Chapter 1 Introduction

This chapter describes the objectives of developing the **R**iverside-**A**rlington numerical **G**roundwater **F**low **M**odel (RAGFM), including a list of intended uses and users of the model. This chapter also compares the modeling objectives to those of prior studies and provides the model development criteria.

1.1 Goals of the Riverside-Arlington Groundwater Flow Model

The general goal of the RAGFM development is to provide multifaceted support to Riverside Public Utilities (RPU) and the Western Municipal Water District (WMWD) as they manage their groundwater resources. RPU and WMWD actively manage groundwater with extensive monitoring and testing. Additionally, there is an ongoing expansion of groundwater management activities, including increased groundwater level monitoring, development of recharge basins, and creation of groundwater management plans (GWMPs), with associated management activities. These activities can be significantly enhanced through the use of the RAGFM.

The RAGFM and its development process afford a more in-depth understanding of the Riverside and Arlington groundwater basins' characteristics and behaviors, and their relationship with neighboring basins. This knowledge will lead to an estimate of the safe yield for Riverside North, Riverside South, and Arlington basins. The understanding of the conditions of the basins, along with the extensive database and visualization tools that are part of the model, will also optimize monitoring, identifying data gaps that need additional monitoring and ensuring that the overall monitoring program is delivering excellent data coverage in an efficient manner.

The RAGFM can assist in the development of conjunctive use projects. Model datasets can help site recharge facilities through analysis of soils data, aquifer data, and unsaturated aquifer storage space. The model also can be used to estimate the mounding and movement of recharged water and the regional benefits of the recharge.

Different management alternatives that are considered as part of GWMPs can be tested using the groundwater model, which can also provide visualization tools to assist in conveying the information to stakeholders and the general public. Variability in supply sources, recharge operations, and levels of demand can all be tested over a long-term horizon using the groundwater model. This ensures that management alternatives meet the goals and objectives developed by the stakeholders in the GWMP process.

1.2 Intended Users of RAGFM

The primary users of the RAGFM will be RPU and the WMWD staff. The RAGFM was developed in cooperation with local water agencies and stakeholders and can be used to simulate their projects of interest. Additionally, regional agencies can use the model to assist in developing regional projects with components in the model area, such as water banking. The local water agencies and stakeholders are:

- City of Colton
- Jurupa Community Services District
- Riverside Highland Water Company
- Rubidoux Community Services District
- West Valley Municipal Water District
- San Bernardino Valley Municipal Water District
- City of San Bernardino – Rapid Infiltration Extraction (RIX) facilities
- Western-San Bernardino Watermaster

The RAGFM was developed in coordination with a Technical Advisory Committee (TAC), consisting of:

- Mark Norton - Santa Ana Watershed Project Authority (SAWPA)
- Dennis Williams - Geoscience Support Services, Inc.
- Ken Williams – Santa Ana Regional Water Quality Control Board (SARWQCB)
- Linda Woolfenden – U.S. Geological Survey (USGS)

1.3 Intended Uses of RAGFM

The overall project goal was to develop the RAGFM so that it could be used to assist in developing the following preliminary projects. The projects of interest are:

- **Water Resources Planning and Basin Management**
  - Development of GWMPs for Riverside Basin and Arlington Basin
  - Generation of simulated water budgets for each basin
  - Calculation of safe yield for each basin
- **Conjunctive Use / Artificial Recharge**
  - Simulation of artificial recharge and groundwater extraction at:
    - Basins adjacent to the Santa Ana River
    - County of Riverside flood control basins
    - The following WMWD basins:
      - Monroe Basin
      - Victoria and Jackson Basin
      - Metrolink Basin
  - Locating additional desalter wells in:
    - Riverside South Basin to produce 10,000 acre-feet per year of potable water
    - Arlington Basin
  - Locating additional WMWD production wells near the Santa Ana River
- **Project Feasibility**
  - Reduced use of RIX facility by cities of San Bernardino and Colton

RPU and WMWD used a subset of these projects to define the model scenarios that were using RAGFM. To meet these goals, the model must be widely accepted by stakeholders. This was achieved through a transparent development process supported by the TAC, local water agencies, and GWMP advisory groups and stakeholders. The model has a firm and accepted technical basis for analysis of future projects and conditions.

1.4 Comparison to Objectives of Previous Studies

There are four groundwater models that were developed for parts or all of the Riverside-Arlington Model area. A summary of the objectives of these models follows.

- **Riverside-Arlington Basin Model** (GeoTrans, 2003):
  - Identify the sources of recharge to the Riverside Basin and determine the quantity and best location of artificial recharge that could be developed to improve water supply reliability

  - Determine the sustainable yield of the Riverside Basin
  - Determine the impact of groundwater production south of Highway 60 on other wells
- **Arlington Basin Model** (Wildermuth, 2008):
  - Determine the impact of desalter expansion producing 10 million gallons per day of product water
  - Evaluate the effect of artificial recharge operations to imitate the drawdown caused by the increased pumping
- **RIX Facility Model** (CH2M HILL, 2003)
  - Evaluate the historical operations of the RIX facility
  - Provide guidance for future operations of the RIX facility
- **Rialto-Colton Basin Model** (USGS, 2001)
  - Determine the movement and disposition of recharged imported water
  - Simulate long-term effects of three artificial recharge projects

The objectives of the RAGFM are more comprehensive than previous models and cover all of the previously modeled areas. The RAGFM is capable of simulating projects similar to the ones simulated in previous studies as well as projects with basin-wide impacts.

1.5 Model Development Criteria

Project objectives influenced the design of the RAGFM by determining the model domain, grid resolution, time scale, calibration target, and model outputs. Some of the design specifications of the RAGFM were defined by the RPU and WMWD in the Request for Proposals. These specifications include:

- Model Domain: Riverside Basin, Arlington Basin, and a portion of the Rialto-Colton Basin. These basins are hydraulically connected and will be simulated as one regional model.
- Transient state numerical model.
- Calibration Period: 1976-2005
- Model Boundaries: The San Jacinto Fault as the northern boundary, use of physical boundaries rather than arbitrary steady-state boundaries.
- Modeling Code: Groundwater Vistas with MODFLOW-2000 code.
- Model Layers: Model layers will be defined using the hydrogeologic cross sections developed by Numeric Solutions, LLC.
- Model Output: The model output should provide information for analysis of model simulations of conjunctive use and desalter wells. Water budgets and safe yield will be calculated for Riverside North, Riverside South, and Arlington basins.

These specifications were incorporated into the model design. Additionally, the following general specifications were considered in the RAGFM development so it can be used to simulate the projects of interest.

- Calibration Period: The suggested calibration period was reviewed and extended to include important historical hydrologic events of 1965 to 1975 period.
- Calibration Wells: Calibration wells were selected to include wells in the project areas.
- Grid Resolution: Model grid resolution was refined to adequately represent the projects of interest.

- Boundary Conditions: Physical boundaries were used for important model boundaries, such as Riverside Narrows, Arlington Narrows, and the Rialto-Colton Fault.
- Hydrologic Components: Major hydrologic components, such as deep percolation from rain and applied water and recharge from the Santa Ana River will be represented.

Chapter 2 Numerical Model Development

The RAGFM is a saturated groundwater flow model that is constructed using the U.S. Geological Survey (USGS) groundwater flow code MODFLOW-2000 (Harbaugh, 2000) and the pre- and post-processor program of Groundwater Vistas (GV) Version 5 (Rumbaugh and Rumbaugh, 2007). The California Department of Water Resources (DWR) IDC code was used for estimation of deep percolation from rainfall and irrigation (Dogrul, 2007).

2.1 Model Domain

The model domain for RAGFM was defined by the hydrologic and hydrogeologic setting of the study area, and with considerations for future applications of the numerical groundwater model. The boundaries of RAGFM are primarily based on the boundaries of the Riverside-Arlington Basin (Basin 8-2.03) and Rialto-Colton Basin (Basin 8-2.04), as defined by the DWR Bulletin 118 (Figure 1). The RAGFM area covers a total of 95.5 square miles, consisting of 23.2 square miles in the Arlington Basin, 65.3 square miles in the Riverside Basin, and 7 square miles in the Rialto-Colton Basin.

The boundaries of RAGFM consist of the Bloomington Divide with the Chino Basin at the northwestern boundary; Jurupa Mountains, Pedley Hills, Riverside Narrows and other surface topographic features at the western boundary; Arlington Narrows at the southwestern boundary; the Box Springs Mountains at the southern and eastern boundaries; the San Jacinto Fault at the northeastern boundary; and Rialto Basin at the northern boundary. The internal boundary between the Riverside Basin and Arlington Basin is based on the 1969 Judgment (1969 Western Judgment) boundaries. The Rialto-Colton Fault represents the internal boundary between the Riverside and Rialto-Colton basins. Riverside Basin is divided into Riverside North and Riverside South basins at the Riverside-San Bernardino county line, consistent with the 1969 Judgment. This is also the boundary between the San Bernardino Valley Municipal Water District and the Western Municipal Water District (WMWD).

The RAGFM area is primarily an urban area, although it has a significant agricultural area. Historically, groundwater has been used for irrigation purposes and municipal water supplies. Groundwater used in the RAGFM area is pumped from wells in both the model area and the Bunker Hill Basin to the northeast. To meet the water demands in the model area, the groundwater supplies are supplemented in dry years by imported water from the Metropolitan Water District. The general movement of groundwater in the model area is from the northeast to the west and southwest direction, towards the Chino and Temescal basins.

2.2 Model Grid

The RAGFM grid was developed using GV (Figure 2). The model grid consists of 300 rows and 609 columns or 182,700 50 x 50 meters (164 x 164 feet) cells per model layer. The grid is rotated 51 degrees counterclockwise from east to approximately align the column directions with the Rialto-Colton Fault and the row directions with the general groundwater flow direction. The coordinates of the lower left corner of the grid, in NAD 83 State Plane Zone 6, are Easting (X) = 6,201,727 feet and Northing (Y) = 2,245,896 feet. The horizontal extent of the active model cells within the model domain is shown in Figure 3. The grid cells outside the model domain are designated as inactive. Zoomed in views of the model area with Flume Wells, RIX Facility, and Arlington Desalter Wells are shown as a reference for model grid resolution.

2.3 Model Layers

The model layering is based on a three dimensional geologic model (3D Geologic Model) of the Arlington, Riverside, and southern parts of Rialto-Colton basins that was developed by Numeric Solutions, LLC of Ventura, California (Numeric Solutions, 2009). The 3D Geologic Model was developed using a database of well logs in the model area. It was also dovetailed with the three neighboring groundwater models for Bunker Hill Basin (Geoscience, 2009), Rialto-Colton Basin (Woolfenden and Koczot. 2001) and Chino Basin (Wildermuth, 2007).

The model layers in MODFLOW are numbered downward with Layer 1 being at the top. The top of the model is equivalent to land surface and the bottom of the model is equivalent to the bedrock surface. RAGFM consists of three layers. Layer 1 represents a band of coarser alluvium and river deposits along the Santa Ana River. The top of Layer 1 corresponds to ground surface. Layer 2 consists of upper alluvium with higher conductivities. The top of Layer 2, where Layer 1 does not exist, corresponds to ground surface. The bottom of Layer 2, where Layer 3 does not exist, corresponds to bedrock surface. Layer 3 consists of deeper alluvium with lower conductivities. The bottom of Layer 3 corresponds to bedrock surface. Layer 3 is not present in Arlington Basin where aquifer thickness is less than Riverside and Rialto-Colton Basins. The active model cells for Layers 1 to 3, as generated by GV, are shown in Figures 4 to 6, respectively. Cross-sections of model layers along row 165 and column 427 are shown in Figures 7 and 8, respectively. There are 13,705; 72,391; and 45,126 active model cells in Layers 1, 2, and 3, respectively. There are a total of 131,222 active model cells.

2.4 Simulation Time Period

The simulation time period of RAGFM is from 1965 to 2007 calendar years, consisting of a forty-one-year calibration period of 1965 to 2005 and a two-year validation period from 2006 to 2007. The simulation period represents the long-term average hydrological conditions in the model area and includes several wet and dry cycles. The long-term annual rainfall at Riverside Station 179 is illustrated in Figure 9 for calendar years 1880-2007. The locations of Riverside Rainfall Station 179 and several stream gages are presented in Figure 10. The 1965-2007 rainfall average of 10.3 inches per year is equal to the long-term (1880-2007) rainfall average of 10.3 inches per year at the Riverside Rainfall Station 179. Approximately 73% of annual rainfall occurs from December to March (Figure 11). The Santa Ana River is the major source of surface water in the model area and provides significant amounts of groundwater recharge, especially during flood events. The simulation period includes eight major flood events of the Santa Ana River (Figure 12).

2.5 Model Stress Periods and Time Steps

The simulation time in MODFLOW is divided into stress periods and time steps. The stress periods are the time periods within which the aquifer stresses such as pumping and recharge rates do not change. Depending on the availability of data, stress periods usually range from one month to one year. The data for RAGFM are available with various frequencies. Rainfall and streamflow data are available on a daily basis. In contrast, groundwater production data is available monthly. Groundwater elevation data for most wells is only available twice per year. A stress period of one month was used for RAGFM. Monthly averages of daily data were used for each stress period. A monthly time step consistent with the monthly stress period was used for the model calibration and validation.

2.6 Initial Groundwater Elevations

The initial groundwater elevations were estimated in GIS from reported groundwater elevations of Spring 1965, and were specified for every active model cell. Figure 13 shows a contour map of the initial groundwater elevations. Since there are not enough data to map the initial groundwater elevations for each layer, same initial groundwater levels were used for all layers.

2.7 Boundary Conditions

The RAGFM area is bounded on the northwest by Chino Basin; to the west by Jurupa Mountains, Pedley Hills, Riverside Narrows and other surface topographic features; to the southwest by Arlington Narrows; to the south and east by the Box Springs Mountains; to the northeast by the San Jacinto Fault; and to the north by the southern parts of Rialto Basin. The RAGFM boundaries are presented in Figure 14 and Table 1 and are represented in the model as follows.

1) **San Jacinto Fault**: Previous studies indicated that underflow from the Bunker Hill Basin through the San Jacinto Fault is correlated with the groundwater elevations in the Heap well (DWR, 1971 and Danskin et al, 2005). Most of the underflow through the San Jacinto Fault occurs in the shallower aquifer in the vicinity of the Santa Ana River. The flow through the San Jacinto Fault will be represented by 5 injection wells in the vicinity of the Santa Ana River. The wells inject water into model Layers 1 and 2. The underflow rates through the San Jacinto Fault are presented in Table 1.
2) **Boundary with Northern Portion of Rialto-Colton Basin**: This boundary is represented as general-head boundary condition with the head values equal to groundwater elevations in Rialto-Colton Basin immediately north of the boundary. The properties and groundwater elevations of this boundary are presented in Table 1.
3) **Chino Basin Boundary**: The underflow through the boundary with Chino Basin at Bloomington Boundary is represented by five wells extracting groundwater from model Layers 2 and 3.
4) **Riverside Narrows**: The current and historical groundwater elevations at Riverside Narrows are approximately 730 feet MSL and show no significant fluctuation with time. Groundwater elevations at the entrance to the Riverside Narrows are the lowest in the Basin and this is a point of discharge for groundwater. Discharge of groundwater at Riverside Narrows is represented by using a set of constant-head cells at the Riverside Narrows.
5) **Hole Lake Area**: Groundwater discharge at the Hole Lake area is represented by a set of general-head boundary conditions. The groundwater elevations for the general-head cells are based on historical groundwater elevations at the Hole Lake area.
6) **Arlington Narrows**: This boundary is represented as general-head boundary condition with the head values equal to groundwater elevations at the Arlington Narrows west of the boundary.
7) **Rialto-Colton Fault:** Rialto-Colton Fault is represented as a leaky horizontal flow barrier and is simulated with the MODFLOW-2000 Horizontal Flow Barrier (HFB) package.
8) **Santa Ana River**: Santa Ana River is simulated with the MODFLOW-2000 River (RIV) package.

2.8 Deep Percolation

Distributed groundwater recharge or deep percolation in the model area is a result of:

- Rainfall over the model area and the surrounding small watersheds, and
- Applied water from irrigation of agricultural lands and urban landscaping.

The model area and the surrounding small watersheds are divided into 113 subregions based on similar land use and hydrologic soil characteristics with 84 subregions covering the groundwater model area and 29 subregions covering small watersheds (Figure 15). Monthly deep percolation rates were calculated by the DWR IDC code for each subregion.

The soil characteristics and acreages of agricultural, urban, native, and park areas of the subregions were determined from the latest soil type data (NRCS, 2009) and several land use coverage sources as follows:

- 1968 Land Use (Scott, 1976)
- 1990, 1993, 2001, and 2005 Land Use (SCAG, 2009)
- 2008 Land Use (RPU, 2008)
- Aerial Photo (WMWD, 2008)

Annual land use data files were generated for the IDC code using the above land use data. The land use characteristics of 1993 and 2008 conditions of the subregions are presented in Tables 2 and 3. The land use characteristics of 1968 were used for 1965 to 1967. The land use characteristics for years without land use data were linearly interpolated from the available land use data.

Monthly deep percolation rates for the subregions in the model area, as calculated by the IDC code, were processed outside MODFLOW and then applied directly to the model cells associated with each subregion. The groundwater underflow as well as recharge from runoff from small watersheds is a source of recharge to the model area. Some of the runoff from the small watersheds is recharged through the unlined segments of drainage canals. Groundwater recharge at the small watersheds is assigned as underflow to the corresponding model cells at the edge of the active model cells.

2.9 Groundwater Production

Groundwater production in the model area is primarily for municipal use, with minor production from private wells used for agricultural and miscellaneous purposes. Groundwater production data in the model area is based on data received from the San Bernardino-WMWD Watermaster, Riverside Public Utilities, and several local water agencies. Locations of the existing and former production wells in the RAGFM area are presented in Figures 16 to 18. Average annual groundwater production rates of these wells are presented in Table 4. Annual groundwater production rates by various agencies in Riverside-North, Riverside South, Arlington, Rialto-Colton basins, and the total model area for 1965 to 2007 are presented in Figures 19 to 24.

In MODFLOW, groundwater production is simulated using the well (WEL) package and assigning pumpage to model cells. Additionally, GV provides a grid-independent analytical element (AE) tool for simulation of wells. Analytical wells are defined by their spatial coordinates (X and Y) rather than grid cell (row and column) coordinates. GV assigns the wells to model cells when it generates the model data files. The production wells of the RAGFM are represented by analytical elements.

2.10 Aquifer Parameters

Aquifer parameters of horizontal and vertical hydraulic conductivity, storage coefficient, and specific yield are provided for each active model cell. The zone option of GV was used for assigning aquifer parameters to model cells. Each zone has uniform properties and aquifer properties do not change from cell to cell within each zone. The initial values of aquifer parameters, prior to adjustment during the calibration process, were based on:

- Values reported by previous modeling studies in the model area (CH2M Hill, 2003; GeoTrans, 2003; Wildermuth, 2008; and Wolfenden and Koczot, 2001),
- Data from recent RPU aquifer test in the Flume wells area (Tom Field, 2009, Personal Communications), and
- Zones of similar aquifer materials as defined by the 3D Geologic Model (Numeric Solutions, 2009).

The above information were used to develop model zones of similar aquifer parameters. The estimated aquifer parameters for model zones were adjusted during the model calibration process. The parameter zones of all model layers are presented in Figures 25 to 27. The calibrated parameter values for each property zone are provided in Table 5.

Chapter 3 Model Calibration

Model calibration can be defined as "a process that uses a model to achieve a match between the recorded (i.e., historical) and simulated distribution(s) of dependent variable(s) by choosing a range of possible values of the independent variable(s)" (AWWA, 2001). In calibration of groundwater models the inverse problem is solved, that is, the distribution of the dependent variable (such as groundwater elevation) is known and measurable, while the distribution of the independent variable (such as hydraulic conductivity of an aquifer) can be estimated within a range of possible values. In such a situation, the independent variables are adjusted for model calibration and these variables are called model 'parameters'. The model parameters are adjusted using manual methods, automatic parameter estimation techniques, or a combination of both. The most important calibration parameters of the RAGFM are the aquifer properties such as hydraulic conductivity and specific yield and properties of model boundary conditions such as streambed hydraulic conductivity of Santa Ana River and hydraulic conductivity of Rialto-Colton Fault.

After calibration, the groundwater model includes the " best or most reasonable estimates of such model parameters, which are then used to predict the future response of a dependent variable (such as groundwater elevation) under a changed land use or water use plan" (AWWA, 2001).

The purpose of this section is to present the process used to calibrate the RAGFM. This section is organized as follows:

- Calibration Process,
- Calibration Data,
- Calibration Targets, and
- Calibration Results.

3.1 Calibration Process

A well-calibrated groundwater model is capable of representing the physical system and may be used for the analysis of groundwater management planning efforts.

The model calibration begins after the model development and input data are complete. The intent of calibration is to compare model output with observed conditions and values and to adjust model parameters so that the simulated conditions (e.g. groundwater elevations hydrographs and groundwater elevation contour maps) reasonably represent observed conditions.

The model calibration can be considered a systematic process, which includes the following series of activities:

1. Set calibration targets;
2. Calibrate simulated groundwater elevations to observed groundwater elevations by changing identified parameters within identified ranges;
3. Compare calibration performance with the calibration targets established in Step 1; evaluate and refine the calibration targets with reference to the available data, modeling and data assumptions, and potential use of the models; and
4. Conduct additional refinements to calibration as necessary.

Calibration of simulated groundwater elevations to observed groundwater elevations was primarily performed manually. PEST, an automated parameter estimation tool, was used in conjunction with the manual calibration. The groundwater elevation calibration is performed in two stages:

1. The initial groundwater elevation calibration effort is focused on conforming to the regional scale conditions. This step ensures that overall groundwater flow directions are representative of the field conditions.
2. The focus of the final groundwater elevation calibration is the local calibration wells; comparisons are made between the historic time series observations at each calibration well and the corresponding simulated time series groundwater elevations.

During the calibration process, adjustments were made to aquifer and model boundaries parameters, including: hydraulic conductivity, specific storage, specific yield, streambed hydraulic conductivity of Santa Ana River, and hydraulic conductivity of the Rialto-Colton fault.

3.2 Calibration Groundwater Elevation Data

RAGFM was calibrated to observed long-term groundwater elevations. Forty-eight wells from the SAWPA and Watermaster databases well inventory were selected for calibration of the model to long-term trends in groundwater elevations and short-term, seasonal, groundwater elevation fluctuations. The criteria to select calibration wells were primarily based on the length of the period of record and availability of information on well location, depth, and perforation intervals. The criteria were applied so that there was sufficient geographic coverage with calibration wells. The locations of calibration wells are presented in Figure 28 and the information pertaining to the calibration wells is summarized in Table 6. The IDs in Table 6 were developed in this study for reference to the calibration wells. The letter in the IDs refers to the groundwater management zones. The selected wells had approximately 4,800 groundwater elevation measurements during the simulation period. The selected calibration wells provide a fairly good representation of geographic and temporal distributions of the observed groundwater elevations in the model area.

3.3 Calibration Target Residual

The calibration target residual is a range of allowable residual between simulated and observed groundwater elevations. The acceptable calibration target residual depends on the model purpose; location, number and accuracy of water level measurements; and the degree of natural heterogeneity or complexity of boundary conditions. The calibration target residual should be a small fraction of the difference between the highest and lowest groundwater elevations across the model domain. As a rule of thumb, if the residual mean and the ratio of the residual standard deviation to the total head change are less than 5% and 10% of the total head change across the model domain, respectively, the model calibration results are within reasonable statistical range (ASTM, 2002, and SRS, 2006). In addition, in the case of RAGFM, it is desired to have most of the groundwater levels to be within 10 feet of the observed heads.

3.4 Calibration Results

The RAGFM was calibrated in accordance with the calibration methodology described above. The performance of the RAGFM calibration exceeds the calibration targets.

The calibrated aquifer parameter values of the RAGFM are presented in Table 5, respectively. Hydraulic conductivity is generally higher in the river channel deposits along the Santa Ana River in model layers 1 and 2.

Simulated groundwater elevations at the calibration wells were compared with the observed values for long-term trends as well as seasonal fluctuations. Appendix A presents the plots of simulated and observed groundwater elevations at 48 calibration wells during the 1965-2007 simulation period. The simulated values are presented by green lines and the observed values are presented by red points.

Overall, the plots in Appendix A show a good match between the simulated and observed values capturing the general long-term trends and seasonal fluctuations.

Comparison of simulated and observed heads for all calibration wells for the 1965-2007 simulation period is shown in Figure 29. Markers with different colors are used for Rialto-Coltin, Riverside, and Arlington Basins. All of the points are distributed around the diagonal line indicating close match of observed and simulated heads and robustness of the RAGFM.

The histogram of residuals between the simulated and observed groundwater elevations for 1965-2007 simulation period is shown in Figure 30. Note that more than 60% of the simulated heads are within 10 feet of observed heads and more than 90% of the simulated are within 25 feet of observed heads. Table 7 presents the residual statistics. The mean of the residual is 0.8 feet indicating a minor overestimation of groundwater elevations by the model. The range in observed groundwater elevations from 1965 to 2005 is 302 feet. The ratio of the residual standard deviation to the range of observed data is 5% which is less than commonly accepted value of 10%.

The RAGFM simulated groundwater elevations contours for spring of 1999, 2001, and 2005 are presented in Figures 31a, b, and c, respectively. The selected years are representative of dry, normal, and wet hydrologic conditions in the model area. These figures also show the corresponding available observed groundwater elevations at the calibration wells. The simulated groundwater elevation trends, flow directions, and groundwater gradients generally match the observed data.

The geographic distribution of mean residuals between simulated and observed groundwater elevations at calibration wells is shown in Figure 32. Most calibration wells have a mean residual of less than 10 feet. The geographic distribution of mean residuals of less than 10 feet is reasonably evenly spread throughout the model area, which is considered fairly good. Calibration well C1, located in the southern parts of Rialto-Colton Basin close to the Rialto-Colton Fault, exhibits a higher residual due to lower simulated heads and higher residuals in the first 10 years of the simulation period. Additional information on characteristics of the Rialto-Colton Fault and impact of the Santa Ana River floods on groundwater levels in the vicinity of calibration well C1 would allow more accurate simulation of groundwater elevations in the southern parts of the Rialto-Colton Basin. Additional hydrogeologic information in vicinity of the calibration wells RF5 and RF7 and information on the volume of groundwater recharge from septic tanks in the Riverside Highland area would improve the simulated groundwater elevations. Generally, additional hydrogeologic information and improved model layers thicknesses in the foothills areas would allow for more accurate simulation of groundwater elevations.

3.5 Model Validation

The validation period of the RAGFM consists of the last two years of the simulation period (2006-2007). The residuals targets for validation period are the same as those of the calibration period. No adjustments were made to the aquifer and model boundary parameters for the validation period. The validation results are shown as the last two years of the simulated values in the hydrographs of Appendix A. Residual statistics for the validation period are also presented in Table 7. There are no significant differences between the model calibration and validation results indicating a close match of observed and simulated heads for the validation period and a robust model.

3.6 Water Budgets

Water budget tables were developed from the model results to quantify the hydrologic components of the groundwater basin. The RAGFM simulates the movement of the primary sources of water coming into and leaving the groundwater basin.

The primary components of the groundwater budget are as follows:

- Inflows:

   - Deep percolation from irrigation applied water and rainfall;
   - Recharge due to stream seepage;
   - Recharge from other sources such as seepage from septic tanks in Riverside Highland area; and
   - Subsurface inflows from adjacent basins.
- Outflows:
   - Groundwater production; and
   - Subsurface outflows to adjacent basins.

Water budget tables were developed for Rialto-Colton Basin, Riverside North Basin, Riverside South Basin, Riverside North and Riverside South Basins, Arlington Basin, and Total model area covering all basins. Annual groundwater budget tables for the simulation period (1965–2007) are presented in Tables 8 to 13. The budget tables show that the primary sources of aquifer recharge are deep percolation of irrigation water and rainfall, gain from streams, and underflow from adjacent basins.

Schematic representation of the groundwater budgets for Riverside North Basin, Riverside South Basin, and Arlington Basin representing the average annual groundwater budget for 1996 to 2007 are presented in Figures 33 to 35. This time period was selected to capture the RIX operation starting in 1996. Net impacts of RIX operation on Santa Ana River streamflows and groundwater in Riverside Basin are presented in Tables 14 and 15. RIX injects and extracts significant quantities of water; however, the net impact of RIX operation on groundwater in Riverside Basin is insignificant. The main impact of RIX is increased streamflows of Santa Ana River.

3.7 Sensitivity Analysis

A sensitivity analysis of the RAGFM was performed to quantify the sensitivity of the calibrated model to specific model parameters and boundary conditions. The sensitivity analysis was performed by running the model with four different values of the selected parameters and comparing the results of the runs to results of the calibration run. Sensitivity analysis was performed for two major aquifer parameters and three boundary conditions parameters. These parameters had significant impacts on model calibration. The parameters are as follows:

- Aquifer Parameters
   - Aquifer hydraulic conductivity
   - Aquifer specific yield
- Boundary Conditions Parameters
   - Hydraulic conductivity of Rialto-Colton Fault
   - Streambed hydraulic conductivity of Santa Ana River
   - Hydraulic conductivity at the model boundary with the Rialto Basin

The sensitivity analysis results were obtained for the following model areas:

- Arlington Basin
- Riverside South Basin
- Riverside North Basin
- Rialto-Colton Basin

3.7.1 Metrics of Sensitivity Analysis

A sensitivity metric is a single number derived from the model results and has a unique value for each model run corresponding to a given set of data or parameter value. Two different metrics were selected to measure the sensitivity of the model. The sensitivity metrics used in the analysis are:

- Average groundwater elevation at calibration wells, and
- Average root mean square (RMS) error between observed and simulated groundwater elevations.

Average groundwater elevations were obtained for Rialto-Colton, Riverside North, Riverside South, and Arlington basins. The average is calculated for groundwater elevations at calibration wells of each basin. This can be mathematically expressed by:

$$\overline{H} = \frac{1}{M}\sum_{k=1}^{M} H_k$$

and,

$$H_k = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{1}{L}\sum_{j=1}^{L} h_j\right]_i^k$$

where,

M total number of simulation periods,

H_k average head in the basin at k-th stress period,

N number of calibration wells in the basin,

L number of model layers in aquifer,

h_j groundwater elevation at layer j, and

i, j, k indices for well, layer, and time, respectively.

The average RMS error at calibration wells in each basin is defined as the average of individual RMS error at each calibration well. The RMS error at a calibration well is defined as follows:

$$RMS_w = \sqrt{\left\{\frac{1}{N_o}\sum_{k=1}^{No}[h_{k,w}^o - h_{k,w}^s]^2\right\}}$$

where,

N_0 number of observations at well k,

$h_{k,w}^o$ observed groundwater elevation at time step k, at well w,

$h_{k,w}^s$ simulated groundwater elevation at time step k, at well w.

3.7.2 Hydraulic Conductivity

The results of the sensitivity analysis are presented with reference to the calibrated RAGFM. The average groundwater elevation in a particular groundwater basin is shown as the difference with the corresponding value for the calibration run; in other words, the average groundwater elevation in the specific groundwater basin for the calibration run of the RAGFM was subtracted from the corresponding value for each sensitivity model run (Figure 36). Figure 36 indicates that if the hydraulic conductivity is twice the calibration value, the range of the change in average groundwater elevations in the RAGFM is 3 to 16 feet lower than that of in calibration.

The RMS error for the groundwater basins calibration wells is also shown as a relative value with reference to the corresponding value for the calibration run; that is, the RMS error value for each sensitivity run of the model was divided by the corresponding value for the calibration run. For example, Figure 36 shows that the RMS error values increase for all hydraulic conductivity values compared to those used in the calibration run of the RAGFM. This implies the calibrated hydraulic conductivity value provides the minimum RMS error for the calibration wells.

Groundwater elevations in the Riverside South Basin are least sensitive to changes in hydraulic conductivity. Groundwater elevations in the Arlington Basin and Rialto-Colton Basin are the most sensitive to decrease in hydraulic conductivity. Groundwater elevations in the Riverside North Basin and Arlington Basins are the most sensitive to increase in hydraulic conductivity.

3.7.3 Specific Yield

The sensitivity of the RAGFM to changes in specific yield is presented in Figure 37. If the specific yield is reduced by half, the range of the change in average groundwater elevations in the groundwater basins will be 0.5 to 1.0 feet lower than calibration groundwater elevations. If the specific yield is doubled, the range of the change in average groundwater elevations will be 0.5 feet lower to 2 feet higher than calibration groundwater elevations. Figure 37 shows that the RMS error values increase for all specific yield values compared to those used in the calibration run of the model. Groundwater elevations in the Arlington Basin are the most sensitive to changes in specific yield.

3.7.4 Hydraulic Conductivity of Rialto-Colton Fault

The sensitivity of the RAGFM to changes in hydraulic conductivity of Rialto-Colton Fault is presented in Figure 38. Reducing hydraulic conductivity of the Rialto-Colton Fault decreases the amount of underflow from Rialto-Colton Basin to Riverside Basin through the fault. When fault hydraulic conductivity is reduced by 50%, heads in the Rialto-Colton Basin increase by approximately 0.6 feet while the heads in the Riverside North Basin decrease by approximately 0.5 feet. The impact is less significant away from the fault in the Riverside South and Arlington Basins. In contrast, increasing hydraulic conductivity of the fault increases the amount of underflow through the fault and the heads in the Rialto-Colton Basin are decreased while the heads in Riverside North Basin increase.

3.7.5 Streambed Hydraulic Conductivity of Santa Ana River

The sensitivity of the RAGFM to changes in streambed hydraulic conductivity of Santa Ana River is presented in Figure 39. It can be seen from the figure that the reduction of streambed hydraulic conductivity to 50% of the calibrated value results in approximately 16 feet, 13 feet, and 8 feet lower groundwater elevation in the Rialto-Colton, Riverside South and Riverside North Basins, respectively. No significant impact is observed for the Arlington Basin. When streambed hydraulic conductivity values are increased two times, the groundwater elevations in the three basins are about 16 feet, 8 feet, and 5 feet higher than calibration heads.

3.7.6 Hydraulic Conductivity of Model Boundary with Rialto Basin

The sensitivity of the RAGFM to changes in hydraulic conductivity of the general head model cells at the boundary with Rialto Basin is shown in Figure 40. It can be seen from the figure that a reduction of hydraulic conductivity at this boundary results in lower subsurface inflow into the model area and lower groundwater heads. The impact is most significant in Rialto-Colton Basin and least significant in the Riverside South Basin. No impact is observed in Arlington Basin. Increase of hydraulic conductivity at the boundary with Rialto Basin results in higher subsurface inflows and groundwater heads. The impact is most significant in the Rialto-Colton Basin and decreases away from the boundary in the Riverside South Basin.

3.7.7 Summary

The results of the sensitivity analysis for the RAGFM indicate that the model responds in the expected manner in response to changes in aquifer and boundary parameters and the calibrated parameters generate a better match of the simulated and observed groundwater elevations.

Chapter 4 RAGFM Summary and Recommendations

4.1 Summary

The RAGFM simulates the monthly groundwater flow in the basin for the 43-year historical hydrologic period of 1965-2007. This simulation period was selected because it includes wet, dry, normal, and extreme conditions of the regional hydrology, such as the 1969 flood event, 1976-77 drought, and 1987-1992 extended drought period. In addition, this period has sufficient data for groundwater model development.

The RAGFM was calibrated by comparing the model results with the following:

1. Regional groundwater trends; and
2. Local groundwater elevations at 48 calibration wells distributed throughout the model area.

The water budgets were developed for the four basins within the model area. In order to assess the sensitivity of model results to specific model parameters and input data, a sensitivity analysis of the RAGFM was conducted by evaluating two different metrics: average groundwater elevation and average RMS error for calibration wells in the four basins within the model area. The results of the sensitivity analysis indicate that the model responds in the expected manner to changes in aquifer and boundary parameters and the calibrated parameters generate a better match of the simulated and observed groundwater elevations.

4.2 Potential Application of RAGFM

The RAGFM was developed and calibrated to support the planning analysis required for development of the Riverside and Arlington Groundwater Management Plans and ongoing water management in the region. The Technical Advisory Committee provided the necessary technical review, guidance, and coordination during the model development and calibration process. The RAGFM is expected to be used for water resources planning and management in the Riverside and Arlington Basins.

The RAGFM is currently being used for safe yield analysis for Riverside North, Riverside South, and Arlington Basins; development of existing and future conditions baseline simulations; and simulation of water resources projects that incorporate artificial recharge operations and groundwater production.

The RAGFM may also be applied to circumstances which require quantification of project or program benefit and effects and comparison of alternatives, such as the impacts of changes in land and water use conditions, impacts of proposed facilities, and changes to surface water and groundwater conditions.

The RAGFM does not currently include water quality (mass transport) modeling capabilities. The model, however, provides the fundamental data and information framework, as well as appropriate level of spatial and temporal details for future development of additional features, such as the water quality simulation. The development of these additional capabilities is anticipated to be included in the next phase of improvement to the RAGFM.

4.3 Recommendations

The following actions are recommended to improve the capability of the RAGFM to simulate the regional surface water and groundwater conditions in the model area more accurately.

Foothills Stratigraphy Data – Conduct additional hydrogeologic studies to obtain better information for model layer thickness in foothills areas. Availability of such information would allow more accurate simulation of groundwater elevations in the Jurupa area north of Highway 60 and in the eastern parts of Riverside and Arlington Basins.

Development of Water Quality Model – The simulation of TDS, nitrate, and various contaminants of concern in the groundwater basin is one of the major goals of the development of a comprehensive hydrologic model. The RAGFM is currently well calibrated for groundwater flow conditions and can serve as a framework for the development of the Water Quality Model in the future.

Linkage to Other Regional Models – The model layering of the RAGFM was developed based on the 3D Geologic Model of the model area. In anticipation of linking the RAGFM to the groundwater models of the neighboring basins, the 3D Geologic Model was dovetailed with the groundwater models of the Bunker Hill Basin (Geoscience, 2009), Rialto-Colton Basin (Woolfenden, 2001), and Chino Basin (Wildermuth, 2007). Development of a comprehensive groundwater model for the groundwater basins in the Upper Santa Ana Valley is a major goal for regional management of the groundwater resources. The RAGFM is capable of linkage to the neighboring regional models and can serve as one of the components of the comprehensive groundwater model of the Upper Santa Ana Valley.

Chapter 5 Scenario 1 - Existing Conditions (EC) Baseline

The EC Baseline is developed to set a benchmark for comparison of other model simulations. The safe yields for Riverside North, Riverside South, and Arlington Basins are estimated based on a water budget analysis of the EC Baseline.

All simulations of the model for the EC Baseline, safe yield analysis, and project scenarios are based on the calibrated RAGFM.

The objective of the EC Baseline simulation is to define the land and water use and hydrologic conditions that will be used as the basis for comparison of model simulations. The EC Baseline represents the basin under the year 2007 land and water use conditions plus 8,200 AF/year groundwater production by Flume Wells 2-6. The EC Baseline is also used to estimate the safe yield for Riverside North, Riverside South, and Arlington basins over the long-term hydrologic conditions. The assumptions and data used for development of the EC Baseline are presented in the following subsection.

5.1 Assumptions and Data

The simulation period for the EC Baseline is 43 years, representing historical hydrologic conditions (1965-2007).

5.1.1 Recharge

Recharge and deep percolation rates were calculated based on the 2007 land and water use conditions and 1965 to 2007 hydrologic conditions. These estimates were developed using the IDC model with similar parameters as in the historical calibrated model, but with the 2007 land and water use conditions.

5.1.2 Groundwater Production

Preliminary EC Baseline modeling analysis were performed using 8,200 AF per year production rate for the Flume wells 2 – 6 and the 2007 production rates at all other active wells including the WMWD Desalter wells, Empire WC wells 1 and 2, and Jurupa CSD Well 21. These preliminary analyses show that the groundwater levels would decline significantly, and the aquifer would dry up at Empire WC Well 1 and WMWD Desalter 5 after 2 and 10 years of pumping, respectively. This would potentially cause damage to the facilities. Therefore, to determine a sustainable level of groundwater production, several iteration of pumping reduction were performed, which resulted in the following production assumptions:

- **Arlington Basin**
    - **WMWD Desalters –** Operating at 70% of 2007 rates
- **Riverside South Basin**

- **Empire Water Company Wells 1 and 2 –** Operating at 50% of 2007 rates
- **Jurupa CSD Well 21 –** Operating at 50% of 2007 rates

The reduced pumping rates allow the wells to remain active through the EC Baseline simulation period. Groundwater production rates of the Flume wells 2 to 6 remained at a total rate of 8,200 AF per year. Groundwater production rates of all other wells remained at 2007 levels. Table 16 provides a summary of assumptions for the EC Baseline scenario.

5.1.3 RIX Operation

Operation of the Rapid Infiltration and Extraction Wastewater Treatment Facility (RIX) is fixed at 2007 levels. Approximately 22% of influent to the RIX facility was processed by a conventional filter in 2007. The remaining 78% of the influent was recharged at the percolation basins. The conventional filtration process (DynaSand Filter) was placed into operation in 2001 and another conventional filter process (AquaAerobics Aqua Disk) was installed and placed in service in 2008. The DynaSand Filter was placed into standby when the disk filters were placed on line. It is assumed that the proportion of RIX flow rates for the percolation basins and the conventional filter process remain at 2007 levels.

RIX groundwater extraction rates at 34 extraction wells were 27% higher than recharge rates at the percolation basins in an effort to capture all percolating wastewater. A summary of RIX operations is provided in Table 17.

5.2 Results – Groundwater Budgets

This section provides a summary of results of the RAGFM for the EC Baseline. The results show the impact of the current level of infrastructure development on groundwater conditions.

The annual average water budget tables for 43 years of the EC Baseline model simulation for Riverside North, Riverside South, and Arlington basins are presented in Tables 18 to 20, respectively. These tables show the inflow, outflow and storage change components of the water budget. Inflow and outflow components are represented by several subcomponents which are described separately for Riverside North, Riverside South, and Arlington basins later in this section.

The groundwater production and recharge components of EC Baseline are summarized in Table 27. The groundwater elevations at the beginning and end of simulation of the EC Baseline are shown in Figures 46a and 46b. The groundwater elevations at 12 calibration wells for the EC are shown in Figures 49a to 49l. The groundwater elevations at the three 1969 Western Judgment Index Wells (Johnson, Flume 2, and Flume 5 wells) are shown in Figures 50a to 50c. The locations of the calibration wells and the Index Wells are shown on Figure 48. The average groundwater elevations at the three Index Wells are shown in Figure 51.

5.2.1 Impact of RIX

RIX receives secondary treated wastewater, recharges most of this water through infiltration basins as part of tertiary treatment, extracts this water along with native groundwater for full containment, and then discharges the water to the Santa Ana River. Operation of RIX in Riverside Basin has a locally significant impact on groundwater levels and Santa Ana River (SAR) gain and loss rates. Data for RIX operation, including wastewater recharge, groundwater extraction, and effluent discharge to SAR, is available. However, quantification of RIX operation on Riverside Basin is a complex task. Therefore, the RAGFM was used to quantify the effects of the operation of RIX on the groundwater basin and SAR recharge.

Two versions of EC Baseline model simulations were developed to quantify the RIX impact. The first model simulation includes operation of RIX, consisting of wastewater recharge, groundwater extraction, and discharge of DynaSand Filter effluent and extracted groundwater to Santa Ana River. The second model simulation does not include RIX recharge, extraction and discharge to Santa Ana River. Water budget tables were developed for these two model simulations and the difference was assumed to be due to RIX operation. The components of water budget tables that represent significant impacts of RIX operation are shown as separate columns in Tables 18 and 19 for Riverside North and Riverside South. Model results indicate that RIX impacts on Arlington Basin are negligible and, thus, are not depicted in Table 20.

Detailed impacts of RIX operation on groundwater in Riverside Basin and on Santa Ana River flows are presented in Tables 21 and 22, and are summarized in Table 17.

5.2.2 Riverside North

The water budget for Riverside North is presented in Table 18. The 43-year average total inflow into Riverside North is 88,900 acre-feet per year (AFY). With a 43-year average total outflow of 90,000 AFY, the annual average storage decreases by approximately 1,100 AFY. This is equivalent to 46,300 AF decrease in groundwater storage of Riverside North over 43 years of EC Baseline model simulation. Figure 41 presents a diagram of the Riverside North Basin depicting the average annual water budget components of Table 18.

Inflow

Inflow into Riverside North consists of the following components (refer to Table 18 for data and column numbers):

- **Deep Percolation**
  - Ag and Native Areas (Columns a and b) – Inflow to groundwater as a result of precipitation over agricultural and native lands and irrigation of agricultural lands.
  - Urban Areas (Columns c and d) – Inflow to groundwater as a result of precipitation and outdoor water use in urban areas.
- **Natural Recharge at Basin Boundary** (Column 2) – Natural recharge at basin boundaries from deep percolation in small watersheds surrounding the model area plus streambed recharge for small creeks at the model boundaries.
- **Santa Ana River Loss to Groundwater**
  - SAR loss to groundwater (Column 3a) – River loss due to natural streamflows only and does not include RIX discharge to SAR. Large variations in streamflows between wet and dry years result in significant changes in river loss.
  - SAR loss to groundwater due to RIX (Column 3b) – River loss due to approximately 43,200 AFY of RIX effluent discharge to SAR. RIX effluent discharge remains at 2007 levels for the 43 year EC Baseline simulation. Fluctuation in river loss estimates is due to changes in groundwater levels and variations in hydraulic gradient between groundwater and river stage.
- **RIX Percolation Basin Feed** (Column 4) – Portion of RIX influent that is recharged to groundwater at the percolation basins. The percolation basin feed remains at the 2007 levels (with slight increases in leap years).
- **Underflow from Rialto-Colton Basin** (Column 5a) – Underflow from Rialto-Colton Basin to Riverside North through the Rialto-Colton Fault. Approximately 260 AFY of additional underflow occurs due to RIX operation (Column 5b). RIX extraction of groundwater results in a higher groundwater gradient across the Rialto-Colton Fault.

- **Underflow from Riverside South** (Column 6a) – Average underflow from Riverside South is 4,740 AFY. Increased river losses due to RIX effluent discharge to SAR and groundwater extraction by RIX changes the hydraulic gradient between Riverside North and Riverside South and impacts the quantity of underflow between these two basins. RIX operation reduces average underflow from Riverside South by 1,120 AFY (Column 6b).

Outflow

Outflow from Riverside North consists of the following components (refer to Table 18 for quantities and column numbers):

- **Santa Ana River Gain from Groundwater** (Column 8) – Flow of groundwater to Santa Ana River occurring mostly at years when groundwater levels are higher near the river.
- **Groundwater Production** (Column 9) – Groundwater production from all wells that were active in 2007. This column does not include RIX groundwater extraction. Production rates are at the 2007 levels (with slight increases in leap years).
- **RIX Extraction Well Production** (Column 10) – Groundwater extraction by RIX wells. The extraction rates are at 2007 levels. RIX groundwater extraction was approximately 27% higher than recharge rates at the percolation basins (Column 4).
- **Underflow to Rialto-Colton Basin** (Column 11) – Underflow to Rialto-Colton Basin through the Rialto-Colton Fault. This only occurs at wet years.
- **Underflow to Riverside South** (Column 12) – Underflow to Riverside South across the County line. RIX operation reduces the hydraulic gradient between the two basins and results in less underflow to Riverside South. RIX operation reduces the average underflow to Riverside South by 3,360 AFY.
- **Underflow to Chino Basin** (Column 13) – Underflow to Chino Basin across the boundary of Chino Basin and Riverside North.

5.2.3 Riverside South

The water budget for Riverside South is presented in Table 19. The 43-year average total inflow into Riverside South is 57,000 AFY. With a 43-year average total outflow of 58,300 AFY the annual average storage decreases by 1,300 AFY. This is equivalent to 54,600 AF decrease in groundwater storage of Riverside South over 43 years of EC Baseline simulation. Figure 42 presents a diagram of the Riverside South Basin depicting the average annual water budget components of Table 19.

Inflow

The inflow into Riverside South consists of the following components (refer to Table 19 for quantities and column numbers):

- **Deep Percolation**
  - Ag and Native Areas (Columns a and b) – Inflow to groundwater as a result of precipitation over agricultural and native lands and irrigation of agricultural lands.
  - Urban Areas (Columns c and d) – Inflow to groundwater as a result of precipitation and outdoor water use in urban areas.

- **Natural Recharge at Basin Boundary** (Column 2) – Natural recharge at basin boundaries from deep percolation in small watersheds surrounding the model area plus streambed recharge for small creeks at the model boundaries.
- **Santa Ana River Loss to Groundwater**
    - SAR loss to groundwater (Column 3a) – River loss due to natural streamflows only (Column 3a). Variations in streamflows between wet and dry years result in significant changes in river losses.
    - SAR loss to groundwater due to RIX (Column 3b) – River loss due to RIX effluent discharge to SAR. RIX effluent discharge remains at 2007 levels for the 43 year EC Baseline simulation. Fluctuation in river loss estimates is due to changes in groundwater levels and variations in hydraulic gradient between groundwater and river stage.
- **Underflow from Arlington Basin** (Column 4) – Underflow from Arlington Basin to Riverside South. The net groundwater flow between Riverside South Basin and Arlington Basin is approximately 570 AFY for the 43 year EC Baseline simulation.
- **Underflow from Riverside North** (Column 5) – Underflow from Riverside North across the County line. RIX operation reduces the hydraulic gradient between the two basins and results in less underflow from Riverside North. RIX operation reduces the average underflow from Riverside North by 3,360 AFY (Column 5b).

Outflow

Outflow from Riverside South consists of the following components (refer to Table 19 for quantities and column numbers):

- **Santa Ana River Gain from Groundwater**
    - SAR gain from groundwater (Column 7a) – Flow of groundwater to Santa Ana River occurring mostly at southern parts of Riverside South Basin and in the vicinity of Riverside Narrows. The SAR gain from groundwater is much higher in Riverside South than Riverside North. This is a result of SAR channel elevation in conjunction with higher groundwater levels.
    - SAR gain from groundwater due to RIX (Column 7b) – Flow of groundwater to Santa Ana River due to RIX operation. RIX operation rates remain at 2007 levels for the 43 year EC Baseline simulation. Fluctuations in river gain estimates are due to changes in groundwater levels and variations in hydraulic gradient between groundwater and river stage.
- **Groundwater Production** (Column 8) – Groundwater production from all wells in Riverside South that were active in 2007. Production rates are at 2007 levels, except for the 3 Jurupa CSD and Empire Water Company wells discussed earlier. There is a slight increase in production rates of leap years.
- **Underflow to Arlington Basin** (Column 9) – Underflow from Riverside South to Arlington Basin.
- **Underflow to Riverside North** (Column 10) – Average underflow to Riverside North is 4,740 AFY. Increased river losses due to RIX effluent discharge to SAR results in higher groundwater levels downstream from RIX and reduced underflow to Riverside North. RIX operation reduces the average underflow to Riverside North by 1,120 AFY.

5.2.4 Arlington Basin

The water budget for Arlington Basin is presented in Table 20. The 43-year average total inflow into Arlington Basin is 6,690 AFY. With a 43-year average total outflow of 7,060 AFY the annual average storage decreases by 370 AFY. This is equivalent to 15,950 AF decrease in groundwater storage of Arlington Basin over 43 years of EC Baseline simulation. Figure 43 presents a diagram of the Arlington Basin depicting the average annual water budget components of Table 20.

Inflow

Inflow into Arlington Basin consists of the following components (refer to Table 20 for quantities and column numbers):

- **Deep Percolation**
  - Ag and Native Areas (Columns a and b) – Inflow to groundwater as a result of precipitation over agricultural and native lands and irrigation of agricultural lands.
  - Urban Areas (Column c and d) – Inflow to groundwater as a result of precipitation and outdoor water use in urban areas.
- **Natural Recharge at Basin Boundary** (Column 2) – Natural recharge at basin boundaries from deep percolation in small watersheds surrounding the model area plus streambed recharge for small creeks at the model boundaries.
- **Underflow from Temescal Basin** (Column 3) – Underflow from Temescal Basin to Arlington Basin at Arlington Narrows.
- **Underflow from Riverside South** (Column 4) – Underflow from Riverside South to Arlington Basin.

Outflow

Outflow from Arlington Basin consists of the following components (refer to Table 20 for quantities and column numbers):

- **Groundwater Production** (Column 6) – Groundwater production from all wells, except the Western Municipal Water District (WMWD) Desalters, in Arlington Basin that were active in 2007. The production rates are at 2007 levels. There is a slight increase in production rates of leap years.
- **Arlington Desalters Production** (Column 7) - Groundwater production by WMWD Desalter wells. The production rates are at 70% of 2007 levels, as discussed previously. There is a slight increase in production rates of leap years.
- **Underflow to Temescal Basin** (Column 8) – Underflow from Arlington Basin to Temescal Basin at Arlington Narrows.
- **Outflow Due to Hole Lake Area** (Column 9) - Groundwater outflow at Hole Lake area.
- **Underflow to Riverside South** (Column 10) – Underflow from Arlington Basin to Riverside South.

Chapter 6 Safe Yield Estimation

The amount of groundwater available from a basin depends on quantities of inflow, outflow, and storage change components of the basin. The maximum long-term average annual amount of groundwater that could be extracted from a basin without undesirable results is commonly referred to as safe yield. The typical undesirable results are as follows:

- Withdrawing in excess of recharge from natural or artificial sources to the basin, resulting in reduced basin storage
- Lowering of groundwater levels below certain operational thresholds
- Reduction of baseflow to streams
- Interference with groundwater rights of other users in the basin
- Intrusion of saline water or saltwater
- Migration of poor quality groundwater
- Land subsidence

The underlying purpose of establishing safe yield is to optimize the withdrawal from the groundwater basin to preserve the groundwater resources and water quality over time.

There are several definitions available for safe yield of a groundwater basin. The definition provided by the 1969 Western Judgment is presented below.

6.1 Safe Yield Definition by the 1969 Western Judgment

The 1969 Western Judgment defines safe yield as follows:

> "Safe yield is that maximum average annual amount of water that could be extracted from the surface and subsurface water resources of an area over a period of time sufficiently long to represent or approximate long-time mean climatological conditions, with a given pattern of extractions, under a particular set of physical conditions or structures as such affect the net recharge of the groundwater body, and with a given amount of usable underground storage capacity, without resulting in long-term progressive lowering of groundwater levels or other undesirable result. In determining the operational criteria to avoid such adverse results, consideration shall be given to maintenance of adequate groundwater quality, subsurface outflow, costs of pumping, and other relevant factors.
>
> The amount of safe yield is dependent in part upon the amount of water that can be stored in and used from the groundwater reservoir over a period of normal water supply under a given set of conditions. Safe yield is thus related to factors which influence or control groundwater recharge, and to the amount of storage space available to carry over recharge occurring in years of above average supply to years of deficit supply. Recharge, in turn, depends on the available surface water supply and the factors influencing the percolation of that supply to the water table.
>
> Safe yield shall be determined in part through the evaluation of the average net groundwater recharge which would occur if the culture of the safe yield year had existed over a period of normal native supply."

The 1969 Western Judgment specifies a wide range of potential undesirable results that must be considered when defining safe yield.

6.2 Methodology for Estimation of Safe Yield

The 1969 Western Judgment description of safe yield and the EC Baseline model simulation have been used to estimate the safe yield for Riverside North and Riverside South Basins. Although the 1969 Western Judgment does not apply to the Arlington Basin, to have consistency in methodology for estimation of safe yield, the 1969 Western Judgment description of safe yield is also used for the Arlington Basin. The EC Baseline simulation has the following characteristics that conform to the 1969 Western Judgment definition of safe yield:

- **Sufficiently long simulation period to represent or approximate long-time mean climatological conditions**: The modeling analysis includes a 43-year hydrologic period (1965-2007) that includes wet, dry, and normal periods and is considered representative of long-term mean climatological conditions. The selected hydrologic period also starts and ends in a dry period.
- **A given pattern of extractions:** The modeling analysis utilizes the current level of production as represented by 2007 production data.
- **A particular set of physical conditions or structures as such affect the net recharge of the groundwater body:** The modeling analysis utilizes 2007 land use and water use conditions and considers RIX operations and WMWD desalters.
- **A given amount of usable underground storage capacity**: The model identifies usable storage capacity through the physical bedrock representation and the incorporation of the depth and screened intervals of wells.

The EC Baseline simulation was used to estimate safe yield that would not result in “long-term progressive lowering of groundwater levels or other undesirable result” through the water budget calculations. The 1969 Judgment reference to “other undesirable results” are reflected in the analysis as follows:

- **Maintenance of adequate groundwater quality**: While the RAGFM is a groundwater flow model and does not simulate groundwater quality, maintenance of water levels in order to offset progressive lowering of groundwater levels will avoid significant changes to regional groundwater flow patterns that could induce movement of lower quality or contaminated groundwater towards the basins.
- **Subsurface outflow**: Subsurface outflow is directly related to groundwater levels. By controlling progressive lowering of groundwater levels in adjacent (downgradient) basins, changes in subsurface outflow will be controlled.
- **Costs of pumping**: The cost of pumping is directly related to groundwater levels. By controlling progressive lowering of groundwater levels, pumping costs will be controlled.

The safe yield of each basin has been calculated using the following general equation:

Safe Yield = Groundwater Production + Change in Storage

The annual water budgets of the EC Baseline simulation, as shown in Tables 18 to 20 are used to estimate the components of the safe yield equation and estimate the safe yield for Riverside North, Riverside South, and Arlington Basin.

One of the major facilities that would potentially be considered for safe yield in the Riverside Basin is the operation of RIX. However, as discussed earlier in this TM, the RIX operation is essentially a closed one with minimal effects on the groundwater in storage, and therefore not included as part of the safe yield estimates. Any change in future RIX operations is not expected to impact the groundwater available to water supply wells in the basin significantly.

6.3 Safe Yield Estimates

The safe yields for the three basins are estimated from the results of the EC Baseline simulation and are presented in Table 23. Table 23 presents annual groundwater production and storage change of the three basins for 43 years of EC Baseline simulation.

For EC Baseline simulation, groundwater production rates for each year of the simulation are fixed at 2007 levels with some exceptions as previously noted; however, the storage change varies based on hydrologic conditions. The safe yield is calculated as the average groundwater production plus the average annual storage change for 43 years of hydrological conditions of EC Baseline simulation. Average annual yields for 6 different hydrological conditions are also presented in Table 23 for comparison with the estimated safe yields. These hydrological conditions are also illustrated in Figure 44. Average annual yields for recent hydrological conditions of 1996 to 2007, corresponding to RIX operation years, are also presented in Table 23.

Using the above methodology, the safe yields for the three basins are summarized in Table 24 (refer to Table 23 for supporting details).
The safe yield of Riverside North, Riverside South, and Arlington Basins may change with time as a result of improved availability of data or changes in hydrology, quantity or pattern of productions, physical conditions, or expansion of water resources projects in the basins. As such, the safe yield should be re-evaluated when significant operational changes occur in the future.

Chapter 7 Scenario 2 – Near-Term Future Projects Conditions

The objective of Scenario 2 is to evaluate the sustainability of selected future groundwater recharge and production projects and the effectiveness of these projects to offset projected overdraft. The impacts of these projects on groundwater resources were evaluated by comparing the results of Scenario 2 to EC Baseline. The EC Baseline simulation represents the basin under 2007 land use and water demand conditions plus 8,200 AFY groundwater production by Flume wells 2 to 6. Scenario 2 represents the EC Baseline conditions with the addition of the Scenario 2 projects. The assumptions, data, and description of projects used for development of Scenario 2 are presented in the following subsections.

7.1 Assumptions and Data

The simulation period for Scenario 2 is the same as for the EC Baseline: 43 years representing historical hydrologic conditions (1965-2007). Scenario 2 uses the assumptions and data used for the EC Baseline as presented in Table 16 plus the following projects.

7.2 Projects

The groundwater recharge and production projects of Scenario 2, as shown in Figure 45, consist of the following:

- **Proposed Aquifer Storage and Recovery (ASR) Facilities consisting of:**

  - **Inflatable Dam and On-Channel Recharge Facilities**
  - **Off-Channel Recharge Facilities**
- **Proposed Flume 7 Well**
- **Proposed Arlington Basin Recharge Facilities**
  - **Metrolink Basins**
  - **Monroe Basin**
  - **Victoria Basin**
- **Operation of Existing Arlington Desalter Wells at 7,840 AFY**

The model input files for Scenario 2 were developed based on the EC Baseline by adding groundwater recharge at ASR Facilities and Arlington Basin Recharge Facilities as well as groundwater production by Flume 7 well to the EC Baseline model input files. Groundwater production for the existing Arlington Desalter Wells was increased by 2,665 AFY from the EC Baseline rate of 5,175 AFY to 7,840 AFY to represent the current level of groundwater production. Details of these changes are described below.

7.2.1 ASR Facilities

The ASR Facilities consists of an inflatable dam, on-channel recharge facilities located within the Santa Ana River channel, and five off-channel recharge basins. The proposed area for the on-channel recharge is approximately 21 acres located within the Santa Ana River channel in the Rialto-Colton Basin. The area for the five off-channel recharge basins is approximately 30 acres in Riverside North Basin. The source of recharge water for the ASR Facilities is Santa Ana River flows.

The operational capacity of the inflatable dam is 1,500 cfs. Santa Ana River flows higher than this threshold for operation can not be captured by the inflatable dam. It is assumed that a total of 13,000 AFY of Santa Ana River flows would be available for recharge at the ASR Facilities. Off-channel recharge basins are assumed to operate 60 days per year during the months of March, April, October, and November. On-channel recharge basins will operate throughout the year, although the monthly volume recharged varies seasonally. The monthly recharge rates at the ASR Facilities is based on average Santa Ana River flow rates for the period 1966 through 2009 (Geoscience, 2010) and is presented in Table 25.

7.2.2 Flume 7 Well

Flume 7 well is located in Riverside North and is assumed to operate continuously at 2,700 gpm or 4,360 AFY. This is a new well and this production is in addition to the Flume wells 2 to 6 production already in the EC Baseline.

7.2.3 Arlington Basin Groundwater Recharge Facilities

The 2007 groundwater production rates at the Arlington Basin represent an annual overdraft of approximately 3,000 AFY. Western Municipal Water District (WMWD) proposes to recharge 3,000 AFY at Victoria, Monroe, and Metrolink flood control basins to offset the groundwater production in excess of the safe yield value of 6,000 AFY. The monthly recharge rates at these basins, as provided by WMWD, are presented in Table 26.

7.2.4 Arlington Desalter Wells

The current groundwater production rates of desalter wells were not sustainable for the EC Baseline simulation. Therefore, a lower sustainable production rate of 5,175 AFY was used for the desalter wells in the numerical model for the EC Baseline simulation. The additional groundwater recharge in Arlington Basin Groundwater Recharge Facilities is expected to allow higher pumping rates of the desalter wells. Groundwater production by the existing Arlington desalter wells is increased to 7,840 AFY (current pumping rates) to demonstrate if the additional recharge and pumping strategy is feasible. The production rates of the desalter wells AD1, AD2, AD3, AD4, and AD5 are 1,830 AFY, 830 AFY, 1,830 AFY, 1,675 AFY, and 1,675 AFY, respectively. AD1 is the most southerly well. For reference, the desalter wells averaged 7,500 AFY over the 2006-2008 time period.

7.3 Results

This section provides a summary of the RAGFM results for Scenario 2. The groundwater production and recharge components of Scenario 2 simulation and the resulting changes in groundwater storage and groundwater elevations are summarized in Table 27. Additionally, the impacts of the proposed projects are illustrated by hydrographs and contour maps of groundwater elevations.

The groundwater elevations at the beginning and end of simulation of Scenario 2 are shown in Figures 46a and 47. The net changes in groundwater elevation due to the proposed projects at the end of simulation are shown in Figure 48. This figure shows the difference (Scenario 2 minus Baseline) of the groundwater elevations shown in Figures 46 and 47. The groundwater elevations at 12 calibration wells for the EC Baseline and Scenario 2 are shown in Figures 49a to 49l. The groundwater elevations at the three 1969 Western Judgment Index Wells (Johnson, Flume 2, and Flume 5 wells) are shown in Figures 50a to 50c. The locations of the calibration wells and the Index Wells are shown on Figure 48. The average groundwater elevations at the three Index Wells are shown in Figure 51.

In general, the groundwater elevation differences match the pattern of groundwater recharge and production projects of Scenario 2 with the increased groundwater elevation occurring in the vicinity of the recharge facilities and decreased groundwater elevations occurring in the vicinity of the groundwater production wells.

The groundwater elevations in Rialto-Colton Basin increase slightly due to 10,000 AFY of groundwater recharge at the on-channel ASR facilities (Figures 48 and 50a). Approximately all of this recharged groundwater flows into Riverside North Basin where an additional 3,000 AFY of groundwater recharge is simulated at the off-channel ASR facilities. The additional 13,000 AFY of ASR groundwater recharge water is used to offset the additional 14,220 AFY of groundwater production by the Flume wells and Colton wells 30 and 31. The net increase (1,220 AFY) in groundwater production in Riverside North Basin results in lower groundwater elevations in Riverside North Basin and northern half of Riverside South Basin (Figures 48, 49a to 49g).

The impacts of the Arlington Basin groundwater recharge operations at Victoria and Monroe basins can be seen by a groundwater mound at the Victoria basin (Figure 48). The groundwater mound is higher at this location due to higher recharge rates combined with lower hydraulic conductivity of the aquifer at this basin. Groundwater elevations of Scenario 2 are lower than the Baseline groundwater elevations in the vicinity of the desalter wells and in the area west of La Sierra Avenue. The groundwater elevation decrease in this area is due to higher desalter production rates of Scenario 2.

The water recharged at the Metrolink Basins is captured by the desalter wells. However, approximately 50% of the water recharged at the Victoria and Monroe Basins is captured by the desalter wells. In Scenario 2, approximately 680 AFY of 1,450 AFY of the water recharged at the Victoria and Monroe Basins flows to the Riverside South Basin as increased groundwater underflow out of Arlington Basin to Riverside Basin. This results in slightly increased groundwater elevations in southern half of the Riverside South Basin.

7.4 Summary

The purpose of Scenario 2 was to evaluate the effectiveness of selected future groundwater recharge and production projects to offset the projected overdraft. The results of the simulation show that the additional future extraction projects will need to be offset by additional recharge facilities to prevent significant impact on groundwater elevations and to keep the basins in balance.

Chapter 8 Scenario 3 – Long-Term Future Projects Conditions

The objective of Scenario 3 is to estimate the maximum volume of water that can be recharged at the ASR Facilities in Riverside Basin, within certain constraints, and evaluate the sustainability of selected future groundwater production projects in Arlington and Riverside Basins. The impacts of these projects on groundwater resources were evaluated by comparing the results of Scenario 3 to the EC Baseline. The EC Baseline simulation represents the basin under 2007 land use and water demand conditions plus 8,200 AFY groundwater production by Flume Wells 2 to 6. Flume Wells were not operating in 2007; however, these wells are currently in operation. Scenario 3 represents the EC Baseline conditions with the addition of the Scenario 3 projects. The assumptions, data, and description of projects used for development of Scenario 3 are presented in the following subsections.

8.1 Assumptions and Data

The simulation period for Scenario 3 is the same as for the EC Baseline: 43 years representing historical hydrologic conditions (1965-2007). Scenario 3 uses the assumptions and data used for the EC Baseline as presented in Table 16 plus the following projects.

8.2 Projects

The groundwater recharge and production projects of Scenario 3, as shown in Figure 52, consist of the following:

- **Proposed Aquifer Storage and Recovery (ASR) Facilities consisting of:**
  - **Inflatable Dam and On-Channel Recharge Facilities**
  - **Off-Channel Recharge Facilities**
- **Proposed Flume 7 Well**
- **Colton Wells 30 and 31**
- **Proposed West Valley Water District (WVWD) wells at 8,630 AFY**
- **Proposed Arlington Basin Recharge Facilities**
  - **Metrolink Basins**
  - **Monroe Basin**
  - **Victoria Basin**
- **Operation of Existing Arlington Desalter Wells**
- **Proposed New Arlington Desalter Wells**

The model input files for Scenario 3 were developed based on the EC Baseline by adding groundwater recharge at ASR Facilities and Arlington Basin Recharge Facilities as well as groundwater production by Flume 7 well, WVWD wells, and new desalter wells to the EC Baseline model input files. Groundwater production for the existing and the proposed Arlington Desalter Wells was increased to 9,350 AFY to represent the expanded level of groundwater production by desalter wells. Details of these changes are described below.

8.2.1 ASR Facilities

For modeling purposes, it is assumed that unlimited recharge water is available for the ASR on-channel and off-channel Facilities. The source of recharge water for the ASR Facilities is Santa Ana River flows. An objective of Scenario 3 is to estimate the maximum water volume that can be recharged at the ASR Facilities without the groundwater elevations rising higher than 25 feet below ground surface in Flume 2 or 5. In other words, the depth to groundwater will not be less than 25 feet at these wells.

It was assumed that a long-term maximum recharge rate of 3.0 feet/day could be achieved at the ASR Facilities (OCWD, Personal Communications, 2008). Operation of the ASR Facilities at these high recharge rates requires 56,400 AFY of recharge water (23,000 AFY and 33,400 AFY for the on-channel and off-channel facilities, respectively). However, the maximum recharge rate of 56,400 AFY results in high groundwater elevations and violation of the 25 feet below ground surface criteria. Several model runs were developed by gradually decreasing the annual recharge rate at the ASR Facilities to determine the maximum acceptable recharge rates. An annual recharge rate of 30,900 at the ASR Facilities generated groundwater levels that were lower than 25 feet below ground surface elevation at 100% of simulation time at the Johnson and Flume 2 wells and at 90% of simulation time at Flume 5 (Figures 50a, b, and c). High groundwater elevations result in reduced recharge rates of the Santa Ana River. Thus, the maximum recharge rate (30,900 AFY) represents a corrected rate that is adjusted for 1,500 AFY reduction in the Santa Ana River recharge rates.

8.2.2 Flume 7 Well

Flume 7 well is located in Riverside North and is assumed to operate continuously at 2,700 gpm or 4,360 AFY. This is a new well and this production is in addition to the Flume Wells 2 to 6 production already in the EC Baseline.

8.2.3 Colton Wells 30 and 31

Colton Wells 30 and 31 are located in Riverside North and are assumed to produce 4,035 AFY per well or a total of 8,070 AFY. This will increase Colton production to 9,735 AFY.

8.2.4 WVWD Wells

The WVWD production rate within the model area is increased by 8,630 AFY from 2,560 AFY to 11,190 AFY. The additional water is produced by nine (9) proposed wells in Riverside North Basin.

8.2.5 Arlington Basin Proposed Groundwater Recharge Facilities

Western Municipal Water District (WMWD) proposes to recharge 3,980 AFY at Victoria, Monroe, and Metrolink basins to offset the groundwater production in excess of the safe yield value of 6,000 AFY. The monthly recharge rates at these basins, as provided by WMWD, are presented in Table 26.

8.2.6 Arlington Desalter Wells

The additional groundwater recharge in Arlington Basin Groundwater Recharge Facilities is expected to allow an increase in production of the desalter wells. Groundwater production by the existing Arlington desalter wells is increased to 7,420 AFY and the two new desalter wells with a total production rate of 1,935 AFY were added to Scenario 3 to demonstrate if the additional recharge and pumping strategy is feasible. The simulated production rates of the existing desalter wells AD1, AD2, AD3, AD4, and AD5 are 1,451 AFY, 1,290 AFY, 1,613 AFY, 1,613 AFY, and 1,451 AFY, respectively. AD1 is the most southerly well. The production rates of the proposed desalter wells of AD-New1 and AD-New2 are 968 AFY per well. For reference, the production rate of the existing desalter wells averaged 7,500 AFY over the 2006-2008 time period.

8.3 Results

The groundwater production and recharge components of Scenario 3 simulation and the resulting changes in groundwater storage and groundwater elevations are summarized in Table 27. Additionally, the impacts of the proposed projects are illustrated by hydrographs and contour maps of groundwater elevations.

The groundwater elevations at the beginning and end of simulation of Scenario 3 are shown in Figures 46a and 53. The net changes in groundwater elevation due to the proposed projects at the end of simulation are shown in Figure 54. This figure shows the difference (Scenario 3 minus Baseline) of the groundwater elevations shown in Figures 46 and 53. The groundwater elevations at 13 calibration wells for Scenario 3 are shown in Figures 49a to 49m. The groundwater elevations at the three 1969 Western Judgment Index Wells (Johnson, Flume 2, and Flume 5 wells) are shown in Figures 50a to 50c. The locations of the calibration wells and the Index Wells are shown on Figure 54. The average groundwater elevations at the three Index Wells are shown in Figure 51.

In general, the groundwater elevation differences match the pattern of groundwater recharge and production projects of Scenario 3 with increased groundwater elevations occurring in the vicinity of the recharge facilities and decreased groundwater elevations occurring in the vicinity of the groundwater production wells.

The groundwater elevations in Rialto-Colton Basin increase significantly due to groundwater recharge at the on-channel ASR facilities (Figures 54 and 50a). The maximum recharge rate of 30,900 AFY of ASR groundwater recharge water is used to offset the additional groundwater production by the Flume Wells, Colton wells 30 and 31, and WVWD. The increase in groundwater recharge in Riverside North Basin results in higher groundwater elevations in Riverside North Basin and northern half of Riverside South Basin (Figures 54, 49a to 49g).

The impacts of the Arlington Basin proposed Groundwater Recharge Facilities at Victoria and Monroe basins can be seen by a groundwater mound at the Victoria basin (Figure 54). The groundwater mound is higher at the Victoria basin due to higher recharge rates combined with lower hydraulic conductivity of the aquifer at this basin. Groundwater elevations of Scenario 3 are lower than the Baseline groundwater elevations in the vicinity of the existing desalter wells and in the area west of La Sierra Avenue. The average groundwater elevation decrease of 15.6 feet in this area is due to higher desalter production rates of Scenario 3.

The water recharged at the Metrolink Basins is captured by the existing desalter wells. However, not all of the water recharged at the Victoria and Monroe Basins is captured by the desalter wells. In Scenario 3, some of the water recharged at the Victoria and Monroe Basins flows to the Riverside South Basin as increased groundwater underflow out of Arlington Basin to Riverside Basin. This results in slightly increased groundwater elevations in southern half of the Riverside South Basin.

Operation of Scenario 3 projects in Arlington Basin results in average annual storage change of -420 AFY, an average of 40 AFY more aquifer storage loss than the EC Baseline. Operation of Arlington Basin under Scenario 3 projects is less sustainable than EC Baseline.

8.4 Summary

The purpose of Scenario 3 was to estimate the maximum recharge rates at the ASR Facilities without groundwater elevations rising above the 25 feet below ground surface elevation and to evaluate the effectiveness of selected future groundwater recharge and production projects to offset the projected overdraft. The results of the simulation show that the additional future extraction projects will need to be offset by additional recharge facilities to prevent significant impact on groundwater elevations and to keep the basins in balance. Additionally, the maximum recharge rates at the ASR Facilities are limited by the available aquifer storage volume in the Riverside North and Colton Basins. The available aquifer storage in Riverside North Basin is limited by the high seepage rates from the Santa Ana River during the wet and normal years and the production rates of the groundwater extraction projects.

Chapter 9 Scenario 4 – 2015 Future Projects Conditions

The objective of Scenario 4 is to evaluate the sustainability of 2015 future groundwater recharge and production projects and the effectiveness of these projects to offset projected overdraft. The intent of Scenario 4 for Riverside North Basin is to evaluate the impact of new production wells with the ASR

Facilities operating at lower recharge rates. Additionally, the impact of the Pellissier Ranch ASR Facilities was evaluated. The impacts of these projects on groundwater resources were evaluated by comparing the results of Scenario 4 to the EC Baseline. Scenario 4 represents the EC Baseline conditions with the addition of the Scenario 4 projects. The assumptions, data, and description of projects used for development of Scenario 4 are presented in the following subsections.

9.1 Assumptions and Data

The simulation period for Scenario 4 is the same as for the EC Baseline: 43 years representing historical hydrologic conditions (1965-2007). Scenario 4 uses the assumptions and data used for the EC Baseline as presented in Table 16 plus the following projects.

9.2 Projects

The groundwater recharge and production projects of Scenario 4, as shown in Figure 55, consist of the following:

- **Proposed Aquifer Storage and Recovery (ASR) Facilities consisting of Off-Channel Recharge Facilities**
- **Pellissier Ranch ASR Facilities**
- **Proposed Flume 7 Well**
- **Colton Well 30**
- **Proposed West Valley Water District (WVWD) wells operating at 5,650 AFY**
- **Proposed Arlington Basin Recharge Facilities**
    - **Monroe Basin**
    - **Victoria Basin**
- **Existing Arlington Desalter Wells**
- **Proposed New Arlington Desalter Wells**
- **Reduced Groundwater Production by La Sierra University Wells**

The model input files for Scenario 4 were developed based on the EC Baseline by adding groundwater recharge at ASR Facilities and Arlington Basin Recharge Facilities as well as groundwater production by Flume 7 well, Colton Well 30, WVWD wells, and new desalter wells to the EC Baseline model input files. Groundwater production for the existing and the proposed Arlington Desalter Wells was increased to 8,640 AFY to represent the expanded level of groundwater production by desalter wells. Details of these changes are described below.

9.2.1 ASR Facilities

It is assumed that limited recharge water is available for the ASR off-channel Facilities to offset the additional groundwater production in Riverside North Basin. The source of recharge water for the ASR Facilities is Santa Ana River flows. An objective of Scenario 4 is to estimate the minimum recharge volume at the ASR Facilities that is necessary to sustain the additional groundwater production in Riverside North Basin.

The additional groundwater production of Scenario 4 in Riverside North Basin could not be sustained without additional recharge at the ASR off-channel Facilities. Several model runs were developed with gradually increasing the annual recharge rates at the ASR off-channel Facilities. The results of these model runs indicated that recharging a minimum of 6,000 AFY at the ASR off-channel Facilities is necessary to sustain the additional groundwater production in Riverside North Basin.

9.2.2 Pellissier ASR Facilities

This project consists of 10,000 AFY of groundwater recharge and an increase in production in RPU potable wells accordingly. The recharge ponds of the Pellissier ASR Facilities will be built at the Pellissier Ranch located just north of the County line in Riverside North Basin. However, the extraction wells will be built in Riverside South Basin just south of the County line. The source of recharge water will be 40% tertiary treated recycled water and 60% diluent water using a 120-month rolling average. The diluent water sources are storm flows during rain events and groundwater supplies from other groundwater basins. The recharge ponds have not been located but they will be inland to minimize the recharged water mixing with the river underflow that leaves the capture zone. The recharge ponds will also need to be at least 6-month (groundwater travel time) north of the extraction wells. In Scenario 4, the Pellissier recharge ponds were placed half a mile from the Santa Ana River and half a mile from the existing RPU production wells.

RPU has 8 existing production wells in this area that are connected to the Palmyrita pipeline. It is assumed that five (5) new production wells will be added to this set of wells to capture the recharged water. In Scenario 4, five new production wells were added to the RPU wells in the vicinity of the Palmyrita pipeline to extract 10,000 AFY of recharge water.

9.2.3 Flume 7 Well

Flume 7 well is located in Riverside North and is assumed to operate continuously at 2,700 gpm or 4,360 AFY. This is a new well and this production is in addition to the Flume wells 2 to 6 production already in the EC Baseline.

9.2.4 Colton Well 30

Colton Well 30 is located in Riverside North and is assumed to produce 4,035 AFY. This will increase Colton production in the model area to 5,700 AFY.

9.2.5 WVWD Wells

The WVWD production rate in the model area is increased by 3,090 AFY from 2,560 AFY to 5,650 AFY. The additional water is produced by nine (9) proposed wells in Riverside North Basin.

9.2.6 Arlington Basin Proposed Groundwater Recharge Facilities

Western Municipal Water District (WMWD) proposes to recharge 2,970 AFY at Victoria and Monroe flood control basins to offset the groundwater production in excess of the safe yield value of 6,000 AFY. The monthly recharge rates at these basins, as provided by WMWD, are presented in Table 26.

9.2.7 Arlington Desalter Wells

The additional groundwater recharge in Arlington Basin Groundwater Recharge Facilities is expected to allow an increase in production of the desalter wells. Groundwater production by the existing Arlington desalter wells is set at 5,025 AFY and three new desalter wells with a total production rate of 3,612 AFY were added to Scenario 4 to demonstrate if the additional recharge and pumping strategy is feasible. The production rates of the existing desalter wells AD1, AD2, AD3, AD4, and AD5 are 1,256 AFY, 603 AFY, 1,005 AFY, 1,156 AFY, and 1,005 AFY, respectively. AD1 is the most southerly well. The production rates of the proposed desalter wells of AD-New8, AD-New11 and AD-New13 are 1,606 AFY, 1,364 AFY, and 642 AFY. For reference, the production rate of the existing desalter wells averaged 7,500 AFY over the 2006-2008 time period.

9.2.8 Reduced Groundwater Production by La Sierra University Wells

The groundwater production by La Sierra University wells will be stopped in Scenario 4. WMWD proposes to provide approximately 1,050 AFY of recycled water to La Sierra University to offset the reduction in groundwater production.

9.3 Results

The groundwater production and recharge components of Scenario 4 simulation and the resulting changes in groundwater storage and groundwater elevations are summarized in Table 27. Additionally, the impacts of the proposed projects are illustrated by hydrographs and contour maps of groundwater elevations.

The groundwater elevations at the beginning and end of simulation of Scenario 4 are shown in Figures 46a and 56. The net changes in groundwater elevation due to the proposed projects at the end of simulation are shown in Figure 57. This figure shows the difference (Scenario 4 minus Baseline) of the groundwater elevations shown in Figures 46 and 56. The groundwater elevations at 13 calibration wells for Scenario 4 are shown in Figures 49a to 49m. The groundwater elevations at the three 1969 Western Judgment Index Wells (Johnson, Flume 2, and Flume 5 wells) are shown in Figures 50a to 50c. The locations of the calibration wells and the Index Wells are shown on Figure 57. The average groundwater elevations at the three Index Wells are shown in Figure 51.

In general, the groundwater elevation differences match the pattern of groundwater recharge and production projects of Scenario 4 with the increased groundwater elevation occurring in the vicinity of the recharge facilities and decreased groundwater elevations occurring in the vicinity of the groundwater production wells.

The groundwater elevations in Rialto-Colton, Riverside North and northern half of Riverside South Basins decrease due to additional groundwater production in Riverside North Basin (Figure 57). Recharging 6,000 AFY at the off-channel ASR Facilities is not sufficient to offset the additional groundwater production by the Flume wells, Colton well 30, and WVWD wells (Figures 57, 49a to 49g).

The impacts of the Arlington Basin groundwater recharge operations at Victoria and Monroe basins can be seen by a groundwater mound at the Victoria basin (Figure 57). Groundwater elevations of Scenario 4 are lower than the Baseline groundwater elevations in the vicinity of the proposed desalter wells. However, the groundwater elevations of Scenario 4 are higher in the area west of La Sierra Avenue. The groundwater elevation increase in this area is due to no production by La Sierra University wells in Scenario 4.

Operation of Scenario 4 projects in Arlington Basin results in average annual storage change of -40 AFY, an average of 340 AFY less aquifer storage loss than the EC Baseline. Operation of Arlington Basin under Scenario 4 projects is sustainable as loss of aquifer storage is not significant.

9.4 Summary

The purpose of Scenario 4 was to evaluate the impact of 2015 future groundwater recharge and production projects to offset the projected overdraft. The results of the simulation show that the additional future extraction projects in the Riverside North and Riverside South Basins will need to be offset by additional recharge facilities to prevent significant impact on groundwater elevations and to keep the basins in balance. The groundwater recharge and production in Arlington Basin is in balance. However, due to changes in production quantities and locations the groundwater elevations are lower in the vicinity of the proposed desalter wells and higher in the vicinity of the existing desalter wells.

Chapter 10 References

ASTM, 2002. *Calibrating a Ground-Water Flow Model Application.* American Society of Testing Material Standards. West Conshohocken, Pennsylvania.

American Water Works Association, 2001, *Water Resources Planning Manual.*

California Department of Water Resources, 1971, *Meeting water demands in the Bunker Hill-San Timoteo area – geology, hydrology, and operation-economics studies:* California Department of Water Resources Bulletin 104-5, Memorandum Report, text and plates, 395 p.

CH2M Hill, 2003. *Update of the Groundwater Flow Model and Assessment of Operational Performance Criteria for the RIX Facility*. Prepared for Colton/San Bernardino Regional Tertiary Treatment and Water Reclamation Authority.

Danskin, W.R., K.R. McPherson, and L.R. Woolfenden, 2005, *Hydrology, Description of Computer Models, and Evaluation of Selected Water-Management Alternatives in the San Bernardino Area, California.* U.S. Geological Survey Open-File Report 2005-1278.

Dogrul, E. C., 2007, *Soil Moisture Routing and Agricultural Demand Computation in IWFM Demand Calculator (IDC v1.0)*. Hydrology Development Unit, Modeling Support Branch, Bay-Delta Office, California Department of Water Resources.

Geoscience, 2009, *BunkerHill model layer elevations*. Personal communications.

Geoscience, 2010. *Groundwater modeling results for evaluation of impacts from pumping the proposed Flume 7 well*. Prepared for City of Riverside, April 29.

GeoTrans, 2003, *Riverside Groundwater Basin Study Report, Project Agreement 16 – Phase 2.* Prepared for the Santa Ana Watershed Project Authority and the City of Riverside Public Utilities Department, Water Division.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald. 2000, *MODFLOW-2000, The U.S. Geological Survery Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-water Flow Process.* U.S. Geological Survey Open-File Report 00-92.

National Resources Conservation Service, 2009, *Soil Survey Data*. Soil Data Mart of National Resources Conservation Service. http://soildatamart.nrcs.usdata.gov

Numeric Solutions, 2009, *Three-Dimensional Geologic Model of Riverside and Arlington Basins*. Personnal Communications.

Riverside Public Utilities, 2008, 2008 Land Use Shape File. Personal communications with Tom Field, Riverside Public Utilities.

Rumbaugh, J.O. and D.B. Rumbaugh, 2007, *Guide to Using Groundwater Vistas, Version 5*. Environmental Simulations, Inc. www.groundwatermodels.com

Savanah River Site (SRS), 2006. *Groundwater Modeling in the RCRA/CERCLA Process.* Environmental Restoration Division, Regulatory Document Handbook, Manual: ERD-AG-003-Part P.1.12, Protocols. *http://www.srs.gov/general/programs/soil/ffa/rdh/rdh.html*

Scott, M.B., 1976, *Development of Water Facilities in the Santa Ana River Basin, California, 1810-1968.* U.S. Geological Survey Open File Report # 77-398. Menlo Park, CA: U.S. Geological Survey.

Southern California Association of Governments (SCAG), 2009; 1990, 1993, 2001, and 2005 Land Use Shape Files. Personal communications with Javier Minjares, Senior Regional Planner, Data & GIS, Southern California Association of Governments. 213-236-1893.

Taghavi, A., S. Najmus, and D. Wang, 2003, *Integrated Groundwater and Surface water Model (IGSM) User's Manual.* Water Resources and Information Management Engineering, Inc. www.wrime.com.

Western Municipal Water District of Riverside County v. East San Bernardino County Water District et al. 1969, Riverside County Superior Court, Case No. 78426. April 17.

Western Municipal Water District, 2008; 2008 Aerial Photo of Riverside and Arlington Basins. Personal communications with Fakhri Manghi, Western Municipal Water District.

Wildermuth, 2007, *2007 CBWM Groundwater Model Documentation and Evaluation of the Peace II Project Description*. Prepared for Chino Basin Watermaster.

Wildermuth, 2008. *Feasibility Study for the Expansion of the Arlington Desalter System – Task 1 Report: Arlington Basin Groundwater Flow Model.* Prepared for Western Municipal Water District.

Woolfenden, L. and K. Koczot. 2001, *Numerical Simulation of Ground-Water Flow and Assessment of the Effects of Artificial Recharge in the Rialto-Colton Basin, San Bernardino County, California*, USGS Water-Resources Investigation Report 00-4243. Prepared in Cooperation with the San Bernardino Valley Municipal Water District.

WRIME, 2009, *Task 3.2 Conceptual Model.* Technical Memorandum for Task 3.2 of Riverside/Arlington Basins Numerical Groundwater Model and GWMPs Development. project.wrime.com

WRIME, 2009, *Task 3.3 Numerical Model.* Technical Memorandum for Task 3.3 of Riverside/Arlington Basins Numerical Groundwater Model and GWMPs Development. project.wrime.com

WRIME, 2010. *Task 4 - Numerical Model Calibration, Validation, and Sensitivity Analysis*. Prepared for the City of Riverside, May 25.