Final

Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Prepared for

United States Environmental Protection Agency

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CH2MHILL®

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Contents

Section **Page**

Tables

Figures

(Figures are located at the end of their respective sections.)

Acronyms and Abbreviations

µg/L	microgram per liter
160-Acre Area	source area at the B.F. Goodrich site
3D	three-dimensional
bgs	below ground surface
COC	constituent of concern
CSM	conceptual site model
CY	calendar year
DEM	digital elevation map
ET	evapotranspiration
ft/day	foot per day
Geo-Logic	Geo-Logic Associates
GHB	general head boundary
GIS	geographic information system
HFB	horizontal flow barrier
in/yr	inch per year
ME	mean error NAVD88 North American Vertical Datum of 1988
Numerical Simulation of Ground-Water Flow	*Numerical Simulation of Ground-Water Flow and Assessment of the Effects of Artificial Recharge in the RCB, San Bernardino County, California*
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RCB	Rialto-Colton Basin
RMSE	root mean square error
EPA RCM	U.S. Environmental Protection Agency Rialto-Colton Model
USEPA	U.S. Environmental Protection Agency

SECTION 1

Introduction

The U.S. Environmental Protection Agency (USEPA) and its consultant, CH2M HILL, have developed a numerical groundwater flow model of the Rialto-Colton Basin (RCB). This numerical model is referred to as the USEPA Rialto-Colton Model (EPA RCM) to differentiate it from the conceptual site model (CSM) and the numerical modeling code on which the EPA RCM is built (i.e., MODFLOW-NWT). This report documents the development and calibration of the EPA RCM.

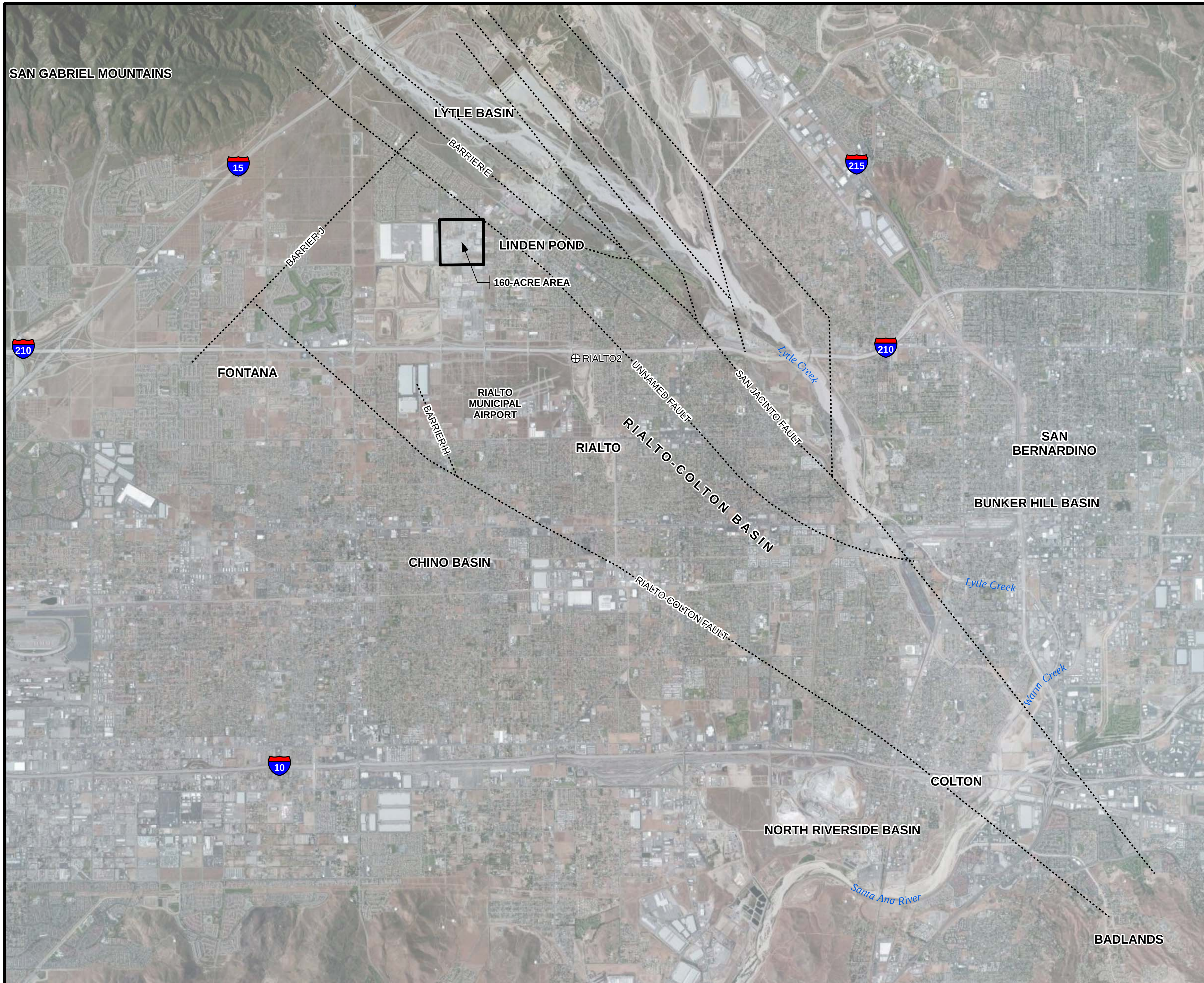
The RCB is an alluvial basin in the upper Santa Ana River drainage area, located approximately 55 miles east of Los Angeles, California, in southwest San Bernardino County. It is a northwest trending basin approximately 10 miles long and 3.5 miles wide at its widest point. The basin is bounded by the San Gabriel Mountains on the northwest, the San Jacinto Fault on the northeast, the Badlands on the southeast, and the Rialto-Colton Fault on the southwest (Figure 1-1) (figures are located at the end of their respective sections).

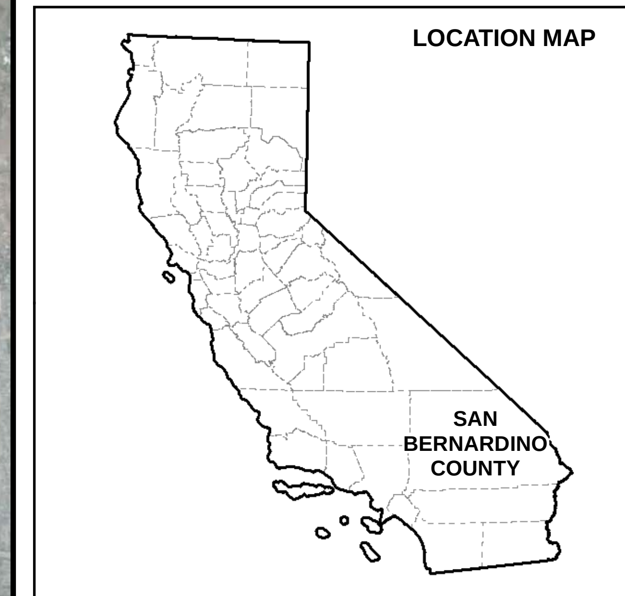
The primary focus of the EPA RCM is the B.F. Goodrich Superfund site, including the 160-Acre Area and downgradient areas of contaminated groundwater (Figure 1-1). The 160-Acre Area is a source area for perchlorate and volatile organic compound (VOC) contamination in groundwater in the RCB. Although investigations are still ongoing to fully delineate the extent of groundwater contamination, the dissolved perchlorate plume, defined as the portion of the aquifer where perchlorate concentrations exceed 6 micrograms per liter (µg/L), is at least 4 miles long. A detailed history of the 160-Acre Area is provided in *Remedial Investigation/Feasibility Study Report, B.F. Goodrich Superfund Site, Rialto, California* (CH2M HILL, 2010).

As part of ongoing environmental investigations, the EPA RCM has been developed to improve the understanding of the physical system and inform decisions related to environmental management in the basin. This model was built to investigate past, present, and potential future groundwater flow in the RCB at and downgradient of the 160-Acre Area. Additionally, the EPA RCM was developed as a tool for hypothesis testing related to evaluation of perchlorate and VOC contamination in the lower RCB and EPA's Source Area Operable Unit (OU) remedy in the upper RCB. The term "upper RCB" refers to the portion of the aquifer northwest of the Rialto Municipal Airport (Figure1-1). The term "lower RCB" refers to the portion of the aquifer southeast of the convergence of the Unnamed and the San Jacinto Faults.

The EPA RCM was designed to provide insight into subsurface parameters and processes that control groundwater flow in the RCB. The EPA RCM simulates transient groundwater flow in three dimensions from calendar year (CY) 1970 through 2009. Specifically, the EPA RCM was designed to meet the following modeling objectives:

- Integrate the CSM, with respect to hydrostratigraphy, groundwater elevations, and subsurface hydraulic characteristics, into a numerical tool to better understand groundwater flow and its variability through time
- Simulate basin-scale changes in groundwater conditions that occurred from CY 1970 through 2009
- Aid in the planning and implementation of the Source Area OU remedial design
- Support evaluations of alternatives for the planned feasibility study for the lower RCB
- Aid in developing the proposed cleanup plans and record of decisions
- Aid in identifying data gaps





LEGEND

- 160-ACRE AREA
- APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)
- WELL LOCATION

NOTE:

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 6,000 12,000 Feet

N

FIGURE 1-1
SITE LOCATION MAP
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

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SECTION 2

Conceptual Site Model Overview

A CSM is a theoretical construct of a physical system developed through assimilation and interpretation of relevant site information. Ideally, a CSM is the simplest representation of a given physical system that provides enough information to fulfill the objectives. The CSM for the RCB was developed and refined based on multiple field and modeling studies over the past 50 years. CSMs for the RCB have been presented in detail in previous documents (Dutcher and Garrett, 1963; Woolfenden and Kadhim, 1997; Woolfenden and Koczot, 2001; Geo-Logic Associates (Geo-Logic), 2007 and 2010; and CH2M HILL, 2010) and is described only briefly in this report.

The RCB is a fault-bounded alluvial basin located in southwestern San Bernardino County, California. The basin is approximately 10 miles long and extends from the San Gabriel Mountains in the northwest to the Badlands in the southeast (Figure 1-1). Land surface in the basin is approximately 2,000 feet above the North American Vertical Datum of 1988 (NAVD88) near the foot of the San Gabriel Mountains and slopes downward to approximately 950 feet NAVD88 in the southeastern portion of the basin near the Santa Ana River. The Santa Ana River is the largest source of surface water inflow to the RCB. It flows into the basin from the Bunker Hill Basin along with Warm Creek. Warm Creek flows into the Santa Ana River in the RCB.

Sediments within the RCB are primarily composed of unconsolidated to partly consolidated alluvium of Quaternary and Tertiary age. The thick alluvial deposits are underlain by consolidated Tertiary deposits of mainly indurated clays, and pre-Tertiary igneous and metamorphic basement rock. Detailed descriptions of the primary stratigraphic units present in the RCB are provided in *Geologic and Hydrologic Features of the San Bernardino Area California with Special Reference to Underflow across the San Jacinto Fault* (Dutcher and Garrett, 1963) and *Geohydrology and Water Chemistry in the RCB, San Bernardino County, California* (Woolfenden and Kadhim, 1997).

In general, the stratigraphic units in the RCB do not form defined aquifers and confining units. Thus, the past convention has been to separate the groundwater system into water bearing units (Dutcher and Garrett, 1963; Woolfenden and Kadhim, 1997). These units are primarily unconfined and hydraulically connected. In the convention of Dutcher and Garrett (1963) and Woolfenden and Kadhim (1997), the four water-bearing units are river-channel deposits, the upper water-bearing unit, the middle water-bearing unit, and the lower water-bearing unit. River-channel deposits are present in a small portion of the basin at and surrounding the current channels of Warm Creek and the Santa Ana River. River-channel deposits consist of coarse sand and gravel interbedded with fine sand and clay. The upper water-bearing unit is present throughout the basin, but is only saturated in the lower RCB (Figure 2-1). The middle water-bearing unit is present throughout the basin and consists of coarse to medium sand and interbedded fine sand and clay. This is the most highly developed unit in terms of groundwater extraction in the RCB. The lower water-bearing unit consists of interbedded sand and clay and is generally less permeable than the middle water-bearing unit.

On the basis of data collected by Geo-Logic Associates, a revised conceptual model of the upper RCB has been suggested. The refined model indicates that groundwater in the upper RCB occurs in three laterally continuous water-bearing units. These units are part of the middle and lower water-bearing units described by Dutcher and Garrett (1963). The Intermediate Aquifer, first encountered at a depth of approximately 400 to 450 feet below ground surface (bgs), is approximately 100 feet thick beneath the 160-Acre Area and thins to the southeast. The Intermediate Aquifer is variably saturated and perched on top of a laterally extensive aquitard (termed the BC Aquitard) that separates the Intermediate Aquifer from the deeper Regional Aquifer (Figure 2-1) . Beneath the 160-Acre Area, potentiometric head differences between the Intermediate Aquifer and Regional Aquifer are as great as 150 feet, resulting in a downward hydraulic gradient between the two aquifers. On the basis of geophysical logs and groundwater level data collected by Geo-Logic (Geo-Logic , 2005), it appears that the BC Aquitard pinches out near well Rialto2 (Figure 1-1). Downgradient of well Rialto2, the BC Aquitard pinches out, and the Intermediate and Regional Aquifers merge into one aquifer. Figure 2-1 shows the relative relationships between the upper RCB and lower RCB.

Groundwater flow directions vary temporally and spatially in the RCB. In the river-channel deposits and upper water-bearing unit in the southeast part of the basin, groundwater generally moves from northeast to southwest, from the Bunker Hill Basin through the RCB to the North Riverside Basin. However, in most of the RCB, groundwater flows from northwest to southeast approximately parallel to the basin's longitudinal axis, primarily in the middle and lower water-bearing units. Three structural features, Barrier J, Barrier H, and the Unnamed Fault, impede groundwater movement in the interior of the basin (Figure 1-1) (Dutcher and Garrett, 1963; Woolfenden and Kadhim, 1997; CH2M HILL, 2010). It is possible that other unmapped structures may be present that could also impede groundwater flow.

The primary components of recharge to the groundwater system within the RCB are subsurface inflow from adjacent areas outside the RCB, groundwater recharge from the Santa Ana River and Warm Creek, groundwater recharge from applied water (artificial recharge ponds and irrigation), and groundwater recharge from precipitation. The primary components of discharge from the groundwater system within the RCB are groundwater pumping by water purveyors, subsurface outflow from the RCB, shallow groundwater evapotranspiration, and groundwater discharge to streams (primarily the Santa Ana River and Warm Creek) during wet years when the groundwater levels in the upper water-bearing unit and the river-channel deposits rise above the stream stages.

Groundwater levels in production wells respond to water use and long-term climatic cycles. Historical measurements indicate that groundwater levels in the RCB have varied significantly in response to extended periods of drought and municipal and agricultural pumping. Extended drought conditions in the region and operation of additional municipal supply wells in the basin have resulted in pronounced reductions in groundwater levels within the RCB, with levels in the Regional Aquifer declining steadily from 2001 through 2009. Even after heavy rainfall during the 2004-2005 winter, groundwater levels in the Regional Aquifer increased by only a small amount.

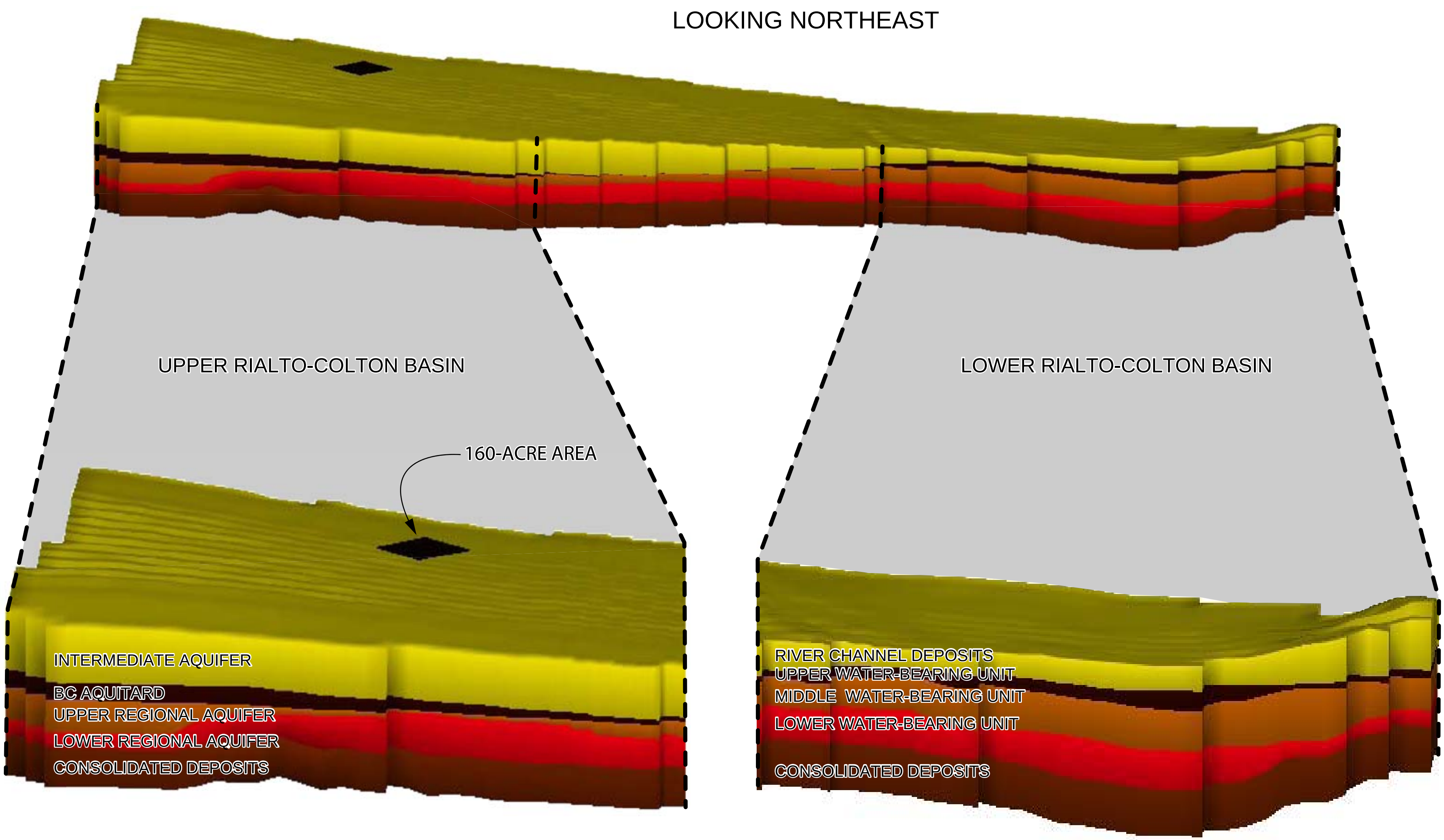

FIGURE 2-1
SCHEMATIC OF RIALTO-COLTON BASIN AQUIFER
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

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SECTION 3

Numerical Model Construction

Multiple numerical groundwater flow models of the RCB and adjacent basins have been developed. Models of the RCB include the U.S. Geological Survey (USGS) basinwide model (Woolfenden and Koczot, 2001), the Geo-Logic upper basin model (Geo-Logic, 2007; 2010), and a previous CH2M HILL upper basin model (CH2M HILL, 2010). Models of the surrounding basins include the Chino Basin model (Wildermuth Environmental, 2007), the Bunker Hill Basin model (Danskin et al., 2005), and the North Riverside Basin model (WRIME, 2010). These models were reviewed during the development of the EPA RCM. Although it was not always possible, an attempt was made to maintain consistency with these models. In development of the EPA RCM, the Woolfenden and Koczot (2001) model was used as the primary source of information for the lower RCB and the Regional Aquifer in the upper RCB, and the CH2M HILL (2010) model, which was primarily based on the Geo-Logic model, was used as the primary source of information for the units above the Regional Aquifer in the upper RCB.

The mathematical model design is the result of translating the CSM into a form that is suitable for numerical modeling. The following steps were completed in the development of the mathematical model:

1. Selecting a numerical groundwater flow model code
2. Establishing a model domain and developing a model grid
3. Spatially distributing land surface elevation values
4. Spatially distributing subsurface hydraulic parameter values
5. Establishing initial groundwater flow conditions
6. Selecting an appropriate time discretization
7. Establishing boundary conditions and horizontal flow barriers to groundwater flow

The following subsections describe the methodology used to execute these seven design steps.

3.1 Code Selection

The MODFLOW-NWT[1] code (Niswonger et al., 2011) was selected for this effort, in conjunction with the Groundwater Vistas Version 6.0[2] pre- and post-processing software package. MODFLOW-NWT is an updated formulation of MODFLOW-2005 (Harbaugh, 2005). It is a standalone program that was developed to provide a more robust solution to the nonlinear unconfined groundwater flow equation. MODFLOW-NWT is a physically based, spatially distributed numerical modeling code that includes several packages for simulating 3D groundwater flow. The MODFLOW-NWT code was selected for the following reasons:

- MODFLOW-NWT is based on MODFLOW-2005, which has been used extensively in groundwater evaluations worldwide for many years and is well documented. MODFLOW-NWT contains an improved solution scheme that can better handle complex, variably saturated conditions and model cells drying and rewetting.
- MODFLOW-NWT has been benchmarked and verified so that the numerical solutions generated by the code have been compared with one or more analytical solutions, subjected to scientific review, and used on previous modeling projects. Verification of the code confirms that MODFLOW-NWT can accurately solve the governing equations that constitute the mathematical model.

The following subsections describe the numerical assumptions, scientific bases, and limitations inherent in MODFLOW-NWT. The MODFLOW-NWT user's manual (Niswonger et al., 2011) contains additional information on the code.

[1] http://water.usgs.gov/nrp/gwsoftware/modflow_nwt/ModflowNwt.html. (Accessed March 9, 2012.)

[2] http://www.groundwatermodels.com/Groundwater_Vistas.php. (Accessed March 9, 2012.)

3.1.1 Numerical Assumptions

The EPA RCM is conceptualized mathematically into a single-density subsurface flow regime. All model layers are treated as vertically integrated, unconfined to leaky confined layers to facilitate accurate simulation of 3D groundwater flow conditions. The EPA RCM also accommodates the standard suite of groundwater flow model boundary conditions.

3.1.2 Scientific Bases

The theory and numerical techniques that are incorporated in the EPA RCM have been scientifically tested. The governing equations for variably saturated subsurface flow have been solved by several modeling codes over the past few decades on a wide range of field problems. Thus, the scientific bases of the theory and the numerical techniques for solving these equations have been well established. The MODFLOW-NWT user's manual (Niswonger et al., 2011) details the governing equations and the numerical techniques used in their solution.

3.1.3 Limitations

Mathematical models can only approximate physical processes. Models are inherently inexact because mathematical descriptions of physical systems are imperfect, and physical and chemical processes are often incompletely understood. It is CH2M HILL's judgment, however, that the EPA RCM incorporates enough detail of the physical system to fulfill the modeling objectives described in Section 1.1.

3.2 Model Domain

The numerical model represents the hydrologic system in discrete space. The simplest way to discretize space is to subdivide the study area into many subregions (i.e., grid blocks) of the same size. Small grid-blocks are often necessary to avoid numerical instabilities, but if they are used throughout the model domain, long simulation run times may result. Thus, it is typically advantageous to use relatively small grid-blocks only in key areas of the modeling domain where more resolution is desired. Larger grid-blocks are often used away from the main areas of interest, especially when the model domain represents a large geographic area. This strategy seeks to maximize the resolution of the numerical solution in areas of interest while minimizing model run times. This grid-building strategy was implemented for this modeling effort and is described in the following subsection.

3.2.1 Areal Characteristics of Model Grid

CH2M HILL developed a numerical model grid that mathematically represents a 31-square-mile area of the RCB and encompasses the 160-Acre Area. Figure 3-1 illustrates the EPA RCM grid, which was areally discretized into grid-block (i.e., cell) spacings ranging from 205 to 820 feet, with finer cell spacings at and downgradient of the 160-Acre Area, southwest of Unnamed Fault. The locations of the lateral model domain boundaries shown on Figure 3-1 were selected to coincide with natural features, such as basin boundaries and faults, to help establish a regional hydrologic framework in the EPA RCM.

3.2.2 Vertical Characteristics of Model Grid

CH2M HILL developed five vertically stacked layers to provide a 3D representation of the subsurface system. Table 3-1 lists the model layer designations and thicknesses; Figure 3-2 illustrates the model grid in profile views. Unlike previous models of the RCB, the EPA RCM explicitly simulates a portion of the consolidated deposits (Model Layer 5) underlying the basin alluvium. Because the thickness of the consolidated deposits is poorly constrained, Model Layer 5 was set to a constant thickness of 300 feet. Excluding Model Layer 5, layer thicknesses are largely based on previous models (Woolfenden and Koczot, 2001; Geo-Logic, 2007). Layer thicknesses in the northwestern portion of the basin are largely based on the Geo-Logic model (Geo-Logic, 2007); layer thicknesses in the southeastern portion of the basin are largely based on the USGS model (Woolfenden and Koczot, 2001). The top elevation of Model Layer 1 was set equal to the ground surface elevation, which was derived from the National Elevation Dataset described in Section 3.3. The top elevation of Model Layer 5 was derived from the bottom of the lower water-bearing unit (i.e., top of the consolidated deposits) from the USGS model (Woolfenden and Koczot, 2001) and soil boring logs.

TABLE 3-1
Summary of Model Layer Designations in the EPA RCM
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Model Layer	Hydrostratigraphic Description (upper basin/lower basin)	Model Layer Thickness (feet)	
		Model Domain	160-Acre Area[a]
1	Intermediate Aquifer/River Channel Deposits	108 to 781	482 to 514
2	BC Aquitard/Upper Water-bearing Unit	0.5 to 133	71 to 99
3	Upper Regional Aquifer/Middle Water-bearing Unit	14 to 345	56 to 88
4	Lower Regional Aquifer/Lower Water-bearing Unit	42 to 479	311 to 390
5	Consolidated Deposits/Consolidated Deposits	300	300

[a] 160-Acre Area shown on Figure 1-1.

Note:

All model layers simulated as unconfined aquifers.

3.3 Topography

Data from the National Elevation Dataset forms the best available dataset for land surface elevations covering the RCB. This dataset formed the basis for land surface elevations in the EPA RCM. These land surface elevations were assigned to the top of Model Layer 1. Elevation data were processed using ArcGIS Version 10[3]. Figure 3-3 illustrates the land surface elevations incorporated into the top of the EPA RCM grid.

3.4 Subsurface Hydraulic Parameters

The subsurface hydraulic parameters required by the EPA RCM are the horizontal hydraulic conductivity (K_h), vertical hydraulic conductivity (K_v), specific storage, and specific yield.

3.4.1 Horizontal Hydraulic Conductivity

Data resulting from aquifer tests, previous modeling efforts, and professional judgment formed the basis for the initial K_h values incorporated into the EPA RCM. Specific capacity-derived K_h estimates were also available; however, most were from production wells screened over large depth intervals. Thus, these values were used as qualitative estimates of K_h rather than layer-specific, quantitative estimates. Section 4 describes the modification of K_h during the calibration process.

3.4.2 Vertical Hydraulic Conductivity

The K_v values were initially assigned according to an assumed K_h:K_v (i.e., vertical anisotropy) ratio of 10:1 for each model layer. K_v was parameterized on a cell-by-cell basis by dividing K_h by a value of 10. Section 4 describes the modification of this value during the calibration process.

3.4.3 Specific Storage

Specific storage is defined as the volume of water released from or taken into storage per unit volume of aquifer per unit change in hydraulic head. All grid cells were initially assigned a specific storage of 1×10^{-6} per foot (ft^{-1}). Section 4 describes the modification of this value during the calibration process.

3.4.4 Specific Yield

Specific yield is defined as the volume of water that an unconfined aquifer takes into or releases from storage per unit surface area of the aquifer per unit change in water table elevation. MODFLOW-NWT calculates unconfined storage differently than previous versions of MODFLOW. When model layers are unconfined, MODFLOW-NWT uses the specific yield parameter, in addition to specific storage, to describe aquifer storage. For unconfined

[3] http://www.esri.com/software/arcgis/index.html. (Accessed March 9, 2012.)

conditions, the confined storage equation is multiplied by a smoothing function to provide a transition between confined storage and zero storage (dry conditions). The total change in storage is equal to this value added to the unconfined storage equation (Niswonger et al., 2011). All grid cells were initially assigned a specific yield of 0.1. Section 4 describes the modification of this value during the calibration process.

3.5 Initial Flow Conditions

The model requires a starting head at each active cell within the model domain. Despite the significant decline in groundwater levels over the last decade, heads at the end of the simulation period are similar to those during the early 1970s. Thus, 2009 heads were used as the initial conditions for the transient simulation and then adjusted during the calibration process. Heads from 2009 were chosen because water levels were similar to those in the early 1970s and the network of wells and available water level data were much greater in 2009.

3.6 Time Discretization

The EPA RCM was set up to simulate transient groundwater flow conditions from CY 1970 through 2009. Given the modeling objectives described in Section 1.1, this simulation period was considered appropriate. Time is continuous in the physical system, but a numerical model must describe the field problem at discrete time intervals. The model was discretized into annual stress periods. This means that stresses acting on the model (boundary conditions) are averaged over a calendar year and allowed to vary on an annual basis during the 40-year simulation period., Discretization of time into annual stress periods minimizes model run times and satisfies model objectives, which are generally focused on longer term processes and groundwater trends.

3.7 Boundary Conditions and Horizontal Flow Barriers

Figure 3-4 and Table 3-2 summarize the boundary conditions in the EPA RCM. Boundary conditions are mathematical statements (i.e., rules) that specify head or water flux at particular locations within the model domain. The following three types of boundary conditions are used in the EPA RCM:

- Specified-flux: Volumetric groundwater fluxes are specified.
- Head-dependent flux: Given elevation and possibly conductance values, depending on the type of head-dependent flux boundary, groundwater fluxes are internally computed across the boundary using an appropriate governing flow equation.
- No-flow: Groundwater can flow parallel to the boundary, but not across it.

3.7.1 Specified-flux Boundaries

3.7.1.1 Groundwater Recharge from Precipitation

Groundwater recharge from precipitation was simulated using the MODFLOW-NWT recharge package. Precipitation grids generated by the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM Climate Group[4]) were used to estimate rates of groundwater recharge from precipitation falling within the model domain. The PRISM grids specify annual precipitation rates on 0.5-mile (800-meter) centers. The PRISM grids were intersected with the model grid using GIS software to provide a precipitation rate for each model grid cell for each year.

[4] http://www.prism.oregonstate.edu/ (Accessed March 9, 2012.)

TABLE 3-2
Summary of Boundary Conditions
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Hydrologic Process	Specified-flux Boundary	Head-dependent Flux Boundary
Groundwater Recharge from Precipitation	X	
Ungaged Runoff and Subsurface Inflow from San Gabriel Mountains and Badlands	X	
Groundwater Recharge from Linden Pond	X	
Subsurface Inflow from Lytle and Bunker Hill Basins	X	
Groundwater Pumping	X	X
Subsurface Outflow to Chino Basin	X	
Evapotranspiration of Shallow Groundwater		X
Groundwater Interaction with Warm Creek and Santa Ana River		X
Subsurface Outflow to North Riverside Basin		X

Notes:

The Horizontal Flow Barrier package simulates impeded groundwater flow across each modeled fault zone.

Figure 3-4 depicts the assigned boundary conditions.

Turner's method (1986) was used to calculate an annual groundwater recharge rate from the annual precipitation rate, as follows:

$$R = P - 2.32 * P^{0.66} \qquad (1)$$

Where:

R = annual groundwater recharge rate in units of inches

P = annual precipitation rate in units of inches

The RCB experiences significant variability in annual precipitation rates. Data recorded at a precipitation station in Riverside, California showed that precipitation rates ranged from less than 2 inches per year (in/yr) to more than 22 in/yr between 1970 and 2009. This variability is reflected in associated groundwater recharge rates specified in the EPA RCM. For example, 1972 was a dry year; the spatial average precipitation across the model domain was approximately 7 inches per year (in/yr) (PRISM Climate Group). No groundwater recharge from precipitation was specified during the stress period representing this year. In contrast, 1983 was a wet year; the spatial average precipitation across the model domain was approximately 38 in/yr (PRISM Climate Group). During the stress period representing this year, groundwater recharge from precipitation was specified at a rate of approximately 12 in/yr, based on Equation 1. In general, specified groundwater recharge rates decrease with decreasing ground surface elevation in a southeast direction.

3.7.1.2 Ungaged Runoff and Subsurface Inflow from San Gabriel Mountains and Badlands

Rates of ungaged runoff from the Badlands and San Gabriel Mountains were specified in Model Layers 2 and 3, respectively, using the MODFLOW-NWT well package. Inflow volumes were taken from Woolfenden and Koczot (2001) for the years between 1970 and 1996, which was the end of their simulation period. For years beyond 1996, the volume of ungaged runoff from the San Gabriel Mountains and the Badlands was calculated from discharge values from Lytle Creek and San Timoteo Creek, respectively, consistent with the approach of Woolfenden and Koczot (2001). Table A-1 in Appendix A lists inflow rates from ungaged runoff from the San Gabriel Mountains and the Badlands. Subsurface inflow, which is separate from ungaged runoff, from the San Gabriel Mountains was specified at a constant rate of 1,200 acre-feet per year (AF/yr). This value is based on work conducted by Geosciences Support Services, Inc. (1994). Subsurface inflow from the Badlands was assumed negligible. Both values of subsurface inflow are consistent with those used in *Numerical Simulation of Ground-Water Flow and Assessment of the Effects of Artificial Recharge in the RCB, San Bernardino County, California* (Numerical Simulation of Ground-Water Flow) (Woolfenden and Koczot, 2001).

3.7.1.3 Groundwater Recharge from Linden Pond

Groundwater recharge from Linden Pond was simulated using the MODFLOW-NWT recharge package. Linden Pond is an infiltration pond that operated in the 1980s and 1990s. Groundwater recharge from Linden Pond was specified in Model Layer 1 (Figure 3-4) at rates listed in Table A-2 in Appendix A.

3.7.1.4 Subsurface Inflow from Lytle and Bunker Hill Basins

Subsurface inflow from Lytle and Bunker Hill Basins was specified using the MODFLOW-NWT well package in a manner consistent with the approach of Woolfenden and Koczot (2001). Subsurface inflow from Lytle Basin was assigned only to Model Layer 3 (Figure 3-4), whereas subsurface inflow from Bunker Hill Basin was assigned to Model Layers 1 and 2 (Figure 3-4). Subsurface inflow values from Lytle and Bunker Hill Basins for CY 1970 through 1996 were taken directly from Numerical Simulation of Ground-Water Flow (Woolfenden and Koczot, 2001). Subsurface inflow from Lytle Basin for CY beyond 1996 were calculated based on discharge measurements from Lytle Creek, as described in Woolfenden and Koczot (2001), and are listed in Table A-3 in Appendix A. Subsurface inflow from Bunker Hill Basin for years beyond 1996 was calculated using Darcy's Law as described in Numerical Simulation of Ground-Water Flow (Woolfenden and Koczot, 2001).

3.7.1.5 Groundwater Pumping

Groundwater pumping was specified using the MODFLOW-NWT well package. Multiple municipal water agencies extract groundwater from the RCB. Figure 3-5 shows the locations of modeled extraction wells that pump during the simulation period. Most groundwater extraction occurs from the middle water-bearing unit (i.e., Model Layer 3). However, most extraction wells are screened in multiple model layers. Pumping rates are therefore allocated by model layer in proportion to the transmissivity calculated using the screen interval thickness within a particular model layer. MODFLOW-NWT does not automatically reallocate pumping to lower model layers as layers go dry. Therefore, pumping was manually shifted to lower model layers if a well was located in a cell that becomes dry during the simulation period to maintain the correct volume of water removed. Tables B-1 and B-2 in Appendix B list pumping rates at all extraction wells simulated in the EPA RCM. Pumping rates were provided by Steven Mains with Watermaster Support Services (Mains, 2010) with supplementary information provided by the individual water purveyors.

3.7.1.6 Subsurface Outflow to Chino Basin

Subsurface outflow from the RCB to the Chino Basin was specified using the MODFLOW-NWT well package. The magnitude and location of flow along the Rialto-Colton Fault was taken from the Chino Basin Model (Wildermuth Environmental, 2007). Figure 3-4 shows the location of grid cells to which outflow was assigned. Subsurface outflow from the RCB was assigned to Model Layers 3 and 4 in the EPA RCM at a steady rate of 3,965 acre-feet per year (af/yr) (Wildermuth Environmental, 2007). The total discharge was apportioned along the boundary based on the transmissivity and width of each model cell.

3.7.2 Head-dependent Flux Boundaries

3.7.2.1 Evapotranspiration of Shallow Groundwater

A maximum evapotranspiration (ET) rate of 38 in/yr was used over the entire model grid with a rooting depth of 15 feet (Hardt and Hutchinson, 1980). The same maximum ET rate and rooting depth were also used in the Bunker Hill Basin model (Danskin et al., 2005) and the USGS basinwide model (Woolfenden and Koczot, 2001). The maximum groundwater ET rates are simulated in the EPA RCM where the simulated groundwater elevations in Model Layer 1 equal or exceed the land surface elevation. The rate of groundwater ET decreases as groundwater elevation within the assigned rooting depth decreases. Thus, the rooting depth represents the depth to which water can be extracted from the ground by phreatophytes; consequently, groundwater ET only occurs within the upper 15 feet of the modeled subsurface.

3.7.2.2 Groundwater Interaction with Warm Creek and Santa Ana River

The Santa Ana River and Warm Creek were simulated in the EPA RCM using the MODFLOW-NWT river package. The river package requires input of river stage and bed hydraulic conductivity values specifying resistance to water exchange between the river and groundwater in Model Layer 1. The river stage was set to 1 foot above the land surface elevations obtained from the National Elevation Dataset along the EPA RCM river cells. The bed hydraulic conductivity was assumed to be 0.1 foot per day based on the assumption of silt and silty sand being the predominant soil types in the river bed.

3.7.2.3 Subsurface Outflow to North Riverside Basin

Consistent with Woolfenden and Koczot (2001), subsurface outflow from the RCB to the North Riverside Basin was simulated in Model Layers 1 through 3 (Figure 3-4). This outflow was simulated using a general head boundary (GHB) condition. At a GHB, the flow of water is internally computed and is proportional to the difference in groundwater elevation between the model boundary cell and a point outside of the model domain. Inputs to a GHB include the groundwater elevation at a point external to the model, a conductance value that acts between the external point and the model cell, and the distance between the model cell and the external point. The groundwater elevations outside of the model domain that were used for the GHB were taken from Table 2 in Numerical Simulation of Ground-Water Flow (Woolfenden and Koczot, 2001) for the simulation period from 1970 through 1996. These elevations were measured at either well 1S/4W-29H2 or 1S/4W-29H1, depending on data availability (Figure 3-4). For the simulation period beyond 1996, groundwater elevations outside of the model domain were taken from well 1S/4W-29H1 because this well had a more complete record of static groundwater level data. Groundwater elevation data for the simulation period beyond 1996 were provided by the City of Riverside and supplemented with data from USGS' Groundwater Site Inventory Database[5]. GHB conductances were calculated based on the hydraulic conductivity, modeled saturated thicknesses, and widths of the individual GHB cells and the distances from the GHB cell to the external groundwater elevation source.

3.7.3 No-flow Boundaries

The lateral model boundaries depicted on Figure 3-4 that were not simulated as prescribed flux or head-dependent flux boundaries were simulated as no-flow boundaries. The bottom of the deepest model layer (i.e., Model Layer 5) was also assigned as a no-flow boundary.

3.7.4 Horizontal Flow Barriers

The horizontal flow barrier (HFB) package (Hsieh and Freckleton, 1993) was used to simulate internal faults within the RCB. Faults simulated with the HFB package include Barrier J, Unnamed Fault, and Barrier H (Figure 3-4). The HFB package requires input of a hydraulic characteristic, which is defined as the hydraulic conductivity divided by the width of the barrier. The hydraulic characteristic determines the effectiveness of the HFB as a barrier to flow. The width of the barrier was assumed to be 100 feet for all HFBs. The hydraulic conductivity for all HFBs was adjusted during model calibration.

5 http://waterdata.usgs.gov/nwis/gw (Accessed May 17, 2012.)

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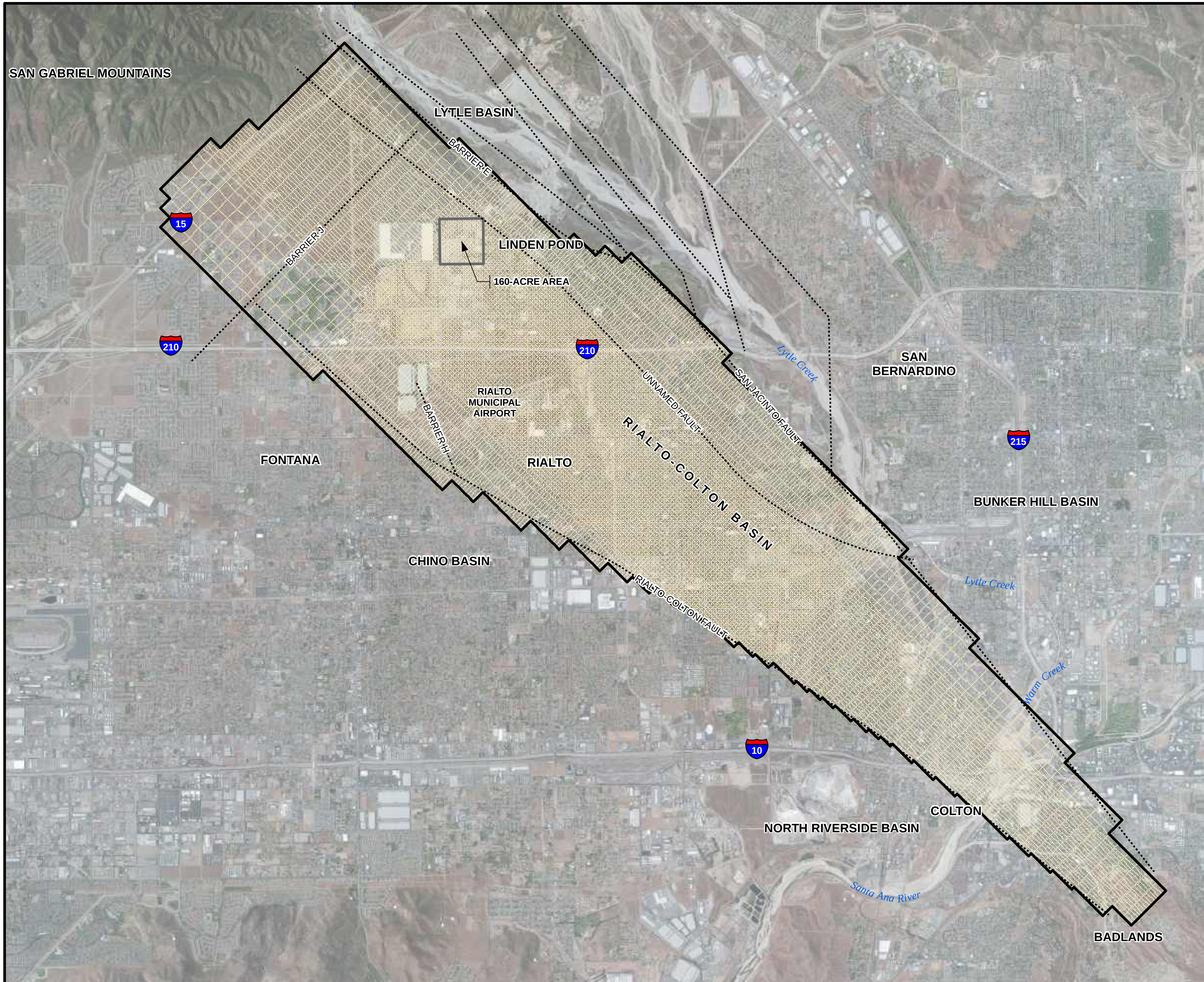


LEGEND

EPA RCM BOUNDARY

ACTIVE MODEL CELL

APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

NOTES:

EPA RCM = U.S. ENVIRONMENTAL PROTECTION AGENCY RIALTO-COLTON BASIN GROUNDWATER MODEL.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP)

0 6,000 12,000 Feet

N

FIGURE 3-1
RCM GRID: PLAN VIEW
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG03-01_MODELGRID.MXD 5/14/2012 6:59:07 PM FELHADID

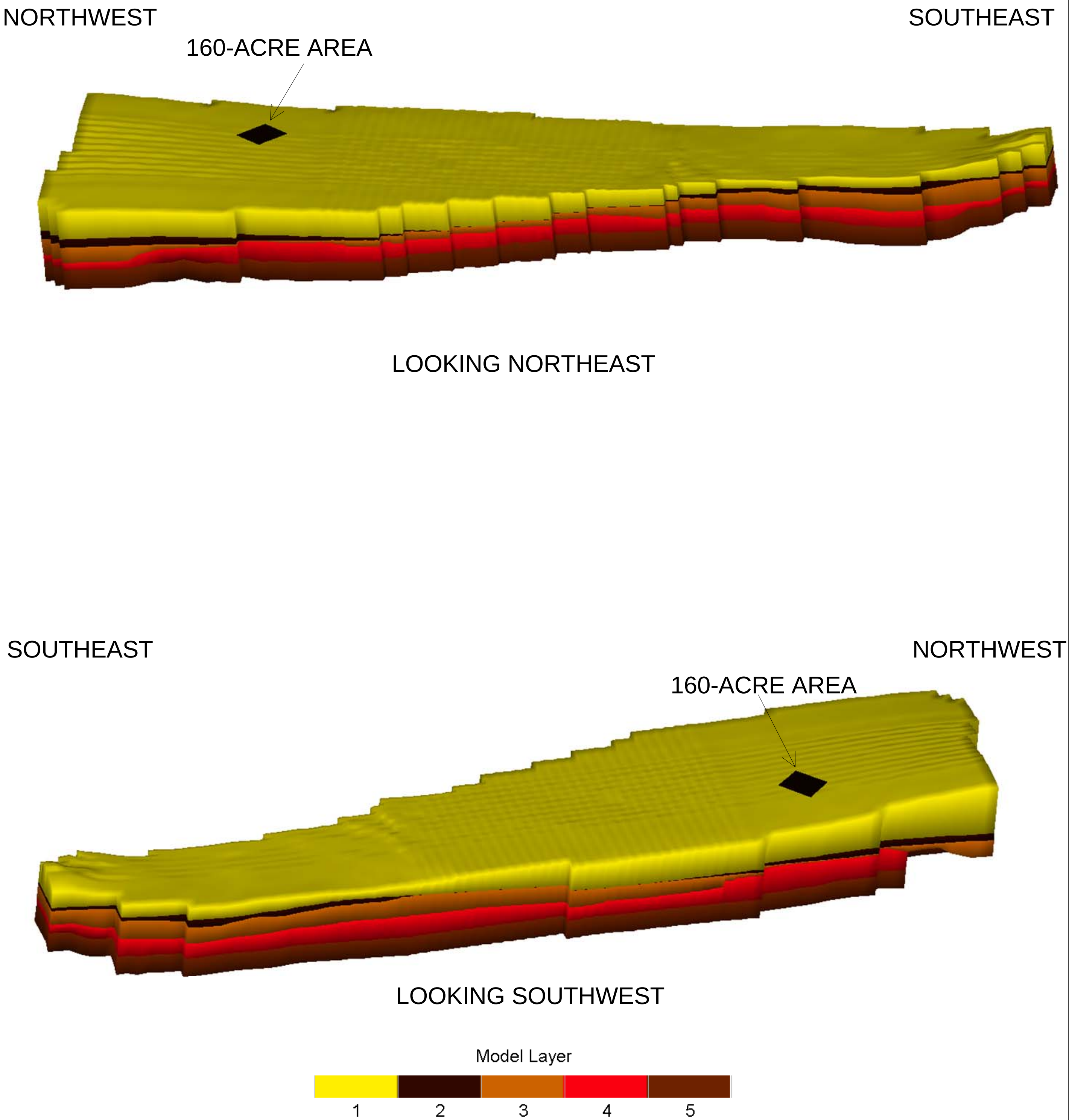
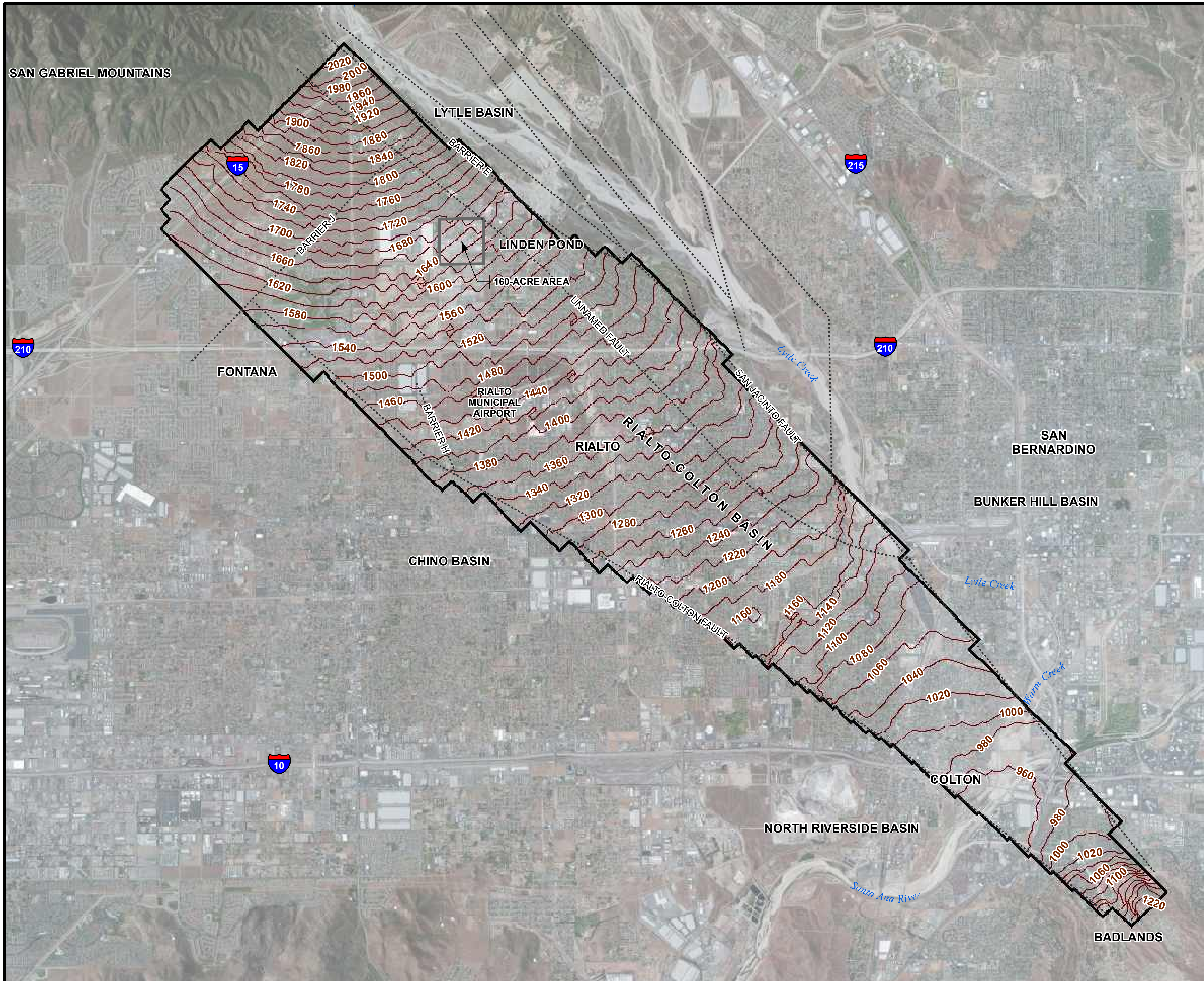


FIGURE 3-2
EPA RCM GRID: PROFILE VIEWS
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

\\odin\proj\Rialto_Colton\2011_GWModel\Doc\Figures\GRF\FIG03_02_GridProfile.grf



LEGEND

APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

EPA RCM BOUNDARY

MODELED GROUND SURFACE ELEVATION (feet NAVD88)

NOTES:

CONTOUR INTERVAL = 20 FEET.

EPA RCM = U.S. ENVIRONMENTAL PROTECTION AGENCY RIALTO-COLTON BASIN GROUNDWATER MODEL.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP)

0 6,000 12,000 Feet

N

FIGURE 3-3
MODELED GROUND SURFACE ELEVATION

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG03-03_MODELGSELEV.MXD 5/14/2012 6:59:59 PM FELHADID

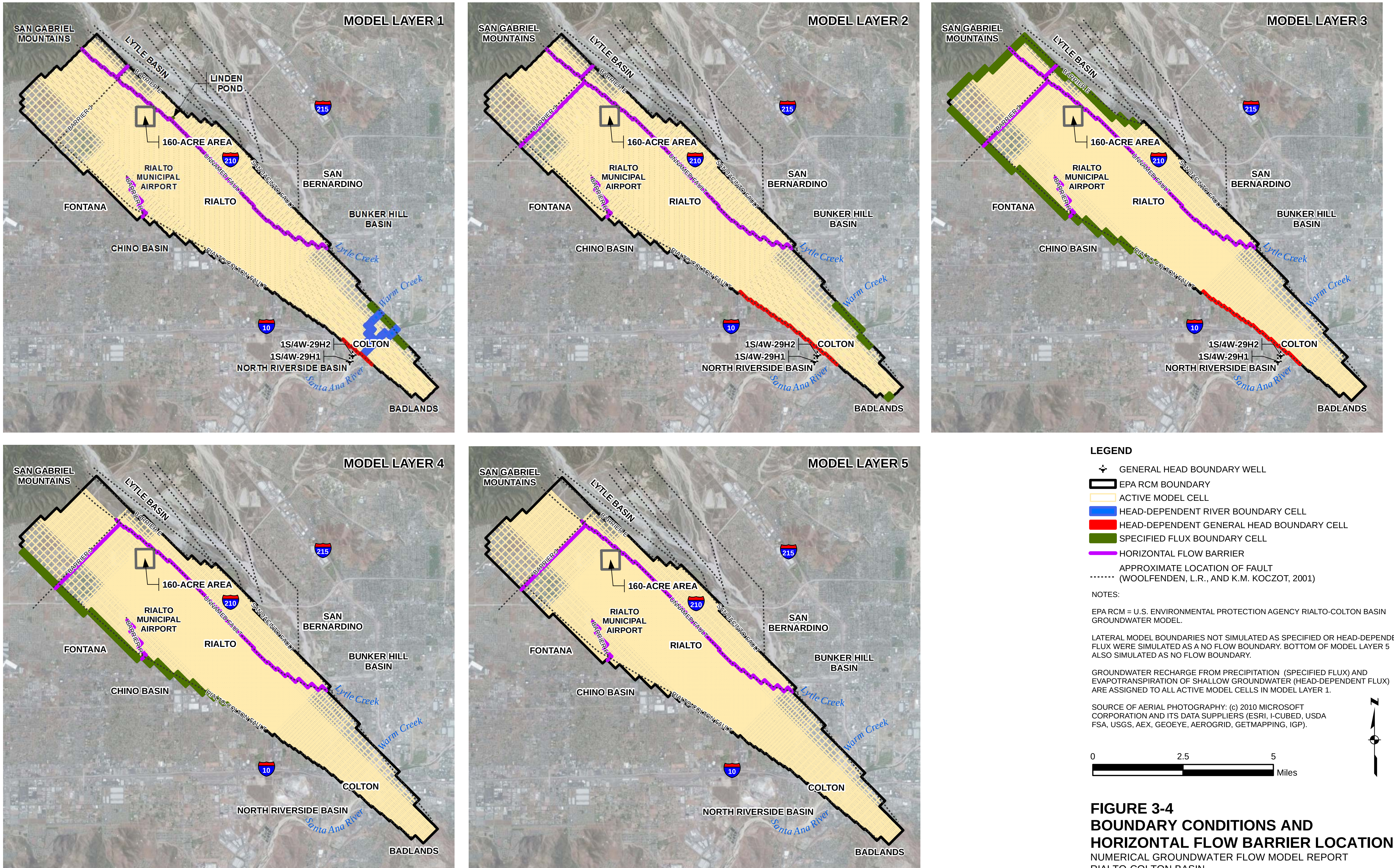


FIGURE 3-4
BOUNDARY CONDITIONS AND HORIZONTAL FLOW BARRIER LOCATIONS
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

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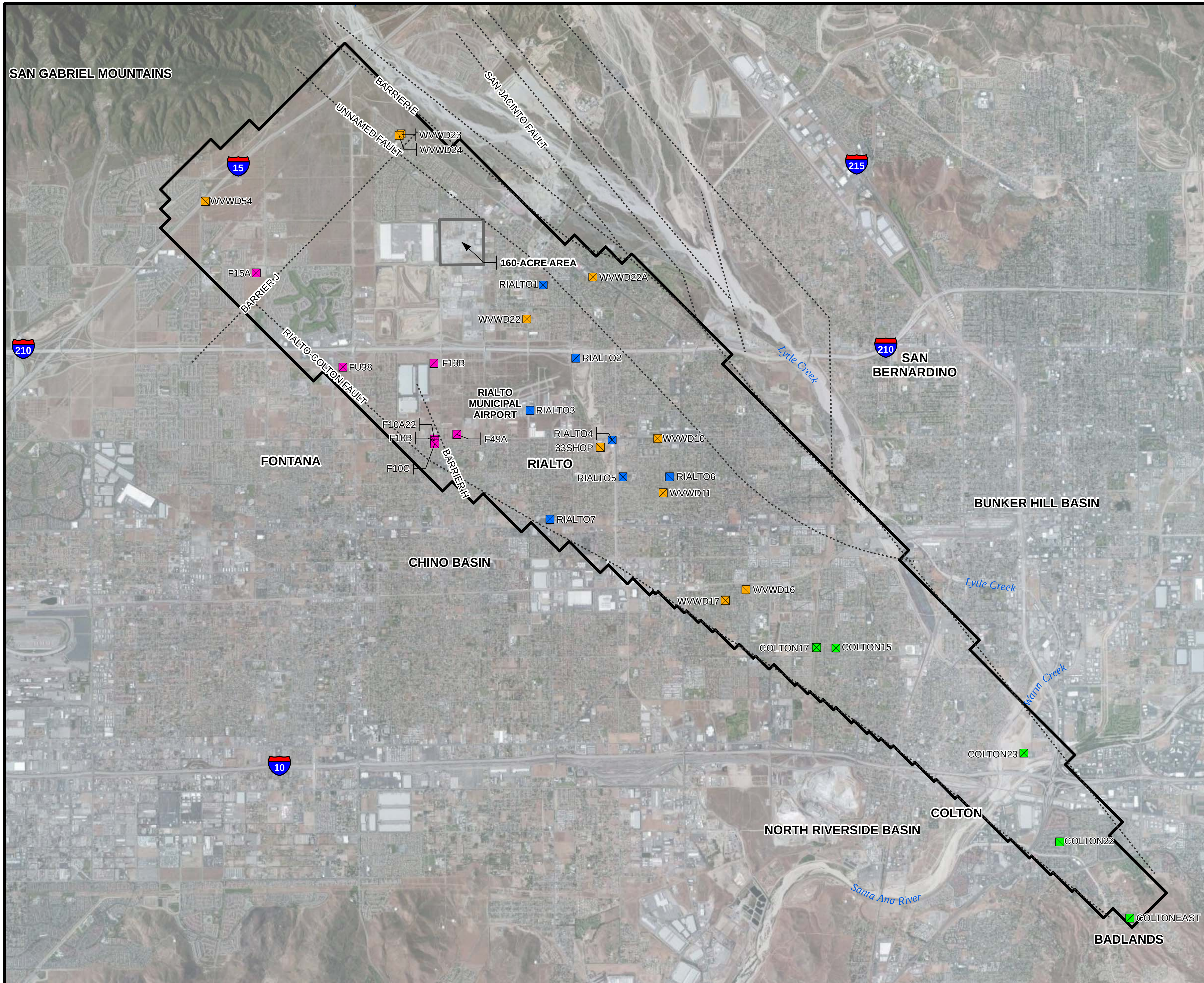
O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG03-04_BOUNDARYCONDITIONS.MXD 5/15/2012 9:57:40 AM FELHADID



LEGEND

EPA RCM BOUNDARY

APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

MUNICIPAL WATER AGENCY

- CITY OF COLTON
- CITY OF RIALTO
- FONTANA WATER COMPANY
- WEST VALLEY WATER DISTRICT

NOTES:

EPA RCM = U.S. ENVIRONMENTAL PROTECTION AGENCY RIALTO-COLTON BASIN GROUNDWATER MODEL.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 6,000 12,000 Feet

N

FIGURE 3-5
ACTIVE EXTRACTION WELLS DURING THE SIMULATION PERIOD

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG03-05_ACTIVEEW.MXD 5/15/2012 11:48:37 AM FELHADID

SECTION 4

Model Calibration

Model calibration is a process of tuning a numerical model to simulate observed conditions in the field (as described with measured data) within a reasonable degree of accuracy. The EPA RCM was calibrated in accordance with the *Standard Guide for Calibrating a Ground-Water Flow Model Application* (American Society for Testing and Materials, 1996). This section discusses the calibration targets, process, and results.

4.1 Calibration Targets

Calibration targets are defined as the selected field-measured values that quantify site conditions of interest with consideration of data quality and reliability. Qualitative and quantitative calibration targets were selected to evaluate progress during calibration of the EPA RCM.

Measured groundwater elevations (i.e., head) over the course of the 40-year simulation period serve as quantitative calibration targets. Some calibration targets were derived from the head data to provide additional constraints and insight into different aspects of the flow system (e.g., vertical head differences between model layers). Because the model uses annual stress periods, measured groundwater elevations were averaged throughout each CY for target locations with more than one measurement per year. Additionally, target values were averaged if more than one target location occurred within a single model cell. The qualitative calibration targets include vertical head differences at locations of wells located within 10 feet of each other and assigned to different model layers, and general groundwater flow patterns (e.g., simulated groundwater flow directions that resemble those inferred from measured groundwater levels). Calibration summary statistics were computed for quantitative targets to provide a quantitative measure of the EPA RCM's ability to replicate calibration target head values. Head calibration was evaluated using the following summary statistics:

- Residual error, computed as the simulated head value minus the target head value
- Mean error (ME), computed as the sum of all residual errors divided by the number of observations
- Coefficient of determination (R^2), computed as the square of the correlation coefficient
- Root mean squared error (RMSE), computed as the square root of the mean of all residual squared errors
- RMSE divided by the range of target head values (RMSE/Range)

During the quantitative calibration, CH2M HILL developed the following general goals:

- Minimize spatial bias of residual errors in key areas of the domain.
- Minimize residual error, ME, RMSE, and RMSE/Range values.
- Maintain R^2 values as close to 1.00 as possible.

Figure 4-1 depicts the locations of the quantitative calibration target locations for the EPA RCM, which includes a total of 190 target head locations.

4.2 Calibration Process

The general calibration procedure consisted of three phases. The first phase was initial manual calibration, which focused on defining locations with field-derived property values and establishing approximate hydraulic values that resulted in a reasonably close match to both quantitative and qualitative targets. The second phase implemented autocalibration techniques, which employed numerical optimization software to obtain the best fit to the quantitative calibration targets. The third phase involved interpreting the autocalibration results with respect to the quantitative and qualitative calibration targets and modifying parameter values to provide a better match to the CSM, as necessary.

Parameter values for K_h, K_v, specific storage, specific yield, and hydraulic conductivity of HFBs were adjusted during the calibration of the EPA RCM.

4.2.1 Initial Manual Calibration Phase

During the first calibration phase, property zones were spatially defined and assigned values using a manual interactive technique. This involved manually running the simulations, comparing model results with qualitative and quantitative calibration targets to assess the progress of calibration, and making manual changes to parameter values and HFB hydraulic conductivities in areas where important calibration mismatches were noted. This procedure was repeated until only minor improvements in calibration were achieved.

4.2.2 Autocalibration

The autocalibration process is much more effective if it begins with modeled parameter values that are in the general range of optimal parameter values. To select initial parameter values, preliminary EPA RCM simulations were conducted making manual changes to boundary conditions and hydraulic parameter values. Output from these manual calibration simulations was compared with qualitative and quantitative calibration targets to note important mismatches and assess the initial level of model calibration.

Parameter values and boundary conditions estimated during the first calibration phase were adjusted using PEST[6] (Doherty, 2004 and 2010) autocalibration software. Autocalibration software can be very useful for complex sites. PEST uses a process of parameter modification and calibration target-matching that is similar to the manual interactive technique used by a groundwater modeler, but PEST has the advantage of performing and analyzing thousands of simulations over a relatively short time. Although PEST cannot exercise professional judgment, it can be a valuable tool if guided by a professional who is familiar with the site and software.

4.2.3 Final Calibration

After the autocalibration phase, further parameter adjustments were made to either maintain consistency with or refine the CSM. For example, PEST might have compromised a good match to one set of calibration targets to improve the match to another calibration target. Therefore, it was necessary to modify some of the optimized parameter values resulting from the autocalibration process in a way that took advantage of the progress made by PEST, but better honored the CSM.

The product resulting from this calibration procedure is a groundwater flow model that takes advantage of numerical parameter estimation and professional judgment of engineers and scientists familiar with the site. Specifically, the end-product is quantitatively and qualitatively calibrated to heads; vertical head-differences; and general groundwater flow patterns.

4.3 Calibration Results and Discussion

The calibrated hydraulic parameters are discussed in the following subsections.

4.3.1 Subsurface Hydraulics

Figure 4-2 presents the calibrated distributions of K_h for each model layer. Calibrated K_h values in the EPA RCM range from 1×10^{-3} to 337 feet per day (ft/day). These values are in general agreement with values used in previous models and are within the range of literature values for the materials present in the basin.

Figure 4-3 presents the calibrated distributions of the ratio of horizontal to vertical hydraulic conductivity (K_h:K_v) for each model layer. The K_h:K_v ratios in the EPA RCM range from approximately 3 to 605. Calibrated K_v values range from $1.3\text{x}10^{-5}$ to 14 ft/day.

Figures 4-4 and 4-5 show the calibrated distribution of specific storage and specific yield, respectively. Calibrated specific storage and specific yield values range from $1\text{x}10^{-7}$ to $1\text{x}10^{-4}$ per foot (ft^{-1}) and 0.05 to 0.28, respectively. These values are within the range of literature values for the materials present beneath the Site.

Figure 4-6 shows the calibrated distribution of the hydraulic conductivity for the HFBs.

[6] http://www.pesthomepage.org/Home.php. (Accessed March 9, 2012.)

4.3.1.1 Groundwater Elevations

Table A-4 in Appendix A and Figures 4-7 through 4-9 provide summary statistics and plots characterizing the match between modeled and calibration-target heads. Figure 4-1 shows target well locations. Figure 4-7 compares modeled and calibration-target head data from all target locations, depths, and times within the 40-year simulation period. Data presented on Figure 4-7 indicate good agreement between modeled and calibration target heads. Because the points fall both above and below, and close to the 1:1 correlation line, no global bias in modeled heads is evident from Figure 4-7. Figure 4-7 presents the following data summary statistics:

- ME = 0.09 feet
- RMSE = 26.29 feet
- Range in calibration-target head values = 1,033.95 feet
- RMSE/Range = 0.03
- R^2 = 0.97
- Number of measurements = 1,690

Figures 4-8A through 4-8G show observed and modeled hydrographs for all target well locations for which more than six time-series target data points were available. The range of values (maximum minus minimum) shown on the vertical axes of these hydrographs is 300 feet, to facilitate comparing magnitudes of fluctuations and trends among the hydrographs. The figures show that modeled hydrographs match the observed data reasonably well at most locations. Figure 4-9 presents a map of the distribution of RMSE in groundwater elevations for all target well locations. This map facilitates identifying whether spatial bias in the RMSE is present; such bias would be revealed by clusters of wells where larger RMSE values occur. Overall, there is little spatial bias in modeled heads. However, a grouping of high RMSE values occurs in the portion of aquifer between Unnamed Fault and the San Jacinto Fault. This most likely results from the impacts of the nearby boundary condition representing inflow from Lytle Basin. Another grouping of high RMSE values is in Model Layer 2 at the 160-Acre Area. The model underpredicts groundwater elevations in this area in Model Layer 2. The inclusion of recent updates to the BC aquitard (Geo-Logic, 2010) may improve modeled groundwater elevations in this area.

The match between modeled and target vertical head-differences was evaluated qualitatively during the calibration process. Figure 4-1 shows the head-difference target locations. Figure A-1 shows hydrographs of vertical head differences. The hydrographs show that the model matches vertical head differences reasonably well among the deeper model layers (Model Layers 3 through 5). However, the model generally overpredicts head differences between Model Layers 1 and 2 near the 160-Acre Area. This is because the model generally underpredicts heads in Model Layer 2 in this area.

Figure 4-10 shows modeled potentiometric surfaces for the last modeled stress period (CY 2009). Groundwater elevation contours show that flow is sub-parallel to the Rialto-Colton Fault in the middle portion of the basin. In the southern portion of the basin, the contours bend indicating southwesterly flow out of the RCB into the North Riverside Basin. These contours are generally consistent with a recently published contour map (CH2M HILL, 2010). However, modeled groundwater elevation contours in the Regional Aquifer in the upper basin near the municipal airport show a clear departure from historical flow directions (Dutcher and Garrett, 1963; Woolfenden and Koczot, 2001) that parallel the basin's longitudinal axis. The model suggests that groundwater flow in the upper basin has recently (since around CY 2003) transitioned to a more southerly to southwesterly flow direction in Model Layers 3 through 5. This change in flow directions is in general agreement with a previously developed groundwater model of the upper RCB (Geo-Logic, 2007), and appears to be a response to increased pumping from production wells in the upper basin.

4.3.1.2 Modeled Groundwater Balance

Table 4-1 lists the components of the modeled groundwater balance for all annual stress periods of the EPA RCM. The groundwater balance is reported for the entire active EPA RCM domain. Figure 4-11 shows the modeled inflows over the simulation period. Subsurface inflows from Lytle and Bunker Hill basins and recharge from precipitation generally make up the bulk of inflows to the RCB. Figure 4-12 shows the modeled outflows over the simulation period. Subsurface outflow to the North Riverside Basin comprises the largest outflow over most of the simulation period. However, the figure shows a steady increase in groundwater pumping since the early 1980s. Figure 4-13 shows the modeled annual change and cumulative change in groundwater storage. The figure shows that since 1998, cumulative groundwater storage has steadily declined with the exception of 2005 and 2006.

4.4 Calibration Outcome

The process of calibrating the EPA RCM to transient groundwater levels and flow directions results in a model that is suitable for its intended application. The following are primary attributes that make the EPA RCM appropriate for its intended uses:

- The EPA RCM is capable of simulating transient heads to within an acceptable degree of accuracy.
- The EPA RCM is capable of simulating reasonable groundwater flow directions: flow directions are initially towards the southeast and parallel the longitudinal axis of the basin but shift towards the southwest in the upper RCB during the early 2000s.
- The numerical solution is constrained by the head values at target locations spatially distributed throughout the RCB. Having a variety of calibration targets and types (e.g., qualitative and quantitative) makes model output more reliable.

TABLE 4-1

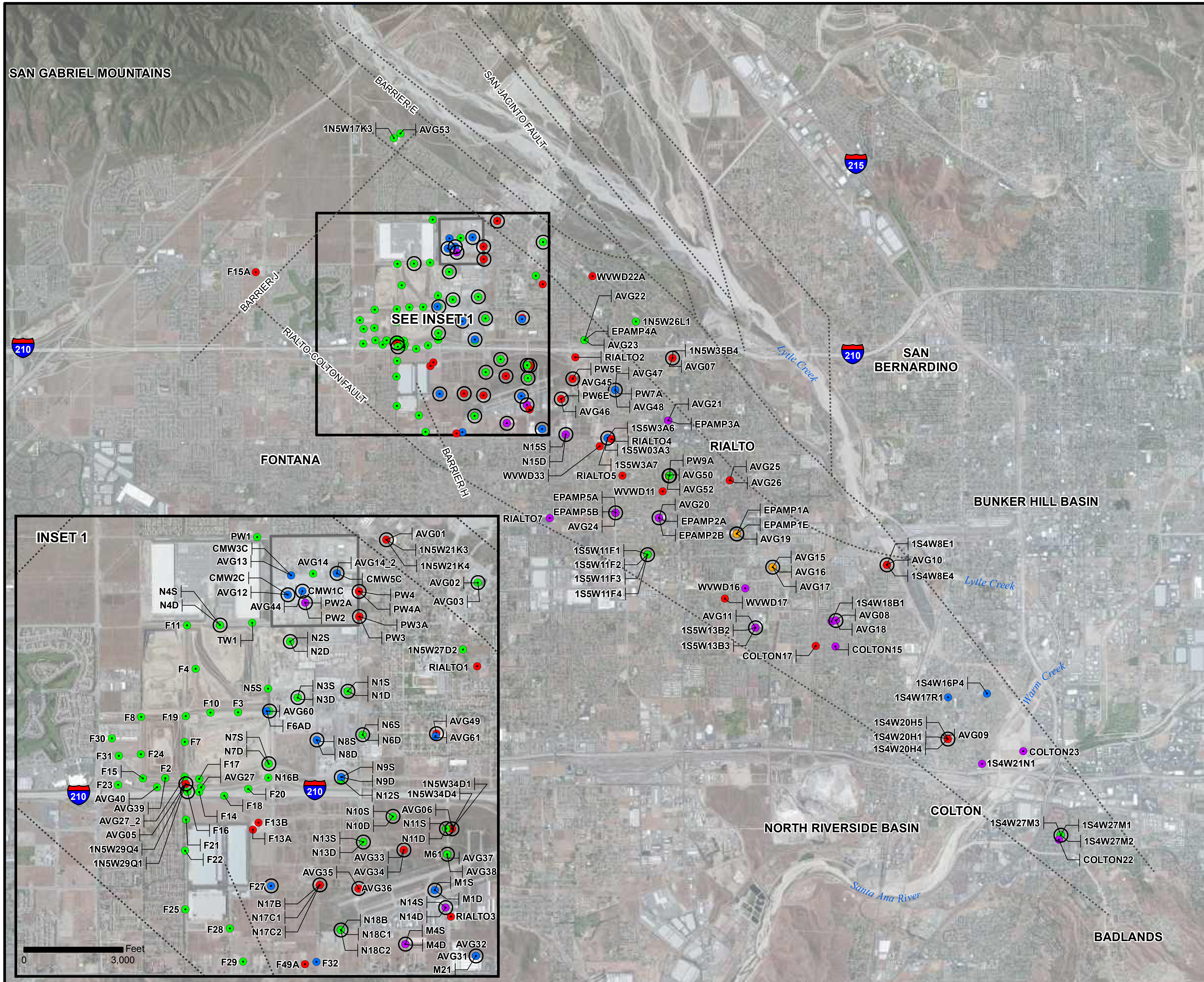
Model-derived Groundwater Balance for the EPA RCM Domain

Numerical Groundwater Flow Model Report, Rialto-Colton Basin

	Inflows										Outflows					
CY	**Precipitation**	**Riverside Basin**	**Streams**	**Linden Pond**	**Bunker Hill Basin**	**Ungaged Runoff San Gabriel Mountains**	**Lytle Basin**	**Ungaged Runoff Badlands**	**Subsurface Inflow San Gabriel Mountains**	**Total Inflow**	**ET**	**Riverside Basin**	**Chino Basin**	**Pumping**	**Total Outflow**	**Change in Total Storage**
1970	2,885	0	1,142	0	6,288	1,193	7,538	56	1,200	20,302	17	4,422	3,965	7,121	15,524	4,777
1971	1,910	0	1,142	0	8,119	940	5,944	32	1,200	19,286	0	15,085	3,965	6,350	25,400	-6,113
1972	0	0	1,142	0	9,976	756	4,780	2	1,200	17,856	0	21,996	3,965	5,801	31,761	-13,906
1973	5,369	0	1,142	0	9,571	1,626	10,276	125	1,200	29,309	0	15,647	3,965	5,299	24,910	4,399
1974	4,572	0	1,142	0	10,005	1,267	8,012	31	1,200	26,229	0	18,885	3,965	5,415	28,264	-2,036
1975	1,383	0	1,142	0	9,828	866	5,478	26	1,200	19,923	0	18,393	3,965	5,205	27,563	-7,640
1976	2,578	0	1,142	0	10,449	866	5,474	41	1,200	21,749	0	20,583	3,965	6,646	31,194	-9,444
1977	4,763	0	1,142	0	12,816	825	5,218	38	1,200	26,002	0	27,994	3,965	4,208	36,167	-10,165
1978	24,268	11,267	1,142	0	6,684	7,192	19,484	370	1,200	71,606	22	0	3,965	5,109	9,095	62,511
1979	6,041	0	1,142	0	11,150	2,862	18,096	295	1,200	40,785	53	17,747	3,965	4,106	25,871	14,914
1980	21,038	0	1,142	0	11,929	6,622	17,940	728	1,200	60,599	356	17,875	3,965	4,532	26,727	33,871
1981	1,198	0	1,142	0	12,461	954	6,030	40	1,200	23,025	343	19,169	3,965	5,346	28,822	-5,797
1982	12,727	0	1,142	3,220	12,678	2,174	13,740	143	1,200	47,023	433	20,322	3,965	4,425	29,145	17,878
1983	24,788	0	1,142	4,736	12,054	5,900	15,986	519	1,200	66,324	618	21,766	3,965	3,850	30,199	36,125
1984	1,435	0	1,142	3,471	15,414	1,290	8,156	59	1,200	32,167	541	23,272	3,965	6,712	34,489	-2,322
1985	1,037	0	1,142	3,879	10,958	896	5,666	29	1,200	24,807	332	20,911	3,965	6,367	31,575	-6,768
1986	5,967	0	1,142	5,345	9,685	1,487	9,398	75	1,200	34,299	258	19,500	3,965	6,972	30,694	3,605
1987	4,232	0	1,142	3,030	10,219	763	4,824	5	1,200	25,414	117	21,622	3,965	10,335	36,039	-10,625
1988	3,692	0	1,142	4,601	9,701	869	5,492	0	1,200	26,697	0	23,311	3,965	10,763	38,038	-11,341
1989	2	0	1,142	4,522	9,210	636	4,018	0	1,200	20,730	0	22,326	3,965	11,173	37,464	-16,734
1990	865	0	1,142	65	9,471	455	2,874	0	1,200	16,072	0	22,060	3,965	12,327	38,352	-22,280
1991	8,390	0	1,142	435	8,936	931	5,884	14	1,200	26,932	0	19,731	3,965	8,580	32,276	-5,344
1992	13,815	0	1,142	1,559	8,644	2,451	15,824	61	1,200	44,696	0	15,302	3,965	14,557	33,823	10,872
1993	22,704	0	1,142	3,747	8,656	6,251	18,450	985	1,200	63,135	0	14,150	3,965	13,873	31,987	31,147
1994	2,913	0	1,142	261	7,271	266	5,816	78	1,200	18,947	0	7,704	3,965	12,701	24,370	-5,423
1995	18,978	0	1,142	0	7,340	2,872	22,726	641	1,200	54,898	208	10,332	3,965	15,662	30,166	24,732
1996	11,209	0	1,142	0	9,554	1,353	8,556	92	1,200	33,106	276	21,797	3,965	18,638	44,674	-11,569
1997	2,867	0	1,142	0	16,352	1,038	6,564	148	1,200	29,311	175	30,784	3,965	14,764	49,687	-20,376
1998	17,037	0	1,142	0	8,678	3,302	20,872	79	1,200	52,311	362	16,257	3,965	11,347	31,931	20,380
1999	38	0	1,142	0	8,912	772	4,882	99	1,200	17,046	240	14,330	3,965	12,039	30,574	-13,528
2000	2,921	0	1,142	0	11,645	680	4,299	118	1,200	22,006	106	17,484	3,965	14,107	35,661	-13,656
2001	4,162	0	1,142	0	10,373	841	5,318	117	1,200	23,153	0	25,900	3,965	19,179	49,043	-25,890
2002	131	0	1,142	0	10,797	436	2,756	66	1,200	16,528	0	29,096	3,965	23,351	56,411	-39,883
2003	4,431	0	1,142	0	10,561	776	4,908	250	1,200	23,268	0	25,764	3,965	24,575	54,304	-31,036
2004	6,959	0	1,142	0	10,332	1,115	7,046	541	1,200	28,335	0	24,136	3,903	23,882	51,921	-23,586
2005	15,461	0	1,142	0	4,093	6,652	18,021	1,346	1,200	47,915	0	5,038	3,822	18,525	27,386	20,529
2006	3,213	64	1,142	0	4,404	1,911	12,077	526	1,200	24,536	0	1,435	3,781	16,828	22,044	2,493
2007	0	0	1,142	0	6,398	629	3,974	365	1,200	13,707	0	21,598	3,682	20,054	45,333	-31,626
2008	5,265	0	1,142	0	5,795	1,084	6,854	653	1,200	21,992	0	18,725	3,532	19,542	41,800	-19,808
2009	789	0	1,142	0	7,789	778	4,916	444	1,200	17,058	0	22,902	3,509	23,012	49,423	-32,365
Minimum	0	0	1,142	0	4,093	266	2,756	0	1,200	13,707	0	0	3,509	3,850	9,095	-39,883
Annual Average	6,801	283	1,142	972	9,630	1,864	9,104	231	1,200	31,227	111	18,384	3,926	11,582	34,003	-2,776
Maximum	24,788	11,267	1,142	5,345	16,352	7,192	22,726	1,346	1,200	71,606	618	30,784	3,965	24,575	56,411	62,511

Note:

Values reported in acre-feet.



LEGEND

VERTICAL HEAD-DIFFERENCE TARGET WELL PAIR

CALIBRATION TARGET WELL LOCATION

- MODEL LAYER 1
- MODEL LAYER 2
- MODEL LAYER 3
- MODEL LAYER 4
- MODEL LAYER 5

160-ACRE AREA

APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

NOTES:

CALIBRATION TARGET WELLS COULD BE SCREENED ACROSS MULTIPLE MODEL LAYERS.

"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL NAMES.

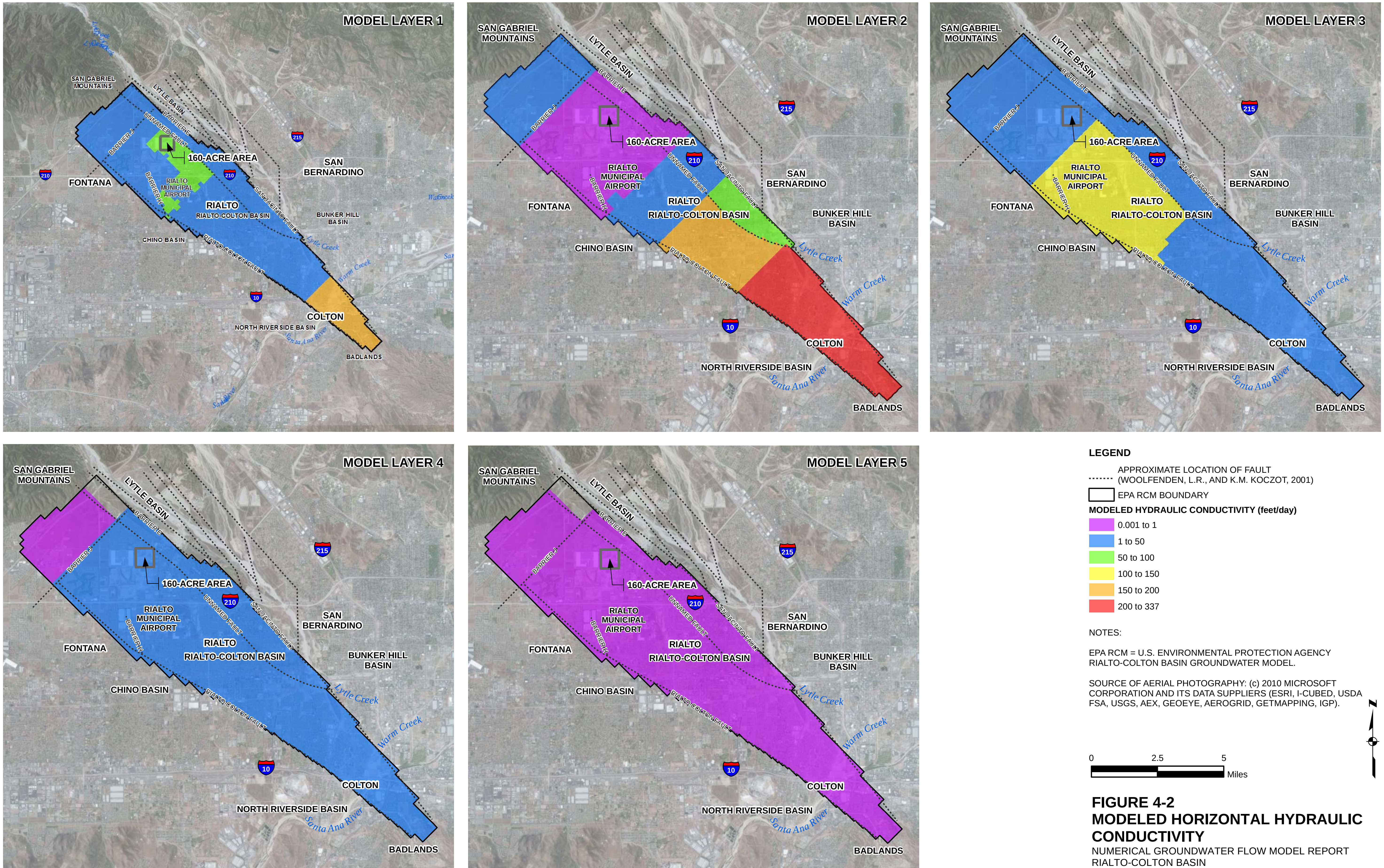
SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

FIGURE 4-1
CALIBRATION TARGET WELL LOCATIONS

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG04-01_CALIBTARGETS.MXD 5/14/2012 7:11:35 PM FELHADID



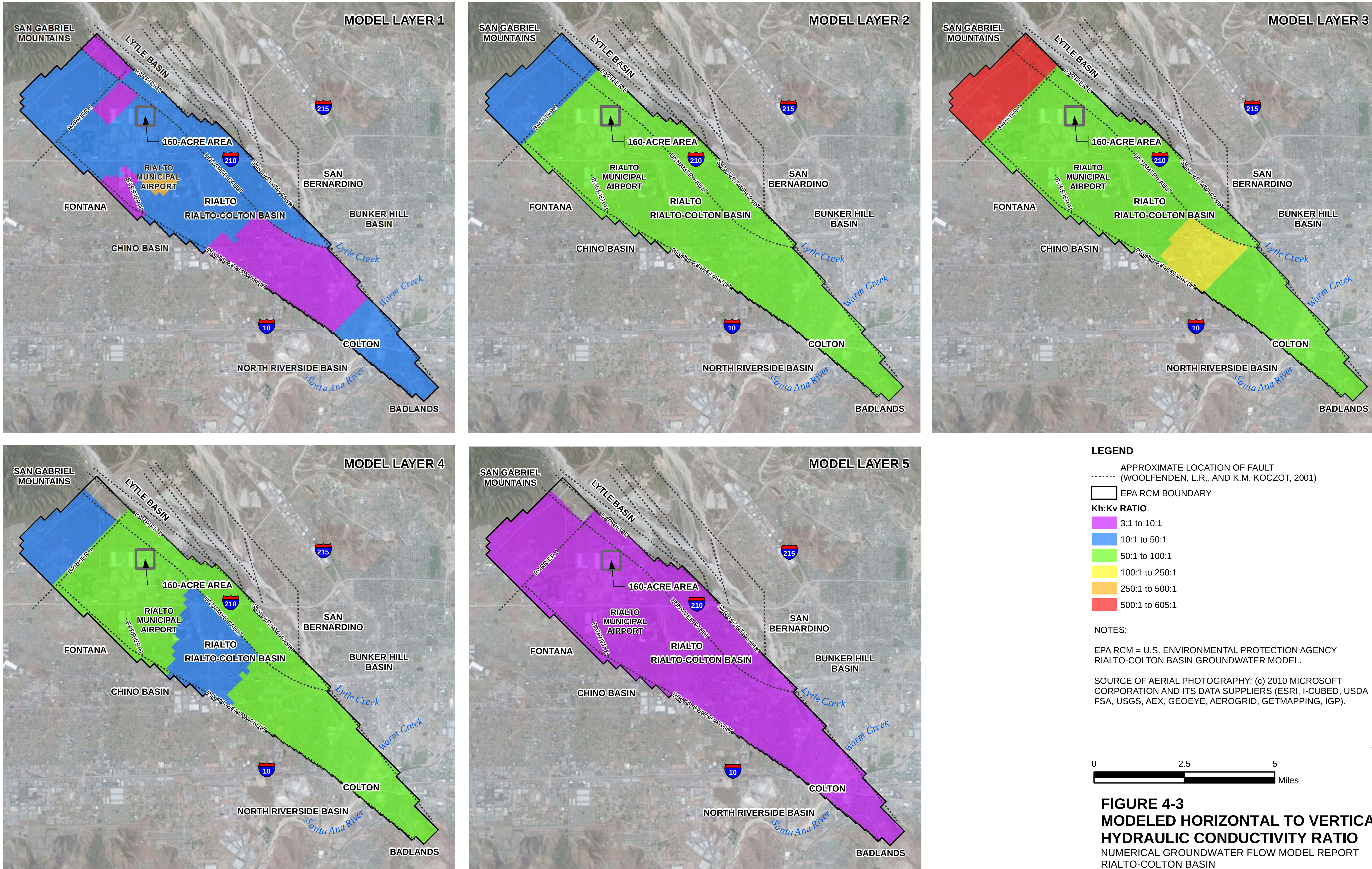
NOTES:

EPA RCM = U.S. ENVIRONMENTAL PROTECTION AGENCY RIALTO-COLTON BASIN GROUNDWATER MODEL.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

FIGURE 4-2
MODELED HORIZONTAL HYDRAULIC CONDUCTIVITY
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.



NOTES:

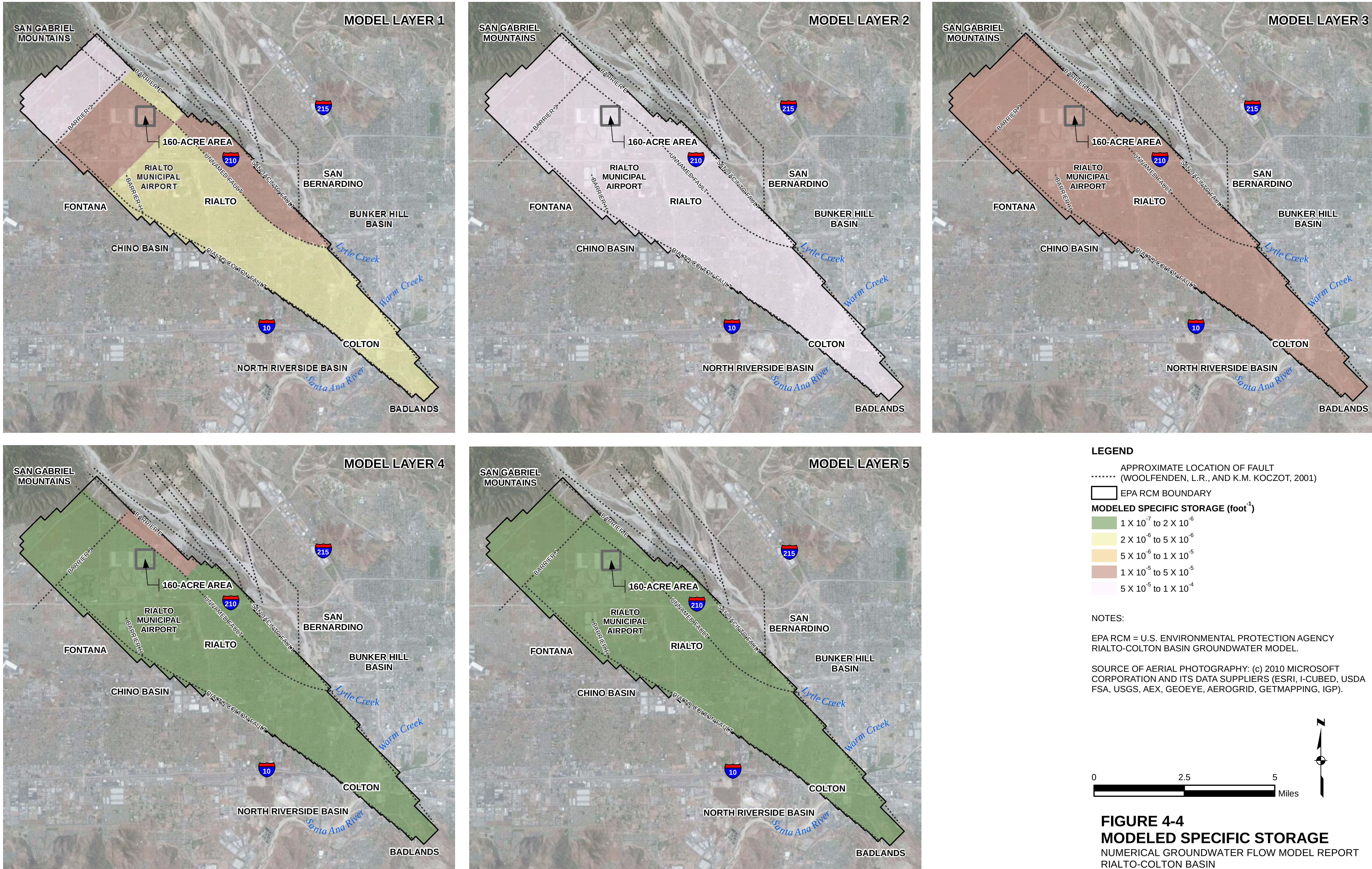
EPA RCM = U.S. ENVIRONMENTAL PROTECTION AGENCY RIALTO-COLTON BASIN GROUNDWATER MODEL.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

FIGURE 4-3
MODELED HORIZONTAL TO VERTICAL HYDRAULIC CONDUCTIVITY RATIO
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG04-03_KHKV.MXD 5/21/2012 8:59:48 AM FELHADID



LEGEND

APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

EPA RCM BOUNDARY

MODELED SPECIFIC STORAGE (foot^{-1})

- 1×10^{-7} to 2×10^{-6}
- 2×10^{-6} to 5×10^{-6}
- 5×10^{-6} to 1×10^{-5}
- 1×10^{-5} to 5×10^{-5}
- 5×10^{-5} to 1×10^{-4}

NOTES:

EPA RCM = U.S. ENVIRONMENTAL PROTECTION AGENCY RIALTO-COLTON BASIN GROUNDWATER MODEL.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 2.5 5 Miles

N

FIGURE 4-4
MODELED SPECIFIC STORAGE
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL

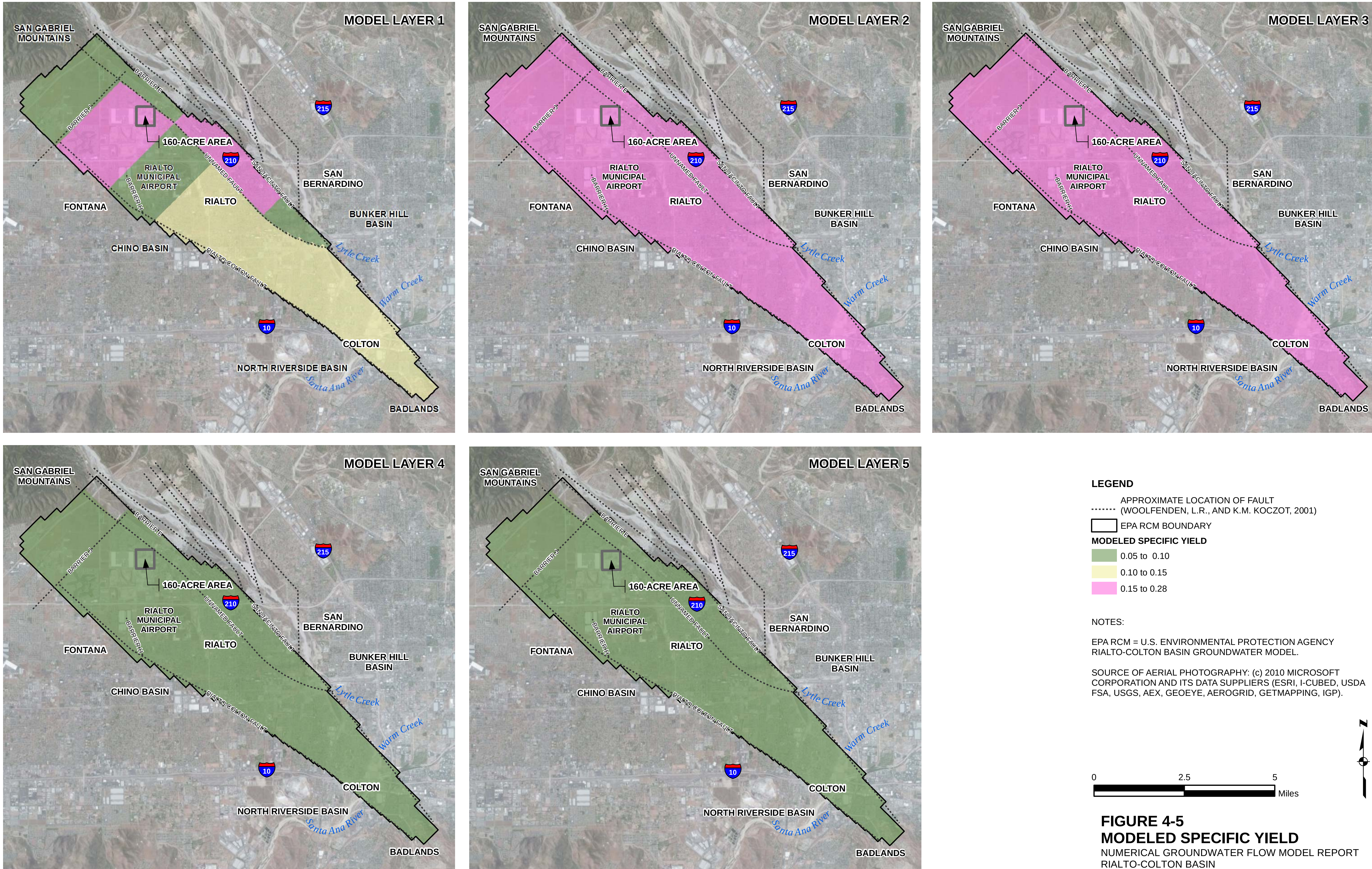


FIGURE 4-5
MODELED SPECIFIC YIELD
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG04-05_SPECIFICYIELD.MXD 5/21/2012 9:00:42 AM FELHADID

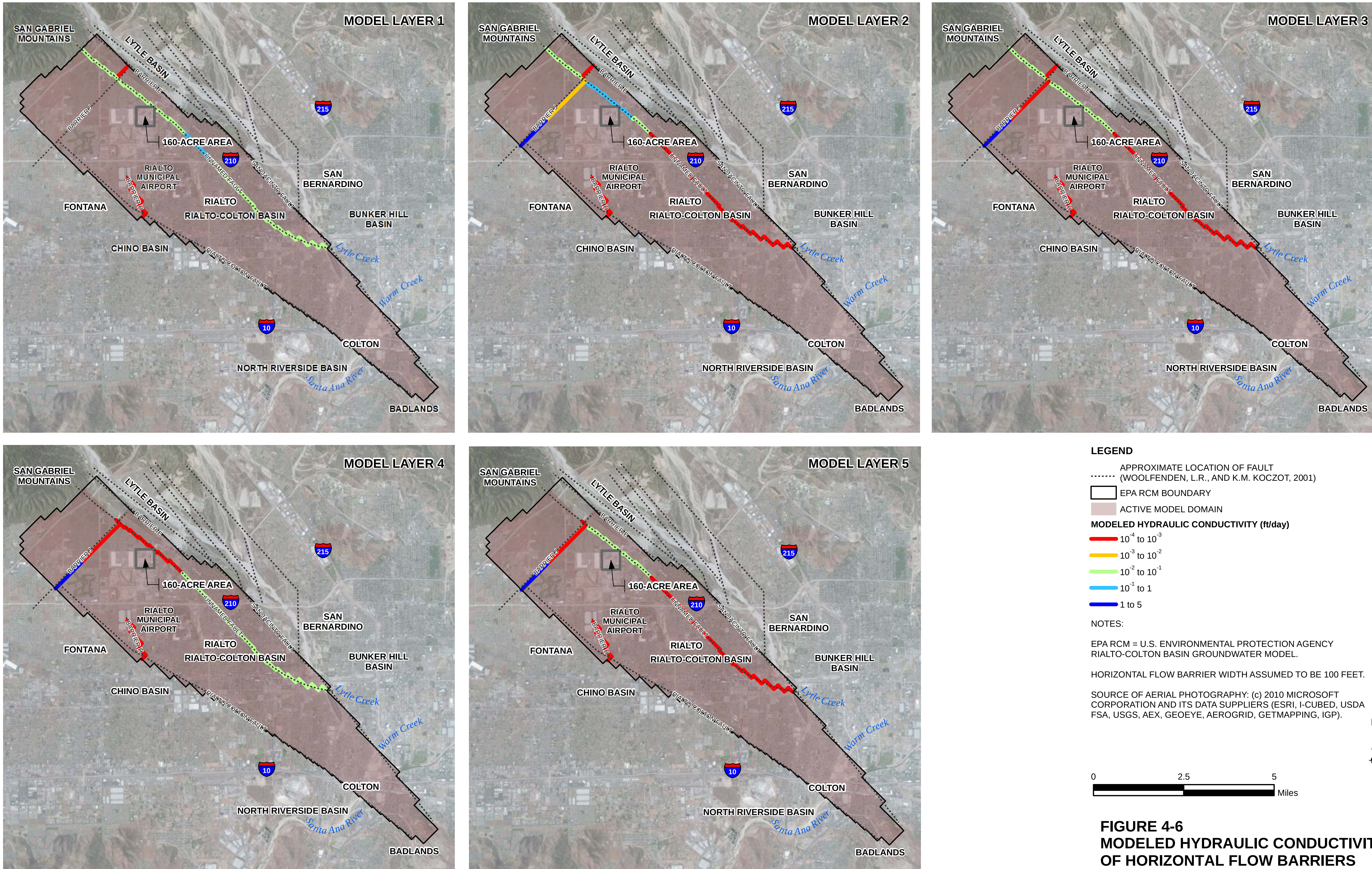
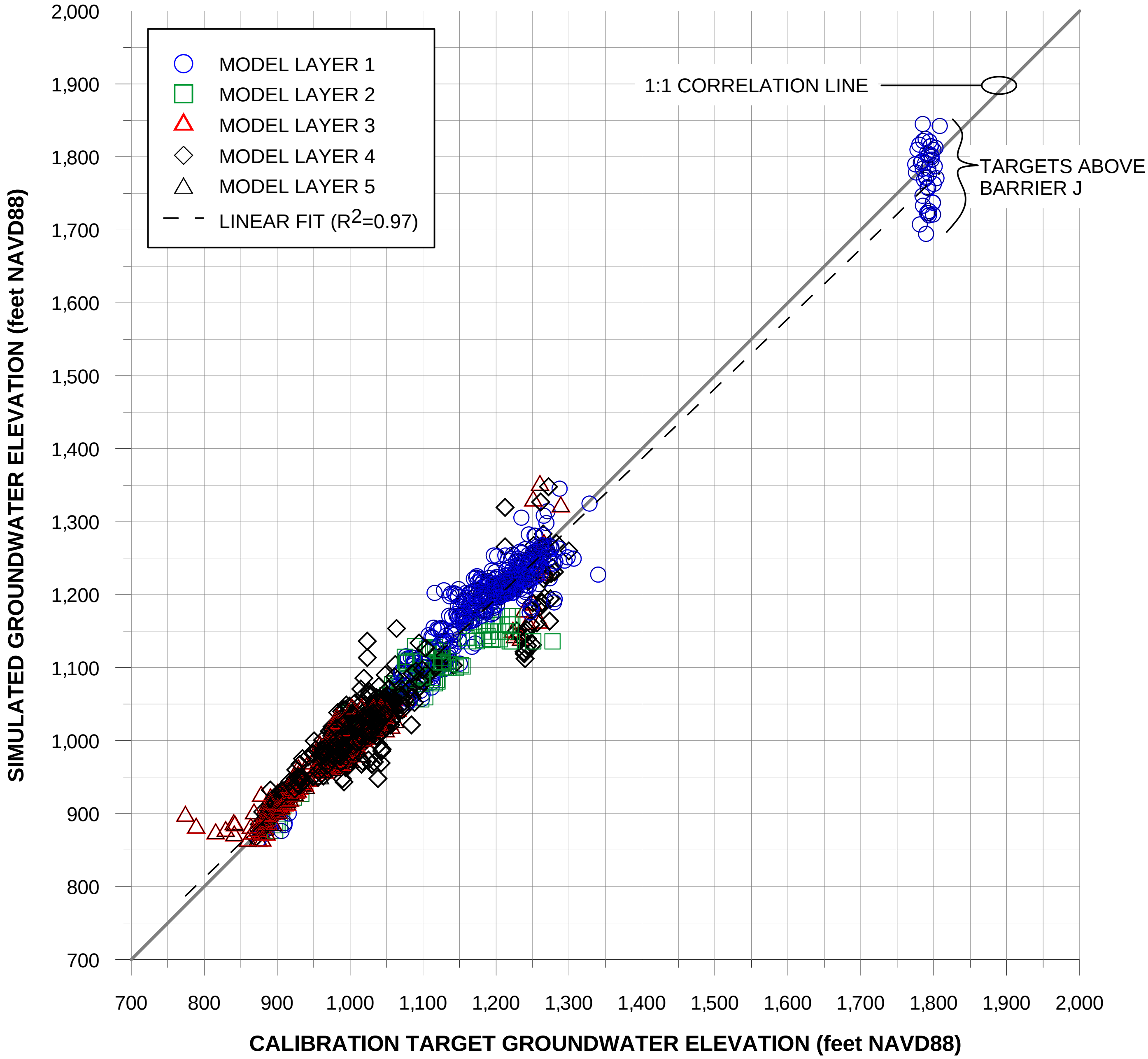


FIGURE 4-6
MODELED HYDRAULIC CONDUCTIVITY OF HORIZONTAL FLOW BARRIERS

RIALTO-COLTON BASIN GROUNDWATER FLOW MODEL

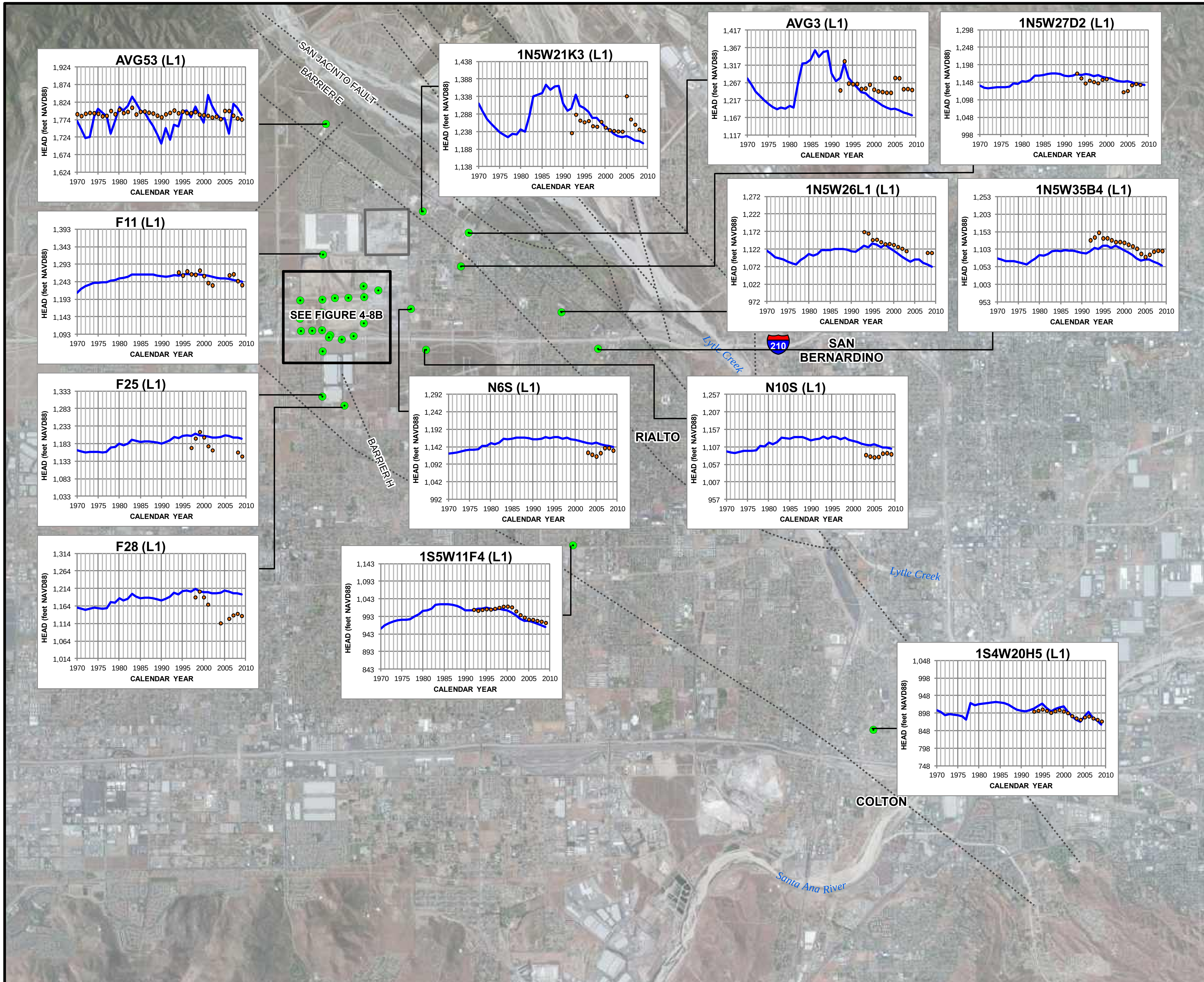
CH2MHILL.



Summary Statistic	Value
ME (feet)	0.09
RMSE (feet)	26.29
Range (feet)	1,033.95
RMSE/Range	0.03
R^2	0.97
n	1,690

FIGURE 4-7
MODELED VERSUS CALIBRATION TARGET GROUNDWATER ELEVATIONS
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL



MAP LEGEND

- MODEL LAYER 1 WELL
- 160-ACRE AREA
- APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

GRAPH LEGEND

- MODELED HEAD (feet NAVD88)
- TARGET HEAD (feet NAVD88)

NOTES:

"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL WELL NAMES ASSOCIATED WITH EACH "AVG" LOCATION.

TEXT APPEARING IN PARENTHESES AFTER THE WELL NAME ON EACH HYDROGRAPH INDICATES THE MODEL LAYER NUMBER TO WHICH THE WELL IS ASSIGNED.

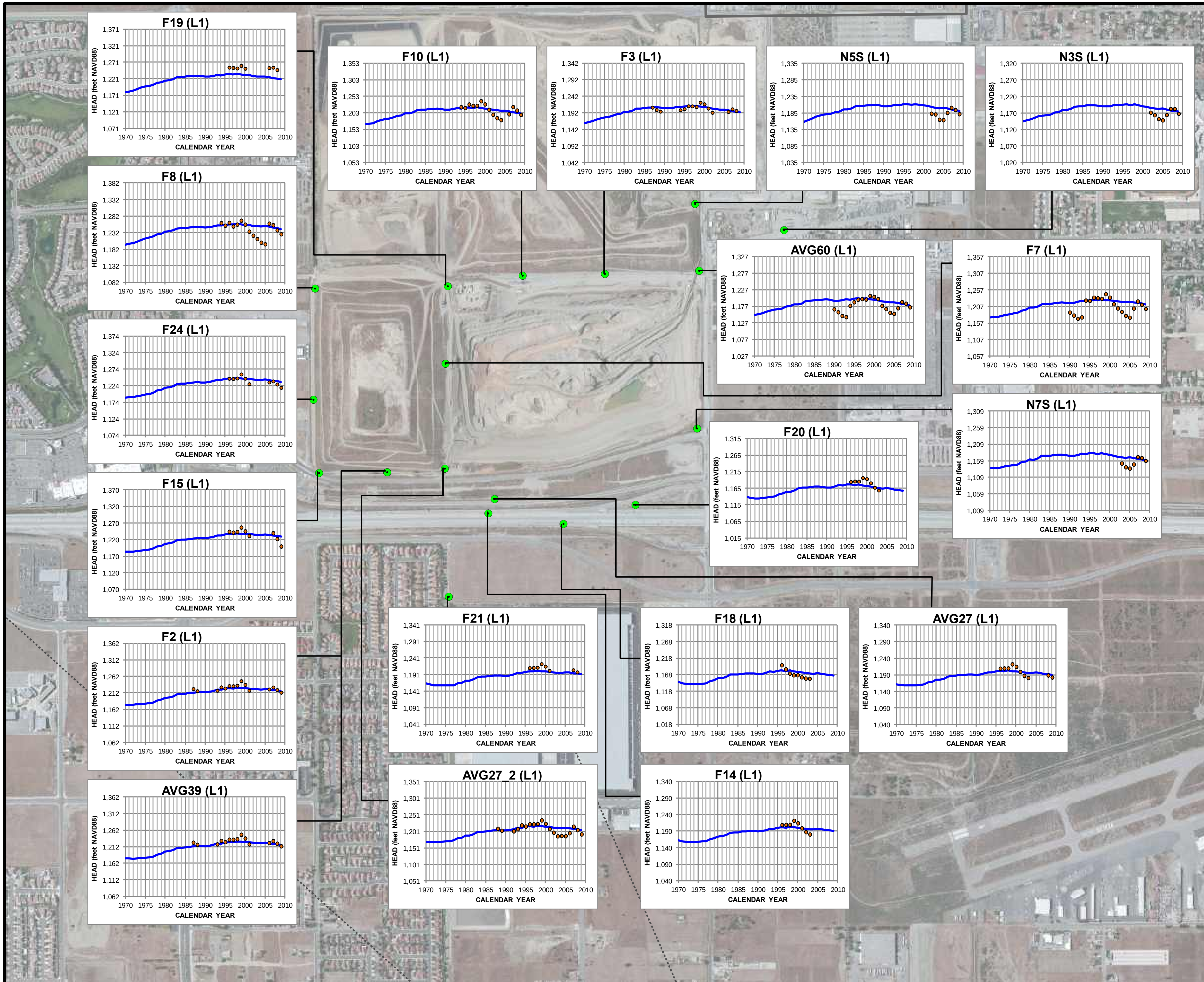
SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 6,000 12,000 Feet

N

FIGURE 4-8A
MODELED VERSUS TARGET HYDROGRAPHS – MODEL LAYER 1

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA



MAP LEGEND

MODEL LAYER 1 WELL

160-ACRE AREA

APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

GRAPH LEGEND

MODELED HEAD (feet NAVD88)

TARGET HEAD (feet NAVD88)

NOTES:

"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL WELL NAMES ASSOCIATED WITH EACH "AVG" LOCATION.

TEXT APPEARING IN PARENTHESES AFTER THE WELL NAME ON EACH HYDROGRAPH INDICATES THE MODEL LAYER NUMBER TO WHICH THE WELL IS ASSIGNED.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 1,000 2,000 Feet

N

FIGURE 4-8B
MODELED VERSUS TARGET HYDROGRAPHS – MODEL LAYER 1

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

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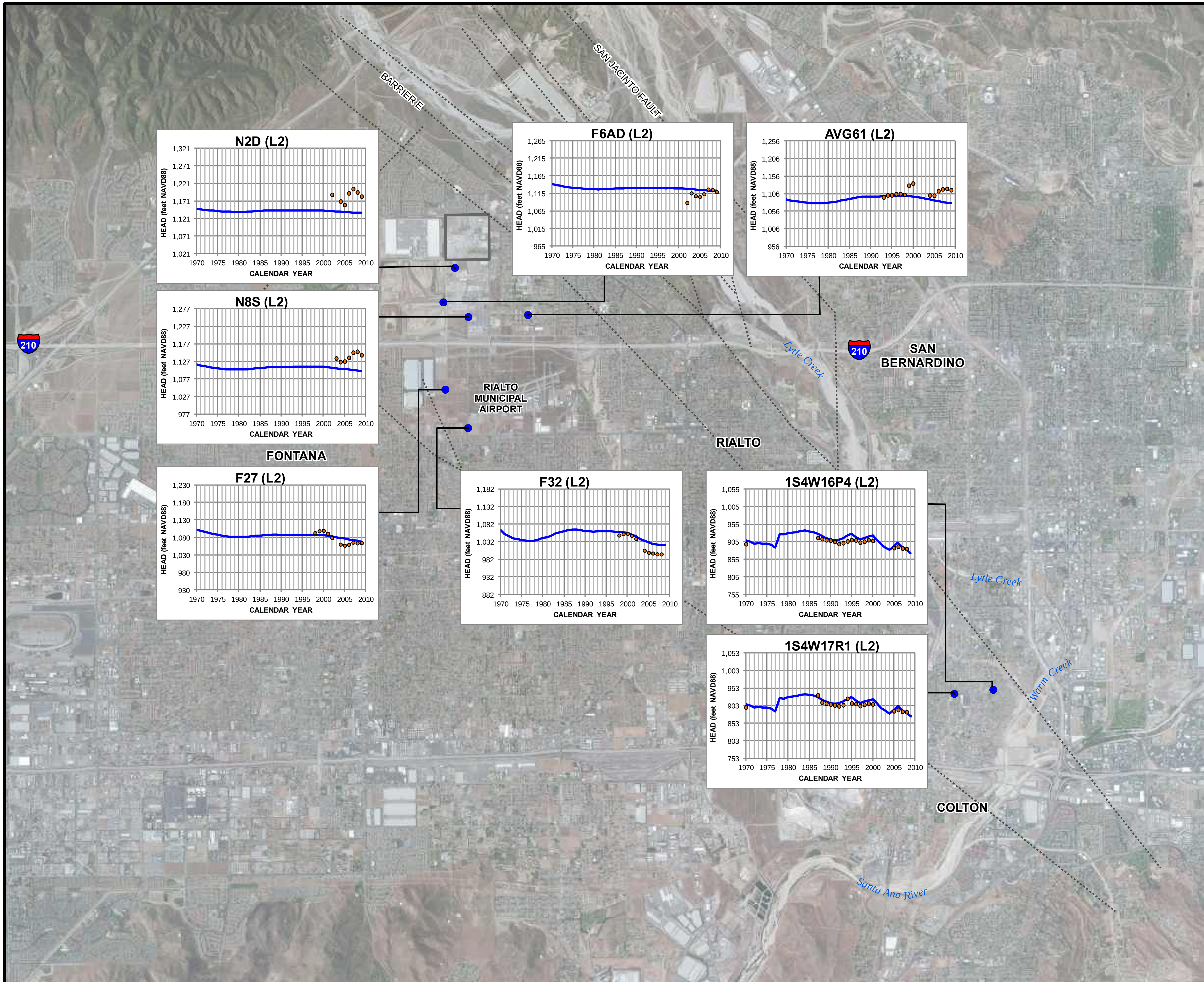


NOTES:

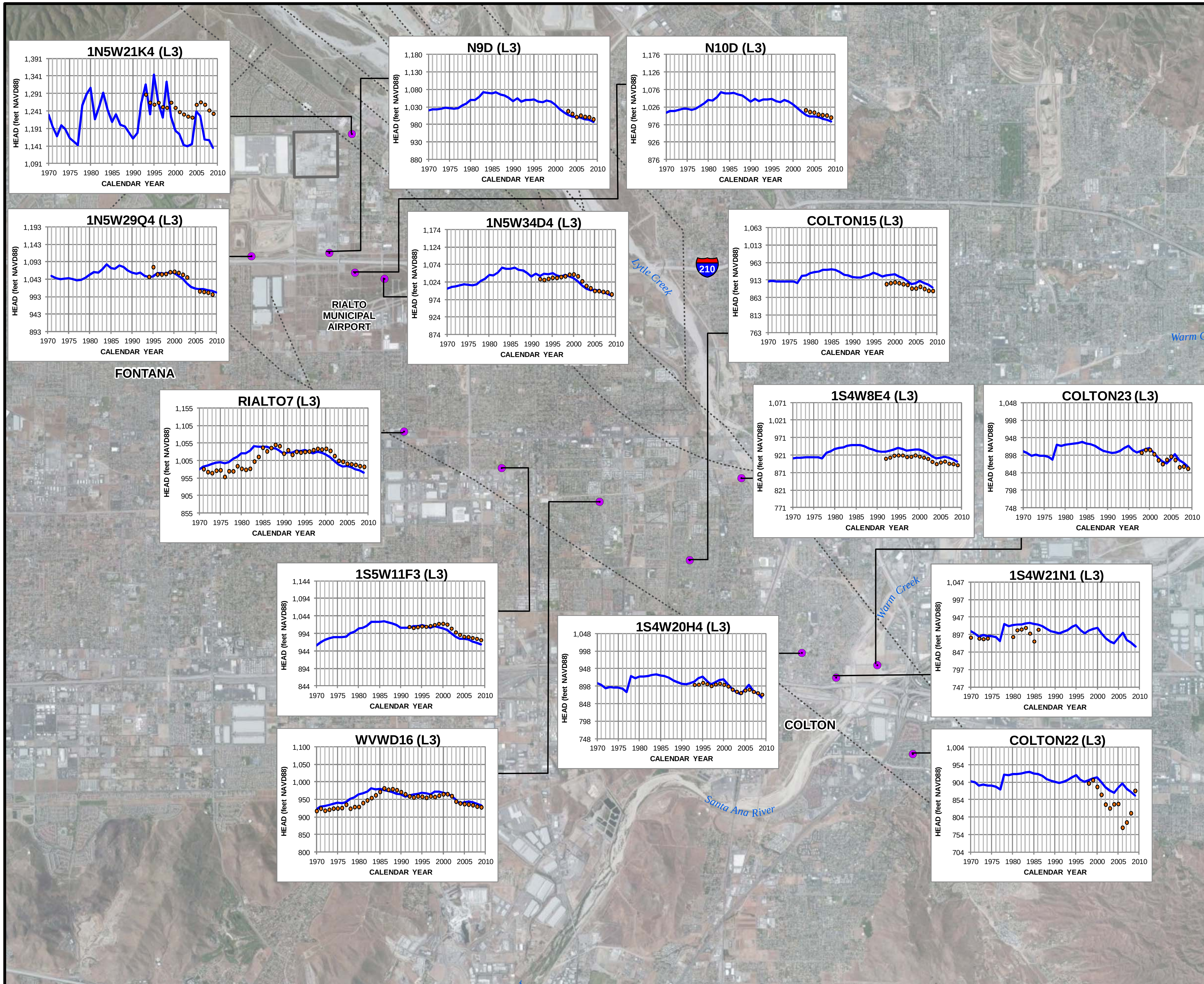
"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL WELL NAMES ASSOCIATED WITH EACH "AVG" LOCATION.

TEXT APPEARING IN PARENTHESES AFTER THE WELL NAME ON EACH HYDROGRAPH INDICATES THE MODEL LAYER NUMBER TO WHICH THE WELL IS ASSIGNED.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

FIGURE 4-8C
MODELED VERSUS TARGET HYDROGRAPHS – MODEL LAYER 2
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL



MAP LEGEND

- MODEL LAYER 3 WELL
- 160-ACRE AREA
- APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

GRAPH LEGEND

- MODELED HEAD (feet NAVD88)
- TARGET HEAD (feet NAVD88)

NOTES:

"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL WELL NAMES ASSOCIATED WITH EACH "AVG" LOCATION.

TEXT APPEARING IN PARENTHESES AFTER THE WELL NAME ON EACH HYDROGRAPH INDICATES THE MODEL LAYER NUMBER TO WHICH THE WELL IS ASSIGNED.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 6,000 12,000 Feet

N

FIGURE 4-8D
MODELED VERSUS TARGET HYDROGRAPHS – MODEL LAYER 3

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL

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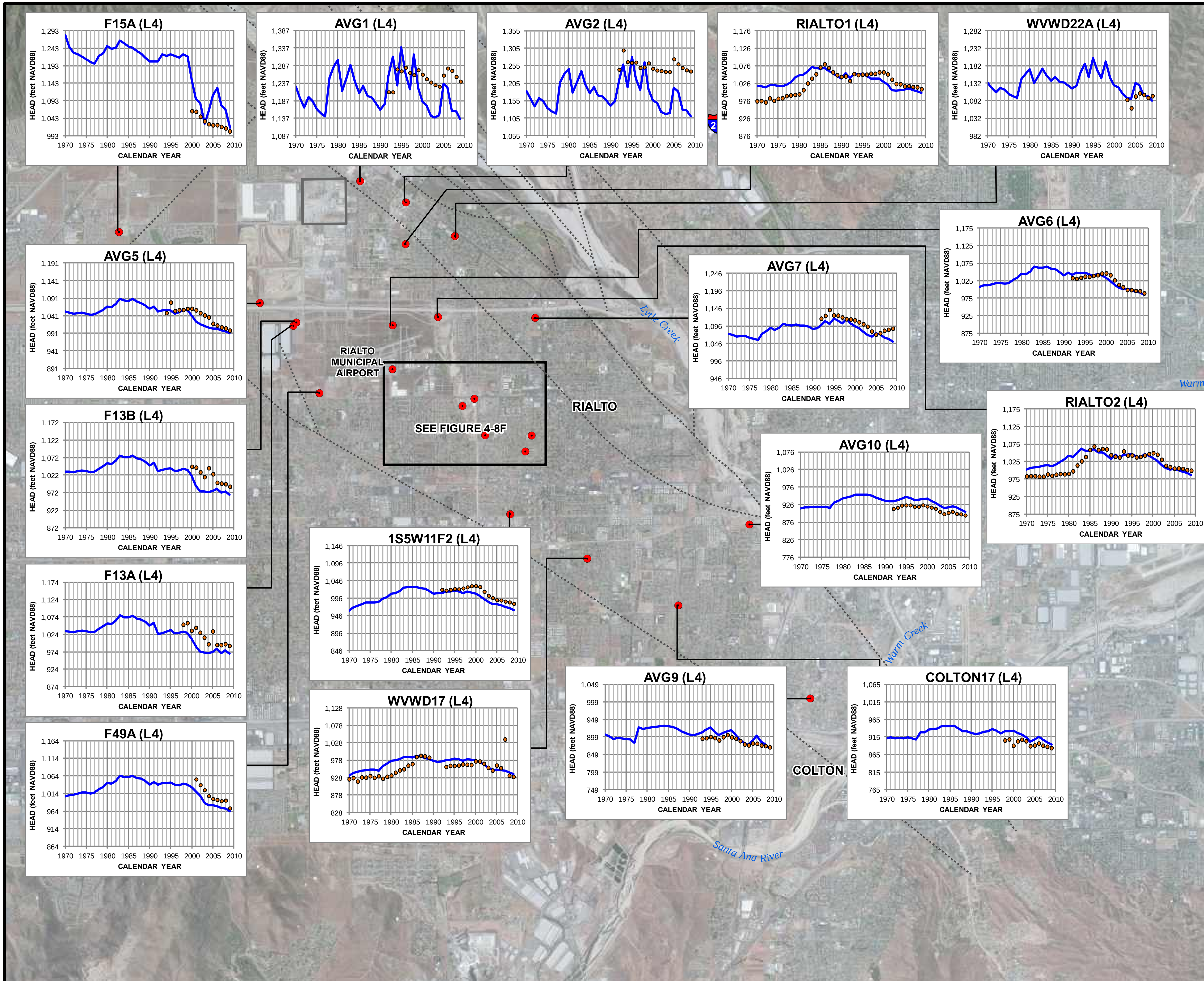

MAP LEGEND

- MODEL LAYER 4 WELL
- 160-ACRE AREA
- APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

GRAPH LEGEND

- MODELED HEAD (feet NAVD88)
- TARGET HEAD (feet NAVD88)

NOTES:

"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL WELL NAMES ASSOCIATED WITH EACH "AVG" LOCATION.

TEXT APPEARING IN PARENTHESES AFTER THE WELL NAME ON EACH HYDROGRAPH INDICATES THE MODEL LAYER NUMBER TO WHICH THE WELL IS ASSIGNED.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 6,000 12,000 Feet

N

FIGURE 4-8E
MODELED VERSUS TARGET HYDROGRAPHS – MODEL LAYER 4

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

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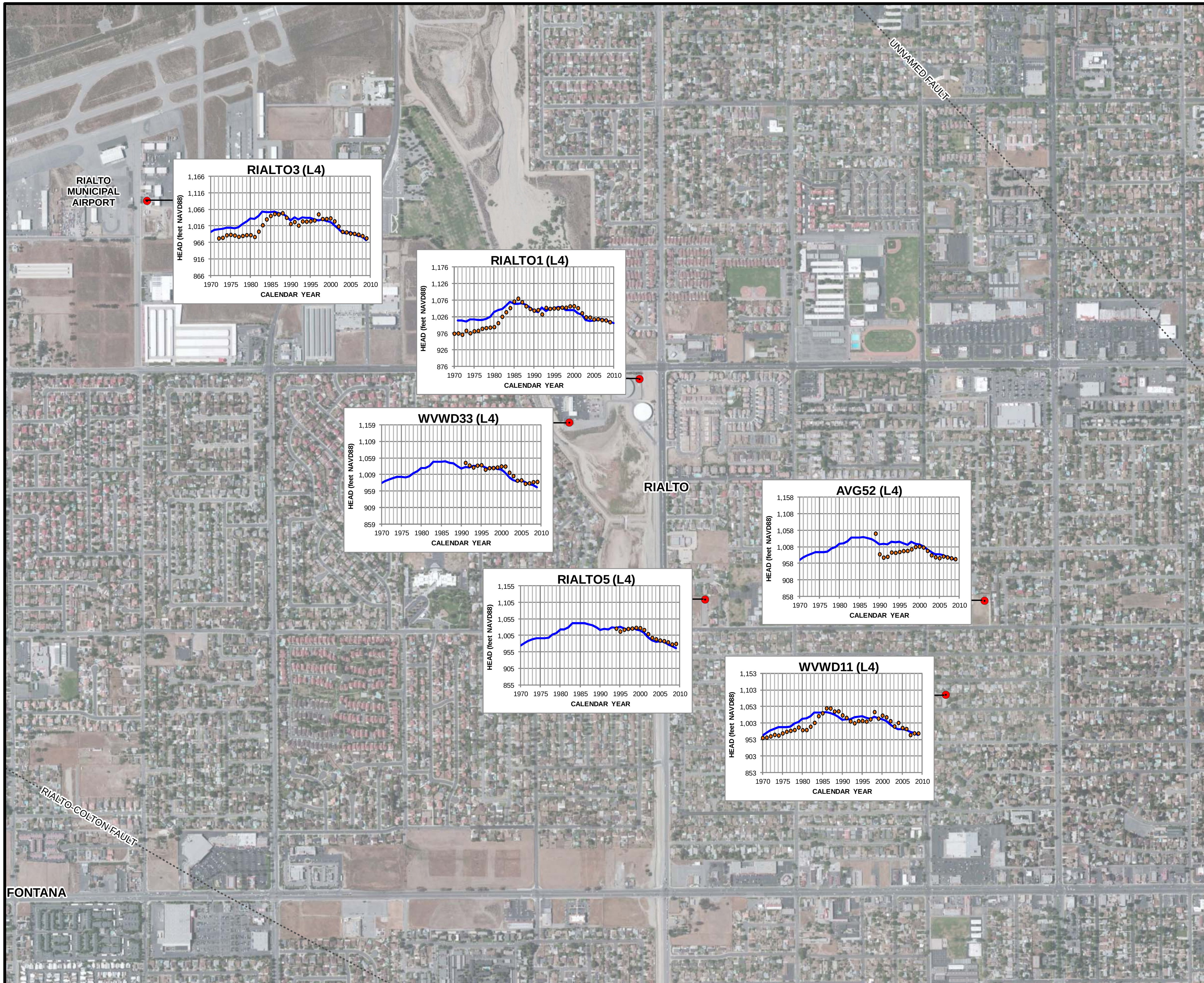


MAP LEGEND

- MODEL LAYER 4 WELL
- APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

GRAPH LEGEND

- MODELED HEAD (feet NAVD88)
- TARGET HEAD (feet NAVD88)

NOTES:

"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL WELL NAMES ASSOCIATED WITH EACH "AVG" LOCATION.

TEXT APPEARING IN PARENTHESES AFTER THE WELL NAME ON EACH HYDROGRAPH INDICATES THE MODEL LAYER NUMBER TO WHICH THE WELL IS ASSIGNED.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

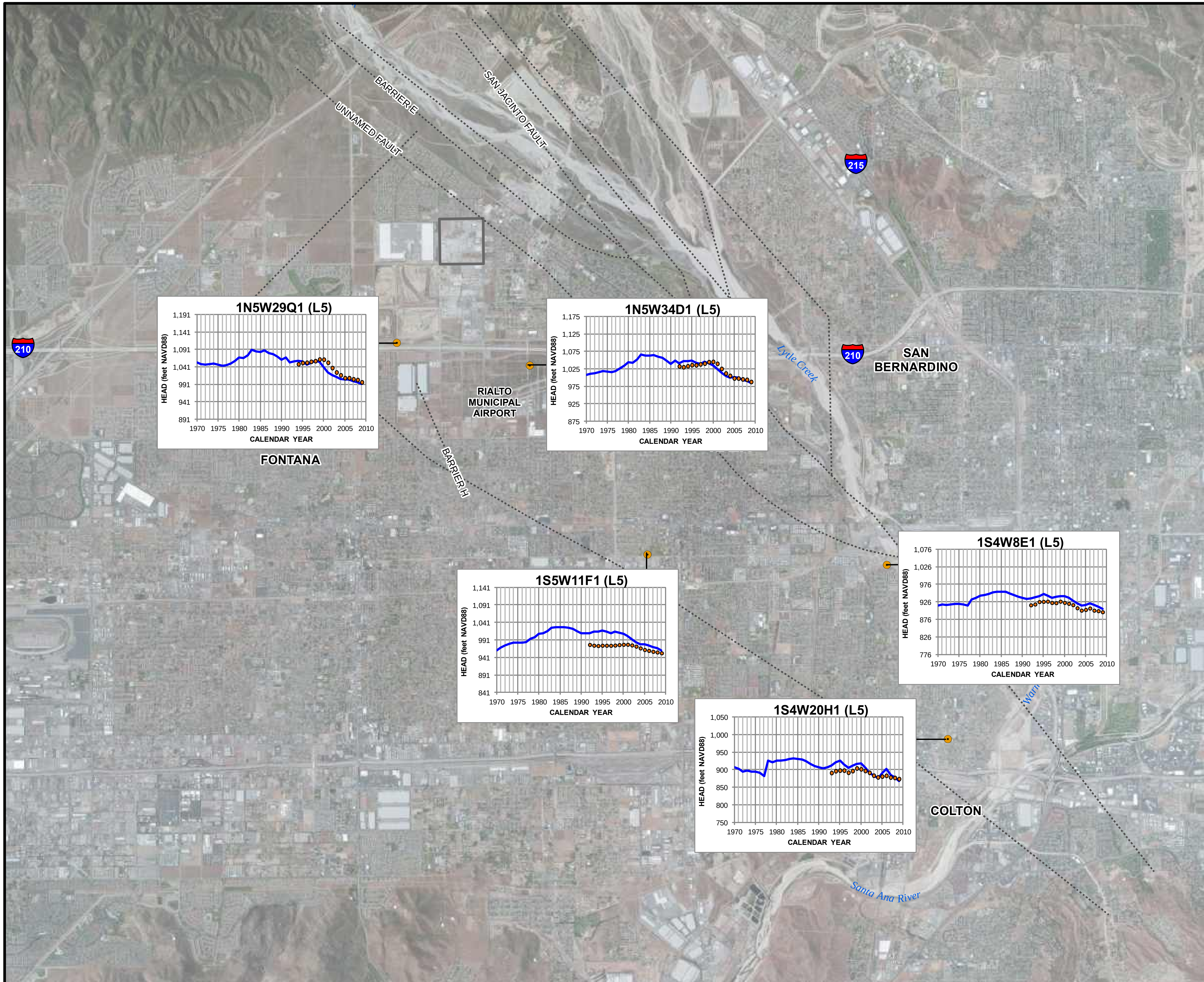
0 1,000 2,000 Feet

N

FIGURE 4-8F
MODELED VERSUS TARGET HYDROGRAPHS – MODEL LAYER 4

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL



MAP LEGEND

- MODEL LAYER 5 WELL
- 160-ACRE AREA
- APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)

GRAPH LEGEND

- MODELED HEAD (feet NAVD88)
- TARGET HEAD (feet NAVD88)

NOTES:

"AVG" WELLS INDICATE MORE THAN ONE WELL PER MODEL GRID CELL. SEE TABLE A-4 FOR INDIVIDUAL WELL NAMES ASSOCIATED WITH EACH "AVG" LOCATION.

TEXT APPEARING IN PARENTHESES AFTER THE WELL NAME ON EACH HYDROGRAPH INDICATES THE MODEL LAYER NUMBER TO WHICH THE WELL IS ASSIGNED.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

FIGURE 4-8G
MODELED VERSUS TARGET HYDROGRAPHS – MODEL LAYER 5

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL

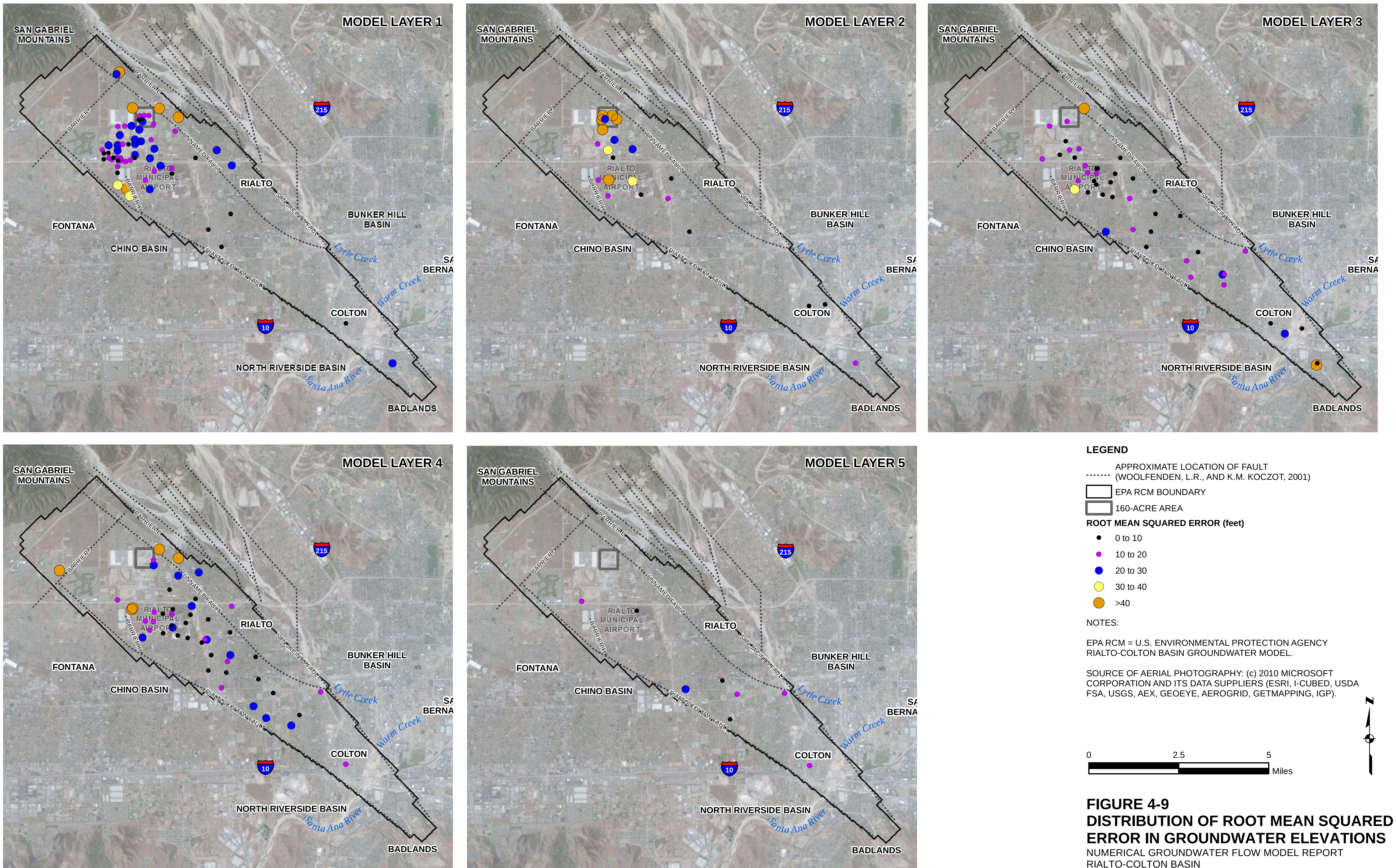
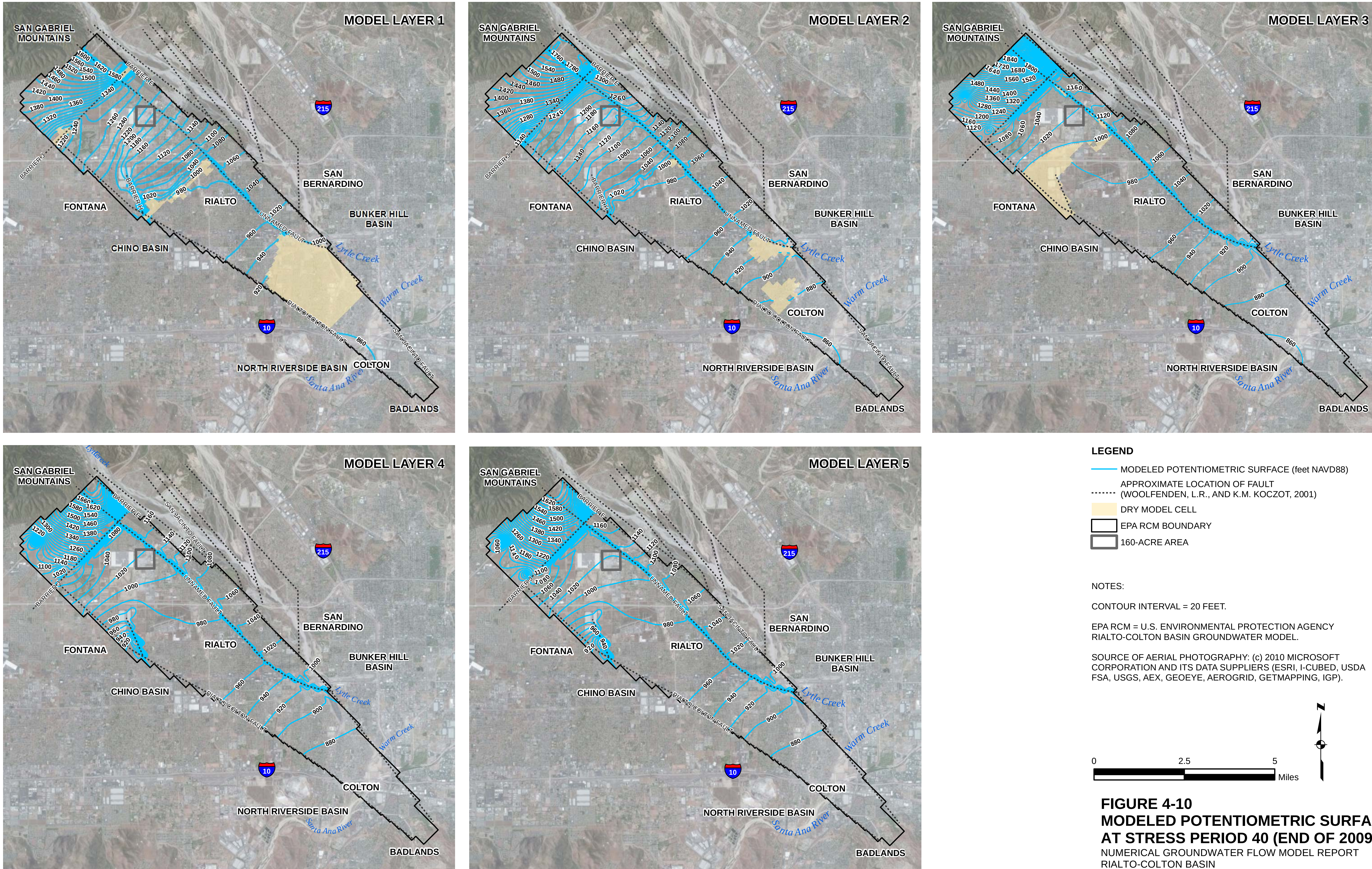


FIGURE 4-9
DISTRIBUTION OF ROOT MEAN SQUARED ERROR IN GROUNDWATER ELEVATIONS
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG04-09_RMSE.MXD 5/15/2012 12:59:14 PM FELHADID



LEGEND

- MODELED POTENTIOMETRIC SURFACE (feet NAVD88)
- APPROXIMATE LOCATION OF FAULT (WOOLFENDEN, L.R., AND K.M. KOCZOT, 2001)
- DRY MODEL CELL
- EPA RCM BOUNDARY
- 160-ACRE AREA

NOTES:

CONTOUR INTERVAL = 20 FEET.

EPA RCM = U.S. ENVIRONMENTAL PROTECTION AGENCY RIALTO-COLTON BASIN GROUNDWATER MODEL.

SOURCE OF AERIAL PHOTOGRAPHY: (c) 2010 MICROSOFT CORPORATION AND ITS DATA SUPPLIERS (ESRI, I-CUBED, USDA FSA, USGS, AEX, GEOEYE, AEROGRID, GETMAPPING, IGP).

0 2.5 5 Miles

N

FIGURE 4-10
MODELED POTENTIOMETRIC SURFACES AT STRESS PERIOD 40 (END OF 2009)

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\RIALTO_COLTON\GIS\MAPFILES\2011GWMODEL\FIG04-10_MODPOTSURFACES.MXD 5/21/2012 9:23:29 AM FELHADID

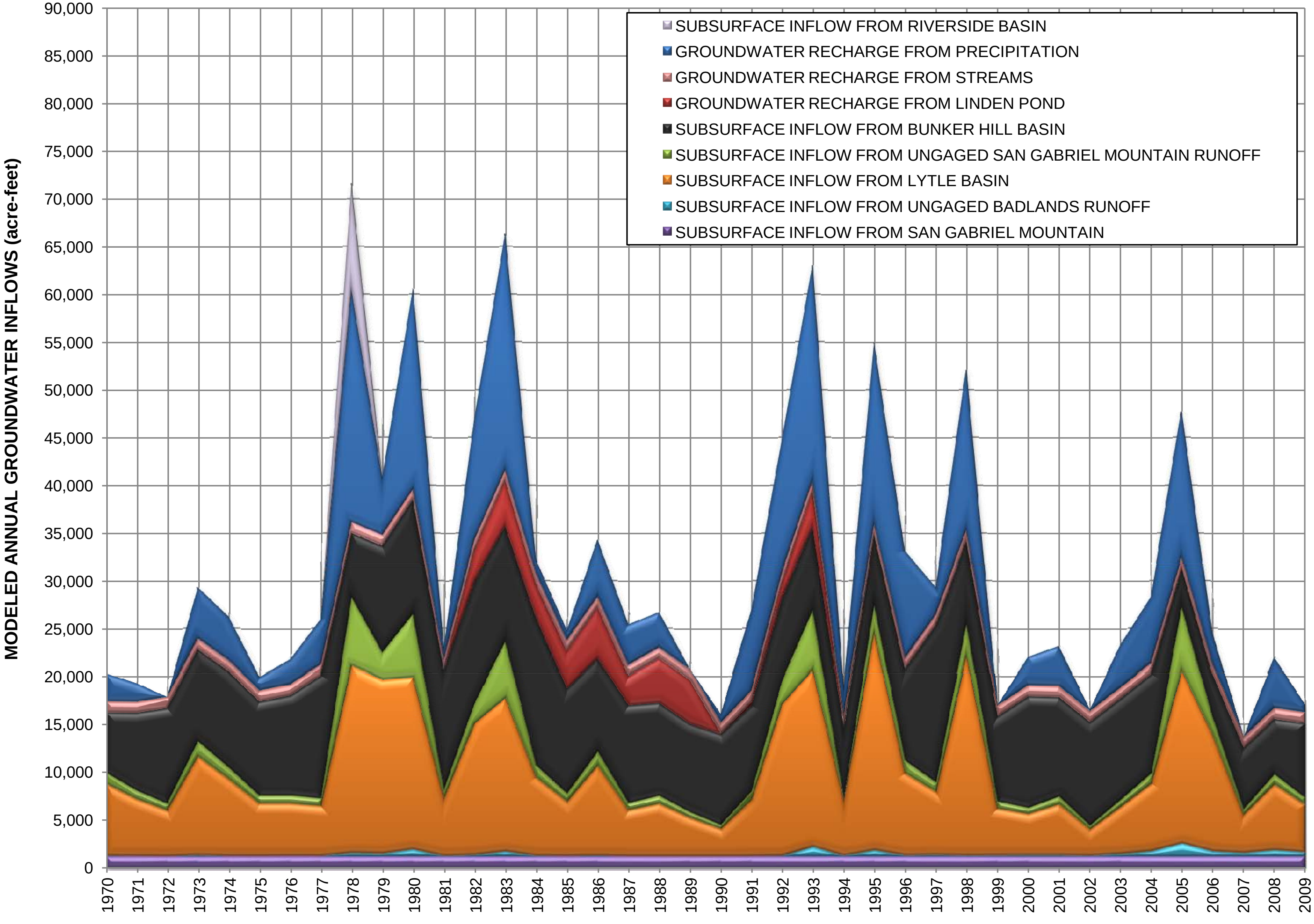


FIGURE 4-11

MODELED ANNUAL GROUNDWATER INFLOWS

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

O:\Rialto_Colton\2011_GWModel\Doc\Figures\EXCEL\FIG04-11_12_AnnGwBudget.xlsx\FIG4-11

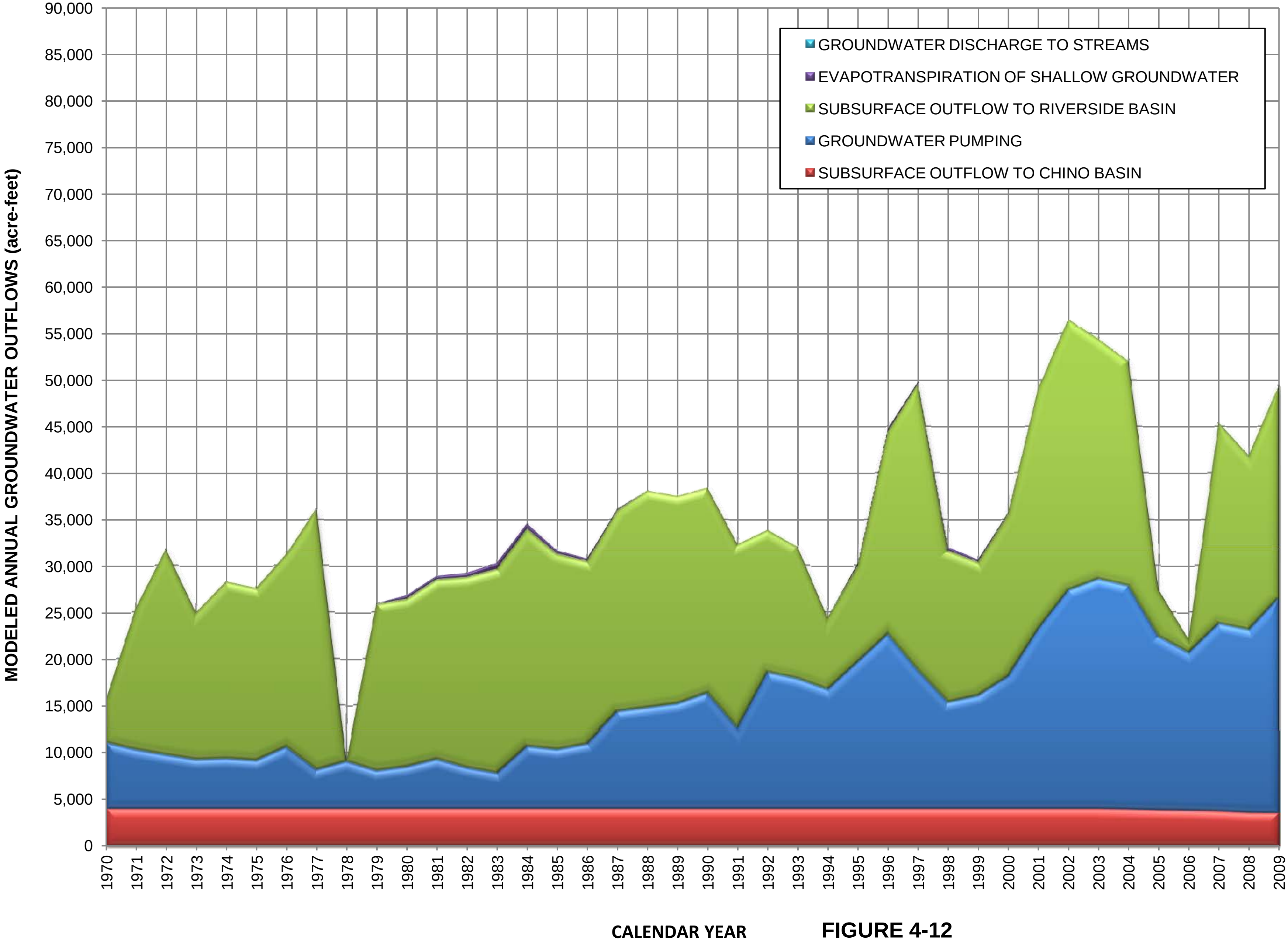


FIGURE 4-12
MODELED ANNUAL GROUNDWATER OUTFLOWS
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

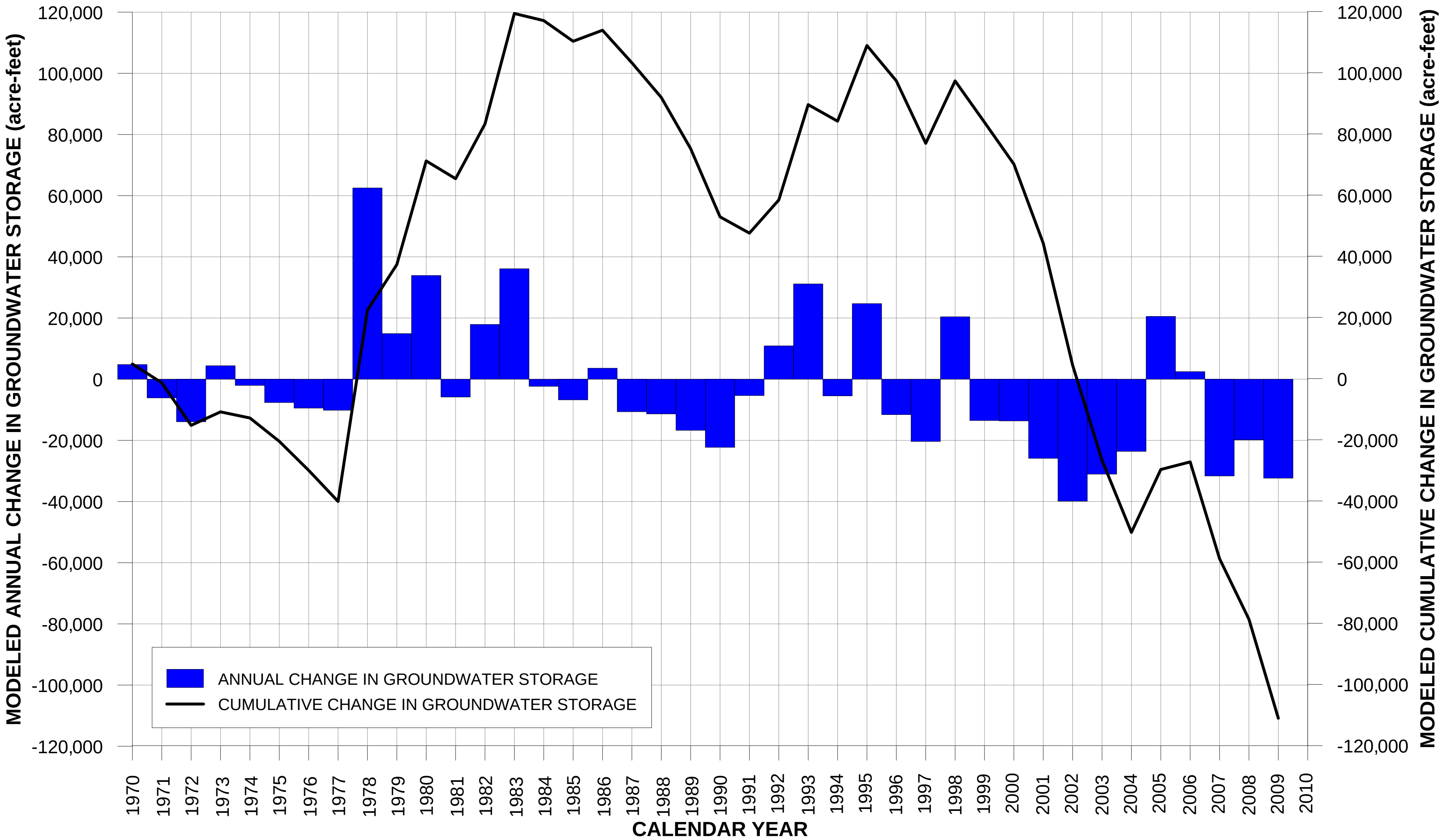


FIGURE 4-13
MODELED ANNUAL AND CUMULATIVE CHANGE IN GROUNDWATER STORAGE
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

CH2MHILL.

\\odin\proj\Rialto_Colton\2011_GWModel\Doc\Figures\GRF\FIG04-13_Storage.grf

SECTION 5

Model Limitations and Recommendations

Models are inherently inexact, because the mathematical description of the physical system is imperfect, and the understanding of interrelated physical processes is incomplete. Thus, the modeling solutions discussed herein should be considered non-unique, meaning that different combinations of model parameter values could produce equally good fits to the calibration targets, but result in predictive results that are quite different. Nevertheless, the EPA RCM is a powerful tool that can provide useful insight into flow processes within the physical system. The EPA RCM output should not be a substitute for continued monitoring of groundwater flow trends and conditions at available wells. The EPA RCM output should be scrutinized and used in conjunction with observational site data and professional judgment.

The EPA RCM also has some specific limitations based on choices made during model development. Although the EPA RCM is a transient model, annual stress periods were used. Thus, seasonal stresses within a CY cannot be addressed given the model's current time discretization. Improved model calibration is challenged near the northern, specified-flux boundaries representing inflow from Lytle Basin and the San Gabriel Mountains. Thus, additional calibration should be undertaken if this portion of the model becomes an area of interest. Finally, the model underpredicts heads near the 160-Acrea Area in Model Layer 2. Updated information related to the BC Aquitard should be incorporated into the next version of the EPA RCM, which could improve consistency between modeled and target data in this area. Finally, the specified-flux boundary representing outflow to the Chino Basin should be implemented as a GHB. Although use of the specified-flux boundary is consistent with the Chino Basin model, it may present some difficulties in some future forecasting scenarios when groundwater levels drop below the bottoms of these model cells.

Recommendations for improving the EPA RCM include the following:

- Use chemistry data to help constrain model parameters and improve model calibration.
- Incorporate new data from aquifer tests and new wells as they become available.
- Incorporate the most recent data related to the BC aquitard. This may improve the modeled groundwater elevations near the 160-Acre Area in Model Layer 2.
- Convert the specified-flux boundary condition at the Chino Basin boundary to a GHB boundary condition.
- Conduct a parameter sensitivity analysis to evaluate which model parameters most strongly influence modeled results.
- Add a solute transport model to the EPA RCM to explicitly simulate the movement of perchlorate in the basin, if necessary.

Although the first version of the EPA RCM is complete, the overall strategy and goal moving forward is to revise and improve the model as new data become available. As more hydraulic and chemical data become available, parameter values should be periodically evaluated and compared with those assigned in the EPA RCM. Obtaining this information would provide the opportunity to improve the CSM and predictive capabilities of the EPA RCM and any future solute transport model.

The EPA RCM can be used as one tool to aid in the following:

- Identifying data gaps
- Improving the long-term monitoring program
- Forecasting potential outcomes from implementing proposed remedial actions
- Testing hypotheses about groundwater hydraulics
- Evaluating groundwater flow directions in the southern portion of the RCB
- Supporting development of decision documents, such as feasibility studies, proposed plans, and records of decision

SECTION 6
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Appendix A
Modeled Groundwater Inflows to the Rialto-Colton Basin during Simulation Period

TABLE A-1

Modeled Ungaged Runoff from the San Gabriel Mountains and Badlands

Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Calendar Year	Ungaged Runoff and Subsurface Inflow from San Gabriel Mountains (acre-feet/yr)	Ungaged Runoff from Badlands (acre-feet/yr)
1970	1,193	56
1971	940	32
1972	756	2
1973	1,626	125
1974	1,267	31
1975	866	26
1976	866	41
1977	825	38
1978	7,192	370
1979	2,862	295
1980	6,622	728
1981	954	40
1982	2,174	143
1983	5,900	519
1984	1,290	59
1985	896	29
1986	1,487	75
1987	763	5
1988	869	0
1989	636	0
1990	455	0
1991	931	14
1992	2,451	61
1993	6,251	985
1994	266	78
1995	2,872	641
1996	1,353	92
1997	1,038	148
1998	3,302	79
1999	772	99
2000	680	118
2001	841	117
2002	436	66
2003	776	250
2004	1,115	541
2005	6,652	1,346
2006	1,911	526
2007	629	365
2008	1,084	653
2009	778	444
Minimum	266	0
Average	1,864	231
Maximum	7,192	1,346

Note:

acre-feet/yr = acre-feet per year

TABLE A-2

Modeled Groundwater Recharge from Linden Pond from 1982 through 1994

Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Calendar Year	Inflow (acre-feet/yr)
1982	3,220
1983	4,736
1984	3,471
1985	3,879
1986	5,345
1987	3,030
1988	4,601
1989	4,522
1990	65
1991	435
1992	1,559
1993	3,747
1994	261

Note:

Inflow equals zero for simulation years not shown.

TABLE A-3

Modeled Subsurface Inflow from Lytle and Bunker Hill Basins

Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Calendar Year	Underflow from Lytle Basin (acre-feet/yr)	Underflow from Bunker Hill Basin (acre-feet/yr)
1970	7,538	6,288
1971	5,944	8,119
1972	4,780	9,976
1973	10,276	9,571
1974	8,012	10,005
1975	5,478	9,828
1976	5,474	10,449
1977	5,218	12,816
1978	19,484	6,684
1979	18,096	11,150
1980	17,940	11,929
1981	6,030	12,461
1982	13,740	12,678
1983	15,986	12,054
1984	8,156	15,414
1985	5,666	10,958
1986	9,398	9,685
1987	4,824	10,219
1988	5,492	9,701
1989	4,018	9,210

TABLE A-3
Modeled Subsurface Inflow from Lytle and Bunker Hill Basins
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Calendar Year	Underflow from Lytle Basin (acre-feet/yr)	Underflow from Bunker Hill Basin (acre-feet/yr)
1990	2,874	9,471
1991	5,884	8,936
1992	15,824	8,644
1993	18,450	8,656
1994	5,816	7,271
1995	22,726	7,340
1996	8,556	9,554
1997	6,564	16,352
1998	20,873	8,678
1999	4,883	8,912
2000	4,299	11,645
2001	5,318	10,373
2002	2,756	10,797
2003	4,908	10,561
2004	7,046	10,332
2005	18,022	4,093
2006	12,077	4,404
2007	3,974	6,398
2008	6,855	5,795
2009	4,917	7,789
Minimum	2,756	4,093
Average	9,105	9,630
Maximum	22,727	16,352

TABLE A-4
Calibration Statistics for Groundwater Elevation Targets
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
1N5W17K3	West of Barrier J	1	4	-33.00	26.85	-2.76	22.98	0.86
AVG53 (WVWD23A, WVWD24)	West of Barrier J	1	40	-95.12	60.01	-14.18	41.31	0.00
F15A	West of Barrier J	4	10	-3.41	112.60	55.08	64.67	0.29
1N5W21K3	North of Unnamed Fault	1	18	-112.67	70.68	-0.45	43.70	0.03
1N5W26L1	North of Unnamed Fault	1	13	-39.38	-1.03	-21.46	24.58	0.69
1N5W35B4	North of Unnamed Fault	1	18	-45.16	-5.99	-23.80	25.83	0.74
AVG03 (1N5W22N3,	North of Unnamed Fault	1	18	-90.45	37.41	-31.18	46.71	0.29

TABLE A-4
Calibration Statistics for Groundwater Elevation Targets
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
1N5W22N5)								
1N5W21K4	North of Unnamed Fault	3	17	-95.43	93.09	-32.05	64.50	0.51
AVG01 (1N5W21K1, 1N5W21K2)	North of Unnamed Fault	4	18	-109.88	107.09	-34.42	73.69	0.02
AVG02 (1N5W22N1, 1N5W22N2, 1N5W22N4)	North of Unnamed Fault	4	18	-127.81	18.60	-74.04	85.80	0.47
AVG07 (1N5W35B1, 1N5W35B2)	North of Unnamed Fault	4	18	-38.52	4.35	-15.73	19.09	0.74
WVWD22A	North of Unnamed Fault	4	7	-13.09	39.19	12.11	20.71	0.22
1N5W27D2	Near MVSL	1	13	-0.24	30.50	14.17	17.68	0.43
AVG12 (CMW2A, CMW2B)	Near MVSL	1	4	-11.58	10.20	-0.96	8.16	0.70
AVG13 (CMW3A, CMW3B)	Near MVSL	1	4	-17.11	1.43	-8.38	11.25	0.80
AVG14 (CMW4A, CMW4B, CMW4C)	Near MVSL	1	4	-14.86	4.51	-6.75	10.35	0.85
AVG14_2 (CMW5A, CMW5B)	Near MVSL	1	4	-19.64	0.40	-10.77	13.13	0.76
AVG27 (F14, F33A, F33B)	Near MVSL	1	10	-19.09	16.94	-0.52	10.79	0.69
AVG27_2 (F26S, F26D, F5,F9)	Near MVSL	1	20	-16.62	27.46	5.22	13.39	0.25
AVG39 (F2, F2A)	Near MVSL	1	15	-20.37	7.44	-3.95	7.92	0.39
AVG40 (F34A, F34B)	Near MVSL	1	2	15.14	22.46	18.80	19.15	1.00
AVG44 (CMW1A, CMW1B)	Near MVSL	1	4	-15.65	4.67	-5.52	9.34	0.69
AVG60 (F6, F6AS)	Near MVSL	1	20	-8.57	55.85	15.75	24.17	0.08
EPAMP4A	Near MVSL	1	1	-2.97	-2.97	-2.97	2.97	NC
F10	Near MVSL	1	15	-19.63	28.78	1.15	13.41	0.37
F11	Near MVSL	1	13	-15.41	25.77	1.97	12.08	0.27
F14	Near MVSL	1	8	-19.68	16.43	-3.07	11.64	0.76
F15	Near MVSL	1	9	-16.92	31.86	1.31	13.31	0.69
F16	Near MVSL	1	6	-16.07	5.32	-4.81	8.07	0.17
F17	Near MVSL	1	4	-25.38	-15.74	-18.47	18.90	0.03
F18	Near MVSL	1	8	-15.32	17.12	8.14	13.71	0.58
F19	Near MVSL	1	8	-30.76	-15.04	-22.10	22.68	0.19

TABLE A-4

Calibration Statistics for Groundwater Elevation Targets

Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
F2	Near MVSL	1	15	-20.37	7.44	-3.95	7.91	0.39
F20	Near MVSL	1	8	-21.67	7.33	-8.72	12.57	0.62
F21	Near MVSL	1	8	-20.79	-2.38	-9.76	11.20	0.55
F23	Near MVSL	1	3	-6.64	0.57	-2.09	3.85	0.07
F24	Near MVSL	1	10	-11.91	18.50	4.86	9.75	0.64
F3	Near MVSL	1	15	-11.82	12.55	2.34	7.42	0.30
F30	Near MVSL	1	3	-22.48	-11.35	-15.83	16.54	0.04
F31	Near MVSL	1	4	-16.66	9.93	-2.96	9.88	0.18
F4	Near MVSL	1	2	19.67	28.53	24.10	24.50	1.00
F7	Near MVSL	1	20	-15.98	51.92	17.28	27.46	0.29
F8	Near MVSL	1	16	-9.61	56.80	13.41	24.59	0.15
N10S	Near MVSL	1	7	16.83	38.78	26.96	28.23	0.59
N11S	Near MVSL	1	6	8.50	24.57	16.22	17.50	0.51
N12S	Near MVSL	1	6	6.42	36.86	19.87	23.26	0.75
N13S	Near MVSL	1	6	2.99	26.75	13.50	16.65	0.77
N16B	Near MVSL	1	1	-0.40	-0.40	-0.40	0.40	NC
N17B	Near MVSL	1	2	-14.25	-13.75	-14.00	14.00	1.00
N1S	Near MVSL	1	6	-2.04	21.77	9.62	13.10	0.19
N2S	Near MVSL	1	6	-0.04	34.31	17.03	20.32	0.10
N3S	Near MVSL	1	8	-4.43	36.66	15.60	21.04	0.24
N4S	Near MVSL	1	4	-4.82	31.20	12.94	18.68	0.06
N5S	Near MVSL	1	8	-4.22	38.23	17.53	22.58	0.21
N6S	Near MVSL	1	7	8.13	40.24	22.71	25.65	0.63
N7S	Near MVSL	1	7	-5.24	35.34	14.25	20.73	0.57
PW1	Near MVSL	1	6	-57.18	-22.10	-41.08	42.57	0.12
PW2	Near MVSL	1	6	-10.65	41.71	11.41	22.99	0.32
PW3	Near MVSL	1	6	-15.39	31.54	3.86	18.75	0.36
TW1	Near MVSL	1	5	-9.14	38.50	10.06	20.24	0.03
AVG61 (PW8A, 1N5W28J2)	Near MVSL	2	14	-38.95	3.97	-16.77	22.87	0.05
CMW1C	Near MVSL	2	4	-29.00	-11.89	-21.72	22.70	0.80
CMW2C	Near MVSL	2	4	-60.78	-38.16	-51.25	51.98	0.80
CMW3C	Near MVSL	2	4	-51.78	-27.57	-40.50	41.49	0.71
CMW5C	Near MVSL	2	4	-64.32	-42.15	-55.80	56.51	0.87
F6AD	Near MVSL	2	8	-3.64	40.23	12.11	18.17	0.63
N17C1	Near MVSL	2	2	-43.66	-41.12	-42.39	42.41	1.00
N1D	Near MVSL	2	6	-11.55	39.74	23.57	28.84	0.18
N2D	Near MVSL	2	7	-66.44	-19.21	-45.09	47.60	0.13

TABLE A-4
Calibration Statistics for Groundwater Elevation Targets
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
N8S	Near MVSL	2	7	-53.53	-17.73	-35.07	37.49	0.57
N9S	Near MVSL	2	1	-1.14	-1.14	-1.14	1.14	NC
PW4	Near MVSL	2	6	-141.58	-25.70	-81.53	90.97	0.82
1N5W29Q4	Near MVSL	3	14	-35.84	11.85	-10.95	18.14	0.69
AVG22 (EPAMP4B, EPAMP4C)	Near MVSL	3	1	-7.45	-7.45	-7.45	7.45	NC
N10D	Near MVSL	3	7	-13.14	-6.24	-10.85	11.08	0.89
N11D	Near MVSL	3	6	-10.61	-2.30	-6.38	7.15	0.75
N18C1	Near MVSL	3	2	-33.58	-27.15	-30.37	30.54	1.00
N3D	Near MVSL	3	2	-4.34	-3.21	-3.77	3.81	1.00
N4D	Near MVSL	3	3	9.87	17.27	12.37	12.85	0.94
N6D	Near MVSL	3	2	-13.63	-10.52	-12.07	12.17	1.00
N7D	Near MVSL	3	2	-9.51	-8.78	-9.14	9.15	1.00
N8D	Near MVSL	3	1	-10.08	-10.08	-10.08	10.08	NC
N9D	Near MVSL	3	7	-11.46	-0.13	-7.11	7.90	0.77
PW2A	Near MVSL	3	6	1.99	18.84	14.28	15.35	0.45
AVG23 (EPAMP4D, EPAMP4E)	Near MVSL	4	1	-7.00	-7.00	-7.00	7.00	NC
AVG49 |(PW8B, PW8C, PW8D, PW8E)	Near MVSL	4	4	-5.15	1.53	-2.03	3.13	0.97
AVG05 (1N5W29Q2, 1N5W29Q3)	Near MVSL	4	16	-32.11	12.08	-13.24	18.26	0.77
F13A	Near MVSL	4	12	-62.65	-13.96	-38.30	41.53	0.64
F13B	Near MVSL	4	10	-73.32	-18.69	-43.77	46.80	0.41
N13D	Near MVSL	4	6	-13.75	-5.93	-9.81	10.22	0.84
N18C2	Near MVSL	4	2	-19.01	-16.38	-17.70	17.75	1.00
PW3A	Near MVSL	4	5	-62.84	9.23	-11.36	29.18	0.04
PW4A	Near MVSL	4	6	9.61	16.62	13.04	13.26	0.89
RIALTO1	Near MVSL	4	40	-31.52	53.88	9.00	26.37	0.38
1N5W29Q1	Near MVSL	5	16	-27.11	12.09	-7.61	12.39	0.86
F22	Near Airport	1	4	-9.30	-1.00	-4.70	5.58	0.42
F25	Near Airport	1	8	-9.42	51.30	25.29	31.88	0.67
F28	Near Airport	1	9	1.74	86.57	46.86	54.38	0.41
F29	Near Airport	1	4	15.43	58.78	35.70	38.88	0.30
M61	Near Airport	1	2	6.27	9.68	7.97	8.15	1.00
N18B	Near Airport	1	2	-27.47	-26.48	-26.98	26.98	1.00
1S5W3A7	Near Airport	2	2	-14.70	-11.13	-12.91	13.04	1.00

TABLE A-4
Calibration Statistics for Groundwater Elevation Targets
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
F27	Near Airport	2	11	-13.26	19.36	3.27	11.27	0.73
F32	Near Airport	2	10	2.73	28.45	16.51	19.56	0.97
M1S	Near Airport	2	2	35.58	38.18	36.88	36.91	1.00
M21	Near Airport	2	5	-11.89	-0.17	-6.98	8.14	0.88
PW7A	Near Airport	2	4	-7.33	1.51	-2.93	4.31	0.99
1N5W34D4	Near Airport	3	18	-14.98	19.76	0.48	9.93	0.83
1S5W3A6	Near Airport	3	2	-14.72	-11.13	-12.92	13.05	1.00
AVG31 (M22, M23, M24, M25)	Near Airport	3	5	-12.41	-0.54	-7.33	8.47	0.87
AVG33 (M31, M32, M33)	Near Airport	3	5	-13.97	-4.25	-9.68	10.34	0.88
AVG35 (M52, M53)	Near Airport	3	2	-14.45	-14.26	-14.36	14.36	1.00
AVG37 (M62, M63, M64)	Near Airport	3	2	-11.72	-10.34	-11.03	11.05	1.00
AVG45 (PW5A, PW5B, PW5C, PW5D)	Near Airport	3	4	-8.51	0.36	-4.25	5.30	0.98
AVG46 (PW6A, PW6B, PW6C, PW6D)	Near Airport	3	4	-9.98	-0.85	-5.67	6.54	0.97
AVG47 (PW7B, PW7C)	Near Airport	3	4	-7.30	1.74	-2.77	4.24	0.99
EPAMP3A	Near Airport	3	1	-6.06	-6.06	-6.06	6.06	NC
M1D	Near Airport	3	2	-3.86	-1.01	-2.43	2.82	1.00
M4S	Near Airport	3	2	-6.55	-3.77	-5.16	5.34	1.00
N14S	Near Airport	3	6	-10.99	-2.54	-6.61	7.16	0.95
N15S	Near Airport	3	6	-9.62	8.83	-2.67	6.61	0.26
1S5W03A3	Near Airport	4	2	-14.58	-10.86	-12.72	12.85	1.00
AVG21 (EPAMP3B, EPAMP3C, EPAMP3D, EPAMP3E)	Near Airport	4	1	-5.23	-5.23	-5.23	5.23	NC
AVG32 (M26, M27)	Near Airport	4	5	-13.49	-0.80	-8.06	9.22	0.86
AVG34 (M34, M35, M36, M37)	Near Airport	4	5	-13.40	-3.25	-8.85	9.59	0.88
AVG36 (M54, M55, M56, M57)	Near Airport	4	2	-17.28	-15.21	-16.25	16.28	1.00

TABLE A-4
Calibration Statistics for Groundwater Elevation Targets
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
AVG38 (M65, M66, M67)	Near Airport	4	2	-12.02	-9.88	-10.95	11.00	1.00
AVG48 (PW7D, PW7E, PW7F, PW7G)	Near Airport	4	4	-7.53	1.88	-2.75	4.33	0.99
AVG06 (1N5W34D2, 1N5W34D3)	Near Airport	4	18	-15.19	19.76	0.56	9.93	0.83
F49A	Near Airport	4	9	-44.94	-12.42	-26.93	28.71	0.91
M4D	Near Airport	4	2	-7.39	-4.46	-5.93	6.11	1.00
N14D	Near Airport	4	6	-14.56	-3.23	-8.59	9.27	0.93
N15D	Near Airport	4	6	-10.02	-1.31	-5.75	6.45	0.92
N17C2	Near Airport	4	2	-20.62	-17.56	-19.09	19.15	1.00
PW5E	Near Airport	4	4	-9.09	-0.11	-4.62	5.61	0.98
PW6E	Near Airport	4	4	-11.60	-2.37	-6.93	7.68	0.99
RIALTO2	Near Airport	4	40	-16.56	51.77	8.33	20.80	0.53
RIALTO3	Near Airport	4	38	-17.32	55.36	12.74	22.34	0.52
1N5W34D1	Near Airport	5	18	-14.19	19.86	1.07	9.77	0.84
1S5W11F4	Middle Basin	1	18	-13.30	7.46	-4.82	8.22	0.90
EPAMP5A	Middle Basin	1	1	-9.41	-9.41	-9.41	9.41	NC
PW9A	Middle Basin	1	4	-5.24	2.98	-1.12	3.18	1.00
1S4W16P4	Middle Basin	2	19	-3.72	17.65	8.50	9.96	0.87
1S4W17R1	Middle Basin	2	19	-6.19	17.55	6.17	8.32	0.79
EPAMP2A	Middle Basin	2	1	-8.39	-8.39	-8.39	8.39	NC
1S4W18B1	Middle Basin	3	1	25.76	25.76	25.76	25.76	NC
1S4W8E4	Middle Basin	3	18	9.34	20.77	15.75	16.01	0.97
1S5W11F3	Middle Basin	3	18	-14.75	6.91	-5.97	9.19	0.89
AVG11 (1S5W13B4, 1S5W13B5)	Middle Basin	3	2	15.04	18.07	16.56	16.63	1.00
AVG15 (CPW16A, CPW16B, CPW16C)	Middle Basin	3	1	5.81	5.81	5.81	5.81	NC
AVG25 (EPAMP6A, EPAMP6B)	Middle Basin	3	1	2.61	2.61	2.61	2.61	NC
AVG50 (PW9B, PW9C)	Middle Basin	3	4	-5.97	-0.73	-3.04	3.57	0.91
AVG08 (CPW17B, CPW17C)	Middle Basin	3	1	13.87	13.87	13.87	13.87	NC
COLTON15	Middle Basin	3	12	9.55	24.59	16.57	17.22	0.92

TABLE A-4
Calibration Statistics for Groundwater Elevation Targets
Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
EPAMP1A	Middle Basin	3	1	0.16	0.16	0.16	0.17	NC
EPAMP2B	Middle Basin	3	1	-8.57	-8.57	-8.57	8.57	NC
EPAMP5B	Middle Basin	3	1	-10.41	-10.41	-10.41	10.41	NC
RIALTO7	Middle Basin	3	39	-17.47	51.39	7.65	21.51	0.45
WVWD16	Middle Basin	3	40	-11.49	34.90	8.50	13.51	0.70
1S5W11F2	Middle Basin	4	18	-23.32	-1.10	-13.30	14.79	0.90
1S5W13B3	Middle Basin	4	2	22.77	25.87	24.32	24.37	1.00
AVG10 (1S4W8E2, 1S4W8E3)	Middle Basin	4	18	10.04	22.87	17.34	17.62	0.97
AVG16 (CPW16D, CPW16E)	Middle Basin	4	1	9.13	9.13	9.13	9.13	NC
AVG18 (CPW17D, CPW17E, CPW17F, CPW17G)	Middle Basin	4	1	9.65	9.65	9.65	9.65	NC
AVG19 (EPAMP1B, EPAMP1C, EPAMP1D)	Middle Basin	4	1	0.82	0.82	0.82	0.82	NC
AVG20 (EPAMP2C, EPAMP2D, EPAMP2E)	Middle Basin	4	1	-6.70	-6.70	-6.70	6.70	NC
AVG24 (EPAMP5C, EPAMP5D, EPAMP5E)	Middle Basin	4	1	-8.92	-8.92	-8.92	8.92	NC
AVG26 (EPAMP6C, EPAMP6D, EPAMP6E)	Middle Basin	4	1	3.45	3.45	3.45	3.45	NC
AVG52 (PW9D, PW9E, PW9F, PW9G, RIALTO6)	Middle Basin	4	21	-21.23	43.51	16.13	22.77	0.38
COLTON17	Middle Basin	4	12	9.44	41.55	18.27	20.23	0.57
RIALTO4	Middle Basin	4	40	-29.41	48.89	4.78	21.98	0.57
RIALTO5	Middle Basin	4	16	-12.76	15.66	-2.64	7.31	0.93
WVWD11	Middle Basin	4	40	-19.54	35.04	6.35	15.92	0.68
WVWD17	Middle Basin	4	37	-90.37	40.55	11.30	24.33	0.27
WVWD33	Middle Basin	4	19	-17.17	7.70	-4.18	8.83	0.89
1S4W8E1	Middle Basin	5	18	8.80	20.73	15.30	15.57	0.97
1S5W11F1	Middle Basin	5	18	8.28	44.36	26.92	29.82	0.81
1S5W13B2	Middle Basin	5	2	7.75	10.82	9.29	9.41	1.00

TABLE A-4

Calibration Statistics for Groundwater Elevation Targets

Numerical Groundwater Flow Model Report, Rialto-Colton Basin

Well Name	Location Description	Model Layer	Number of Observations	Minimum Residual Error (ft)	Maximum Residual Error (ft)	Mean Error (ft)	Root Mean Squared Error (ft)	R^2
AVG17 (CPW16F, CPW16G)	Middle Basin	5	1	10.62	10.62	10.62	10.62	NC
EPAMP1E	Middle Basin	5	1	-7.31	-7.31	-7.31	7.31	NC
1S4W20H5	Lower Basin	1	17	-10.15	15.56	3.63	8.14	0.95
1S4W27M3	Lower Basin	1	4	-30.06	-15.82	-23.75	24.31	0.99
1S4W27M2	Lower Basin	2	4	-21.44	-6.95	-15.45	16.33	0.93
1S4W20H4	Lower Basin	3	17	-8.93	16.94	5.15	9.01	0.94
1S4W21N1	Lower Basin	3	11	4.75	49.18	18.45	22.45	0.36
1S4W27M1	Lower Basin	3	4	-2.07	16.83	6.06	9.17	0.55
COLTON22	Lower Basin	3	12	-13.77	125.56	42.84	56.47	0.20
COLTON23	Lower Basin	3	12	-11.36	19.31	4.59	9.25	0.80
AVG09 (1S4W20H2, 1S4W20H3)	Lower Basin	4	17	-3.51	25.98	11.42	14.16	0.86
1S4W20H1	Lower Basin	5	17	-7.00	27.52	10.05	14.01	0.81

Notes:

ft = feet
MVSL = Mid Valley Sanitary Landfill
NC = not calculated
R^2 = coefficient of determination

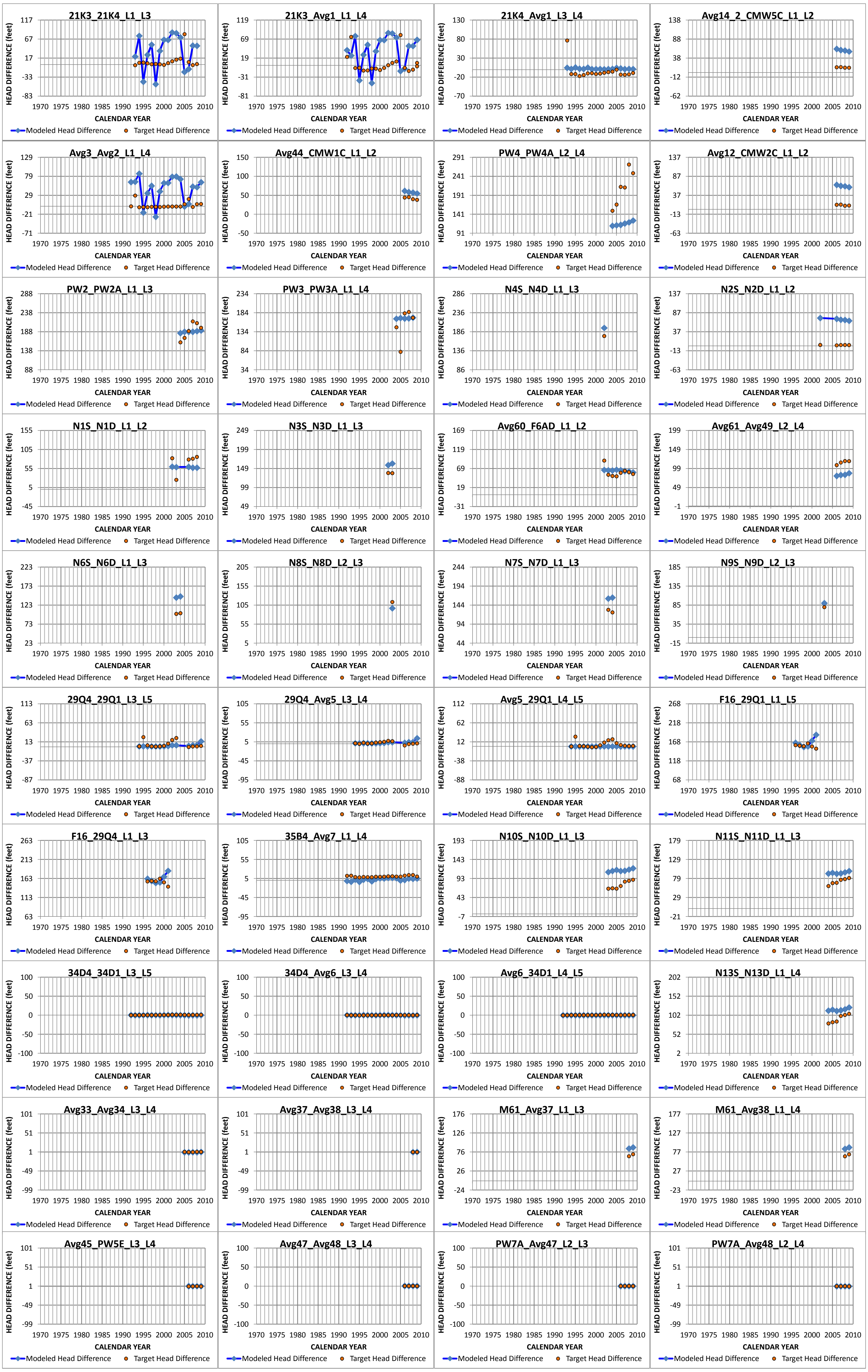


FIGURE A-1 (PAGE 1 OF 3)
MODELED AND OBSERVED
HEAD DIFFERENCE TARGETS
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

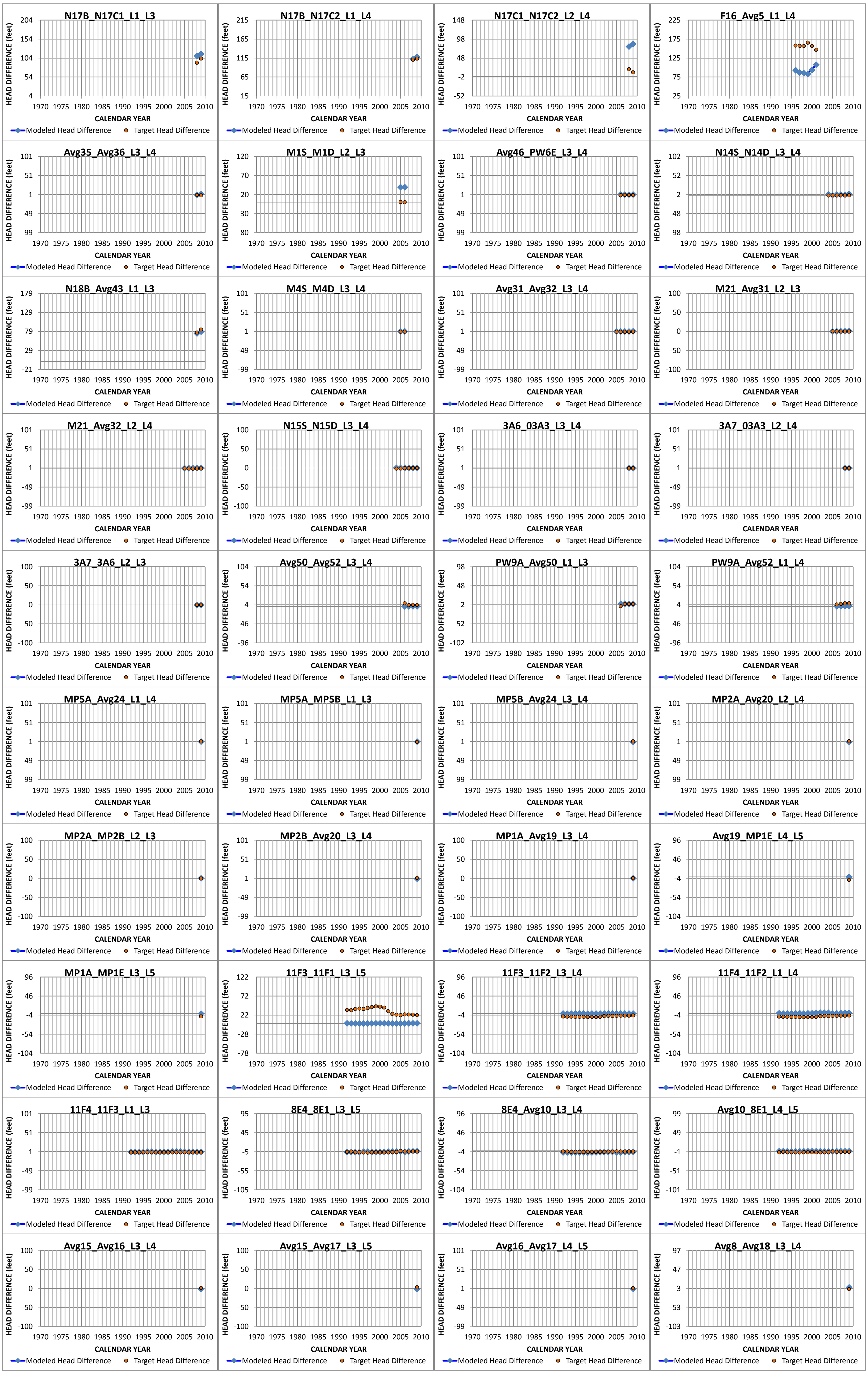
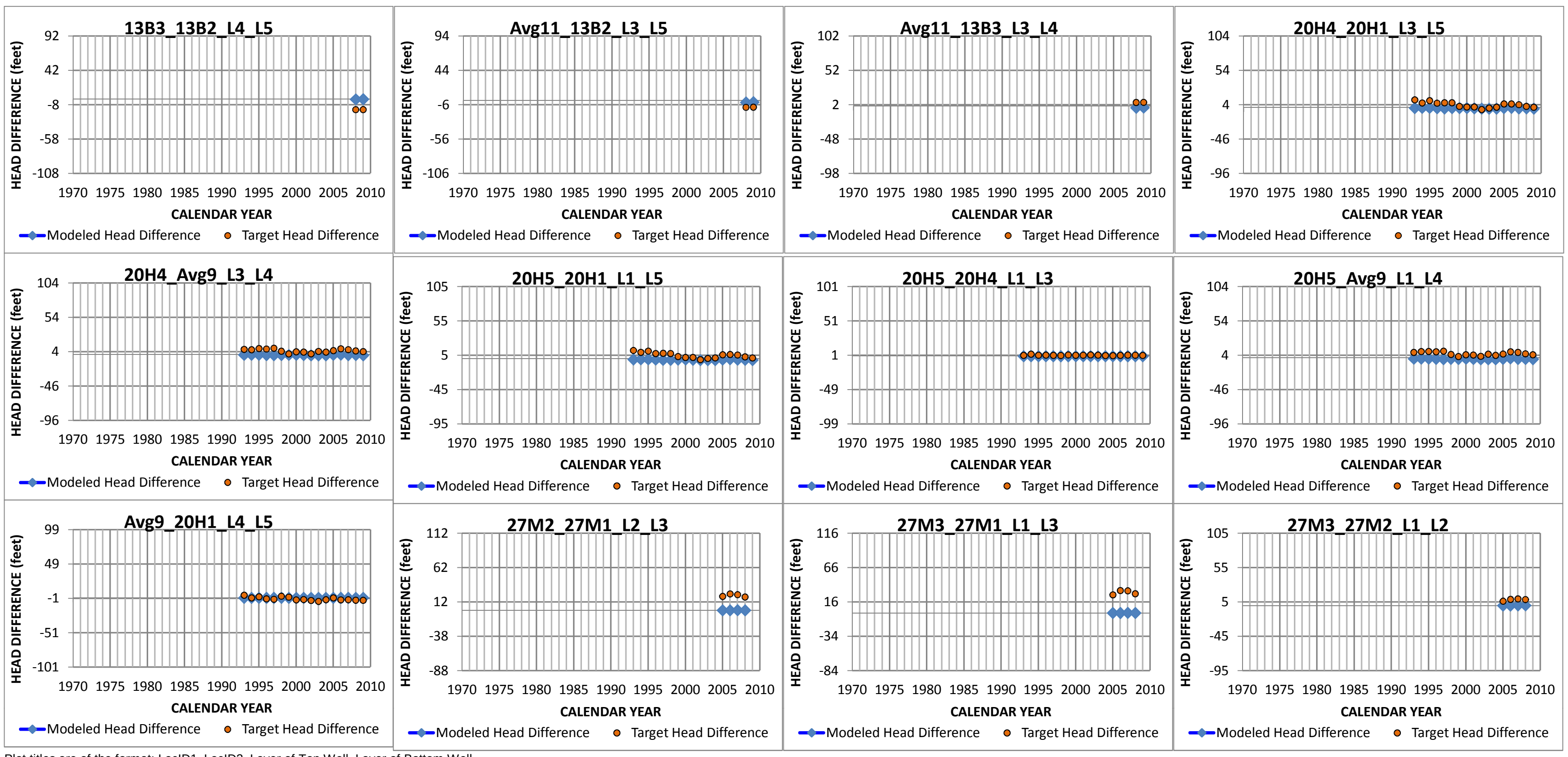


FIGURE A-1 (PAGE 2 OF 3)
MODELED AND OBSERVED
HEAD DIFFERENCE TARGETS
NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA



Plot titles are of the format: LocID1_LocID2_Layer of Top Well_Layer of Bottom Well

See Figure 4-1 for well locations. Wells denoted by state well ID on Figure 4-1 have been abbreviated on plots such that township and range identifiers have been removed.

Head difference calculated as head in upper layer minus head in bottom layer.

FIGURE A-1 (PAGE 3 OF 3)
MODELED AND OBSERVED
HEAD DIFFERENCE TARGETS

NUMERICAL GROUNDWATER FLOW MODEL REPORT
RIALTO-COLTON BASIN
SAN BERNARDINO COUNTY, CALIFORNIA

Appendix B
Groundwater Pumping Rates in the Rialto-Colton Basin during Simulation Period

TABLE B-1

Groundwater Pumping Rates from City of Colton and West Valley Water District Wells within the Rialto-Colton Basin

Rialto-Colton Basin Groundwater Flow Model

Year	ColtonEast (2 to 5)	Colton15 (3 to 4)	Colton17 (3 to 5)	Colton22 (1 to 5)	Colton23 (2 to 5)	WVWD33 (3 to 5)	WVWD10 (1 to 4)	WVWD11 (1 to 4)	WVWD16 (1 to 4)	WVWD17 (1 to 5)	WVWD22 (1 to 4)	WVWD22A (1 to 4)	WVWD23 (1)	WVWD24 (1)	WVWD54 (3 to 5)
1970	28	98	170				784	1,526	1,165				223	330	
1971	22	137	116				4	1,358	1,056				25	397	
1972	19	106	245						1,289	15			3	268	
1973	16	158	369						1,204	22			0	239	
1974	20	329	545						1,077	213			0	300	
1975	14	292	194						791	305			0	315	
1976	18	259	467						943	278			4	266	
1977	18	314	452						401	655			0	229	
1978	15	273	572						553	575			3	235	
1979	15	612	1,148						833	6			90	258	
1980	15	698	728						661	138				391	
1981	15	447	763						651	94	204			155	
1982	15	586	1,030						505	283	69			246	
1983	15	537	909						42	729	1			253	
1984	15	667	811						492	825	1			514	
1985	15	306	725	467					374	1,015	3			374	
1986	15	668	507	661					941	339	0			350	
1987		1,018	1,088	620					1,120		26			336	
1988		1,286	1,448	778				597	1,055		76			464	
1989		968	667	599				716	1,162		324			464	
1990		1,014	795	176				1,662	600		543			277	
1991		1,143	888	380	613			1,745	1,133		1			401	
1992		1,149	1,030	503	1,512			1,182	800					550	
1993		990	846	494	2,718			688	944					685	
1994		1,074	1,159	727	2,049			206	896					452	
1995		994	992	976	1,925			318	983					581	
1996		981	978	763	2,918	1,197		513	1,013					368	
1997		739	1,311	0	1,791	1,125		12	605					473	
1998		746	681	0	1,497	653		50	28					475	
1999		726	1,070	0	1,251	1,269		8	70					452	
2000		632	971	318	1,232	614			174					252	
2001		773	830	511	1,780	847			37					589	

TABLE B-1

Groundwater Pumping Rates from City of Colton and West Valley Water District Wells within the Rialto-Colton Basin

Rialto-Colton Basin Groundwater Flow Model

Year	ColtonEast (2 to 5)	Colton15 (3 to 4)	Colton17 (3 to 5)	Colton22 (1 to 5)	Colton23 (2 to 5)	WVWD33 (3 to 5)	WVWD10 (1 to 4)	WVWD11 (1 to 4)	WVWD16 (1 to 4)	WVWD17 (1 to 5)	WVWD22 (1 to 4)	WVWD22A (1 to 4)	WVWD23 (1)	WVWD24 (1)	WVWD54 (3 to 5)
2002		91	180	413	2,053	2,375			2					331	
2003		160	339	618	2,437	1,826			550			652		492	
2004		507	1,470	583	1,950	1,838			970			1,069		524	
2005		729	846	566	1,806	887			415			467		413	
2006		875	325	513	2,005	1,517			88	393		320		464	
2007		572	720	659	2,060	1,792			23					177	1,021
2008		537	1,414	328	1,684	1,315			147					494	795
2009		539	1,053	5	1,683	1,715			37					523	1,466

Notes:

Values reported in acre-feet.

Values in parentheses in column headings represent model layers over which the well is screened.

TABLE B-2

Groundwater Pumping Rates from City of Rialto and Fontana Water Company Wells within the Rialto-Colton Basin

Rialto-Colton Basin Groundwater Flow Model

Year	F10A22 (1 to 5)	F10B (4 to 5)	F10C (3 to 5)	F13A (4 to 5)	F13B (4 to 5)	F15A (2 to 5)	FU38 (2 to 3)	F49A (1 to 5)	RIALTO1 (4)	RIALTO2 (3 to 5)	RIALTO3 (3 to 4)	RIALTO4 (3 to 4)	RIALTO5 (1 to 4)	RIALTO6 (3 to 4)	RIALTO7 (1 to 4)
1970	674								993	84		1,046			
1971	871								1,105	167		1,092			
1972	868								1,508	332		966			182
1973	292								878	805	440	694			182
1974	88								1,223	378	494	736			12
1975	550								1,279	326	364	775			677
1976	815								1,167	573	440	739			121
1977	382								767	105	330	434			199
1978	439								1,119	283	254	589			182
1979	105								208	249	41	541			0
1980	416								701	281	0	503			0
1981	951								168	729	98	902			169
1982	549								74	348	2	571			147
1983	85								338	380	24	535			2
1984	1,216								494	1,253	104	319			1
1985	1,219								489	1,130	13	226			11
1986	460								800	713	97	659			762
1987	1,060								925	1,626	148	1,186			1,182
1988	1,227								1,314	996	94	1,080			348
1989	1,083								1,648	1,477	98	1,500			467
1990	1,426								1,198	1,656	1,146	1,120		69	645
1991	837								220	414	101	399		299	6
1992	1,061			2,615			53		1,328	1,539	479	70		672	14
1993	1,447			2,320			0		676	1,153	463	424		23	2
1994	1,261			2,171			0		425	840	674	279		488	
1995	1,032	1,203		1,504			607		701	962	1,419	317	202	946	
1996	931	2,207		1,683			588		682	1,130	1,270	79	443	894	
1997	172	732		1,840			756		1,260	1,157	944	142	355	1,350	
1998				2,226			665		2,152		1,572	179	346	77	
1999				2,286			649		1,473		1,595	481	35	674	
2000	1,019	1,270		2,654		898			1,882		921	805	8	457	
2001		3,123		2,137	2,577	1,391			1,658		1,185	1,486	247	7	
2002		2,609	526	2,152	3,463	1,385		2,450	2,416		1,025	994	883	2	
2003		1,790	1,993	2,168	2,279	2,120		2,753	1,699		1,307	137	1,255		
2004		2,195	1,735	1,877	2,062	1,448		2,786	790		830	1	1,247		
2005		2,016	1,534	1,455	1,676	994		3,127	690		1	1	902		

TABLE B-2

Groundwater Pumping Rates from City of Rialto and Fontana Water Company Wells within the Rialto-Colton Basin

Rialto-Colton Basin Groundwater Flow Model

Year	F10A22 (1 to 5)	F10B (4 to 5)	F10C (3 to 5)	F13A (4 to 5)	F13B (4 to 5)	F15A (2 to 5)	FU38 (2 to 3)	F49A (1 to 5)	RIALTO1 (4)	RIALTO2 (3 to 5)	RIALTO3 (3 to 4)	RIALTO4 (3 to 4)	RIALTO5 (1 to 4)	RIALTO6 (3 to 4)	RIALTO7 (1 to 4)
2006		1,897	1,786	736	1,058	719		3,183	1		623	1	324		
2007		2,282	1,648	1,533	1,602	1,090		3,100	1		756		1,018		
2008		1,974	2,191	768	1,617	1,184		2,743			621		1,731		
2009		1,730	2,562	1,828	1,990	1,608		3,054			1,739		1,480		

Notes:

Values reported in acre-feet.

Values in parentheses in column headings represent model layers over which the well is screened.