Paso Robles Groundwater Basin Model Update

PREPARED FOR:

San Luis Obispo County Flood Control and Water Conservation District

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THIS MODELING REPORT HAS BEEN PREPARED FOR COUNTY OF SAN LUIS OBISPO BY OR UNDER THE DIRECTION OF THE FOLLOWING PROFESSIONALS LICENSED BY THE STATE OF CALIFORNIA.

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PASO ROBLES GROUNDWATER BASIN MODEL UPDATE

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ATTACHMENT

Ltr.	Description
A	Electronic Database of Paso Robles Groundwater Basin Model Update Files (Compact Disk)

ABBREVIATIONS AND DEFINITIONS

AC	acre
ACO	Agricultural Commissioner's Office (San Luis Obispo County)
Acre-ft or AF	acre-foot
acre-ft/yr or AFY	acre-feet per year
AET	actual evapotranspiration
Alluvial	A geologic term describing beds of sand, gravel, silt, and clay deposited by flowing water.
amsl	above mean sea level
AMWC	Atascadero Mutual Water Company
Aquifer	A geologic formation or group of formations which store, transmit, and yield significant quantities of water to wells and springs.
Basin	Paso Robles Groundwater Basin
Basin Watershed	The surrounding watershed which is tributary to the Paso Robles Groundwater Basin.
bgs	below ground surface
CD	compact disc
CDEC	California Data Exchange Center
CDFFP	California Department of Forestry and Fire Protection
CDMG	California Division of Mines and Geology
cfs	cubic foot per second
CIMIS	California Irrigation Management Information Systems
Consumptive Use	Water removed from available supplies without return to a water resource system.
CSD	Community Services District
CY	Calendar Year
DEM	Digital Elevation Model
District	San Luis Obispo County Flood Control and Water Conservation District (SLOC FC&WCD)

ABBREVIATIONS AND DEFINITIONS (CONT.)

Drawdown	The change in hydraulic head or water level relative to a background condition.
DU	dwelling unit
DWR	California Department of Water Resources
ER	effective rainfall
ET	Evapotranspiration
Evapotranspiration (ETo)	The combined loss of water from a given area by evaporation from the land and transpiration from plants.
eWRIMS	Electronic Water Rights Information Management System
Fault	A fracture in the earth's crust, with displacement of one side of the fracture with respect to the other.
Formation	A geologic term that designates a body of rock or rock/sediment strata of similar lithologic type or combination of types.
FP	frost protection
ft	feet, foot
ft/day	feet per day
FTP	file transfer protocol
GEOSCIENCE	Geoscience Support Service, Inc.
GIS	Geographic Information System
gpm	gallons per minute
Groundwater	Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer.
GW	groundwater
Groundwater Storage	Groundwater which becomes part of an aquifer system until it is removed (either naturally or anthropologically).
Head	Energy, produced by elevation, pressure, or velocity, contained in a water mass.
HSPF	Hydrologic Simulation Program - Fortran

ABBREVIATIONS AND DEFINITIONS (CONT.)

Hydraulic Conductivity	The measure of the ability of the soil to transmit water, dependent upon both the properties of the soil and those of the fluid.
in.	inch
in/yr	inch per year
K	See Hydraulic Conductivity
Kc	crop coefficient
LR	leaching requirement
MCWRA	Monterey County Water Resources Agency
mgd	million gallons per day
mg/L	milligrams per liter
MODFLOW-2000	A modular finite-difference flow model developed by the United States Geologic Survey (USGS) to solve the groundwater flow equation.
MWC	Mutual Water Company
MWR	Master Water Report
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service (branch of the USDA)
NWCC	Natural Resources and Climate Center
NWIS	National Water Information System (USGS database)
NWP	Nacimiento Water Project
Perennial Yield	The amount of usable water of a groundwater basin that can be withdrawn and consumed economically each year for an indefinite period of time. It cannot exceed the sum of the natural recharge, artificial recharge, and incidental recharge, without causing depletion of the basin.
Permeability	The capability of soil or other geologic formations to transmit water. The term is used to separate the effects of the medium from those of the fluid on the hydraulic conductivity.
PEST	Parameter ESTimation software

ABBREVIATIONS AND DEFINITIONS (CONT.)

PET	potential evapotranspiration
PRISM	Parameter-elevation Regression on Independent Slopes Model
RDI	Regulated Deficit Irrigation
SLO	San Luis Obispo
SMCSD	San Miguel Community Services District
SNMP	salt nutrient management plan
Spring	A water resource formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of groundwater at or below the local water table, below which the subsurface material is saturated with water.
Specific Yield	The ratio of the volume of water that a saturated rock or soil will yield by gravity to the total volume of the rock or soil.
SSURGO	Soil Survey Geographic database (distributed by the NRCS)
Stress Period	Represents a period of time during which all model stresses remain constant.
TCSD	Templeton Community Services District
Transient	Model calibration process for which the groundwater rate and flow direction vary with time.
UC	University of California
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
Watershed	An area of land that drains all the streams and rainfall to a common outlet.
Water Year or WY	Term used in hydrology to describe a time period of 12 months for which precipitation totals are measured.
WPA	water planning area
WTP	Water treatment plant

ABBREVIATIONS AND DEFINITIONS (CONT.)

WWG	Western Weather Group
WWTP	Wastewater treatment plant
yr. or YR	year

PASO ROBLES GROUNDWATER BASIN MODEL UPDATE

1.0 EXECUTIVE SUMMARY

1.1 Introduction

Local agencies, including the San Luis Obispo County Flood Control and Water Conservation District (District) and local stakeholders are working cooperatively to manage the Paso Robles Groundwater Basin (Basin). Work has included extensive monitoring, development of a management plan, conduct of studies, and development in 2005 of a numerical groundwater flow model (Basin Model). This report summarizes the Basin Model Update, which was undertaken to extend the model study period over water years 1981-2011, to improve the water balance assessment and refine the perennial yield, and to evaluate the Basin's response to "Growth" and "No Growth" scenarios projected over the period water years 2012-2040.

The study area consists of the Paso Robles Groundwater Basin which encompasses 790 square miles in the upper Salinas River watershed in northern San Luis Obispo County and southern Monterey County. The original Basin Model was constructed using MODFLOW, the widely-accepted groundwater flow modeling code[1] developed by the United States Geologic Survey. Development of the original Basin Model involved definition of the geologic framework including basin boundaries (such as the boundary between the Atascadero Sub-Basin and the remainder of the Basin) and four layers representing the recent alluvial deposits and portions of the Paso Robles Formation. The original Basin Model also included estimation of aquifer properties and evaluation of the water balance for water years 1981-1997.

This update of the original Basin Model did not change the established geologic framework, but focused on update and refinement of the water balance, which extended the water balance from the limits of the Basin to the surrounding watershed. Consideration of the entire Basin watershed allowed for checking and validation of the water balance against actual streamflow data at established gages.

[1] Groundwater models are mathematical representations of the movement (both lateral and vertical) of groundwater within a defined system (i.e., basin). These models include assumptions and simplifications made for various specific purposes.

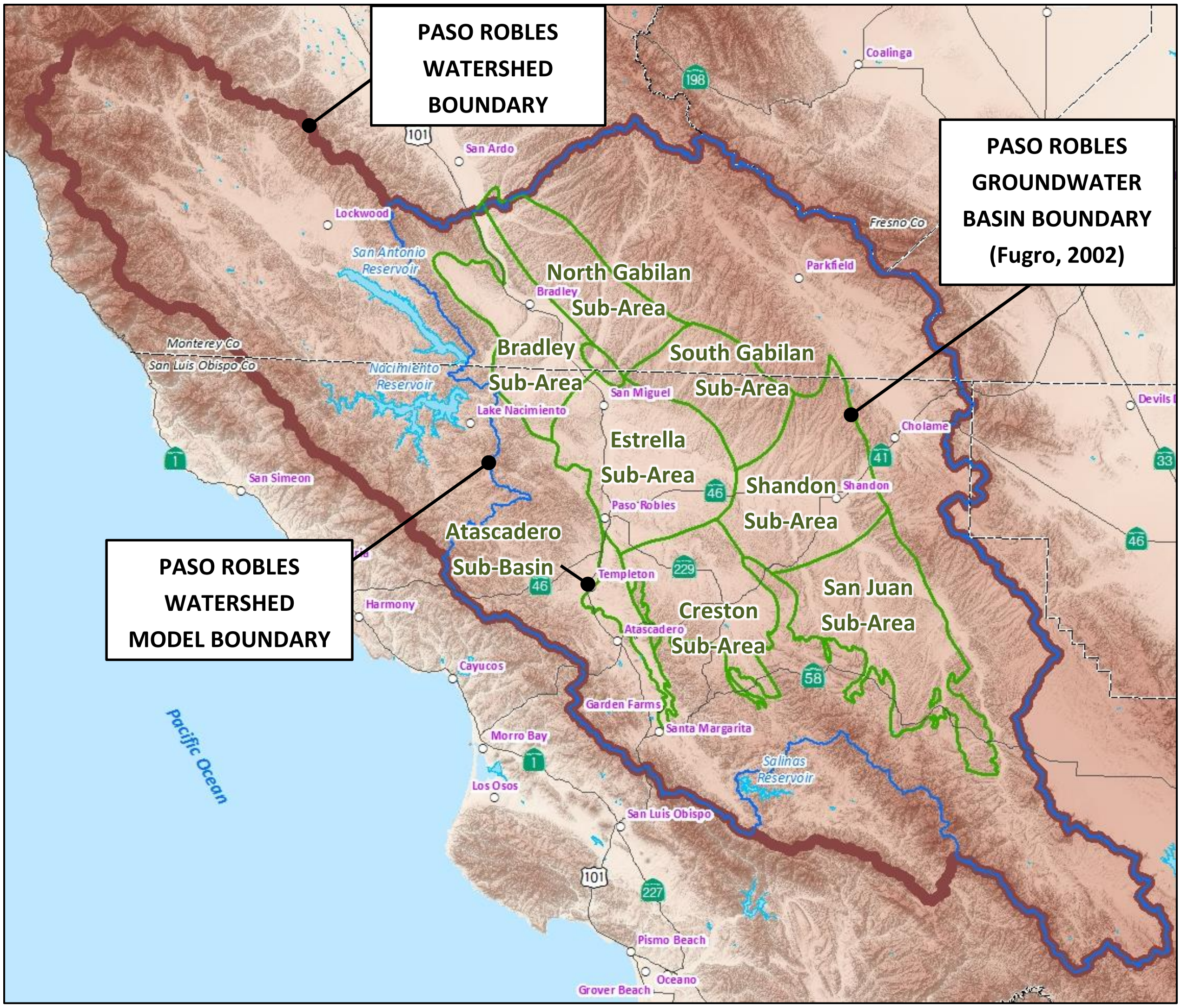

Figure ES-1. Overview of the Paso Robles Groundwater Basin and Surrounding Watershed

1.2 Water Balance Estimation

The Basin Model Update evaluated each component of the water balance independently using available data. The primary groundwater recharge components for the Basin are:

- Deep percolation of direct precipitation,
- Deep percolation of streambed seepage,
- Deep percolation of applied irrigation water,
- Subsurface inflows through the Basin boundary,
- Deep percolation of discharged treated wastewater effluent, and
- Recharge from urban water and sewer pipe leakage.

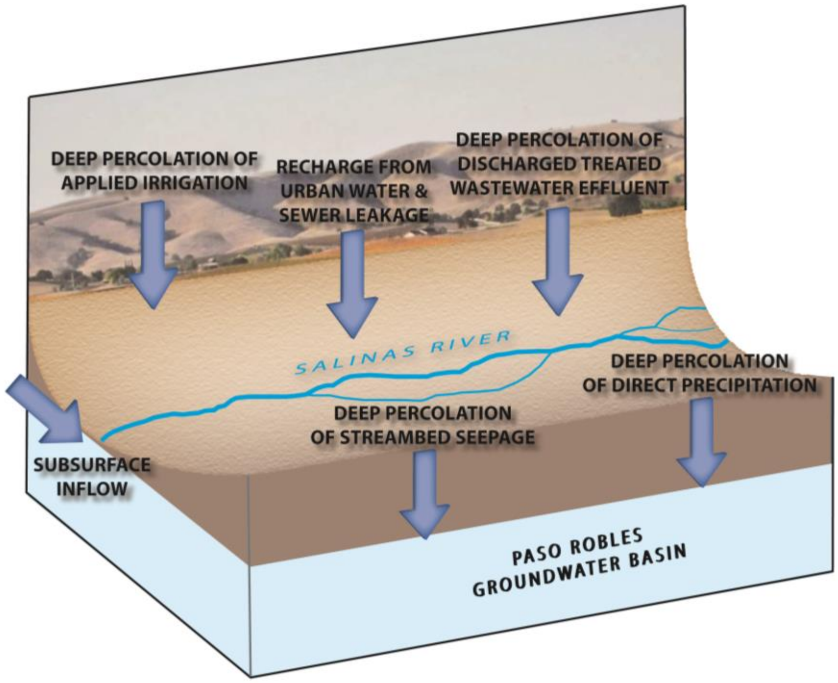

Figure ES-2. Primary Recharge Components for the Paso Robles Groundwater Basin

This report provides detailed description of the data and methodologies used in evaluating each recharge component.

A major new feature was development of a rainfall-runoff model[2] of the watershed[3] that is tributary to the Basin (see Figure ES-1). Such watershed hydrologic modeling uses extensive data to characterize the water balance and hydrologic processes that occur in a watershed. These data include land surface elevations, soil types, land use, precipitation, evaporation, streamflow, surface diversions, reservoir releases, wastewater recharge, crop coefficients, and irrigation efficiency. Historical data were collected, compiled (mostly in spreadsheets and a GIS database), and reviewed prior to incorporating them into the Basin Watershed Model. The available data are summarized in this report and have been made available to the District.

[2] The Watershed Model was developed using the Hydrologic Simulation Program – FORTRAN (HSPF), a successor to the FORTRAN version of the Stanford Watershed Model, widely-used codes developed with support of the United States Environmental Protection Agency (EPA).

[3] Surface water occurring in the watershed areas above the Nacimiento, San Antonio, and Salinas Reservoirs represent an external source of water coming into the Basin Watershed Model area. As such, daily releases from each reservoir are included as input to the Basin Watershed Model to help establish a water balance.

In addition, this report describes the primary steps used to construct the Basin Watershed Model involving 81 defined sub-watersheds and calibrating to four streamflow gaging stations with relatively long records. These gaging stations include the Salinas River near Bradley (at the outlet of the Basin), Salinas River above Paso Robles, Estrella River near Estrella, and Santa Margarita Creek near Santa Margarita; comparison of model-simulated and measured streamflow indicates a very good match for the Salinas River near Bradley gaging station and good or fair matches for the other stations.

The Basin Watershed Model provided independent analysis of recharge to the Basin, including subsurface inflow and streambed percolation; issues in the estimation of these recharge components had been identified by the original Paso Robles Basin modelers and later reviewers. These components remain difficult to assess accurately, reflecting a lack of data on percolation rates, streamflow and nearby groundwater levels, particularly around the margins of the Basin. As a result, these components became a major topic of the peer review conducted near the end of the Basin Model Update process and a focus of subsequent recommendations for additional model refinement.

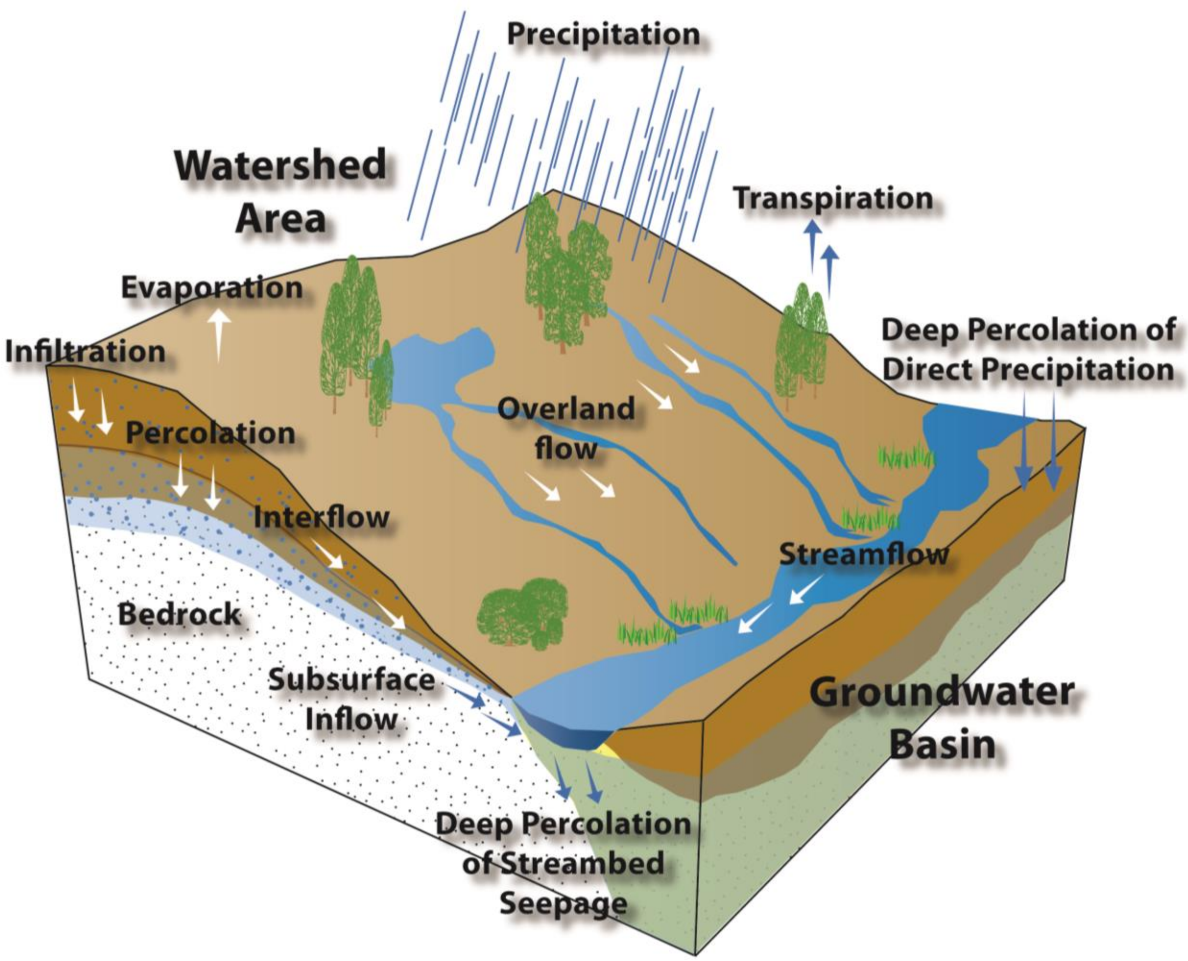

Figure ES-3. Relationship Between Watershed and Groundwater Basin

The primary groundwater discharge components for the Basin are:

- Agricultural pumping (average 68% for 1981-2011),
- Municipal pumping (11% for 1981-2011),
- Private Domestic pumping (3% for 1981-2011),
- Small commercial pumping (2% for 1981-2011),
- Evapotranspiration (ET) by riparian vegetation (3% for 1981-2011),
- Groundwater discharge to rivers (12% for 1981-2011) and
- Subsurface outflow (1% for 1981-2011).

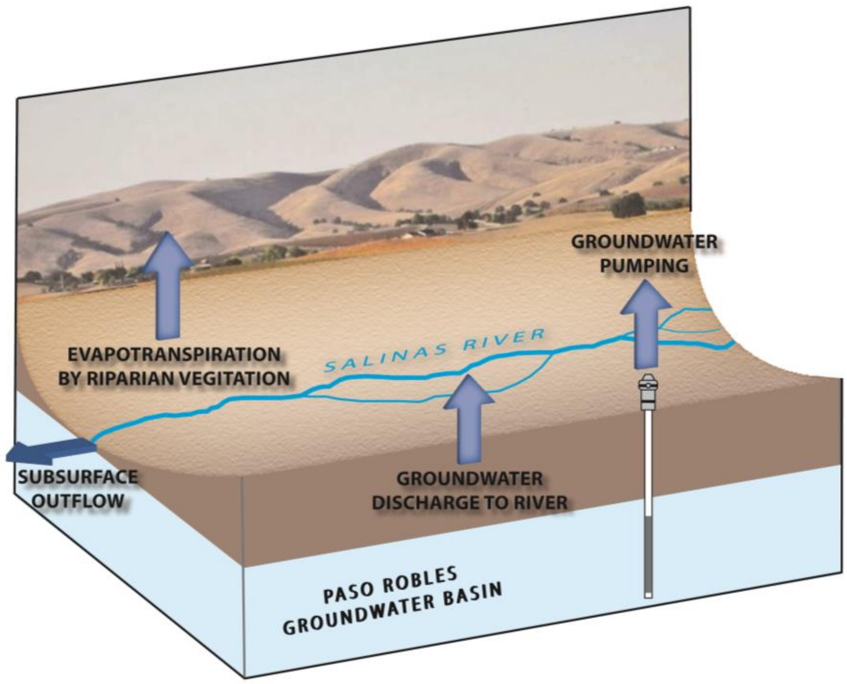

Figure ES-4. Primary Discharge Components for the Paso Robles Groundwater Basin

Of the discharge components, agricultural pumping accounts for the major portion (averaging about 68% over the model study period). Agricultural pumping is not metered and thus was subject to detailed analysis. As described in this report, this included development of crop-specific daily soil moisture water balances accounting for soil available water capacity, daily rainfall and reference evapotranspiration, crop water coefficient, bare soil evaporation, and increasing irrigation efficiency over time. Annual crop acreages estimated from Department of Water Resources (DWR) land use maps, digital San Luis Obispo County crop coverage maps for 2000 through 2011, and digital coverage of Monterey County 2012 crops. Crop acreages within groundwater basin boundaries from 2000 to 2010 were corrected/verified based on review of historical aerial photography.

Given the rapid increase in vineyards to dominate irrigated acreage (vineyards are more than 80% of irrigated acreage in the Basin), considerable attention was given to factors in vineyard water demand such as frost protection, regulated deficit irrigation (RDI) management, and increasing use of RDI management over time.

A relatively small but increasing discharge component is rural domestic pumping. This was a subject of concern because it is largely unmetered. Because meter data are lacking, previous studies (including the Phase I Study) relied on application of an assumed water demand factor of 1.7 AFY per dwelling unit (DU). The 2012 MWR also assumed a single water demand factor, in this case, 1.0 AFY/DU. This was significantly smaller and highlighted the uncertainty. Moreover, rural residences are quite variable—ranging from modest farmsteads to landscaped estates—suggesting that the variability of associated water demand was not evaluated adequately, particularly with regard to the extent of irrigated landscaping.

This concern was addressed in a special survey for this Basin Model Update and in a parallel survey for the concurrent Salt Nutrient Management Plan. The SNMP investigation focused on a San Luis Obispo County land use category termed *farmstead*, examined 59 farmsteads across the groundwater basin, and measured the landscaped areas, which averaged 0.13 acres per farmstead. For this Basin Model Update, a slightly different survey was performed focusing on five rural residential areas across the basin. The average landscape area was determined, resulting in a representative value is 0.13 acres per parcel, which happens to be the same value as that derived from the SNMP survey. Accordingly, both studies showed that rural residents irrigate a limited and fairly uniform acreage. For this study, available rural water demand information was used to estimate water demand per rural residential at 0.75 AFY/dwelling unit. This is a reasonable estimate of rural domestic use based on actual data. Of this amount, an average 38% is used indoors and can be assumed to return to the basin through onsite septic systems. An average of 62% is used outdoors and can be assumed consumed or lost to ET.

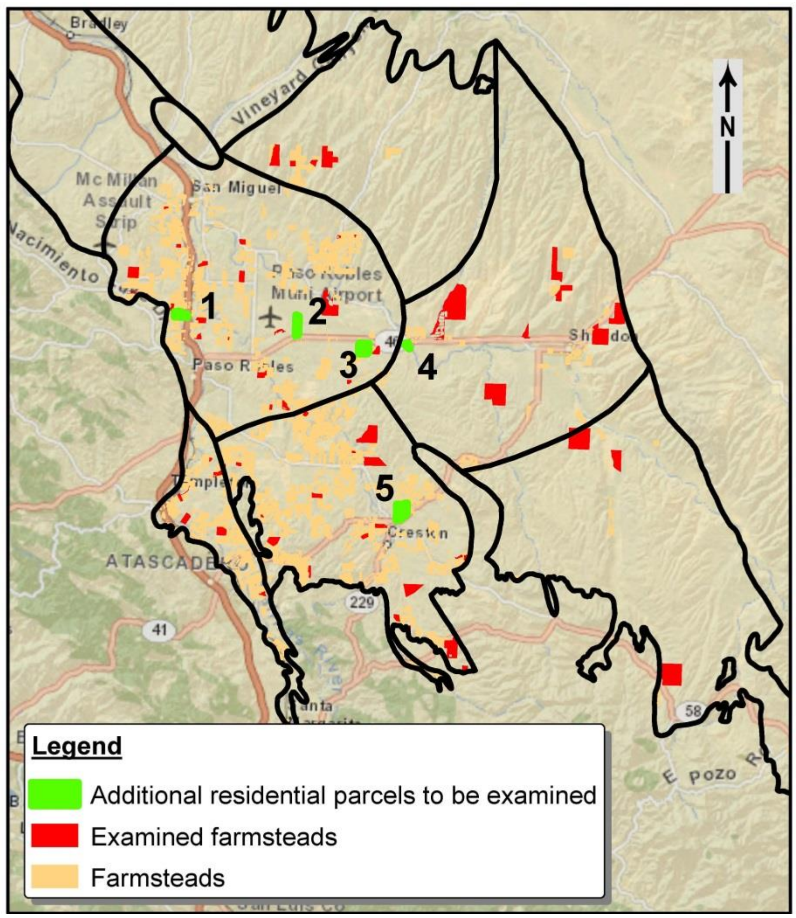

Figure ES-5. Locations of Landscaped Areas Used for Special Surveys

1.3 Hydraulic Separation of Atascadero Sub-Basin

The geologic conceptual model developed during the Phase I Study (Fugro and Cleath, 2002) defined the boundaries and hydrogeologic layers within the Basin, and identified the Atascadero Sub-Basin as a sub-basin with partial hydraulic separation across the Rinconada Fault from the remainder of the Basin[4]. An attempt to reevaluate the degree of separation was made for this Basin Model Update through review of post-2007 background reports and documents, driller's logs and well construction information, historic groundwater elevations, and historic groundwater pumping for wells located in the area of the reevaluation. Results of the reevaluation revealed there is a lack of wells and respective data within close proximity to the Rinconada Fault to adequately determine the degree of separation. Accordingly, the barrier conductivity values that were established by the Phase I Study were maintained for this Basin Model Update.

1.4 Basin Model Update

The original Basin Model was calibrated for water years 1981 through 1997 with a semiannual stress period. This update extended the model period to water year 2011, and replaced the recharge and discharge terms using the updated water balance analysis. This report provides details on the modeling software (MODFLOW packages) used to handle the estimated Basin inflows and outflows. The model domain, cell size and aquifer layering were unchanged from the original model. The updated Basin Model was run successfully with semiannual stress periods and evaluated in terms of its ability to produce simulated groundwater level trends that match observed trends; this evaluation triggered a recalibration of the model to improve its accuracy. Recalibration involved adjustments (using professional judgment and staying within reasonable bounds) to aquifer properties, and inflow and outflow terms. The recalibrated Basin Model is able (within industry standards) to simulate observed changes in groundwater levels that are driven by hydrological and groundwater pumping fluctuations.

Based on results of the recalibration run, model-generated total annual inflow for 1981-2011 ranged from 24,700 AF to 384,300 AF with an annual average of 108,400 AFY. Total annual outflow calculated by the updated Basin Model ranged from 84,400 AF to 142,160 AF with an annual average of 110,800 AF over the period 1981-2011. Applying the equation for change in groundwater storage (inflow minus outflow), the average annual change in groundwater storage for 1981-2011 is approximately -2,400 AFY.

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[4] Except for any separation of the Atascadero Sub-Basin, the Basin is considered to be an interconnected groundwater basin.

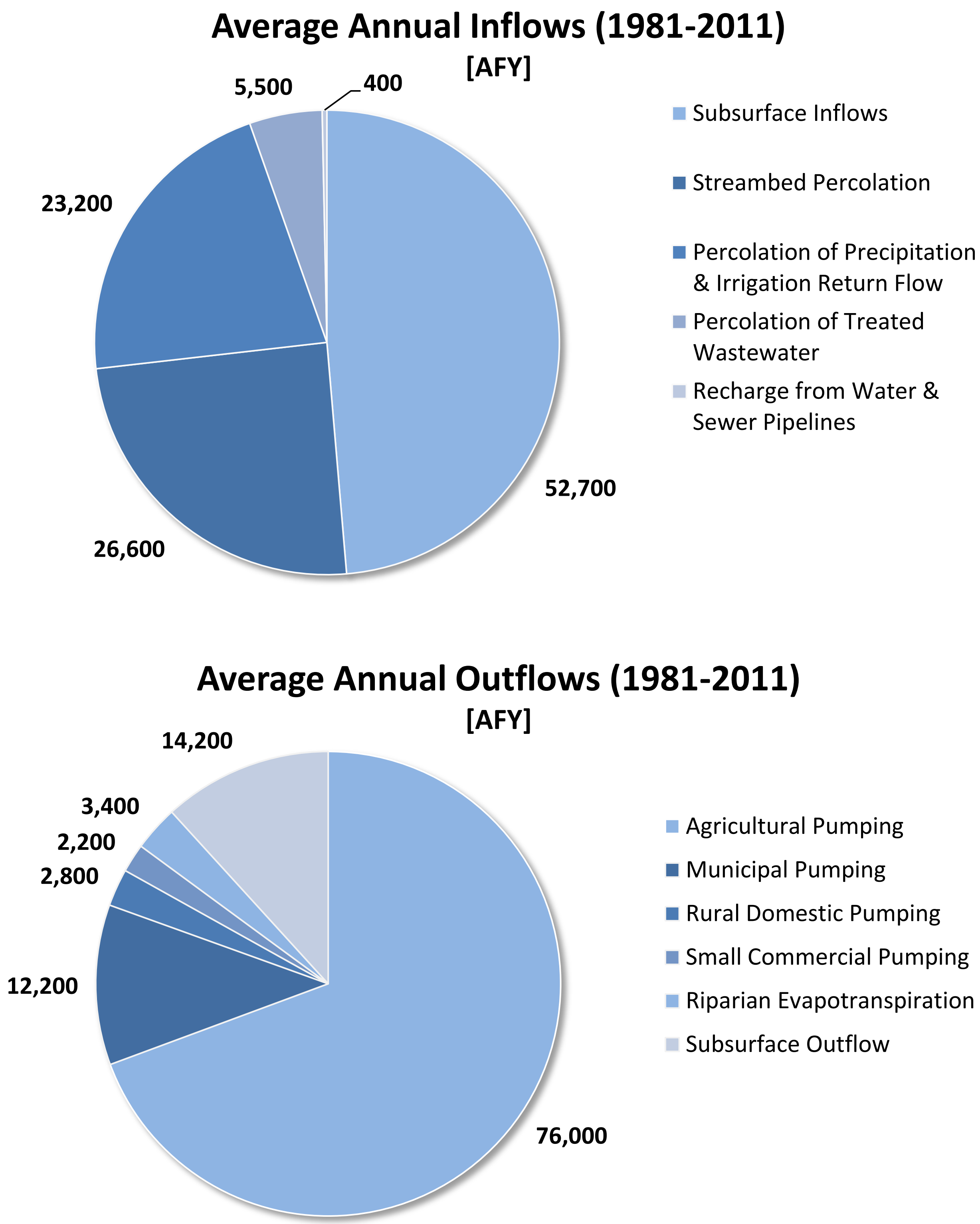


Figure ES-6. Average Annual Inflows and Outflows for the Paso Robles Groundwater Basin

Sensitivity analysis was performed on the recalibrated Basin Model in order to assess the model input parameters that have the greatest effects on the model's simulation results. The sensitivity analysis indicates that the Basin Model is most sensitive to changes to groundwater pumping and recharge from streambed percolation.

1.5 Perennial Yield Estimate

The maximum quantity of water that is available from a groundwater basin on a perennial basis is limited by the possible harmful side effects that can be caused by both pumping and operation of wells within the basin. The perennial yield, for purposes of this report is defined as:

Perennial Yield = Groundwater Pumping +/- Change in Storage

For the purposes of discussing perennial yield, the base period 1982 to 2010 covers wet, dry and average hydrologic cycles for the groundwater basin. The updated estimate for the perennial yield of the Basin based on that base period is 89,600 AFY.

1.6 Groundwater Model Predictive Scenarios

Two predictive scenarios were examined using the updated and recalibrated Basin Model to evaluate how groundwater levels and storage respond to varying groundwater pumping and recharge conditions. The variables included water demand and the amount of Nacimiento Water Project delivery. The model runs were simulated for a period of 29 years (water years 2012-2040) with a semiannual stress period. For the two scenarios, the hydrologic conditions (e.g., rainfall) that occurred during the hydrologic base period (the 29 years from October 1981 through September 2010) were simply repeated for 29 years into the future (i.e., 2012-2040). The hydrologic base period represents "wet", "dry" and "average" rainfall cycles which are characteristic of the Basin area.

Model Run 1, Baseline with No Growth, was developed to determine the response of the Basin to continuation of 2011 Nacimiento Water Project delivery, 2011 water demands, and no growth projected 29 years into the future (2012-2040). Accordingly, actual 2011 Nacimiento deliveries were used as input for every year. For water demands, 2011 values were repeated every year for 29 years with no growth.

Model Run 2, Baseline with Growth, examined the response of the Basin to Nacimiento Water Project deliveries projected to occur after September 2011, projected water demands, and a growth rate of 1% per year projected 29 years into the future[5]. Accordingly, Model Run 2 used actual Nacimiento deliveries for 2012-13 and those forecast for 2014-2040. For agricultural water demand, the 2011

[5] The projected 1% growth does not take into account the urgency ordinance (No. 3246) on new or expanded development of groundwater supplies in the Paso Robles Basin area.

acreages for all non-vineyard crops (e.g., alfalfa, etc.) were kept steady into the future; this is reasonable given relatively flat historical trends. For vineyards in 2012, the actual 2012 vineyard acreages were applied directly. For future years, forecasts developed by the modeling subcommittee for vineyards to be planted by July 2013, 2014, and 2017 were combined with the 2012 vineyard coverage to develop complete vineyard coverages from 2013 through 2017. Thereafter, a 1% growth rate in vineyard acreage was assumed from 2018 to 2040, with the growth applied spatially over the 2017 vineyard coverage. A 1% annual increase was also applied to municipal, private domestic and small commercial pumping.

Modeling results for Model Runs 1 and 2 are described in this report in terms of average annual water budgets, groundwater basin storage by year, and changes in groundwater levels. As shown in Table ES-1 below, total outflow would exceed total inflow on average 5,592 AFY and 26,159 AFY under the No Growth and Growth scenarios, respectively.

Table ES-1. Summary of Average Annual Water Budgets for Model Run 1 (No Growth) and Model Run 2 (Growth)

Flux Terms		Unit	Model Run 1	Model Run 2
Inflow	Deep Percolation of Direct Precipitation and Return Flow from Applied Irrigation Water	AFY	22,311	24,916
	Deep Percolation of Streambed Seepage	AFY	27,938	27,537
	Subsurface Inflow	AFY	47,612	37,590
	Nacimiento Reservoir Water Project Supplies	AFY	139	5,451
	Deep Percolation of Discharged Treated Wastewater Effluent	AFY	6,789	7,909
	Deep Percolation of Urban Water and Sewer Pipe Leakage	AFY	398	464
	Average Annual Total Inflow	**AFY**	**105,187**	**103,867**
Outflow	Groundwater Pumping	AFY	95,749	110,742
	Evapotranspiration by Riparian Vegetation	AFY	3,453	3,453
	Groundwater Discharge to Rivers	AFY	10,133	11,937
	Subsurface Outflow	AFY	1,444	1,447
	Average Annual Total Outflow	**AFY**	**110,779**	**130,027**
Average Annual Change in Groundwater Storage (Total Inflow – Total Outflow)		AF	-5,592	-26,159
Cumulative Changes in Groundwater Storage Over the 29-Year Modeling Period		AF	-162,163	-758,621

Figure ES-7 shows that at the end of the model simulation in WY 2040, the cumulative change in groundwater storage would be a decline of approximately 162,100 acre-ft for the no growth scenario and a decline of approximately 758,600 acre-ft for the growth scenario.

Figure ES-7. Predicted Annual and Cumulative Change in Storage for Paso Robles Groundwater Basin Model Runs 1 and 2 (Water Years 2012-2040)

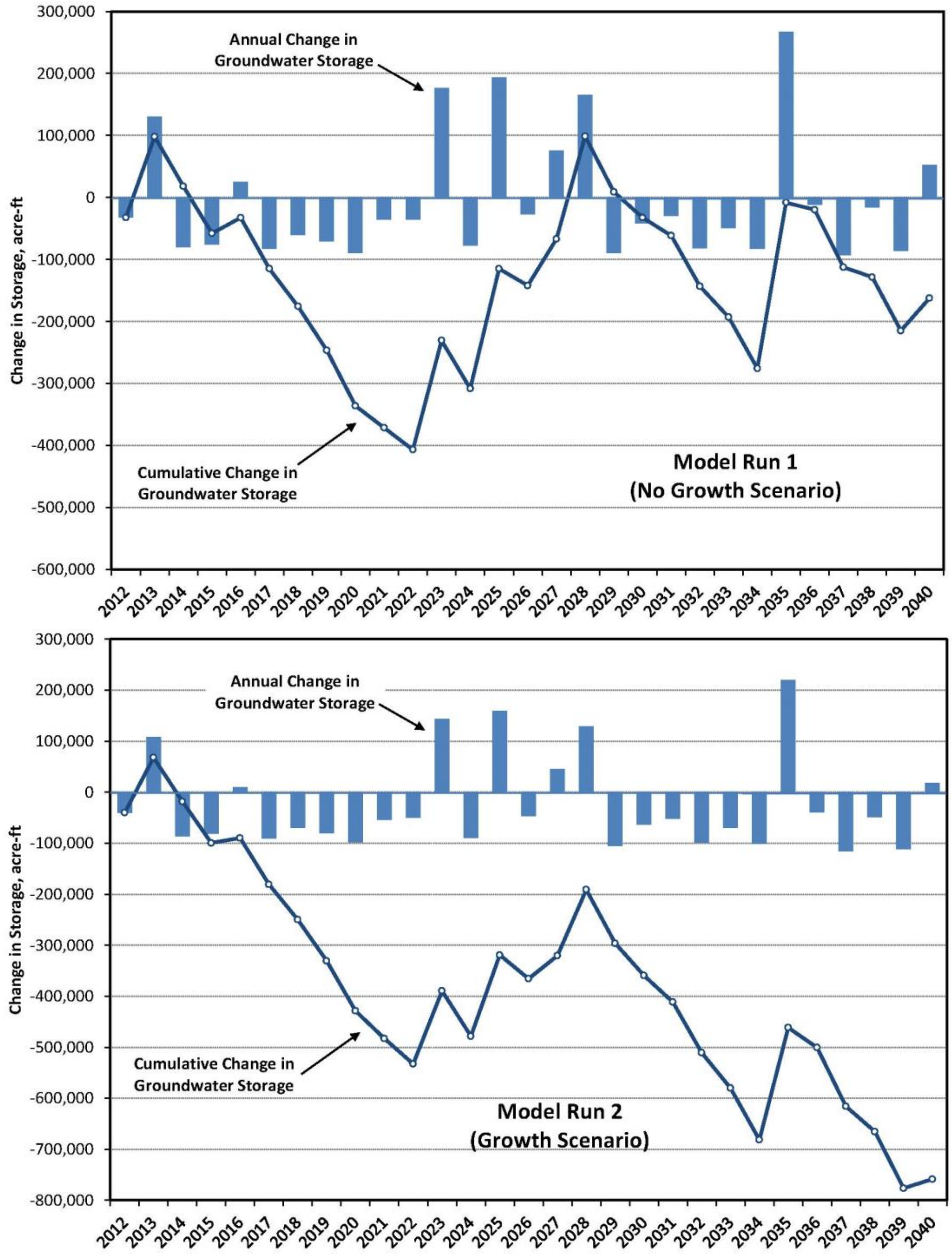
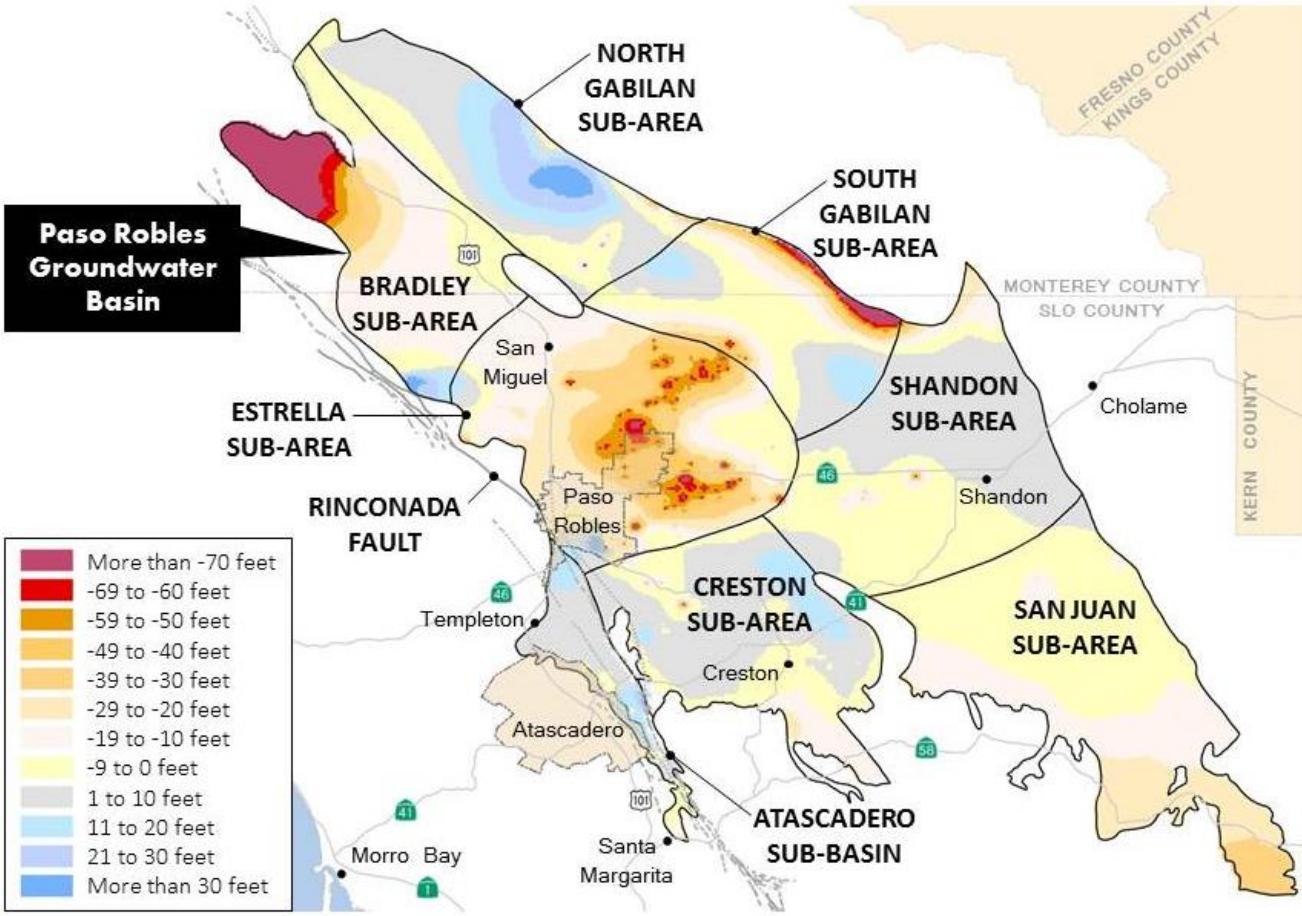


Figure ES-8 below shows that under the Model Run 1 (No Growth scenario) conditions, groundwater levels would decline more than 70 feet in the northern portion of the Bradley Sub-Area, along the eastern boundary of the South Gabilan Sub-Area, and within the central portion of the Estrella Sub-Area.

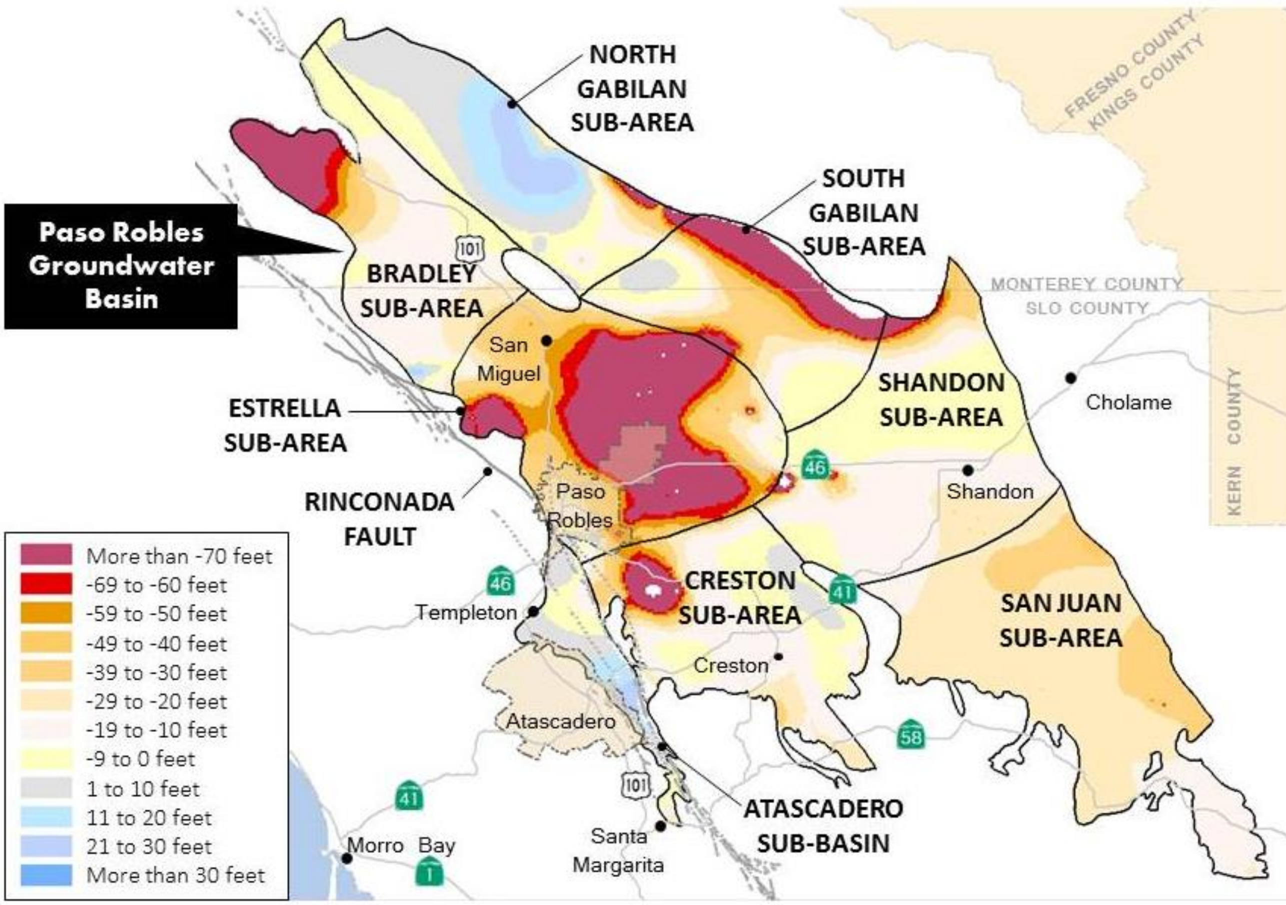
Figure ES-8. Change in Layer 4 Groundwater Elevations (2012-2040) – Model Run 1



Note: Change in groundwater elevations were also generated for model layers 1-3 for Model Run 1 and Model Run 2 conditions. Results provided in Figures ES-8 and ES-9 are for model layer 4, where changes in groundwater elevations are predicted to be highest under the no growth and growth scenarios.

Figure ES-9 below shows that under Model Run 2 (Growth scenario) conditions, the area of groundwater level declines in excess of 70 feet are more pronounced in the South Gabilan and Estrella Sub-Areas, and includes a significant area in the northwestern portion of the Creston Sub-Area.

Figure ES-9. Change in Layer 4 Groundwater Elevations (2012-2040) – Model Run 2



1.7 Model Limitations and Uncertainty

The Basin Model is a useful tool for evaluating the effects on Basin water levels due to changing hydrological and land use changes. Nonetheless, it is a simplified approximation of a complex hydrogeologic system and has been designed with built-in assumptions. To address such uncertainty, the Basin Model Update was evaluated independently through a peer review provided by Fugro Consultants. Discussion among GEOSCIENCE, Todd Groundwater and Fugro representatives focused on issues including certain aquifer properties, and the relative amounts and areal distribution of subsurface inflow, streambed percolation and rainfall recharge.

1.8 Recommendations

Based on the post-review discussion by GEOSCIENCE, Todd Groundwater and Fugro, specific tasks have been defined to reevaluate and further refine the Basin Model. These include the following:

- Reevaluate fate and recharge mechanisms of water from the watershed entering the groundwater basin;
- Replace the recharge/streamflow modeling package used to simulate streamflow and groundwater discharges to rivers with a streamflow routing package;
- Reevaluate deep percolation of direct precipitation and agricultural return flows in the groundwater basin; and
- Establish an acceptable range of hydraulic conductivity values for the groundwater basin.

In addition, the following scenarios have been identified for potential simulation with the refined Basin Model:

Baseline

- Updated Baseline with Growth Run

Specific Action Analyses

- Analysis 1 – Demand Reduction Scenario
- Analysis 2 – Salinas River Recharge
- Analysis 3 – Offset Basin Pumping with Recycled Water

Basin Management Objectives Analyses

- Analysis 4 – Offset Water Demand in Estrella Sub-Area
- Analysis 5 – Additional Releases to Huer Huero Creek
- Analysis 6 – Additional Releases to Estrella Creek
- Analysis 7 – Offset Pumping in Creston Sub-Area with Supplemental Water
- Analysis 8 – Offset Pumping in Shandon Sub-Area with Supplemental Water

Refinement of the Basin Model will provide improved understanding and simulation of the groundwater-surface water relationship and response to recharge and discharge components as they vary through time. Also, these proposed predictive analyses using the refined Basin Model will provide Basin managers and stakeholders the means to identify the actions which may be most effective at stabilizing groundwater levels on a sub-regional level.

2.0 INTRODUCTION

2.1 Background

Local agencies, including the San Luis Obispo County Flood Control and Water Conservation District (District) and local stakeholders[6] are continuing their cooperative efforts to address the state of the Paso Robles Groundwater Basin (Basin). These efforts are primarily directed toward improved Basin management, which includes providing technical tools to evaluate supplemental water supply options that are needed for sustaining the Basin.

One of these groundwater management activities is the *Paso Robles Groundwater Basin Study Phase II – Numerical Model Development, Calibration, and Application* (Fugro, ETIC Engineers and Cleath, 2005). The model domain covers the entire Basin (referred to henceforth as the Basin Model) and was developed as a quantitative tool to evaluate future hydraulic conditions of the Basin. The conceptual model and input values were established during the *Paso Robles Groundwater Basin Study* (Phase I Study). The purpose of the Phase I study, conducted by Fugro and Cleath (2002) was to develop a conceptual geologic and hydrogeologic understanding of the Basin and to quantify its groundwater capacity (i.e., perennial yield).

The Basin Model was developed for the period 1981 to 1997, and was used to refine uncertainties and estimates in the hydrologic budget and perennial yield, and to predict potential future trends with and without supplemental water supplies. Since its publication, needed improvements to the Basin Model have been identified by the original modelers, and by others[7]. These issues are related to the model conceptualization and water balance. For example, the conceptual model developed by the original modelers includes the hydraulic disconnection between the Atascadero Sub-Basin and the main Basin. The degree of disconnection, however, needs to be reevaluated utilizing new data which may have become available since the Phase I Study. Improvements needed for the water balance included updating the evaluation of rainfall recharge, subsurface inflow, stream-groundwater interactions, agricultural irrigation rates, rural water use, and groundwater storage change; some of which had insufficient documentation in the previous studies.

Basin conditions have changed significantly over the past 15 years (specifically, land use and climate), and recent studies have shown that the Basin pumping is at or approaching its perennial yield. The

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[6] Stakeholders participate via public meetings of Basin Advisory Committee, which was formed by the District, and includes participating agencies, stakeholder groups and individuals for the purpose of implementation of a groundwater management plan (GMP) for the Basin. A Model Update Subcommittee of the committee provided data review and model input.

[7] Gus Yates, 2010.

impacts to the Basin, such as long-term declining groundwater levels in areas of Basin, are apparent and widespread. In order to mitigate these conditions and evaluate emerging supplemental water supply options, the District and Basin stakeholders elected to update the Basin Model. Goals of the update include:

1. Extend model period from 1981-1997 to 1981-2011;
2. Refine the perennial yield for the Basin;
3. Assessing the model input parameters that have the greatest effects on the model's simulation results to determine the certainty of model predictions; and
4. Evaluating the Basin's response to "Growth" and "No Growth" scenarios projected over the period 2011 to 2040.

GEOSCIENCE Support Services, Inc. (GEOSCIENCE) teamed with Todd Groundwater[8] to provide the District and Basin stakeholders with an updated model. As part of the Basin Model update and to improve the water balance estimation, the water balance analysis performed for the Phase II Study has been replaced with a new method. The new water balance estimation covers the period 1981 through 2011, and includes:

- Replacement of the original model's Blaney method for evaluating rainfall recharge with a rainfall-runoff modeling system approach (i.e., watershed model);
- Application of recently available California Irrigation Management Information Systems (CIMIS) data to assess evapotranspiration losses; and,
- Analysis of water balance components on a monthly basis, as opposed to a semiannual basis.

The new method extends the water balance from the limits of the Basin to its surrounding watershed (see Figure 1). Accordingly, the study area includes the Basin and contributing watershed[9]. The benefits of a watershed approach and application of a watershed model include a comprehensive understanding of the water balance, and validation of the water balance estimations against actual streamflow data at established gages (i.e., model-generated versus observed data).

2.2 Purpose

This report is intended to supplement and update the Phase II Study regarding the original Basin Model

[8] Formally Todd Engineers.

[9] The water balances of the watershed areas above Salinas, Nacimiento, and San Antonio dams are addressed by examining the reservoir inflows, outflows, and change in storage.

documentation. The primary objective of the Basin Model update is to provide the District and Basin stakeholders with an updated, accepted tool for simulating Basin response under current and future conditions to specific scenarios in order to evaluate management options for addressing the documented groundwater level declines that are persisting, particularly within the Creston, Shandon and Estrella Sub-Areas of the Basin.

2.3 Scope of Work

The scope of work was based on the recommended improvements to the original Basin Model listed in the County of San Luis Obispo (County) Request for Proposal (RFP) #1178, dated April 23, 2012. The scope was further defined by the GEOSCIENCE/Todd Groundwater Team, as the development of a watershed model to replace the Basin inflow terms was not included in the original scope. The scope of work included:

- Collect and compile data to develop a watershed model and update the Basin Model,
- Develop and calibrate a watershed model (HSPF[10]) for the Basin area to calculate inflow components,
- Reevaluate the conceptualized hydrologic connection between the Atascadero Sub-Basin[11] and main Basin,
- Update the existing Basin Model with updated recharge and discharge terms from the water balance analysis,
- Conduct post-update audit on the Basin Model and determine the need to recalibrate,
- Recalibration of the Basin Model according to industry standards,
- Development of predictive model runs that to evaluate how the Basin responds to varying groundwater recharge conditions,
- Preparation of draft technical memorandums to provide the approach and results of water balance analysis, reevaluation of the aquifer system conceptualization, model update and post-update audit, and
- Preparation of draft and final model reports summarizing the components and results of the model update and predictive runs.

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10 Hydrologic Simulation Program - Fortran

11 The terms Sub-Area and Sub-Basin are interchangeable in the case of the Atascadero area.

2.4 Description of Study Area

The study area consists of the Paso Robles Groundwater Basin, located in the upper portion of the Salinas River watershed in northern San Luis Obispo County and southern Monterey County. The Basin covers approximately 505,000 acres (790 square miles) that extends from the Garden Farms area south of Atascadero to San Ardo in Monterey County, and from the Highway 101 corridor east to Shandon (see Figure 1). In order to effectively discuss findings based on technical studies, the Basin was subdivided for the Phase I Study into eight study areas[12]: Atascadero Sub-Basin; Bradley Sub-Area; Creston Sub-Area; Estrella Sub-Area; North Gabilan Sub-Area; San Juan Sub-Area; Shandon Sub-Area; and, South Gabilan Sub-Area. The major water-bearing units in the Basin include recent alluvial deposits and the Paso Robles Formation. The alluvial deposits are located primarily beneath the flood plains of the Salinas River and its tributaries. The Paso Robles Formation extends throughout the entire Basin and, in some areas, exceeds a depth of 2,000 ft.

2.5 Existing Paso Robles Basin Groundwater Model

The original Basin Model, which addresses the period Water Years (WYs) 1981-1997, is based on the 2002 Phase I work developed for the Paso Robles Groundwater Basin (Fugro, ETIC Engineers and Cleath, 2005). The primary purpose of the Basin Model was to develop a numerical groundwater flow model as a quantitative tool to evaluate future basin hydraulic conditions.

The Basin Model covers an area of approximately 734 square miles (469,830 acres). The model was constructed using MODFLOW-2000, a block-centered, finite-difference groundwater flow code developed by the USGS (Harbaugh *et al*., 2000). The Basin Model consists of four layers:

- Layer 1 consists of the recent alluvium that is distributed primarily within the Salinas and Estrella River valleys,
- Layer 2 represents the upper portion of the Paso Robles Formation, which is limited to the center of the Basin between Paso Robles and Shandon,
- Layer 3 represents the portion of the Paso Robles Formation which covers most of the Basin (but does not extend to the outer edge), and
- Layer 4 represents the deepest portion of the Paso Robles Formation and extends across the entire Basin.

[12] Except for the Atascadero Sub-Basin, the Sub-Areas are hydraulically interconnected by continuous water-bearing sedimentary formations which define the Paso Robles Groundwater Basin. The Sub-Areas were delineated for the Phase I Study (Fugro and Cleath, 2002) for discussion purposes, based on water quality, source of recharge, groundwater movement, and contours on the base of permeable units. Full descriptions of each Sub-Area are provided in the Phase I Study.

The calibration period of the original Basin Model was October 1981 through September 1997 (i.e., 17 years) with semiannual stress periods.

2.6 Cooperation

The update of the original Basin Model required a collaborative effort between County and District personnel, members of the Modeling Subcommittee, and independent and consulting technical advisors. During the update process, which included development of a watershed model and two predictive model scenarios, four teleconferences were conducted to present and discuss specific project tasks and to address comments by the County, District, Modeling Subcommittee, and others on methodologies and results. In addition, one County Board of Supervisors meeting and two public meetings were held to discuss the update of the Basin Model.

2.7 Sources of Data

Data used to update the Basin Model, which included development of a watershed model, required collection and organization of a substantial body of data obtained from multiple sources. This data collection and organization in itself represents considerable value to San Luis Obispo County and the local stakeholders, recognizing that the information can be used for other investigations and as a basis for future data collection efforts. Accordingly, the data compilation effort was systematically tracked in terms of types, sources, responsible data collector, and date of receipt. In general, the data were organized into the following categories:

- Climate
- Geology
- Groundwater
- Groundwater Model
- Land Use
- Soils
- Surface Water
- Topography/Ground Cover
- Wastewater

Throughout the duration of the Basin Model update, an electronic database was made accessible to District and County staff. The database was established and maintained by GEOSCIENCE. Access was gained via a File Transfer Protocol (FTP) system that was allocated for the project. All electronic files of data received from the sources indicated above are contained on a compact disk as Attachment A[13] to

13 Confidential and proprietary data has been redacted in the public version of Attachment A.

this report.

Table 1 provides a summary of the data inventory, including data type, a brief description, source, and FTP folder.

3.0 WATER BALANCE ESTIMATION

The water balance estimation takes into consideration the volumes of water that enters (recharges) and exits (discharges) the Basin, plus or minus the change in groundwater storage. It is used to assess the status of water availability in an area over a specific period of time. It is also a valuable tool for Basin management decision making. The simplest form of the water balance equation is:

$$P = Q + E \pm \Delta S$$

Where:

P = Precipitation
Q = Runoff
E = Evaporation
ΔS = Change in groundwater storage

The primary groundwater recharge components for the Basin are:

- Deep percolation of direct precipitation,
- Deep percolation of streambed seepage,
- Deep percolation of applied irrigation water,
- Subsurface inflows through the Basin boundary,
- Deep percolation of discharged treated wastewater effluent, and
- Recharge from urban water and sewer pipe leakage.

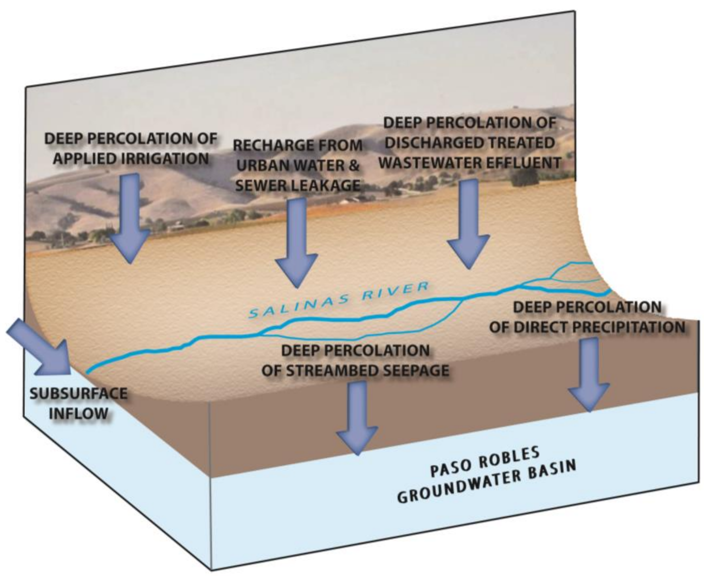

Figure 3-1 Diagram of Primary Groundwater Recharge Components for the Paso Robles Groundwater Basin

The primary groundwater discharge components for the Basin are:

- Agricultural pumping,
- Municipal pumping,
- Rural domestic pumping,
- Small commercial pumping,
- Small community systems pumping,
- Evapotranspiration by riparian vegetation, and
- Subsurface outflow.

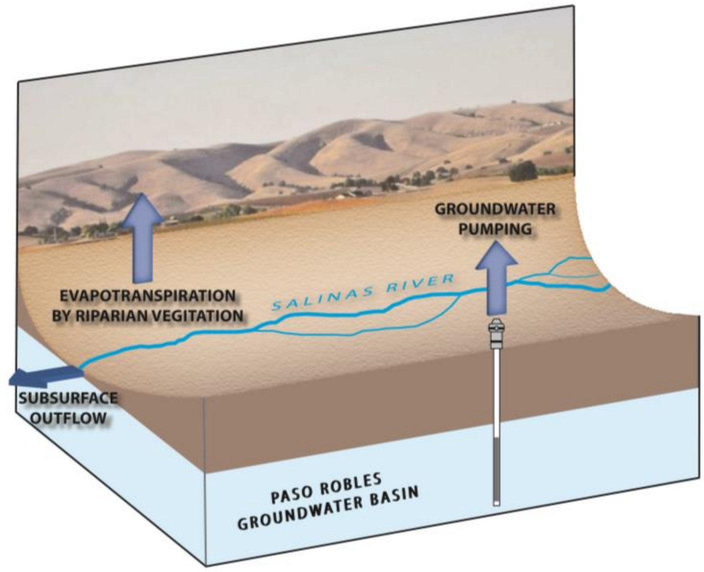

Figure 3-2 Diagram of Primary Discharge Components for the Paso Robles Groundwater Basin

A requirement of the water balance equation is to quantify, either through measured data or estimation (e.g., linear regression), each recharge and discharge component. The methodologies and data used for the original Basin Model and this update are discussed in the following sections.

3.1 Previous Method Used to Estimate Water Balance Components

The initial approach to estimate the water balance components of the Paso Robles Groundwater Basin for the period 1981-1997 was performed for the Phase I Study (Fugro and Cleath, 2002). The Phase II Study included development and use of the Basin Model to compare the inflow and outflow components using results from the Phase I work (Fugro, ETIC Engineers and Cleath, 2005). Phase II results provided projected hydrologic budgets for build-out. In a subsequent study, Todd (2009) evaluated and updated the total estimated groundwater pumping for 2006.

The methodology used for the Phase I Study to estimate the water balance components consisted of comparing the annual totals for each recharge and discharge term ("inventory method") for the period 1981-1997 with the annual changes in groundwater in storage ("specific yield method"). Both methods were used for the seven sub-areas of the Basin and the Atascadero Sub-Basin. Results from the inventory method indicated that over the 17-year period, the main Basin experienced an average deficit of approximately 2,700 AFY, while the Atascadero Sub-Basin had no overall change in storage. The specific yield method for the same period resulted in an annual increase in storage of 700 AFY for the Basin, with a slight increase of 200 AFY in storage for the Atascadero Sub-Basin. The differences in annual amounts of changes in storage as calculated by both methods were described as not being unexpected, and likely associated with inaccuracies of some recharge and discharge components, and limitations in the calculations for percolation of precipitation (Fugro and Cleath, 2002). The projected build-out water balance estimation by Fugro (2005) was performed using the calibrated Basin Model. Results were comparable with those of the Phase I Study (i.e., 1997 estimation); however, a higher estimate of inflow and outflow (17%) was projected for build-out.

The 2009 evaluation by Todd included analysis of all types of groundwater pumping in the Basin that occurred in WY 2006: agricultural, municipal systems, small community systems, small commercial systems, and rural domestic pumping. Each type of pumping demand was calculated using various methods, but in general were comparable to those used for the 1997 estimations.

3.2 Revised Method Used to Estimate Water Balance Components

The approach used for the Basin Model update evaluated each component of the water balance equation independently by extending the water balance from the limits of the Basin to the surrounding watershed. This was achieved by developing a calibrated rainfall-runoff model of the watershed that is tributary to the Basin (i.e., watershed model). The use of a watershed model resulted in improved quantification of the Basin recharge components and the spatial and temporal distributions of recharge through inclusion of changes in land use. Also, results of streambed percolation from the watershed model were used to recalibrate the updated Basin Model on the streambed conductance—particularly for the variations that occur during spring and fall as well as wet and dry years.

Results from the watershed model were used to update the following four recharge components of the water balance equation for the Basin:

- Deep percolation of direct precipitation,
- Deep percolation of streambed seepage,
- Deep percolation of applied irrigation water, and
- Subsurface inflows through the Basin boundary.

Deep percolation of discharged treated wastewater effluent was based on reported data from the City of Atascadero, City of Paso Robles, Templeton Community Services District, and San Miguel Community Services District (see Section 3.3.4). Recharge from urban water and sewer pipe leakage was estimated (see Section 3.2.1.3.5).

3.2.1 Paso Robles Basin Watershed Model

A rainfall-runoff model of the watershed overlying and contributing to the Paso Robles Groundwater Basin, referred to herein as the Basin Watershed Model, was developed using the HSPF. HSPF is a successor to the FORTRAN version of the Stanford Watershed Model. The Stanford Watershed Model evolved over the period from approximately 1956 through 1966. In 1974, work resulted in the widely available codes developed for and with support of the U.S. EPA. The most recent release of HSPF is version 12. HSPF is a comprehensive and physically based watershed model that can simulate the hydrology and water quality with a time step less than a day (hourly). A schematic diagram of the HSPF model is shown on Figure 2. The diagram below illustrates the primary components of a HSPF model, and the relationship between a watershed and associated groundwater basin.

3.2.1.1 Data Requirements of the Basin Watershed Model

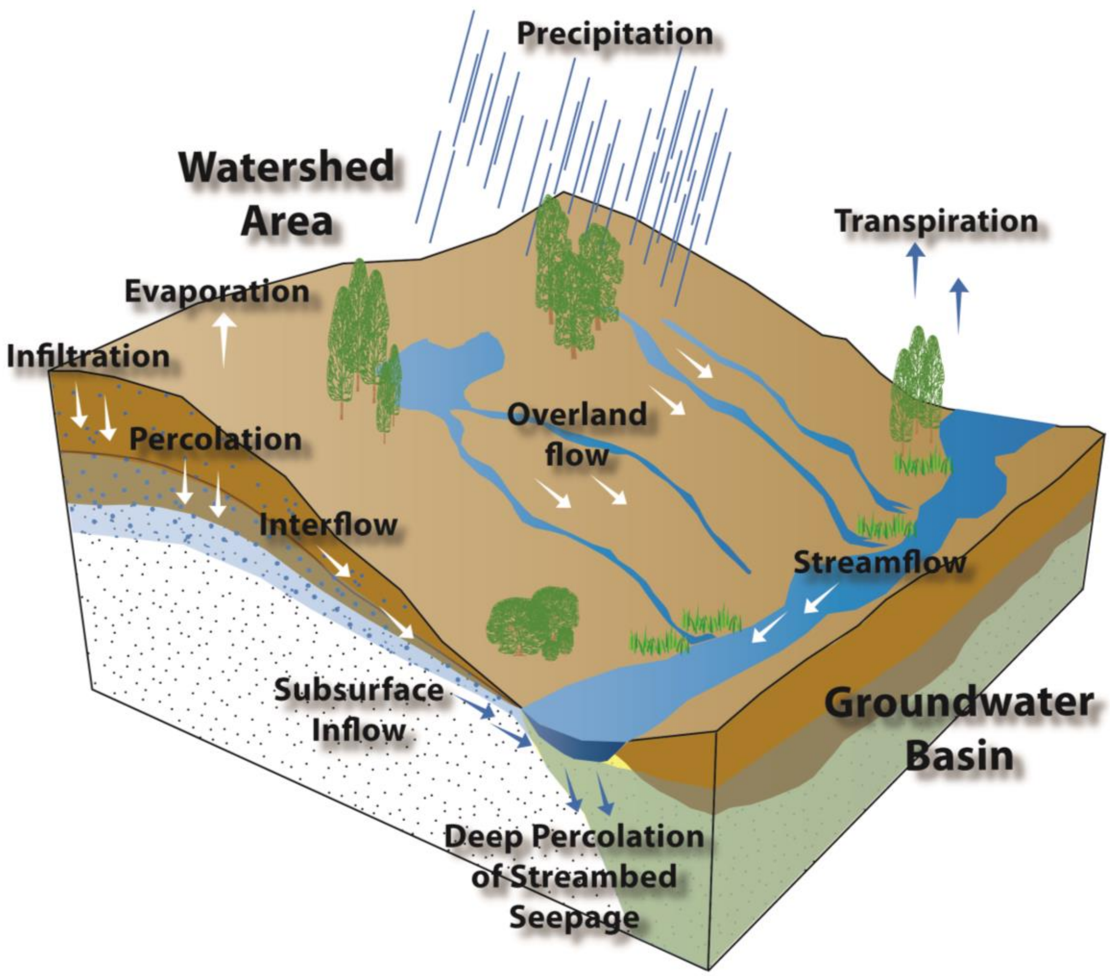

Figure 3-3 Illustration of Watershed Model HSPF Components

Watershed hydrologic modeling requires a variety of data to characterize the water balance and hydrologic processes that occur in a watershed. These data include:

1. Land surface elevations,
2. Soil types,
3. Land use,

4. Precipitation,
5. Evaporation,
6. Streamflow,
7. Surface diversions,
8. Reservoir releases,
9. Wastewater recharge,
10. Crop coefficients, and
11. Irrigation efficiency.

Descriptions of each data type used to develop the Basin Watershed Model are provided in the following sections.

3.2.1.1.1 Land Surface Elevations

Land surface elevations were obtained by using a USGS 10-meter-by-10-meter DEM in ESRI ArcMap 10. The DEMs are used to evaluate surface water runoff patterns, and in turn to delineate the watershed and sub-watershed boundaries.

3.2.1.1.2 Soil Types

Soil type and distribution in the Basin and surrounding watershed was obtained from an ESRI shapefile of Soil Survey Geographic Database (SSURGO) hydrologic soil group information (Soil Survey Staff et al., 2012) (see Figure 3). There are four basic types of soils under this classification system (Group A through D), which are based on soil texture and properties. A discussion of soil descriptions and how they affect infiltration is provided in Section 3.2.1.2.4.

3.2.1.1.3 Land Use

Information on land use and land cover was obtained from State and County sources. Data on land use within the watershed was obtained from San Luis Obispo County and Monterey County Agricultural Commissioner's Office (ACO) crop reports, Department of Water Resources (DWR) land use maps, and County-provided parcel GIS shapefiles. Annual crop reports list acreage and type of agriculture (such as animal, field, nursery and seed, fruit and nut, or vegetable); however, no geographic information was provided. These crop reports are available from 1981 through 2011 for both counties.

Land use GIS shapefiles from various sources and years were also used to determine the locations for each land use category. These shapefiles include:

- Riparian vegetation distribution (1994) from the California Department of Forestry and Fire Protection;

- Vineyard locations from San Luis Obispo and Monterey Counties;
- San Luis Obispo County crop layers for 1996-2002 and 2004-2012 from the County Department of Agriculture[14];
- Monterey County ranch maps for 2012;
- South Central Coast land use (1996-1997) from the DWR;
- Information from the City of Atascadero regarding city limits and land use for 2011;
- Information from the City of Paso Robles regarding city limits and land use for 2011;
- Land use files used for the Phase II Study (Fugro, ETIC Engineers and Cleath, 2005) covering San Luis Obispo County for 1985 and 1996, and Monterey County for 1989 and 1997;
- Land use code changes from 1981 to the present from San Luis Obispo County;
- Land use coverage for 2001 from United States Department of Agriculture National Resources Conservation Service;
- San Luis Obispo County parcel information from ParcelQuest; and
- San Luis Obispo County general plan with land use codes.

3.2.1.1.4 Precipitation

Precipitation data were obtained from 32 gaging stations within the model boundary in San Luis Obispo and Monterey counties (see Figure 4). Hourly data for 11 stations were downloaded from the National Climatic Data Center (NOAA) database. Daily records are available for 16 District stations, as well as from five Western Weather Group precipitation stations in San Luis Obispo County. Each station has varying periods of recorded precipitation data. Station information is listed in Table 2 and annual precipitation for selected stations is shown on Figures 5 through 8.

In addition to data from the precipitation stations, gridded estimates of monthly and annual precipitation were obtained in the form of PRISM maps. PRISM (Parameter-elevation Regression on Independent Slopes Model) was developed by the National Resources Conservation Service (NRCS) National Water and Climate Center (NWCC) and the PRISM Climate Group at Oregon State University. Gridded data represents the long-term annual precipitation from 1981-2010. Isohyetal contours of long-term annual precipitation from 1900-1960, which were compiled from the USGS, DWR, and California Division of Mines maps and information sources, were also obtained.

3.2.1.1.5 Evaporation

Evaporation zones and monthly average reference evapotranspiration (ETo) values (inches/month) for the model area were obtained from the 1999 CIMIS Reference Evapotranspiration Map for the State of

[14] Department staff was unable to locate crop layer data for 2003 (Trapp, R., personal communication, 29-Jan-13).

California. The ETo zones displayed on the reference map represent regions of similar climate and vegetation characteristics that are used by CIMIS to define ETo values for water use and irrigation demand estimation. ETo refers to the total evaporative losses (evaporation and plant transpiration) from a reference crop, usually a short-turf grass growing with no moisture stress. ETo can be estimated for different crop types by applying a crop coefficient, as discussed in Section 3.2.1.2.3.

In addition to the CIMIS data, daily evapotranspiration were obtained for six[15] Western Weather Group stations within the Basin and surrounding watershed (see Figure 9). These stations are listed below in Table 3-1. Daily evapotranspiration from these sites are shown on Figures 10 through 14. As discussed in Section 3.2.1.2.8, the station information was compared to the CIMIS data to assign evapotranspiration values to the model area.

Table 3-1. Evapotranspiration Stations in the Paso Robles Basin Area

Station Name/Location	Agency/Source	Annual Average ET[1,2] [in/year]	CIMIS ETo Zone	Period of Record
Paso Robles	Western Weather Group	54.1	16	2005-2012
Tablas Creek	Western Weather Group	48.8	6	2005-2012
Shandon	Western Weather Group	54.7	10	2005-2012
Templeton Gap	Western Weather Group	47.4	16	2005-2012
Creston	Western Weather Group	54.0	16	2005-2012
Hames Valley	Western Weather Group	47.8	-	2006-2012

[1] Annual average ET for the period 2005-2011, except for the Hames Valley station.
[2] Annual average ET for the Hames Valley station for full years 2007-2011.

3.2.1.1.6 Streamflow

Historic daily streamflow data were obtained from four (4) District gages as well as from nine (9) USGS gages (downloaded from the National Water Information System webpage) for varying periods of record (see Figure 15). Gage station information is provided in Table 3-2, and historical daily streamflow is shown on Figures 16 through 28. The daily readings from all 13 gages were used to help calibrate the Basin Watershed Model, as discussed in Section 3.2.1.3.

[15] A seventh station, Camatta Hills, was also included in the data set from the Western Weather Group; however, coordinates were not provided, and the period of record was significantly less: January 2010 through September 2012.

Table 3-2. Streamflow Gaging Stations in San Luis Obispo County

Station Name/Location	Station Number	Agency/Source	Period of Record
Yerba Buena Creek in Santa Margarita	-	SLO FC&WCD	1965-1985
Cholame Creek at Palo Prieta (Bitterwater Road) near Cholame	3	SLO FC&WCD	1973-1983 1985-1991
Salinas River below Salinas Dam near Pozo	8	SLO FC&WCD	1974-2004
Santa Margarita Creek near Santa Margarita	15	SLO FC&WCD	1961-2000
Salinas River near Bradley	11150500	USGS NWIS	1948-2012
Nacimiento River below Nacimiento Dam near Bradley	11149400	USGS NWIS	1957-2012
Nacimiento River below Sapaque Creek near Bryson	11148900	USGS NWIS	1971-2012
Estrella River near Estrella	11148500	USGS NWIS	1956-1996
Salinas River above Paso Robles	11147500	USGS NWIS	1939-2012
Santa Rita Creek near Templeton	11147070	USGS NWIS	1961-1994
Salsipuedes Creek near Pozo	11144200	USGS NWIS	1969-1983
Toro Creek near Pozo	11144000	USGS NWIS	1960-1983
Salinas River near Pozo	11143500	USGS NWIS	1942-1983

3.2.1.1.7 Surface Diversions

Information on surface water diversions was obtained from diversion permits available through the State Water Resources Control Board's Public Water Rights Database. Information includes water planning area (WPA), permit holder name, diversion source and type, status of permit, and allowable diversions in AFY. These data were reviewed to ascertain if any diversions are permitted for uses other than the agricultural, rural domestic, or rural commercial uses that were assessed based on land use data. The permits also may be revealing about specific well locations, recognizing that most local surface water diversions are probably achieved through stream-side wells.

3.2.1.1.8 Reservoir Operations

There are three reservoirs operating in the watershed that drains into the Paso Robles Groundwater Basin: San Antonio, Nacimiento, and Salinas Reservoirs. Daily releases in cubic-ft per second (cfs) are available for all three reservoirs from January 1, 1981 through September 30, 2011. The data for the Salinas Reservoir (i.e., Santa Margarita Lake) includes information on lake elevation, storage, releases, discharges, and diversions out of the upper Salinas River watershed to the City of San Luis Obispo. In addition, daily deliveries from the Nacimiento Dam (i.e., the Nacimiento Water Project) in million gallons per day (mgd) are also available for January 1, 2011 through September 4, 2012. Delivery data are in the form of daily flow totals from turnouts at Templeton and Atascadero; the Paso Robles turnout has yet to take delivery.

3.2.1.1.9 Wastewater Recharge

There are five significant wastewater treatment facilities within the Paso Robles Groundwater Basin (see Figure 29) that either discharge effluent into the Salinas River channel or release wastewater into infiltration (percolation) ponds. Average daily effluent flows in mgd, as well as the locations and percolation rates for the infiltration ponds, were obtained for inclusion in the Basin Model. Site names and information are listed in the following Table 3-3.

Table 3-3. Wastewater Treatment Discharge Site Information in Paso Robles Groundwater Basin

Facility	Data Type	Period of Record
City of Paso Robles WWTP	Daily Average Effluent by Month	1990-2012
	Daily Average Effluent by Year	1981-2011
City of Atascadero WWTP	Daily Average Effluent by Month	1996-2007
	Daily Average Effluent by Year	1981, 1988-2011
	Monthly Percolation (ft)	1996-2007
Templeton CSD WWTP	Daily Average Effluent by Year[1]	2001-2011
San Miguel CSD WWTP	Daily Average by Month	2004-2007, 2010-2012
Camp Roberts WWTP	Daily Average Effluent by Month	2009-2011

Note:
[1] Actual data was not available. Used assumed average daily flow as per Tina Mayer of TCSD (e-mail correspondence to Todd Groundwater, 12-Feb-13).

3.2.1.1.10 Crop Coefficients

The crop coefficient (Kc) is a dimensionless number that is used to estimate a particular plant's water requirements in a particular region[16]. Crop coefficients are listed in Table A7 of Appendix A of the San Luis Obispo County Master Water Report (2012). As discussed in the later section on Applied Water (3.2.1.2.3), these county-wide crop coefficients were reviewed and adjusted in light of conditions and agricultural practices in the Paso Robles basin.

3.2.1.1.11 Irrigation Efficiency

Irrigation efficiency refers to the percentage of irrigation water beneficially used compared to the total water applied in a region. Estimated irrigation efficiencies for irrigation system types (sprinkler or micro) and the current usage of irrigation system types for different crop types are listed in Tables A13 and A14 of Appendix A of the San Luis Obispo County Master Water Report (2012). Comparable information is available for Monterey County in the annual Ground Water Extraction Summary Reports.

[16] Crop coefficients have been developed by UC scientists to accurately estimate water use by particular crops under the specific measureable conditions on the surface of the Paso Robles Basin.

The estimated irrigation efficiencies for major crop groups (alfalfa, nursery, pasture, citrus and deciduous, vegetable, or vineyard) are listed in Table A15 of Appendix A of the San Luis Obispo County Master Water Report (2012) for current conditions. Estimated irrigation efficiencies are also provided for historical conditions in the Phase I Study (Fugro and Cleath, 2002).

3.2.1.2 Construction of the Basin Watershed Model

Historical data were collected, compiled, and reviewed prior to incorporating them into the Basin Watershed Model. Extensive use of spreadsheets and a comprehensive geographic information system (GIS) database were instrumental in the creation of the model. The following sections provide a description of the primary steps used to construct the Basin Watershed Model.

3.2.1.2.1 Delineation of Tributary Sub-Watersheds and Stream Segmentations

Sub-watersheds are areas that are assumed to have similar hydrogeologic characteristics. They were created for the Basin Model using the US EPA BASINS 4.1 program. This program segments the delineated watershed into sub-watersheds and stream reaches using a delineation tool and a DEM, as well as user-specified outlet locations. The location of these outlets was based on topography, location of existing streamflow gages, and change in channel type (i.e., the point where an ephemeral stream intersects a perennial stream). Through this process, 81 sub-watersheds and 81 corresponding stream reaches were defined (see Figure 30). A list of the names, drainage areas, and stream reach lengths for each sub-watershed is provided in Table 3. Reaches have the same numbers as the sub-watershed in which they are found. These numbers serve only as identifiers in the HSPF modeling process and do not need to be sequential or continuous.

Each stream reach segment was analyzed to determine the hydraulic behavior through the use of an FTABLE (hydraulic table). FTABLEs determine the infiltration volume of free-flowing stream reaches by using the HSPF BMP Toolkit created by the US EPA, which takes into account the lining type (all streams in the watershed are unlined[17]), slope, Manning's Roughness Coefficient (used for flow calculations), and the length of the stream reach. The HSPF BMP Toolkit builds FTABLES for each delineated sub-watershed.

Each of the sub-watersheds was assigned model parameter values based on the available data in the area. The assignment process for each parameter is discussed in greater detail in the following sections.

17 All streams within the Paso Robles area watershed have natural channel bottoms.

3.2.1.2.2 Designation of Pervious and Impervious Land

Land use and development affect how water enters or leaves a system by altering infiltration, surface runoff, location, and degree of evapotranspiration, and where water is applied in the form of irrigation. Since land use changes over time, information from 1985, 1997, and 2011 was used to locate and designate areas as being pervious or impervious within the model boundary during the simulation period (see Figures 31a, 32a, and 33a, respectively). There are six main land use categories for the purpose of identifying perviousness:

- Agriculture/Parks/Golf Course,
- Commercial/Industrial/Public Facility[18],
- Open Space/Dry Agriculture/Water Body,
- Residential Low Density,
- Residential Medium Density, and
- Residential High Density.

Higher Perviousness Land Use Type
↑ (Greater Onsite Infiltration Rate)
↓ (Lesser Onsite Infiltration Rate)
Lower Perviousness Land Use Type

As shown on Figures 31b, 32b, and 33b, the Agriculture/Parks/Golf Course category is further broken down into Alfalfa, Deciduous, Nursery, Pasture, Truck, and Vineyard sub-categories for the purposes of water demand estimates assigning crop coefficients and irrigation factors, as discussed in the following Section 3.2.1.2.3. The acreages of each land use category and sub-category for 1985, 1997, and 2011 are shown in Tables 4, 5, and 6, respectively.

The land use category determines to what degree areas are pervious or impervious. Even areas with residential or commercial land use categories are assumed to have a percentage of pervious area associated with them (i.e., landscaping). These percentages are listed below for each land use type in Table 3-4.

Table 3-4. Assumed Pervious Percentages for Land Use Categories

Land Use Category	% Pervious
Agriculture/Parks/Golf Course	100
Commercial/Industrial/Public Facility	20
Open Space/Dry Agriculture/Water Body	100
Residential Low Density	90
Residential Medium Density	50
Residential High Density	40

[18] Agricultural processing was assigned to "industrial" for the purpose of pervious analysis.

3.2.1.2.3 Determining Type of Applied Water

The Basin includes significant areas of both agricultural and developed commercial and residential land. Water is applied to the land differently depending on the land use. Areas designated as being industrial or residential still typically have an applied water value associated with the irrigation of landscape. The Basin Model considers both urban and agricultural irrigation practices.

The overall approach to simulate applied water in both urban and agricultural irrigation settings is based on the assumption that irrigation systems are used, and that the water is applied in amounts sufficient to satisfy the monthly crop and land evapotranspiration (ET) demands that exceed available rainfall. The 2012 Master Water Report analysis (ESA, 2010) calculated the crop-specific applied water for crop types by using information on crop evapotranspiration, effective rainfall, leaching requirements, irrigation efficiency, and frost protection. The following equation was used to evaluate annual applied water demand for specific crop types:

$$\text{Annual Crop-Specific Applied Water (AF/AC/YR)} = \frac{ETc - Er}{(1 - LR) \times IE} + FP$$

Where,

ETc = Crop Evapotranspiration [AF/AC/YR]

Er = Effective Rainfall [AF/AC/YR]

FP = Frost Protection [AF/AC/YR]

LR = Leaching Requirements [%]

IE = Irrigation Efficiency [%]

Crop Evapotranspiration (ETc). The crop evapotranspiration were calculated by multiplying a specific crop coefficient with the CIMIS ETo (see Section 3.2.1.1.5). For the 2012 Master Water Report, crops were assigned monthly crop coefficients for alfalfa, nursery, irrigated pasture, citrus, deciduous, vegetable, and vineyard crop groups. These coefficients were used in this model update, with modifications as discussed below, and are reproduced in Table 3-5 below.

Table 3-5. Crop Water Use Coefficients for Watershed Model

Month	Alfalfa	Citrus	Deciduous	Nursery	Pasture	Vegetables	Vineyard[1]
January	0.00	0.56	0.00	0.50	0.00	0.00	0.00
February	0.00	0.56	0.00	0.50	0.00	0.00	0.00
March	0.90	0.56	0.60	0.50	1.00	0.00	0.00
April	0.90	0.56	0.70	0.50	1.00	0.00	0.20
May	0.90	0.56	0.80	0.50	1.00	0.00	0.40
June	0.90	0.56	0.90	0.50	1.00	0.00	0.60
July	1.00	0.56	1.00	0.50	1.00	0.00	0.60
August	1.00	0.56	1.00	0.50	1.00	1.00	0.60
September	1.10	0.56	0.90	0.50	1.00	1.00	0.60
October	1.00	0.56	0.80	0.50	1.00	1.00	0.40
November	0.00	0.56	0.00	0.50	0.00	1.00	0.00
December	0.00	0.56	0.00	0.50	0.00	1.00	0.00

[1] Kc values modified from 2012 SLO Water Master Plan based on conversations with Mark Battany (2013a).

In San Luis Obispo County, vegetables are often double-cropped. This was assumed in the 2006 Pumping Update and in the Master Water Report, while the Phase I Study assumed one vegetable crop per year. Specific truck crop types (e.g., carrots, melons) are not indicated in the recent maps. However, discussion with Upper Salinas/Las Tablas RCD staff indicates the presence of lettuce, spinach, carrots, and various vegetables. Consideration of frost potential in the Basin and surrounding watershed suggests one truck crop per year between April and October; for the purpose of this model update, the vegetable crop coefficient (1.00) is adopted from the Master Water Report and applied to the months of May through September.

Irrigation Efficiency. The Phase I Study (pg. 129) presented a table of assumed efficiencies by crop category and by five-year periods from 1980 through 1997. The 2012 Master Water Report (Appendix A, pg. 11-13) evaluated irrigation efficiency through literature review and consultation with Central Coast RCD staff, growers and other stakeholders in San Luis Obispo County. This analysis considered irrigation system types (sprinkler and micro) for the crop categories and distribution uniformities. Existing efficiencies are expressed as low and high values for the crop categories. For the purposes of this evaluation, average efficiencies also were computed. Comparison of the Phase I Study values for 1980 through 1997 and the Master Water Report's existing and future values indicates a general consistency, with efficiency generally increasing over time. When plotted over time, the computed average values for existing and future conditions provided the smoothest fit to the trend of preceding Phase I Study values.

For the purposes of this model update, irrigation efficiency values need to be considered as they have changed over the study period. First, the five-year irrigation efficiencies developed in the Phase I Study are retained in the evaluation of agricultural pumping from 1981 through 1997. Second, the computed average values for irrigation efficiencies from the 2012 Master Water Report are used to represent existing conditions (with modifications as described below). For the years between 1997 and the end of the study period, a linear trend in irrigation efficiency is generally assumed for each crop. Consistent with the Phase I Study, the period between 1997 and 2011 can be divided into five-year segments (e.g., 1998-2002, 2003-2007, and 2008-2011).

It should be recognized that improving efficiency is (or will be) increasingly difficult and costly, and that the rate of improvement levels off, unlikely to reach 100%. While the irrigation method (for example, conversion from sprinklers to drip or micro systems) is not the sole means of water conservation, it has been a major factor. Review of available information on irrigation systems in the Salinas Valley (MCWRA, 2011) indicates that the percentage of vineyards on drip has increased from 80% in 1997 to 97% in 2007 and 98% in 2011. The San Luis Obispo 2012 Master Water Report similarly concludes that 100% of vineyards currently use micro irrigation systems. It can be assumed that the rate of efficiency improvements probably has leveled off in recent years (e.g., after 2007) and will continue to flatten in the future. Accordingly, the average efficiencies for recent and future vineyards were adjusted.

Table 3-6 below presents assumed efficiency values for major crops applied in the model update. Values from the Phase I Study were used for the five-year periods from 1980 through 1997. For the current period (WYs 2008-2011) and the future, the values were developed from the average, adjusted efficiency values for existing and future conditions from the 2012 Master Water Report. For the intervening periods (WYs 1998-2002 and WYs 2003-2007), the values are interpolated, and in the case of vegetables, show a leveling off in the rate of efficiency improvement. Efficiency values are indicated to be stable for alfalfa and pasture. Based on conversations with Mark Battany, the irrigation efficiency for vineyards was increased from the 2012 Master Water Report as follows: from 76% to 78% for 1998-2002; from 77% to 81% for 2003-2007; and from 78% to 85% for 2008-2011[19].

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[19] Data from the Cal Poly ITRC website summarizing results of recent irrigation system tests support the increase in distribution uniformity over time; the average of the most recent drip/micro emitter data set is 84 percent (see http://www.itrc.ogr/irrecvaldata/isedata.htm, "Drip Micro" data set) (Battany, 2014).

Table 3-6. Irrigation Efficiencies as Percentages for Crop Groups

Crop Groups	1980-1985	1986-1990	1991-1995	1996-1997	1998-2002	2003-2007	2008-2011	Future
Alfalfa	63	65	68	72	70	70	70	70
Citrus	63	68	72	75	76	77	78	79
Deciduous	63	68	72	75	76	77	78	79
Nursery	63	65	67	70	70	70	70	70
Pasture	63	65	67	70	70	70	70	70
Vegetable	63	65	67	70	73	76	78	80
Vineyard	63	68	72	75	78	81	85	85

Notes: For citrus, the irrigation efficiency for deciduous was assumed.

Urban irrigation is typically limited to lawn watering by homes and businesses. As such, the dominant vegetation is assumed to be turf grass, which has a crop coefficient of 0.6 (from AQUA TERRA, 2003). In addition, an irrigation efficiency of 85% was used from AQUA TERRA (2003), which corresponds to a well-designed and well-operated sprinkler irrigation system.

With regard to geographic variability, it is assumed that Master Water Report countywide values for irrigation efficiency and methods are reasonably representative of the Paso Robles Basin. Moreover, the San Luis Obispo County values are extended to the Monterey County portion of the basin. This extrapolation is supported by comparison of the usage of irrigation system types in the two counties. The 2012 Master Water Report Appendix A (pg. 12) documents the percentage of acreage with sprinkler and micro irrigation systems; similarly, the MCWRA 2011 Ground Water Summary Report (MCWRA, 2011) documents the acreage of sprinkler systems and drip systems in Salinas Valley. The irrigation system distribution of major comparable crop types summarized in Table 3-7 below shows that the use of irrigation systems is very similar. This suggests comparable irrigation practices throughout the basin and across the County line.

Table 3-7. Distribution of Irrigation System Types as a Percentage

Crop Group	Monterey County[1]			San Luis Obispo County		
	Drip/Micro	Sprinkler	Other[2]	Drip/Micro	Sprinkler	Other[2]
Truck/Vegetable	52	48	0	60	40	0
Forage/Pasture/Alfalfa	0	47	53	0	80	20
Grapes/Vineyard	98	2	0	100	0	0
Tree Crops/Deciduous	83	17	0	80	20	0

[1] Representative of systems used only as a primary irrigation system, not as a secondary or frost protection system.
[2] Includes combinations, furrow, and surface irrigation.

Vineyard Canopy Development. Water use by a vineyard varies with climate conditions and with the size of the vineyard canopy (Prichard, et al., no date). In general, the larger the canopy, the greater the water use. Seasonal canopy growth is accounted for in the crop coefficient for vineyards, which begins as a small value after bud break, increases as the canopy expands in spring and summer, and then declines in autumn. However, there are other factors in canopy extent, including the design of the vineyard (row spacing and trellis design) and the age and condition of the grapevines. Vineyards with wider spaced rows, young grapevines or low vigor vines with a small canopy use less water on a per-acre basis than vines with a larger canopy (Prichard, et al., no date).

Vineyard design is recognized as a significant factor in the water consumption on a vineyard basis. For example, the water use with a VSP trellis with 9-foot row spacing has been estimated to be about 60% of the water use of a high density planting (Williams, 2001). On a regional scale, this could be significant to an evaluation of agricultural pumping if there were a predominance of low-water or high-water use vineyard designs in a Sub-Area or a strong trend over time. A trend toward smaller row spacing (e.g., higher density of grapevines) has been noted in the Central Coast (Bettiga, 2013). At this time, data are not readily available on vineyard designs. Accordingly, this factor is not quantified for this model update, but should be considered in the future. Similarly, data are not available on the health of vineyards and this factor is not considered here. A significant factor is vineyard management with Regulated Deficit Irrigation methods, in which water application is restricted and the growth of the canopy is managed; this widespread practice is addressed in the next section.

Regulated Deficit Irrigation (RDI). Regulated deficit irrigation refers to the practice of regulating or restricting the application of irrigation water to a vineyard, thereby limiting the vine water use to below that of a fully watered vine (Prichard, et al., no date). The objectives are to improve the quality of the grape, control growth of the canopy, manage grape yield, and conserve water.

Regulated deficit irrigation was not addressed in the 2012 Master Water Report. However, its importance was noted in recent water balance studies (Yates, 2010). This practice was recognized in the Phase I Study and termed intentional water stress. The Phase I Study subdivided vineyard acreage into normal and stressed and assumed that third-year and mature vineyards were subject to stressing (i.e., RDI). Stressed vineyards were assumed to experience a 30% reduced ET. The adoption of this irrigation technique was recognized as increasing at a constant rate of 15% every five years from 0% of vineyard acreage in 1980-1985 to 30% in 1991-1995, and then reaching 35% in the last two years, 1996-1997.

For the purposes of this model update, Regulated Deficit Irrigation has been addressed through modifications to the soil moisture balance methodology used to assess the consumption of applied water; as discussed in Section 3.4.1.2, this involved consideration of dynamic water consumptive use and soil moisture conditions through the irrigation season.

The estimated expansion of this technique in five-year increments from 1981 through 1997 is retained for the evaluation of pumping. For the subsequent period, the constant-rate increase from 1980-1985 through 1991-1995 is projected in five-year increments to 2011 (see Table 3-8 below). This results in a current estimate of 75%. This value is in reasonable agreement with a recent survey in San Luis Obispo County that indicated use of RDI by 83% of survey respondents (Beal, 2011), presuming that survey respondents (as compared to the total grower community) are more likely to be engaged in state-of-the-art irrigation practices.

Table 3-8. Percent of Acreage with Deficit Irrigation (Stressed)

Paso Basin Study Phase I*			Projected Percent Acreage		
1980-1985	1986-1990	1991-1995	1998-2000	2001-2005	2006-2011
0	15	30	45	60	75

* Interim 1996-1997 value not shown, 35%.

Effective Rainfall (ER). Effective rainfall is the amount of rainfall that occurs on a crop and is used effectively for the crop's water demand. Previous estimates of effective rainfall have involved application of rainfall on a seasonal or annual basis. The Phase I Study (pgs. 125-127) evaluated the distribution of rainfall across the basin, estimated a representative soil moisture holding capacity, and applied relationships between gross rainfall and crop water use to estimate effective rainfall on a semiannual basis. The 2012 Master Water Report estimated ER by applying a range of low and high percentages for each crop type to a local average annual rainfall (e.g., Paso Robles total of 15 inches). These values range from about 30% to 60%, suggesting the importance of effective rainfall.

For this model update, we note that, assuming a perfect irrigator, effective rainfall represents a direct, commensurate reduction in irrigation pumping. It also depends on the timing and intensity of rainfall, soil moisture conditions, and crop growth, which change (at least) on a daily basis. Recognizing this, daily soil moisture balances were prepared for this model update that account for daily rainfall, ETc, and soil moisture, and thereby provide an estimate of effective rainfall on a daily basis.

Frost Protection (FP). Frost protection was addressed in the Phase I Study (pgs. 129-130) by assuming 11 nights with frost in March and April, an application rate of 0.5 AF/AC/YR, and use of frost control by 50% of vineyards. The 2012 Master Water Report analysis in Appendix A (pgs. 9-11, ESA, 2010) evaluated sprinkler frost protection water requirements for vineyards throughout the County; this method was reviewed for application to this model update. Water is used for frost protection of vineyards generally from bud break in March through April (recognizing that bud swell is also a vulnerable period, that bud break varies, e.g., with location and varietal, and that frosts can occur in May). Because of the short-term need for copious spraying, the water typically is pumped from a reservoir (which in turn is supplied from a well). Use of sprinkler frost protection is also predicated on the risk of frost, which typically is greatest in low-lying areas of poor air drainage, and on availability of a reservoir.

In estimating agricultural pumping, the frost protection value ESA used was 0.25 AF/AC/YR for vineyards throughout the County. This was based on information provided by the UC Farm Advisors and input from the WRAC and other agricultural stakeholders. The value was based on overhead sprinkling for four to six hours per night for 10 to 12 nights per year with an assumed system flow rate of 50 gpm/AC. Using these estimates resulted in a range of annual application rates from 0.34 to 0.62 AF/AC/YR (see Table A11 in Appendix A, Carollo, 2012). Taking a representative value of 0.5 AF/AC/YR, ESA assumed that approximately 50% of the vineyards use frost protection. Therefore, ESA used 0.25 AF/AC/YR for annual vineyard frost protection on a regional basis.

Consultation with Central Coast viticulture experts (Larry Bettiga and Mark Battany) indicates that the estimate of 10 to 12 frost nights per year is overstated. Hames Valley is relatively frost-susceptible and 10 nights is a reasonable albeit high value for that area. The San Luis Obispo portion of the Basin watershed has fewer frost nights, especially in recent decades.

For this model update, review focused on the number of nights with frost, the timing of frost protection during the year, and the geographic distribution of frost protection.

Readily available information on minimum temperatures in Paso Robles (Battany, 2011) indicates that freezing temperatures can occur from March into May and even June. Frost protection also is used in late September and October in Hames Valley (Bettiga, 2013). For the purposes of this model update, water use for frost protection is distributed to the two months, March and April, when frost protection is most likely to be needed. An application of 0.5 inches of water was assumed.

Frost protection is used in some areas and not others; for example, vineyards in the San Luis Obispo County portion of the Basin watershed west of Highway 101 typically do not practice sprinkler frost protection because of lack of available water (Battany, 2013a). As noted previously, low-lying areas are more susceptible than sloping land. Several ways are available to address the geographic distribution of frost protection across vineyards. One method assumes an even distribution across all vineyards (e.g., at the previously used 50% rate), while an alternative method links the distribution to proximity to holding ponds (which are visible on aerial photographs). For this Basin Model update, the latter approach was applied, whereby frost protection was applied to fields on parcels under the same ownership as mapped holding ponds.

It is noted that frost protection is most significant for *gross* agricultural pumping. With regard to agricultural consumption, frost protection results mostly in return flows; ET consumption is limited to short-term evaporation from wet soil.

Heat Protection. Heat protection involves use of sprinklers to reduce heat stress, for example, on vineyards. This practice in not widespread in the Paso Robles area and is not considered further for this model update.

Leaching Requirements (LR). Leaching requirements for the Paso Robles Basin were presented in the Phase I Study (pgs. 127-128). This study addressed crop-specific threshold salinity, regional groundwater quality, and rainfall, and focused on vineyards in the eastern portions of the basin (Shandon, Camatta Canyon, and San Juan Creek). In the 2012 Master Water Report (Appendix A, pg. 11), ESA used these estimates, approximately 5% to 16% for different crops, to estimate current annual LR for the crop groups in inland areas. To account for build-up of salts in the soil, ESA assumed that future leaching requirements would be one to 2% higher than existing leaching requirements.

Consideration of leaching requirements for this model update focused on vineyards, which are the most sensitive of the local crop categories, the amount and timing of water application for leaching, and any geographic variability. Consultation with the Central Coast viticulture experts (Larry Bettiga and Mark Battany) indicates that the application of water for salt leaching is variable, depending on the local soil and water quality, irrigation system, and grower's practices. A survey of soil salinity status (Battany, 2007) in central Paso Robles basin vineyards (generally in the Estrella, Shandon, and Creston Sub-Areas) indicates that soil salinity is below general levels of concern for most vineyards. However, in some vineyards, soil salinity conditions are at levels that can adversely impact vineyard growth and yield. Elevated soil salinity appears more pronounced in the western portions of the survey area (see Figure 6 in Battany, 2007). The presence of local elevated soil salinity does not necessarily mean that soil leaching is being practiced; in fact, it suggests that soil leaching is inadequate to manage soil salinity in the long term.

While the soil leaching estimates developed in the 2002 Phase I Study and adopted in the 2012 Master Water Report are reasonable (recognizing the current lack of data and the considerable local variation), the values are likely to be overestimated, given trends toward increasing soil salinity levels that suggest insufficient salt leaching (Battany, 2013a). Consultation with the Central Coast viticulture experts indicates that water is not applied for leaching during the growth season for vineyards; during this period, growers practice careful deficit irrigation in order to manage the growth of the vineyard canopy and the quality of the grapes. Many growers may pre-irrigate vineyards, in part for salt leaching, especially if the preceding winter was dry. However, a common local practice with deficit irrigation is to allow the soil moisture to be depleted during the course of the growing season, and then apply a post-harvest irrigation that provides leaching (Battany, 2013a). However, it is recognized that rainfall in a wet year provides salt leaching, and that growers probably would not choose to provide additional leaching in the subsequent season. Recognizing the current uncertainties and variability in soil leaching practices and observations of increasing soil salinity across the basin, for the model update, it is assumed that periodic deep percolation of precipitation in wet years along with (more consistent) deep percolation of applied irrigation water provide a reasonable estimate of current soil salinity management practices across the basin.

With regard to geographic variability, the amount of water needed (not necessarily applied) for long-term effective salt leaching can be computed based on the specific crop sensitivity, local soil salinity, and applied water quality (which varies across the basin). With the compilation of water quality data for the current Salt and Nutrient Management Plan process, such an analysis should be conducted in the future, but is beyond the scope of this model update.

3.2.1.2.4 Distribution of Soil Types

In addition to land use, soil type and distribution also affect infiltration, surface runoff, interflow, groundwater storage, and deep groundwater losses. As mentioned previously, there are four main hydrologic soil groups, all of which are present in the model area. SSURGO describes each type as the following:

- Group A soils have a high infiltration rate (low runoff potential) when thoroughly wet. They consist mainly of deep, well drained to excessively drained sands or gravelly sands and have a high rate of water transmission.
- Group B soils have a moderate infiltration rate when thoroughly wet. They consist mainly of moderately deep or deep, moderately drained soils that have moderately fine texture to

moderately coarse texture and have a moderate rate of water transmission.

- Group C soils have a slow infiltration rate when thoroughly wet. They consist mainly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. They have a slow rate of water transmission.
- Group D soils have a very slow infiltration rate (high runoff potential) when thoroughly wet. They consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. Therefore, they have a very slow rate of water transmission.

A relative infiltration rate is associated with each soil group, ranging from soils with a high infiltration rate characteristic of coarser sediments (Group A) to a very low infiltration rate characteristic of finer-grained materials (Group D). The extent to which each sub-watershed is covered in these soil types was determined through GIS and these values are listed in Table 7.

Each sub-watershed is given an average infiltration index based on the percentage of the various soil types within its borders. HSPF uses a soil index coefficient of four for Group A soils, three for Group B, two for Group C, and one for Group D. These index coefficients are multiplied by the area percentage of each soil in each sub-watershed, and then summed to yield the average infiltration index value for that particular sub-watershed.

3.2.1.2.5 Determining Average Daily Precipitation

Precipitation adjustment factors were assigned to each sub-watershed. These factors were used to determine average daily precipitation values for each sub-watershed based on the precipitation recorded at select stations in the model area. Four (4) precipitation stations were chosen for the calculation of the adjustment factors, and were also used for future assignment of daily values based on the completeness of the data record and their spatial distribution within the Paso Robles Groundwater Basin. The selected stations include: the Oak Shores Wastewater Plant (Station 201), San Miguel Wolf Ranch (Station 47867), Paso Robles (Station 46730), and Santa Margarita Booster (Station 47933) (see Figure 34).

The process of calculating the precipitation adjustment factors for each sub-watershed involved the following steps:

- An average annual precipitation value was determined by averaging the 1981-2010 PRISM grid values for each sub-watershed.
- The average annual precipitation value from the 1981-2010 PRISM grids for each select

precipitation station was noted.

- The averages within each sub-watershed were compared to the averages of the select precipitation stations. The station with an average annual precipitation value closest to each individual sub-watershed was used to assign daily values.
- The precipitation adjustment factor was then calculated by dividing the average annual precipitation value for each sub-watershed by the average precipitation value of the station that was designated as being the closest match in terms of long-term average precipitation (PRISM values).
- Historical daily precipitation values for each station were then multiplied by the precipitation adjustment factor to determine daily precipitation within each sub-watershed.

The same method above was used to analyze the long-term annual average precipitation values from the 1900-1960 isohyetal contours. However, since the PRISM data set contains annual precipitation values spanning the model simulation period, it was chosen in preference to the isohyetal contours to calculate the precipitation adjustment factors for each sub-watershed. Precipitation adjustment factors and designated precipitation stations are listed in Table 8.

3.2.1.2.6 Reservoir Releases

As noted previously, the watershed areas above the major reservoirs are addressed by examining reservoir operations data. Accordingly, diversions from Santa Margarita Lake/Salinas Dam are exported from the watershed and Nacimiento Project Water deliveries are incorporated into the Basin Model as municipal recharge and return flows. Water releases from the Nacimiento, San Antonio, and Salinas Reservoirs represent an external source of water coming into the Basin Watershed Model area. As such, they are included as input to the Basin Watershed Model to help establish a water balance.

3.2.1.2.7 Wastewater Treatment Plant Discharges

The four wastewater treatment facilities listed previously in Table 3-3 also represent a source of external water in the water balance equation. The effluent releases from each facility are included in the Basin Watershed Model while recharge from percolation ponds is included in the groundwater portion of the model.

3.2.1.2.8 Potential Evaporation

Monthly evapotranspiration rates were applied to the sub-watersheds based on which CIMIS ETo Zone the centroid of each sub-watershed is located within (see Figure 35). Daily evapotranspiration values are assumed to be constant within each month. The CIMIS ETo values for the ETo Zones within the model area are reproduced in Table 3-9 below.

Table 3-9. CIMIS Monthly Average Reference Evapotranspiration

Month	ETo Zone 6 [in/month]	ETo Zone 10 [in/month]	ETo Zone 16 [in/month]
January	1.86	0.93	1.55
February	2.24	1.68	2.52
March	3.41	3.10	4.03
April	4.80	4.50	5.70
May	5.58	5.89	7.75
June	6.30	7.20	8.70
July	6.51	8.06	9.30
August	6.20	7.13	8.37
September	4.80	5.10	6.30
October	3.72	3.10	4.34
November	2.40	1.50	2.40
December	1.86	0.93	1.55
TOTAL	***49.7***	***49.1***	***62.5***

To ensure that the method described above is valid, the monthly CIMIS reference evapotranspiration rates were compared to the monthly evapotranspiration rates (compiled from daily data) from the six (6) Western Weather Group stations within the model area. A regression analysis was performed to determine how closely the two data sets matched. This was done using the RSQ Function in Excel, which returns an r-squared value which is representative of the proportion of the variance in "y" that is attributable to the variance in "x" (1.00 corresponds to a very good fit). Based on the analysis, the r-squared values at each station ranged from 0.97-1.00, indicating that the CIMIS data is a good fit for the observed. These results are provided in Table 9.

Bare Soil Evaporation. The Phase I Study addressed the evaporation from wet soils. Subsequent peer review (Yates, 2010) suggested that bare soil evaporation was overestimated by a factor of two and recommended application of a more rigorous technique (Allen et al., 1998). Bare soil evaporation was accounted for in the Basin Watershed Model.

Cover Crops. Since the 1990s, cover crops have been widely used in vineyards (Battany, 2013b). A major objective is to manage the soil erosion that can occur with intense rainfall or use of sprinklers for frost protection. Other potential benefits include dust control, weed suppression and an increase in soil organic matter (Bettiga, 2013). Cover crops may involve grasses (such as brome or fescue) that are allowed to self-seed, or grains (e.g., barley) or legumes that are planted. The cover crops generally grow in the winter and spring (e.g., November through March), relying on rainfall. In early spring, the cover crops typically are mown and allowed to senesce through the dry season, or are tilled. Mowing or tilling of cover crops may coincide with bud break in order to reduce the risk of frost damage by exposing the soil to solar heating.

In water-short areas of the Central Coast, farmers are aware that growing cover crops involves added water consumption. However, cover crops also reduce runoff and promote infiltration (Bettiga, 2013). As summarized in the literature (Smith, et al., 2008), it is recognized that competition between vines and cover crops for soil moisture in spring could result in water stress that reduces grape production. This concern is less with wine-grape production because water stress may be induced to enhance wine quality (i.e., deficit irrigation). Growers in dry portions of Monterey County (Smith, et al., 2008) reduce the water consumption by using narrow cover-crop strips (e.g., 32 inches wide).

It is recognized that: 1) the type of cover crop varies, 2) the growth of cover depends on rainfall, and 3) the areal extent of cover varies with row spacing and other vineyard-specific factors. For this model update, we assume that all vineyards have cover crops over the entire simulation period, the cover crop is a grass or grain, the cover crop is present and growing from November through March, and the coverage within the vineyard is 70%.

3.2.1.3 Recharge Components

Recharge components include all components of the watershed hydrology which represent inflow terms in the Basin water balance. Recharge occurs as a result of deep percolation of direct precipitation falling on the basin; deep percolation from seepage occurring in the streambeds, deep percolation from applied irrigation water in agricultural application as well as return flows from irrigation and operations in rural domestic, small system, small commercial (e.g., wineries). Recharge to the groundwater basin also comes from subsurface inflow from outside the basin but within the watershed and from operational losses from water distribution systems and sewer systems.

3.2.1.3.1 Deep Percolation of Direct Precipitation

The quantity of water that will recharge the groundwater aquifer as a result of the deep percolation of direct precipitation was calculated by the Watershed Model based on input parameters discussed in Section 3.2.1.1 and on the historical hydrology and land use in the groundwater basin.

3.2.1.3.2 Deep Percolation of Streambed Seepage

The quantity of water that will recharge the groundwater aquifer as a result of the streambed seepage was calculated by the Basin Watershed Model based on input parameters of the physical characteristics for each of the stream reaches of the watershed and in consideration of the historical hydrology. Input parameters such as channel geometry, soil type and infiltration rate reflect the specific site conditions along the stream reaches providing spatial and temporal distribution of recharge within the watershed.

3.2.1.3.3 Deep Percolation of Applied Irrigation and Landscape Water

Return flows from agricultural application can be a significant portion of the basin water balance both in volume and in groundwater quality. The amount of return flow is directly related to groundwater pumping, irrigation practices, and hydrology. Therefore, the quantity of return flow (recharge to the groundwater system) from agricultural water was calculated using the Basin Watershed Model and is based on input parameters developed for this study for applied water in the watershed. Included in this estimation are return flows from landscaping, rural domestic, small system, and small commercial operations based on a percentage of surface applied water and land cover.

3.2.1.3.4 Subsurface Inflow

Subsurface inflow is water that enters a groundwater basin from its surrounding watershed. The water originates from precipitation falling in the watershed area that has infiltrated the vadose zone, weathered bedrock zones, and bedrock fractures. As the vertical infiltration decreases with depth, the water moves laterally (percolates) and towards the groundwater basin (see Figure 3-3). Many components of subsurface inflow (e.g., percolation rates, degree of bedrock weathering/fracturing, etc.) remain difficult to assess accurately for the Basin and watershed area, reflecting a lack of data on percolation rates, streamflow within the watershed area, and groundwater levels, particularly around the margins of the Basin.

The Phase II Study estimated the subsurface inflow to the groundwater basin from the surrounding bedrock areas along the margins of the groundwater basin as follows:

- The inflow was input as a region of recharge wells along the margin of the basin in model layer 4 (see Figure 31 of the 2005 Phase II Study).
- Minor modifications were made during the calibration process to increase groundwater elevations in areas of the Atascadero Sub-Basin, Creston, and San Juan areas. These changes accounted for less than a 400 AFY increase in recharge into the Basin.

- Areas of elevated local subsurface inflow were added where the Basin Model required significant additional recharge that was not accounted for in the Phase I Study hydrologic budget.
- These areas were identified during calibration of the original model as areas where insufficient inflow was available to simulate the measured groundwater elevations.
- These areas were simulated in the original model using a head-dependent boundary condition (see Figure 31 of the 2005 Phase II Study). Specifically, these areas were simulated by:
  - A MODFLOW constant head boundary with an elevation of 1,425 ft above mean sea level (amsl) in the Creston area.
  - A MODFLOW constant head boundary with an elevation of 1,425 ft amsl in the area north of Paso Robles.
  - A MODFLOW general head boundary with an elevation of 1,450 ft amsl in the South Gabilan area.

For this model update, the subsurface inflow was determined from the Basin Watershed Model as described later in Section 3.3.3. Estimation of subsurface inflow was supported with watershed analysis of precipitation, surface runoff, and groundwater recharge.

3.2.1.3.5 Urban Water and Sewer Pipe Leakage

Operational losses from water distribution located within the Basin that represents a recharge component in the Basin water balance is quantified through obtaining reasonable estimates of “unaccounted” water from water purveyors. Losses from sewer systems were assumed to be a small percentage.

3.2.1.4 Calibration of the Basin Watershed Model

Model calibration is a trial-and-error process which consists of iteratively adjusting model parameters, within acceptable ranges, until the model provides a reasonable match between the model-simulated and measured data. Proper calibration is important in order to reduce uncertainty in the model results (Engel et al., 2007). The accuracy of data simulated by the calibrated model is evaluated using the techniques recommended by the authors of HSPF (AQUA TERRA, 2009).

After the Basin Watershed Model was constructed, it was calibrated against measured streamflow data for the period January 1, 1981 to December 31, 2011. Streamflow data from the 13 gaging stations discussed in Section 3.2.1.1.6 were used during the calibration process; however, only four stations had available data which span the entire calibration period (see Table 3-2). Model calibration was performed in accordance with guidelines provided by the United States Environmental Protection Agency (U.S. EPA, 2000). The major parameters adjusted during calibration of the Paso Robles Watershed Model included the following:

- Lower zone nominal soil moisture storage,
- Base groundwater recession,
- Fraction of groundwater inflow to deep recharge,
- Fraction of remaining ET from baseflow,
- Interflow inflow parameter,
- Lower zone ET parameter, and
- Function tables (FTABLE) which includes physical information (shape, depth, width, slope, length, Manning Factor and materials), and infiltration rates for reaches of each sub-watershed.

The calibration process also included checking the model-simulated values for each water balance recharge component; average annual values must be consistent with expected values for the watershed.

3.2.1.4.1 Calibration Criteria

As mentioned above, the Basin Watershed Model was calibrated against measured streamflow for the period January 1, 1981 to December 31, 2011. Although gages with partial period of record were used for consistency checks as part of the calibration process, discussion on calibration results only includes the four gages having data spanning the entire period[20].

3.2.1.4.2 Calibration Results

Hydrographs of model-simulated and measured monthly streamflow during the calibration period at four gaging stations are presented in Figures 36 through 39. As shown, there are similar temporal dynamics in both model-simulated and measured monthly streamflow for all four gaging stations, which indicates a "good" model calibration.

Standard regression analysis, known as the Pearson's coefficient of determination, "Goodness-of-Fit" or r-squared (R^2), was used to evaluate how well the calibrated Basin Watershed Model simulated streamflow. This technique provided an indication of the strength of the linear relationship between model-simulated and measured monthly streamflow data. The R^2 value was calculated through scatter

[20] Attachment A (provided on CD) includes the complete set of model results for each of the streamflow gage site.

plots generated for measured and simulated monthly streamflow at four streamflow gaging stations (see Figure 15 for locations). Scatter plots are provided as Figures 40 through 43. Results, summarized in Table 3-10 below, indicate there is a "very good" match between the model-simulated and measured streamflow at Salinas River near Bradley gaging station, a "good" match at the Salinas River above Paso Robles, and Santa Margarita Creek near Santa Margarita, and a "fair" match at the Estrella River near Estrella gage.

Table 3-10. Summary of Basin Watershed Model Calibration

Gage Name and Number	Monthly Streamflow	
	Goodness-of-Fit (R^2)	Model Calibration Performance
Salinas River near Bradley (Station No. 11150500)	0.86	Very Good
Salinas River above Paso Robles (Station No. 11147500)	0.78	Good
Estrella River near Estrella (Station No. 11148500)	0.71	Fair
Santa Margarita Creek near Santa Margarita (Station No. 15)	0.79	Good

Note: Performance criteria were determined based on Aqua Terra Consultants (2009).

3.3 Estimation of Groundwater Recharge Components

3.3.1 Deep Percolation of Streambed Seepage

The amount of recharge from deep percolation of streambed seepage was calculated by the Basin Watershed Model as the percolation of each stream segment within the groundwater basin domain. During the development of the Basin Watershed Model, the stream segment of each sub-watershed was analyzed to determine the hydraulic behavior through the use of an FTABLE (hydraulic table). FTABLEs determine the infiltration volume of a stream reach by using the HSPF BMP Toolkit created by the US EPA. The toolkit takes into account the lining type, slope, Manning's Roughness Coefficient (used for flow calculations), and the length of the stream reach. From this, the percolation rates were initially estimated to range from 0.1 ft/day to 2 ft/day for the different streambed reaches, and then adjusted during the Basin Watershed Model calibration process.

Streambed percolation that occurs outside of the Basin was modeled as subsurface inflow through the Basin boundary.

3.3.2 Deep Percolation of Direct Precipitation and Return Flow from Applied Water

The amount of recharge from deep percolation of direct precipitation and return flow from applied water was calculated as the deep percolation of pervious land by the Basin Watershed Model within the groundwater basin domain. Land use plays a major role in this calculation since it affects how water enters or leaves a system by altering infiltration, surface runoff, location and degree of evapotranspiration, and where water is applied in the form of irrigation.

The deep percolation of pervious land for the sub-watersheds outside the groundwater basin was modeled as subsurface inflow through the Basin boundary.

3.3.3 Subsurface Inflow through the Basin Boundary

The amount of recharge from subsurface inflow entering the Basin from the watershed area was calculated as the sum of streambed percolation for each stream segment that crosses over the boundary of the watershed and groundwater basin and deep percolation of pervious land (by the Basin Watershed Model) minus groundwater pumping outside the groundwater basin domain (i.e., within the watershed).

3.3.4 Deep Percolation of Discharged Treated Wastewater Effluent

There are five wastewater treatment facilities (City of Paso Robles, City of Atascadero, Templeton Community Services District, San Miguel Community Services District, and Camp Roberts) within the Paso Robles Groundwater Basin that either discharge effluent into the Salinas River channel and/or release wastewater into infiltration (percolation) ponds. Average daily effluent flows in mgd were obtained and used to evaluate the deep percolation of discharged treated wastewater effluent. Additionally, return flow from urban indoor use was accounted as deep percolation of discharged treated wastewater.

Figure 44 shows the annual recharge from deep percolation of discharged treated wastewater effluent. During the period for WYs 1981 to 2011, the annual recharge ranges from 4,047 acre-ft to 6,801 acre-ft with an annual average of 5,487 AFY.

3.3.5 Deep Percolation of Urban Water and Sewer Pipe Leakage

The amount of recharge from deep percolation of urban water and sewer pipe leakage was calculated as 2% of the discharged treated wastewater effluent and 2% of the municipal groundwater pumping. Figure 45 shows the annual recharge from deep percolation of urban water and sewer pipe leakage. During the period for WYs 1981 to 2011, the annual recharge ranges from 225 acre-ft to 461 acre-ft with an annual average of 354 AFY.

3.4 Estimation of Groundwater Discharge Components

Basin outflow components include groundwater pumping, evapotranspiration by riparian vegetation (phreatophytes), and subsurface outflow. The following sections describe the data and data sources, technical approach, and analytical methods used to estimate basin outflow terms over the 31-year model simulation period from WY 1981 through WY 2011. Outflows were calculated and apportioned across the watershed and Basin Model domain to allow for model simulation using semiannual or monthly stress periods.

3.4.1 Agricultural Groundwater Pumping

Agricultural pumping accounts for approximately 80% of total annual basin outflow over the model simulation period. This section describes the methods used to estimate the agricultural irrigation demand and applied water within the Basin and surrounding watershed. This task required three key steps:

Step 1. Compile, assimilate, and verify available spatial land use information to estimate the location and area of irrigated crops on an annual basis.

Step 2. Develop soil water balance spreadsheet models accounting for the effects of variable soil and climatic conditions, crop water use coefficients, and irrigation management practices on crop irrigation demand on a daily basis.

Step 3. Apply estimated daily (one-dimensional) irrigation demand and applied water rates to annual crop acreages and aggregate resulting volumetric rates by sub-watershed (for the Basin Watershed Model) and MODFLOW model cell (for the Basin Model).

The following sections describe the data and data sources, methods, assumptions, and resulting estimates of agricultural irrigation demand and applied water.

3.4.1.1 Estimation of Annual Crop Acreages from Calendar Years 1980-2011

To simulate changing water demand of agricultural crops over the 31-year study period, available digitized land use data were first obtained. Key sources of information are shown in Table 3-11 below and include four land use surveys conducted by the DWR in the 1980s and 1990s, twelve annual SLO County crop coverage maps developed by the SLO County Agricultural Commissioner's Office (SLO ACO) from 2000 through 2012 (missing 2003), and a 2012 map of agricultural parcels in Monterey County within the Basin watershed provided by the Monterey County Agricultural Commissioner's Office (Monterey ACO). Additionally, annual SLO and Monterey County crop reports were obtained to identify the timing of crop growth and decline.

Table 3-11. Data Sources Used for Annual Crop Acreage Estimation

Agency	Area	Period
DWR	Monterey County	1989 and 1997[1]
	SLO County	1985 and 1996[1]
SLO ACO	SLO County	2000 through 2011, missing 2003[2]
	SLO County	2012[3]
Monterey ACO	Monterey County	2012[2]

DWR = California Department of Water Resources
SLO ACO = San Luis Obispo County Agricultural Commissioner's Office
Monterey ACO = Monterey County Agricultural Commissioner's Office
[1] Digitized 1989 Monterey County and 1985 SLO County GIS shapefiles were provided by SLO County; Digitized 1997 Monterey County and 1996 SLO County GIS shapefiles were downloaded from the DWR website.
[2] Crop areas verified by Todd Groundwater using historical aerial imagery provided in Google Earth.
[3] Crop areas verified by SLO County.

In early communications, SLO ACO staff identified the need to verify and revise historical crop maps from 2000 through 2011, as the provided annual maps were developed from permit applications for pesticide use and mapped acreage includes areas that are not used for irrigated crop production. Additionally, permit applications are submitted on an annual basis for rotational crops and up to three years for permanent crops for both existing and planned crops that may not get planted that calendar year or at all. To address this data gap, historical aerial imagery provided through Google Earth and communication with SLO ACO staff was used to verify acreages identified in all SLO ACO and Monterey ACO GIS shapefiles (with the exception of the SLO ACO 2012 map, which was verified by SLO ACO staff for this study).

The four DWR land use surveys were deemed accurate for the purposes of this study, as these maps were developed by DWR's evaluation of aerial imagery, and according to DWR, about 95% of the developed agricultural areas within each survey area are verified in the field.

The available crop land use data was used to estimate acreages for the following seven irrigated crop groups:

1. Alfalfa
2. Citrus

3. Deciduous
4. Nursery
5. Pasture
6. Vegetable
7. Vineyard

For most crops and time periods, a linear interpolation was performed to estimate crop acreages for each year of the model simulation period lacking verified crop acreages (e.g., between DWR land use survey years; between the last DWR land use survey and verified 2000 SLO County and Monterey County crop maps; and for 2003 in SLO County). However, because the locations of crops change considerably between two time periods used for interpolation, the following procedure was developed to apportion interpolated annual crop acreages spatially:

Step 1. Calculate the relative difference (in percent) between the interpolated crop acreage for a given year and the crop acreage for the nearest year with verified crop data.

Step 2. Apply the relative difference to crop acreages identified in the nearest year with verified crop data to obtain a spatially distributed crop map for the given year of interest.

To allow for this method of spatial interpolation, the two 1980s and two 1990s DWR land use surveys were assumed to represent 1985 and 1997 conditions, respectively. The error introduced by this assumption is considered insignificant for the purposes of this study. As an example, according to the DWR land use surveys, there were 10,672 acres of alfalfa in 1985 in the watershed and only 3,373 acres of alfalfa in 1997 (an average annual decline of 608 acres). For 1986, the interpolated 10,064 acres represents 94.3% of the alfalfa acreage in 1985. This percentage is applied to each of the verified 1985 alfalfa fields to develop the 1986 alfalfa crop coverage. The same procedure is used for 1987 through 1990. For years 1991 through 1996, the relative difference between annual interpolated acreages compared to 1997 is applied to alfalfa field locations identified by DWR in 1997.

While verification of SLO annual crop maps with aerial imagery and linear interpolation was successful for most crops and time periods, consultation with SLO ACO staff was required to resolve specific discrepancies in available crop data, as described below.

Alfalfa – Review of historical aerial imagery could not resolve the apparent underestimation of alfalfa acreage in SLO ACO crop maps from 2000 to 2011. A discrepancy was also observed between the 1985 DWR survey alfalfa acreage (10,554 acres in SLO County) and the SLO ACO annual crop report acreage (7,245 acres). The original model estimates 11,483 acres in 1985. Discrepancies between the 1997 DWR-based alfalfa acreage and SLO County crop report acreages were minor. Similarly, the 2012 crop map provided by the County was in close agreement to the 2012 crop report. For these reasons and after consultation with SLO ACO, alfalfa acreages identified in the DWR 1984/85 and 1996/97 land use surveys and in the SLO ACO 2012 crop map were used, and alfalfa acreages were interpolated linearly between these years.

Citrus – The Citrus category includes subtropical orchards such as olives. It is not present in any of the four DWR land use surveys. SLO ACO annual crop maps indicate gradual growth of citrus starting from 5 acres in 2000 up to 745 acres in 2012; however, data are highly variable from 2006 through 2011. For these reasons and after consultation with SLO ACO, citrus are assumed to be non-existent through 1999, and citrus acreage is interpolated annually from 5 acres in 2000 to 745 acres in 2012.

Deciduous – DWR land use surveys indicate that there were 724 acres of deciduous in the watershed in 1984/85 and 368 acres in 1996/97. The original SLO ACO annual crop maps indicate deciduous acreages were consistent from 1999 through 2002; however, acreages appear to be erroneous in 2004 to 2011 crop maps. The 2012 SLO ACO crop map indicates 470 acres of deciduous crops. For these reasons and after consultation with SLO ACO, a linear interpolation between the DWR survey periods was used. The 1997 acreage (368 acres) was used to represent 1997-2004 conditions; and the 2012 SLO ACO crop map was used to represent 2005-2011 conditions.

Nursery – DWR land use surveys indicate that there were 113 acres of nursery in the watershed in 1984/85 and 112 acres in 1996/97; however the locations of the nurseries were very different. There is a slight decrease to 76 acres in 2012. Due to the relatively small differences compared to other crops, verified acreages were used to develop three maps. The DWR 1984/85 land use map was used to represent 1981-1990 nursery conditions; the DWR 1996/97 land use map was used to represent 1991-2004 nursery conditions; and the 2012 SLO ACO crop map was used to represent 2005-2011 conditions.

Pasture – Review of historical aerial imagery could not resolve the variability of +/- 2,000 acres in pasture acreage in SLO ACO crop maps from 2000 to 2011. For these reasons and after consultation with SLO ACO[21], irrigated pasture acreages identified in the DWR 1984/85 and 1996/97 land use surveys and in the SLO ACO 2012 crop map were used, and irrigated pasture acreages were interpolated linearly between these years.

[21] The permit system used by the SLO ACO does not differentiate between irrigated and non-irrigated pasture.

Vegetable – The original Basin Model assumed a flat average from 1981 through 1997; however, DWR land use maps indicate 208 acres in the watershed in 1984/85 and 469 acres in 1996/97. GIS shapefiles provided by the SLO ACO overestimates vegetable acreages from 2007-2012. A review of historical aerial imagery could not resolve the apparent overestimation. For these reasons and after consultation with SLO ACO, the 1984/85 acreages were used to represent 1981-1990 conditions; the 1996/97 acreages were used to represent 1991-1997 conditions; 1998-2006 acreages were linearly interpolated from 1996/97; and, the 2012 SLO ACO and 2012 Monterey County coverages were used to represent 2007-2012 acreages.

Table 3-12 and Figure 46 show the annual irrigated crop acreages within the groundwater basin. Total irrigated crop acreage declined gradually but consistently from 1980 through 1997, as significant declines in alfalfa combined with smaller declines in irrigated pasture were only partially offset by the moderate growth of vineyards. From 1997 through 2004, total irrigated agricultural acreage increased dramatically, during which vineyard acreage in the Basin nearly tripled from about 11,000 acres to over 30,000 acres. From 2004 to 2011, vineyard growth in the Basin slowed somewhat, increasing by about 1,800 acres over this period, equating to 5.8% growth over this period.

Table 3-12. Annual Irrigated Crop Acreages in Paso Robles Groundwater Basin

CY	Alfalfa	Citrus	Deciduous	Nursery	Pasture	Vegetable	Vineyard	TOTAL
1980	13,714	0	872	113	5,381	101	4,112	**24,293**
1981	13,106	0	843	113	5,195	101	4,474	**23,831**
1982	12,497	0	813	113	5,009	101	4,836	**23,369**
1983	11,889	0	783	113	4,823	101	5,197	**22,907**
1984	11,281	0	754	113	4,637	101	5,559	**22,445**
1985	10,672	0	724	113	4,451	101	5,921	**21,983**
1986	10,064	0	694	113	4,266	101	6,395	**21,633**
1987	9,456	0	665	113	4,080	101	6,870	**21,284**
1988	8,848	0	635	113	3,894	101	7,344	**20,935**
1989	8,239	0	605	113	3,708	101	7,819	**20,586**
1990	7,631	0	576	113	3,522	101	8,294	**20,237**
1991	7,023	0	546	112	3,388	491	8,413	**19,973**
1992	6,414	0	517	112	3,253	491	8,872	**19,660**
1993	5,806	0	487	112	3,119	491	9,331	**19,346**
1994	5,198	0	457	112	2,984	491	9,789	**19,032**
1995	4,590	0	428	112	2,850	491	10,248	**18,719**
1996	3,981	0	398	112	2,715	491	10,707	**18,405**
1997	3,373	0	368	112	2,221	491	11,166	**17,731**
1998	3,330	0	368	112	2,158	566	14,478	**21,013**
1999	3,287	0	368	112	2,096	642	17,162	**23,667**
2000	3,244	3	368	112	2,034	717	19,845	**26,323**
2001	3,200	38	368	112	1,971	793	23,578	**30,061**
2002	3,157	74	368	112	1,909	868	26,831	**33,319**
2003	3,114	109	368	112	1,846	943	28,595	**35,089**
2004	3,071	145	368	112	1,784	1,019	30,836	**37,335**
2005	2,447	180	421	70	1,701	1,094	31,068	**36,981**
2006	2,413	216	421	70	1,639	1,170	31,307	**37,235**
2007	2,379	251	421	70	1,578	2,890	31,809	**39,397**
2008	2,345	287	421	70	1,516	2,890	31,852	**39,380**
2009	2,311	322	421	70	1,454	2,890	32,428	**39,896**
2010	2,277	358	421	70	1,393	2,890	32,443	**39,851**
2011	2,243	393	421	70	1,331	2,890	32,613	**39,960**

Table 3-13 and Figure 47 show the annual irrigated crop acreages within the Basin watershed. Overall, similar trends to crop acreages in the Basin are observed in the watershed. Minor differences include the stabilizing of total crop acreages by the early 1990s due to the method of estimating acreages for used in the watershed for vegetables. Additionally, vineyard growth in the overall watershed from 2004 to 2011 was equivalent to about 8.6%, slightly higher than within the groundwater basin.

Table 3-13. Annual Irrigated Crop Acreages in Paso Robles Basin Watershed

CY	Alfalfa	Citrus	Deciduous	Nursery	Pasture	Vegetable	Vineyard	TOTAL
1980	13,714	0	872	113	5,381	101	4,112	**24,293**
1981	13,106	0	843	113	5,195	101	4,474	**23,831**
1982	12,497	0	813	113	5,009	101	4,836	**23,369**
1983	11,889	0	783	113	4,823	101	5,197	**22,907**
1984	11,281	0	754	113	4,637	101	5,559	**22,445**
1985	10,672	0	724	113	4,451	101	5,921	**21,983**
1986	10,064	0	694	113	4,266	101	6,569	**21,807**
1987	9,456	0	665	113	4,080	101	7,216	**21,631**
1988	8,848	0	635	113	3,894	101	7,864	**21,455**
1989	8,239	0	605	113	3,708	101	8,512	**21,279**
1990	7,631	0	576	113	3,522	101	9,160	**21,103**
1991	7,023	0	546	112	3,388	1,148	9,808	**22,024**
1992	6,414	0	517	112	3,253	1,148	10,455	**21,899**
1993	5,806	0	487	112	3,119	1,148	11,103	**21,775**
1994	5,198	0	457	112	2,984	1,148	11,751	**21,650**
1995	4,590	0	428	112	2,850	1,148	12,399	**21,526**
1996	3,981	0	398	112	2,715	1,148	13,047	**21,401**
1997	3,373	0	368	112	2,221	1,148	13,694	**20,916**
1998	3,330	0	368	112	2,158	1,324	16,800	**24,093**
1999	3,287	0	368	112	2,096	1,500	19,906	**27,269**
2000	3,244	5	368	112	2,034	1,676	23,011	**30,450**
2001	3,200	67	368	112	1,971	1,852	26,346	**33,917**
2002	3,157	128	368	112	1,909	2,028	30,691	**38,394**
2003	3,114	190	368	112	1,846	2,205	33,260	**41,096**
2004	3,071	252	368	112	1,784	2,381	35,831	**43,798**
2005	3,028	313	470	76	1,722	2,557	36,477	**44,642**
2006	2,985	375	470	76	1,659	2,733	37,038	**45,335**
2007	2,941	437	470	76	1,597	2,913	37,663	**46,096**
2008	2,898	498	470	76	1,534	2,913	37,871	**46,260**
2009	2,855	560	470	76	1,472	2,913	38,448	**46,794**
2010	2,812	621	470	76	1,410	2,913	38,537	**46,839**
2011	2,769	683	470	76	1,347	2,913	38,913	**47,171**

3.4.1.2 Estimation of Annual Crop Consumptive Use from Water Years 1981-2011

Overview of Technical Approach. For each of the seven irrigated crop groups, a set of daily soil water balances was developed according to a modified Thornthwaite and Mather method (Dunne and Leopold, 1978). Each set of soil water balances was used to develop an array of reference crop irrigation demand rates (in units of inches per month) over the model simulation period for the observed range of soil and climatic conditions across the Basin and surrounding watershed. Reference monthly irrigation demand schedules were matched to individual crop fields based on three parameters, including: 1) available soil water storage capacity (which is dependent on soil physical properties and crop rooting depth), 2) average annual precipitation, and 3) ETo zone. In addition, the effect of crop management practices for vineyards, including irrigation for frost-prevention, RDI, and use of cover crops were also considered in the soil water balances for vineyards. It is recognized that some vineyards are table grapes, which are not subject to RDI. However, these vineyards encompass an area that is likely less than 1,000 acres and are not differentiated.

Reference crop irrigation demand rates were matched to individual fields using the following steps:

Step 1. Assign to each crop field identified during the model simulation period an area-weighted average soil water storage capacity, precipitation adjustment factor, and applicable ETo zone.

Step 2. Identify vineyards over time with agricultural ponds (used for frost-prevention irrigation) using SLO ACO-provided agricultural pond and parcel boundary coverage.

Step 3. Calculate a combined vineyard consumptive use and irrigation demand profile weighted according to the percentage of vineyards under deficit irrigation (also known as RDI) and traditional non-RDI irrigation management over time.

For the model update, cover crops were assumed to exist for all vineyards identified to reduce the number of reference soil water balances for each crop array. While this assumption may result in the slight underestimation of soil water content at the start of the growing season in a dry year, its effect on crop irrigation demand is relatively minor, as cover crops increase the consumptive use of vineyards in winter and spring, prior to the driest portion of the growing season.

After individual crop fields were matched to respective monthly irrigation demand schedules, estimated monthly volumetric irrigation demand rates for each field were aggregated and assigned to a MODFLOW model cell for the Basin Model. For the surface water model, irrigation demand rates were further divided by the respective crop's irrigation efficiency to derive the volumes of applied irrigation water, which were then aggregated by sub-watershed. Factors used in vineyard soil water balances were compared to irrigation rates measured in three years (WYs 2010, 2011, and 2012), as documented in the April 2013 publication of *Grape Notes* for the UC Cooperative Extension Paso Robles Vineyard Irrigation Study[22] (Battany, 2013b). Additional discussion on the comparison of simulated vs. measured irrigation rates is provided later in this section.

<u>Soil Water Balance Method.</u> Each soil water balance tracks on a daily basis potential evapotranspiration (PET), actual ET (AET), change in soil moisture, applied irrigation water, and excess water that is available for groundwater recharge or surface runoff. For each day of the water balance, AET is dependent on PET and the amount of available water, which is comprised of precipitation, available soil water in the root zone at the start of the day, and applied irrigation water (assuming 100% irrigation efficiency). When available water exceeds PET, AET is equal to PET, and additional available water

22 Consisted of volunteer vineyards.

carries over to the next month as soil water in the root zone. When available water exceeds AET and the soil water storage capacity of the root zone, excess available water is available for runoff and groundwater recharge. When available water is less than PET, AET is limited to available water, and no water is available for groundwater recharge or surface runoff.

While the soil moisture water balance method estimates excess water available for surface runoff or groundwater recharge, the soil moisture balances were used only to estimate crop consumptive use for the model update. Applied water rates were estimated by dividing the crop irrigation demand estimates by crop-specific irrigation efficiency outside of the soil water balance. Applied water rates were then incorporated in the surface water model to estimate groundwater recharge and surface water runoff by sub-watershed.

A function simulating application of irrigation water based on soil moisture water thresholds was incorporated in each soil water balance. In general, irrigation is simulated based on a comparison of daily simulated soil water storage and estimated soil water storage capacity. When soil water storage is above the 50% of the soil storage capacity underlying the crop of interest, irrigation is applied to satisfy half the PET, resulting in gradually declining soil water storage conditions over time when there is no precipitation. Once the soil water storage reaches 50% of the soil water storage capacity, irrigation is applied at a rate that satisfies the PET. Additional factors affecting the irrigation scheduling for vineyards (e.g., frost-prevention and RDI) were incorporated in the irrigation function, the methods for which are discussed later in this section.

The following sections describe the data/data sources and methods used to develop the soil water balances for each crop group.

Data and Sources for Soil Water Balances. Specific data sources used in the water balances are summarized below and described in more detail in the following sections:

- Daily precipitation measured at the Paso Robles Station (46730) (Jan-1980 to Nov-2011)
- 1981-2010 PRISM rainfall isohyetal map (PRISM Climate Group, 2013)
- Daily air temperature and ETo measured at Atascadero, CIMIS Station #163 (Nov-2000 to Sep-2011)
- Daily ETo measured at Paso Robles, Shandon, Creston, Hames Valley, Tablas Creek, and Templeton Gap stations, Western Weather Group (Jan-2005 to Sep-2011)
- Soil water holding capacity data from soil surveys of SLO and Monterey counties (USDA NRCS, 2008 and 2009)

- Plant water-use coefficients (Kc) values from SLO Water Master Plan (SLO County, 2010)

Crop Rooting Depth. Soil water storage capacity is a function of crop rooting depth and soil physical properties. Assumed rooting depths for the seven crop groups are provided in Table 3-14 and are generally the same as those assumed for the original Basin Model (Fugro and Cleath, 2002). The one exception is for vineyards. The initial assumption of 3.0 ft resulted in irrigation rates that were higher than the average rates measured for Paso Robles vineyard irrigation study (Battany, 2013b), despite consideration of RDI and assumed high irrigation efficiencies. The assumed vineyard rooting depth was adjusted upwards to 5.0 ft to increase the soil water storage capacity beneath vineyards.

Table 3-14. Assumed Crop Root Zone Depth

Crop Group	Root Zone Depth (ft)
Alfalfa	5.0
Citrus	4.0
Deciduous	4.0
Nursery	2.0
Pasture	2.5
Vegetables	2.0
Vineyard[1]	5.0

[1] Initially assumed 3.0-foot root zone depth resulted in overestimation of irrigation rates relative to average measured data from UC Extension Paso Robles vineyard study (Battany, 2013b). A 5.0-foot root zone provided improved calibration.

Soil Water Storage. Soil water storage is the capacity of the soil in the root zone to store water, which is then available for crop uptake and ET. Shallow, coarse-grained soils have lower soil water storage capacities than deeper, fine-grained soils. Soil water storage across the Basin and surrounding watershed was estimated using soil hydraulic property information contained in two soil surveys of San Luis Obispo County (Carrizo Plain Area and Paso Robles Area) and a 2009 soil survey of Monterey County (USDA NRCS, 2008 and 2009). Using the USDA Soil Data Viewer® for ArcGIS, a continuous GIS coverage was developed for the Basin and surrounding watershed representing the weighted-average soil water storage (in inches) for the upper 5 ft of soil, the maximum root depth of the seven agricultural crop groups and (not coincidentally) maximum depth of soil survey data. Water storage capacities within the upper 5 ft of soil beneath irrigated crop areas ranged from 3 to 11 inches.

The weighted-average soil water storage capacity for the upper 5 ft of soil (rounded to the nearest inch) for each individual agricultural field over the 31-year simulation period was identified using the ArcGIS Spatial Analyst zonal statistics tool. For crops with rooting depths less than 5 ft, the water storage in the upper 5 ft of soil was reduced accordingly by the relative difference in rooting depth. For example, the soil water storage for a crop with a root depth of 3 ft was assigned 60% of the weighted-average water storage calculated for the upper 5 ft of soil. This method assumes that the vertical distribution of soil water storage capacity within the upper five ft of soils is consistent. Spot evaluation of soil water storage properties with depth indicates that potential errors introduced by this assumption are likely to be insignificant.

Precipitation. Daily rainfall is a key data input in the soil water balance. Daily precipitation at the Paso Robles rain gage (46730) was used to represent daily rainfall from WY 1981 through WY 2011. To account for the variability in rainfall across the Basin and surrounding watershed, a rainfall adjustment factor was assigned to each crop field based on the relative difference between the average annual rainfall at the center point of the field of interest and the average annual rainfall at the Paso Robles rain gage based on the 1981-2010 PRISM rainfall isohyetal grid (PRISM Climate Group, 2013). For example, the average annual rainfall at the Paso Robles rain gage is 15 inches. If the average annual rainfall at the location of a specific field is 18 inches, then a rainfall adjustment factor of 1.2 (equal to 18 inches divided by 15 inches) was assigned to that crop field, and daily rainfall was adjusted upwards by a factor of 1.2 for this field. Rainfall adjustment factors for irrigated crop areas ranged from 0.6 to 2.0. Rainfall adjustment factors assigned to each field were rounded to the nearest 0.2.

Reference Evapotranspiration (ETo). When quantifying water loss from a vegetated landscape, the loss of water from plant leaves through transpiration and the loss of water from the soil surface through evaporation cannot be easily separated. As a consequence, the two processes are often considered as a single process, called ET.

Because ET for one crop may differ significantly from another crop, a reference crop is commonly used to estimate a ETo. The CIMIS estimates ETo for numerous locations in California using well-watered grass as the reference crop. The nearest CIMIS weather station is in Atascadero. The weather station has been operational since November 1990. The weather station at Atascadero provides a reliable estimation of ETo throughout the year. However, Atascadero is located in the upland central coast region (CIMIS Zone 6), while most of the Paso Robles Basin is located in the Central Coast Range (CIMIS Zone 10), which has a slightly higher ETo than Zone 6 (CIMIS, 2007). The Phase I Study (Fugro and Cleath, 2002) identified the apparent error in the assignment of a portion of the Paso Robles region to CIMIS ETo Zone 16, which has a higher annual ETo than Zone 10 to the east.

To more reliably characterize the variability of ETo across the Basin and surrounding watershed, daily ETo data were obtained from six weather stations maintained by the Western Weather Group (WWG) to supplement the CIMIS Atascadero data and ETo map. The WWG stations are located in Shandon, Paso Robles, Creston, Templeton Gap, Hames Valley, and Tablas Creek. The WWG weather stations have generally been operational since January 1, 2005. Figure 48 shows the locations of the CIMIS and WWG weather stations. The average annual ETo estimated from 2005 through 2011 data is also shown for each station. As shown on Figure 48, the average annual ET of the WWG Creston, Paso Robles, and Shandon stations fall in a narrow range between 53.06 inches and 54.15 inches. The ETo data for the WWG Paso Robles station also confirms that the average annual ETo of CIMIS ETo Zone 16 (62.51 inches) in the Paso Robles area is significantly overestimated. The CIMIS Atascadero and WWG Hames Valley, Templeton Gap, and Tablas Creek stations also fall in a narrow range between 47.02 inches and 48.99 inches. Based on these data, two ET zones were assumed for the model update, as shown on Figure 48. For the soil water balances, daily ETo data for the CIMIS Atascadero weather station were applied to agricultural fields located in the western zone, while ETo data from the WWG Paso Robles station were applied to agricultural fields in the eastern zone.

The following method was used to create a complete daily ETo dataset for the entire simulation period:

Step 1. For a given model simulation calendar day prior to November 2000, the average ET from 2000 through 2011 for the CIMIS Atascadero weather station was applied in the western ET zone (e.g., the average ET for November 1 from 2000 through 2011 is applied to November 1, 1980 and November 1, 1981, etc.).

Step 2. For a given model simulation day prior to January 2005, the average ET from 2005 through 2011 for the WWG Paso Robles weather station was applied in the eastern ET zone.

<u>Crop Water Use Coefficients (Kc).</u> Crop water use coefficients (Kc) have been developed to relate ETo to the PET of various crop types. Crop ET potential is calculated by multiplying a crop-specific Kc value with the ETo. Kc values used in the soil water balances are shown in Table 3-15 and are derived primarily from monthly Kc values identified in the 2012 Master Water Report (Carollo, 2012). Monthly vineyard Kc values were modified, based on discussion with Mark Battany.

Table 3-15. Crop Water Use Coefficients for Analysis of Agricultural Pumping

Month	Alfalfa	Citrus	Deciduous	Nursery	Pasture	Vegetables	Vineyard[1]
January	0.00	0.56	0.00	0.50	0.00	0.00	0.00
February	0.00	0.56	0.00	0.50	0.00	0.00	0.00
March	0.90	0.56	0.60	0.50	1.00	0.00	0.00
April	0.90	0.56	0.70	0.50	1.00	0.00	0.20
May	0.90	0.56	0.80	0.50	1.00	0.00	0.40
June	0.90	0.56	0.90	0.50	1.00	0.00	0.60
July	1.00	0.56	1.00	0.50	1.00	0.00	0.60
August	1.00	0.56	1.00	0.50	1.00	1.00	0.60
September	1.10	0.56	0.90	0.50	1.00	1.00	0.60
October	1.00	0.56	0.80	0.50	1.00	1.00	0.40
November	0.00	0.56	0.00	0.50	0.00	1.00	0.00
December	0.00	0.56	0.00	0.50	0.00	1.00	0.00

[1] Kc values modified from 2012 SLO Water Master Plan based on conversations with Mark Battany (2013a).

For the soil water balances, monthly Kc values were distributed evenly to produce a constant daily ETo value for each month.

Regulated Deficit Irrigation (RDI) in Soil Water Balances. To simulate RDI in the soil water balances, three modifications were made to the soil water balances following communications with Mark Battany (2013a): 1) irrigation water was applied to satisfy 50% of the non-RDI vineyard water demand from June 16 through September 30, 2) vineyard PET subject to deficit irrigation was assumed to be 50% of vineyard PET under non-RDI conditions for this period, and 3) irrigation rates were applied to maintain soil water storage at or above 25 percent of the soil water storage capacity over this period (versus 50% for other crops and for vineyards under non-RDI conditions).

For the Basin Model update, no attempt was made to identify which vineyards were managed under deficit irrigation or non-RDI irrigation. Rather, a weighted-average consumptive use rate for vineyards was applied to all vineyards in a given year based on the assumed percentages of vineyards managed under deficit irrigation, as shown in Table 3-16 below.

Table 3-16. Percent of Acreage with Regulated Deficit Irrigation (Stressed)

1980-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2011
0%	15%	30%	45%	60%	75%

Irrigation for Frost-Prevention in Vineyard Soil Water Balances. Frost days were identified using raw air temperature data measured at the CIMIS Atascadero weather station, which has been active since November 2000. A frost season from March 16 through April 15 was assumed following conversations with Mark Battany. For nights when the low air temperature was below 34 degrees, 0.5 inches of water application were simulated for vineyards determined to have frost-prevention systems (e.g., vineyards with agricultural ponds). For the eleven frost seasons from 2001 through 2011, 65 frost days were identified, or an average of approximately six days per year. For 1981 through 2000, six frost days were assumed, and frost irrigation was spaced evenly over the frost season (three days in March and three days in April).

Cover Crop ET and Bare Soil Evaporation in Soil Water Balances. Cover crop ET and bare soil evaporation were simulated for vineyards within the soil water balances. The existence of cover crops is assumed for all vineyards from November 1 through March 31. During this period, cover crops are assumed to cover 70% of the vineyard ground surface, while bare soil covers the remaining 30% of area (based on communications with Mark Battany). Bare soil conditions are assumed to cover 100% of the ground surface from April 1 through October 31. Rainfall and irrigation for frost-prevention (assumed to be applied by sprinkler systems) are subject to bare soil evaporation across the entire vineyard acreage in the soil water balances. In contrast, it is assumed that bare soil evaporation of irrigation water applied via micro-spray or drip irrigation lines during the growing season is minor and is not considered in the soil water balances.

The Kc value of cover crops was assumed to be equal to 1.0 on a day when rainfall or irrigation for frost-prevention occurs (i.e., PET equals that of well-watered grass). The cover crop Kc value decreases to 0.9 one day following the last day of rainfall or frost irrigation, and decreases further to 0.8 for each subsequent day thereafter. Similar to cover crops, the Kc value of bare soil was assumed to equal 1.0 on a day when rainfall or irrigation for frost-prevention occurs, 0.9 one day following the last rainfall or frost irrigation day, and 0.8 two days after the last rainfall or frost irrigation. In contrast to the cover crop Kc, the Kc value of bare soil was assumed to decline from after day two by 0.2 each day until reaching 0.0 six days after the last rainfall or frost irrigation day. The lack of evaporative potential of bare soil after several days of dry weather is reasonable given that there are no plant roots to tap stored soil water below the first few inches of soil. A weighted-average Kc value was used to represent the combination of cover crop and bare soil in the soil moisture water balance from November 1 through March 31.

Irrigation Efficiency. Table 3-17 below presents assumed efficiency values for major crops applied in the model update. Values from the Phase I Study were used for the five-year periods from 1980 through 1997. For the current period (WYs 2008-2011) and the future, the values were developed from the average, adjusted efficiency values for existing and future conditions from the 2012 Master Water Report. For the intervening periods (WYs 1998-2002 and WYs 2003-2007), the values are interpolated, and in the case of vegetables, show a leveling off in the rate of efficiency improvement. Efficiency values are indicated to be stable for alfalfa and pasture. Based on conversations with Mark Battany, the irrigation efficiency for vineyards was increased from the 2012 Master Water Report as follows: from 76% to 78% for 1998-2002; from 77% to 81% for 2003-2007; and from 78% to 85% for 2008-2011[23].

Table 3-17. Irrigation Efficiencies as Percentages for Crop Groups

Crop Groups	1980-1985	1986-1990	1991-1995	1996-1997	1998-2002	2003-2007	2008-2011	Future
Alfalfa	63	65	68	72	70	70	70	70
Citrus	63	68	72	75	76	77	78	79
Deciduous	63	68	72	75	76	77	78	79
Nursery	63	65	67	70	70	70	70	70
Pasture	63	65	67	70	70	70	70	70
Vegetable	63	65	67	70	73	76	78	80
Vineyard	63	68	72	75	78	81	85	85

Notes: For citrus, the irrigation efficiency for deciduous was assumed.

Estimated Annual Irrigation Demand and Applied Water Rates. Table 10 and Figure 49 show the estimated annual irrigation demand and applied water rates (in AFY per acre per year, or ft per year) for the seven crop groups. Also provided in the table and figure are the annual precipitation amounts as measured at the Paso Robles gage (46730).

Based on Table 10 and Figure 49, the following points can be made regarding the irrigation demand and applied water rates for the seven crops types simulated:

23 Data from the Cal Poly ITRC website summarizing results of recent irrigation system tests support the increase in distribution uniformity over time; the average of the most recent drip/micro emitter data set is 84 percent (see http://www.itrc.ogr/irrecvaldata/isedata.htm, "Drip Micro" data set) (Battany, 2014).

- The difference between applied water and irrigation demand rates is largest at the beginning of the model simulation period (early 1980s) and decreases over time, reflecting improving irrigation efficiency over time.
- Irrigation demand and applied water rates are generally lower during years when annual rainfall is above average and generally higher when annual rainfall is below average. This relationship reflects the concept of effective rainfall, which is inherently captured in the soil water balance methodology.
- Irrigation demand rates correspond well with estimated crop Kc values, whereby those for alfalfa and pasture are much higher than for other crop types.
- Vineyards use the least amount of water, ranging from 0.8 to 1.6 ft per year. Estimates for vineyards reflect the combined RDI and non-RDI rate weighted annually according to the percentage under each irrigation management method.

Comparison of Simulated and Measured Vineyard Irrigation Rates. Measured daily irrigation rates from the Paso Robles vineyard irrigation study were obtained and compared to simulated vineyard irrigation rates derived from soil water balances for the model update. Figure 50 shows the simulated cumulative and measured vineyard irrigation rates for the three years measured rates are available (WY 2010 through WY 2012).

The simulated irrigation rates shown on the figure are for a hypothetical vineyard in the eastern ETo zone with a soil water storage capacity of 7 inches and a precipitation factor of 1, generally representative of vineyards included in the vineyard irrigation study. Two simulated vineyard irrigation rates are shown in the figure: 1) the rate for a vineyard under a traditional irrigation schedule, wherein the full vineyard PET is satisfied (green dashed line), and 2) the rate for a vineyard under deficit irrigation (blue dashed line). The charts show that simulated cumulative irrigation rates are similar to rates measured over for the three-year period. Simulated cumulative irrigation is slightly greater than the measured rates in WY 2010 and WY 2012, while simulated RDI and non-RDI rates are below and above measured rates in WY 2011, respectively (the latter of which shows very good agreement). It is noted that the exact locations of vineyards for which measured data were collected are confidential and were not provided for this study. Thus, a detailed examination of the soil water storage and precipitation factors associated with the each individual vineyard from the irrigation study was not possible. The measured irrigation rates shown in the charts represent the average irrigation rate of the 84 vineyards that participated in the study. Results from the study revealed that measured irrigation rates varied widely in each of the three years, ranging from less than 5 inches to greater than 25 inches each year.

Simulated irrigation rates for a vineyard under deficit irrigation were also compared to measured irrigation rates for the two months period from July 1 through August 31. Table 3-18 shows the total simulated RDI-irrigation and measured irrigation rates in terms of depth (in inches) and as a percentage of the full vineyard PET (under non-RDI irrigation).

Table 3-18. Comparison of Simulated Versus Measured Vineyard Irrigation (July/August)

Water Year	Applied Water (inches)		%PET[3] (Jul/Aug)	
	Simulated[1] (Jul/Aug)	Measured[2] (Jul/Aug)	Simulated[1] (Jul/Aug)	Measured[2] (Jul/Aug)
2010	10.11	9.57	41%	49%
2011	7.87	8.70	34%	41%
2012	14.29	11.61	50%	50%

[1] Simulated values for a vineyard within eastern ETo zone with a 7-inch soil water storage capacity and precipitation factor of 1.0.

[2] Measured data represents average irrigation rate from Battany, April 2013.

[3] Percentage of PET estimated for non-RDI vineyard.

Table 3-18 shows that simulated and measured cumulative irrigation in July and August are relatively close in terms of depth and percent PET. The measured data further indicate that, on average, deficit irrigation of vineyards is being implemented in the Basin.

<u>Estimated Annual Irrigation Demand and Applied Water Volumes.</u> Table 11 and Figure 51 show the estimated annual irrigation demand and applied water volumes (in AFY) for the seven crop groups in the Basin. As shown in the table and chart, agricultural irrigation demand (consumptive use) in the Basin declined from a high of about 110,000 AFY in 1981 to about 48,000 AFY in 1998. This decline coincides with the decline in alfalfa (primarily) and pasture (secondarily). Since 1998, the development of agricultural land for vineyards has resulted in increased agricultural irrigation water demand. Over the past five years (WYs 2007-2011), average irrigation water demand in the Basin has averaged about 59,000 AFY, similar to the irrigation water demand during the mid-1980s.

Table 12 and Figure 52 show the estimated annual irrigation demand and applied water volumes (in AFY) for the seven crop groups in the watershed surrounding the Basin. As shown in the table and chart, agricultural water demand is slightly higher in the watershed relative to the Basin, as expected. Over the model simulation period, the difference between irrigation demand within the watershed versus within the Basin has steadily increased since the early 1980s to on average about 15% over the past ten years (i.e., 15% of agricultural irrigation demand within the watershed is located outside of the Basin).

In Figures 51 and 52, the variability of water use after 1998 (in comparison to the relative stability before 1998) reflects the availability of annual land use data.

Agricultural Pond Evaporative Water Demand. Evaporative water demand of agricultural ponds was estimated for the model update outside of the soil water balances. A GIS map provided by SLO County ACO indicated that there were 218 acres of agricultural ponds in the watershed in 2012. These ponds are filled with groundwater over the winter, topped up by the beginning of frost season, and used for frost-prevention and supplemental irrigation during the growing season (communication with Rob Miller with the Wallace Group, October 24, 2013). While the loss of applied water for frost-prevention to ET is simulated in the soil water balance, direct evaporation of water from the pond surfaces was calculated separately.

For the model update, agricultural ponds were assumed to be 50% full (based on average operating conditions) from December through August and empty from September through November. To estimate historical pond acreage, ponds mapped by SLO ACO were assumed to exist since the inception of a vineyard on the same parcel of the pond. Individual ponds are identified as being located within the western or eastern ETo zone and a pond evaporation Kc value of 1.0 from December through August was applied to respective daily ETo value. The resulting evaporative rate was then applied to 50% of the pond area in the GIS coverage[24]. Table 3-19 shows the estimated annual agricultural pond area and associated evaporative water demand of agricultural ponds.

[24] Given the relatively small evaporative water demand of the agricultural ponds, an analysis of pond geometry was not conducted.

Table 3-19. Evaporative Water Demand of Agricultural Ponds

Calendar Year	Total Pond Area[1] (acres)	Evaporative Water Demand (AFY)
1981	107	231
1982	107	214
1983	107	224
1984	107	262
1985	107	243
1986	107	235
1987	107	231
1988	107	246
1989	107	240
1990	107	252
1991	79	164
1992	79	167
1993	79	166
1994	79	163
1995	79	165
1996	79	159
1997	79	179
1998	79	155
1999	131	276
2000	131	280
2001	131	275
2002	131	294
2003	142	337
2004	142	340
2005	142	314
2006	142	303
2007	142	375
2008	143	398
2009	165	401
2010	165	367
2011	165	317

[1] Reference ETo was applied to 50% of the total pond area as shown in the table to estimate evaporative water demand.

3.4.2 Municipal Groundwater Pumping

Evaluation of municipal groundwater pumping was based on actual records of metered[25] production from wells for Atascadero MWC, City of Paso Robles, Templeton CSD, and San Miguel CSD. The municipal well locations and construction (e.g., depth of screens) were provided by each purveyor; groundwater pumping was allocated respectively to the well locations and vertical zones based on these data.

With regard to pumping through time, monthly production data generally are available on a well-by-well basis for the entire study period. Nonetheless, some data gaps were identified in all four municipal records in the first few years of the study period, mostly WYs 1981 and 1982. In general, data gaps in monthly pumping values were addressed by applying the respective monthly value from the next year. Similarly, several missing or anomalous values for San Miguel in 1983 were estimated by using comparable 1982 values. For the City of Paso Robles prior to January 1989, monthly total pumping values are available but are not subdivided by individual well. However for this early period, the existing and active wells are known (Thunderbird 10, Thunderbird 13, and Butterfield 12) and the monthly production was allocated based on pumping patterns in the subsequent two years.

Table 3-20 shows the annual municipal groundwater production volumes from WY 1981 through WY 2011.

[25] Water use of parks and landscaping within cites and CSDs is subsumed in metered municipal pumping and is not reported separately.

Table 3-20. Municipal Groundwater Production

Water Year	Atascadero MWC	City of Paso Robles	San Miguel CSD	Templeton CSD	TOTAL
1981	3,647	2,990	228	351	7,216
1982	3,647	2,990	210	351	7,198
1983	3,787	3,169	189	285	7,429
1984	4,925	3,825	227	350	9,327
1985	4,779	4,056	185	412	9,432
1986	5,292	3,856	262	469	9,879
1987	5,798	4,043	247	601	10,689
1988	5,964	4,115	256	674	11,009
1989	5,962	4,480	246	646	11,334
1990	5,371	4,616	249	596	10,832
1991	4,644	4,599	449	574	10,266
1992	5,126	4,759	479	621	10,985
1993	5,326	4,735	375	785	11,221
1994	5,573	5,067	286	760	11,687
1995	5,105	4,919	121	711	10,856
1996	5,894	5,589	101	811	12,395
1997	6,312	5,872	179	816	13,179
1998	5,483	5,121	77	772	11,453
1999	5,995	5,939	112	853	12,898
2000	6,554	6,516	108	1,023	14,201
2001	6,339	6,682	273	1,013	14,306
2002	6,574	7,257	406	1,157	15,394
2003	6,337	7,349	467	1,284	15,437
2004	6,826	7,897	481	1,362	16,566
2005	5,257	7,159	404	1,312	14,132
2006	6,141	7,484	472	1,406	15,503
2007	6,721	8,056	142	1,550	16,470
2008	6,563	7,923	84	1,535	16,105
2009	5,902	6,873	99	1,434	14,309
2010	5,549	6,386	96	1,286	13,317
2011	5,369	6,408	91	1,249	13,117

3.4.3 Private Domestic Groundwater Pumping

The Phase I Study estimated private domestic water demand as the product of County estimates of rural DUs and a water demand factor of 1.7 AFY per DU; small community system water demand was included. The Pumping Update for 2006 applied the same water factor to dwelling units, with geographic distribution provided by the County GIS. The Pumping Update estimated rural domestic pumping at 10,891 AF in 2006 (not including small community water systems). The 2012 MWR also used the County GIS to define the distribution and number of rural DUs and applied a 1.0 AFY/DU factor.

For the model update, the County Land Use ArcGIS layer and associated spreadsheets were used to define the location of occupied rural DUs (as of 2012) in San Luis Obispo County. Monterey County rural population is very small and was not accounted. The methodology used to 1) estimate an indoor and outdoor rural residential water demand factor and 2) simulate rural population growth and associated water demand over time is described below.

3.4.3.1 Evaluation of Irrigated Landscaping Area

Previous use of a single water demand factor for all rural residences had raised concern that the variable water demand of rural residences—ranging from modest farmsteads to landscaped estates—was not evaluated adequately, particularly with regard to the extent of irrigated landscaping. This concern was addressed both in a special survey for this model update and in an investigation for the Salt Nutrient Management Plan (SNMP) that is currently underway for the City of Paso Robles.

The SNMP investigation used the current San Luis Obispo County Parcel Quest land use coverage and considered a category termed *farmstead*, with a parcel size of 2.5 acres or greater (even exceeding 80 acres). To assess irrigated areas, the SNMP examined 59 farmsteads across the groundwater basin (see Figure 53) and delineated irrigated agricultural fields (which had been included in the irrigated crop acreages of the crop database), areas of dry farming, and landscaped areas, which were measured and confirmed by Todd Groundwater. While the SNMP-examined farmstead parcels range widely in size, the irrigated landscaping was found to be quite limited. On the surveyed farmsteads, a total of 7.8 acres of irrigated landscaping was delineated, averaging 0.13 acres per farmstead. Of the 59 examined farmsteads, 28 farmsteads (47%) have no irrigated landscaping and the median landscape acreage is 0.017 acres. One parcel included 1.4 irrigated acres, including a private soccer field. Otherwise, the largest irrigated acreage was less than 0.8 acres.

For this model update, a similar survey was performed. Figure 53 also shows five areas of rural residential parcels that were identified for additional sampling. The areas are identified on the basin-wide map (Figure 53) in green, and on individual maps showing parcels proposed for examination. These areas were selected to include parcels that are less than 2 acres and depend on private wells, and to represent different portions of the Basin and types of development. For each parcel (outlined in yellow in each individual map) the extent of landscaping was measured using current Google Earth aerial photography. Table 3-21 summarizes the findings.

Table 3-21. Summary of Irrigated Landscaping Area per Rural Residential Parcel (2013)

Sample Area	# of Parcels	Total Parcel Area	Total Irrigated Landscaping	Percent Irrigated Area	Irrigated Area per Parcel
		acres	acres	%	acres
Del Salina Via	21	77.3	3.6	4.7%	0.17
Jardine	61	93.3	4.6	4.9%	0.08
Compere Way	65	100.0	5.3	5.3%	0.08
Green River	11	22.8	2.0	8.8%	0.18
Rancho Loma Linda	46	213.5	8.2	3.9%	0.18
TOTAL	204	506.9	23.7	4.7%	0.12
Average (of areas)				5.5%	0.14

The average landscape area was computed two ways (as the total irrigated area/total parcel area and as the average of the irrigated area per parcel) with similar results; a representative value is 0.13 acres per parcel, which happens to be the same value as that derived from the SNMP survey. The percent irrigated area (averaging about 5%) and the range of irrigated acreage (from 0.08 to 0.18 acres) indicates that rural residents irrigate a limited portion of their property; this is borne out by review of the aerial imagery.

3.4.3.2 Evaluation of Water Demand

The water demand for outdoor landscaping was estimated through evaluation of monthly ET and rainfall. As a basic analysis, average monthly Paso Robles ETo from the WWG Paso Robles (PR1) Station (period of record from 1-Jan-05 through 30-Sep-11) and monthly Paso Robles rainfall (COOP Station 46730) were compared to compute the amount of water needed to fulfill the potential ET on a monthly basis. A crop coefficient of 1.0 was assumed, representing a well-watered turf. This basic analysis (conducted over the period October 1980 through September 2011) yields an irrigation rate of 3.7 ft per year.

To test this basic analysis, similar analyses were conducted for comparison with three rural residential communities (Shandon, Green River, and Garden Farms) that have actual pumping data. Monthly ET and rainfall were adjusted as follows:

- For Shandon, average monthly ET data from WWG Shandon (SDN) station (period of record from 1-Jan-05 through 30-Sep-11) were used along with monthly rainfall data from Paso Robles, adjusted downward (to 80%) for the drier conditions in Shandon.

- For comparison to Green River, average monthly ET data from the WWG Paso Robles (PR1) station were used along with monthly rainfall data from Paso Robles, adjusted downward for Green River (93%).
- For comparison to Garden Farms, Atascadero ET data were used and the Paso Robles rainfall was adjusted upward (160%).[26]

The monthly analysis was performed for the entire period October 1980 through September 2011 in order to provide a long-term estimate. Figure 54 shows the available monthly pumping data for the three communities along with the estimated water demand. The pumping records from the three communities are variously discontinuous with some anomalous values, but are sufficient for comparison for "historical conditions" (for example, before 1997) and recent conditions (for example, after 2005).

To compute water demand in acre-ft (as shown on Figure 54), the acreage of irrigated landscaping per parcel was used. The Green River analysis used the 0.18 acres per parcel indicated as shown in Table 3-21. For Garden Farms, the average irrigated acreage per parcel of 0.13 acres per parcel was used. For Shandon, the average 0.13 acres per parcel-value was used for the period up to July 1990 and then halved to match the pumping data. This may reflect construction over time of residences on smaller parcels. The pumping data also showed the effect of rural residential growth; this was addressed through application of available information on the number of residential connections over the years. The estimate for Shandon also addressed public landscaping (school, park, etc.).

The pumping data include not only outdoor but also indoor water demand; the indoor demand was readily estimated as the average monthly water demand in the months of December, January, and February, which was applied throughout the year.

The hydrographs for Garden Farms (middle chart on Figure 54) show a change in summer/outdoor water use in the mid-1990s. Before that time, summer/outdoor water use rates apparently were very high and afterward, the summer/outdoor rates were lower. The focus of the model update is on the post-1997 years; accordingly, only the values after June 1995 were used to estimate rural water demand. For the recent Garden Farms analysis and the entire records for Shandon and Green River, a crop coefficient of 1.0 provided a reasonable match to pumping data.

Based on the above analysis, the average water demand for rural residences is summarized in Table 3-22 below.

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[26] Adjustment factors are based on the digital isohyetal map developed by the PRISM Climate Group at Oregon State University. The map was developed from 1981 to 2010 rainfall data.

Table 3-22. Average Water Demand for Rural Residences (AFY/Dwelling Unit)

Use Type	Rural Residential Area			Water Demand	
	Shandon	Green River	Garden Farms*	Average	Percent
Outdoor	0.29	0.68	0.41	0.46	62%
Indoor	0.18	0.36	0.32	0.29	38%

* After 1995.

As indicated, total water demand per rural residential is 0.75 AFY/dwelling unit. Of this amount, 38% is used indoors and can be assumed to return to the basin through onsite septic systems. An average of 62% is used outdoors and can be assumed consumed or lost to ET. (The amount of indoor use that is consumptively used and the amount of outdoor use that is not consumptively used and returns to groundwater can be considered as offsetting.)

The outdoor landscaping irrigation water rate in terms of ft per year also was computed as summarized in Table 3-23 below.

Table 3-23. Outdoor Landscaping Irrigation Water Rate

	Shandon	Green River	Garden Farms*	Average
Irrigation, ft/year	3.65	3.76	3.19	3.5

* After 1995.

The average of 3.5 ft/year is effectively equivalent to the basic analysis result of 3.7 ft/year. As a matter of perspective, there are 5,414 occupied rural residential parcels distributed across the Basin. Assuming that 0.13 acres per parcel are irrigated, then 704 total acres are irrigated. Application of a rate of 3.5 or 3.7 ft/year/acre results in a landscape irrigation consumption of 2,463 or 2,605 AFY, respectively.

Final Estimated Annual Private Domestic (Rural Residential) Water Demand Volumes. To simulate rural water demand over time, an historical annual growth rate of 2.25% for rural population was assumed based on recommendation from the SLO County Planning Department. Because it was not feasible to identify the locations of individual occupied residential parcels for each year of the simulation period, growth in rural residential water demand was simulated by 1) adjusting (decreasing) the estimated indoor and outdoor water demand factors each year by 2.25%, and 2) applying the adjusted demand factors to the 2012 coverage of occupied rural residential parcels.

Table 13 shows the outdoor rural consumptive use and indoor rural demand. For the model update, it is assumed that irrigation for outdoor rural use is 100% efficient (i.e., there are no return flows). All rural residential indoor use is assumed to return groundwater system (via septic tank leach fields).

3.4.4 Small Commercial Groundwater Pumping

The category of small rural commercial water demand involves a wide variety of establishments and facilities including major institutions with wells (Atascadero State Hospital, Camp Roberts, and the now closed El Paso de Robles Youth Authority), golf courses, wineries, rural schools, and rural businesses. The Phase I Study identified 20 small systems and estimated annual water demand using a mix of pumping data and estimates. The Pumping Update for 2006 identified 18 small commercial systems (using County lists of regulated small water systems) and 64 wineries and used a mix of pumping data and estimates for type-specific water demand rates for 2006. The 2006 Pumping Update estimated small commercial pumping amounted to 2,324 AFY. The 2012 Water Master Plan used the County GIS to define the distribution and number of commercial systems at the time and applied a single annual factor of 1.5 AFY per system.

For the model update, the analysis from the Phase I Study was retained for the years up to 1997. For subsequent years, actual pumping data were used insofar as available to provide a monthly record over the study period. The three major institutions provided partial data that were applied as follows:

- Monthly pumping data are available for Atascadero State Hospital from October 2004 through June 2009. These monthly values were averaged and then used to estimate the respective monthly values for the remainder of the record.
- Monthly pumping data are available for Camp Roberts for January 2005 through December 2011. These monthly values were averaged and then used to estimate the respective monthly values for the remainder of the record.
- Monthly pumping data are available for the El Paso de Robles Youth Authority for October 2005 through September 2006. These monthly values were averaged and then used to estimate the respective monthly values for the remainder of the period during which the Youth Authority operated. The facility was closed in July 2008.

Five major golf courses with wells have been identified in the Basin. One of these is the Chalk Mountain in Atascadero, which is irrigated with groundwater pumped from underneath the City of Atascadero wastewater ponds. Pumping data are available for Chalk Mountain from July 1998 through December 2009; for the remainder of the study period, average monthly values were applied. In addition, there are four golf courses in Paso Robles: The Links, Hunter Ranch, Paso Robles, and River Oaks. While all of the other golf courses have existed throughout the study period, River Oaks Golf Course was established in

2003. Groundwater is pumped to irrigate these golf courses, but pumping data are not available. Accordingly, the monthly water demand was estimated as the difference between the monthly ET and the monthly rainfall. Monthly ET was represented by the average monthly ETo measured at the Paso Robles ET Station; a crop coefficient of one was used as representative for turf. Monthly rainfall was represented by the NOAA station in Paso Robles. The monthly water demand rates were then applied to the general golf course areas measured from Google Earth: The Links (143 acres), Hunter Ranch (128 acres), Paso Robles (107 acres), and River Oaks (23 acres).

Water use for wineries was estimated by identifying each winery and its permitted capacity and applying a water use rate; return flows also are accounted. Wineries (not served by public water systems) were identified through examination of the State Department of Alcohol Beverage Control permit data (ABC, 2012). This is the same method as was used in the 2006 Pumping Update. The evaluation of active ABC licenses indicates that the number of wineries in the Basin and surrounding watershed since 2006 has increased significantly; while 64 wineries were identified in 2006, 201 wineries were identified in 2012. Year of winery establishment was documented for medium-sized and large wineries (i.e., greater than 100,000 gallons) through online searches. This research (plus documentation of vineyard expansion) indicated that many wineries were established in the early 2000's. Small wineries are assumed to have started in 2000. For each winery, it was assumed that the winery is operating at capacity. This is an overestimate; however, the growth of wineries indicates that local wine production is not keeping up with demand and suggests that wineries are operating near capacity.

In the 2006 Pumping Update, winery water use was estimated using an average value of 2.5 gallons per gallon of wine produced. This value is on the low end of winery water use. While water use rates vary considerably from one winery to another, an acknowledged "rule of thumb" has been 6 gallons per water per gallon wine (Franson, 2008). A rate of 5 gallons of water per gallon of wine was applied to each winery's permitted annual production. This recognizes that most local wineries are new and presumably have state-of-the-art water-conserving equipment and practices. However, it is also realized that water use at a specific winery may include landscaping and wine tasting/restaurant functions that are not reflected in the rule of thumb value. Annual water demand was distributed throughout the months of the year with a seasonal peak in September/October (ESA, 2012).

For wineries in unincorporated areas, on-site groundwater supply is assumed. Following use, on-site wastewater disposal also is assumed through leach fields or percolation ponds. It is recognized that some wineries have treatment systems and may use process wastewater for irrigation. Such irrigation already is assumed to be based on groundwater pumping, and no data are readily available to discern different sources. In addition, the proportion of winery return flows also is variable, with a general estimate of 30% to 40% (Chrobak, 2013). For the purposes of this model update, a general return rate of 35% is assumed.

For this model update, fifteen small commercial/institutional water systems were identified, not including the major institutions noted above or wineries. Most of these were identified in the Phase I Study and that pumping analysis has been retained for the period 1981 through 1997. For the years after 1997, the approach is similar to the Pumping Update for 2006, wherein water use coefficients are applied. The small commercial systems identified from previous studies and County lists of small water systems include:

Creston Country Store	Creston Elementary School	Emmanual Heights Camp
Loading Chute	Long Branch Saloon	Paso Robles RV Ranch
San Paso Truck & Auto	Pete Johnson Chevrolet	Pleasant Valley Elementary School
Shandon Rest Stop	Bradley Rest Stop	Philips School
Santa Lucia School	Black Mountain RV Resort	SATCOM Facility at Camp Roberts

For these small commercial/institutional water systems without available pumping records, water use coefficients were applied and the total groundwater pumping was estimated. As in the 2006 Pumping Update, commercial water use coefficients (per employee) are available from research conducted by the Pacific Institute (2003). These coefficients included the following: camp (0.208), school (0.163), institution (0.107) and restaurant (0.229). Other estimates were based on discussion with owners or operators. Estimation of gross pumping indicates that the fifteen small commercial/institutional water systems use a total of about 120 AFY. These sites involve limited irrigation; an annual water demand of 3.6 AFY per acre was applied. Accordingly, most of the water use is for indoor purposes and can be assumed to return to the groundwater basin via onsite septic systems. Given the small values and limited data, no seasonal pattern was applied.

Table 3-24 shows the estimated total small commercial water demand in the watershed.

Table 3-24. Small Commercial Water Demand

Water Year	Small Commercial Water Demand (AFY)
1981	2,163
1982	1,929
1983	1,871
1984	2,213
1985	2,165
1986	2,078
1987	2,203
1988	2,046
1989	2,152
1990	2,252
1991	2,251
1992	2,171
1993	2,164
1994	2,112
1995	2,104
1996	2,182
1997	2,249
1998	1,988
1999	2,129
2000	2,206
2001	2,175
2002	2,288
2003	2,170
2004	2,391
2005	2,110
2006	2,304
2007	2,420
2008	2,384
2009	2,270
2010	2,113
2011	2,103

The percentage breakdown of small commercial production over the simulation period is shown in Table 3-25.

Table 3-25. Summary of Small Commercial Groundwater Production

Small Commercial Type	Average Annual Production	Percent of Total Production
Atascadero State Hospital	325	15%
Camp Roberts	173	8%
El Paso de Robles Youth Authority	91	4%
Golf Courses	1,413	65%
Misc. Small Commercial	102	5%
Wineries	71	3%
Total	2,175	100%

3.4.5 Evapotranspiration by Riparian Vegetation

Riparian vegetation (specifically, phreatophytes) not only use available rainfall and soil moisture, but also pull up and consume groundwater. This groundwater uptake, assumed to occur when rainfall and soil moisture are inadequate, is accounted for in the original model and for this model update. The Phase I Study (Fugro and Cleath, 2002) used the California Department of Forestry and Fire Protection (CDFFP) GIS coverage for 1991 to estimate phreatophyte groundwater demand. The CDFFP map was part of a state-wide project to inventory hardwood rangelands (CDFFP, 1994). Riparian vegetation was delineated from LANDSAT imagery and defined within a 375-meter distance from perennial streams as mapped by USGS. The mapping also included inspection of aerial photographs and field checking. For this model update, the availability of more recent riparian woodland mapping was investigated. Currently, the USDA Forest Service is mapping existing vegetation throughout California (USDA, 2013). However, the mapping of the Central Coast (Calveg Zone 6) is currently incomplete; in fact, the Paso Robles Basin and watershed south of the county line is not yet mapped. Recognizing that vegetation mapping is well beyond the scope of this update, the CDFFP mapping is retained for this model update.

The Phase I Study estimated that the average annual phreatophyte groundwater consumption was 3,800 AFY. This estimate was based on an assumed annual groundwater demand (0.8 AF/AC/YR), adjusted annually in response to annual rainfall. Subsequently, in the Phase II Study, the average groundwater consumption was increased from 3,800 AFY to 7,700 AFY; however, no reason is provided for the upward adjustment (other than the implied reason that model calibration was improved).

The single reference cited in the Phase 1 Study (Robinson, 1958) states that groundwater demand for a given phreatophyte is expected to decrease (not increase) during high rainfall years, because the phreatophyte is able to draw from percolating rainfall in the soil zone. However, given that some vegetative growth is likely following high rainfall years, it is arguable that total riparian groundwater demand may be relatively consistent from year to year. Additionally, spot-checking of riparian density using historical aerial imagery from the early 1990s to present for this study indicates that the extent and density of riparian vegetation over the last 20 years has not changed significantly, even in areas subject to significant groundwater level declines.

For this model update, the annual groundwater demand of riparian vegetation (phreatophytes) of 0.8 ft was assumed in eastern ETo zone (see Figure 35). To account for the effect of variable ET on riparian water demand across the Basin and surrounding watershed, a slightly lower groundwater demand of 0.75 ft was applied to riparian vegetation located within the western ETo zone identified for this model update. These groundwater demand rates result in an estimated annual riparian groundwater demand of 3,452 AFY in the Basin watershed. Annual riparian demand was applied at a constant rate (i.e., the rate was not adjusted as a function of rainfall or other factors). Annual rates were apportioned monthly according to the average monthly ET distribution for the CIMIS Atascadero and WWG Paso Robles weather stations.

3.4.6 Subsurface Outflow through the Basin Boundary

According to the results from the Basin Model (Fugro, ETIC Engineers and Cleath, 2005), the annual discharge from subsurface outflow through the Basin boundary was estimated to be 1,600 AFY. As discussed in Section 5.4.1 of this report, the average annual discharge from subsurface outflow calculated by the recalibrated model is slightly less than the previous estimate.

4.0 AQUIFER SYSTEM CONCEPTUALIZATION ANALYSIS

The conceptual model developed during the Phase I Study (Fugro and Cleath, 2002) defined the Paso Robles Groundwater Basin as the area where the water-bearing unconsolidated aquifer sediments are separated by non-water bearing geologic units or faults. The Rinconada Fault generally defines the entire eastern border of the Atascadero Sub-Basin, and hydraulically separates the confined aquifer associated with the Paso Robles Formation from the rest of the groundwater basin (Fugro and Cleath, 2002). Justification for this separation was supported through groundwater level trends on either side of the Rinconada Fault and the juxtaposition of water-bearing (i.e., Paso Robles Formation) with non-water bearing formations (Monterey Formation) due to historic lateral displacement along the Rinconada Fault.

The conceptual model was anticipated to be retained for this update of the Paso Robles Groundwater Basin Model. Since there is more hydraulic connectivity at the northern area of the Atascadero Sub-Basin than along the majority of the Rinconada Fault which defines the Sub-Basin's eastern boundary, a reevaluation was performed to verify whether geologic and hydrogeologic data generated by others since 1997 supports modifying the existing designation of the Atascadero Sub-Basin.

4.1 Methodology

The focus of the reevaluation is on the hydraulic connectivity between the confined Paso Robles aquifer in the northern area of the Atascadero Sub-Basin and the southern area of the Estrella Sub-Area (see Figures 1 and 55). In order to revise the conceptual model for the Atascadero Sub-Basin, the degree of hydraulic connectivity at the northern area would need to have a minimal effect on groundwater elevations on either side of the Rinconada Fault. The reevaluation includes review of background reports and documents, driller's logs and well construction information, historic groundwater elevations, and historic groundwater pumping for wells located in the area of the reevaluation. The documents and data used to evaluate the aquifer system were obtained from multiple sources. The primary sources and types of data by each are summarized as follows:

- San Luis Obispo County: GIS coverages of geology and faults.
- California DWR: Well Completion Reports (i.e., Driller's Logs).
- City of Paso Robles: Well locations and construction information, groundwater elevations, and groundwater pumping.
- Templeton Community Services District: Well locations and construction information, and groundwater elevations.
- Fugro and Cleath: Phase I Study (2002), geologic map, and geologic cross-sections.

A complete list of references is provided in Section 8.0 of this report.

Additional data and information specific to the Atascadero Sub-Basin and Estrella Sub-Area made available since the work for the Phase I Study was completed includes surface geology (SLOCPBD, 2007), fault lines (SLOCMGD, 2001), and groundwater elevation and pumping data (up to 2012). Driller's logs and well construction information (i.e., well screen interval) were also obtained; however, correlation with wells used for the Phase I Study could not be confirmed. In addition, data from pumping tests performed for municipal water supply wells located in the Basin and surrounding watershed were available for this evaluation.

A comparison was made between the surficial geology used for the Phase I Study and geology obtained from the San Luis Obispo County Planning & Building Department. In general, the description and extent of mapped geologic units are similar, if not equal. The dataset provided by the county was developed by digitizing scanned geologic maps published mainly by the USGS and California Geological Survey (CGS). It serves as an interim update of the geology map database created for the county's 1999 Safety Element.

Figure 55 shows the surficial geology and prominent faults in the northern Atascadero Sub-Basin and southern Estrella Sub-Area. The Rinconada Fault defines the groundwater boundary that separates the Atascadero Sub-Basin from the main Paso Robles Groundwater Basin (Fugro and Cleath, 2002). Locally, the Sub-Areas consist of Quaternary-age unconsolidated alluvial recent and older channel deposits (Qrs/Qya and Qoa), non-marine terrace deposits (Qa), and Paso Robles Formation (QTp) which comprise the primary aquifer systems within the area. These deposits are underlain and/or bound on the west by essentially non-water bearing bedrock units of Tertiary-age consolidated sedimentary formations of the Monterey (Tm) and Vaqueros (Tvt) Formations, and the Cretaceous-age crystalline quartz diorite and granodiorite (gr).

4.2 Findings

4.2.1 Groundwater Movement Across Flow Barriers

In general, groundwater barriers in alluvial basins tend to be less effective (i.e., more "leaky") near the surface of the ground. This can be due to the absence of recent faulting in the near-surface alluvial deposits. Also, active fluvial systems—such as the Salinas River—can cut through a fault plane and deposit sedimentary units that readily transmit shallow (aquifer) groundwater flow. However, areas along a fault where historic offset has occurred, the permeability may be low enough to disrupt the flow of groundwater within an otherwise highly transmissive aquifer. As a result, groundwater on either side of the barrier (i.e., fault) is compartmentalized, with leakage between compartments that is dependent on the particular morphology[27] of the fault barrier, as well as water level differences across the fault.

Obtaining data that can be used to determine actual fault morphology is scarce because water wells are typically located away from known faults in order to minimize the geologic complexities that characterize a fault zone. However, understanding the degree to which a fault may or may not serve as a groundwater barrier is aided by analysis of groundwater levels in adjacent storage units. When a difference in hydraulic head occurs across a barrier, groundwater may flow due to leakage from the higher water level compartment to the adjacent lower water level compartment. Although the groundwater level may be affected by other factors (e.g., natural recharge, pumping, etc.), a careful comparison of water levels and water level differences may reveal useful information concerning geohydrologic continuity between two groundwater storage compartments.

4.2.2 Hydraulic Separation of Atascadero Sub-Basin

An attempt to quantify the difference in hydraulic head within the Paso Robles aquifer[28] between the Atascadero Sub-Basin and Estrella Sub-Area was made using historical groundwater elevation data measured from 1970 to 2012. A total of 69 water wells were located within the area of interest; 24 of the wells were determined to be suitable for the reevaluation (see Table 4-1 below). These wells were selected based on their proximity to the Rinconada and San Marcos Faults (from either side), available well construction information[29], and the quality of available water level data. Monthly pumping data and relative drawdown for municipal wells in the area were also evaluated.

[27] Fault morphology typically consists of either (1) a low-permeable zone surrounded by (2) a fractured and disrupted zone of generally higher permeability (Dafny, Gvirtzman, and Burg, 2012).

[28] This evaluation was not performed for the Younger Alluvium aquifer since the conceptual model includes groundwater flow in this aquifer across the Rinconada Fault into the Estrella Sub-Area.

[29] Maximum depth of the aquifer units associated with the Younger Alluvium is 100 ft (Fugro and Cleath, 2002).

Page 71 (Table 4-1) has been redacted (confidential well log information)

Hydrographs are provided on Figure 55 to show groundwater elevations that were determined to be representative of three areas: the area immediately north of the Rinconada Fault; the area in between the Rinconada and San Marcos Faults; and, the area immediately south of the San Marcos Fault.

Evaluation of groundwater elevations on either side of the Rinconada Fault shows the static water elevations to be similar, ranging from approximately 600-750 ft amsl on the south side and approximately 650-700 ft amsl on the north side. Also, water level response to local pumping (i.e., up to 200 ft of drawdown) is shown to be similar on either side of the Rinconada Fault. Static groundwater elevations south of the San Marcos Fault are similar to slightly higher than the area in between both faults, ranging from approximately 700 to 750 ft amsl. It appears that local pumping has a much lower effect on water levels in the area south of the San Marcos Fault, with an apparent drawdown of less than 50 ft.

Although there is known evidence of vertical displacement along the Rinconada Fault (GeoSolutions, 2000) and that it acts as a groundwater barrier within the Paso Robles aquifer near the Atascadero Sub-Area/Estrella Sub-Area boundary (Fugro and Cleath, 2002), the degree to which the fault limits flow from the Atascadero Sub-Basin into the adjacent Estrella Sub-Area (i.e., main Basin) could not be determined based on review of available data and subsequent analysis. The historical water elevations in five of the six wells that are perforated within the Paso Robles aquifer are similar on either side of the Rinconada Fault; however, the wells are not located close enough to the Fault to be conclusive about the degree of connectivity. There are many dynamics to faulting and the potential effect it may have on groundwater flow within an alluvial basin. For example, it is also possible that the Rinconada Fault hinders, but not completely blocks groundwater movement between the Atascadero Sub-Basin and the main Basin. Close evaluation of the hydrographs shown on Figure 55 indicate there are subtle differences on either side of the Rinconada Fault in this area, which may be an indication of fault-related flow disruption. However, as stated earlier, water wells are typically located away from known fault zones, which is most likely the case of the wells used for this evaluation. These wells were constructed for the purpose of extracting potable groundwater and may have screened intervals that cross through multiple aquifers. As a result, it is difficult to know with a high level of certainty if the observed changes in water levels are due to a groundwater flow barrier. In order to obtain subsurface information and data that could be used to accurately quantify the effects of a groundwater barrier, wells that are strategically located and constructed with screen intervals that are exclusive to a specific aquifer (e.g., Paso Robles aquifer) are required. Accordingly, the degree to which the Rinconada Fault acts as a groundwater barrier as determined by the Phase I Study (Fugro and Cleath, 2002) was retained for this Basin Model Update.

5.0 GROUNDWATER BASIN MODEL UPDATE AND RECALIBRATION DETERMINATION

The existing Basin Model is a four-layer finite-difference model. It covers an area of approximately 2,024 square miles (1,295,360 acres) consisting of 368 rows in the north to south direction and 352 columns in the west to east direction for a total of 129,536 cells per layer, or 518,144 cells in total. Each model cell represents an area of 660 ft x 660 ft (see Figure 56). The existing Basin Model was calibrated for WY 1981 through WY 1997 with a semiannual stress period.

The existing Basin Model has issues recognized by the initial modelers, by Gus Yates in his 2010 peer review, and by others. The identified issues include evaluation of rainfall recharge, subsurface inflow, stream-groundwater interactions, agricultural irrigation rates, rural water use, and groundwater storage change.

This Basin Model update extends the model period from WY 1997 to WY 2011, and also replaces the recharge and discharge terms using an updated water balance analysis.

Table 5-1 shows the recharge and discharge components in the updated Basin Model as well as the MODFLOW package used to simulate the terms.

Table 5-1. Paso Robles Groundwater Basin Model Recharge and Discharge Components

	Term	MODFLOW Package Used
INFLOW (RECHARGE)	Deep Percolation of Streambed Percolation	Recharge Package
	Deep Percolation from Direct Precipitation and Return Flow from Applied Water	Recharge Package
	Subsurface Inflow through the Basin Boundary	Recharge Package
	Deep Percolation from Discharge Treated Wastewater Effluent	Well Package
OUTFLOW (DISCHARGE)	Groundwater Pumping (Including Agricultural, Municipal, Private Domestic, and Small Commercial)	Well Package
	Evapotranspiration by Riparian Vegetation	Well Package
	Groundwater Discharge to Rivers	Stream Package
	Subsurface Outflow through the Basin Boundary	Constant Head Boundary

5.1 Inflow Terms Update

5.1.1 Recharge Package for Inflow Terms

The results of the Basin Watershed Model were exported as monthly data, compiled manually into semiannual[30] data, and incorporated into the Basin Model as model input values using the recharge package. These values include deep percolation of streambed seepage, deep percolation of direct precipitation and return flow from applied water, and subsurface inflow through the Basin boundary.

5.1.1.1 Deep Percolation of Streambed Seepage

The Basin Model cells were digitized along the watershed stream segment using ArcGIS and then assigned the stream segment number based on the sub-watershed number (see Figure 57). According to the segment numbers, the flux result from the Basin Watershed Model was input to each groundwater model stream cell correspondingly. A total of 2,601 model cells, including 72 stream segments of the sub-watershed, were used for the deep percolation of streambed seepage.

Model input for deep percolation streambed seepage for each six-month stress period is summarized in Table 14 (Water Years 1981-1990), Table 15 (Water Years 1991-2001) and Table 16 (Water Years 2002-2011) by stream segment number.

5.1.1.2 Deep Percolation of Direct Precipitation and Return Flow from Applied Water

To update the deep percolation from direct precipitation and return flow from applied water, the groundwater model area was broken up into zones based on the sub-watershed number areas (see Figure 58). A total of 46,912 model cells, representing 72 deep percolation zones based on the sub-watershed, were used for the deep percolation of direct precipitation and return flow from applied water.

Model input for this recharge component is provided in Table 17 (Water Years 1981-1990), Table 18 (Water Years 1991-2001) and Table 19 (Water Years 2002-2011) by deep percolation zones for each semiannual stress period.

5.1.1.3 Subsurface Inflow through the Basin Boundary

Subsurface inflow through the Basin boundary varies based on the same zones used for deep percolation of direct precipitation, but occurs only along the edges of the active and inactive cells for

30 Initially, this model update was to include refining the stress period from semiannual to monthly; however, available groundwater level and streamflow data was determined to be insufficient.

each zone (see Figure 59). A total of 2,297 model cells, representing 56 zones, were used for the subsurface inflow through the Basin boundary.

Model input for subsurface inflow through the Basin boundary for each stress period is summarized in Table 20 (Water Years 1981-1990), Table 21 (Water Years 1991-2001) and Table 22 (Water Years 2002-2011).

5.1.2 Well Package for Inflow Terms

5.1.2.1 Deep Percolation of Discharged Treated Wastewater Effluent

Deep percolation of discharged treated wastewater effluent was incorporated into the Basin Model using the well package. In accordance with the locations of percolation ponds, model cells are assigned to San Miguel CSD WWTP, City of Paso Robles WWTP, Templeton CSD WWTP and City of Atascadero WWTP, respectively (see Figure 60). An additional 2% volume was added due to the contribution from sewer pipe leakage.

Model input for wastewater recharge by each treatment facility for each stress period is provided in Table 23. A total of seven (7) model cells were used.

5.2 Outflow Terms Update

5.2.1 Well Package for Outflow Terms

Outflow terms, which includes groundwater pumping and evapotranspiration, were incorporated into the Basin Model as model input values using the well package.

5.2.1.1 Agricultural Groundwater Pumping

Agricultural groundwater pumping is the largest outflow with significant trends over time. A total of 1,426 model cells were used to simulate the agricultural pumping. Table 24 provides the agricultural pumping for each stress period. Figure 61 shows the locations of agricultural groundwater pumping model cells.

5.2.1.2 Municipal Groundwater Pumping

A total of 47 model cells were used to simulate the municipal groundwater pumping. Table 24 provides the municipal groundwater pumping for each stress period. Only 98% of the amount of pumping was input into the model to account for the urban water transport leakage. Figure 62 shows the locations of municipal groundwater pumping model cells.

5.2.1.3 Private Domestic Groundwater Pumping

A total of 2,977 model cells were used to simulate the private domestic groundwater pumping. Table 24 provides the private domestic groundwater pumping for each stress period. Figure 63 shows the locations of private domestic groundwater pumping model cells.

5.2.1.4 Small Commercial Groundwater Pumping

A total of 133 model cells were used to simulate the small commercial groundwater pumping. Table 24 provides the small commercial groundwater pumping for each stress period. Figure 64 shows the locations of small commercial groundwater pumping cells.

5.2.1.5 Evapotranspiration by Riparian Vegetation

Based more recent riparian woodland mapping, a total of 3,358 model cells were used to simulate the evapotranspiration by riparian vegetation. Table 24 provides the evapotranspiration by riparian vegetation for each stress period. Figure 65 shows the locations of evapotranspiration by riparian vegetation model cells.

5.2.2 Constant Head Boundary

5.2.2.1 Subsurface Outflow through the Basin Boundary

Subsurface outflow through the Basin boundary was incorporated into the Basin Model using the Constant Head Boundary. A total of 16 model cells are assigned as constant head cells to simulate the subsurface outflow close to the Salinas River outlet (see Figure 66).

5.2.3 Stream Package for Groundwater Discharge to Rivers

A Stream Package was used to simulate the interaction between surface water and groundwater. Net volume (i.e., groundwater discharge to rivers) is obtained by subtracting groundwater inflow from rivers from groundwater outflow to rivers. A total of 2,918 model cells are included in Stream Package and Figure 67 shows the location of these cells for each model layer.

5.3 Post-Update Audit to Determine Need for Recalibration

The Basin Model was updated using the revised inflows and outflows for the 31-year period from WY 1981 through WY 2011. The model domain, aquifer layering and permeability values were unchanged from the original model. The update included changing the inflow and outflow rates relative to the original model.

5.3.1 Results of Groundwater Model Update

The updated Basin Model was run with semiannual stress periods and successfully converged with low mass-balance errors.

The updated Basin Model results were evaluated to determine whether the model required recalibration. The evaluation (post-audit) focused on simulated water level patterns and trends, as compared with the hydrogeologic site conceptual model, and calibration quality in terms of observed versus simulated head residuals.

5.3.2 Simulated Groundwater Levels and Trends

Model-simulated groundwater elevations by layer were tabulated and mapped for selected periods to evaluate the need for model recalibration**.** Figures 68 through 70 present contours of simulated groundwater levels (equipotentials) in map view for each model layer for three time periods: 1985 (five years into the historical simulation), 1995 (fifteen years into the historical simulation), and 2010 (29 years into the simulation, near the end of the model). The contour patterns reflect the boundary conditions, sources and sinks such as pumping wells, and permeability zones, which cause changes in gradient magnitudes and directions. The simulated groundwater elevations also change over time, in response to the dynamic inflows and outflows. Comparison of Figures 68, 69 and 70 reveals the changes in groundwater elevations in several Sub-Areas. Overall declines in groundwater elevations for each model layer are noted in several Sub-Areas. The number of dry cells in model layers 2 through 4 also increases over time. In model layers 2 and 3, dry cells are present along the edges of the active model areas in the Estrella, Creston, Shandon, and South Gabilan Sub-Areas. In model layer 4, a small area of dry cells is present at the end of the simulation near the edges of several Sub-Areas. These dry cells in the deeper model layers are problematic in that they are not observed (based on measured water level data) and they influence the simulation results by inactivating portions of the model area.

To assess whether the updated model correctly simulates the natural system (i.e., does not require recalibration), simulated water levels also were compared to specific observed water level data from target wells. For this comparison, 101 wells were selected as representative wells based on the following criteria.

Hydrographs for selected observation wells were constructed for the Basin Sub-Areas. The hydrographs show simulated and observed water levels for each calibration target. For comparison, hydrographs of observed and model-simulated water levels for the original model were also plotted. Figures 71 through 75 are hydrographs for the original model, while Figures 76 through 81 are hydrographs of the updated model (note: one well in the South Gabilan Sub-Area is now included for calibration of the updated model; this well was not included in the original model).

The hydrographs revealed trends in groundwater elevations with time. The following summarizes the results of comparing observed to model-simulated levels used to determine the need for model recalibration.

Atascadero Sub-Basin

- Layer 1 – Simulated water levels in the northern Sub-Area drop around 40 ft between 1980 and 1992, then stabilize. Simulated water levels in the southern area are generally 20 ft higher than observed.
- Layer 2 – No observation data are available.
- Layer 3 – Simulated water levels in the northern-middle area are around 40 ft lower than observed then increase after 1992. Pumping/seasonal fluctuations appear to be simulated. Simulated water levels in the southernmost area are around 20 ft higher than observed.
- Layer 4 – Some simulated water levels are lower than observed, others are higher than observed. Pumping/seasonal fluctuations are simulated.

Creston Sub-Area

- Layer 1 – No observation data are available.
- Layer 2 – No observation data are available.
- Layer 3 – Simulated water levels exhibit significant divergence from observed. Simulated water levels drop continuously to around 160 ft lower than observed.
- Layer 4 – Similar to Layer 3. Simulated levels are lower than observed, and drop throughout the simulation period.

San Juan Sub-Area

- Layer 1 – No observation data are available.
- Layer 2 – No observation data are available.
- Layer 3 – Simulated water levels are similar to observed for the one target well in this Layer. Pumping/seasonal fluctuations are simulated.
- Layer 4 – Simulated levels drop throughout the simulation period, and are significantly lower than observed.

Estrella Sub-Area

- Layer 1 – Simulated water levels exhibit a general uptrend, while observed water levels are stable or declining. Pumping/seasonal fluctuations are not well simulated.
- Layer 2 – Only one target exists in this Layer, and appears well calibrated.
- Layer 3 – Simulated water levels exhibit a few downtrends, others more stable.

- Layer 4 – Simulated water levels show significant divergence in 3 westernmost targets. Simulated levels drop around 200 ft, then stabilize after 1992. Two southeastern area targets exhibit better calibration.

Shandon Sub-Area

- Layer 1 – No observation data are available.
- Layer 2 – Only one target exists in this Layer, and appears well calibrated.
- Layer 3 – Some simulated water levels exhibit downtrends that stabilize after 1992. Other simulated levels are more stable, then exhibit late-time uptrends.
- Layer 4 – Similar response as Layer 3.

South Gabilan Sub-Area

- Layer 1 – No observation data are available.
- Layer 2 – No observation data are available.
- Layer 3 – Only one target is in this Sub-Area. The initial condition appears to be 80 ft lower than observed. The simulated water level trend exhibits significant divergence dropping continuously to around 160 ft lower than observed.
- Layer 4 – No observation data are available.

The following summarizes the overall calibration quality for the updated model that lead to the determination of whether recalibration was needed after updating the Basin Model.

5.3.3 Quality of Updated Groundwater Model Calibration

Both qualitative and quantitative methods were used to assess calibration quality. Qualitative considerations include the general flow features and the degree of correspondence between the model simulation and the physical hydrogeologic system. For example, where there are mounds and depressions in the potentiometric surface, then the modeled contours should also indicate a mound or depression in approximately the same area. Trends such as increasing, stable, or declining water levels over time should be matched in the model simulation. Different hydrologic conditions over time include periods of high and low recharge, and the degree to which the model matches the different conditions over time is an important indicator of calibration quality (ASTM, 2002).

In general, the updated model without recalibration appeared to diverge from observed water level trends. Specifically, simulated water levels in several of the Sub-Areas and model layers dropped significantly over time. This result is not surprising, given the smaller net recharge for the update model as compared with the original model. However, the significant and continuing divergence over time indicates that the updated model was not an accurate predictor of transient flow.

Quantitative techniques were also used to assess the updated Basin Model calibration. These techniques included calculating potentiometric head residuals (the difference or error between the computed heads and the measured heads), assessing correlation among head residuals, and calculating summary statistics for the residuals. These include the mean error, the mean absolute error, and the root mean square error. The mean error (ME) is the mean of the differences between measured and simulated heads. The mean absolute error (MAE) is the mean of the absolute value of the differences between measured heads and simulated heads. The root mean square (RMS) error is the square root of the average of the squared differences between measured heads and simulated heads. Metrics based on these statistics are sometimes used to judge the adequacy of a numerical model. These metrics examine mean residual, absolute mean, root mean square, and residual standard deviation as a percent of the range in observations. Indicators of acceptable calibration include a ME of less than 5% of the range in observations, and RMS error of less than 10% of the range in observations (Anderson and Woessner, 1992).

Table 5-2 lists the summary statistics for both the original and updated Basin Model used to determine the need for recalibration. For the original model, the overall ME and RMS errors for the entire model period were 0.32 ft and 25.6 ft, respectively. As a percent of range these are 1.52% and 2.30%, respectively. For the updated model, the overall ME and RMS errors for the entire model period were 23.2 ft and 70.87 ft, respectively. As a percent of range these are 4.50% and 6.73%, respectively. However, the calibration quality for later periods of the model decreased. This was due to the significant simulated declines in groundwater elevations over time.

Table 5-2. Calibration Statistics for Paso Robles Groundwater Basin Model Update

Parameter	Original Model	Updated Model
Number of Observations	4596	4833
Range in Observations (ft)	1110.70	1052.80
Minimum Residual (ft)	-189.03	-208.14
Maximum Residual (ft)	129.31	251.92
Residual Mean (ft)	0.32	23.20
Absolute Residual Mean (ft)	16.93	47.36
Root Mean Squared Error (ft)	25.60	70.87
Scaled Residual Mean	0.0%	2.2%
Scaled Absolute Residual Mean	1.5%	4.5%
Scaled Root Mean Squared Error	2.3%	6.7%

Based on the qualitative and quantitative assessments, it was recommended to the District that the updated Basin Model should be recalibrated. This recommendation included making adjustments to hydraulic conductivities in each layer and recalibrating prior to conducting predictive simulations of management scenarios.

5.4 Groundwater Model Recalibration

5.4.1 Method of Basin Model Recalibration

Model calibration is performed to improve the accuracy of the model in simulating observed groundwater levels. The method used to recalibrate the updated Basin Model was the industry standard "history matching" technique in which hydrogeologic parameters are manually varied until the best fit is achieved for transient conditions. These parameters included horizontal and vertical hydraulic conductivity, specific yield, and specific storativity. The updated Basin Model was recalibrated for the period October 1980 through September 2011 (i.e., WYs 1981-2011).

To assist in the trial-and-error adjustment of parameters for "history matching," the software package Visual PEST (Parameter ESTimation) (Doherty, 2000) was used to aid in the recalibration of the updated Basin Model. PEST was used to optimize aquifer parameters in the model based on observed water levels over time[31]. These aquifer parameters included horizontal hydraulic conductivity, vertical hydraulic conductivity and storage coefficient. Aquifer parameters were input to PEST in the form of ranges of acceptable values for each established parameter zone that were established by the Phase II Study (Fugro, ETIC Engineers and Cleath, 2005). Through a nonlinear estimation technique known as the Gauss-Marquardt-Levenberg method, PEST adjusted the values assigned to each of the parameter zones to best fit the model-generated heads to the observed heads (reduce residual error) at wells across the model area[32].

In addition, the Watershed Model was revised to adjust the amount of recharge during the model recalibration in order to match the observed water levels.

The recalibration process used 4,602 water level measurements from 101 calibration target wells from which to match model-generated head values against the measured values. Target wells used for model flow calibration are shown on Figure 82.

5.4.1.1 Recalibrated Horizontal Hydraulic Conductivity and Vertical Hydraulic Conductivity

The hydraulic conductivity values were iteratively adjusted within pre-established upper and lower

31 The calibration of complex models can be labor-intensive, in which case including automatic parameter estimation in the calibration process is appropriate (Moriasi et al., 2007).

32 Parameter values for the final recalibrated model are within the upper and lower parameter boundaries.

bounds, during model recalibration in order to minimize the residuals between the measured and model-generated groundwater levels. The final horizontal hydraulic conductivity values range from 0.1 ft/day (0.75 gallons per day [gpd]/ft^2) to 20 ft/day (149.6 gpd/ft^2) for model layers 2 through 4, and 60 ft/day (449 gpd/ ft^2) to 550 ft/day (4,114 gpd/ ft^2) for layer 1 (see Figure 83). Figure 84 shows the final vertical hydraulic conductivity values for model layers 1 through 4, which range from 0.0001 ft/day (0.0007 gpd/ft^2) to 1 ft/day (7.48 gpd/ft^2).

5.4.1.2 Revised Storativity

In the original 2005 Basin Model, the model input values for the storage coefficient were incorrectly used as the specific storage, and required new values to be assigned during the recalibration. Revised unconfined storage coefficient ranges from 0.02 to 0.25 and recalibrated confined storage coefficients range from 0.001 to 0.00001.

5.4.1.3 Revised Initial Groundwater Elevation

Initial groundwater elevations used in the recalibrated Basin Model are shown on Figure 85. Based on the original 2005 Basin Model, these elevations (October 1980) were revised according to historical measured water levels.

5.4.1.4 Revised Inflow and Outflow Terms

Inflow terms, including: 1) deep percolation of streambed seepage; 2) deep percolation of direct precipitation and return flow from applied irrigation water; and 3) subsurface inflow were adjusted to meet the model recalibration criteria. Since these three flux terms were based on results of the Basin Watershed Model, the Basin Model was correspondingly adjusted, re-run, and re-verified. Figure 86 shows the annual recharge from deep percolation of streambed seepage. During the period for WYs 1981 to 2011, the annual recharge ranges from 9,833 acre-ft to 78,098 acre-ft with an annual average of 26,596 AFY. Final model input for deep percolation of streambed seepage is provided in Tables 14 through 16. Figure 87 shows the annual recharge from deep percolation of direct precipitation and return flow from applied water. During the period for WYs 1981 to 2011, the annual recharge ranges from 6,208 acre-ft to 76,967 acre-ft with an annual average of 23,218 AFY. Final model input for deep percolation of direct precipitation and return flow from applied irrigation water is provided in Tables 17 through 19. Figure 88 shows the annual subsurface inflow through the Basin boundary. During the period for WYs 1981 to 2011, the annual recharge from subsurface inflow through the Basin boundary ranges from 2,743 acre-ft to 222,216 acre-ft with an annual average of 52,725 AFY. Final model input for subsurface inflow is provided in Tables 20 through 22. The recalibrated model also includes inflow from Camp Roberts WWTP.

Based on the results of the recalibration model run, annual volumes of subsurface outflow through the basin boundary and groundwater discharge to rivers are shown on Figures 89 and 90. Average values were calculated by the recalibrated Basin Model as 1,428 AFY for subsurface outflow and 12,862 AFY for groundwater discharge to rivers. Semiannual volumes for subsurface outflow and groundwater discharge to rivers are listed in Table 25.

Figure 91 shows the total annual inflow for the Paso Robles Groundwater Basin. As shown, total annual recharge ranges from 24,706 acre-ft to 384,269 acre-ft with an annual average of 108,380 AFY during WYs 1981 to 2011. Figure 92 shows the total annual outflow for the Paso Robles Groundwater Basin. During the period for WYs 1981 to 2011, total annual discharge ranges from 84,405 acre-ft to 142,157 acre-ft with an annual average of 110,853 AFY.

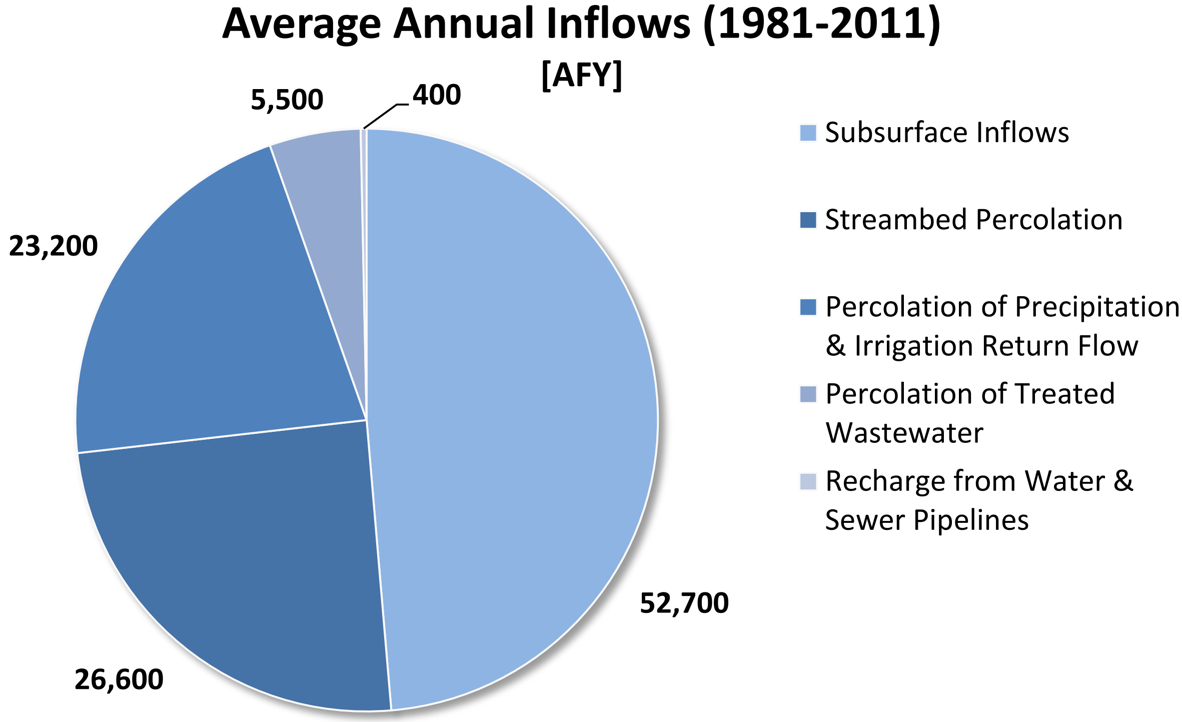
5.4.2 Recalibration Results

Hydrographs for the Basin Model recalibration for wells within the Atascadero Sub-Basin, Creston Sub-Area, Estrella Sub-Area, San Juan Sub-Area, Shandon Sub-Area and South Gabilan Sub-Area are shown on Figures 93 through 98, respectively. In general, the water levels calculated by the recalibrated Basin Model match well with the measured water levels. Figure 99 shows measured versus model-calculated water levels. As shown, the 4,602 groundwater level measurements are mainly clustered around a diagonal line (representing where measured water levels match model-calculated water levels) and within a band of plus/minus one standard deviation water level residual (i.e., +/-27.5 ft). This reflects what is considered in groundwater flow modeling to be a good match between measured and model-calculated water levels. Temporal distribution of groundwater level residuals used as a measure of how the model underestimates and overestimates groundwater levels is provided on Figure 100.

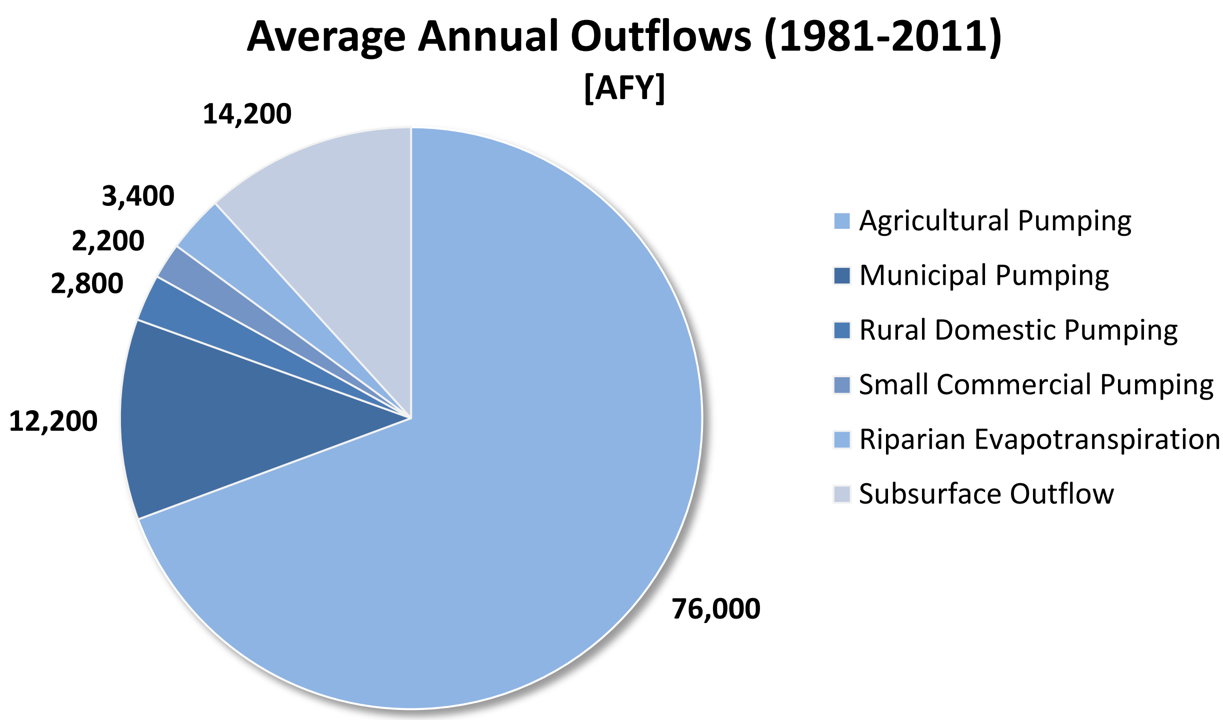
Figure 101 shows a histogram of the residuals (difference between observed and modeled values) from 101 target wells. As shown, the histogram is bell shaped with over 78% of the water level residuals found in the range of +/-30 ft, indicating a good model calibration. The good calibration is further supported by a low relative error of 2.6% (see Figure 99). The relative error is determined from the water level residuals (i.e., observed water level less model-calculated water level) and is the standard deviation of the residuals divided by the range in observed values. Common modeling practice considers the calibration to be a good fit if the relative error is less than 10% (Spitz and Moreno, 1996; and Environmental Simulations, Inc., 1999).

Average annual Basin inflows and outflows for WYs 1981-2011 are shown graphically on Figure 5-1. Applying the equation for change in groundwater storage (inflow minus outflow), the average annual change in groundwater storage for 1981-2011 is approximately -2,400 AFY. The water budgets from the model recalibration are presented in Table 26.

Figure 5-1. Average Annual Inflows and Outflows for the Paso Robles Groundwater Basin



Average Annual Inflow = 52,700 + 26,600 + 23,200 + 5,500 + 400 = 108,400 AFY



Average Annual Outflow = 76,000 + 12,200 + 2,800 + 2,200 + 3,400 + 14,200 = 110,800 AFY

5.4.3 Sensitivity Analysis

Sensitivity analysis was performed on the calibrated Basin Model using the estimated subsurface inflow from the Basin Watershed Model. The purpose of the sensitivity analysis is to assess the model input parameters which have the greatest effect on the model's simulation results. For this analysis, the model's sensitivity was evaluated after first increasing the value of model input parameters by 50% (relative to the calibrated input value) and then decreasing the value of model input parameters by 50%. The following input parameters were varied for this analysis:

- Horizontal Hydraulic Conductivity,
- Vertical Hydraulic Conductivity,
- Specific Yield,
- Streambed Percolation[33], and
- Groundwater Pumping.

The purpose of the sensitivity test was to demonstrate the sensitivity of the model simulations and the uncertainty of model input values. The sensitivity analysis indicates that the model is most sensitive to changes to groundwater pumping and recharge from streambed percolation.

Figure 102 shows the normalized sensitivity for selected model parameters. Normalized sensitivity is the difference between the sum of squared residuals from the sensitivity run and the calibration run, divided by the sum of squared residuals of the calibration run. The greater the normalized sensitivity value, the more sensitive the parameter is to the model residuals (i.e., the difference between model-generated and measured groundwater levels). Input parameter sensitivity is dictated by the magnitude of impact on groundwater level residuals resulting from increasing or decreasing the value of the input parameter. Thus, an increase or decrease in groundwater pumping and/or an increase or decrease in recharge from streambed percolation would have a greater impact on groundwater residuals than similar changes in the other input parameters for the model.

5.5 Perennial Yield Estimates

The maximum quantity of water that is actually available from a groundwater basin on a perennial basis is limited by the possible deleterious side effects that can be caused by both pumping and operation of wells within the basin. The Perennial Yield, for purposes of this report is defined as:

Perennial Yield = Groundwater Pumping +/- Change in Storage

33 Includes aerial recharge, recharge from mountain front runoff and return flow.

As discussed in Section 3.4, source of groundwater pumping within the Basin consists of municipal, small commercial, agricultural, and private domestic systems. Annual totals for each pumping system from 1981 through 2011 are provided in Table 26.

Estimates of Perennial Yield of the Basin using the water budgets from the recalibrated Basin Model are provided below in Table 5-3.

Table 5-3. Estimates of Perennial Yield for the Paso Robles Groundwater Basin

Water Year	Estimated Perennial Yield [AFY]
1981-1997	88,800
1998-2011	92,900
1981-2011	90,600
1982-2010	89,600

The perennial yield was previously estimated (Fugro, ETIC Engineers, and Cleath, 2005) to be 97,700 AFY for the Basin for the period 1981-1997 using the original model. The estimated perennial yield of the Basin for the same period using the updated and recalibrated Basin Model is 88,800 AFY. For the purposes of discussing perennial yield, the period during water years 1982 to 2010 is the most representative of historical average rainfall in the Basin area. As presented in Table 5-3 above, the estimated perennial yield based on that period is 89,600 AFY.

5.6 Groundwater Model Predictive Scenarios

Two predictive model runs were made using the updated and recalibrated Basin Model to evaluate how Basin water levels and storage may respond to varying groundwater use and recharge conditions. The model runs were simulated for a period of 29 years (Water Years 2012-2040) with a semiannual stress period by varying the assumptions for water demands, the amount of Nacimiento Water Project deliverables, and percent growth (i.e., change in land use) within the Basin.

5.6.1 Model Run 1 – Baseline with No Growth

Model Run 1, Baseline with No Growth, was developed to determine the response of the Basin to continuation of 2011 Nacimiento Water Project delivery, 2011 water demands, and no growth projected 29 years into the future (2012-2040). Accordingly, actual 2011 Nacimiento deliveries were used as input for every year. For water demands, 2011 values were repeated every year for 29 years with no growth.

5.6.2 Model Run 2 – Baseline with Growth

Model Run 2, Baseline with Growth, examined the response of the Basin to Nacimiento Water Project deliveries projected to occur after September 2011, projected water demands, and a growth rate of 1% per year projected 29 years into the future. Accordingly, Model Run 2 used actual Nacimiento deliveries for 2012-13 and those forecast for 2014-2040. For agricultural water demand, the 2011 acreages for all non-vineyard crops (e.g., alfalfa,) were kept steady into the future; this is reasonable given relatively flat historical trends. For vineyards in 2012, the actual 2012 vineyard acreages were applied directly. For future years, forecasts from the San Luis Obispo Agricultural Commissioner's Office for vineyards to be planted by July 2013, 2014, and 2017 were combined with the 2012 vineyard coverage to develop complete vineyard coverages from 2013 through 2017. Thereafter, a 1% growth rate in vineyard acreage was assumed from 2018 to 2040, with the growth applied spatially over the 2017 vineyard coverage. A 1% annual increase was also applied to municipal, private domestic, and small commercial pumping.

5.6.3 Assumptions for Predictive Model Runs

Table 5-4 summarizes the assumptions used for the predictive model runs.

Table 5-4. Summary of Assumptions Used for Predictive Model Runs

Model Run	Model Simulation Period	Hydrology[1]	Nacimiento Water Project Deliverables	Water Demand
Run 1	WY 2012-2040	WY 1982-2010	2011 (Actual)	2011 (Actual)
Run 2	WY 2012-2040	WY 1982-2010	2012-2040 (Projected)[2]	Projected 1% increase per year

[1] It should be noted that the actual hydrologic conditions (e.g., rainfall) which occurred in the Paso Robles Basin area in 2012, 2013, and 2014 were set to be equal to the conditions measured in 1982, 1983, and 1984. It is recognized by the model update team that the hydrologic conditions for 2012-14 may not be representative of the hydrology for the period 1982-84. However, rainfall measurement data for the period 2012-14 was compared with the 1982-84 data, and the overall difference of water volume was determined to be negligible (i.e., less than 5% of the overall volume for the 29-year simulation period).

[2] Includes actual NWP deliverables for 2012.

5.6.3.1 Hydrologic Base Period

A hydrologic base period is the period of time over which elements of the equation of hydrologic equilibrium[34] are evaluated. The time period selected should:

[34] The equation of hydrologic equilibrium is a quantitative statement of the conservation of mass. In groundwater hydrology, it is simply Inflow = Outflow ± Change in Storage. This is also known as a water balance or hydrologic budget.

- Be representative of long-term hydrologic conditions,
- Include wet, dry, and average years of precipitation,
- Span a 20- to 30-year period (Mann, 1968),
- Include recent cultural conditions (DWR, 2002), and
- Have its starting and ending years preceded by comparatively similar rainfall quantities (DWR, 2002).

Based on the analyses of historical precipitation, the 29-year period from October 1981 through September 2010 (WYs 1982-2010) was selected for the hydrologic base period of both predictive model runs. This base period covers both wet and dry hydrologic cycles, and the average precipitation is approximately the same as the long-term average (see Figure 103). The hydrologic base period was assumed to represent future conditions for the 29-year period from October 2011 through September 2040 for both model predictive runs. Monthly stress periods for predictive scenarios duplicated historical hydrogeologic conditions of the base period.

5.6.3.2 Nacimiento Project Water Conveyance, Deliverables, and Usage

The Nacimiento Water Project (NWP) has been recently constructed to deliver raw water annually from Lake Nacimiento through 45 miles of pipeline to its service area within San Luis Obispo County. The NWP includes four turnouts to provide deliverables to the Atascadero Mutual Water Company (T6), City of Paso Robles (T2), City of San Luis Obispo (T11), and the Templeton Community Services District (T4). The locations of the four NWP turnouts are shown on Figure 104. Daily volumes delivered to the four turnouts during 2011-13 and projected volumes forecast for 2014-2040 were provided by County. As provided in Table 27, the County included information on how the NWP deliverables will be distributed at the turnout (i.e., percolation pond, treatment plant or underflow recharge).

Actual 2011 deliverables were used as model input for Model Run 1. Input for Model Run 2 included actual deliverables for 2012-13 and those forecast for 2014-2040 at all four turnouts. Percolation of discharged NWP water was incorporated into the Basin Model using the well package (see Section 5.1.2).

5.6.3.3 Water Demands

5.6.3.3.1 Estimation of Annual Crop Acreages from Calendar Years 2012-2040

For all non-vineyard crops (alfalfa, citrus, deciduous, nursery, pasture, vegetable), 2011 acreages were maintained and applied to each year of the future model simulation period for all scenarios. This approach is considered reasonable given that recent historical trends show primarily flat to slightly declining trends for all non-vineyard crops.

Vineyards. For Model Run 1 (Baseline with No Growth), 2011 acreages were maintained and applied to each year of the future model simulation period for all scenarios.

For Model Run 2 (Baseline with Growth), the GIS coverage provided by SLO ACO for existing 2012 vineyard acreages were applied directly. For future years, coverages showing forecasted vineyards to be planted by July 2013, 2014, and 2017 were combined with the 2012 vineyard coverage to develop complete vineyard coverages from 2013 through 2017 (see Figures 105-107). Pursuant to guidance from SLO County Planning Department, a 1% growth rate in vineyard acreage was assumed from 2018 to 2040. This growth rate was applied spatially over the 2017 vineyard coverage.

Table 5-5 provides the estimated annual irrigated crop acreages within the groundwater basin for CYs 2012-2040 for Model Run 2. Based on the predicted new vineyards to be planted (in 2013, 2014, and 2017), the average annual vineyard growth rate in the groundwater basin from 2012 to 2017 is 2.9%. The annual vineyard growth rate in the Basin from 2018 to 2040 is 1% (as assumed).

Table 5-5. Annual Irrigated Crop Acreages in Groundwater Basin for Model Run 2 (CYs 2012-2040)

CY	Alfalfa	Citrus	Deciduous	Nursery	Pasture	Vegetable	Vineyard	TOTAL
2012	2,243	393	421	70	1,331	2,890	32,604	39,952
2013	2,243	393	421	70	1,331	2,890	32,641	39,989
2014	2,243	393	421	70	1,331	2,890	33,238	40,586
2015	2,243	393	421	70	1,331	2,890	33,238	40,586
2016	2,243	393	421	70	1,331	2,890	33,238	40,586
2017	2,243	393	421	70	1,331	2,890	37,399	44,747
2018	2,243	393	421	70	1,331	2,890	37,773	45,121
2019	2,243	393	421	70	1,331	2,890	38,151	45,499
2020	2,243	393	421	70	1,331	2,890	38,532	45,880
2021	2,243	393	421	70	1,331	2,890	38,918	46,266
2022	2,243	393	421	70	1,331	2,890	39,307	46,655
2023	2,243	393	421	70	1,331	2,890	39,700	47,048
2024	2,243	393	421	70	1,331	2,890	40,097	47,445
2025	2,243	393	421	70	1,331	2,890	40,498	47,846
2026	2,243	393	421	70	1,331	2,890	40,903	48,251
2027	2,243	393	421	70	1,331	2,890	41,312	48,660
2028	2,243	393	421	70	1,331	2,890	41,725	49,073
2029	2,243	393	421	70	1,331	2,890	42,142	49,490
2030	2,243	393	421	70	1,331	2,890	42,564	49,912
2031	2,243	393	421	70	1,331	2,890	42,989	50,337
2032	2,243	393	421	70	1,331	2,890	43,419	50,767
2033	2,243	393	421	70	1,331	2,890	43,853	51,201
2034	2,243	393	421	70	1,331	2,890	44,292	51,640
2035	2,243	393	421	70	1,331	2,890	44,735	52,083
2036	2,243	393	421	70	1,331	2,890	45,182	52,530
2037	2,243	393	421	70	1,331	2,890	45,634	52,982
2038	2,243	393	421	70	1,331	2,890	46,090	53,438
2039	2,243	393	421	70	1,331	2,890	46,551	53,899
2040	2,243	393	421	70	1,331	2,890	47,017	54,365

Unit: acres

Table 5-6 provides the estimated annual irrigated crop acreages within the Basin watershed for CYs 2012-2040. Based on the predicted new vineyards to be planted (in 2013, 2014, and 2017), the average annual vineyard growth rate in the watershed from 2012 to 2017 is 5.5 percent (higher than the 2.9% calculated within the groundwater basin). The annual vineyard growth rate from 2018 to 2040 is 1% (as assumed).

Table 5-6. Annual Irrigated Crop Acreages in Watershed for Model Run 2 (CYs 2012-2040)

CY	Alfalfa	Citrus	Deciduous	Nursery	Pasture	Vegetable	Vineyard	TOTAL
2012	2,769	683	470	76	1,347	2,913	39,172	47,430
2013	2,769	683	470	76	1,347	2,913	45,149	53,407
2014	2,769	683	470	76	1,347	2,913	45,746	54,004
2015	2,769	683	470	76	1,347	2,913	45,746	54,004
2016	2,769	683	470	76	1,347	2,913	45,746	54,004
2017	2,769	683	470	76	1,347	2,913	49,908	58,166
2018	2,769	683	470	76	1,347	2,913	50,407	58,665
2019	2,769	683	470	76	1,347	2,913	50,911	59,169
2020	2,769	683	470	76	1,347	2,913	51,420	59,678
2021	2,769	683	470	76	1,347	2,913	51,934	60,192
2022	2,769	683	470	76	1,347	2,913	52,453	60,711
2023	2,769	683	470	76	1,347	2,913	52,978	61,236
2024	2,769	683	470	76	1,347	2,913	53,508	61,766
2025	2,769	683	470	76	1,347	2,913	54,043	62,301
2026	2,769	683	470	76	1,347	2,913	54,583	62,841
2027	2,769	683	470	76	1,347	2,913	55,129	63,387
2028	2,769	683	470	76	1,347	2,913	55,680	63,938
2029	2,769	683	470	76	1,347	2,913	56,237	64,495
2030	2,769	683	470	76	1,347	2,913	56,799	65,057
2031	2,769	683	470	76	1,347	2,913	57,367	65,625
2032	2,769	683	470	76	1,347	2,913	57,941	66,199
2033	2,769	683	470	76	1,347	2,913	58,520	66,778
2034	2,769	683	470	76	1,347	2,913	59,106	67,364
2035	2,769	683	470	76	1,347	2,913	59,697	67,955
2036	2,769	683	470	76	1,347	2,913	60,294	68,552
2037	2,769	683	470	76	1,347	2,913	60,897	69,155
2038	2,769	683	470	76	1,347	2,913	61,506	69,764
2039	2,769	683	470	76	1,347	2,913	62,121	70,379
2040	2,769	683	470	76	1,347	2,913	62,742	71,000

Unit: acres

5.6.3.3.2 Estimated Annual Irrigation Demand and Applied Water Volumes for Water Years 2012-2040

Estimates of agricultural crop consumptive use (for the Basin Model) and applied water (for the Basin Watershed Model) were developed for the predictive simulation period (WYs 2012-2040) by applying the same soil moisture water balance methodology described in Section 3.4.1.2 to estimated annual crop acreages for Model Run 1 and Model Run 2. Additionally, the following assumptions were applied:

1. The hydrologic cycle for the baseline calibration period (WYs 1982-2010) was repeated for the predictive simulation period. For the soil moisture water balances, crop consumptive use for WY 2012 is based on WY 1982 climate, crop consumptive use for WY 2013 is based on WY 1983 climate, and so forth.
2. The estimated proportion of vineyards managed under RDI in 2011 (75%) is assumed to remain constant over the future simulation period for both model runs.
3. The respective irrigation efficiency estimated in WY 2011 is assumed to remain constant for all crops over the future simulation period for both model runs.

Model Run 1 – Baseline with No Growth

Table 28 provides the estimated annual irrigation demand and applied water volumes (in AFY) for the seven crop groups in the Basin for Model Run 1.

Table 29 provides the estimated annual irrigation demand and applied water volumes (in AFY) for the seven crop groups in the watershed for Model Run 1.

As shown in the tables, agricultural water demand is slightly higher in the watershed relative to the Basin, as expected. Over the future model simulation period, the average annual difference between irrigation demand within the watershed versus within the Basin is about 14% in Model Run 1 (i.e., 14% of agricultural irrigation demand within the watershed is located outside of the Basin).

The average annual crop demand in the Basin and watershed over the simulation period for Model Run 1 is 58,811 AFY and 66,928 AFY, respectively.

Model Run 2 – Baseline with Growth

Table 30 provides the estimated annual irrigation demand and applied water volumes (in AFY) for the seven crop groups in the groundwater basin for Model Run 2.

Table 31 provides the estimated annual irrigation demand and applied water volumes (in AFY) for the seven crop groups in the watershed for Model Run 2.

As shown in the tables, agricultural water demand is slightly higher in the watershed relative to the Basin, as expected. Over the future model simulation period, the average annual difference between irrigation demand within the watershed versus within the Basin is about 24% in Model Run 2 (i.e., 24% of agricultural irrigation demand within the watershed is located outside of the Basin).

The average annual crop irrigation demand in the groundwater basin and watershed over the simulation period for Model Run 2 is 68,064 and 84,111 AFY, respectively. The average annual agricultural irrigation demand in the Basin for Model Run 2 is 9,253 AFY greater in comparison to Model Run 1; likewise, the average annual agricultural irrigation demand in the watershed for Model Run 2 is 17,183 AFY greater in comparison to Model Run 1.

5.6.4 Modeling Results

Modeling results for the two model runs are described in this report in terms of basin storage by year, average annual water budgets, and changes in groundwater levels.

5.6.4.1 Changes in Groundwater Levels

Initial (end of September 2011) groundwater elevations generated by the transient recalibration (see Section 5.4.2) that were used for Model Runs 1 and 2 are shown on Figure 108. Model-generated groundwater elevation contours by the end of the 29-year simulation period (i.e., end of September 2040) for Model Runs 1 and 2 are shown on Figures 109 and 110, respectively. The model-predicted change in groundwater levels between WY 2011 and WY 2040 for Model Run 1 and Model Run 2 are shown on Figures 111 and 112, respectively.

Results for Model Run 1 (i.e., No Growth) show groundwater elevations in layer 1 are predicted to decline as much as 20 ft in the Estrella Sub-Area and increase up to 10 ft in the Atascadero Sub-Basin. Groundwater elevations in layer 2 are predicted to remain unchanged in the Shandon Sub-Area and Atascadero Sub-Basin, and decline up to 40 ft in the Estrella Sub-Area. For model layer 3, groundwater levels are predicted to increase in the Creston, South Gabilian, North Gabilian and Shandon Sub-Areas as much as 20 ft, and decline up to 60 ft in the Estrella Sub-Area. Groundwater elevations in layer 4 are predicted to increase as much as 20 ft in the Atascadero Sub-Basin and North Gabilian Sub-Area, and over 70 ft in the northern Bradley Sub-Area, along the eastern boundary of the South Gabilian Sub-Area, and within the central portion of the Estrella Sub-Area.

Results for Model Run 2 (i.e., Growth) show groundwater elevations in layer 1 are predicted to increase up to 20 ft in the Atascadero Sub-Basin, and decline as much as 50 ft in the Estrella Sub-Area. Groundwater elevations in layer 2 are predicted to increase as much as 20 ft in the Atascadero Sub-Basin, and decline over 100 ft in the Estrella Sub-Area. For model layer 3, groundwater levels are predicted to decline throughout the Creston, South Gabilian, Bradley and San Juan Sub-Areas, with declines exceeding 120 ft in the Estrella Sub-Area. Groundwater elevations in layer 4 are predicted to increase 20 ft in some portions of the Bradley and North Gabilian Sub-Areas, and decline over the majority of the Basin. Significant declines of over 120 ft are predicted to occur in the Estrella Sub-Area. Compared to historical conditions, additional recharge from the Nacimiento Reservoir Water Project appears to increase layer 1 groundwater levels in the Atascadero Sub-Basin.

Figure 113 shows predicted differences in groundwater elevations between Model Run 1 and Model Run 2 by the end of predictive period (i.e., September 2040). Compared to Model Run 1, operations under Model Run 2 conditions would result in additional water levels declines ranging from about 30 ft in model layer 1 to 80 ft in model layers 3 and 4 in the Estrella and Creston Sub-Areas.

Hydrographs at selected wells for Model Runs 1 and 2 are shown on Figure 114. These hydrographs show the temporal variations in groundwater levels reflecting the hydrologic conditions, artificial recharge, and groundwater pumping assumed for these model predictive runs.

5.6.4.2 Water Budgets and Change in Groundwater Storage

The overall water budgets for Model Runs 1 and 2 were compiled in order to assess the potential impacts that each scenario may have on groundwater storage. The inflow terms for the Basin Model include deep percolation of direct precipitation and return flow from applied irrigation water, deep percolation of streambed seepage, subsurface inflow, Nacimiento Reservoir Water Project supplies, deep percolation of discharged treated wastewater effluent, and deep percolation of urban water and sewer pipe leakage. Annual amount for these inflow flux terms under Model Runs 1 and 2 conditions are provided on Figures 115 and 116, respectively. The outflow terms are comprised of groundwater pumping, evapotranspiration by riparian vegetation, groundwater discharge to rivers and subsurface outflow. Annual amount for these outflow flux terms under Model Runs 1 and 2 conditions are provided on Figures 117 and 118, respectively. The difference between the total inflow and total outflow is the change in groundwater storage. Annual groundwater budgets for Model Runs 1 and 2 are provided in Tables 32 and 33, respectively. The average annual groundwater budgets for WYs 2012 through 2040 for each model run are summarized in the following Table 5-7.

Table 5-7. Summary of Average Annual Water Budgets for Model Run 1 and Model Run 2

Flux Terms		Unit	Model Run 1	Model Run 2
Inflow	Deep Percolation of Direct Precipitation and Return Flow from Applied Irrigation Water	AFY	22,311	24,916
	Deep Percolation of Streambed Seepage	AFY	27,938	27,537
	Subsurface Inflow	AFY	47,612	37,590
	Nacimiento Reservoir Water Project Supplies	AFY	139	5,451
	Deep Percolation of Discharged Treated Wastewater Effluent	AFY	6,789	7,909
	Deep Percolation of Urban Water and Sewer Pipe Leakage	AFY	398	464
	Average Annual Total Inflow	**AFY**	**105,187**	**103,867**
Outflow	Groundwater Pumping	AFY	95,749	110,742
	Evapotranspiration by Riparian Vegetation	AFY	3,453	3,453
	Groundwater Discharge to Rivers	AFY	10,133	11,937
	Subsurface Outflow	AFY	1,444	1,447
	Average Annual Total Outflow	**AFY**	**110,779**	**130,027**
Average Annual Change in Groundwater Storage (Total Inflow – Total Outflow)		AF	-5,592	-26,159
Cumulative Changes in Groundwater Storage Over the 29-Year Modeling Period		AF	-162,163	-758,621

As shown in the above table, groundwater storage in the Basin declines 5,592 acre-ft/year during the period WYs 2012 through 2040 under Model Run 1 conditions. Groundwater storage under Model Run 2 conditions is predicted to decline 26,159 acre-ft/year. At the end of the model simulation in WY 2040, the cumulative change in groundwater storage would be a decline of 162,163 acre-ft for Model Run 1 and a decline of 758,621 acre-ft for Model Run 2 (see Table 5-7 and Figures 119 and 120, respectively).

6.0 CONCLUSIONS

Through the cooperation from representatives of the District, County, Modeling Subcommittee, and the District's consultants (GEOSCIENCE and Todd Groundwater), the Paso Robles Groundwater Basin Model was successfully updated with revised hydrologic data and recalibration over the period from October 1980 through September 2011 (i.e., WYs 1981-2011). The updated Basin Model is able to simulate the effects of water demands, NWP deliverables, and changes in land use (i.e., growth) on future Basin water levels and storage.

In order to accomplish the goals of updating the Basin Model and to ensure the District reliable predictions, the Basin Model was updated with all currently available hydrologic and hydrogeologic data since development of the original 2005 Basin Model. In addition, a water balance analysis approach to quantify groundwater recharge was included in the development of the Basin Watershed Model, which was developed to simulate all the hydrologic components of the watershed on a daily basis. Wastewater discharge, agricultural demand, and groundwater extraction data were collected and combined to estimate other recharge and discharge components for the Basin. The Basin Watershed Model improves not only the quantification of the recharge terms for the Basin Model, but also provides the spatial and temporal distributions of the recharge terms. The calibrated Basin Watershed Model shows similar temporal dynamics as well as a good to very good match between model-simulated and measured streamflow at the Salinas River near Bradley, Salinas River above Paso Robles, Estrella River near Estrella, and Santa Margarita Creek near Santa Margarita gaging stations.

Evaluation of the conceptualized aquifer system was inconclusive as to whether the Rinconada Fault serves as a hydraulic barrier separating groundwater flow between the Atascadero Sub-Basin and the main Basin. More information and data are required in order to obtain subsurface information and data that could be used to accurately quantify the effects the Rinconada Fault may or may not have on groundwater flow from the Atascadero Sub-Basin into the main Basin. At a minimum, these include construction of wells that are strategically located on either side of the fault, geophysical borehole data, pumping test data, and water quality data.

The results of the Basin Watershed Model were incorporated into the Basin Model as model input values for deep percolation of streambed seepage, deep percolation of direct precipitation and return flow from applied water, and subsurface inflow through the Basin boundary. The updated model results were evaluated (i.e., post-audit) to determine whether recalibration was needed. The post-audit of the updated Basin Model focused on simulated water level patters and trends, as compared with the hydrogeologic site conceptual model, and calibration quality in terms of observed versus simulated head residuals. As recommended, the Basin Model was recalibrated and used to run two predictive scenarios.

The recalibrated Basin Model has a relative error of 2.6%, which is well below the industry standard recommended error of 10%.

Results from Model Run 1 (i.e., No Growth) and Model Run 2 (i.e., Growth) indicate changes in groundwater levels at the end of the 29-year predictive period are greatest in the Estrella Sub-Area and northern portion of the Bradley Sub-Area with levels predicted to decline by as much as 60 to 80 ft for Model Run 1, and up to 120 ft in the Estrella Sub-Area for Model Run 2. Cumulative change in storage for the period WY 2012-2040 was estimated to be a decline of 162,163 acre-ft for Run 1 and a decline of 606,102 acre-ft for Run 2.

7.0 MODEL LIMITATIONS AND UNCERTAINTY

The Basin Model is a useful tool for evaluating the effects of hydrologic and land use changes on Basin water levels. However, it is a simplified approximation of a complex hydrogeologic system and has been designed with certain built-in assumptions. As with any groundwater model, there are data and numerical limitations that are inherent in the reasonable use of the Basin Model. Watershed and groundwater modeling have very extensive data requirements (Skahill, 2004). A reliable model depends upon accurate and abundant sources of measured data and a previous satisfactory calibration period. Often, in absence of complete or accurate records, model input represents estimated and/or averaged values. The accuracy of the predictions made by the model is highly dependent on the simplifying assumptions used. In addition, the modeling results are not absolutes, but are indications that will need to be confirmed by actual operations, monitoring and refinement through an adaptive management process.

The overall design of the model and computer code used for the Basin Model, however, encourages incremental improvements so that the model can be revised to answer a variety of water management questions. To address such uncertainty, the Basin Model Update was evaluated independently through a peer review provided by Fugro Consultants. Discussion among GEOSCIENCE, Todd Groundwater and Fugro representatives focused on issues including certain aquifer properties, and the relative amounts and areal distribution of subsurface inflow, streambed percolation and rainfall recharge.

8.0 RECOMMENDATIONS

Based on discussions between the GEOSCIENCE/Todd Groundwater Team and Fugro, specific tasks have been defined to reevaluate and further refine the Basin Model. These include the following:

- Reevaluate fate and recharge mechanisms of water from the watershed entering the groundwater basin;
- Replace the recharge/streamflow modeling package used to simulate streamflow and groundwater discharges to rivers with a streamflow routing package;
- Reevaluate deep percolation of direct precipitation and agricultural return flows in the groundwater basin; and
- Establish an acceptable range of hydraulic conductivity values for the groundwater basin.

In addition, the following scenarios have been identified for potential simulation with the refined Basin Model:

<u>Baseline</u>

- Updated Baseline with Growth Run

<u>Specific Action Analyses</u>

- Analysis 1 – Demand Reduction Scenario
- Analysis 2 – Salinas River Recharge
- Analysis 3 – Offset Basin Pumping with Recycled Water

<u>Basin Management Objectives Analyses</u>

- Analysis 4 – Offset Water Demand in Estrella Sub-Area
- Analysis 5 – Additional Releases to Huer Huero Creek
- Analysis 6 – Additional Releases to Estrella Creek
- Analysis 7 – Offset Pumping in Creston Sub-Area with Supplemental Water
- Analysis 8 – Offset Pumping in Shandon Sub-Area with Supplemental Water

Refinement of the Basin Model will provide improved understanding and simulation of the groundwater-surface water relationship and response to recharge and discharge components as they vary through time. Also, these proposed predictive analyses using the refined Basin Model will provide Basin managers and stakeholders the means to identify the actions which may be most effective at stabilizing groundwater levels on a sub-regional level.

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