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26 July 2013

Via Electronic Mail

Mr. Wayne Praskins
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Subject: Final Groundwater Flow Modeling Report
Source Area Operable Unit, B.F. Goodrich Superfund Site

Dear Mr. Praskins:

On behalf of Emhart Industries, Inc. (Emhart), ERM-West, Inc. (ERM) submits this Final Groundwater Flow Modeling Report for the Source Area Operable Unit at the B.F. Goodrich Superfund Site. This Groundwater Flow Modeling Report was modified based on comments provided by U.S. Environmental Protection Agency (USEPA) on the draft document, Emhart's responses, and USEPA's approval of the responses. This work is associated with implementing the remedial actions described within the *Statement of Work for Remedial Design and Remedial Action for the Source Area Operable Unit, B.F. Goodrich Superfund Site*, which is Appendix F to the Consent Decree that was lodged on 4 December 2012 with the United States District Court for the Central District of California in *City of Colton v. American Promotional Events, Inc. West et al.*, Case No. ED CV 09-01864 PSG.

If you have any questions or concerns, please contact Mr. Truong Mai at (949) 623-4700 or Ms. Heather Balfour at (916) 924-9378.

Sincerely,

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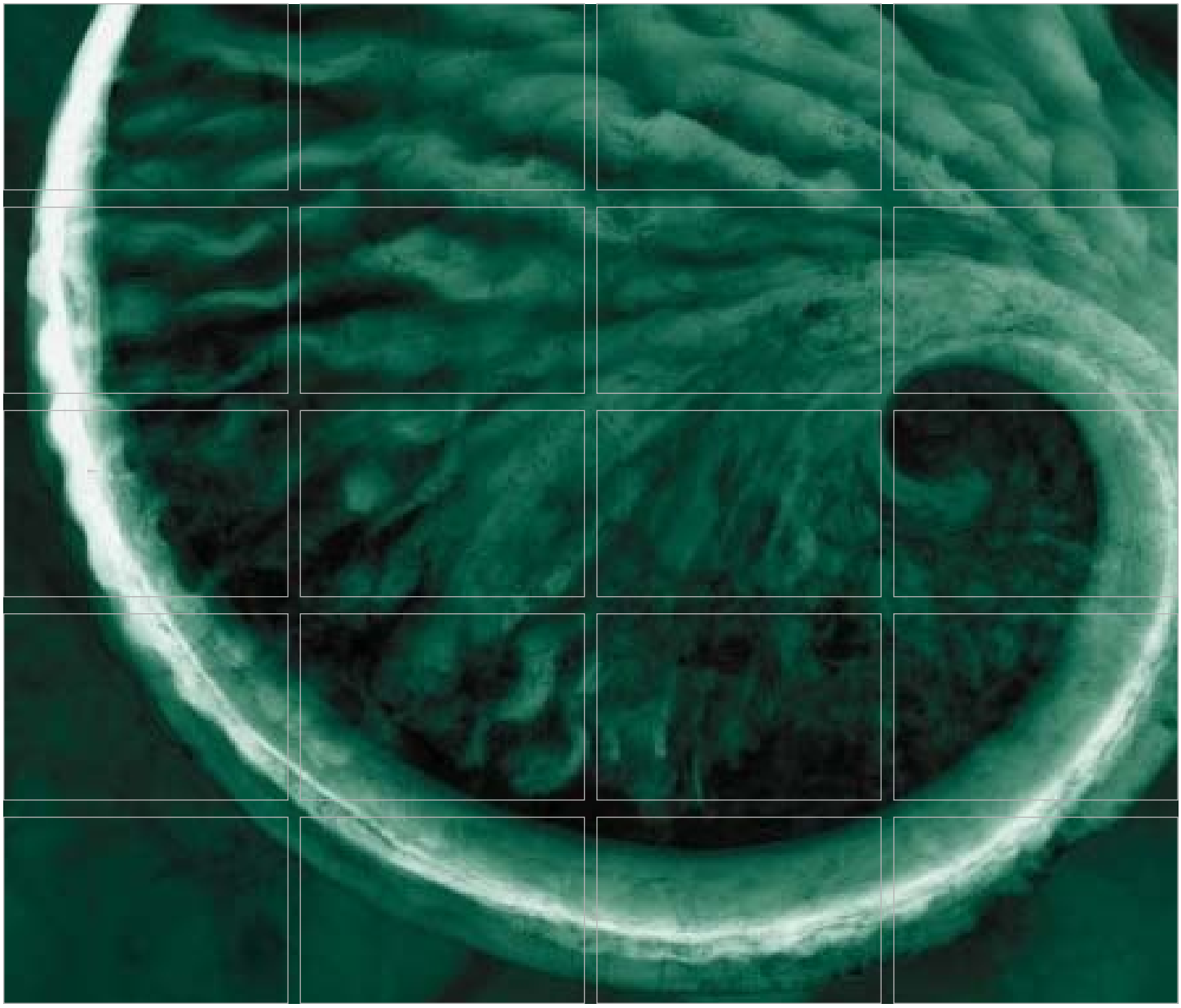

Groundwater Flow Modeling Report

Source Area Operable Unit
B.F. Goodrich Superfund Site
EPA ID: CAN000905945

Prepared for:
Emhart Industries, Inc.

July 2013

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Groundwater Flow Modeling Report

Source Area Operable Unit
B. F. Goodrich Superfund Site
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July 2013

Project No. 0179962

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LIST OF ACRONYMS

°F	Degrees Fahrenheit
AF/yr	Acre-feet per year
amsl	Above mean sea level
AOI	Area of Interest
ASTM	American Society for Testing and Materials
bgs	Below ground surface
ERM	ERM-West, Inc.
FS	Feasibility Study
ft	Feet
GHB	General head boundary
GLA	GeoLogic Associates
gpm	Gallons per minute
HFB	Horizontal-Flow Barrier
in/yr	Inches per year
RABSP	Rialto Ammunition Backup Storage Point
RAO	Remedial Action Objectives
RCB	Rialto-Colton Groundwater Basin
RI	Remedial Investigation
ROD	Record of Decision
RWQCB	Regional Water Quality Board
SAOU	Source Area Operable Unit
SOW	Statement of Work
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile organic compound
WVWD	West Valley Water District

1.0 INTRODUCTION

On behalf of Emhart Industries, Inc. (Emhart), ERM-West, Inc. (ERM) prepared this Groundwater Flow Modeling Report (Modeling Report) to provide a tool to support the selection and design of the remedy components necessary to implement the 2010 Record of Decision (ROD). ERM collaborated with ENVIRON International Corporation (ENVIRON) to complete the modeling effort. This Modeling Report for the Source Area Operable Unit (SAOU) at the B. F. Goodrich Superfund Site (site) has been prepared in accordance with the *Statement of Work for Remedial Design and Remedial Action for the Source Area Operable Unit, B.F. Goodrich Superfund Site* (SOW), which is Attachment F to the Work Consent Decree that was lodged on 4 December 2012, with the U.S. District Court for the Central District of California in *City of Colton v. American Promotional Events, Inc. West, et al.*, Case No. ED CV 09-01864 PSG, (Work Consent Decree). This Modeling Report describes the process undertaken to prepare and calibrate the model, the alternative well locations and pump rate scenarios evaluated, and the recommended alternative selected for the remedial design required under the Work Consent Decree (the "Work"), which includes sequential installation of two new extraction wells in combination with the existing extraction wells to achieve the Remedial Action Objectives (RAOs).

1.1 SITE LOCATION

The site is located in San Bernardino County, California, approximately 50 miles east of downtown Los Angeles. The site includes a 160-acre parcel and immediate vicinity (160-acre area) in Rialto, California (Figure 1-1) where volatile organic compounds (VOCs) and perchlorate have impacted soil and groundwater, and all areas where contamination from the 160-acre area has come to be located, including groundwater contamination downgradient of the 160-acre area.

1.2 OBJECTIVES OF GROUNDWATER FLOW MODEL

The objective of the groundwater flow model (the Emhart Model) is to inform remedial design decision-making including the selection of groundwater extraction rates and location(s) needed to achieve the RAOs for the SAOU set forth in Section 3.1 of the SOW. The RAOs are to protect

water supply wells and groundwater resources downgradient of a target area, described in Section 2.4.8 of the 2010 ROD and Section 2.2 of the SOW (Target Area) (see Section 5.1.4 of this Modeling Report, below), by limiting the spread of contaminated groundwater from the 160-acre area and removing contaminants from groundwater in the Target Area.

As required by Section 4.1.3 of the SOW, the Emhart Model:

- was calibrated over a wide-range of hydrogeologic conditions;
- is capable of simulating transient conditions in three dimensions;
- is capable of conducting particle tracking simulations to evaluate hydraulic control; and
- was developed with consideration of the United States Environmental Protection Agency's (USEPA) guidance set forth in *A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems* [USEPA, 2008]).

1.3 REPORT ORGANIZATION

Following this introductory section, the document is organized as follows:

- Section 2.0 summarizes the hydrogeologic setting;
- Section 3.0 describes the design of the Emhart Model;
- Section 4.0 describes the calibration of the Emhart Model;
- Section 5.0 describes predictive simulations conducted with the Emhart Model;
- Section 6.0 provides a summary, conclusions, and recommendations; and
- Section 7.0 includes a list of references.

Figures, tables, and appendices follow the text.

This Groundwater Flow Modeling Report was modified based on comments provided by USEPA on the draft document. Revisions include changes in the text, figures, tables, and appendices. USEPA's comments and Emhart's responses associated with this report are provided in Appendix F.

2.0 *HYDROGEOLOGICAL SETTING*

The hydrogeology of the Rialto-Colton Groundwater Basin (RCB) has been presented in detail in previous studies (Dutcher and Garrett, 1963; U.S. Geological Survey (USGS), 1997; USGS, 2001; CH2M HILL, 2010; CH2M HILL, 2012; GeoLogic Associates [GLA], 2007; GLA, 2010; Paulinski, 2012) and is summarized below.

2.1 *GEOGRAPHIC SETTING*

The RCB is located in western San Bernardino County approximately 50 miles east of downtown Los Angeles (Figure 1-1). The RCB is a northwest-southeast trending alluvial basin approximately 10 miles long and varies in width from about 3.5 miles in the northwest to about 1.5 miles in the southeast. The RCB is bounded by the San Jacinto Fault on the northeast, the Rialto-Colton Fault on the southwest, the San Gabriel Mountains to the northwest, and the Badlands to the southeast. Elevations range from approximately 2,000 feet above mean sea level (amsl) in the northwest to approximately 950 feet amsl in the southeast. The Santa Ana River crosses the southeastern end of the RCB in the vicinity of U.S. Interstate 10.

2.2 *CLIMATE*

The Rialto area has a semiarid climate characterized by hot, dry summers and mild winters with limited precipitation. The average annual rainfall is approximately 16.45 inches (USGS, 1997). Most of this rainfall occurs from December to April with February being the wettest month on average. The average summertime high temperature is 95 degrees Fahrenheit (°F) and occurs in July to September and the average wintertime low temperature is 42°F and occurs in December to January.

2.3 *LAND USE*

Prior to the 1940s, developed land uses in the RCB consisted mainly of agriculture. Between 1942 and 1946, the U.S. Army owned and occupied a 2,800-acre site in the northern part of the RCB, known as the Rialto Ammunition Backup Storage Point (RABSP), which was used as an

inspection, consolidation, and storage facility for rail cars transporting ordnance to the Port of Los Angeles for shipment to the Pacific Theatre during World War II. Urban development increased following World War II and, currently, approximately two-thirds of the RCB consists of residential, commercial, and industrial land use.

2.4 *GEOLOGY*

The geology consists of unconsolidated deposits of sand, gravel, and coarser materials interbedded with silts and clays. These unconsolidated sediments are underlain by partially consolidated and consolidated sediments, which are in turn underlain by basement complex granitic and metamorphic rocks that crop out in the San Gabriel Mountains to the north.

The RCB is fault-bounded to the northeast and southwest by the San Jacinto and Rialto-Colton Faults. Other faults that intersect the RCB include the Unnamed Fault, Barrier E, Barrier H, and Barrier J. The deepest portion of the basin is the northeastern area between the San Jacinto Fault Zone and a parallel unnamed fault; the total sediment thickness in this area ranges between 2,500 feet and 5,000 feet. The remainder of the RCB is approximately 500 to 1,000 feet deep.

2.5 *HYDROGEOLOGY*

2.5.1 *Surface Water*

The Santa Ana River is the primary surface water feature and the largest source of surface water inflow to the RCB (Figure 1-1). The river crosses the southern end of the RCB near the confluences of Lytle Creek and Warm Creek. The Santa Ana River flows into the RCB from Bunker Hill Basin along with Warm Creek.

2.5.2 *Groundwater*

Based on the results of investigation and groundwater modeling undertaken by Emhart to develop the Emhart Model, the USEPA's development of the SAOU, the County of San Bernardino's (County) development of its remedy to address releases emanating from and near the area proposed to be used for the future Unit 5 of the Mid-Valley Sanitary Landfill (County Remedy Area), and other historical

investigations of the RCB, the following three laterally continuous water-bearing hydrogeologic units have been defined:

1. Upper Aquifer - From 1996-1998, the Upper Aquifer had a saturated thickness of about 15 to 35 feet. However, the current regional drought has resulted in the unit's dewatering (GLA, 2012).
2. Intermediate Aquifer – The Intermediate Aquifer is first encountered at a depth of approximately 400 to 450 feet below ground surface (bgs). It is unconfined, with thickness of approximately 40 to 140 feet, and is underlain by the laterally extensive BC Aquitard that is approximately 100 feet thick under the 160-acre area.
3. Regional Aquifer – The Regional Aquifer is generally unconfined to partly confined, and is approximately 300 to 500 feet thick.

Under the 160-acre area, the 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. Downgradient of the 160-acre area, the BC Aquitard thins to the southeast and appears to end north/upgradient of EPA-MW9 (Figure 2-1). Southeast of the terminus of the BC Aquitard, the Intermediate and Regional Aquifers merge into one aquifer.

Groundwater elevations and flow rates in the RCB vary spatially, seasonally, and year-to-year. In the southeastern part of the basin, in the river-channel deposits and upper water-bearing unit, groundwater generally flows from northeast to southwest. For most of the RCB, groundwater in both the Intermediate and Regional Aquifers generally flows to the southeast, parallel to the Rialto-Colton and San Jacinto Faults. The cause of the seasonal and year-to-year variability is year-to-year change in precipitation and associated recharge, and seasonal and year-to-year variability in groundwater pumping.

The principal recharge components of the basin have been identified as underflows from Lytle Creek Basin and run-off/inflows from the San Gabriel Mountains in the northwestern part of the basin and the Bunker Hill Basin underflows in the southeastern part of the basin (USGS, 1997). Smaller components of recharge to the basin have also come from irrigation return flow and urban recharge pathways (USGS, 2001) and from the Badlands in younger Santa Ana River deposits at the southern end of the basin (Dutcher and Garrett, 1958; USGS, 2001). The average inflows from Lytle Creek Basin, the Bunker Hill Basin, the San Gabriel Mountains, and the Badlands to RCB for the purposes of current modeling study are described in Section 3.7.3 of this report.

Groundwater recharge from precipitation falling directly on the basins in this semiarid region is likely to be minimal (Danskin et al., 2006). The RCB has an average precipitation of about 16.45 inches measured in San Bernardino for the period of 1871-1998 (USGS, 2001). Most precipitation is evaporated or transpired before it can infiltrate or run-off (Danskin et al., 2006). Also typical of a semiarid basin, many storms have short duration and high intensity, which means these events are less affected by evapotranspiration and may produce some run-off (Danskin et al., 2006). Limited direct recharge from precipitation occurs only in exceptionally wet years (Danskin et al., 2006).

The principal sources of discharge from the RCB are evapotranspiration groundwater extraction by water purveyors, and outflow to the Riverside Basin, as described in Section 3.7.4.2 of this document.

3.0 MODEL DESIGN

3.1 MODEL DEVELOPMENT BACKGROUND

Many groundwater flow models have been developed and documented for the RCB. The subsections below describe four relevant groundwater flow models that have been developed and documented.

3.1.1 USGS Model

The earliest model, developed by the USGS, is described in *Numerical Simulation of Ground-Water Flow and Assessment of the Effects of Artificial Recharge in the RCB, San Bernardino County, California* (USGS, 2001) (USGS Model). The USGS Model was prepared to better understand the groundwater flow system and evaluate the hydraulic effects of artificial recharge of imported water in the RCB.

The USGS Model domain extends throughout the RCB. The unconsolidated sediments in the basin were represented as four horizontal layers of varying thickness designated by the USGS as the river-channel deposits and the upper, middle, and lower water-bearing units. The Unnamed Fault, Barrier J, and Barrier H were represented as barriers that restrict the flow of groundwater.

The USGS used the groundwater modeling software MODFLOW. In the horizontal dimension, uniform square cells of side length 820 feet were used throughout the model domain. Annual stress periods were used. The USGS Model was calibrated using water-level data from the period of 1945-1996, and used to perform predictive recharge simulations for the period of 1997-2027.

3.1.2 County Model

In response to Regional Water Quality Control Board (RWQCB) Order R8-2003-0013, as amended by Order R8-2004-0072, between 2006 and 2011 GLA, on behalf of the County of San Bernardino, developed a groundwater flow and contaminant transport model of the upper RCB (County Model). The purpose of the County Model was to evaluate flow and transport conditions and containment strategies to address groundwater impacts originating from the County Remedy Area. The

County Model was first described in GLA's 2007 report (GLA, 2007), with model updates presented in subsequent reports (GLA, 2010; GLA, 2011).

The County Model domain covers the upper portion of RCB, extending from Barrier J to the vicinity of the Rialto Municipal Airport, an area of approximately 17.7 square miles. Initially, four layers of varying thickness were used to represent the Upper and Intermediate Aquifers (Layer 1), the BC Aquitard (Layer 2), and the Regional Aquifer (Layers 3 and 4). In the 2011 update of the model, the Regional Aquifer was further subdivided so that the current version of the County Model has seven layers, with Layers 3 through 7 representing the Regional Aquifer. The Unnamed Fault and Barrier H were represented as barriers that restrict the flow of groundwater.

The County Model used the following modeling software:

- MODFLOW was used to simulate groundwater flow. In the horizontal dimension, uniform square cells of side length 200 feet were used throughout the County Model domain. Annual stress periods were used. Calibration statistics are reported for water-level data from 1998 and 2004; and
- MT3DMS was used to simulate contaminant transport. Contaminant transport model calibration statistics are reported for perchlorate data from the period of 2002-2004.

For purposes of evaluating future flow and transport conditions and containment strategies, the County used its model to perform predictive simulations for the period of 2011-2020.

3.1.3 USEPA Models (2010 and 2012)

The USEPA adapted the County Model during preparation of the Remedial Investigation/Feasibility Study (RI/FS) and 2010 ROD to evaluate the extent to which the extraction of contaminated groundwater near the Target Area would satisfy the RAOs for the SAOU. This model is described in the *Remedial Investigation/Feasibility Study Report* (CH2M HILL, 2010) (USEPA 2010 Model).

The USEPA 2010 Model used the groundwater flow modeling software MicroFEM instead of MODFLOW. The USEPA 2010 Model modified the County Model by adjusting the hydraulic conductivity near Rialto-3 and, the location of Barrier H, aligning the model boundaries with faults, and increasing the spatial resolution at flow barriers.

The USEPA 2010 Model was not recalibrated because of its reliance on the calibrated County Model.

In 2012, USEPA developed a second groundwater flow model, described in *Numerical Groundwater Flow Model Report, Rialto-Colton Basin* (CH2M HILL, 2012) and a PowerPoint presentation dated 9 July 2012 (USEPA 2012 Model). The USEPA 2012 Model was developed to:

- Better understand groundwater flow in the RCB and its variability through time;
- Simulate basin-scale changes in groundwater conditions that occurred from 1970 through 2009;
- Aid in the planning and implementation of the SAOU remedial design;
- Support evaluation of alternatives for the planned FS for the lower RCB;
- Aid in developing the proposed cleanup plans and RODs;
- Aid in identifying data gaps; and
- Forecast locations of new extraction wells and pumping rates necessary to provide adequate capture of the SAOU Target Area.

The USEPA 2012 Model domain extends throughout the RCB. Five layers of varying thickness were used to represent the RCB. In the upper portion of the basin, the five layers represent the Intermediate Aquifer (Layer 1), the BC Aquitard (Layer 2), the Upper Regional Aquifer (Layer 3), the Lower Regional Aquifer (Layer 4), and the Consolidated Deposits (Layer 5). In the lower portion of the RCB, the five layers represent the river-channel deposits (Layer 1), the upper water-bearing unit (Layer 2), the middle water-bearing unit (Layer 3), the lower water-bearing unit (Layer 4), and the consolidated deposits (Layer 5). The Unnamed Fault, Barrier J, and Barrier H were represented as barriers that restrict the flow of groundwater.

The groundwater modeling software MODFLOW-SURFACT was used. In the horizontal dimension, square cells of side lengths ranging from 205 feet to 820 feet were used throughout the model domain, with refinement of the grid in the vicinity of the SAOU. The USEPA 2012 Model was calibrated using water-level data from the period of 1970-2009. The USEPA used its 2012 Model to perform predictive simulations for the period of 2010-2048.

3.1.4 *Emhart Model*

The Emhart Model is an update of the USEPA 2012 Model. Emhart updated the USEPA 2012 Model by integrating data and information from the relevant stakeholders through the model development process. The stakeholders include: USEPA, California Department of Public Health, City of Rialto, City of Colton, San Bernardino County, San Bernardino Valley Municipal Water District, West Valley Water District, Fontana Water Company, and USGS. Coordination with the stakeholders included:

- Groundwater flow modeling kick-off meeting on 31 October 2012;
- Project status update conference calls every 2 weeks (13 November 2012 through 19 March 2013);
- Email and telephone communication with stakeholders regarding data;
- Memorandum (dated 15 February 2013) documenting information obtained from stakeholders and analysis of groundwater and contaminant distribution data (Appendix A); and
- Memorandum (dated 28 February 2013) summarizing model calibration including a list of significant differences from USEPA 2012 Model (Appendix A).

Additional details on the data gathered for development of the Emhart Model are described more fully in later sections of this report. See also Table 1 of the 19 March 2013 presentation materials to the stakeholders (included in Appendix A), which sets forth assumptions used in the Emhart Model that differ from those used in the USGS Model, County Model, and USEPA 2012 Model.

The Emhart Model was designed and calibrated in accordance with the American Society for Testing and Materials (ASTM) guidelines for groundwater modeling (ASTM, 1996), and generally accepted industry practice (Anderson and Woessner, 1992).

3.2 *MODEL CODE SELECTION*

The model code used to develop the Emhart Model is MODFLOW-SURFACT, a three-dimensional, finite-difference, groundwater flow model developed by Hydrogeologic, Inc. (1996). MODFLOW-SURFACT is an enhanced version of MODFLOW, a three-dimensional groundwater

flow model code developed by the USGS (McDonald and Harbaugh, 1988).

MODFLOW-SURFACT simulation software was selected because it possesses the necessary capabilities for development of the groundwater flow model and model simulations. The MODFLOW-SURFACT model code is capable of: simulating a complex, three-dimensional groundwater flow system; handling drying and re-wetting of grid-blocks as the water table fluctuates; and incorporating well flow for wells screened in multiple units. The model code is also well documented, widely used, verified for a wide range of field conditions, and widely accepted by the environmental industry, and state and federal regulatory agencies.

3.3 MODEL DOMAIN AND GRID

The model domain (Figure 3-1) encompasses the site and covers an area of approximately 31 square miles. The extent of the model domain is consistent with the USEPA 2012 Model, except for a small area in the vicinity of Barrier H, where grid refinement results in minor differences in the extent of the model domain. The numerical model domain is bounded on the northeast by Barrier E and the San Jacinto Fault, on the northwest by the San Gabriel Mountains, along the southwest by the Rialto-Colton Fault, and in the south by the Badlands.

In a numerical groundwater model, the continuous groundwater flow field is approximated by a discretized domain consisting of an array of grid nodes and associated grid blocks. This nodal grid forms the framework of the numerical model. MODFLOW-SURFACT uses a block-centered, finite-difference grid to simulate a continuous groundwater flow field (McDonald and Harbaugh 1988; Hydrogeologic, Inc. 1996). With this method, the grid blocks are rectangular in shape and the grid nodes are located at the center of the grid blocks.

The horizontal and vertical coordinate systems used by the Emhart Model are California State Plane V and National Geodetic Vertical Datum (NGVD88). The model grid is rotated and oriented north 45 degrees west, approximately parallel to the direction of groundwater flow in the vicinity of the site. The model grid-block resolution varies from 205 to 820 feet (Figure 3-1). Grid resolution is finest in the vicinity of the SAOU, extending from west of the Unnamed Fault to the western boundary of the model, and from Barrier J to approximately 6 miles downgradient of Barrier J. Coarser grid blocks are used outside this area (Figure 3-1). This

approach allows for higher resolution in the area of interest (AOI), which is the primary focus of the modeling effort, as depicted on Figure 3-1, while minimizing computational run-times.

3.4 *MODEL GRID LAYERS*

The groundwater flow system is represented in the Emhart Model by five layers. Table 3-1 lists the model layer designations and thicknesses; Figure 3-2 shows a cross-sectional schematic of the model from northwest to southeast. Model layers are described as follows:

- Layer 1 – Intermediate Aquifer and river-channel deposits;
- Layer 2 – BC Aquitard and upper water-bearing unit;
- Layer 3 – Upper Regional Aquifer and middle water-bearing unit;
- Layer 4 – Lower Regional Aquifer and lower water-bearing unit; and
- Layer 5 – A portion of the consolidated deposits.

Figure 3-3 shows the modeled surface elevation, which is set to the ground surface as defined in the USEPA 2012 Model. Figure 3-4 shows the model layer bottom elevations in the Emhart Model. The model layering is generally based on geologic interpretations within the County Model in the northwest portion of the SAOU (GLA, 2007) and the USGS Model in the southeast, in an area not covered by County Model. Consistent with the USEPA 2012 Model, the model incorporates an additional layer (Model Layer 5) that represents a portion of the consolidated deposits. Model Layer 5 is set to a constant thickness of 300 feet (CH2M HILL, 2012). Model Layer 3 was adjusted in the area beneath the BC Aquitard based on review of the County Model (GLA, 2010) and well boring logs. Model Layer 4 was adjusted based on review of well borings logs.

3.5 *MODEL CALIBRATION PERIOD*

The model was calibrated using groundwater level data from 1970 through 2011 (calendar years). The calibration period is similar to the USEPA 2012 Model, which estimates groundwater levels from 1970 through 2009. The calibration period was established in order to evaluate long-term groundwater trends and is based on available data used to construct and calibrate the model.

The Emhart Model was discretized into quarterly stress periods. Boundary conditions in the model were averaged and varied on a quarterly basis during the 42-year calibration period. Discretization to quarterly stress periods was implemented to improve the Emhart Model's ability to simulate seasonal variability of the RCB and to allow it to simulate variability of pumping rates and basin behavior.

3.6 INITIAL GROUNDWATER LEVELS

The model requires an initial head at each active cell within the model domain. Initial heads were assigned to each active cell within the model domain at the beginning of the model calibration period. Initial heads from the USEPA 2012 Model were used as the basis for initial heads in the Emhart Model. Figure 3-5 shows the initial groundwater elevations in the model for 1970.

3.7 MODELED BOUNDARY CONDITIONS

The following flow boundary conditions are used in the Emhart Model (Figure 3-6):

- Upper boundary of model grid – free-surface (water table) boundary;
- No-flow boundaries - Lateral margins of model grid in the northeast, the southeast, and the south; and lower boundary of model grid;
- Specified flux boundaries including:
  - Underflow from Lytle Creek Basin and Bunker Hill Basin;
  - Run-off and inflows from San Gabriel Mountains and Badlands;
  - Recharge from Linden Ponds; and
  - Flow out of the model due to groundwater pumping.
- Head-dependent boundary conditions - evapotranspiration; subsurface flow at the southwestern end of the model (Riverside Basin); and Santa Ana River and Warm Creek; and
- Recharge from precipitation and return flow recharge.

3.7.1 *Upper Boundary of the Model Grid*

The upper boundary of the model grid is a free-surface boundary representing the water table. The elevation of this boundary is calculated by MODFLOW-SURFACT during the course of the model simulation (McDonald and Harbaugh 1988; Hydrogeologic, Inc. 1996).

3.7.2 *No-Flow Boundaries*

The RCB extends from the San Gabriel Mountains in the north to the Badlands in the south. The basin is bounded eastern side by the San Jacinto Fault Zone and Barrier E; the basin is bounded on the western side by the Rialto-Colton Fault. Only a negligible amount of groundwater is assumed to flow across these faults, and, therefore, a no-flow boundary is assigned.

The lower boundary of the model grid is a no-flow boundary (Layer 5). Vertical groundwater flow from the consolidated deposits downward is assumed to be insignificant.

3.7.3 *Specified Flux Boundary Conditions*

A specified flux or the Neumann boundary conditions in the RCB are inflows from the surface water bodies and aquifers in adjacent basins and outflows from pumping wells.

For modeling purposes, the specified flux boundaries are simulated in the model as injection wells with positive discharge. Specified flux boundaries are used to simulate baseflow from the Lytle Creek Basin, underflows from Bunker Hill Basin, run-off and inflows from the San Gabriel Mountains, artificial recharge through Linden Pond, and inflow from the Badlands. Pumping wells are simulated as extraction wells with negative discharge.

3.7.3.1 *Underflows from the Lytle Creek Basin*

A specified flux boundary is used to represent underflows from the Lytle Creek Basin on the east side of the Unnamed Fault in Layers 1, 2, and 3 of the model as shown on Figure 3-6. The total flow is distributed among 61 cells on the eastern boundary of the model domain. Of the 61 cells, 8 model cells are above Barrier J and 53 cells are below Barrier J. The total inflow is distributed both above and below Barrier J in the ratio of 60:40, except for Layer 2, where no inflow is assigned below Barrier J. Layer 2

below Barrier J in the vicinity of the Lytle Creek Basin boundary represents the BC Aquitard; hence it is assumed that none of the Lytle Creek Basin underflow enters via Layer 2.

For purposes of calculating the Lytle Creek Basin underflow, the approach adopted in the USGS Model was used. In this approach, underflow volumes were estimated by multiplying measured discharge in the Lytle Creek Basin (USGS gauging station number 11062001) by a specified percentage. In the calibrated Emhart Model, the quarterly streamflow was multiplied by 50 percent for most quarters. For quarters where the annual streamflow discharge was more than 80th percentile above the annual mean discharge, the streamflow discharge was multiplied by 15 percent.

The daily streamflow data for USGS gauging station number 11062001 were downloaded from the USGS website for the period of 1970 through 2011. Station 11062001 is not a physical recording gage; it combines the flow from three different stations: Lytle Creek (station 11062000), Southern California Edison Co.'s Lytle Creek Conduit (station 11060900), and Fontana Water Co.'s Infiltration Line Diversion (station 11061000). The daily mean discharge is calculated as the sum of the three contributing stations. The quarterly streamflow data and calibrated values of underflows in Layers 1, 2, and 3 distributed between above and below Barrier J are presented in Appendix B (Table B-1).

3.7.3.2 Underflows from the Bunker Hill Basin

A specified flux boundary is used to represent underflows from the Bunker Hill Basin assigned to 10 model cells in Layers 1 and 2 near the Santa Ana River. The total underflow is distributed in the 80:20 ratio between Layers 1 and 2. Within each layer, the flux is distributed equally among 10 model grid cells. The specified flux boundary across the Bunker Hill Basin is shown on Figure 3-6.

The daily streamflow data for USGS gauging station number 11059300 were downloaded from the USGS website for the period of 1970 through 2011. The annual underflow volumes for the time period 1970 through 2009 are taken directly from USEPA 2012 Model and are distributed quarterly based on streamflow discharge volumes. For the years 2010 and 2011, the underflow volumes are estimated as 35 percent of the streamflow discharge. This is consistent with the method used in the USGS Model.

The quarterly streamflow data and underflow volumes are presented in Appendix B (Table B-2).

3.7.3.3 *Run-off and Inflows from the San Gabriel Mountains*

A specified flux boundary is used to represent run-off and inflows from the San Gabriel Mountains on the northern boundary of the model domain in Layers 1, 2, and 3 as shown on Figure 3-6. The total flow is distributed among 34 grid cells of the model domain. The total flow is distributed in the ratio of 15:15:70 among Layers 1, 2, and 3, respectively. The amount of flux in each layer and in each grid cell is defined on the basis of grid size.

The quarterly fluxes of ungaged run-off are a function of streamflow data for USGS gauging station number 11062001. The data were downloaded from the USGS website for the period of 1970 through 2011 and compiled quarterly as discussed in Section 3.7.3.1. The annual run-off volumes are taken directly from the USGS Model and the USEPA 2012 Model and are distributed quarterly based on the streamflow discharge.

The USGS Model reported the subsurface inflow from the San Gabriel Mountains to be 1,200 acre-feet per year (AF/yr). This value was used in the Emhart Model, consistent with the USGS Model and the USEPA 2012 Model. The annual rates are distributed equally among four quarters for modeling purposes.

The quarterly flux rate for each model's stress period is presented in Appendix B (Table B-3).

3.7.3.4 *Run-off and Inflows from the Badlands*

A specified flux boundary is used to represent run-off and inflows from the Badlands. The fluxes are distributed equally to three grid cells of the model domain in Layer 2 as shown on Figure 3-6.

The quarterly fluxes of ungaged run-off are a function of streamflow data for USGS gauging station San Timoteo Creek, site 11057500. The data were downloaded from the USGS website for the period of 1970 through 2011 and compiled quarterly. The annual run-off volumes are taken directly from the USGS Model and the USEPA 2012 Model and are distributed quarterly based on the streamflow discharge.

Subsurface inflow from the Badlands was assumed to be negligible. This is consistent with the approach as given in the USGS Model and the USEPA 2012 Model. The combined flux was not adjusted during calibration. The quarterly flux rate for each model's stress period is presented in Appendix B (Table B-4).

3.7.3.5 Imported Groundwater in Linden Pond

The groundwater recharge from imported water at Linden Pond was simulated in the model using the approach adopted by the USEPA 2012 Model. The monthly recharge rates were received from the San Bernardino Valley Municipal Water District (Muni Valley District) and distributed quarterly in various stress periods as listed in Table B-5 (Appendix B). The flux is assigned in one model grid cell in Layer-1. It has been assumed that the recharged water will reach the water table in the same quarter as the quarter in which it is released at the surface. The imported water is a known quantity and hence not adjusted during model calibration.

3.7.3.6 Groundwater Pumping

Groundwater is a major source of water supply for the RCB, with a total of 45 production wells operating in the RCB between 1970 and 2011, as shown on Figure 3-7. Table 3-3 shows the annual production totals for the RCB in AF/yr. As shown on Figure 3-8, production varies annually. In general, production rates were highest in the 2001-2011 timeframe, with the highest annual production of 25,351 AF/yr occurring in 2010, and the lowest annual production of 4,339 AF/yr occurring in 1983. The annual average groundwater production during the Emhart Model time period was 14,370 AF/yr.

Production wells in the RCB were located based on the State Well Number. Well locations were verified from maps provided by Steven Mains with Watermaster Support Services and boring logs where available.

Production data collected from the following sources were incorporated into the Emhart Model:

- Watermaster Database annual production data for the RCB provided by Steven Mains with Watermaster Support Services (Mains, 2012);

- Fontana Water Company (San Gabriel Valley Water Company, hence forth referred to as Fontana) annual production data provided as supplemental data from CH2M HILL;
- Fontana monthly production data for selected years provided by USEPA, and subsequently by Fontana; and
- West Valley Water District (WVWD), City of Colton, and City of Rialto monthly production data for selected years provided by individual purveyors.

Appendix C presents the following tables regarding the production well data:

- Table C-1 - Summary of the production data obtained from various sources;
- Table C-2 – Well screen and model layer designation;
- Table C-3 - Summary of annual production for each of the production wells; and
- Table C-4 - Summary of basin-wide average quarterly allocations of pumping rates based on monthly pumping data.

To the extent available, monthly pumping data were used for purposes of assigning quarterly pumping rates in the Emhart Model. For some wells, monthly pumping data were not available, but annual pumping data were available. For those wells, quarterly pumping rates were estimated by using the percentages reported in Table C-4 to allocate annual pumping rates to each quarter.

In general, production totals in the Emhart Model for individual wells are consistent with previous models for the RCB.

3.7.4 Head Dependent Boundary Conditions

3.7.4.1 Evapotranspiration

Evapotranspiration is assigned to the Emhart Model in the same manner as in the USEPA 2012 Model. A rate of 38 inches per year (in/yr) was assigned to Layer 1 with an extinction depth of 15 feet, which is consistent with assigned values in the Bunker Hill Model (Danskin et al., 2006). Evapotranspiration loss occurs in the model when water levels in the model cells are above the assigned extinction depth.

3.7.4.2 *Outflow to the Riverside Basin*

Subsurface outflow from the RCB to the Riverside Basin is assigned using the same approach as the USEPA 2012 Model. Subsurface outflow was simulated in Layers 1, 2, and 3 as shown on Figure 3-6. Outflow is simulated using a general head boundary (GHB) condition, where a cell assigned a GHB will have groundwater flow into, or out of the cell. The flow is calculated based on the difference in groundwater elevation in that cell and the groundwater elevation of a fixed point (usually represented by a monitoring well) outside of the model domain.

Groundwater elevations used for inputs to the GHB were developed from monitoring wells 1S/4W-29H02S, 1S/4W-29H01S, and 1S/4W-29H06S (Figure 3-6). Water-level data were obtained from the USGS National Water Information System Web Interface (waterdata.usgs.gov) files provided by John Izbicki of the USGS, and water levels from the Watermaster Cooperative Monitoring Program (Mains, 2012). Quarterly averages of water levels were used for input into the GHB cells. Data from monitoring well 1S/4W-29H02S were primarily used, as this well has the most complete record of data. Where data were not available for this well, water levels from monitoring well 1S/4W-29H01S and 1S/4W-29H06S were used. Due to the infrequent monitoring of wells 1S/4W-29H01S and 1S/4W-2H02S after 2002, data were obtained from a new monitoring well (1S/4W-29H06S) to supplement the dataset. Data were interpolated for several quarters when no data were available from either well. Water level data are presented in Table 3-4.

GHB conductances were calculated based on the hydraulic conductivity, the saturated thicknesses, the width of the individual GHB cells, and the distance from the GHB cell to the external groundwater elevation source.

3.7.4.3 *River Boundary Conditions*

The Santa Ana River and Warm Creek are represented in the model as river (head-dependent) boundaries in Layer 1 (Figure 3-6) A river boundary simulates groundwater flow between a surface water body and the underlying aquifer. Groundwater flow to or from the boundary depends upon the difference between river stage and head in the underlying model layer (McDonald and Harbaugh, 1988). When the stage elevation in the river boundary is higher than the head in the underlying model layer, the model layer receives groundwater recharge along the river boundary.

The river boundary condition is consistent with the USEPA 2012 Model. The stage elevations of the river boundary were assumed to be 1 foot above the land surface elevations obtained from the National Elevation Dataset along the model cells depicting the Santa Ana River and Warm Creek (CH2M HILL, 2012). The river stage elevations vary across the model grid, but were assumed to be constant with simulation time.

The streambed conductance values are identical to the USEPA 2012 Model with the hydraulic conductivity of the streambed material assigned a value of 0.1 foot per day.

3.7.5 Chino Basin

The Chino Basin boundary is simulated in the Emhart Model as a no-flow boundary. Although the USEPA 2012 Model represented the Chino Basin boundary as a specified flux boundary, with an outflow of 4,000 AF/yr, the Chino Basin boundary is represented as a no-flow boundary in the Emhart Model for the following reasons:

- Large head differences (reportedly up to 400 feet) have been observed in wells on opposite sides of the Rialto-Colton Fault (Dutcher and Garrett, 1963). These head differences indicate the Rialto-Colton Fault acts as a significant barrier to groundwater flow supporting the no-flow simulation of that boundary.
- After analyzing the available data and information, other modeling professionals, as reported in USGS (2001), GLA (2007, 2010, and 2011), and CH2M HILL (2010), all concluded that the Rialto-Colton Fault acts as a barrier to groundwater flow. In addition, a recent Master's Thesis by Paulinski (2012) reached the same conclusion.
- The USEPA 2012 Model used an assumed Chino Basin outflow value of 4,000 AF/yr based on a Chino Basin Model described in Wildermuth (2007). Wildermuth provided no technical basis for the value of 4,000 AF/yr other than model calibration. Moreover, Wildermuth indicated that some boundary flow rates in the Chino Basin Model, including the 4,000 AF/yr across the Chino Basin boundary, seem to be high and recommended additional investigations of these flow rates.
- When used with all other inflow and outflow data-driven assumptions, the assumption that the Chino Basin boundary is effectively a no-flow boundary (i.e., that any flow across the boundary is negligible) was corroborated by and is consistent with the calibration of the Emhart Model and relevant available information, see Table 4-3.

As can be seen in Table 4-3, when either 2,000 or 4,000 AF/yr values are assumed to cross the Chino Basin boundary, the Emhart Model statistics in the AOI indicate poorer correlation between simulated and actual conditions.

3.7.6 Recharge

3.7.6.1 Precipitation Recharge

Groundwater recharge from precipitation can be difficult to estimate, particularly in a semiarid basin with a 400-foot unsaturated zone like the RCB.

Danskin et al. (2006) discuss precipitation recharge in the area as part of their development of a groundwater flow model of the adjacent Bunker Hill Basin. Based on the recharge rate estimated by California Department of Water Resources (1986) and model calibration results, a value of 0.5 in/yr was used (Danskin et al., 2006).

Based on the analysis of available data and information, the USGS (2001), GLA (2007, 2010, 2011), and CH2M HILL (2010), also determined that it was appropriate to use a value of 0.5 in/yr to represent precipitation recharge in their model simulations. Although the preliminary model developed for the RI/FS (USEPA 2010 Model), used a precipitation recharge rate of 0.5 in/yr, USEPA applied Turner's method to calculate an annual groundwater recharge rate from the annual precipitation rate in the USEPA 2012 Model. The estimated recharge rate from this method ranges from 12 in/yr to zero in/yr, with an average of 3.19 in/yr for the model simulation period from 1970 through 2009.

A precipitation recharge rate of 0.5 in/yr was assigned to all cells in Layer 1 of the Emhart Model grid based on the technical information available on likely recharge rates, and the assumptions and calibrations of the other models of the RCB.

3.7.6.2 Return Flow Recharge

The return flow is the quantity of pumped groundwater that returns to the groundwater system as a result of percolation. The excess water from crop irrigation and watering in urban areas such as lawns, parks, and golf courses returns to the groundwater system. There are other recognized urban recharge pathways to the groundwater system that include water mains and sewerage leakage. USGS (1997) estimated return flows in the

San Bernardino area to range from approximately 2,600 to 7,500 AF/yr, for the period of 1947 to 1994. The USGS Model used 30 percent of the annual pumping rate as the return flow in their RCB groundwater model. For modeling purposes, the USGS reduced the total pumping rate by 30 percent to account for irrigation returns (USGS, 2001).

In the Emhart Model, the return flows are assigned to the model and have been slightly modified from the USGS Model approach to reflect likely seasonal variations. The Emhart Model uses the USGS's 30 percent rate in the warmer months (second and third quarters) and a lower value of 15 percent in the cooler months (first and fourth quarters) based on the understanding that application of water for irrigation and lawn watering are greater in the warmer months than in the cooler months.

The estimated volume of return flows is distributed over each active cell in Layer 1 and is simulated along with precipitation recharge using MODFLOW recharge package (Harbaugh et al., 2000). The estimated values of return flows for each quarter are presented in Table B-6 (Appendix B).

3.7.7 Water Balance

The individual water balance components for each simulation period are presented in Table 3-2 and described in various sections of this report. The components of recharge and discharge in the RCB vary seasonally. The overall water balance of the basin suggests that there is an average annual net loss of about 4,000 AF of groundwater each year over the last four decades. This value is consistent with the average groundwater storage depletion as presented in the USGS Model and the USEPA 2012 Model. Table 3-2 also shows that the rate of loss of water from the basin increased beginning in about 2000. Much of this increased rate of loss can be attributed to production well pumping in the basin.

The cumulative groundwater storage of the calibrated model in Figure 3-9 shows a consistent depletion of groundwater storage in the basin after 1998, which is in agreement with the USEPA 2012 Model.

3.8 MODEL INPUT PARAMETERS

The initial input parameters used in the Emhart Model are primarily based on the previous groundwater flow models (USEPA, USGS, and County Models). These parameters were refined during the model

calibration process (Section 4.0). The following subsections describe the input parameters used in the calibrated model.

3.8.1 *Horizontal Flow Barriers*

Three faults exist within the model domain: Barrier J, Unnamed Fault, and Barrier H. These faults act as partial barriers to horizontal groundwater flow. The faults are modeled as horizontal-flow barriers using the HFB (Horizontal-Flow Barrier) package at the approximate location of each barrier (Hsieh and Freckleton, 1993). Each HFB is a vertical boundary representing reduced conductance between adjacent cells, restricting groundwater flow between the cells. The distribution of HFB boundaries in the model is shown on Figure 3-10. The range of hydraulic properties of each fault is presented in Table 3-5. The presented values on Table 3-5 and Figure 3-10 represent the "hydraulic characteristic" as defined by the HFB package to be the hydraulic conductivity of the HFB divided by the width of the HFB.

All barriers are modeled in Layers 1 through Layer 5. Conductivity values were adjusted during model calibration. The conductivity of the Unnamed Fault is higher in the upper basin as compared to the lower basin. This is consistent with the description given in the USGS Model that shows mixing of water northeast of the Unnamed Fault with water southwest of the Unnamed Fault in Layer 3.

3.8.2 *Hydraulic Conductivity*

The values of horizontal hydraulic conductivity used in the entire Emhart Model range from 0.0005 to 337 feet per day (ft/day). In the smaller AOI, horizontal hydraulic conductivity values are as follows:

- Layer 1 – 2.511 to 68 ft/day;
- Layer 2– 0.0005 to 20.4 ft/day;
- Layer 3– 100 to 120 ft/day;
- Layer 4 – 22 to 60 ft/day; and
- Layer 5 – 0.34 ft/day.

The spatial distribution of horizontal hydraulic conductivity used in the model is shown on Figure 3-11. These values are in general agreement with values used in previous models and values reported from specific capacity tests and aquifer test results reported by GLA (GLA, 2010).

The spatial distribution of vertical hydraulic conductivity used in the model is shown on Figure 3-12. The horizontal/vertical hydraulic conductivity ratios were determined by calibration of the model to observed groundwater elevations and range from 3 to 650. Calibrated vertical conductivity values are generally consistent with previous models, except for values assigned to the BC Aquitard in the County Model.

3.8.3 Specific Yield and Storage Coefficient

The spatial distribution of specific storage used in the Emhart Model is shown on Figure 3-13. Specific storage values range from 1.0×10^{-7} to 1.38×10^{-4}. These values were adopted from the USEPA 2012 Model and were adjusted to a limited degree during model calibration.

The spatial distribution of specific yield used in the Emhart Model is shown on Figure 3-14. Calibrated, specific yield values used in the Emhart Model range from 0.01 to 0.25. These values were adopted from the USEPA 2012 Model and were adjusted during model calibration. A lower value for specific yield was assigned in the vicinity of the BC Aquitard in Model Layers 1, 2, and 3. The calibrated values are comparable with values used in the USGS Model and reported specific yield values from the GLA 2010 Rialto-3 aquifer test results (GLA, 2010).

3.8.4 Adjustment of the BC Aquitard

Figure 3-15 shows the interpretation of the BC Aquitard as presented in the USEPA 2012 Model and the updated interpretation implemented in the Emhart Model. Based on a review of boring logs and water-level differences, wells screened above and below the interpreted zone of the BC Aquitard, as well as the interpretation of the BC Aquitard in the County Model, the terminus of the BC Aquitard was adjusted as presented in Figure 3-15. This interpretation differs slightly when compared to the USEPA 2012 Model due to the recent data available from monitoring well EPA-MW9. The BC Aquitard was not identified in the available well logs for this well nor are there significant differences in water level measurements among the well screen intervals, indicating that the terminus of the BC Aquitard is located to the north of this well. The terminus of the BC Aquitard was also adjusted northwards of monitoring wells M-1, N-14, M-4 and production well Rialto-2 based on review of water-level differences and well log data.

4.0 MODEL CALIBRATION

The Emhart Model was calibrated over a wide range of hydrogeologic conditions to demonstrate that the model is capable of simulating the variable groundwater conditions observed in the RCB. Calibration of the flow model was accomplished by using model design and input parameters that produced simulated groundwater elevations that reasonably match field measurements. This section describes the calibration targets, calibration methods, calibration results, and sensitivity analysis of the calibrated model.

4.1 CALIBRATION TARGETS

Prior to the start of model calibration, groundwater elevation data in the RCB were compiled to create a calibration dataset spanning the 42-year simulation period. Sufficient data were collected to describe various groundwater flow conditions within the RCB; however the majority of water-level data collected within the basin have been collected from year 2000 onwards. The long calibration period provides a wide variety of hydraulic and water-use conditions, including periods of high and low water-level conditions.

The Emhart Model includes 270 calibration targets as presented on Figure 4-1 and summarized in Table 4-1. Quarterly water-level measurements were selected for each well where available. If more than one water-level measurement was reported in a quarterly stress period, the water-level measurement collected nearest to the middle of the quarter was selected as a calibration target. The dates of the water-level measurements were entered into the model for calibration targets.

4.2 CALIBRATION METHOD

Model calibration was evaluated both qualitatively and quantitatively. Qualitative methods included a visual review of the model's ability to simulate basin-wide water-level trends and vertical hydraulic gradients, and amplitudes of water levels in monitoring wells. Water quality data from monitoring wells located immediately west of the 160-acre area perchlorate plume were also considered.

Quantitative calibration methods included evaluation of statistics calculated from the difference between simulated and observed heads (observed minus simulated). The following statistics were evaluated:

- Mean error;
- Residual mean error;
- Minimum and maximum error;
- Root mean squared error;
- Standard deviation; and
- Goodness-of-fit (R^2).

4.3 *CALIBRATION PROCEDURE*

The Emhart Model was calibrated using an iterative approach. Initially, the Emhart Model incorporated parameters assigned from the USEPA 2012 Model with updates as discussed above.

As a first step in the calibration process, water balance terms were adjusted to achieve a reasonable water balance in the basin. Adjustment of water balance terms was necessary because the Emhart Model used a lower areal recharge rate and updated (higher) pumping values than the USEPA 2012 Model. Adjustment of fluxes representing underflow from the San Gabriel Mountains, Lytle Creek Basin, and the Chino Basin produced more reasonable basin-wide flow patterns and an improved overall mass-balance.

Following initial adjustment of the water balance terms, model parameters such as hydraulic conductivity, specific yield, and the hydraulic conductance of Barrier J and the Unnamed Fault were modified to provide a better match between simulated heads and observed heads. Water balance terms were further adjusted as part of the calibration process.

4.4 *MODEL SOLUTION CONVERGENCE CRITERIA AND VOLUMETRIC MASS BALANCE*

A head convergence criterion of 0.005 foot was specified for the model simulations. The volumetric mass-balance (difference between total groundwater inflow and outflow simulated by the model) was monitored during model calibration as a check on the model solutions and to identify

errors in the model design. Model solutions with less than 1-percent volumetric mass-balance error were considered to be acceptable.

4.5 *CALIBRATION RESULTS*

The calibrated model represents the distribution of hydraulic parameters and boundary fluxes that are in general agreement with the values used in previous geohydrologic modeling studies for RCB (USGS, 2001; GLA, 2007; GLA, 2010; and CH2M HILL, 2012).

Figure 4-2 presents the comparison between calibration targets and simulated heads for all targets throughout the model domain. The scatter plot shows that the data points fall close to the 1:1 correlation line with the exception of a few points that fall either above or below the correlation line.

The statistical summary of the calibration results is shown in Table 4-2. The calibration statistics have been presented for the full model domain and the AOI separately. These results show that the calibration in the AOI is better than for the full model domain. There are three areas within the model domain where the Emhart Model is under-predicting or over-predicting the groundwater elevations.

- There are five target wells located above Barrier J on the east side of Unnamed Fault in the Intermediate Aquifer. These wells have similar screen intervals and are located in close proximity to one another, yet they exhibit significant differences in water levels. The Emhart model lacks sufficient spatial discretization to simulate these differences.
- There are other target wells (PW-1, CMW-05, F-30, or F-21) in the Intermediate Aquifer, Layer 1 of the model in the 160-acre area and in the County Remedy Area where the calibrated model shows a mix of under-estimations and over-estimations in groundwater elevation. This appears to be due to model spatial discretization in this area. A more refined grid may be necessary to represent the heterogeneity existing in these areas.
- The target wells (i.e., N-2D, PW-4, or N-8S) in Layer 2 lying in the BC Aquitard also show poorer calibration as compared to target wells in Layers 3 and 4. The Emhart Model generally under-predicts heads in this layer.

In addition, similar to the USGS Model and USEPA 2012 Model, the Emhart Model tends to overpredict water levels in the 1970-1985 timeframe. During this time period, the available data are only from production wells with very little data from monitoring wells or piezometers. Water level measurements from production wells may be biased due to pumping conditions prior to the measurement of water level. Figures 4-3, 4-4, and 4-5 show the basin-wide simulated groundwater elevations for the last stress period (end of calendar year 2011) for Model Layers 1, 3, and 4, respectively. The potentiometric contours show that groundwater flows almost parallel to Barrier J in the upper part of the basin and sub-parallel to the Unnamed Fault in the middle of the basin. In the southern part of the basin, groundwater moves southwesterly and exits the RCB to the adjacent Riverside Basin. In the AOI, potentiometric contours exhibit a westward component. This westward gradient is due to production well pumping in the general vicinity of Barrier H. As discussed above, water supply pumping in the basin increased beginning in about 2000. Most of the increase in water supply pumping is located in the general vicinity of Barrier H. In addition, local variations in groundwater flow due to heterogeneity of the aquifer material and groundwater pumping are evident.

Figures 4-6, 4-7, and 4-8 show the basin-wide simulated groundwater elevations for the 4th quarter of 1995 for Model Layers 1, 3, and 4. These figures show basin conditions prior to the increase in production well pumping beginning in about 2000. Consistent with USGS Figure 9, which shows potentiometric contours in the spring of 1996, Figures 4-6, 4-7, and 4-8 show that the groundwater gradient is to the southeast, generally parallel to the Rialto-Colton and San Jacinto Faults.

The calibration statistics/hydrographs for all other wells are presented in Appendices D and E. The calibration statistics and the data presented in the hydrographs in general show a good agreement between modeled and calibration target heads. Figures 4-9 through 4-12 represent plots showing the match between observed and simulated heads in target wells in the AOI for Model Layers 1, 2, 3, and 4, respectively. Figure 4-13 presents a map of the distribution of root mean squared error in groundwater elevations for target well locations. Comparison of Figure 4-13 with Figure 4-9 in the USEPA 2012 Model shows that the root mean squared error values are generally similar between the Emhart Model and the USEPA 2012 Model.

The calibration hydrographs presented in Figure 4-9 in the Intermediate Aquifer (Layer 1 of the model) show the simulated heads in the same

range as observed water levels. However, for some target wells, for example, CMW-1, N-5S, F-8, and F-10, the calibrated model is not able to capture the variability in heads. As referred to above, this appears to be due to model discretization.

4.6 MODEL CALIBRATION SENSITIVITY ANALYSIS

The sensitivity of the model calibration to changes in the values of the input parameters was evaluated for:

- Recharge rate;
- Hydraulic conductivity of each model layer in the AOI;
- Storage terms of each model layer;
- Conductivity of Barrier H;
- Chino Basin boundary flux; and
- Lytle Creek Basin fluxes.

Each of these input parameters was varied, while all other input parameters were kept at their calibrated values.

The impacts of changes in the values of the input parameters were evaluated based on changes in the calibration statistical parameters.

The results of the sensitivity analysis are summarized in Table 4-3. The model calibration is more sensitive to changes in fluxes, as reflected in the values of Residual Mean, RMS Error, and, to a lesser extent, R^2. For example, increasing the Chino Basin boundary flux from zero to 2,000 or 4,000 AF/yr increases the Residual Mean in the AOI from 0 ft to 8.23 and 16.10 ft, respectively, and the Residual Mean in the entire model domain from 8.66 ft to 15.81 and 22.69 ft, respectively.

The model calibration is less sensitive to hydraulic properties, particularly the storage coefficient. The calibration is least sensitive to conductivities of hydraulic Barrier H.

The results of the sensitivity analysis are consistent with experience gained during model calibration and show that the model is sensitive to the overall basin water balance.

5.0 *PREDICTIVE SIMULATIONS*

Following submission of the 10 April 2013 *Draft Groundwater Flow Modeling Report* (ERM, 2013a), Emhart obtained the following information:

- The County clarified that it operates Rialto-3 at an annual average of 1,300 gallons per minute (gpm), rather than 1,157 gpm as previously understood;
- The City of Rialto requested that EW-1 (originally proposed to be located west of Ayala Drive) be relocated in Jerry Eaves Park, approximately 150 feet east of its original proposed location; and
- The modeling team discovered that, in its initial predictive simulations, instead of calculating frequency of capture for a 42-year predictive simulation period, a 35-year predictive simulation period was erroneously used in the frequency of capture analysis presented in the *Draft Groundwater Flow Modeling Report* (ERM, 2013a).

Based on this new information, and in response to USEPA's comments, Emhart used the model to conduct revised simulations of select scenarios. A detailed analysis of the impacts of the above new information is provided in the correspondence between Emhart and USEPA included in as Appendix F.

This section presents the revised predictive scenarios. In addition to accounting for the above new information, the groundwater model simulations described in this section incorporate changes to address minor discrepancies in parameter values between the version of the model used for purposes of calibration and that used for predictive simulations in the 10 April 2013 *Draft Groundwater Flow Modeling Report.* These minor discrepancies are noted in ERM's 16 May 2013 transmittal letter to USEPA (ERM, 2013b) (Appendix F). These discrepancies were addressed by modifying parameter values in the predictive scenario model to match those in the calibrated model.

Appendix G presents the entirety of Section 5 from the 10 April 2013 *Draft Groundwater Flow Modeling Report* (ERM, 2013a), including text, tables, and figures.

Only those portions of this section that have been changed to present the revised predictive scenarios are presented in this section.

5.1 *PREDICTIVE SIMULATION ASSUMPTIONS*

The revised predictive simulation assumptions are the same as those described in Section 5.1 of the 10 April 2013 *Draft Groundwater Flow Modeling Report* (see Appendix G) with the following exception:

- Frequency of Capture – As noted above, the modeling team discovered an error in the frequency of capture calculations in the *Draft Groundwater Flow Modeling Report*. This section presents the results of frequency of capture analysis for a 42-year simulation period for select scenarios.

5.2 *PREDICTIVE SCENARIOS*

Based on the above new information, Emhart used the model to conduct revised simulations of two scenarios:

- Scenario 2B, as presented in the *Draft Groundwater Flow Modeling Report*, was revised as Scenario 2Br; and
- Scenario 2D-3, as presented in the *Draft Groundwater Flow Modeling Report*, was revised as Scenario 2D-3r.

Tables 5-1 and 5-2 show the annual average pumping rates for the evaluated combined remedy extraction wells in gpm and AF/yr, respectively. In addition, these tables include the frequency of capture as a percentage.

5.2.1 *County Remedy Considerations*

The considerations regarding the County Remedy wells applied in development of predictive Scenarios 2Br and 2D-3r were the same as applied in the *Draft Groundwater Flow Modeling Report* (ERM, 2013a) (Appendix G, Section 5.2.1) with the following exception:

- At a minimum, the County Remedy operates at its current extraction rate. The County currently operates Rialto-3 at an annual average of 1,300 gpm. The County Remedy currently achieves adequate hydraulic capture, as approved by the RWQCB. Therefore, this minimum threshold pumping was maintained for development of combined capture predictive scenarios.

Tables 5-1 and 5-2 summarize the quarterly pumping rates used for Scenarios 2Br and 2D-3r, as well as the annual averages in gpm and AF/yr, respectively.

5.2.2 *SAOU Remedy Extraction Well Considerations*

The considerations regarding the extraction well(s) for the SAOU Remedy applied in development of predictive Scenarios 2Br and 2D-3r were the same as applied in the *Draft Groundwater Flow Modeling Report* (ERM, 2013a) (Appendix G, Section 5.2.2) with the following exception:

- EW-1 was relocated approximately 150 feet east of its original proposed location.

Under Scenario 2D-3r, multiple pumping rates for both new extraction wells (EW-1 and EW-2) were evaluated.

5.2.3 *Simulated Groundwater Elevations*

As presented in Section 4.5, Figures 4-3, 4-4, and 4-5 show the basin-wide simulated groundwater elevations for the last stress period (end of calendar year 2011) for Model Layers 1, 3, and 4, respectively. This is the distribution used for the beginning of the predictive scenarios. Figures 5-1, 5-2, and 5-3 show the basin-wide simulated groundwater elevations for Scenario 2Br at the end of the simulation period (2053) for Model Layers 1, 3, and 4, respectively. Figures 5-4, 5-5, and 5-6 show the basin-wide simulated groundwater elevations for Scenario 2D-3r at the end of the simulation period (2053) for Model Layers 1, 3, and 4, respectively.

5.2.4 *Potential Recharge at Cactus Basins*

No changes were made to this subsection. The original version of this subsection, included in the 10 April 2013 *Draft Groundwater Flow Modeling Report,* is presented in Appendix G.

5.3 *PREDICTIVE SIMULATION RESULTS*

This section presents the results for revised predictive simulations.

5.3.1 *Predictive Simulation Results for Target Area*

The results of particle tracking and frequency of capture for the scenarios listed in Tables 5-1 and 5-2 are shown on Figures 5-7 through 5-10.

Figures 5-7 and 5-8 present the particle tracks and frequency of capture for Scenario 2Br. These results indicate that a high level of efficient capture can be achieved with pumping from Rialto-3 and EW-1.

Figures 5-9 and 5-10 present the particle tracks and frequency of capture for Scenario 2D-3r. These results indicate that a high degree of capture can also be achieved with the same overall pumping from Rialto-3 and two new extraction wells.

Based on a review of the updated scenarios presented in this section, the conclusions remain the same as those presented in the *Draft Groundwater Flow Modeling Report*:

- Scenarios 2Br (one new extraction well pumping with Rialto-3) and 2D-3r (two new extraction wells pumping with Rialto-3) provide a high degree of capture while maintaining efficient pumping rates that are within the available, or potentially available, water rights for the project.
- Scenarios 2Br and 2D-3r also indicate that, should groundwater flow shift further to the west, necessitating a shift in the location at which remedy groundwater extraction occurs, extraction wells Miro-2 and Miro-3 are viable future extraction well options.

5.3.2 *Predictive Simulation Results for Combined Target Area*

A preliminary evaluation of the effectiveness of the County Remedy combined with the SAOU Remedy was performed for Scenarios 2Br and 2D-3r. For this purpose, a combined target area was defined to include the SAOU Target Area and the target area estimated for the County Remedy as outlined by the County (GLA, 2011). Emhart also consulted with the County to confirm that the estimated combined target area at the distal end of the BC Aquitard is reasonably represented.

Figures 5-11 through 5-14 present particle tracks and frequency of capture results for a combined target area using corrected Rialto-3 pumping rates and SAOU extraction well pumping rates for Scenarios 2Br and 2D-3r. Particles were released at the beginning of the simulation period. The results of these simulations are consistent with those presented in Section 5.3.2 of the 10 April 2013 *Draft Groundwater Flow Modeling Report* (Appendix G).

5.4 *PREDICTIVE SIMULATIONS SENSITIVITY ANALYSIS*

No changes were made to this subsection. The original version of this subsection, included in the 10 April 2013 *Draft Groundwater Flow Modeling Report,* is presented in Appendix G.

5.5 *UNCERTAINTY IN MODEL SIMULATIONS*

No changes were made to this subsection. The original version of this subsection, included in the 10 April 2013 *Draft Groundwater Flow Modeling Report,* is presented in Appendix G.

6.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Models are but one of several reasonable tools available to support decision-making. Comprehensive groundwater models, such as the Emhart Model, that reasonably simulate historical conditions can be used to predict potential influences of simulated extraction well locations and pumping rates of the groundwater in the RCB. As a tool, such models are necessarily limited due to the inexact and limited nature of much of the information gathered to develop the model and the uncertain, complex dynamics that influence groundwater movement in the actual environment. With these cautions in mind, the following summary and conclusions are presented in this Modeling Report.

- The Emhart Model can simulate the complex, three-dimensional groundwater flow system in the northern half of the RCB. Thus, it can be used to conduct predictive simulations to support remedial design decision-making associated with the Work Consent Decree. The Emhart Model: was developed using an approach and model code that is widely used and accepted in the environmental industry, including regulatory agencies; incorporates a basin-wide (RCB) water balance evaluation using data and information currently available to Emhart; and has been calibrated.
- The sensitivity analysis completed during model development indicates that the calibrated model is most sensitive to changes in fluxes; conversely, the model is less sensitive to hydraulic properties.
- Predictive simulations were conducted to assess varying scenarios for achieving RAOs in the SAOU. The scenarios included the use of existing supply and/or extraction wells and new extraction wells. The assessment of capture was completed using an approach similar to that used by USEPA in its 2012 model study—particle tracking and endpoint analysis (resulting in calculations of frequency of capture). The predictive simulations, as presented in Section 5.0, indicate the following:
    - Using only existing wells (Rialto-2, Rialto-3, Miro-2, and Miro-3), RAOs can be achieved, but only with relatively high annual average pumping rates ranging from approximately 3,600 gpm to over 4,300 gpm (Appendix G, Table 5-3). Rialto-2 appears to have limited effectiveness for hydraulic capture and contaminant mass removal due to its location (near the estimated eastern boundary of the contaminant plume).

- As simulated, using a combination of Rialto-3 and a single new extraction well, with a total annual average pumping rate of approximately 3,000 gpm, achieves the RAOs. Combining Rialto-3 with two new extraction well(s), using the same total annual average extraction rate, achieves the RAOs.
- As simulated, combining Rialto-3 with the phased installation of two new extraction wells not only allows for Emhart to achieve the RAOs, using a total annual average extraction rate of 3,000 gpm, but provides needed flexibility in selecting the optimal location of a second extraction well, given known uncertainties, which include: (1) the characteristics of the Intermediate Aquifer; (2) the location of the northern boundary of the Target Area; (3) the potential long-term impact of increased pumping near Barrier H; (4) the potential influence of the County's shift in pumping to include the Miro wells; and (5) the implementation of any recharge project utilizing some combination of the Cactus Basins.
- For all the simulations, existing Miro-2 and Miro-3 extraction wells provide additional flexibility should groundwater flow directions shift further to the west.
- Water rights currently available from Rialto and Colton to the County and Emhart appear adequate to accommodate both the County's remedy and the SAOU Remedy.
- Preliminary recharge simulations suggest that use of Basins 1, 2, and 3 to recharge groundwater may have some impact on hydraulic capture of impacted groundwater emanating from the 160-acre area. In contrast, recharge in Basins 4 and 5 may have a potentially significant adverse impact on the SAOU Remedy, mainly due to the proximity of Basins 4 and 5 to the potential SAOU Remedy extraction wells. As discussed in Appendix G, use of any of the Cactus Basins for groundwater recharge appears to cause other potential adverse impacts, which as noted, requires further study by the project proponent.

Thus, it is recommended that the predictive simulations described in this Modeling Report should be used to select the well location and pump rate parameters for the remedial design and that installation of the proposed two new extraction wells should be implemented as follows:

- Select predictive simulation Scenario 2Br. Install one new extraction well (EW-1) and connect it to an expanded County treatment system. The combined average annual flow rate of Rialto-3 and EW-1 will be approximately 3,000 gpm. The capacity of the County treatment

system will be expanded to approximately 4,000 gpm, to accommodate seasonal variability of flow rate/water demand, and the anticipated installation and use of a second extraction well (EW-2).

- Install necessary monitoring wells in coordination with the installation of EW-1 as required in the SOW. Install additional monitoring well(s) to support cost allocation (between the County and Emhart) necessary for the combined capture system. The cost-allocation monitoring wells will also be used to monitor contaminants in and west of the Target Area, upgradient of EW-1. All of these wells will inform future decision-making regarding the location of EW-2.
- Following system permitting, construction, testing, and startup, a hydraulic capture analysis will be conducted to assess the effectiveness of capture. This analysis will be conducted in accordance with USEPA's guidance (*A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems* [USEPA, 2008]). Appropriate system monitoring and groundwater monitoring data will be collected to support this analysis.
- Should the hydraulic capture analysis indicate insufficient capture or the monitoring wells indicate that groundwater flow is shifting more westerly, as suggested in both the USEPA 2012 Model and Emhart Model, EW-2 will be installed at an optimal location to address the circumstance and/or extraction at Miro-2 and Miro-3 will be initiated.

Emhart and the County have reached a tentative agreement in principle regarding an implementation agreement for Combined Remedies. Emhart and the County will develop the essential terms of the implementation agreements with the Cities of Rialto and Colton and, if necessary, with WVWD.

On 28 June 2013, USEPA approved groundwater extraction rates and locations consistent with those recommended above, as set forth in USEPA's letter included in Appendix F (USEPA, 2013).

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