the threshold, subsidence is abated. When groundwater levels are below the threshold, subsidence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

1. Describe the current state of knowledge of the hydrogeology of Northwest MZ-1—particularly with respect to the occurrence and mechanisms of aquifer-system deformation and pre-consolidation stress.
2. Identify the data gaps that need to be filled-in order to fully describe the occurrence and mechanisms of aquifer-system deformation and pre-consolidation stress.

The initial hydrogeologic conceptual model is described in Section 2. Section 3 describes a proposed monitoring and testing program for Northwest MZ-1 to fill the data gaps described in Section 2.



Prepared by:

WILDERMUTH ENVIRONMENTAL, INC.

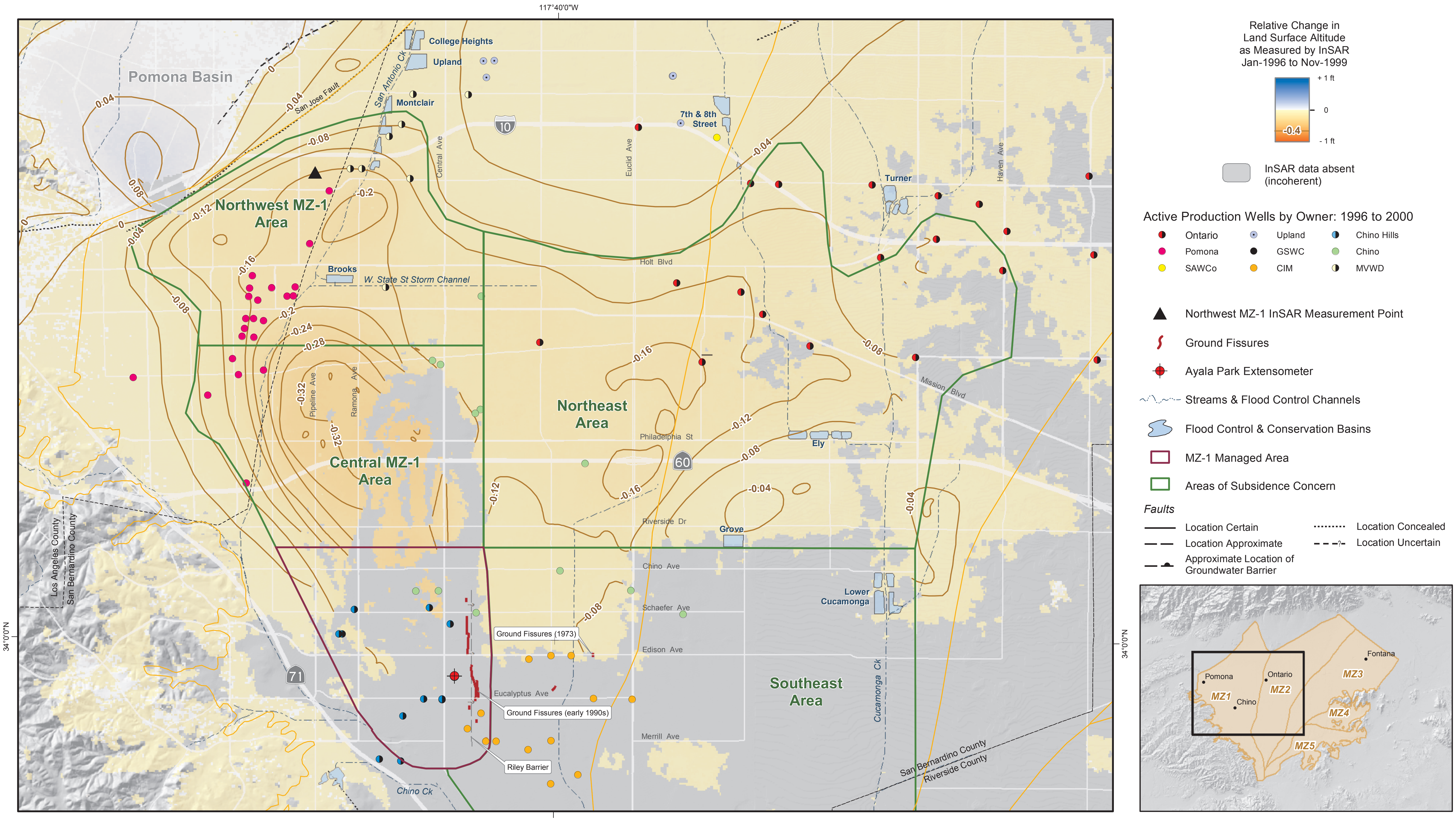
Author: NWS
Date: 12/19/2017
Document Name: Figure 1-1a

Initial Hydrogeologic Conceptual Model
& Monitoring and Testing Program
for the Northwest MZ-1 Area

Historical Vertical Ground Motion in the Western Chino Basin

Surveys 1987-99, InSAR 1992-95

Figure 1-1a



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Initial Hydrogeologic Conceptual Model
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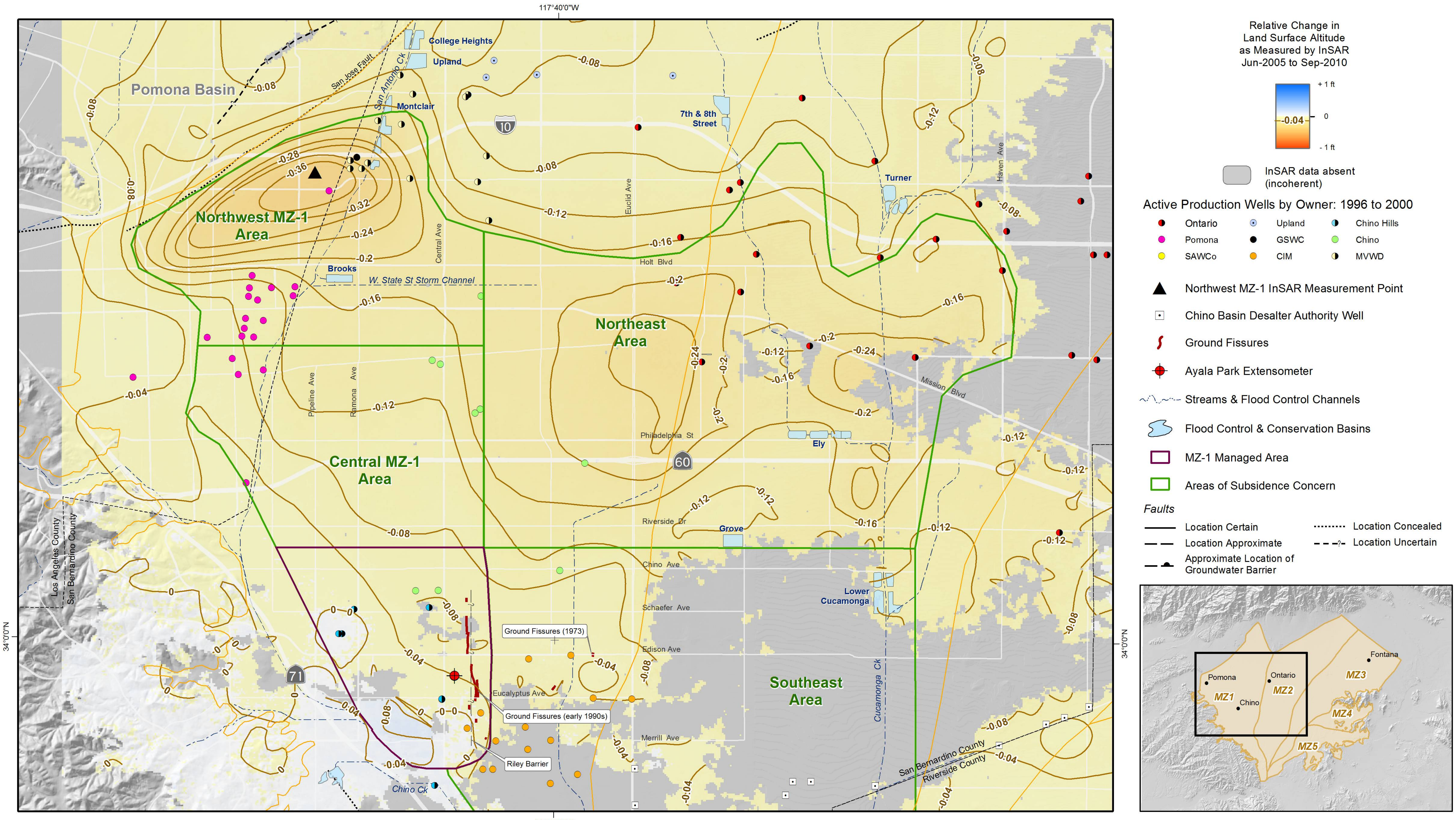
Historical Vertical Ground Motion in the Western Chino Basin

1996 to 1999

Figure 1-1b



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WEI
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Author: NWS
Date: 8/5/2016
Document Name: Figure 1-1c

Initial Hydrogeologic Conceptual Model
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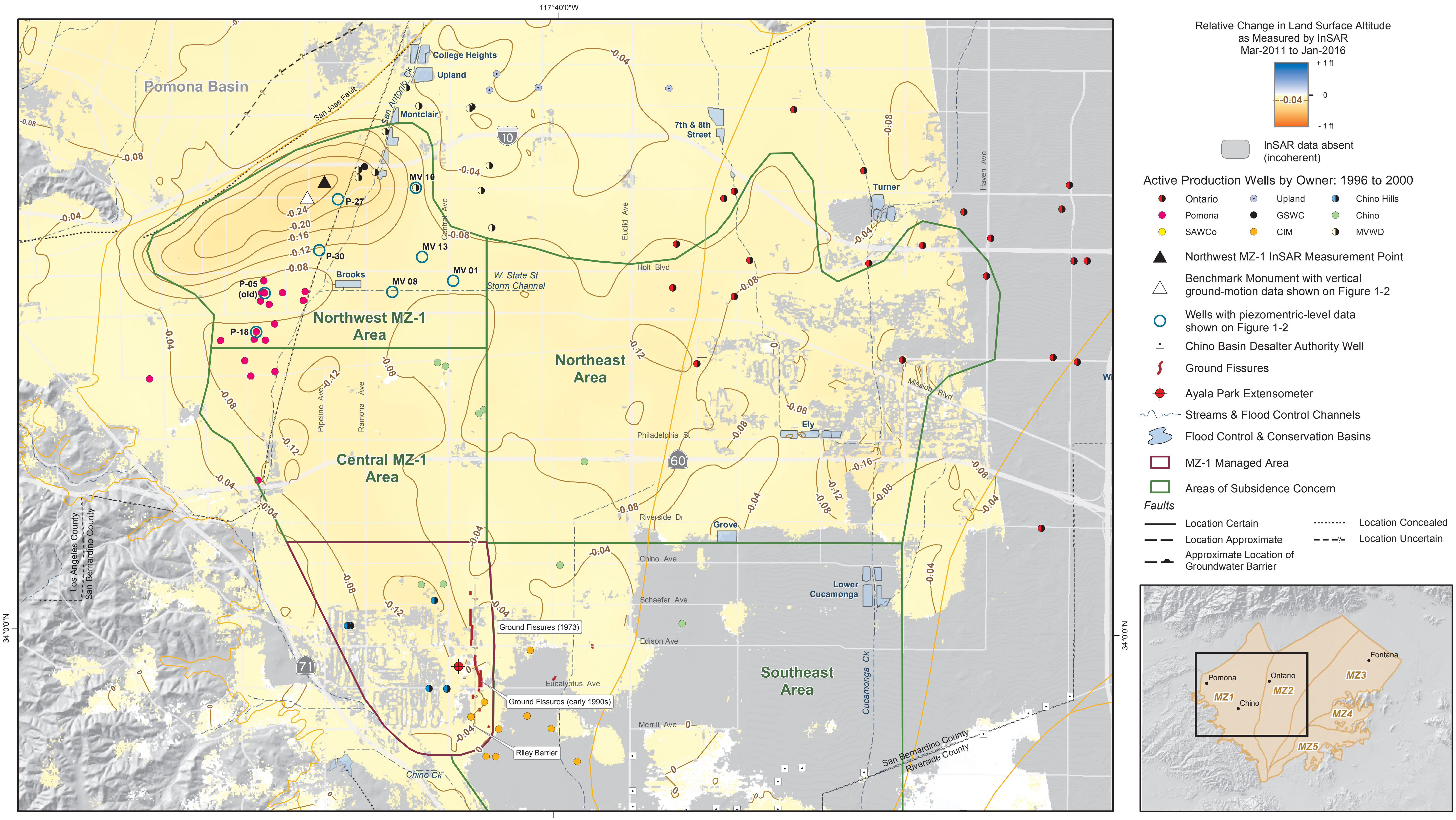
Historical Vertical Ground Motion in the Western Chino Basin
2005 to 2010

Figure 1-1c



Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: TCR
Date: 8/11/2016
Document Name: Figure 1-1d

0 1 2 3 Miles
0 2 4 Kilometers

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Initial Hydrogeologic Conceptual Model
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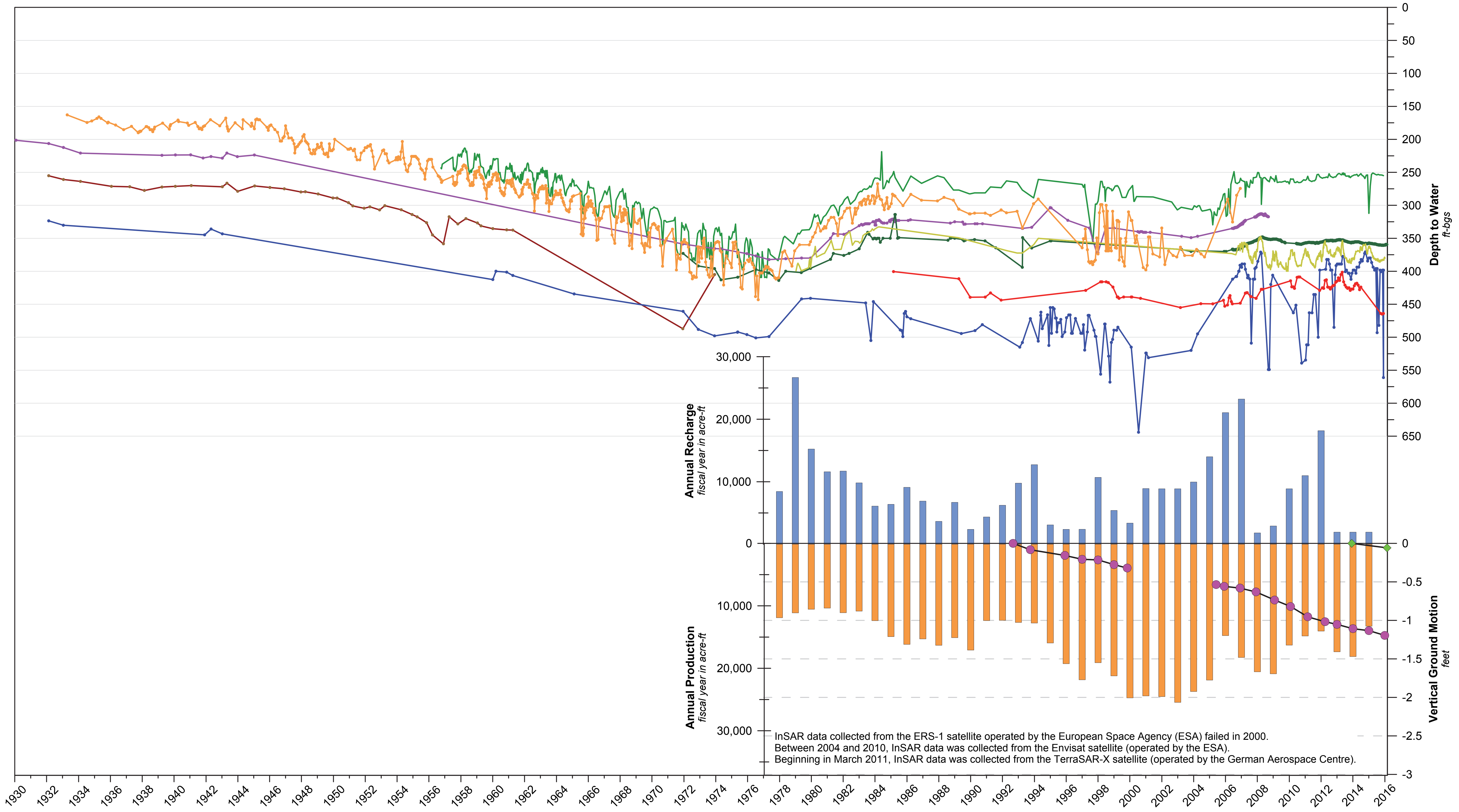
Historical Vertical Ground Motion in the Western Chino Basin
2011 to 2016

Figure 1-1d



InSAR data collected from the ERS-1 satellite operated by the European Space Agency (ESA) failed in 2000.
Between 2004 and 2010, InSAR data was collected from the Envisat satellite (operated by the ESA).
Beginning in March 2011, InSAR data was collected from the TerraSAR-X satellite (operated by the German Aerospace Centre).

Piezometric 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-05old (141-488 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
- BM B-403

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 recharge is assumed to be 2,380 acre-ft/yr prior to Fiscal Year 04/05
- Groundwater Production from Wells in Northwest MZ-1

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Author: TCR
Date: 20160808
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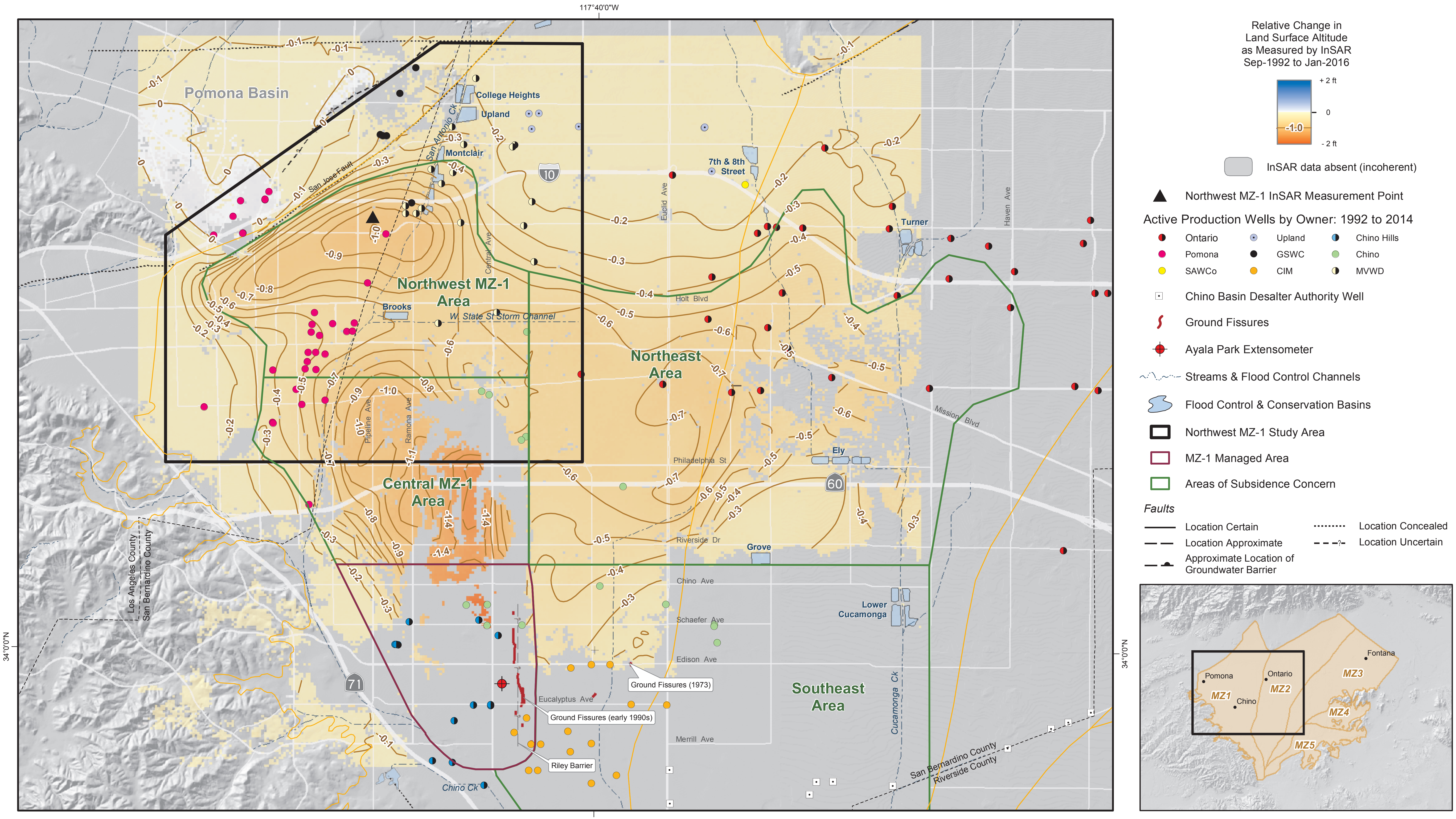
The History of Land Subsidence in the Northwest MZ-1 Area

Figure 1-2



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WILDERMUTH ENVIRONMENTAL, INC.

Author: NWS
Date: 8/11/2016
Document Name: Figure 1-3

Initial Hydrogeologic Conceptual Model & Monitoring and Testing Program for the Northwest MZ-1 Area

Historical Vertical Ground Motion in the Western Chino Basin
1992 to 2016

Figure 1-3

Section 2 – Initial Hydrogeologic Conceptual Model

This section describes the hydrogeology of Northwest MZ-1, based on the most current information available with respect to the occurrence and mechanisms of land subsidence. Covered topics include: the geologic setting, the hydrostratigraphy of the area, the spatial distribution of compressible and fine-grained sediments within the underlying aquifer system, the spatial distribution of historical production and recharge, and historical changes in piezometric levels.

For each topic covered in this section, the main observations and interpretations are described and “data gaps” that need to be filled-in order to fully describe the occurrence and mechanisms of aquifer-system deformation are identified. Data gaps are the additional information necessary to develop a Subsidence Management Plan for the Northwest MZ-1 Area. A monitoring and testing program to help fill the data gaps is described in Section 3.

2.1 Geologic Setting

The geologic setting and hydrostratigraphy of the western Chino Basin have been discussed and documented in reports that describe the development, calibration, and use of the Chino Basin Watermaster’s groundwater-flow model (WEI, 2007; 2015). The contents of those reports have been modified and incorporated into this report.

The Northwest MZ-1 Area is located within the western portion of the Chino Basin. Figure 2-1 is a generalized geologic map of the western Chino Basin. The Chino Basin was formed because of tectonic activity along major fault zones during the Quaternary Period.[3] It is part of a large, broad, alluvial-filled plain located between the San Gabriel Mountains to the north (Transverse Ranges) and the elevated Perris Block to the south (Peninsular Ranges).

The major faults in the Chino Basin area—the Cucamonga Fault Zone, the Rialto-Colton Fault, the Red Hill Fault, the San Jose Fault, and the Chino Fault—are at least partly responsible for the uplift of the surrounding mountains and the depression of the Chino Basin. The bottom of the basin, the effective base of the freshwater aquifer, consists of impermeable[4] sedimentary and igneous bedrock formations that are exposed at the surface in the surrounding mountains and hills. Sediments that were eroded and washed out from the surrounding mountains filled the Chino Basin to form its groundwater reservoirs.

The major faults are also significant in that they are known barriers to groundwater flow within the aquifer sediments and, hence, define some of the external boundaries of the basin by influencing the magnitude and direction of groundwater flow.

The San Jose Fault, which borders the Chino Basin and Northwest MZ-1 to the northwest, is a barrier to groundwater flow, as evidenced by piezometric elevations approximately several hundred feet higher in the Upper Claremont Heights and Pomona Basins compared to the Chino Basin (Eckis, 1934; DWR, 1970). Groundwater migrates across the San Jose Fault as underflow from the Upper Claremont Heights and Pomona Basins to the Chino Basin,

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[3] Approximately 2 million years ago to the present.

[4] It should be noted that the terms used in this report to describe bedrock, such as “consolidated,” “non-water bearing,” and “impermeable,” are used in a relative sense. The water content and permeability of these bedrock formations, in fact, is not zero. However, the primary point is that the permeability of the bedrock formations is much less than within the aquifer system.

especially during periods of high groundwater elevations within the Upper Claremont Heights and Pomona Basins.

Observations and Interpretations. The geologic setting of the Northwest MZ-1 Area is typical of alluvial aquifer systems in tectonically active areas. The aquifer system and the underlying bedrock formations are composed of unconsolidated and semi-consolidated sediments that are susceptible to permanent compaction when groundwater is pumped. The San Jose Fault is a known groundwater barrier that can focus and augment drawdown in the aquifer-system when pumping and drawdown are concentrated on one side of the fault, which then can lead to differential land subsidence and a threat of ground fissuring. There are numerous examples of land subsidence and ground fissuring due to groundwater extraction in similar geologic settings, especially in the arid southwestern United States (USGS, 1999). The process of aquitard drainage and compaction occurring south of the San Jose Fault is the most plausible explanation for the differential land subsidence observed in Northwest MZ-1.

Tectonic movement along faults, including aseismic creep, is also a plausible mechanism for the occurrence of differential land subsidence in Northwest MZ-1. Figure 2-1 shows seismicity data for the period 1992-2015. The historic earthquake epicenters do not show a clear relationship between the seismicity and the historical and ongoing differential subsidence in Northwest MZ-1. Nevertheless, without direct evidence of compaction within the aquifer system, tectonic deformation cannot be ruled out as a cause for the observed differential subsidence.

Data Gap. The main data gap with regard to the current understanding of the geologic setting in the Study Area, and its role in the occurrence of land subsidence, are:

> *Lack of depth-specific data on aquifer-system deformation*. The necessary information to eliminate tectonic movement as the cause of the differential land subsidence, and identify aquitard drainage and compaction as the cause, is: (i) the direct measurement of aquifer-system deformation via extensometers, and (ii) a comparison of the extensometer data to the ground-motion measured by InSAR and ground-level surveys. In addition, knowledge of the spatial location and depth of where aquifer-system compaction is occurring is critical to developing a subsidence management plan.

2.2 Hydrostratigraphy

The stratigraphy of the western Chino Basin is divided into two natural divisions: (1) the permeable formations that comprise the primary groundwater reservoirs are termed “water-bearing sediments,” and (2) the less permeable formations that enclose the groundwater reservoirs are termed “consolidated bedrock.” The water-bearing sediments overlie the consolidated bedrock, with the bedrock formations coming to the surface in the surrounding hills and mountains.

2.2.1 Consolidated Bedrock

The consolidated bedrock formations of the western Chino Basin area include the basement complex, consolidated sedimentary and volcanic strata, and more recent, semi-consolidated, continental sedimentary deposits. Figure 2-1 shows the surface outcrops of the consolidated bedrock that surround the western Chino Basin.

The basement complex consists of deformed and re-crystallized metamorphic rocks that have been invaded in places by masses of granitic and related igneous rocks. The intrusive granitic rocks, which make up most of the basement complex, were emplaced about 110 million years ago in the late Middle Cretaceous (Larsen, 1958). These rocks were subsequently uplifted and exposed by erosion, as presently seen in the San Gabriel Mountains and in the uplands of the Perris Block (Jurupa Mountains and La Sierra Hills). They have been the major source of detritus to the younger sedimentary formations and the water-bearing sediments of the Chino Basin.

Consolidated sedimentary and volcanic rocks that unconformably overlie the basement complex outcrop along the western margin of the Chino Basin in the Chino and Puente Hills. They consist of well-stratified marine sandstones, conglomerates, shales, and interlayered lava flows that range in age from late Cretaceous to Miocene.[5]

A thick series of semi-consolidated clays, sands, and gravels of marine and non-marine origin of Pliocene age[6] overlie the older consolidated bedrock formations. These sediments have been named the Fernando Group (Eckis, 1934) and outcrop in the Chino and Puente Hills along the western margin of the Chino Basin. In this report, the Fernando Group is considered consolidated bedrock and may be the shallowest bedrock encountered in Northwest MZ-1. The upper portion of the Fernando Group is more permeable than the lower portion and thus represents a gradual transition from the consolidated bedrock to the water-bearing sediments. The upper Fernando sediments are similar in texture and composition to the overlying water-bearing sediments, which make the distinction between the formations difficult to identify in borehole data.

2.2.2 Water-Bearing Sediments

During the Quaternary Period and continuing to present, an intense episode of faulting depressed the Chino Basin area and uplifted the surrounding mountains and hills. Sediments eroded from the mountains were transported and deposited in the Chino Basin atop the consolidated bedrock as interbedded, discontinuous layers of gravel, sand, silt, and clay to form the water-bearing sediments.

The water-bearing sediments are typically composed of gneissic and granitic debris from the San Gabriel Mountains and can be differentiated into the older alluvium of Pleistocene age[7] and younger alluvium of Holocene age.[8] The general character of these formations is known from well driller's logs and surface outcrops.

The older alluvium was deposited on top of the consolidated bedrock. The older alluvium contains many local unconformities because of the nature of the alluvial fan deposition process. It is typically thicker than the younger alluvium and is the main source of groundwater in the western Chino Basin. In Northwest MZ-1, the older alluvium is composed of thick sediment sequences that contain layers of clay-rich, fine-grained sediments

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[5] Approximately 145 to 5 million years ago.

[6] Approximately 5 to 2 million years ago.

[7] Approximately 2 million to 12,000 years ago.

[8] Approximately 12,000 years ago to the present.

interstratified with coarser-grained sediments. These fine-grained layers are of low permeability and can cause confining conditions in the aquifer system.

The younger alluvium was deposited on top of the older alluvium after a period of weathering and erosion of the older alluvium. The younger alluvium consists of rounded fragments derived from the erosion of bedrock, reworked older alluvium, and the mechanical breakdown of larger fragments within the younger alluvium itself. The younger alluvium varies in thickness from over 100-feet near the mountains to a just few feet south of Interstate 10, and it generally covers most of the northern half of the Chino Basin. Where it exists, it is commonly unsaturated and lies above the regional water table.

2.2.3 Hydrostratigraphic Cross-Sections

The hydrostratigraphy of the Study Area is illustrated by three hydrostratigraphic cross-sections. Figure 2-2 shows the plan-view location of the cross-sections. Figures 2-3a through 2-3c are profile-view cross-sections. Plotted on the profile-view cross-sections are well and borehole data, including: borehole lithology, short-normal resistivity logs, well casing perforations, specific capacities, water-quality data, and spring 2014 groundwater elevations. These cross-sections also show the three hydrostratigraphic layers (Layer 1, Layer 2, and Layer 3) that were delineated from the CBWM groundwater model reports prepared by WEI (2007 and 2015).

Layer 1 consists of the upper 500 to 1,000-feet of interbedded layers of coarse-grained sands and gravels, clay-gravel-sand mixtures, and clays. The upper portion of Layer 1 is unsaturated. The lower portion of Layer 1 is saturated and represents the shallow, unconfined aquifer system. The lower portion of Layer 1 appears to consist of a higher percentage of compressible, fine-grained sediments (silts and clays) than the upper portion of Layer 1.

Layer 2 consists of approximately 100 to 300-feet of sediment underlying Layer 1 and represents the upper portion of the deep aquifer system. Layer 2 sediments are generally characterized by an abundance of soft and firm clay layers and clay-sand-gravel mixtures and appear to contain a higher percentage of fine-grained sediments (silts and clays), compared to Layer 1. In the southwestern portion of MZ-1, the Layer 2 sediments have been shown to create confined groundwater conditions within and beneath Layer 2.

Layer 3 consists of up to 800-feet of sediment underlying Layer 2 and represents the lower portion of the deep aquifer system. Within the Study Area, few wells completely penetrate Layer 3. Layer 3 is generally characterized by a higher percentage of coarse-grained sediments (sand and gravel layers), compared to Layer 2. Like Layer 2, borehole resistivity in Layer 3 is low compared to Layer 1. This is likely because of the greater age, consolidation, and weathering of the sediments compared to Layers 1 and 2.

The bedrock formations underlying Layer 3 consist of semi-consolidated to consolidated sedimentary rocks that outcrop along the western margin of the Chino Basin in the Chino and Puente Hills. They consist of well-stratified marine sandstones, conglomerates, and shales.

Observations and Interpretations. Based on the hydrostratigraphic cross-sections, certain interpretations can be made about the relationship between the underlying lithology and the occurrence of land subsidence. Cross-sections A-A’ and C-C’ were drawn in a northeast to southwest direction to transect the areas of greatest historical land subsidence. These cross-sections show that the underlying saturated sediments in all three hydrostratigraphic layers contain multiple, interbedded fine-grained layers. These fine-grained layers (silt and clay layers) are susceptible to permanent compaction under reduced piezometric heads within the aquifer-system and are likely responsible for the historical land subsidence.

Data Gaps. The main data gaps with the current understanding of the hydrostratigraphy in the Study Area, and its role in the occurrence of land subsidence, are:

> *Lack of deep, high-resolution lithologic data in areas that experienced the greatest amount of land subsidence*. In the areas of maximum historical subsidence, there is a lack of deep-borehole lithologic data. Many boreholes did not penetrate the full thickness of the aquifer system in this area. For the deep-borehole data that does exist across Northwest MZ-1, it is not of high resolution and/or quality.[9] This is because high-resolution lithologic sampling and sediment description were not considered necessary for production wells in the early and mid-1900’s. At least one deep borehole in the area of maximum recent subsidence, with high-resolution and high-quality descriptions of borehole lithology and geophysics, is necessary to understand the occurrence and mechanisms of aquifer-system deformation. These data are also critical for predictive modeling of the aquifer-system deformation to assist in developing a subsidence management plan.
>
> *Lack of depth-specific piezometric data*. Aquifer-system compaction may be occurring (or may have occurred historically) at specific depths within a complex, stratified, multiple aquifer system. There is a lack of depth-specific piezometric data in Northwest MZ-1—particularly in the deep portions of the aquifer system. This is because: (i) there are few wells located in the areas that have shown the greatest subsidence, and (ii) most of the deep wells in Northwest MZ-1 are screened across all three hydrostratigraphic layers. Depth-specific piezometric data is necessary to understand the depth-specific occurrence and mechanisms of aquifer-system deformation. These data are also critical for predictive modeling of the aquifer-system deformation to assist in developing a subsidence management plan.

2.3 Spatial Distribution of Fine-Grained Sediments versus Vertical Ground Motion

The fine-grained layers (silt and clay layers) within the aquifer-system in Northwest MZ-1 are susceptible to permanent compaction under reduced piezometric heads and are likely responsible for historical land subsidence. To explore the relationship between the texture of the underlying sediments and the occurrence of land subsidence, the spatial distribution of the

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[9] In the context of land subsidence studies, “high resolution and quality” refers to a one-foot sampling interval that follows the Unified Soils Classification System and contains a detailed description of the sediments—particularly the fine-grained sediments.

fine-grained sediments was mapped versus the historical land subsidence as measured by InSAR over various periods since 1992.

Figure 2-4a to 2-4c are maps of the Study Area that show the spatial distribution of the percent fine-grained sediments versus vertical ground motion for each hydrostratigraphic layer. Each figure compares the spatial distribution of fine-grained sediments to the vertical ground motion that occurred over four periods:

- September 1992 to December 1995
- January 1996 to November 1999
- June 2005 to September 2010, and
- March 2011 to January 2016

Mapping the spatial distribution of the percentage of fine-grained sediments within each hydrostratigraphic layer followed these steps:

1. Identify all boreholes within the Study Area (excluding the area north of the San Jose Fault) with available lithologic data from well driller's logs and well completion reports.
2. Determine the percentage of borehole penetration across each hydrostratigraphic layer. Only boreholes with 90% or greater penetration across a hydrostratigraphic layer were used in the analysis for a given layer. For Layer 1, the percentage of borehole penetration was determined using the saturated thickness of the aquifer. The saturated thickness of Layer 1 was based on 1933 groundwater elevations (WEI, 1999). Only boreholes with 90% or greater penetration across the 1930s saturated thickness of hydrostratigraphic Layer 1 were used in the analysis.
3. Assign each lithologic unit described in the borehole lithologic logs to a hydrostratigraphic layer based on the depth interval of the lithologic unit. Lithologic units that cross two stratigraphic layers were split between the hydrostratigraphic layers based on the depth of the hydrostratigraphic layer top or bottom.
4. Categorize each lithologic unit as either "fine-grained" or "coarse-grained," based on the primary grain size(s) as described in the borehole lithologic log. Lithologic units described as being primarily composed of sands, gravels, cobbles, and/or boulders were categorized as coarse-grained. Lithologic units described as being primarily composed of clays and/or silts were categorized as fine-grained.
5. Calculate the percentage of fine-grained sediments for each borehole by hydrostratigraphic layer by: (i) adding the thickness of each fine-grained lithologic unit in a given stratigraphic layer, (ii) dividing that sum by the total thickness of the stratigraphic layer, and (iii) multiplying that quotient by 100 to convert it to a percentage.
6. Create a raster of the percent of fine-grained sediment by hydrostratigraphic layer using the following method:
    a. In ArcGIS, map each borehole with the attribute of percent fine-grained sediment for each hydrostratigraphic layer.

b. Use the Ordinary Kriging method of interpolation in the ArcGIS Geostatistical Analyst to create a raster of fine-grained sediment distribution for each hydrostratigraphic layer. There was not a sufficient spatial distribution of boreholes that penetrated hydrostratigraphic Layer 3 by 90% or more to create a raster.

Observations and Interpretations. Figure 2-4a to 2-4c indicate a general relationship between the spatial distribution of fine-grained sediments and the occurrence of land subsidence:

- Figure 2-4a is a map of percent fine-grained sediments in Layer 1 versus vertical ground motion. Layer 1 has the greatest number and widest distribution of boreholes that penetrated at least 90% of the layer. For each time-period of ground motion, the locations of greatest subsidence are in the northern Central MZ-1 and central and western portions of Northwest MZ-1. These areas generally correspond to locations with a high percentage of fine-grained sediments in Layer 1.

- Figure 2-4b is the same type of map for Layer 2 but has fewer boreholes that penetrated at least 90% of the layer. Still, for each time-period of ground motion, the locations of greatest subsidence are in the northern Central MZ-1 and central and western portions of Northwest MZ-1. These areas generally correspond to locations with a high percentage of fine-grained sediments in Layer 2.

- Figure 2-4c is the same type of map for Layer 3, but has too few boreholes that penetrated at least 90% of the layer to create a raster across the Study Area.

Data Gap. The main data gap regarding the current understanding of the spatial distribution of fine-grained sediments and its role in the occurrence of land subsidence is:

> *Lack of deep, high-resolution lithologic data in areas that experienced the greatest amount of land subsidence*. In the areas of maximum historical subsidence, there is a lack of deep-borehole lithologic data. There are few wells in these areas, and many of these wells do not penetrate the full thickness of the aquifer system. For the deep-borehole data that does exist across Northwest MZ-1, it is not of high resolution nor quality.[8] This is because the high-resolution of lithologic sampling and description of sediments was not considered necessary for production wells in the early to mid-1900's. At least one deep borehole in the area of maximum recent subsidence, with high-resolution and high-quality descriptions of borehole lithology and geophysics, is necessary to understand the occurrence and mechanisms of aquifer-system deformation. These data are also critical for predictive modeling of the aquifer-system deformation to assist in developing a subsidence management plan.

2.4 Groundwater Production, Recharge, Groundwater Levels, and Vertical Ground Motion

Groundwater production and recharge are stresses to the aquifer-system and can change groundwater levels within the aquifer-system. Groundwater level declines can cause inelastic (permanent) compaction of the aquifer-system sediments, which results in permanent land subsidence. Understanding how groundwater production and recharge affect groundwater levels and the occurrence of land subsidence is crucial to the development of a subsidence-management plan.

To explore the relationship between groundwater production and recharge and the occurrence of land subsidence, the historical patterns and magnitude of groundwater production and recharge were mapped versus the historical land subsidence as measured by InSAR.

Observations and Interpretations. Figure 2-5 shows the spatial distribution of historical groundwater production, artificial recharge at flood-control and water conservation basins,[10] and vertical ground motion within the Study Area for the following periods:

- September 1992 to December 1995
- January 1996 to November 1999
- June 2005 to September 2010, and
- March 2011 to January 2016

The main observations and interpretations from these maps are:

- The spatial distribution of production has not always been spatially coincident with the main areas of subsidence: note that typically, the main centers of production are on the periphery of the main areas of subsidence. This observation suggests that the spatial distribution of the subsidence is controlled, at least in part, by the spatial distribution of the fine-grained, compressible sediments within the aquifer-system.
- Beginning around 2005, the areas of maximum subsidence in Northwest MZ-1 shifted closer to the San Jose Fault as production increased in the area near the Montclair Basins. This observation indicates that production has some control on the spatial distribution of subsidence.
- Between 1993 and 2015, annual recharge at the College Heights, Upland, Montclair, and Brooks Basins ranged from approximately 2,000 to 23,000 acre-ft/yr and averaged 8,400 acre-ft. The maps in Figure 2-5 show that artificial recharge does not have an immediate discernable effect on the spatial distribution of subsidence.

Figure 2-6 is a time-series chart that shows groundwater production and artificial recharge in Northwest MZ-1 since 1978 (post-Judgment measurements), the long-term history of groundwater levels at wells in the area from 1930-2015, and the history of land subsidence at three locations as measured by InSAR from 1993-2016. The chart shows that from about 1930 to 1978, groundwater levels in Northwest MZ-1 declined by about 175 feet, presumably due to groundwater production exceeding the yield of the Chino Basin, which was the reason for stipulation of the Chino Basin Judgment. Since 1978, groundwater levels partially recovered but have remained below the levels of 1930. The chart also shows a gradual and persistent trend of land subsidence from 1993-2016 as measured by InSAR within Northwest

---

[10] Artificial recharge includes recycled water, storm water, and imported water.

MZ-1 (Point A and Point B) – about 1.2-feet of subsidence occurred from 1993 through 2016, even though groundwater levels remained relatively stable during this period. In Central MZ-1 at Point C, the chart shows a different time-series of subsidence compared to Northwest MZ-1: a greater rate of subsidence during 1992-2000 and a lesser rate of subsidence from 2005-2016.

Figures 2-7a and 2-7b are time-series charts that more closely compare groundwater levels at wells to the vertical ground motion near those wells during 1992-2016 in Northwest MZ-1. The locations of the wells and the InSAR measurements are shown in the Figure 2-6 inset.

The main observations and interpretations from these charts are:

- Figure 2-6 shows that groundwater levels respond to changes in production and recharge in Northwest MZ-1. Groundwater levels rise when production declines and recharge increases. Groundwater levels decline when production increases and recharge declines. However, subsidence in Northwest MZ-1 has persistently and gradually occurred from 1992-2016 (see Points A and B). The persistent subsidence cannot be explained entirely by the concurrent changes in groundwater levels. A plausible explanation for the subsidence is that thick, slow-draining aquitards underlying Northwest MZ-1 are compacting in response to the historical declines in groundwater levels that occurred from 1930 to 1978.

- Figure 2-6 shows that during 1992-2000, the highest rates of subsidence in the Study Area were in the northern portions of Central MZ-1 (Point C). After 2005, the location of the highest rates of subsidence shifted away from Central MZ-1 to Northwest MZ-1 adjacent to the San Jose Fault (Points A and B). The decreasing subsidence rates in Central MZ-1 were coincident with decreased groundwater production and recovery of groundwater levels further to the south in the Managed Area during the development of the MZ-1 Plan between 2000 and 2006. These observations suggest that groundwater-management activities in the Managed Area and Central MZ-1 do not directly and immediately impact ground motion in Northwest MZ-1. However, there is not enough groundwater level data available in this portion of the basin to confirm these interpretations.

- Figures 2-7a and 2-7b show that the rates of subsidence in Northwest MZ-1 have slightly increased and decreased contemporaneously with the drawdown and recovery of groundwater levels, but that subsidence remains persistent even during periods of groundwater level recovery. These observations suggest that in Northwest MZ-1: (i) changes in groundwater levels have at least some control on rates of compaction within the aquifer system and (ii) that the pre-consolidation head within some portions of the aquifer system are at higher elevations than the current groundwater elevations. The exact elevation(s) of the pre-consolidation head is unknown.

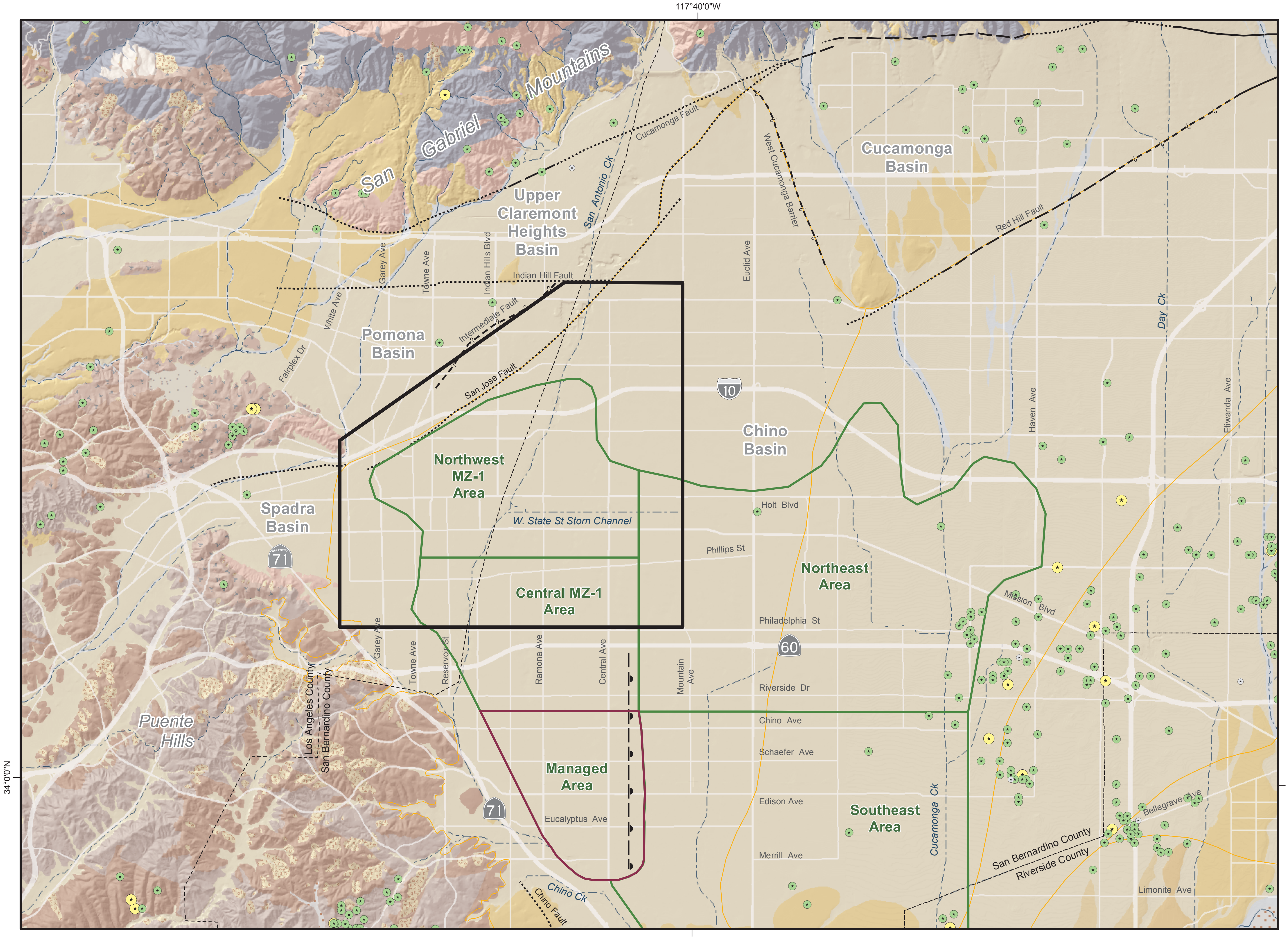
- It is logical to assume that subsidence began when groundwater levels began to decline in 1930. If subsidence has been occurring at an averaged constant rate of 0.05 ft/yr since 1930, then portions of Northwest MZ-1 have subsided by about 4.3 feet.

Figure 2-8 is a map of change in groundwater levels from 1933 to 2014. The map shows that groundwater levels have declined across most of Northwest MZ-1 by up to 200 feet during this period. These declines in groundwater levels were a result of the long-term history of production and recharge in the Chino Basin. Figure 2-8 also shows a color-ramped raster of the land subsidence that occurred from 1992-2016. The contours of groundwater level declines generally coincide with the spatial pattern of historical subsidence, but not precisely. The main observations and interpretations from this map are:

- There has been a long-term imbalance of recharge and discharge in the area.
- The spatial coincidence of the declines in groundwater levels and the subsidence indicates a cause-and-effect relationship. That said, it appears that the areas of maximum historical subsidence do not precisely coincide the areas of greatest declines in groundwater levels. This suggests that the subsidence was, in part, controlled by the distribution of fine-grained sediments within the aquifer-system.

Data Gaps. The main data gaps with regard to the current understanding of how groundwater production and recharge affect groundwater levels and the occurrence of land subsidence are:

> *Lack of data to reveal cause-and-effect relationships*. Aquifer-system compaction may be occurring (or may have occurred historically) at specific depths within Northwest MZ-1 under depth-specific groundwater level conditions. There is a lack of depth-specific groundwater level and aquifer-system compaction data in areas that show the highest rates of subsidence. Depth-specific data, obtained from piezometers and extensometers, is critical to understanding how groundwater production and recharge affect groundwater levels and the deformation of the aquifer-system. These data are also critical for predictive modeling of the aquifer-system deformation to assist in developing a subsidence management plan.
>
> *Lack of knowledge of the pre-consolidation head within the compacting intervals of the aquifer system*. The observation that subsidence remains persistent, even during periods of groundwater level recovery, indicates that the pre-consolidation head is higher than the current groundwater heads in the aquifer system. Knowing the pre-consolidation head within the compacting intervals of the aquifer-system is necessary to develop a subsidence management plan to minimize or abate the ongoing subsidence. The groundwater level and aquifer-system deformation data necessary to identify the pre-consolidation head are best obtained from depth-specific piezometers and extensometers, located in the area of maximum subsidence, during the performance of passive and/or controlled aquifer-system stress tests in Northwest MZ-1.



Surface Geology

(Source: CGS Special Report 217)

Water-Bearing Sediments

▨	Qya/f	Younger Alluvium: Quaternary (Holocene to late-Pleistocene) undifferentiated alluvial deposits
▨	Qoa/f	Older Alluvium: Quaternary (Pleistocene) undifferentiated alluvial deposits

Consolidated Bedrock Formations

▨	Tss	Tertiary sedimentary and volcanic rocks
▨	Tsh	
▨	Tv	
▨	gr	Cretaceous and Pre-Cretaceous igneous and metamorphic rocks
▨	pKm	

Faults

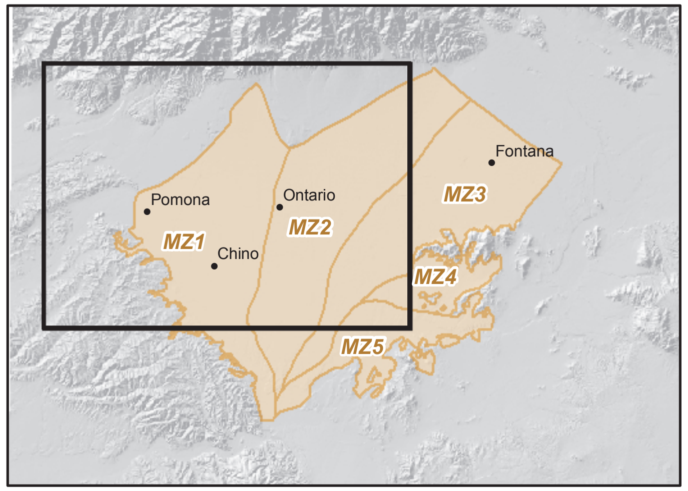
— Fault - Dashed where approximately located, dotted (?) where concealed

SCEDC Earthquake Catalog (1992 to 2015)

Earthquake Epicenters (local magnitude)

●	< 2.0
●	2 - 3
●	3 - 4
●	4 - 5
●	5 - 6

▭ Northwest MZ-1 Study Area



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Author: NWS
Date: 8/11/2016
Document Name: Figure 2-1

0 1 2 3 *Miles*
0 2 4 *Kilometers*

Initial Hydrogeologic Conceptual Model
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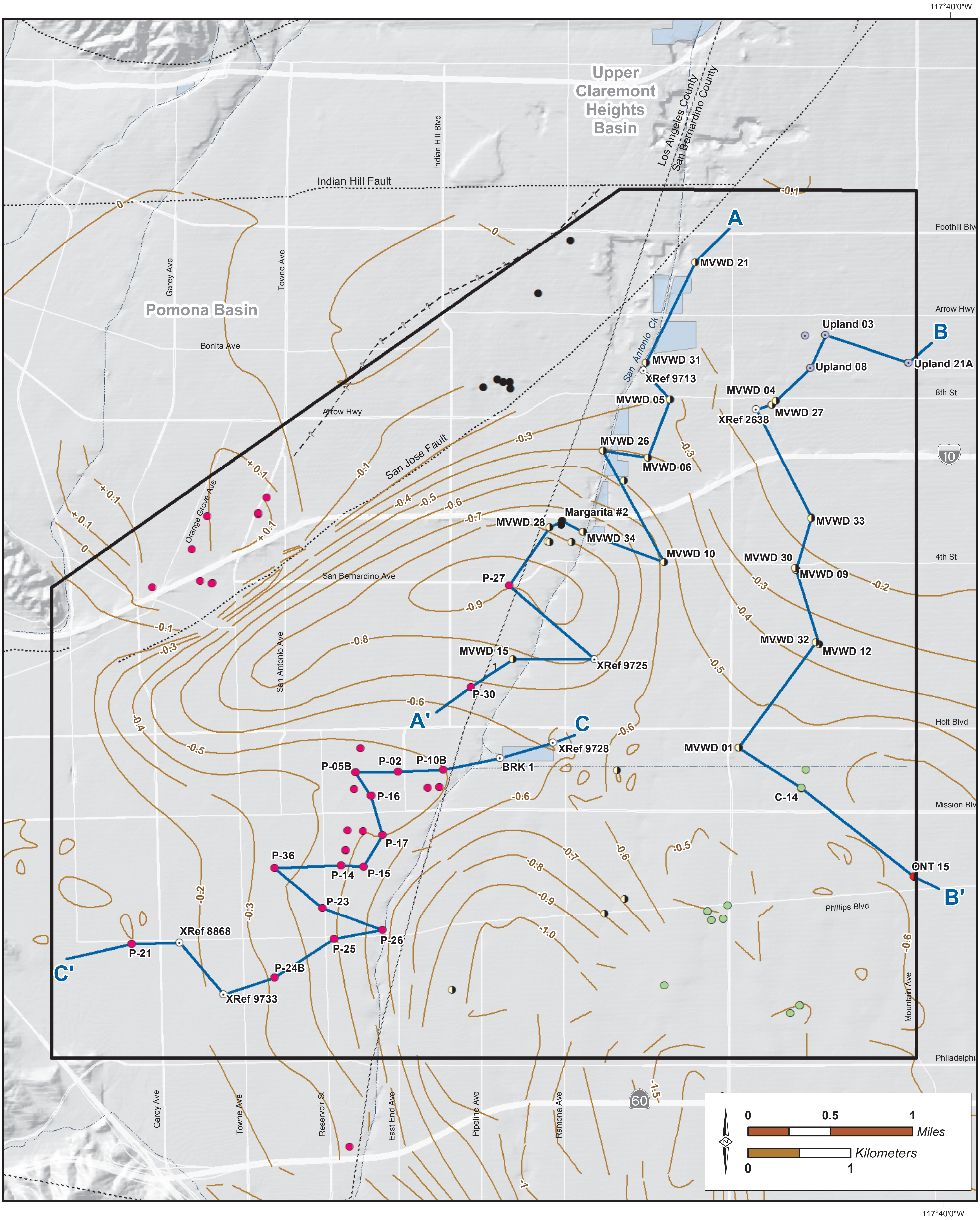
Geologic Map of the Western Chino Basin

Figure 2-1



-0.1- Contours of Relative Change in Land Surface Altitude as Measured by InSAR Sep-1992 to Dec-2014 (feet)

Hydrostratigraphic Cross-Sections on Figures 2-3a, 2-3b, and 2-3c

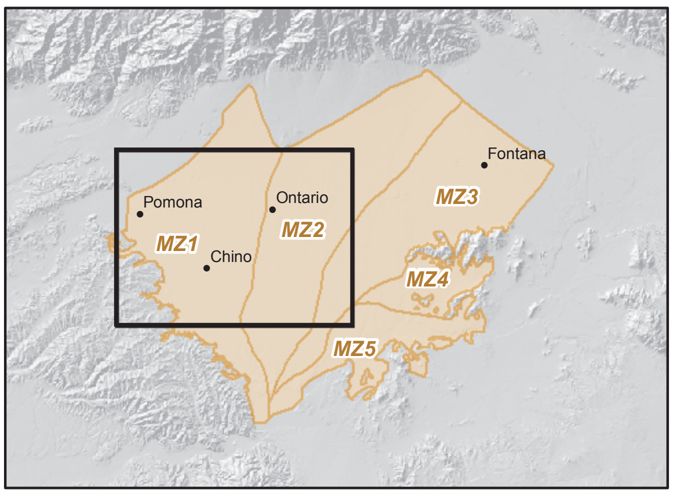
Northwest MZ-1 Study Area

Production Wells by Owner

◐ Ontario	⊙ Upland	● Chino
● Pomona	● GSWC	◐ MVWD
⊙ Private		

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain



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Wildermuth Environmental, Inc.

Author: NWS
Date: 8/11/2016
Document Name: Figure 2-2

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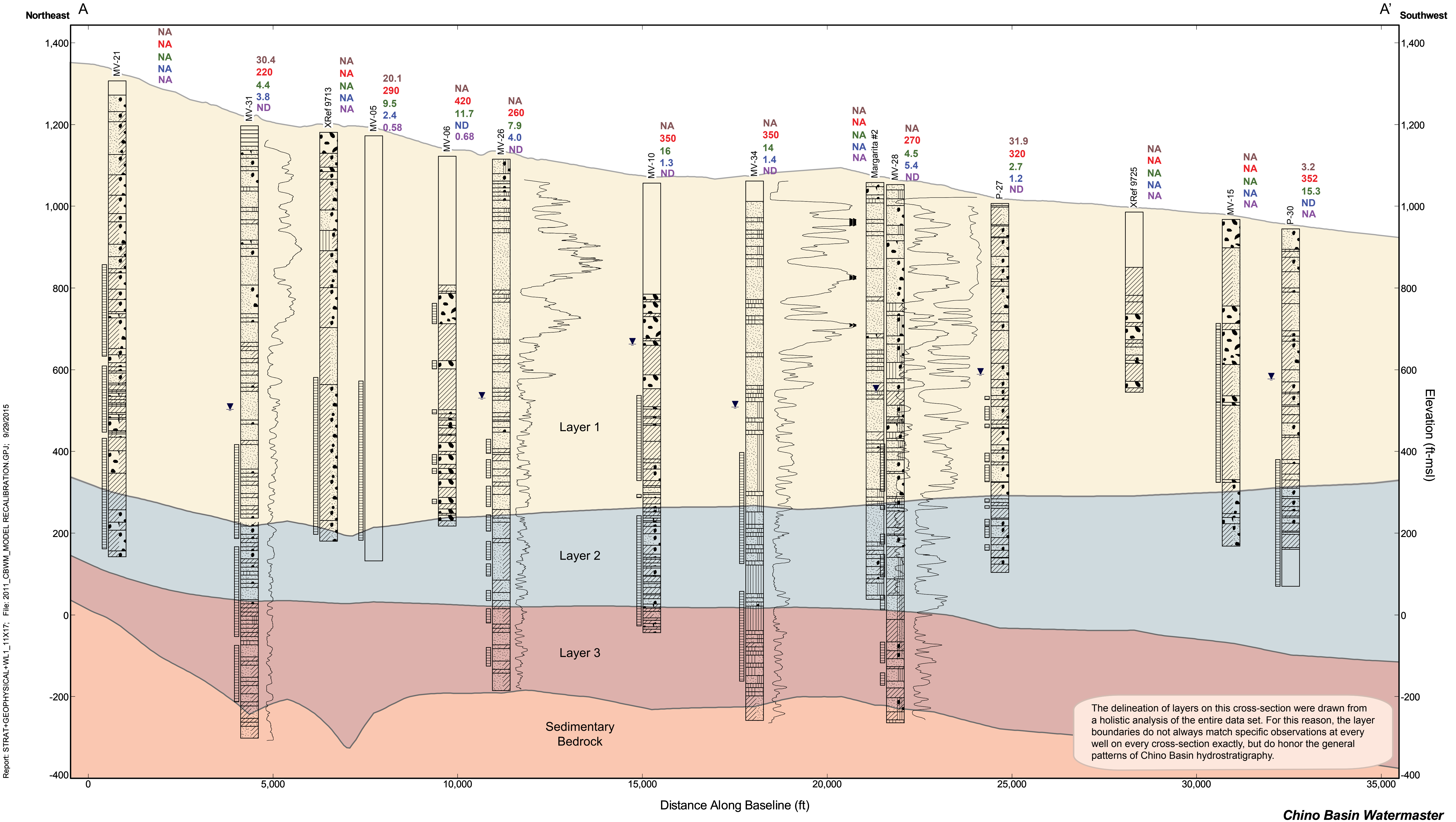
Hydrostratigraphic Cross-Section and Well Location Map

Figure 2-2



The delineation of layers on this cross-section were drawn from a holistic analysis of the entire data set. For this reason, the layer boundaries do not always match specific observations at every well on every cross-section exactly, but do honor the general patterns of Chino Basin hydrostratigraphy.

Report: STRAT+GEOPHYSICAL+WL1_11X17; File: 2011_CBWM_MODEL RECALIBRATION.GPJ; 9/29/2015

Prepared by:

WEI
www.weiwater.com

Vertical Scale: 1" = 217'
Horizontal Scale: 1" = 2,283'
Vertical Exaggeration = 1:11

Borehole Lithologic Graphics

⬚	Topsoil	⬚	Granite
●	Gravel	⬚	Decomposed Granite
⬚	Sand	▨	Interbeded Sandstone/Siltstone
▥	Silt		
▨	Clay		

Where the lithologic graphic column is split, the primary component is on the left side of the column; secondary component(s) are on the right.

▥ Well Screen Interval

▼ Water Level (Spring 2014)

∫ 16" Short Normal Geophysical Log

Well Information

25.2	Specific Capacity (gpm/ft-dd)
200	TDS (mg/L)
3	Nitrate as N (mg/L)
2.15	Arsenic (ug/L)
4.25	TCE (ug/L)

Water quality is shown as maximum concentration for 2009-2014

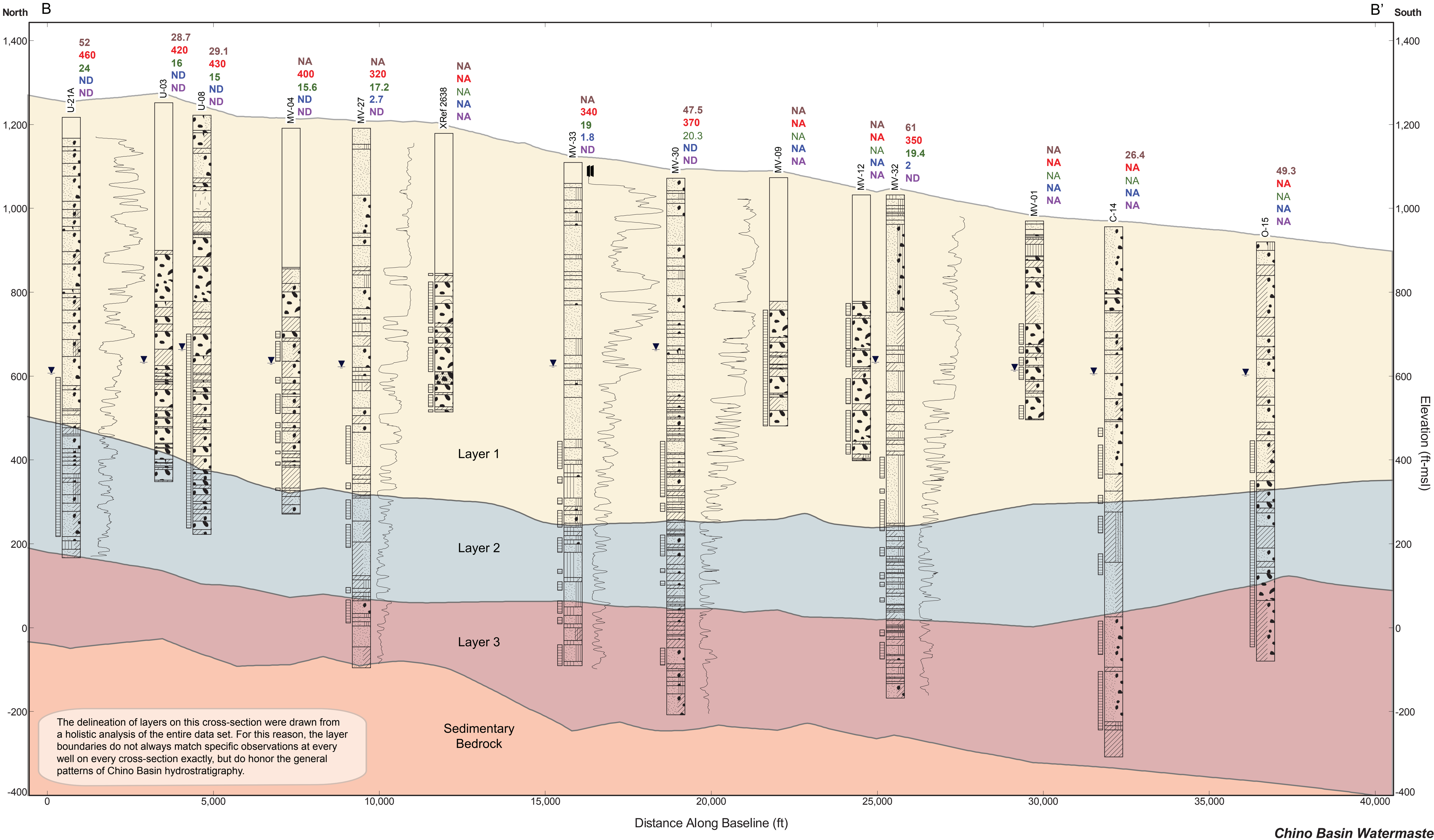
ND Non Detect
NA No Analysis

Chino Basin Watermaster

Initial Hydrogeologic Conceptual Model, Monitoring, and Testing Program for the Northwest MZ-1 Area

Cross-Section A-A'

Figure 2-3a



The delineation of layers on this cross-section were drawn from a holistic analysis of the entire data set. For this reason, the layer boundaries do not always match specific observations at every well on every cross-section exactly, but do honor the general patterns of Chino Basin hydrostratigraphy.

Report: STRAT+GEOPHYSICAL+WL1_11X17; File: 2011_CBWM_MODEL RECALIBRATION.GPJ; 9/29/2015

Prepared by:

WEI
www.weiwater.com

Vertical Scale: 1" = 217'
Horizontal Scale: 1" = 2747'
Vertical Exaggeration = 1:13

Borehole Lithologic Graphics

⬚ Topsoil	⬚ Granite
● Gravel	⬚ Decomposed Granite
⬚ Sand	⬚ Interbedded Sandstone/Siltstone
▥ Silt	
▨ Clay	

Where the lithologic graphic column is split, the primary component is on the left side of the column; secondary component(s) are on the right.

▥ Well Screen Interval

▼ Water Level (Spring 2014)

∫ 16" Short Normal Geophysical Log

Well Information

25.2	Specific Capacity (gpm/ft-dd)
200	TDS (mg/L)
3	Nitrate as N (mg/L)
2.15	Arsenic (ug/L)
4.25	TCE (ug/L)

ND Non Detect
NA No Analysis

Water quality is shown as maximum concentration for 2009-2014

Chino Basin Watermaster

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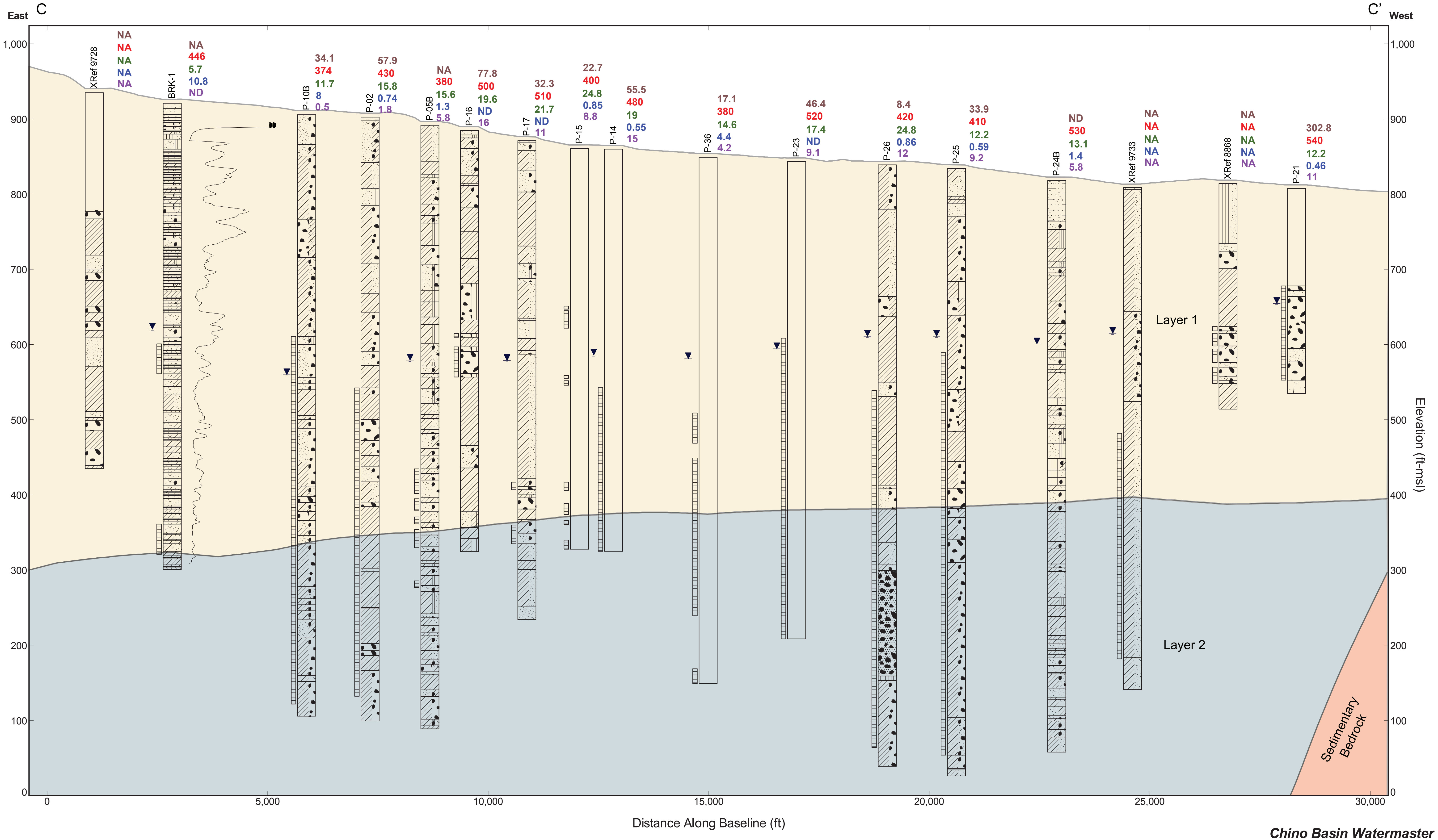
Cross-Section B-B'

Figure 2-3b



Report: STRAT+GEOPHYSICAL+WL1_11X17; File: 2011_CBWM_MODEL RECALIBRATION.GPJ; 9/29/2015

Prepared by:

WEI
www.weiwater.com

Vertical Scale: 1" = 217'
Horizontal Scale: 1" = 2,075'
Vertical Exaggeration = 1:10

Borehole Lithologic Graphics

▨ Topsoil	▨ Granite
● Gravel	▨ Decomposed Granite
▨ Sand	▨ Interbedded Sandstone/Siltstone
▥ Silt	
▨ Clay	

Where the lithologic graphic column is split, the primary component is on the left side of the column; secondary component(s) are on the right.

▥ Well Screen Interval

▼ Water Level (Spring 2014)

∿ 16" Short Normal Geophysical Log

Well Information

25.2	Specific Capacity (gpm/ft-dd)
200	TDS (mg/L)
3	Nitrate as N (mg/L)
2.15	Arsenic (ug/L)
4.25	TCE (ug/L)

ND Non Detect
NA No Analysis

Water quality is shown as maximum concentration for 2009-2014

Chino Basin Watermaster

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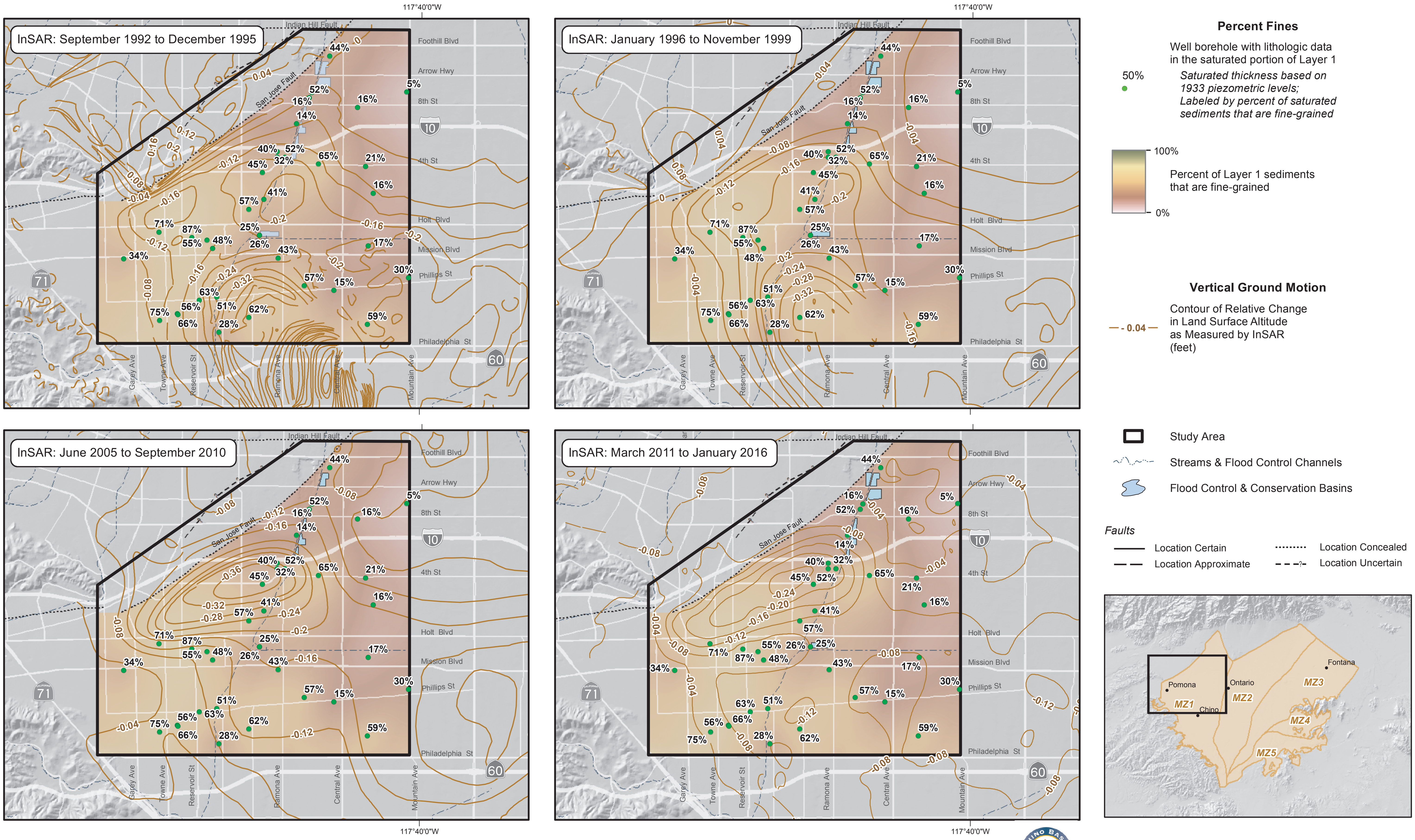
Cross-Section C-C'

Figure 2-3c



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Document Name: Figure 2-4a

0 1 2 3 Miles
0 2 4 Kilometers

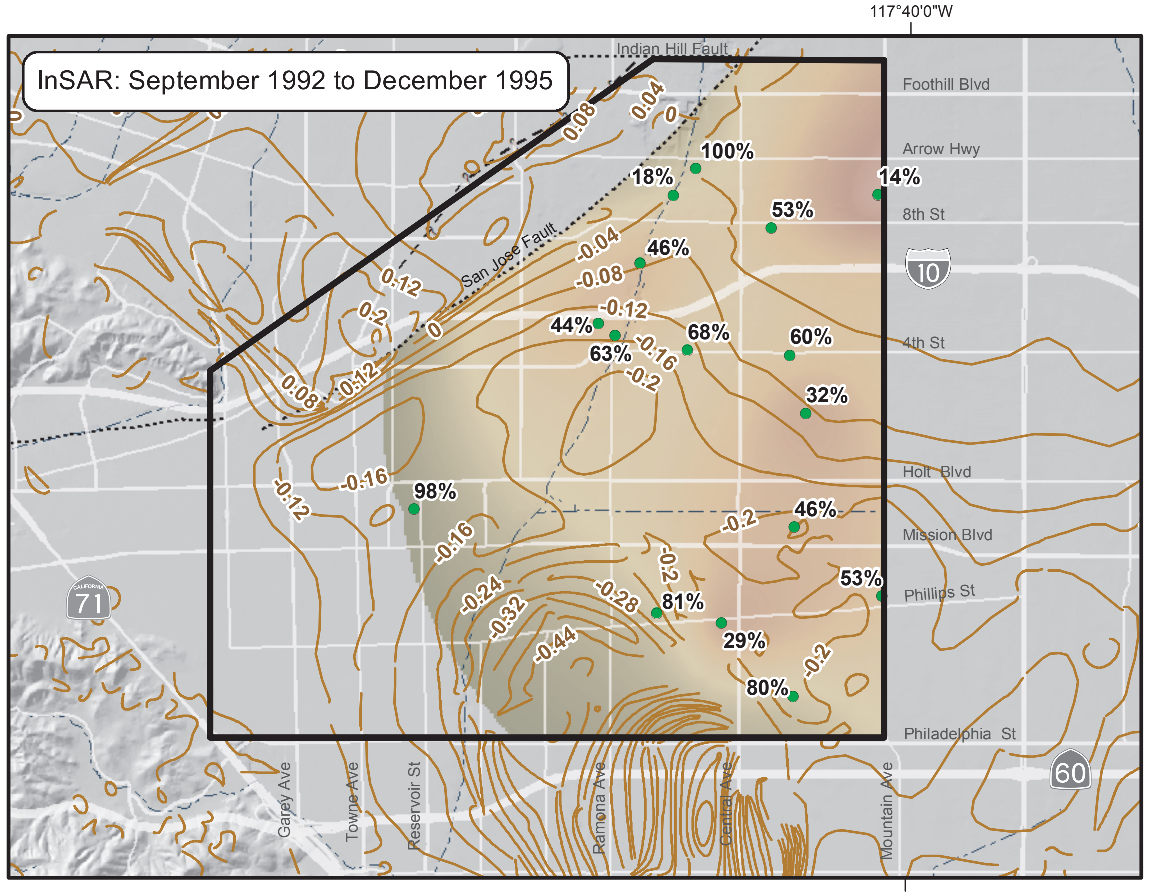
Chino Basin Watermaster
Partners in Basin Management

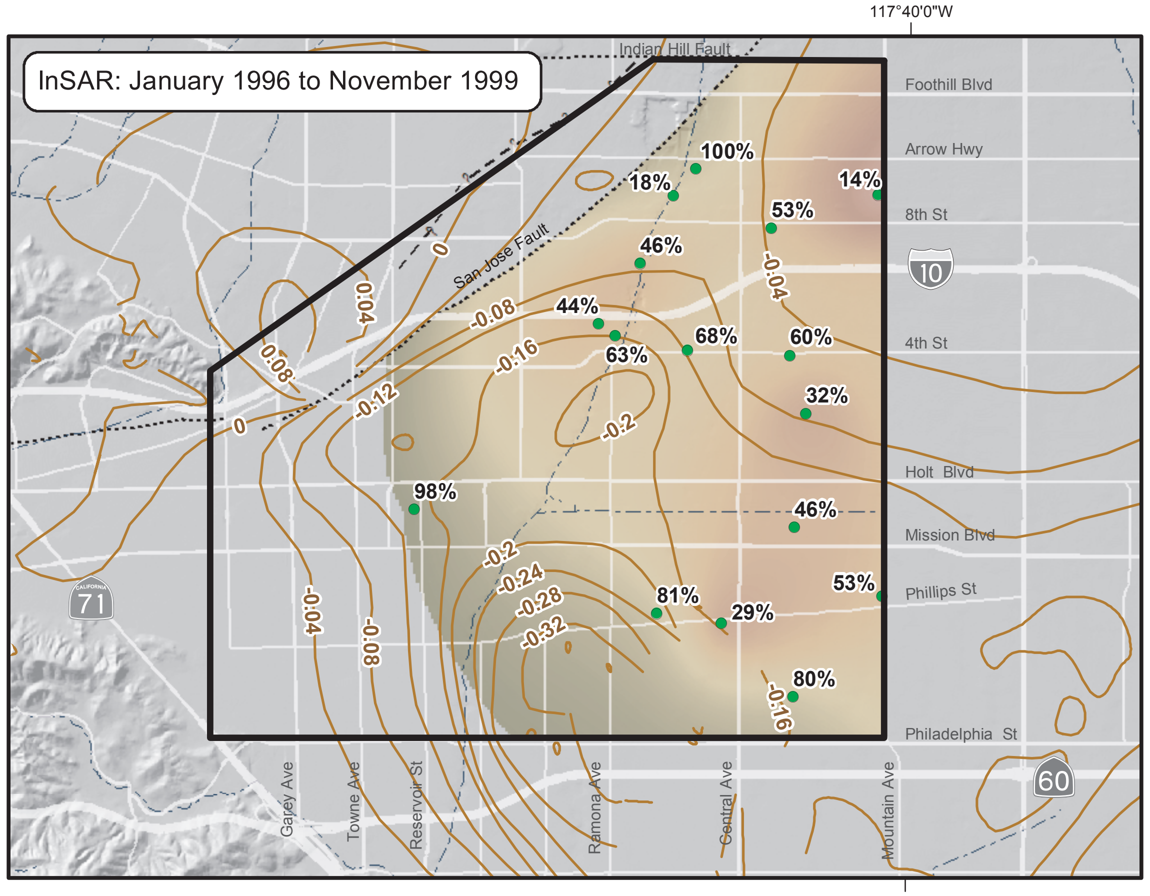
Initial Hydrogeologic Conceptual Model & Monitoring and Testing Program for the Northwest MZ-1 Area

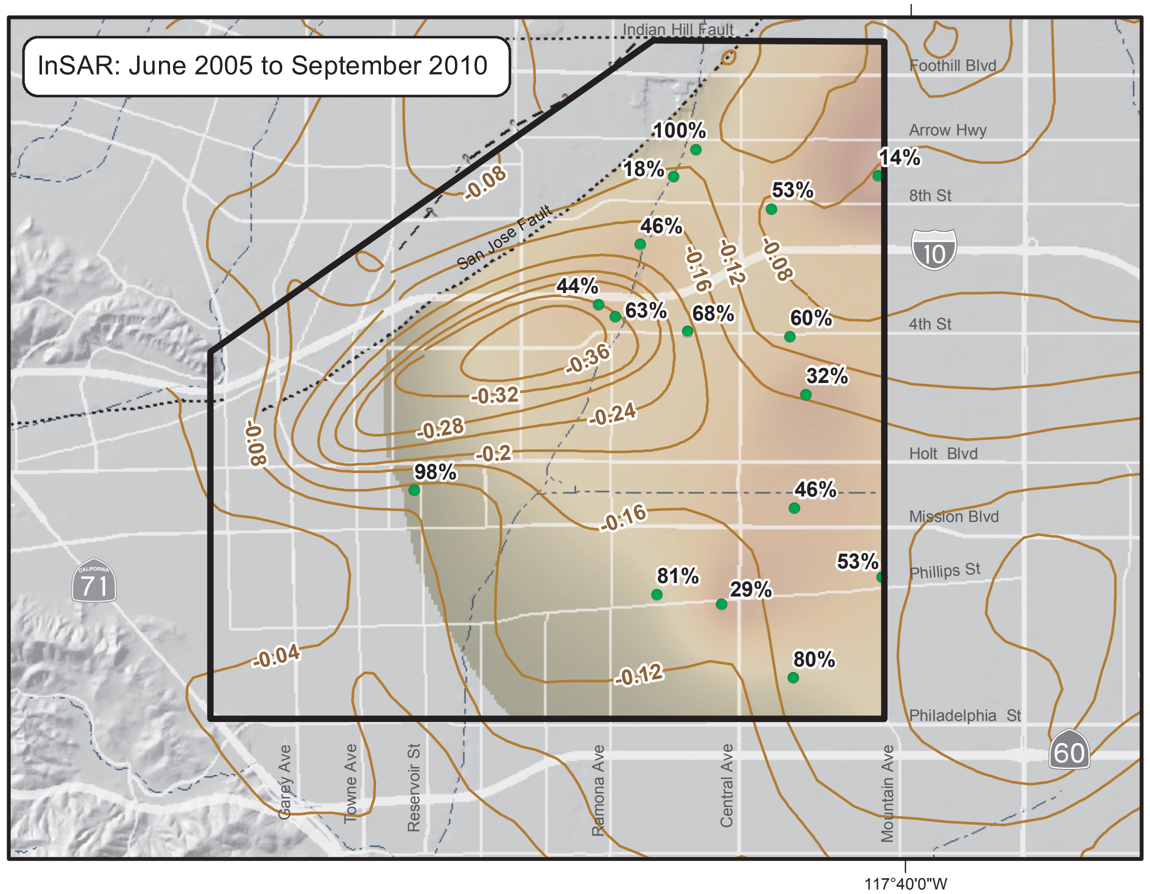
Spatial Distribution of Fine-Grained Sediment versus Vertical Ground Motion

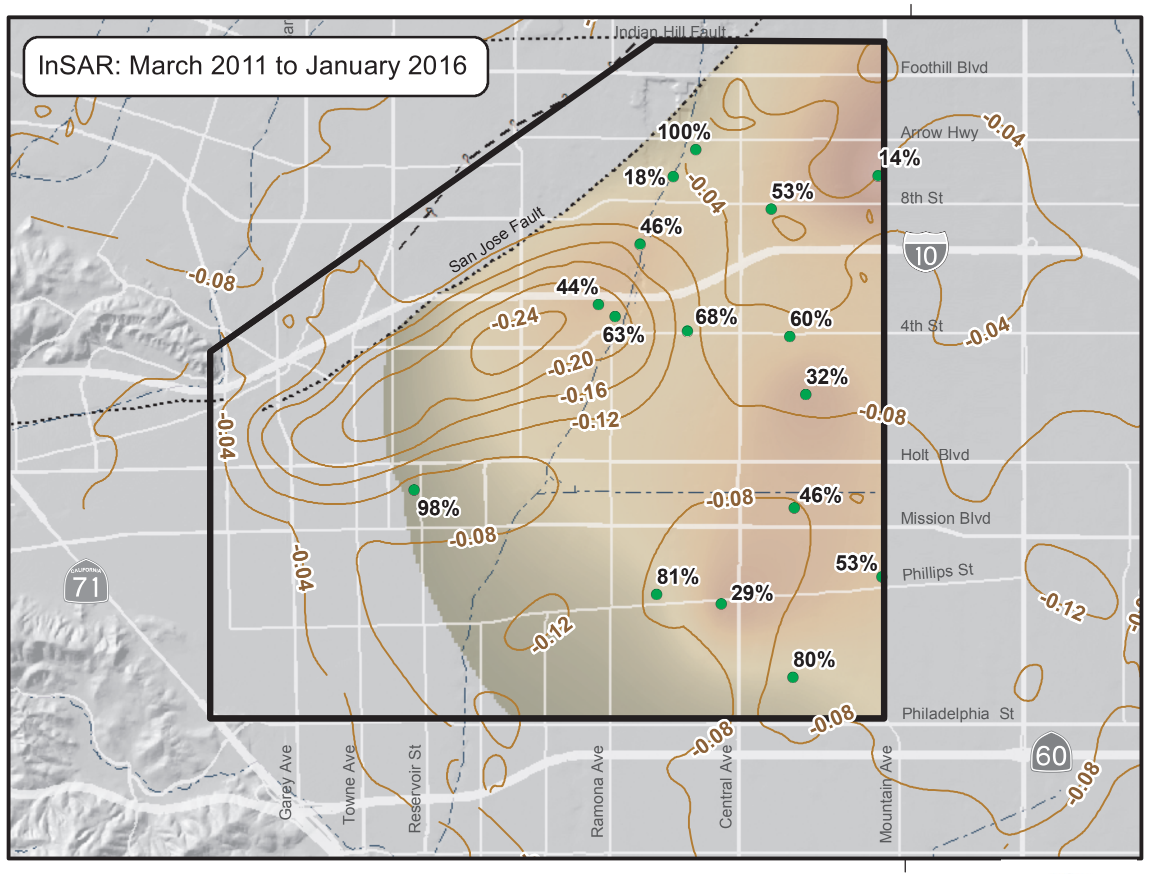
Layer 1

Figure 2-4a


InSAR: September 1992 to December 1995


InSAR: January 1996 to November 1999


InSAR: June 2005 to September 2010


InSAR: March 2011 to January 2016

Percent Fines

50% ● Well borehole with lithologic data in Layer 2
Labeled by percent of sediments that are fine-grained

100% – 0% Percent of Layer 2 sediments that are fine-grained

Vertical Ground Motion

— - 0.04 — Contour of Relative Change in Land Surface Altitude as Measured by InSAR (feet)

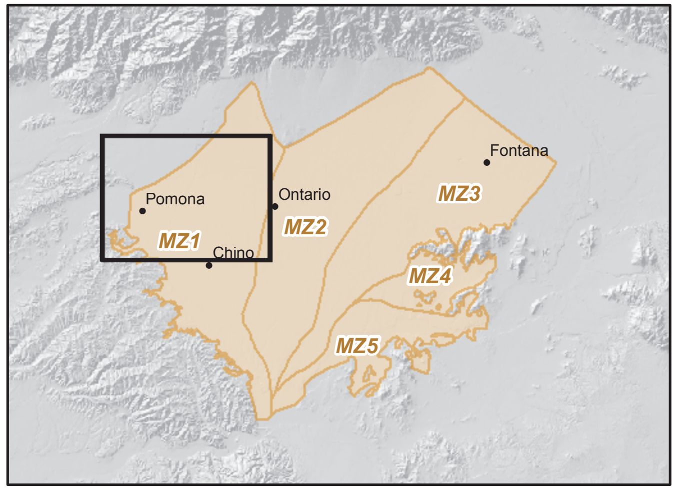
▭ Study Area

Streams & Flood Control Channels

Flood Control & Conservation Basins

Faults

—— Location Certain	········ Location Concealed
— — Location Approximate	- - -?- Location Uncertain



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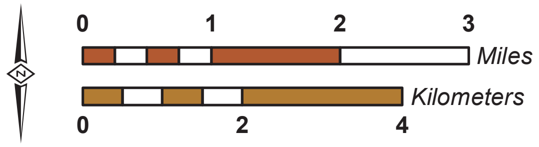
Author: NWS
Date: 8/11/2016
Document Name: Figure 2-4b



Initial Hydrogeologic Conceptual Model
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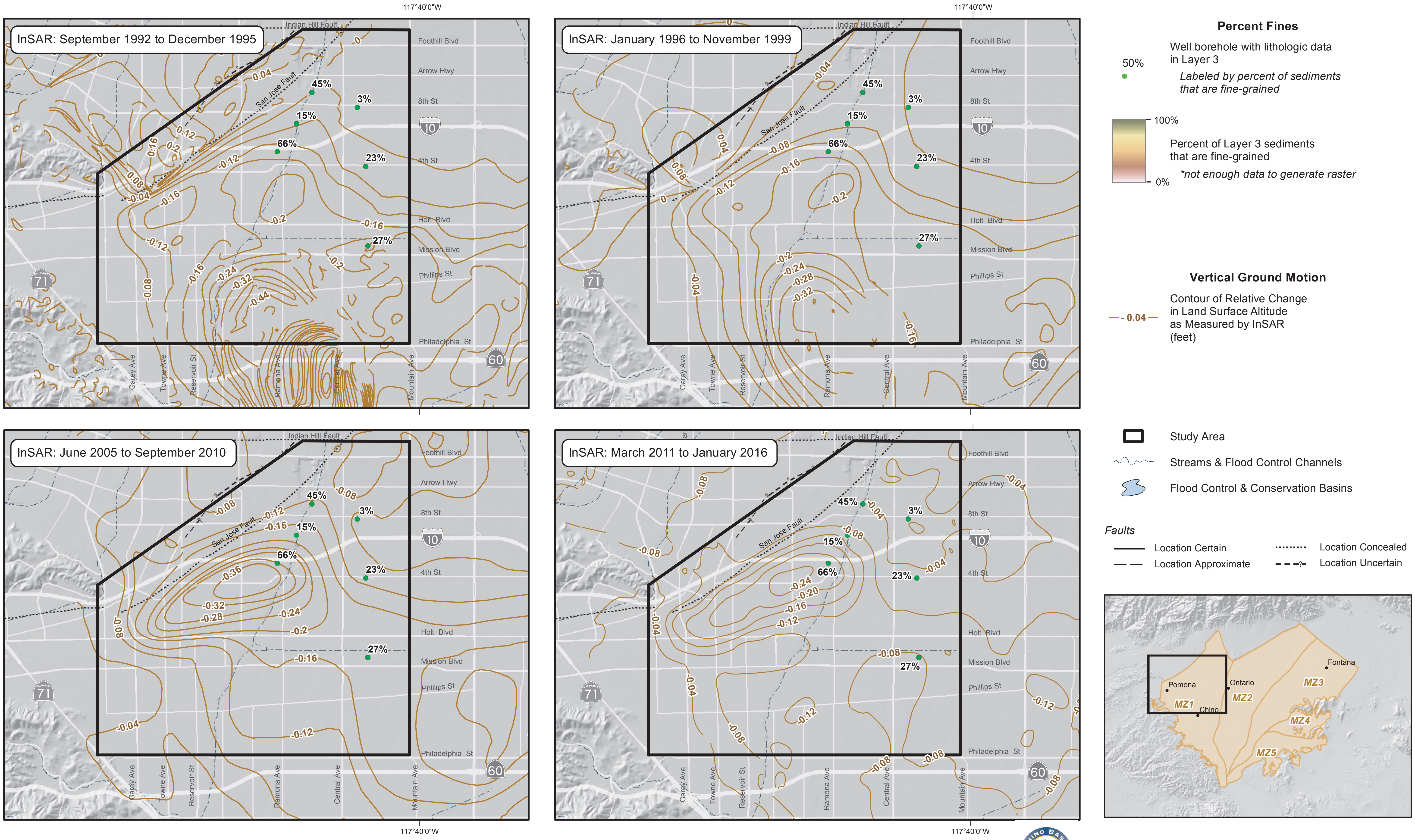
Spatial Distribution of Fine-Grained Sediment versus Vertical Ground Motion

Layer 2

Figure 2-4b



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Wildermuth Environmental, Inc.

Author: NWS
Date: 8/11/2016
Document Name: Figure 2-4c

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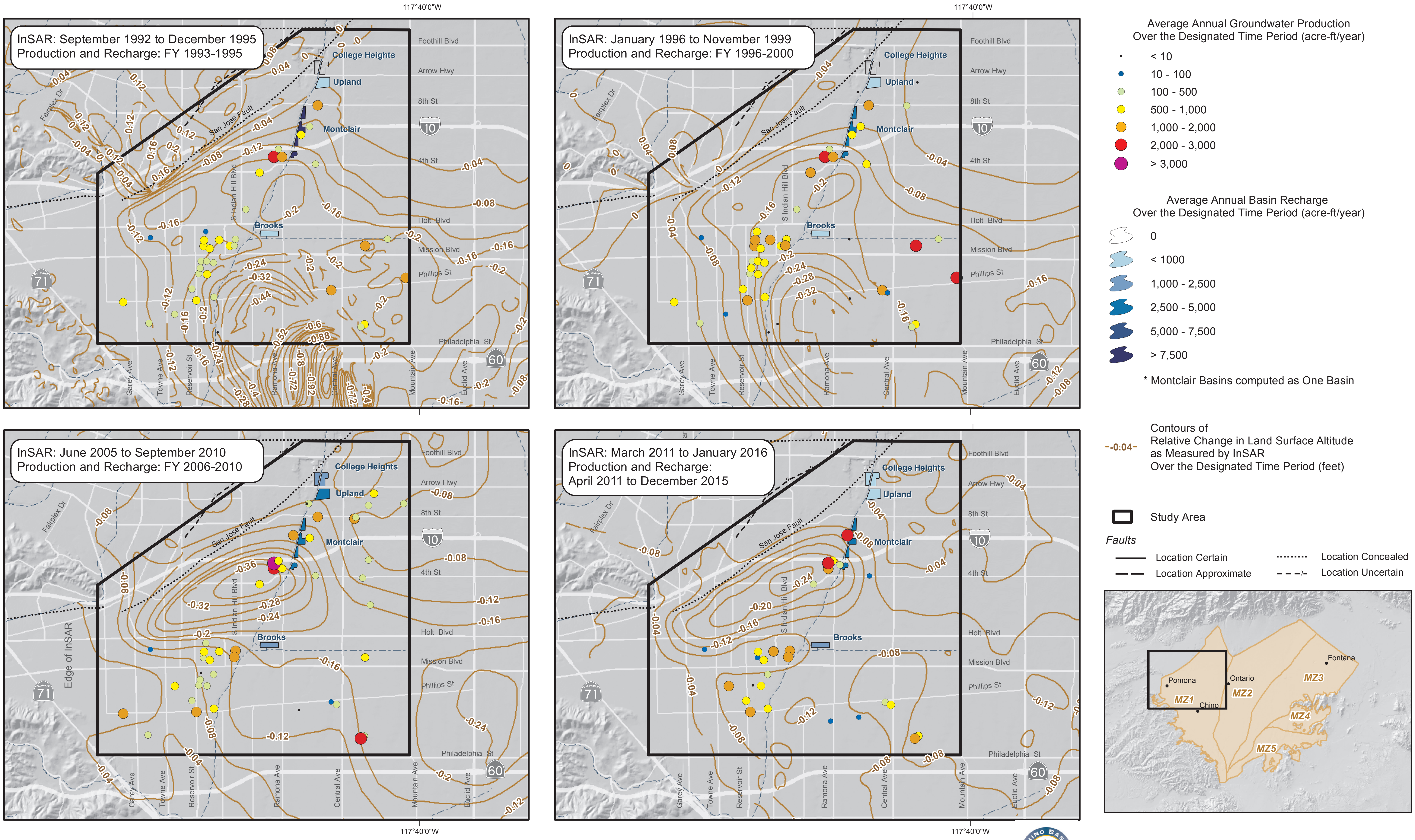
Spatial Distribution of Fine-Grained Sediment versus Vertical Ground Motion

Layer 3

Figure 2-4c



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WILDERMUTH ENVIRONMENTAL, INC.

Author: NWS
Date: 8/23/2016
Document Name: Figure 2-5

0 1 2 3 Miles
0 2 4 Kilometers

Initial Hydrogeologic Conceptual Model
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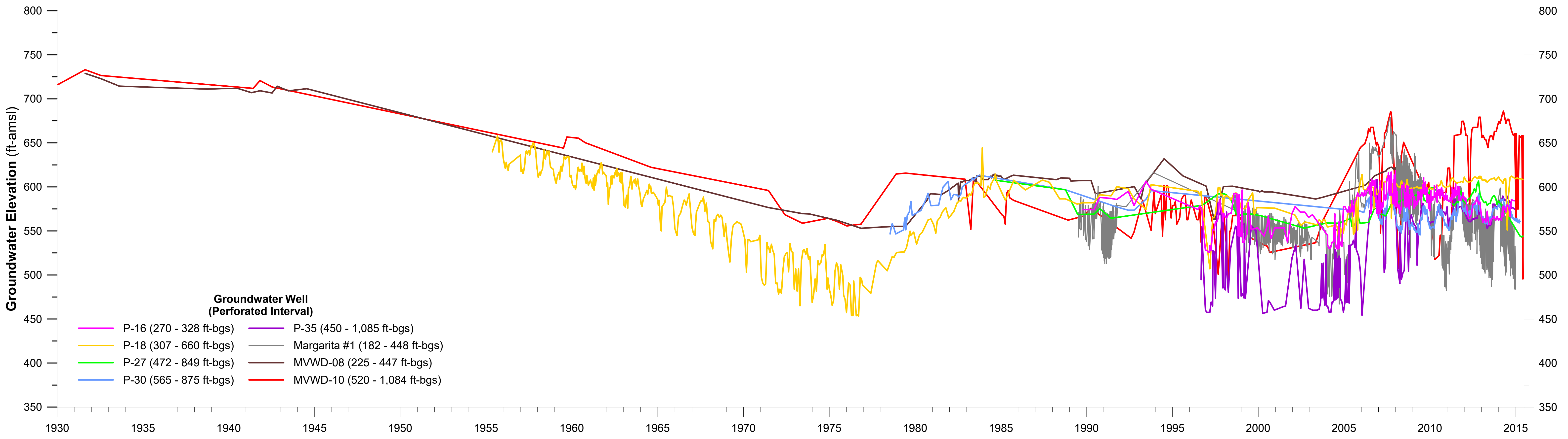
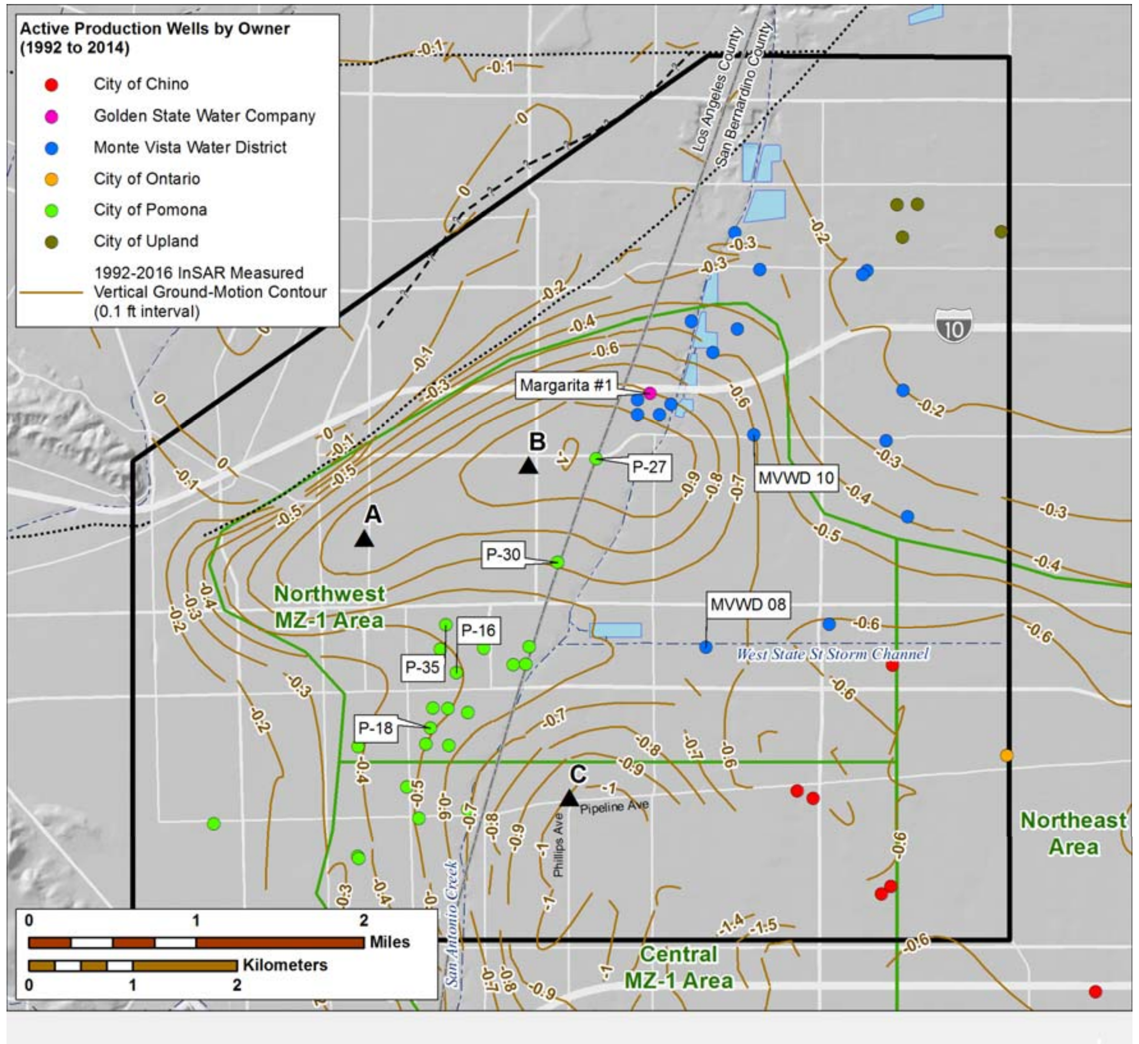
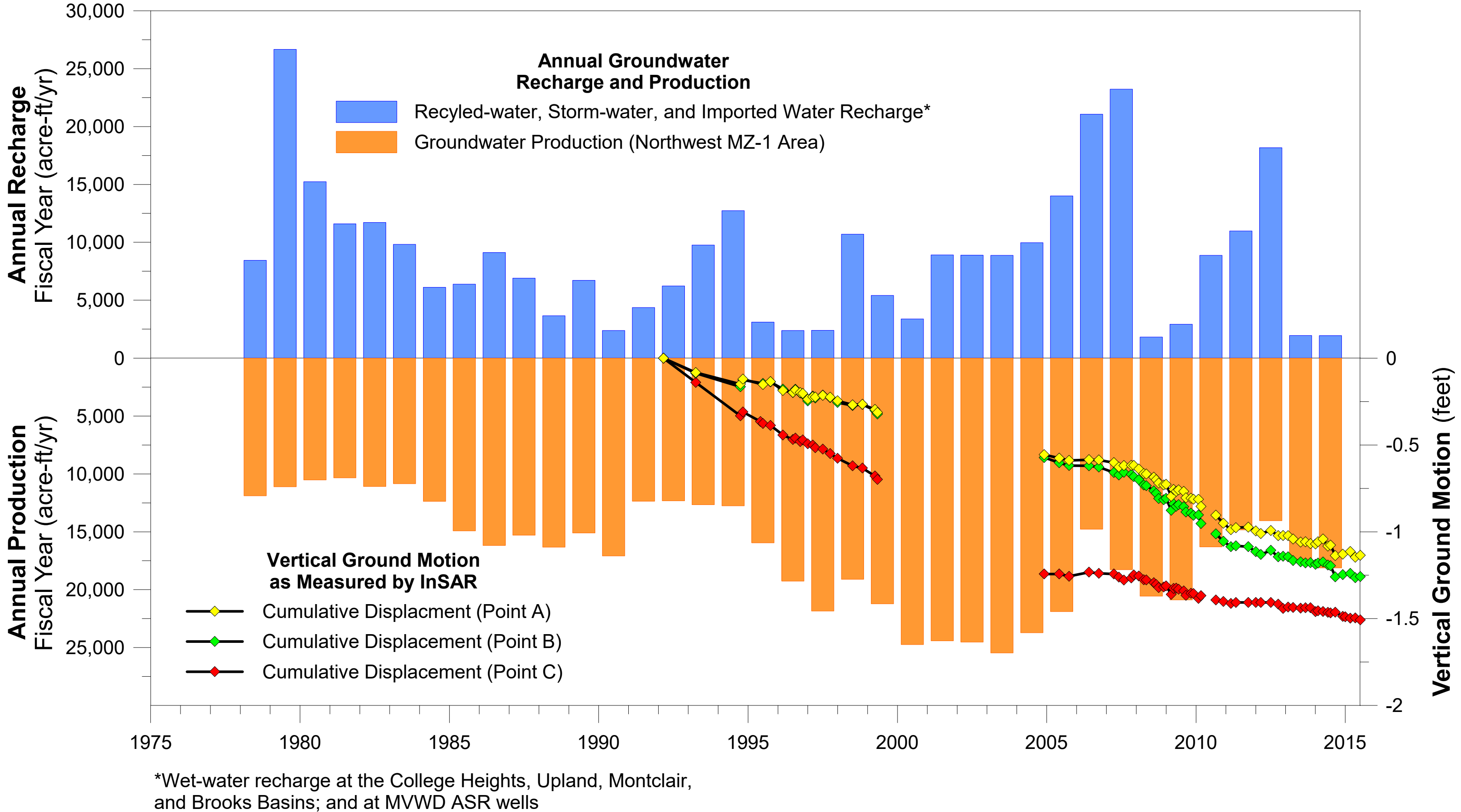
Groundwater Production and Recharge versus Vertical Ground Motion

Figure 2-5



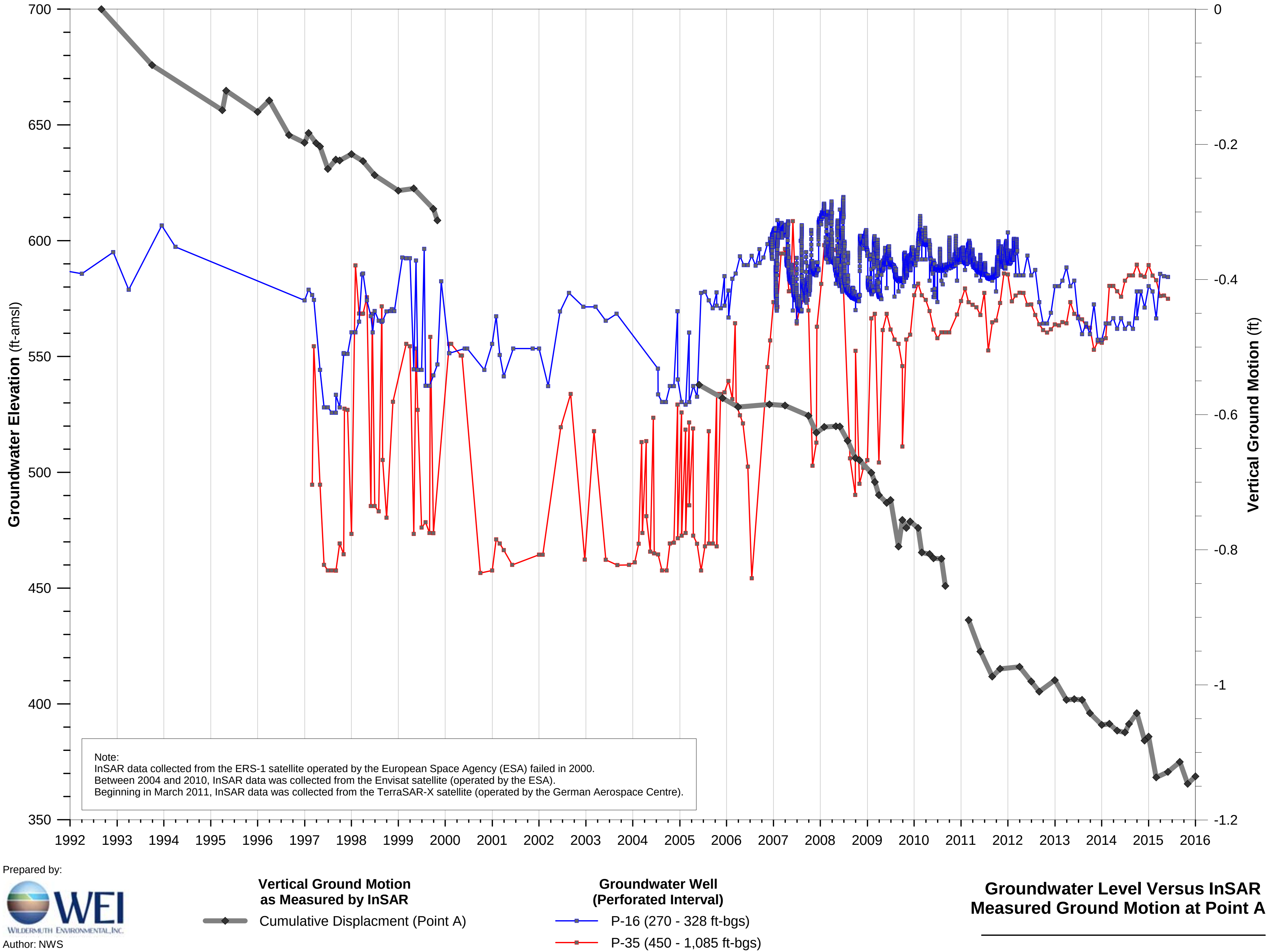




*Wet-water recharge at the College Heights, Upland, Montclair, and Brooks Basins; and at MVWD ASR wells

Time-History of Recharge, Production, Groundwater Levels, and Ground Motion in the Northwest MZ-1 Area

Figure 2-6



Note:
InSAR data collected from the ERS-1 satellite operated by the European Space Agency (ESA) failed in 2000.
Between 2004 and 2010, InSAR data was collected from the Envisat satellite (operated by the ESA).
Beginning in March 2011, InSAR data was collected from the TerraSAR-X satellite (operated by the German Aerospace Centre).

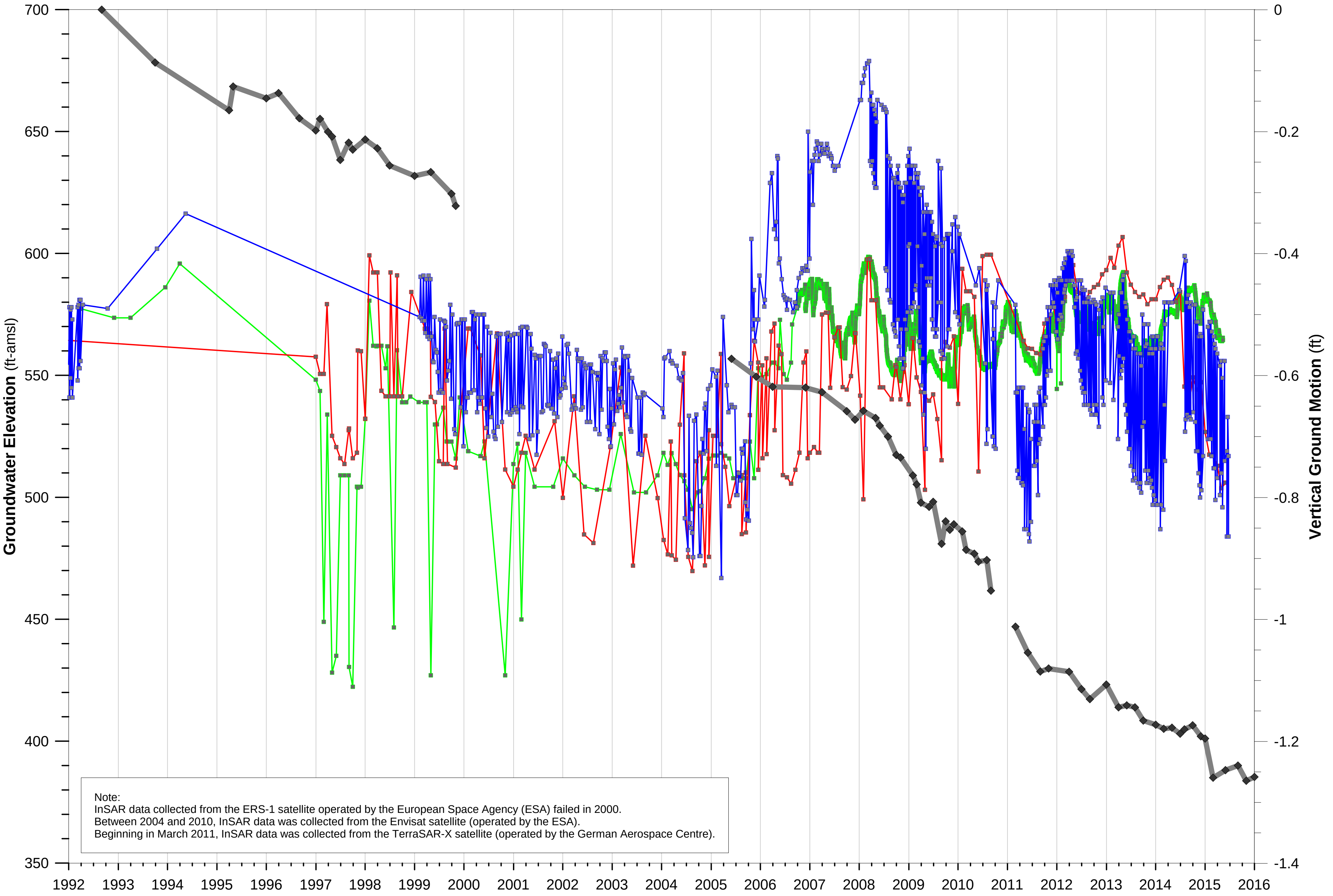
Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: NWS
Date: 20150810
Filename: Figure_2-7a.grf

Groundwater Level Versus InSAR Measured Ground Motion at Point A

Figure 2-7a



Note:
InSAR data collected from the ERS-1 satellite operated by the European Space Agency (ESA) failed in 2000.
Between 2004 and 2010, InSAR data was collected from the Envisat satellite (operated by the ESA).
Beginning in March 2011, InSAR data was collected from the TerraSAR-X satellite (operated by the German Aerospace Centre).

Vertical Ground Motion as Measured by InSAR

◆ Cumulative Displacement (Point B)

Groundwater Well (Perforated Interval)

🟦 Margarita #1 (182 - 448 ft-bgs)
🟥 P-27 (472 - 849 ft-bgs)
🟩 P-30 (565 - 875 ft-bgs)

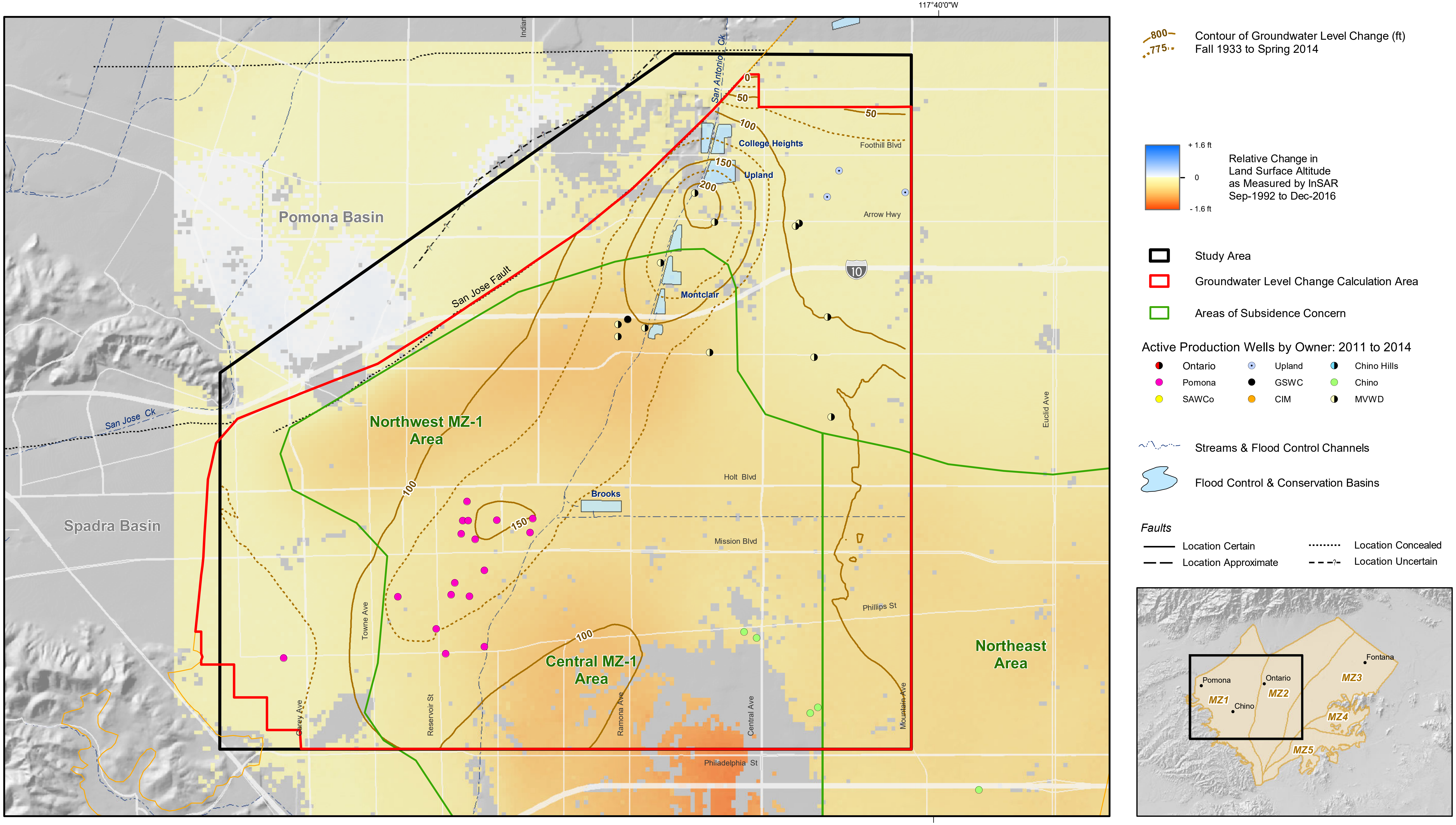
Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: NWS
Date: 20150810
Filename: Figure_2-7a.grf

Groundwater Level Versus InSAR Measured Ground Motion at Point B

Figure 2-7b



Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: NWS
Date: 12/18/2017
Document Name: Figure 2-8_mab_v2

Initial Hydrogeologic Conceptual Model
& Monitoring and Testing Program
for the Northwest MZ-1 Area

Groundwater Level Change from Fall 1933 to Spring 2014
Shallow Aquifer System

Figure 2-8

3.1 Objectives of the Monitoring and Testing Program

Section 2 described the major gaps in the current understanding of the occurrence and mechanisms of ongoing land subsidence in Northwest MZ-1. Those gaps include:

- Lack of deep, high-resolution lithologic data in areas that show the greatest amount of land subsidence
- Lack of depth-specific piezometric data
- Lack of depth-specific aquifer-system deformation data
- Lack of data to reveal cause-and-effect relationships
- Lack of knowledge of the pre-consolidation stress within the compacting intervals of the aquifer-system

A monitoring and testing program must be developed and implemented to fill these gaps in understanding and to develop a subsidence management plan for Northwest MZ-1. This section describes the monitoring and testing program that will be implemented in steps:

1. Setup the monitoring network and implement an initial monitoring and testing program.
2. Locate, design, and install an extensometer facility.
3. Design and perform controlled aquifer-system stress tests.

The information derived from the monitoring and testing will better describe the occurrence and mechanisms of the subsidence in Northwest MZ-1. This information will assist in the construction and calibration of modeling tools that can be used to test management strategies and predict the responses of the aquifer system (i.e. piezometric levels and aquifer-system deformation). Ultimately, the results of the monitoring and modeling efforts will be used to develop a subsidence management plan.

The monitoring and testing program described herein will be continually reviewed and revised (if appropriate) by Watermaster under the supervision and recommendations from the GLMC.

3.2 Initial Monitoring and Testing Program

The initial monitoring and testing program will expand upon current monitoring efforts being performed by Watermaster in Northwest MZ-1. The immediate objective of this task is to improve the understanding of the aquifer-system in Northwest MZ-1, which will assist in the siting and design of an extensometer.

Figure 3-1 is a map that shows the main facilities included in the initial monitoring program for groundwater production, artificial recharge, piezometric levels, vertical ground motion, and horizontal ground motion.

3.2.1 Groundwater Production

Watermaster will collect on/off times and pumping rates for all production wells in Northwest MZ-1 from the well owners. Pumping rates will be recorded at the highest practicable frequency. To the extent possible, the monitoring program will utilize the existing Supervisory control and data acquisition (SCADA) systems of the well owners.

3.2.2 Artificial Recharge

The Inland Empire Utilities Agency monitors the recharge of storm, imported, and recycled water at the College Heights, Upland, Montclair, and Brooks Basins within the Study Area. There are currently four aquifer storage and recovery wells within the Study Area owned and operated by the Monte Vista Water District. Watermaster will collect artificial recharge estimates at recharge basins from the Inland Empire Utilities Agency and at injection wells from the Monte Vista Water District.

3.2.3 Piezometric Levels

Figure 3-1 shows the monitoring network of wells that are being equipped with pressure transducers to measure and record piezometric levels. Watermaster has canvassed all wells in Northwest MZ-1 and has installed about 39 pressure transducers. To the extent possible, this monitoring program will use the existing SCADA systems of the well owners. Piezometric levels will be recorded once every 15 minutes at all wells equipped with transducers. The transducer will be downloaded and checked once per quarter. Watermaster will collect manually measured piezometric level data from pumpers for all wells that are not equipped with a pressure transducer.

3.2.4 Vertical Ground Motion

Watermaster will collect and compile vertical ground motion measurements via InSAR and leveling surveys at benchmarks:

- The InSAR data covers the western portion of Chino Basin. Data from the German Aerospace Center's TerraSAR-X satellite is collected for Watermaster approximately five times per year. Watermaster maintains an InSAR record of the Study Area from 1993 to the present. InSAR data is processed, checked, and analyzed annually.
- Watermaster has installed survey benchmarks across the Study Area that transect the areas of greatest historical subsidence and cross the San Jose Fault into the Pomona Basin. Figure 3-1 shows the location of these benchmarks. Leveling surveys will be performed annually in the fall when piezometric levels are at seasonal lows.

3.2.5 Horizontal Ground Motion

Watermaster has installed two arrays of survey benchmarks that cross the San Jose Fault for EDMs to measure the horizontal deformation of the land surface. Figure 3-1 shows the benchmark locations. The first array trends north along North San Antonio Avenue from its intersection with San Bernardino Avenue. The second array trends west along San Bernardino Avenue from its intersection with North San Antonio Avenue. EDM surveys across these arrays are measured annually in concert with the leveling surveys.

3.2.6 Passive Monitoring and Preliminary Stress Testing

The initial monitoring and testing program consists of the following components:

- Establish monitoring and reporting strategies for production and piezometric level data with well owners within the Study Area and conduct passive monitoring. This monitoring effort will produce data during a period of "uncontrolled" operations for groundwater production and artificial recharge. The data will be analyzed and shared with the GLMC. The objective of this effort is to understand better the dynamics of the aquifer-system via the monitoring of production and piezometric levels at a high frequency.
- Based on the analysis of the passive monitoring data, plans will be developed for short-term controlled pumping tests, if deemed appropriate by the GLMC. The objective of this effort is to further the understanding of the aquifer-system dynamics to assist with the location and design of an extensometer and the subsequent controlled aquifer-system stress testing.
- Prepare a technical memorandum, titled *Results of Initial Monitoring and Testing Program*, to document the improved understanding of the hydraulic stresses and responses of the aquifer-system in Northwest MZ-1. The improved understanding will assist in siting an extensometer facility and in the preparation of its plans and specifications.

3.3 Installation of an Extensometer Facility

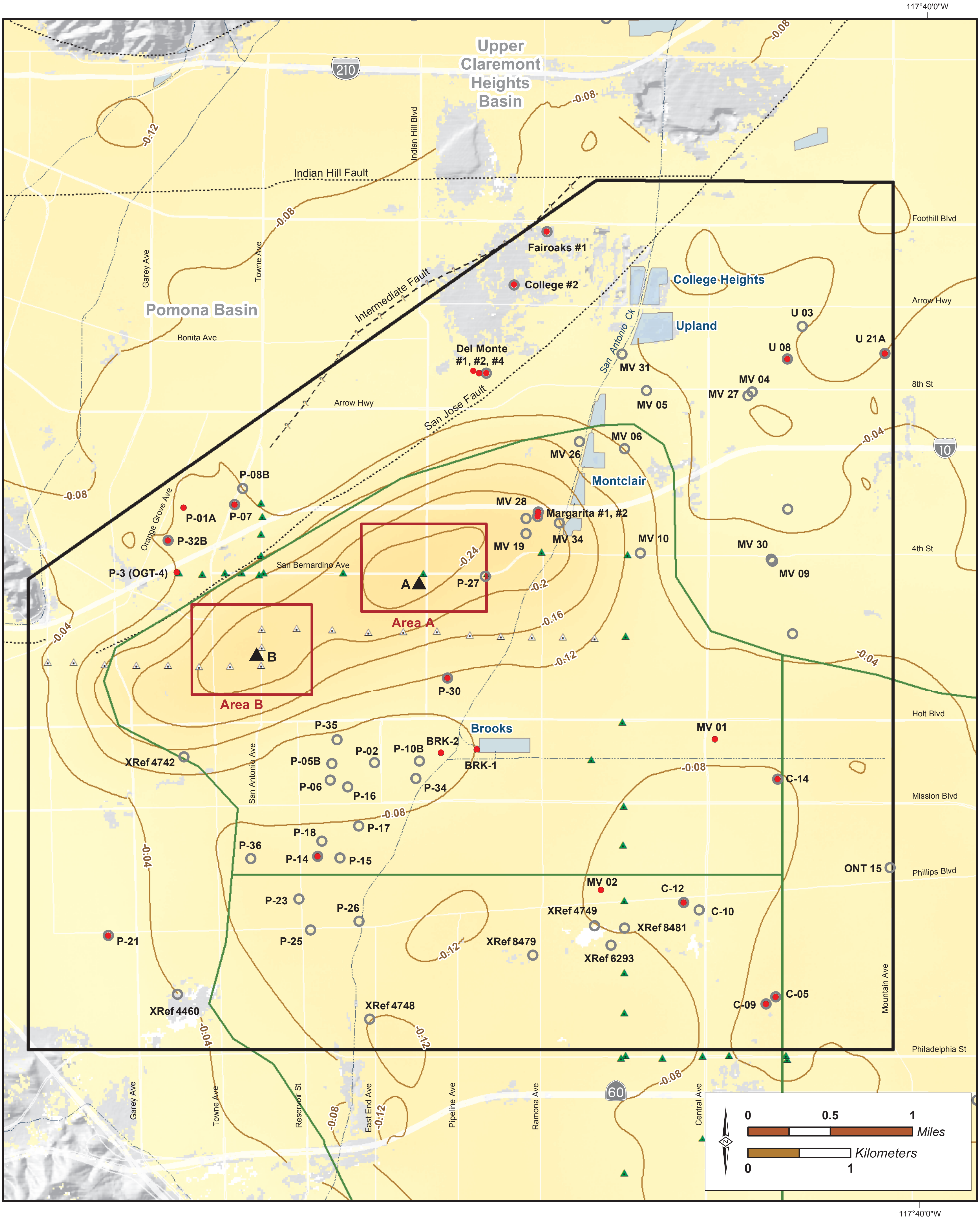
At least one extensometer facility is needed within the Study Area to provide the necessary information to develop a subsidence management plan. Figure 3-1 shows two logical locations for an extensometer facility. These locations are within areas that show the maximum historical subsidence, are adjacent to the major well fields in the Study Area, and are adjacent to the San Jose Fault where the differential land subsidence is occurring.

The extensometer facility will likely include a shallow borehole drilled to a total depth of about 750 ft-bgs and a deep borehole drilled to a total depth of about 1,500 ft-bgs. Two piezometers will be installed in each borehole at progressively deeper depths to measure piezometric levels and water quality at various depths within the aquifer system. Each piezometer will be equipped with a cable extensometer to measure the aquifer-system deformation occurring within the depth interval of the piezometer. The wellhead completions and data-loggers will be installed in two vaults that will be flush with the ground surface. Figure 3-2 illustrates the conceptual design of one dual-borehole extensometer facility.

The tasks associated with the installation of the extensometers will include: perform a siting study to choose a preferred site, perform California Environmental Quality Act (CEQA) compliance, acquire the site and obtain construction and permanent easements, prepare plans and specifications, prepare a bid package, select a contractor, construct the extensometer facility, equip the extensometer facility with monitoring devices, prepare the extensometer completion report, and commence monitoring. Figures 3-3a and 3-3b show the two logical locations, Area A and Area B, respectively, for an extensometer facility over a recent air photo to illustrate current land uses in these areas.

3.4 Long-Term Aquifer-System Stress Testing

After installation of the extensometers, Watermaster will coordinate and conduct a long-term and controlled stress test of the aquifer-system. The existing evidence, described in this report, indicates that the pre-consolidation stress is higher than the current piezometric levels in the Study Area. Therefore, the stress test will likely involve the increase of piezometric levels in an effort to identify the pre-consolidation stress. There are several methods to increase piezometric levels, such as modification of pumping patterns, in-lieu recharge, wet-water recharge via spreading, injection, or a combination of methods. Watermaster anticipates that the stress testing will last for at least one year. The long-term stress testing will result in the information critical to the development of the subsidence management plan, just as it was with the development of the Guidance Criteria in the Managed Area (WEI, 2006).



-0.4 Contours of Relative Change in Land Surface Altitude as Measured by InSAR Mar-2011 to Jan-2016 (feet)

+1 ft / 0 / -0.1 / -1 ft Relative Change in Land Surface Altitude as Measured by InSAR Mar-2011 to Jan-2016

▭ InSAR data absent (incoherent)

Survey Benchmarks

- ▲ Existing Monument
- △ Proposed Monument (FY2016-17)

▭ Target Areas for the Pomona Extensometer (detail shown on Figure 3-3)

● Well Monitored by Pressure Transducer

○ Active Production Well - 2015

▲ InSAR Measurement Point

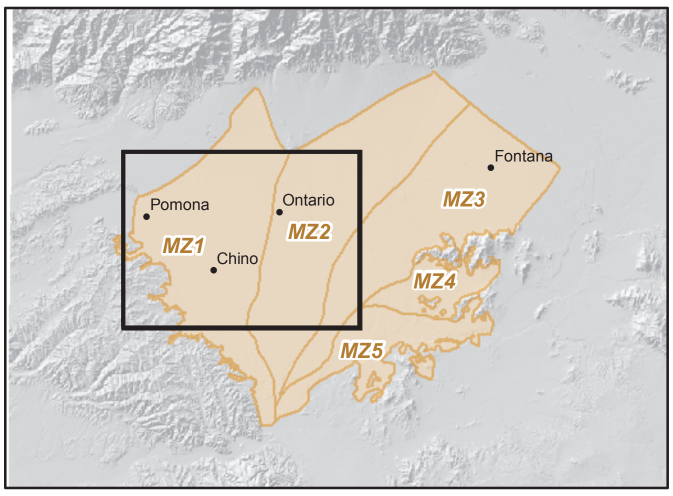
▭ Study Area

▭ Areas of Subsidence Concern

Flood Control & Conservation Basins

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain



Prepared by:

WEI
Wildermuth Environmental, Inc.

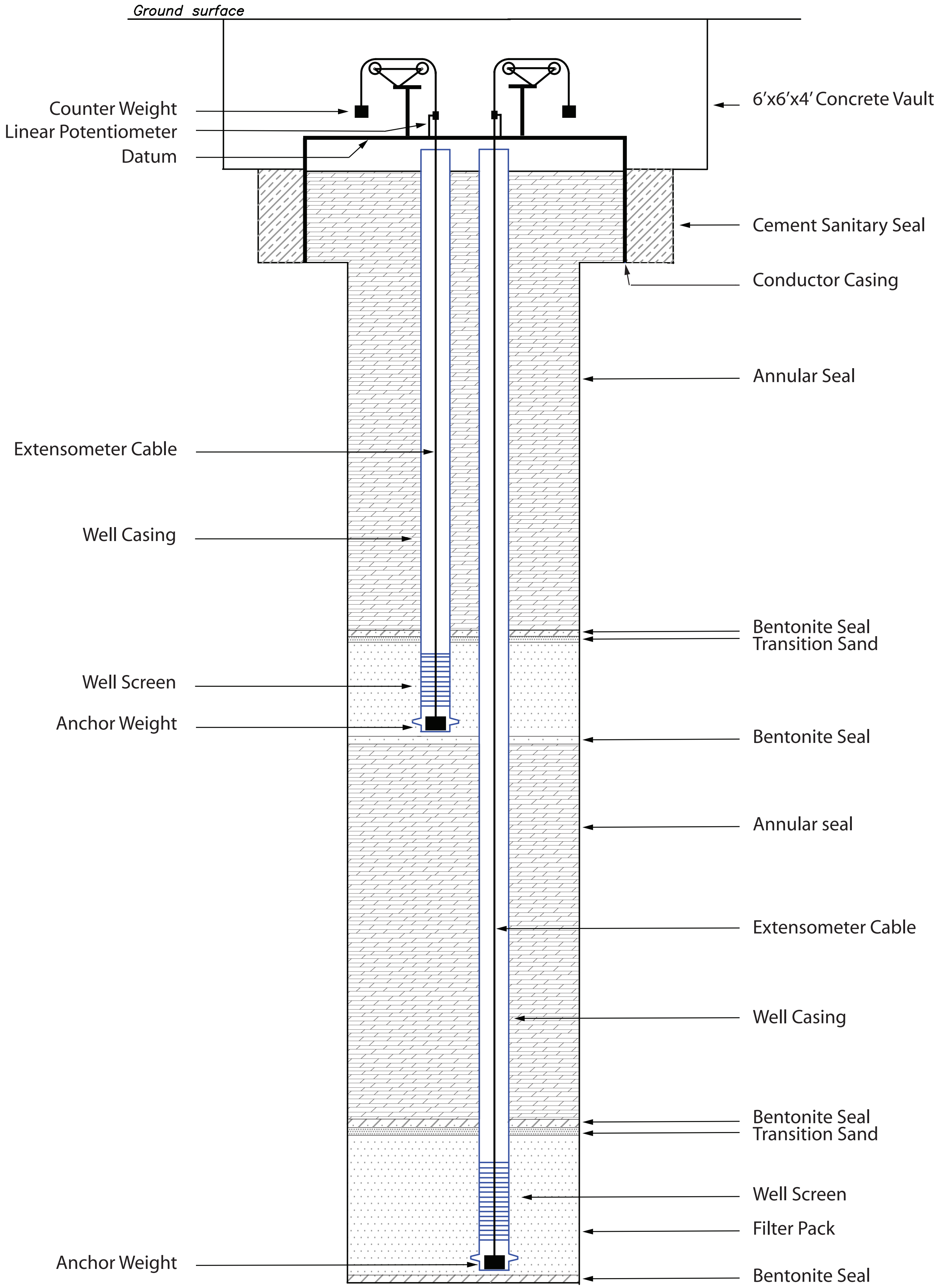
Author: AEM
Date: 8/15/2016
Document Name: Figure 3-1

Initial Hydrogeologic Conceptual Model & Monitoring and Testing Program for the Northwest MZ-1 Area

Chino Basin Watermaster

Target Locations for the Pomona Extensometer

Figure 3-1



Not to Scale

Prepared by:

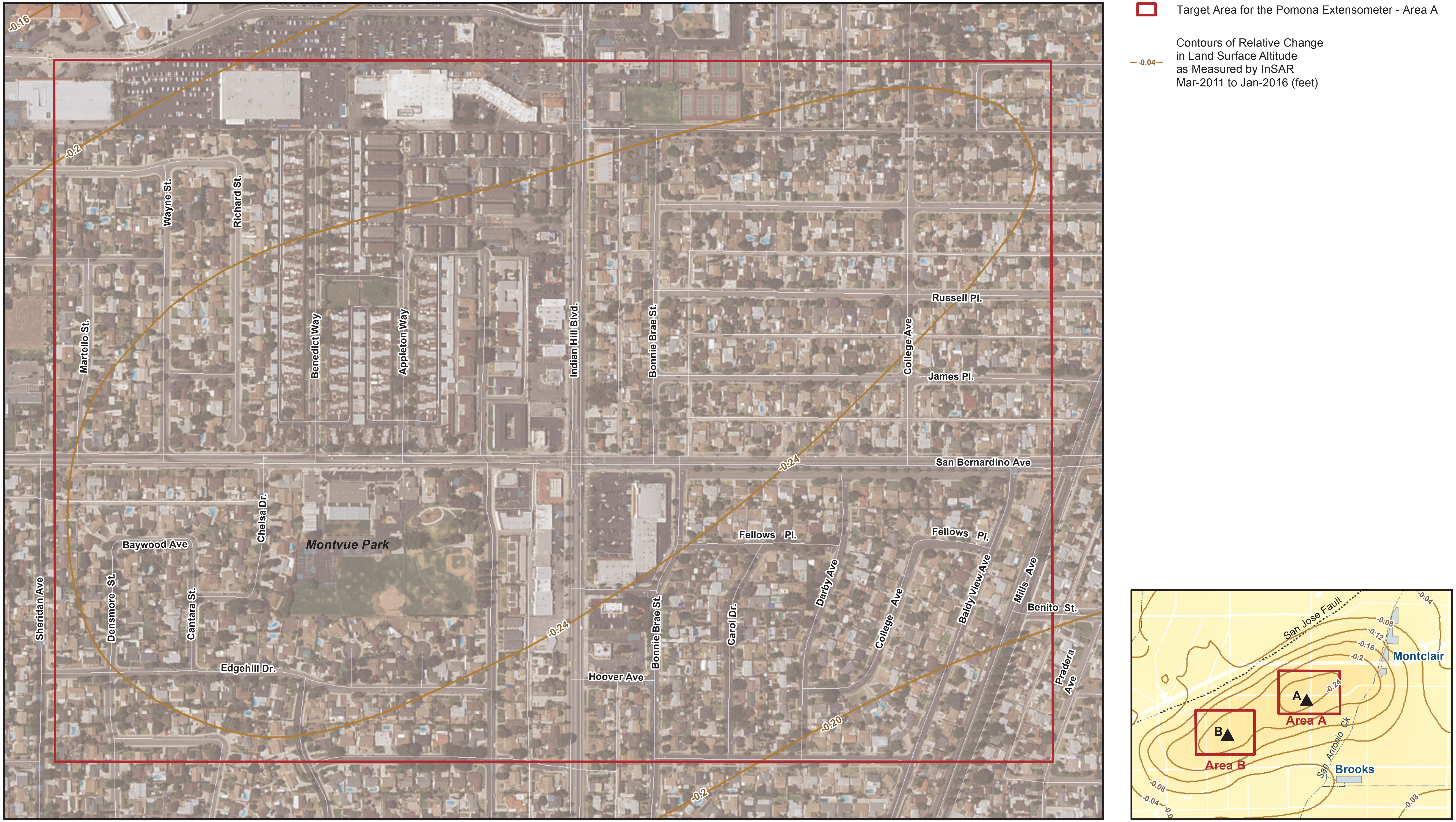
WEI
WILDERMUTH ENVIRONMENTAL, INC.

Author: TCR
Date: 20151110
File: Figure 3-2.pdf

Initial Hydrogeologic Conceptual Model,
Monitoring, and Testing Program
for the Northwest MZ-1 Area

Dual-Nested Cable Extensometer
Conceptual Schematic

Figure 3-2



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: TCR
Date: 8/15/2016
Document Name: Figure 3-3a

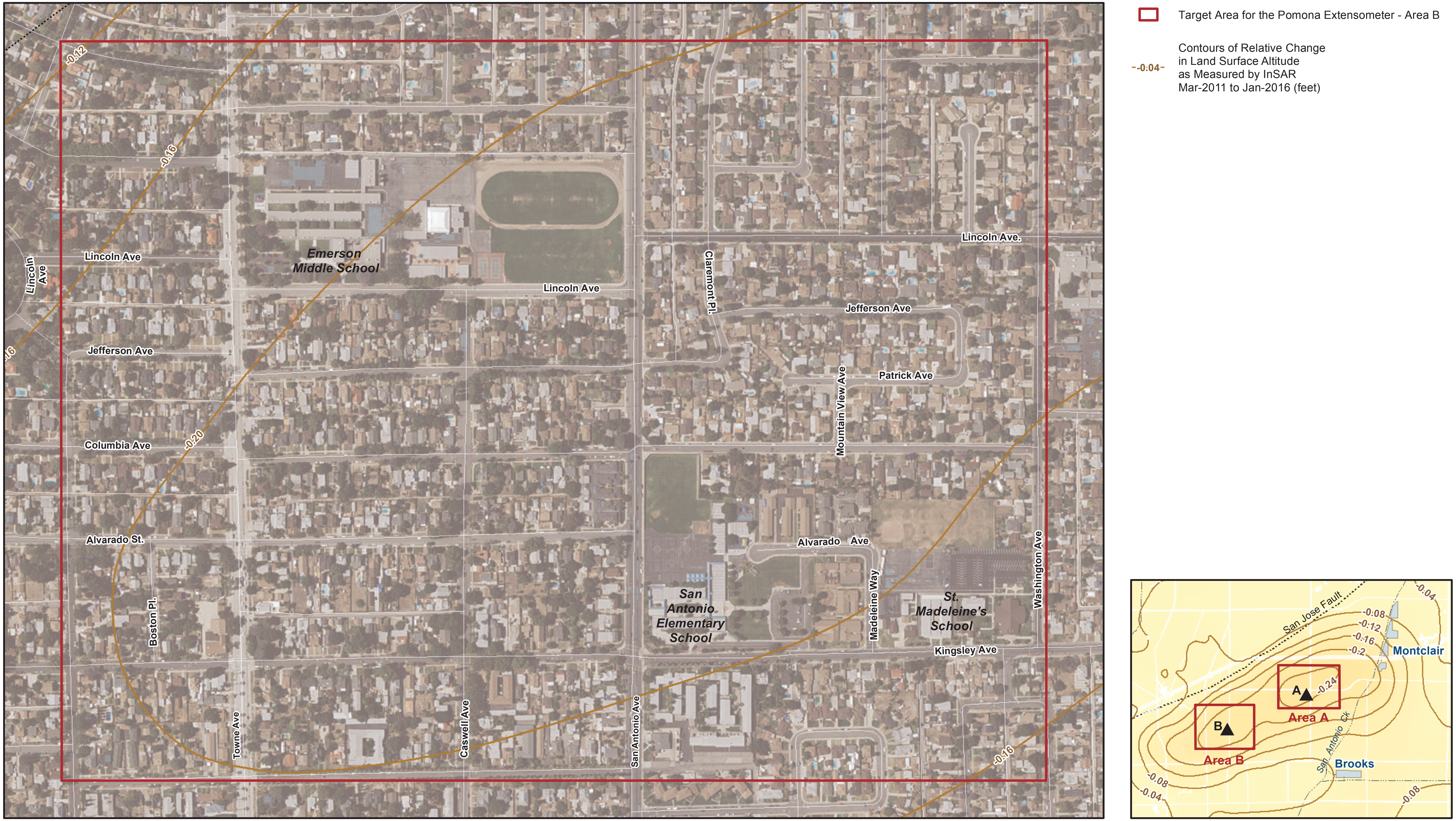
0 255 510 1,020 Feet
0 75 150 300 Meters

Chino Basin Watermaster
Partners in Basin Management

Initial Hydrogeologic Conceptual Model,
Monitoring, and Testing Program
for the Northwest MZ-1 Area

Target Area for the Pomona Extensometer Facility
Area A

Figure 3-3a



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Prepared by:

WEI
Wildermuth Environmental, Inc.

Author: TCR
Date: 8/15/2016
Document Name: Figure 3-3b

0 250 500 1,000 *Feet*
0 75 150 300 *Meters*

Initial Hydrogeologic Conceptual Model
& Monitoring and Testing Program
for the Northwest MZ-1 Area

Target Area for the
Pomona Extensometer Facility
Area B

Figure 3-3b

Section 4 – Glossary of Terms

The following is glossary of terms and definitions that 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, confined – An aquifer which is bounded on the upper (and/or lower) surface by an aquitard that strongly inhibits the vertical propagation of head changes to or from an overlying (or underlying) aquifer. The heads in a confined aquifer may be intermittently or consistently different than in the overlying (or underlying) aquifer.

Aquifer, semi-confined – An aquifer which is bounded on the upper (and/or lower) surface by semi-pervious aquitards such that a difference in hydraulic head above and below the semi-confined layer may cause water to flow vertically upward or downward. Also known as leaky aquifer.

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

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

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

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

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.

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

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

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

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

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

Nested Piezometer – A single borehole containing more than one piezometer. Piezometer is a general term for a monitoring well which measures head. Piezometers can be installed in unconfined, semi-confined, and confined aquifer-systems.

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 that represents 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 that becomes effective as intergranular stress.

Stress, Pre-consolidation – 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 pre-consolidation stress produce elastic deformations of small magnitude. In fine-grained materials, stress increases beyond the pre-consolidation stress produce much larger deformations that are principally inelastic (non-recoverable). Synonymous with "virgin stress."

Stress – Stress (pressure) that is borne by and transmitted through the grain-to-grain contacts of a deposit and thus affects its porosity and other physical properties. In one-dimensional compression, effective stress is the average grain-to-grain load per unit area in a plane normal to the applied stress. At any given depth, the effective stress is the weight (per unit area) of sediments and moisture above the water table, plus the submerged weight (per unit area) of sediments between the water table and the specified depth, plus or minus the seepage stress (hydrodynamic drag) produced by downward or upward components, respectively, of water movement through the saturated sediments above the specified depth. Effective stress may also be defined as the difference between the geostatic stress and fluid pressure at a given depth in a saturated deposit and represents that portion of the applied stress that becomes effective as intergranular stress.

Subsidence – Permanent or non-recoverable sinking or settlement of the land surface due to any of several processes.

Transducer, Pressure – An electronic device that can measure groundwater levels by converting water pressure to a recordable electrical signal. Typically, the transducer is connected to a data logger, which records the measurements.

Water Table – The surface of a body of unconfined groundwater at which the pressure is equal to atmospheric pressure and is defined by the level to which the water will rise in wells or piezometers that are screened within the unconfined aquifer system.

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Appendix A

Comments and Responses – Ground Level Monitoring Committee

A.1 GeoPentech (Eric Fordham) for the City of Chino

Comment Number	Reference	Comment	Response
1	Page 1-1	Background, 4th paragraph, first sentence add "potential" prior to ground fissuring and change "were a concern." to "are a concern."	The text has been modified to address this comment.
2	Page 1-3	Objectives, first paragraph following bullet item 5, first sentence states that it is necessary to "***definitively*** answer." To definitively answer the stated questions may be beyond what is economically or technically achievable. Suggest using a word/phrase that softens the expectation of this statement.	The text has been modified to address this comment.
3	Page 2-4	Hydrostratigraphic Cross-sections, 4th paragraph of section 2.2.3, third sentence states that "Layer 3 is generally characterized by a higher percentage of coarse grained sediments…" As a whole based on the data presented, there is not much discernible differences in the percent coarse grained sediments between Layers 2 and 3. The age and weathering of Layer 3 would suggest a greater breakdown of the sedimentary deposits of this layer to silt and clay.	Close inspection of the borehole lithology within Layer 2 and Layer 3 shows that on average, Layer 3 sediments are generally more coarse-grained than Layer 2 sediments. No changes have been made to the text.
4	Page 2-7	Spatial Distribution of Fine-Grained Sediments versus Vertical Ground Motion, Observations and Interpretations, first bullet, last sentence. In contrast to the statement, while the percentage of fine grained sediments is high, the greatest subsidence appears to	The text has been modified in Section 2.3 to more generally describe the relationship between the spatial distribution of fine-grained sediments and the occurrence of subsidence.

Comment Number	Reference	Comment	Response
		correspond to either pre-Forbearance subsidence in the south or to where the greatest groundwater production occurred. The panel for June 2005 to Sept. 2010 shows the greatest subsidence in an area with less than 50% fines, but has the highest production of the four panels.	
5	Page 2-7	second bullet, last sentence. The northwest projection of the MZ-1 Managed area subsidence is evident for the 92/95 and 96/99 time series in the area of higher fines content to the south; following implementation of Forbearance in the Managed area, the subsidence appears to diminish and the northwest area subsidence appears to become more dominant with increased production in the area. Though the subsidence doesn't correspond to the area of greatest fines content that is shown to the west and south (though there is limited control on distribution of fines in these areas).	The text has been modified in Section 2.4 to recognize that the mechanisms and occurrence of subsidence in Central MZ-1 appear to be distinct from the mechanisms and occurrence of subsidence in Northwest MZ-1.
6	Page 2-7	third bullet, last sentence. There is too little control with existing data in Layer 3 to make this statement.	The text has been modified to address this comment.
7	Page 2-8	Last paragraph on page. In addition to comparing groundwater levels in the two areas shown on Figures 2-7a and 2-7b, the report should also compare the groundwater levels in P-16 and P-35 of Figure 2-7A to a measured ground motion point near the intersection of Phillips Blvd. and Pipeline Ave. where the maximum vertical ground motion was observed by InSAR prior to 2000.	Figure 2-6 has been modified to include a time series of subsidence in the northern portion of Central MZ-1 as a comparison to the time series of subsidence in Northwest MZ-1. The main conclusion here is that groundwater-management activities in the Managed Area and Central MZ-1 do not directly and immediately impact ground motion in Northwest MZ-1. However, there is not enough groundwater-level data available in this portion of Central MZ-1 to confirm these interpretations.

Comment Number	Reference	Comment	Response
8	Page 2-9	main observations and interpretations of Figures 2-7a and 2-7b, second bullet. The preconsolidation stress within the aquifer system was ***less*** than the current stress condition, consistent with inferred groundwater levels.	The text has been modified to describe the following interpretation: The occurrence of persistent subsidence in Northwest MZ-1, despite periods of stable or increasing groundwater levels, indicates that "pre-consolidation heads" within the aquifer system are at higher elevations than the current hydraulic heads.
9	Page 2-9	main observations and interpretations of Figures 2-7a and 2-7b, third bullet, second sentence add "averaged" before "constant" to read, "…occurring at an averaged constant rate of 0.05 ft/yr…"	The text has been modified to address this comment.
10	Page 2-9	middle paragraph that starts "Figure 2-8 is a map…", second sentence. Contours of estimated groundwater level **drawdown** since the 1930's may be more informative as to the magnitude of the "trough" and its' association with subsidence. Also, what effect would decreasing the leakage across the San Jose Fault in the groundwater model have on the simulated area/size of the trough? Does Figure 2-8 represent piezometric contours for Layer 1?	Agree. Figure 2-8 and the text has been modified to compare long-term decline in groundwater levels to the recent subsidence in Northwest MZ-1. A decrease in sub-surface flow across the San Jose Fault from the Six Basins would reduce recharge to the Chino Basin, and potentially cause a lowering of groundwater levels in Northwest MZ-1. The contours of change in groundwater levels on Figure 2-8 were generated from the analysis of measured water levels at wells. The wells in Northwest MZ-1 are screened across the shallow and deep aquifer systems, so, depending on the well screen interval(s), their measured water levels represent a composite of hydraulic heads across the aquifer system.
11	Page 2-9	last bullet on page, last sentence replace "indicates" with "suggests" as there are still too many unknowns at this time.	The text has been modified to address this comment.

Comment Number	Reference	Comment	Response
12	Page 2-10	Last paragraph. Why does the area identified by Points A and B continue to subside post 2000, while the area near the intersection of Phillips Blvd and Pipeline Ave. show a decreased subsidence rate post 2000 concordant with an increase in groundwater level? The percent of fine grained sediments in both areas are similar. Perhaps there is something to learn by comparing the southern and northern areas.	See responses to Comments 5 and 7.
13	Page 3-2	Section 3.2.3, Piezometric Levels and Figure 3-1. In order to assess the possible communication of groundwater extraction/recharge between the Managed Area and the Northwest area, I suggest adding a couple more transducers near P-26 and P-35.	Agree. Watermaster Engineer is currently working with City of Pomona Staff to equip wells P-26, P-35, and other City wells with groundwater-level recording transducers that can be integrated with the City's SCADA.

A.2 GEOSCIENCE Support Services, Inc. (Dr. Dennis Williams) for Monte Vista Water District, City of Chino Hills, and City of Pomona

Comment Number	Reference	Comment	Response
1	Page 1-1	Suggest changing "subsidence" to land surface change as Figure 1-1 talks about "land surface altitude changes" as measured by land leveling surveys and InSAR not non recoverable compaction (i.e. subsidence). Also, labeling the contours in the south MZ-1 area would be helpful. Also, point out that the greatest change in land surface altitude between land leveling surveys and InSAR do not match.	No changes have been made to the text with regard to changing the use of “subsidence” to “land surface change.” The available data at the time of the MZ-1 Summary Report (WEI, 2006) indicated that non-recoverable subsidence had occurred in the Northwest MZ-1 Area. Labels were added to the leveling survey contours shown in Figure 1-1a. The InSAR gradient bar and value range shown in the Figure 1-1a legend has been modified. No changes have been made to the text to address the discrepancy between subsidence measured by InSAR and leveling surveys shown on Figure 1-1a. The date range of the leveling surveys (1987-1999) and InSAR surveys (1992-1995) are not the same. Because the time-frame between the two survey methods are different, they cannot be compared directly.
2	Page 1-1/1-2	That may be however figures 1-1b, 1-1c and 1-1d are only based on InSAR. It would be instructive to also overlay land altitude changes on these maps.	There were no leveling data available in Northwest MZ-1 for this report.

Comment Number	Reference	Comment	Response
3	Page 1-2	Also, it should be emphasized again that the time series for vertical ground motion is solely based in InSAR. I would be careful how the word "subsidence" is used throughout this document as that implies permanent "sinking" or lowering of the land surface. Again, until the committee has a consensus that InSAR can be used as the primary metric for non-recoverable compaction, I would use with caution.	No changes have been made to the text. InSAR is an established technique in the scientific community to measure changes in land surface altitude, including the USGS.
4	Page 1-2	Be careful regarding foregone conclusions. We don't know at this time that the NW MZ-1 area is being subjected to a permanent change in the land surface due to non-recoverable compaction (from ground water pumping). There is a possibility (albeit somewhat remote), that the change in land surface in the NW MZ-1 area may be due to tectonic forces (e.g. "pull apart basin") which could also result in lowering of the land surface which is unrelated to ground water pumping. Until we install extensometers in this area we really can't explain why the InSAR shows lowering of the land surface where no ground water pumping depressions exist. Seems like there are a lot of hypotheses suggested without the backup data for support at this point in time. However, the good thing is that the committee realizes this and therefore supports the additional monitoring and eventual extensometers in this area.	The text makes no definitive conclusion that the subsidence is related to aquifer-system compaction, but states that the available evidence supports such a cause-and-effect relationship. The intent of implementing the Work Plan to Develop a Subsidence Management Plan for Northwest MZ-1 is to obtain more information to reveal the mechanisms behind the subsidence.
5	Page 1-3	Add Question 6. Potential tectonic forces resulting in slow long-term lowering of the land surface between the San Jose Fault and an "unknown" fault (e.g. sw	The text has been modified to recognize tectonics as another plausible mechanism behind the observed subsidence.

Comment Number	Reference	Comment	Response
		extension of the Red Hill Fault??--need to ask the USGS if this is possible)	
6	Page 1-3	as well as a "fresh look" at all other factors such as detailed mapping of faults and tectonic stresses.	The investigation is not proposed to directly investigate tectonics, but will indirectly assess tectonics by investigating the aquitard-drainage hypothesis.
7	Page 1-3	What if the lowering of the land surface is not related to ground water pumping? This needs to be discussed as a possible alternative also.	If the subsidence is not caused by changes in hydraulic head, then the subsidence is not related to groundwater basin management, nor can it be managed through groundwater basin management.
8	Page 2-7	Have there been any geophysical surveys done in the area which might shed some light on the NW area. Perhaps, one recommendation could be to: Run shallow and deep geophysical surveys to try and identify faults and lithologic changes such as: - shallow method: High resolution survey called a Sting Resistivity Survey (for upper 200 ft) - deep method: Controlled Source Audio Magnetotellurics Survey (depths 50 to 2,500 feet) The methods are generally used together to provide good detail near the surface and depth to bedrock.	We are unaware of the existence of geophysical surveys of the subsurface geology in Northwest MZ-1. These recommendations to perform geophysical surveys should be discussed at future GLMC meetings.
9	Page 2-8	Frankly, this doesn't make sense unless I misunderstood. The fact that there is no data on production doesn't justify stating that subsidence is controlled by something else such as only lithologic changes. The industry completely understands subsidence of the land due to non-recoverable	To further clarify and explain: In the Managed Area, the main areas of subsidence were spatially coincident with the centers of groundwater production. That is not the case in Northwest MZ-1, where the main centers of

Comment Number	Reference	Comment	Response
		compaction of fine-grained interbeds -- that is a given. What we don't understand--especially in the Chino Basin, if there are causation factors other than over pumping which could cause the perceived change in ground surface altitude (as suggested by InSAR in the NW area).	production are on the periphery of the main areas of subsidence. This observation suggests that head declines caused by production propagated into areas with thick and abundant clay layers that subsequently drained and compacted, causing land subsidence in areas where no wells currently exist. There are other plausible explanations for the subsidence, but aquitard drainage is the most plausible. The text has been modified to clarify these points.
10	Page 2-9	Here again is the foregone conclusion that all changes in the land surface are due to ground water changes (--which very well may be the case). However, the whole presumption of the report is that nothing other than ground water lowering is the problem. In a highly faulted area such at the Chino Basin, it seems like other things should be considered and then dismissed if sound scientific evidence shows that they are not the cause--or at least contributing to the problem.	No changes have been made to the text to address this comment. The Watermaster Engineer’s working hypothesis is that the likely mechanism causing subsidence in Northwest MZ-1 is the compaction of fine-grained sediment layers due to groundwater withdrawals. We do not rule-out that other subsidence-causing mechanisms, such as tectonic activity, play a role in the observed subsidence. One of the objectives of the Work Plan is to identify the mechanisms behind the observed subsidence. The GLMC agrees and supports the installation of an extensometer to help monitor and characterize the causes behind the subsidence in Northwest MZ-1.
11	Figure 2-1	If the Red Hill Fault extended in this direction and being that both the Red Hill and San Jose Faults are right lateral, could a "pull apart" basin occur in this area?	No changes have been made to the text to address this comment. Based on currently available data, no surficial expression, seismic activity, and/or head data suggests an extension of the Red Hill Fault that transects the Northwest MZ-1 area. However, we do not rule-out that other subsidence-causing

Comment Number	Reference	Comment	Response
			mechanisms, such as the Northwest MZ-1 structural geometry, play a role in the observed subsidence.
12	Figure 2-4b	Is there any pattern to change in land surface altitude and predominance of fine-grained materials in these charts? Also, just because the materials are fine grained, they may not experience non-recoverable compaction based on pre-consolidation stresses imposed or not imposed upon them in the past.	No changes have been made to the text to address this comment. The maps show a general relationship between the spatial distribution of fine-grained sediments and the occurrence of land subsidence. However, this section of the report recognizes a data gap: Lack of deep, high-resolution lithologic data in areas that experienced the greatest amount of land subsidence. The proposed Pomona Extensometer in the area of greatest historical subsidence in Northwest MZ-1 will help fill this data gap, as well as reveal the occurrence of non-recoverable compaction.
13	Figure 2-5	Seems like a lot of ground water production in model layer 2 where a predominance of fine-grained materials occur. Does this make sense?	The maps in Figure 2-5 are not showing groundwater production by model layer. The maps are showing groundwater production by well across Northwest MZ-1 versus ground motion over different time periods.
14	Figure 2-8	Note that the darker shaded areas of the InSAR color code do not correspond to ground water pumping centers.	No changes have been made to the text to address this comment. The Watermaster Engineer agrees with the comment, and contends the spatial distribution of subsidence is not necessarily controlled strictly by pumping, and that at least in part, the spatial distribution of the observed subsidence is controlled by the spatial distribution of fine-grained, compressible sediments within the aquifer-system.
15	Page 3-1	I also think that one of the purposes of the monitoring and testing program is to see what is the reason(s) that	Agree. Please see responses to Comments 5, 6, and 7.

Comment Number	Reference	Comment	Response
		the InSAR shows a change in land surface altitude in the NW MZ-1 area--geohydrologic and/or tectonic??	
16	Page 3-2	Sometime, the committee needs to make a decision on the long-term method for ground level monitoring--this however may take several more years of comparison between InSAR, land leveling surveys and extensometer data.	Agree. No changes have been made to the text to address this comment.
17	Page 3-4	These long-term aquifer stress tests seem to be very difficult to perform much less reproduce with any degree of reliability. In order to establish metrics as important as "guidance levels", it must be demonstrated, with a high degree of certainty that the water level lowering and non-recoverable compaction are scientifically consistent (i.e. reproducible).	Agree. However, long-term monitoring and testing remain as the recommended approach to development of a subsidence management plan, as well as making any subsequent adaptations of the plan. No changes have been made to the text to address this comment.
18	Page 4-1	Add Semi-Confined or (Leaky Aquifer). An aquifer which is bounded on the upper (and/or lower) surface by semi-pervious aquitards such that a difference in hydraulic head above and below the semi-confined layer may cause water to flow vertically upward or downward.	The text has been modified to address this comment.
19	Page 4-2	delete regional	The text has been modified to address this comment.
20	Page 4-2	Define compression and rebound also	“Compression” and it reversible nature (rebound) is defined on Page 4-1.
21	Page 4-2	could also be non vertical below ground surface	Disagree. A vertical extensometer measures the vertical deformation of the aquifer system.

Comment Number	Reference	Comment	Response
22	Page 4-2	Hydraulic Head not Head	The text has been modified to address this comment.
23	Page 4-2	General term for a monitoring well which measures ground water levels. Piezometers can be installed in unconfined, semi-confined and confined aquifer systems	The text has been modified to address this comment.
24	Page 4-3	However, for purposes of this report, subsidence (of the land) is the permanent lowering of the land surface due to non-recoverable compaction of fine-grained interbeds within the aquifer system(s)	Disagree. There are multiple potential mechanisms for the observed land subsidence. No changes have been made to the text to address this comment.
24	Page 4-3	Basically the water level (or phreatic) surface in an unconfined aquifer.	Agree.

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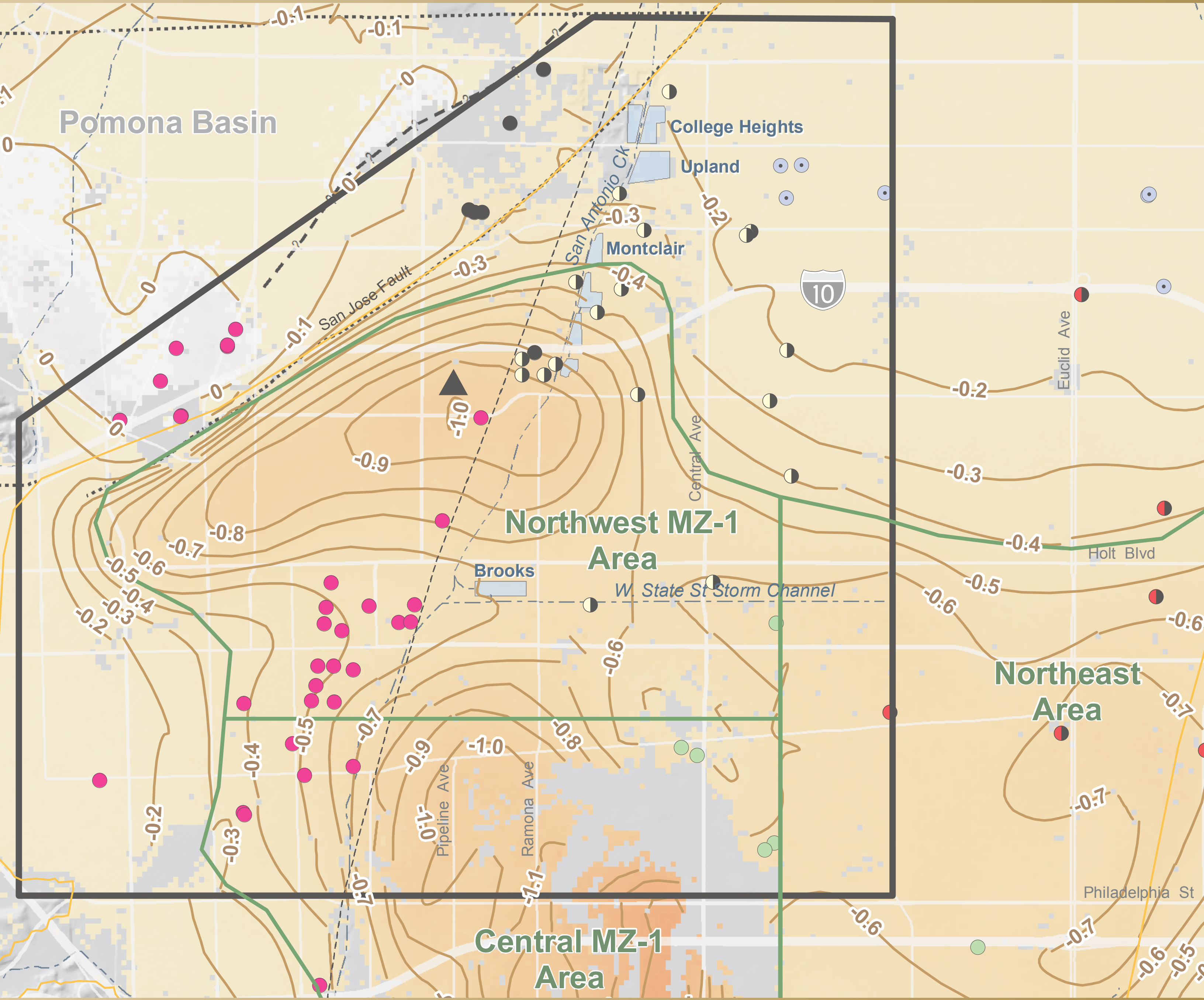

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