

## TECHNICAL MEMORANDUM

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<b>From:</b>	Reza Namvar	<b>Date:</b>	December 11, 2008
<b>Subject:</b>	<b>Task 2-Review of Previous Models Riverside-Arlington Basins Numerical Groundwater Model and GWMPs Development Project</b>		
<b>Project Reference:</b>	212.T02.00		

### MEMORANDUM OBJECTIVES

The objective of this memorandum is to summarize the existing numerical models, their objectives, and their prior uses. In addition, this memorandum provides specific recommendations for using any of the existing numerical models' data for developing the Riverside-Arlington basins numerical groundwater model (Riverside-Arlington Model).

### OBJECTIVE OF TASK 2

The objectives of Task 2 are to:

- Review reports and the computer program of the existing numerical models for the Riverside and Arlington basins, and surrounding basins, to determine if some input data from existing models can be used in the current model to reduce duplication of effort related to data collection and input files
- Compile and analyze any additional relevant information related to the development of the conceptual and numerical models

### PREVIOUS MODELS

There are four previous models that simulate groundwater flow in parts or all of the area of interest for the Riverside-Arlington Model. These models are:

- CH2M HILL Local and Regional Models of Rapid Infiltration Extraction (RIX) Facilities (2003)
- GeoTrans Riverside Groundwater Flow Model (2003)
- U.S. Geological Survey (USGS) Rialto-Colton Basin Groundwater Flow Model (2001)
- Wildermuth Arlington Groundwater Flow Model (2008)

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This task includes review of the reports and model files of these previous models. Results of the review are in this memorandum.

## **SOURCES OF INFORMATION**

The main sources of information for this task are the reports and computer files from the previous groundwater models. The information used for Task 2 includes:

- Model reports
  - Riverside Groundwater Basin Model (GeoTrans, 2003)
  - Arlington Basin Groundwater Flow Model (Wildermuth, 2008)
  - Rialto-Colton Basin Model (USGS, 2001)
  - Groundwater Flow Model for the RIX Facility - (CH2M HILL, 2003)
- Model computer files
  - Riverside Groundwater Basin Model (GeoTrans, 2003)
  - Arlington Basin Groundwater Flow Model (Wildermuth, 2008)
  - Rialto-Colton Basin Model (USGS, 2001)

Computer files for the CH2M HILL model of the RIX facility were not available for this review.

## **DESCRIPTION OF PREVIOUS MODELS**

Brief descriptions of the previous groundwater models and their objectives are in the following subsections. Table 1 summarizes specifications of these models.

### **USGS'S MODEL OF RIALTO-COLTON BASIN**

USGS studied the groundwater flow system and water chemistry in the Rialto-Colton Basin in a two-phase cooperative program with the San Bernardino Valley Municipal Water District. In the first phase of the program, USGS described the geohydrology and water chemistry of the basin. In the second phase, USGS:

- Evaluated and quantified the hydrologic information from phase one
- Determined the movement and disposition of recharged imported water
- Simulated the long-term effects of three artificial recharge projects

The second phase of the program included development of the Rialto-Colton Basin model. This USGS model was used with a particle-tracking post processor to evaluate the effectiveness of various artificial recharge alternatives. Figure 1 shows the southern area of the Rialto-Colton model.

**Table 1 - Summary of Previous Models**

Specification	MODELS				
	Arlington Basin Model	Rialto-Colton Basin Model	Riverside Basin Model	RIX Facilities Regional Model	RIX Facilities Local Model
<b>Developer</b>	Wildermuth Environmental	USGS	GeoTrans	CH2M Hill	CH2M Hill
<b>Prepared For</b>	Western Municipal Water District	San Bernardino Valley Municipal Water District	SAWPA and Riverside Public Utilities	Colton/San Bernaradino Regional Tertiary Treatment and Water Reclamation Authority	Colton/San Bernaradino Regional Tertiary Treatment and Water Reclamation Authority
<b>Report Year</b>	2008	2001	2003	2003	2003
<b>Groundwater Basins</b>	Arlington	Rialto-Colton	Riverside and portions of Arlington and Rialto-Colton	Riverside and portions of Rialto-Colton	Portions of Riverside
<b>Model Code</b>	MODFLOW 2000	MODFLOW	MODFLOW	CFEST	CFEST
<b>Solution Technique</b>	Finite Difference	Finite Difference	Finite Difference	Finite Element	Finite Element
<b>Grid Resolution</b>	50 x 50 meters (164 x 164 feet)	250 x 250 meters (820 x 820 feet)	100 x 100 meters (328 x 328 feet)	N/A	3,021 elements
<b>Model Area (acres)</b>	7,000 (11,428 active cells)	42,700 (2,768 active cells)	57,300 (44,300 acres for 1997 area)	34,200	8,000
<b>Number of Model Layers</b>	1	4	2	1	9
<b>Calibration Period</b>	1966-2004	1945-1996	Steady State Conditions with No Flooding River Flow Conditions	1965-2000	1999
<b>Calibration Tool</b>	PEST	-	-	PEST	Manual Adjustment of K and Sy
<b>Stress Periods</b>	1 year	1 year	Steady State	-	1 day
<b>Time Steps</b>	1 month *		Steady State	-	-
<b>Prediction Period</b>	2005-2034	1997-2027	Steady State Conditions based on 1997 conditions representing 25-year average values	N/A	2-yr simulations by repeating 1999 conditions except for extractions which varied for scenarios

**Notes:**

\* - In the model files reviewed by WRIME, the first stress period is broken into 12 one month time steps while stress periods 2 to 39 have only one time step of 365 days.

**CH2M HILL'S MODEL OF RIX FACILITY**

The RIX wastewater treatment facility provides tertiary treatment of wastewater from the cities of Colton and San Bernardino prior to discharge to the Santa Ana River. The RIX facility has been in operation since May 1995. The secondary effluent infiltration rates are approximately 24 million gallons per day (mgd); however, the extraction rates are 1.25 to 1.45 times higher, at 30 to 35 mgd (CH2M HILL, 2003). The higher extraction rates are to meet the requirements of the Regional Water Quality Control Board (RWQCB) that a minimum of 90 percent of infiltrated secondary effluent be recaptured.

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In 1992, CH2M HILL developed a groundwater flow model as a basis for the design and operation of the current full-scale RIX facility. The 1992 model consisted of a regional model, to evaluate potential impacts on the existing groundwater users, and a local model, to provide the basis for the design and operation of the RIX facility. The local model was situated within the regional model, using the boundary conditions from the regional model.

The 1992 models were updated in 2002 to evaluate the historical operations of the RIX facility, ensure that the 90 percent containment/extraction goal is met, and provide guidance for future operations to comply with the containment goal. Figure 1 shows the areas of the 2002 models.

### **GEOTRANS' MODEL OF RIVERSIDE BASIN**

GeoTrans developed the Riverside Basin model for the Santa Ana Watershed Project Authority (SAWPA) and the City of Riverside (GeoTrans, 2003). It covers the Riverside Basin and portions of the Rialto-Colton and Arlington basins (Figure 1). The objectives of this model were to:

- Identify the sources of recharge to the Riverside Basin and determine the quantity and the 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

### **WILDERMUTH'S MODEL OF ARLINGTON BASIN**

Wildermuth Environmental developed a model of Arlington Basin in 2008 to predict the hydrologic impacts of an expanded Arlington Desalter. The USGS MODFLOW-2000 model code was used to develop the Arlington Basin groundwater flow model. The domain of the model (shown in Figure 1) covers approximately 7,000 acres (11 square miles) of the Arlington Basin. The spatial extent of the model domain is limited to regions where the saturated thickness was greater than 40 feet in 1966, when the groundwater levels were at historical lows.

The expansion of the Arlington Desalter was analyzed using three model simulations:

- A baseline alternative for simulation of the continuation of existing conditions with no expansion of the desalter
- A desalter expansion alternative for simulation of a desalter facility producing 10 mgd of product water
- A desalter expansion and artificial recharge alternative for simulating mitigation of drawdown caused by the increased pumping

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## **HYDROSTRATIGRAPHY**

### **WILDERMUTH'S ARLINGTON BASIN MODEL**

In their model, Wildermuth used lithological descriptions from well driller's reports and bedrock signatures on borehole geophysical logs to construct a three-dimensional raster of the bedrock surface. Wildermuth developed the aquifer geometry of the Arlington Basin model from this raster. A one-layer model was used to represent the aquifer in the Arlington Basin.

### **GEOTRANS' RIVERSIDE GROUNDWATER MODEL**

The primary source of information for delineation of the hydrostratigraphic units of GeoTrans' Riverside groundwater model is lithologic well logs from several municipal wells in the Riverside and Rialto-Colton basins. GeoTrans updated the California Department of Water Resources' (DWR) 1971 contour map of the bedrock surface and used it to delineate the base of alluvial aquifer. The conceptual hydrostratigraphic model is composed of three alluvial units: the Upper Unit, consisting of river channel deposits and younger alluvium; the Middle Unit; and the Lower Unit. The Upper and Middle units were combined to form groundwater model layer 1, with approximately 200 feet of saturated thickness. The Lower Unit comprises groundwater model layer 2, with approximately 270 feet of saturated thickness.

### **CH2M HILL'S LOCAL AND REGIONAL MODELS OF RIX FACILITIES**

The regional model of the RIX facility used the results of two studies by DWR (1970 and 1971) to develop the bedrock surface. However, the lithologic data obtained during the drilling and construction of the extraction and monitoring wells of the RIX facility were used to define the site stratigraphy and the geologic layers of the local model. CH2M HILL used a one-layer model for the regional model to represent the aquifer in the Riverside Basin and a nine-layer model for the local groundwater model of the RIX facility.

### **USGS'S RIALTO-COLTON BASIN GROUNDWATER FLOW MODEL**

Based on the analysis of lithology from drill cuttings and borehole geophysical logs, USGS divided the groundwater system into four water-bearing units, including the river-channel deposits and the upper, middle, and lower water-bearing units (Woolfenden and Kadhim, 1997). The water-bearing units range from unconfined to partly confined and are in hydraulic connection with each other. Four model layers were used to represent the four water-bearing units of the Rialto-Colton Basin. USGS modified model layer elevations during the model calibration process. The changes included a decrease in the bottom elevation of layer 3, in the vicinity of Barrier J, by 50 to 400 feet to eliminate the drying of cells in the layer.

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## **INFORMATION AVAILABLE FOR RIVERSIDE-ARLINGTON MODEL**

The geometries of layers of the existing models were developed from well driller's reports and borehole geophysical logs. The model files of the existing models could be used to develop the top and bottom elevations of the layers of the new Riverside-Arlington Model. However, the geologic cross sections and aquifer geometry being developed by Numeric Solutions as part of Task 3 will be used to build the new model. The cross sections being developed by Numeric Solutions are expected to provide a better and more complete representation of the Riverside and Arlington basins than previous studies.

## **AQUIFER PARAMETERS**

### **HYDRAULIC CONDUCTIVITY**

#### **GeoTrans' Riverside Model**

Specific capacity data from eleven wells in Riverside Basin, one well in Arlington Basin, and one well in Rialto-Colton Basin were used to estimate transmissivity values of the GeoTrans model. The transmissivity values from specific capacity data ranged from approximately 2,000 square feet per day to 47,000 square feet per day. Corresponding estimates of hydraulic conductivity ranged from 5 to 128 feet per day. The calibrated hydraulic conductivity ranged from 10 to 250 feet per day, with higher values occurring in Rialto-Colton Basin (200 feet per day) and areas in the vicinity of desalters in Arlington Basin (250 feet per day) and lower values occurring east of Hwy 91 (10 feet per day).

#### **Wildermuth's Arlington Model**

The hydraulic conductivity was estimated through analysis of several pumping tests (24-hour, constant-discharge pumping tests and well-efficiency tests). The wells along the central axis of the basin show higher hydraulic conductivities (approximately 100 to 200 feet per day) than the other wells. The model domain was divided into nine zones based on the location of pumping wells and calibration wells. Uniform hydraulic conductivity values were assigned to model cells in each zone. The hydraulic conductivity ranged initially from 10 to 100 feet per day and was adjusted during the calibration process to range from 3 to 180 feet per day.

#### **CH2M HILL's RIX Model**

CH2M HILL designated 13 aquifer property zones for the regional RIX model. Uniform values of hydraulic conductivity and specific yield were assigned to each zone. Hydraulic conductivity ranged from 15 to 530 feet per day, while a specific yield of 0.22 was assigned to 11 zones. The remaining two zones had specific yields of 0.12 and 0.32. Hydraulic conductivity ranges from 442 to 522 feet per day in a two-mile-wide band along the Santa Ana River. Areas north of the

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Santa Ana River have hydraulic conductivity of 15 to 51 feet per day. Areas south of the Santa Ana River have hydraulic conductivity of 30 to 148 feet per day. Hydraulic conductivity for Rialto-Colton Basin is 346 feet per day.

### **USGS's Rialto-Colton Model**

USGS assigned constant hydraulic conductivities to four model layers in the southern parts of the model area, where the area overlaps with the Riverside-Arlington Model area. A hydraulic conductivity of 130 feet per day was assigned to layer 1, which represents river-channel deposits. A constant hydraulic conductivity value of 337 feet per day was assigned to layer 2 based on hydraulic conductivities reported by Dutcher and Garrett (1963) for younger alluvium. A hydraulic conductivity of 50 feet per day was assigned to layer 3. USGS estimated that the hydraulic conductivity of layer 4 (12.5 feet per day) was one-fourth of the conductivity of layer 3, which is consistent with the finer-grained material in the lower-water-bearing unit. The vertical conductivity of layers 1, 2, and 3 is one-tenth of the horizontal conductivity and the conductivity of layer 4 is one-hundredth of the horizontal conductivity.

### **SPECIFIC YIELD**

#### **Wildermuth's Arlington Model**

The specific yield was estimated through the analysis of lithologic descriptions from well driller's reports. Specific yield from well reports range from 0.02 to 0.19. A specific yield raster was created from the thickness-weighted, average specific yield at each borehole in Arlington Basin. The interpolated specific yield ranges from 0.01 to 0.16. The specific yield raster was used to populate the model grid cells with initial values. Specific yields are highest in the thicker water-bearing sediments along the central trough of the basin. Specific yields are lowest in the thinner water-bearing sediments on the southern and northern flanks of the basin. The specific yield was adjusted during the calibration process, with multiplier values ranging from 0.8 to 1.7 (larger multipliers correspond to the higher specific-yield zones).

#### **CH2M HILL's RIX Model**

A uniform specific yield of 0.22 was assigned to 11 zones. The remaining two zones had specific yield of 0.12 in the vicinity of Highway 60 east of Highway 91 and 0.32 in the area south of Chino Basin boundary.

#### **USGS's Rialto-Colton Model**

The original specific storage values were based on those given by Heath (1983) for confined and unconfined aquifers. The final specific storage values were determined in the calibration

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process. The specific storage values assigned to the four model layers in the southern parts of the model area where it overlaps with the Riverside-Arlington Model area are:

- Layer 1 - unconfined: Specific yield = 0.30
- Layer 2 - confined/unconfined: Specific yield = 0.30; Specific storage= 0.0001
- Layer 3 - confined: Specific storage = 0.0001
- Layer 4 - confined: Specific storage = 0.0001

## **INFORMATION AVAILABLE FOR RIVERSIDE-ARLINGTON MODEL**

The aquifer properties used for the existing models were obtained from well driller's reports, pump tests, and available references. The estimated aquifer properties were adjusted during the calibration process. The hydraulic conductivities of the RIX model are generally higher than the other models. Aquifer properties will be assigned to model cells based on the aquifer properties of the existing models, reported aquifer test results, and any new aquifer tests that will be conducted as part of this project. These values will be further adjusted during the calibration process.

## **SANTA ANA RIVER INTERACTION WITH AQUIFER**

### **USGS's Rialto-Colton Model**

Stream recharge and discharge from the Santa Ana River and Warm Creek were modeled using a package that simulates interaction between the stream and the aquifer (Prudic, 1989). Model input data included stream discharge into the basin measured at USGS stream gages, stream geometry, stream stage, and stream conductance of 0.1 square foot per second. In the Rialto-Colton Basin, the average seepage loss from the Santa Ana River and Warm Creek was 4,860 acre-feet from 1945 to 1996. River seepage loss was 5,490 acre-feet in 1996. The simulated stream recharge values were not modified during Rialto-Colton groundwater model calibration.

### **GeoTrans' Riverside Model**

The MODFLOW river package was used to simulate the interaction of the Santa Ana River with the groundwater basin. Using the average historical pumping rates, the river package was adjusted to match the 1997 head distribution. The calibrated model showed that in the Rialto-Colton and Riverside basins, the Santa Ana River loses 9,500 acre-feet per year and gains 5,800 acre-feet per year during average conditions from 1976 to 2000.

### **CH2M HILL's RIX Model**

CH2M HILL's model uses the water budget studies by James M. Montgomery (JMM) (1991a and 1991b) to determine the infiltration of storm water and treated wastewater through the



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Santa Ana River bed. Annual recharge estimates were obtained from a calibration run of the Basin Planning Model. The recharge volumes were normalized to the riverbed area and assigned to the model elements representing the Santa Ana River. JMM's water budget was estimated for 1960 to 1986 and was extended through 2000 using reported stream gage data and wastewater discharges. In the calibration period of 1965 to 2000, losses from the Santa Ana River to groundwater averaged 27,000 acre-feet per year, ranging from 8,500 acre-feet in 1981 and 1968 to 77,000 acre-feet in 1969. Gains of the Santa Ana River from groundwater averaged 28,000 acre-feet per year, ranging from 23,000 acre-feet in 1973 to 32,000 acre-feet in 1998.

Outflow of groundwater to the Santa Ana River through the Riverside Narrows was based on model calibration assigning constant head values in this area.

A limited, one-day, field-work effort was performed in September 2002 to assess the flow in the Santa Ana River below the RIX outfall. At this time, flow rates were measured at several points between the outfall and Riverside Avenue. Results showed that approximately 11 percent of the 70 cubic feet per second streamflow infiltrated into groundwater.

#### **INFORMATION AVAILABLE FOR RIVERSIDE-ARLINGTON MODEL**

CH2M HILL's RIX model and the steady-state GeoTrans model simulated the infiltration of streamflow and treated wastewater into the Santa Ana River in the Rialto-Colton and Riverside basins, and the discharge of groundwater into the Santa Ana River at Riverside Narrows.

USGS's model provided estimates of the Santa Ana River losses in the Rialto-Colton Basin only. Arlington model does not include the Santa Ana River. The estimates of Santa Ana River losses and gains to and from groundwater are mostly calibrated values. These estimates will be used as references for development of the Riverside-Arlington Model. Details of the Santa Ana River flows and losses will be investigated as part of Task 3 (Conceptual Model Development) of this study.

#### **FAULTS AND BOUNDARY CONDITIONS**

The major boundaries and faults in the Riverside-Arlington Model area include:

- San Jacinto Fault
- Underflow from Northern parts of Rialto-Colton Basin
- Rialto-Colton Fault
- Riverside Narrows
- Arlington Narrows

The following subsections detail the methodology of the existing models for simulation of the faults and boundary conditions.

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## **SAN JACINTO FAULT**

CH2M HILL's estimate of groundwater flow from the Bunker Hill Basin and across the San Jacinto Fault is based on the flow estimates and groundwater modeling work of Danskin, et al. (2006). Danskin, et al. used a correlation equation relating groundwater elevations in the Bunker Hill Basin to flow across the San Jacinto Fault. Inflows were adjusted during model calibration.

GeoTrans' estimate of groundwater flow from the Bunker Hill Basin is based on HSI GeoTrans modeling study of the Bunker Hill Basin (HSI GeoTrans, 1998). A constant value of 4,500 acre-feet per year was used for underflow through the San Jacinto Fault.

USGS's model uses specified-flux boundaries to simulate underflow from the Bunker Hill Basin to the Rialto-Colton Basin, across the San Jacinto Fault. Specified-flux boundaries were simulated as injection wells in model layers 1 and 2. Underflow was assigned to model layers 1 and 2 based on water chemistry from wells adjacent to the San Jacinto Fault. Water in wells perforated at depths that corresponded to lower layers did not have similar chemistry. Model calibration indicated that 75 percent of underflow occurs in layer 1 and 25 percent of underflow occurs in layer 2. The quantity of underflow was based on calculation of Darcy's Law, using hydraulic gradient between well 1S/4W-3Q1 in the Bunker Hill Basin and 1S/4W-29H2 in the Riverside Basin. These wells are approximately 4 miles apart. The hydraulic conductivity used in the calculation is an average of the conductivities for layers 1 and 2. The underflow from the Bunker Hill Basin to the Rialto-Colton Basin across the San Jacinto Fault had an annual average of 11,400 acre-feet per year from 1945 to 1996, with a range from 6,300 acre-feet in 1970 to 16,500 acre-feet in 1961.

## **UNDERFLOW FROM RIALTO-COLTON BASIN**

Underflow from a portion of Rialto-Colton Basin outside of CH2M HILL's model to the portion of the basin in the model area was estimated by adding groundwater production from the area of the basin in the model area to Woolfenden and Koczot's flow estimates of the Rialto-Colton Basin to the Riverside Basin (2001). Inflows were adjusted during model calibration. CH2M HILL's model report only presents annual quantities of combined underflow from the Bunker Hill and Rialto-Colton basins. Total inflow from the Bunker Hill Basin and Rialto-Colton basins averaged 17,900 acre-feet per year from 1965 to 2000 and ranged from 10,800 acre-feet in 1980 to 26,000 acre-feet in 1996.

GeoTrans' estimate of the rate of underflow from the Rialto-Colton Basin is based on USGS's model of the Rialto-Colton Basin (Woolfenden and Koczot, 2001) and DWR's Bulletin No. 53. GeoTrans used a constant value of 20,000 acre-feet per year for underflow from the Rialto-Colton Basin.

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## **RIALTO-COLTON FAULT**

USGS used general-head boundary condition to simulate underflow from the Rialto-Colton Basin to the Riverside Basin, across the Rialto-Colton Fault. Underflow was assigned to layers 1, 2, and 3, with 7 cells in layer 1 and 21 cells each in layers 2 and 3. The boundary heads were obtained from wells 1S/4W-29H2 and 1S/4W-28L1 in Riverside Basin, approximately 0.1 mile downstream from Rialto-Colton Fault. Conductance values for the general-head boundary cells are 4,300 square feet per day for layer 1 and 3,500 square feet per day for layers 2 and 3. These values were determined during model calibration. The average underflow from Rialto-Colton Basin to Riverside Basin for was 23,700 acre-feet per year from 1945 to 1996.

## **RIVERSIDE NARROWS**

CH2M HILL's model uses constant head boundary conditions in the Riverside Narrows area to simulate outflow of groundwater to the Santa Ana River and the Chino Basin. Outflows were adjusted during model calibration. Simulated outflows at Riverside Narrows averaged 28,000 acre-feet per year from 1965 to 2000, ranging from 22,600 acre-feet in 1975 to 32,000 acre-feet in 1998.

GeoTrans' estimate of groundwater outflows at the Riverside Narrows was based on the estimate of underflow across the San Jacinto Fault at Colton Narrows shown in the HSI GeoTrans modeling study of the Bunker Hill Basin (HSI GeoTrans, 1998). A constant value of 4,000 acre-feet per year was selected for underflow at the Riverside Narrows.

## **ARLINGTON NARROWS**

Wildermuth used general head boundary conditions to simulate groundwater outflow from the Arlington Basin to the Temescal Basin, through the Arlington Narrows. General head boundary conditions were assigned to 11 active model cells at Arlington Narrows. The groundwater outflow from each cell depends on groundwater levels in the Temescal Basin, computed head in the boundary cell of the Arlington model, and the boundary conductance. An historical average groundwater elevation of 630 feet was used to represent the groundwater levels in Temescal Basin. The initial estimate of the conductance value of 880 square feet per day was based on the aquifer horizontal hydraulic conductivity and the distance between the boundary cells at the Arlington Narrows to the location of a groundwater elevation measurement point in Temescal Basin. The boundary conductance was adjusted to 532.95 square feet per day in transient calibration.

GeoTrans assumed a groundwater underflow of zero at the Arlington Narrows. GeoTrans' model was insensitive to the flow component through the Arlington Narrows.

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## **INFORMATION AVAILABLE FOR RIVERSIDE-ARLINGTON MODEL**

The estimates of underflow through faults and model boundaries are mostly calibrated values. These estimates will be used as references for development of Riverside-Arlington Model. Details of the underflow will be investigated as part of Task 3 (Conceptual Model Development) of this study.

## **RECHARGE FROM PRECIPITATION AND APPLIED WATER**

### **CH2M HILL's RIX Model**

CH2M HILL's model uses soil-moisture budget methodology to estimate deep infiltration of precipitation and applied water. During the calibration process, the estimated deep infiltration rates were generally increased by reported losses from City of Riverside water distribution systems to groundwater. Surface recharge as a result of infiltration of precipitation, return flow of applied waters, and losses from distribution systems averaged 44,000 acre-feet per year from 1965 to 2000, ranging from 32,600 acre-feet in 1999 to 72,000 acre-feet in 1969.

### **USGS's Rialto-Colton Model**

Irrigation return flow for the USGS Rialto-Colton model was estimated to be 30 percent of total pumpage for each well, based on the groundwater flow model for the Bunker Hill Basin (Hardt and Hutchinson, 1980). The irrigation return flow was accounted for by reducing pumpage by 30 percent throughout the model simulation period of 1945 to 1996. The average irrigation return flow is 3,300 acre-feet per year. This estimate of recharge from applied water is inconsistent with the land use changes from agricultural to urban.

Infiltration of precipitation for the USGS Rialto-Colton model was simulated as uniformly distributed recharge over the active model cells. The rate of areal recharge assigned to each cell was 0.5 inch per year, or a total of 870 acre-feet per year for the entire basin. This recharge rate was based on the Bunker Hill Basin model (Hardt and Hutchinson, 1980).

### **GeoTrans' Riverside Model**

For the GeoTrans model of Riverside Basin, a recharge rate of 0.5 inch per year was applied throughout the model area. This rate is based on modeling studies of the Bunker Hill Basin (HSI GeoTrans, 1998). The rate of recharge from agricultural irrigation, based on the Bunker Hill Basin modeling studies of Hardt and Hutchinson (1980), was estimated to be 30 percent of the applied irrigation volume in the agricultural areas.

For the Riverside model, GeoTrans assumed that 50 percent of domestic water supply is used outdoors and 20 percent of outdoor volume (or 10 percent of domestic water supply) becomes aquifer recharge.

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## Wildermuth's Arlington Model

Wildermuth's Rainfall, Runoff, Router, and Root zone (R4) model estimated recharge from precipitation and irrigation for each hydrologic subarea overlying the model domain. Recharge from precipitation and applied water ranged from 4,900 acre-feet in 2004 to 6,800 acre-feet in 1966. Conversion of land uses from agricultural to urban resulted in a decreasing trend in recharge rates. The average recharge rate between 1966 and 2004 ranged from 0.3 foot per year for urban areas to 1.75 feet per year for agricultural areas.

## INFORMATION AVAILABLE FOR RIVERSIDE-ARLINGTON MODEL

WRIME will use DWR's IDS model to estimate the recharge from precipitation and applied water. This model uses land use and hydrological information to estimate recharge from precipitation and applied water. The recharge rates will be adjusted during model calibration. WRIME will use estimated recharge rates from previous models as reference.

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