Upper Santa Ana River Integrated Model
Summary Report

Prepared For: San Bernardino Valley Municipal Water District

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GEOSCIENCE

UPPER SANTA ANA RIVER INTEGRATED MODEL

SUMMARY REPORT

1.0 EXECUTIVE SUMMARY

1.1 Introduction

GEOSCIENCE Support Services, Inc. (GEOSCIENCE) was tasked with constructing a groundwater flow model for the Upper Santa Ana Valley Groundwater Basin by integrating existing groundwater and surface water models. This model, known as the Integrated SAR Model, was used as a management tool to determine what factors contribute to reduced streamflow in the SAR, and to evaluate potential effects from proposed projects on streamflow and groundwater levels across the basin, including Upper SAR Habitat Conservation Plan (HCP) “Covered Activities”.

The development of the Integrated SAR Model represents a cooperative technical effort involving:

- Representatives of participating parties, including San Bernardino Valley Municipal Water District (Valley District), Western Municipal Water District (Western), Inland Empire Utilities Agency (IEUA), Orange County Water District (OCWD), City of Riverside Public Utilities (RPU), United States Geological Survey (USGS), United States Fish and Wildlife Survey (USFWS), and the California department of Fish and Wildlife (CDFW);
- Representatives of participating parties’ consultants Aspen Environmental Group (Aspen), GEOSCIENCE, Leidos, and Numeric Solutions;
- Technical advisors representing the Balleau Groundwater, Inc. (BGW), Chino Basin Watermaster, ICF, the Santa Ana Regional Water Quality Control Board, the Santa Ana Watershed Project Authority (SAWPA), University of California, Riverside (UCR), U.S. Army Corps of Engineers (USACE), and Wildermuth Environmental, Inc. (WEI).

Collectively, this group represents the Technical Advisory Committee (TAC). Collaboration by these representatives to develop the Integrated SAR Model was achieved through participation at project conference calls, model workshops, and by reviewing and commenting on draft technical memoranda and model files. During the course of this project, individual tasks were summarized in several technical memorandums (TMs). Each draft TM was submitted to the Technical Advisory Committee (TAC) for comment and review. This Summary Report incorporates the material from all previously issued TMs and TAC comments.

Previous groundwater models that were used as a basis for the Integrated SAR Model are the:

- Yucaipa Groundwater Model (GEOSCIENCE, 2017),
- Refined Basin Flow Model/Newmark Groundwater Flow Model (RBFM/NGFM) for the SBBA (GEOSCIENCE, 2009; GEOSCIENCE and Stantec, in progress),
- Rialto-Colton Groundwater Model (GEOSCIENCE, 2015),
- Riverside-Arlington Groundwater Model (WRIME, 2010), and
- Chino Basin Model (WEI, 2015; reconstructed by GEOSCIENCE for this project).

The process of updating and integrating the existing models was summarized in TM No. 1: Model Integration (GEOSCIENCE, 2018a) and is included here as Section 5.0. Since model files were not available for the WEI Chino Basin Model, GEOSCIENCE constructed a separate version of the model based on the approach and data presented in WEI's modeling report (2015). This is discussed in Section 6.0.

Existing watershed models include the:

- Wasteload Allocation Model (WEI, 2009),
- SBBA Riverside Basin Watershed Model (GEOSCIENCE, 2013),
- Yucaipa Watershed Model (GEOSCIENCE, 2014), and
- Wasteload Allocation Model Update (GEOSCIENCE, 2019e).

A watershed model for the Upper SAR Watershed was developed and calibrated from 1966 through 2016 to simulate runoff generated within the watershed and quantify runoff for the Integrated SAR Model (Section 7.0).

Development and calibration of the Integrated SAR Model is discussed in Sections 8.0 and 9.0, respectively. Following model calibration, scenario runs were developed and conducted to assess the hydrologic response of the Upper SAR to various project activities, as presented in Section 10.0. Sections 11.0 and 12.0 of this Summary Report discuss uses and limitations of the Integrated SAR Model, as well as future work.

1.2 Conceptual Model of the Integrated SAR Model

The Upper Santa Ana Valley Groundwater Basin incorporates the Yucaipa, SBBA, Rialto-Colton, Riverside-Arlington, Chino, and Temescal Groundwater Basins. In general, the conceptual geologic models for the six groundwater basins within the Upper Santa Ana Valley Groundwater Basin are similar with respect to the geologic materials present, with minor variations. With respect to geologic history, the Yucaipa, SBBA, and Rialto-Colton basins share similar and overlapping depositional histories due to local tectonics associated with movement along the San Jacinto, San Andreas, and associated faults. Likewise, the Riverside-Arlington, Temescal, and Chino Basins share similar geologic histories. The geologic conceptual model forms the basis for the hydrogeologic conceptual model, which in turn informed the construction of the numerical Integrated SAR Model for the simulation of groundwater flow through the geologic formations.

In order to integrate the existing groundwater models, it was necessary to review the individual conceptual models and identify similarities and differences. It was also necessary to develop an approach for extending model layers – representing geologic units – across existing model boundaries. The hydrogeologic conceptual model provided a framework for identifying geologic units within the Integrated SAR Model domain, identifying sources of inflow and outflow to the groundwater systems, and correlating hydrogeologic units (model layers) between groundwater basins. The hydrogeologic conceptual model of the Integrated SAR Model domain, in combination with the three-dimensional (3-D) lithologic model that was developed for the Integrated SAR Model area, was used to delineate and assign model layers.

1.3 Update of Existing Groundwater Models

Model integration involved updating the existing groundwater flow models (i.e., Yucaipa, SBBA, Rialto-Colton, and Riverside-Arlington Models) with the appropriate resolution, or cell size, and orientation to match that of the Integrated SAR Model. The existing groundwater flow models were also updated so that the hydrologic data covered the model calibration period from January 1966 through December 2016. To complete the model integration process, the unified model layers were applied to the updated groundwater flow models. The individual models were then rerun within the Integrated SAR Model grid to ensure the updated results were consistent with the original existing models. Next, the specified underflow boundary conditions in the individual models were removed and the Integrated SAR Model was run and calibrated without specific underflow across basin boundaries (underflow inflow and outflow across existing model boundaries are simulated by the Integrated SAR Model).

1.4 Construction and Calibration of the Chino Basin Model

In the Chino Basin area of the Integrated SAR Model, existing model files were unavailable. Therefore, a separate version of the Chino Basin Model was constructed and calibrated in the Integrated SAR Model grid. Construction was initially based on available data presented in WEI's model report (2015), but the Chino Basin Model presented herein does differ from the WEI model. Some model parameters and fluxes were developed using different approaches and model parameters were refined through model calibration.

1.4.1 Chino Basin Model Initial Calibration Results

During the Chino Basin Model calibration, model parameters were manually adjusted within acceptable limits until model-generated water levels match historical water level measurements at wells across the model area, thereby reducing residual error. The Chino Basin Model was calibrated using this industry standard "history matching" technique for the period from January 1966 through December 2016. The calibration process used 23,086 water level measurements from 115 calibration target wells from which to match model generated head values against the measured values. These target water levels were later down-sampled to monthly measurement intervals during calibration of the Integrated SAR Model based on feedback from the TAC. Aquifer parameters varied during the model calibration included horizontal and vertical hydraulic conductivity, specific yield, specific storage, horizontal flow barrier conductance, and streambed conductance.

1.5 Upper Santa Ana River Watershed Model

In order to simulate the streamflow more accurately, runoff generated from precipitation within the Upper Santa Ana Valley Groundwater Basin was calculated using a watershed model, which was then included in the Streamflow Package for the Integrated SAR Model. The Upper SAR Watershed Model was developed for the Santa Ana Watershed Project Authority (SAWPA) during the SAR Waste Load Allocation Model (WLAM) Update using the Hydrologic Simulation Program - Fortran (HSPF) computer code (GEOSCIENCE, 2019e). This watershed model was calibrated for the period from October 1, 2006 through September 30, 2016 (Water Year 2007 through 2016) using 2012 land use. For the Integrated SAR Model, the watershed model calibration period was expanded to include the period from January 1966 through December 2016 with additional land use maps from 1963, 1984, 1994, and 2005.

1.5.1 Watershed Model Calibration

The model was calibrated against measured streamflow for the period from January 1, 1966 through December 31, 2016. Streamflow data from three major gaging stations along the SAR were used during the calibration process, including:

- Santa Ana River at E Street,
- Santa Ana River at MWD Crossing, and
- Santa Ana River into Prado Dam.

The results of the Upper SAR Watershed Model calibration are summarized in the following tables.

Table 1-1. Summary of Upper SAR Watershed Model Results – Daily Simulated Streamflow Performance

Gaging Station	Avg. Observed Flow [cfs]	Avg. Model-Simulated Flow [cfs]	Mean Residual [cfs]	Mean Residual as % of Avg. Observed Flow	R^2	Performance
Santa Ana River at E Street	75.4	82.7	-8.2	-11%	0.78	Good
Santa Ana River at MWD Crossing	130.5	133.3	2.1	2%	0.74	Good
Santa Ana River into Prado Dam	273.0	262.7	10.3	4%	0.85	Very Good

Table 1-2. Summary of Upper SAR Watershed Model Results – Monthly Simulated Streamflow Performance

Gaging Station	Avg. Observed Flow [cfs]	Avg. Model-Simulated Flow [cfs]	Mean Residual [cfs]	Mean Residual as % of Avg. Observed Flow	R^2	Performance
Santa Ana River at E Street	75.9	83.3	-8.4	-11%	0.84	Good
Santa Ana River at MWD Crossing	130.5	134.2	1.8	1%	0.85	Very Good
Santa Ana River into Prado Dam	274.7	264.3	10.4	4%	0.94	Very Good

As seen in the tables above, model calibration for the Upper SAR Watershed Model shows good to very good performance at all of the streamflow gages from 1966 to 2016.

1.6 Integrated SAR Model

The Integrated SAR Model domain covers an area of approximately 1,389 square miles (888,768 acres) with a finite-difference grid consisting of 1,642 rows in the northeast to southwest direction and 2,243 columns in the northwest to southeast direction. The grid is rotated at 27° clockwise to be consistent with the previous SBBA, Rialto-Colton, and Yucaipa Models and minimize the number of model cells.

The cell size for the Integrated SAR Model area is 102.5 ft x 102.5 ft – mimicking the high-resolution cell size used in the previous Yucaipa, SBBA, and Rialto-Colton models. This cell size is smaller than those used in the previous Riverside-Arlington Model (164 ft x 164 ft) and Chino Basin Model (200 ft x 200 ft). The purpose of maintaining or enhancing existing model cell size is to preserve the integrity and functionality of each of the five individual groundwater flow models. Following model calibration, any of the individual models may be "de-coupled" from the Integrated SAR Model and be run as a stand-alone model to assess smaller-scale projects within the individual groundwater basins.

Active and inactive model cells of the Integrated SAR Model were assigned according to the designation used by the existing individual models. These active/inactive areas were based on published groundwater basin boundaries and geologic mapping. Active model cells generally represent high-permeability, water-bearing basin fill materials (e.g., alluvium) while inactive, or no-flow, cells represent bedrock or low-permeability, consolidated sedimentary material.

The Integrated SAR Model consists of five model layers:

- Model Layer 1: Shallow river, wash, and axial-channel deposits present in distinct channels, very young and young alluvial deposits, and the upper portion of old and very old alluvial deposits.
- Model Layer 2: Old and very old alluvial deposits and Live Oak Canyon deposits (Yucaipa Basin).
- Model Layer 3: Old and very old alluvial deposits and Live Oak Canyon deposits (Yucaipa Basin).
- Model Layer 4: Old and very old alluvial deposits and Live Oak Canyon deposits (Yucaipa Basin).
- Model Layer 5: Old and very old alluvial deposits, Live Oak Canyon deposits (Yucaipa Basin), and Fernando Group (Chino Basin).

1.6.1 Aquifer Parameters

The original development of aquifer parameters in the individual groundwater models is discussed in the previous modeling reports for each model area. Since the development of a groundwater model for the

Chino Basin area was included in the scope of the development of the Integrated SAR Model, the establishment of initial aquifer parameters in this area is outlined in Section 6.0. During the model update and integration process, the aquifer parameters for the previous groundwater models were modified through individual model calibration. These updated values were then used as initial values for the Integrated SAR Model calibration. During model calibration, these initial values were refined through iterative manual adjustments within pre-established upper and lower bounds in order to minimize the residuals between measured and model-calculated groundwater levels.

1.6.2 Recharge and Discharge Terms

Model recharge and discharge components, along with the MODFLOW package used to simulate each water budget term, are summarized in Table 1-3 below.

Table 1-3. Summary of Recharge and Discharge Terms for the Integrated SAR Model

Term		Model Package
Recharge	Recharge from Mountain Front Runoff	Well Package
	Areal Recharge from Precipitation	Recharge Package
	Streambed Percolation	Streamflow Routing Package
	Artificial Recharge	Well Package
	Anthropogenic Return Flow	Well Package and Recharge Package
	Underflow Inflow	Well Package
Discharge	Evapotranspiration	Evapotranspiration Package
	Groundwater Pumping	Well Package
	Rising Water Discharge to Streamflow	Streamflow Routing Package and Drain

1.6.3 Model Calibration

Calibration is the process of adjusting model parameters to produce the best-fit between simulated and observed groundwater system responses. Initial model parameters were based on the updated existing individual models. These values were further adjusted to better match historical observations of groundwater levels and streamflow. The Integrated SAR model calibration consisted of:

- Initial condition simulation (1966), and
- Transient calibration (monthly stress periods from 1966 through 2016).

The Integrated SAR Model was calibrated against 108,502 measurements of groundwater level in 879 calibration wells, as well as streamflow at three gaging stations within the groundwater basin. During the course of the project, 164 calibration runs were made to arrive at the calibrated parameter set.

1.6.3.1 Initial Condition Simulation

The Integrated SAR Model calibration included an initial condition simulation, or model spin-up period, with model input from January of 1966. The goal of the initial condition model run was to develop a numerically stable initial condition, in good agreement with observed water levels, for the beginning of the transient calibration run. Results of the initial condition simulation are summarized below.

Table 1-4. Summary of Initial Condition Model Simulation Results

Statistic	Integrated SAR Model
Mean Residual	-1.00 ft
Minimum Residual	-73.81 ft
Maximum Residual	223.76 ft
RMSE	38.68 ft
Relative Error	2.2%
NSE	0.99
R^2	0.99

1.6.3.2 Transient Calibration

The transient calibration run for the Integrated SAR Model covers the period from 1966 through 2016 with monthly stress periods. The goal of the transient model calibration was to produce model-calculated water level and streamflow measurements that match observed water levels and historical streamflow at locations within the model domain. Analysis of model water budget, water level hydrographs, and residuals was conducted after each model calibration run to assess the effects of changes made to model parameters. Parameter values adjusted during the calibration included hydraulic conductivity, storativity/specific storage, specific yield, hydraulic flow barrier conductance, and streambed conductance.

1.6.3.2.1 Groundwater Elevations

The transient model calibration process used 108,502 water level measurements from 879 calibration target wells from which to match model-calculated water levels against observed measurements. Calibration statistics are summarized in the following table.

Table 1-5. Summary of Integrated SAR Model Transient Model Calibration Statistics – All Layers

Statistic	Integrated SAR Model
Mean Residual	1.67 ft
Minimum Residual	-289.49 ft
Maximum Residual	409.88 ft
RMSE	62.81 ft
Relative Error	1.7%
NSE	0.99
R^2	0.99

In general, the measured and model-calculated heads compared favorably, and the calibration is further supported by a low relative error 1.7%. In addition, no large changes in the quality of the model calibration are observed between the beginning, middle, and end of the model period.

The model active area is approximately 505 square miles or 322,925 acres. Some areas within the model domain exhibit more error than others. In general, under-simulation of water levels at basin boundaries is more likely. Uncertainty regarding boundary inflows, model layer thickness, and hydraulic properties at the boundaries of the groundwater model also contribute to error at the model boundaries. Another contributing factor to larger residuals in upgradient wells (and also one of the reasons for considering relative error as a calibration metric) is that water levels that exhibit a larger degree of natural variability are also inherently harder to simulate or predict, and are subject to a greater range of natural change and thus, error. Secondly, some water levels may represent pumping conditions or perched conditions, and as such, are not representative of regional groundwater levels. Some differences between model-simulated and measured values are also potentially due to model cell size (102.5 ft by 102.5 ft) being larger than the local scale of observation. Residuals tend to be lower in the center of the basin, where geologic observations are more numerous and regional hydraulic properties and gradients are better defined.

Overall, the calibration results indicate that the standard of calibration achieved in the Integrated SAR Model is suitable for the scale and purpose for which it was developed. Of approximately 108,500 observations, over 41,000 (38%) fell within +/- 20 ft of the observed water level while over 82,000 (76%) fell within +/- 60 ft. Errors were found to be generally randomly distributed in space and time, with the exception of the anomalies noted herein.

The model calibration performance for the individual basin model area is summarized in the following tables.

Table 1-6. Summary of Transient Model Calibration Statistics – Yucaipa Basin Model Area (All Model Layers)

Statistic	Previous Model (GEOSCIENCE, 2017) 1998-2015 Monthly Stress Period	Integrated SAR Model 1966-2016 Monthly Stress Period	
		Individual Model (TM No. 1)	Integrated SAR Model
Mean Residual	5.40 ft	27.51 ft	43.93 ft
Minimum Residual	NA	-264.34 ft	-229.19 ft
Maximum Residual	NA	397.00 ft	359.01 ft
RMSE	64.52 ft	74.27 ft	79.01 ft
Relative Error	2.9%	2.9%	3.1%
NSE	NA	NA	0.95
R^2	NA	NA	0.96

Table 1-7. Summary of Transient Model Calibration Statistics – SBBA Model Area (All Model Layers)

Statistic	Previous Model (Stantec and GEOSCIENCE) 1983-2015 Monthly Stress Period	Integrated SAR Model 1966-2016 Monthly Stress Period	
		Individual Model (TM No. 1)	Integrated SAR Model
Mean Residual	11.14 ft	8.61 ft	-20.08 ft
Minimum Residual	NA	-320.86 ft	-289.49 ft
Maximum Residual	NA	362.32 ft	363.80 ft
RMSE	64.16 ft	64.57 ft	62.69 ft
Relative Error	3.5%	3.5%	3.4%
NSE	NA	NA	0.94
R^2	NA	NA	0.96

Table 1-8. Summary of Transient Model Calibration Statistics – Rialto-Colton Basin Model Area (All Model Layers)

Statistic	Previous Model (GEOSCIENCE, 2015) 1945-1969 Annual Stress Period, 1970-2014 Monthly Stress Period	Integrated SAR Model 1966-2016 Monthly Stress Period	
		Individual Model (TM No. 1)	Integrated SAR Model
Mean Residual	-6.66 ft	-1.06 ft	19.36 ft
Minimum Residual	NA	-176.99 ft	-112.68 ft
Maximum Residual	NA	351.79 ft	290.71 ft
RMSE	69.40 ft	59.52 ft	54.21 ft
Relative Error	6.2%	5.7%	5.2%
NSE	NA	NA	0.93
R^2	NA	NA	0.96

Table 1-9. Summary of Transient Model Calibration Statistics – Riverside-Arlington Basin Model Area (All Model Layers)

Statistic	Previous Model (WRIME 2010) 1965-2007 Monthly Stress Period		Integrated SAR Model 1966-2016 Monthly Stress Period	
	Calibration (1965-2005)	Validation (2006-2007)	Individual Model (TM No. 1)	Integrated SAR Model
Mean Residual	12.10 ft	13.20 ft	-0.37 ft	4.69 ft
Minimum Residual	NA	NA	-63.12 ft	-67.78 ft
Maximum Residual	NA	NA	69.95 ft	82.30 ft
RMSE	16.00 ft	11.80	19.29 ft	23.85 ft
Relative Error	5.0%	5.0%	6.3%	8.3%
NSE	NA	NA	NA	0.87
R^2	NA	NA	NA	0.89

Table 1-10. Summary of Transient Model Calibration Statistics – Chino Basin Model Area (All Model Layers)

Statistic	Previous Model (WEI, 2015) 1961-2011 Quarterly Stress Period		Integrated SAR Model 1966-2016 Monthly Stress Period	
	Calibration Wells	Validation Wells	Individual Model (TM No. 1)	Integrated SAR Model
Mean Residual	0.50 ft	-8.64 ft	17.86 ft	1.19 ft
Minimum Residual	-238.56 ft	NA	-244.67 ft	-262.44 ft
Maximum Residual	153.85 ft	NA	673.83 ft	409.88 ft
RMSE	25.38 ft	NA	58.93 ft	33.46 ft
Relative Error	NA	NA	5.2%	3.0%
NSE	NA	NA	NA	0.92
R^2	NA	NA	NA	0.93

Table 1-11. Transient Model Calibration Statistics – Prado Basin Area (All Model Layers)

Statistic	Integrated SAR Model 1966-2016 Monthly Stress Period
Mean Residual	0.77 ft
RMSE	5.71 ft
Relative Error	11.6%
NSE	0.88
R^2	0.89

1.6.3.2.2 Underflow across Basin Boundaries

In contrast to the previous individual groundwater models, the Integrated SAR Model explicitly simulates underflow between adjacent groundwater basins for the first time. Instead of treating boundary inflows between groundwater basins as boundary conditions, the boundaries between adjacent groundwater basins were removed – allowing the groundwater model to solve for underflow across basin boundaries. Groundwater flow across basin boundaries was computed from the cell-by-cell groundwater flow output from the groundwater model simulation, and is summarized in the following table.

Table 1-12. Summary of Underflow across Basin Boundaries

Basin	Underflow [acre-ft/yr]
Underflow from Yucaipa Basin to the SBBA	
Yucaipa Basin Model (GEOSCIENCE, 2017)	3,500
SBBA Model (GEOSCIENCE, 2009)	4,100
Integrated SAR Model	***7,900***
Underflow from Bunker Hill Basin to Rialto-Colton Basin	
SBBA Model (GEOSCIENCE, 2009)	3,800
Rialto-Colton Basin Model (GEOSCIENCE, 2015)	4,000
Integrated SAR Model	***4,060***
Underflow from Lytle Basin to Rialto-Colton Basin	
SBBA Model (GEOSCIENCE, 2009)	2,000
Rialto-Colton Basin Model (GEOSCIENCE, 2015)	14,100
Integrated SAR Model	***14,550***
Underflow from Rialto-Colton Basin to Riverside Basin	
Rialto-Colton Basin Model (GEOSCIENCE, 2015)	17,900
Riverside-Arlington Model (WRIME, 2010)	25,400
Integrated SAR Model	***16,370***
Underflow from Riverside Basin to Chino Basin	
Riverside-Arlington Model (WRIME, 2010)	2,800
Chino Basin Model (GEOSCIENCE, 2018a)	11,300
Integrated SAR Model	***16,310***

1.6.3.2.3 Streamflow

Results of the streamflow calibration at the three gaging stations used for calibration are summarized in the following table. Performance is based on the suggested criteria by Donigian (2002).

Table 1-13. Summary of Integrated SAR Model Results – Monthly Simulated Streamflow Performance

Gaging Station	Avg. Observed Flow [cfs]	Avg. Model-Simulated Flow [cfs]	Mean Residual [cfs]	Mean Residual as % of Avg. Observed Flow	NSE	R^2	Performance
Santa Ana River at E Street	75.9	86.4	-10.5	-14%	0.80	0.84	Good
Santa Ana River at MWD Crossing	130.5	108.2	22.3	17%	0.74	0.82	Good
Santa Ana River into Prado Dam	274.7	290.5	-15.8	-6%	0.79	0.93	Very Good

In general, the model is able to reproduce similar streamflow dynamics seen in observed measurements.

1.6.3.2.4 Water Balance

Groundwater budgets for the individual basin areas summarize all inflow and outflow terms. As outlined previously, inflow terms to the Integrated SAR Model include mountain front runoff, underflow inflow from adjacent groundwater basins, artificial recharge in spreading basins, areal recharge of precipitation, anthropogenic return flow from applied water, and streambed percolation. Discharge terms include groundwater pumping, evapotranspiration from groundwater, and rising water discharge to streamflow. The difference between the total inflow and total outflow equals the change in groundwater storage. The annual change in groundwater storage for each basin area is summarized below.

Table 1-14. Summary of Average Annual Change in Groundwater Storage

Basin	Average Annual Change in Groundwater Storage [acre-ft/yr]
Yucaipa Basin	-1,980
SBBA	-8,010
Rialto-Colton Basin	250
Riverside-Arlington Basin	-3,330
Chino Basin	-16,260
Temescal Basin	-1,310
Prado Basin	-180

1.6.3.2.5 Cumulative Change in Groundwater Storage

Many of the basin areas have cumulative change in groundwater storages that respond to changes in hydrologic conditions (i.e., wet and dry periods cause rises and declines in groundwater storage, respectively). Basin response to hydrology is greatest in the SBBA, and generally diminishes in basins with increasing distance from mountain front recharge sources.

It appears that the Integrated SAR Model tends to over-estimate groundwater declines in the SBBA during the latter part of the model simulation period since the model-calculated cumulative change in groundwater storage declines at a faster rate during the last 15 years of simulation than the cumulative change in storage calculated by the groundwater level method. The greater cumulative decline in groundwater storage calculated by the Integrated SAR Model is likely due to the large amount of underflow from Lytle Basin to the Rialto-Colton Basin. This over-estimation in cumulative storage decline can be corrected through future work on the model calibration.

1.7 Predictive Scenarios

Predictive scenarios were run using the calibrated Integrated SAR Model to evaluate the effects of proposed HCP covered activities and other basin management strategies on riparian habitat, groundwater levels, and streamflow. Each model run was developed through collaboration and consultation with the TAC and HCP Team. The general scenario categories include:

- Scenario 1: Evaluate Flow in the SAR and Identify Factors that May be Causing Reduced Flows
- Scenario 2: Evaluate the Proposed HCP Activities with Hydrologic Effects
- Scenario 4: Evaluate Groundwater Management Activities and Changes in Groundwater Pumping

The scenario runs simulate various project effects individually or in combination to assess hydrologic responses in comparison to the baseline (no project) scenario, Scenario 2a. This allowed project impacts to be isolated. For each scenario run, model-predicted flow and groundwater impacts were evaluated, including water level and water budgets for each groundwater basin (e.g., evapotranspiration and underflow across each groundwater basin). In Scenario 2, time history of water levels, water budgets and streamflow were compared to a baseline, no project condition simulation to estimate impacts attributable to individual HCP Covered Activities or combinations of HCP Covered Activities. In addition, this information was provided to the Environmental Impact Report (EIR) team for them to establish thresholds of significance.

1.8 Uses and Limitations

The Integrated SAR Model, an integrated surface water model (HSPF) and groundwater flow model (MODFLOW), was constructed as a management tool for the Upper Santa Ana Valley Basin to assess the effects of various projects, including the Habitat Conservation Plan “Covered Activities.” As a management tool, the model is intended to be used to inform the decision-making process.

The Integrated SAR Model has combined previous modeling efforts and knowledge base in the Upper Santa Ana Valley Basin into one model. The Integrated SAR Model added key components to the unified numerical model that were absent or not contiguous in previous models to allow the simulation of streamflow and evapotranspiration for the purpose of assessing the effect of various projects on flows and riparian habitat in the Upper Santa Ana River. Calibration of the model was conducted with a focus on time-history matching of streamflow and groundwater levels in Upper Santa Ana River.

An understanding of the intended uses of the model and limitations and uncertainties associated with modeling results is key to interpreting modeling results and informing the decision-making process. The results of the modeling scenarios provided in this report are meant to serve as an indication of anticipated effects from proposed HCP covered activities and should be verified with field observations. As outlined in the Draft Final Upper Santa Ana River Wash Habitat Conservation Plan (ICF, 2019), the HCP includes a compliance monitoring and reporting program to measure and respond to potential project impacts.

The model is not intended to exactly predict water levels or streamflow beyond a level that could be reasonably anticipated from the residual statistics. The goal of the calibration process is to minimize the difference between observed and simulated water levels and streamflow. Minimization of these errors through calibration should not be interpreted as an absence of uncertainty or error. Model calibration was directed at addressing observed biases in the model-simulated water levels and streamflow, and additional focus was placed on areas of interest in the vicinity of the SAR.

One goal of this report is to characterize the magnitude, spatial, and temporal distribution of residuals in the model. This information can guide future applications of the model and indicate if additional calibration in a given area of interest is warranted. As the model is applied in different applications, an assessment of the calibration and suitability for the intended purpose should be conducted prior to using the model.

1.9 Future Work

The Integrated SAR Model is the first integration of pre-existing, individual numerical groundwater (MODFLOW) models in the Upper Santa Ana River Basin. Future work with the Integrated SAR Model on additional applications is anticipated and ongoing refinement and improvement of areas of interest throughout the model is expected. Improvements or additional work in specific areas of interest can be incorporated back into the Integrated SAR Model. Potential future work includes:

- Development of individual basin models from the larger Integrated SAR Model to reduce simulation time or refine localized conditions;
- Development of solute transport modeling capability in the Integrated SAR Model to help identify and manage water quality (e.g., TDS and TIN) in the Upper SAR, excluding Chino Basin;
- Additional calibration in the Yucaipa Groundwater Basin to resolve higher residuals from hydrogeologic complexity; and
- Refinement/standardization of flux terms (e.g., areal recharge, return flow, mountain front runoff) throughout the model domain, which currently follow existing methodologies from previous modeling efforts.