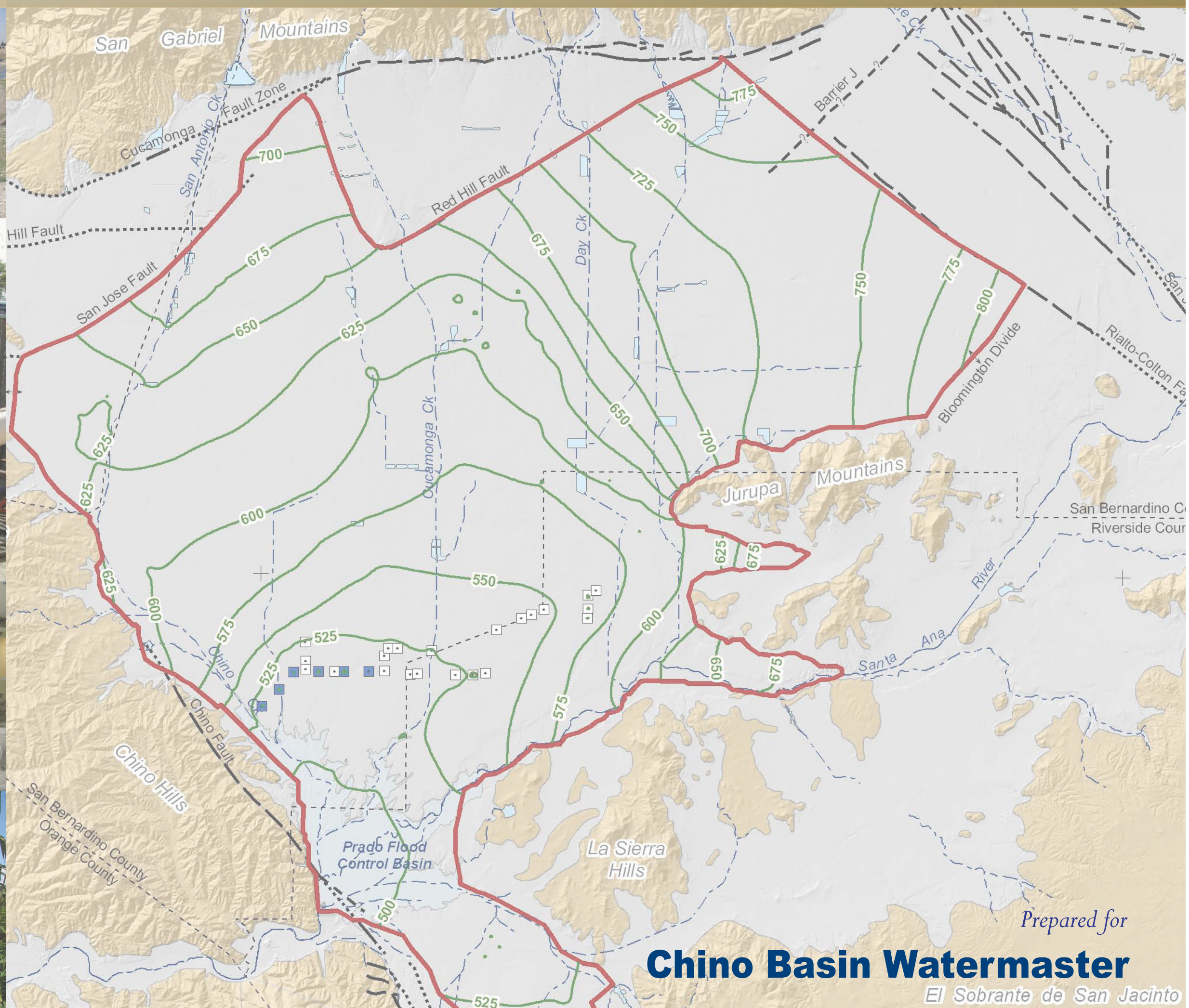
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description







Prepared for

Chino Basin Watermaster

WILDERMUTH™
ENVIRONMENTAL INC.

FINAL REPORT
November 2007

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ES-1 Investigation Objectives

There are four objectives of this investigation that include:

- Update analytical tools (groundwater model) to evaluate the Peace II project description
- Evaluate, using updated analytical tools, the state of hydraulic control without implementation of the Peace II project description
- Evaluate, using updated analytical tools, the state of hydraulic control with implementation of the Peace II project description
- Determine if implementation of the Peace II project description will cause material physical injury to a party or the basin

Hydraulic control is defined as the reduction of groundwater discharge from the Chino North Management Zone to the Santa Ana River to de minimis quantities. Hydraulic control ensures that the water management activities in the Chino North Management Zone will not impair the beneficial uses of the Santa Ana River downstream of Prado Dam. Achieving hydraulic control also maximizes the safe yield of the Chino Basin as required by Paragraphs 30 and 41 of the Judgment. Two reports by Wildermuth Environmental, Inc. (WEI), prepared in 2006 at the direction of Watermaster, demonstrate that hydraulic control has not yet been achieved in the area between the Chino Hills and Chino Desalter I, well number 5 (WEI, 2006a and b). Without hydraulic control, the IEUA and Watermaster will have to cease the use of recycled water in Chino Basin and will have to mitigate the effects of using recycled water back to the adoption of the 2004 Basin Plan Amendment, which is December 2004.

Per the Peace Agreement, material physical injury is defined as: *"material injury that is attributable to Recharge, Transfer, storage and recovery, management, movement or Production of water or implementation of the OBMP, including, but not limited to, degradation of water quality, liquefaction, land subsidence, increases in pump lift and adverse impacts associated with rising groundwater"* (Peace Agreement, page 8).

ES-2 Model Description

A numerical computer-simulation model of groundwater flow was prepared for the Chino Basin using USGS MODFLOW-2000 model code (Harbaugh et al., 2000). Figure ES-2 displays the domain of the Chino Basin groundwater flow model. The model grid within the domain consists of 577 rows, 562 columns, and three layers. In the horizontal direction, each cell has a dimension of 60 x 60 meters (196 x 196 feet). This fine cell size was selected to model the curvature of drawdown near the desalter wells. The grid cells are designated as "inactive" outside the model domain and as "active" inside the domain. There are a total of 462,250 active cells.

The spatial extent of the model domain was determined by the saturated extent and thickness of the aquifer system—the extent was limited to regions where the saturated thickness was greater than 40 feet. The saturated thickness was determined based on the effective base of the freshwater aquifer and

1960 groundwater levels—a time when groundwater levels were at historical lows. The model was calibrated over the 1960 through 2006 period.

ES-3 Project Alternatives and Model Simulations

The proposed project has two main features: the expansion of the desalter program such that the groundwater pumping for the desalters will reach 40,000 acre-ft/yr and that the pumping will occur in amounts and at locations that contribute to the achievement of hydraulic control; and the strategic reduction in groundwater storage (Re-operation) that, along with the expanded desalter program, significantly achieves hydraulic control.

Three planning alternatives were investigated in the final analysis of the Peace II process. These alternatives were developed from the Peace II Project Description as of October 17, 2007 and include the following:

- Baseline Alternative – Expansion of the Desalter Capacity and the 100,000 acre-ft Dry-Year Yield Program (DYYP). Desalter groundwater production would increase from the current level of about 28,000 acre-ft year (2006/07) to the full capacity of the existing desalters at about 40,000 acre-ft/yr. This corresponds to an expansion of the product water capacity of about 24.2 mgd to about 34.2 mgd. This alternative includes the existing 100,000 acre-ft DYYP. This alternative will serve as the baseline as it currently authorized and would occur without the adoption of the Peace II Instruments. This alternative is representative of what would occur without Peace II.
- Alternative 1 – Expansion of the Desalters, Re-Operation, and the 100,000 acre-ft Dry-Year Yield program (DYYP). Desalter groundwater production would increase from the current level of about 28,000 acre-ft year (2006/07) to the full capacity of the existing desalters at about 40,000 acre-ft/yr. This corresponds to an expansion of the product water capacity of about 29.2 mgd to about 34.2 mgd. Up to 400,000 acre-ft of the desalter replenishment obligation would be met by reductions in groundwater storage (Re-operation). There are two variants of Alternative 1 – 1A and 1B which utilize slightly different Re-operation strategies. This alternative includes the existing 100,000 acre-ft DYYP. This alternative is what is being asked for with Peace II.

These alternatives were evaluated with the updated 2007 Watermaster Model. They have been implemented in the model through groundwater production and replenishment projections.

ES-4 Evaluation Criteria

Per the Peace Agreement, material physical injury is defined as: *"material injury that is attributable to Recharge, Transfer, storage and recovery, management, movement or Production of water or implementation of the OBMP, including, but not limited to, degradation of water quality, liquefaction, land subsidence, increases in pump lift and adverse impacts associated with rising groundwater"* (Peace Agreement, page 8). The analysis of material physical injury was performed using the evaluation criteria described below and the results of 2007 Watermaster Groundwater Model. Hydraulic control was assessed through the development and assessment of detailed groundwater level maps for the southern part of the Chino Basin and from tabulations of the water balance for each management zone. Each planning alternative was simulated with and without the DYYP.

Each planning alternative was evaluated to determine changes in groundwater level, changes in Santa Ana River discharge, changes in basin balance, hydraulic control effectiveness, changes in safe yield, and potential subsidence. This was accomplished using the updated 2007 Watermaster Model to estimate the groundwater and surface water response to the planning alternatives. The impacts of Alternatives 1A and 1B were assessed by comparing the results of these simulations to the Baseline Alternative. Information was extracted from the model results to produce:

- Groundwater level projections to determine the change in groundwater levels throughout the basin, to assess hydraulic control and potential new subsidence. Maps were produced, showing the areal distribution of groundwater elevations and the change in elevations across the entire basin. Local maps were prepared in the southern end of the basin to assess hydraulic control.
- Surface water discharge projections of the Santa Ana River at Prado Dam to determine change in safe yield and water lost from the basin from groundwater storage programs.
- Water balance tables to determine outflow from the Chino North Management Zone to the Prado Basin Management Zone and the Santa Ana River, new recharge from the Santa Ana River into the Chino South and Prado Basin Management Zones, the change in storage, and the change in safe yield.

The safe yield of the basin was estimated using a mass balance method, which was one of the methods used by William Carroll in the original estimate of the safe yield for the Chino Basin Judgment (WEI, 1999).

ES-5 Simulation Results for the Baseline and Peace II Alternatives

Integrated Planning Process

The integrated regional water planning process for the Chino Basin area needs to be improved to be consistent with the limitations in the groundwater system and the regional facilities. In the past planning studies, it has always been assumed by the parties that they could pump as much as they desired from the basin anywhere they wanted and that Watermaster would always be able to replenish overproduction regardless of the magnitude of the overproduction. This is best illustrated by reviewing the process to develop the Baseline Alternative for the investigation of the Peace II project description:

- Several iterations were required to develop a feasible Baseline Alternative. Initially, the Baseline Alternative used the explicit groundwater production plans of the parties to the Judgment. These groundwater production plans were modified in the near term (through 2019/20) to reflect actual production and to gradually (linearly) approach their projected production at 2019/20 and to match their projections thereafter. The resulting aggregate groundwater pumping plan required more replenishment capacity than Watermaster currently has available or will have available. This pumping projection is referred to as the Trial 1 projection.

- The groundwater production plans were modified again by reducing the appropriator production, excluding the desalters, such that the replenishment obligation would, on average, be less than the replenishment capacity of about 91,000 acre-ft/yr. This pumping projection is referred to as the Trial 2 projection.
- The first complete simulations of the Baseline Alternative produced a surprising result: the safe yield would decline from the 140,000 acre-ft/yr determined in the Judgment to slightly less than 120,000 acre-ft/yr by 2059/60. This required an adjustment in the replenishment plan for the Baseline Alternative. The increase in replenishment, required by a lower safe yield, exceeded the replenishment capacity. The factors that lead to the projected replenishment capacity of 91,000 acre-ft/yr were reviewed to determine if there were readily available means to increase the replenishment capacity. The 91,000 acre-ft/yr capacity assumed that the basins will be offline three months every summer for maintenance. The replenishment capacity was increased to about 104,000 acre-ft/yr by reducing the maintenance period from three to two months. Utilizing the expanded replenishment capacity resulted in a Baseline Alternative that was feasible pursuant to the Judgment.
- The groundwater simulations based on the Trial 2 groundwater production plan and the expanded replenishment capacity produced another surprising result: the expanded future groundwater production specifically by the CVWD and the City of Ontario and generally by the surrounding parties resulted in a large groundwater level depression centered in the CVWD well field in the north-central part of the basin. By the fall of 2023, the groundwater elevations fell by more than 80 feet in the CVWD well field and fell by over 100 feet by the fall of 2053. This groundwater depression radiates outward to the east, south, and west of the CVWD well field. It is doubtful that the CVWD and the City of Ontario would produce groundwater in such a way as to create this depression. The groundwater elevation in individual production wells would fall even greater than the model projections. Groundwater production was reduced in the out years by the model to prevent individual model cells from drying up. To mitigate this projected groundwater depression, future net groundwater production by the CVWD and the City of Ontario were capped at 23,800 and 29,000 acre-ft/yr, respectively. This production cap could be lifted by increasing replenishment in this area.

Future Safe Yield for the Baseline Alternative

The safe yield was projected to decline in the future due to changes in land use and associated water use practices that have occurred in the recent past and that will occur in the future. For the period 2005/06 through 2015/16, the safe yield for the Baseline Alternative was projected to decline from about 145,000 to about 134,000 acre-ft/yr. For the period after 2016/17 the safe yield for the Baseline Alternative was projected to gradually decrease from about 134,000 acre-ft/yr to about 119,000 acre-ft/yr by the end of 2059/60. These estimates of safe yield over the planning period for the Baseline Alternative were developed from a series of trial simulations of the Baseline Alternative.

New Recharge from the Santa Ana River

The new Santa Ana River recharge achieved by Re-operation is about 8,600 acre-ft/yr for Alternative

1A and 9,000 acre-ft/yr for Alternative 1B; the difference between these two projections is not significant given the uncertainty of the water supply and replenishment plans in the out years. These values represent the average change in discharge from 2034/35 through 2059/60. During the period 2005/06 and 2034/35, the new Santa Ana River recharge grows rapidly from zero to 9,000 to 10,000 acre-ft/yr. That said it never reaches the assumed constant recharge assumed in Table 7-6a and Table 7-6b. The result of this shortfall is a reduction in storage by 2029/30 of about 198,000 acre-ft/yr and 212,000 acre-ft/yr for Alternatives 1A and 1B, respectively, above the 400,000 acre-ft provided by Re-operation. This shortfall in induced recharge should be mitigated preferably after 2030 to ensure that hydraulic control is achieved as soon as possible.

Predicted Changes in Groundwater Levels

There are significant groundwater elevation changes throughout the basins as a result of the implementation of water supply plans and the associated replenishment plans contained in the Baseline, 1A and 1B Alternatives. Groundwater elevations and elevation changes for the planning alternatives are shown on Figures E-1 through E-36. The general shape of the groundwater elevation contours is similar to the current groundwater elevation contours with the following exceptions:

- Groundwater flow from the Santa Ana River into the basin is more pronounced;
- The occurrence of pumping depression centered on CVWD's wells in the north central part of the basin; and
- The development of a pumping depression and capture zone in the Chino Desalter I well field.

Generally speaking, groundwater levels increase in parts of the northwestern portion of the basin due to supplemental recharge in MZ1. Groundwater levels decrease in the central portion of the basin due to pumping by the City of Ontario and the CVWD. This decrease propagates east to the Fontana area or the eastern portion of the basin. Lastly, the desalter wells create a depression in the southern portion of the basin north of the Prado Basin. Groundwater levels are lower in Alternatives 1A and 1B relative to the Baseline. Listed below are groundwater level results from Alternative 1A (Alternative 1B can be assumed to have very similar water level results) and a comparison of the results relative to the Baseline Alternative for specific locations in the basin.

- Through fall 2023, groundwater elevations in the MVWD and City of Pomona production area are projected to change by about -30 to +20 feet in layer 1, from 0 to -60 feet in layer 2 and from 0 to -40 feet in layer 3. By the fall of 2053, groundwater elevations are projected to change by -30 to +20 feet in layer 1, from 0 to -60 feet in layer 2 and from 0 to -40 feet in layer 3. Relative to the Baseline Alternative groundwater elevations are projected to be about 20 to 40 feet lower with Alternative 1A from the fall of 2023 through the end of the planning period.
- Through fall 2023, groundwater elevations in the MZ1 subsidence area (the production area for the Cities of Chino and Chino Hills) are projected to change by about 0 to -25 feet in layer 1, 0 to -60 feet in layer 2, and -40 to -50 feet in layer 3. Through fall 2053, groundwater elevations in the MZ1 subsidence area are projected to change by about 0 to -25 feet in layer

1, 0 to -60 feet in layer 2, and -40 to -50 feet in layer 3. The groundwater level declines in layers 2 and 3 are still above the subsidence threshold and therefore new inelastic subsidence is not expected to occur for Alternative 1A. Relative to the Baseline Alternative, groundwater elevations in Alternative 1A are projected in 2023 to be about 10 to 20 feet lower in layer 1, and 20 feet lower in layer 2, and 20 feet lower in layer 3. Relative to the Baseline Alternative groundwater elevations are projected to be about 20 to 30 feet lower with Alternative 1A from the fall of 2023 through the end of the planning period.

- Similar to the Baseline Alternative, a large pumping depression is projected to form centered on the area where CVWD produces groundwater and to radiate outward through the City of Ontario production area. The pumping hole is the result of the projected expansion of groundwater production by CVWD and the City of Ontario. Near the center of this pumping depression groundwater levels are projected to change by about -100 to -110 feet in all layers by the fall of 2023, and by about -110 to -120 feet by the fall of 2053. This pumping depression appears to affect the entire central part of the basin and to radiate outward to the eastern, southern, and western parts of the basin. Relative to the Baseline Alternative groundwater elevations are projected to be about 40 to 50 feet lower with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater levels in the JCSD production area are projected to change by about -60 to -90 feet in all layers by the fall of 2023, and by about -80 to -90 feet by the fall of 2053. Relative to the Baseline Alternative groundwater elevations are projected to be about 40 feet lower with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the City of Ontario production area are projected to change by about -40 to -100 feet in all layers and by about -60 to -110 feet by the fall of 2053 for all layers. Relative to the Baseline Alternative groundwater elevations are projected to be about 20 to 50 feet lower with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the FWC production area are projected to change by about -60 to -90 feet in all layers and by about -80 to -90 feet by the fall of 2053 for all layers. Relative to the Baseline Alternative groundwater elevations are projected to be about 20 to 50 feet lower with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the Desalter No. 1 well field area are projected -20 to -50 feet in all layers and to remain at these levels through the fall 2053. Relative to the Baseline Alternative, groundwater elevations in Alternative 1A are projected in the fall of 2023 to be about 5 to 25 feet lower across all layers through the end of the planning period. Re-operation has depressed the groundwater elevations at the desalter wells relative to the Baseline Alternative.

- Through fall 2023, groundwater elevations in the Desalter No. 2 well field area are projected -50 to -70 feet in all layers and to remain at these levels through the fall 2053. Relative to the Baseline Alternative, groundwater elevations in Alternative 1A are projected in the fall of 2023 to be about 10 to 20 feet lower across all layers through the end of the planning period. Re-operation has depressed the groundwater elevations at the desalter wells relative to the Baseline Alternative.

Hydraulic Control

One of the assumptions in the Baseline Alternative is that the basin is operated in balance pursuant to the Judgment with the desalters offsetting the decline in agricultural production. That balance has historically included a significant discharge from the basin to the Santa Ana River. Managing the net production from the basin to the operating yield and the dependence on the sustained production of others will produce a marginal state of hydraulic control at best—a state of hydraulic control that cannot be assured (literally a groundwater depression of a few feet in the center of the CCWF well field). The model projections of Alternatives 1A and 1B demonstrate the achievement of hydraulic control. Re-operation is required to rapidly achieve and maintain hydraulic control.

Predicted Changes in Safe Yield

The safe yield estimate for any year was estimated from the hydrology of the prior ten years. Historically the safe yield reached a high of about 160,000 acre-ft/yr in the late 1980s and systematically declines through the remaining part of the calibration period and through the planning period.

The safe yield has been projected to decline in the future due to changes in land use and associated water use practices that have occurred in the recent past and that will occur in the future. For the period 2005/06 through 2015/16, the safe yield for the Baseline Alternative declines from about 145,000 to about 134,000 acre-ft/yr. For the period after 2016/17 the safe yield for the Baseline Alternative declines gradually from about 134,000 acre-ft/yr to about 119,000 acre-ft/yr by the end of 2059/60. The safe yield declines due to the reductions in the deep percolation of applied water and precipitation and the reduction in storm water recharge. The reduction in recharge is caused by historical and projected changed in land use and associated water use patterns from the conversion of agricultural and vacant land uses to urban uses through 2025.

For the period 2005/06 through 2016/17, the safe yield increase associated with Re-operation is projected to reach about 2,000 acre-ft/yr by 2016/17, steadily increase to about 8,000 to 9,000 acre-ft/yr by 2030, and to average about 8,500 to 9,000 acre-ft/yr for the period 2030/31 through 2059/60. Note that the average safe yield for the period 2030/31 through 2059/60 is about the same as the increase in Santa Ana Recharge. There are no reductions in yield projected for Alternatives 1A and 1B relative to the Baseline Alternative; thus, there is no material injury related to safe yield changes.

Subsidence in the Managed Area of MZ1

Figure ES-3 shows the projected piezometric elevations at the PA-7 piezometer for all of the planning alternatives. The PA-7 piezometer is used in the Watermaster's MZ1 Long Term Management Plan. In this plan, basin management activities that maintain piezometric elevations greater than 400 ft at the PA-7 piezometer (corresponding to a depth to water of 245 feet) will not cause inelastic subsidence. In all cases, the projected piezometric elevations are 50 to 80 feet higher than the subsidence threshold elevation of 400 ft for the managed area of MZ1; thus, no inelastic subsidence is projected to occur in

MZ1. There are no material physical injuries related to subsidence from any of the planning alternatives.

Material Physical Injury

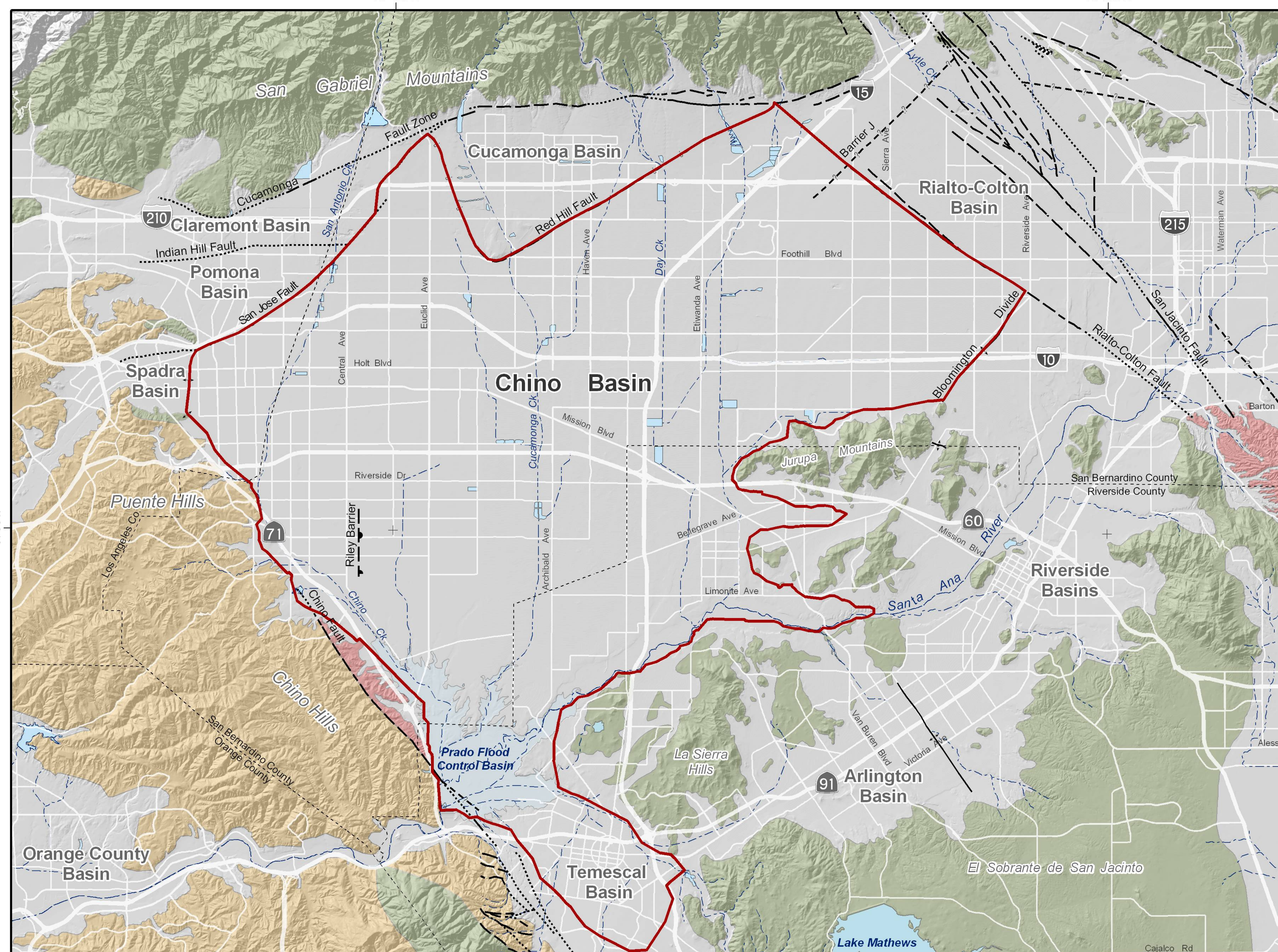
Based on the alternatives analysis described in Section 7, there does not appear to be a material physical injury caused by the implementation of the Peace II project description.

Future Due Diligence

In Section 6, the 2007 Watermaster model was demonstrated to be a well calibrated groundwater model. The data used to calibrate the model include actual and estimated groundwater recharge and production data. The future simulations are based on educated estimates of land use, associated water use practices, and future production. There is no way to determine the accuracy of these estimates. The model was used to refine these projections in the Baseline Alternative. Groundwater models, by definition, represent the essence of a system: they are not the system. As complicated as it may be, the model is a simplified version of the groundwater system: it's not perfect.

Therefore, even though the groundwater model is well calibrated, it is possible that the planning information used to evaluate the future alternatives could be flawed and the modeling results could be questionable. The following should be done to overcome potential inaccuracies due to planning data and to maintain the model:

- Groundwater production and recharge projections should be revised as new information becomes available. New alternatives should be evaluated with the model on a periodic basis if future production and replenishment plans change significantly either in time or location.
- Groundwater and recharge monitoring programs should continue into the foreseeable future. These programs will provide information that can be used to assess the consistency of real world behavior and what was assumed in the planning alternatives and provide information for use in model calibration updates. This is especially important on a go forward basis as the projected operation of the basin is outside the bounds of the historical operation used in the calibration of the 2007 Watermaster model.



MODFLOW Groundwater Flow Model Boundary

Geology

Water-Bearing Sediments

- Quaternary Alluvium

Consolidated Bedrock

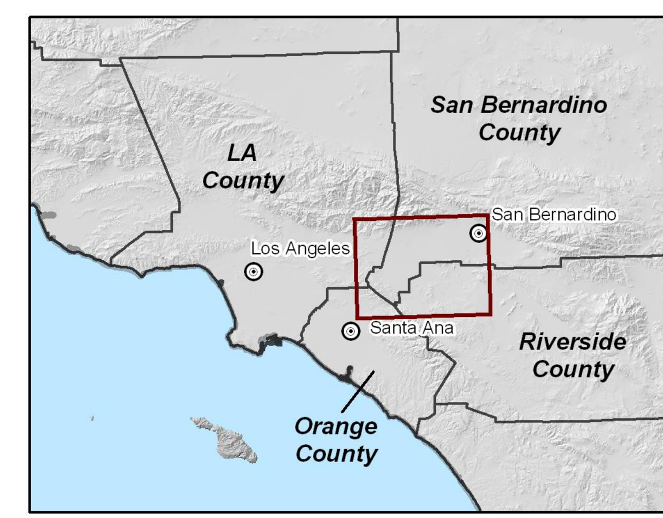
- Plio-Pleistocene Sedimentary Rocks
- Cretaceous to Miocene Sedimentary Rocks
- Pre-Tertiary Igneous and Metamorphic Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Groundwater Divides
- Flood Control and Conservation Basins
- Streams, Rivers, and Flood Control Channels



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WILDERMUTH ENVIRONMENTAL INC.
23692 Birtcher Drive
Lake Forest, CA 92630
949.420.3030
www.wildermuthenvironmental.com

Author: MJC
Date: 20071005
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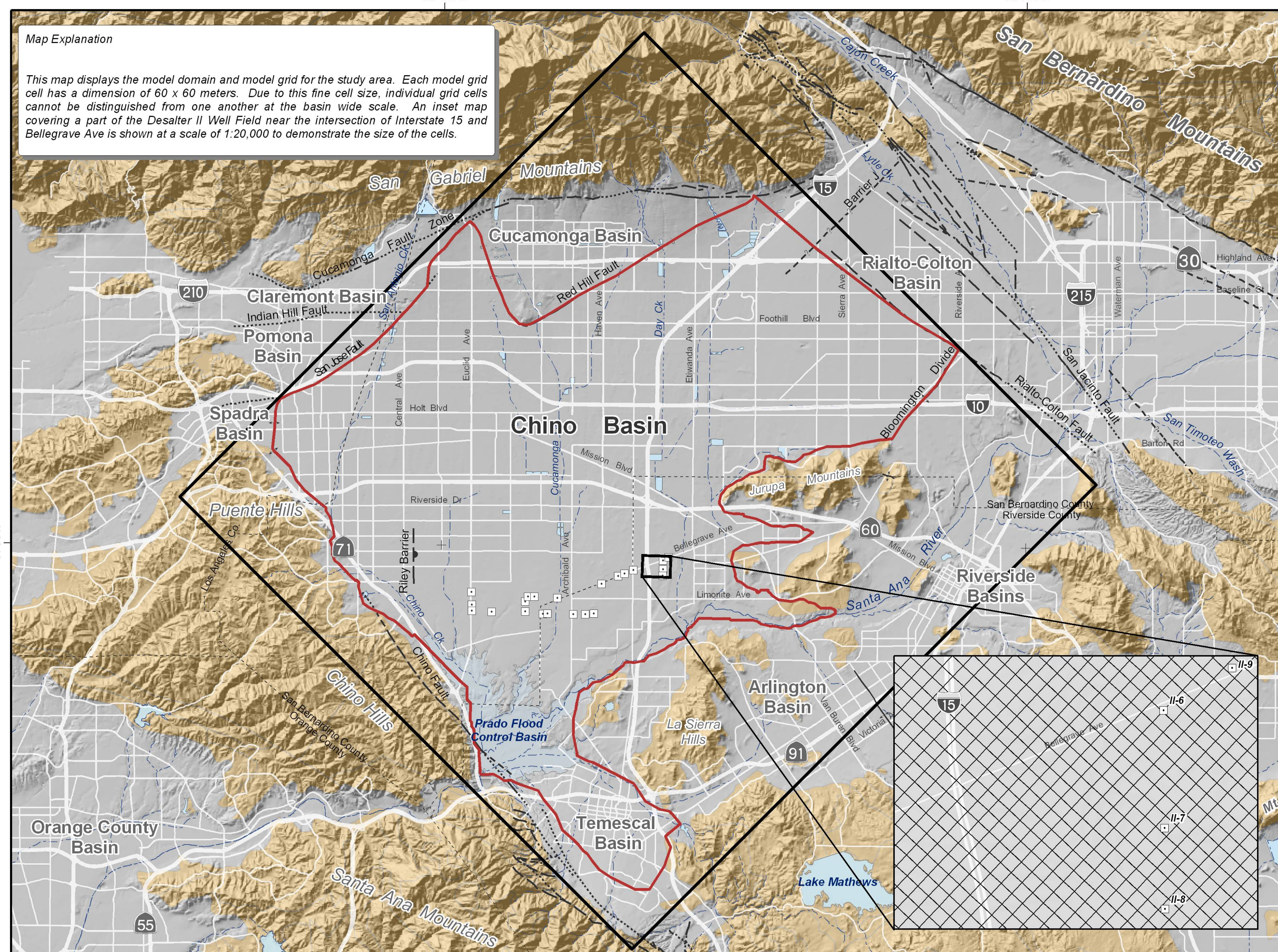
0 1 2 3 4 5 Miles
0 2 4 6 8 KM

CHINO BASIN WATERMASTER Partners in Basin Management

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Executive Summary

Study Area and Basin Boundaries

Figure ES-1



Legend

Model Domain

MODFLOW Groundwater Flow Model Boundary (Active Model Domain)

Chino Desalter Well

Model Grid

Faults

Location Certain

Location Approximate

Location Concealed

Location Uncertain

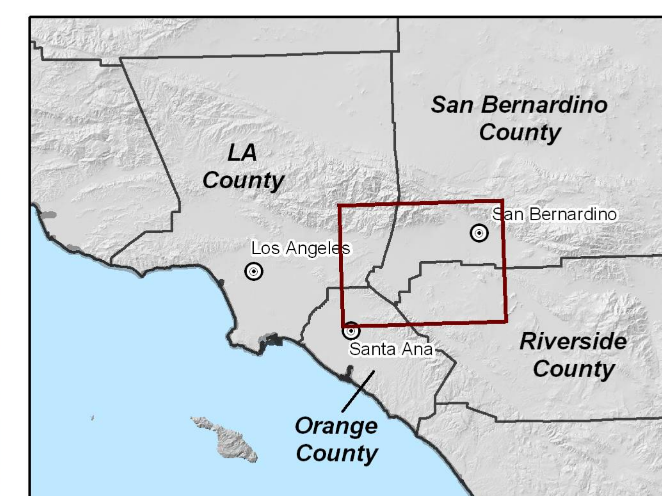
Approximate Location of Groundwater Barrier

Other Features

Groundwater Divides

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels



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Lake Forest, CA 92630
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Executive Summary

Map of Model Domain and Model Grid

Figure ES-2

1.1 Background

The Chino Basin consists of about 235 square miles of the upper Santa Ana River watershed. The basin is bounded by the Cucamonga Basin and the San Gabriel Mountains to the north; the Rialto-Colton Basin to the northeast; the chain of Jurupa, Pedley, and La Sierra Hills to the southeast; the Temescal Basin to the south; the Chino and Puente Hills to the southwest; and the San Jose Hills and the Pomona and Claremont Basins to the northwest. The basin lies within the Counties of San Bernardino and Riverside and includes the Cities of Chino, Ontario, Chino Hills, Norco, and several other communities.

The Chino Basin is an integral part of the regional and statewide water supply system. One of the largest groundwater basins in Southern California, the Chino Basin contains about 5,000,000 acre-ft (ac-ft) of water and has an unused storage capacity of about 1,000,000 acre-ft. Cities and other water supply entities produce groundwater for all or part of their municipal and industrial supplies. Agricultural users also produce groundwater from the basin, but irrigated agriculture has declined substantially in recent years and is projected to be almost nonexistent by 2020 [Ref. 1].

The boundary of the Chino Basin is legally defined in the Stipulated Judgment (Judgment) issued in 1978 (Chino Basin Municipal Water District vs. the City of Chino et al. [SBSC Case No. RCV 51010]). Since that time, the basin has been operated, as described in the Judgment, under the direction of a court-appointed Watermaster. The OBMP is being implemented pursuant to the Judgment and a 1998 ruling of the court in its exercise of continuing jurisdiction.

1.2 Project Objectives

There are two objectives in this investigation. The first objective is to evaluate, using updated analytical tools, the state of hydraulic control and the amount of Re-Operation water required to achieve and maintain hydraulic control.

Hydraulic control is defined as the reduction of groundwater discharge from the Chino North Management Zone to the Santa Ana River to de minimis quantities. Hydraulic control ensures that the water management activities in the Chino North Management Zone will not impair the beneficial uses of the Santa Ana River downstream of Prado Dam. Achieving hydraulic control also maximizes the safe yield of the Chino Basin as required by Paragraphs 30 and 41 of the Judgment. Two reports by Wildermuth Environmental, Inc. (WEI), prepared in 2006 at the direction of Watermaster, demonstrate that hydraulic control has not yet been achieved in the area between the Chino Hills and Chino Desalter I, well number 5 (WEI, 2006a and b). Without hydraulic control, the IEUA and Watermaster will have to cease the use of recycled water in the Chino Basin and will have to mitigate the effects of using recycled water back to the adoption of the 2004 Basin Plan Amendment, which is December 2004.

"Re-operation" means the increase in controlled overdraft, as defined in the Judgment, from 200,000 acre-ft over the period of 1978 through 2017 to 600,000 acre-ft through 2030 with the 400,000 acre-ft increase allocated specifically to the meet the replenishment obligation of the desalters. Previous investigations have shown that Re-operation is required to achieve hydraulic control.

The second objective is to conduct a material physical injury analysis for the implementation measures of the Peace II term sheet which includes, among other things, the Chino Creek Well Field, expanded desalter production, and Re-Operation.

1.3 Report Organization

The bulk of this report (Sections 2 through 6, and Appendices) describes the careful scientific work performed to update Watermaster's groundwater models. Section 7 contains the planning and material physical injury analyses.

Section 1 Introduction: This section describes the general setting and presents the overall project objectives and the purpose and use of the computer-simulation groundwater-flow model.

Section 2 Hydrogeologic Setting: This section describes the hydrogeologic conditions of the Chino Basin. The topics covered include geologic setting, hydrostratigraphy, the occurrence and movement of groundwater, aquifer properties, groundwater levels, and groundwater quality. These data were used to construct a hydrogeologic conceptual model of the Chino Basin for input to the groundwater-flow model.

Section 3 Water Balance: This section presents a description of the inflows and outflows to the groundwater system of the Chino Basin.

Section 4 Computer Code: This section presents a description of the computer codes used in the groundwater-flow model.

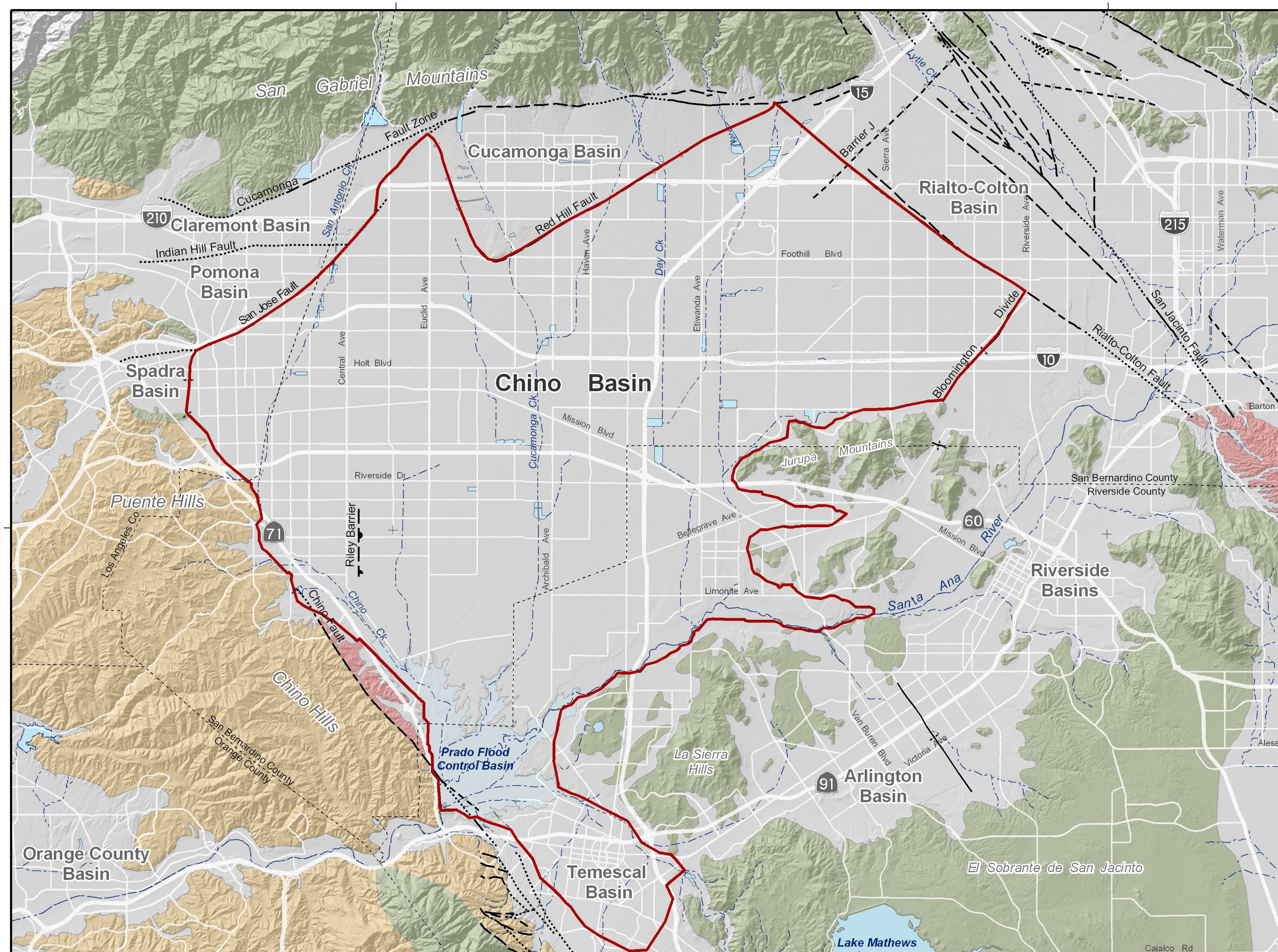
Section 5 Model Construction: This section describes how the hydrogeologic conceptual model was translated into a numerical model. The model domain, initial conditions, boundary conditions, and hydraulic conditions are defined in this section.

Section 6 Calibration: This section discusses the model calibration procedures. The simulated results over the calibration period (Fiscal year 1960-2006) are quantitatively compared to observed data in this section.

Section 7 Predictive Simulations: This section describes each predictive simulation and how it relates to the study objectives. Results of the simulations are presented in graphical and tabular form.

Section 8 Summary, Conclusions, and Recommendations: This section summarizes the modeling effort and draws conclusions related to the simulations and the study objectives.

Section 9 References: This section lists the references for data, computer codes, and modeling procedures used in the modeling effort.



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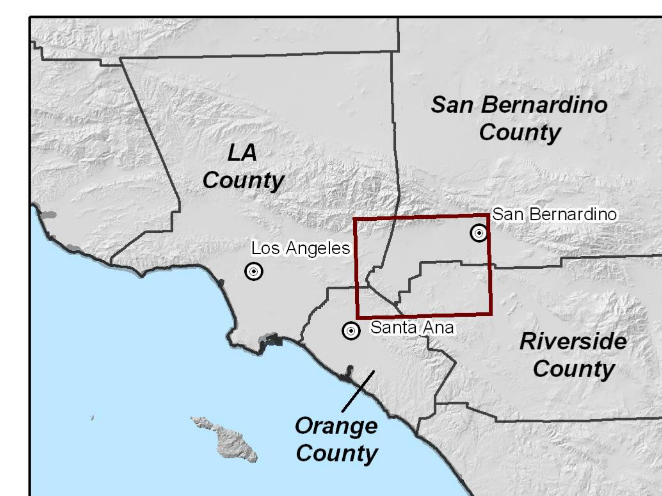

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23692 Birtcher Drive
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949.420.3030
www.wildermuthenvironmental.com

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CHINO BASIN WATERMASTER Partners in Basin Management

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Introduction

Study Area and Basin Boundaries

Figure 1-1

Section 2 – Hydrogeologic Setting

The understanding of Chino Basin geology continually improves as new wells are drilled and tested across the basin, new monitoring data are collected and analyzed, and new hydrogeologic investigations proceed (e.g. MZ-1 subsidence investigation). The purpose of this section is to describe the geology and hydrogeology of Chino Basin based on the most current information available.

2.1 Hydrogeologic Conceptual Model Update (2007)

In 2000/01, a numerical computer-simulation groundwater flow model was constructed to simulate the effects of a proposed conjunctive use storage program (WEI, 2003), hereafter referred to as the "2003 model." The hydrogeologic conceptual model, which was used as an input to the 2003 model, was based on Watermaster's understanding of Chino Basin hydrogeology at that time. Since then, Watermaster has conducted hydrogeologic investigations and collected new hydrogeologic data. These new data have been utilized to update the hydrogeologic conceptual model of the Chino Basin for its update of the 2003 model, hereafter referred to as the "2007 model update." The sources of the new hydrogeologic data include:

- *The Hydraulic Control Monitoring Program (HCMP).* Data from the HCMP were derived from the drilling, testing, and monitoring of nine (9) nested sets of piezometers that were constructed to support the HCMP. These data include geologic data that were derived from borehole drilling and the subsequent water level and water quality data that were collected at each piezometer. This provided depth-specific hydrogeologic data across the southern portion of the Chino Basin.

- *Land subsidence investigation to support the Management Zone 1 Interim Monitoring Program.* Data from this program were derived from the drilling, testing, and monitoring of the Ayala Park Extensometer facility in the City of Chino and the subsequent aquifer-system testing that was conducted during 2003-2005.

- *Recycled water recharge monitoring.* Data from this program were derived from the drilling, testing, and monitoring of the multiple nested sets of piezometers that were constructed downgradient from recharge basins that percolate recycled water. These data include the geologic data derived from the borehole drilling and the subsequent water level and water quality data collected at each piezometer. This provided relatively shallow hydrogeologic data across the central portions of the Chino Basin.

- *Watermaster's comprehensive monitoring programs for water levels and water quality.* Data from these programs were derived from water level measurements and water quality sampling and analysis at wells across the entire Chino Basin.

- *New wells drilled and tested by the appropriator pumpers.* Data from these efforts were derived from the drilling, testing, and monitoring several new wells that were completed across the central and northern portions of the Chino Basin. These new wells are owned by the following agencies:
    1. Chino Desalter Authority (Chino 1 Expansion and Chino 2)
    2. City of Chino
    3. City of Ontario
    4. City of Upland
    5. Fontana Water Company
    6. Monte Vista Water District

- *Regional geophysical data.* These data—more specifically, gravity station data that were reduced to Bouguer anomalies—were compiled to provide insight on basement geometry.

A detailed description of Watermaster's current understanding of Chino Basin geology and hydrogeology follows. Special attention should be given to the portions of the hydrogeologic conceptual model that were significantly modified during the 2007 model update, such as the geometry of the effective base of the freshwater aquifer (Section 2.3.3) and the hydrostratigraphy (Section 2.4.4).

2.2 Geologic Setting

The Chino Basin was formed as a result of tectonic activity along major fault zones. It is part of a larger, broad, alluvial-filled valley located between the San Gabriel/San Bernardino Mountains to the north (Transverse Ranges) and the elevated Perris Block/San Jacinto Mountains to the south (Peninsular Ranges). The Santa Ana River is the main tributary draining the valley; hence, the valley is commonly referred to as the Upper Santa Ana Valley. Chino Basin is located in the western portion of this valley and is shown on Figure 2-1.

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 in part 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 sedimentary and igneous bedrock formations that are exposed at the surface in the surrounding mountains and hills. Sediments eroded from the surrounding mountains filled the Chino Basin to provide reservoirs for groundwater. In the deepest portions of the Chino Basin, these sediments are greater than 1,000 feet thick.

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 locations of these major faults and their spatial relations to the Chino Basin are shown in Figure 2-1. These faults, their effects on groundwater movement, and the hydrogeology of the general Chino Basin area have been documented by various entities and authors (Eckis, 1934; Gleason, 1947; Burnham, 1953; MacRostie and Dolcini, 1959; Dutcher & Garrett, 1963; Gosling, 1966; DWR, 1970; Woolfenden and Kadhim, 1997).

2.3 Stratigraphy

In this report, the stratigraphy of the 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. Consolidated bedrock is further differentiated as (a) metamorphic and igneous rocks of the basement complex, which is overlain in places by (b) consolidated sedimentary rocks. Water-bearing sediments overlie the consolidated bedrock, and bedrock formations come to the surface in the surrounding hills and highlands. Below, these geologic formations are described in stratigraphic order, starting with the oldest formations first.

Terms used throughout 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. Pervious strata or fracture zones in bedrock formations may yield water to wells locally; however, the storage capacity is typically inadequate for sustained production. The primary point is that the permeability of the geologic formations in the areas flanking the basin is much less than the aquifers in the groundwater basin.

2.3.1 Consolidated Bedrock

The consolidated bedrock formations of the Chino Basin area include the basement complex, which is comprised of crystalline igneous and metamorphic rocks of pre-Tertiary age; the marine sedimentary and volcanic strata of late Cretaceous to late Tertiary age; and the continental deposits of late Pliocene to middle-Pleistocene age. Figure 2-1 shows the surface outcrops of the consolidated bedrock formations that surround the Chino Basin. Note that the basement complex is the exposed bedrock to the north and southeast of the Chino Basin. Consolidated sedimentary rocks are the exposed bedrock to the west of Chino Basin.

The general character of the consolidated bedrock formations, which is described below, is known from drillers' logs and surface outcrops.

2.3.1.1 Basement Complex

The basement complex consists of deformed and re-crystallized metamorphic rocks that have been invaded and displaced 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, in particular, to the water-bearing sediments of Chino Basin.

2.3.1.2 Undifferentiated Pre-Pliocene Formations

Consolidated sedimentary and volcanic rocks that unconformably overlie the basement complex outcrop along the western margin of the Chino Basin (in the Chino Hills 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. According to Durham and Yerkes (1964), this sequence reaches a total stratigraphic thickness of more than 24,000 feet in the Puente Hills and is down-warped more than 8,000 feet below sea level in the Prado Dam area. Wherever mapped, these strata are folded and faulted and, in most places, dip from 20 to 60 degrees.

2.3.1.3 Plio-Pleistocene Formations

A thick series of semi-consolidated clays, sands, and gravels of marine and non-marine origin overly the older consolidated bedrock formations. These sediments have been named the Fernando Group (Eckis, 1934) and outcrop in two general locations of the study area: the Chino Hills on the western margin of the Chino Basin and the San Timoteo Badlands southeast of the Chino Basin. In surface outcrop, the entire group is mapped as consolidated bedrock for this study, and it is likely that the first bedrock penetrated in southwest Chino Basin. The upper portion of the Fernando Group is more permeable than the lower portion and thus represents a gradual transition from non-water-bearing consolidated rocks to water-bearing sediments in the subsurface. Furthermore, 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.

2.3.2 Water-Bearing Sediments

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

Eckis (1934) speculated that the contact between consolidated bedrock and water-bearing sediments in the Chino Basin is unconformable, as indicated by an ever-present weathered zone in the consolidated bedrock directly underlying the contact with the water-bearing sediments. This observed relationship suggests that the consolidated bedrock in the Chino Basin area was undergoing erosion prior to the deposition of water-bearing sediments.

The water-bearing sediments can be differentiated into Older Alluvium of the Pleistocene age and Younger Alluvium of the Holocene age. The general character of these formations is known from driller's logs and surface outcrops and is described below.

2.3.2.1 Older Alluvium

The Older Alluvium varies in thickness from about 200 feet thick near the southwestern end of the Chino Basin to over 1,100 feet thick southwest of Fontana and averages about 500 feet throughout the basin. It is commonly distinguishable in surface outcrop by its red-brown or brick-red color and is generally more weathered than the overlying Younger Alluvium. The pumping capacities of wells completed in the Older Alluvium generally range between 500 and 1,500 gallons per minute (gpm). Capacities exceeding 1,000 gpm are common, and some modern production wells test-pumped at over 4,000 gpm (*e.g.* Ontario Wells 30 and 31 in southeastern Ontario). In the southern part of the basin where sediments tend to be more clayey, wells generally yield 100 to 1,000 gpm.

2.3.2.2 Younger Alluvium

The Younger Alluvium occupies streambeds, washes, and other areas of recent sedimentation. Oxidized particles tend to be flushed out of the sediments during transport, and the Younger Alluvium is commonly light yellow, brown, or gray. It 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 generally covers most of the north half of the basin in undisturbed areas. The Younger Alluvium is not saturated and, thus, does not yield water directly to wells. Water percolates readily in the Younger Alluvium, and most of the large spreading basins in Chino Basin are located in the Younger Alluvium.

2.3.3 Effective Base of the Freshwater Aquifer

Figure 2-2 shows Watermaster's current interpretation of the effective base of the freshwater aquifer in Chino Basin, herein referred to as the "bottom of the aquifer." The bottom of the aquifer is depicted in Figure 2-2 by equal elevation contour lines. These contours were first drawn by the California Department of Water Resources (DWR, 1970) and were subsequently modified by Watermaster for the Chino Basin Dry-Year Yield Program Modeling Report (WEI, 2003) and again for the 2007 model update. The modifications to the bottom of the aquifer for the 2007 model update were based on currently available data and Watermaster's hydrogeologic interpretations, which are described below.

2.3.3.1 Eastern Chino Basin

On the east side of Chino Basin (*i.e.* east of Archibald Avenue), the contours of the bottom of the aquifer are based on depth to the Basement Complex (*i.e.* crystalline bedrock) in well boreholes (see Figure 2-2). Crystalline bedrock was penetrated in these boreholes at depths of about 35-1,100 feet below ground surface (ft-bgs). Since 2003, several new wells were drilled in the southeastern portion of Chino Basin that penetrated crystalline bedrock, including several HCMP monitoring wells and the desalter wells associated with the Chino 1 Desalter expansion and the Chino 2 Desalter. These wells are shown on Figure 2-2 and were used to refine the contours of the effective base of the freshwater aquifer in the southeastern portion of Chino Basin.

2.3.3.2 Western Chino Basin

On the west side of the Chino Basin (*i.e.* west of Archibald Avenue) and in the Temescal Basin, the determination of the bottom of the aquifer is not as straightforward. Boreholes of depths up to 1,400 ft-bgs did not penetrate the crystalline bedrock of the Basement Complex, but terminated in highly-weathered and consolidated sediments that may be formations of the sedimentary bedrock (Undifferentiated Pre-Pliocene Formations and the Plio-Pleistocene Formations). These sedimentary bedrock formations are similar in texture and composition to the overlying water-bearing sediments, which make the contact between the formations difficult to identify in borehole data. In addition, there is evidence to suggest that the upper portions of the sedimentary bedrock formations have a porosity and permeability greater than zero and that these formations contribute water to deep production wells. For these reasons:

1. It is now believed that the bottom of the aquifer in the western Chino Basin includes the upper portion of the sedimentary bedrock, where present.
2. Other data (as opposed to a simple delineation based on the contact between bedrock and unconsolidated sediments) is used to estimate the geometry of the bottom of the aquifer in the western Chino Basin.

The Basement Complex underlies sedimentary bedrock in the western Chino Basin, but at depths too great to play a factor in the shallow freshwater aquifers. Durham and Yerkes (1964) estimated a depth to the Basement Complex of several thousand ft-bgs and a contact of angular unconformity with the overlying sedimentary bedrock. Geophysical data supports this conceptualization. Figure 2-3 shows regional gravity data plotted and contoured as Bouguer anomalies with a contour interval of 5 milligals (MGal). The gravity data was collected in May 2007 from GEONET at the United States Gravity Data Repository System. The Bouguer anomalies in the Chino Basin area range between -80 MGal in the western Chino Basin to about -55 MGal in the granitic Jurupa Mountains and La Sierra Hills. Gravity lows can be attributed to a greater thickness of low-density rock formations, such as loose sediments and sedimentary rocks. Note how the Bouguer anomaly contours have a similar shape to the contours of the bottom of the aquifer in Figure 2-2 with a trough of low values in western Chino Basin. These gravity data are consistent with a deep sedimentary trough in the western Chino Basin with progressively shallower crystalline bedrock to the east and southeast toward the granitic Jurupa Mountains and La Sierra Hills.

The contours in Figure 2-2 show Watermaster's new conceptualization of the bottom of the aquifer beneath the western Chino Basin as a deep, north-striking trough with a maximum depth of about 1,300 feet. The multiple data sources that Watermaster utilized to estimate the geometry of the bottom of the aquifer beneath the western Chino Basin include data from deep wells and information gleaned from the land subsidence investigation in MZ-1 (described in detail below).

Figure 2-2 shows two well locations along Central Avenue in the westernmost portion of Chino Basin. At one location, there is a deep production well (CH-19), which is screened from 340-1,000 ft-bgs. At the other location (Ayala Park in the City of Chino), there is a subsidence monitoring facility that contains multiple piezometers; two of which are highlighted here (PA-7, which is screened from 438-448 ft-bgs, and PB-2, which is screened from 1,086-1,096 ft-bgs). Note that PB-2 is screened about 100 feet below the deepest screens of CH-19.

Both PA-7 and PB-2 are completed in sand and gravel units. Slug test data from PA-7 and PB-2 have indicated that the hydraulic conductivity of PA-7 (48 ft/day) is much greater than that of PB-2 (0.5 ft/day).

Figure 2-4 is a water level time series chart that shows the water level responses at PA-7 and PB-2 to pumping at CH-19. Note the immediate response (drawdown) of water levels at PA-7 to the initiation of pumping at CH-19. Also, note the relatively delayed and muted response (drawdown) of water levels at PB-2.

The above observations indicate that pumping of the aquifer system in the western Chino Basin above 1,000 ft-bgs causes:

1. The horizontal flow of groundwater to pumping wells within the high-permeability sand and gravel units of the Older Alluvium, like those screened in PA-7 at 438-448 ft-bgs.
2. The oblique (with upward component) flow of groundwater to pumping wells within the low-permeability sands and gravels of the sedimentary bedrock formations, like those screened in PB-2 at 1,086-1,096 ft-bgs.

Figure 2-5 is a cartoon of this hydrogeologic conceptualization compared to the stratigraphy of the western Chino Basin. The data analyzed to reach this hydrogeologic conceptualization of the western Chino Basin came from a unique data set that was compiled to investigate land subsidence in a focused area of the City of Chino. However, there are additional data from other deep wells that have led Watermaster to extrapolate this hydrogeologic conceptualization across the entire west side of the Chino Basin.

Figure 2-2 shows all deep wells in the western Chino Basin and the Temescal Basin with screens deeper than 1,000 ft-bgs. The wells are labeled by the bottom elevation of the well screens. All of the well boreholes penetrated a similar sequence of sediments that include sands, gravels, silts, and clays. At some of these wells, spinner tests were performed after well development. Figure 2-5 shows a hypothetical example of a spinner test result that is typical of a deep well, demonstrating that the pumped groundwater enters a well primarily from shallower sediments (probably from the higher-permeability sediments of the Older Alluvium) with a much smaller contribution from deeper sediments (probably from the lower-permeability sediments of the "sedimentary bedrock" formations). The deepest production wells in the western Chino Basin are about 1,200 ft-bgs. This information is the basis for Watermaster's decision to set the bottom of the aquifer at approximately 1,300 ft-bgs across most of the western portion of the Chino Basin and the Temescal Basin.

2.3.3.3 Bedrock Fault

Another major feature of the bottom of the aquifer in the southern Chino Basin is the assumed bedrock fault that underlies Archibald Avenue. This bedrock fault has uplifted the crystalline bedrock of the Basement Complex in the eastern Chino Basin relative to the sedimentary bedrock and water-bearing sediments in the western Chino Basin. The evidence for this bedrock fault comes from well borehole data.

Figure 2-6 displays the map view of several hydrogeologic cross-sections that have been drawn across Chino Basin to support the 2007 model update. Figure 2-6a is a profile view of a hydrogeologic cross-section that crosses the bedrock fault in the southern Chino Basin. Note that the borehole of well

CD1-13 terminates in crystalline bedrock at a depth of 320 ft-bgs. Also, note that just 4,500 ft to the west, the borehole of well CD1-7 was drilled to a depth of 680 ft-bgs without penetrating crystalline bedrock. These and other similar observations were used to define the location and orientation of the assumed bedrock fault.

The location and orientation of the bedrock fault and the existence of deep, low-permeability aquifers in the western Chino Basin are entirely consistent with past work in this area (French, 1972).

2.4 Groundwater Occurrence and Movement

The physical nature of Chino Basin groundwater reservoirs is described below with regard to basin boundaries, recharge, groundwater flow, discharge, distinct aquifer systems, hydrostratigraphy, aquifer properties, and internal faults.

2.4.1 Chino Basin Boundaries

The physical boundaries of the Chino Basin are shown in Figure 2-1 and include:

- **Red Hill Fault to the north.** The Red Hill Fault is a recently active fault, evidenced by recognizable fault scarps such as Red Hill at the extreme southern extent of the fault near Foothill Boulevard. The fault is a known barrier to groundwater flow, and groundwater elevation differences on the order of several hundred feet on opposite sides of the fault are typical (Eckis, 1934; DWR, 1970). Groundwater seeps across the Red Hill Fault as underflow from the Cucamonga Basin to the Chino Basin, especially during periods of high groundwater elevations within the Cucamonga Basin.
- **San Jose Fault to the northwest.** The San Jose Fault is known as an effective barrier to groundwater flow with groundwater elevation differences on the order of several hundred feet on opposite sides of the fault (Eckis, 1934; DWR, 1970). Groundwater seeps across the San Jose Fault as underflow from the Claremont and Pomona Basins to the Chino Basin, especially during periods of high groundwater elevations within the Pomona and Claremont Heights Basins.
- **Groundwater divide to the west.** A natural groundwater divide near Pomona separates the Chino Basin from the Spadra Basin in the west. The divide, which extends from the eastern tip of the San Jose Hills southward to the Puente Hills, is produced by groundwater seepage from the Pomona Basin across the southern portion of the San Jose Fault (Eckis, 1934).
- **Puente Hills/Chino Hills to the southwest.** The Chino Fault extends from the northwest to the southeast along the western boundary of the Chino Basin. It is, in part, responsible for uplift of the Puente Hills and Chino Hills, which form a continuous belt of low hills west of the fault. The Chino and Puente Hills, which are primarily composed of consolidated sedimentary rocks, form a low permeability barrier to groundwater flow.
- **Flow system boundary with Temescal Basin to the south.** A comparison of groundwater elevation contour maps over time suggests a consistent distinction between flow systems within the lower Chino Basin and Temescal Basin. As groundwater within Chino Basin flows southwest into the Prado Basin area, it converges with groundwater flowing northwest out of the Temescal Valley (Temescal Basin). These groundwaters commingle and flow southwest toward Prado Dam and can rise to become surface water in Prado Basin. This area of convergence of Chino and Temescal groundwaters is indistinct and probably varies with changes in climate and production patterns. As a result, the boundary that separates Chino

Basin from Temescal Basin was drawn along the legal boundary of the Chino Basin (Chino Basin Municipal Water District v. City of Chino, *et al.*, San Bernardino Superior Court, No. 164327).

- **La Sierra Hills to the south.** The La Sierra Hills outcrop south of the Santa Ana River, are primarily composed of impermeable crystalline bedrock, and form a barrier to groundwater flow between the Chino Basin and the Arlington and Riverside Basins.
- **Shallow bedrock at the Riverside Narrows to the southeast.** Between the communities of Pedley and Rubidoux, the impermeable bedrock that outcrops on either side of the Santa Ana River narrows considerably. In addition, the alluvial thickness underlying the Santa Ana River thins to approximately 100 feet or less (*i.e.*, shallow bedrock). This area of narrow and shallow bedrock along the Santa Ana River is commonly referred to as the Riverside Narrows. Groundwater upgradient of the Riverside Narrows within the Riverside Basins is forced to the surface and becomes rising water within the Santa Ana River (Eckis, 1934). Downstream of the Riverside Narrows, the bedrock configuration widens and deepens, and surface water within the Santa Ana River can infiltrate to become groundwater in the Chino Basin.
- **Jurupa Mountains and Pedley Hills to the southeast.** The Jurupa Mountains and Pedley Hills are primarily composed of impermeable bedrock and form a barrier to groundwater flow that separates the Chino Basin from the Riverside Basins.
- **Bloomington Divide to the east.** A flattened mound of groundwater exists beneath the Bloomington area as a likely result of groundwater flow from the Rialto-Colton Basin through a gap in the Rialto-Colton Fault north of Slover Mountain (Dutcher and Moyle, 1963; Gosling, 1966; DWR, 1970). This mound of groundwater extends from the gap in the Rialto-Colton Fault southwest towards the northeast tip of the Jurupa Mountains. Groundwater to the northwest of this divide recharges the Chino Basin and flows westward staying north of the Jurupa Mountains. Groundwater southeast of the divide recharges the Riverside Basins and flows southwest towards the Santa Ana River.
- **Rialto-Colton Fault to the northeast.** The Rialto-Colton Fault separates the Rialto-Colton Basin from the Chino and Riverside Basins. This fault is a known barrier to groundwater flow along much of its length—especially in its northern reaches (south of Barrier J) where groundwater elevations can be hundreds of feet higher within the Rialto-Colton Basin (Dutcher and Garrett, 1963; DWR, 1970; Woolfenden and Kadhim, 1997). The disparity in groundwater elevations across the fault decreases to the south. To the north of Slover Mountain, a gap in the Rialto-Colton Fault exists. Groundwater within the Rialto-Colton Basin passes through this gap to form a broad groundwater mound (divide) in the vicinity of Bloomington and, hence, is called the Bloomington Divide (Dutcher and Moyle, 1963; Gosling, 1966; DWR, 1970).
- **Extension of the Rialto-Colton Fault north of Barrier J.** Little well data exist to support the extension of the Rialto-Colton Fault north of Barrier J (although hydraulic gradients are steep through this area). Groundwater flowing south out of Lytle Creek Canyon, in part, is deflected by Barrier J and likely flows across the extension of the Rialto-Colton Fault north of Barrier J and into the Chino Basin.

2.4.2 Groundwater Recharge, Flow, and Discharge

The predominant source of recharge to Chino Basin groundwater reservoirs is the percolation of direct precipitation and returns from applied water. The following is a list of all potential sources of recharge in Chino Basin:

- Infiltration of flow within unlined stream channels overlying the basin
- Infiltration of stormwater flow and municipal wastewater discharges within the channel of the Santa Ana River
- Underflow from the saturated sediments and fractures within the bounding mountains and hills
- Artificial recharge at storm water, imported water, and recycled water spreading grounds
- Underflow from seepage across the bounding faults, including the Red Hill Fault (from Cucamonga Basin), the San Jose Fault (from the Claremont Heights and Pomona Basins), and the Rialto-Colton Fault (from the Rialto-Colton Basin)
- Intermittent underflow from the Temescal Basin
- Deep percolation of precipitation and returns from use

In general, groundwater flow mimics surface drainage patterns: from the forebay areas of high elevation (areas in the north and east, flanking the San Gabriel and Jurupa Mountains) towards areas of discharge near the Santa Ana River within the Prado Flood Control Basin. Figure 2-7a is a groundwater elevation contour map for fall 2006 that shows this general groundwater flow pattern (perpendicular to the contours). A comparison of this contour map to groundwater elevation contour maps from other periods shows similar flow paths, indicating consistent flow systems within the Chino Basin (WEI, 2000).

While considered one basin from geologic and legal perspectives, the Chino Basin can be hydrologically subdivided into at least five flow systems that act as separate and distinct hydrologic units. Each flow system can be considered a management zone. Each management zone has a unique hydrology, and water resource management activities that occur in one management zone have limited impacts on other management zones.

Figure 2-7a also shows the location of the five management zones in Chino Basin that were developed during the TIN/TDS Study (WEI, 2000) of which Watermaster, the Chino Basin Water Conservation District (CBWCD), and the Inland Empire Utilities Agency (IEUA) were study participants. Nearing the southwestern (lowest) portion of the basin, these flows systems become less distinct as all groundwater flow within Chino Basin converges and rises beneath the Prado Basin. In detail, groundwater discharge throughout Chino Basin primarily occurs via:

- Groundwater production
- Rising water within Prado Basin (and potentially other locations along the Santa Ana River depending on climate and season)
- Evapotranspiration within Prado Basin (and potentially other locations along the Santa Ana River depending on climate and season) where groundwater is near or at the ground surface
- Intermittent underflow to the Temescal Basin

2.4.3 Aquifer Systems

The saturated sediments within Chino Basin comprise one groundwater reservoir, but the reservoir can be sub-divided into distinct aquifer systems based on the physical and hydraulic characteristics of the aquifer-system sediments and the contained groundwater. These aquifer systems include a shallow aquifer system and at least one deep aquifer system.

The sediments that comprise the shallow aquifer system are almost fully saturated in the southern portion of the Chino Basin. Depth to groundwater increases to the north to provide a thick vadose zone for percolating groundwater in the forebay regions of the Chino Basin (see Figure 2-7b). The sediments that comprise the deep aquifer system are always fully saturated. Section 2.4.4 – *Hydrostratigraphy* describes and illustrates the detailed configurations of the shallow and deep aquifer systems.

The shallow aquifer system is generally characterized by unconfined to semi-confined groundwater conditions, high permeability within its sand and gravel units, and high concentrations of dissolved solids and nitrate (especially in the southern portions of the Chino Basin). The deep aquifer system is generally characterized by confined groundwater conditions, lower permeability within its sand and gravel units, and lower concentrations of dissolved solids and nitrate. Where depth-specific data are available, piezometric head tends to be higher in the shallow aquifer system, indicating a downward vertical hydraulic gradient.

To illustrate the above generalizations, Figure 2-8 shows the location of Well 1A and Well 1B, which are owned by the City of Chino Hills. These two wells are physically located within 30 feet of each other on the west side of the Chino Basin, but their non-pumping water-level time histories are distinctly different. Figure 2-9 displays the water-level time series of Well 1A (perforated within the shallow aquifer system), which maintains a relatively stable water level that fluctuates annually by about 20-30 feet, which is probably in response to seasonal production and recharge. Depth to water averages about 80 feet-bgs. Comparatively, Well 1B (perforated within the deep aquifer system) displays a wildly fluctuating piezometric level that can vary seasonally by as much as 250 feet. Depth to water in Well 1B averages about 220 feet-bgs. The water level fluctuations observed in the deep aquifer system are typical of confined groundwater conditions where small changes in storage (caused by pumping in this case) can generate large changes in piezometric levels.

Wells 1A and 1B also display significant differences in water quality. Nitrate concentrations in 1A and 1B averaged 7 mg/L and 1 mg/L, respectively, from 1997 to 2002. Total dissolved solids (TDS) concentrations in 1A and 1B averaged 288 mg/L and 175 mg/L, respectively, from 1997 to 2002. Arsenic concentrations are relatively high in the deep aquifer system (averaging 66 micrograms per liter [μg/L] in Well 1B from 1997 to 2002 compared to non-detectable in Well 1A). Similar vertical water quality gradients have been noted between deep and shallow groundwater in the area of the Chino-1 and Chino-2 Desalter well fields (see Figure 2-8) (GSS, 2001; Dennis Williams, GSS, pers. comm., 2003).

Watermaster's recently constructed Ayala Park Extensometer facility is also in Figure 2-8 (near Wells 1A and 1B). At this facility, there are 11 piezometers with screens of 5-20 feet in length that were completed at various depths, ranging from 139-1,229 ft-bgs. Slug tests were performed at a number of these piezometers to determine, among other objectives, the permeabilities of the sediments at various depths within the total aquifer system. Figure 2-6g is a cross-section that includes the deep borehole at Ayala Park and some of these slug test data at the piezometers. In general, the piezometers in the shallow aquifer system (less than about 350 ft-bgs) display relatively high hydraulic conductivities of 20 to 27 ft/day. The piezometers within the deep aquifer system display relatively low hydraulic conductivities of 1.6 to 0.5 ft/day. A notable exception is a piezometer that was completed in a gravelly sand in the uppermost portion of the deep aquifer system (438-448 ft-bgs), which displays a relatively high hydraulic conductivity of 48 ft/day, indicating the existence of some higher permeability zones within the deep aquifer system.

The distinction between aquifer systems is most pronounced within the west-southwest portions of the Chino Basin. This is likely because of the relative abundance of fine-grained sediments in the southwest (multiple layers of clays and silts). Groundwater flowing from high-elevation forebay areas in the north and east become confined beneath these fine-grained sediments in the west-southwest, and these sediments effectively isolate the shallow aquifer system from the deep aquifer system(s).

The three-dimensional extent of these fine-grained sedimentary units and their effectiveness as confining layers has never been mapped in detail across the Chino Basin. However, the following data, shown on Figure 2-8, can be used to estimate the lateral extent of these units:

- Historical flowing artesian conditions were mapped in the early 1900s in the southwest portion of the Chino Basin (Mendenhall, 1905, 1908; Fife *et al.*, 1976), which indicates the existence of confining layers in these areas.
- Remote sensing studies were conducted to analyze land subsidence in Chino Basin (Peltzer, 1999a, 1999b). These studies employed InSAR, which utilizes radar imagery from an Earth-orbiting spacecraft to map ground surface deformation. InSAR has indicated the occurrence of persistent subsidence across the western portion of Chino Basin from 1992 to 2000. It is likely that this subsidence is due to the compaction of fine-grained sediments, resulting from lower pore pressures within the aquifer system (WEI, 2002). The southern extent of persistent subsidence is currently unknown because InSAR data is difficult to obtain in areas of agricultural land uses, but it may extend southward to encompass the historical artesian area.

North and east of these areas, the distinction between aquifer systems is less pronounced because the fine-grained layers in the west-southwest thin and/or pinch-out to the north and east, and much of the shallow aquifer system sediments are unsaturated in the forebay regions of Chino Basin.

Geologic descriptions from well completion reports in the Chino Basin confirm the predominance of fine-grained sediments in the west-southwest portion of the Chino Basin and the predominance of coarser-grained sediments in the north and east portions of Chino Basin. These observations are described and illustrated in more detail in the following two sections (2.4.4 – *Hydrostratigraphy* and 2.4.5 – *Aquifer Properties*).

2.4.4 Hydrostratigraphy

The analysis and documentation of Chino Basin stratigraphy, occurrence and movement of groundwater, and aquifer system characteristics has allowed Watermaster to create a hydrostratigraphic conceptual model of the basin. Watermaster created a hydrostratigraphic model to support the 2003 groundwater flow model. In order this model in 2003, nine hydrogeologic cross-sections were constructed across the Chino Basin (WEI, 2003). These cross-sections were revised for the 2007 model update based on new data and hydrogeologic interpretations.

The plan-view locations of these cross-sections are shown in Figure 2-6, and the profile-view cross-sections are shown in Figures 2-6a through 2-6i. Plotted on these cross-sections are selected well and borehole data, including borehole lithologies, short-normal resistivity logs, well casing perforations, specific capacities, slug test and spinner test analyses, water quality, and piezometric levels.

Through the analyses of these cross-sections and other hydrogeologic data, the aquifer system of Chino Basin was sub-divided into three hydrostratigraphic units—herein referred to as Layer 1, Layer 2, and Layer 3. In the descriptions of each layer below, specific examples from individual wells and cross-sections are discussed to highlight certain characteristics of the hydrostratigraphic layers, but the delineation of these layers in three dimensions was drawn from a holistic analysis of the entire data set. In other words, 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.

2.4.4.1 Layer 1

Layer 1 consists of the upper 150-950 feet of sediments and is generally representative of the shallow aquifer system. Layer 1 sediments are typically coarse-grained (sand and gravel layers) and, where saturated, transmit large quantities of groundwater to wells due to high hydraulic conductivities. On the west side of Chino Basin, Layer 1 sediments are composed of a greater fraction of finer-grained sediments (silt and clay layers), especially in the uppermost 100 feet. Layer 1 water quality is generally poor in the southern portion of the Chino Basin with relatively high concentrations of TDS and nitrate. Water quality is generally excellent in the northern portions of the Chino Basin.

Figures 2-6e and 2-6f display the profile view of cross-sections E-E' and F-F'. Both cross sections are aligned southwest-northeast and illustrate the thickening of Layer 1 in the northeastern direction at the expense of Layer 2. The thickening of Layer 1 is supported by the observation that the silt and clay layers, which are typical of Layer 2 sediments in the southwestern Chino Basin, become thinner and less abundant in the eastern and northeastern portions of the Chino Basin.

Figure 2-6g displays the profile view of cross-section G-G', which is aligned southeast-northwest and bisects Management Zone 1. This cross-section displays three of the newly-installed HCMP monitoring wells (HCMP-3, 4, and 6) and the piezometers at Ayala Park (AP Piezometer), which were used to refine the layer geometries in the southern Chino Basin. These monitoring wells are nested sets of piezometers that allow for depth-specific monitoring of the aquifer system. Note the vertical stratification of the groundwater quality in Figure 2-6g (and other cross-sections with vertically distinct groundwater quality data). The relatively high TDS and nitrate concentrations in the shallow aquifer system (Layer 1) decrease significantly with depth (Layers 2 and 3), especially in the southern portions of the Chino Basin.

Figure 2-6a displays the profile view of cross-section A-A', which is aligned west-east and bisects the southern portion of the Chino Basin through the Chino 1 Desalter well field. Note the depth of the well screens relative to the water quality and specific capacity data. The wells with shallow well screens (at least, in part, in Layer 1) have relatively high TDS and nitrate concentrations while the wells screen exclusively in Layers 2 and 3 have relatively low TDS and nitrate concentrations. The same pattern can be observed in the specific capacity data: wells with shallow well screens have relatively high specific capacities, indicating relatively high permeability in the shallow aquifer system; and wells with screens exclusively in Layers 2 and 3 have relatively low specific capacities, indicating relatively low permeability in the deep aquifer system.

2.4.4.2 Layer 2

Layer 2, where present, consists of 0-500 feet of sediments underlying Layer 1 and is representative of the upper portion of the deep aquifer system. Layer 2 is generally characterized by an abundance of fine-grained sediments (*e.g.* silt and clay layers), confined groundwater conditions, and lower permeabilities and better water quality than in Layer 1 (relatively low TDS and nitrate concentrations—especially in the southern Chino Basin).

Figures 2-6c, 2-6e, and 2-6f display the profile view of cross-sections C-C', E-E', and F-F', respectively. These cross-sections, which are generally aligned southwest-northeast, illustrate that Layer 2 is spatially restricted to the western portion of Chino Basin and that it "pinches out" to the northeast as Layer 1 thickens. This pinching out is supported by the observation that the silt and clay layers, which are typical of Layer 2 sediments in the southwestern Chino Basin, become thinner and less abundant in the eastern and northeastern portions of the Chino Basin.

The confined groundwater conditions of Layer 2 and the low concentrations of TDS and nitrate are best illustrated in Figures 2-6a and 2-6g (cross-sections A-A' and G-G') and in Figure 2-9 (Water Level Time Histories [Non-Pumping]: City of Chino Hills Wells 1A and 1B). In Figure 2-6a, note that well CH-1B is screened across Layers 2 and 3. The water level time series for CH-1B (shown in Figure 2-9) displays a wildly fluctuating piezometric level that varies seasonally by as much as 250 feet, mainly in response to nearby pumping. These water level fluctuations observed in CH-IB are typical of confined groundwater conditions where small changes in storage (caused by pumping in this case) can generate large changes in piezometric levels. This is a consistent observation that can be seen in all wells screened exclusively in the deep aquifer system in southwestern Chino Basin and indicates the existence of an effective upper confining layer separating the deep and shallow aquifer systems. The silt and clay layers above the well screens in CH-1B were correlated to other wells in the southwestern Chino Basin (see Figures 2-6a and 2-6g), which assisted in the delineation of the boundary between Layers 1 and 2.

As stated above (Section 2.4.4.1) and as shown in Figure 2-6a, wells with shallow well screens have relatively high TDS/nitrate concentrations and relatively high specific capacities, and wells with screens exclusively in Layers 2 and 3 have relatively low TDS/nitrate concentrations and relatively low specific capacities.

2.4.4.3 Layer 3

Layer 3 consists of 0-800 feet of sediments underlying Layers 1 and 2 within the deep aquifer system. Layer 3 is generally characterized by an abundance of coarse-grained sediments (*e.g.* sand and gravel layers), but due to their greater age, consolidation, and state of weathering, these sediments have lower permeability than the coarse-grained sediments of Layers 1 and 2. In the western Chino Basin, Layer 3 sediments underlie Layer 2 and represent the lower portion of the deep aquifer system. As depicted in Figure 2-5, Layer 3 is likely composed of the sedimentary bedrock formations in the western Chino Basin. In the eastern Chino Basin, Layer 3 sediments underlie Layer 1 and represent the deep aquifer system. In this area, Layer 3 sediments are likely composed of the lower portion of the Older Alluvium. In the southeastern Chino Basin, Layer 3 does not extend east of the assumed Bedrock Fault toward the Jurupa Mountains and La Sierra Hills.

The best example of Layer 3 characteristics are observed at the Ayala Park Extensometer facility located on the west side of the Chino Basin. In Figure 2-6g, note how the boundary between Layer 2 and 3 is drawn where the fraction of coarse-grain sediments begins to increase with depth. Also, note the very low concentrations of TDS and nitrate and the very low hydraulic conductivity at PB-2 (Layer 3), as estimated from slug testing. In other regions of the Chino Basin, these same characteristics of Layer 3 can be estimated from lithology (lithologic descriptions from well boreholes and geophysical logs) and spinner test analyses. For example, in Figure 2-6f, note how the top of Layer 3 is drawn in Well MP-2 at the transition from the relatively fine-grained sediments of Layer 2 to the relatively coarse-grained sediments of Layer 3. Also, in this figure, note how the spinner test analysis for Well FWC-17C indicates that only 30 percent of the total well discharge comes from Layer 3 despite the fact that most of the screened interval resides in it. Wherever available, these types of observations assisted in the delineation of the top of Layer 3.

2.4.4.4 Creation of a Three-Dimensional Hydrostratigraphic Model

At each well on each cross-section, the bottom elevations of all the three layers were plotted on maps and hand-contoured. The contours were digitized, brought into a Geographic Information System

(GIS) (ArcGIS 9.1), converted to point values, and combined with the bottom elevation point values at the wells into a single point Environmental Systems Research Institute (ESRI) shapefile. The Geostatistical Analyst extension of ArcGIS was used to interpolate between point values and create three-dimensional rasters (ESRI grids) of the layer bottom elevations. These raster images represent the updated hydrostratigraphic model of the Chino Basin and were used as input files for the aquifer-system geometry for the 2007 model update.

2.4.5 Aquifer Properties

Effective porosity (specific yield) and hydraulic conductivity are the most important aquifer properties in groundwater modeling efforts. Quantitatively, these aquifer properties cannot be measured everywhere within the basin, but can be estimated qualitatively through various methods.

2.4.5.1 Effective Porosity

The effective porosity of the aquifer-system sediments in the Chino Basin was estimated through the analysis of lithologic descriptions from driller's logs. Watermaster maintains a library of driller's logs of all known well boreholes that have been drilled in the Chino Basin. Lithologic descriptions from the driller's logs were input into a relational database along with corresponding US Geological Survey (USGS) estimates of effective porosity by sediment type (Johnson, 1967).

A thickness-weighted, average effective porosity was calculated at each borehole for each layer in the Chino Basin, and these point values were imported to ArcGIS. Using a Kriging interpolation method within the Geostatistical Analyst extension of ArcGIS, effective porosity rasters were created for each hydrostratigraphic layer. The effective porosity rasters are limited to the spatial extent of their respective layers and are shown in Figures 2-10 through 2-12.

Figure 2-10 displays spatial distribution of effective porosity for Layer 1. Effective porosities are highest (up to 20 percent) in the northern (Upland) and eastern (Fontana) portions of the Chino Basin. A belt of similarly high effective porosity runs north of the Jurupa Mountains from Fontana toward the Prado Flood Control Basin. This belt may represent coarse-grained sediments deposited by an ancestral Santa Ana River or Lytle Creek. Average effective porosities in Layer 1 are the lowest (8 to 10 percent) on the west side of the Chino Basin (Pomona and Chino). This area of relatively low effective porosity overlaps the historical artesian area and likely represents the shallow fine-grained sediments that historically acted as confining layers.

Figure 2-11 displays spatial distribution of effective porosity for Layer 2. Effective porosities are highest, ranging up to 15 percent, in the central (Ontario) portions of the Chino Basin. Effective porosities are lowest, ranging down to 5 percent, on the west side of the Chino Basin (Pomona and Chino). The areas of relatively low effective porosity overlap the historical artesian area and the area of historical subsidence as indicated by InSAR and may represent the fine-grained sediments that have experienced compaction due to reduced pore pressures.

Figure 2-12 displays spatial distribution of effective porosity for Layer 3. The primary observation in Layer 3 is a generally higher effective porosity in the eastern Chino Basin relative to a lower effective porosity in the western Chino Basin. This observation is consistent with Watermaster's current hydrostratigraphic conceptual model; the deep aquifer sediments of the western Chino Basin represent the highly-weathered and partially-consolidated sedimentary bedrock formations, and the deep sediments of the eastern Chino Basin represent the more recent coarse-grained sediments of the Older Alluvium.

2.4.5.2 Hydraulic Conductivity

The hydraulic conductivity of water-bearing sediments is a measure of their capacity to transmit water. Generally, sands and gravels have high hydraulic conductivities while clays and silts have low hydraulic conductivities. Since the effective porosity figures (Figure 2-10 through 2-12) were created from lithologic descriptions of well bore cuttings, they can also qualitatively display the distribution of hydraulic conductivity of the aquifer system. If this assumption is generally true, hydraulic conductivities are highest in the northern (Upland) and eastern (Fontana) portions of the Chino Basin and a belt of similarly high hydraulic conductivity runs north of the Jurupa Mountains from Fontana to the Prado Basin. Hydraulic conductivities are lowest on the west side of the Chino Basin (Pomona, Chino, and west Ontario).

There is solid evidence to suggest that hydraulic conductivities decrease with depth. This is likely true because deeper sediments typically have experienced a greater degree of secondary alteration (*e.g.* the weathering of feldspars to clay minerals, the cementation of pore space, *etc.*). An example of this trend is shown on Figure 2-6g, which displays the analytical results of the slug tests performed at the Ayala Park piezometers, which were completed in all three hydrostratigraphic layers. Note that the estimated hydraulic conductivity of the sand gravel units in Layer 1 (27 ft/day) and Layer 2 (48 ft/day) are significantly higher than the estimated hydraulic conductivity for Layer 3 (0.5 ft/day). Spinner test analyses and specific capacity data on several cross-sections (Figures 2-6a, 2-6d, 2-6f, 2-6h) also suggest that hydraulic conductivities decrease with depth in other areas of the basin.

2.4.6 Internal Faults

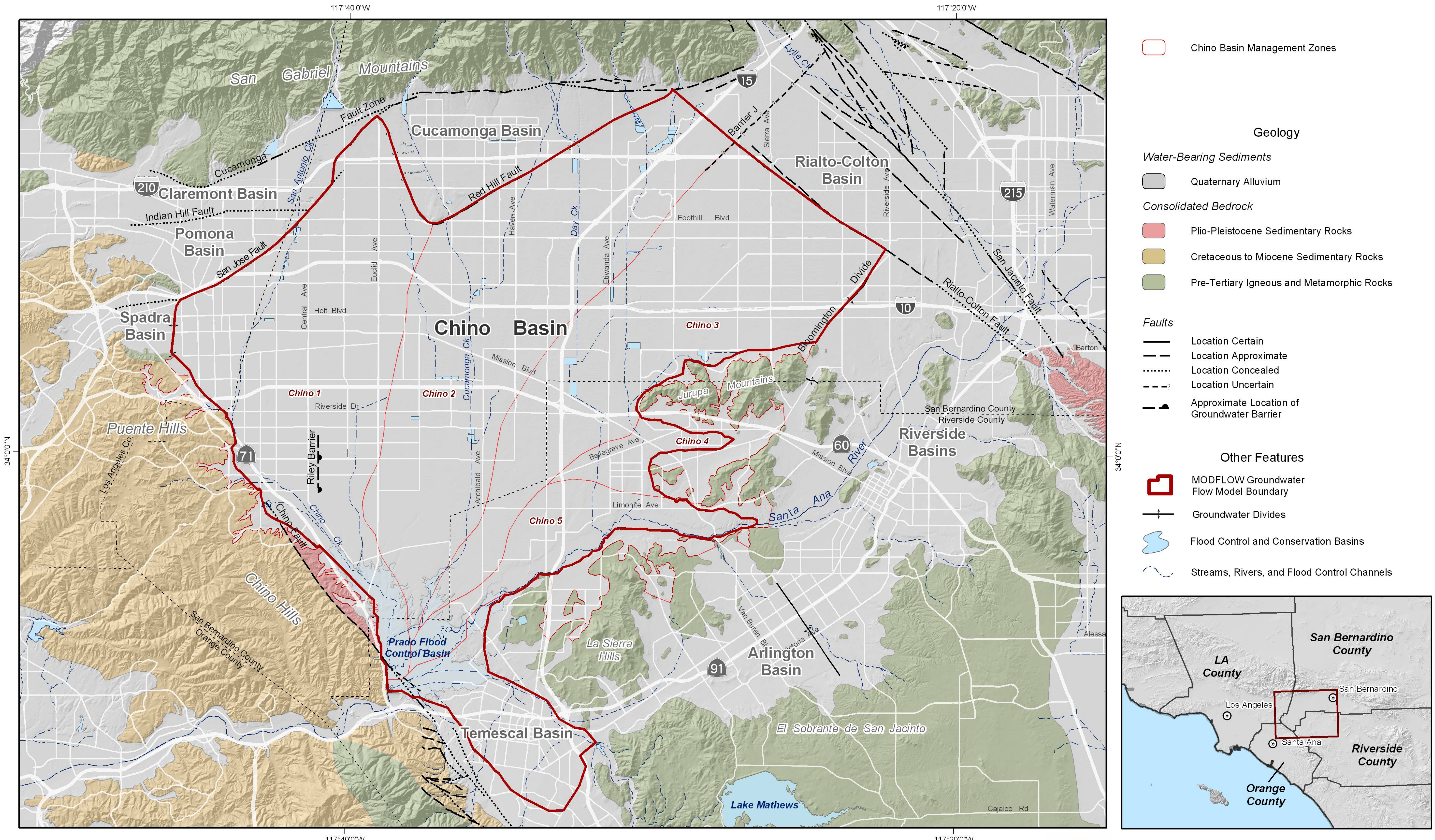
There is only one documented groundwater flow barrier within the aquifer system of the Chino Basin. This barrier exists only within deep aquifer system (Layers 2 and 3) of the western Chino Basin and was discovered during the land subsidence investigation in MZ-1. The barrier has been named the "Riley Barrier" by Watermaster to recognize Francis Riley (a retired USGS hydrogeologist) for his invaluable contributions to the design and implementation of the subsidence monitoring program in MZ-1.

2.4.6.1 Riley Barrier

Multiple lines of evidence suggest that a previously unknown groundwater barrier exists within the deep aquifer-system of the western Chino Basin—approximately aligned with the zone of historical ground fissures that appeared in the early 1990s.

Controlled aquifer-system stress (pumping) tests in October 2003 and April 2004 provided piezometric response data that revealed a potential groundwater barrier within the sediments below about 300 ft-bgs and aligned north-south with the historic fissure zone. Figure 2-13 shows the location of a pumping well that was perforated in the deep aquifer system (CH-19, 340-1,000 ft-bgs) and the locations of other surrounding wells that were also perforated exclusively in the deep system. Figure 2-14 shows the water level responses in these wells during various pumping cycles at CH-19. The groundwater barrier is evidenced by a lack of water level response in CH-18 (east of the fissure zone) due to pumping at CH-19 (west of the fissure zone). Image-well analyses of pumping-test data also indicate that this barrier approximately coincides with the location of the historic zone of ground fissuring.

Ground level survey data (via traditional benchmark surveys and remote sensing techniques [InSAR]) corroborate the water level data, further indicating the existence of the barrier and its coincident location with the fissure zone. In short, the groundwater barrier causes greater water level fluctuations on the west side of the barrier where deep-aquifer pumping has historically been concentrated. These greater water level fluctuations on the west side of the barrier, in turn, cause greater deformation of the aquifer-system matrix, which, in turn, causes greater vertical land surface deformation on the west side of the barrier. These ground surface displacements have been measured precisely and repeatedly by the ground level surveys, revealing the spatial location of the Riley Barrier (coincident with the historical fissure zone). A more extensive discussion of the Riley Barrier can be found in the MZ-1 Summary Report (WEI, 2006a).



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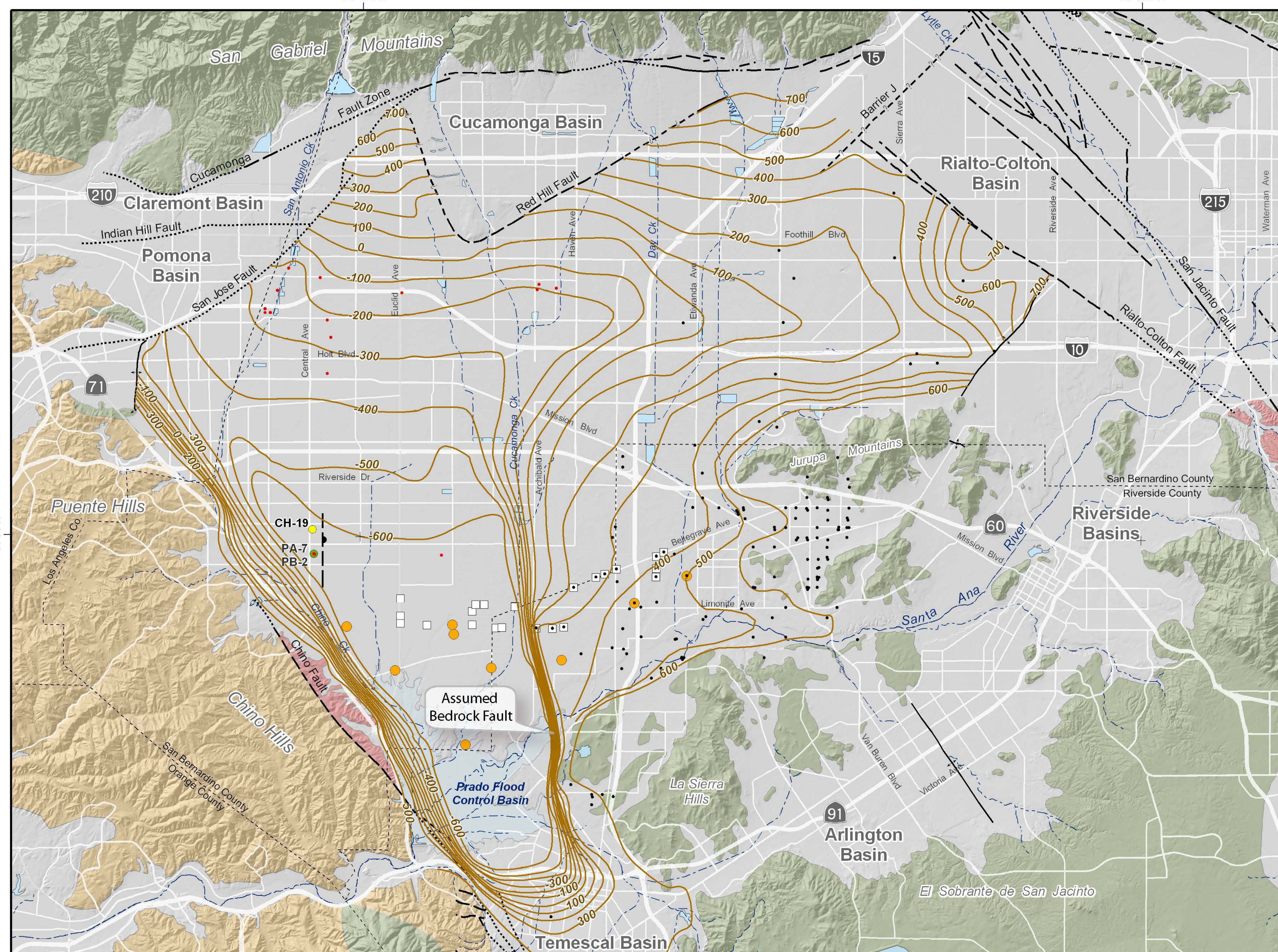
Hydrogeologic Setting

Chino Basin Management Zones

and Other Surrounding Groundwater Basins

Figure 2-1



-600- Equal Elevation Contour of the Effective Base of Freshwater Aquifer (ft-above msl)

Well Owned by City of Chino Hills

Ayala Park Extensometer/Piezometer Facility

Well Location in Western Chino Basin Where Well Perforations are Deeper than 1,000 feet

Well Location in Eastern Chino Basin Where Borehole Penetrated Crystalline Bedrock

HCMP Monitoring Well

Chino Desalter Well

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

Plio-Pleistocene Sedimentary Rocks

Cretaceous to Miocene Sedimentary Rocks

Pre-Tertiary Igneous and Metamorphic Rocks

Faults

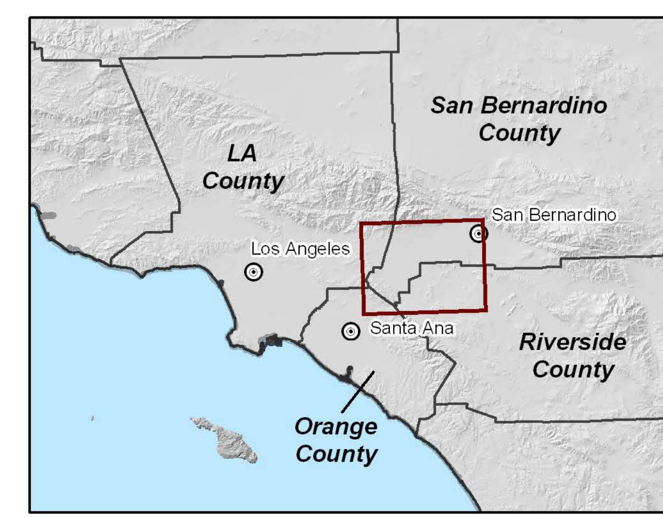
Location Certain

Location Approximate

Location Concealed

Location Uncertain

Approximate Location of Groundwater Barrier



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

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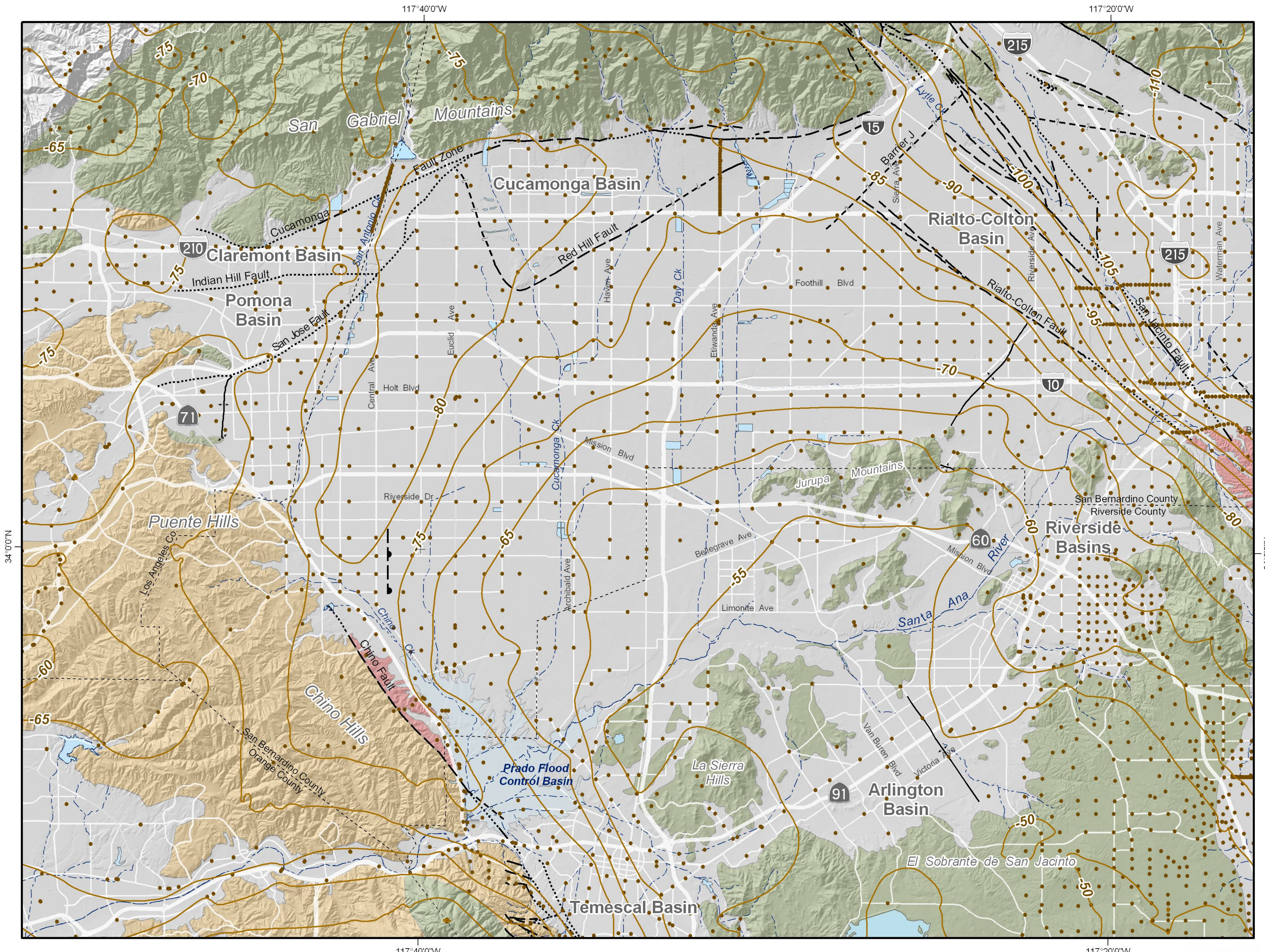
Hydrogeologic Setting

Base of Freshwater Aquifer

Chino Basin

Figure 2-2



-50 Lines of equal Bouguer gravity anomaly (milligals)

• Gravity Station*

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

Plio-Pleistocene Sedimentary Rocks

Cretaceous to Miocene Sedimentary Rocks

Pre-Tertiary Igneous and Metamorphic Rocks

Faults

Location Certain

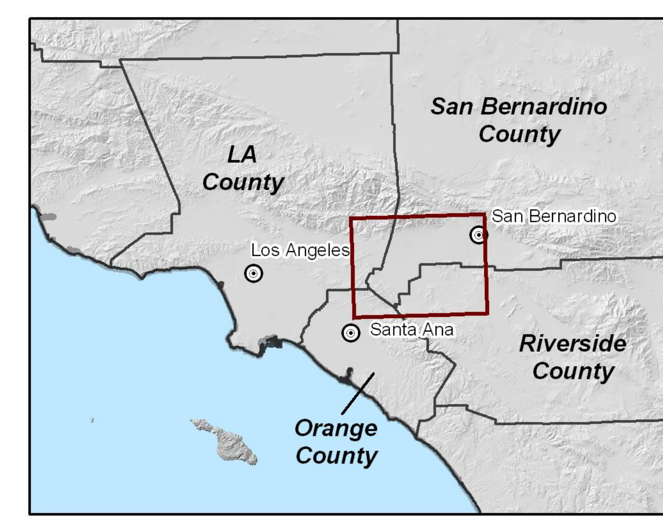
Location Approximate

Location Concealed

Location Uncertain

Approximate Location of Groundwater Barrier

* GEONET, United States Gravity Data Repository System accessed on May 15, 2007



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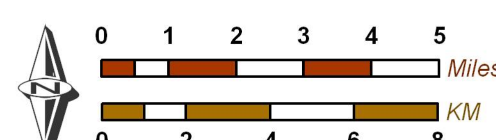

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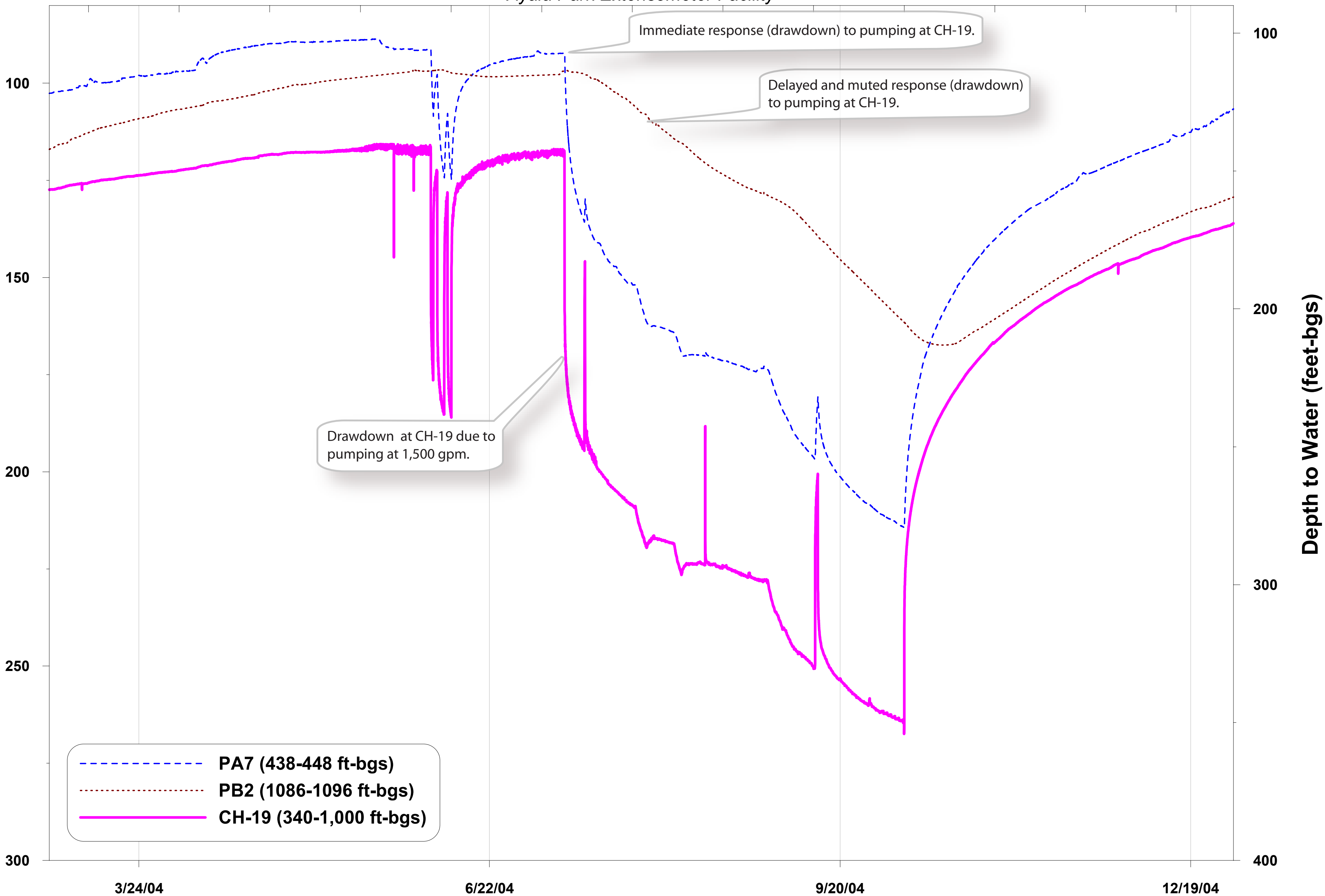
Hydrogeologic Setting

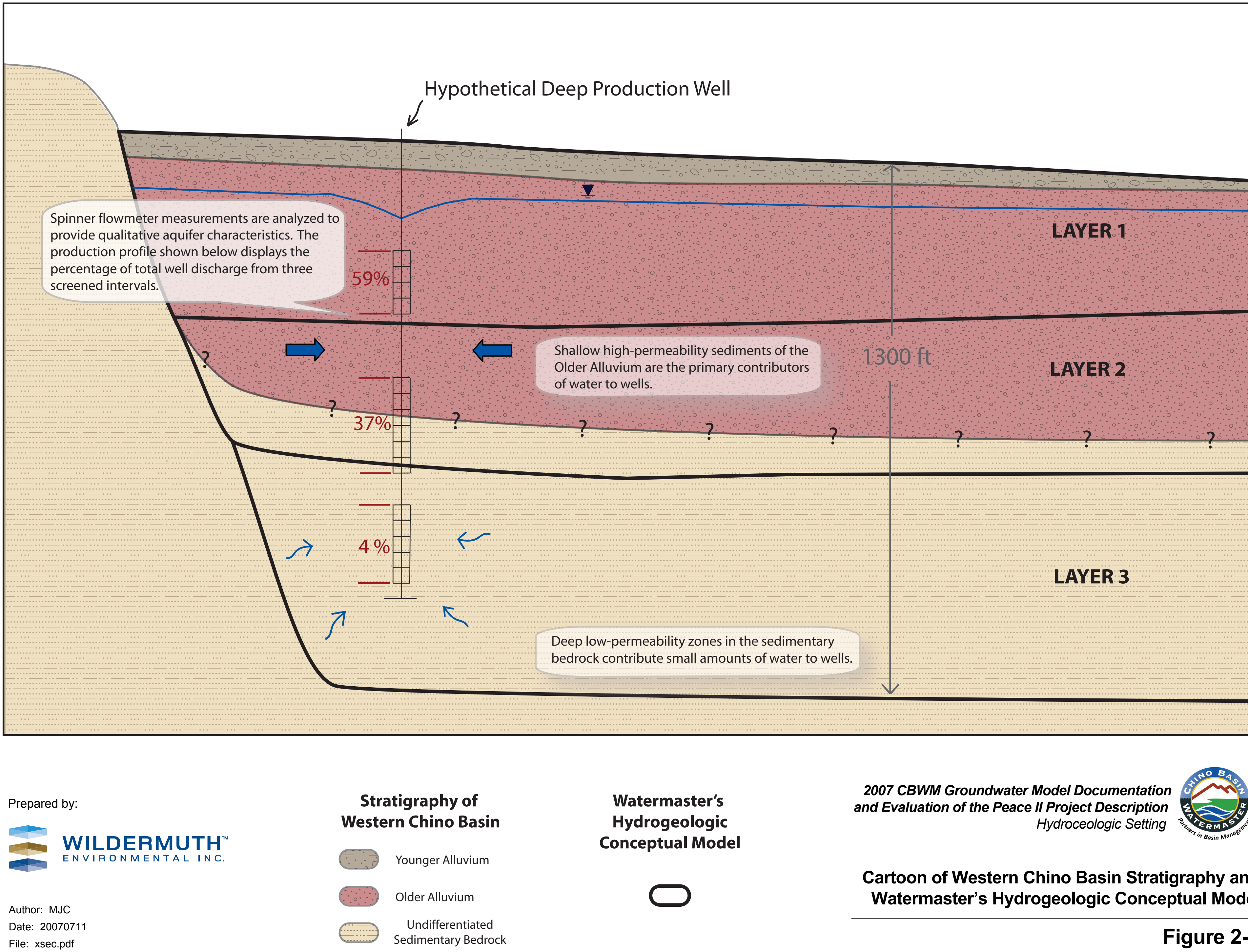
Bouguer Gravity Map

Chino Basin and Other Surrounding Basins

Figure 2-3

Figure 2-4
Piezometric Time Series
Ayala Park Extensometer Facility





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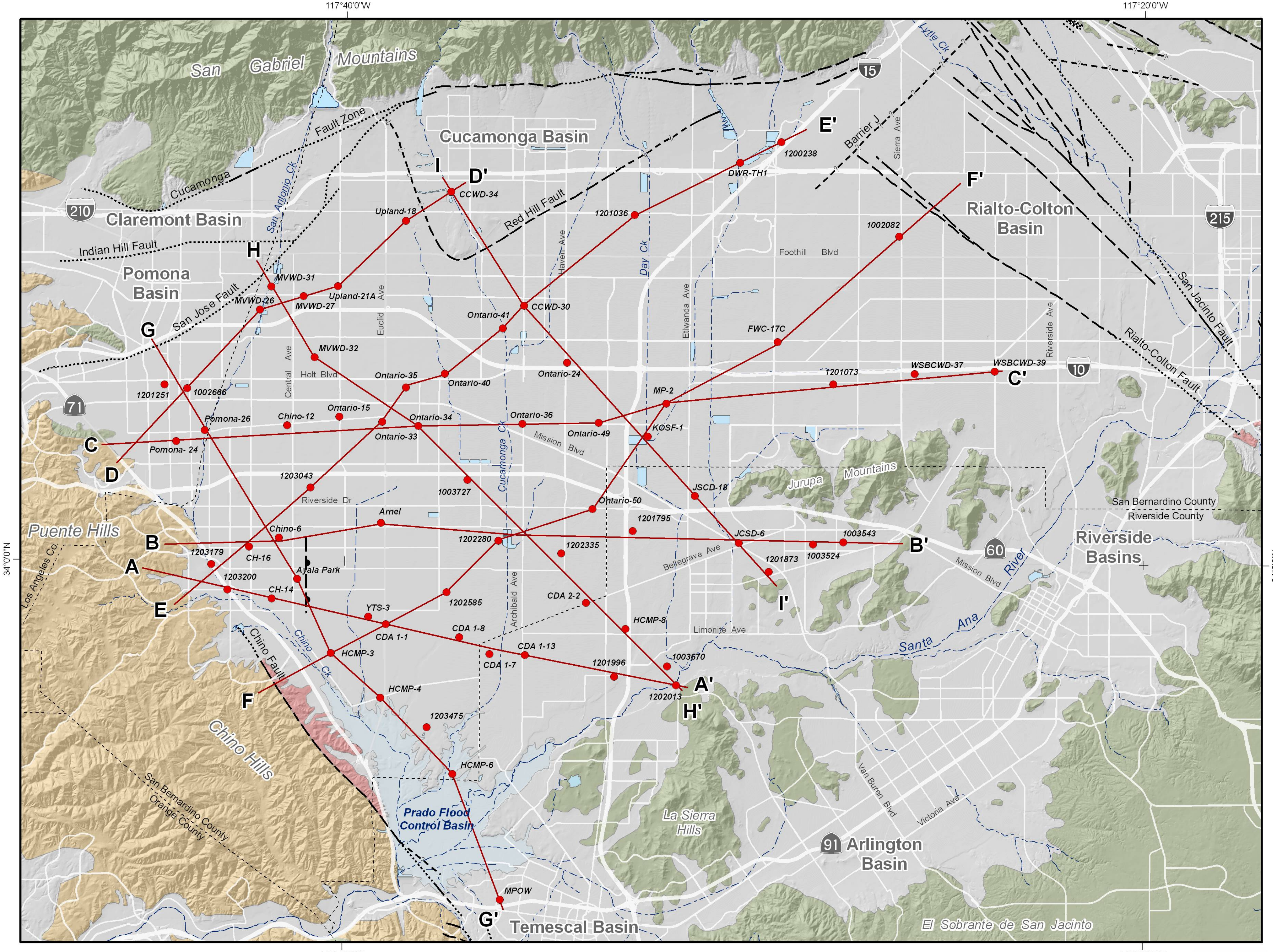
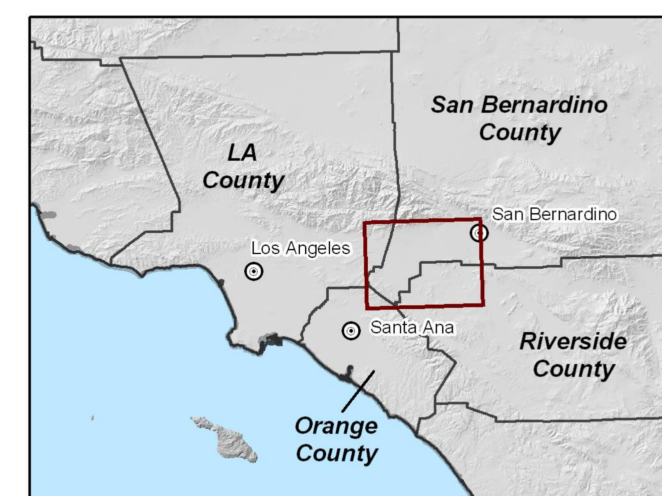
Hydroceologic Setting

Cartoon of Western Chino Basin Stratigraphy and Watermaster's Hydrogeologic Conceptual Model

Figure 2-5





Line of Geologic Cross-Section
{shown in Figures 2-6a thru 2-6i and E-sized in Exhibits A2 thru A10}

Well Used in Cross-Section

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

Plio-Pleistocene Sedimentary Rocks

Cretaceous to Miocene Sedimentary Rocks

Pre-Tertiary Igneous and Metamorphic Rocks

Faults

Location Certain

Location Approximate

Location Concealed

Location Uncertain

Approximate Location of Groundwater Barrier

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0 1 2 3 4 5 Miles

0 2 4 6 8 KM

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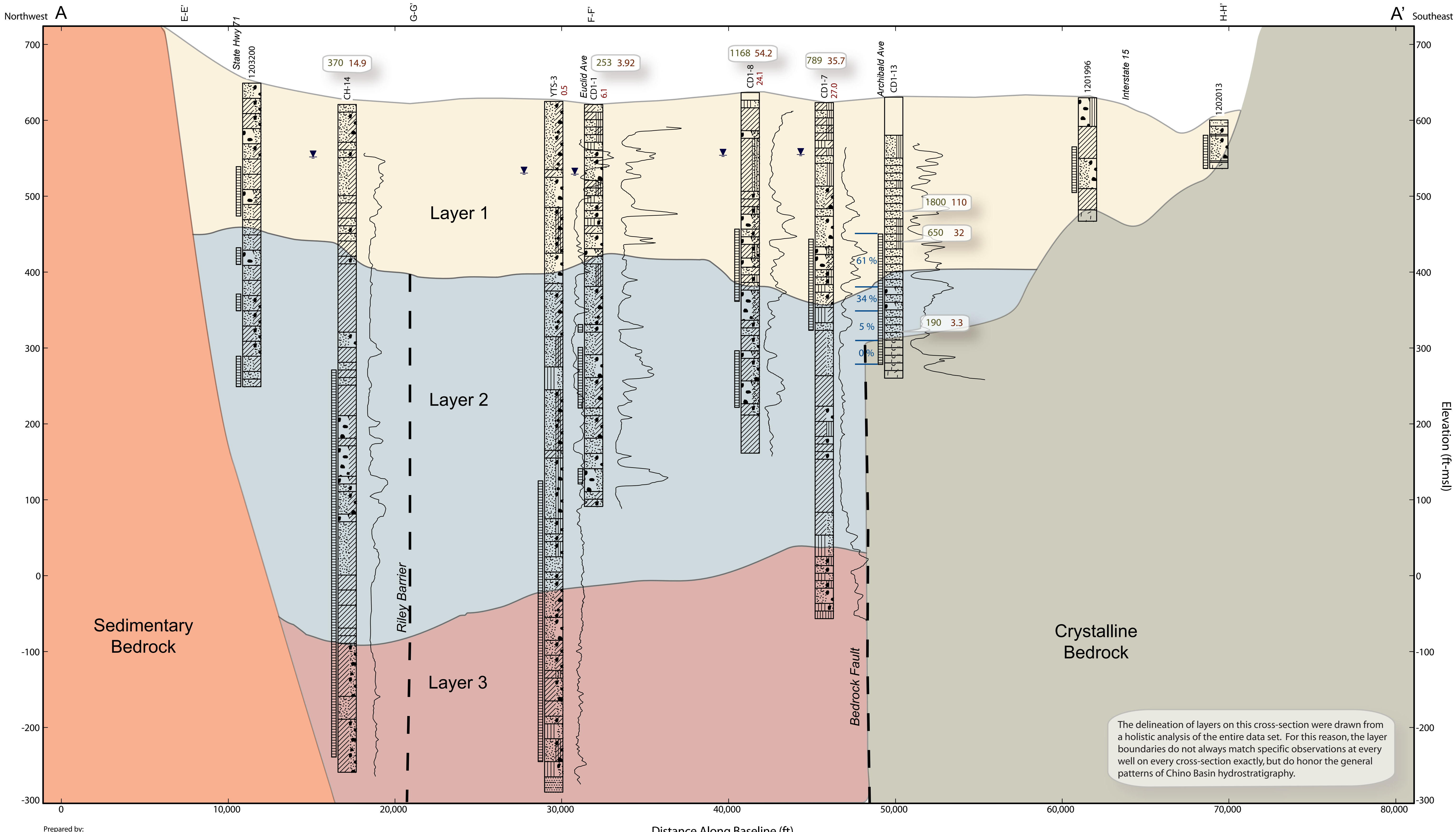
Hydrogeologic Setting

Map View of Geologic Cross-Sections

Chino Basin

Figure 2-6



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Vertical Scale: 1" = 120'
Horizontal Scale: 1" = 5500'
Vertical Exaggeration: 46:1

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Date: 20070822
File: a-a.pdf

Lithologic Graphics

Gravel, Sand, Silt, Clay, Granite, Decomposed Granite, Topsoil, Interbedded Sandstone\Siltstone

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 (Fall 2006)
16" Short Normal Geophysical Log

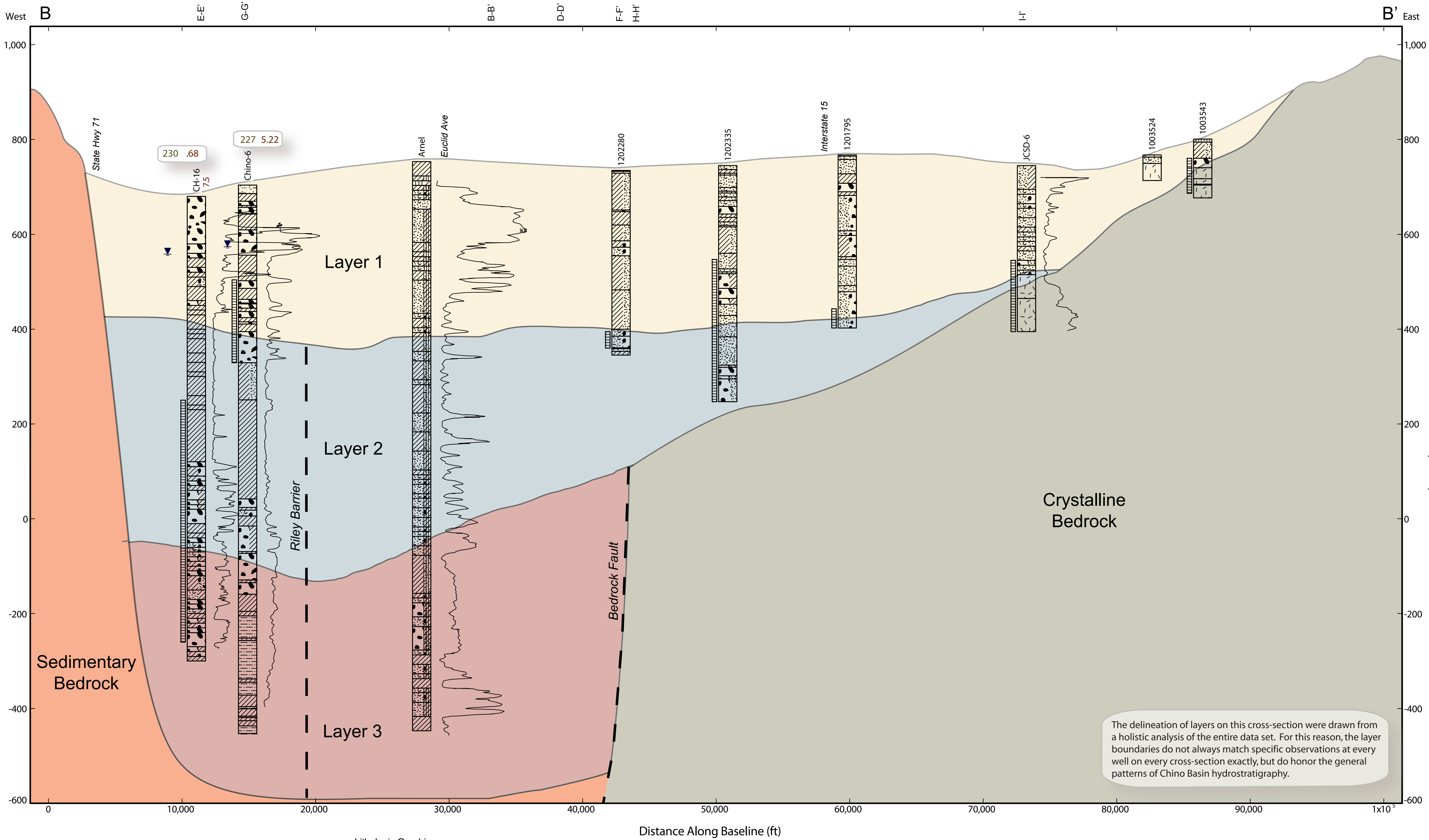
50 % Spinner Log Analysis (% of flow from depth interval)
27.2 Specific Capacity (gpm/ft)

Average Water Quality (1999- 2006; mg/L)
TDS NO_3-N Well Discharge Sample
TDS NO_3-N Depth Specific Sample

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Hydrogeologic Setting

Cross-Section A-A'

Figure 2-6a



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Vertical Scale: 1" = 200'
Horizontal Scale: 1" = 6850'
Vertical Exaggeration: 34.25:1

Author: MJC
Date: 20070822
File: b-b.pdf

Lithologic Graphics

Gravel
Sand
Silt
Clay
Granite
Sedimentary Bedrock
Topsoil

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 (Fall 2006)
16" Short Normal Geophysical Log

Spinner Log Analysis (% of flow from depth interval)
50 %

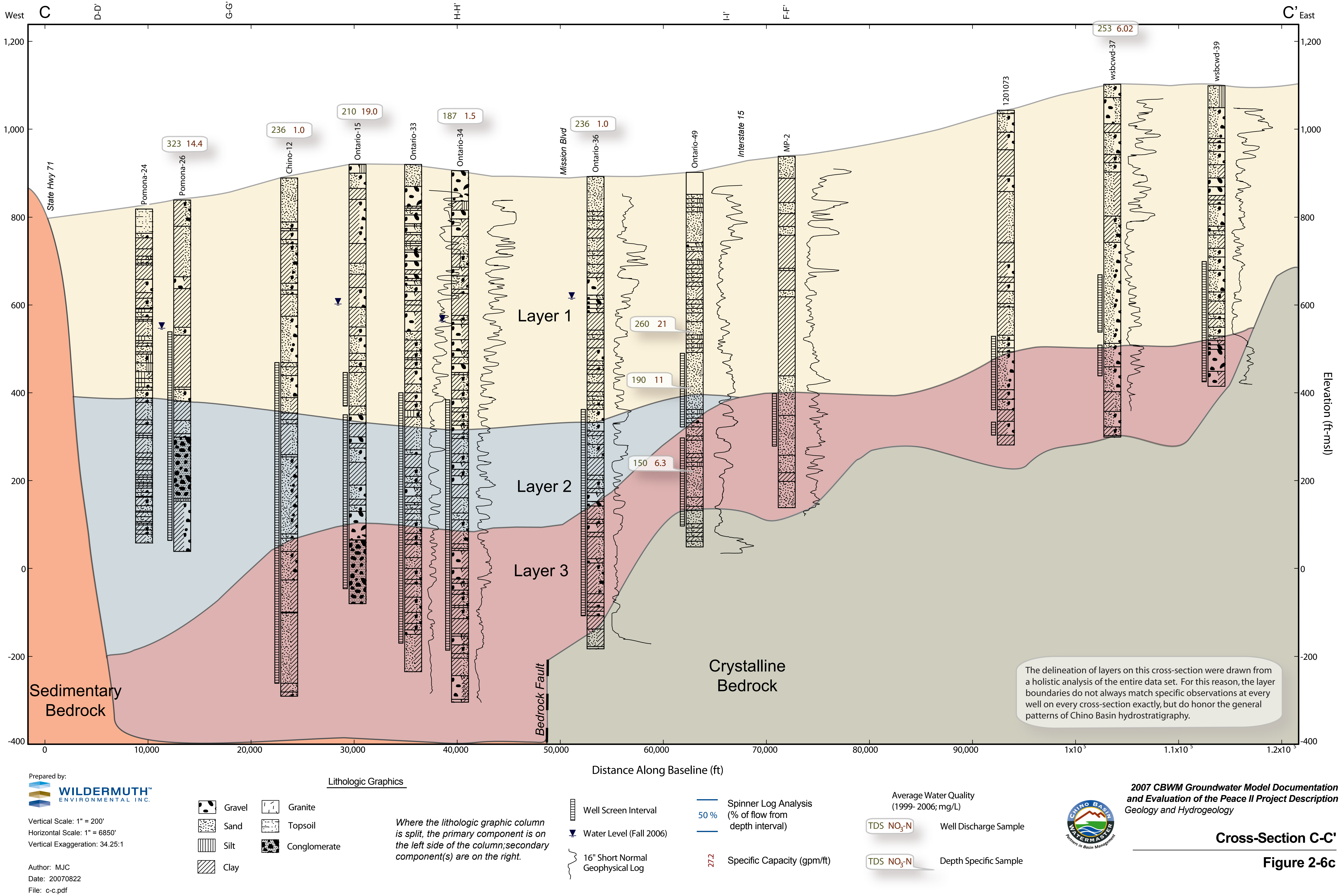
27.2 Specific Capacity (gpm/ft)

Average Water Quality (1999- 2006; mg/L)
TDS NO_3-N Well Discharge Sample
TDS NO_3-N Depth Specific Sample

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Hydrogeologic Setting

Cross-Section B-B'

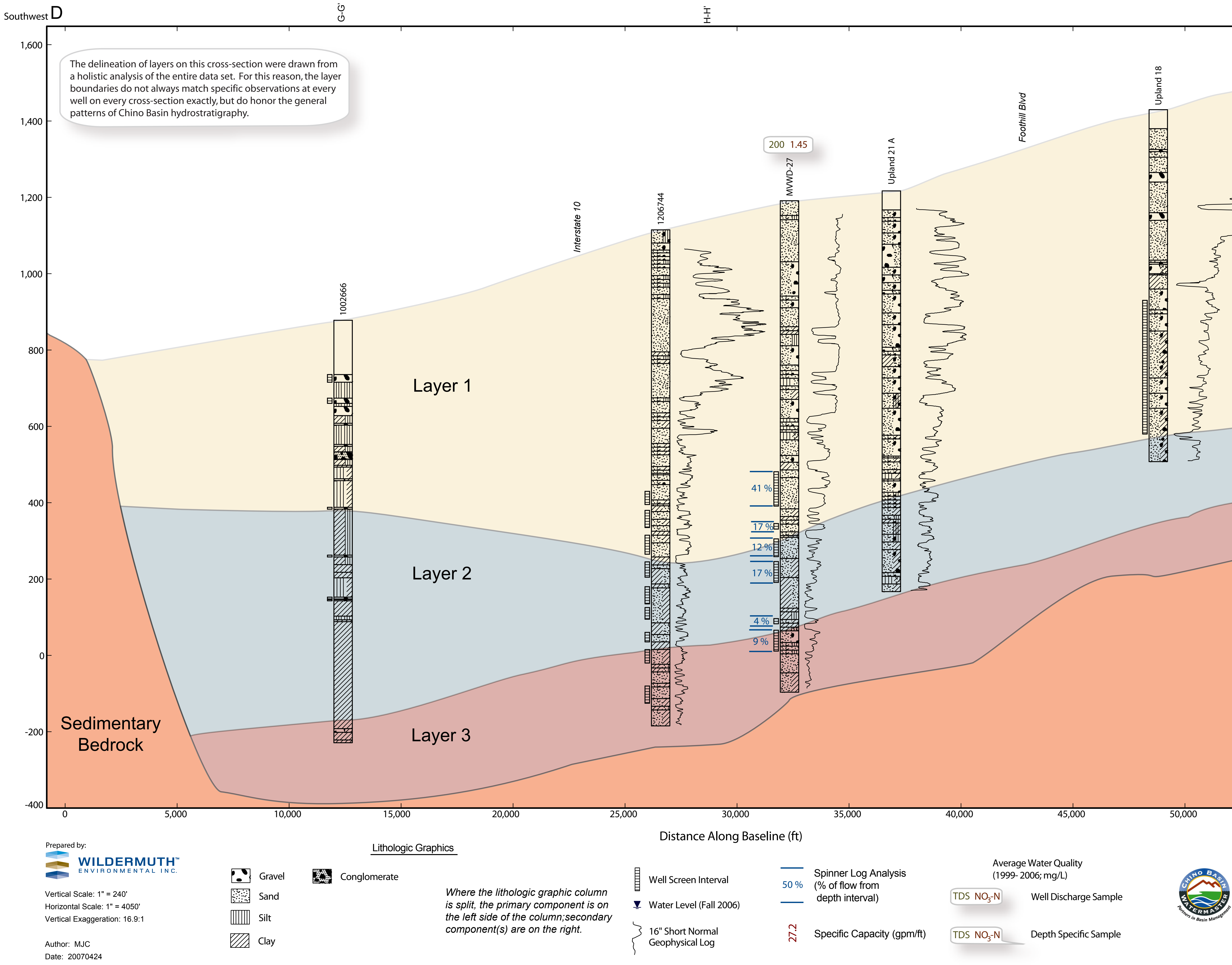
Figure 2-6b



2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Geology and Hydrogeology

Cross-Section C-C'

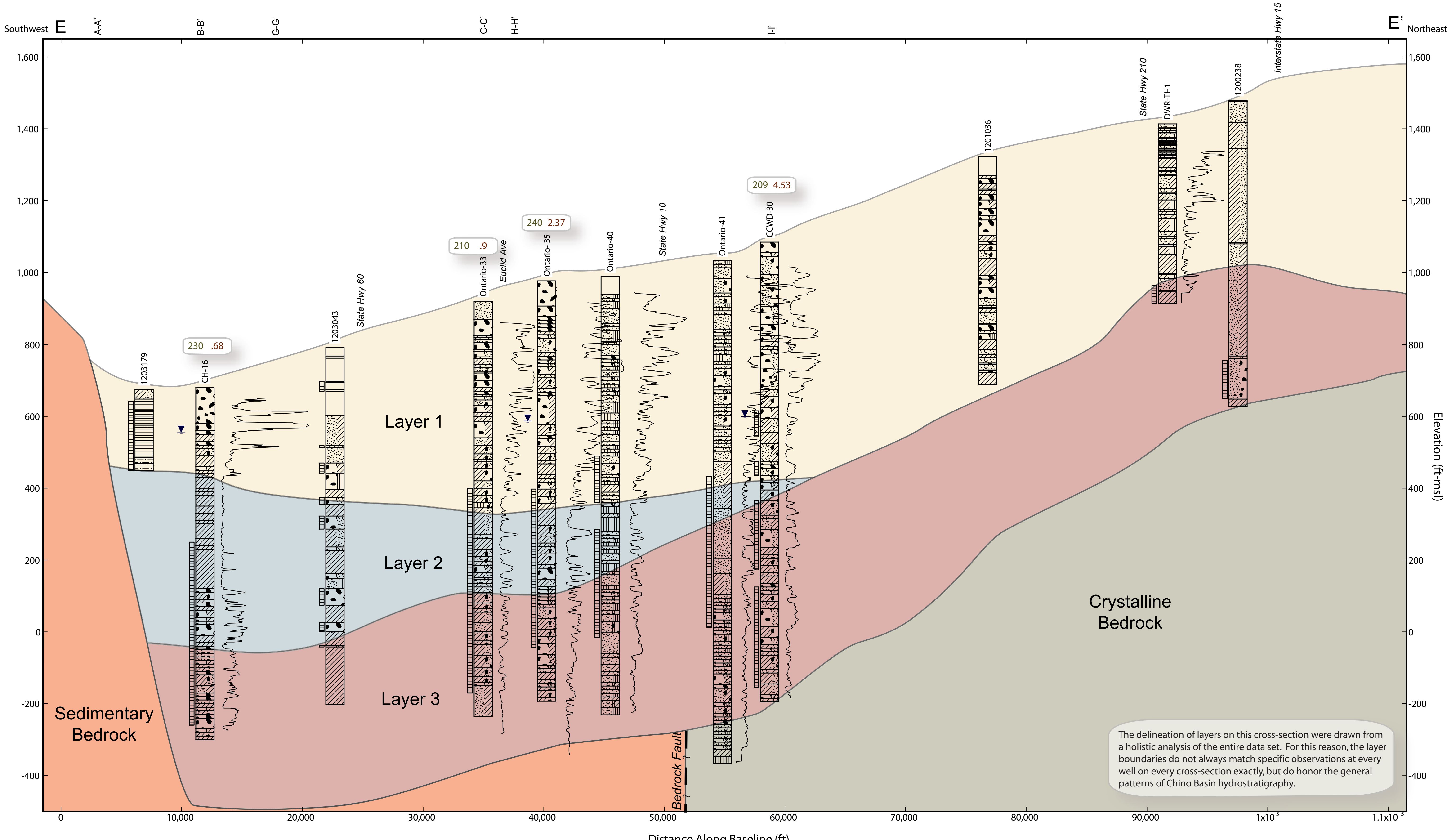
Figure 2-6c



2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Hydrogeologic Setting

Cross-Section D-D'

Figure 2-6d



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Vertical Scale: 1" = 250'
Horizontal Scale: 1" = 7500'
Vertical Exaggeration: 30:1

Author: MJC
Date: 20070822
File: e-e.pdf

Lithologic Graphics

Gravel
Sand
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 (Fall 2006)
16" Short Normal Geophysical Log

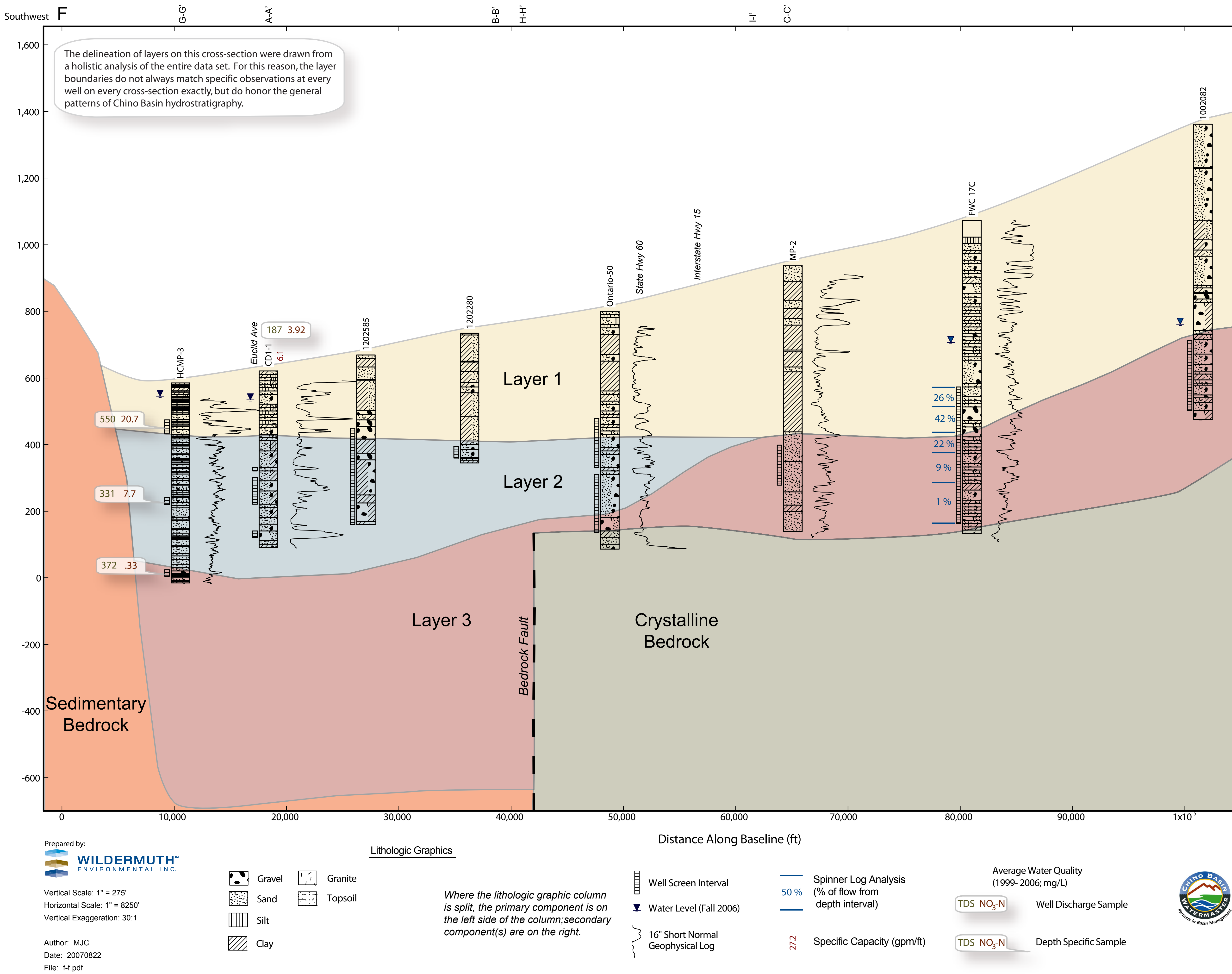
50 % Spinner Log Analysis (% of flow from depth interval)
27.2 Specific Capacity (gpm/ft)

Average Water Quality (1999- 2006; mg/L)
TDS NO_3-N Well Discharge Sample
TDS NO_3-N Depth Specific Sample

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Hydrogeologic Setting

Cross-Section E-E'

Figure 2-6e

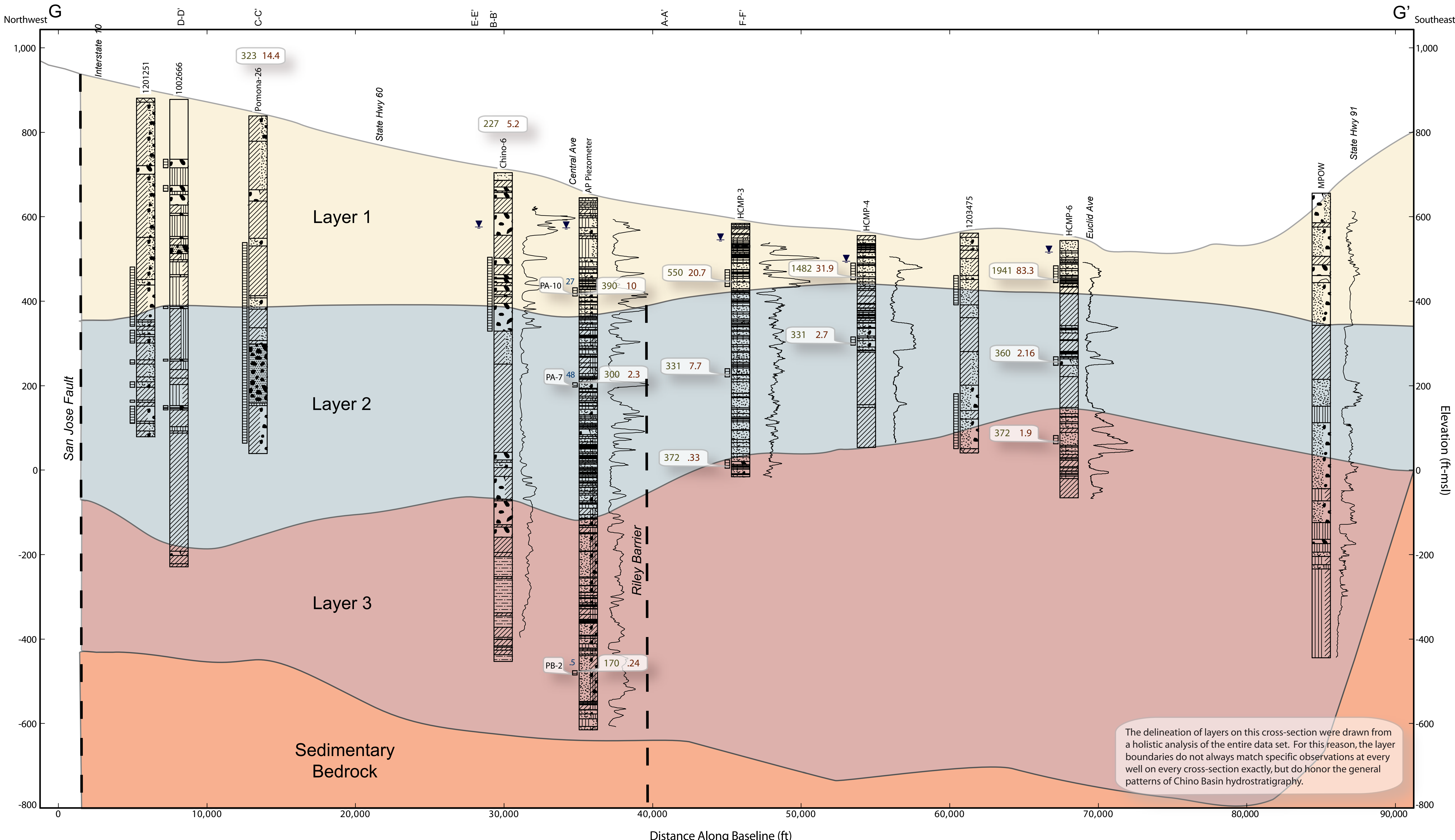


2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Hydrogeologic Setting

Cross-Section F-F'

Figure 2-6f



Prepared by:
WILDERMUTH™ ENVIRONMENTAL INC.

Vertical Scale: 1" = 215'
Horizontal Scale: 1" = 6150'
Vertical Exaggeration: 28.6:1

Author: MJC
Date: 20070822
File: g-g.pdf

Lithologic Graphics

- Gravel
- Sand
- Silt
- Clay
- Conglomerate
- Topsoil
- Sedimentary Bedrock
- Fill (made ground)

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 (Fall 2006)
- 16" Short Normal Geophysical Log
- 50 % Spinner Log Analysis (% of flow from depth interval)
- 50 Hydraulic Conductivity data from slug tests (ft/day)

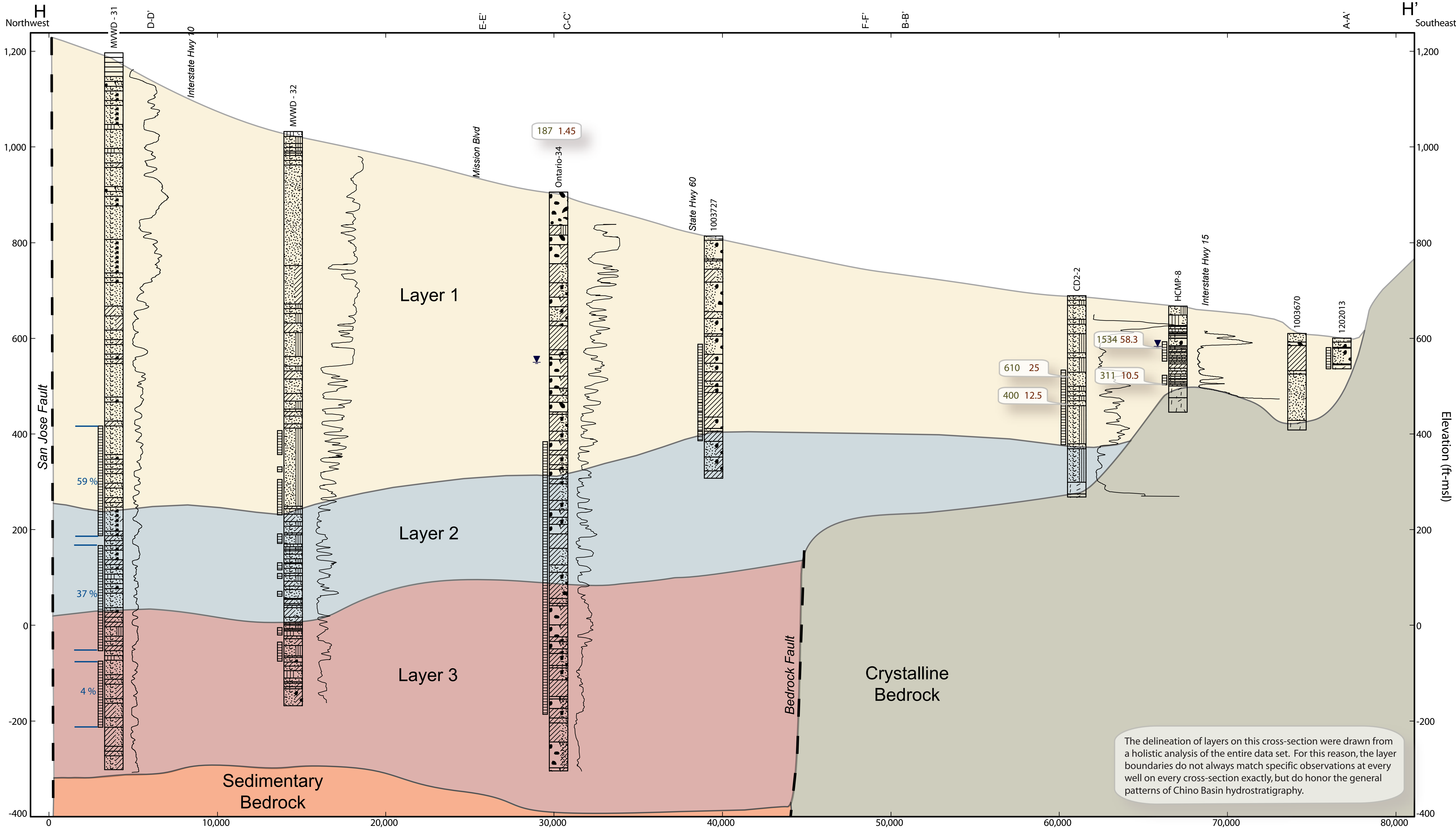
Average Water Quality (1999- 2006; mg/L)

- TDS NO_3-N Well Discharge Sample
- TDS NO_3-N Depth Specific Sample

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Hydrogeologic Setting

Cross-Section G-G'

Figure 2-6g



Prepared by:

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Vertical Scale: 1" = 190'
Horizontal Scale: 1" = 5450'
Vertical Exaggeration: 28.7:1

Author: MJC
Date: 20070822
File: h-h.pdf

Lithologic Graphics

- Gravel
- Sand
- Silt
- Clay
- Granite
- Topsoil

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 (Fall 2006)
- 16" Short Normal Geophysical Log
- 50 % Spinner Log Analysis (% of flow from depth interval)
- 27.2 Specific Capacity (gpm/ft)

Average Water Quality (1999- 2006; mg/L)

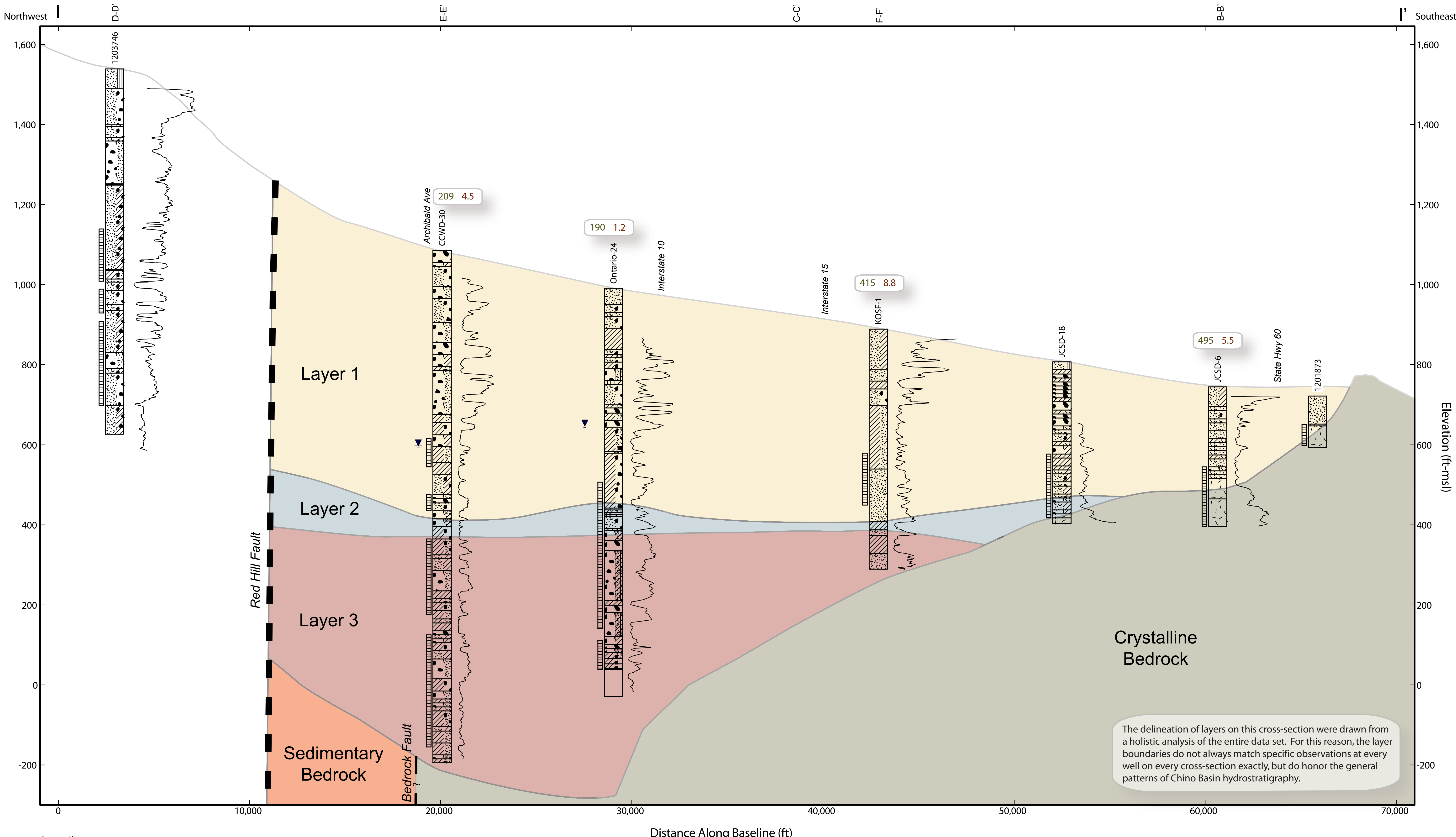
- TDS NO_3-N Well Discharge Sample
- TDS NO_3-N Depth Specific Sample

CHINO BASIN WATERMASTER Partners in Basin Management

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Hydrogeologic Setting

Cross-Section H-H'

Figure 2-6h



Prepared by:

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Vertical Scale: 1" = 225'
Horizontal Scale: 1" = 4800'
Vertical Exaggeration: 21.3:1

Author: MJC
Date: 20070822
File: I-I.pdf

Lithologic Graphics

- Gravel
- Granite
- Sand
- 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 (Fall 2006)
- 16" Short Normal Geophysical Log
- 50 % Spinner Log Analysis (% of flow from depth interval)
- 27.2 Specific Capacity (gpm/ft)

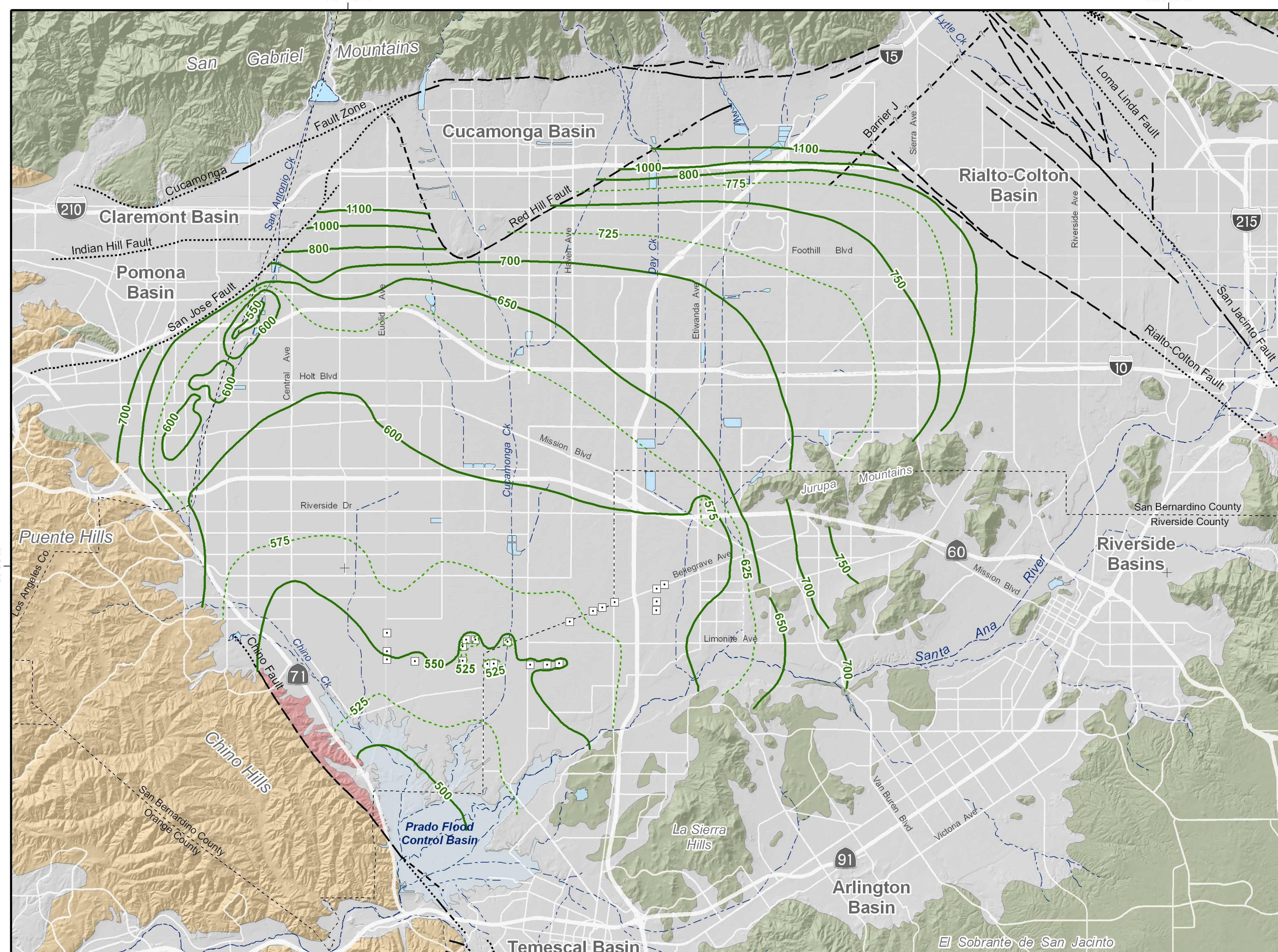
Average Water Quality (1999- 2006; mg/L)

- TDS NO_3-N Well Discharge Sample
- TDS NO_3-N Depth Specific Sample

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Hydrogeologic Setting

Cross-Section I-I'

Figure 2-6i



Groundwater Elevation Contours (feet above mean sea-level)

800

775

Other Features

Chino Desalter Well

Flood Control and Conservation Basins

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

Plio-Pleistocene Sedimentary Rocks

Cretaceous to Miocene Sedimentary Rocks

Pre-Tertiary Igneous and Metamorphic Rocks

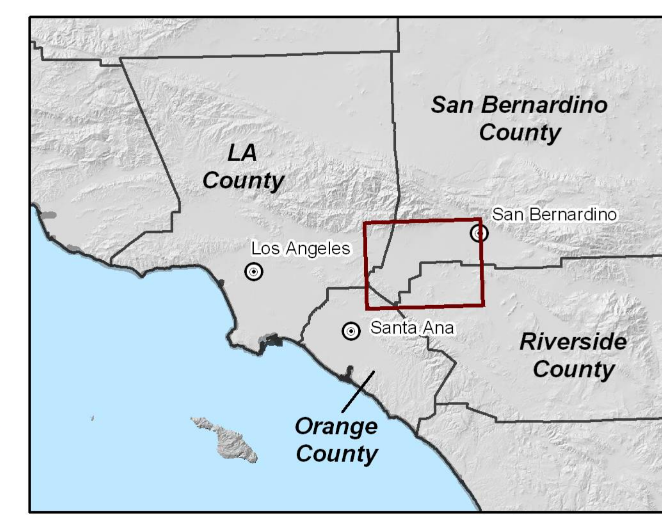
Faults

Location Certain

Location Approximate

Location Concealed

Location Uncertain



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Date: 20070511

File: Figure_3-18.mxd

0 1 2 3 4 5 Miles

0 2 4 6 8 KM

CHINO BASIN WATERMASTER — Partners in Basin Management

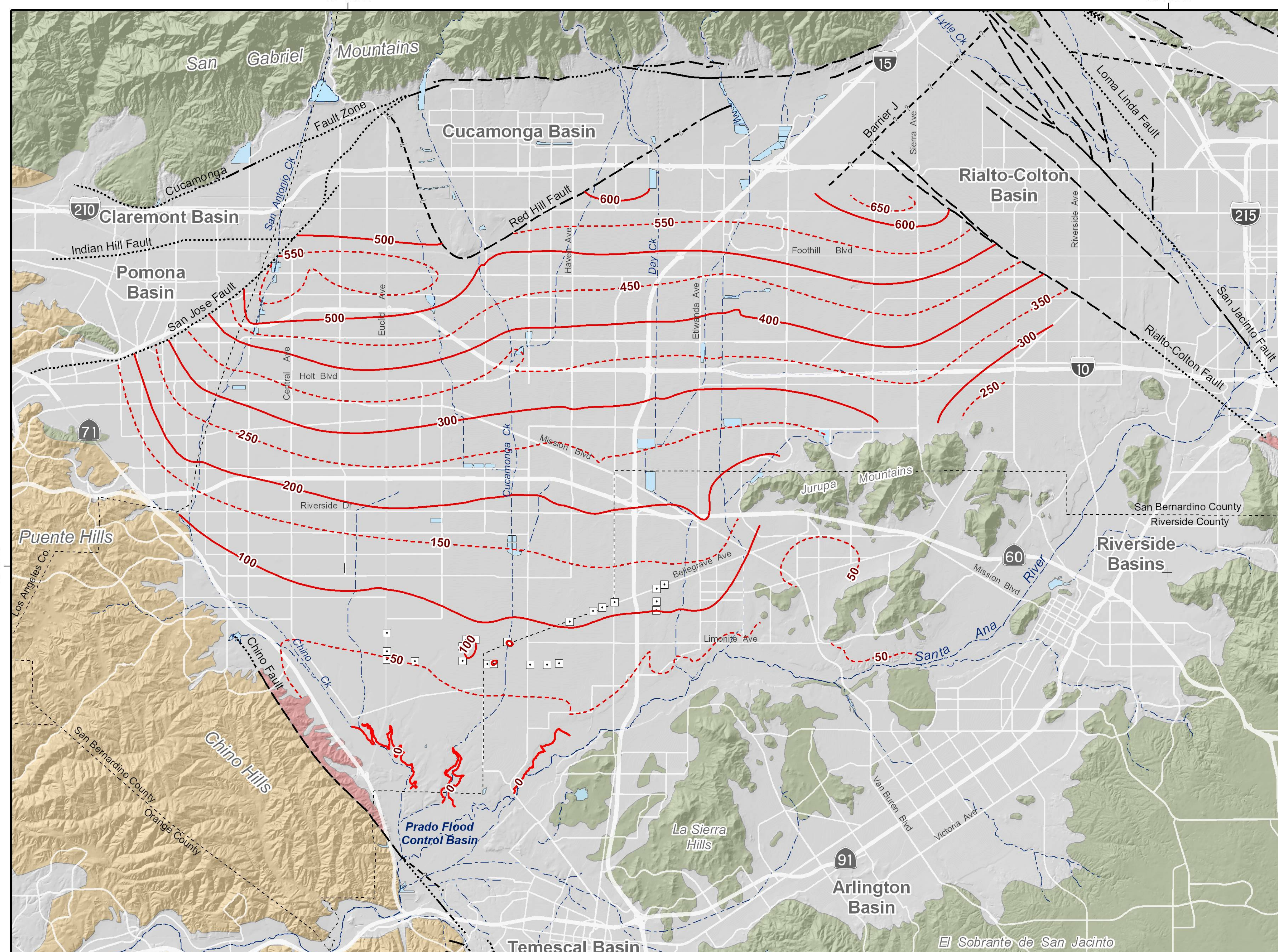
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Hydrogeologic Setting

Groundwater Elevation Contours

Fall 2006 -- Chino Basin

Figure 2-7a



Depth to Groundwater Contours (feet below ground surface)

800
775

Other Features

Chino Desalter Well

Flood Control and Conservation Basins

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

Plio-Pleistocene Sedimentary Rocks

Cretaceous to Miocene Sedimentary Rocks

Pre-Tertiary Igneous and Metamorphic Rocks

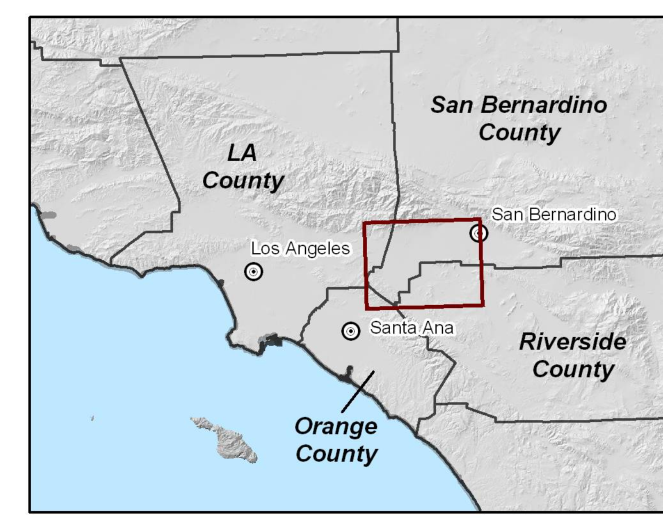
Faults

Location Certain

Location Approximate

Location Concealed

Location Uncertain



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Date: 20070720

File: Figure_2-7b.mxd

0 1 2 3 4 5 Miles

0 2 4 6 8 KM

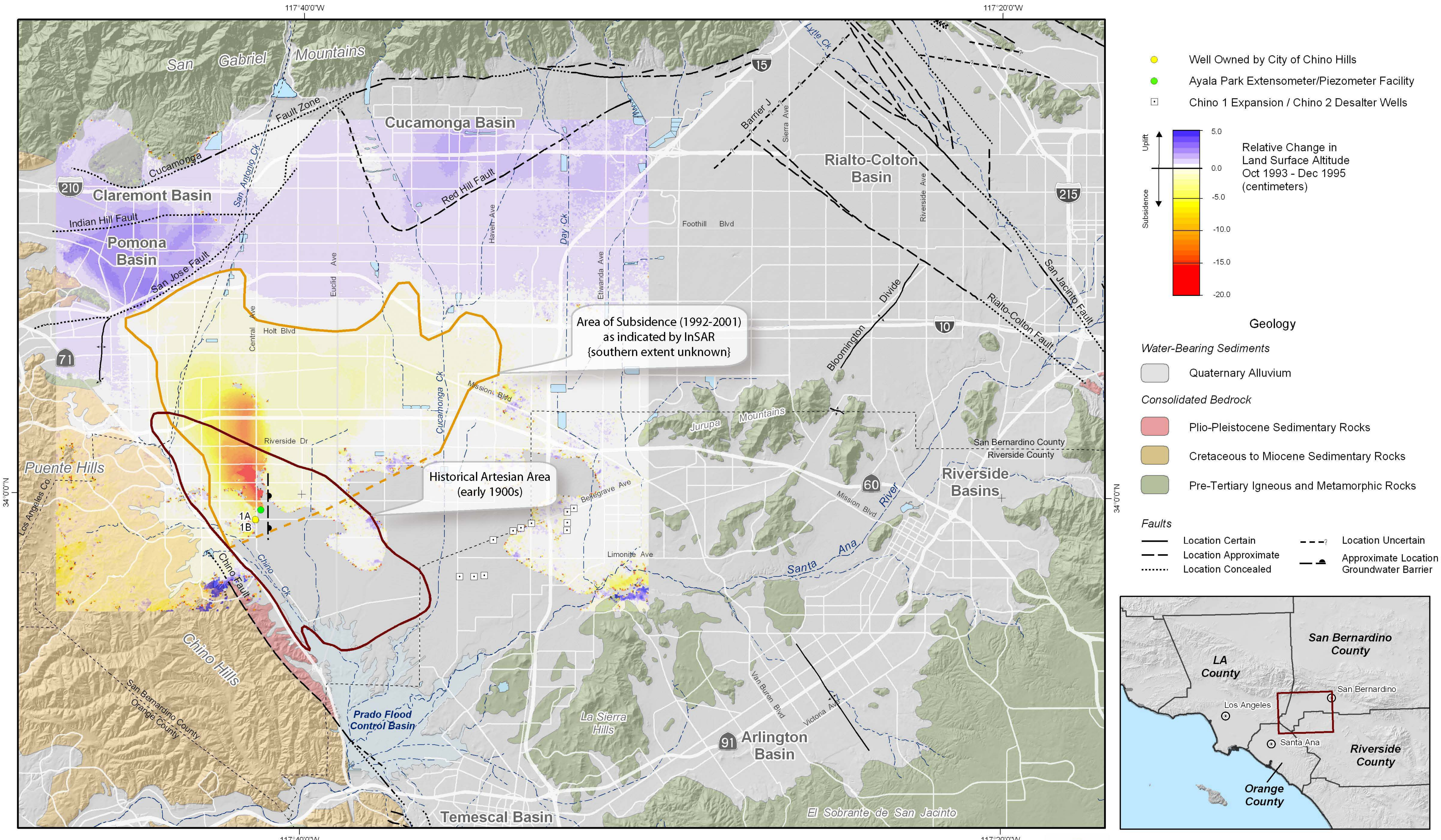
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Hydrogeologic Setting

Depth to Groundwater Contours

Chino Basin -- Fall 2006

Figure 2-7b



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2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

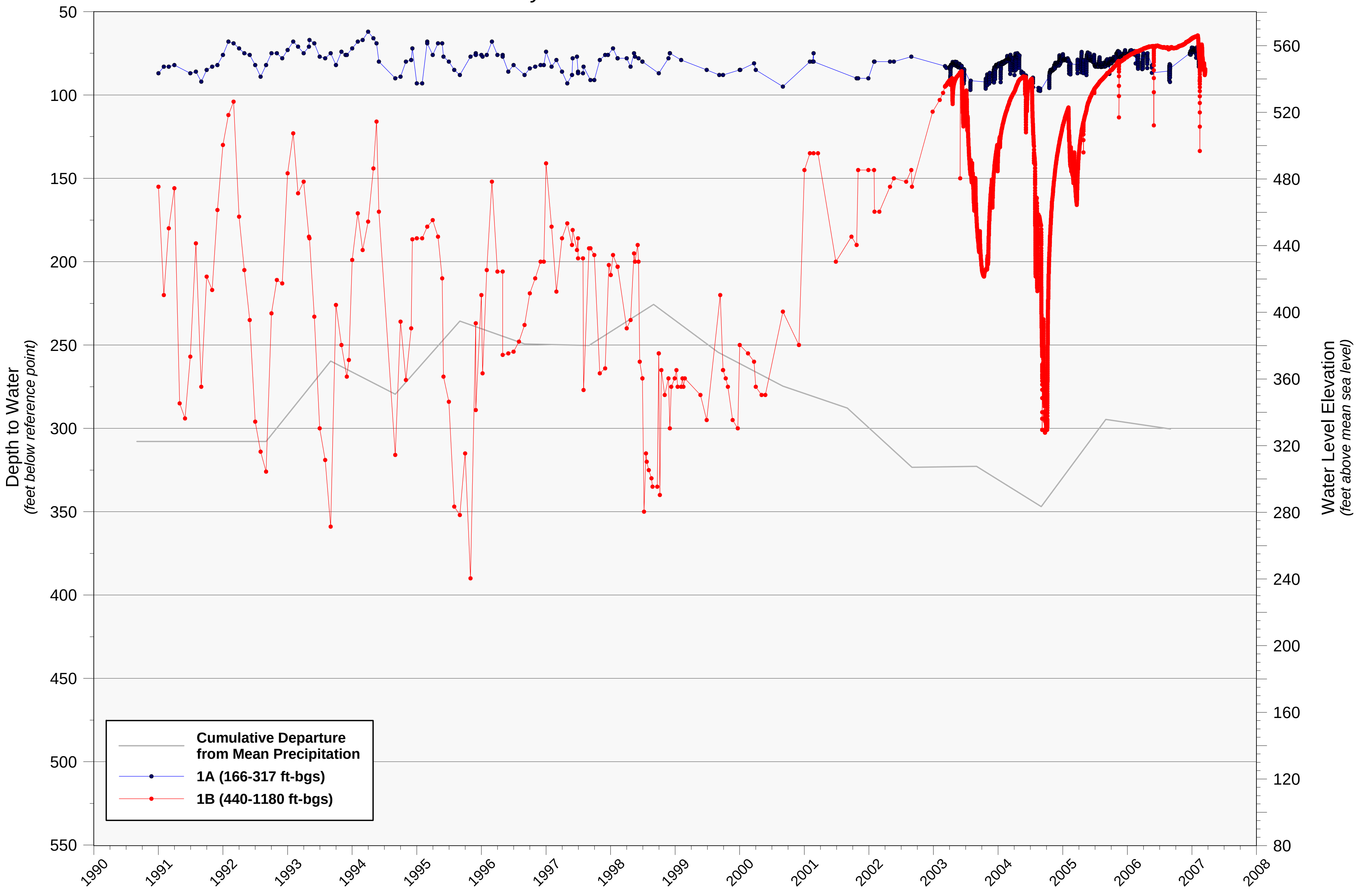
Hydrogeologic Setting

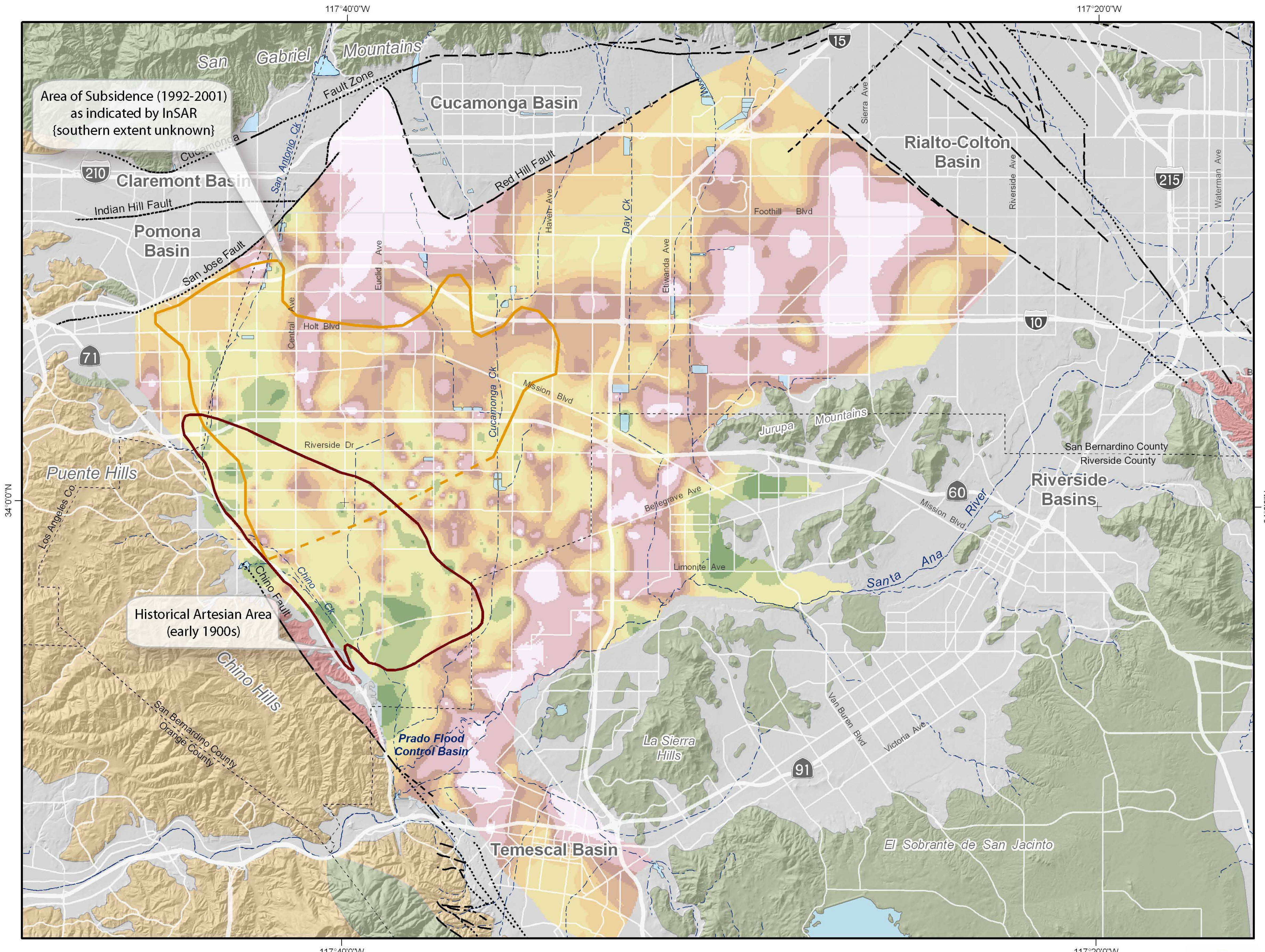
Chino Basin Hydrogeology

Areas of Subsidence and Historical Artesian Conditions

Figure 2-8

Figure 2-9
Water Level Time Histories (Non-Pumping)
City of Chino Hills Wells 1A and 1B





Specific Yield of Water-Bearing Sediments

- 0 - 5%
- 5 - 7%
- 7 - 9%
- 9 - 10%
- 10 - 11%
- 11 - 12%
- 12 - 13%
- 13 - 15%
- 15 - 20%

Geology

Water-Bearing Sediments

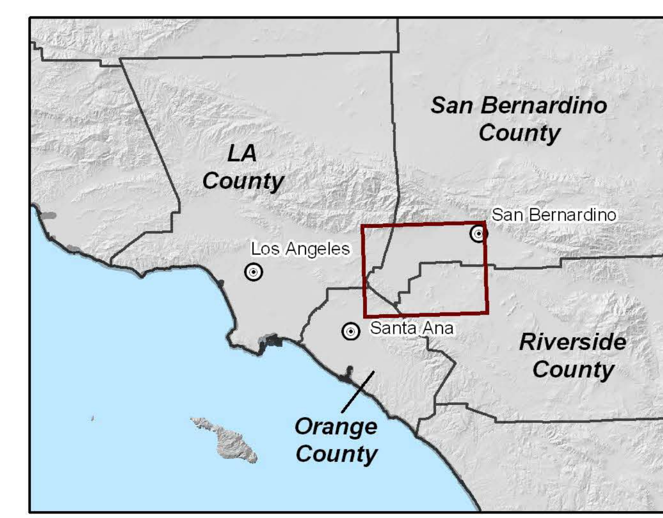
- Quaternary Alluvium

Consolidated Bedrock

- Plio-Pleistocene Sedimentary Rocks
- Cretaceous to Miocene Sedimentary Rocks
- Pre-Tertiary Igneous and Metamorphic Rocks

Faults

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



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Date: 20070925
File: SYL1.mxd

0 1 2 3 4 5 Miles
0 2 4 6 8 KM

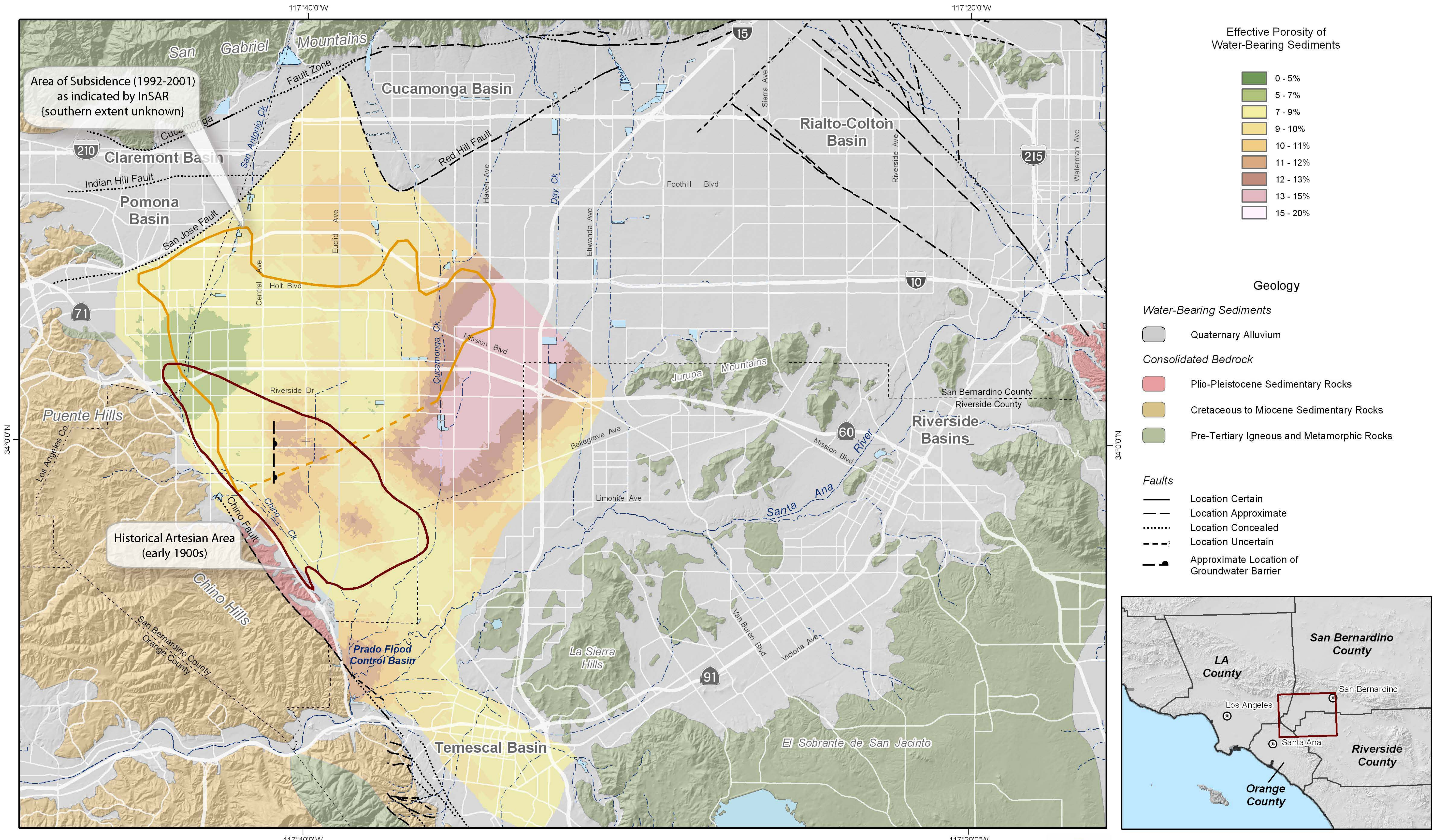
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Hydrogeologic Setting

Average Specific Yield of Sediments

Layer 1

Figure 2-10



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Author: MJC
Date: 20070925
File: Figure_2-11.mxd

0 1 2 3 4 5 Miles
0 2 4 6 8 KM

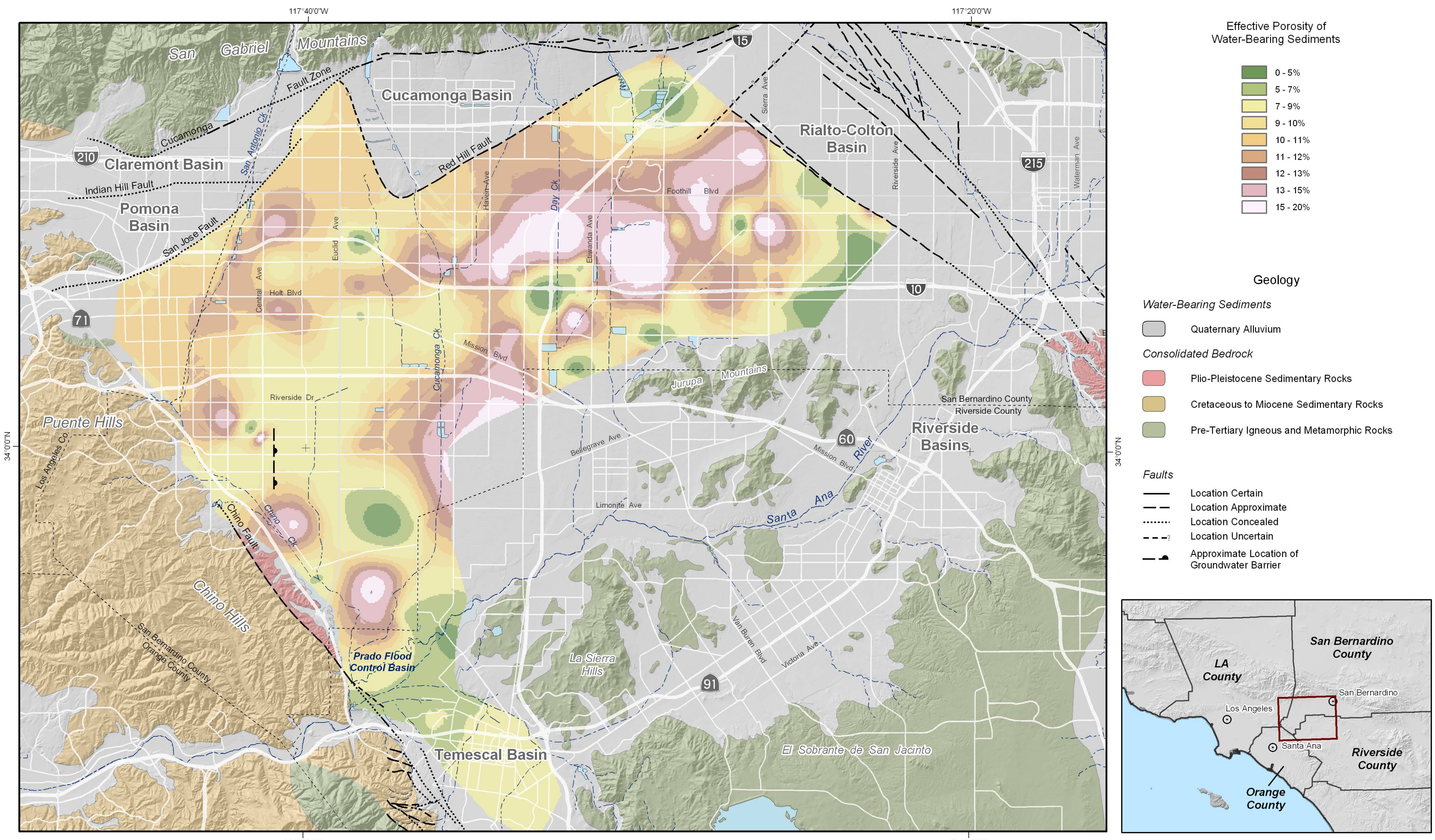
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Hydrogeologic Setting

Effective Porosity of Sediments

Layer 2

Figure 2-11



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Author: MJC
Date: 20070925
File: Figure_2-12.mxd

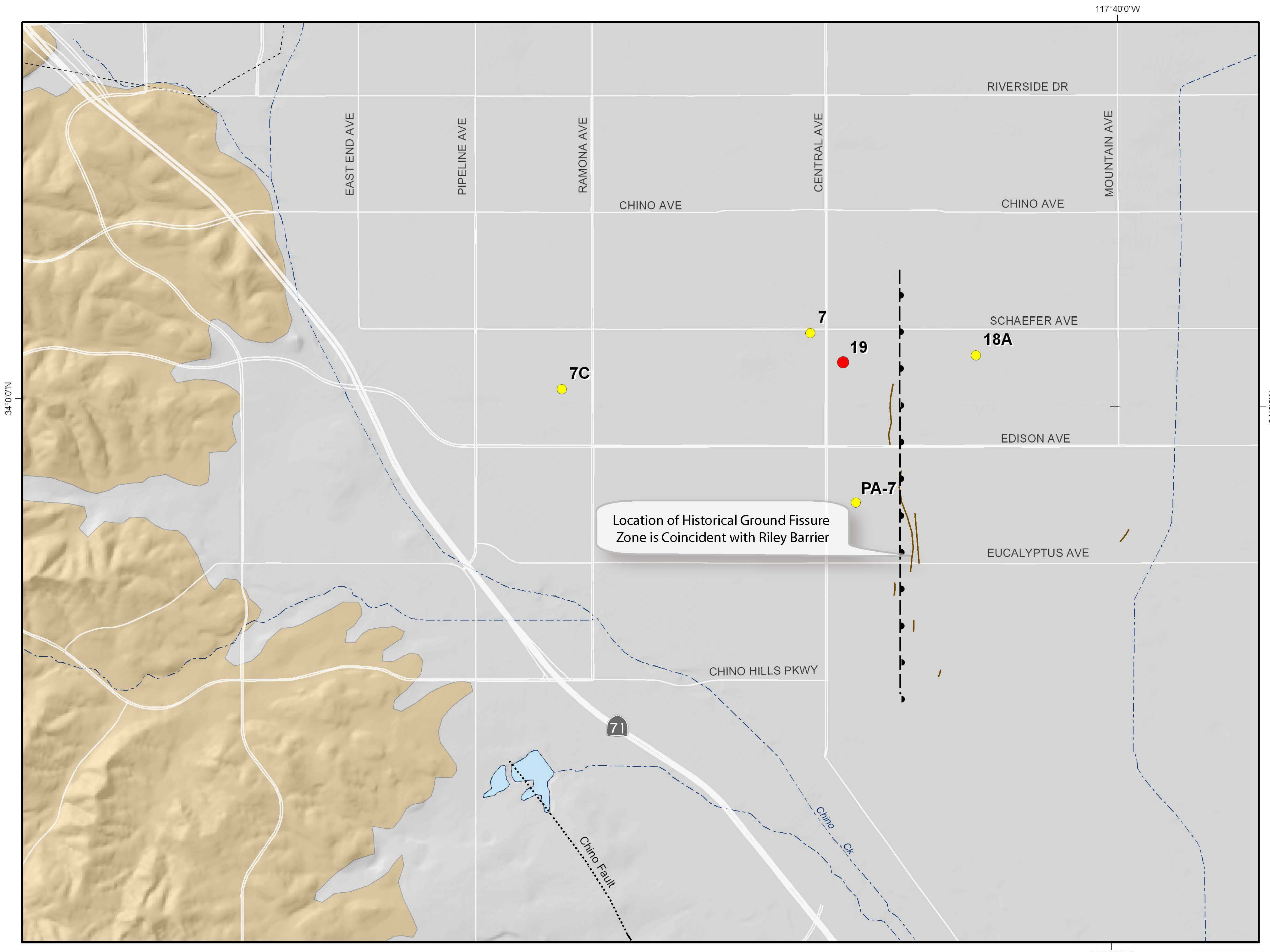
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Hydrogeologic Setting

Effective Porosity of Sediments

Layer 3

Figure 2-12



Main Features

- Pumping Well
- Observation Well

Note: See water level responses at these wells in Figure 2-14.

- Ground Fissure (1994)

Geology

Water-Bearing Sediments

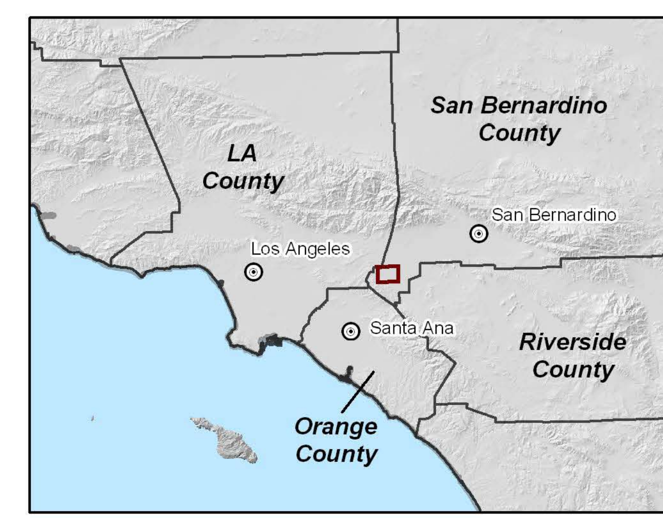
- Quaternary Alluvium

Consolidated Bedrock

- Cretaceous to Miocene Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier



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File: figure_2-13.mxd

0 1,000 2,000 3,000 Feet
0 300 600 900 Meters

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

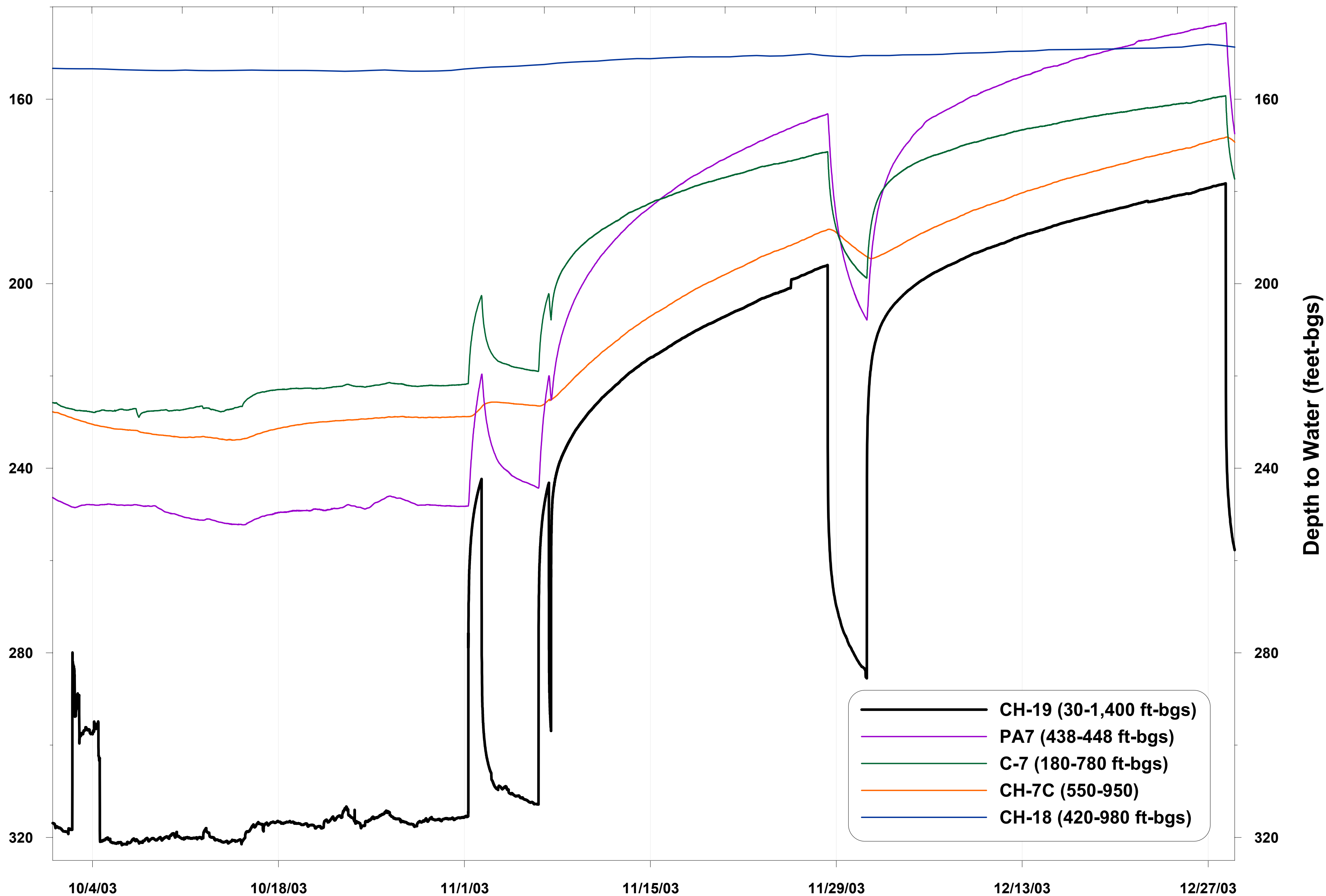
Hydrogeologic Setting

Riley Groundwater Barrier

Evidence from Pumping Test

Figure 2-13

Figure 2-14
Water Level Responses at Nearby Wells to Pumping at CH-19
Deep Aquifer Pumping Test



Recharge and discharge are defined as the contributions of water to a groundwater system (recharge) and the loss of water outside a groundwater system (discharge). Figure 3-1 shows the components of recharge, which consist of boundary inflows, recharge from streams or creeks, supplemental recharge (imported or recycled water), storm water recharge, and areal recharge. The bottom half of this figure displays the three components of discharge for the model: evapotranspiration, discharge to streams and creeks, and groundwater pumping. For the calibration period, the total inflow was less than the total outflow; in other words, water was removed from storage to meet the discharge. This section reviews the components of recharge and discharge for the calibration and planning periods.

This section discusses the water balance during the calibration period, which is defined as fiscal year 1960/61 through fiscal year 2005/06 (July 1960 through June 30, 2006). The values in the water balance were derived from measurements and estimates. These values are summarized in Table 3-1. The mean values for the calibration period are also shown graphically in Figure 3-1.

3.1 Recharge

3.1.1 Subsurface Inflow

Subsurface boundary inflows were derived during the calibration process and are listed in Table 3-1. The locations of boundary inflow are shown in Figure 3-2. The initial estimates for some of the boundary inflows for mountain areas were developed from the Rainfall, Runoff, Router, and Root Zone Model (R4) developed by WEI. This model was used to calculate total runoff for contributing watersheds (when applicable). Subsurface inflow was assumed to be variable over time for each segment with about 44,770 acre-ft per year (acre-ft/yr) in the Chino management zones and about 4,940 acre-ft/yr in the Temescal management zone for a total of about 49,610 acre-ft/yr for the model area. Subsurface inflow was assumed constant over the calibration period for most subsurface boundary inflows with the Bloomington divided and the Santa Ana Mountain inflows being the only exceptions. The magnitude of the subsurface boundary inflows that were developed in calibration were compared to the reported hydrology of adjacent basins, when available, to ensure that the adjacent groundwater basins were capable of discharging into the study area.

3.1.2 Streambed and Storm Water Recharge

Streambed recharge occurs in unlined stream channels and in flood control and water conservation basins. Most of the major stream channels in the Chino Basin were concrete-lined as of March 2003 (WEI, 2003). For future projections, all stream channels were assumed to be concrete-lined. Figure 3-3 shows the locations of flood control and recharge basins and major stream channels.

The R4 Model was used to estimate the storm water recharge in stream channels and in flood control and recharge basins. The R4 Model was developed from the Chino Basin Watermaster Recharge Model (Wildermuth, 1998; WEI, 2001) and the Wasteload Allocation Model (WEI, 2002). R4 contains three modules: Runoff, Router, and Root Zone. The Runoff module estimates daily runoff from discrete drainage areas. The Router module routes runoff from each drainage area through the drainage system and calculates, among other things, discharge and recharge in channels and in flood control and conservation basins. The Root Zone module is used to estimate the amount of water that recharges to the aquifer out of the root zone. Important data that were used in the R4 model include precipitation data, Soil Conservation Service (SCS) hydrologic soil types, land use, and the physical properties of the drainage system (channel geometry, slope, lining, *etc.*). A description of the R4 model and its application to the study area is provided in Appendix A of this report.

Table 3-2 lists the annual time history of calculated storm water recharge by tributary system. Over the calibration period, about 9,040 acre-ft/yr of storm water was recharged to the study area.

Figure 3-4 shows streambed recharge over the calibration period. The streambed recharge is greatest in wet years (such as 1968, 1978, and 1983) and lowest in dry years (such as 1977 and 1961), and drops with the lining of stream channels. The average streambed recharge over the calibration period is 27,060 acre-ft/yr for the Chino and Temescal Basins. After 1988, when most of the channel lining projects were completed, streambed recharge, excluding the Santa Ana River, dropped to an average of 290 acre-ft/yr. The maximum streambed recharge for the study area is 33,900 acre-ft/yr, which occurred in 1978. The maximum streambed recharge in the Chino Basin occurred the same year and was 30,440 acre-ft. Figure 3-4 shows how streambed recharge has decreased over time for all creeks in the study area, excluding the Santa Ana River.

Streambed recharge in the Santa Ana River has increased due to the increase in discharges to the Santa Ana River, including recycled water and increased storm water runoff from upstream urbanization.

3.1.3 Areal Recharge

WEI estimated the areal recharge (deep percolation of precipitation and applied water) with the R4 model and routed this recharge through the vadose zone with the HYDRUS-2D model. Deep percolation was assumed to occur when soil moisture exceeded field capacity. Field capacity is the maximum volume of water that can be stored in the soil zone against the force of gravity. Soil moisture in excess of field capacity is assumed to percolate beyond the root zone and migrate through the vadose zone to the saturated zone.

Applied water for urban areas was estimated from reports prepared by the IEUA. These reports show the volume of water produced by each water purveyor in the IEUA service areas and the volume of sewage produced by each purveyor. The difference was assumed to be equal to applied water. Evapotranspiration was estimated for various vegetation types based on unit water use rates and California Irrigation Management Information System (CIMIS) data.

Within the Chino Basin, the travel time from the root zone to the water table varies depending on water application rate, thickness of the vadose zone, lithology of the vadose zone, and land use. For example, in the northern Chino Basin the vadose zone is over 600 feet thick; whereas, near the Prado Basin, the vadose zone may be 15 feet thick. HYDRUS-2D, a flow and transport model, was used to estimate the amount of time water takes to travel through the unsaturated zone. For a detailed discussion of this process, refer to Appendix B. Figure 3-5 shows recharge at the root zone and recharge at the water table. There is a lag time between root zone discharge to the vadose zone and discharge to the saturated zone.

3.1.4 Supplemental Water Recharge

Supplemental water consists of water imported from outside the Chino and Temescal Basins and recycled water. Supplemental water is recharged in the Chino Basin by the Chino Basin Watermaster pursuant to the 1978 Chino Basin Judgment and the 2000 Peace Agreement. Table 3-3 lists the annual time history of the Chino Basin Watermaster's supplemental water recharge by recharge facility. Figure 3-6 shows the supplemental recharge that occurred over the calibration period. All of Watermaster's supplemental water recharge occurred in the Chino North MZ—more specifically, in the Montclair, San Sevaine, Turner, Day Creek, and Etiwanda recharge facilities. The average supplemental recharge for the calibration period is 5,240 acre-ft/yr; although, supplemental recharge was zero until approximately 1978.

3.2 Discharge

3.2.1 Subsurface Outflow

In the Chino Basin, subsurface outflow can only occur to the Temescal Basin and as underflow at Prado Dam. Historical groundwater levels in the Temescal Basin have caused groundwater outflow into the Chino Basin. However, it is possible for groundwater levels in the Temescal Basin to drop to levels where groundwater outflow from Chino to Temescal Basin could occur. The subsurface outflow from Chino to Temescal is not included in the water budget shown in Table 3-1 because the boundary between the basins is internal to the study area. The discharge across this boundary is computed in the model calibration and in the planning simulations.

The Army Corps of Engineers constructed a grout curtain under Prado Dam. As is such, the subsurface outflow from Chino Basin at Prado Dam is assumed to be negligible. Subsurface outflow from the model domain area was assumed to be zero.

3.2.2 Rising Groundwater

Rising groundwater can occur in the Santa Ana River and its tributaries in the southern Chino and Temescal Basins when the piezometric level of groundwater under the river exceeds the elevation of the streambed. The magnitude of rising groundwater varies seasonally, being greater in the winter and lesser in the summer. Rising groundwater cannot be directly calculated from existing monitoring programs. The available data consist of surface water discharge monitoring stations on the Santa Ana River at the Metropolitan Water District of Southern California (MWD) pipeline crossing located in the City of Riverside and at below Prado Dam as well as stations on the following tributaries: Chino Creek, Cucamonga Creek, and Temescal Creek. Other measured non-tributary discharges include recycled water discharges from the Cities of Corona and Riverside, the IEUA, the Western Riverside Regional JPA, Arlington Desalter discharge, and State Project water discharges to San Antonio Creek in Upland. Between the MWD Crossing and Prado Dam, there are few measurements of surface water discharge that can be used to define reaches of rising groundwater or streambed recharge. The great stands of riparian vegetation along the Santa Ana River and the Prado Reservoir area are likely to contribute to the seasonal variation of base flow in the Santa Ana River and may impact rising groundwater in the Prado Reservoir area. Rising groundwater estimates were made during model calibration and are listed in Table 3-1. For the calibration period, the average annual discharge to streams is approximately 14,610 acre-ft/yr.

3.2.3 Evapotranspiration

Evapotranspiration (ET) is the combination of water loss due to evaporation from the soil and transpiration from plants. In the majority of the study area, ET occurs from the unsaturated zone and is not accounted for by the groundwater model. Within the Prado Basin, however, ET occurs from the saturated zone and must be considered in the groundwater model.

In order to calculate actual ET, potential evapotranspiration (PET) is calculated first. PET is the amount of water that can be used in the evapotranspiration process given an unlimited supply of water, and ET is the actual amount used in the evapotranspiration process that is influenced by water availability. The data needed to calculate PET were collected from one station in the proximity of the study area (Station 044 at the University of California Riverside, CIMIS for reference crops). The PET observations for this station range from 1986 to present. The actual ET for specific vegetation is estimated as follows:

$$ET_c = K_c * PET$$

Where K_c = vegetation type coefficient, ET_c = evapotranspiration, and PET = potential evapotranspiration.

Vegetation type coefficients vary by many factors, including crop type, stage of growth, and soil type. In 2006, Merkel & Associates, Inc. (See Appendix C) conducted a study to estimate vegetation communities and the appropriate K_c for different vegetation communities within the Prado Basin using archived areal imagery to estimate and validate ET for 1974 and 1984. For the remainder of the time periods, an interpolation method was adopted to estimate ET between the 3 years of available vegetation data. ET was calculated for each quarter of the calibration period. The mean ET rate used in the model was about 14,500 acre-ft/yr.

Based on the Merkel & Associates study, the range of ET for 2006 is between 20,480 and 34,290 acre-ft/yr, which is much greater than the model calculated values. The groundwater model only accounts for ET discharging strictly from the groundwater body. The difference between the modeled ET and the calculated ET estimate by Merkel & Associates is due to the difference between ET from the groundwater body and ET from the vadose zone and open water bodies. ET from the vadose zone occurs from many understory species (such as grasses), while ET from open water bodies occurs at freshwater marshes and constructed wetlands.

3.2.4 Groundwater Production

Estimates of groundwater production were developed from the records of the Chino Basin Watermaster for the Chino Basin, production records compiled by the WMWD for the Temescal Basin, previous modeling reports, crop transpiration requirements, and diary operation records. Watermaster determined the physical locations of wells in the Chino Basin using Global Positioning System (GPS) technology. The locations of wells in the Temescal Basin were digitized from well location maps prepared by the WMWD and the City of Corona. Figure 3-7 shows the locations of wells within the study area that were active at some time during the calibration period. Figure 3-8 shows and Table 3-4 lists the groundwater production time history that occurred during the calibration period by water use type and basin.

Groundwater production was categorized into three groups based on water use. Agricultural production includes water pumped by dairymen, farmers, and the State of California. Overlying non-agricultural water users include industrial and other non-agricultural users. Appropriative users include local cities, public water districts, and private water companies.

3.2.4.1 Overlying Agricultural Production

Over the calibration period, agricultural production averaged 78,710 acre-ft/yr. The maximum agricultural production during the calibration period was 122,160 acre-ft/yr, and the minimum during this period was 29,020 acre-ft/yr. The trend for agricultural production is decreasing over the calibration period. Agricultural production was estimated because reliable historical records were not available.

Agricultural production was divided into two categories: irrigation and dairy. This production was estimated on a quarterly basis by accounting for irrigation production, dairy production, and surface water diversions. Agricultural production was determined by estimating the crop demand (after precipitation) and diary demands and then subtracting any non-groundwater source of water, such as water in the soil profile, surface water, or dairy wash water. The agricultural production from 1960/61 to 2005/06 were estimated with a computer code that uses a grid-based method to incorporate hydrological processes, agricultural practices, and land use properties. Land use data from 1957, 1963, 1975, 1984, 1990, 2000, and 2006 were used in the spatial calculation of production. A linear interpolation method was used to estimate groundwater production between each published land use.

Irrigation demands can be satisfied by rainfall, groundwater production, and other sources. Groundwater production for irrigation is estimated as the water needed by the crops minus the water supplied through non-groundwater sources. The study area was divided into Hydrologic Sub-Areas (HSA). HSAs are primarily sub-drainage areas and are the primary level of discretization used in the R4 model. The R4 Model accounts for the hydrologic processes and agricultural properties of the land surface and is used to calculate applied water for each HSA. A GIS-based approach was used to intersect the HSA units with the quarter-mile grid to calculate the proportional areas of HSAs within each cell. The applied water within each cell is then calculated according to the following equation:

$$AW_s = \sum_{j=1}^{G} \left(AW_j \times A_j \right)$$

Where AW_s = applied water at each ¼ mile by ¼ mile cell, AW_j = applied water at HSA_j, A_j = proportional area of HSA_j within each cell, and G = number of HSAs within each square.

The quarterly applied irrigation water (water needed by the crops minus the water supplied through non-groundwater sources) is then assigned as the production rate at the centroid of each cell.

The active dairy areas of the Chino Basin were also discretized into quarter-mile section cells. The available land use data within the period of record were then overlaid on the quarter sections in order to estimate the dairy land use within each cell. The total dairy area within each cell was then multiplied by the production rate per unit area for each year. The production rate per unit area was calculated by dividing total dairy production by the total dairy area for each year. Total diary production was based on cow density records (RWQCB, 1990; RWQCB, 2007; Webb, 1974; USDA, 1988) and usage rates per cow type (RWQCB, 2007; Dairy Practices Council, 1975). The quarterly production estimates were then assigned to the production wells at the centroid of each cell.

In practice, dairy wash water is discharged to ponds and eventually to pastures. Personal communication with dairy operators (Wildermuth, 2007) provided guidance as to how much wash water is used for irrigation. Dairy wash water that was discharged to pasture was taken into consideration when calculating the irrigation water demand for the pastures.

The total quarterly agricultural production for each grid was then calculated by aggregating the irrigation and dairy production estimates.

3.2.4.2 Overlying Non-Agricultural Production

Over the calibration period, the overlying non-agricultural production had an average production rate of 5,330 acre-ft/yr. The maximum overlying non-agricultural production during the calibration period was 10,534 acre-ft/yr, and the minimum during this period was 2,320 acre-ft/yr. Overlying non-agricultural production decreases during the calibration period. The production histories prior to 1978 (when Watermaster records begin) are based on state recordation number production records (JMM, 1992; and Carroll, 1974). After 1978, Watermaster records were used.

3.2.4.3 Appropriator Production

Over the calibration period, appropriator production had an average production rate of 83,090 acre-ft/yr. The maximum appropriator production during the calibration period was 135,080 acre-ft/yr, and the minimum during this period was 47,630 acre-ft/yr. Appropriator production increases during the calibration period by more than 100%. The production histories prior to 1978 (when Watermaster records begin) are based on state recordation number production records (JMM, 1992; and Carroll, 1974). After 1978, Watermaster records were used.

3.3 Balance of Recharge and Discharge

Table 3-1 contains the recharge and discharge components and the balance for the 1960/61 through 2005/06 period. This table is based on estimates of recharge and discharge that are the result of data collection and modeling, and it includes the final calibration results. Historically, the basin has often operated with greater discharge than recharge.

3.4 Planning Alternatives Water Balance

3.4.1 Recharge

All inflow boundaries, with the exception of the Bloomington Divide, Riverside Narrows, Arlington Narrows, and the Santa Ana Mountains, were held constant during the calibration process. These same constant fluxes were applied for the planning alternatives—all inflow boundaries were held constant in the planning alternatives. Subsurface inflow for the Bloomington Divide was changed from the calibration condition of variable head (when head was known from historical measurements) to the 2006 flux across the boundary. This change was made as simulations of the planning alternatives suggested that the boundary flows at the Bloomington Divide that were near the safe yield of the neighboring basin, which could not reasonably occur. The change from head dependent inflow to the flow that occurred in 2006 was assumed to be conservative; this change limits the flow across the Bloomington Divide from the Riverside North Basin to a flux determined within the calibration period.

Streambed recharge in the Santa Ana River and its un-lined tributaries is dynamic and depends on surface discharge and underlying groundwater water levels. The discharge plans of publicly owned treatment works were incorporated based on a report that modeled Santa Ana River flow and water quality (WEI, 2002) and based on the current Basin Plan (RWQCB, 2004). These discharges were used to estimate the total discharge in the Santa Ana River and its tributaries. The R4 Model was used to estimate the surface water discharge in the flood control and recharge basins. WEI currently estimates 11,830 acre-ft/yr of storm water recharge to reflect the completion of the Chino Basin Facilities Improvement Project. This estimate was used for the dry-year yield scenarios. Surface water recharge in the Santa Ana River and its unlined tributaries was estimated by the groundwater model.

Supplemental water recharge is a variable that was determined in the planning alternatives, and it is discussed in detail in Section 7.

The areal recharge of precipitation and applied water was computed using the R4 Model, as done in calibration but with the following differences. The land use for 2006 that was used in the model calibration was assumed to represent 2006 conditions. Year 2025 land use conditions were estimated by assuming all undeveloped land in 2006 was developed except land projected to remain in agricultural uses in the Prado Basin area, California Institute for Men, and the California Institute for Women. The deep percolation of precipitation and applied water was estimated for each year in the planning period alternatives using the following steps:

1. Estimate the annual deep percolation of precipitation and applied water for the 2006 and 2025 land use conditions from the precipitation record of 1961 through 2006. In other words, run all the daily precipitation with the 2006 land use and all precipitation conditions with the 2025 land use.
2. Compute the average deep percolation of precipitation and applied water from the 45-year record for the 2006 runs and use that value for 2006. Then, do the same for 2025.
3. For each year between 2006 and 2025, estimate the deep percolation of precipitation and applied water by linear interpolation. Assume all deep percolation after 2025 is constant.

The resulting estimates of the deep percolation of precipitation and applied water are expected value estimates for any given year. A time lag for deep percolation water to reach the water table is applied based on location and is consistent with the calibration time lag. The deep percolation of precipitation and applied water estimates are identical for all planning alternatives the baseline and dry-year yield scenarios.

3.4.2 Discharge

Streambed discharge is calculated by the groundwater model.

Prado Basin ET was set to the 2006 rate, such that, at a minimum, the existing condition would be maintained.

The Chino Basin groundwater production used in future simulations is described in Section 7. Groundwater pumping projections for the Temescal Basin are far greater than the Temescal Basin can sustain. Total production from the Temescal Basin was limited to about 10,000 acre-ft/yr, the estimated yield of the basin observed during the later stages of the calibration period.

Table 3-1
Annual Water Budget for the Calibration Period, 1960/61 - 2005/06

(acre-ft/yr)

Year	Recharge						Discharge				
	Boundary Inflow	Recharge from Streams	Supplemental Recharge	Storm Water	Areal Recharge	Total Recharge	Discharge to Streams	Pumping	Evapo-transpiration	Total Discharge	Balance
1960/1961	46,829	14,916	-	2,652	99,215	163,612	15,212	193,346	11,895	220,453	(56,841)
1961/1961	59,796	15,035	-	10,653	100,746	186,230	16,346	187,484	12,325	216,155	(29,925)
1962/1961	45,712	14,282	-	3,877	100,008	163,880	15,656	188,636	12,186	216,478	(52,598)
1963/1961	45,000	16,150	-	5,251	99,747	166,149	15,471	191,011	12,174	218,655	(52,507)
1964/1961	48,413	15,935	-	5,471	100,514	170,333	15,256	189,900	12,137	217,293	(46,960)
1965/1961	54,765	17,025	-	9,790	104,613	186,193	16,146	190,415	12,445	219,006	(32,813)
1966/1961	62,901	18,801	-	12,505	108,787	202,995	16,866	175,587	12,605	205,058	(2,063)
1967/1961	48,297	16,482	-	7,082	109,489	181,350	16,619	190,468	12,431	219,517	(38,167)
1968/1961	79,547	26,752	-	17,031	108,817	232,146	17,630	165,075	12,875	195,580	36,566
1969/1961	45,878	16,927	-	5,738	106,449	174,992	17,859	175,030	12,660	205,549	(30,557)
1970/1961	48,860	16,824	-	8,293	103,143	177,119	15,827	176,932	12,409	205,168	(28,049)
1971/1961	43,496	16,673	-	4,124	100,443	164,737	14,208	189,453	12,225	215,886	(51,150)
1972/1961	63,278	17,479	-	16,018	102,352	199,126	15,383	164,764	12,389	192,535	6,591
1973/1961	49,071	16,011	-	7,896	101,403	174,380	15,679	167,369	12,401	195,449	(21,069)
1974/1961	53,655	17,382	-	9,366	97,792	178,195	14,702	175,219	12,499	202,419	(24,224)
1975/1961	46,256	18,778	-	5,125	95,136	165,295	12,524	197,316	12,531	222,372	(57,076)
1976/1961	47,884	20,436	-	7,984	95,386	171,692	12,091	174,373	12,568	199,032	(27,341)
1977/1961	85,836	30,850	6,239	26,302	102,689	251,916	14,635	172,508	13,517	200,660	51,256
1978/1961	60,891	25,718	11,141	15,940	107,016	220,706	15,386	164,868	13,875	194,129	26,577
1979/1961	77,077	32,659	1,549	24,836	104,470	240,590	15,601	165,906	14,523	196,029	44,561
1980/1961	50,268	29,609	12,150	6,965	98,456	197,449	14,247	173,983	14,550	202,779	(5,330)
1981/1961	53,599	27,014	16,609	16,193	96,910	210,325	13,041	159,945	14,462	187,448	22,877
1982/1961	75,471	31,531	13,188	30,958	103,007	254,155	15,969	149,346	15,552	180,867	73,288
1983/1961	50,607	20,390	13,777	10,179	101,660	196,613	15,986	166,636	15,545	198,167	(1,554)
1984/1961	49,024	27,477	12,188	9,806	96,657	195,152	13,377	171,365	15,191	199,933	(4,782)
1985/1961	53,181	32,171	16,332	14,762	96,445	212,891	14,112	176,051	15,745	205,907	6,984
1986/1961	43,990	27,590	10,086	7,520	93,063	182,249	13,328	176,092	15,390	204,810	(22,561)
1987/1961	38,863	30,682	2,494	15,992	92,936	180,967	12,731	176,610	15,320	204,662	(23,695)
1988/1961	37,888	29,278	7,407	16,313	94,012	184,898	12,995	174,664	15,352	203,010	(18,111)
1989/1961	38,515	30,062	-	9,773	90,016	168,366	12,257	184,675	15,291	212,222	(43,857)
1990/1961	39,583	35,496	3,291	18,326	90,356	187,052	12,203	168,008	15,623	195,834	(8,782)
1991/1961	39,984	33,760	3,790	24,870	93,470	195,873	13,174	167,168	15,973	196,315	(442)
1992/1961	42,311	40,156	12,535	63,504	97,308	255,813	14,873	167,974	16,790	199,636	56,176
1993/1961	43,147	35,043	8,859	15,057	94,052	196,158	14,800	154,282	16,629	185,711	10,447
1994/1961	49,817	38,106	-	50,438	93,867	232,228	14,706	166,956	16,842	198,504	33,724
1995/1961	40,203	32,174	82	12,589	95,774	180,822	14,969	187,559	16,854	219,382	(38,560)
1996/1961	40,721	34,752	17	20,059	95,489	191,038	14,185	196,632	16,955	227,772	(36,734)
1997/1961	44,569	37,294	8,323	36,981	101,284	228,451	15,973	167,516	17,443	200,932	27,519
1998/1961	37,521	29,930	5,796	8,122	95,402	176,771	15,577	184,496	16,905	216,978	(40,207)
1999/2000	41,134	33,553	1,001	11,098	89,644	176,430	13,276	210,159	16,695	240,131	(63,700)
2000/2001	41,195	33,710	6,530	12,689	91,919	186,043	13,592	188,746	16,870	219,208	(33,165)
2001/2002	42,454	33,536	6,500	4,114	86,269	172,873	12,025	209,953	16,338	238,315	(65,442)
2002/2003	41,661	38,964	6,499	18,067	87,167	192,359	11,949	196,176	16,499	224,624	(32,265)
2003/2004	44,365	35,155	7,582	9,877	87,437	184,416	11,729	202,061	16,391	230,181	(45,764)
2004/2005	43,060	43,939	12,259	33,438	91,462	224,157	13,857	184,852	17,327	216,036	8,121
2005/2006	45,583	38,408	34,568	16,132	89,256	223,947	14,391	173,817	17,019	205,227	18,720
Minimum	37,521	14,282	-	2,652	86,269	163,612	11,729	149,346	11,895	180,867	(65,442)
Maximum	85,836	43,939	34,568	63,504	109,489	255,813	17,859	210,159	17,443	240,131	73,288
Average	49,612	27,063	5,235	15,212	97,642	194,764	14,531	178,943	14,613	208,087	(13,324)

Table 3-2
Stormwater Recharge for the Calibration Period
(acre-ft/yr)

Year	San Sevaine Creek and Tributaries[1]	Day Creek	Cucamonga Creek	Upland Basin[2]	Total
1960/61	1,012	2	519	0	1,532
1961/62	5,240	281	712	0	6,233
1962/63	1,471	40	527	0	2,038
1963/64	1,791	17	524	0	2,331
1964/65	2,179	63	553	0	2,795
1965/66	5,331	277	463	0	6,071
1966/67	6,584	364	706	0	7,654
1967/68	3,321	41	572	0	3,934
1968/69	9,921	682	686	0	11,289
1969/70	2,311	111	468	0	2,890
1970/71	2,745	125	526	0	3,396
1971/72	1,616	148	211	0	1,975
1972/73	6,668	390	770	0	7,828
1973/74	3,110	192	521	0	3,823
1974/75	2,980	106	666	0	3,752
1975/76	1,850	24	399	0	2,272
1976/77	2,706	54	655	0	3,415
1977/78	12,513	1,147	891	0	14,551
1978/79	7,002	296	804	0	8,102
1979/80	13,471	1,334	851	0	15,656
1980/81	2,038	30	638	0	2,705
1981/82	7,064	377	833	0	8,275
1982/83	16,865	867	1,011	0	18,743
1983/84	3,946	125	693	0	4,764
1984/85	2,892	191	770	0	3,853
1985/86	5,779	278	847	0	6,904
1986/87	2,993	19	717	0	3,728
1987/88	7,032	135	877	404.8	8,449
1988/89	8,494	106	818	566.5	9,984
1989/90	5,140	70	667	222.1	6,100
1990/91	12,128	273	379	438	13,218
1991/92	16,749	345	624	606.2	18,324
1992/93	49,923	1,332	817	1001.1	53,073
1993/94	8,541	60	691	458.2	9,751
1994/95	38,037	890	962	1003.7	40,893
1995/96	4,828	281	416	640.5	6,166
1996/97	9,751	429	588	1186	11,954
1997/98	17,415	1,048	1,124	1915.5	21,503
1998/99	1,514	112	657	264.6	2,547
1999/00	3,509	218	438	633.2	4,797
2000/01	3,835	267	632	819.9	5,554
2001/02	536	9	472	54.5	1,072
2002/03	7,939	424	579	1093.9	10,035
2003/04	3,179	208	633	472.5	4,492
2004/05	15,843	1,438	939	1589.5	19,810
2005/06	5,730	385	744	590.4	7,450
Minimum	536	2	211	0	1,072
Maximum	49,923	1,438	1,124	1,916	53,073
Average	7,729	339	665	304	9,037

Notes:

1. Carville, C.A and Flick C.W, "Freash Water Artificial Recharge for the Chino-Riverside Area in Orange County Water District vs. City of Chino, et al case No. 117628 in the Superior court of the state of California in and for the County of Orange. Appendix "A" Basic Data, Volume II

2. Terminal drainage, operational history based on conversation with Barrett Kehl of IEUA

Values in this table have been calculated with the R4 Model

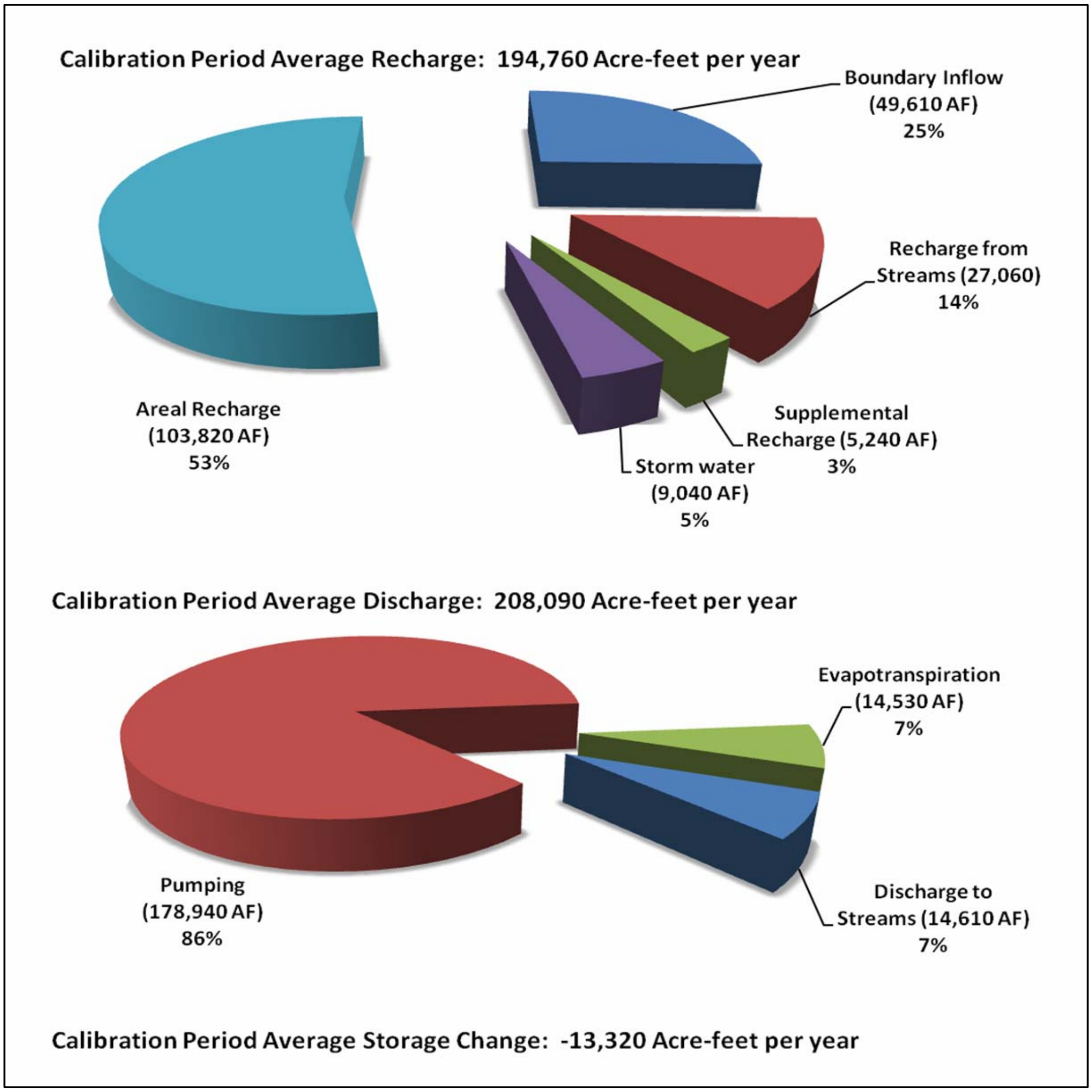
Table 3-3
Supplemental Recharge for the Calibration Period
(acre-ft/yr)

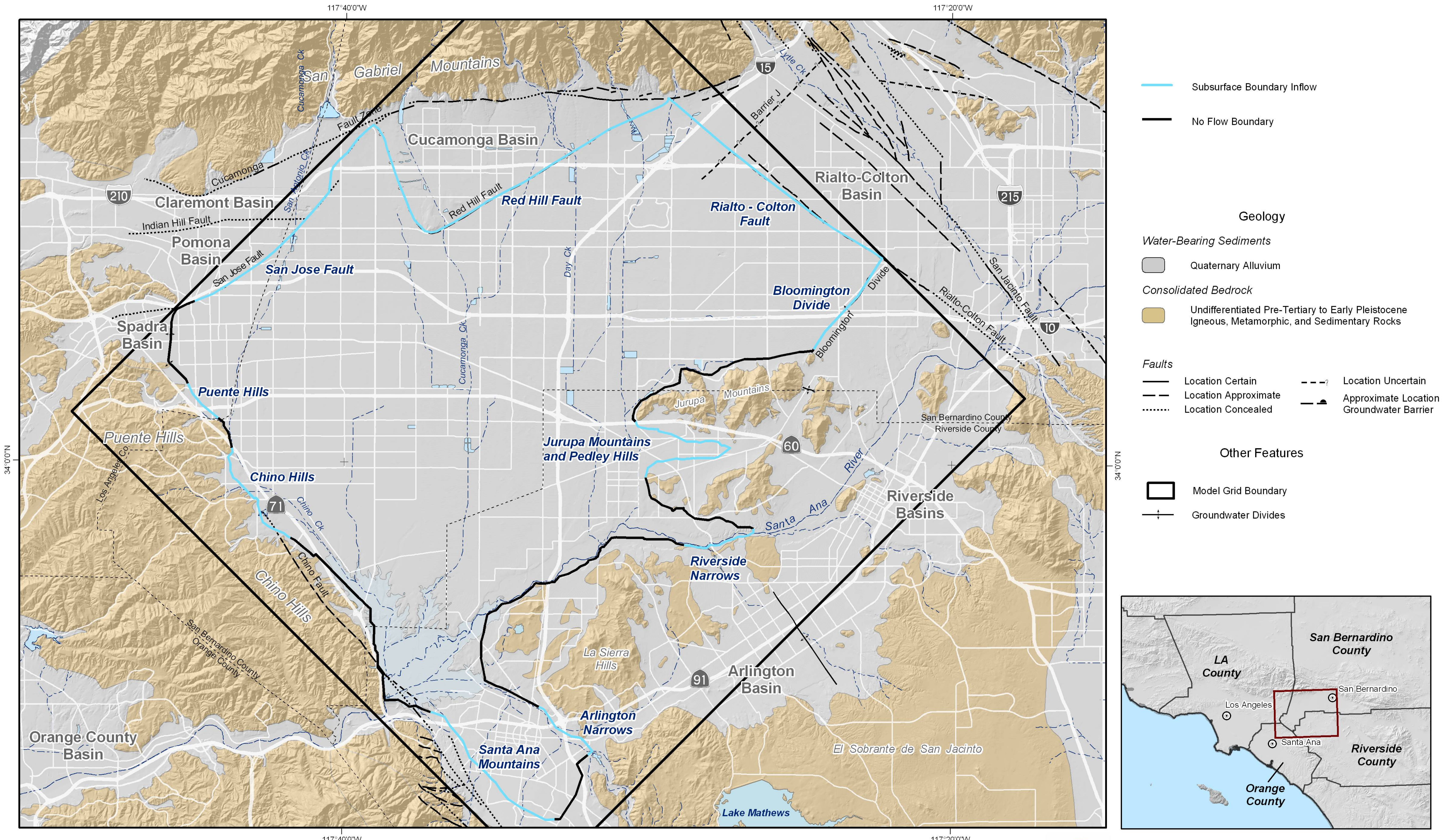
Year	San Sevaine Creek # 1,2,3,4	Montclair #1,2,3,4	Turner Basin/Deer Creek	Etiwanda Creek Channel	Day Creek	Total
1960/1961	0	0	0	0	0	0
1961/1962	0	0	0	0	0	0
1962/1963	0	0	0	0	0	0
1963/1964	0	0	0	0	0	0
1964/1965	0	0	0	0	0	0
1965/1966	0	0	0	0	0	0
1966/1967	0	0	0	0	0	0
1967/1968	0	0	0	0	0	0
1968/1969	0	0	0	0	0	0
1969/1970	0	0	0	0	0	0
1970/1971	0	0	0	0	0	0
1971/1972	0	0	0	0	0	0
1972/1973	0	0	0	0	0	0
1973/1974	0	0	0	0	0	0
1974/1975	0	0	0	0	0	0
1975/1976	0	0	0	0	0	0
1976/1977	0	0	0	0	0	0
1977/1978	0	5,324	138	1	775	6,239
1978/1979	0	8,321	0	0	2,821	11,141
1979/1980	0	1,333	0	0	216	1,549
1980/1981	2,830	6,322	0	978	2,021	12,150
1981/1982	920	9,326	0	1,544	4,819	16,609
1982/1983	3,569	2,669	0	3,351	3,599	13,188
1983/1984	3,686	1,540	0	4,090	4,461	13,777
1984/1985	2,676	4,006	0	2,694	2,812	12,188
1985/1986	2,969	6,729	0	3,080	3,554	16,332
1986/1987	2,095	4,193	0	1,844	1,955	10,086
1987/1988	607	1,278	0	608	0	2,494
1988/1989	0	4,325	0	2,470	612	7,407
1989/1990	0	0	0	0	0	0
1990/1991	0	1,988	0	828	475	3,291
1991/1992	0	2,583	0	705	501	3,790
1992/1993	3,182	6,444	0	2,909	0	12,535
1993/1994	2,688	4,886	0	1,285	0	8,859
1994/1995	0	0	0	0	0	0
1995/1996	82	0	0	0	0	82
1996/1997	0	17	0	0	0	17
1997/1998	0	8,323	0	0	0	8,323
1998/1999	1,526	3,032	0	1,237	0	5,796
1999/2000	0	1,001	0	0	0	1,001
2000/2001	0	6,530	0	0	0	6,530
2001/2002	0	6,500	0	0	0	6,500
2002/2003	0	6,499	0	0	0	6,499
2003/2004	0	7,582	0	0	0	7,582
2004/2005	1,621	7,887	310	2,137	107	12,259
2005/2006	9,172	18,923	346	2,488	2,810	34,568
Minimum	0	0	0	0	0	0
Maximum	9,172	18,923	346	4,090	4,819	34,568
Average	818	2,990	17	701	686	5,235

Table 3-4
Annual Groundwater Production for the Calibration Period
(acre-ft/yr)

Year	Agricultural	Overlying Non-Agricultural	Appropriators	Chino Basin Total	Temescal Basin Total	Study Area Total
1960/1961	119,440	5,816	53,164	178,420	14,927	356,839
1961/1962	120,908	5,537	49,049	175,495	11,990	350,989
1962/1963	122,163	5,930	47,631	175,724	12,912	351,447
1963/1964	118,776	5,793	53,051	177,620	13,391	355,240
1964/1965	114,391	6,151	57,105	177,647	12,254	355,293
1965/1966	121,285	5,649	52,324	179,258	11,157	358,516
1966/1967	109,942	6,681	48,527	165,150	10,437	330,301
1967/1968	114,295	6,589	57,399	178,284	12,184	356,568
1968/1969	90,051	4,709	59,721	154,481	10,595	308,961
1969/1970	99,154	5,853	58,542	163,549	11,481	327,098
1970/1971	97,199	6,964	61,569	165,731	11,200	331,463
1971/1972	107,369	7,539	61,352	176,259	13,194	352,519
1972/1973	87,237	6,863	58,394	152,494	12,270	304,988
1973/1974	84,243	7,299	62,485	154,026	13,343	308,053
1974/1975	79,284	9,222	73,863	162,369	12,849	324,739
1975/1976	95,867	6,586	81,195	183,648	13,669	367,296
1976/1977	78,752	9,548	73,644	161,944	12,429	323,888
1977/1978	86,919	10,534	64,971	162,424	10,084	324,849
1978/1979	85,465	8,187	63,934	157,587	7,281	315,174
1979/1980	81,715	7,768	68,057	157,539	8,366	315,079
1980/1981	87,155	5,852	73,689	166,696	7,287	333,391
1981/1982	77,681	6,165	69,139	152,985	6,960	305,970
1982/1983	76,227	2,318	65,022	143,568	5,778	287,135
1983/1984	83,057	3,132	73,206	159,395	7,241	318,789
1984/1985	84,088	2,343	78,064	164,495	6,870	328,990
1985/1986	83,497	3,183	82,402	169,082	6,969	338,163
1986/1987	78,924	2,526	86,427	167,876	8,215	335,752
1987/1988	71,082	3,199	92,935	167,215	9,395	334,431
1988/1989	65,908	3,717	94,830	164,455	10,209	328,910
1989/1990	67,691	5,093	102,612	175,396	9,279	350,792
1990/1991	67,570	5,642	87,528	160,740	7,268	321,481
1991/1992	59,851	4,964	93,048	157,863	9,305	315,726
1992/1993	65,217	5,437	87,420	158,074	9,900	316,147
1993/1994	59,203	4,306	82,603	146,112	8,170	292,223
1994/1995	56,743	4,995	96,160	157,898	9,058	315,796
1995/1996	66,956	4,688	105,796	177,441	10,118	354,881
1996/1997	68,191	3,879	113,162	185,232	11,400	370,463
1997/1998	51,370	2,725	100,868	154,963	12,553	309,925
1998/1999	55,685	3,439	111,845	170,969	13,528	341,937
1999/2000	63,919	5,244	129,106	198,269	11,890	396,538
2000/2001	51,147	6,137	118,325	175,609	13,137	351,218
2001/2002	53,383	4,433	132,822	190,639	19,314	381,278
2002/2003	42,032	3,721	131,845	177,597	18,578	355,195
2003/2004	44,785	2,939	135,080	182,804	19,257	365,608
2004/2005	36,319	2,819	123,293	162,431	22,422	324,862
2005/2006	29,024	3,604	118,767	151,395	22,422	302,791
Minimum	29,024	2,318	47,631	143,568	5,778	287,135
Maximum	122,163	10,534	135,080	198,269	22,422	396,538
Average	78,705	5,331	83,085	167,121	11,502	334,241

Figure 3-1
Calibration Period Water Balance for the Entire Model Area





Produced by:
WILDERMUTH ENVIRONMENTAL INC.
23692 Birtcher Drive
Lake Forest, CA 92630
949.420.3030
www.wildermuthenvironmental.com

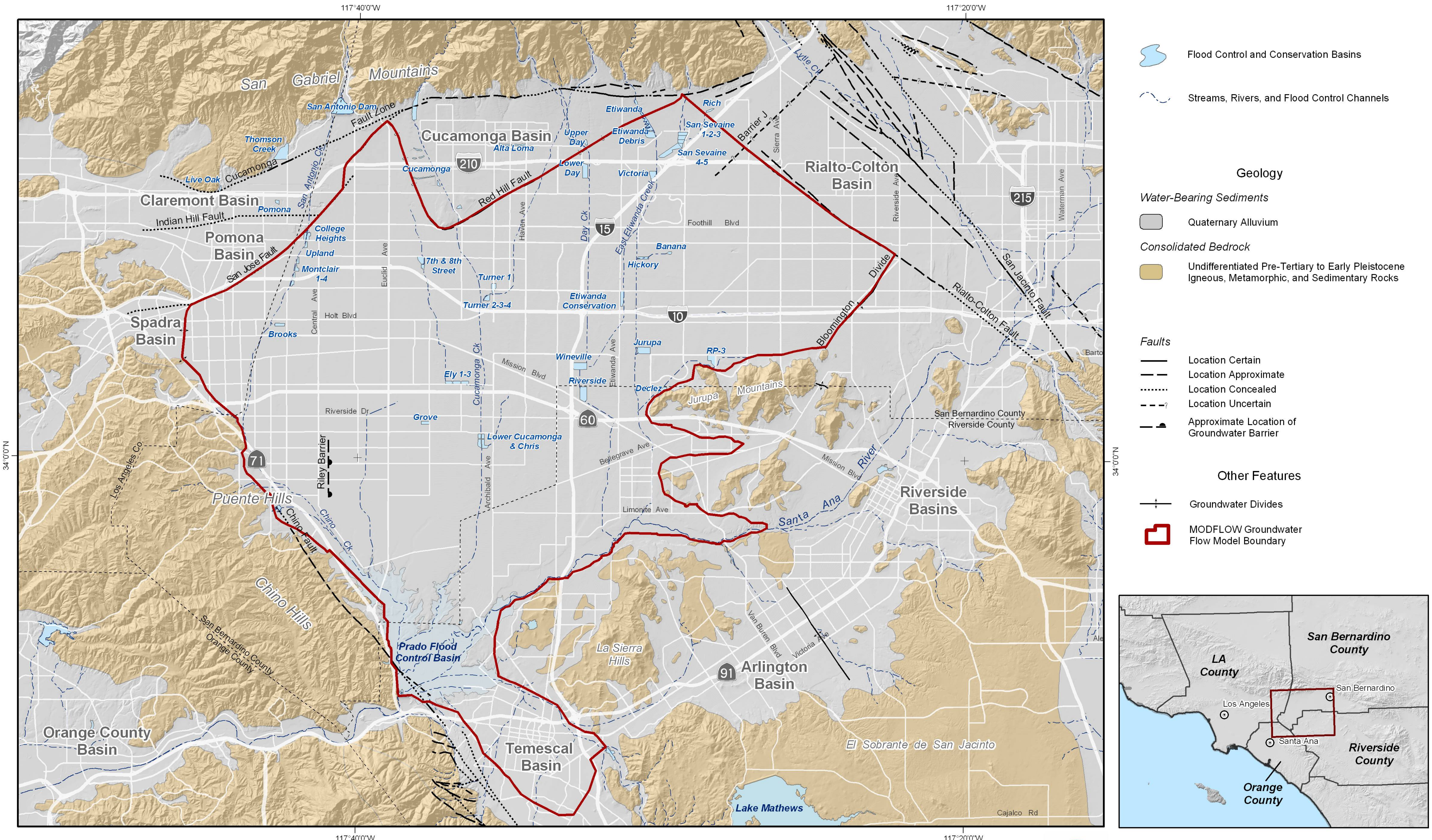
Author: MJC
Date: 20070925
File: Figure_3-2.mxd

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Water Balance

Location of Subsurface Boundary Inflows

Figure 3-2



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Author: MJC
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File: Figure_3-3.mxd

0 1 2 3 4 Miles
0 2 4 6 KM

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Water Balance

Location of Flood Control and Recharge Basins and Major Stream Channels

Figure 3-3

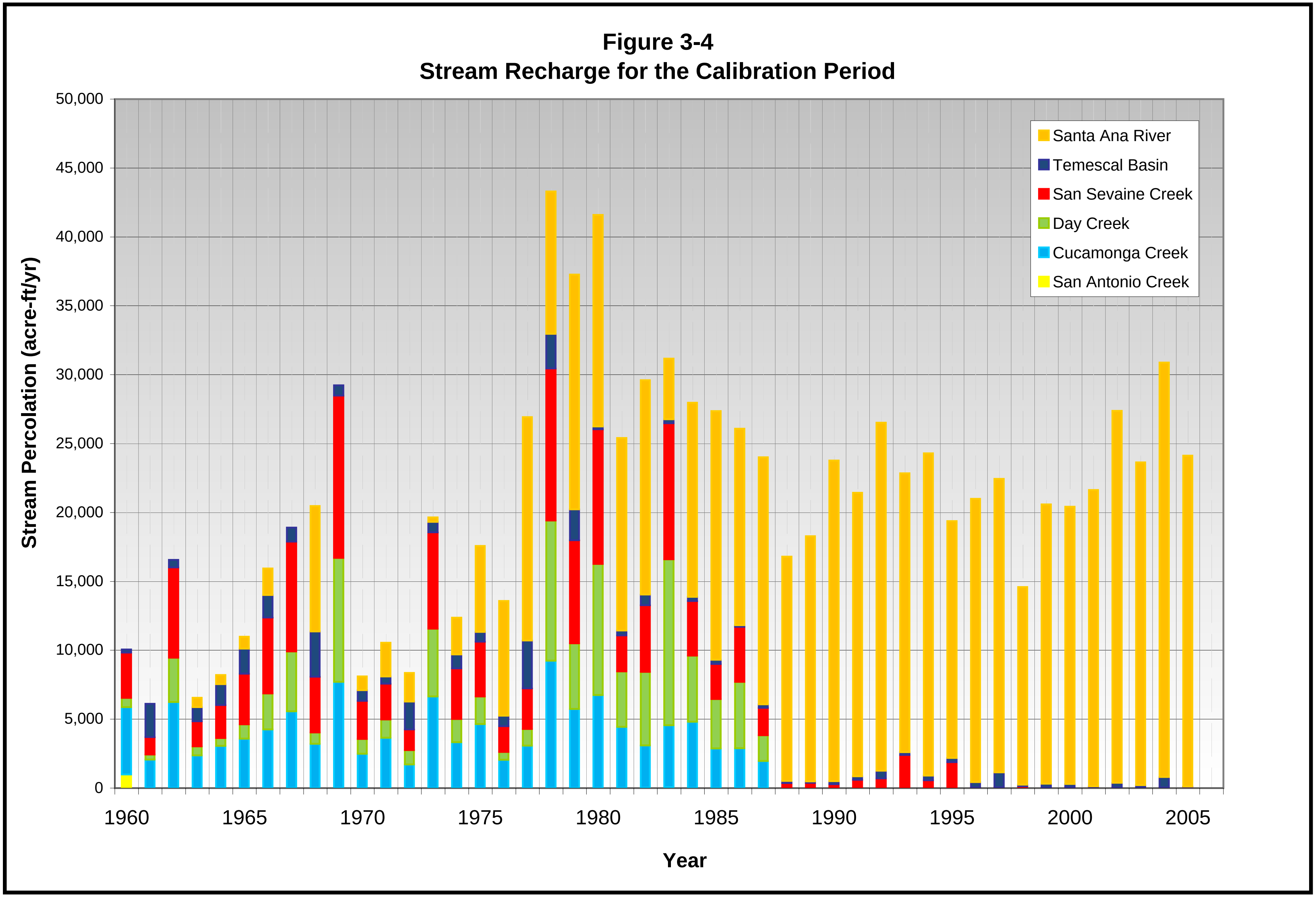

Figure 3-4.xls -- Fig. 3-5 By Creek Figure w SAR
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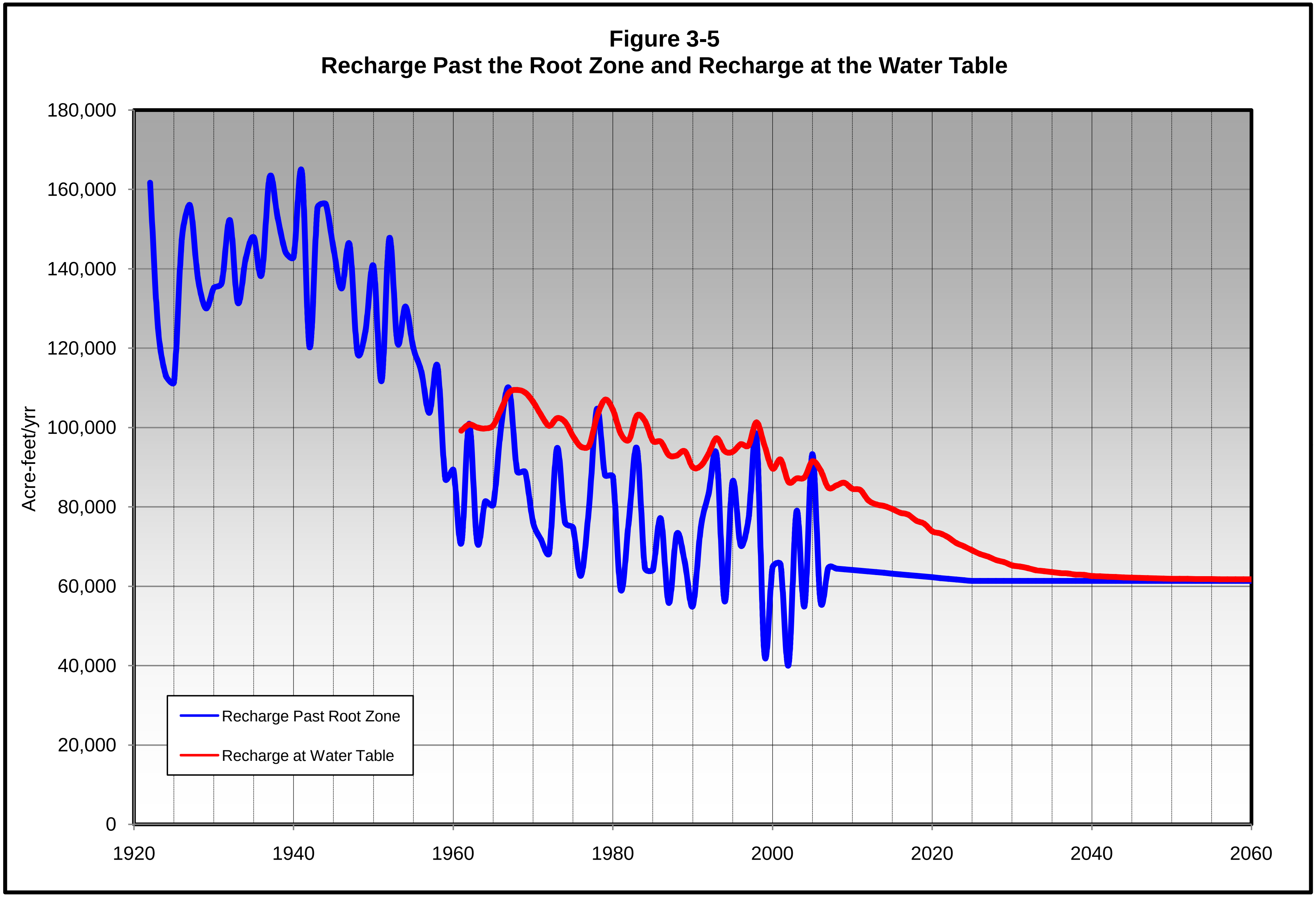

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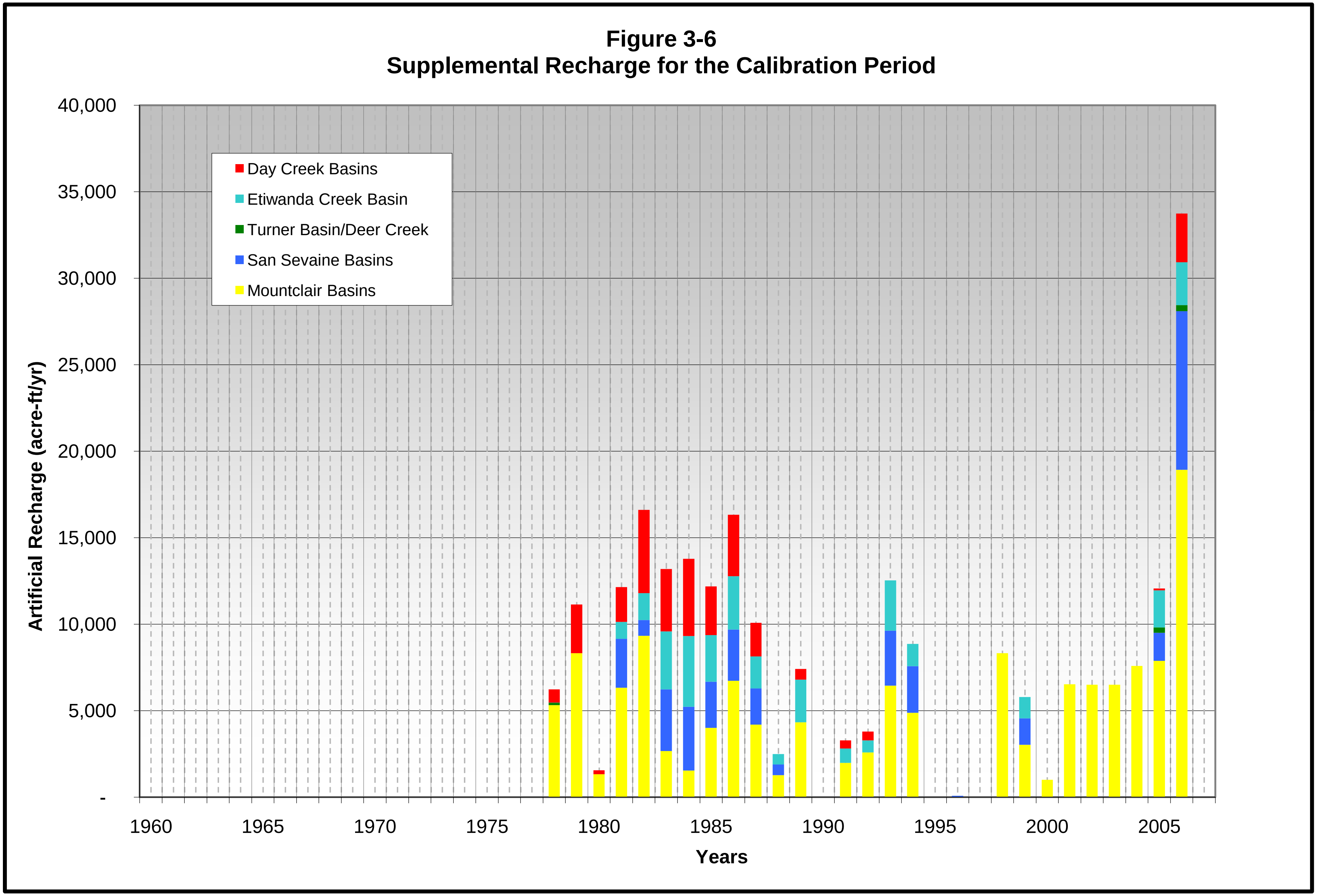
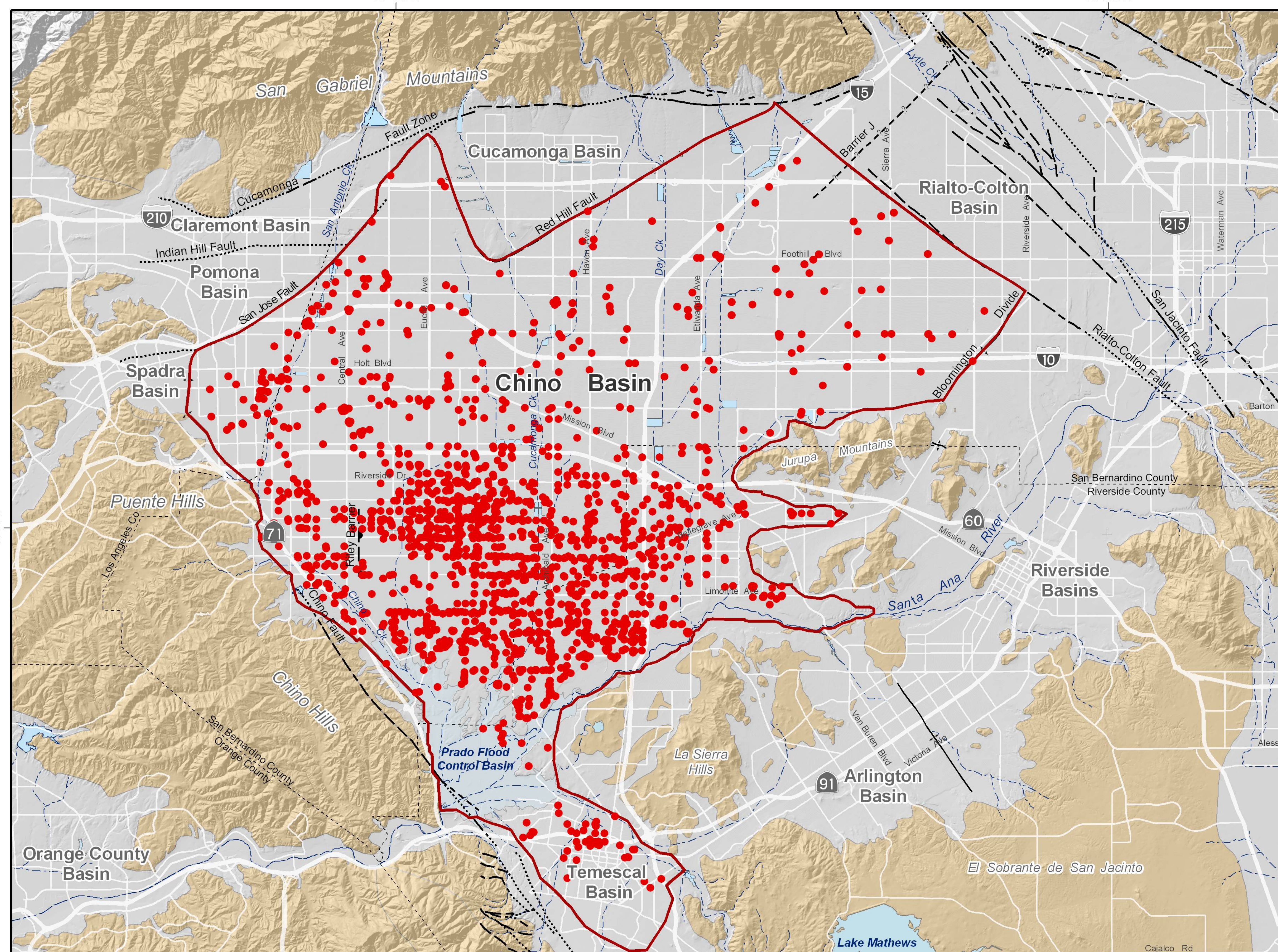


Figure 3-6.xls



Active Well

MODFLOW Groundwater Flow Model Boundary

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

Location Certain

Location Approximate

Location Concealed

Location Uncertain

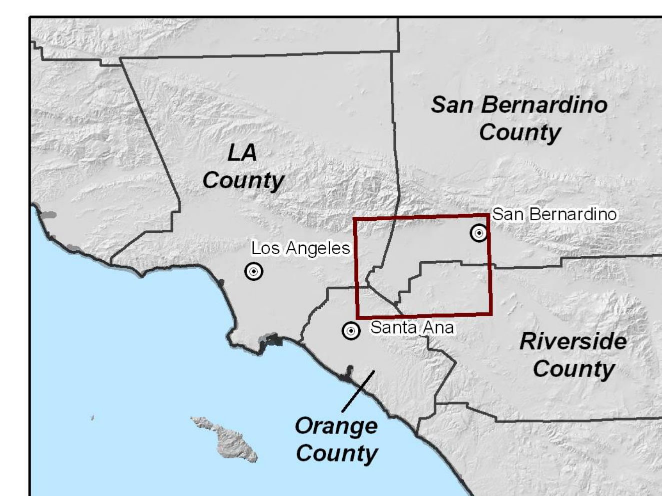
Approximate Location of Groundwater Barrier

Other Features

Groundwater Divides

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels



Produced by:
WILDERMUTH ENVIRONMENTAL INC.
23692 Birtcher Drive
Lake Forest, CA 92630
949.420.3030
www.wildermuthenvironmental.com

Author: MJC
Date: 20071005
File: Figure_3-7.mxd

0 1 2 3 4 5 Miles
0 2 4 6 8 KM

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Water Balance

Location of Active Wells During the Calibration Period

Figure 3-7

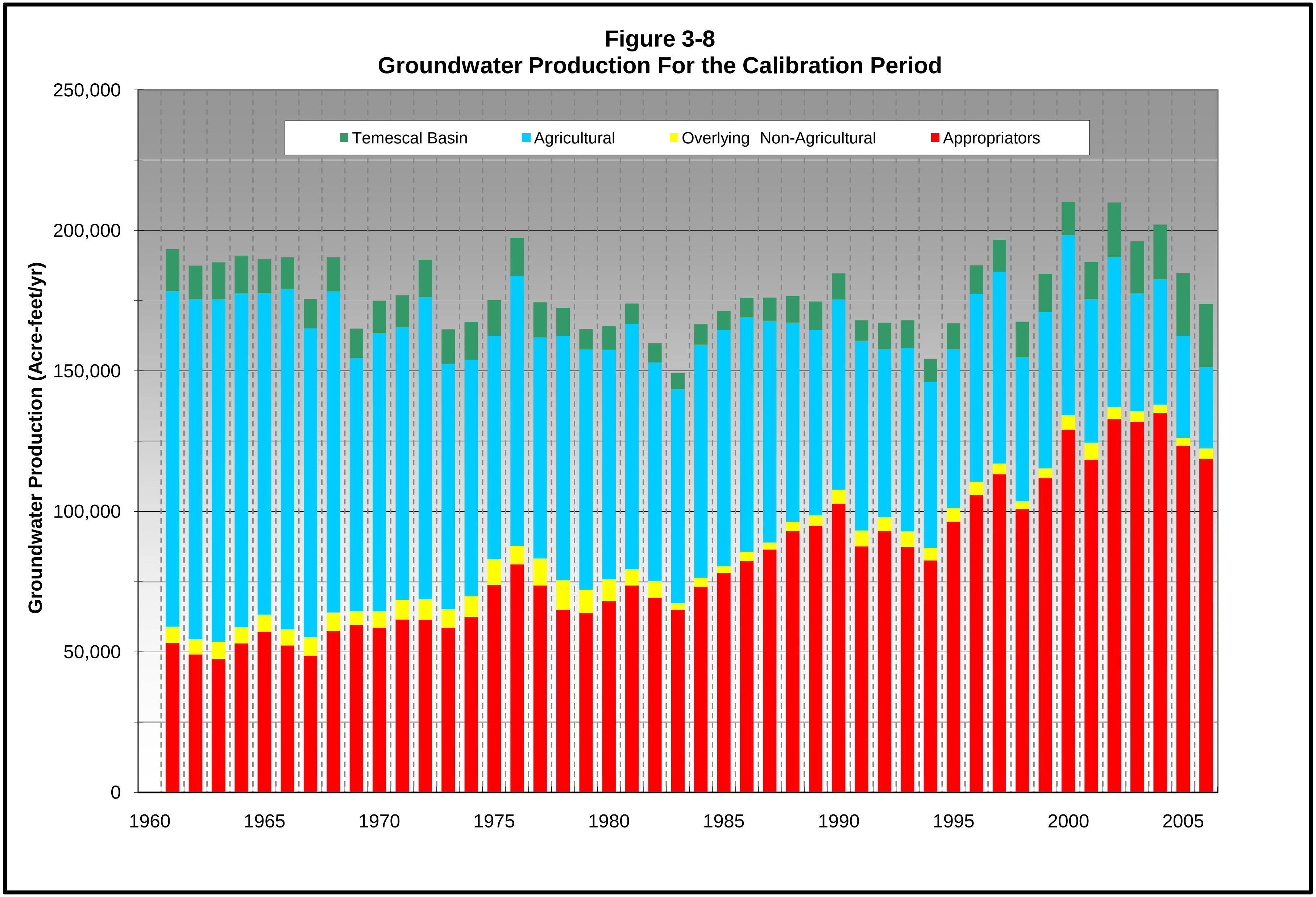


Figure 3-8.xls

This section presents a description of the computer codes used for this project and addresses the selection criteria, assumptions, limitations, and governing equations relative to each computer code.

A groundwater flow model was prepared to represent the physical properties of the Chino Basin aquifer system and test conceptual management decisions. This model employed four model codes for the purposes listed below:

- Groundwater flow: MODFLOW (McDonald and Harbaugh, 1988)
- Surface flow, recharge, runoff, and routing: R4 (WEI, 1995)
- Unsaturated flow and trsnport: HYDRUS-2D (Simunek et al., 1999)
- Parameter estimation and calibration: PEST and SENSAN (Doherty, 2004)

4.1 MODFLOW

The USGS has developed a wide range of computer models to simulate saturated and unsaturated subsurface flow, solute transport, and chemical reactions. The most widely used of these programs is the MODFLOW (McDonald and Harbaugh, 1988) model, which simulates three-dimensional groundwater flow using the finite-difference method (Harbaugh, 2005). Although it was conceived solely as a groundwater flow model in 1984, MODFLOW's modular structure has provided a robust framework for the integration of additional simulation capabilities that build on and enhance its original scope. The family of MODFLOW-related models now includes capabilities for simulating coupled groundwater/surface water systems and solute transport.

MODFLOW-2000 (Harbaugh et al, 2000) was chosen for this project because 1) it has extensive publicly available documentation, 2) it has sustained rigorous USGS and academic peer review, 3) it has a long history of development and use, 4) the code is widely used around the world in public and private sectors, and 5) it can easily operate with additional simulation tools published by others due to its availability and robust framework.

MODFLOW requires several general assumptions to approximate the partial differential equations that represent flow in a system. The groundwater system must be divided up into a series of finite difference cells, each with uniform hydraulic properties. Typically, layers are identified and linked with Darcy's Law; although, this model consists of a single layer. Boundary conditions must be simplified to constant head, head dependent, or specified flux estimates. Transmissivity is calculated based on the saturated thickness of layers, but it is constant for the entire saturated thickness of each layer. Time must be simplified into a consistent series of discrete time units for the estimation of partial differential equations—the higher the frequency the longer the processing time. MODFLOW also assumes all groundwater flow is laminar.

There are some limitations to the MODFLOW codes. The limitations of MODLFOW are provided below:

- MODFLOW is only capable of simulating fully saturated groundwater flow and lacks the ability to model percolating groundwater in the unsaturated zone. This limitation was mitigated by combining MODFLOW with HYDRUS-2D.

- There are limitations associated with representing a system as a finite-difference grid. This is not exclusive to MODFLOW. This was mitigated in the approach by using very small grid cells.
- The MODFLOW code has a steep learning curve and requires an experienced user to obtain reliable results.

4.2 Rainfall, Runoff, Router, and Root Zone: R4

The R4 Model was used to calculate surface water runoff and areal recharge from precipitation and applied water. This code estimates recharge using three modules for processing precipitation to determine recharge: Runoff (Runoff Module), Router (Router Module), and Root Zone (Root Zone Module). Collectively, this model is referred to as the R4 Model, developed by WEI, and has been used for several surface water and groundwater modeling projects.

The origin of this model can be traced to the Chino Basin Water Conservation District and the Chino Basin Watermaster. These agencies wanted to estimate the volume of storm water recharge that occurred in the recharge basins, flood retention basins, and unlined streams of the Chino Basin. WEI developed a daily simulation model to estimate runoff, route the runoff through the Chino Basin drainage system, calculate recharge on a daily basis, and produce reports that summarized recharge performance. This model was initially developed in 1994 for the western portion of the Chino Basin (Mark J. Wildermuth, 1995) and was expanded to the entire Chino Basin in 1996 (WEI, 1998). Subsequently, it was used in the Chino Basin to estimate the recharge performance of new basins and the recharge benefits of improved basin maintenance (Black and Veatch, 2001). The model was then expanded to include water quality simulation and applied to the Wasteload Allocation Investigation for the Santa Ana Watershed (WEI, 2002). After the root zone simulation module was added, the model was successfully used to estimate areal recharge from precipitation, returns from urban and agricultural land uses, and stormwater percolation in the basins and channel systems of several groundwater basins for which WEI has developed groundwater models, including the Chino Basin (WEI, 2003) and the Beaumont Basin (WEI, 2005).

The Runoff Module is used to determine two key elements of areal recharge: the actual runoff volume and the rainfall abstraction. Runoff is calculated with the SCS method and imported into the Router Module, which in this case was used for routing flows through the Chino Basin and estimating recharge water where applicable. The rainfall abstraction is imported into the Root Zone Module to calculate the amount of water that infiltrates into and through the root zone. The Router Module collects daily runoff flows from the hydrologic areas specified in the Runoff Module, boundary inflows, and other point discharges, and routes the water through the drainage system. The drainage system is represented by nodes and links. Nodes collect flows from upstream links; add runoff from upstream areas, boundary inflows, and point loads; and send totalized flows to the downstream links. Some of this flow may percolate to the groundwater system based on the routed flow and channel lining characteristics. The Root Zone Module calculates the amount of water required for evapotranspiration based on land use and the amount of water that percolates to the groundwater system past the root zone.

The deep percolation of precipitation and applied water, or areal recharge, is the daily totalized discharge from the root zone for each hydrologic subarea within the active groundwater domain. This areal recharge considers applied water, precipitation, losses to evapotranspiration, and losses to surface runoff.

The R4 Model is limited by available accurate historical weather data, evapotranspiration data, soil data and land use maps. When these data are not available, they must be estimated, thereby limiting the accuracy of the deep percolation results.

The hydrologic soil type and land use data were used to develop runoff curve number (CN) tables, based on average conditions. The CNs reflect the abilities of soils in retaining rainfall from storm events. The CNs are lower for well draining sandy soils and higher for poor draining silty clay soils. These CNs were based on the recommended values in the hydrology manuals of the Riverside County Flood Control and Water Conservation District (RCFC&WCD) and in the USDA Urban Hydrology for Small Watersheds Technical Release 55 (USDA, 1986). The rainfall-runoff data do not fit the CN runoff concept precisely, and the variability of the CN results from rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature. That said, the SCS method is the most widely used method to estimate inflow from storms.

The specific application of R4 for this model is described in detail in Appendix A.

4.3 HYDRUS-2D

The HYDRUS-2D software package is a major upgrade and extension of the HYDRUS-2D/MESHGEN-2D software package that was originally developed and released by the U.S. Salinity Laboratory, PC-Progress, and the International Ground Water Modeling Center. HYDRUS-2D is a Microsoft Windows-based modeling environment for the analysis of water flow and solute and heat transport in variably saturated porous media.

The HYDRUS-2D (Simunek et al., 1999) computer model was used to simulate unsaturated flow and solute transport in the Chino Basin. This program numerically solves the Richards equation for saturated-unsaturated flow and the Fickian-based advection-dispersion equations for heat and solute transport. This program can be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media.

HYDRUS-2D has been updated numerous times since its development. It is currently used worldwide and is arguably considered a standard in unsaturated flow modeling. The program continues to be updated and supported. The specific application of HYDRUS-2D for this model is described in detail in Appendix B.

4.4 PEST and SENSAN

PEST (Doherty, 2004), an acronym for Parameter ESTimation, is a computer code model calibration and predictive analysis. During the calibration process, parameters are adjusted until model generated results fit a set of observations as closely as possible. PEST adjusts model parameters until the fit between model outputs and field observations is optimized in terms of the weighted least squares. PEST is not unique to groundwater flow models or MODFLOW. PEST is a public domain code that applies the Gauss-Marquardt-Levenberg algorithm. The mathematics of PEST are further described in Section 6 of this report. PEST has been successfully applied in many fields of the geophysical sciences, including groundwater modeling in particular. It has been proven to be a robust tool and was therefore applied to the Chino Basin groundwater model.

SENSAN (Doherty, 2004), an acronym for SENSitivity ANalysis, is a command-line program that provides the ability to carry out multiple model runs in parallel. WEI is able to operate 24 systems in parallel with key model output from each run being recorded for later analysis. This allows for very complex multiple parameter sensitivity analyses to be completed in a much shorter time period.

PEST and SENSAN are prepared by Watermark Consulting and distributed as standalone packages as well as with numerous groundwater modeling packages, (*e.g.* Groundwater Vistas and Groundwater Modeling System). The PEST software bundle was first distributed in 1994 and has since been updated five times.

PEST and SENSAN were chosen for this project because 1) they reduce modeling time and significantly increase the value of the results, 2) the software has extensive publicly available documentation, 3) it has a strong history of development, and 4) it is considered a standard in the groundwater industry and has been incorporated into most MODFLOW model processors.

This section describes how the conceptual model of the groundwater system, as described in Section 2, was translated into a numerical model. The topics discussed in this section include the model domain and grid, the assignment of hydraulic properties to the model grid, the initial conditions, and the boundary conditions.

5.1 Model Domain and Grid

The model domain and the model grid within the domain are shown in Figure 5-1. The model grid consists of 577 rows, 562 columns, and three layers. Horizontally, each cell has a dimension of 60 by 60 meters (196 by 196 feet). This fine cell size was selected to model the curvature of drawdown near the desalter wells and to provide a model that is flexible for potential future needs. The grid cells are designated as "inactive" outside the model domain and as "active" inside the domain. There are a total of 462,250 active cells.

The spatial extent of the model domain was determined by the saturated extent and thickness of the aquifer system; the extent was limited to regions where the saturated thickness was greater than about 40 feet. The saturated thickness was determined based on initial condition water levels and the effective base of the aquifer.

The vertical extent of the model is comprised of three layers, representing three hydrostratigraphic layers. The discretization of these layers is discussed in Section 2.4.4. Layer 1 represents the unconfined system, is classified as an unconfined aquifer within the MODFLOW model, and has a minimum thickness of 75 feet and maximum thickness of 1,300 feet. Layer 2 is classified as a confined aquifer within the MODFLOW model. Layer 2 has a minimum thickness of 25 feet and a maximum thickness of 600 feet. As discussed in Section 2 and shown Figures 2-6a through 2-6h, layer 2 pinches out in the Fontana area north of the Jurupa Mountains. For numerical purposes, layer 2 must be maintained in the model; therefore, a thickness of 25 feet was assigned to layer 2 in the locations where it pinches out. The layer properties for the pinched out area are the same in layer 3, essentially creating a 25 foot extension to layer 3. Layer 3 is also classified as a confined aquifer within the MODFLOW model. Layer 3 has a minimum thickness of 75 feet and maximum thickness of 925 feet.

5.2 Time Discretization

The discretization of time is a critical step in model construction because the resolution of model results is related to the stress period of the model. The temporal discretization in MODFLOW 2000 includes stress periods and time steps. The transient stress period of the model is three months or one-quarter year, based primarily on the availability of historic pumping and the distinct seasonal features of water recharge, such as precipitation, irrigation return flow, and stream flow.

5.3 Hydraulic Properties

The hydraulic properties used in the model include horizontal hydraulic conductivity, vertical hydraulic conductivity, the specific yield for an unconfined aquifer, and the specific storage for confined aquifers. Although the hydrogeologic systems in the Chino Basin are inherently heterogeneous on many scales, site-scale hydrogeologic heterogeneity was incorporated into this revised model.

Hydraulic conductivity is the measure of a fluid's ability to flow through a medium. The value relates to fluid density (ρ), dynamic viscosity (μ), and the effective grain size (d_{10}) in unconsolidated deposits, as depicted in the following equation:

$$K = \frac{C{d_{10}}^2 \rho g}{\mu}$$

Where C is a constant of proportionality.

The definition of hydraulic conductivity suggests that its value increases with the median grain size. For a given median grain size, hydraulic conductivity is lower in a poorly sorted medium than in well-sorted medium because poorly sorted mediums have a smaller effective grain size.

All of the hydraulic properties mentioned above are related to the lithology of aquifers. The values of hydraulic conductivity and specific yield are generally higher in coarse-grained deposits than in fine-grained deposits. To address this, a method was developed to describe the heterogeneity of hydraulic properties in the Chino Basin using zonation and hydraulic parameter multipliers.

There are 853 wells with lithologic descriptions in the Chino Basin and Temescal area. First, the lithologies were grouped into three categories, representing coarse, mixed, and fine-grained deposits. The thicknesses of each category were then summed at each well for layers 1, 2, and 3, respectively. Finally, the thickness percentages of coarse, mixed, and fine-grained materials in each layer at each well were calculated. These fractional thicknesses are referred to as multiplier values.

Based on pumping tests in the Chino Basin, three empirical equations were derived to calculate multipliers of hydraulic properties:

$$KHMULT = MLT_c + 0.4MLT_m + 0.04MLT_f$$
$$KVMULT = 1 - MLT_f - 0.5MLT_m$$
$$SYMULT = MLT_c + 0.4MLT_m + 0.1MLT_f$$

Where MLT_c, MLT_m, and MLT_f represent the fractional thicknesses of coarse, mixed, and fine-grained sediments in each layer at each well; and, $KHMULT$, $KVMULT$, and $SYMULT$ represent the multipliers of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific yield in unconfined aquifers or specific storage in confined aquifers, respectively.

The procedure for estimating multipliers of the hydraulic properties included:

1. Compute the fractional thickness of coarse, mixed, and fine-grained deposits in each layer at each well location.
2. Compute each hydraulic parameter's multiplier in each layer at each well location.
3. Conduct variogram analyses of hydraulic property multipliers in each layer, determine their spatial variation structure, obtain the best-fitted variogram spatial structure model and model parameters, and complete the same analysis for vertical and horizontal hydraulic conductivity as well as specific yield in each layer.
4. Conduct kriging based on the multiplier value at each well location, using the best-fit variogram model and parameters, and generate heterogeneity multiplier grids for the model

domain, representing the heterogeneity of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific yield or storage in layers 1 through 3.

The hydraulic property values in each cell of the model domain were then calculated using MODFLOW 2000 based on the following equations:

$$K_h(i,j,k) = K_h(zone)KHMLT(i,j,k)$$
$$K_v(i,j,k) = K_v(zone)KVMLT(i,j,k)$$
$$S_y(i,j,k) = S_y(zone)SYMLT(i,j,k)$$

Where *i, j, and k* represent row, column, and layer in the model domain; and, $K_h(zone)$, $K_v(zone)$, and $S_y(zone)$ are the base values of horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific yield or specific storage in each zonation. Figures 5-2a through 5-2i show the parameter zonation, base values, and multipliers for horizontal hydraulic conductivity, vertical hydraulic conductivity, and specific yield or specific storage in each layer, respectively. Simply put, the calculated parameter value is the product of the zonation base value and the individual cell multiplier value. This allows for the model to have a heterogeneous K_h, K_v, S_y, and S_s. Figures 5-3 through 5-5 show base zonation with the mean, minimum, and maximum parameter values (K_h, K_v, and S_y or S_s) for each layer.

In an attempt to reduce the number of parameters to a manageable level, the model domain was subdivided into a number of zones of assumed similar parameter values. Zonation was primarily based on geological and hydrogeologic conditions. These conditions were postulated based on sediment facies, lithologic descriptions in well completion reports, pump test data, and water level measurements in wells. In the configuration of parameter zonation, the location of calibration wells were also considered. A total of 31 zones comprise layer 1 of the model domain, 20 zones comprise layer 2 and 15 zones comprise layer 3. Table 5-1 lists the calibrated values of the model parameters by zone and layer. The horizontal hydraulic conductivity values for this model range from 5.7 to 226.7 feet per day for layer 1, 1.9 to 52.0 feet per day for layer 2, and 1.1 to 37.2 feet per day for layer 3. The vertical hydraulic conductivity values for this model range from 8.86 x 10^{-9} to 6.57 feet per day for layer 1, 3.05 x 10^{-8} to 3.83 feet per day for layer 2, and 1.04 x 10^{-6} to 4.76 feet per day for layer 3. On average, hydraulic conductivities are highest in the northern (City of Upland) and eastern (City of Fontana) portions of the Chino Basin. A belt of similarly high hydraulic conductivity runs north of the Jurupa Mountains to the northern model boundary. Average hydraulic conductivities are lowest on the west side of the Chino Basin (Cities of Pomona, Chino, and west Ontario) and in layer 1 between the Jurupa Mountains and the La Sierra Hills. Generally, hydraulic conductivities decrease with depth because deeper sediments typically have experienced a greater degree of secondary alteration (*e.g.* weathering of feldspars to clay minerals, cementation of pore space, *etc.*).

The specific yield (S_y) is the volume of water released from aquifer storage per unit surface area of aquifer per unit change in the water table. The specific storage (S_s) is the volume of water released from a unit volume of aquifer under a unit decline in hydraulic head. The usual range of S_y (dimensionless) is 0.01 to 0.30; the range for this model is 0.0158 to 0.353. The results of numerous pumping tests in the Chino Basin and Temescal Basin have shown that the storativity value, which is defined as the product of the specific storage and the aquifer thickness, ranges from 10^{-5} to 10^{-3}. Considering the thickness of aquifer in layer 2 and layer 3, the range of specific storage in layer 2 and layer 3 is typically from 10^{-8} to 10^{-5}. The calibrated range for this model is 9.20 x 10^{-9} to 1.07 x 10^{-6} for layer 2 and 8.64 x 10^{-7} to 1.35 x 10^{-6} for Layer 3.

5.4 Initial Condition

An initial conditions is required to solve numerical groundwater flow problems. The initial condition for the Chino Basin flow model was the water level distribution at the beginning of the transient simulation period. The calibration period starts in fiscal year 1960/61 and ends fiscal year 2005/06. The model initial condition was based on published water level maps (JMM, 1992) and historic water level records. The initial condition or water level contour map was further adjusted in areas lacking water level data, using the estimated hydraulic parameters to extrapolate reasonable hydraulic gradients. Figure 5-6 is the final water level elevation contour map, representing the initial condition of groundwater flow for layers 1, 2, and 3. All layers started with the same initial head for following reasons: 1) there is limited deep pumping before the 1960s, and 2) the deep pumping that occurs before 1960 is located in areas of high vertical hydraulic conductivity, which makes the water level in the different layers very similar.

5.5 Boundary Conditions

Boundary conditions are necessary in solving numerical groundwater flow problems. Ideally, in groundwater investigations, the study area is bound by identifiable hydrogeologic features that can be quantified relative to the groundwater system. These boundaries can also occur within the active model domain (*e.g.* a creek). For the study area, the numerous faults and groundwater divides required calculations of inflow from these boundaries. Boundary conditions from creeks were developed outside of the groundwater model and were input as a given flux for a model stress period. Boundary inflows across fault zones (*e.g.* the San Jose Fault and Red Hill Fault) were determined during the calibration process.

Table 5-2 lists the boundary conditions by geographic name, the type of boundary, and the MODFLOW package utilized to simulate the boundary. Figure 5-7 shows the mean boundary condition inflows for the calibration period.

The boundary condition along Bloomington Divide was carefully specified. The Bloomington Divide is regarded as a groundwater divide (USGS, 1967); however, more recent studies (WEI, 2003, 2006) have postulated that a certain amount of water recharges from east side across north part of the divide. Figure 5-8 shows the locations of wells with historical water level measurements. Figure 5-9 shows that the water levels in wells located on the north side of Rialto-Colton Fault, near Bloomington, are about 50 to 100 feet higher than those on the south side. Figure 5-10 shows that the water levels on the east side of the "divide" are about 20 feet higher than the water levels on the west side and that the water levels in the north along the "divide" are higher than those in the south. This similar groundwater level fluctuation indicates a hydraulic connection from the north of the fault, through the east of the divide, to the west of the divide. Based on relatively detailed water level data along the divide (historical groundwater measurements), the boundary condition during the calibration period was set as a variable head boundary. The hydraulic conductivity of layers 1 and 3 in the divide area was then calibrated using local historical water level measurements. The boundary inflow was therefore computed using calibrated hydraulic conductivity and boundary heads or water levels. During the simulation of the planning alternatives, however, the boundary heads and their fluctuation are unknown. The boundary condition was thus set to a constant flux condition. The constant flux condition is equivalent to a flow of 8,600 acre-feet/yr into the model, which is the 2005/06 computed flow from the model calibration.

5.5.1 MODFLOW Packages for Boundary Conditions

5.5.1.1 Recharge Package

The Recharge Package (McDonald and Harbaugh, 1988) was used to simulate the deep percolation (areal recharge) from precipitation and applied water (*e.g.* agricultural and landscape irrigation). This package was used to assign a constant flux for each stress period. The flux rates were determined using the R4 Model. The following factors were used by the model to compute the deep percolation of precipitation and applied water: historical daily rainfall, daily evapotranspiration, soil type, drainage area, and estimated irrigation rates based on land use. The output from the R4 Model is the calculated recharge out of the root zone into the vadose zone. An unsaturated flow and transport model, HYDRUS-2D, calculated the amount of time for recharge to travel from the root zone to the piezometric surface. The Recharge Package applies a constant flux to the piezomentric surface. The Recharge Package used the R4 Model results that had been time adjusted (or lagged) based on calculated travel time from the root zone to the piezometric surface.

5.5.1.2 Flow and Head Boundary Package (FHB)

The Flow and Head Boundary Package (Leake and Lilly, 1997) was used to specify subsurface inflows to the study area aquifer system and to specify streambed percolation along unlined channels that cross the model domain, storm water recharge, and supplemental recharge. . The Flow and Head Boundary Package allows MODFLOW users to specify flow or head boundary conditions that vary at times other than the starting and ending times of stress periods and associated time steps.

5.5.1.3 Evapotranspiration Package (EVT)

The MODFLOW ET Package was used in the model to simulate the discharge of water to evaporation and transpiration in the Prado Basin. For the remainder of the study area, it was assumed that ET does not occur from the saturated zone.

The ET Package simulates ET with a relationship between the ET rate and hydraulic head. In the ET Package, the relation of the ET rate to the hydraulic head is conceptualized as a piece-wise linear curve relating the ET surface, defined as the elevation where the evapotranspiration rate reaches a maximum, and an elevation located at an extinction depth below the evaporation surface where the evapotranspiration rate reaches zero (Banta, 2000).

The ET rate for a model cell is calculated for each stress period based on its calculated head, the ET Surface value, the Extinction Depth, and the maximum ET flux rate. If the elevation of the calculated head in the cell is at or above the ET surface value, the ET rate is the maximum evapotranspiration rate (high groundwater condition). If the calculated head is is equal to or below the extinction depth, the evapotranspiration rate is zero (low groundwater dry condition). When the head is between the ET Surface and the Extinction Depth, the ET rate is a linear function of the head below the ET Surface. This relation is defined by the equation below:

$$Q_{ET} = Q_{ETMax}\left(1 - \frac{D}{X}\right)$$

Where Q is the volumetric evapotranspiration rate for the cell, Q_{ETMAX} is the maximum evapotranspiration flux rate times the area of the cell, D is the depth of the head below the ET surface, and X is the extinction depth.

5.5.1.4 Well Package (WEL)

The Well Package was used to simulate the withdrawal of water from aquifers by wells. The Well Package can also be used to simulate any other source of withdrawal or recharge that occurs at a known rate, including specified flow boundaries. This package uses a constant flow rate for each stress period.

5.5.1.5 Stream Package (STR)

The Stream Package was used to simulate the Santa Ana River and the lower reaches of some of its tributaries in the Prado Basin. The Stream Package (Prudic, 1998) was used to simulate stream aquifer interactions. The Stream Package routes surface flow and calculates flow to and from the aquifer based on the elevation of a stream, water level in the stream, piezometric surface of the aquifer, and conductance of the stream bottom. The shift from recharge of the aquifer to discharge to the stream occurs at the point where the head in the aquifer equals the head in the stream.

Streams were divided into segments and reaches with each reach corresponding to a single cell in MODFLOW. Reaches were grouped into segments. Each segment consists of a series of contiguous reaches where flows can be routed.

Flow between a stream and an aquifer is computed using the streambed's conductance, the head in the stream, and the calculated head of the aquifer in each cell. Volumetric flow between the streambed and groundwater system is computed as:

$$Q_{STR} = C_{STR}\,(h_{STR} - h(i,j,k))$$

Where Q_{STR} is the flow rate across the streambed, C_{STR} is the conductance of the riverbed, h_{STR} is the head in stream stage, and $h(i,j,k)$ is the hydraulic head in the cell of row i, column j, and layer k underlying the streambed.

The conductance of the riverbed is given by:

$$C_{STR} = (K_v L W)/M$$

Where K_v is the vertical hydraulic conductivity of the riverbed sediment, W is the width of the river reach, L is the length of the river reach, and M is the thickness of riverbed sediment.

However, K, W, L, and M are not individually specified. Instead, conductance of the riverbed (C_{STR}) is specified. The stream segment is specified such that the conductance of the riverbed in each segment remains constant but varies from one segment to another segment.

Figure 5-11 shows the stream segments and reaches in the Chino and Temescal Basins. The streambed elevations along creeks and channels were extracted from the USGS 10-meter digital elevation model (DEM) cell by cell. The assigned streambed elevations are about 3-10 feet below the DEM elevation, depending on location, because the center of a model stream cell is not exactly located in the middle of a stream.

The stream stage in each reach was computed using Manning's equation prior to calculating leakage to or from the aquifer. The stage for each reach was calculated using the specified inflow into the stream segment. The initial slope of the stream channel was computed based on the 10-meter DEM. The stream channel slopes were further adjusted as needed to ensure a decresing slope.. The estimates of Manning's roughness coefficient were based on the streambed characteristics of the Santa Ana River and its tributaries; the values range from 0.025 to 0.04. If no stream flow is specified into a segment, the stage for all reaches in the segment will equal the top of the streambed. Leakage was iteratively computed on the basis of the computed stream stage, streambed conductance, and head for each model cell.

5.5.1.6 Precondition Conjugated-Gradient Package (PCG)

The Preconditioned Conjugated-Gradient Package (PCG) was selected as a numerical solver in the MODFLOW 2000 model. When calibration was initiated, the convergence criteria were set with a head change criterion for convergence (HCLOSE) of 0.01 feet and a residual criterion for convergence (RCLOSE) of 10. However, these strict criteria provided only a limited improvement of the solution at the cost of a longer computation time. Considering the long computing time required with PEST inverse modeling, the MODFLOW 2000 closure criteria were relaxed to reduce computation time during the calibration without reducing the precision of solution. Head change criterion for convergence was set to 0.1 feet (HCLOSE) and residual criterion for convergence was set to 55.0 (RCLOSE). To be consistent, the criteria remained the same as in calibration model for all future flow simulations.

Table 5-1
Calibrated Aquifer Parameter Values by Zone

Layer 1									
	Horizontal Hydraulic Conductivity (ft/day)			Vertical Hydraulic Conductivity (ft/day)			Storage Coefficient (-)		
Zone	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
1	41.1	157.3	137.7	3.06E+00	4.05E+00	3.56E+00	8.19E-02	1.26E-01	1.06E-01
2	36.3	188.6	133.2	2.90E+00	5.42E+00	3.97E+00	7.95E-02	1.57E-01	1.10E-01
3	88.6	226.7	163.5	2.54E+00	6.23E+00	4.83E+00	8.93E-02	1.86E-01	1.36E-01
4	105.5	224.5	181.5	3.49E+00	6.23E+00	5.25E+00	9.08E-02	1.85E-01	1.51E-01
5	37.9	204.3	65.3	2.61E+00	5.76E+00	4.21E+00	7.41E-02	1.70E-01	1.19E-01
6	35.9	84.8	72.3	2.92E+00	6.57E+00	5.60E+00	4.16E-02	9.23E-02	7.86E-02
7	28.6	77.8	59.3	6.11E-02	6.07E+00	4.62E+00	3.29E-02	8.60E-02	6.55E-02
8	23.3	73.0	49.9	5.94E-02	5.48E+00	3.92E+00	2.93E-02	1.25E-01	5.65E-02
9	21.3	93.8	34.7	3.10E-02	3.60E+00	7.10E-02	4.45E-02	1.24E-01	9.68E-02
10	25.6	133.8	50.4	6.66E-02	5.43E+00	4.07E+00	4.03E-02	1.33E-01	5.69E-02
11	23.0	121.9	81.7	6.35E-01	5.62E+00	3.82E+00	1.97E-02	1.53E-01	5.39E-02
12	55.6	152.1	95.1	1.96E+00	6.57E+00	4.35E+00	3.81E-02	1.49E-01	6.17E-02
13	37.1	116.7	70.7	3.33E-08	8.82E-02	5.51E-02	3.84E-02	1.52E-01	9.18E-02
14	23.0	88.1	48.8	1.32E-08	6.82E-08	3.65E-08	3.83E-02	1.21E-01	6.95E-02
15	50.3	110.7	76.9	4.37E-08	8.45E-02	6.04E-02	6.62E-02	1.46E-01	1.03E-01
16	12.1	86.5	32.5	1.95E-02	2.49E+00	6.49E-02	4.17E-02	1.44E-01	9.19E-02
17	23.9	162.6	103.8	9.25E-01	3.17E+00	2.08E+00	4.89E-02	1.26E-01	8.06E-02
18	66.9	161.6	109.8	1.32E+00	3.07E+00	2.19E+00	4.26E-02	1.18E-01	8.21E-02
19	49.3	186.2	101.2	1.36E+00	3.50E+00	2.61E+00	5.41E-02	1.38E-01	1.02E-01
20	19.0	127.0	64.8	3.28E-01	3.09E+00	1.71E+00	2.78E-02	1.24E-01	7.13E-02
21	8.2	106.7	41.5	9.86E-02	2.73E+00	1.10E+00	1.84E-02	1.10E-01	4.97E-02
22	8.6	91.1	19.2	4.67E-08	6.73E-02	4.11E-02	2.71E-02	1.20E-01	5.68E-02
23	11.3	85.2	48.4	8.86E-09	5.36E-02	5.71E-04	4.01E-02	1.28E-01	7.62E-02
24	18.4	82.4	54.8	1.97E-08	5.29E-02	6.20E-04	4.02E-02	1.20E-01	8.28E-02
25	6.0	51.7	19.2	1.01E-02	6.53E-02	4.00E-02	2.42E-02	9.36E-02	5.73E-02
26	13.1	151.3	69.2	8.60E-05	1.64E+00	4.32E-02	1.92E-02	1.01E-01	4.94E-02
27	19.2	156.6	108.4	1.95E-01	3.14E+00	2.16E+00	2.50E-02	1.19E-01	8.24E-02
28	39.7	208.9	126.6	6.80E-01	3.79E+00	2.42E+00	3.65E-02	1.51E-01	9.49E-02
29	5.7	130.0	62.5	6.58E-02	3.61E+00	2.42E+00	1.58E-02	1.26E-01	8.27E-02
30	31.8	74.6	46.5	1.96E+00	3.91E+00	2.71E+00	8.22E-02	3.53E-01	2.42E-01
31	33.7	51.0	40.6	2.05E+00	2.97E+00	2.47E+00	1.71E-01	2.65E-01	1.90E-01

Layer 2									
	Horizontal Hydraulic Conductivity (ft/day)			Vertical Hydraulic Conductivity (ft/day)			Storage Coefficient (-)		
Zone	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
2	5.2	22.5	19.8	4.84E-03	2.78E+00	2.54E+00	5.77E-05	7.62E-05	6.88E-05
3	19.9	49.2	25.4	5.68E-03	3.81E+00	3.15E+00	2.21E-08	1.07E-04	8.39E-05
4	19.0	47.9	26.6	2.33E+00	3.76E+00	3.20E+00	6.40E-05	1.06E-04	9.00E-05
5	2.2	6.1	4.9	4.14E-08	2.56E+00	1.13E-02	1.02E-08	6.62E-05	2.31E-07
6	3.2	9.6	4.0	3.05E-08	4.12E-03	8.39E-05	9.20E-09	1.40E-08	1.13E-08
7	4.6	11.9	5.5	4.08E-08	2.72E+00	4.20E-02	1.30E-08	7.00E-05	1.02E-06
8	2.6	47.3	34.3	3.74E-03	3.29E+00	2.95E-02	1.15E-08	8.71E-05	4.64E-07
9	4.4	52.0	45.2	5.87E-03	3.83E+00	3.44E+00	1.87E-08	1.03E-04	1.36E-06
10	3.3	43.2	32.9	1.02E+00	3.33E+00	2.76E+00	4.65E-07	8.33E-05	8.88E-07
12	1.9	4.3	2.8	3.08E-08	6.01E-03	4.23E-03	9.45E-09	6.57E-07	4.60E-07
13	2.1	13.7	9.0	2.92E-08	4.79E-03	1.03E-05	8.57E-09	4.61E-07	1.31E-08
14	4.1	15.1	12.7	4.44E-03	6.35E-03	5.60E-03	1.32E-08	2.04E-08	1.75E-08
15	2.9	5.3	4.0	4.94E-08	6.46E-03	5.27E-03	1.39E-08	7.96E-07	6.18E-07
16	2.6	13.3	3.7	4.15E-03	6.25E-03	5.03E-03	1.16E-08	1.99E-08	1.57E-08
17	2.8	11.1	3.8	3.80E-03	1.30E+00	9.59E-01	1.59E-08	7.83E-07	5.84E-07
18	2.8	10.9	4.0	4.72E-03	3.71E+00	1.09E+00	1.52E-08	9.47E-07	6.23E-07
19	8.9	13.5	11.4	8.73E-01	1.27E+00	1.06E+00	5.13E-07	8.68E-06	6.95E-06
20	10.9	13.7	12.1	9.28E-01	1.07E+00	9.96E-01	6.33E-06	5.14E-05	4.75E-05

Layer 3									
	Horizontal Hydraulic Conductivity (ft/day)			Vertical Hydraulic Conductivity (ft/day)			Storage Coefficient (-)		
Zone	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
1	1.5	28.9	15.3	1.70E+00	4.70E+00	3.23E+00	1.64E-05	1.33E-04	7.78E-05
2	2.4	29.6	18.7	1.23E+00	4.76E+00	3.36E+00	6.62E-06	1.35E-04	8.74E-05
3	1.6	19.9	10.8	6.30E-01	3.52E+00	2.29E+00	1.64E-05	9.13E-05	5.30E-05
4	5.9	33.1	22.1	5.72E-02	3.29E+00	2.29E+00	1.37E-05	1.09E-04	7.51E-05
5	1.7	37.2	23.0	1.06E+00	3.56E+00	2.56E+00	4.69E-06	1.27E-04	7.89E-05
6	3.4	24.9	10.1	2.92E-06	6.78E-02	5.97E-02	8.80E-07	1.98E-05	1.64E-05
7	6.1	27.6	9.1	4.87E-03	2.55E+00	5.80E-02	8.64E-07	8.52E-05	1.53E-05
8	2.4	10.3	3.3	2.38E-06	3.09E-06	2.71E-06	8.65E-07	1.21E-06	1.09E-06
9	2.2	11.3	9.0	2.33E-06	6.48E-03	5.30E-03	1.15E-05	2.03E-05	1.57E-05
10	1.1	9.3	3.2	1.04E-06	4.06E-06	2.59E-06	5.04E-07	1.97E-05	1.31E-06
11	2.0	29.7	7.9	3.84E-03	2.04E+00	7.53E-03	5.10E-06	2.58E-05	1.47E-05
12	2.0	30.9	18.6	2.02E-01	2.18E+00	1.55E+00	2.35E-06	1.89E-05	1.15E-05
13	2.0	20.2	13.9	6.71E-01	1.73E+00	1.54E+00	3.10E-06	1.24E-05	8.88E-06
14	4.5	17.3	9.5	1.90E-01	9.84E-01	4.22E-01	4.73E-06	5.42E-05	8.74E-06
15	7.8	15.3	13.8	5.59E-01	1.10E+00	8.37E-01	3.79E-05	6.15E-05	5.57E-05

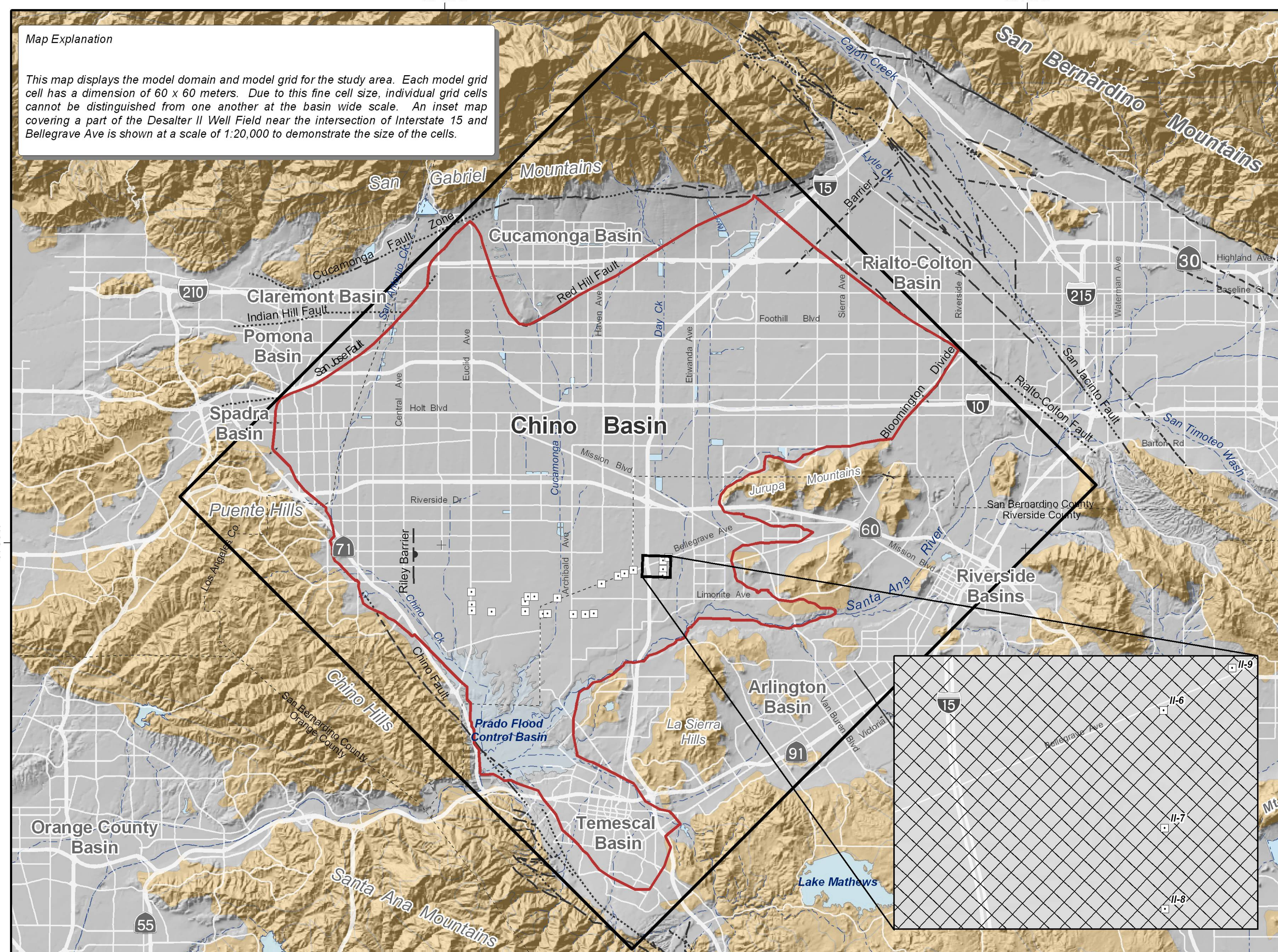
Table 5-2
Boundary Conditions

Geographic Name	Boundary Condition	MODFLOW Package Applied for Condition
Red Hill Fault	Constant Flux	FHB[1]
San Jose Fault	Constant Flux	FHB[1]
Groundwater divide (Chino Basin from the Spadra Basin)	No Flow	NA
Puente Hills/Chino Hills	Constant Flux	FHB[1]
La Sierra Hills	Constant Flux	FHB[1]
Riverside Narrows	Variable Flux	FHB[2]
Jurupa Mountains and Pedley Hills	Constant Flux	FHB[1]
Bloomington Divide	Variable Head	FHB[2]
Rialto-Colton Fault	Constant Flux	FHB[1]
Extension of the Rialto-Colton Fault north of Barrier J	Constant Flux	FHB[1]
Santa Ana Mountains	Variable Flux	FHB[2]
Arlington Narrows	Variable Flux	FHB[2]
Areal Recharge	Variable Flux	RCH[3]
Wells	Variable Flux	WEL[4]
Santa Ana River	Variable Flux	STR1[5]
Cucamonga Creek	Variable Flux	FHB[1]
Chino Creek	Variable Flux	FHB[1]
Day Creek	Variable Flux	FHB[1]
Artificial Recharge Basins	Variable Flux	FHB[1]
Stormwater Recharge	Variable Flux	FHB[1]
Evapotranspiration	Variable Flux	EVT[6]
Calculated Stream Recharge (calibration only)	Variable Flux	FHB[1]

1. FHB - Flow Head Boundary Package - constant flux
2. FHB - Flow Head Boundary Package - variable head for calibration period and constant flux for planning alternatives
3. RCH - Recharge Package
4. WEL - Well Package
5. STR1 - Stream Package
6. EVT - Evapotranspiration Package

Map Explanation

This map displays the model domain and model grid for the study area. Each model grid cell has a dimension of 60 x 60 meters. Due to this fine cell size, individual grid cells cannot be distinguished from one another at the basin wide scale. An inset map covering a part of the Desalter II Well Field near the intersection of Interstate 15 and Bellegrave Ave is shown at a scale of 1:20,000 to demonstrate the size of the cells.



Model Domain

MODFLOW Groundwater Flow Model Boundary (Active Model Domain)

Chino Desalter Well

Model Grid

Faults

Location Certain

Location Approximate

Location Concealed

Location Uncertain

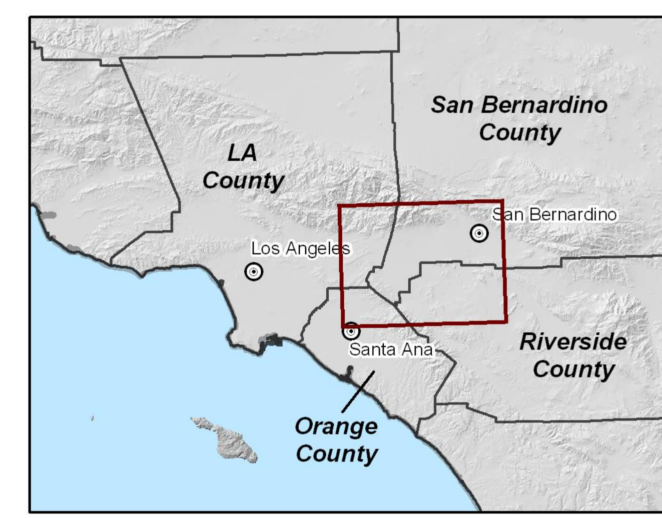
Approximate Location of Groundwater Barrier

Other Features

Groundwater Divides

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels



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0 1 2 3 4 5 Miles

0 2 4 6 8 KM

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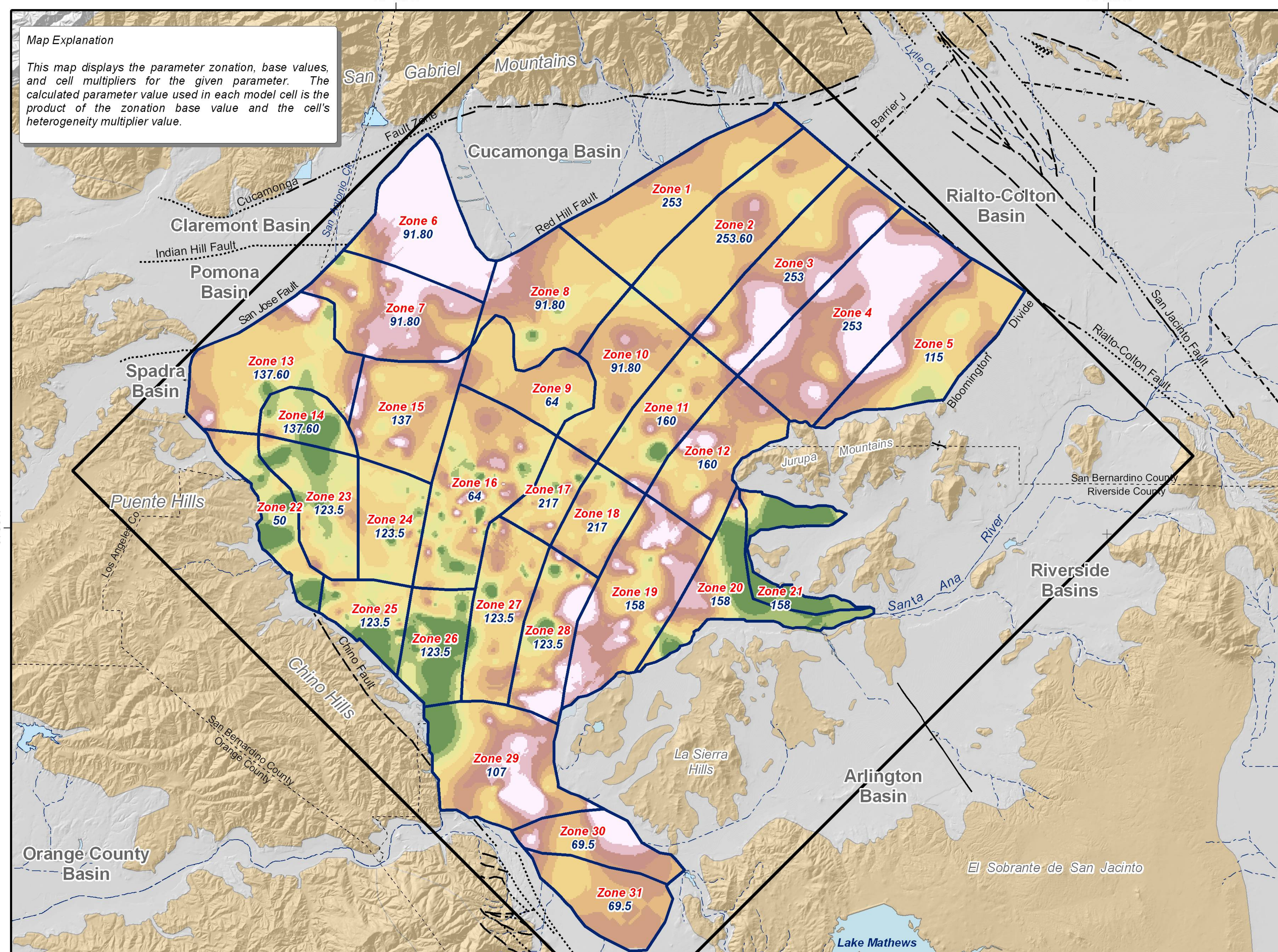
Model Construction

Map of Model Domain and Model Grid

Figure 5-1



Layer 1 Horizontal Hydraulic Conductivity Heterogeneity Multiplier

- 0 - 30%
- 30- 35%
- 35 - 40%
- 40 - 45%
- 45 - 55%
- 55 - 60%
- 60 - 65%
- 65 - 70%
- 70 - 75%
- > 75%

Zone 10 — Model Zone
50 — Zonation Base Value

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

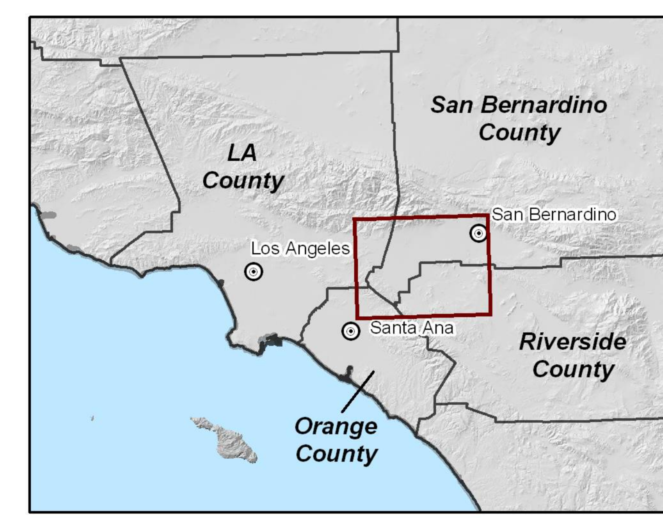
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Model Grid Boundary
- Groundwater Divides



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

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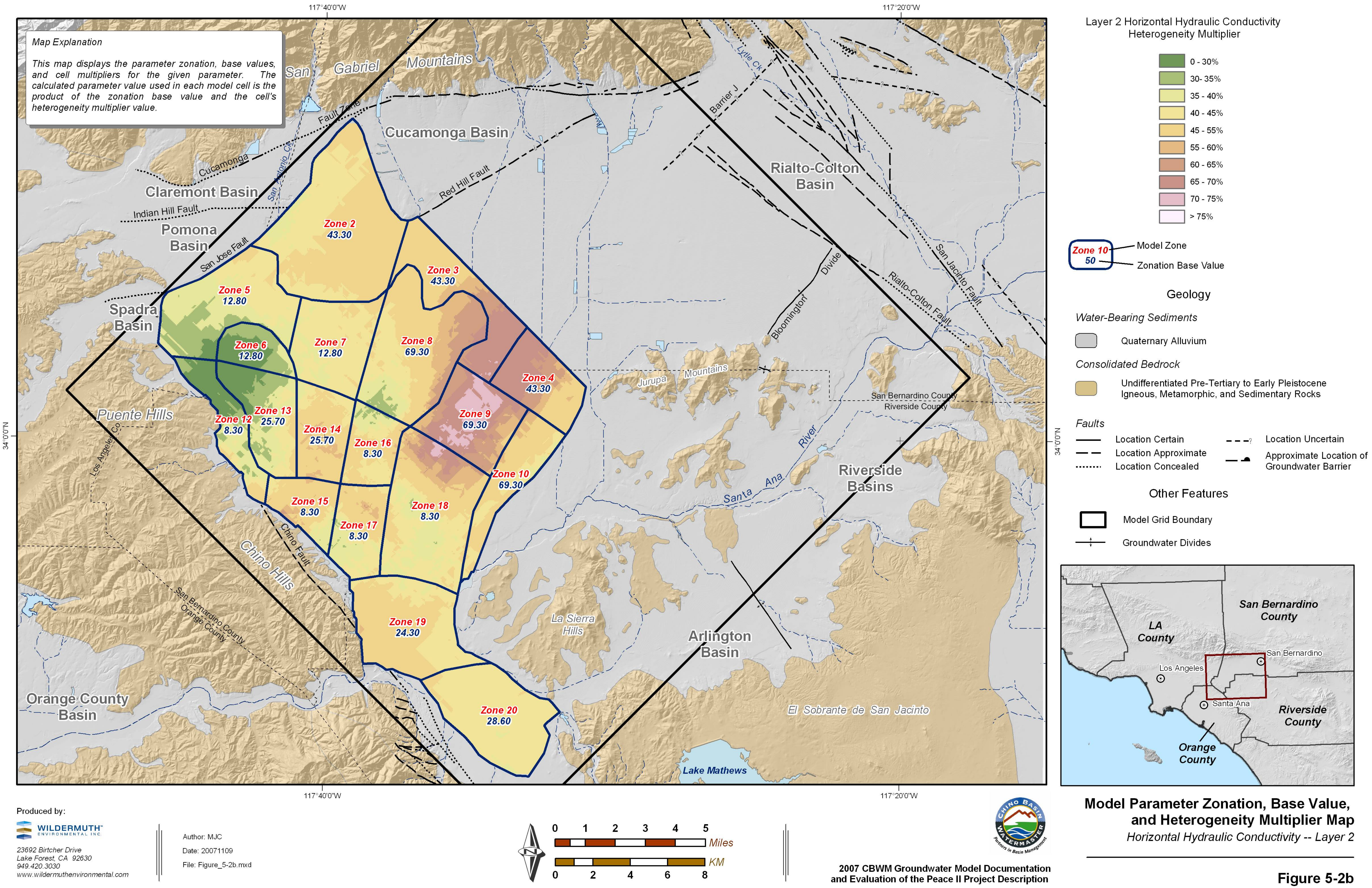
Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Horizontal Hydraulic Conductivity -- Layer 1

Figure 5-2a



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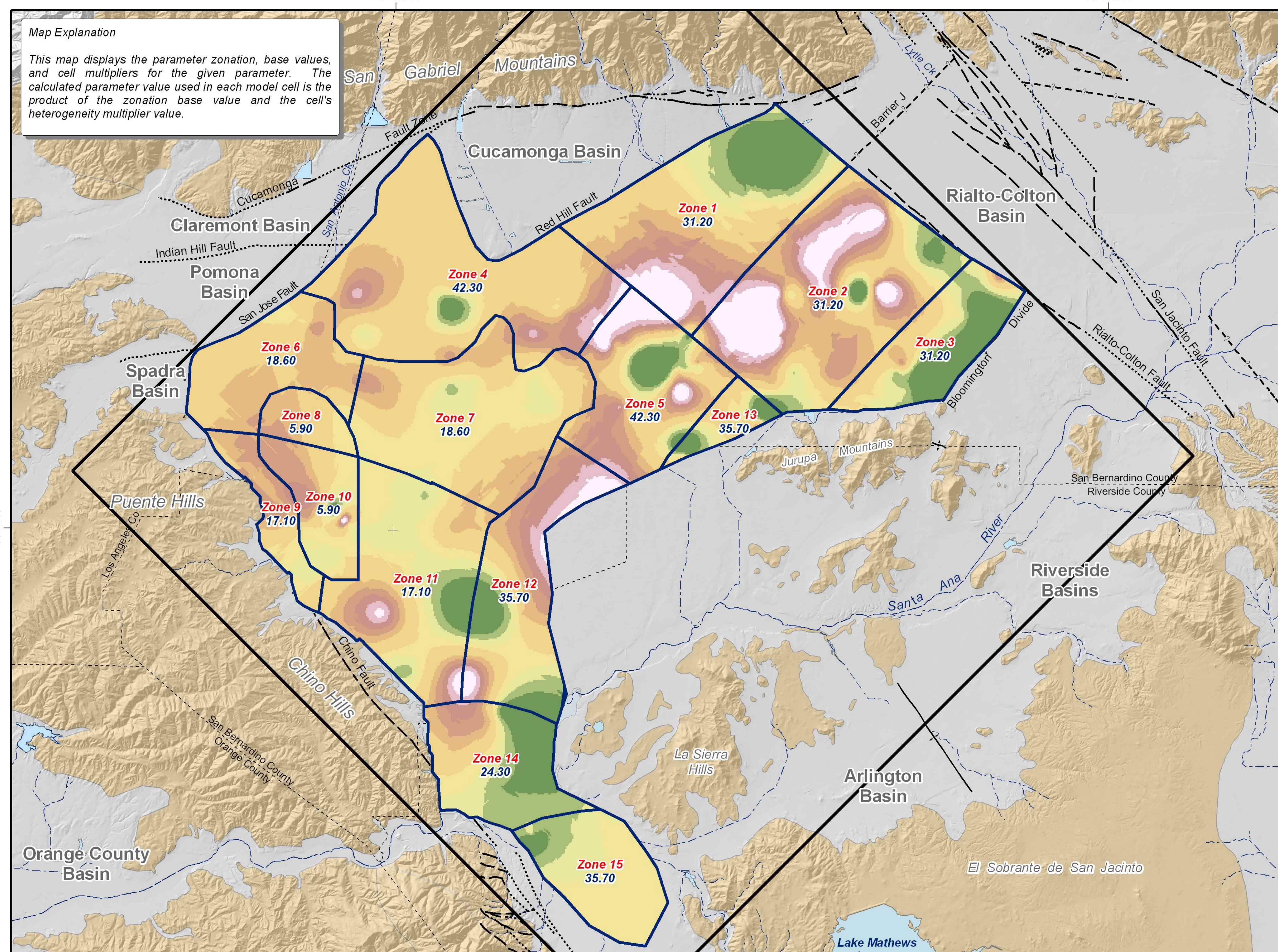
Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Horizontal Hydraulic Conductivity -- Layer 2

Figure 5-2b



Layer 3 Horizontal Hydraulic Conductivity Heterogeneity Multiplier

- 0 - 30%
- 30- 35%
- 35 - 40%
- 40 - 45%
- 45 - 55%
- 55 - 60%
- 60 - 65%
- 65 - 70%
- 70 - 75%
- > 75%

Zone 10 — Model Zone
50 — Zonation Base Value

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

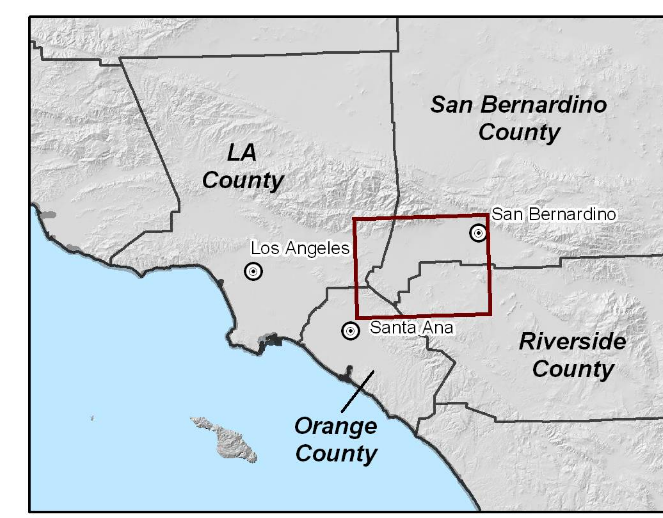
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Model Grid Boundary
- Groundwater Divides



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

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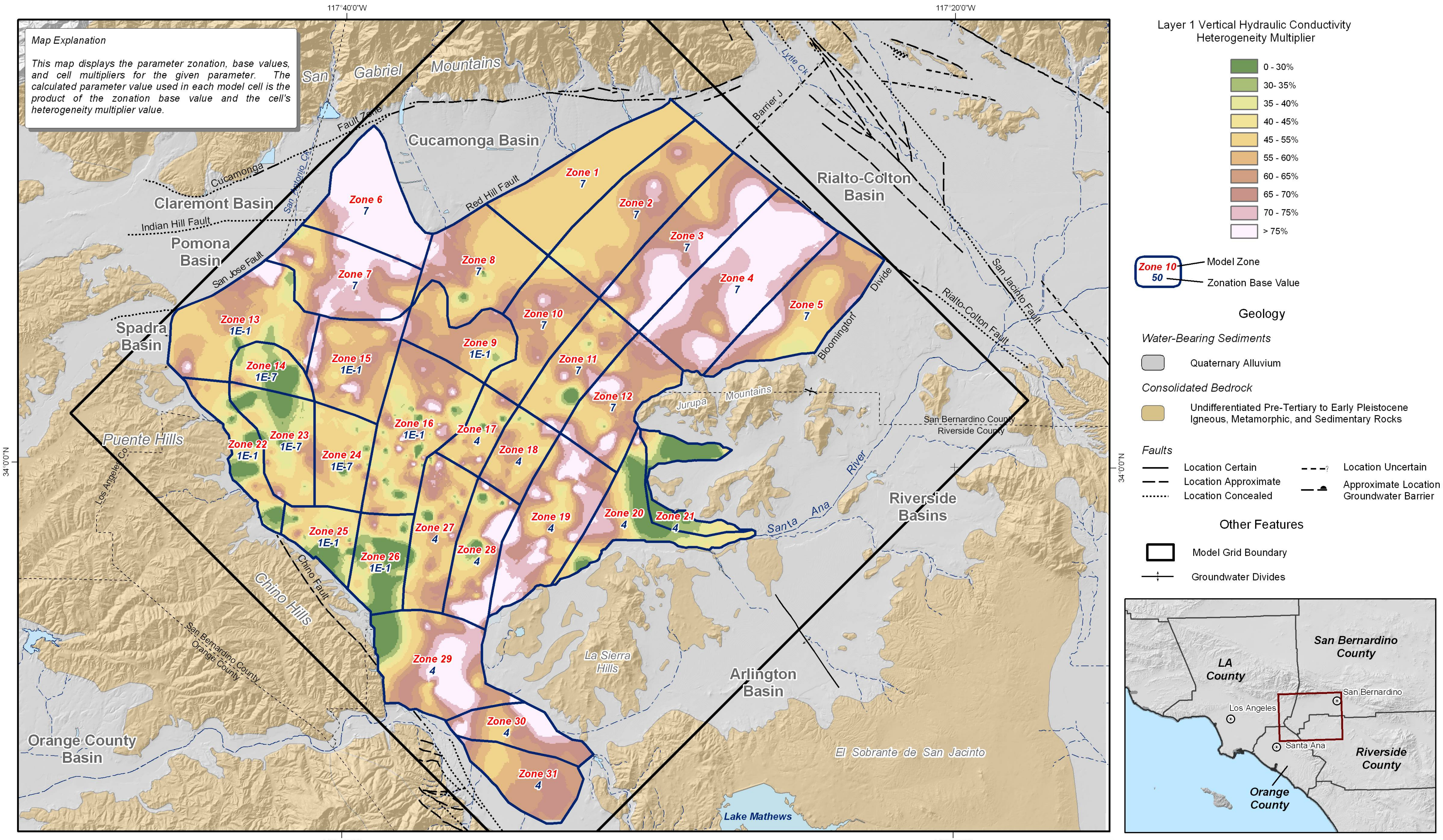
Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Horizontal Hydraulic Conductivity -- Layer 3

Figure 5-2c



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

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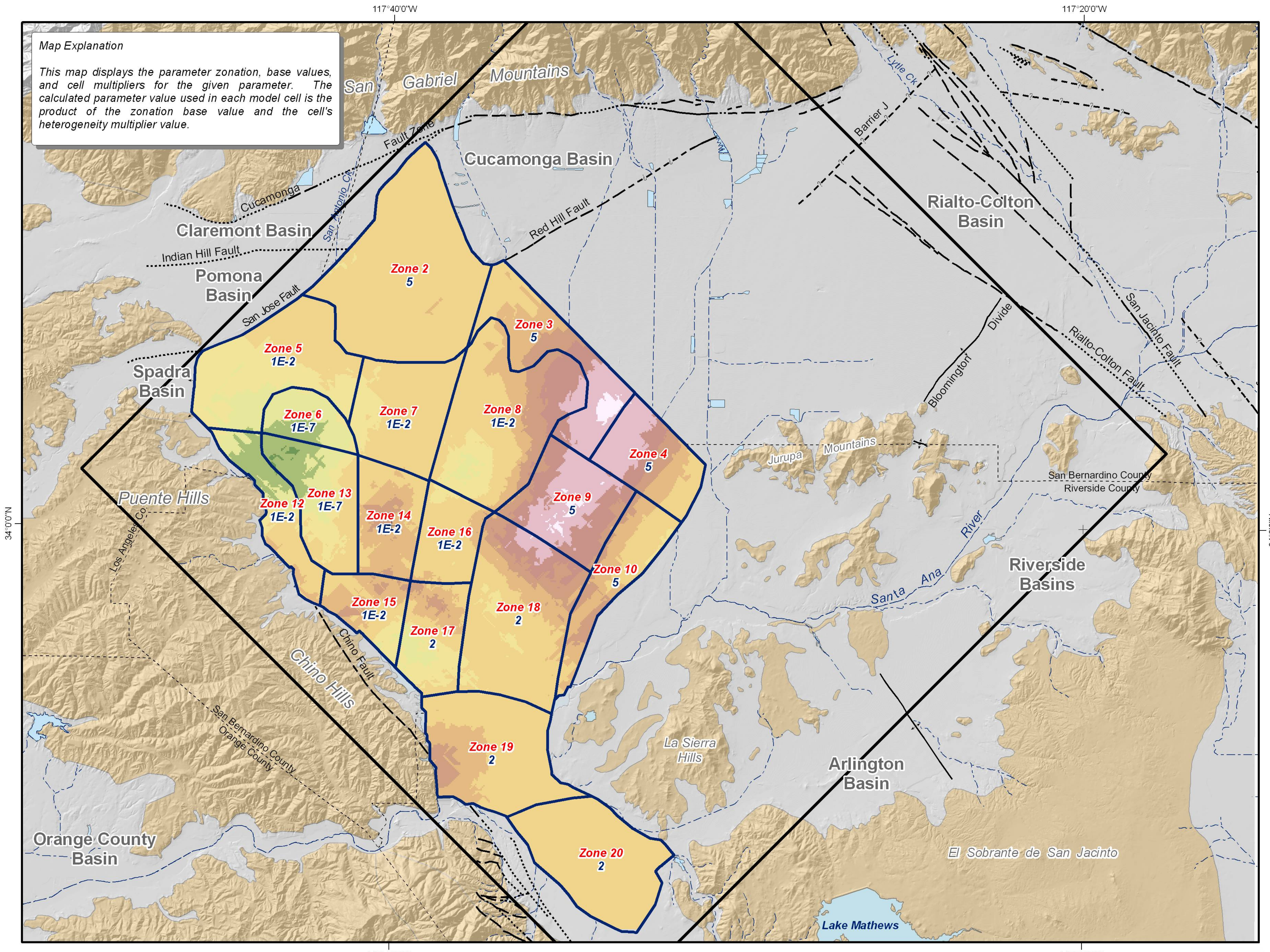
Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Vertical Hydraulic Conductivity -- Layer 1

Figure 5-2d



Layer 2 Vertical Hydraulic Conductivity Heterogeneity Multiplier

- 0 - 30%
- 30- 35%
- 35 - 40%
- 40 - 45%
- 45 - 55%
- 55 - 60%
- 60 - 65%
- 65 - 70%
- 70 - 75%
- > 75%

Zone 10 — Model Zone
5 — Zonation Base Value

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

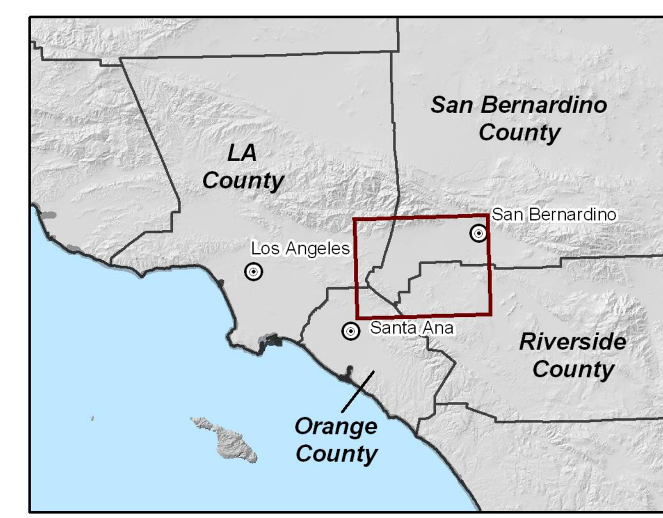
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Model Grid Boundary
- Groundwater Divides



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

CHINO BASIN WATERMASTER — Partners in Basin Management

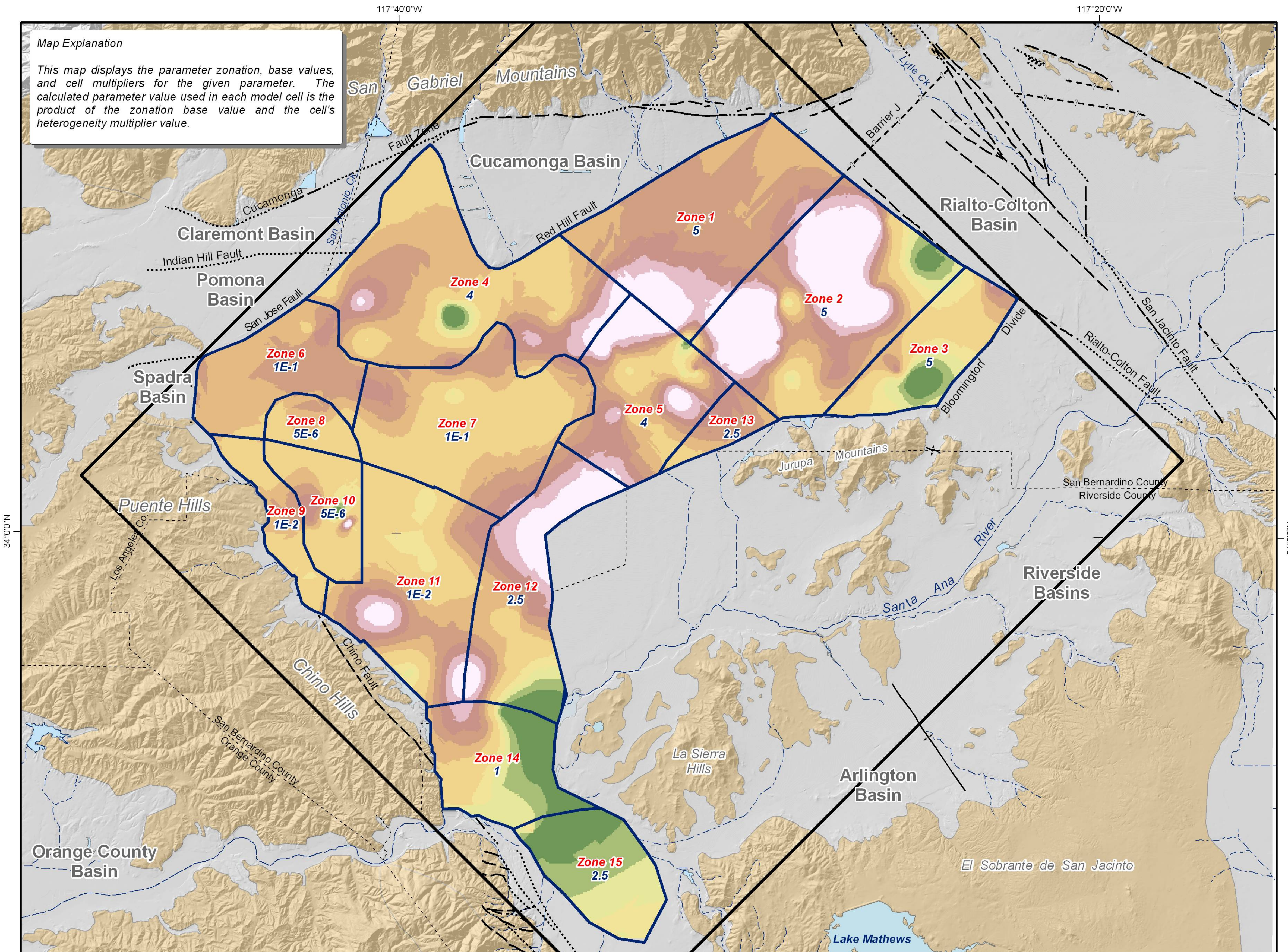
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Vertical Hydraulic Conductivity -- Layer 2

Figure 5-2e



Layer 3 Vertical Hydraulic Conductivity Heterogeneity Multiplier

- 0 - 30%
- 30- 35%
- 35 - 40%
- 40 - 45%
- 45 - 55%
- 55 - 60%
- 60 - 65%
- 65 - 70%
- 70 - 75%
- > 75%

Zone 10 — Model Zone
5 — Zonation Base Value

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

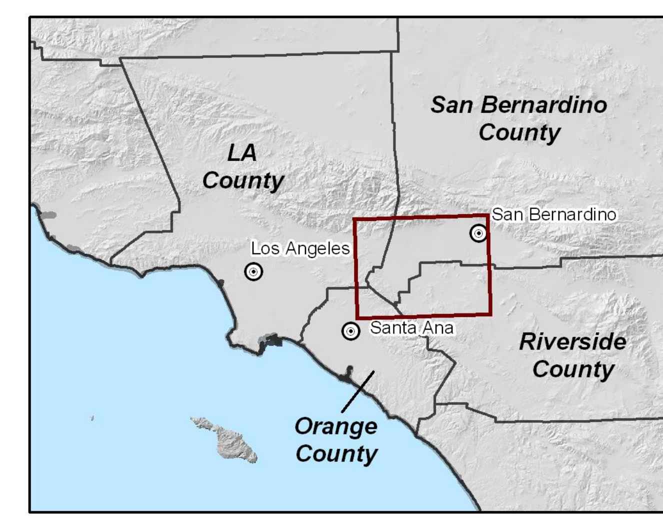
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Model Grid Boundary
- Groundwater Divides



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

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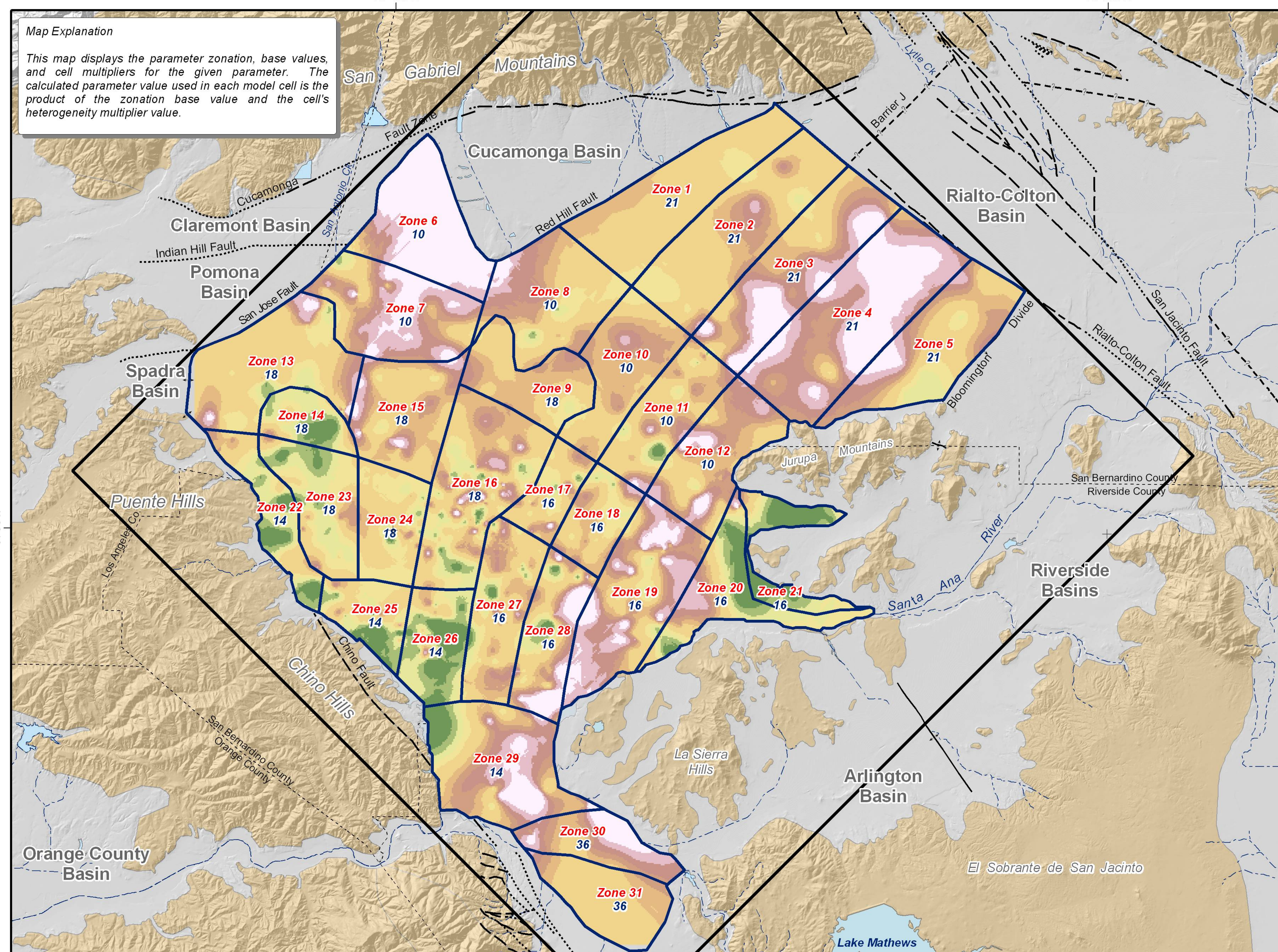
Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Vertical Hydraulic Conductivity -- Layer 3

Figure 5-2f



Layer 1 Specific Yield Heterogeneity Multiplier

- 0 - 30%
- 30- 35%
- 35 - 40%
- 40 - 45%
- 45 - 55%
- 55 - 60%
- 60 - 65%
- 65 - 70%
- 70 - 75%
- > 75%

Zone 10 50 — Model Zone; Zonation Base Value

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

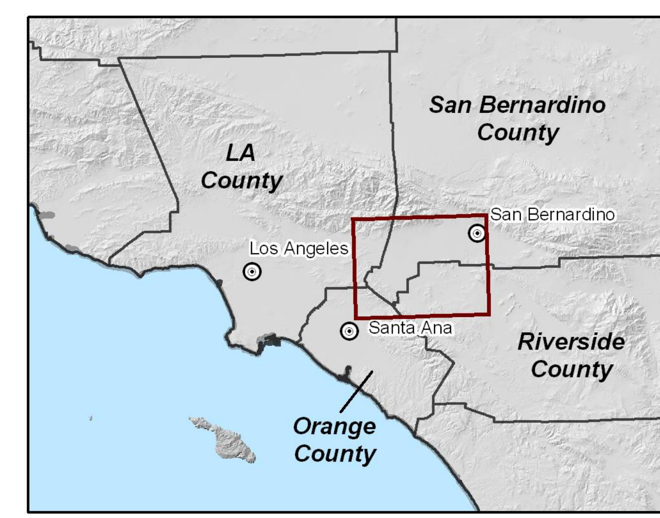
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Model Grid Boundary
- Groundwater Divides



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File: Figure_5-2g.mxd

0 1 2 3 4 5 Miles
0 2 4 6 8 KM

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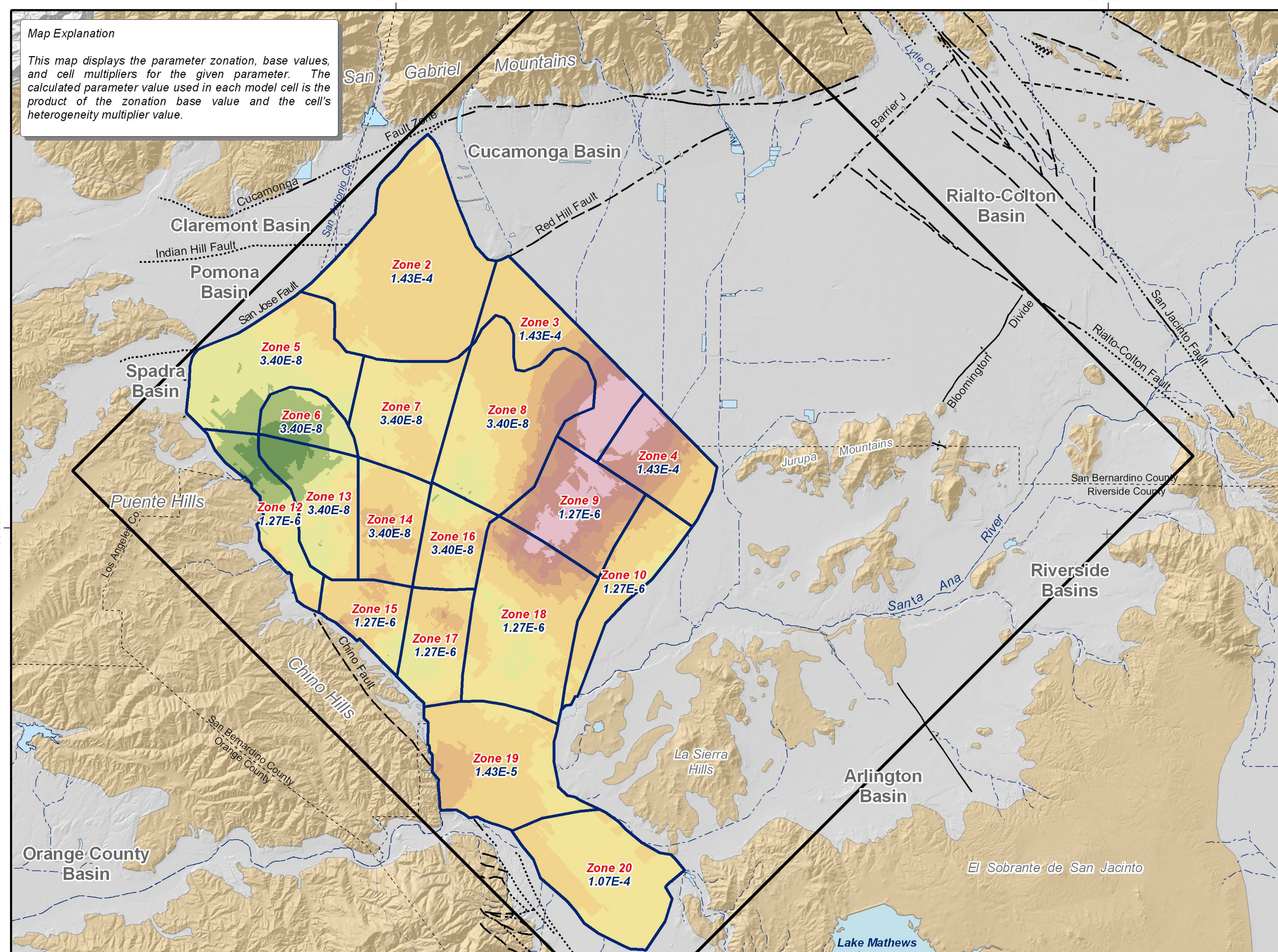
Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Specific Yield -- Layer 1

Figure 5-2g



Layer 2 Specific Storage Heterogeneity Multiplier

- 0 - 30%
- 30- 35%
- 35 - 40%
- 40 - 45%
- 45 - 55%
- 55 - 60%
- 60 - 65%
- 65 - 70%
- 70 - 75%
- > 75%

Zone 10 1.27E-6 — Model Zone; Zonation Base Value

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

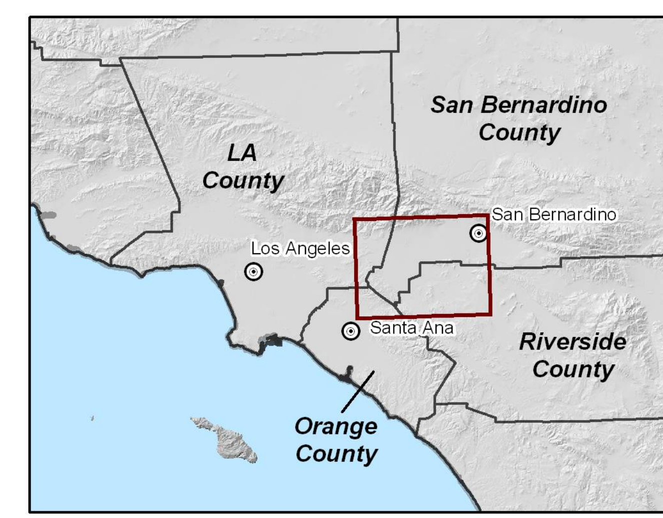
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

Location Certain
Location Approximate
Location Concealed
Location Uncertain
Approximate Location of Groundwater Barrier

Other Features

Model Grid Boundary
Groundwater Divides



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

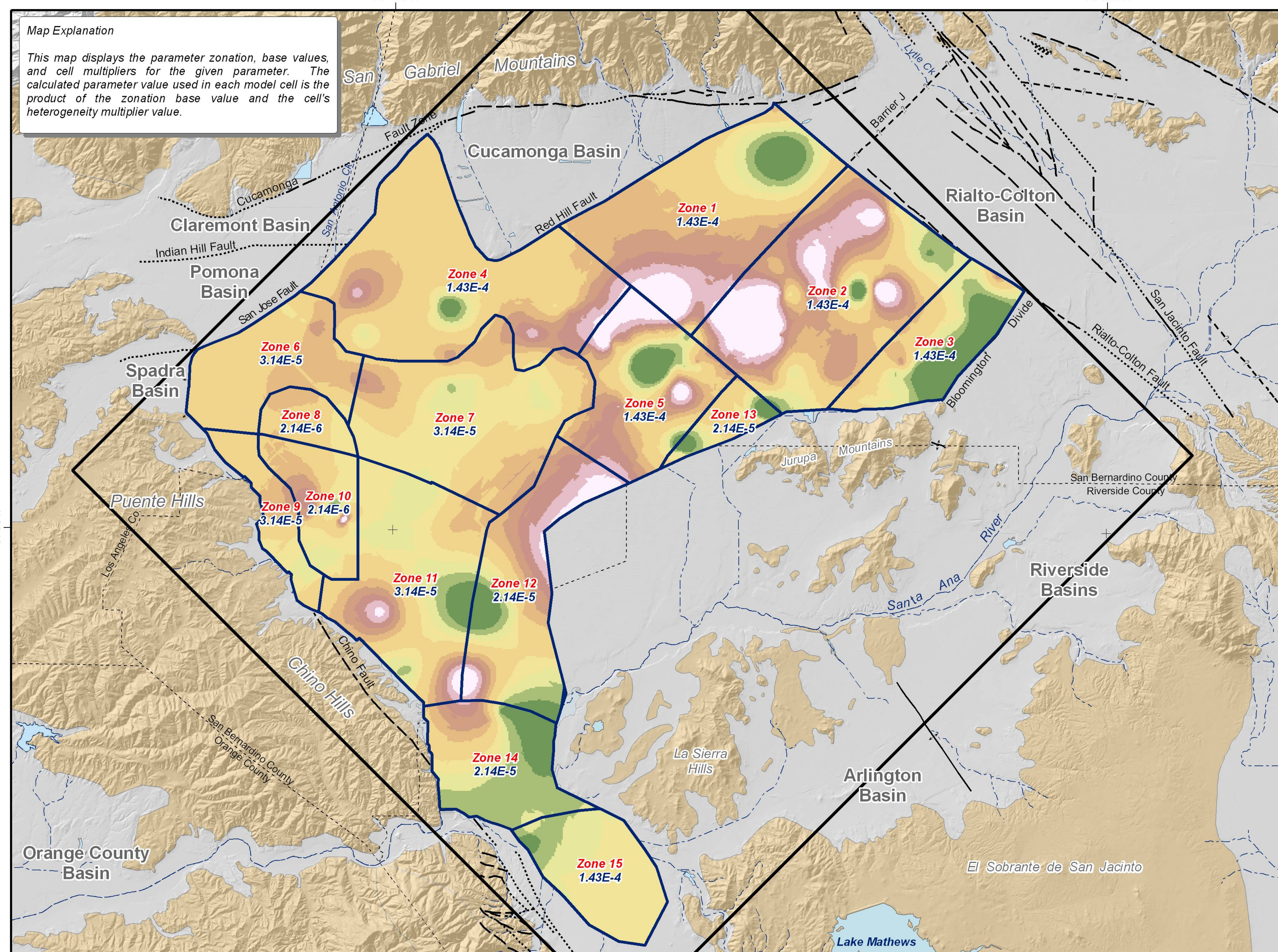
Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Specific Storage -- Layer 2

Figure 5-2h

117°40'0"W 117°20'0"W



117°40'0"W 117°20'0"W

Layer 3 Specific Storage Heterogeneity Multiplier

- 0 - 30%
- 30- 35%
- 35 - 40%
- 40 - 45%
- 45 - 55%
- 55 - 60%
- 60 - 65%
- 65 - 70%
- 70 - 75%
- > 75%

Zone 10 — Model Zone
1.27E-6 — Zonation Base Value

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

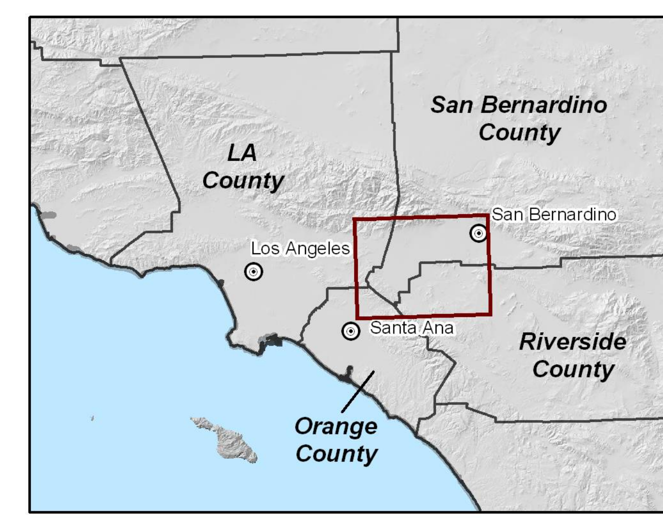
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Model Grid Boundary
- Groundwater Divides



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

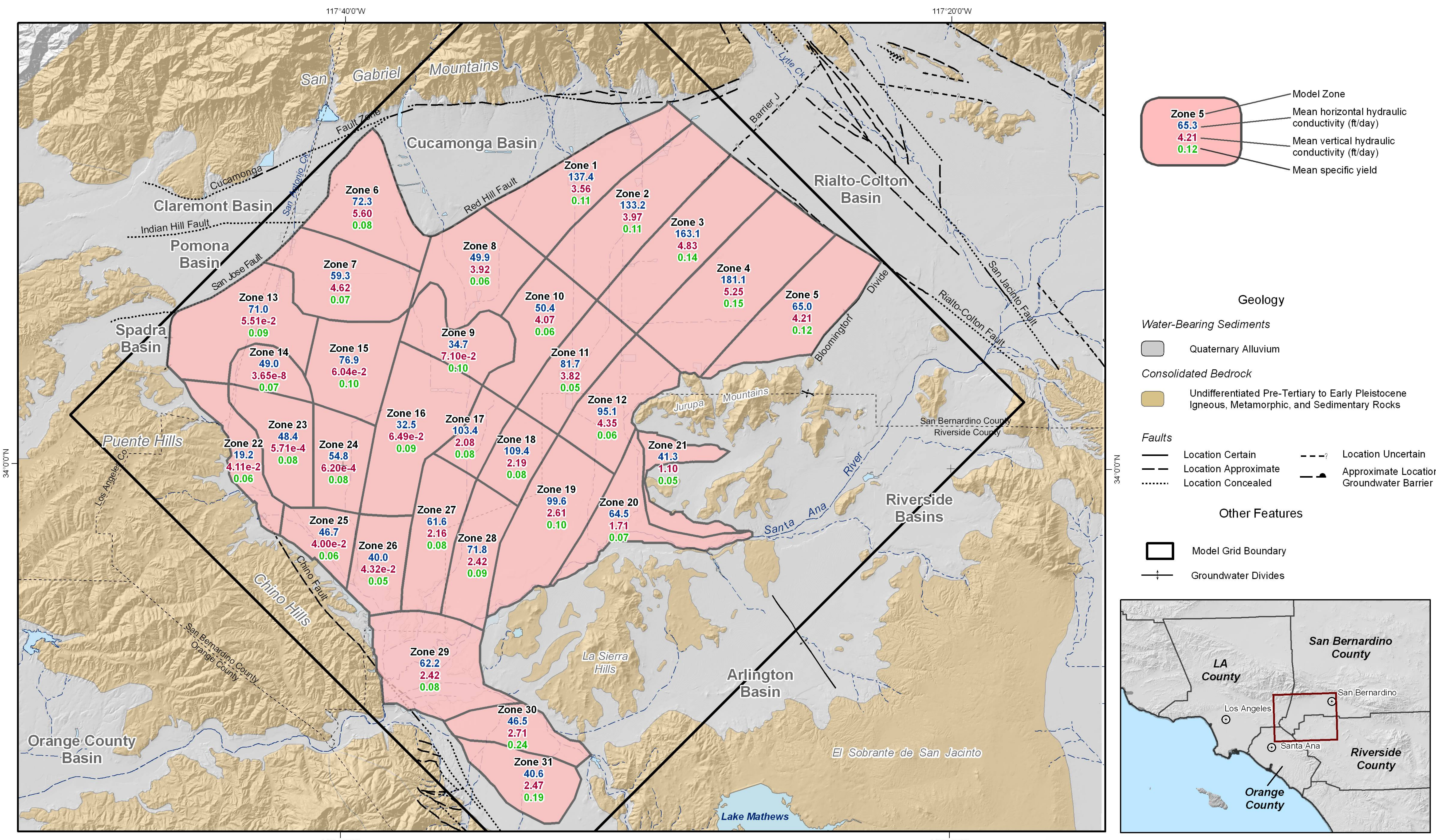
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Model Construction

Model Parameter Zonation, Base Value, and Heterogeneity Multiplier Map

Specific Storage -- Layer 3

Figure 5-2i



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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

CHINO BASIN WATERMASTER — Partners in Basin Management

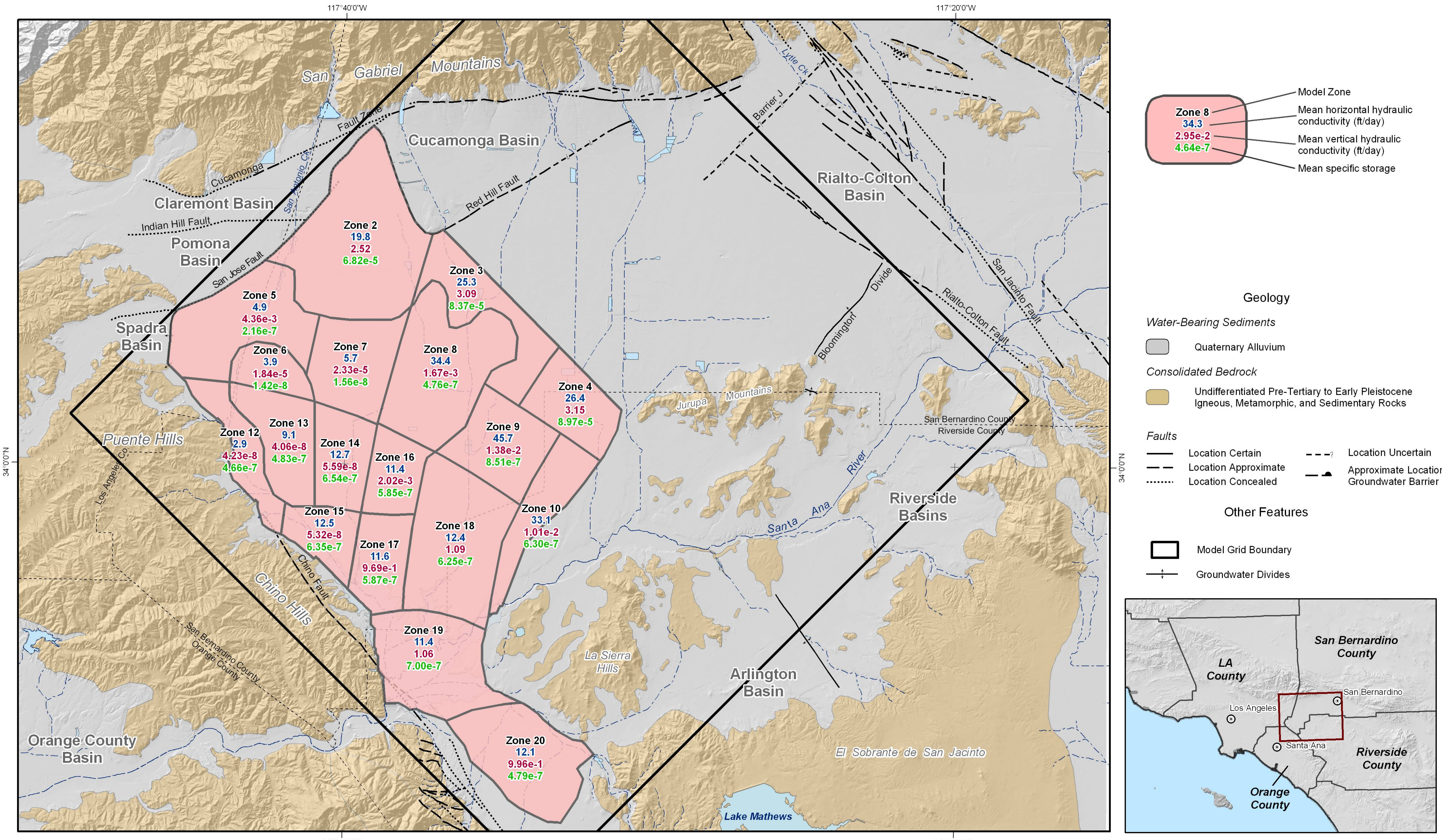
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Model Construction

Mean Aquifer Parameter Values

Layer 1

Figure 5-3



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File: Figure_5-4a.mxd

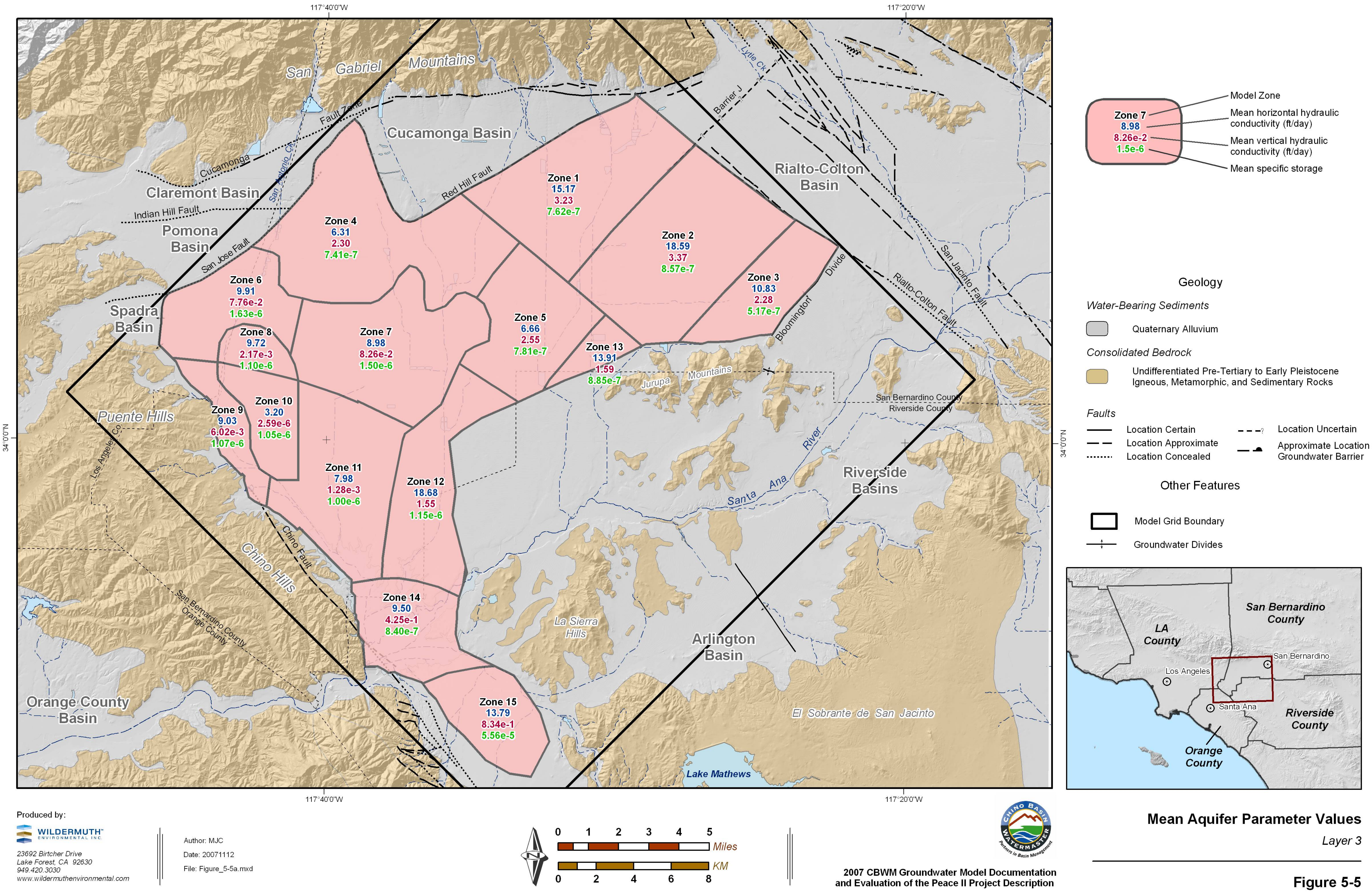
0 1 2 3 4 5 Miles
0 2 4 6 8 KM

CHINO BASIN WATERMASTER
Partners in Basin Management

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Model Construction

Mean Aquifer Parameter Values
Layer 2

Figure 5-4



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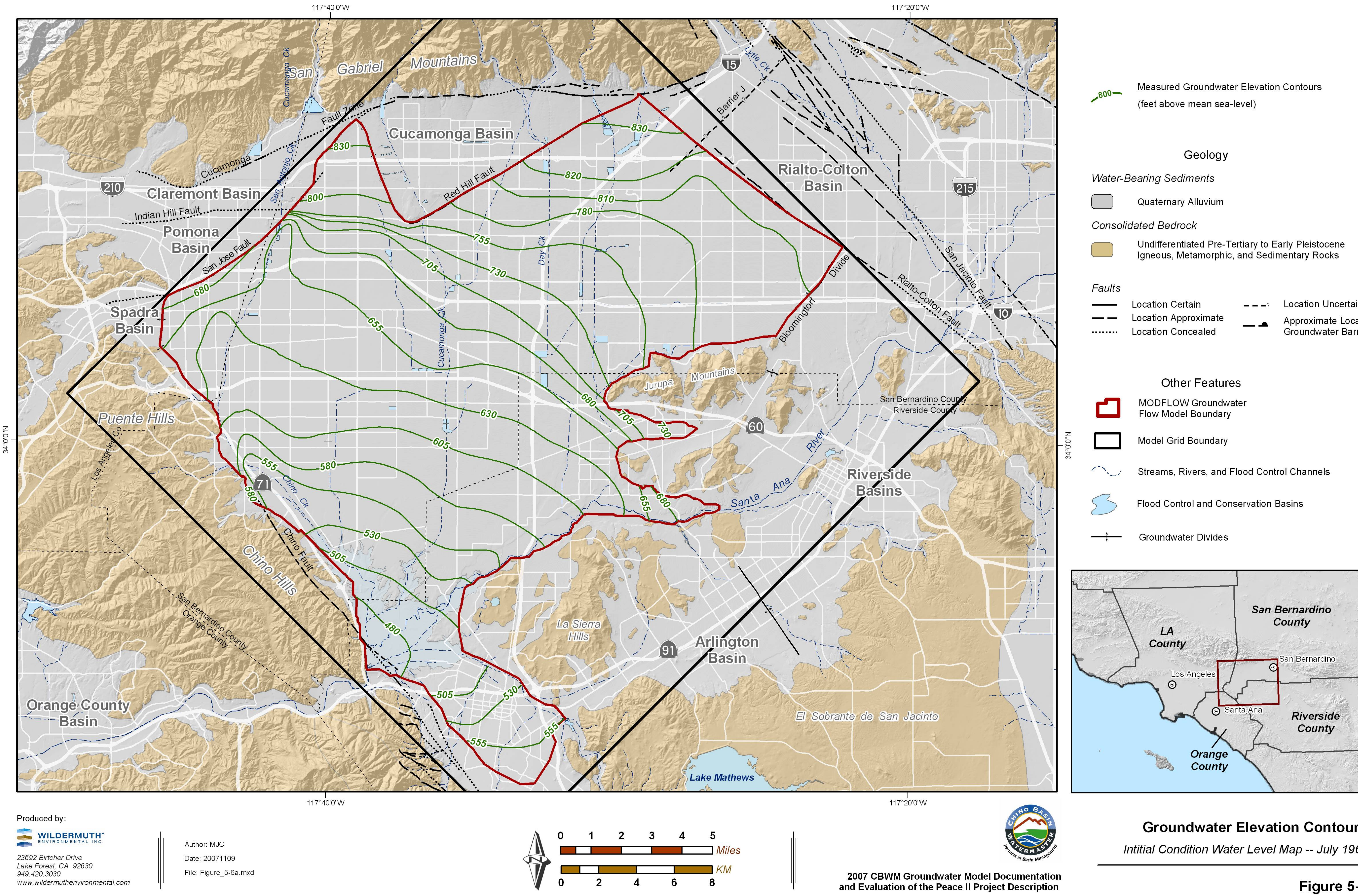
Model Construction

Mean Aquifer Parameter Values
Layer 3

Figure 5-5



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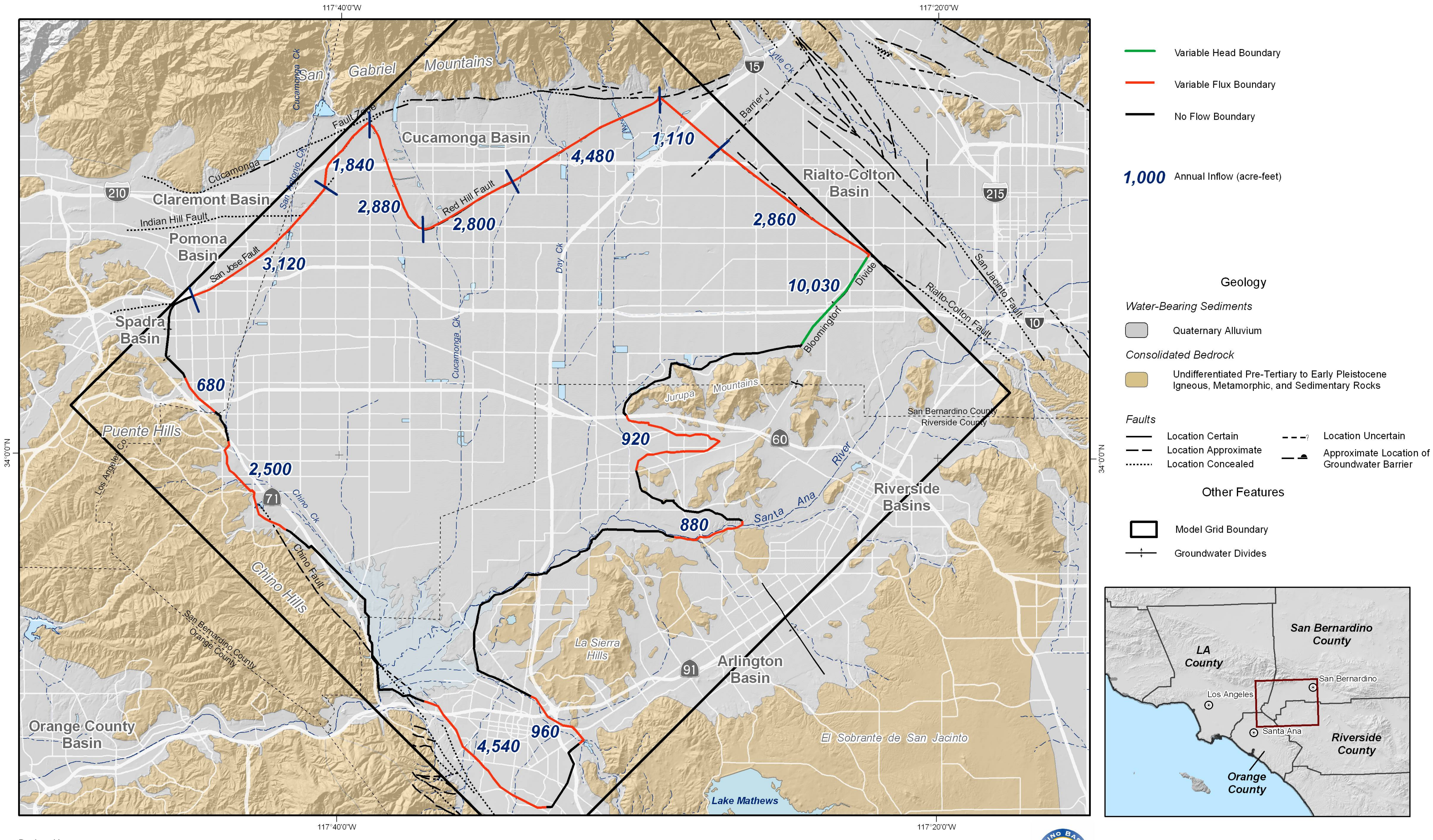
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Model Construction

Groundwater Elevation Contours

Intitial Condition Water Level Map -- July 1960

Figure 5-6



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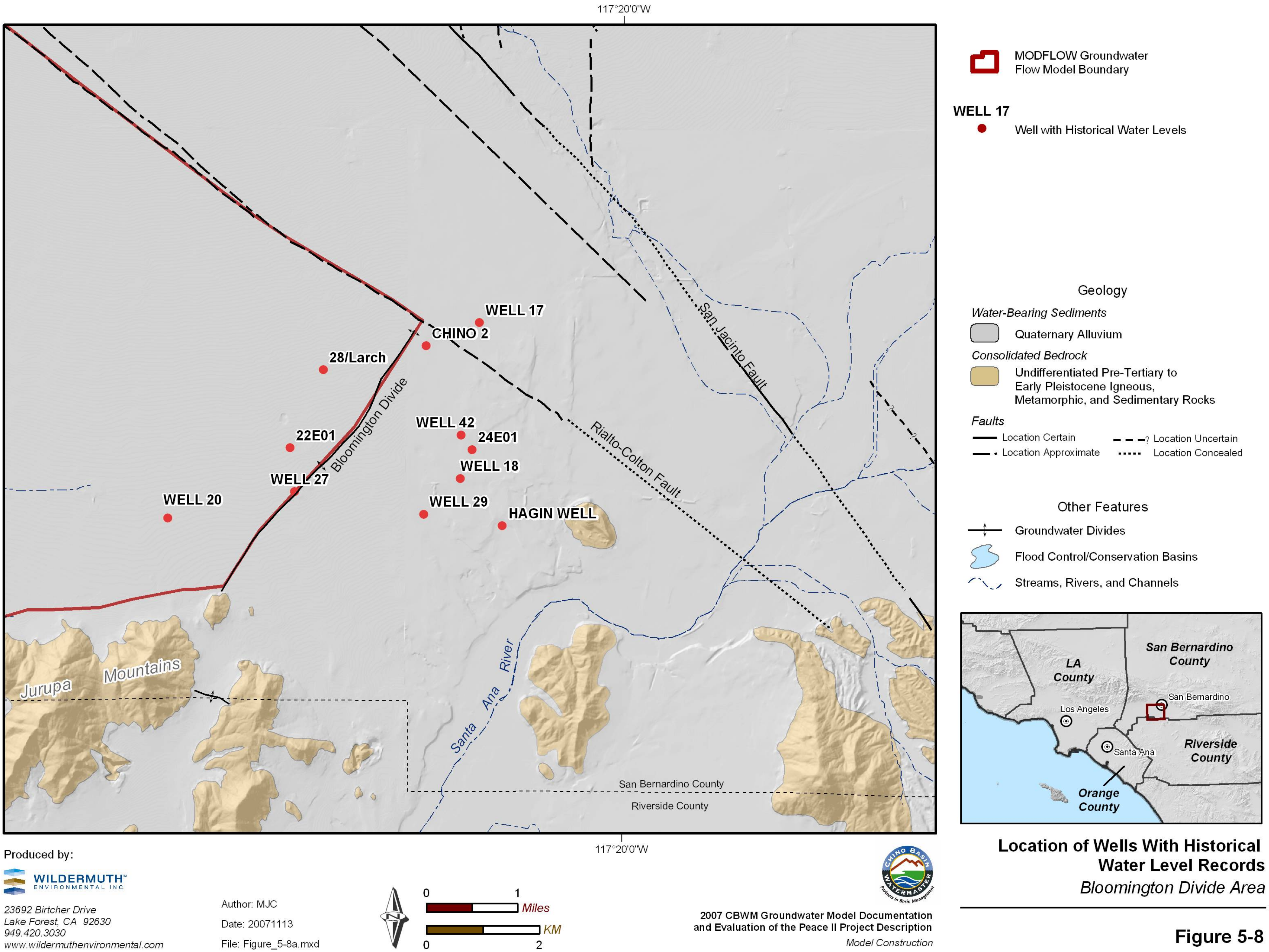
Model Construction

Groundwater Model Boundary Conditions

Figure 5-7



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Model Construction

Location of Wells With Historical Water Level Records
Bloomington Divide Area

Figure 5-8

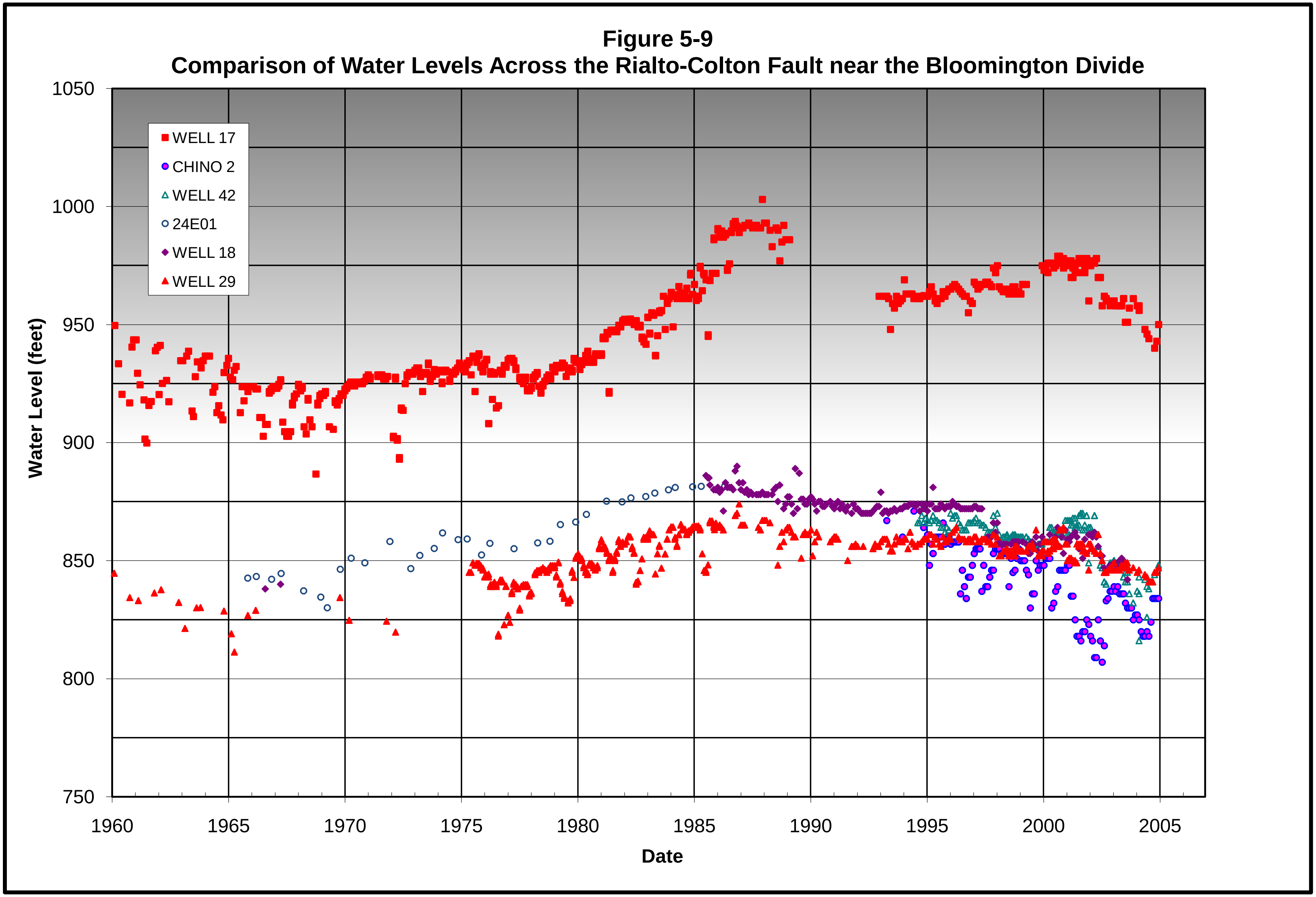

Figure 5-9 and 5-10.xls

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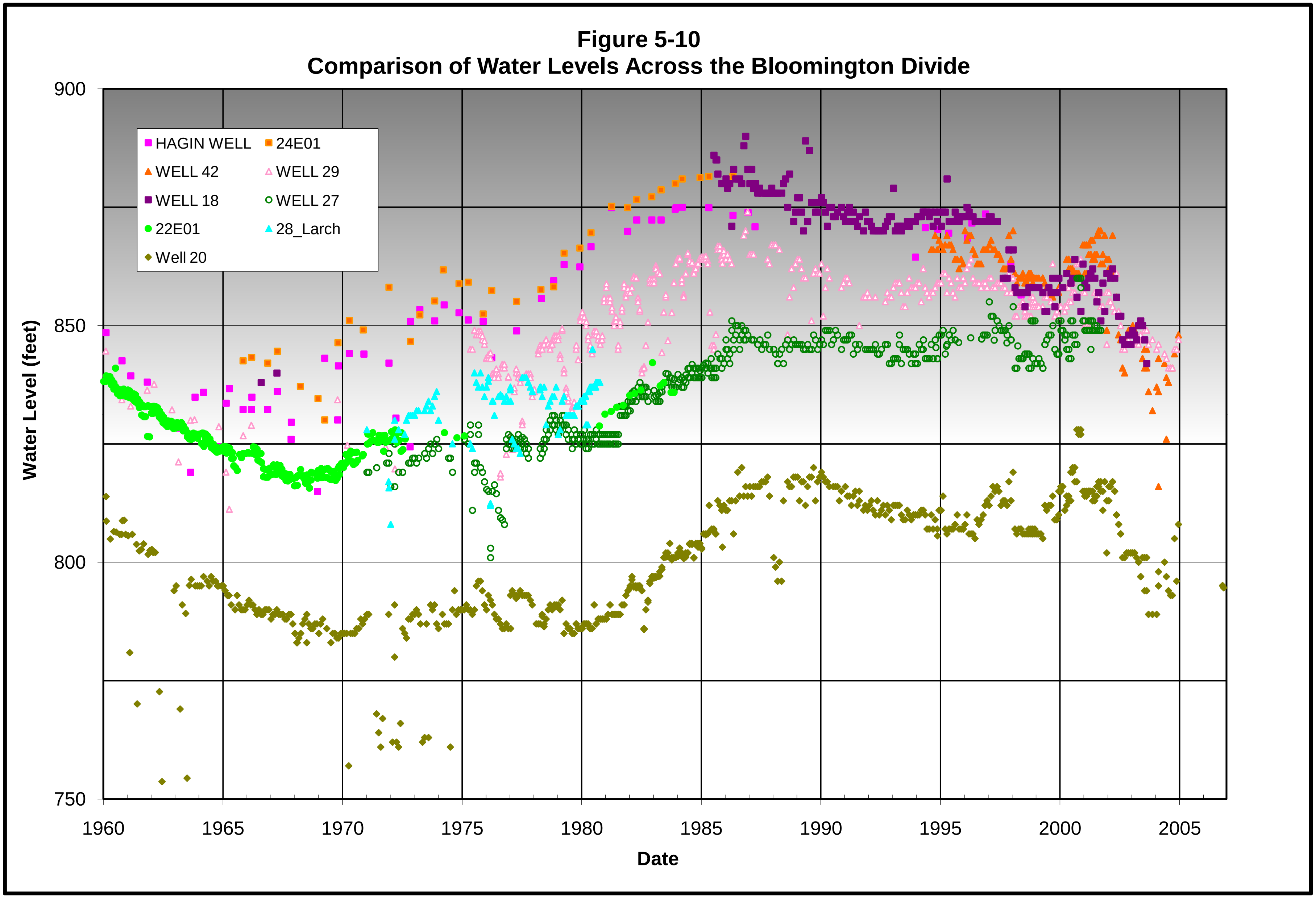

Figure 5-9 and 5-10.xls

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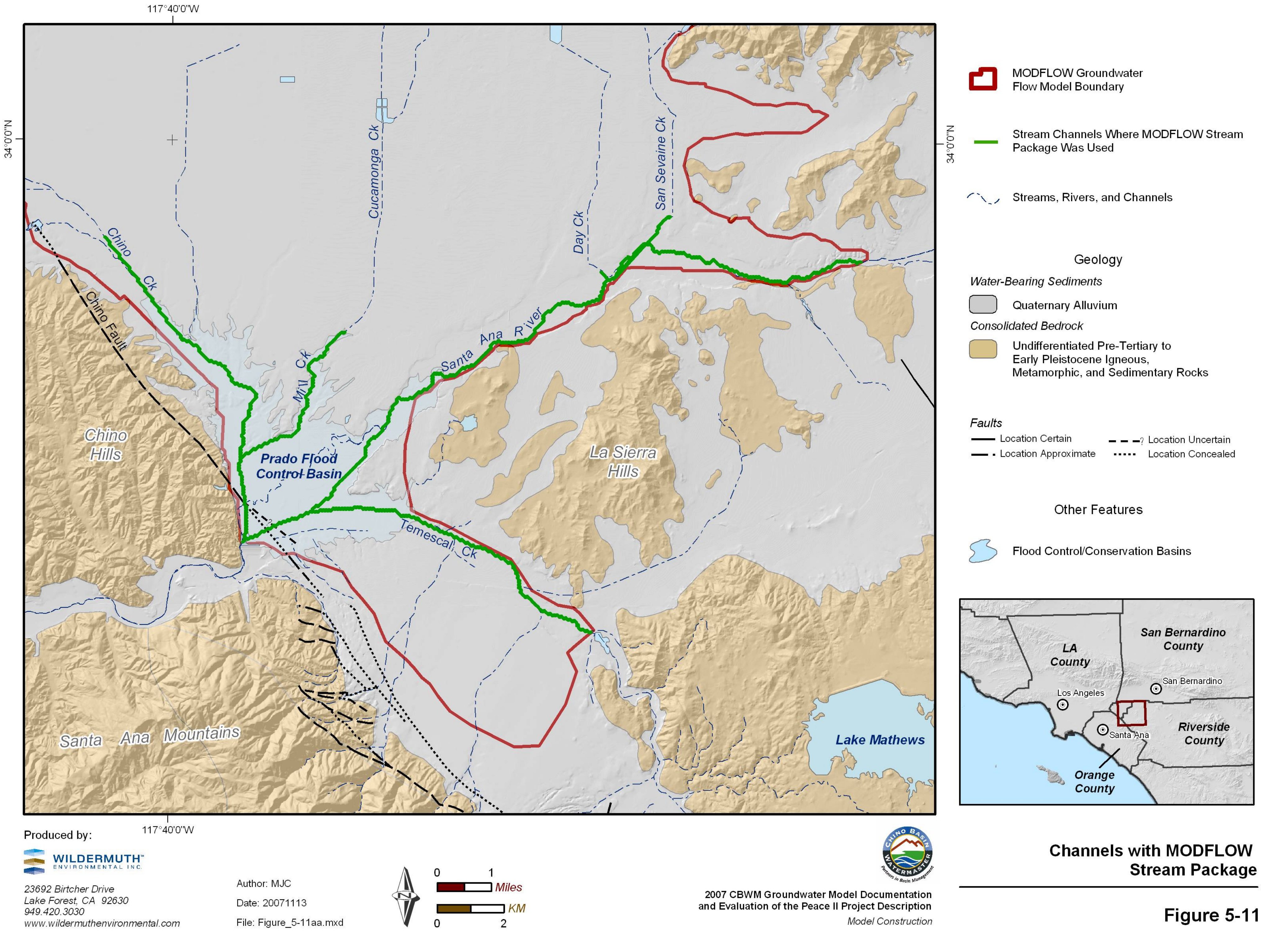

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2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Model Construction

Channels with MODFLOW Stream Package

Figure 5-11

The purpose of model calibration is to estimate the best set of hydraulic and storage parameters for a numerical groundwater flow model. Calibration is the process of adjusting the model parameters to produce the best match between simulated and observed groundwater system responses, such as water levels at wells. In the process of calibration, model parameters are adjusted (subject to reasonable bounds) with manual methods or automatic parameter estimation techniques to match observed water levels at wells. Automatic parameter estimation is also termed inverse modeling. Numerical inverse methods are widely used in hydrology and are discussed in numerous scientific publications and books. Milestone papers include those of Neuman (1973), Yeh (1986), and Carrera and Neuman (1986a, b, and c). Inverse modeling was utilized for the calibration of the 2007 Chino Basin groundwater flow model.

Both MODFLOW-2000 (Harbaugh et al, 2000) and PEST (Doherty, 2004) provide a means to automate parameter estimation and further evaluate a model. PEST was selected due to its robust calibration capabilities. This section describes the procedure for calibrating the 2007 Chino Basin groundwater flow model; defines the objective function, minimization algorithm, and sensitivity analysis; and discusses the selection of calibration data, residual analysis, and model validation.

6.1 Model Calibration Procedure

The parameter estimation program PEST Version 10 (Doherty, 2004) was used to calibrate the Chino Basin groundwater flow model. The major steps in the model calibration process include:

1. Numerical Formulation of Developed Conceptual Model: Calibration starts with the development of model conceptualization and mathematical-numerical description of relevant physical processes. First, a developed conceptual model is converted to a numerical model. The numerical conversion includes the definition of the model aquifer geometry, the assignment of the initial and boundary conditions, discretization in space and time, and the selection of hydraulic parameter zonation and heterogeneity. Next, forward modeling is conducted to check the water balance and possible errors caused in the process of conversion. Last, modeling results are checked to see whether the developed numerical model is capable of simulating the groundwater system's behavior under specifically measured conditions. All of the model parameters, including the model input that can be parameterized, are then fixed at their best estimates. Forward modeling is solved by the MODFLOW-2000 groundwater model.

2. Sensitivity Analysis: The next step is to determine which model parameters should be calibrated. The model parameters include the hydraulic properties of the aquifer, boundary conditions, as well as any other aspect of the model that can be parameterized. It is unnecessary to adjust all of the model parameters in the calibration process, and not all of the selected parameters should be subjected to each iterative optimization process. In general, reducing the number of estimated parameters can significantly simplify inverse modeling, but this comes at a cost; that is, it might sacrifice the model's reliability. The selection criterion for deciding which parameters should be subjected to inverse modeling should not be subjective. It should depend on the importance of the parameters, which can be measured by parameter sensitivity. The model parameters with high sensitivity coefficients should be determined as accurately as possible. For this reason, a sensitivity analysis is conducted to examine the importance of model parameters before inverse modeling commences. Because parameter sensitivities vary in each iterative optimization process, sensitivity analyses should be conducted in all steps of the calibration processes.

3. Selection of Calibration Data: These data points are a key element to the success or failure of model development. Information about the model parameters is drawn from measurements of the groundwater system. Model output and measured data are compared only at discrete points in space and time—the calibration data points. The differences between the measured and the computed system responses at the calibration points are termed residual vectors. Calibration is the process of minimizing the sum of the squared weighted residuals by updating the model parameters.

4. Forward Modeling: A MODFLOW-2000 simulation is performed with current parameter values to obtain the simulated water levels that correspond to measured water levels in terms of location, time, and scale.

5. Parameter Estimation: The calculated and measured system responses (water levels) are compared using the sum of the squared weighted residuals, which is also known as the objective function. PEST uses the Marquardt-Levenberg method to minimize the objective function. Details of this method are given in the PEST user's manual (Doherty, 2004). The purpose of the minimization algorithm is to find the minimum of the objective function by iteratively updating the model parameters. There are a number of strategies for updating model parameters, as discussed in the papers of Neuman (1973, 1986a, 1986b, 1986c), Finsterle and Najita (1998), and Sun and Yeh (1990). The value of the objective function decreases iteratively with the progress of calibration. The simulation is repeated (Step 4) with updated parameters, using the minimization algorithm.

6. Analysis of Residuals: If the measured data are not properly reproduced by the model (*i.e.* if the final residuals are large or exhibit system errors), the resulting parameters are likely to be inadequate or highly biased. Another possibility is that inconsistencies and/or errors exist in a developed conceptual model. And, a good match does not imply that all of the estimates are reasonable.

6.2 Sensitivity Analysis

Parameter sensitivity measures the impact of a small parameter change on the calculated system response. If a small hydraulic parameter change results in a large change in the simulated water levels of the model domain, the parameter is regarded as highly sensitive. PEST calculates sensitivities for values of hydraulic head throughout the model using the Jacobian matrix. Because certain parameter values, such as storage coefficients and hydraulic conductivity, differ greatly in orders of magnitude and are therefore incomparable for parameter sensitivities, PEST scales the elements of the Jacobian matrix by the magnitude of the parameter value to make parameter sensitivities comparable with one another. This feature allows for measuring the sensitivity of a calibration point and for measuring the importance of the parameters.

Table 6-1 lists the model parameter sensitivities, relative sensitivities, and sensitivity rankings. This table demonstrates that the horizontal hydraulic conductivities of zones 1, 2, 3, and 4 are very sensitive and important while the horizontal barrier and specific storage of zone 19 are the least important. These results were used to determine which parameters were to be estimated with PEST and which were not. This process allows for the most efficient use of computer processing time. These results can also be used to determine future data collection sites, areas with high uncertainty, and/or tests in order to refine the model.

6.3 Selection of Calibration Data

The transient calibration period is July 1, 1960 through June 30, 2006, or fiscal year 1960/61 though fiscal year 2005/06. This period was chosen based primarily on the availability of continuous groundwater level records.

The 2007 model was calibrated using water-level measurements and validated with historic surface water flows. Based on the following principles, water-level measurements were selected from all of the recorded water levels of the selected wells in the basin:

1) Measurement locations with time-series data should have sufficient sensitivities.
2) Calibration wells should be evenly distributed horizontally in the basin if possible.
3) Calibration wells should be evenly distributed vertically in model layers if possible.
4) Measurements should be relatively evenly distributed over time if possible.

A total of over 2,436 water-level measurements from 47 different wells were used in the model calibration. Figure 6-1 shows the location of the selected calibration wells in the Chino Basin. Table 6-2 lists the owners, local names, and screen positions of these wells. For the calibration wells that span multiple layers, a weight was assigned to the water levels of each layer to derive a final value for comparison to the observed data. The weights were assigned to the layers based on the thickness of the aquifer and initial estimated hydraulic conductivity.

6.4 PEST Settings and Calibration Results

All of the efforts taken within a calibration process are ultimately evaluated on the success or failure of meeting three conditions: (1) the groundwater system processes and geometry are adequately represented and simulated, (2) weighted true errors are independent, and (3) errors in the observation data used for calibration are independent (Hill and Tiedeman 2007). As to condition 3, it was assumed that the water level measurements were taken by numerous personnel, representing numerous agencies, and that these measurements would therefore have random errors. It was also assumed that there are no natural processes that might make these observations biased. In this report, only conditions 1 and 2 are addressed.

6.4.1 PEST Settings

PEST was used to calibrate the model parameters. The forward simulation of the flow model for the calibration period requires 45 to 55 minutes of computational time. Since the model output, as it corresponds to the calibration points, depends on the estimation of parameters and the fit can be improved by appropriately changing model parameters, a number of strategies were used to find a parameter set that iteratively yields smaller values of the objective function. The major methods used in the PEST inverse modeling are described below.

The initial model parameter values were estimated based on local pumping test results and the parameter estimates of the 2003 model. It is important to set good initial parameter values, making PEST converge faster to the global minimum of objective function. The necessity of the logarithmic transformation of hydraulic conductivity was checked before running inverse modeling. Some of the adjusted hydraulic parameters were log-transformed. Such log-transformed parameter settings made the optimization more reasonable.

The Levenberg-Marquardt algorithm was used to minimize the objective function. Details of this method are given in the PEST user's manual (Doherty, 2004) and in numerous inverse modeling books. Herein, it is necessary to note how to make the best choice for the Marquardt parameter (λ), as it is referred to PEST (some other books and papers refer to it as Levenberg parameter [i.e. Levenberg (1944), Finsterle (1999)]). The choices for this value depend on how well-scaled the initial problem is. Marquardt recommends starting with a value λ and a factor ν>1 (1963). When λ becomes large, this algorithm acts as the steepest-descent algorithm. When λ is zero, it is reduced to the Gauss-Newton method, which is better suited for small residuals. During iteration, the algorithm decreases or increases the parameter λ value through multiplication or division by ν so as to accelerate convergence. Based on theoretical study of the algorithm as well as trial and error, the initial value of the Marquardt parameter λ was set to 10.0 and ν was fixed to 2.0.

The parameter updated step size was limited in the PEST settings. During any optimization iteration, the objective function reduction rate was set to be less than 30 percent. This setting prevented the minimization algorithm from moving too far beyond the region in which the linearity assumption is justified. The parameter maximum relative and factor change limits were also set to prevent parameter adjustment from overshooting.

Upper and lower parameter bounds were set to limit the parameters to being adjusted to a reasonable range. These bounds were carefully chosen based on pumping tests and hydrogeological practices in the Chino and Temescal Basins (Table 6-3). For regional a groundwater flow model like the 2007 Chino Basin flow model, where a large number of parameters are being estimated based on a large number of measurements, PEST may try to force a fit between model and measurements by adjusting some parameters to extremely large or small values. The upper and lower bounds, combined with the step size limitation and parameter selection technology (discussed in detail below); can make the calibration stable and the results reasonable.

The error analyses for several trial inverse modeling runs revealed that some of the hydraulic parameters are highly correlated with others. For example, the hydraulic conductivity in zone 29 of layer 1 is highly correlated with many hydraulic parameters. This finding was not surprising because zone 29 is located in the Prado Basin, which controls the surface and subsurface flow of the entire Chino Basin and Temescal area. However, PEST does not provide a function that can automatically select the most independent parameters for each optimization process. To settle this correlation problem, the correlation coefficients among parameters were examined, using the trial inverse modeling runs, and then some of the parameters that strongly correlated to others from the optimization process were excluded (e.g. the hydraulic conductivity in zone 29 of layer 1). In addition, prior information was incorporated into the estimation process. Using the above combination methods, PEST was able to adjust a large number of parameters, avoiding unnecessary numerical difficulties.

Automatic User Intervention was activated in the PEST settings. PEST was forced to compute the Jacobian matrix in each optimization-iteration. The Jacobian matrix reveals the sensitivity of model parameters. By using scaling relative sensitivity, only adjustments to sufficiently sensitive parameters were allowed. The maximum number of adjustable parameters was limited to less than 10 for each iteration. Consequently, the flow model, which has a large number of parameters, was updated in each iteration with only a limited number of parameter changes. During each iteration, PEST was forced to hold any model parameter value if the ratio of the highest sensitivity of any given parameter to the sensitivity of said parameter was lower than 4.0. Only highly sensitive parameters were subjected to the minimization algorithm, while the relatively insensitive and troublesome parameters were temporarily held and remained at their current value. The selection of adjustable parameters was reviewed in each iteration; all of the calibration processes were guided by sensitivity analyses. This methodology requires additional computational time. For example, to compute the Jacobian matrix, one parameter requires 50 minutes of computational time. For this regional flow model, which has more than several dozen adjustable parameters, several days could be required to calculate the Jacobian matrix. To address this time constraint, a 26-processor computer system was used.

6.4.2 Calibration Results

The calibrated model converged and resulted in reasonable aquifer property values and a generally excellent fit to the observed field measurements. Figure 6-2 is a plot of the modeled versus measured heads for all calibration wells. All of the points that are distributed closely around the diagonal line indicate good inverse modeling performance and the robustness of the developed groundwater model. The deviation of points from the diagonal line is randomly distributed indicating no trends. Appendix D contains plots of simulated and measured water levels for the calibration wells during the 1960-2006 calibration period. Inverse modeling significantly improved these matches, compared to forward modeling. With the application of the inverse model exercise, the sum of weighted head residuals dropped from 2.12×10^6 to 5.36×10^5 or 75 percent.

The calibration plots in Appendix D are one example of the many tools used to evaluate the calibration of the model. Calibration plots are useful indicators for success as they show transient calculated water levels compared to measured water levels at a single location. Overall, the plots in Appendix D show a good match between the simulated and measured values, indicating that the general trends within the aquifer are being simulated well (e.g. Figure D-2 for Well F35A [this well has a long history of measurements and the trends match well]).

Table 6-4 compares the initial and final mean model parameter values by zone. Due to system heterogeneity, there are too many individual parameters to list. The final estimates are within a reasonable range, based on hydrogeologic unit type and geologic location. There are areas with very low vertical hydraulic conductivity and storage coefficients. These low values are reasonable considering the lakebed depositional facies they are associated with.

The MODFLOW water budget was reviewed for an overall check of the acceptability of the numerical solution. The water balance error, which compares the modeled inflow and modeled outflow, should ideally less be than 0.10% (Konikow, 1978). During the calibration period, the water balance error was never greater than 0.031%.

6.4.3 Residual Analysis

Residual analysis is critical in evaluating the performance of inverse modeling and calibration. Minimizing the objective function using Levenberg-Marquardt algorithm may lead to the best-estimate parameters for a given groundwater flow model. However, this does not imply that a real groundwater system is properly represented by a model. If a conceptual model fails to reproduce the salient features of a system, the given calibrated model may not be able to match observed data as expected. Residual analysis can reveal potential trends in residuals, indicating a systematic error in a model or the data, and can point out aspects in a model that need to be modified.

Statistics on hydraulic head residuals aid in the evaluation of model calibration. The mean of the residuals is expected to be close to zero. A large positive or negative mean indicates that data are systematically under-predicted or over-predicted by a model. The standard error in a regression is the square root of the calculated error variance. If, a model fits the observations in a way that is consistent with the assigned weighting, the calculated standard error of the regression will equal 1.0. Smaller values indicate that the model fits the observations better than was indicated by the assigned weighting. A large variance or standard deviation either indicates that the data were nosier than expected or that there is a trend in the residuals. The skewness of the residuals characterizes the degree of asymmetry in the distribution. Kurtosis compares the peakedness or flatness of the distribution relative to the Gaussian distribution; a distribution with Kurtosis greater than 3 is relatively peaked and less than 3 is relatively flat. A large difference between the mean and the median is indicative of a robustness problem; that is, the distribution is likely to be heavy-tailed and asymmetric.

Figure 6-3 shows the frequency residual distribution, and Figure 6-4 shows the frequency density residual distribution and the Gaussian distribution based on the residual's mean and the standard distribution. Table 6-5 lists the hydraulic-head residual statistics. These data illustrate that the mean of the residuals is around -1, which indicates a minor underestimation of the model, with a standard deviation of 14.8. The value of skewness indicates that the residual is almost symmetrically distributed. In the residuals distribution of the model, the Kurtosis was greater than 3, which means that there are more residuals around zero.

The residual distribution is statistically random and shows little spatial trend when observed in map form. Figure 6-5 shows each calibration well and its mean residual by geographic location. Some wells in the western portion of the basin have a mean residual greater than 20 feet, which might be attributed to historical data collection. Nonetheless, these wells are next to wells with very small mean residuals, indicating little spatial trending.

Table 6-6 lists residual errors, classified by percentage group. This table indicates that 99% of the residual errors are less than 40 feet. Similarly, this table indicates that 80% of the residual errors are less than 15 feet.

6.5 Future Work to Improve Calibration

Within the calibration process areas of the model were identified that could be improved upon. All models have inherent uncertainties; the intent here is to list the areas of potential improvement for this modeling effort. Listed below are areas of future work:

- Refinement of the boundary discharges into the Chino Basin from the Cucamonga, Rialto, and Riverside Basins. The calibrated values seem high and additional investigations should be done in these basins to refine the inflow to the Chino Basin. The deep percolation of precipitation and applied water would need to be refined to counter any changes in the boundary inflows. These refinements will be useful in predicting the fate and transport of contaminant plumes in the basin, but will have little impact on the accuracy of the future impacts of the planning alternatives investigated herein.
- Model refinement of the subsidence area in the MZ1. Currently the model is capable of simulating most of the groundwater elevations in the subsidence area for the period since the OBMP was implemented and, in particular, the groundwater elevation data collected as part of the MZ1 investigations. The geology in the subsidence area of MZ1 is much more complicated than represented in the conceptual model embedded in the 2007 Watermaster model. The model should be refined in the future to incorporate the complexity of this area. These refinements will produce more reliable estimates of the impacts of groundwater management activities outside of the subsidence area on the subsidence area. Additional aquifer stress tests should be done as described in the MZ1 Long Term Management Plan (WEI, 2007), and sensitivity studies should be done prior to revising the model.
- Evaluation of ET from the saturated groundwater body and ET from non-groundwater sources. The ET study conducted by Merkel & Associates and utilized for this study is the most detailed ET evaluation incorporated into a Chino Basin groundwater model. The report

stops short of identifying ET from groundwater and ET from perched water, stream and rivers, and open water bodies. This next step should be completed to bracket the amount of ET from the groundwater system and ET from other non groundwater sources.

Table 6-1
Model Parameter Sensitivity

Parameter Name	Parameter Type	Layer	Zone	Relative Sensitivity	Ranking
HK1Z1	HK	1	1,2,3,4	7.849	1
HK1Z13	HK	1	13,14,15	7.526	2
HK1Z5	HK	1	5	7.309	3
SY1Z3	SY	1	6,7,8,10,11,12,	6.415	4
HK1Z6	HK	1	6,7,8,10	6.350	5
HK3Z4	HK	3	4,5	5.628	6
HK1Z11	HK	1	11,12,	5.390	7
HK1Z17	HK	1	17,18,26,27	4.357	8
SY1Z30	SY	1	30,31,	3.856	9
SY1Z13	SY	1	13,14,15,9,16,23,24	3.424	10
HK3Z1	HK	3	1,2	3.371	11
HK1Z16	HK	1	9,16,	3.133	12
HK1Z29	HK	1	29,	3.119	13
HK1Z31	HK	1	30,31	3.044	14
HK1Z23	HK	1	23,24	3.031	15
SY1Z1	SY	1	1,2,3,4,5	2.781	16
HK2Z12	HK	2	12,15,16,17,18	2.551	17
HK2Z8	HK	2	8,9,10,11	2.416	18
HK2Z1	HK	2	1,2,3,4	2.205	19
HK2Z5	HK	2	5,6,7	1.963	20
HK3Z6	HK	3	6,7	1.941	21
HK3Z12	HK	3	12,13	1.765	22
HK1Z22	HK	1	22,25	1.724	23
HK3Z9	HK	3	9,11	1.684	24
HK1Z19	HK	1	19,20,21	1.471	25
HK2Z20	HK	2	20	1.306	26
HK3Z14	HK	3	14,	1.029	27
HK2Z13	HK	2	13,14,	1.002	28
SS2Z20	SS	2	20	0.985	29
SS2Z5	SS	2	5,6,7,8,13,14,16	0.951	30
SS3Z6	SS	3	6,7,9,11	0.892	31
HK3Z15	HK	3	15,	0.784	32
SS3Z4	SS	3	4,5	0.745	33
HK3Z3	HK	3	3,	0.642	34
HK2Z19	HK	2	19	0.622	35
SY1Z22	SY	1	22,25,26	0.612	36
SS2Z1	SS	2	1,2,3,4	0.552	37
SS3Z1	SS	3	1,2,3	0.518	38
SY1Z17	SY	1	17,18,19,27,28	0.511	39
SS3Z8	SS	3	8,10	0.225	40
SS2Z9	SS	2	9,10,11,12,15,17,18	0.210	41
SS3Z15	SS	3	15	0.208	42
SY1Z29	SY	1	29	0.200	43
SS3Z12	SS	3	12,13	0.123	44
HK3Z10	HK	3	8,10	0.101	45
SY1Z20	SY	1	20,21,	0.096	46
SS3Z14	SS	3	14	0.067	47
SS2Z19	SS	2	19	0.038	48
HFB1	HFB	2,3	Horizontal Barrier	0.032	49

Abbreviations:

HK:Hydrolic Conductivity   SS: Specific Storage

SY: Specific Yield   HFB: Horizantal Flow Barrier

Table 6-2
Calibration Wells

Owner	Local Name	Screened Layer(s)	Model	
			Row	Column
Archibald Ranch Community Church	Dom	2	350	260
Basque American Dairy	Dairy/Dom	2	393	229
California Speedway	1	123	157	250
Chino Basin Desalter Authority	I-10	1	419	283
Chino Basin Watermaster	AP-PA/7	2	474	181
Chino Basin Watermaster	AP-PA/10	1	474	181
City Of Chino	09	123	412	127
City Of Chino	13	1	428	181
City Of Chino	15	1	469	138
City Of Chino	YMCA	1	464	184
City Of Chino Hills	17	2	465	160
City Of Chino Hills	07C	2	489	148
City Of Chino Hills	18A	2	452	178
City Of Chino Hills	19	2	464	168
City Of Chino Hills	15B	2	486	178
City Of Chino Hills	15A	1	486	179
City Of Corona	15	1	507	437
City Of Corona	14	1	525	447
City of Norco	11	1	345	336
City of Ontario	31	123	220	275
City of Ontario	20	123	224	210
City of Ontario	09	1	312	100
City of Ontario	04	1	300	137
City of Ontario	07	1	299	178
City of Ontario	11	1	326	169
City of Ontario	08	1	304	212
City of Ontario	36	1	302	212
City of Pomona	32G1	2	467	63
City of Pomona	P-29	1	478	92
County Of San Bernardino, Mill	M-3	1	283	265
Cucamonga Valley Water District	CB-3	123	245	174
Fontana Water Company	F31A	1	54	271
Fontana Water Company	F35A	123	75	319
Fontana Water Company	FU6	123	131	365
Fontana Water Company	F30A	123	101	267
Fontana Water Company	F21A	123	161	316
General Electric Corporation	MW-11	2	350	149
Jurupa Community Services Dist	16	1	268	335
Michel, Louise	5	1	421	331
Santa Ana River Water Company	07	1	308	376
Stark, Everett	74200-IRR	1	453	268
State Of California, Cim	9	1	477	226
State Of California, Cim	MW-24I	1	486	193
State Of California, Cim	MW-24S	1	486	193
Van Leeuwen, John	ABANDONED	1	500	251
West End Consolidated Water Co	WE#1	1	327	66
West Valley Water District	WELL 20	1	96	381

Table 6-3
Calibrated Parameters and the Range of Parameter Values Used in PEST

Parameter Name	Parameter Type	Calibrated Base Value	Parameter Lower Bound	Parameter Upper Bound
HK1Z1	HK[1]	253.00	42.90	500.00
HK1Z5	HK	115.00	42.90	500.00
HK1Z6	HK	91.76	20.00	300.00
HK1Z11	HK	160.00	14.30	214.00
HK1Z13	HK	137.58	14.30	214.00
HK1Z16	HK	64.00	14.30	214.00
HK1Z17	HK	217.00	28.60	429.00
HK1Z19	HK	158.00	28.60	429.00
HK1Z22	HK	50.00	10.00	150.00
HK1Z23	HK	123.54	10.00	150.00
HK1Z29	HK	107.00	21.40	321.00
HK1Z31	HK	69.50	11.40	171.00
SY1Z1	SY[2]	2.13E-01	6.67E-02	4.00E-01
SY1Z3	SY	9.77E-02	4.00E-02	2.40E-01
SY1Z13	SY	1.82E-01	4.77E-02	2.86E-01
SY1Z17	SY	1.61E-01	5.23E-02	3.14E-01
SY1Z20	SY	1.57E-01	5.23E-02	3.14E-01
SY1Z22	SY	1.43E-01	4.77E-02	2.86E-01
SY1Z29	SY	1.43E-01	4.77E-02	2.86E-01
SY1Z30	SY	3.60E-01	9.33E-02	5.60E-01
VK1Z1	VK[3]	7.00E+00	7.00E-01	1.40E+01
VK1Z12	VK	7.00E+00	7.00E-01	1.40E+01
VK1Z9	VK	1.00E-01	1.00E-02	2.00E-01
VK1Z14	VK	1.00E-07	1.00E-08	1.00E-05
VK1Z17	VK	4.00E+00	4.00E-01	8.00E+00
HK2Z1	HK	43.32	16.70	150.00
HK2Z8	HK	69.30	16.70	150.00
HK2Z5	HK	12.75	5.00	45.00
HK2Z13	HK	25.70	8.57	77.10
HK2Z12	HK	8.33	3.33	30.00
HK2Z19	HK	24.30	8.10	72.90
HK2Z20	HK	28.60	9.53	85.80
SS2Z1	SS[4]	1.43E-06	1.43E-05	7.15E-04
SS2Z5	SS	3.40E-08	5.40E-08	2.70E-06
SS2Z9	SS	1.27E-06	2.63E-07	1.31E-05
SS2Z19	SS	1.43E-06	1.43E-05	7.15E-04
SS2Z20	SS	1.07E-06	2.14E-06	1.07E-04
VK2Z1	VK	5.00E+00	5.00E-01	1.00E+01
VK2Z5	VK	1.00E-02	1.00E-03	2.00E-02
VK1Z6	VK	1.00E-07	1.00E-08	2.00E-07
VK2Z17	VK	2.00E+00	2.00E-01	4.00E+00
HK3Z1	HK	31.00	14.30	214.00
HK3Z3	HK	31.00	14.30	214.00
HK3Z4	HK	12.00	11.40	171.00
HK3Z6	HK	18.60	3.71	55.70
HK3Z9	HK	17.10	3.43	51.40
HK3Z10	HK	5.86	0.50	15.00
HK3Z12	HK	35.70	7.14	107.00
HK3Z14	HK	24.30	2.86	42.90
HK3Z15	HK	35.70	7.14	107.00
SS3Z1	SS	1.40E-06	1.43E-05	7.15E-04
SS3Z4	SS	1.40E-06	1.43E-05	7.15E-04
SS3Z6	SS	3.10E-06	3.14E-06	1.57E-04
SS3Z8	SS	2.14E-06	2.14E-07	1.07E-05
SS3Z12	SS	2.14E-06	2.14E-06	1.07E-04
SS3Z14	SS	2.14E-06	2.14E-06	1.07E-04
SS3Z15	SS	1.43E-06	1.43E-05	7.15E-04
VK3Z1	VK	5.00E+00	5.00E-01	1.00E+01
VK3Z3	VK	5.00E+00	5.00E-01	1.00E+01
VK3Z4	VK	4.00E+00	4.00E-01	8.00E+00
VK3Z6	VK	1.00E-01	1.00E-02	2.00E-01
VK3Z9	VK	1.00E-02	1.00E-03	2.00E-02
VK3Z10	VK	5.00E-06	5.00E-07	1.00E-05
VK3Z12	VK	2.50E+00	2.50E-01	5.00E+00
VK3Z14	VK	1.00E+00	1.00E-01	2.00E+00
VK3Z15	VK	2.50E+00	2.50E-01	5.00E+00
HFB1	HFB	1.43E-07	1.43E-08	1.43E-02

1- Horizontal Hydraulic Conductivity (ft/day)
2- Specific Yeild (dimensionless)
3- Vertical Hydraulic Conductivity (ft/day)
4- Specific Storage (1/ft)

Table 6-4
Initial and Final Calibrated Aquifer Parameter Values by Zone

Layer 1

	Initial			Final		
Zone	Horizontal Hydraulic Conductivity (ft/day) Mean	Vertical Hydraulic Conductivity (ft/day) Mean	Specific Yield (-) Mean	Horizontal Hydraulic Conductivity (ft/day) Mean	Vertical Hydraulic Conductivity (ft/day) Mean	Specific Yield (-) Mean
1	124.1	3.56E+00	1.18E-01	137.7	3.56E+00	1.06E-01
2	80.8	3.97E+00	8.10E-02	133.2	3.97E+00	1.10E-01
3	124.4	4.83E+00	1.19E-01	163.5	4.83E+00	1.36E-01
4	83.7	5.25E+00	8.50E-02	181.5	5.25E+00	1.51E-01
5	106.1	4.21E+00	1.03E-01	65.3	4.21E+00	1.19E-01
6	64.2	5.60E+00	1.37E-01	72.3	5.60E+00	7.86E-02
7	49.9	4.62E+00	1.10E-01	59.3	4.62E+00	6.55E-02
8	44.3	3.92E+00	9.73E-02	49.9	3.92E+00	5.65E-02
9	36.0	7.10E-02	7.30E-02	34.7	7.10E-02	9.68E-02
10	37.9	4.07E+00	8.48E-02	50.4	4.07E+00	5.69E-02
11	25.4	3.82E+00	8.13E-02	81.7	3.82E+00	5.39E-02
12	42.5	4.35E+00	1.29E-01	95.1	4.35E+00	6.17E-02
13	40.2	5.51E-02	8.08E-02	70.7	5.51E-02	9.18E-02
14	36.9	3.65E-08	7.36E-02	48.8	3.65E-08	6.95E-02
15	40.4	6.04E-02	8.20E-02	76.9	6.04E-02	1.03E-01
16	38.0	6.49E-02	7.65E-02	32.5	6.49E-02	9.19E-02
17	75.6	2.08E+00	8.54E-02	103.8	2.08E+00	8.06E-02
18	100.9	2.19E+00	1.13E-01	109.8	2.19E+00	8.21E-02
19	78.5	2.61E+00	8.80E-02	101.2	2.61E+00	1.02E-01
20	92.3	1.71E+00	1.03E-01	64.8	1.71E+00	7.13E-02
21	77.5	1.10E+00	8.72E-02	41.5	1.10E+00	4.97E-02
22	32.3	4.11E-02	9.29E-02	19.2	4.11E-02	5.68E-02
23	39.4	5.71E-04	1.12E-01	48.4	5.71E-04	7.62E-02
24	26.4	6.20E-04	7.46E-02	54.8	6.20E-04	8.28E-02
25	27.3	4.00E-02	7.22E-02	19.2	4.00E-02	5.73E-02
26	37.4	4.32E-02	4.44E-02	69.2	4.32E-02	4.94E-02
27	57.2	2.16E+00	6.98E-02	108.4	2.16E+00	8.24E-02
28	70.2	2.42E+00	8.04E-02	126.6	2.42E+00	9.49E-02
29	72.0	2.42E+00	9.66E-02	62.5	2.42E+00	8.27E-02
30	33.5	2.71E+00	7.53E-02	46.5	2.71E+00	2.42E-01
31	19.9	2.47E+00	5.08E-02	40.6	2.47E+00	1.90E-01

Layer 2

	Initial			Final		
Zone	Horizontal Hydraulic Conductivity (ft/day) Mean	Vertical Hydraulic Conductivity (ft/day) Mean	Specific Storage (1/ft) Mean	Horizontal Hydraulic Conductivity (ft/day) Mean	Vertical Hydraulic Conductivity (ft/day) Mean	Specfic Storage (1/ft) Mean
2	33.3	2.54E+00	7.01E-05	19.8	2.52E+00	6.82E-05
3	34.7	3.15E+00	7.14E-05	25.3	3.09E+00	8.37E-05
4	25.2	3.20E+00	5.41E-05	26.4	3.15E+00	8.97E-05
5	17.1	1.13E-02	7.04E-05	4.9	4.36E-03	2.16E-07
6	17.1	8.39E-05	7.10E-05	3.9	1.84E-05	1.42E-08
7	23.5	4.20E-02	9.57E-05	5.7	2.33E-05	1.56E-08
8	17.8	2.95E-02	7.34E-05	34.4	1.67E-03	4.76E-07
9	12.2	3.44E+00	5.24E-05	45.7	1.38E-02	8.51E-07
10	11.2	2.76E+00	4.74E-05	33.1	1.01E-02	6.30E-07
12	9.8	4.23E-03	5.63E-05	2.9	4.23E-08	4.66E-07
13	11.0	1.03E-05	6.33E-05	9.1	4.07E-08	4.83E-07
14	12.8	5.60E-03	7.31E-05	12.7	5.59E-08	6.54E-07
15	11.8	5.27E-03	6.88E-05	12.5	5.32E-08	6.35E-07
16	10.9	5.03E-03	6.39E-05	11.4	2.02E-03	5.85E-07
17	11.7	9.59E-01	6.61E-05	11.6	9.69E-01	5.87E-07
18	11.5	1.09E+00	6.59E-05	12.4	1.09E+00	6.25E-07
19	8.9	1.06E+00	9.00E-05	11.4	1.06E+00	7.00E-07
20	16.6	9.96E-01	8.44E-05	12.1	9.96E-01	4.79E-07

Layer 3

	Initial			Final		
Zone	Horizontal Hydraulic Conductivity (ft/day) Mean	Vertical Hydraulic Conductivity (ft/day) Mean	Specific Storage (1/ft) Mean	Horizontal Hydraulic Conductivity (ft/day) Mean	Vertical Hydraulic Conductivity (ft/day) Mean	Specfic Storage (1/ft) Mean
1	27.9	3.23E+00	5.62E-05	15.2	3.23E+00	7.62E-07
2	34.6	3.36E+00	7.03E-05	18.6	3.37E+00	8.57E-07
3	37.0	2.29E+00	7.66E-05	10.8	2.28E+00	5.17E-07
4	30.5	2.29E+00	7.13E-05	6.3	2.30E+00	7.41E-07
5	29.4	2.56E+00	7.29E-05	6.7	2.55E+00	7.81E-07
6	7.1	5.97E-02	5.94E-05	9.9	7.76E-02	1.63E-06
7	6.4	5.80E-02	5.30E-05	9.0	8.26E-02	1.50E-06
8	1.7	2.71E-06	8.75E-05	9.7	2.17E-03	1.10E-06
9	9.3	5.30E-03	7.96E-05	9.0	6.02E-03	1.07E-06
10	1.6	2.59E-06	7.57E-05	3.2	2.59E-06	1.05E-06
11	8.3	7.53E-03	7.78E-05	8.0	1.28E-03	1.00E-06
12	13.8	1.55E+00	5.57E-05	18.7	1.55E+00	1.15E-06
13	16.6	1.54E+00	6.70E-05	13.9	1.59E+00	8.85E-07
14	7.7	4.22E-01	7.53E-05	9.5	4.25E-01	8.40E-07
15	17.1	8.37E-01	6.91E-05	13.8	8.34E-01	5.56E-05

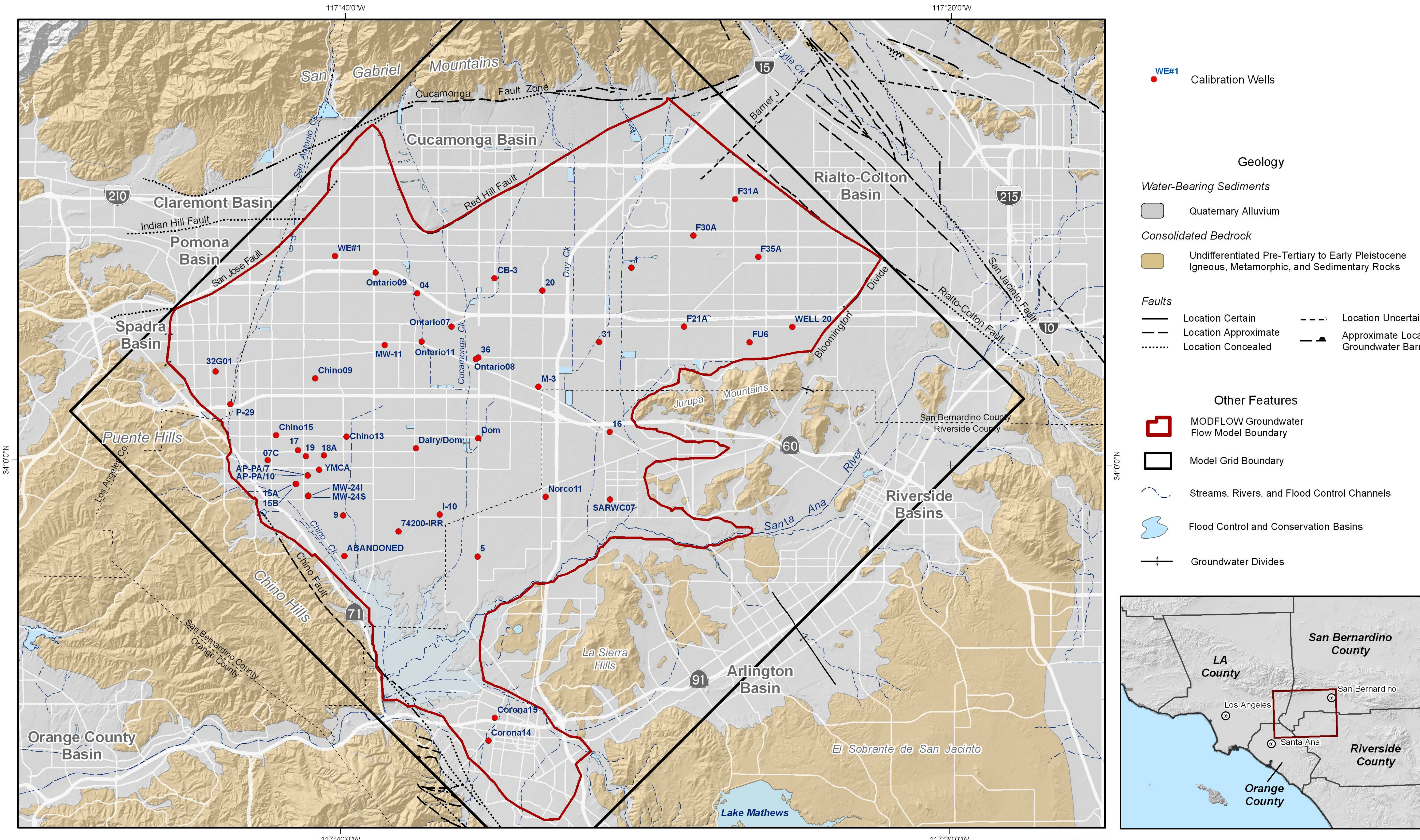
Table 6-5
Residual General Statistics

Residual Statistics	
Mean[1]	-1.064
Standard Deviation	14.800
Skewness[2]	-0.353
Kurtosis[3]	4.217
Range	131.445
Standard Error[4]	0.300
Minimum	-84.626
Median	-0.416
Maximum	46.819

1) A bias mean towards -1 indicates an overall small underestimation of the model.
2) Small skewness indicates a highly symmetrical distribution.
3) k >3 (Kurtosis is leptokurtic) indicates a distribution that has a more acute peak around the mean.
4) Standard error values less than 1 indicates that the model fits the observation better than was indicated by the assigned weights.

Table 6-6
Residual Error Classification

Residual Error	Percent of Residuals within the Corresponding Residual Error
±5	40%
±10	63%
±15	80%
±20	88%
±25	93%
±30	96%
±35	98%
±40	99%



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Date: 20071005
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0 1 2 3 4 5 Miles
0 2 4 6 8 KM

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Model Calibration

Location of Calibration Wells

Figure 6-1

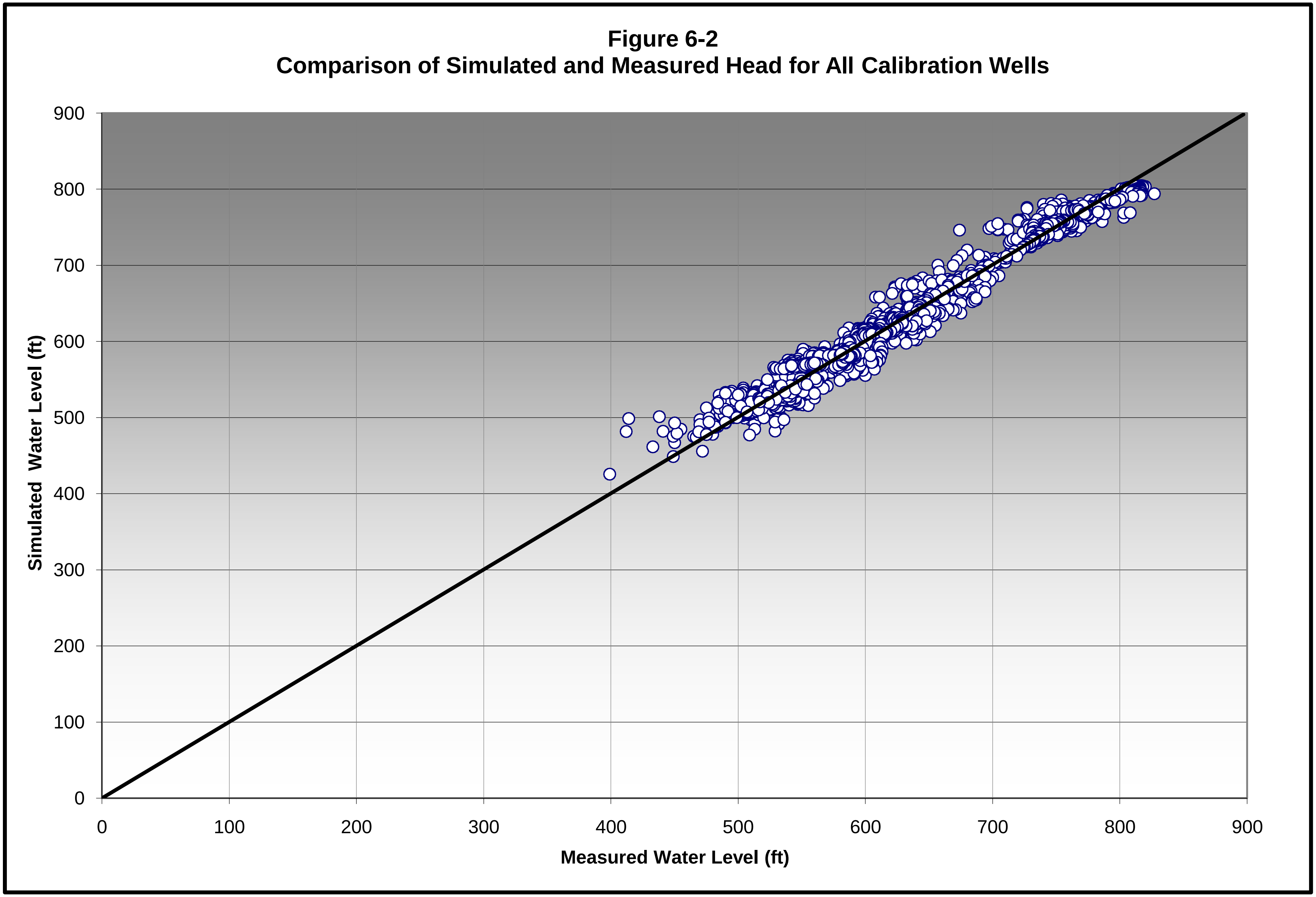


Figure 6-2
Comparison of Simulated and Measured Head for All Calibration Wells
900
800
700
600
500
400
300
200
100
0
Simulated Water Level (ft)
0
100
200
300
400
500
600
700
800
900
Measured Water Level (ft)

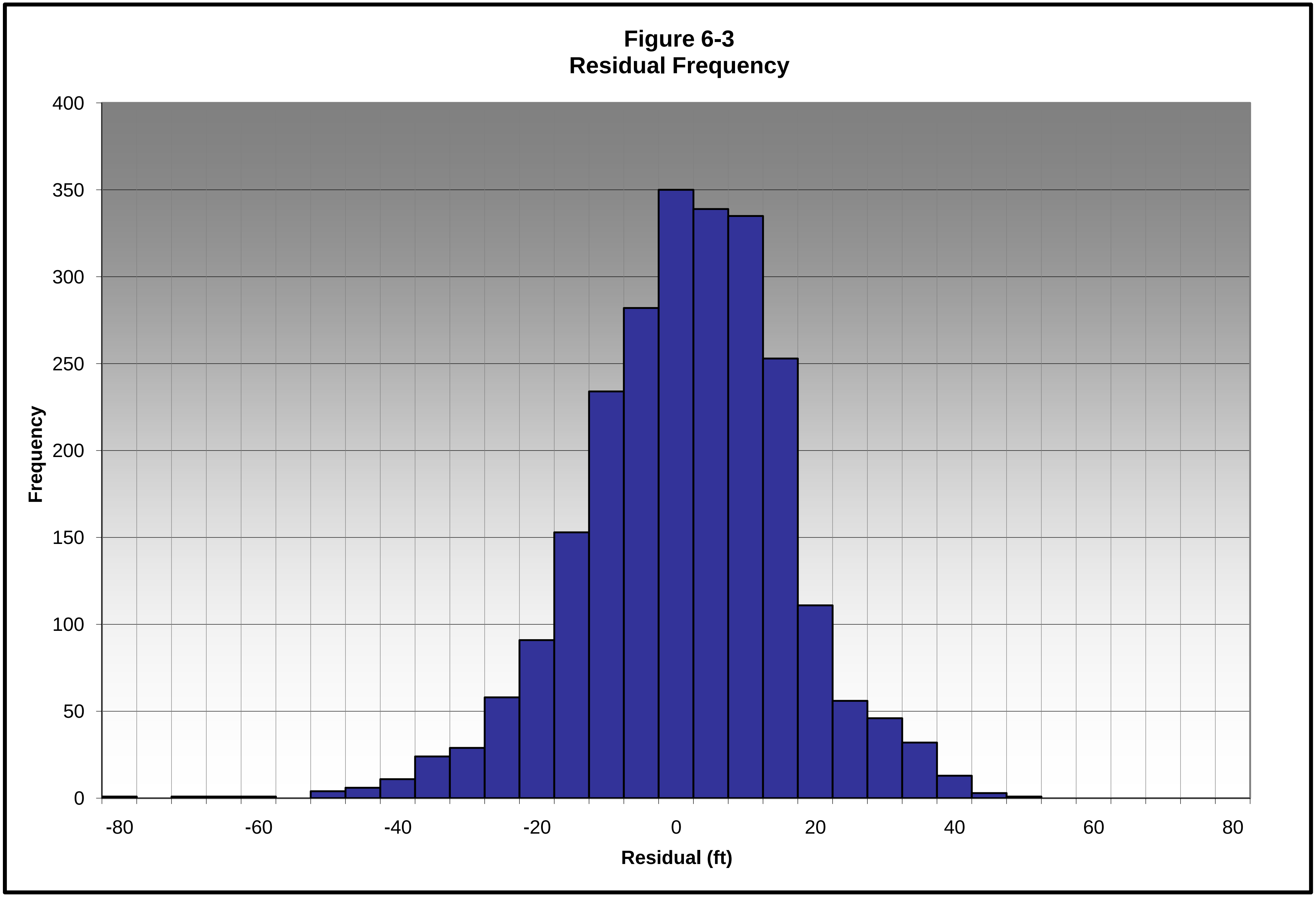


Figure 6-3
Residual Frequency
Frequency
400
350
300
250
200
150
100
50
0
-80
-60
-40
-20
0
20
40
60
80
Residual (ft)

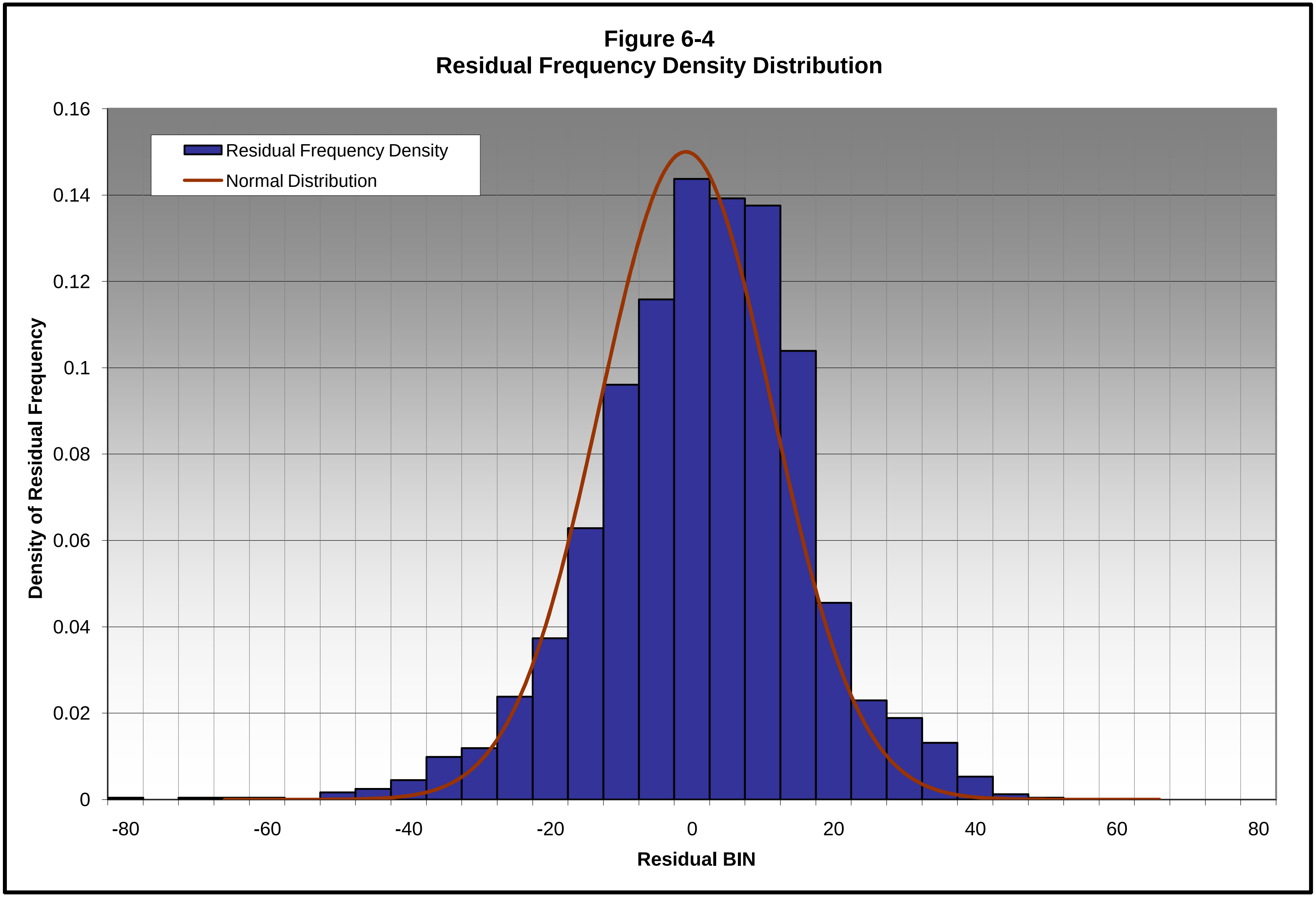
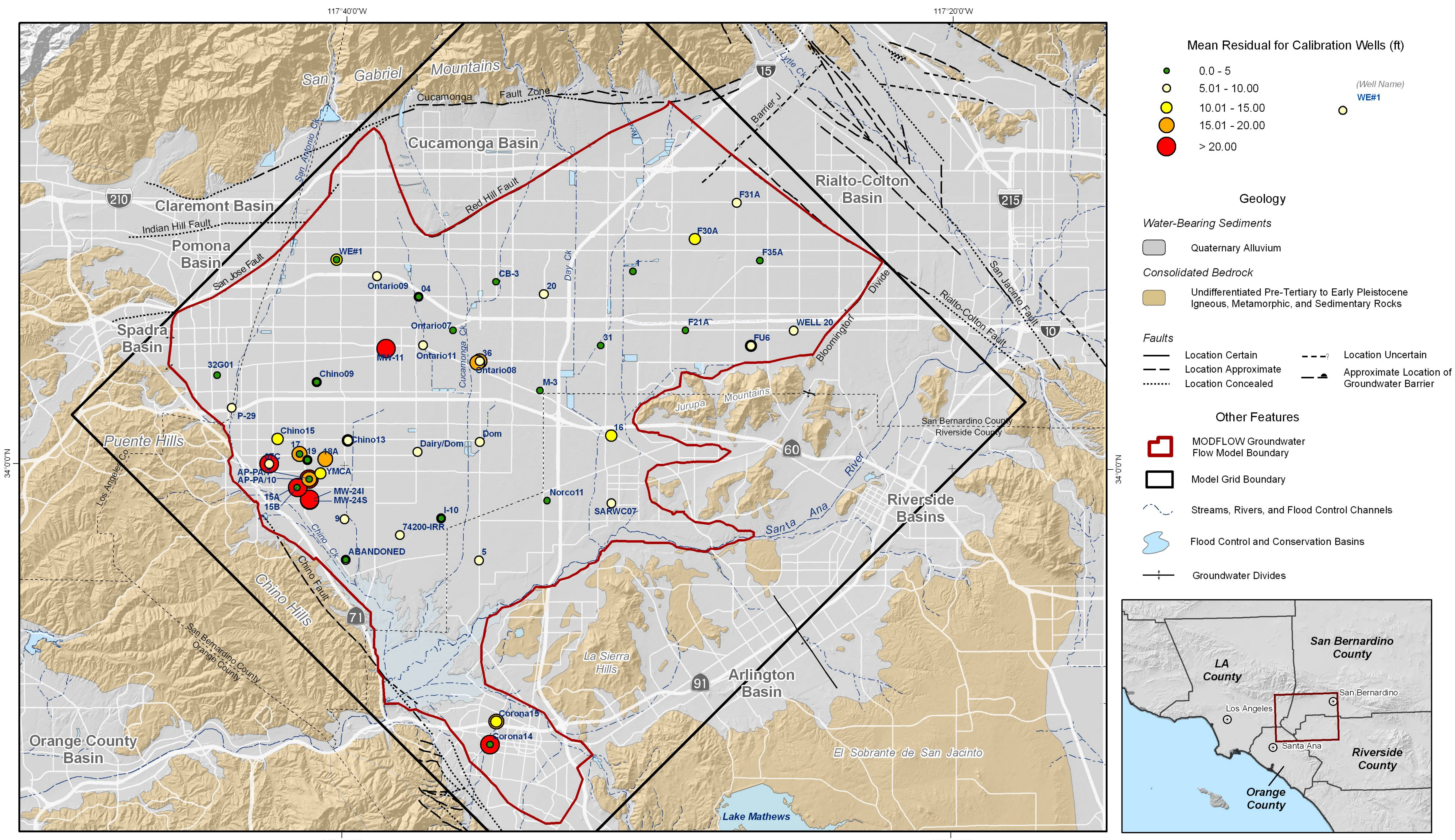


Figure 6-4
Residual Frequency Density Distribution
Residual Frequency Density
Normal Distribution
Density of Residual Frequency
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-80
-60
-40
-20
0
20
40
60
80
Residual BIN



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Lake Forest, CA 92630
949.420.3030
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Model Calibration

Mean Residual of Calibration Wells

Figure 6-5

Section 7 – Analysis of the Peace II Project Description

Sections 2 through 6 describe the evolution of the new 2007 Watermaster Model. This model was used to evaluate the groundwater and surface water responses to the project description included in the Peace II instruments.

7.1 Project Description

This section contains the project descriptions for the Chino Basin desalting and Re-operation programs, which have been distilled from various planning investigations, the Stakeholder Non-Binding Term Sheet, and a working version of the Peace II Instruments as of October 2007. First, the requirements of the 2004 Amendment to the Water Quality Control Plan are described. These requirements are fundamental to water supply reliability for producers that rely on the Chino Basin. Next, the key features of the Non-Binding Stakeholder Term Sheet and the Peace II instruments are discussed. These features provide a description and the intent of the stakeholders; that is, they describe what the stakeholders are asking for. These features also implement some of the requirements of the 2004 Basin Plan Amendment. Finally, the project is described.

7.1.1 Requirements of the 2004 Amendment to the Water Quality Control Plan for the Santa Ana Watershed

Water quality objectives are established by the Regional Water Quality Control Board, Santa Ana Region (Regional Board) to preserve the beneficial uses of the Chino Basin and the Orange County Basin, located downstream of the Chino Basin. Prior to the 2004 Amendment, the Regional Water Quality Control Plan (Basin Plan) contained restrictions on the use of recycled water for irrigation and groundwater recharge within the Chino Basin. The pre-2004 Basin Plan contained TDS "anti-degradation" objectives that ranged from 220 to 330 mg/L over most of the Chino Basin. Ambient TDS concentrations slightly exceeded these objectives. There was no assimilative capacity for TDS; thus, the use of the IEUA's recycled water for irrigation and groundwater recharge would have required mitigation even though the impact of this reuse would not have materially impacted future TDS concentrations or impaired the beneficial uses of Chino Basin groundwater.

In 1995, the Regional Board initiated a collaborative study with 22 water supply and wastewater agencies, including Watermaster and the IEUA, to devise a new TDS and nitrogen (total inorganic nitrogen or TIN) control strategy for the Santa Ana Watershed. This study culminated in the Regional Board's adoption of the 2004 Basin Plan Amendment in January 2004 (Santa Ana Regional Water Quality Control Board, 2004). The 2004 Basin Plan Amendment included two sets of TDS objectives: anti-degradation objectives that ranged between 280, 250 and 260 mg/L for Management Zones 1, 2, and 3, respectively; and a maximum benefit based TDS objective of 420 mg/L for the Chino North Management Zone, which consists of almost all of Management Zones 1, 2, and 3. The relationship of the Management Zones that was developed for the OBMP and the maximum benefit based management zones is shown in Figure 7-1. Under the maximum benefit based objective, the new TDS concentration limit for recycled water that is to be used for recharge and other direct uses is 550 mg/L as a 12-month average. This discharge requirement has been incorporated into the IEUA's National Pollutant Discharge Elimination System (NPDES) permits for its wastewater treatment facilities.

In order for the IEUA and Watermaster to gain access to the assimilative capacity afforded by the maximum benefit based objectives, they have to demonstrate that the maximum beneficial use of the waters of the State is being achieved. The 2004 Basin Plan Amendment contains a series of commitments that must be met in order to demonstrate that the maximum benefit is being achieved. These commitments include:

1. The implementation of a surface water monitoring program
2. The implementation of groundwater monitoring programs
3. The expansion of Desalter I to 10 mgd and the construction of a 10-mgd Desalter II
4. The commitment to future desalters pursuant to the OBMP and the Peace Agreement
5. The completion of the recharge facilities included in the Chino Basin Facilities Improvement Program (CBFIP)
6. The management of recycled water quality
7. The management of the volume-weighted TDS and nitrogen in artificial recharge to less than or equal to the maximum benefit objectives
8. The achievement and maintenance of hydraulic control of the subsurface outflows from the Chino Basin to protect Santa Ana River water quality
9. The determination of ambient TDS and nitrogen concentrations in the Chino Basin every three years

The IEUA and Watermaster have previously demonstrated compliance with all of these requirements with the sole exception of hydraulic control. Hydraulic control is defined as the reduction of groundwater discharge from the Chino North Management Zone to the Santa Ana River to de minimis quantities. Hydraulic control ensures that the water management activities in the Chino North Management Zone will not impair the beneficial uses of the Santa Ana River downstream of Prado Dam. Achieving hydraulic control also maximizes the safe yield of the Chino Basin as required by Paragraphs 30 and 41 of the Judgment. Two reports by WEI, prepared in 2006 at the direction of Watermaster, demonstrate that hydraulic control has not yet been achieved in the area between the Chino Hills and Chino Desalter I, well number 5 (WEI, 2006a and b).

Without hydraulic control, the IEUA and Watermaster will have to cease the use of recycled water in the Chino Basin and will have to mitigate the effects of using recycled water back to the adoption of the 2004 Basin Plan Amendment, which occurred in December 2004. Table 7-1 shows the projected aggregate water supply plans for Chino Basin municipal water purveyors. The demand for recycled water in the Chino Basin is projected to increase from about 12,500 acre-ft/yr in 2005 to 58,000 acre-ft/yr in 2010, 68,000 acre-ft/yr in 2015, 79,000 acre-ft/yr in 2020, and 89,000 acre-ft/yr in 2025. Recycled water reduces the demand of State Water Project (SWP) water by an equal amount, thereby reducing the demand on the Sacramento Delta and reducing energy consumption. Recycled water is a critical element of the OBMP and water supply reliability in the Chino Basin area.

Failure to achieve hydraulic control will lead to restrictions from the Regional Board on the use of imported SWP water for replenishment when the TDS concentration in SWP water exceeds the antidegradation objectives. The Regional Board produced a draft order that would treat the recharge of SWP water as a waste discharge. There would be no assimilative capacity if the Chino Basin antidegradation objectives were in force. Figure 7-2 shows the percent of time that the TDS concentration at Devil Canyon is less than or equal to a specific value based on observed TDS concentrations at the Devil Canyon Afterbay. This restriction will occur about 35, 52, and 50 percent of the time for Management Zones 1, 2, and 3, respectively. This will affect other basins in the Santa Ana Watershed, and the Regional Board is encouraging all basin managers to propose maximum benefit based objectives similar to those in the Chino Basin. With the maximum benefit based TDS objective in the Chino Basin, there is assimilative capacity, and there would be no such restriction on the recharge of imported water.

The Regional Board is using its discretion in granting maximum benefit based objectives even though hydraulic control has not been demonstrated. The Regional Board will continue to use maximum benefit based objectives in the Chino Basin as long as the IEUA and Watermaster continue to develop and implement, in a timely manner, the OBMP desalter program as described in the project description below.

7.1.2 The Stakeholder Non-Binding Term Sheet: Peace II Implementing Measures

Under Watermaster oversight, the Chino Basin OBMP stakeholders have been engaged in, among other things, complying with the Peace Agreement provision regarding the planning and financing of the expansion of the OBMP desalting program to its full planned capacity, generally referred to as Future Desalters (see Peace Agreement Article VII). The stakeholders have been evaluating various alternatives since early 2004 and produced the Stakeholders' Non-Binding Term Sheet that was transmitted to the Court along with a request from Watermaster for further technical review by the Assistant to the Special Referee in May of 2006. The Assistant's review was completed in March of 2007.

The Non-Binding Term Sheet includes several items that collectively will further implement the existing OBMP Implementation Plan (Peace II Measures). The two items of interest in this project description are: the expansion of the desalting program and "Basin Re-Operation," which are both physically described in Section II, Refined Basin Management Strategy, subsections A and B; and Section IV, Future Desalters.

The construction of a new desalter well field will be sized and located to achieve hydraulic control. This new desalter well field will produce at least 9-mgd of product water. Some of this new desalter supply will come from a new well field that will be constructed in a location among Desalter I wells 1 through 4 and west of these wells. These wells will be constructed to pump groundwater from the shallow part of the aquifer system, which is defined herein as the saturated zone that occurs within about 300 feet of the ground surface. The total groundwater pumping for all of the desalters authorized in the term sheet will be about 40,000 acre-ft/yr.

"Re-operation" means the increase in controlled overdraft, as defined in the Judgment, from 200,000 acre-ft over the period of 1978 through 2017 to 600,000 acre-ft through 2030 with the 400,000 acre-ft increase allocated specifically to the meet the replenishment obligation of the desalters. Re-operation is required to achieve hydraulic control. Re-operation and Watermaster's apportionment of controlled overdraft will not be suspended in the event that Hydraulic Control is secured in any year before the full 400,000 acre-ft has been produced so long as: (i) Watermaster has prepared, adopted, and the Court has approved a contingency plan that establishes conditions and protective measures to avoid Material Physical Injury and that equitably addresses this contingency; and (ii) Watermaster continues to demonstrate credible material progress toward obtaining sufficient capacity to recharge sufficient quantities of water to cause the basin to return to a new equilibrium at the conclusion of the Re-operation period. In addition to contributing to the achievement of hydraulic control, Re-operation will contribute to the creation of new yield. Watermaster has the discretion to apportion the 400,000 acre-ft increase in controlled overdraft under a schedule for Re-operation that best meets the needs of the Parties and the conditions of the basin over the Initial Term of the Peace Agreement (before June 30, 2030).

7.1.3 The Proposed Project

The proposed project has two main features: the expansion of the desalter program, such that the groundwater pumping for the desalters will reach about 40,000 acre-ft/yr and the pumping will occur in amounts and at locations that contribute to the achievement of hydraulic control; and the strategic reduction in groundwater storage (Re-operation), which, along with the expanded desalter program, significantly achieves hydraulic control.

7.1.3.1 The Expanded Desalting Program

A new well field, referred to as the Chino Creek Well Field (CCWF), will be constructed. The capacity of this well field could range from about 5,000 acre-ft/yr to 7,700 acre-ft/yr. The constructed capacity of the CCWF will be determined during its design. Groundwater produced at the CCWF will be conveyed to Desalter I. The location of the CCWF is shown in Figure 7-3. The capacity of Desalter I will not be increased; although, it is likely that the treatment systems at Desalter I will be modified to accommodate the chemistry of the raw water pumped from the CCWF. The product water capacity of Desalter I is about 14,200 acre-ft/yr, which corresponds to a raw water pumping requirement of about 16,100 acre-ft/yr. The volume of groundwater pumping at existing Desalter I wells 13, 14, and 15 will be reduced to accommodate new pumping at the CCWF.

The treatment capacity of Desalter II will be increased from 10,400 acre-ft/yr to about 21,000 acre-ft/yr, which corresponds to expanding the raw water pumping requirement of 11,800 acre-ft/yr to 23,900 acre-ft/yr. The increase in groundwater pumping for Desalter II will come in part from greater utilization of the existing Desalter II wells and the addition of new wells to the Desalter II well field from either the construction of new wells and/or connecting Desalter I wells 13, 14, and 15. For this investigation, it was assumed that Desalter I wells 13, 14, and 15 will produce water for the expansion of Desalter II. The Desalter II treatment plant would be expanded to increase its capacity from 10,400 acre-ft/yr to 21,000 acre-ft/yr. The new product water developed at Desalter II would be conveyed to the Jurupa Community Services District (JCSD), the City of Ontario, and/or WMWD through existing and new pipelines. The facilities required to convey this water include pipelines, pump stations, and reservoirs. The precise locations of these facilities are unknown at this time.

The parties that are engaged in developing the desalter expansion are planning for a total of 40,000 acre-ft/yr of desalter groundwater pumping. The most current working description of these facilities is contained a report that was prepared for the City of Ontario and WMWD, entitled Chino Desalter Phase 3 Alternatives Evaluation (Carollo, 2007). Currently (June 2007), the City of Ontario and the WMWD are working with the JCSD and others to refine the alternatives in the Carollo report. The assumed startup for the expanded desalters is January 2013.

7.1.3.2 Re-Operation

Through Re-operation and pursuant to a Judgment Amendment, Watermaster will engage in controlled overdraft and use up to a maximum of 400,000 acre-ft to offset desalter replenishment through 2030. After the 400,000 acre-ft is exhausted and the period of Re-operation is complete, Watermaster will recalculate the safe yield of the basin. The Re-operation period will have no impact on the Operating Safe Yield or on the Parties' respective rights thereto. For project evaluation purposes, Re-operation and the controlled overdraft of 400,000 will be examined under two different schedules that bracket the range in expected schedules. The first schedule will be based on allocating the 400,000 acre-ft at a constant percentage of desalter pumping such that the 400,000 acre-ft is used up in a constant proportion of the desalter pumping through 2030. The second schedule will use the controlled overdraft to offset the applicable desalter replenishment obligation completely each year until the 400,000 acre-ft is completely exhausted.

The new yield, as defined by the Peace Agreement, which is attributable to authorized desalters and the reduction in storage from Re-operation, will be assigned to authorized desalters. The resulting replenishment obligation assigned to authorized desalters will then be handled as any other replenishment obligation pursuant to the Judgment. The new yield is expected to come from a reduction in groundwater discharge from the Chino Basin to the Santa Ana River within the reservoir created by the Prado Dam and from newly induced recharge of the Santa Ana River upstream of the Prado Dam.

7.1.3.3 Expansion of Storage and Recovery Programs

Currently, there is only one groundwater storage program approved in the Chino Basin: the 100,000 acre-ft Dry-Year Yield Program (DYYP) with the Metropolitan Water District of Southern California (Metropolitan). Metropolitan, the IEUA, and Watermaster are considering expanding this program by an additional 50,000 acre-ft to 150,000 acre-ft over the next few years. Watermaster is also considering an additional 150,000 acre-ft in programs with non-party water agencies. The total volume of groundwater storage allocated to storage programs that could overlay the proposed project is about 300,000 acre-ft.

These storage programs, if not sensitive to the needs of hydraulic control, could cause groundwater discharge to the Santa Ana River and result in noncompliance with hydraulic control and a loss in safe yield. The proposed project will be analyzed with the existing 100,000 acre-ft DYYP because the facilities and operational plans to expand beyond the 100,000 acre-ft program have not been described in sufficient detail for credible analysis.

7.2 Alternatives Investigated in the 2007 Peace II Process

This section describes the project alternatives. First, the new groundwater production projections for groundwater pumpers in the Chino Basin are described and compared to past planning projections. The resulting projection of Watermaster's replenishment obligation is made based on the requirements of the Judgment, the Peace Agreement, as well as the existing and planned replenishment facilities. Limitations in replenishment capacity are then used to refine future groundwater production and replenishment plans that implement the planning alternatives.

Two alternatives were investigated in the final analysis of the Peace II process. These alternatives were developed from the Peace II Project Description as of October 17, 2007 and include the following:

- Baseline Alternative – Expansion of Desalter Capacity and the 100,000 acre-ft DYYP. Desalter groundwater production would increase from the current level of about 28,000 acre-ft year (2006/07) to the full capacity of the existing desalters at about 40,000 acre-ft/yr. This corresponds to an expansion of the product water capacity of about 24.2 mgd to about 33.2 mgd. This alternative includes the existing 100,000 acre-ft DYYP. This alternative will serve as the baseline as it currently authorized and would occur without the adoption of the Peace II Instruments. This alternative is representative of what would occur without Peace II.
- Alternative 1 – Expansion of the Desalters, Re-Operation, and the 100,000 acre-ft DYYP. Desalter groundwater production would increase from the current level of about 28,000 acre-ft year (2006/07) to the full capacity of the existing desalters at about 40,000 acre-ft/yr. This corresponds to an expansion of the product water capacity of about 24.2 mgd to about 33.2 mgd. Up to 400,000 acre-ft of the desalter replenishment obligation would be met by reductions in groundwater storage (Re-operation). There are two variants of Alternative 1 – 1A and 1B which utilize slightly different Re-operation strategies. This alternative includes the

existing 100,000 acre-ft DYYP. This alternative is what is being asked for with Peace II.

These alternatives were evaluated with the updated 2007 Watermaster Model. They have been implemented in the model through groundwater production and replenishment projections.

7.2.1 Projected Chino Basin Groundwater Production and Replenishment Obligations

7.2.1.1 Initial Groundwater Production Projection

Black and Veatch (B&V) developed a groundwater production plan for the Chino Basin (B&V unpublished, 2005) during the fall of 2004 and winter of 2005. This groundwater production plan is the basis of the groundwater pumping plan used in this investigation. The B&V groundwater production plan is based on the current and future water supply plans espoused by the groundwater producers for the period of 2005 through 2025 and was prepared based on the producers' 2005 Urban Water Management Plans. The producers' water supply plans include existing and new master-planned wells, an expanded desalter program, and the assumption that Watermaster will secure access to replenishment facilities to enable the producers to pump what they need. The B&V groundwater production plan was vetted early through the Peace II attorney-manager and Watermaster processes and was accepted by the appropriators as the groundwater production plan in the earlier Peace II modeling assessments (WEI, 2006a and 2006b).

Table 7-2 lists the historical groundwater production by the members of the Appropriative Pool for the period 1999/00 through 2006/07. Figure 7-4 shows the service areas of all the water purveyors that either produce or have rights to produce groundwater from the Chino Basin. The total production of the Appropriators during this period averaged about 129,000 acre-ft/yr and ranged from a low of about 120,000 acre-ft/yr to a high of about 137,000 acre-ft/yr. Table 7-3 shows the historical total Chino Basin production for the eight-year period, including fiscal years 1999/00 through 2006/07 and the 21-year B&V projection period for 2005/06 through 2024/25. Table 7-3 suggests that groundwater production will increase from about 177,000 acre-ft/yr (average 1999/00 through 2003/04) to about 206,000 acre-ft/yr in 2005 (an increase of about 29,000 acre-ft/yr over the prior five-year average) and will reach about 250,000 acre-ft/yr in 2025 (an increase of about 74,000 acre-ft/yr over the average for 1999/00 through 2003/04). Note that the groundwater production projection does not track with the historical groundwater production. For example, the B&V 2004/05 production projection is about 205,000 acre-ft, which is about 34,000 acre-ft higher than the recorded production of about 171,000 acre-ft.

The B&V groundwater production projection was modified in this investigation to be more consistent with the historical pumping; it was assumed that each appropriators' pumping will grow starting with their actual production in 2005/06, increase linearly to match the B&V production projection in 2020, and thereafter track the B&V projection. This new projection is referred to herein as the WEI Trial 1 Projection and is shown in Table 7-3. The growth in projected groundwater production is still large, increasing at a compounded rate of about 2.8 percent. Later in this section, the WEI Trial 1 projection will be reduced even more to live within the known wet-water replenishment capacity of the basin.

7.2.1.2 Replenishment Capacity

Supplemental water is recharged in the Chino Basin by Watermaster pursuant to the 1978 Chino Basin Judgment (Case No. RCV 51010, Chino Basin Municipal Water District vs. City of Chino et al.) and the 2000 Peace Agreement. Watermaster's replenishment obligation was estimated using the following assumptions:

- The increase in storm water recharge (new yield) that is anticipated from the OBMP recharge improvements is about 12,000 acre-ft/yr. This new recharge is reviewed every five years and changed to reflect actual storm water recharge and to correct for prior estimates.
- The safe yield is 140,000 acre-ft/yr.
- The Judgment allows a 5,000 acre-ft/yr controlled overdraft of Chino Basin through 2017.
- Water in storage accounts as of fiscal year 2005/06 is not used to meet replenishment obligations.
- Under-producers will transfer un-pumped rights to over-producers; that is, there is an efficient market that moves valuable unexercised rights from under-producers to over-producers.
- Re-operation will result in a new permanent increase in safe yield, and this yield will be used to meet the replenishment obligations of the OBMP desalters.

Table 7-3 shows the gross potential replenishment obligation that occurred during the period of 1999/00 through 2005/06 and the estimated replenishment obligation. The gross potential replenishment obligation that occurred during the period of 1999/00 through 2005/06 was largely satisfied by Appropriators augmenting their share of the operating yield from their storage accounts, Appropriators purchasing water from other Appropriators (from storage and unused operating yield), or from Watermaster replenishment. Table 7-3 suggests that the gross overproduction with the B&V projection would be about 45,000 acre-ft/yr in 2004/05, reach about 98,000 acre-ft/yr in 2014/15, and reach about 104,000 acre-ft/yr by 2019/20. As shown in Table 7-3, the actual pumping by the appropriators is much less than was articulated in their urban water management plans. The gross replenishment obligation from the WEI Trial 1 Projection is shown in Table 7-3 and ranges from near 8,000 in 2006/07 to about 69,000 acre-ft/yr in 2014/15 and to 95,000 acre-ft/yr in 2019/20. The gross overproduction in the planning period was assumed to be entirely satisfied through wet water recharge.

For this investigation, the supplemental water recharge capacity in the basin was estimated currently (2007) to be about 61,000 acre-ft/yr, which will reach about 91,000 acre-ft/yr when planned improvements are completed in mid-2008. The future replenishment obligation exceeds the supplemental water recharge capacity available to Watermaster by variable amounts that increase over time. Table 7-4 lists the recharge facilities within the Chino Basin and their associated estimates of storm water recharge and supplemental water recharge capacity. The locations of these facilities are shown in figure 7-5. The initial storm water recharge estimates suggested that the new storm water recharge created by the CBFIP would reach an average annual total of about 12,000 acre-ft/yr. Storm water recharge performance since these facilities were completed suggests a much lower storm water recharge estimate of about 6,000 acre-ft/yr. The reduction in projected storm water recharge occurs because the recharge basins are not operated to maximize storm water recharge and because the physical recharge performance of the basins is less than originally estimated.

The sources of supplemental water available to Watermaster are SWP water, purchased from the Metropolitan, and recycled water, purchased from the IEUA. Metropolitan has not always been able to deliver enough State Project water to meet Watermaster's replenishment obligation in the past and will likely have shortages of replenishment water in the future. These shortages occur, in part, due to capacity limitations in the Rialto Reach of Metropolitan's Foothill feeder and from shortages on the SWP. The DWR completed an assessment of the reliability of the SWP in 2002 (DWR, 2002) and found that the SWP would be able to deliver an average of 72 percent of the contracted Table "A" allocation and that deliveries would range between about 19 and 82 percent. Subsequent unpublished reliability estimates developed by DWR suggest that the average reliability could be as low as 69 percent. Results from Metropolitan's Integrated Regional Planning simulations were obtained to determine the average reliability of Metropolitan's delivery of SWP water to the Chino Basin for replenishment (Metropolitan, 2007). From these results, it appears that Metropolitan believes it will meet the full replenishment demands of Watermaster about 80 percent of the time and it will have surplus water available for replenishment about 60 percent of the time. This means that if the Metropolitan allocated its SWP water uniformly among all of its member agencies and water service types and had no capacity limitations in their system, the physical recharge capacity of the Chino Basin would need to be about 125 percent (125 equals 1.0/0.8 times 100 percent) of the average replenishment obligation. Another way of looking at this is to simply rate the replenishment capacity based as the physical recharge capacity times 80 percent.

Recycled water is available for replenishment pursuant to a new recharge permit that was issued jointly to Watermaster and the IEUA (RWQCB Resolution R8-2007-0033). This permit replaces an older permit and requires that the 60-month, moving, volume-averaged contribution of recycled water is based on measured total organic carbon removal through soil aquifer treatment. The expected recycled water contribution will range between 30 and 40 percent of total recharge. Recycled water will be available for recharge, consistent with available dilution waters, 100 percent of the time. That said, recycled water is not available to all of the recharge basins. Table 7-4 lists the recharge basins that are capable of receiving recycled water, denoted by the value 100 percent in the column entitled *Average Reliability of Recycled Water*.

The *Effective Replenishment Capacity* of each recharge facility and the aggregate of these facilities is shown in Table 7-4 under the group of columns entitled *Supplemental Water Recharge*. The group of columns under the column heading *Operational Plan* specify which months the basins will generally be online and available to receive supplemental water. A "0" means the basin is not available for supplemental water recharge. A positive value ranging up to 1.0 is an estimate of the fraction of time that the basin is available exclusively for the recharge of supplemental water. The operational plan assumes that the recharge facilities will be available for use nine out of twelve months or 75 percent of the time. The *Average Recharge Rate* was provided by the IEUA and is based on recent measurements and observations (IEUA, 2007). The *Current Estimate of Supplemental Recharge Capacity* is based on the *Operational Plan*, *Utilization*, and *Average Recharge Rate* for existing facilities as of August 2007 and is estimated to be about 61,000 acre-ft/yr. The *Future Estimate of Supplemental Recharge Capacity* is based on the facilities that are expected to be online by mid-year 2008 and is about 91,000 acre-ft/yr.

The *Average Reliability of Replenishment Water* was estimated as the volume-weighted reliability of SWP water from Metropolitan and recycled water from the IEUA (varying from 29 to 36 percent based on the recharge permit). The volume-weighted *Average Reliability of Replenishment Water* varies by recharge facility from about 80 to 87 percent and is about 83 percent in aggregate. The resulting *Effective Replenishment Capacity* is about 76,000 acre-ft/yr.

7.2.1.3 Desalter Well Field and Allocation of Re-Operation Water

Table 7-5 summarizes the allocation of current and assumed desalter capacity for this investigation. The current capacity for the desalter is about 29.2 mgd. Of this capacity, about 24.2 mgd has been subscribed to by various members of the Chino Desalter Authority (CDA). For planning purposes, it was assumed that the JCSD and the City of Ontario would contract for the remaining 5 mgd of existing capacity and an additional 5 mgd of new capacity for a total desalter system capacity of 33.2 mgd. The groundwater production capacity associated with the desalters would be 39,400 acre-ft/yr. The Chino Creek Well Field was assumed to have a capacity of 7,500 acre-ft/yr.

Two different replenishment scenarios were used for the desalters. These scenarios are listed in Tables 7-6a and 7-6b. Table 7-6a illustrates the desalter replenishment with the most rapid depletion of the water made available through Re-Operation. The projected desalter well production is about 28,700 acre-ft/yr in 2006/07 and expands to 39,400 acre-ft/yr in 2013/04. The column titled *New Yield* corresponds to an assumed increase in yield from the Santa Ana River attributable to the desalters coupled with Re-Operation. The new yield is assumed to be 30 percent of the desalter production. The water made available through Re-Operation is allocated at 10,000 acre-ft/yr to the desalter capacity expansion through the period of the Peace Agreement ending in 2029/30 for a total of about 175,000 acre-ft. The remaining 225,000 acre-ft of Re-Operation water is allocated to existing desalter capacity and is used for desalter replenishment at the maximum rate until the 225,000 acre-ft is exhausted. Wet water replenishment for the existing desalter capacity will start in about 2018 and will total about 213,000 acre-ft through 2029/30.

7.2.1.4 Dry-Year Yield Program

The Baseline and planning alternatives include DYYPs. The existing 100,000 acre-ft DYYP is included in Baseline and Alternatives 1A and 1B. The DYYPs consist of "puts" and 'takes" where Metropolitan, in consultation with Watermaster and the IEUA, makes surplus water available to the basin, which is recharged into the basin via wet water recharge or by in-lieu means (the "put"). Under the existing program, Metropolitan can recharge up to 25,000 acre-ft/yr in the basin and can call on up to 33,300 acre-ft/yr from the basin. When Metropolitan makes a call, the appropriators that participate in the DYYP reduce their demands on Metropolitan's imported supplies and make up the difference by producing more groundwater from Metropolitan's storage account (the "take"). Table 7-7 illustrates the put and take assumptions that have been incorporated into this investigation. For the existing 100,000 acre-ft DYYP, the puts were assumed to have been made by in-lieu means; this is the preferred method of the appropriators, and it frees up wet water recharge capacity for future replenishment. The take commitments are actual contractual commitments between the listed Appropriators and the IEUA.

7.2.1.5 Final Estimates of Groundwater Production and Replenishment for the Initial Baseline Alternative Simulation

In programming the DYYPs and replenishment, a 15-year cycle was used that consists of the following: three *take* years in which no replenishment water would be available, four *put* years in which Metropolitan would put water into its DYYP account and replenishment water would be available, and eight *hold* years in which replenishment water would be available. In total, replenishment water would be available 12 out of the 15 years or 80 percent of the time.

Currently, beyond the recharge improvements that are expected to be completed in 2008, there are no plans to expand replenishment capacity in the Chino Basin; thus, all future estimates of groundwater production need to be capped in a way that will not allow groundwater production to create a situation wherein Watermaster will not be able to replenish overproduction. The groundwater production estimates used in this investigation are included in Table 7-3 under the group of columns entitled *Projected Watermaster Production for WEI Trial 2 Projection for the 2007 Peace II Analysis*. The columns labeled *Overlying Non-Ag Pool* and *CDA Desalters* have not changed. The column labeled *Overlying Ag Pool* has been reduced in the out years from 10,000 acre-ft/yr to 5,000 acre-ft/yr. The column labeled *Appropriative Pool less CDA Desalters* has been modified in some planning years so that the aggregate Appropriators' production, excluding the CDA Desalters, does not create a replenishment obligation in excess of the wet-water replenishment capacity available to Watermaster. Compared to the WEI Trial 1 Projection, this projection includes a 24,000 acre-ft reduction in production by 2014/15 and a 33,000 acre-ft/yr reduction by 2019/20 and thereafter.

These groundwater production projections are substantially less than proposed by the Appropriators in the B&V projections. These projections have been reduced first, as mentioned earlier, to be consistent with actual Appropriator production; second, to live within the capacity of the existing wet water replenishment capacity; third, to provide for redundant replenishment capacity; and fourth, to avoid large declines in storage from operating the basin in a deficit when imported water is not available for replenishment. The Trial 2 projections will result in temporary maximum reduction in storage of about 150,000 acre-ft during periods when supplemental water is not available for replenishment.

Figure 7-6 illustrates the time histories of groundwater pumping, replenishment, and replenishment balance for the initial simulations of the Baseline Alternative and Alternative 1A. The 15-year cycle for the DYYP is clearly evident with take periods occurring starting in years 2008/09, 2023/24, 2038/39, and 2053/54, and put and hold periods occurring in between. During take periods the replenishment drops to zero for three consecutive years, and the replenishment balance (the cumulative unmet replenishment obligation) grows to about 200,000 acre-ft. Subsequent to the take periods, replenishment occurs at the maximum rate the recharge facilities can sustain until the replenishment balance is eliminated and the replenishment is then equal to the gross overproduction. The DYYP starts with a take period in fiscal 2008/09 for two reasons: first the DYYP account has already been almost completely filled (~90,000 acre-ft); and it is likely, given the projected rainfall for 2007/08, that Metropolitan may make a call on the DYYP water stored in the Chino Basin in 2008/09.

The production projections used in the initial evaluations of the planning alternatives are shown by party in Table 7-8. These projections should be characterized as "net" production projections. That groundwater production has been reduced in the groundwater simulations from prior planning investigations does not necessarily mean that total production would actually be reduced. Watermaster and others could expand the replenishment capacity, or the Appropriators could increase recharge capacity on their own through the construction of aquifer storage and recovery (ASR) wells. ASR wells could be used to inject treated SWP water when SWP water is available and there is surplus treatment plant capacity.

7.3 Adjustments to Baseline and Planning Alternatives Based on Preliminary Groundwater Simulations of the Baseline Alternative

The planning data for the Baseline Alternative was input to the groundwater model and simulated from 2005/06 through 2059/60. Interpretation of the model results indicated that the safe yield of the basin is declining from the currently used value of 140,000 acre-ft/yr to just less than about 120,000 acre-ft/yr at the end of the planning period. A total of 14 simulations of the Baseline Alternative were required to develop a time history of safe yield and the associated replenishment obligation over the planning period. The safe yield used in the Baseline Alternative was also used in Alternatives 1A and 1B along with the assumed time history of new Santa Ana River recharge (Tables 7-6a and 7-6b) to estimate the replenishment obligations for these alternatives.

Watermaster, pursuant to the Peace Agreement, will estimate the safe yield in 2011 and every ten years thereafter (Peace Agreement, Exhibit B, Page 45). Watermaster can, on its own initiative, estimate the safe yield in any year after 2011. The year 2010/11 was selected in the Peace Agreement as it was the first year that Watermaster believed it would have at least ten years of good concurrent estimates of groundwater pumping and groundwater levels from which it would be able to estimate safe yield. In the preliminary simulations of the Baseline Alternative, it was discovered that the safe yield of the basin was declining steadily from about 140,000 acre-ft/yr to about 116,000 acre-ft/yr. Starting in 2010/11, the safe yield was estimated each year and the associated replenishment obligation was estimated based on the safe yield. The safe yield will be discussed in greater detail in Section 7.4.5.

Reducing the safe yield in the planning alternatives results in a greater replenishment obligation than estimated in Section 7.2.1.5. In fact, the required replenishment capacity exceeds the assumed maximum capacity of about 91,000 acre-ft/yr after 2026/27. The replenishment capacity was increased to about 104,000 acre-ft/yr by reducing the duration of the annual maintenance period from three to two months. Presumably, this can accomplished without any new facilities. This adjustment in replenishment capacity was included in final Baseline Alternative and Alternatives 1A and 1B.

The Baseline Alternative was simulated with the new time history of the safe yield and the revised replenishment capacity. The groundwater model projected that groundwater levels in the area centered in the Cucamonga Valley Water District (CVWD) Chino Basin well field would rapidly decline, and in the out years, the computational cells near some of these wells would dry up, effectively eliminating production from these wells. This groundwater level depression is the result of the projected expansion of groundwater production specifically by the CVWD and the City of Ontario and somewhat due to the production of the parties surrounding the CVWD well field and the City of Ontario. Near the center of this pumping depression, groundwater levels were projected to change by about -60 to -70 feet in all layers by the fall of 2023 and hold constant through 2053. This groundwater level depression radiated outward to the eastern, southern, and western parts of the basin. The projected increase in groundwater production by the CVWD and the City of Ontario in the north central part of the basin could not be mitigated by the associated increase in replenishment at the existing recharge facilities in the basin. These available recharge facilities are too far away from the

CVWD Chino Basin well field to provide a significant offset to the increased production. It was determined through a sensitivity analysis that the net groundwater production in this area would need to be reduced to maintain groundwater levels at reasonable levels. It was assumed that the increase in net groundwater production by CVWD and the City of Ontario would be limited to 23,800 acre-ft/yr and 29,000 acre-ft/yr, respectively, which is 5,000 acre-ft/yr each over their projected production in 2006/07. Their groundwater production could be greater if the local recharge capacity in the north central part of the basin was increased in the future.

With this change in groundwater production projections, the simulation of the Baseline Alternative was complete. The same production and safe yield projections were used in the simulations of Alternatives 1A and 1B. The projected replenishment plan in the Baseline Alternative was modified in Alternatives 1A and 1B to include the projected new Santa Ana River recharge and reductions in replenishment created by Re-operation as shown in Tables 7-6a and 7-6b.

7.4 Evaluation of Planning Alternatives

Per the Peace Agreement, material physical injury is defined as: *"material injury that is attributable to Recharge, Transfer, storage and recovery, management, movement or Production of water or implementation of the OBMP, including, but not limited to, degradation of water quality, liquefaction, land subsidence, increases in pump lift and adverse impacts associated with rising groundwater"* (Peace Agreement, page 8). An analysis of material physical injury was performed using the evaluation criteria described below and the results of the 2007 Watermaster Groundwater Model. Hydraulic control was assessed through the development and assessment of detailed groundwater level maps for the southern part of the Chino Basin and from tabulations of the water balance for each management zone. Each planning alternative was simulated with and without the DYYP.

7.4.1 Evaluation Criteria

Each planning alternative was evaluated to determine changes in groundwater level, changes in Santa Ana River discharge, changes in basin balance, hydraulic control effectiveness, changes in safe yield, and potential subsidence. This was accomplished using the updated 2007 Watermaster Model to estimate groundwater and surface water responses to the planning alternatives. The impacts of Alternatives 1A and 1B were assessed by comparing the results of these simulations to the Baseline Alternative. Information was extracted from the model results to produce:

- Groundwater level projections to determine the change in groundwater levels throughout the basin and to assess hydraulic control and potential new subsidence. Time series charts were prepared to show the projected groundwater level changes at selected wells in the basin (Appendix D). Maps were produced, showing the areal distribution of groundwater elevations, the change in groundwater elevations relative to the start of the planning period, and the difference in groundwater elevations caused by Re-operation (Appendix E). Local maps were prepared in the southern end of the basin to assess hydraulic control.

- Surface water discharge projections of the Santa Ana River at Prado Dam to estimate the induced Santa Ana River recharge caused by Re-operation.

- Water balance tables to determine outflow from the Chino North Management Zone to the

Prado Basin Management Zone and the Santa Ana River, new recharge from the Santa Ana River into the Chino South and Prado Basin Management Zones, the change in storage, and the change in safe yield (Appendix F).

The safe yield of the basin was estimated using a mass balance method, which is one of the methods that was used by William Carroll in the original estimate of the safe yield for the Chino Basin Judgment (WEI, 1999).

7.4.2 Projected Changes in Santa Ana River Discharge

Figure 7-7 summarizes the projected changes in Santa Ana River discharge at Prado Dam for Alternatives 1A and 1B, respectively, relative to the Baseline Alternative. The Santa Ana River discharge that corresponds to the Baseline Alternative is assumed herein to be the threshold to measure future changes in basin outflow and new yield due to Re-operation. Differences between the discharge for the Baseline Alternative and Alternatives 1A and 1B is the new recharge caused by Re-operation and approximates the new yield generated by Re-operation; that is, if an alternative results in a decrease in Santa Ana River discharge compared to the Baseline Alternative, the decrease in discharge would approximate the increase in yield in the Chino Basin. The new Santa Ana River recharge achieved through Re-operation is about 8,600 acre-ft/yr for Alternative 1A and 9,000 acre-ft/yr for Alternative 1B; the difference between these two projections is not significant given the uncertainty of the water supply and replenishment plans in the out years. These values represent the average change in discharge from 2034/35 through 2059/60. During the period 2005/06 and 2034/35, the new Santa Ana River recharge grows rapidly from zero to 9,000 and 10,000 acre-ft/yr for Alternatives 1A and 1B, respectively. That said, it never reaches the assumed constant recharge assumed in Table 7-6a and Table 7-6b. The result of this shortfall is a reduction in storage by 2029/30 of about 198,000 acre-ft/yr and 212,000 acre-ft/yr for Alternatives 1A and 1B, respectively, above the 400,000 acre-ft provided by Re-operation. This shortfall in induced recharge should be mitigated preferably after 2030 to ensure that hydraulic control is achieved as soon as possible.

7.4.3 Projected Groundwater Levels in the Chino Basin

Figure 7-8 is a map that shows the locations of selected wells that have groundwater level time history projections for the planning alternatives that are shown in Figures 7-9a through 7-9l. The projected groundwater elevations in 2022/23 for each planning alternative and the difference between the 2022/23 groundwater elevation projections and the 2005/06 initial condition were mapped for each planning scenario for layers 1, 2, and 3. Similar maps were prepared for 2052/53. These maps show how groundwater elevations are projected to change over the planning period. A second set of maps was prepared that show the projected difference in groundwater elevations for Alternatives 1A and 1B relative to the Baseline Alternative for 2022/23 and 2052/53. All of these maps are contained in Appendix E. The groundwater level maps were prepared from simulations without the DYYP so that the transients introduced by the DYYP would not be confused with the change in groundwater levels caused by Re-operation. The groundwater level projections at wells were prepared from the simulations with the DYYP to illustrate the impacts of Re-Operation and the DYYP. The groundwater elevation changes are not uniform across the basin, and therefore some water agencies will experience greater lift and related energy expenses from Re-operation. That said, the parties to the Judgment have indicated that they are willing to accept an increase in energy expenses with the expectation of other financial gains and certainties made possible by implementing the Peace II project description and other Peace II related agreements. Therefore, no material physical injury is projected to occur from the decline in groundwater levels caused by Alternatives 1A and 1B. In all cases, groundwater production is projected to be maintained in Alternatives 1A and 1B although some changes in production and replenishment plans may be required. From a production perspective, no material physical injury is projected to occur from the decline in groundwater levels caused by Alternatives 1A and 1B.

7.4.3.1 Baseline Alternative

There are significant groundwater elevation changes throughout the basin as a result of the implementation of water supply plans and the associated replenishment plans contained in the Baseline Alternative. Figures E-1 through E-3 show the projected groundwater elevations for the Baseline Alternative in the fall of 2023 for layers 1 through 3, respectively. Similarly, Figures E-4 through E-6 show the projected groundwater elevations for the Baseline Alternative in the fall of 2053 for layers 1 through 3, respectively. Recall that 2023 and 2053 correspond to dates that are 10 and 40 years after the completion of the desalter system. The general shape of the groundwater elevation contours is similar to the current groundwater elevation contours with the following exceptions:

- Groundwater flow from the Santa Ana River into the basin is more pronounced
- The occurrence of a pumping depression centered on CVWD's wells in the north central part of the basin
- The development of a pumping depression and capture zone in the Chino Desalter I well field

Figures E-7 through E-9 show the projected changes in groundwater elevations for the Baseline Alternative in the fall of 2023 for layers 1 through 3, respectively. Similarly, Figures E-10 through E-12 show the projected groundwater levels for the Baseline Alternative in the fall of 2053 for layers 1 through 3, respectively. These changes are relative to groundwater elevations in the fall of 2005. Note the following changes in groundwater elevations:

- Through fall 2023, groundwater elevations in the MVWD and City of Pomona production area are projected to change by about +20 to +60 feet in layer 1 and from -20 to +40 feet in layers 2, and 0 to +40 feet in layer 3. By the fall of 2053, groundwater elevations are projected to change by +10 to +60 feet in layer 1, -20 to +20 feet in layer 2, and -20 to +20 feet in layer 3.
- Through fall 2023, groundwater elevations in the MZ1 subsidence area (the production area for the Cities of Chino and Chino Hills) are projected to change by 0 to +20 feet in layer 1, -30 to -40 feet in layer 2, and -10 to -20 feet in layer 3. Through fall 2053, groundwater elevations in the MZ1 subsidence area are projected to change by 0 to +10 feet in layer 1, -40 to -50 feet in layer 2, and -10 to -25 feet in layer 3. The groundwater level declines in layers 2 and 3 are still well above the subsidence threshold, and therefore new inelastic subsidence is not expected to occur for the Baseline Alternative.
- A large pumping depression is projected to form centered on the area where CVWD produces groundwater and to radiate outward through the City of Ontario production area. The pumping hole is the result of the projected expansion of groundwater production by CVWD and the City of Ontario. Near the center of this pumping depression, groundwater levels are projected to change by about -60 to -70 feet in all layers by the fall of 2023 and to remain at these levels through 2053. This pumping depression appears to affect the entire central part

of the basin and radiate outward to the eastern, southern, and western parts of the basin.

- Through fall 2023, groundwater elevations in the JCSD production area are projected to change by about -20 to -40 feet in all layers and to remain at these levels through the fall 2053.
- Through fall 2023, groundwater elevations in the City of Ontario production area are projected to change by about -20 to -60 feet in all layers. By fall 2053 groundwater elevations are projected to change by about -10 to -60 feet by the fall of 2053 for layer 1, and -20 to -60 feet in layers 2 and 3.
- Through fall 2023, groundwater elevations in the FWC production area are projected to change by about -40 to -50 feet in all layers. By the fall of 2053, groundwater elevations are projected to change by -30 to -40 feet in all layers.
- Through fall 2023, groundwater elevations in the Desalter No. 1 well field area are projected to change by about -15 to -25 feet in all layers and are projected to remain at these levels through the fall of 2053.
- Through fall 2023, groundwater elevations in the Desalter No. 2 well field area are projected to change by about -40 to -50 feet in all layers and are projected to remain at these levels through the fall of 2053.

7.4.3.2 Alternative 1A – Expansion of the Desalters, Re-Operation, and the 100-KAF Dry-Year Yield Program, with Most Rapid Depletion of the Re-Operation Account

There are groundwater elevation changes throughout the basin as a result of the implementation of water supply plans and the associated replenishment plans contained in Alternative 1A. Figures E-13 through E-15 show the projected groundwater elevations for Alternative 1A in the fall of 2023 for layers 1 through 3, respectively. Similarly, Figures E-16 through E-18 show the projected groundwater elevations for Alternative 1A in the fall of 2053 for layers 1 through 3, respectively. Recall that 2023 and 2053 correspond to dates that are 10 and 40 years after the completion of the desalter system. Figures E-19 through E-21 show the projected changes in groundwater elevations for Alternative 1A in the fall of 2023 for layers 1 through 3, respectively. Similarly, Figures E-22 through E-24 show the projected changes in groundwater elevations for Alternative 1A in the fall of 2053 for layers 1 through 3, respectively. These changes are relative to groundwater elevations in the fall of 2005. The general shape of the groundwater elevation contours is similar to the Baseline Alternative groundwater elevation contours with the following exceptions:

- Groundwater flow from the Santa Ana River into the basin is more pronounced than in the Baseline Alternative
- The expansion of the pumping depression centered on CVWD's wells in the north central part of the basin relative to the Baseline Alternative
- The development of a more expansive and deeper pumping depression and capture zone in the Chino Desalter No. 1 well field relative to the Baseline Alternative

Figures E-19 through E-21 show the projected changes in groundwater elevations for Alternative 1A in the fall of 2023 for layers 1 through 3, respectively. Similarly, Figures E-22 through E-24 show the projected groundwater levels for Alternative 1A in the fall of 2053 for layers 1 through 3, respectively. These changes are relative to groundwater elevations in the fall of 2005. Generally, groundwater elevations in Alternative 1A are less than the groundwater elevation projections in the Baseline Alternative. The decline in groundwater levels is attributable to Re-operation. The following changes in groundwater elevations are of note:

- Through fall 2023, groundwater elevations in the MVWD and City of Pomona production area are projected to change by about -30 to +20 feet in layer 1, from 0 to -60 feet in layer 2, and from 0 to -40 feet in layer 3. By the fall of 2053, groundwater elevations are projected to change by -30 to +20 feet in layer 1, from 0 to -60 feet in layer 2, and from 0 to -40 feet in layer 3. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 40 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the MZ1 subsidence area (the production area for the Cities of Chino and Chino Hills) are projected to change by about 0 to -25 feet in layer 1, 0 to -60 feet in layer 2, and -40 to -50 feet in layer 3. Through fall 2053, groundwater elevations in the MZ1 subsidence area are projected to change by about 0 to -25 feet in layer 1, 0 to -60 feet in layer 2, and -40 to -50 feet in layer 3. The groundwater level declines in layers 2 and 3 are still above the subsidence threshold, and therefore new inelastic subsidence is not expected to occur with Alternative 1A. Relative to the Baseline Alternative, in 2023, groundwater elevations in Alternative 1A are projected to be about 10 to 20 feet less in layer 1, 20 feet less in layer 2, and 20 feet less in layer 3. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 30 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Similar to the Baseline Alternative, a large pumping depression is projected to form centered on the area where CVWD produces groundwater and to radiate outward through the City of Ontario production area. The pumping hole is the result of the projected expansion of groundwater production by CVWD and the City of Ontario. Near the center of this pumping depression groundwater levels are projected to change by about -100 to -110 feet in all layers by the fall of 2023, and by about -110 to -120 feet by the fall of 2053. This pumping depression appears to affect the entire central part of the basin and to radiate outward to the eastern, southern, and western parts of the basin. Relative to the Baseline Alternative, groundwater elevations are projected to be about 40 to 50 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater levels in the JCSD production area are projected to change by about -60 to -90 feet in all layers by the fall of 2023, and by about -80 to -90 feet by the fall of 2053. Relative to the Baseline Alternative, groundwater elevations are projected to be about 40 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the City of Ontario production area are projected to change by about -40 to -100 feet in all layers and by about -60 to -110 feet in all layers by the fall of 2053. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 50 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the FWC production area are projected to change by about -60 to -90 feet in all layers and by about -80 to -90 feet in all layers by the fall of 2053 for. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 50 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the Desalter No. 1 well field area are projected to change by about -20 to -50 feet in all layers and to remain at these levels through the fall 2053. Relative to the Baseline Alternative, in the fall of 2023, groundwater elevations in Alternative 1A are projected to be about 5 to 25 feet less across all layers through the end of the planning period. Re-operation has depressed the groundwater elevations at the desalter wells relative to the Baseline Alternative.

- Through fall 2023, groundwater elevations in the Desalter No. 2 well field area are projected to change by about -50 to -70 feet in all layers and to remain at these levels through the fall 2053. Relative to the Baseline Alternative, in the fall of 2023, groundwater elevations in Alternative 1A are projected to be about 10 to 20 feet less across all layers through the end of the planning period. Re-operation has depressed the groundwater elevations at the desalter wells relative to the Baseline Alternative.

7.4.3.3 Alternative 1B – Expansion of the Desalters, Re-Operation, and the 100-KAF Dry-Year Yield Program, with Proportional Depletion of the Re-Operation Account

The groundwater elevations with Alternative 1B are almost identical to Alternative 1A. Figures E-25 through E-27 show the projected groundwater elevations for Alternative 1B in the fall of 2023 for layers 1 through 3, respectively. Similarly, Figures E-28 through E-30 show the projected groundwater elevations for Alternative 1B in the fall of 2053 for layers 1 through 3, respectively. Recall that 2023 and 2053 correspond to dates that are 10 and 40 years after the completion of the desalter system. Figures E-31 through E-33 show the projected changes in groundwater elevations for Alternative 1B in the fall of 2023 for layers 1 through 3, respectively. Similarly, Figures E-33 through E-36 show the projected changes in groundwater elevations for Alternative 1B in the fall of 2053 for layers 1 through 3, respectively. These changes are relative to groundwater elevations in the fall of 2005. The difference between Alternatives 1A and 1B are related to the timing of Re-operation and result in slight changes in the timing of desalter replenishment deliveries.

7.4.4 Hydraulic Control

Hydraulic control refers to the elimination or reduction of groundwater discharge from the Chino North Management Zone to the Santa Ana River to negligible levels. It is a requirement of Watermaster and the IEUA's recycled water recharge permit and a condition to gaining access to the assimilative capacity for TDS and nitrogen afforded by the maximum benefit based TDS and nitrogen objectives. Hydraulic control was assessed herein from detailed groundwater elevation contour maps.

Figures 7-10a and 7-10b show the groundwater elevation contours for layer 1 with the Baseline Alternative for the fall of 2023 and 2053, respectively, which correspond to 10 and 40 years after the completion of the desalter system. These maps also show the direction of groundwater flow in the form of simple unit vectors. The water level contour maps for the Baseline Alternative generally suggest that groundwater flows away from the Santa Ana River upstream of the Prado Reservoir, south of the Desalter II well field, and south of the eastern part of the Desalter I well field. There is some indication that hydraulic control is achieved in the Baseline Alternative with about a maximum 5 to 7 foot groundwater level depression in the center of the CCWF relative to the apparent stagnation point down gradient from the CCWF (assumed at an elevation of 507 feet) by the fall of 2023; and the depression expands slightly by the fall of 2053. Hydraulic control cannot be assured with this marginal depression in the center of the CCWF.

Figures 7-11a and 7-11b show the groundwater elevation contours for layer 1 with Alternative 1A for the fall of 2023 and 2053, respectively, which correspond to 10 and 40 years after the completion of the desalter system. The general shape of the groundwater elevation contours for Alternative 1A is similar to the Baseline except that the state of hydraulic control is demonstrably more certain. The groundwater level depression in the center of the CCWF is about 17 feet by the fall of 2023 and reaches about 23 feet by the fall of 2053 or about twice that of the Baseline Alternative. The shape of the groundwater level contours around the eastern half of the Desalter I well field demonstrates a much stronger flow pattern to the wells from the north and the south than exhibited in the Baseline Alternative. From Figure 7-7, it appears that most of this drawdown occurs by 2030, the end of the Re-operation period. There is an appearance of slight leakage along the Chino Hills margin of the basin; however, this leakage is a numerical artifact and is negligible.

Figures 7-12 and 7-12b show the groundwater elevation contours for layer 1 with Alternative 1B for the fall of 2023 and 2053, respectively. The shape and locations of the groundwater elevation contours for Alternative 1B are almost identical to Alternative 1A. The groundwater level depression in the center of the CCWF reaches about 15 feet by the fall of 2023 and about 25 feet by the fall of 2053 or more about double that of the Baseline; and, the shape of the groundwater level contours around the eastern half of the Desalter I well field demonstrates a much stronger flow pattern to the wells from the north and the south than exhibited in the Baseline Alternative. Alternative 1A is superior to 1B in the near term and comparable to 1B after 2030.

One of the assumptions in the Baseline Alternative is that the basin is operated in balance pursuant to the Judgment with the desalter production offsetting the decline in agricultural production. That balance has historically included a significant discharge from the basin to the Santa Ana River. Managing the net production from the basin to the operating yield and the dependence on the sustained production by others will produce a marginal state of hydraulic control at best, a state of hydraulic control that cannot be assured. The model projections for Alternatives 1A and 1B demonstrate a more robust state of hydraulic control. Re-operation is required to rapidly achieve and maintain hydraulic control.

7.4.5 Projected Safe Yield

Todd defines the safe yield of a groundwater basin as the amount of water that can be withdrawn from it annually without producing an undesired result (1959). Undesired results include the depletion of groundwater reserves, the intrusion of water of undesirable quality, the contravention of existing water rights, and the deterioration of the economic advantages of pumping (Cherty and Freeze, 1979).

The safe yield of the Chino Basin was established to be 140,000 acre-ft/yr in the 1978 Judgment. The basis for this estimate was described by William J. Carroll in his testimony during the adjudication process on December 19 and 20, 1977 (Carroll, 1977). Carroll based his estimate, in part, on the average net inflow (recharge minus natural and uncontrolled discharge) for the period of 1965 to 1974. Carroll characterized this period as the base period. Carroll estimated the average change in storage to be about 40,000 acre-ft/yr over the base period. Carroll also estimated the safe yield as the average extraction over the base period plus the average change in storage during the base period:

$$\text{safe yield} = \text{average extraction} + \text{average change in storage}$$
$$= 180{,}000 - 40{,}000$$

= 140,000 acre-ft/yr

The 140,000 acre-ft/yr value, so derived, was almost identical to the value derived from Carroll's average net inflow estimate and thus the value of 140,000 acre-ft/yr was incorporated into the Judgment. For a detailed discussion of Carroll's work, review pages 2-28 and 2-29 of the Optimum Basin Management Program - Phase I Report (WEI, 1999) or the transcripts of Carroll's testimony (see Section 9, References).

The methods employed by Carroll produced a yield that, in theory, would stabilize groundwater levels and storage for the pumping and water use patterns that occurred in the 1965 to 1974 period. The same method was used herein to estimate the safe yield on an annual basis for period of 2015/16 through 2059/60. The method used by Carroll was modified to reflect Watermaster's replenishment requirements pursuant to the Judgment. That is:

$$\text{safe yield} = (\text{total extraction} - \text{total replenishment} + \text{change in storage}) \,/\, \Delta t$$

The total production, total replenishment, and change in storage were abstracted from simulation results for the calibration period and each planning alternative. Figure 7-13 shows a 90-year estimate of safe yield starting with the year 1970/71 and extending through the remaining part of the calibration period and through the entire planning period to 2059/60. The safe yield estimate for any year was estimated from the hydrology of the prior ten years. The safe yield reached a high of about 160,000 acre-ft/yr in the late 1980s and systematically declines through the remaining part of the calibration period and through the planning period.

Table 7-9 contains the safe yield estimates for each planning alternative and period. For the period of 2005/06 through 2015/16, the safe yield for the Baseline Alternative declines from about 145,000 to about 134,000 acre-ft/yr. For the period after 2016/17 the safe yield for the Baseline Alternative declines gradually from about 134,000 acre-ft/yr to about 119,000 acre-ft/yr by the end of 2059/60. The safe yield declines due to the reductions in the deep percolation of applied water and precipitation and the reduction in storm water recharge. The reduction in recharge is caused by historical and projected changes in land use and associated water use patterns from the conversion of agricultural and vacant land uses to urban uses through 2025.

For the period 2005/06 through 2016/17, the safe yield increase associated with Re-operation is projected to reach about 2,000 acre-ft/yr by 2016/17, steadily increase to about 8,000 to 9,000 acre-ft/yr by 2030, and to average about 8,500 to 9,000 acre-ft/yr for the period of 2030/31 through 2059/60. Note that the average safe yield for the period of 2030/31 through 2059/60 is about the same as the increase in Santa Ana Recharge discussed in Section 7.4.2. There are no reductions in yield projected for Alternatives 1A and 1B relative to the Baseline Alternative; thus, there is no material injury related to safe yield changes.

7.4.6 Subsidence

WEI has been conducting subsidence investigations in MZ1 for Watermaster since September 2000. As part of this process, WEI has been reviewing recent historical subsidence across the basin using InSAR, ground level surveys, controlled pumping tests, and a rigorous review of the basin hydrogeology. Figure 7-14 shows the location of recent subsidence in MZ1 (1996-2000) and defines the southern and central sub-areas of subsidence within MZ1. Figure 7-15 shows the projected the piezometric elevations at the PA-7 piezometer for all of the planning alternatives. The PA-7 piezometer is used in the Watermaster's MZ1 Long Term Management Plan. In this plan, basin management activities that maintain piezometric elevations greater than 400-feet at the PA-7 piezometer (corresponding to a depth to water of 245 feet) will not cause inelastic subsidence. In all cases, the projected piezometric elevations are 50 to 80 feet higher than the subsidence threshold elevation of 400 ft for the managed area of MZ1; thus, no inelastic subsidence is projected to occur in MZ1. There are no material physical injuries related to subsidence from any of the planning alternatives.

7.5 Future Reviews

The data used to calibrate the model include actual and estimated groundwater recharge and production data. In contrast, the future simulations are based on educated estimates of future land use and associated water use practices and future production. There is no way to determine the accuracy of the information used in the future simulations. The model was used to refine the projected groundwater production and replenishment in the Baseline Alternative. Therefore, even though the groundwater model is well calibrated, it is possible that the planning information used to evaluate the future alternatives could be flawed and the modeling results questionable. The following should be done to overcome potential inaccuracies due to the planning data and to maintain the model:

- Groundwater production and recharge projections should be revised as new information becomes available. New baselines and alternatives should be evaluated with the model on a periodic basis if the future production and replenishment plans change significantly either in time or location.
- Groundwater and recharge monitoring programs should continue into the foreseeable future. These programs will provide information that can be used to assess the consistency of real world behavior with what was assumed in the planning alternatives and used in model calibration updates. This is especially important on a go forward basis as the projected operation of the basin is outside the bounds of historical range of operation that occurred in the calibration period of the 2007 Watermaster model.

Table 7-1
Aggregate Water Supply Plan for the Municipal Water Purveyors in the Chino Basin Area[1]

(acre-ft/yr)

Water Type	Water Demand 2005	2010	2015	2020	2025
Chino Basin	174,600	205,000	200,700	208,100	215,300
Desalters + Pomona Nitrate[3]	34,500	46,400	49,200	49,200	49,200
Other Groundwater[2]	36,200	37,900	38,700	38,800	38,800
Local Surface Water	20,700	20,700	20,700	20,700	20,700
Recycled Water	12,500	38,900	49,100	58,400	65,600
MWDSC Direct	66,800	72,200	77,700	84,000	85,900
Total Water Use	345,300	421,100	436,100	459,200	475,500
Replenishment					
MWDSC Replen	52,100	75,400	73,900	84,300	89,500
Recycled Replen	0	19,000	19,000	21,000	23,000
Total Replenishment	52,100	94,400	92,900	105,300	112,500
Total MWDSC	118,900	147,600	151,600	168,300	175,400
Total Recycled	12,500	57,900	68,100	79,400	88,600

1 -- Based on the 2005 Urban Water Management Plans of the municipal pumpers in the Chino Basin

2 -- Groundwater basins adjacent to the Chino Basin

3 -- CDA and City of Pomona total pumping, and in addition to the Chino Basin pumping listed above

Table 7-2
Appropriator Share of Safe Yield and Production for the Period 1999/00 through 2006/07

Appropriator	Share of Safe Yield		Chino Basin Production by Fiscal Year for Fiscal Years 1999/00 through 2006/07									
			1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	Maximum	Average
	(%)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)	(acre-ft/yr)
Arrowhead Mountain Spring Water Company	0.0%	0	115	143	76	116	55	95	260	392	392	156
Chino Desalter Authority	0.0%	0	0	15,978	9,458	10,439	10,605	9,854	16,476	26,356	26,356	12,396
City of Chino	7.4%	4,034	10,201	7,147	5,613	4,707	3,588	4,180	3,262	5,100	10,201	5,475
City of Chino Hills	3.9%	2,112	4,264	4,063	3,398	1,655	1,985	2,153	458	1,583	4,264	2,445
City of Norco	0.4%	202	257	227	407	539	397	84	0	0	539	239
City of Ontario	20.7%	11,374	36,523	33,988	31,968	33,295	28,115	26,291	28,419	23,956	36,523	30,320
City of Pomona	20.5%	11,216	18,966	17,453	17,666	17,571	16,111	15,981	9,945	10,888	18,966	15,573
City of Upland	5.2%	2,852	1,737	2,580	2,390	1,783	1,929	1,910	2,202	1,521	2,580	2,006
Cucamonga Valley Water District	6.6%	3,620	7,250	6,765	8,282	11,962	11,139	12,059	14,458	18,786	18,786	11,338
Fontana Union Water Company	11.7%	6,397										
Fontana Water Company	0.0%	0	20,947	17,900	23,565	19,455	25,828	21,959	15,137	16,112	25,828	20,113
Jurupa Community Services District	3.8%	2,078	15,672	11,253	12,586	12,707	16,556	16,147	17,558	17,840	17,840	15,040
Inland Empire Utilities Agency	0.0%	0	3	4	4	4	2	1	1	0	4	2
Marygold Mutual Water Company	1.2%	655	0	1	0	0	183	132	136	184	184	80
Metropolitan Water District of Southern California	0.0%	0	0	0	1	1	1	1	1	0	1	1
Monte Vista Irrigation Company	1.2%	677	0	0	0	0	0	0	0	0	0	0
Monte Vista Water District	8.8%	4,824	9,313	10,505	12,968	12,894	12,666	10,046	8,338	11,279	12,968	11,001
Niagara	0.0%	0	0	0	0	109	522	808	763	1,106	1,106	413
San Antonio Water Company	2.7%	1,507	294	72	932	1,061	908	1,612	1,837	1,276	1,837	999
San Bernardino County (Olympic Facility)	0.0%	0	6	14	15	12	13	14	13	16	16	13
Santa Ana River Water Company	2.4%	1,301	693	951	758	456	567	499	415	0	951	542
Golden State Water Company	0.8%	411	482	372	225	260	171	216	438	881	881	381
West End Consolidated Water Company	1.7%	948	0	0	0	0	0	0	0	0	0	0
West Valley Water District	1.2%	644	0	0	0	0	0	0	0	0	0	0
Totals	100.0%	54,834	126,722	129,415	130,313	129,025	131,340	124,041	120,117	137,275		128,531
Totals less Desalters			126,722	113,437	120,856	118,586	120,735	114,188	103,642	110,919		116,136

Table 7-3
Historical Estimates and Initial Projections of Groundwater Production and Replenishment Obligations

Fiscal Year	Reported/Projected Watermaster Production: Overlying Ag Pool	Overlying Non-Ag Pool	Appropriative Pool less CDA Desalters	CDA Desalters	Total Groundwater Production	Operating Yield	New Yield from Peace II: Storm Water[3]	Santa Ana River[4]	Total	Annual Re-Operation Contribution[12]	Gross Pumping Rights[6]	Gross Potential Replenishment Obligation[7]	Effective Replenishment Capacity[5]	Surplus Replenishment Capacity[8]
Historical Period[1]														
1999/00	44,401	7,774	126,645	0	178,820	145,000	0	0	0	0	145,000	33,820	25,000	-8,820
2000/01	39,954	8,084	105,448	7,989	161,475	145,000	0	3,995	3,995	0	148,995	12,480	25,000	12,520
2001/02	39,494	5,548	112,031	9,458	166,531	145,000	0	4,729	4,729	0	149,729	16,802	25,000	8,198
2002/03	37,457	4,853	111,147	10,439	163,896	145,000	0	5,220	5,220	0	150,220	13,677	25,000	11,324
2003/04	41,978	2,915	120,735	10,605	176,233	145,000	12,000	5,303	17,303	0	162,303	13,931	50,528	36,597
2004/05	34,450	2,327	114,188	9,854	160,819	145,000	12,000	4,927	16,927	0	161,927	-1,108	50,528	51,636
2005/06	31,304	3,025	103,576	16,542	154,446	145,000	12,000	4,962	16,962	0	161,962	-7,516	50,528	58,044
2006/07	29,733	3,241	110,919	26,356	170,249	145,000	12,000	7,907	19,907	0	164,907	5,342	50,528	45,186
For the Planning Period Assumed in the B&V Production Projection Period[2]														
2004/05	47,441	2,877	139,873	17,009	207,199	145,000	12,000	4,927	16,927	0	161,927	45,272	50,528	5,256
2009/10	38,379	2,877	172,916	24,451	238,623	145,000	0	0	0	0	145,000	93,623	75,745	-17,878
2014/15	29,130	2,877	175,455	42,000	249,462	145,000	6,000	0	6,000	0	151,000	98,462	75,745	-22,717
2019/20	17,392	2,877	188,181	42,000	250,449	140,000	6,000	0	6,000	0	146,000	104,449	75,745	-28,705
2024/25	17,392	2,877	188,181	42,000	250,449	140,000	6,000	0	6,000	0	146,000	104,449	75,745	-28,705
WEI Trial 1 Projection for the 2007 Peace II Analysis[9]														
2006/07	29,733	3,241	110,919	26,356	170,249	145,000	12,000	4,927	16,927	0	161,927	8,322	50,528	42,206
2009/10	23,200	3,241	135,329	29,800	191,570	145,000	0	0	0	0	145,000	46,570	75,745	29,175
2014/15	16,600	3,241	161,755	39,400	220,996	145,000	6,000	0	6,000	0	151,000	69,996	75,745	5,749
2019/20	10,000	3,241	188,181	39,400	240,822	140,000	6,000	0	6,000	0	146,000	94,822	75,745	-19,077
2024/25	10,000	3,241	188,181	39,400	240,822	140,000	6,000	0	6,000	0	146,000	94,822	75,745	-19,077
WEI Trial 2 Projection for the 2007 Final Peace II Analysis														
2006/07	29,733	3,241	110,919	26,356	170,249	145,000	12,000	4,927	16,927	0	161,927	8,322	50,528	42,206
2009/10	21,492	3,241	115,177	29,800	169,709	145,000	0	8,610	8,610	20,090	173,700	-3,991	75,745	79,735
2014/15	13,251	3,241	141,311	39,400	197,203	145,000	6,000	11,820	17,820	27,580	190,400	6,803	75,745	68,942
2019/20	5,010	3,241	159,606	39,400	207,257	140,000	6,000	11,820	17,820	10,000	167,820	39,437	75,745	36,308
2024/25	5,010	3,241	157,515	39,400	205,166	140,000	6,000	11,820	17,820	10,000	167,820	37,346	75,745	38,399

1 -- Pumping is actual, gross replenishment obligations are actually less because they do not reflect explicit transactions among the parties or storage activities

2 -- Pumping estimates from the parties developed by B&V and IEUA, gross replenishment obligations are actually less because they do not reflect explicit transactions among the parties or storage activities

3 -- Pursuant to Watermaster resolution , Watermaster assumed that the new stormwater recharge from the CBFIP would be 12,000 acre-ft/yr for the first five years and be adjusted in subsequent five-year periods to reflect basin performance and to correct for prior years performance. New stormwater recharge was re-estimated to be 6,000 acre-ft/yr requiring the second five year period to have a zero new recharge assignment and subsequent five-year periods to have 6,000 acre-ft/yr new recharge assignment.

4 -- Watermaster assumed new Santa Ana River recharge due to desalter pumping and planned reductions in storage. Assumed 50 % of desalter pumping through 2004/05, 30% 2006/06, 9,000 acre-ft/yr during the 400,000 acre -ft re-operation period, and 12,000 acre-ft/yr after the 400,000 acre-ft of controlled overdraft is exhausted. The 9,000 and 12,000 acre-ft/yr values will be trued up with the model for each alternative.

5 -- The effective recharge capacity is based on Table 7-4.

6 -- Gross pumping rights is equal to the operating yield plus the new Yield provided by the Peace Agreement and the Peace II instruments plus a portion of the controlled overdraft equal to the desalter pumping (starting in fiscal year 2006/07 and continuing until the cumulative total of desalter pumping less Santa Ana River reaches 400,000 acre-ft.

7 -- *Gross Replenishment Obligation* is equal to *Total Groundwater Production* minus *Gross Pumping Rights* . The actual replenishment obligation could be less parties choose to offset some or all of their replenishment obligation by transferring water from storage.

8 -- *Surplus Replenishment Capacity* is equal to the *Effective Replenishment Capacity* minus the *Gross Replenishment Obligation. Negative values mean that there is not enough wet water recharge facilities to meet Watermaster's replenishment obligation and therefore water must be taken from storage accounts or Watermaster must limit pumping.. Positive values mean that there is a surplus of water recharge capacity.*

9 -- Overlying agricultural pool production projection is reset to OBMP projection after 2004/05; overlying non-agricultural pool production assumed to be 3,000 acre-ft/yr based on recent historical production; appropriative pool production, excluding CDA production, uses a linear interpolation from the historical production in 2004/05 to the B&V estimate for 2019/20 and the B&V 2024/25 estimate.

Table 7-4
New Storm Water Recharge and Supplemental Water recharge Capacity Estimates[1]

Basin	Revised Estimates Based on CBFIP Designs and Improved Model: Pre-Project Estimate with 1993 Land Use (acre-ft/yr)	Revised Estimates Based on CBFIP Designs and Improved Model: Post-Project Estimate with Ultimate Land Use (acre-ft/yr)	Revised Estimates Based on CBFIP Designs and Improved Model: Increase (acre-ft/yr)	Average Annual Storm Water Recharge Used in Future Simulations[1] (acre-ft/yr)	Supplemental Water Recharge: Operational Availability J	F	M	A	M	J	J	A	S	O	N	D	Average Recharge Rate[2] (cfs)	Supplemental Water Recharge Capacity: Current Estimate of Supplemental Recharge Capacity (acre-ft/yr)	Supplemental Water Recharge Capacity: Future Estimate of Supplemental Recharge Capacity (acre-ft/yr)	Average Reliability of SWP Water for Replenishment from MWDSC IRP	Average Reliability of Recycled Water	Fraction of Recycled Water in Replenishment Blend	Average Reliability of Replenishment Water	Effective Replenishment Capacity (acre-ft/yr)
Brooks Street Basin	1,260	1,710	450	1,710	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	5	2,066	2,066	80%	100%	30%	86%	1,777
College Heights Basins	0	50	50	0	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	15	6,199	6,199	80%	0%	0%	80%	4,960
Montclair Basin 1	260	340	80	340	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70								
Montclair Basin 2	320	370	50	370	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	40	16,532	16,532	80%	0%	0%	80%	13,225
Montclair Basin 3	160	160	0	160	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70								
Montclair Basin 4	220	250	30	250	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70								
Seventh and Eighth Street Basins	0	1,020	1,020	510	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	5	2,066	2,066	80%	100%	30%	86%	1,777
Upland Basin	500	580	80	580	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	20	0	8,266	80%	0%	0%	80%	6,613
Subtotal Management Zone 1	***2,720***	***4,480***	***1,760***	***3,920***														***26,864***	***35,130***					***28,352***
Ely Basins	1,870	1,570	-300	500	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	5	0	2,066	80%	100%	29%	86%	1,773
Etiwanda spreading area (joint use of Etiwanda debris basin)	0	0	0	500	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	6	0	2,480	80%	0%	0%	80%	1,984
Hickory Basin	0	780	780	780	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	5	2,066	2,066	80%	100%	36%	87%	1,802
Lower Day Basin	0	2,180	2,180	1,090	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	10	4,133	4,133	80%	0%	0%	80%	3,306
San Sevaine No. 1	200	930	730	930	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70								
San Sevaine No. 2	20	110	90	110	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	60	24,798	24,798	80%	100%	30%	86%	21,326
San Sevaine No. 3	380	770	390	770	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70								
San Sevaine No.'s 4 and 5	150	630	480	630	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70								
Turner Basins No. 1 and 2	160	1,240	1,080	200	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	6	0	2,480	80%	100%	33%	87%	2,147
Turner Basins No. 3 and 4	0	640	640	200	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70								
Victoria Basin	30	2,090	2,060	1,045	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	6	0	2,480	80%	0%	0%	80%	1,984
Subtotal Management Zone 2	***2,810***	***10,940***	***8,130***	***6,755***														***30,997***	***40,503***					***34,322***
Banana Basin	0	410	410	410	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	5	2,705	2,705	80%	100%	36%	87%	2,359
Declez Basin	0	80	80	80	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	6	0	4,370	80%	100%	30%	86%	3,758
IEUA RP3 Ponds	0	1,330	1,330	665	0.70	0.70	0.70	0.70	1.00	1.00	0.00	0.00	0.00	0.70	0.70	0.70	7	0	8,085	80%	100%	30%	86%	6,953
Subtotal Management Zone 3	***0***	***1,820***	***1,820***	***1,155***														***2,705***	***15,160***					***13,070***
Totals	***5,530***	***17,240***	***11,710***	***11,830***														***60,567***	***90,793***				***83%***	***75,745***

1 -- Recharge Basins not optimized for storm water recharge; actual recharge performance could be improved.
2 -- Per Andy Campbell of IEUA, August 2007

50528.04988

Table 7-5
Desalter Water Deliveries for All Planning Alternatives

Agency	Share of First 24.2 mgd (mgd)	Share of First 24.2 mgd (acre-ft/yr)	Share of Unused 5 mgd (mgd)	Share of Unused 5 mgd (acre-ft/yr)	Share of Next 5 mgd (mgd)	Share of Next 5 mgd (acre-ft/yr)	Total Deliveries (mgd)	Total Deliveries (acre-ft/yr)
City of Chino	4.91	5,000	0.00	0	0.00	0	4.91	5,000
City of chino Hills	4.12	4,200	0.00	0	0.00	0	4.12	4,200
City of Norco	0.98	1,000		0		0		0
City of Ontario	4.91	5,000	2.50	2,600	2.50	2,600	9.91	10,100
Jurupa Community Services District	8.04	8,200	2.50	2,600	2.50	2,600	13.04	13,300
Santa Ana River Water Company	1.18	1,200	0.00	0	0.00	0	1.18	1,200
Western Municipal Water District	0.00	0	0.00	0	0.00	0	0.00	0
Total Deliveries	24.13	24,600	5.00	5,200	5.00	5,200	33.15	33,800
Total Groundwater Production by Desalters		28,700		6,100		6,100		39,400

Table 7-6a
Desalter Replenishment with Most Rapid Depletion of the Re-Operation Account

(acre-ft/yr)

Fiscal Year	Desalter Pumping	New Yield	Re-Operation			Residual Replenishment Obligation
			Replenishment Allocation for Desalter III	Replenishment Allocation to CDA	Balance	
					400,000	0
2006 / 2007	28,700	8,610	0	20,090	379,910	0
2007 / 2008	28,700	8,610	0	20,090	359,820	0
2008 / 2009	28,700	8,610	0	20,090	339,730	0
2009 / 2010	28,700	8,610	0	20,090	319,640	0
2010 / 2011	28,700	8,610	0	20,090	299,550	0
2011 / 2012	28,700	8,610	0	20,090	279,460	0
2012 / 2013	34,050	10,215	5,000	18,835	255,625	0
2013 / 2014	39,400	11,820	10,000	17,580	228,045	0
2014 / 2015	39,400	11,820	10,000	17,580	200,465	0
2015 / 2016	39,400	11,820	10,000	17,580	172,885	0
2016 / 2017	39,400	11,820	10,000	17,580	145,305	0
2017 / 2018	39,400	11,820	10,000	15,305	120,000	2,275
2018 / 2019	39,400	11,820	10,000		110,000	17,580
2019 / 2020	39,400	11,820	10,000		100,000	17,580
2020 / 2021	39,400	11,820	10,000		90,000	17,580
2021 / 2022	39,400	11,820	10,000		80,000	17,580
2022 / 2023	39,400	11,820	10,000		70,000	17,580
2023 / 2024	39,400	11,820	10,000		60,000	17,580
2024 / 2025	39,400	11,820	10,000		50,000	17,580
2025 / 2026	39,400	11,820	10,000		40,000	17,580
2026 / 2027	39,400	11,820	10,000		30,000	17,580
2027 / 2028	39,400	11,820	10,000		20,000	17,580
2028 / 2029	39,400	11,820	10,000		10,000	17,580
2029 / 2030	39,400	11,820	10,000		0	17,580
Totals	876,050	262,815	175,000	225,000		213,235

Table 7-6b
Desalter Replenishment with Proportional Depletion of the Re-Operation Account
(acre-ft/yr)

Fiscal Year	Desalter Pumping	New Yield	Re-Operation			Residual Replenishment Obligation
			Replenishment Allocation for Desalter III	Replenishment Allocation to CDA	Balance	
					400,000	0
2006 / 2007	28,700	8,610	0	7,371	392,629	12,719
2007 / 2008	28,700	8,610	0	7,371	385,258	12,719
2008 / 2009	28,700	8,610	0	7,371	377,886	12,719
2009 / 2010	28,700	8,610	0	7,371	370,515	12,719
2010 / 2011	28,700	8,610	0	7,371	363,144	12,719
2011 / 2012	28,700	8,610	0	7,371	355,773	12,719
2012 / 2013	34,050	10,215	5,000	8,745	342,028	10,090
2013 / 2014	39,400	11,820	10,000	10,119	321,908	7,461
2014 / 2015	39,400	11,820	10,000	10,119	301,789	7,461
2015 / 2016	39,400	11,820	10,000	10,119	281,670	7,461
2016 / 2017	39,400	11,820	10,000	10,119	261,551	7,461
2017 / 2018	39,400	11,820	10,000	10,119	241,431	7,461
2018 / 2019	39,400	11,820	10,000	10,119	221,312	7,461
2019 / 2020	39,400	11,820	10,000	10,119	201,193	7,461
2020 / 2021	39,400	11,820	10,000	10,119	181,073	7,461
2021 / 2022	39,400	11,820	10,000	10,119	160,954	7,461
2022 / 2023	39,400	11,820	10,000	10,119	140,835	7,461
2023 / 2024	39,400	11,820	10,000	10,119	120,715	7,461
2024 / 2025	39,400	11,820	10,000	10,119	100,596	7,461
2025 / 2026	39,400	11,820	10,000	10,119	80,477	7,461
2026 / 2027	39,400	11,820	10,000	10,119	60,357	7,461
2027 / 2028	39,400	11,820	10,000	10,119	40,238	7,461
2028 / 2029	39,400	11,820	10,000	10,119	20,119	7,461
2029 / 2030	39,400	11,820	10,000	10,119	0	7,461
Totals	876,050	262,815	175,000	225,000		213,235

Table 7-7
Adjustment in Production to Effect the Dry-Year Yield Program
(acre-ft/yr)

DYYP Participant	Existing 100,000 Acre-ft Program			
	Reductions in Production for "Put"	Take Commitments		
		New Wells	New Treatment	Total
City of Chino	2,770	0	1,159	1,159
City of Chino Hills	1,450	0	1,448	1,448
City of Ontario	7,809	6,532	1,544	8,076
City of Pomona	7,701	0	2,000	2,000
City of Upland	1,958	0	3,001	3,001
Cucamonga Valley Water District	0	6,532	3,088	9,620
Fontana Water Company	0	0	1,733	1,733
Jurupa Community Services District	0	0	2,000	2,000
Monte Vista Water District	3,312	2,419	1,544	3,963
TVMWD	0	0	0	0
WMWD	0	0	0	0
Total	25,000	15,483	17,517	33,000

Table 7-8
Groundwater Production Projection for the Chino Basin for All Planning Alternatives

(acre-ft/yr)

Producer	Baseline Pumping Projection without Dry Year Yield Program						
	2006/07 (acre-ft/yr)	2009/10 (acre-ft/yr)	2014/15 (acre-ft/yr)	2019/20 (acre-ft/yr)	2024/25 (acre-ft/yr)	2029/30 (acre-ft/yr)	2059/60 (acre-ft/yr)
Overlying Agricultural Pool	*29,733*	*21,492*	*13,251*	*5,010*	*5,010*	*5,010*	*5,010*
Overlying Non-Agricultural Pool							
San Bernardino County (Chino Airport)	0	0	0	0	0	0	0
Ameron Inc	0	0	0	0	0	0	0
California Steel Industries Inc	1,284	1,284	1,284	1,284	1,284	1,284	1,284
Swan Lake Mobile Home Park	0	0	0	0	0	0	0
Vulcan Materials Company	5	5	5	5	5	5	5
Space Center Mira Loma Inc.	0	0	0	0	0	0	0
Angelica Textile Service	29	29	29	29	29	29	29
Sunkist Growers Inc	147	147	147	147	147	147	147
Praxair Inc	0	0	0	0	0	0	0
General Electric Company	451	451	451	451	451	451	451
California Speedway	621	621	621	621	621	621	621
Reliant Energy Etiwanda	705	705	705	705	705	705	705
Subtotal Overlying Non-Agricultural Pool Production	3,241	3,241	3,241	3,241	3,241	3,241	3,241
Appropriative Pool							
Arrowhead Mountain Spring Water Company	392	263	318	335	308	308	308
Chino Desalter Authority	26,356	26,356	39,400	39,400	39,400	39,400	39,400
City of Chino	5,100	6,316	8,652	10,030	10,766	10,766	10,766
City of Chino Hills	1,583	2,373	2,870	3,025	2,781	2,781	2,781
City of Norco	0	0	0	0	0	0	0
City of Ontario	23,956	22,281	28,298	34,099	35,133	35,133	35,133
City of Pomona	10,888	12,200	14,755	15,552	14,301	14,301	14,301
City of Upland	1,521	2,519	3,047	3,211	2,953	2,953	2,953
Cucamonga Valley Water District	18,786	20,001	28,958	33,035	33,846	33,846	33,846
Fontana Union Water Company	0	0	0	0	0	0	0
Fontana Water Company	16,112	16,432	19,872	20,946	19,261	19,261	19,261
Jurupa Community Services District	17,840	20,087	18,123	21,616	21,419	21,419	21,419
Inland Empire Utilities Agency	0	0	0	0	0	0	0
Marygold Mutual Water Company	184	0	0	0	0	0	0
Metropolitan Water District of Southern California	0	0	0	0	0	0	0
Monte Vista Irrigation Company	0	0	0	0	0	0	0
Monte Vista Water District	11,279	10,549	13,744	14,867	14,022	14,022	14,022
Mutual Water Company of Glen Avon Heights	0	0	0	0	0	0	0
Niagara	1,106	657	795	838	770	770	770
San Antonio Water Company	1,276	894	1,149	1,282	1,244	1,244	1,244
San Bernardino County (Olympic Facility)	16	13	16	17	15	15	15
Santa Ana River Water Company	0	263	318	335	308	308	308
Golden State Water Company	881	329	397	419	385	385	385
West End Consolidated Water Company	0	0	0	0	0	0	0
West Valley Water District	0	0	0	0	0	0	0
Subtotal Appropriators	137,275	141,533	180,711	199,006	196,915	196,915	196,915
Total Production	170,249	166,266	197,203	207,257	205,166	205,166	205,166

1 -- Desalter Production as per Table 7-4 and is not reduced to match replenishment

2 -- Non desalter Appropriator Production projection has been modified from early Peace II investigations (WEI, 2006a and 2006b) to live within Watermaster's availability to replenish.

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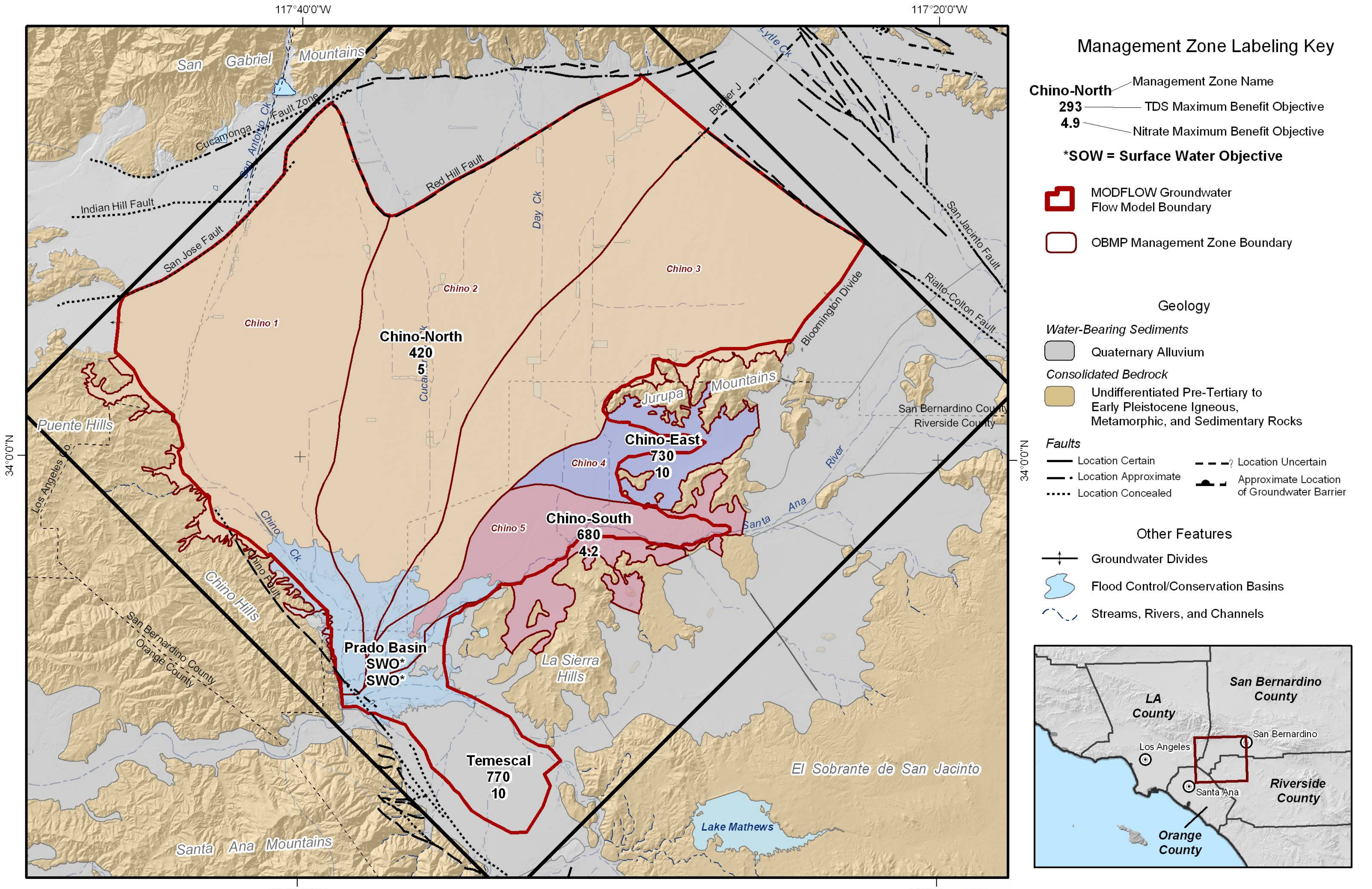
Table 7-9

Safe Yield of the Chino Basin Based for the Planning Alternatives

(acre-ft/yr)

Year	Baseline	Alternative 1A		Alternative 1B	
		Safe Yield	Increase Over Baseline	Safe Yield	Increase Over Baseline
2016	133,795	135,413	1,618	135,321	1,526
2017	134,116	136,104	1,987	135,933	1,816
2018	134,040	136,473	2,432	136,196	2,155
2019	133,708	136,640	2,932	136,235	2,527
2020	133,238	136,693	3,455	136,139	2,901
2021	132,656	136,637	3,980	135,924	3,267
2022	132,083	136,590	4,507	135,718	3,634
2023	131,325	136,387	5,061	135,363	4,038
2024	130,417	136,076	5,659	134,921	4,504
2025	129,436	135,738	6,302	134,488	5,052
2026	128,466	135,428	6,962	134,128	5,662
2027	127,543	135,135	7,591	133,822	6,278
2028	126,767	134,889	8,122	133,602	6,835
2029	126,077	134,607	8,530	133,387	7,310
2030	125,544	134,361	8,817	133,249	7,705
2031	125,048	134,047	9,000	133,072	8,025
2032	124,598	133,712	9,113	132,892	8,293
2033	124,214	133,378	9,164	132,730	8,516
2034	123,852	133,013	9,161	132,537	8,684
2035	123,492	132,585	9,093	132,276	8,784
2036	123,105	132,088	8,983	131,939	8,834
2037	122,667	131,522	8,855	131,530	8,863
2038	122,201	130,954	8,753	131,113	8,912
2039	121,725	130,433	8,708	130,729	9,004
2040	121,315	130,047	8,732	130,460	9,145
2041	120,985	129,805	8,819	130,316	9,331
2042	120,772	129,707	8,935	130,298	9,526
2043	120,687	129,719	9,032	130,366	9,679
2044	120,681	129,755	9,073	130,444	9,763
2045	120,734	129,789	9,055	130,508	9,774
2046	120,823	129,794	8,971	130,531	9,708
2047	120,910	129,757	8,847	130,503	9,593
2048	121,003	129,704	8,701	130,455	9,452
2049	121,070	129,603	8,534	130,357	9,287
2050	121,094	129,424	8,331	130,179	9,085
2051	121,026	129,118	8,092	129,871	8,845
2052	120,866	128,695	7,829	129,447	8,581
2053	120,626	128,209	7,583	128,962	8,336
2054	120,339	127,737	7,398	128,488	8,149
2055	120,061	127,360	7,298	128,108	8,047
2056	119,846	127,139	7,293	127,881	8,036
2057	119,727	127,070	7,343	127,803	8,076
2058	119,706	127,106	7,401	127,830	8,124
2059	119,761	127,215	7,454	127,926	8,165
2060	119,986	127,498	7,511	128,198	8,212



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Predictive Simulations

Comparison of OBMP Management Zones and RWQCB Basin Plan Management Zones

Figure 7-1

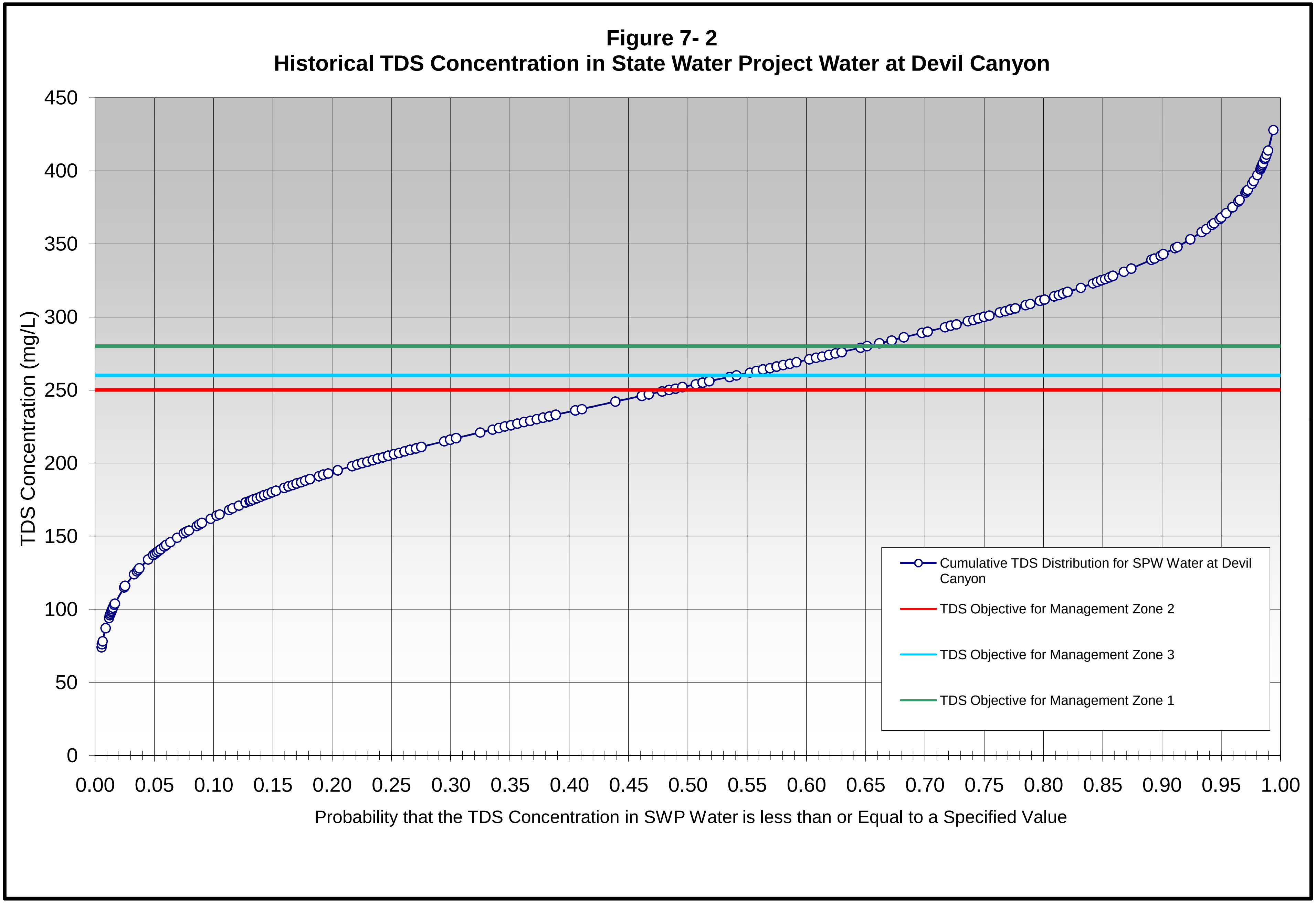

Figure 7-2_Devils_TDS.xls

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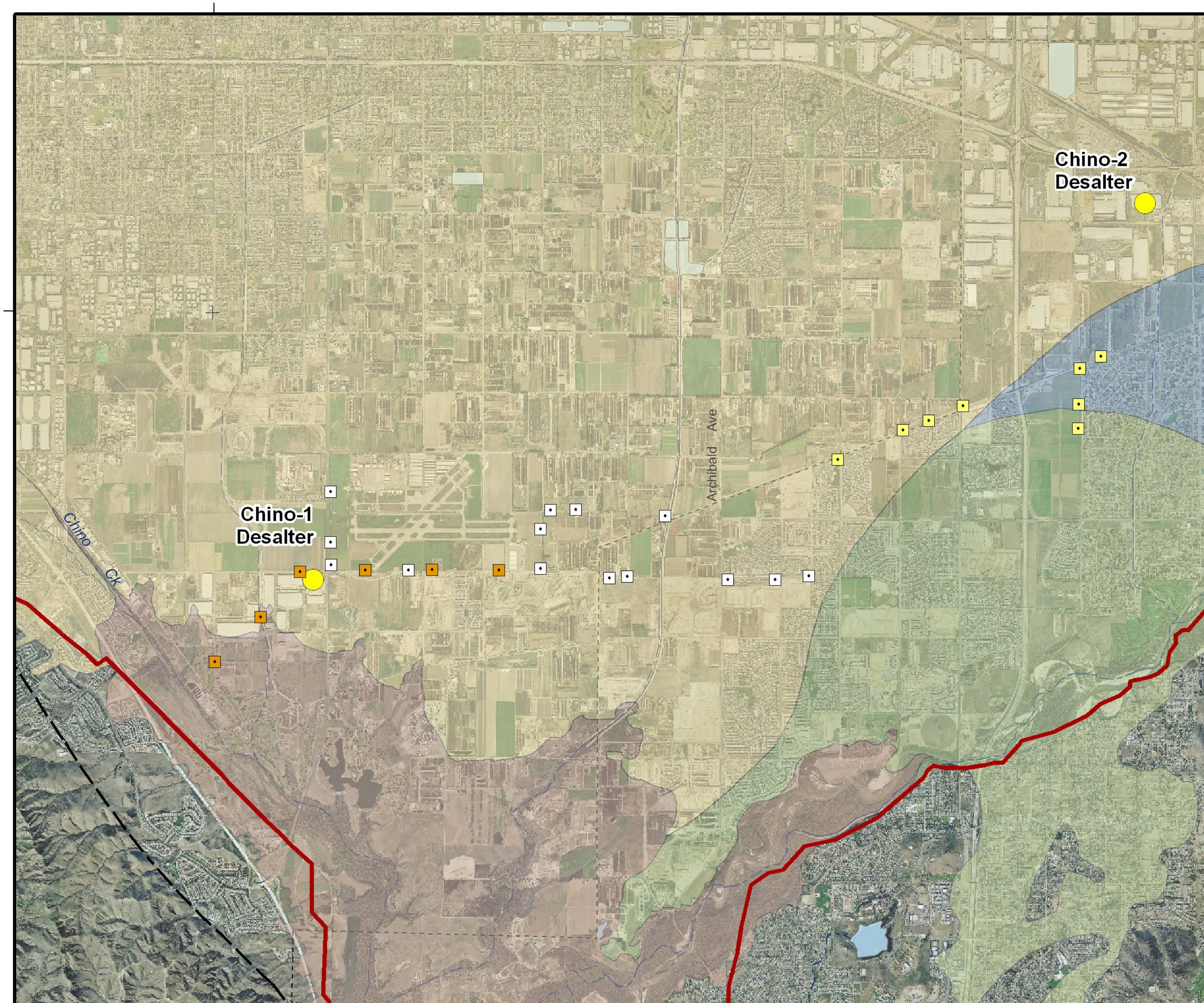


Existing Chino 1 Desalter Well

Existing Chino 2 Desalter Well

Proposed Chino Creek Well

Existing Desalter Facilities

Other Features

Groundwater Management Zone

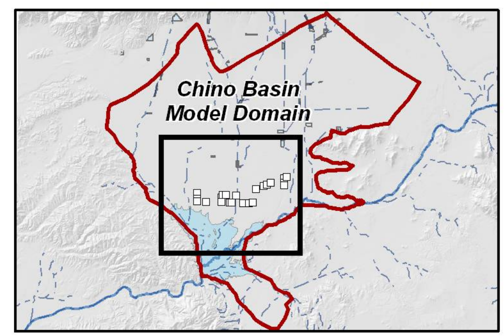
Chino-East | Chino-South

Chino-North | Prado Basin

MODFLOW Groundwater Flow Model Boundary

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels



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0 1 2 Miles

0 1 2 3 KM

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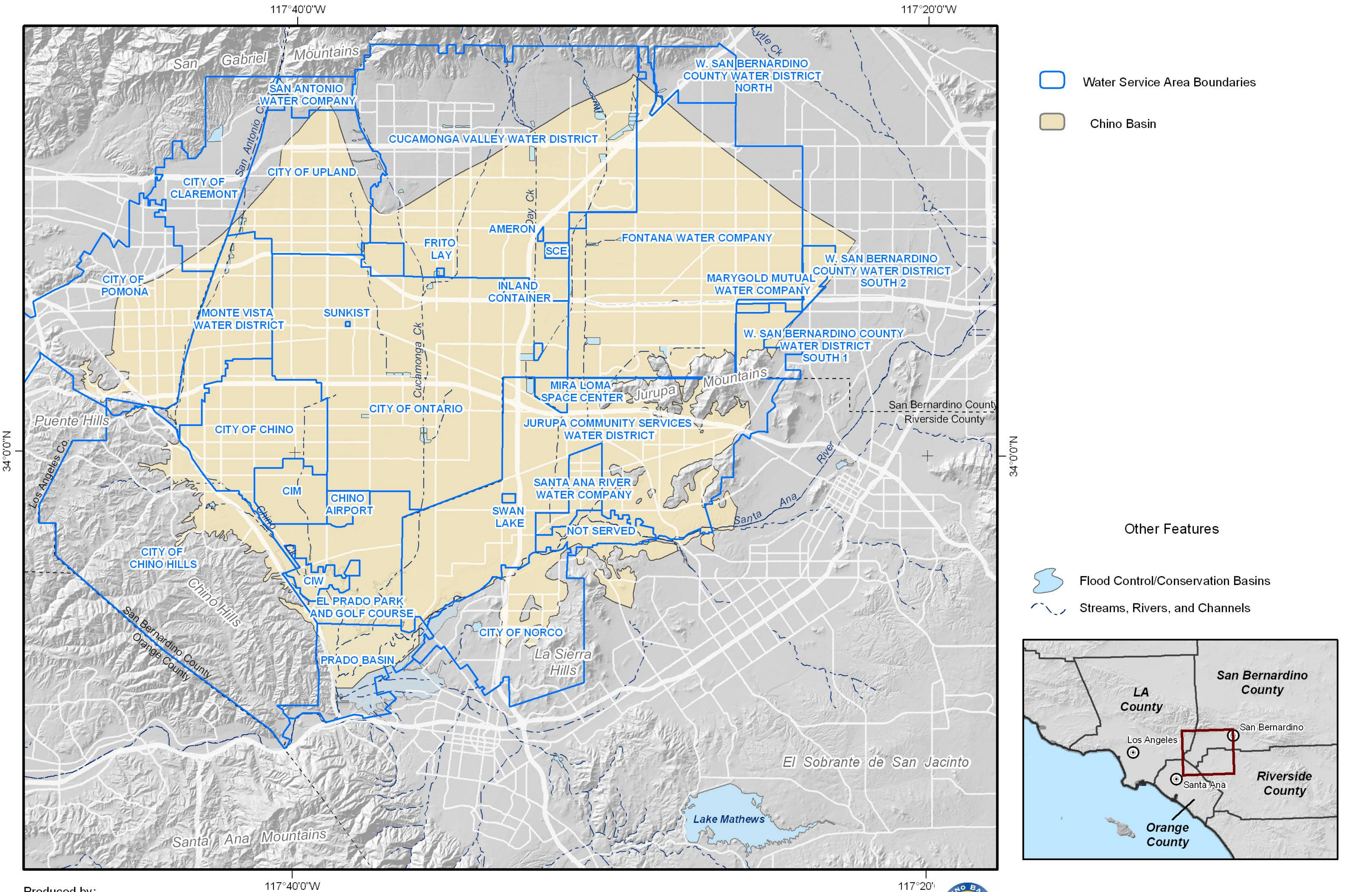
Predictive Simulations

Location of the Proposed Chino Creek Well Field and Existing Desalter Wells

Chino Basin

Figure 7-3



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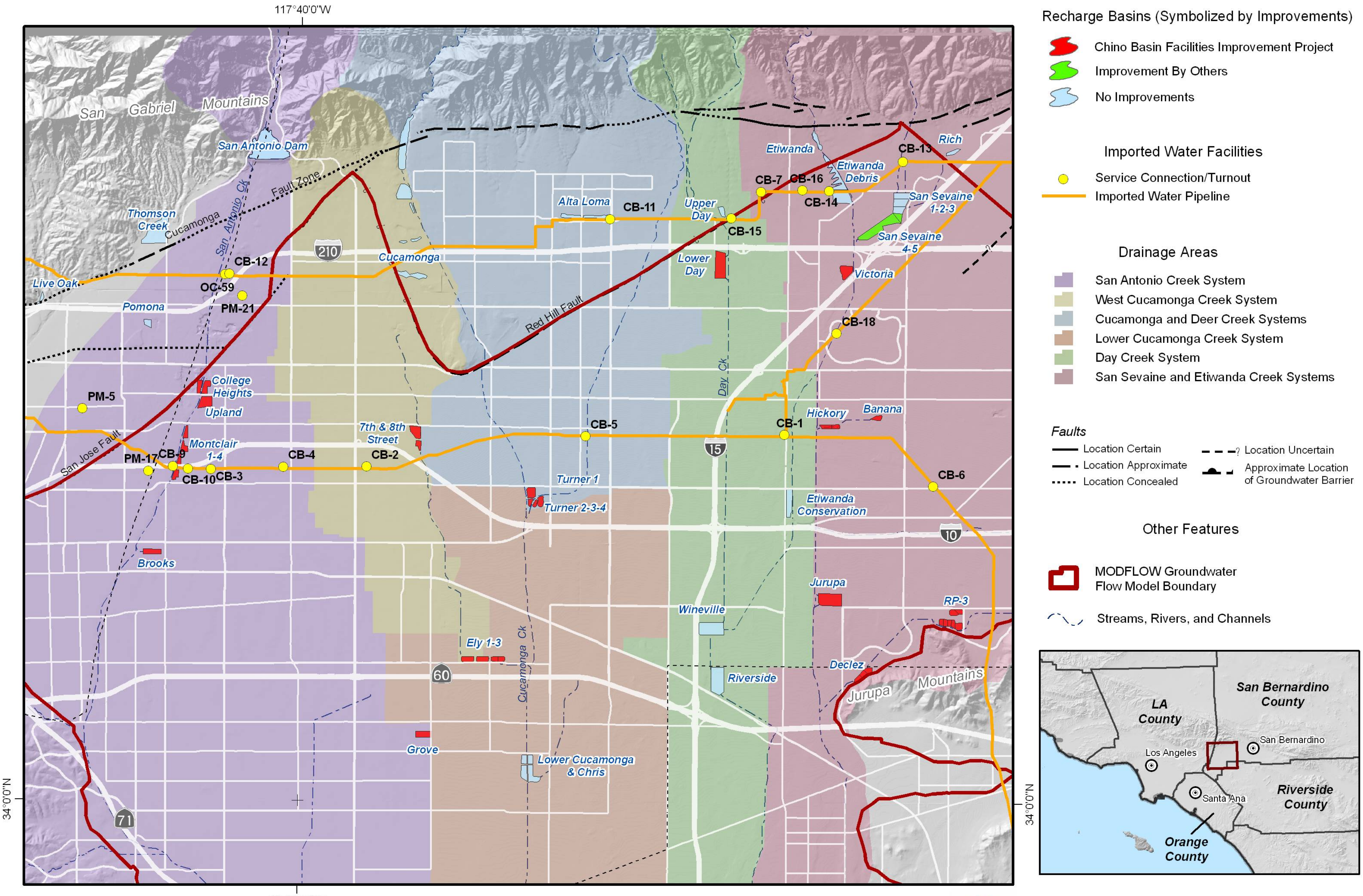
Predictive Simulations

Water Service Area Boundaries

Figure 7-4



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and Evaluation of the Peace II Project Description
Predictive Simulations

Location of Groundwater Recharge and Imported Water Facilities

Figure 7-5

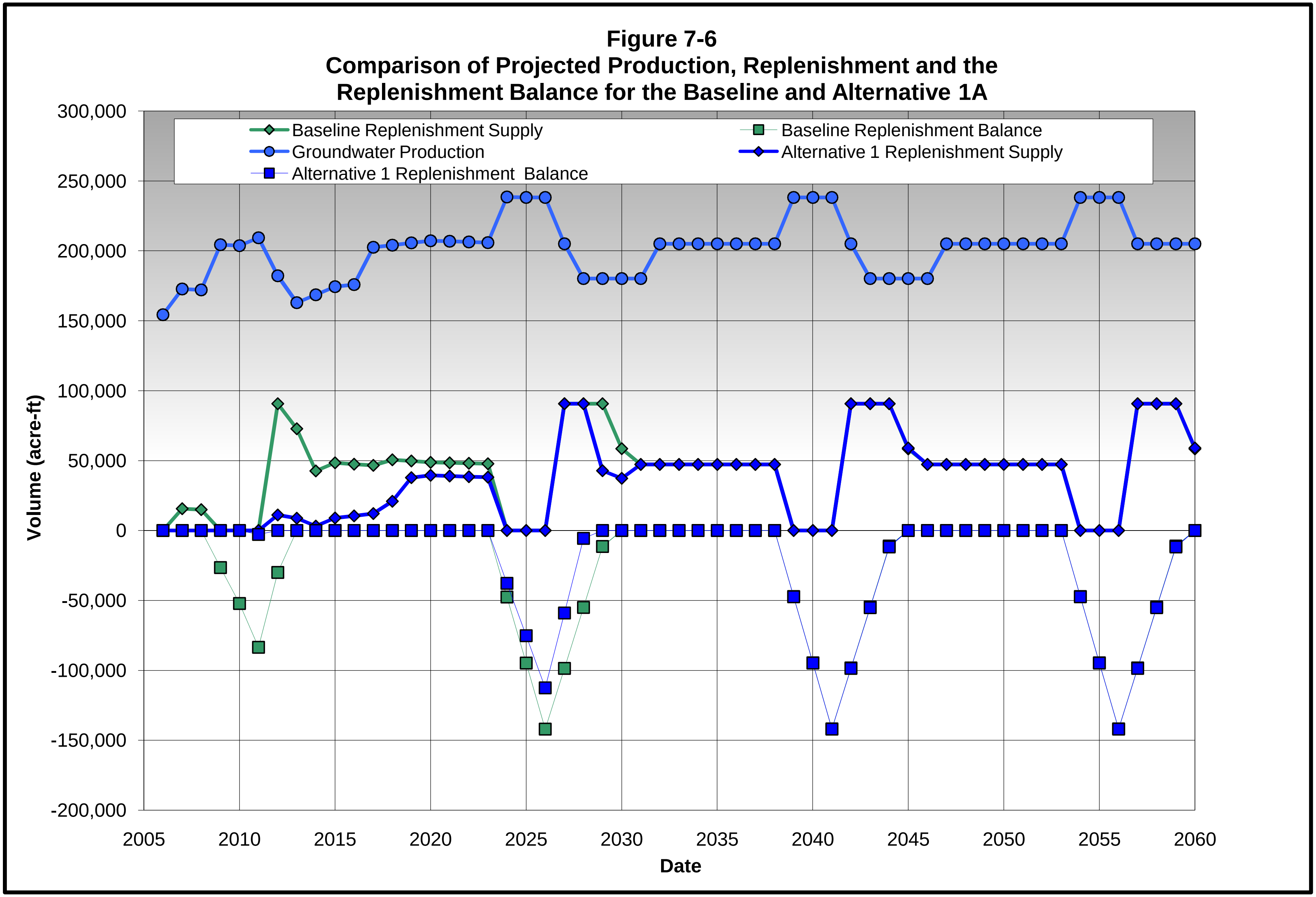


Figure 7-6
Comparison of Projected Production, Replenishment and the
Replenishment Balance for the Baseline and Alternative 1A
Baseline Replenishment Supply
Baseline Replenishment Balance
Groundwater Production
Alternative 1 Replenishment Supply
Alternative 1 Replenishment Balance
Volume (acre-ft)
300,000
250,000
200,000
150,000
100,000
50,000
0
-50,000
-100,000
-150,000
-200,000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
Date

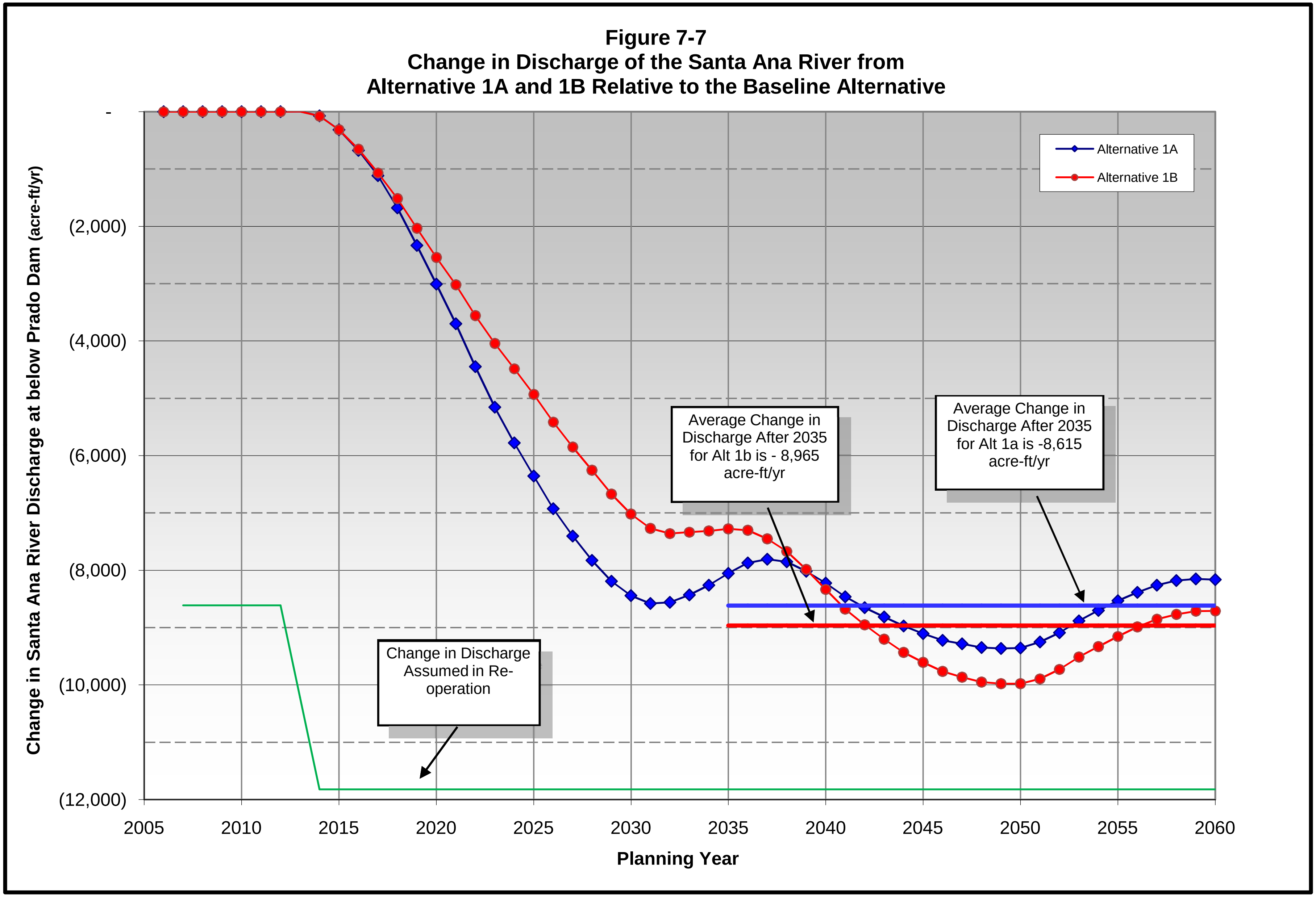
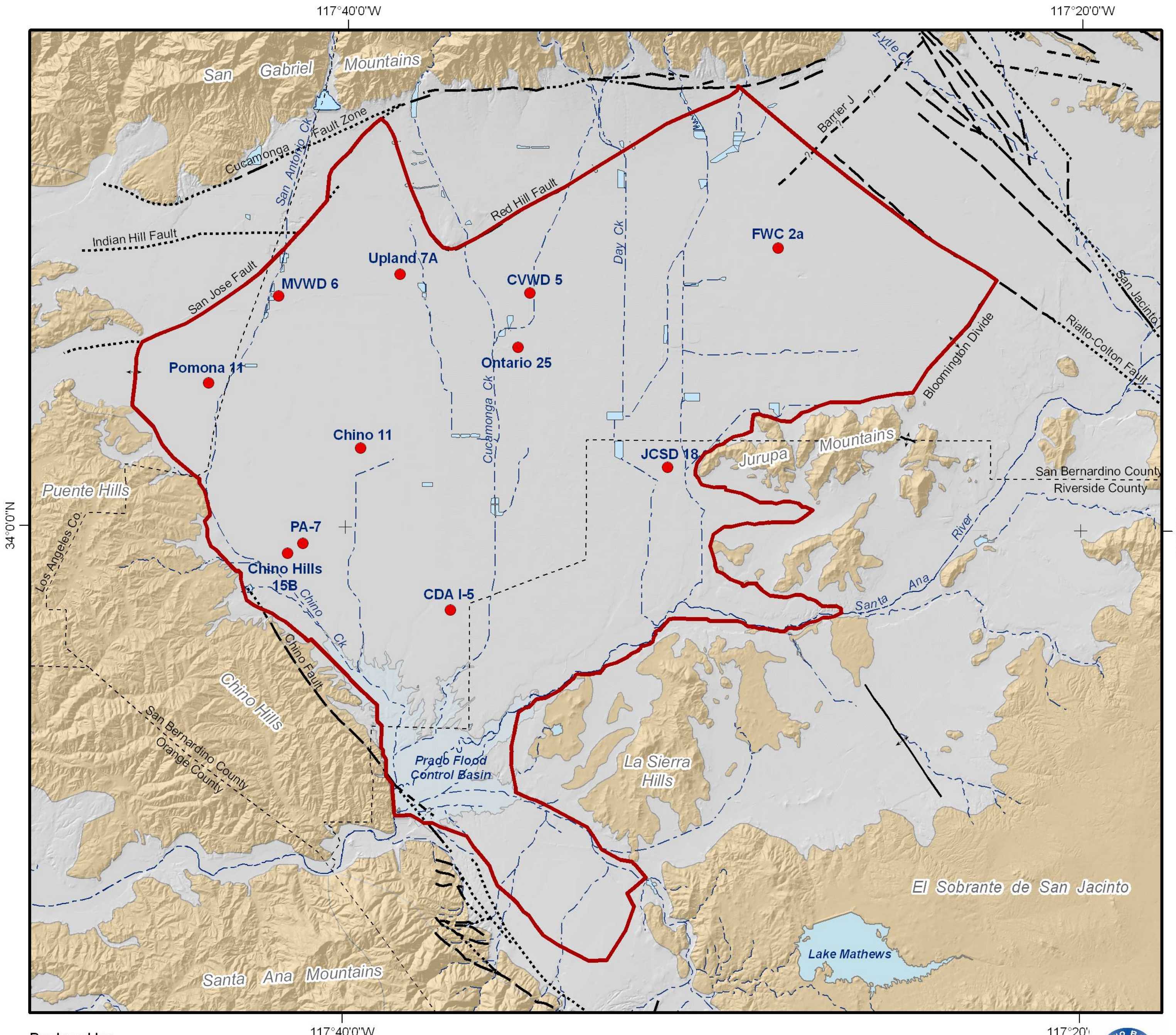


Figure 7-7 Stream Flow Below Prado_planv19.xls



● Hydrograph Well

Geology

Water-Bearing Sediments

Quaternary Alluvium

Consolidated Bedrock

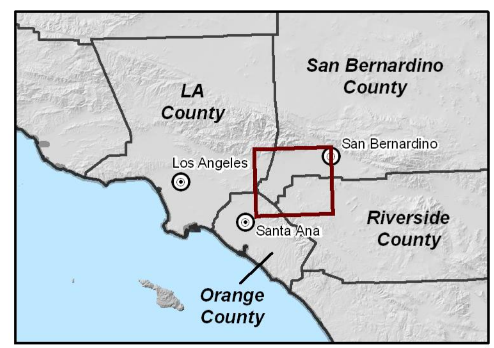
Undifferentiated Pre-Tertiary to Early Pleistocene Igneous, Metamorphic, and Sedimentary Rocks

Faults

- Location Certain
- Location Approximate
- Location Concealed
- Location Uncertain
- Approximate Location of Groundwater Barrier

Other Features

- Groundwater Divides
- Flood Control/Conservation Basins
- Streams, Rivers, and Channels



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0 1 2 3 4 Miles

0 2 4 6 KM

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Predictive Simulations

Planning Alternative Hydrograph Well Location Map

Figure 7-8

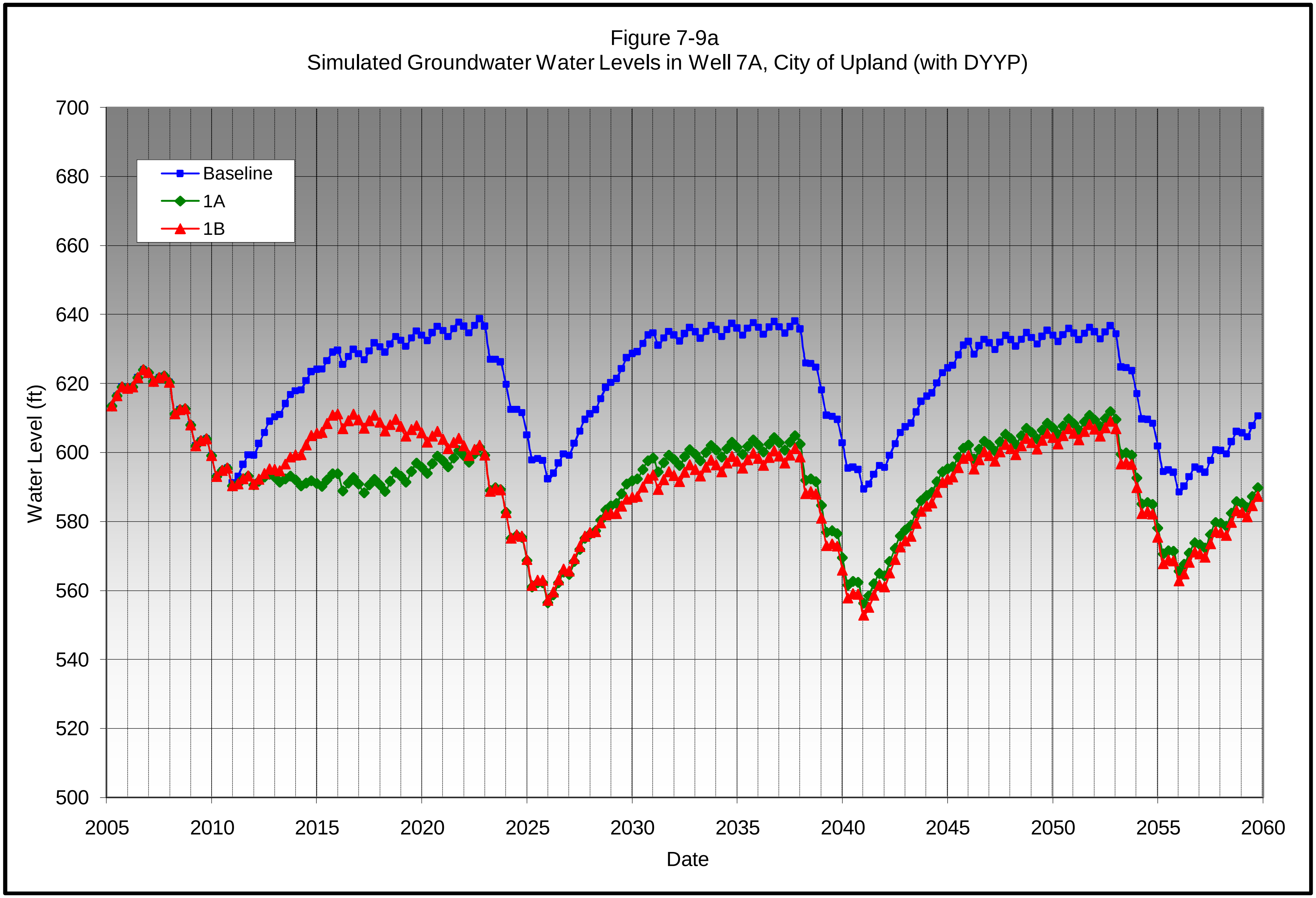

Figure 7-9a thru 7-9l hydrographs_version20.xls

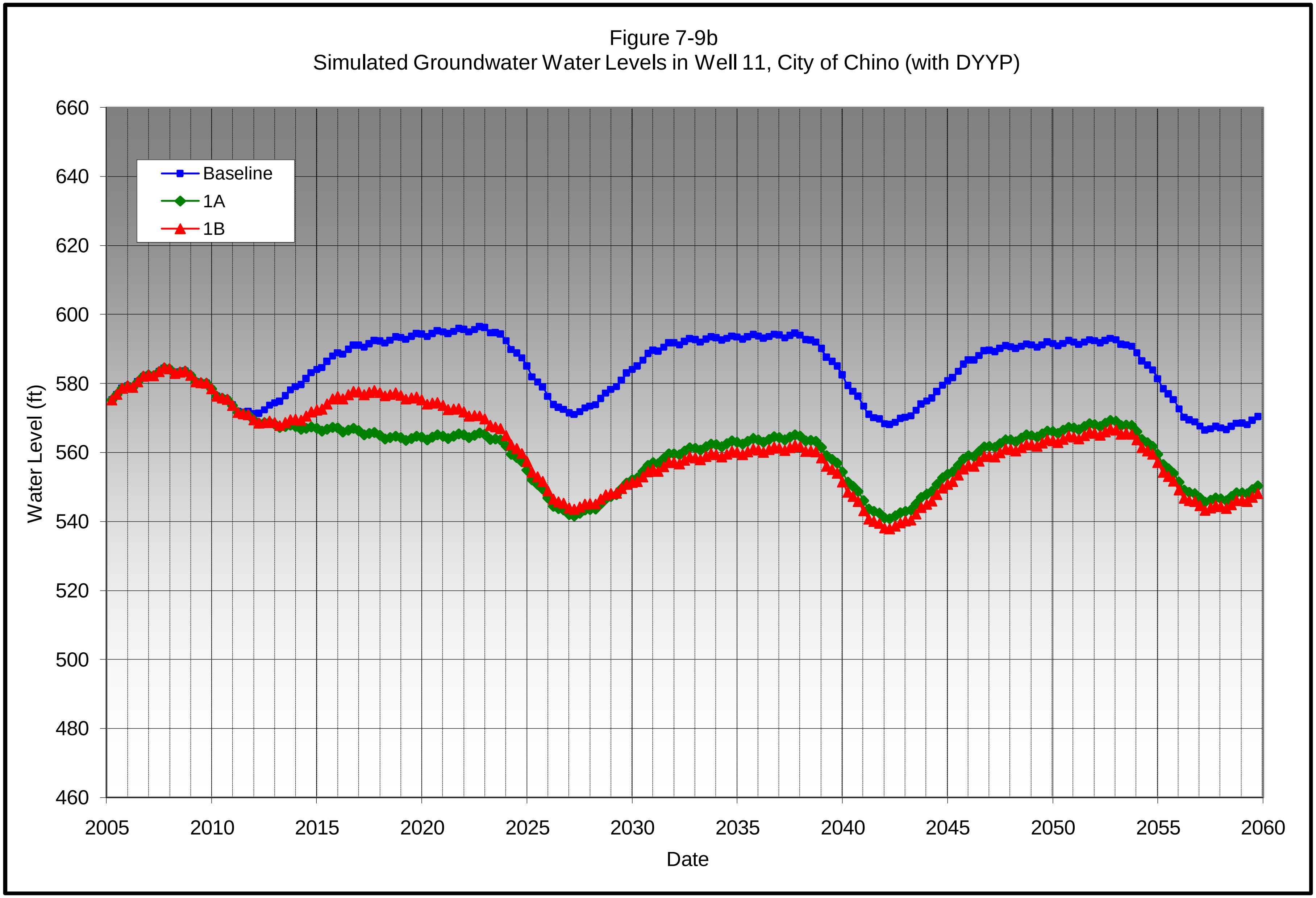

Figure 7-9a thru 7-9l hydrographs_version20.xls

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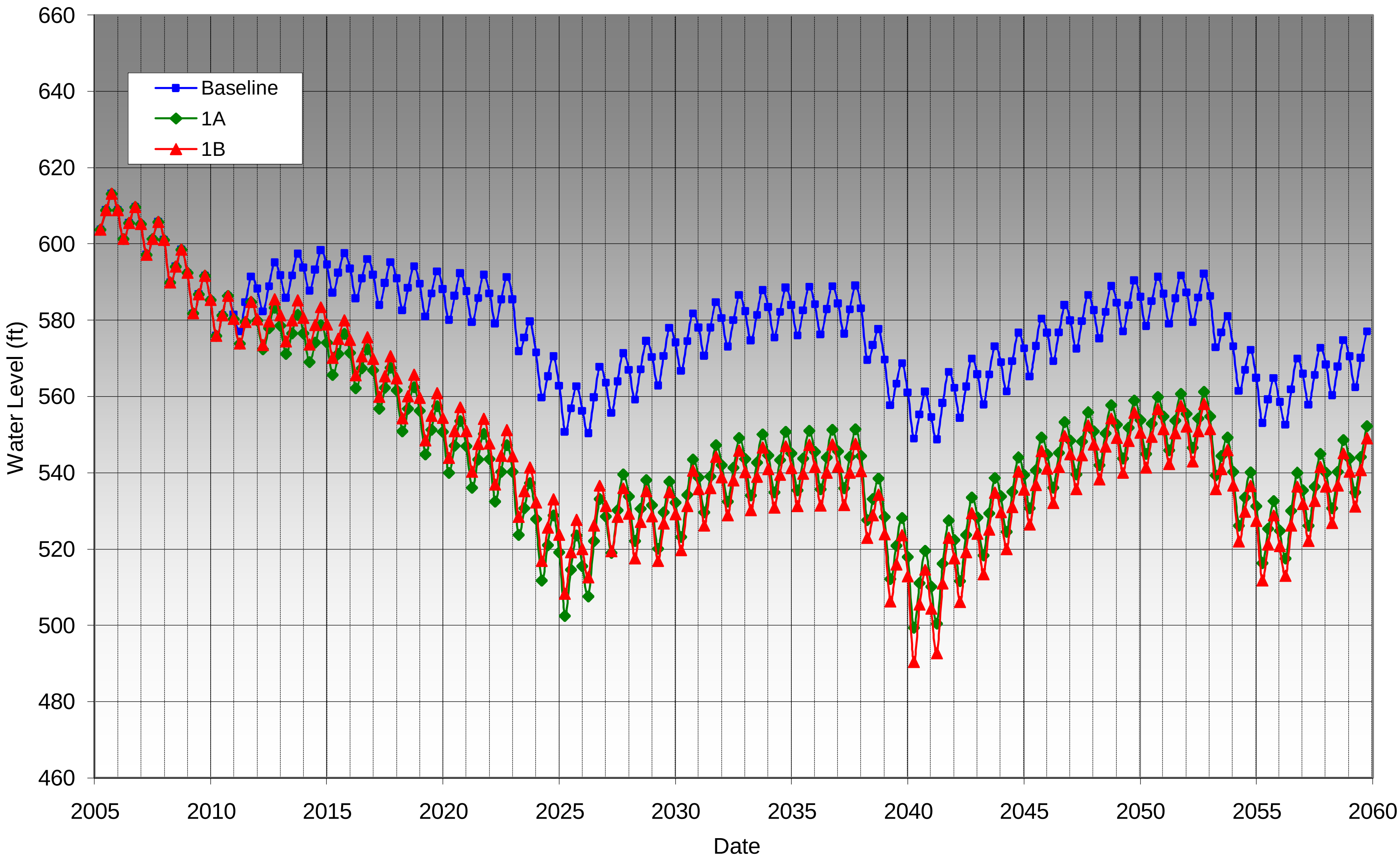
Figure 7-9c
Simulated Groundwater Water Levels in Well18, Jurupa Community Services District (with DYYP)



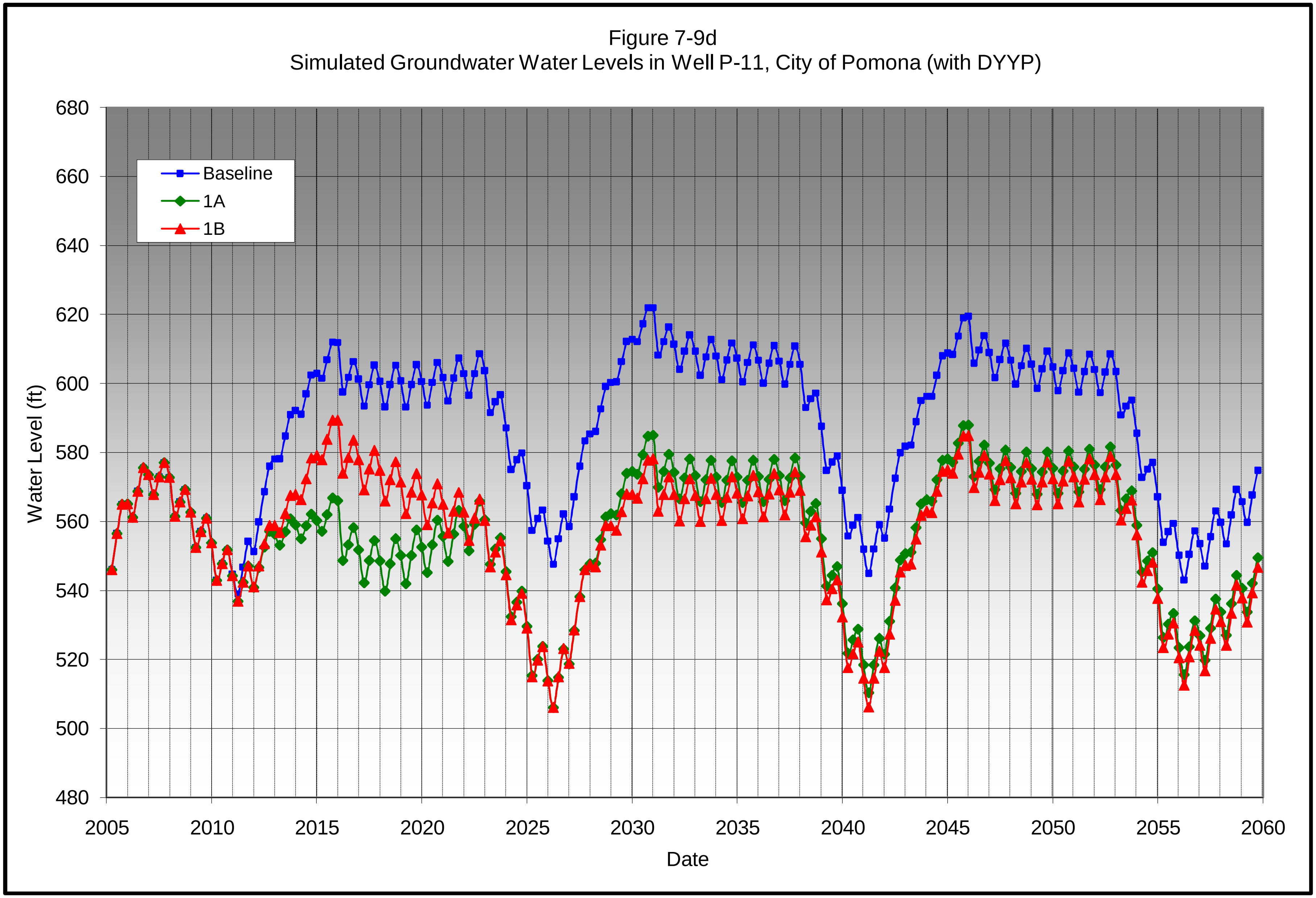


Figure 7-9a thru 7-9l hydrographs_version20.xls

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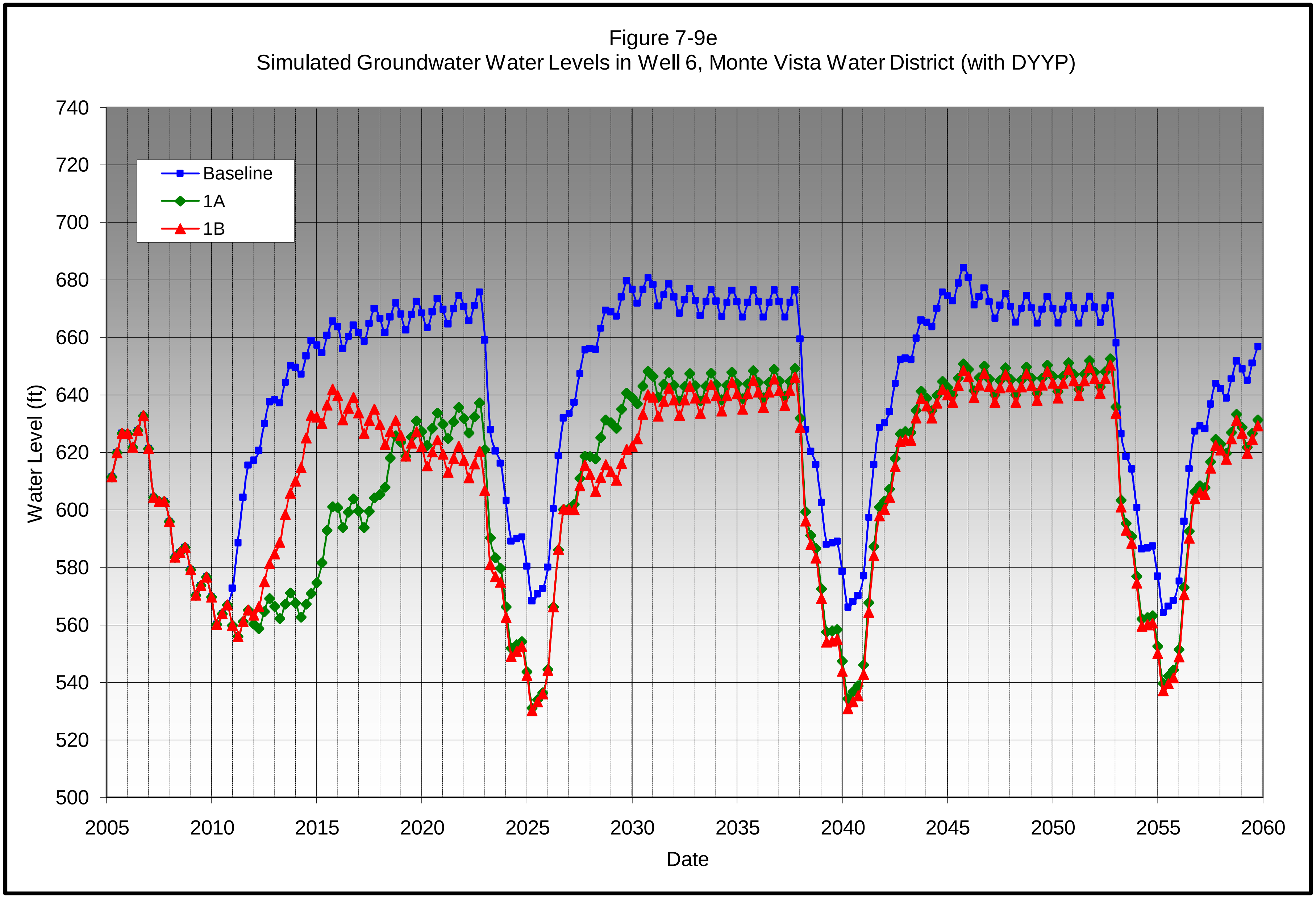

Figure 7-9a thru 7-9l hydrographs_version20.xls

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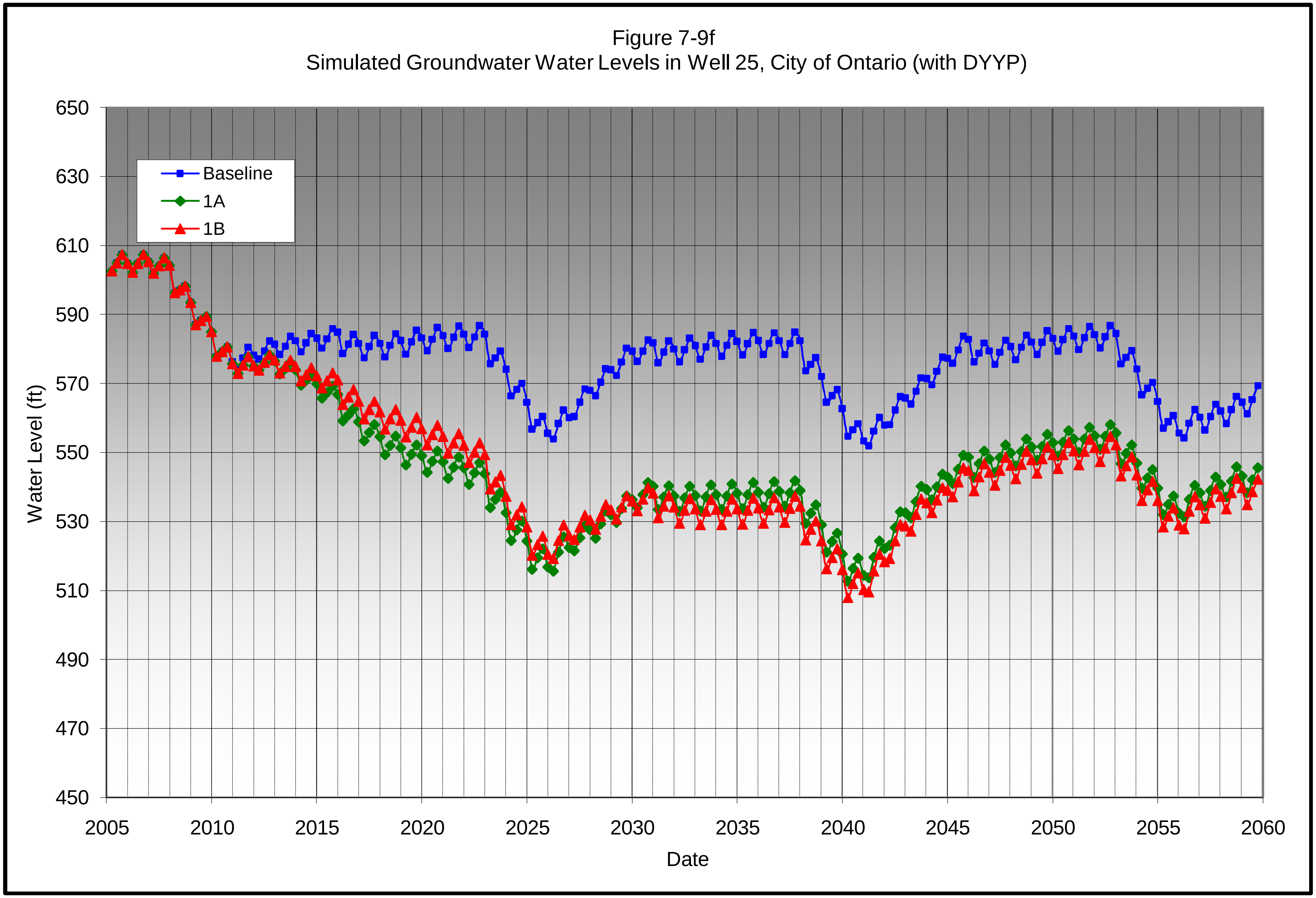

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Figure 7-9g
Simulated Groundwater Water Levels in Well CB-5, Cucamonga Valley Water District (with DYYP)

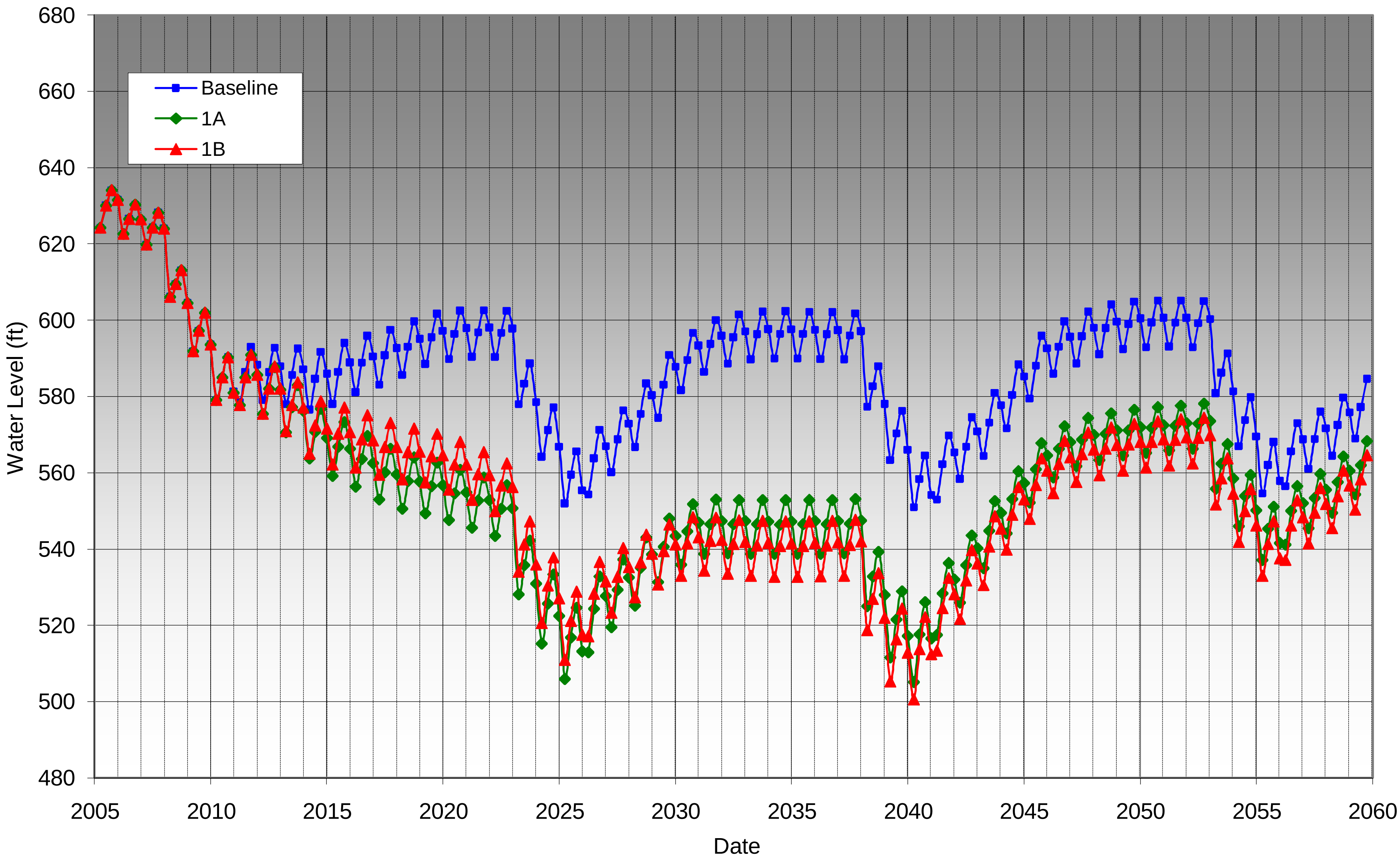

Figure 7-9a thru 7-9l hydrographs_version20.xls

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Figure 7-9h
Simulated Groundwater Water Levels in Well 1, Chino Desalter Authority (with DYYP)

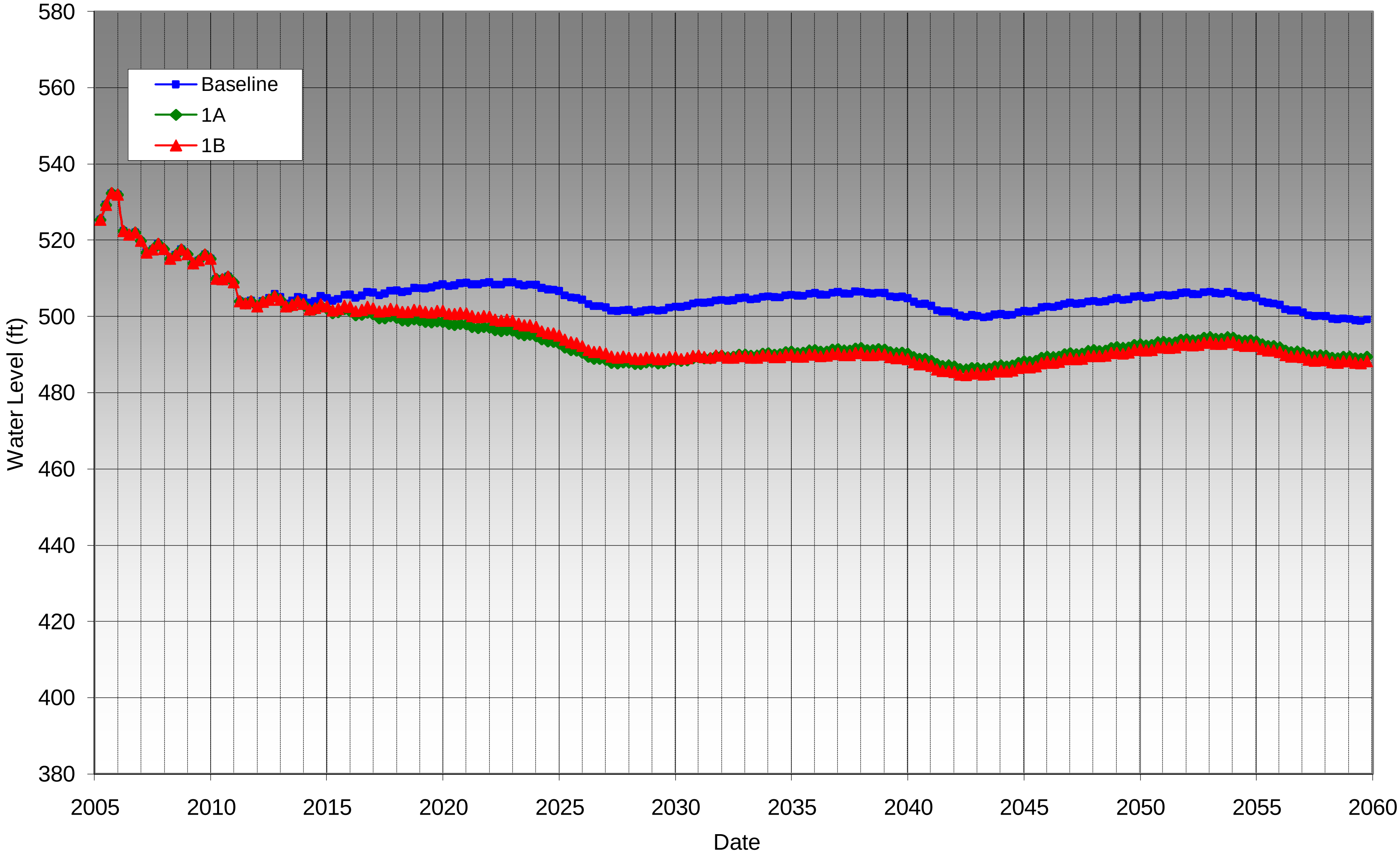

Figure 7-9a thru 7-9l hydrographs_version20.xls

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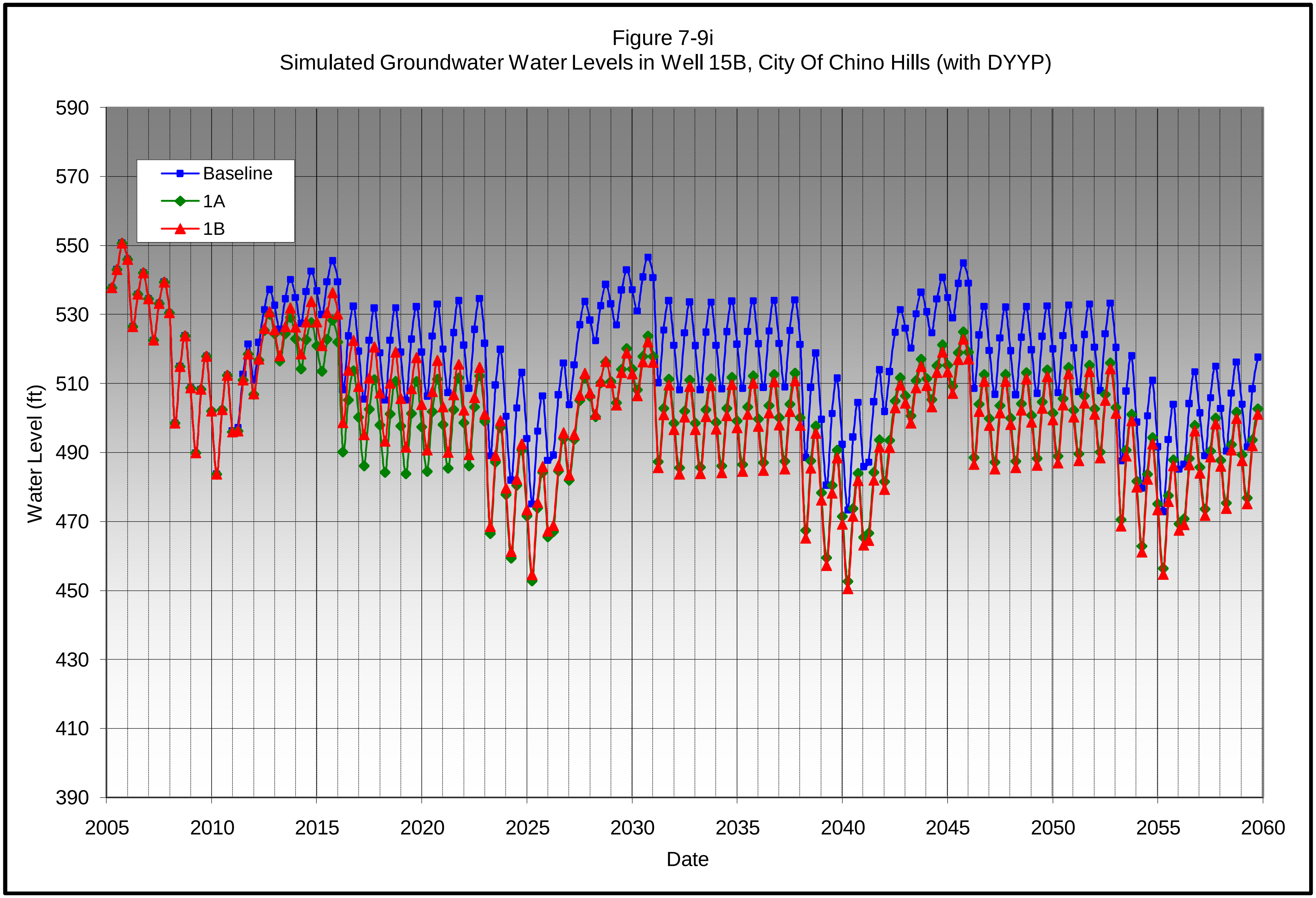

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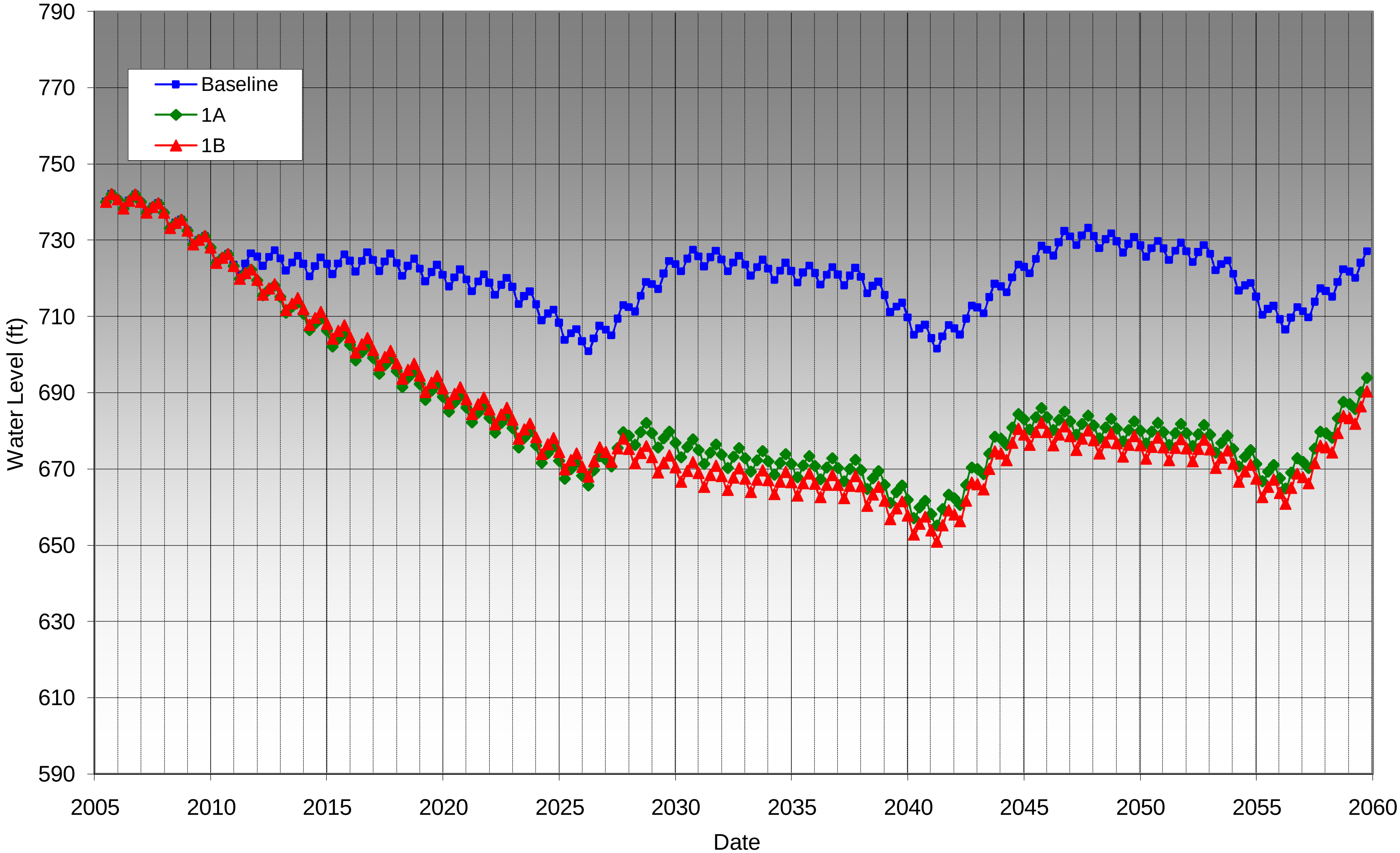
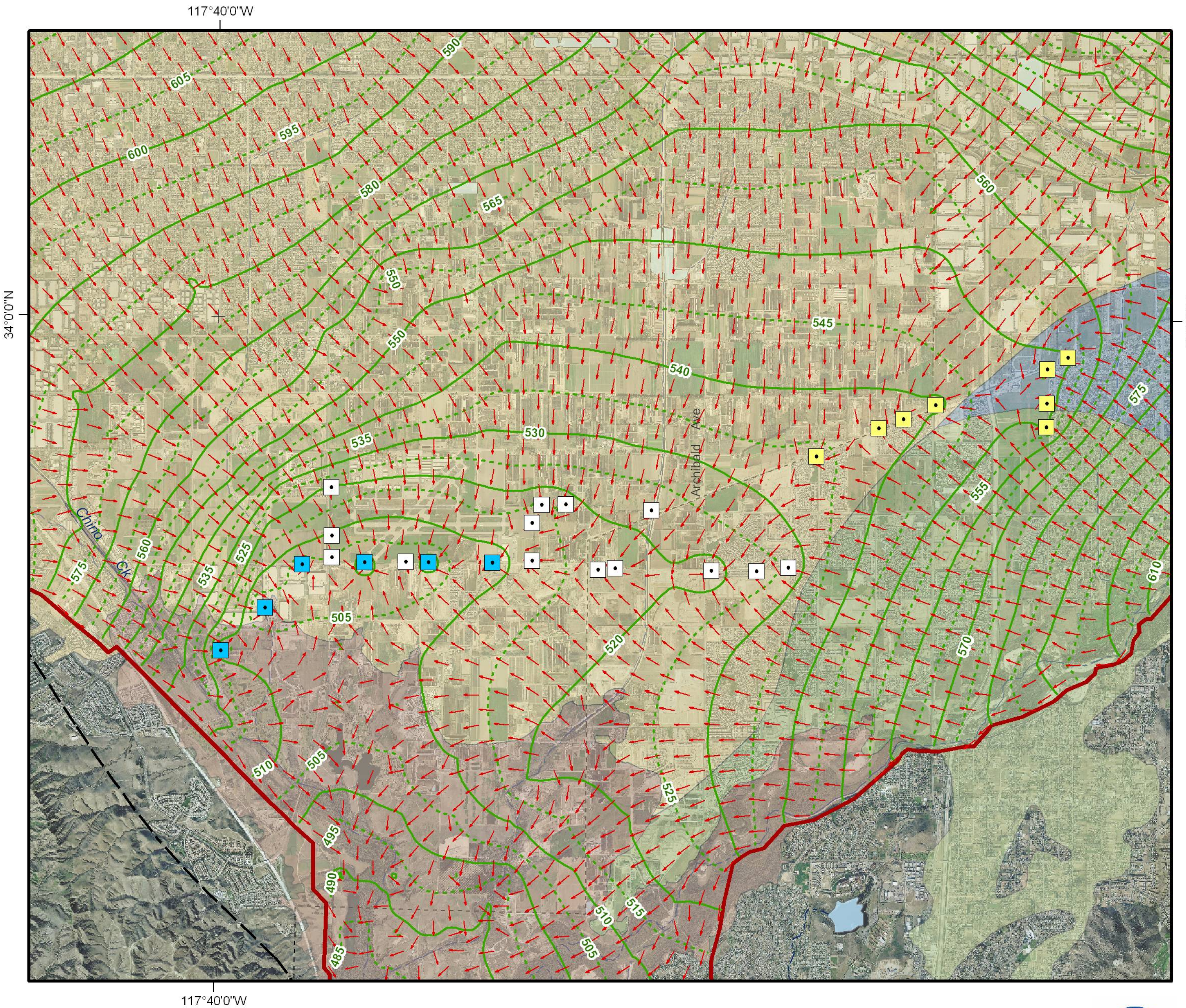
Figure 7-9j
Simulated Groundwater Water Levels in Well F2A, Fontana Water Company (with DYYP)





Groundwater Elevation Contours (feet above mean sea-level)

Existing Chino 1 Desalter Well

Existing Chino 2 Desalter Well

Proposed Chino Creek Well

Groundwater Flow Direction

Other Features

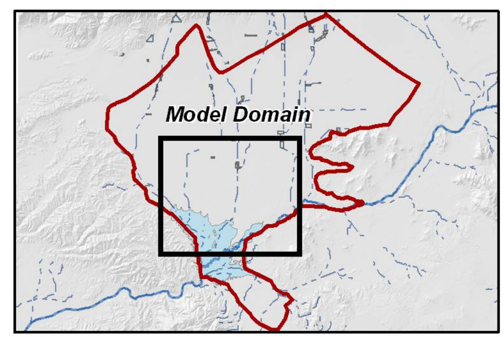
Groundwater Management Zone

Chino-East
Chino-South
Chino-North
Prado Basin

MODFLOW Groundwater Flow Model Boundary

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels



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0 1 2 Miles

0 1 2 3 KM

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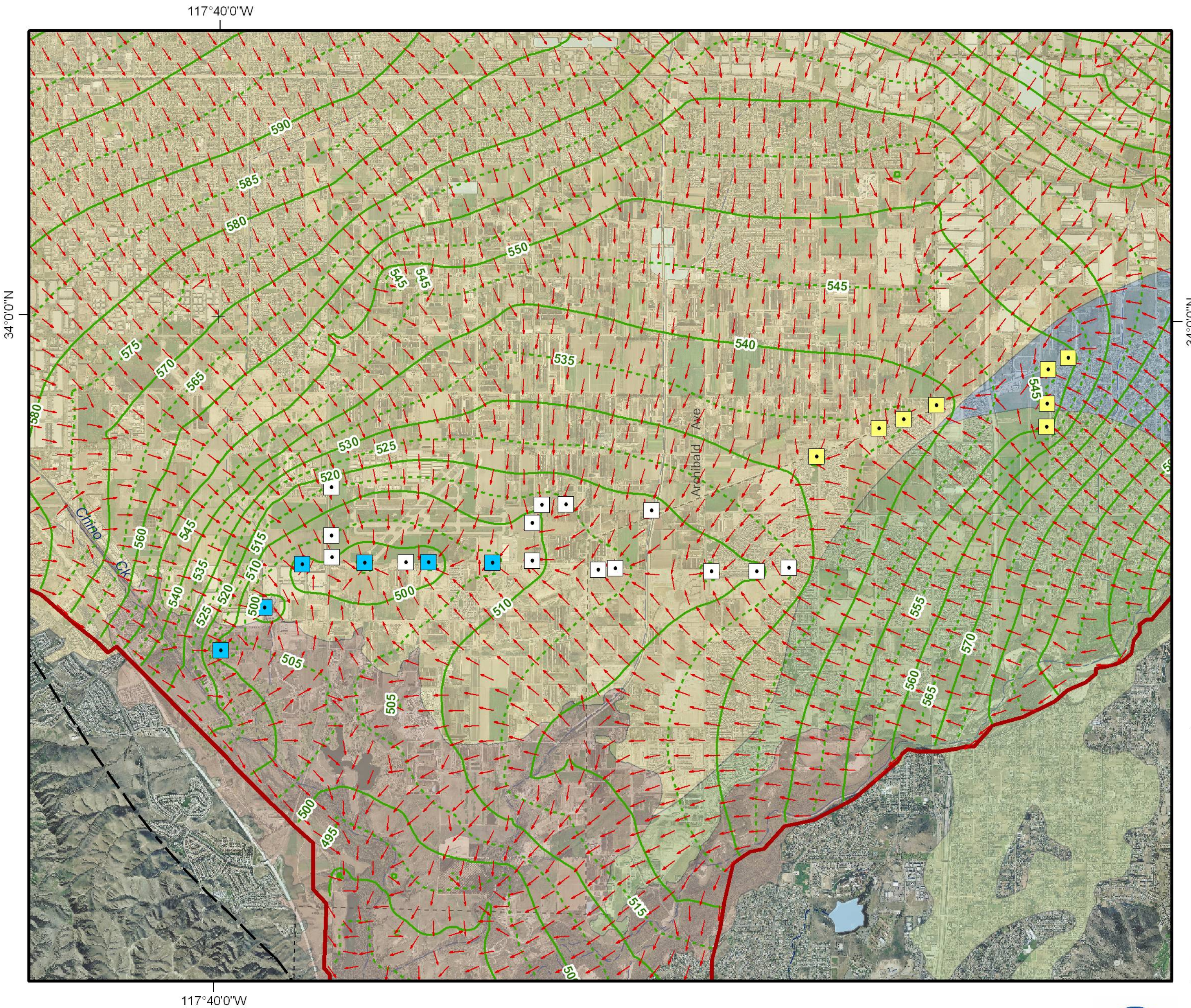
Predictive Simulations

Groundwater Elevation Contours and Flow Direction in the Vicinity of the Desalters

Baseline Alternative in Layer 1 -- 2023

Figure 7-10a



Groundwater Elevation Contours (feet above mean sea-level)
800
775

Existing Chino 1 Desalter Well

Existing Chino 2 Desalter Well

Proposed Chino Creek Well

Groundwater Flow Direction

Other Features

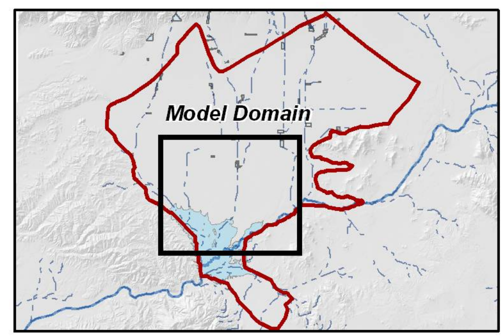
Groundwater Management Zone

Chino-East
Chino-South
Chino-North
Prado Basin

MODFLOW Groundwater Flow Model Boundary

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels



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0 1 2 Miles
0 1 2 3 KM

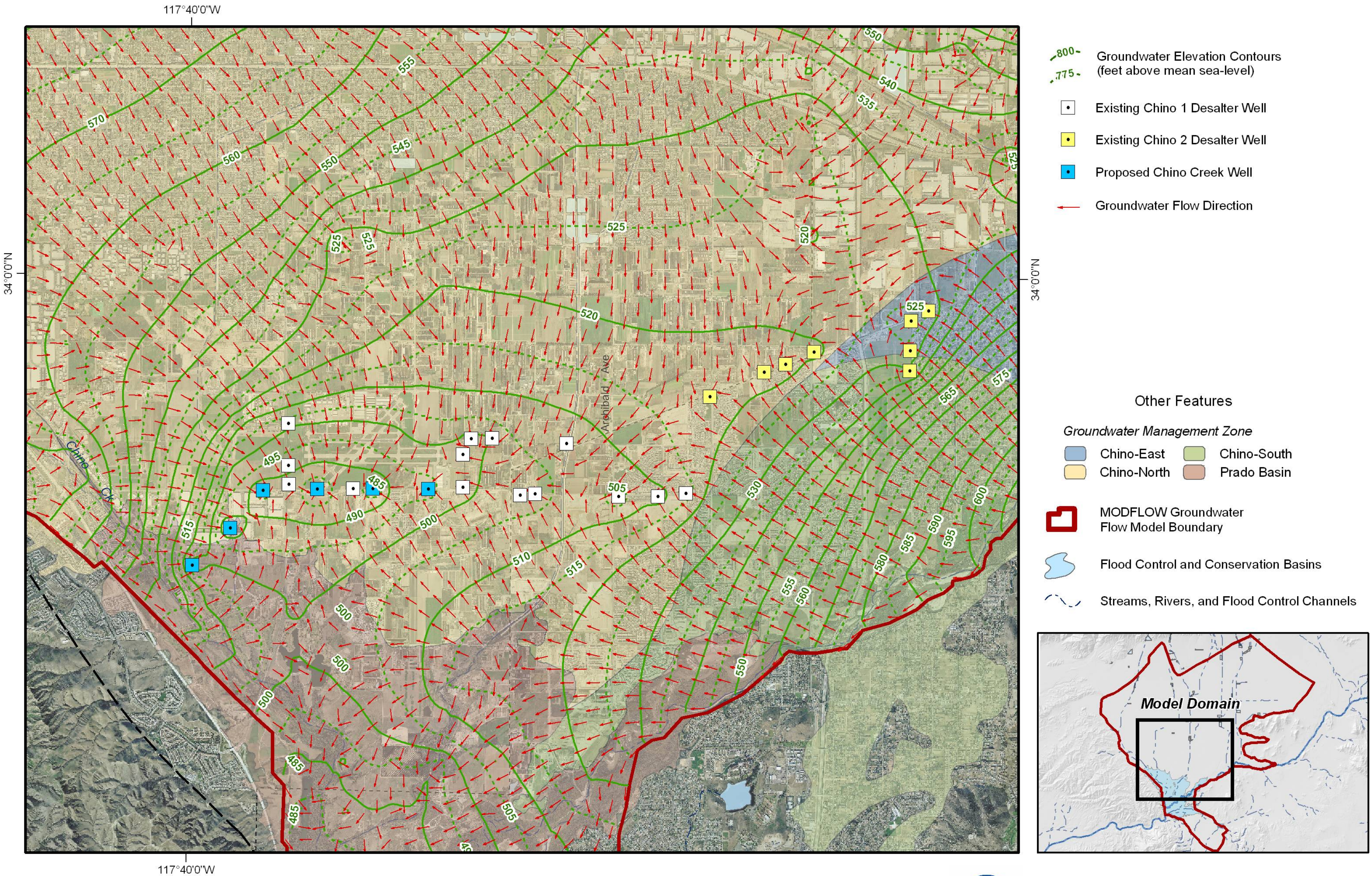
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Predictive Simulations

Groundwater Elevation Contours and Flow Direction in the Vicinity of the Desalters

Baseline Alternative in Layer 1 -- 2053

Figure 7-10b



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0 1 2 Miles

0 1 2 3 KM

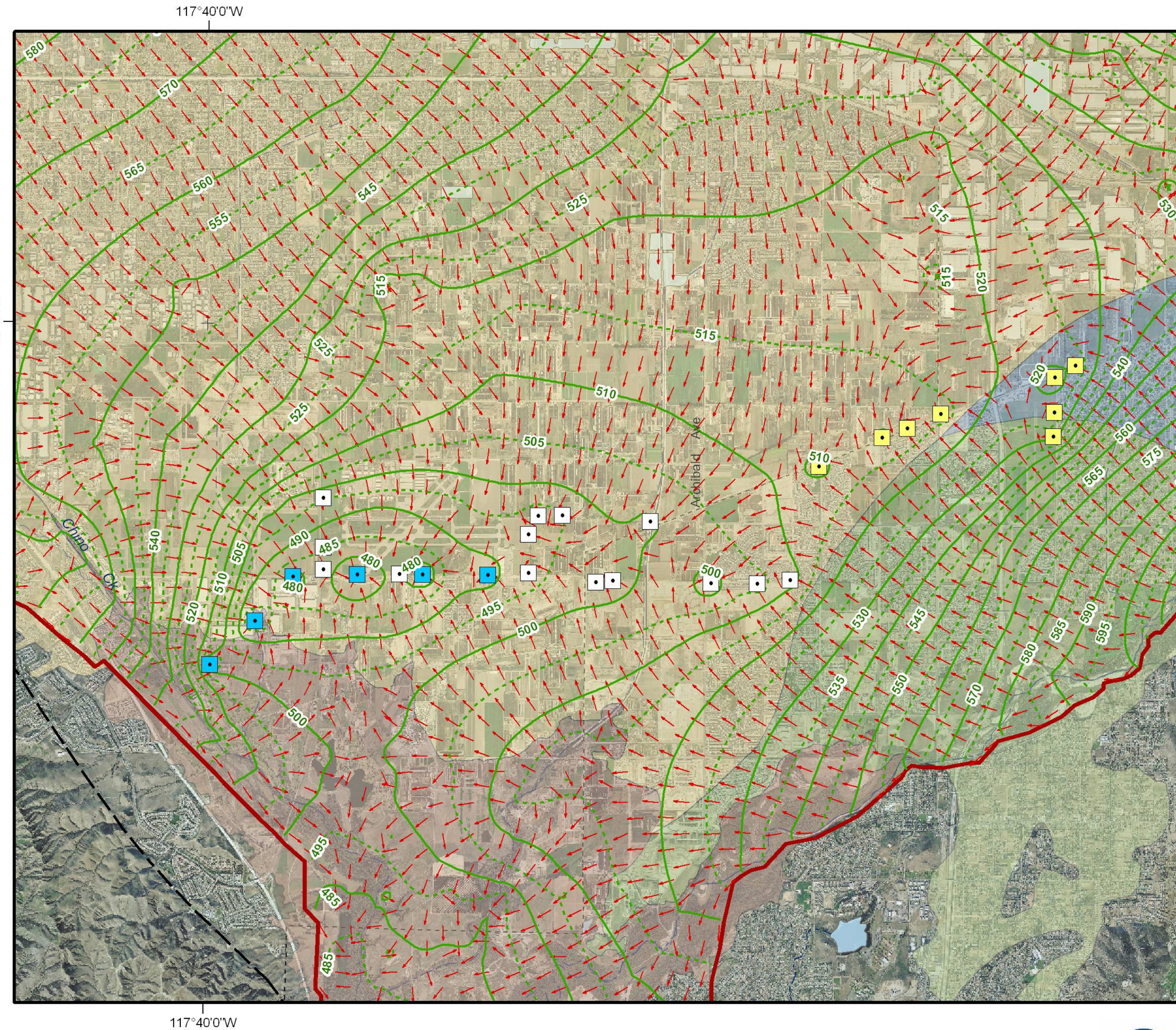
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

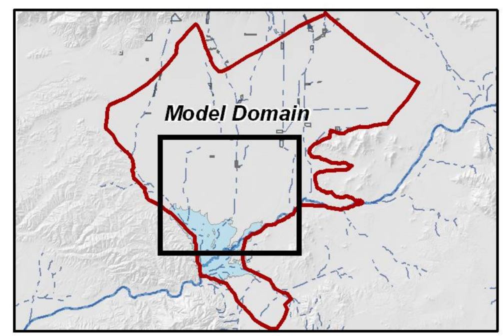
Predictive Simulations

Groundwater Elevation Contours and Flow Direction in the Vicinity of the Desalters

Alternative 1A in Layer 1 -- 2023

Figure 7-11a





Groundwater Elevation Contours (feet above mean sea-level)

Existing Chino 1 Desalter Well

Existing Chino 2 Desalter Well

Proposed Chino Creek Well

Groundwater Flow Direction

Other Features

Groundwater Management Zone

Chino-East | Chino-South

Chino-North | Prado Basin

MODFLOW Groundwater Flow Model Boundary

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels

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0 1 2 Miles

0 1 2 3 KM

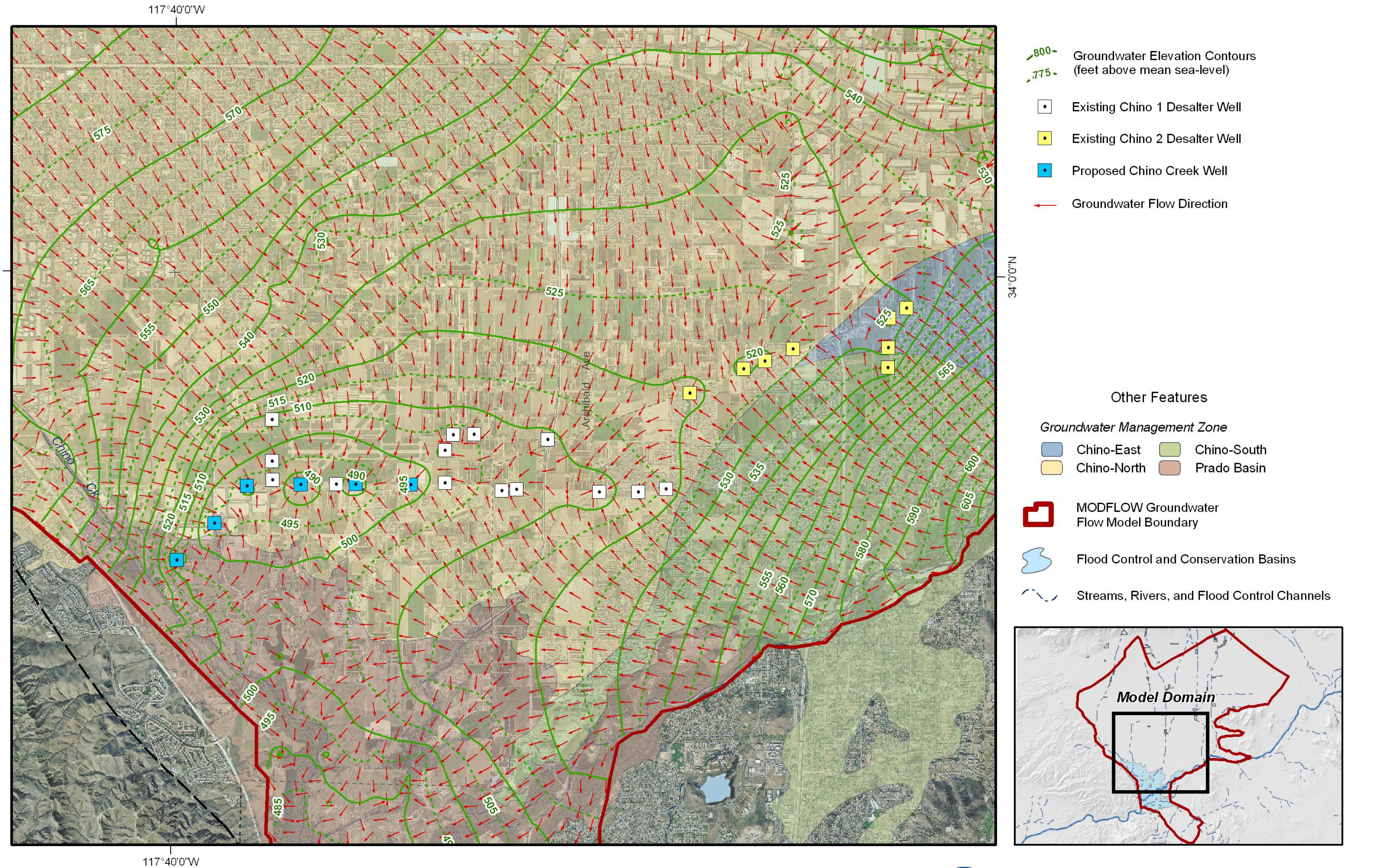
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Predictive Simulations

Groundwater Elevation Contours and Flow Direction in the Vicinity of the Desalters

Alternative 1A in Layer 1 -- 2053

Figure 7-11b



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0 1 2 Miles

0 1 2 3 KM

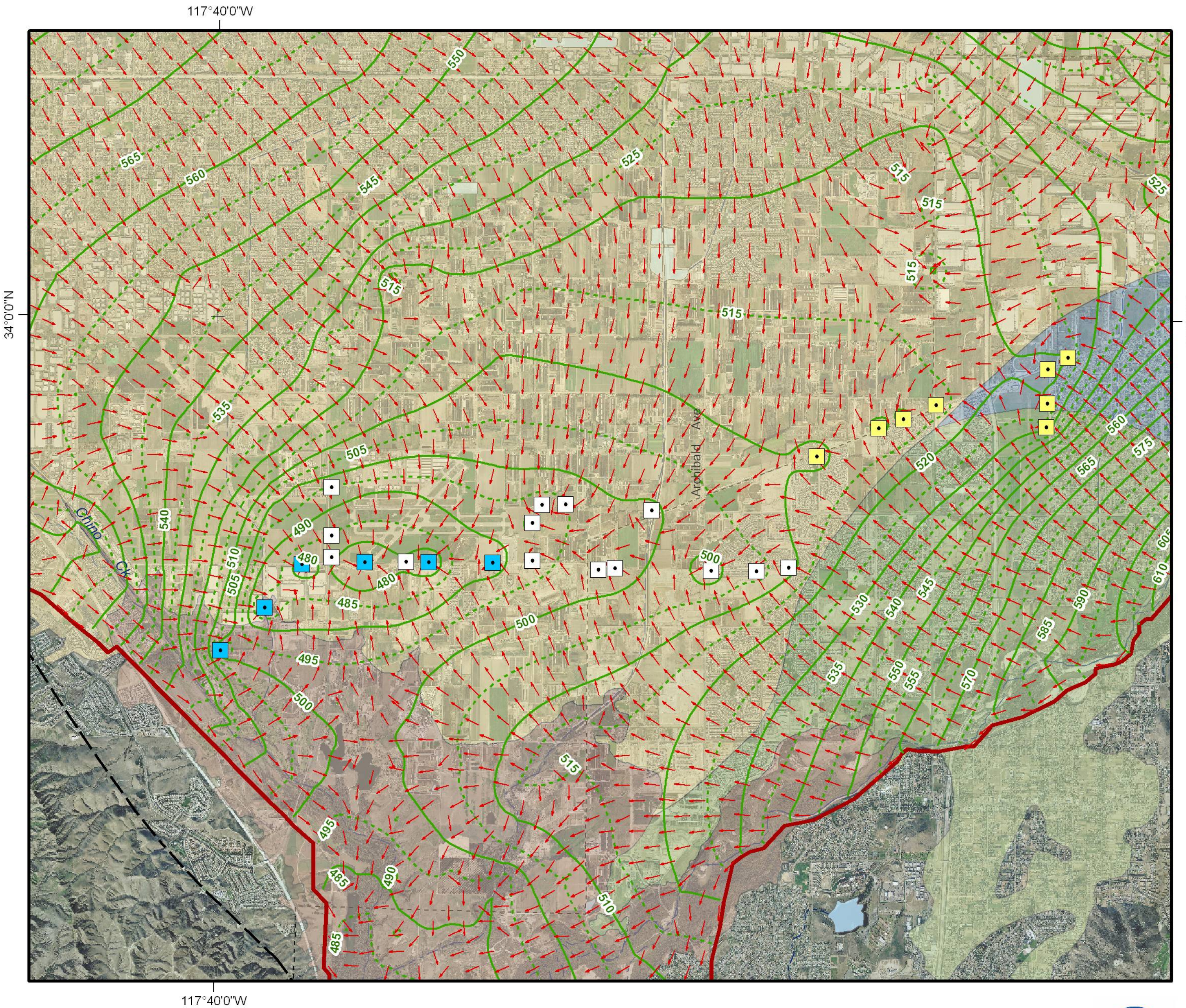
2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Predictive Simulations

Groundwater Elevation Contours and Flow Direction in the Vicinity of the Desalters

Alternative 1B in Layer 1 -- 2023

Figure 7-12a



Groundwater Elevation Contours (feet above mean sea-level)

Existing Chino 1 Desalter Well

Existing Chino 2 Desalter Well

Proposed Chino Creek Well

Groundwater Flow Direction

Other Features

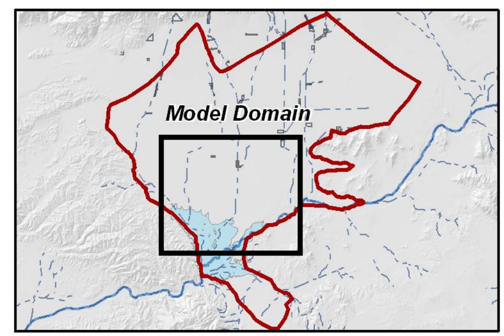
Groundwater Management Zone

Chino-East
Chino-South
Chino-North
Prado Basin

MODFLOW Groundwater Flow Model Boundary

Flood Control and Conservation Basins

Streams, Rivers, and Flood Control Channels



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949.420.3030
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File: Figure_7-12b.mxd

0 1 2 Miles

0 1 2 3 KM

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description

Predictive Simulations

Groundwater Elevation Contours and Flow Direction in the Vicinity of the Desalters

Alternative 1B in Layer 1 -- 2053

Figure 7-12b

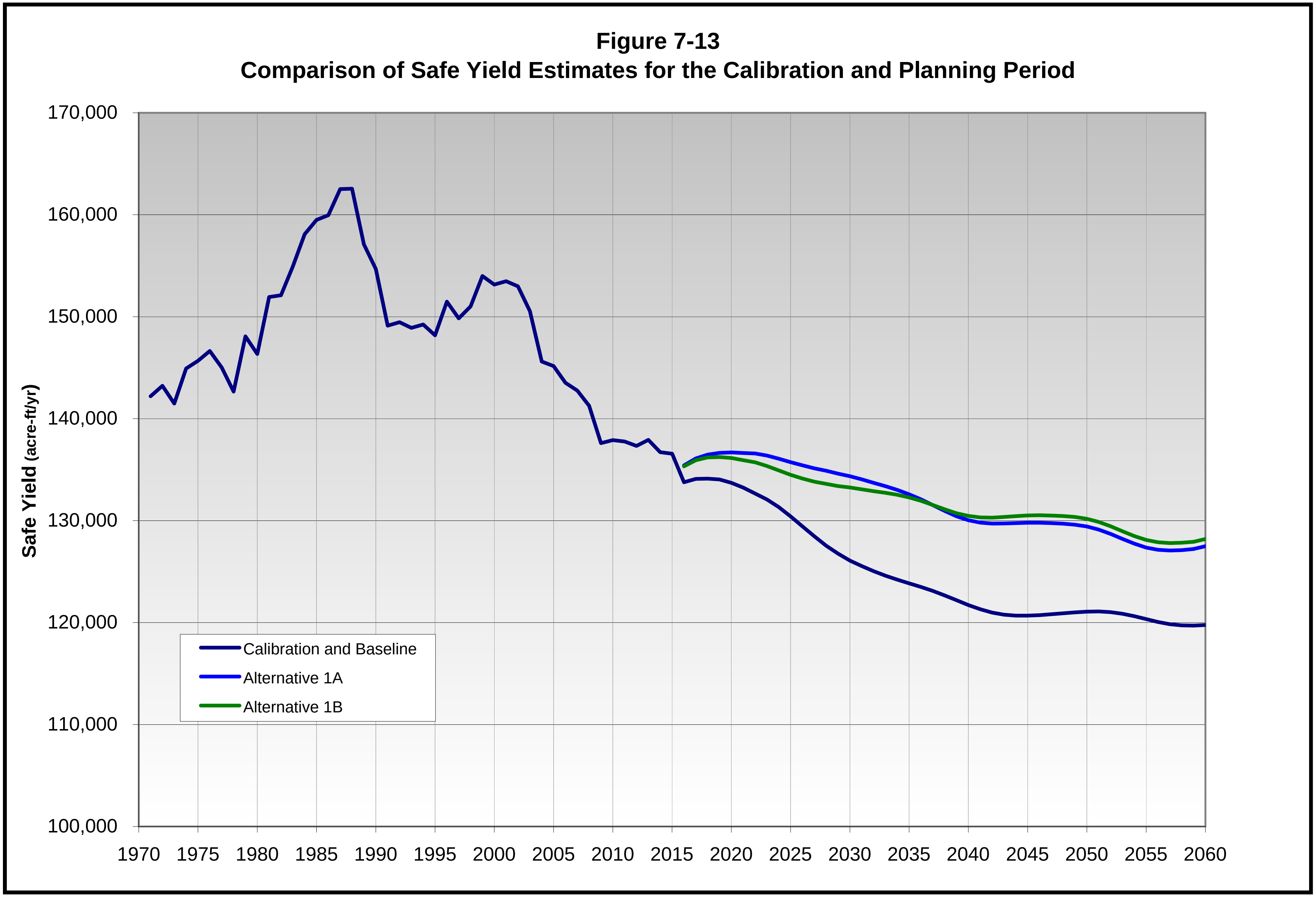

Figure 7-13 yield check with v20 1961-2060.xls

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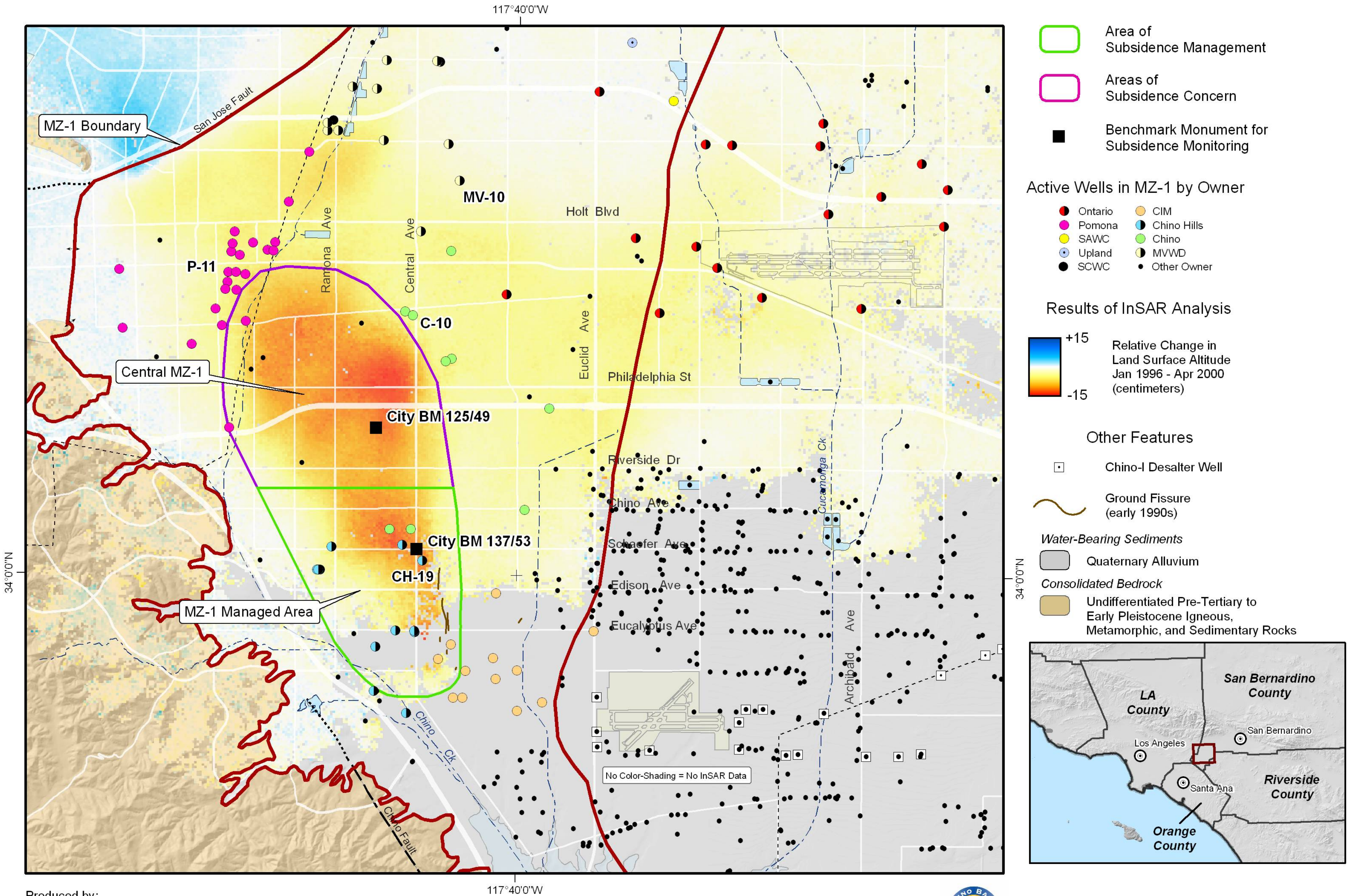

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WILDERMUTH ENVIRONMENTAL INC.

23692 Birtcher Drive
Lake Forest, CA 92630
949.420.3030
www.wildermuthenvironmental.com

Author: AEM/MJC
Date: 20071015
File: Figure_7-14.mxd

2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description
Predictive Simulations

Subsidence Area in MZ-1

Figure 7-14

Figure 7-15
Simulated Groundwater Water Levels in Well PA-7 Baseline, Alternative A, and Alternative 1B (with DYYP)

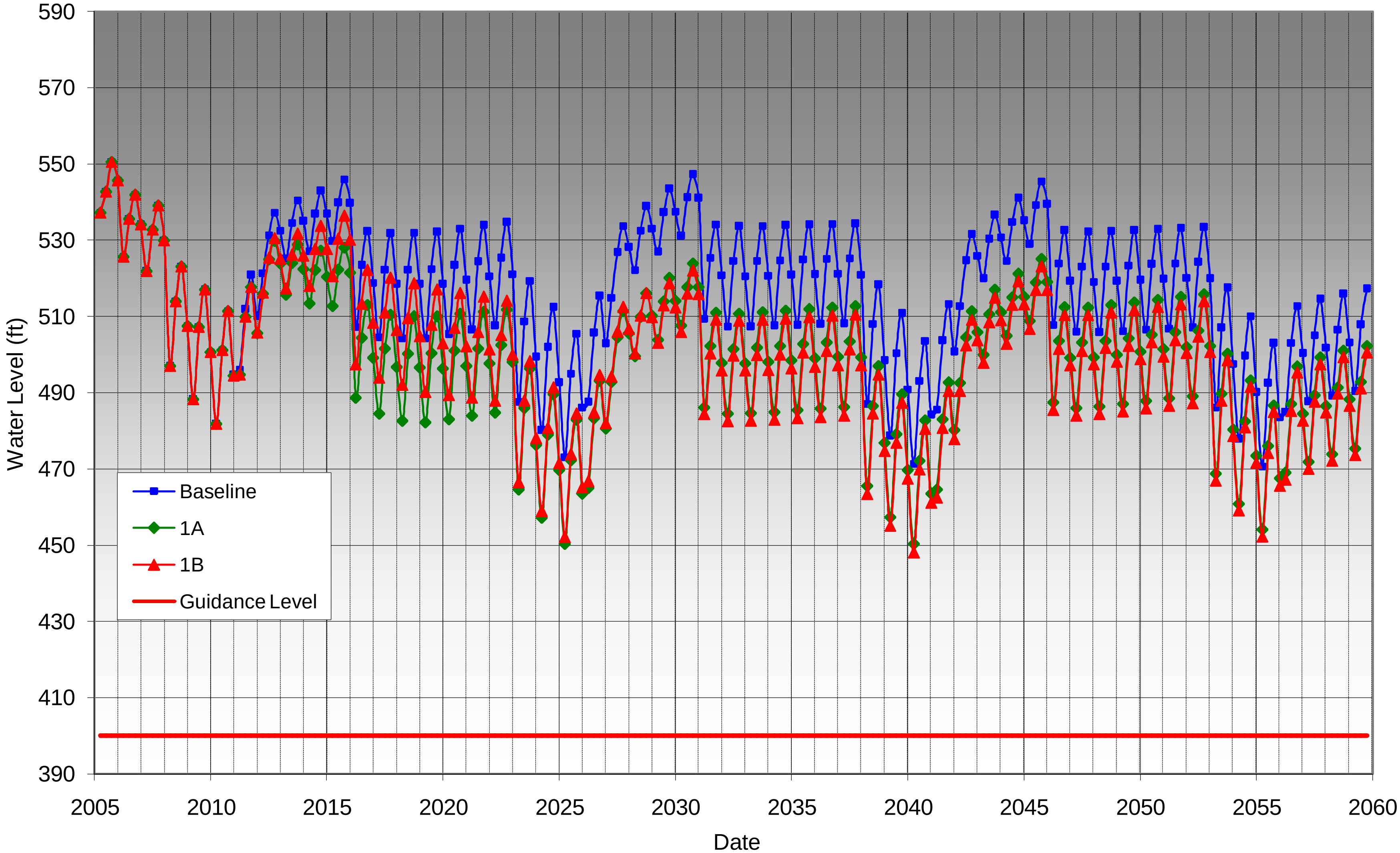

Figure 7-9a thru 7-9l hydrographs_version20.xls

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Section 8 – Conclusions and Recommendations

8.1 The 2007 Watermaster Model

Watermaster's new model, the 2007 Watermaster Model Version 1.0, was developed based on experience in the development and use of the 2003 Watermaster Model and the significant increase in hydrogeologic information that has been developed since the OBMP process started in 1998. The model was calibrated over the 46-year period of 1960/61 through 2005/06. The calibration involved the matching of model estimated groundwater levels at wells to historical observations. The calibration process involved professional judgment, sensitivity analyses, and automated parameter estimating techniques. In total, 59 wells were used in the calibration, and the calibration results are excellent.

In its current form, the model is a reliable tool for estimating the impacts of the future planning alternatives required for Peace II.

There are some areas for improvement in the calibration of the model, and additional work should be done in the near future. These improvements include:

- Refinement of the boundary discharges into the Chino Basin from the Cucamonga, Rialto, and Riverside Basins. The calibrated values seem high, and additional investigations should be done in these basins to refine inflow to the Chino Basin. The deep percolation of precipitation and applied water would need to be refined to counter any changes in the boundary inflows. These refinements will be useful in predicting the fate and transport of contaminant plumes in the basin, but will have little impact on the accuracy of the future impacts of the planning alternatives investigated herein.
- Model refinement of the subsidence area in the MZ1. Currently, the model is capable of simulating most of the groundwater elevations in the subsidence area for the period since the OBMP was implemented and, in particular, the groundwater elevation data collected as part of the MZ1 investigations. The geology in the subsidence area of MZ1 is much more complicated than represented in the conceptual model embedded in the 2007 Watermaster model. The model should be refined in the future to incorporate the complexity of this area. These refinements will produce more reliable estimates of the impacts of groundwater management activities outside of the subsidence area on the subsidence area. Additional aquifer stress tests should be done as described in the MZ1 Long Term Management Plan (WEI, 2007), and sensitivity studies should be done prior to revising the model.

8.2 Simulation Results for the Baseline and Peace II Alternatives

8.2.1 Integrated Planning Process

The integrated regional water planning process for the Chino Basin area needs to be improved to be consistent with the limitations in the groundwater system and the regional facilities. In past planning studies, the parties have assumed that they could pump as much as they desired from anywhere they wanted to pump in the basin and that Watermaster would always be able to replenish overproduction regardless of the magnitude of overproduction. This is best illustrated through the process of developing the Baseline Alternative for the investigation of the Peace II project description:

- Several iterations were required to develop a feasible Baseline Alternative. Initially, the Baseline Alternative used the explicit groundwater production plans of the parties to the Judgment. These groundwater production plans were modified to reflect actual production in the near term (through 2019/20), to gradually (linearly) approach their projected production at 2019/20, and to match their projections thereafter. The resulting aggregate groundwater pumping plan required more replenishment capacity than Watermaster currently has available or plans to have available. This production projection is referred to as the Trial 1 projection.
- The groundwater production plans were modified again by reducing the appropriator production, excluding the desalters, such that the replenishment obligation would, on average, be less than the replenishment capacity of about 91,000 acre-ft/yr. This production projection is referred to as the Trial 2 projection.
- The first complete simulations of the Baseline Alternative produced a surprising result: the safe yield would decline from the 140,000 acre-ft/yr determined in the Judgment to slightly less than 120,000 acre-ft/yr by 2059/60. This required an adjustment in the replenishment plan for the Baseline Alternative. The increase in replenishment, required by a lower safe yield, exceeded the replenishment capacity. The factors that lead to the projected replenishment capacity of 91,000 acre-ft/yr were reviewed to determine if there was readily available means to increase the replenishment capacity. In establishing the 91,000 acre-ft/yr capacity, it was assumed that the basins will be offline three months during every summer for maintenance. The replenishment capacity was increased to about 104,000 acre-ft/yr by reducing the maintenance period from three to two months. Utilizing the expanded replenishment capacity resulted in a Baseline Alternative that was feasible pursuant to the Judgment.
- The groundwater simulations based on the Trial 2 groundwater production plan and the expanded replenishment capacity produced another surprising result: the expanded future groundwater production specifically by the CVWD and the City of Ontario and generally by the surrounding parties resulted in a large groundwater level depression centered in the CVWD well field in the north-central part of the Basin. By the fall of 2023, groundwater elevations in the CVWD well field fell by more than 80 feet, and by the fall of 2053, groundwater elevations fell by over 100 feet. This groundwater depression radiates outward to the east, south, and west of the CVWD well field. It is doubtful that the CVWD and the City of Ontario would produce groundwater in such a way as to create this depression. The groundwater elevation in individual production wells would fall even greater than the model projections. In the out years, groundwater production was reduced in the model to prevent individual model cells from drying up. To mitigate this projected groundwater depression, future net groundwater production by the CVWD and the City of Ontario was capped at 23,800 and 29,000 acre-ft/yr, respectively. This production cap could be lifted by increasing replenishment in this area.

8.2.2 Future Safe Yield for the Baseline Alternative

The safe yield has been projected to decline in the future due to changes in land use and associated water use practices that have occurred in the recent past and will occur in the future. For the 2005/06 through 2015/16 period, the safe yield for the Baseline Alternative declines from about 145,000 to about 134,000 acre-ft/yr. For the period after 2016/17, the safe yield for the Baseline Alternative declines gradually from about 134,000 acre-ft/yr to about 119,000 acre-ft/yr by the end of 2059/60. The safe yield declines due to reductions in the deep percolation of applied water and precipitation and a reduction in storm water recharge. The reduction in recharge is caused by historical and projected changes in land use and associated water use patterns from the conversion of agricultural and vacant land uses to urban uses through 2025.

For the 2005/06 through 2016/17 period, the safe yield increase associated with Re-operation is projected to reach about 2,000 acre-ft/yr by 2016/17, steadily increase to about 8,000 to 9,000 acre-ft/yr by 2030, and average about 8,500 to 9,000 acre-ft/yr for the 2030/31 through 2059/60 period. Note that the average safe yield for the 2030/31 through 2059/60 period is about the same as the increase in Santa Ana River recharge discussed in Section 7.4.2. There are no reductions in yield projected for Alternatives 1A and 1B relative to the Baseline Alternative; thus, there is no material physical injury related to safe yield changes.

8.2.3 New Recharge from the Santa Ana River

The new Santa Ana River recharge achieved by Re-operation is about 8,600 acre-ft/yr for Alternative 1A and 9,000 acre-ft/yr for Alternative 1B. The difference between these two projections is not significant given the uncertainty of the water supply and replenishment plans in the out years. These values represent the average change in discharge from 2034/35 through 2059/60. During the 2005/06 through 2034/35 period, the new Santa Ana River recharge grows rapidly from zero to about 9,000 to 10,000 acre-ft/yr. There is no material physical injury from this induced recharge. This new recharge never reaches the new recharge assumed in Tables 7-6a and 7-6b. By 2029/30, this recharge shortfall results in a reduction in storage of about 198,000 acre-ft/yr and 212,000 acre-ft/yr above the 400,000 acre-ft provided by Re-operation for Alternatives 1A and 1B, respectively. This shortfall in induced recharge should be mitigated preferably after 2030 to ensure that hydraulic control is achieved as soon as possible.

8.2.4 Predicted Changes in Groundwater Levels

There are significant groundwater elevation changes throughout the basin as a result of the implementation of water supply plans and the associated replenishment plans contained in the Baseline, 1A, and 1B Alternatives. Groundwater elevations and elevation changes for the planning alternatives are shown in Figures E-1 through E-36. The general shape of the groundwater elevation contours is similar to the current groundwater elevation contours with the following exceptions:

- Groundwater flow from the Santa Ana River into the basin is more pronounced,
- The occurrence of pumping depression centered on CVWD's wells in the north central part of the basin,
- The development of a pumping depression and capture zone in the Chino Desalter I well field.

Generally speaking, groundwater levels increase in the western portion of the basin due to supplemental recharge in MZ1. Groundwater levels decrease in the central portion of the basin due to pumping by the City of Ontario and the CVWD. This decrease propagates east to the Fontana area or the eastern portion of the basin. Lastly, the desalter wells create a depression in the southern portion of the basin north of Prado Basin. Groundwater levels are lower in Alternatives 1A and 1B relative to the Baseline Alternative. Below, the groundwater level results from Alternative 1A (Alternative 1B has very similar water level results [see Section 7.4.3.3]) and a comparison of the results relative to the

Baseline Alternative for specific locations in the basin are listed.

- Through fall 2023, groundwater elevations in the MVWD and City of Pomona production area are projected to change by about -30 to +20 feet in layer 1, from 0 to -60 feet in layer 2, and from 0 to -40 feet in layer 3. By the fall of 2053, groundwater elevations are projected to change by -30 to +20 feet in layer 1, from 0 to -60 feet in layer 2, and from 0 to -40 feet in layer 3. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 40 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the MZ1 subsidence area (the production area for the Cities of Chino and Chino Hills) are projected to change by about 0 to -25 feet in layer 1, 0 to -60 feet in layer 2, and -40 to -50 feet in layer 3. Through fall 2053, groundwater elevations in the MZ1 subsidence area are projected to change by about 0 to -25 feet in layer 1, 0 to -60 feet in layer 2, and -40 to -50 feet in layer 3. The groundwater level declines in layers 2 and 3 are still above the subsidence threshold, and therefore new inelastic subsidence is not expected to occur with Alternative 1A. Relative to the Baseline Alternative, in 2023, groundwater elevations in Alternative 1A are projected to be about 10 to 20 feet less in layer 1, 20 feet less in layer 2, and 20 feet less in layer 3. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 30 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Similar to the Baseline Alternative, a large pumping depression is projected to form centered on the area where CVWD produces groundwater and to radiate outward through the City of Ontario production area. The pumping hole is the result of the projected expansion of groundwater production by CVWD and the City of Ontario. Near the center of this pumping depression groundwater levels are projected to change by about -100 to -110 feet in all layers by the fall of 2023, and by about -110 to -120 feet by the fall of 2053. This pumping depression appears to affect the entire central part of the basin and to radiate outward to the eastern, southern, and western parts of the basin. Relative to the Baseline Alternative, groundwater elevations are projected to be about 40 to 50 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater levels in the JCSD production area are projected to change by about -60 to -90 feet in all layers by the fall of 2023, and by about -80 to -90 feet by the fall of 2053. Relative to the Baseline Alternative, groundwater elevations are projected to be about 40 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the City of Ontario production area are projected to change by about -40 to -100 feet in all layers and by about -60 to -110 feet in all layers by the fall of 2053. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 50 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the FWC production area are projected to change by about -60 to -90 feet in all layers and by about -80 to -90 feet in all layers by the fall of 2053 for. Relative to the Baseline Alternative, groundwater elevations are projected to be about 20 to 50 feet less with Alternative 1A from the fall of 2023 through the end of the planning period.

- Through fall 2023, groundwater elevations in the Desalter No. 1 well field area are projected to change by about -20 to -50 feet in all layers and to remain at these levels through the fall 2053. Relative to the Baseline Alternative, in the fall of 2023, groundwater elevations in

Alternative 1A are projected to be about 5 to 25 feet less across all layers through the end of the planning period. Re-operation has depressed the groundwater elevations at the desalter wells relative to the Baseline Alternative.

- Through fall 2023, groundwater elevations in the Desalter No. 2 well field area are projected to change by about -50 to -70 feet in all layers and to remain at these levels through the fall 2053. Relative to the Baseline Alternative, in the fall of 2023, groundwater elevations in Alternative 1A are projected to be about 10 to 20 feet less across all layers through the end of the planning period. Re-operation has depressed the groundwater elevations at the desalter wells relative to the Baseline Alternative.

8.2.5 Hydraulic Control

One of the assumptions in the Baseline Alternative is that the basin is operated in balance pursuant to the Judgment with the desalter production offsetting the decline in agricultural production. That balance has historically included a significant discharge from the basin to the Santa Ana River. Managing the net production from the basin to the operating yield and the dependence on the sustained production by others will produce a marginal state of hydraulic control at best; a state of hydraulic control that cannot be assured. The model projections for Alternatives 1A and 1B demonstrate a more robust state of hydraulic control. Re-operation is required to rapidly achieve and maintain hydraulic control.

8.2.6 Predicted Changes in Safe Yield

For the 2005/06 through 2016/17 period, the safe yield increase associated with Re-operation is projected to reach about 1,100 to 1,300 acre-ft/yr by 2016/17, to increase steadily to about 7,200 to 8,100 acre-ft/yr by 2040, and to increase to about 8,500 to 9,000 acre-ft/yr by 2060. Note that the post 2034/35 estimates of safe yield are consistent with the increase in Santa Ana River recharge discussed in Section 7.4.2. There are no reductions in yield projected for Alternatives 1A and 1B relative to the Baseline Alternative; thus, there is no material physical injury related to changes in the safe yield.

8.2.7 Subsidence in the Managed Area of MZ1

Figure 7-14 shows the projected piezometric elevations at the PA-7 piezometer for all of the planning alternatives. The PA-7 piezometer is used in Watermaster's MZ1 Long Term Management Plan. In this plan, basin management activities that maintain piezometric elevations greater than 400 ft at the PA-7 piezometer (corresponding to a depth to water of 245 feet) will not cause inelastic subsidence. In all cases, the projected piezometric elevations are 50 to 80 feet higher than the subsidence threshold elevation of 400 ft for the managed area of MZ1; thus, no inelastic subsidence is projected to occur in MZ1. There are no material physical injuries related to subsidence from any of the planning alternatives.

8.2.8 Material Physical Injury

Based on the model analysis described in Section 7, there does not appear to be a material physical injury caused by the implementation of the Peace II project description.

8.3 Future Due Diligence

In Section 6, the 2007 Watermaster model was demonstrated to be a well calibrated groundwater model. The data used to calibrate the model include actual and estimated groundwater recharge and production data. The future simulations are based on educated estimates of land use, associated water use practices, and future production. There is no way to determine the accuracy of these estimates. The model was used to refine these projections in the Baseline Alternative. Groundwater models, by definition, represent the essence of a system: they are not the system. As complicated as it may be, the model is a simplified version of the groundwater system: it's not perfect.

Therefore, even though the groundwater model is well calibrated, it is possible that the planning information used to evaluate the future alternatives could be flawed and the modeling results could be questionable. The following should be done to overcome potential inaccuracies due to planning data and to maintain the model:

- Groundwater production and recharge projections should be revised as new information becomes available. New alternatives should be evaluated with the model on a periodic basis if future production and replenishment plans change significantly either in time or location.
- Groundwater and recharge monitoring programs should continue into the foreseeable future. These programs will provide information that can be used to assess the consistency of real world behavior and what was assumed in the planning alternatives as well as provide information for use in model calibration updates. This is especially important on a go forward basis as the projected operation of the basin is outside the bounds of the historical operation used in the calibration of the 2007 Watermaster model.

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