Refinement of the Paso Robles Groundwater Basin Model and Results of Supplemental Water Supply Options Predictive Analysis

San Luis Obispo County Flood Control & Water Conservation District

Prepared by: GEOSCIENCE Support Services, Inc.

December 6, 2016

GEOSCIENCE

GEOSCIENCE Support Services, Inc. | P (909) 451-6650 | F (909) 451-6638

620 Arrow Highway, Suite 2000, La Verne, CA 91750 | Mailing: P.O. Box 220, Claremont, CA 91711

Acknowledgements

GEOSCIENCE wishes to extend its appreciation to Dr. Iris Priestaf, Gus Yates and Edwin Lin (Todd Groundwater) and Paul Sorensen (GSI Water Solutions, Inc. for their technical support throughout the process to refine and recalibrate the Paso Robles Groundwater Basin numerical flow model.

GEOSCIENCE also wishes to acknowledge the project team for all their dedicated time and effort in developing the predictive analyses using the refined and recalibrated model for the supplemented water supply options: San Luis Obispo County Flood Control and Water Conservation District (Courtney Howard, Scott Duffield and Carolyn Berg), Carollo Engineers (Lydia Holmes), RMC Water and Environment (Rob Morrow) and Water Systems Consulting, Inc. (Dan Heimel).

THIS REPORT HAS BEEN PREPARED FOR THE SAN LUIS OBISPO COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT UNDER THE DIRECTION OF THE FOLLOWING PROFESSIONALS LICENSED BY THE STATE OF CALIFORNIA. ALL CALCULATIONS WERE PERFORMED USING ACCEPTED PROFESSIONAL STANDARDS.

AS DATA IS UPDATED FROM TIME TO TIME, ANY RELIANCE ON THIS REPORT AT A FUTURE DATE SHOULD TAKE INTO ACCOUNT UPDATED DATA. NO FURTHER MODIFICATION OF THIS MODEL CAN BE MADE WITHOUT THE CONCURRENCE OF SAN LUIS OBISPO COUNTY.

Johnson Yeh, PhD, PG, CHG
Principal Geohydrologist
CHG No. 422

Joseph D. Kingsbury, PG, CHG
Senior Geohydrologist
CHG No. 1019

REFINEMENT OF THE PASO ROBLES GROUNDWATER BASIN MODEL AND RESULTS OF SUPPLEMENTAL WATER SUPPLY OPTIONS PREDICTIVE ANALYSIS

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APPENDIX

Ltr.	Description
A.	Response to Public Comments on Draft Technical Memorandum “Refinement of the Paso Robles Groundwater Basin Model and Results of Supplemental Water Supply Options Predictive Analysis” (Dated July 20, 2016)

REFINEMENT OF THE PASO ROBLES GROUNDWATER BASIN MODEL AND RESULTS OF SUPPLEMENTAL WATER SUPPLY OPTIONS PREDICTIVE ANALYSIS

1.0 EXECUTIVE SUMMARY

1.1 Introduction

This report supplements the 2014 Paso Robles Groundwater Basin Model Update report, and summarizes the details and results for refinements made to the model and predictive model runs. The main purpose of the refinements was to address the technical concerns raise by a peer review team and improve the accuracy and functionality while maintaining the basic integrity of the Basin Model. GEOSCIENCE completed the following tasks to refine and recalibrate the model, and to use the model to perform predictive scenarios for the Paso Robles Groundwater Basin Supplemental Supply Options Feasibility Study:

1. Re-evaluate the fate of water from the Paso Basin watershed entering the groundwater basin.
2. Replace the combined recharge and streamflow model packages with the streamflow routing (SFR) package.
3. Re-evaluate the deep percolation of direct precipitation in the Basin.
4. Establish minimum hydraulic conductivity values to be used for the recalibration of the refined model.
5. Recalibrate the refined Basin Model.
6. Perform eight (8) predictive groundwater model runs.

A step-by-step and collaborative approach was used to successfully refine and recalibrate the Basin Model and to fully develop the predictive model scenarios for the Supplemental Supply Options Feasibility Study.

1.2 Basin Groundwater Model Refinements

1.2.1 Adjust Groundwater Basin Recharge by Subsurface Inflow from Surrounding Watershed

The amount of rainfall and streamflow that recharges the bedrock and enters the groundwater basin as subsurface inflow from the surrounding watershed used for the 2014 Basin Model Update was determined by the peer review to be over-estimated. Although the overall contribution from the surrounding watershed to groundwater basin recharge appeared reasonable, the contribution via streambed percolation within the groundwater basin is likely greater than simulated and subsurface inflow is less than simulated.

In order to determine the correlation between precipitation intensity to deep percolation (which ultimately contributes to underflow inflow) and surface flow runoff, a statistical method was used to establish “cutoff” criteria. The cutoff provided the ability to limit the amount of deep percolation that can occur within the watershed, thereby reducing the previous estimated amount of underflow inflow of 52,725 acre-ft/yr to something nearer to the expected value of approximately 25,000 acre-ft/yr. This approach resulted in a revised average annual underflow inflow of 23,750 acre-ft/yr (see Figure 8). The revised annual values were then input and used during the iterative process to recalibrate the Basin Model. Annual values were adjusted during the recalibration process; however, the average annual value for subsurface inflow of 27,283 acre-ft/yr is consistent with the expected average of 25,000 acre-ft/yr (see column 3 of Table 1).

1.2.2 Replace Original Modeling Package Used for Streamflow Routing

The original Basin Model combined MODFLOW recharge and streamflow packages to simulate streamflow recharge and discharge. Until recently, this was a widely applied and accepted method. However, the method is unable to account for the time delay which occurs for water to flow (percolate) from the surface water body (streams, etc.) to the water table which may result in a less accurate representation of the interaction between surface water and groundwater.

In order to improve the ability of the Basin Model to accurately simulate an exchange between surface water and groundwater, the original combined recharge/streamflow model package was replaced with the MODFLOW Streamflow Routing (SFR) package. This refinement allows the Basin Model to accurately simulate the spatial and temporal variability of the interchange of water between a stream and the underlying aquifer, and resulted in improving the amount of surface flow reaching the interior of the groundwater basin from the surrounding watershed.

1.2.3 Re-evaluate Fate of Deep Percolation of Direct Precipitation

The water balance component for deep percolation from direct precipitation occurring in the Basin was re-evaluated by determining the difference between irrigation demand (i.e., consumptive use) and gross applied water in order to identify other pathways (besides return flows) for water that is in excess of irrigation demand. The method provided estimations for how much precipitation falling directly on the

Basin recharges the deep aquifers, the amount of return flow from applied irrigation water, and the amount of excess applied irrigation water that follows other pathways.

The first step separated annual values for deep percolation of direct precipitation from values for return flow from applied irrigation. The second step broke down applied irrigation water into evapotranspiration (ET), surface flow runoff, deep percolation and streambed percolation for WYs 1981-2011. For the Basin, the 33,070 acre-ft/yr of applied irrigation water (i.e., total applied water less consumptive uses by crops) resulted in approximately 27,020 acre-ft/yr of ET, 1,600 acre-ft/yr of surface flow runoff, 2,210 acre-ft/yr of deep percolation and 2,240 acre-ft/yr of streambed percolation (see Figure 11).

1.2.4 Adjust Hydraulic Conductivity Values Used for Model Recalibration

The horizontal and vertical hydraulic conductivity values adjusted during recalibration of the 2014 Basin Model Update were generally lower than expected for sediments in the groundwater basin interior and too high at the margins.

Following discussions among GEOSCIENCE and the peer reviewers, it was agreed that the horizontal and vertical conductivity values used to recalibrate the refined Basin Model will be representative of those established by the Phase I Paso Robles Groundwater Basin Study. The range of horizontal hydraulic conductivity values used is summarized in the following table.

Model Layer	Horizontal Hydraulic Conductivity	
1	50-300 ft/day	374-2,241 gpd/ft^2
2	0.1-1.0 ft/day	0.7-7.5 gpd/ft^2
3	0.5-50 ft/day	3.7-374 gpd/ft^2
4	0.5-50 ft/day	3.7-374 gpd/ft^2

These hydraulic conductivity values for model layers 1 through 4 are representative of the geologic materials mapped in the groundwater basin by others.

1.3 Groundwater Model Recalibration

After the model refinements were completed, the Basin Model was recalibrated for the period October 1980 through September 2011 against observed streamflow and groundwater level data. The streamflow gaging stations used for model recalibration were the Estrella River near Estrella, Salinas River above Paso Robles and Salinas River near Bradley gaging stations (see Figure 15). The recalibration process also used 4,602 water level measurements from 101 calibration target wells from which to match model-generated groundwater elevation values against measured values. Target wells used for groundwater elevation calibration are shown on Figure 16. The recalibration process involved adjusting model parameters until the model provided a reasonable match between the simulated and measured parameters.

Results of regression analysis for the recalibration indicate that the performance of the Basin Model to simulate streamflow is rated as:

- “Good” at the Salinas River near Bradley gage, and
- “Fair” at all other streamflow gages.

The most improved performance of the recalibration is the ability of the Basin Model to simulate streamflow that percolates into the underlying groundwater aquifer system. Additionally, the performance of the recalibrated Basin Model to simulate groundwater elevations is summarized as:

- “Good” with one standard deviation water level residual of ± 30.73 ft, and
- Relative error of 2.9% compared to the recommended industry standard relative error of less than 10%.

The ability of the (refined and) recalibrated Basin Model to simulate groundwater elevations throughout the Basin and within the primary aquifers with a relative high level of confidence is significant because it also reflects the model’s ability to accurately simulate percolating streamflow which occurs throughout the Basin.

Applying the equation for change in groundwater storage (i.e., total inflow minus total outflow) to the values from the recalibrated Basin Model, the average annual change in groundwater storage is approximately –3,184 AFY (see Table 1).

1.4 Supplemental Water Supply Options Predictive Model Runs

The District has initiated the Paso Basin Supplemental Water Supply Options Feasibility Study (Supply Options Study) to evaluate various basin management methods used to replenish and stabilize Basin water levels by 2040. The methods selected for the study include:

- Reducing groundwater pumping in areas of the Basin experiencing chronic water level declines,
- Direct delivery of supplemental water supplies to irrigation users in lieu of groundwater pumping, and
- Artificial recharge of supplemental water supplies using percolation basins.

Supplemental supplies used for the study include Nacimiento Water Project, State Water Project, and recycled water produced by the City of Paso Robles. The overall goals of the Supply Options Study are to:

1. Identify which areas of the Basin benefit from the various basin management methods;
2. Attempt to quantify the amounts of supplemental water supplies required to replenish and stabilize the Basin; and,
3. Determine the efficiency of percolation basins used for artificial recharge.

In support of the Supply Options Study, GEOSCIENCE was tasked with using the refined and recalibrated Basin Model to perform eight predictive model scenarios ("Alternatives") and evaluate the degree of improvement and stabilization of Basin water levels as a result of using the basin management methods compared to baseline conditions with 1% percent growth over a 29 year period. Results of the predictive analysis will be used by the District and Supply Options Study team to determine where the supplemental water needs to go and how much is needed in a way that achieves BMOs. The objectives for each predictive scenario were developed in conjunction with the Computer Model Subcommittee of the PBAC, and address the following questions:

- How much pumping needs to be reduced (and by whom and where) in order to stabilize Basin groundwater levels by 2040?
- What are the potential benefits of using available surplus Nacimiento Water Project, State Water Project and recycled water supplies to either offset agricultural pumping or to artificially recharge the Basin?

Using the hydrologic base period already established for the 2014 Basin Model update, the predictive model runs were simulated for WYs 2012-2040. The model stress period used is semi-annual. Assumptions for reduced groundwater pumping, offset pumping, available quantities of supplemental water supplies, and location and capacities of percolation basins were varied for each alternative. The predictive model runs performed for this analysis included the following:

- Updated Baseline with Growth Run
- Alternative 1 – Demand Reduction Scenario
- Alternative 2 – Salinas River Recharge
- Alternative 3 – Offset Basin Pumping with Recycled Water
- Alternative 4 – Offset Water Demand in Estrella Sub-Area
- Alternative 5 – Additional Releases to Huer Huero Creek
- Alternative 6 – Additional Releases to Estrella Creek
- Alternative 7 – Offset Pumping in Creston Sub-Area with Supplemental Water
- Alternative 8 – Offset Pumping in Shandon Sub-Area with Supplemental Water

It is important to note that some alternatives simulate more supplemental water supplies than are actually available or feasible because the main purpose was to quantify the supplies required to stabilize the Basin by 2040. Additionally, the proposed new percolation basins used to simulate artificial recharge of the supplemental water supplies range in size from 10 to 120 acres, which may or may not be actually feasible for the Basin.

The benefits of Alternatives 1 through 7[1] were measured in terms of increases in groundwater levels and storage compared to projected Baseline conditions. Basin Management Objectives previously established by the District were used for the purposes of groundwater level stabilization targets established for the Basin sub-areas. Water budgets (i.e., inflow and outflow terms) for each alternative were compiled in order to assess the potential impacts that each may have on groundwater storage. The difference between the total inflow and total outflow equals change in groundwater storage. Results of the Supplemental Water Supply Options model predictive alternatives are summarized in the following table.

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[1] Results of the Updated Baseline run indicated that the objective for the Shandon Sub-Area was already met; therefore, Alternative 8 was removed from the model runs.

Alternative	Targeted Basin Sub-Area	BMO Achieved for All Targeted Sub-Areas?	Net Benefit
1	Atascadero, Creston, Estrella, Shandon, San Juan	Yes	30,233 AFY
2A	Atascadero and Estrella	No	740 AFY
2B	Atascadero and Estrella	No	1,975 AFY
3	Estrella	No	2,035 AFY
4A	Estrella	No	16,955 AFY
4B	Estrella	Yes	20,855 AFY
5A1	Estrella	No	7,891 AFY
5A2	Estrella	Yes	15,785 AFY
5B1	Estrella and Creston	No	10,985 AFY
5B2	Estrella and Creston	Yes	18,878 AFY
6A	Estrella	No	9,554 AFY
6B	Estrella and Shandon	No	13,019 AFY
6C	Estrella and Shandon	Yes	22,806 AFY
7A	Creston	No	1,516 AFY
7B	Creston	Yes	4,057 AFY

2.0 INTRODUCTION

2.1 Background

GEOSCIENCE Support Services, Inc. (GEOSCIENCE) and Todd Groundwater were selected by the San Luis Obispo County Flood Control and Water Conservation District (District) in 2012 to update the existing Paso Robles Groundwater Basin (Basin) Model (Basin Model). The model update was completed in 2014[2] and was successful in providing the District and Basin stakeholders with an updated and accepted tool for simulating Basin response under current and future conditions. Other benefits of the model update include a calibrated surface flow model[3] of the Basin watershed that is integrated with the Basin Model, and a revised estimation of Basin perennial yield.

A peer review of the draft model update report was performed by Fugro Consultants, and identified the following technical issues:

1. The amount of rainfall and streamflow that recharges the bedrock and enters the groundwater basin as subsurface inflow from the surrounding watershed is over-estimated based on the expected permeability of the bedrock geologic formations which characterize the area of the watershed outside of the groundwater basin. Although the overall contribution from the surrounding watershed to groundwater basin recharge may be reasonable, the contribution via streambed percolation within the groundwater basin is likely greater than simulated and subsurface inflow is less than simulated.
2. The amount of recharge from deep percolation of direct precipitation (not including stream recharge) within the groundwater basin is lower than expected.
3. The horizontal and vertical hydraulic conductivity values adjusted during recalibration of the updated Basin Model are generally lower than expected for sediments in the groundwater basin interior and too high at the margins.
4. Paso Robles Basin Watershed Model calibration scatter plots indicate the model tends to over-estimate streamflow less than 100 cubic feet per second (cfs) and under-estimate flows which exceed 100 cfs. This condition suggests that the overall groundwater basin recharge

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2 Paso Robles Groundwater Basin Model Update, dated 19-Dec-14. The full document is available to download at: www.slocountywater.org

3 Paso Basin Watershed Model.

estimate may be reasonable but that the temporal and areal distribution of that recharge is somewhat different than was simulated.

5. Review of gross applied water for irrigation versus consumptive use indicates a significant component of applied water is in excess of crop demands. The fate of this excess irrigation water should be determined – if most of it goes to return flows then essentially there is no precipitation recharge being simulated in the groundwater basin.

A meeting was held during which GEOSCIENCE, Todd Groundwater and Fugro Consultants discussed the technical concerns identified by Fugro. This technical team also developed recommended model refinements for each issue. After the final 2014 Basin Model update report was issued, the District approved the proposed scope of work for GEOSCIENCE to complete the recommended refinements, and also requested the refined model is used to perform an updated baseline run and supplemental water supply options predictive runs.

In July 2016, a draft technical memorandum (TM) summarizing the refinement of the Basin Model and results of the predictive model runs was submitted by GEOSCIENCE to the District. Following a public meeting to present the draft TM, and receipt of written public comments (see Appendix A), personnel from GEOSCIENCE, the District and Carollo Engineers worked together to review any technical concerns, finalize the Supplemental Water Supply Options predictive model runs and complete this final TM. In general, these predictive runs include evaluating how the groundwater basin responds to:

- Reduced agricultural and municipal groundwater pumping on a Basin-wide scale;
- Offset agricultural groundwater pumping via direct delivery of supplemental water supplies; and
- Artificial recharge at existing and/or proposed percolation basins with supplemental water supplies.

The supplemental water supplies used for the predictive analysis include Nacimiento Water Project water, State Water Project water and recycled water. The benefit of each proposed basin management alternative is measured in terms of increases in groundwater levels and increases in groundwater storage compared to the updated baseline condition. Predicted groundwater levels at key wells located within the Basin sub-areas are compared to established Basin Management Objectives (BMOs)[4] levels. Each predictive alternative is also evaluated to determine its ability to provide localized benefits to the

[4] Paso Robles Basin Groundwater Management Plan, 2011.

Basin through year 2040, which is consistent with the state's Sustainable Groundwater Management Act (SGMA) timing requirement for the Paso Basin to achieve sustainability.

2.2 Purpose and Scope of Work

This report is intended to supplement the model update report completed by GEOSCIENCE and Todd Groundwater (2014). The processes through which the updated Basin Model was refined and recalibrated and used to perform predictive runs are presented herein. The main purpose of the model refinements was to address the technical concerns of the 2014 updated Basin Model raised by the peer review process. The recommended model refinements were developed through a collaborative effort by GEOSCIENCE, Todd Groundwater and Fugro Consultants, and address the technical concerns of the Basin Model and provide additional enhancements to improve its accuracy and functionality. Additionally, the refined model provides insight into how the groundwater basin responds to various pumping reduction and supplemental water supply predictive scenarios.

The scope of work includes the following tasks:

- Re-evaluate the fate of water from the Paso Basin watershed entering the groundwater basin.
- Replace the combined recharge and streamflow model packages with the streamflow routing (SFR) package.
- Re-evaluate the deep percolation of direct precipitation in the Basin.
- Establish minimum hydraulic conductivity values to be used for the recalibration of the refined model.
- Recalibrate the refined Basin Model.
- Perform predictive alternatives for supplemental water supply options using the refined and recalibrated Basin Model.

2.3 Description of the Study Area

The original Basin Model, and the surface water model developed for the 2014 update, covers the Paso Robles Basin area in San Luis Obispo and Monterey Counties, California (see Figure 1). The Paso Robles Basin is located within the upper Salinas Valley Groundwater Basin, which is part of a large elongated topographical depression that runs in a southeast to northwest alignment. The Paso Basin is bordered by the Upper Valley Aquifer Subbasin in the north, Temblor Ridge to the east, the La Panza Range to the south, and the Santa Lucia Range to the west. A number of faults bound the basin, including the San

Andreas fault zone on the northeast, the San Marcos-Rinconada system on the west, and the Red Hill, San Juan and White Canyon faults on the east. The Paso Basin is drained by the Salinas River and Estrella, San Juan and Huer Huero Creeks (DWR, 2003).

The Paso Basin watershed covers an area of approximately 1,830 square miles[5] and extends from a few miles inland of the Pacific Ocean along the Santa Lucia Mountains where it extends to the east across the southern Salinas Valley (Paso Robles Basin area) and the Cholame Hills (see Figure 1). The boundaries of the watershed are defined by topographical divides generally consisting of mountain ranges or hills. Surface water on the other side of these divides flows toward other collection points. Elevations within the watershed range from approximately 430 ft above mean sea level (amsl) at the northern area where the watershed intersects the Salinas Valley to approximately 4,300 ft amsl in mountains east of Parkfield. There are three reservoirs—San Antonio, Nacimiento and Salinas—located within the watershed (see Figure 1), which are managed to provide flood protection and water conservation.

The Paso Robles Groundwater Basin covers approximately 790 square miles that extends from the Santa Margarita area south of Atascadero to a groundwater divide located south of 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 has been subdivided by others into eight study areas[6]: 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, extending to a maximum depth of approximately 100 ft. The Paso Robles Formation is present throughout the entire Basin. Thickness of the sediments which compose the Paso Robles Formation ranges from 700 to 1,200 ft, with a maximum thickness of 2,500 ft (Fugro and Cleath, 2001). Additional information on the study area can be found in the Paso Robles Groundwater Basin Model Update report (GEOSCIENCE and Todd Groundwater, 2014).

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5 Surface water occurring in the watershed areas above the Nacimiento, San Antonio, and Salinas Reservoirs is effectively captured by each corresponding downstream reservoir prior to entering the Paso Basin. For purposes of the watershed model, these areas are not included in the estimated total area of the watershed. See Figure 1 for views of the total watershed area (approximately 2,600 mi^2) and the modeled watershed area.

6 The study areas are hydraulically interconnected by continuous water-bearing sedimentary formations which define the Paso Robles Groundwater Basin. The study 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 study area are provided in the Phase I Study.

2.4 Evolution of the Basin Model

Between 2001 and 2005, a groundwater flow model was developed for the Paso Robles Groundwater Basin (Fugro West, ETIC Engineering and Cleath and Associates, 2003). The primary purpose of this initial numerical flow model was to develop a quantitative tool to evaluate future Basin hydraulic conditions. The model was constructed using MODFLOW, which is a widely-accepted groundwater flow modeling code[7] developed by the USGS. 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 main areas of the Basin) and four layers representing the primary aquifer system (i.e., 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, and was used to evaluate the Basin response to water demands, with and without supplemental water, and to identify areas of declining water levels.

In subsequent years (2012-2014), the original Basin Model was updated to extend the model study period over water years (WYs) 1981 to 2011, to improve the previous water balance assessment, refine the perennial yield, and to evaluate the Basin's response to "Growth" and "No Growth" scenarios[8] projected over a 29-year period (WYs 2012 to 2040). The update included the addition of a rainfall-runoff model[9] of the watershed that is tributary to the Basin (see Figure 1). The model update did not change the geologic framework established for the original model.

2.5 Cooperation

The refinement and recalibration of the updated Basin Model was a collaborative effort between GEOSCIENCE, Todd Groundwater and Fugro Consultants. During this process, technical meetings were conducted to present and discuss ongoing methods and results. A collaborative effort between the District, PBAC Computer Model Subcommittee, GEOSCIENCE, Carollo Engineers (Carollo), RMC Water & Environment (RMC) and Water Systems Consulting (WSC) was used to evaluate the predictive model results of alternatives for reduced groundwater pumping, offset pumping and supplemental water supply options. Several meetings were held during the work to perform the predictive runs, including a public Open House, a technical workshop and bi-weekly team progress meetings via teleconference.

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[7] 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.

[8] See Section 5.6 of the Basin Model update report (GEOSCIENCE and Todd Groundwater, 2014) for details.

[9] Hydrologic Simulation Program – FORTRAN (HSPF), a successor to the FORTRAN version of the Stanford Watershed Model.

2.6 Sources of Data

Data types used to refine the model includes climate, geology, soils, streamflow and groundwater levels which were obtained during the 2014 update process. A comprehensive summary of data types, descriptions and sources are provided in the Basin Model update report (GEOSCIENCE and Todd Groundwater, 2014). In addition to these data, the assumptions used for the updated baseline with growth and predictive model runs were developed using data provided by sources summarized below:

- Atascadero Mutual Water Company:
- District: BMO key well locations, construction details and groundwater levels and projected Nacimiento Water Project deliveries.
- City of Atascadero: Projected wastewater treatment plant effluent discharge volumes to existing percolation ponds and dimension of existing percolation ponds.
- City of Paso Robles: Projected treated wastewater effluent discharge to Salinas River, projected Nacimiento water use, and projected recycled water direct use.
- Templeton Community Services District: Projected wastewater treatment plant effluent discharge volumes to existing percolation ponds.

2.7 Abbreviations and Acronyms

acre-ft	Acre foot; equivalent to a one acre area covered with water one foot deep
acre-ft/yr or AFY	Acre feet per year
amsl	Above mean sea level
AMWC	Atascadero Mutual Water Company
Basin	Paso Robles Groundwater Basin
Basin Watershed	The surrounding watershed which is tributary to the Paso Robles Groundwater Basin
bgs	Below ground surface
District	San Luis Obispo County Flood Control & Water Conservation District
DWR	California Department of Water Resources
ft	Feet
ft/day	Feet per day

ft^2/day	Square feet per day
ft^3/day	Cubic feet per day
GEOSCIENCE	GEOSCIENCE Support Services, Inc.
gpd/ft	Gallons per day per foot
gpd/ft^2	Gallons per day per square foot
gpm	Gallons per minute
in/yr	Inches per year
MGD	Millions of gallons per day
mg/L	Milligrams per liter
mi^2	Square miles
NWP	Nacimiento Water Project
PEST	Parameter ESTimation software
PBAC	Paso Robles Groundwater Basin Advisory Committee
RW	Recycled Water
SLO	San Luis Obispo
SMCSD	San Miguel Community Services District
SWP	State Water Project
TCSD	Templeton Community Services District
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
WTP	Water Treatment Plant
WY	Water Year
yr. or YR	year

2.8 Terms and Definitions

The principle definitions used in this report were taken from *California's Groundwater: Bulletin 118* (DWR, 2003), the *Handbook of Hydrology* (Maidment, ed., 1993), the *Dictionary of Geological Terms*, 3rd edition (Bates et al., ed., 1984), and *Groundwater & Wells*, 3rd edition (Johnson Screens, 2007). In some cases, authors have expanded or clarified terms, staying consistent with industry standards.

Alluvium	A geologic term describing beds of sand, gravel, silt and clay deposited by flowing water. In the Basin Model area, alluvium occurs beneath the flood plains of the rivers and streams to a maximum depth of

	approximately 100 ft.
Aquifer	A geologic formation or group of formations which store, transmit and yield significant quantities of water to wells and springs. See also “confined aquifer,” “unconfined aquifer,” and “semiconfined aquifer.”
Aquitard	A less permeable geologic unit that stores but does not readily transmit water.
Base Flow	The sustained dry weather flow in a stream or river, which occurs when groundwater seeps into the channel.
BMOs	Stands for “Basin Management Objectives” which are established groundwater management goals and objectives established in the 2011 Paso Robles Groundwater Management Plan. Current BMOs are developed for groundwater levels to protect unacceptable depletion of groundwater in storage, and to identify potential groundwater quality impacts and land subsidence impacts.
CASGEM	Stands for “California Statewide Groundwater Elevation Monitoring” which is a mandated program by the California Water Code to track seasonal and long-term trends in groundwater elevations in groundwater basins.
Conceptual Model	A hypothesis that explains how a hydrogeologic system works. It consists of basic elements such as inflow, outflow, and system geometry.
Confined Aquifer	A permeable geologic unit located beneath a relatively impermeable unit whose piezometric water level is higher than the confining layer.
Consumptive Use	Water removed from available supplies without return to a water resource system.
Direct Recharge	The process of moving surface water from storage aboveground to an aquifer via percolation. This process is typically done artificially using percolation basins.
Drawdown	The change in hydraulic head or water level relative to a background condition.
Effective Porosity	A fraction consisting of the void space that forms part of the interconnected flow paths through the medium, per unit volume of porous medium (excluding void space in isolated or dead-end pores). Also known as “specific yield.”

Effluent Seepage	The slow movement of groundwater from a basin or aquifer to a collection point such as a surface water lake or dry lake.
Ephemeral Stream	A stream that has flow only for hours or days following a rainfall event.
Evaporation	The rate of liquid water transformation to vapor from open water, bare soil, or vegetation with soil beneath. The process by which water is changed from the liquid or solid state into the gaseous state through the transfer of heat energy.
Evapotranspiration (ET)	A term embracing that portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation (no attempt is being made to distinguish between the two).
Extraction	Generally refers to the pumping of groundwater from wells.
Fan	An accumulation of debris brought down by a stream descending through a steep ravine and debouching onto the plain below, where the detrital material spreads out in the shape of a fan, forming a section of a very low cone. The fans generally form where streams issue from mountains upon the lowland.
Fault	A fracture in the earth's crust, with displacement of one side of the fracture with respect to the other.
Field Capacity	The moisture content of the soil after the so-called gravitational water has been removed by deep seepage.
Formation	A geologic term that designates a body of rock or rock/sediment strata of similar lithologic type or combination of types.
Groundwater	The water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined or semi-confined aquifer.
Groundwater Storage	Groundwater which becomes part of an aquifer system until it is removed (either naturally or anthropologically).
GMAs	Stands for "Groundwater Management Activities" which are intended to identify the steps or actions taken to meet the BMOs for specific areas of the Basin.
GMP	Groundwater Management Plan. The goal of the GMP is to locally manage and protect groundwater resources for all beneficial uses in a long-term sustainable, environmentally sound, economical and

	equitable manner.
Hydraulic Conductivity	The measure of the ability of soil or rock to transmit (either horizontally or vertically) water through pore spaces or fractures.
Hydraulic Gradient	The rate of change in total hydraulic head per unit distance of flow in a given direction (e.g. the slope of the water table).
Hydraulic Head	A measure of the total mechanical energy per weight of the groundwater flow system. For example, the water level in a well rises to the elevation of the hydraulic head represented by the potential (energy) at the intake end (i.e., well screen) of the well.
Hydrology	The origin, distribution, and circulation of the water of the earth, including precipitation, streamflow, infiltration, groundwater storage, and evaporation.
Infiltration	The process of water entry into the soil surface from rainfall, snowmelt or irrigation, and the subsequent percolation downward through the soil. (Stored soil water may be consumptively used by vegetation, may percolate further downward to groundwater storage, or may exit the soil surface as seeps or springs.)
Leaky Aquifer	An aquifer bound by one or two aquitards. Also known as a "semiconfined aquifer."
Natural Streamflow	Streamflow conditions that are not under the influence of human activities such as groundwater pumping and construction of dams.
Offset Pumping	Use of surface water supplies to replace groundwater pumped and delivered to irrigation users, which thereby increases groundwater storage.
Overdraft	The temporary condition of a groundwater basin where the amount of water withdrawn by pumping exceeds the amount of water replenishing the basin over a period of time.
Paso Robles Formation	A sedimentary deposit consisting of relatively thin, often discontinuous sand gravel layers interbedded with thicker layers of silt and clay, which wholly comprises the primary aquifer system of the Paso Robles Groundwater Basin.
Percolation	The vertical migration of water through the soil or alluvium to the

	groundwater table.
Percolation Basin	A shallow artificial pond designed to hold surface water long enough for it to percolate into the subsurface and replenish a groundwater basin.
Perennial Stream	A stream that has continuous flow in parts of its stream bed all year round during years of normal rainfall.
Perennial Yield	The maximum quantity of groundwater perennially available if all possible methods and sources are developed for recharging the basin. In effect, this quantity depends upon the amount of water economically, legally, and politically available to the water producers.
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 (see also intrinsic permeability).
Phreatophytes	Riparian vegetation with deep root systems which draw moisture from groundwater.
Potential Evaporation	The quantity of water evaporated per unit area, per unit time, from an idealized, extensive, free water surface under existing atmospheric conditions.
Recharge	Flow to groundwater storage from precipitation, infiltration from streams, and other sources of water.
Recoverable Water	The sum of surface runoff (streamflow adjusted for anthropogenic diversions and storage, if any) and underflow (groundwater).
Recycled Water	Municipal wastewater that has been purified so it can be used again for new purposes, both potable and non-potable.
Residual Error	The deviation of the model-simulated value (e.g., groundwater elevation) from the measured value.
Safe Yield	The maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse effects. Due to its vague definition and the implication of a fixed quantity of extractable water based on the average annual basin recharge, the term “maximum perennial yield” is favored.
Semiconfined Aquifer	An aquifer bound by one or two aquitards. Also known as a “leaky aquifer.”
Soil Moisture Percentage	Percentage of moisture in the soil, based on the weight of oven-dry

	material.
Specific Capacity	An expression of the productivity of a well, obtained by dividing the rate of discharge of water from the well by the drawdown of the water level in the well.
Specific Storativity	The volume of water that a unit volume of porous medium releases from or takes into storage per unit change in hydraulic head.
Standard Deviation	A number used to express how measurements for a group are spread out from the average (mean) or expected value. A low number means that most of the numbers are very close to the average, while a high number means the numbers are spread out from the average.
Storativity	The volume of water that an aquifer releases or takes into storage per unit change in hydraulic head. Term is interchangeable with "storage coefficient."
Streambed Conductance	The measure of how effectively water is transported through the streambed, which affects the rate of groundwater recharge or interaction with groundwater.
Stress Period	Represents a period of time during which all model stresses (boundary conditions, pumping rates, etc.) remain constant. (Only applies to transient models.)
Sub-Area	An area of the Paso Robles Groundwater Basin delineated by 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.
Sub-Basin	An area of the Paso Robles Groundwater Basin which encompasses Atascadero and Templeton and delineated by the Phase I Study (Fugro and Cleath, 2002) as having some degree of hydraulic separation from the main groundwater basin based on groundwater movement and water quality information.
Sustainable Groundwater Management Act (SGMA)	California legislation which provides a framework for sustainable management of groundwater supplies by local authorities, with a limited role for state intervention only if necessary to protect the resource. The act provides 20 years to implement plans and achieve long-term groundwater sustainability.
Transient Model	A numerical model which simulates flow (water) occurring when the

	magnitude and direction of the flow changes with time.
Unconfined Aquifer	A permeable geologic unit with the water table forming its upper boundary.
Water Budget	An evaluation of all the sources of supply and the corresponding discharges with respect to an aquifer or a drainage basin.
Watershed	A watershed is the upslope area that contributes flow to a common outlet as concentrated drainage. It can be part of larger watershed and can also contain smaller watersheds called sub-basins. The boundaries between watersheds are termed drainage divides.
Water Year	Term used to describe the 12 month period from October 1 through September 30 during which precipitation totals are measured.

2.9 Technical Memorandum

The purpose of this draft technical memorandum (TM) is to summarize the components of the refinement and recalibration efforts made to the Basin Model and results of the model predictive runs. The aspects of each model refinement and the recalibration are summarized. This draft TM also includes tabulated assumptions, tabulated groundwater budgets, groundwater level difference maps, and hydrographs at selected target wells and key BMO wells for the updated Baseline run and each predictive analysis scenario.

3.0 GROUNDWATER MODEL REFINEMENT

A step-by-step collaborative approach was used to systematically refine the existing Basin Model to address the technical issues identified during the peer review process. This approach allowed for participants of the technical team to assist throughout the processes used to develop each model refinement. The goal of the refinements was to improve its accuracy and functionality while maintaining the basic integrity of the original model.

The main technical issues of the Basin Model included:

1. The amount of rainfall and streamflow that recharges the bedrock and enters the groundwater basin as subsurface inflow from the surrounding watershed is over-estimated based on the expected permeability of the bedrock geologic formations which characterize the area of the watershed outside of the groundwater basin. Although the overall contribution from the surrounding watershed to groundwater basin recharge may be reasonable, the contribution via streambed percolation within the groundwater basin is likely greater than simulated and subsurface inflow is less than simulated.
2. The amount of recharge from deep percolation of direct precipitation (not including stream recharge) within the groundwater basin is lower than expected.
3. The horizontal and vertical hydraulic conductivity values adjusted during recalibration of the Basin Model are generally lower than expected for sediments in the groundwater basin interior and too high at the margins.
4. Paso Robles Basin Watershed Model calibration scatter plots indicate the model tends to over-estimate streamflow less than 100 cubic feet per second (cfs) and under-estimate flows which exceed 100 cfs. This condition suggests that the overall groundwater basin recharge estimate may be reasonable but that the temporal and areal distribution of that recharge is somewhat different than was simulated.
5. Review of gross applied water for irrigation vs. consumptive use indicates a significant component of applied water is in excess of crop demands. The fate of this excess irrigation water should be determined – if most of it goes to return flows then essentially there is no precipitation recharge being simulated in the groundwater basin.

The technical approaches used to address each main issue and to refine the Basin Model are summarized in the table below.

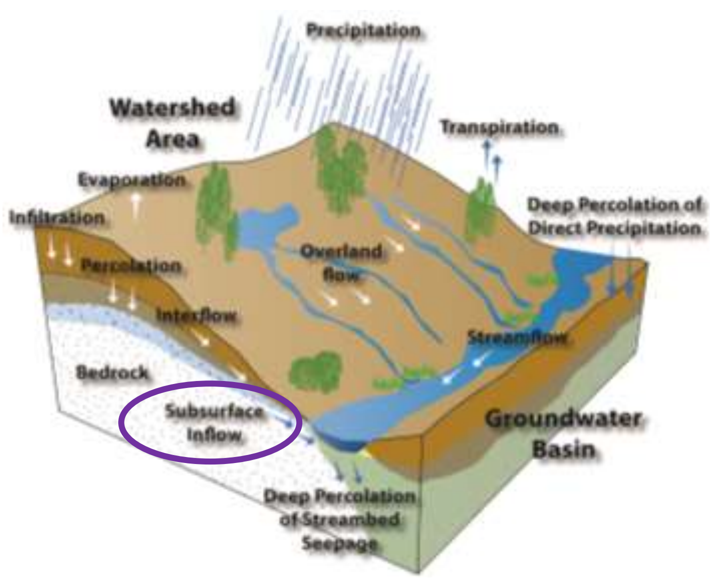
Issue	Technical Approach
1	Re-evaluate Fate of Water from the Watershed Entering the Groundwater Basin (Section 2.1) and Replace Combined Recharge and Streamflow Packages with Streamflow Routing (SFR) Package (Section 2.2)
2, 5	Re-evaluate Deep Percolation of Direct Precipitation in the Groundwater Basin (Section 2.3)
3	Establish Minimum Hydraulic Conductivity Values for the Basin Model Recalibration (Section 2.4)
4	Recalibrate Refined Basin Model (Section 3)

The following sections discuss the development and results for each model refinement. The method and results of the model recalibration are discussed in Section 4.0 of this report.

3.1 Re-evaluate Fate of Water from the Watershed Entering the Groundwater Basin

3.1.1 Issue with Previous Method

As shown in the conceptual diagram, water enters the Basin from the watershed as subsurface inflow and overland flow (e.g., streams). For the Basin Model update, the amount of water entering the groundwater basin as subsurface inflow was calculated as the sum of streambed percolation for all streams that cross over the watershed boundary and groundwater basin boundary and deep percolation of pervious land calculated by the Basin Watershed Model minus groundwater pumping that occurs in the watershed area outside the groundwater basin. In simplified terms, subsurface inflow is expressed as:



Subsurface Inflow = *Streambed Percolation* + *Deep Percolation of Precipitation* – *Groundwater Pumping*

The quantity of subsurface inflow was calculated for the previous (2014) Basin Model using the Basin Watershed Model to be approximately 52,700 acre-ft/yr. However, the general consensus of the technical team assigned to develop the refinements for the Basin Model was that this amount of underflow inflow is too high relative to estimations used for other models having similar geologic/hydrogeologic characteristics, and to simulated volumes for deep percolation of streambed seepage. The team agreed that the maximum average annual subsurface inflow should not exceed approximately 25,000 acre-ft/yr. This shared opinion was primarily based on the relative impermeable characteristic of the bedrock types which surrounds (and underlies) the groundwater basin and observations to how rapidly surface flow develops within the ephemeral streams and creeks of the watershed during rainfall events. Based on these characteristics of the watershed hydrology, it was recognized there should be a good correlation between rainfall rates and model-calculated volumes of underflow inflow (i.e., deep percolation of streambed seepage plus deep percolation of precipitation) and surface flow runoff which occurs within the area in the watershed but outside the groundwater basin.

3.1.2 Approach and Method

In general, the watershed areas located outside of the groundwater basin lack the ability to retain and store substantial amounts of water that infiltrates from the surface. This condition occurs primarily because the surficial sediments, which are much more permeable than the underlying bedrock units, are relatively thin and become saturated quickly during recharge events (i.e., storms). Once the sediments become oversaturated, they no longer have the ability to accept more infiltrating surface water. Depending upon the physical characteristics (topography, geology and land use) of the area, this rejected recharge may flow along the ground surface and eventually enter the groundwater basin as surface flow runoff (streamflow). Therefore, rainfall events that occur over a prolonged period or that occur at a high intensity will likely produce relatively higher volumes of surface water—that leaves the watershed area and enters the groundwater basin as surface flow—than during shorter or low intensity events.

The watershed area outside of the groundwater basin covers a large area that has wide range of average annual rainfall (approximately 13-25 in./yr) and is characterized by multiple Tertiary-age and Cretaceous-age geologic formations that bound the sediments of the Paso Robles Groundwater Basin. The hydraulic conductivity of the primary bedrock units ranges from approximately 0.01-1 gpd/ft^2 (Fugro and Cleath, 2002). Based on these characteristics, it was determined that the ratio of rainfall intensity to deep percolation and surface flow occurring within the watershed area outside of the groundwater basin will vary by location. Areas with high rainfall and geologic formations having low hydraulic conductivity should contribute more surface flow runoff but less underflow inflow to the groundwater basin than an area characterized by low rainfall and bedrock units having high hydraulic conductivity.

In order to determine the correlation between precipitation intensity to deep percolation (which ultimately contributes to underflow inflow) and surface flow runoff, a statistical method was used to establish "cutoff" criteria. The cutoff provided the ability to limit the amount of deep percolation that can occur within the watershed, thereby reducing the amount of underflow inflow from the previous overestimation to the expected value (i.e., from 52,000 acre-ft/yr to 25,000 acre-ft/yr). The steps used to establish the cutoff included:

1. Annual volumes of deep percolation of streamflow seepage, deep percolation of precipitation and return flow from applied irrigation water for the areas within the watershed but outside of the groundwater basin were extracted from Basin Watershed Model output files and compiled.
2. An iterative process was used to review average annual flows for deep percolation recharge, surface flow runoff and precipitation on a sub-watershed level, until a good correlation was established for adjacent sub-watersheds.
3. Based on an evaluation of the percent contribution to underflow inflow from both deep percolation terms, mean annual precipitation within the watershed areas outside of the Basin, and the hydraulic conductivity of primary bedrock units which bound the Basin, each sub-watershed was assigned to a "precipitation zone."
4. Time-series plots of surface water inflow, deep percolation of precipitation, deep percolation of streambed seepage, and total underflow inflow occurring within each precipitation zone during WYs 1981-2011 were prepared and evaluated. Each plot includes the average annual precipitation and standard deviation values.
5. A plot comparing average annual precipitation rates with average annual deep percolation of precipitation, deep percolation of streambed seepage and underflow inflow was prepared. Mean values for precipitation and underflow inflow at one and two standard deviations were calculated and used to provide recommendations for the cutoff value.

The four precipitation zones (Northeast, Northwest, Southeast and Southwest) are shown on Figure 2. Each zone represents adjacent sub-watersheds where the correlation between average annual precipitation with the two deep percolation recharge terms and surface flow runoff is highest. As shown, average (mean) annual precipitation (WYs 1981-2011) for the Southeast zone is 13 inches, 14 inches for the Northwest zone, 15 inches for the Northeast zone and 25 inches for the Southwest zone. Comparison plots of average annual precipitation rate to average annual surface flow runoff and the two deep percolation terms (i.e., precipitation and streambed seepage) for the Northeast, Southeast, Northwest and Southwest zones are provided on Figures 3-6, respectively. Values for mean annual underflow inflow, which is the combined values of the two deep percolation terms, are also shown to provide a comparison to surface water runoff values generated by the previous 2014 Basin Model. One and two standard deviations for mean annual precipitation values were included for each precipitation zone in order to determine a measureable redistribution of underflow inflow to surface flow runoff entering the groundwater basin.

3.1.3 Results

As shown on Figures 3-6, the model-calculated values for the recharge and runoff components which bring water into the groundwater basin from the watershed correlates well to the mean annual precipitation for each zone. Using this relationship, mean annual values for precipitation, the combined two deep percolation terms (i.e., underflow inflow) and surface water runoff for the watershed area outside of the groundwater basin used for the previous 2014 Basin Model were compiled. Figure 7 provides a comparison of average annual precipitation rates (x-axis) to average annual underflow inflow (y-axis). As shown, the correlation of these two terms is high ($R^2 = 0.94$). Upon approval from the technical team, the average annual value for underflow inflow where it intersects with average annual precipitation (16.15 in./yr.) and average annual precipitation plus one standard deviation (23.58 in./yr.) was selected to evaluate further and to determine if either one would result in lowering the total average annual underflow inflow to the targeted value of approximately 25,000 acre-ft/yr. Figure 7 show the average annual underflow inflow for average precipitation using this step is 38,110 acre-ft/yr, and 90,336 acre-ft/yr under average precipitation plus one standard deviation. These two values represented the potential cutoff value for maximum underflow inflow (as discussed previously in Section 3.1.2).

Annual total subsurface underflow inflow for WYs 1981-2011 was then calculated and evaluated for both proposed cutoff values. GEOSCIENCE presented the results to the technical team, and it was agreed to use the underflow inflow amount under the average hydrology (38,110 acre-ft/yr) as the cutoff value because it resulted in an annual average underflow inflow which is closest to the target value of 25,000 acre-ft/yr. Results of revised annual underflow inflow values for WYs 1981-2011 compared to values generated by the previous 2014 Basin Model are provided on Figure 8. Using a cutoff of 38,110 acre-ft/yr provided the following:

1. Annual underflow inflow values which are more consistent on a year-by-year basis;
2. Average annual underflow inflow of 23,750 acre-ft/yr which is approximately equal to the anticipated amount of 25,000 acre-ft/yr; and

3. An improved representation of how water moves within the bedrock units.

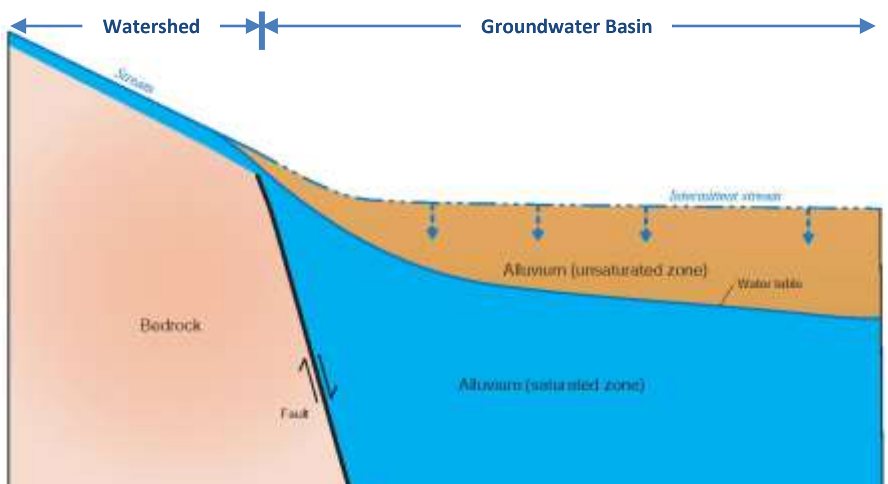
The revised annual values were then input for the Basin Model recalibration iterations. Annual values for underflow inflow were adjusted slightly during the Basin Model recalibration process (see Section 4.0); however, the average annual value for subsurface inflow of 27,283 acre-ft/yr is consistent with the expected average of 25,000 acre-ft/yr (see column 3 of Table 1).

In addition, the revised (i.e., reduced) annual values for underflow inflow resulted in leftover (excess) water for ten years during the period 1981-2011. As previously mentioned in Section 3.1.1, the annual surface flow which enters the Basin from the surrounding watershed was determined by the peer reviewer to be underestimated by the previous 2014 Basin Model. Therefore, any leftover water resulting from the revised underflow inflow values was reapportioned as surface flow runoff and input to the Streamflow Routing Package, which calculates Basin recharge from deep percolation from streambed seepage (see Section 3.2).

3.2 Replace Combined Recharge and Streamflow Packages with Streamflow Routing (SFR) Package

3.2.1 Approach and Methodology

The original Basin Model combined MODFLOW recharge and streamflow packages to simulate streamflow recharge and discharge. This method essentially simulates surface and subsurface flow as a continuum, for the purpose of considering all exchanges of water between the land surface and the underlying groundwater. Until recently, this was a widely applied and accepted method. However, the method is unable to account for the time delay which occurs for water to flow (percolate) from the surface water body (streams, etc.) to the water table. As shown in the conceptual profile, an alluvial groundwater basin located in an arid region (such as the Paso Robles Groundwater Basin), the depth to the water table (or unsaturated zone) can be substantial (typically from tens to hundreds of feet). Therefore, the inability to



Profile of a typical alluvial groundwater basin and relationship between an intermittent stream and the unsaturated zone. (From Niswonger and Prudic, 2010.)

account for this time delay within the unsaturated zone may result in less accurate representation of changes in water resources of the areas where an exchange between surface water and groundwater occurs. In order to improve a model's ability to simulate the interaction of surface water with groundwater, the USGS added a new MODFLOW Streamflow Routing (SFR) package[10]. Use of the SFR package provides a more accurate simulation of the stream-aquifer interaction occurring within a groundwater basin.

For this model refinement step, GEOSCIENCE replaced the combined packages used for the original Basin Model with the SFR2 package. Combined with the surface water outflows calculated by the Basin Watershed Model, this refinement improves the simulated groundwater recharge and Basin outflows. Surface flow with a network of streams located throughout the Basin is simulated by the MODFLOW SFR2 package. Surface water runoff and base flow generated by groundwater discharge to the stream reaches are routed downstream by the sequential numbering of reaches and segments. A stream reach is a section of the stream that is associated with a particular finite-difference cell. The reaches are numbered in a downstream order to represent the direction of flow. Reaches can be grouped into segments that represent lengths of the stream between connections with another stream or tributary, lake, or watershed boundary. Figure 9 shows the location of the model stream network.

Inflows to a stream reach include user-specified inflow to the first reach of a stream segment, inflows from upstream reaches, precipitation directly onto the stream channel, surface runoff and interflow, and groundwater discharge to the streambed. Outflows include diversions, evaporation, downward leakage across the streambed, and stream outflow. The downward leakage or streambed percolation is calculated as a function of the hydraulic conductivity of the streambed, the wetted perimeter of the streambed, the length of the stream reach, the hydraulic head of the underlying groundwater, the stream stage, and the streambed thickness.

A stream gains or loses water depending on the relative hydraulic head in the stream and in the underlying aquifer. When the hydraulic head in the stream is higher than the head in the aquifer, the stream loses water to the aquifer; when the head in the stream is lower than the head in the aquifer, the stream gains water from the aquifer. This interchange of water between the stream and the aquifer (e.g., alluvium) varies spatially and temporally, and is influenced most by changes in the height of the nearby groundwater table and by changes in the hydraulic conductivity of the streambed deposits.

[10] The original SFR package is referred to as SFR1, which has been replaced with SFR2. SFR2 includes all the capabilities of SFR1, but is designed to be used with newer model codes (MODFLOW-2000) and is able to simulate seepage loss from a stream which may be restricted by the hydraulic conductivity of the unsaturated zone.

3.3 Re-evaluate Deep Percolation of Direct Precipitation in the Groundwater Basin

3.3.1 Approach and Methodology

The water balance component for deep percolation from direct precipitation occurring in the Basin was re-evaluated by determining the difference between irrigation demand (i.e., consumptive use) and gross applied water in order to identify other pathways (besides return flows) for water that is in excess of irrigation demand. This method evaluated how much precipitation falling directly on the Basin recharges the deep aquifers, the amount of return flow[11] from applied irrigation water, and the amount of excess applied irrigation water that follows other pathways.

3.3.2 Results

The data was evaluated for the period December through March on an annual basis as the first of two steps to estimate the contribution of precipitation recharge versus the contribution from irrigation return flows (which are assumed to occur annually from April to November). Figure 10 shows the amount of annual deep percolation from precipitation and from irrigation return flows for each Basin sub-area. For the modeling period, average annual deep percolation from precipitation is about 21,010 acre-ft/yr, while return flow from applied irrigation water is about 2,210 acre-ft/yr.

The second step broke down applied irrigation water into ET, surface flow runoff, deep percolation and streambed percolation for WYs 1981-2011. For the Basin, the 33,070 acre-ft/yr of applied irrigation water (i.e., total applied water less consumptive uses by crops) resulted in approximately 27,020 acre-ft/yr of ET, 1,600 acre-ft/yr of surface flow runoff, 2,210 acre-ft/yr of deep percolation and 2,240 acre-ft/yr of streambed percolation (see Figure 11). Figure 12 provides the analysis results for each Basin sub-area. It should be noted that these long-term values for applied irrigation water are based on historical (WYs 1981-2011) data and information, and do not reflect higher irrigation efficiencies which have recently become available to the agricultural industry.

3.4 Establish Minimum Hydraulic Conductivity Values for the Basin Model Recalibration

Following discussions among GEOSCIENCE, Fugro and Todd Groundwater, it was agreed that the horizontal and vertical conductivity values used to recalibrate the refined Basin Model will be representative of those established by the Phase I Paso Robles Groundwater Basin Study. Figure 13

[11] Return flow is applied water that is not consumed by the crop and percolates into the underlying aquifers.

provides the spatial distribution of horizontal conductivity values for model layers 1 through 4. The range of horizontal hydraulic conductivity values used is summarized in the following table.

Model Layer	Horizontal Hydraulic Conductivity	
1	50-300 ft/day	374-2,241 gpd/ft^2
2	0.1-1.0 ft/day	0.7-7.5 gpd/ft^2
3	0.5-50 ft/day	3.7-374 gpd/ft^2
4	0.5-50 ft/day	3.7-374 gpd/ft^2

Values of vertical hydraulic conductivity used in the Basin Model after the recalibration are provided in Figure 14. The hydraulic conductivity values for model layers 1 through 4 are representative of the geologic materials mapped in the study area under the Phase I Study.

4.0 GROUNDWATER MODEL RECALIBRATION

4.1 Approach and Methodology

Model calibration is performed by choosing one or multiple parameters and comparing model-simulated predicted values to field-measured values. The method used to recalibrate the refined Basin Model was the industry standard "history matching" technique in which hydrogeologic parameters (i.e., streamflow and groundwater elevations) are manually varied until the best fit is achieved for transient conditions. These parameters included horizontal and vertical hydraulic conductivity and streambed conductance.

Initial testing was followed by model runs that adjusted the hydraulic conductivity of the streambeds. 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 model recalibration. PEST was used to optimize aquifer parameters in the model based on observed water levels over time[12]. 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 collaborative effort between GEOSCIENCE, Todd Groundwater and Fugro Consultants. 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 groundwater elevations to the observed groundwater elevations (reduce residual error) at wells across the model area[13]. Other runs involved sensitivity runs that varied streamflow routing (SFR2) parameters.

4.1.1 Recalibration Criteria

The refined Basin Model was recalibrated for the period October 1980 through September 2011 against observed streamflow and groundwater level data. Including streamflow in the recalibration process was required because the method used by the original model to simulate the fate of surface water was replaced with the SFR2 package. The streamflow gaging stations used for model recalibration were the Estrella River near Estrella, Salinas River above Paso Robles and Salinas River near Bradley gaging stations (refer to Figure 15 for locations). These gages established and maintained by the USGS record daily streamflow; however, the data record during the calibration period (WYs 1981-2011) is incomplete at two of the three gages. The following table summarizes the available data for each streamflow gage.

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[12] 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).

[13] Parameter values for the final recalibrated model are within the upper and lower parameter boundaries.

Streamflow Gage	Range of Available Measured Daily Streamflow	Total Number of Days
Salinas River above Paso Robles (USGS No. 11147500)	Oct. 1, 1980-Sep. 30, 2011	11,322
Estrella River near Estrella (USGS No. 11148500)	Jan. 1, 1981-Jul.31, 2011	5,709
Salinas River near Bradley (USGS No. 11150500)	Jan. 1, 1990-Jun.30, 1996	1,010

The recalibration process also used 4,602 water level measurements from 101 calibration target wells from which to match model-generated groundwater elevation values against measured values. Target wells used for groundwater elevation calibration are shown on Figure 16. The recalibration process involved adjusting model parameters until the model provided a reasonable match between the simulated and measured parameters. Qualitative recalibration results for streamflow and water levels are shown as:

- Hydrographs of measured and model-simulated streamflow and groundwater elevations, and
- Scatterplots of measured versus model-simulated streamflow and groundwater elevations.

Quantitative recalibration results are shown as:

- Goodness of fit (R^2 values), and
- Statistical tests on residuals.

4.1.2 Results

4.1.2.1 Measured and Model-Simulated Streamflow

Streamflow hydrographs of measured and model-simulated semi-annual[14] streamflow during WYs 1981-2011 are shown on Figure 17. As shown, the refined and recalibrated Basin Model is able to simulate streamflow very close to observed flows at the Salinas River near Bradley gage (No. 11150500). The recalibrated model is also able to match measured streamflow at the Salinas River above Paso Robles gage (No. 11147500), although the model tends to overestimate flow during the lowest

[14] Since the original Basin Model was setup using a semi-annual stress period, all measured daily streamflow is averaged over each 6 month period of the calibration period.

measured flow rates (i.e., base flow). Model-simulated streamflow matches the peak flows measured at the Estrella River near Estrella gage (No. 11148500); however, available measured data is too limited to provide a clear understanding of the model's performance at this gage.

Scatterplots of measured and model-simulated streamflow for each gaging station are provided as Figures 18 through 20. As shown, most of the data points cluster around the straight line (R-squared values ranges from 0.68 to 0.80) for all three gages. The relatively lower R-squared values (0.68 and 0.78) are mostly attributed to the lack of measured data available for two of the three gages.

At the Salinas River near Bradley gage (which is located at the point where streamflow leaves the Paso Robles Basin and has the highest R-squared value), over 11,000 daily streamflow measurements are available for the period 1981-2011. By comparison, the Salinas River above Paso Robles gage and the Estrella River gage only have approximately 5,700 and 1,000 measured daily values, respectively, during the same period. The method of calculating an R-squared value (coefficient of determination) is a standard practice for assessing model performance for both daily and monthly streamflow (Aqua Terra, 2003). Model performance is rated as "Poor" to "Very Good" based on an R-squared value range of less than 0.75 to greater than 0.95. The value range for daily flows is lower than for monthly flows because it is more difficult for a model to simulate flow on a daily scale. To illustrate, the performance for a model with an R-squared value of 0.7 rates as "Fair to Good" for daily streamflow but only as "Fair" for monthly flows. In order to provide an assessment of the recalibrated Basin Model's performance—which simulates semi-annual flows—a nearly linear relationship between daily and monthly flows was assumed. Based on this relationship, the performance of the recalibrated Basin Model to simulate streamflow is "Fair" (0.68) to "Good" (0.8).

It should be noted that although the recalibrated model is shown to be capable of simulating streamflow which closely matches observed flows, the most improved performance is its ability to simulate streamflow that percolates into the underlying groundwater aquifer system. An assessment of the Basin Model's performance for simulating groundwater elevations is provided in the following section.

4.1.2.2 Measured and Model-Simulated Water Levels

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 21 through 26, respectively. In general, groundwater elevations simulated by the recalibrated Basin Model match well with measured water levels throughout the Basin sub-areas and within the shallow and deep aquifers. Figure 27 provides a comparison of measured versus model-simulated groundwater levels. As shown, the 4,602 groundwater level measurements are mainly clustered around a diagonal line (representing where measured water levels match model-simulated water levels) and within a band of plus/minus one standard deviation water level residual (i.e., +/- 30.73 ft). This reflects what is considered in groundwater flow modeling to be a "Good" match between measured and model-simulated 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 28. Figure 29 shows a histogram of the residuals (difference between observed and modeled values) from the 101 calibration target wells. As shown, the histogram is bell shaped with over 72% of the water level residuals found in the range of +/-30 ft, which indicates a good model calibration.

The good model calibration is further supported by a low relative error of 2.9% (see Figure 27). The relative error is determined from the water level residuals (i.e., observed water level less model-simulated 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).

As discussed in the next section (4.1.2.3), the majority of Basin recharge occurs through deep percolation of streambed percolation. Therefore, the recalibrated model's ability to simulate groundwater elevations throughout the Basin and within the primary aquifers with a relative high level of confidence is significant because it also reflects the model's ability to accurately simulate percolating streamflow which occurs throughout the Basin.

4.1.2.3 Average Annual Water Budgets

A comparison of average annual Basin inflow and outflow terms for WY 1981-2011 generated by the previous 2014 Basin Model and the refined and recalibrated model (2015) are shown on Figure 30. The simple graphic represents the relationship between changes in groundwater storage and the primary ways by which water is added to the Basin (inflows) and is removed from the Basin (outflows).

Applying the equation for change in groundwater storage (i.e., total inflow minus total outflow) to the values from the recalibrated Basin Model, the average annual change in groundwater storage is approximately –3,184 AFY (i.e., 109,306 AFY – 112,490 AFY). A summary of all water budgets from the model recalibration are provided in Table 1. A comparison of annual and cumulative change in groundwater storage between the previous 2014 model and the 2016 refined and recalibrated model is provided on Figure 31. The differences shown are a result of the refinements made to the Basin Model.

5.0 SUPPLEMENTAL WATER SUPPLY MODEL PREDICTIVE ANALYSIS

5.1 Supplemental Water Supply Options Feasibility Study

The District has initiated the Paso Basin Supplemental Water Supply Options Feasibility Study (Supply Options Study) to evaluate various basin management methods used to replenish and stabilize Basin water levels by 2040. The methods selected for the study include:

- Reducing groundwater pumping in areas of the Basin experiencing chronic water level declines,
- Direct delivery of supplemental water supplies to irrigation users in lieu of groundwater pumping, and
- Artificial recharge of supplemental water supplies using percolation basins.

Supplemental supplies used for the study include Nacimiento Water Project (NWP), State Water Project (SWP), and recycled water (RW) produced by the City of Paso Robles. The overall goals of the Supply Options Study are to:

4. Identify which areas of the Basin benefit from the various basin management methods;
5. Attempt to quantify the amounts of supplemental water supplies required to replenish and stabilize the Basin; and,
6. Determine the efficiency of percolation basins used for artificial recharge.

In support of the Supply Options Study, GEOSCIENCE was tasked with using the refined and recalibrated Basin Model to perform eight predictive model scenarios ("Alternatives") and evaluate the degree of improvement and stabilization of Basin water levels as a result of using the basin management methods compared to baseline conditions with 1% percent growth[15] over a 29 year period. Results of the predictive analysis will be used by the District and Supply Options Study team[16] to determine where the supplemental water needs to go and how much is needed in a way that achieves BMOs. The objectives

[15] Previously performed for the 2014 Basin Model update and referred to as "Model Run 2 – Baseline with Growth" (GEOSCIENCE and Todd Groundwater, 2014).

[16] Currently includes Carollo Engineers, RMC Water & Environment, Water Systems Consulting, Todd Groundwater and GEOSCIENCE.

for each predictive scenario were decided by the Computer Model Subcommittee of the PBAC, and address the following questions:

- How much pumping needs to be reduced (and by whom and where) in order to stabilize Basin groundwater levels by 2040?
- What are the potential benefits of using available surplus NWP water[17] to either offset agricultural pumping or to artificially recharge the Basin?
- What are the potential benefits of using SWP water to either offset agricultural pumping or to artificially recharge the Basin?
- What are the potential benefits of using available RW to either offset agricultural pumping or to artificially recharge the Basin?

Using the hydrologic base period already established for the 2014 Basin Model update, the predictive model runs were simulated for WYs 2012-2040[18]. The model stress period used is semi-annual. Assumptions for reduced groundwater pumping, offset pumping, available quantities of supplemental water supplies, and location and capacities of percolation basins were varied for each alternative. The predictive model runs performed for this analysis included the following:

- Updated Baseline with Growth Run
- Alternative 1 – Demand Reduction Scenario
- Alternative 2 – Salinas River Recharge
- Alternative 3 – Offset Basin Pumping with Recycled Water
- Alternative 4 – Offset Water Demand in Estrella Sub-Area
- Alternative 5 – Additional Releases to Huer Huero Creek
- Alternative 6 – Additional Releases to Estrella Creek

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[17] Surplus Water refers to the portion of the County's NWP entitlement that remains after satisfying Participant delivery requests and other obligations (PBAC, 2014a).

[18] The 29-year period used for all predictive simulations represents the hydrologic base period which covers both wet and dry hydrologic cycles that occurred during WYs 1982-2010. These long-term historical hydrologic conditions are projected forward along with all other assumptions and proposed water supply options that are specific to each predictive scenario. Refer to Section 5.6.3.1 of the Paso Robles Groundwater Basin Model Update report (GEOSCIENCE and Todd Groundwater, 2014).

- Alternative 7 – Offset Pumping in Creston Sub-Area with Supplemental Water
- Alternative 8 – Offset Pumping in Shandon Sub-Area with Supplemental Water

The purpose of these alternatives varies—some evaluate the potential benefit to the Basin using existing available supplemental water supplies and/or percolation facilities, while others evaluate the maximum supplemental supplies needed to meet BMOs. It should be noted that for many cases of the later purpose, more NWP and SWP supplies than are actually available or feasible were simulated. In other words, using projected allocations of NWP and SWP were not enough to meet BMOs by 2040. The only limiting term was the maximum capacity of the proposed new percolation basins. In addition, Alternatives 2, 4, and 7 included two model runs ("A" and "B"), Alternative 6 included three runs ("A", "B" and "C") and Alternative 5 included four runs ("A1", "A2", "B1" and "B2") in order to evaluate the potential benefit of pairing multiple basin management methods and/or supplemental water supplies. A full description of the updated baseline run and Alternatives 1 through 8 is provided in Section 5.4. The following table summarizes the purpose and supply options of each alternative.

Predictive Alternative	Purpose of Alternative	Supply Options	
		Type	Restrictions?
Alternative 1	Estimate how much pumping reduction is needed to stabilize groundwater levels in the Estrella, Creston and San Juan Sub-Areas by 2040.	Pumping Reduction	Unlimited
Alternative 2	Estimate the benefits of recharging surplus NWP at one existing and one proposed percolation basin located adjacent to the Salinas River within the Atascadero Sub-Basin.	NWP	Surplus Only
Alternative 3	Estimate the effects and benefit of using RW projected to be available for direct use in lieu of groundwater pumping in the Estrella Sub-Area.	RW	WWTP Max. Capacity
Alternative 4	Estimate how much artificial recharge of supplemental water supplies at two locations along with offset groundwater pumping using RW is needed to achieve the BMO for the Estrella Sub-Area.	RW	WWTP Max. Capacity
		NWP	Perc. Basin Max. Capacity
Alternative 5	Estimate how much artificial recharge of supplemental water supplies at four locations adjacent to Huer Huero Creek is needed to achieve BMOs for the Estrella and Creston Sub-Areas	RW	WWTP Max. Capacity
		NWP	Perc. Basin Max. Capacity
		SWP	Perc. Basin Max. Capacity
Alternative 6	Estimate how much artificial recharge of supplemental water supplies at six locations along Estrella River is needed to achieve BMOs for the Estrella and Shandon Sub-Areas	RW	WWTP Max. Capacity
		NWP	Perc. Basin Max. Capacity
		SWP	Perc. Basin Max. Capacity
Alternative 7	Estimate how much artificial recharge of SWP supplies at one location along with offset groundwater pumping using supplemental supplies is needed to achieve the BMO for the Creston Sub-Area.	NWP	Projected Allocations
		SWP	Perc. Basin Max. Capacity
Alternative 8	Estimate how much supplemental water supply for direct use in the Shandon Sub-Area is needed to offset groundwater pumping and achieve BMOs.	SWP	Unlimited

5.2 Assumptions for Predictive Model Runs

Assumptions for Basin inflow (which includes supplemental water supplies) and outflow terms were obtained from multiple sources, including output data from the Basin Model and Basin Watershed Model, the City of Paso Robles[19] and their Recycled Water Master Plan (AECOM, 2014), and other participating agencies. Details for inflow and outflow terms are provided in the groundwater budget summary table for each alternative predictive run, as discussed in the following subsections. Information on the hydrologic base period and agricultural water demands (vineyard and non-vineyard crops) used for the predictive model runs is available in the Basin Model update report (GEOSCIENCE and Todd Groundwater, 2014).

The proposed new percolation basins used for Alternatives 2, 4, 5, 6 and 7 range in size from 10 to 120 acres. It is recognized that the size of a proposed basin may be larger than actually feasible; however, the size of each proposed percolation basin was determined by the amount of supplemental water supply required to stabilize groundwater levels within the BMO range. The percolation rate for proposed basins was assumed to be 0.5 ft/day, which is a conservative estimation for expected long-term performance of a recharge facility located in the Basin. The percolation rate for the existing AMWC NWP facility (Alternative 2) was assumed to be approximately 5 ft/day, which is based on the projected maximum NWP supplies available for recharge. Actual dimensions of a percolation basin for any future project will be sized to account for proposed volumes to be recharged and actual percolation rates that are site-specific.

Assumptions for simulated pumping reduction values, and quantities of supplemental water supplies used to simulate offset pumping and artificial recharge vary for each alternative. Some terms are limited to projected annual allocations, and others are limited to the capacity of an existing or proposed recharge facility. The amount of RW simulated to offset 50% of agricultural pumping for Alternatives 3 and 4 is limited to the projected annual volumes allocated for discharge into the Salinas River by the City of Paso Robles. It was assumed that using RW to offset groundwater pumping for irrigation would be limited to 50% of that pumping in order to minimize potential impacts to water quality. Assumptions which are specific to each alternative are provided in Section 5.4, accordingly.

5.3 Evaluation Process

The alternatives were designed with the overall intention to efficiently improve Basin groundwater storage and to stabilize water levels. In order to determine the degree each alternative met these

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[19] Values of projected water demands and supplies used for modeling were agreed upon before the City's 2015 UWMP was finalized and, therefore, may be slightly different.

objectives, model predicted long-term groundwater levels were generated for 23 BMO wells (targets). As shown on Figure 32, the BMO targets which were established by the District are located throughout the Basin, and within the Atascadero Sub-Basin and the Estrella, Creston, Shandon, San Juan and South Gabilan Sub-Areas. The predicted water level trends are compared to a range of acceptable levels established by the District composite BMO hydrographs, one for each sub-area.

Additionally, each predictive alternative was evaluated to determine its ability to stabilize groundwater levels throughout the Basin by 2040, which is consistent with SGMA timing requirements. The methods used to vary each alternative, which may have included any one or a combination of techniques, consisted of:

- Reducing groundwater pumping by a certain percentage and within a specific Basin sub-area,
- Simulating direct delivery of NWP, RW and/or SWP to water districts to offset agricultural pumping, and
- Simulating artificial recharge of NWP, SWP or RW supplies at select locations adjacent to the Salinas River, Estrella River and Huer Huero Creek.

The following steps were used to complete the predictive analysis for each alternative:

1. Compile and format for input into the refined and recalibrated Basin Model data and assumptions developed for the predictive run (e.g., projected RW available for direct delivery and to offset groundwater pumping).
2. Run the Basin Model.
3. Check the water balance to ensure the predictive alternative scenario is represented appropriately.
4. Prepare spring water surface elevation trend hydrographs (i.e., composite BMO hydrograph) for each Basin sub-area which benefits from the model run.
5. Prepare water use and water demand differences tables (i.e., difference from the updated Baseline run) to check model input and for predictive model simulation documentation.
6. Prepare groundwater level hydrographs at selected locations within the groundwater basin to identify the magnitude of the difference in groundwater levels (i.e., difference from the updated Baseline run) at pre-determined key points of interest.

7. Prepare groundwater level difference map (i.e., difference from the updated Baseline run) to identify the affected area(s) within the groundwater basin.

Projected annual volumes of each supplemental water source (i.e., NWP, RW and SWP) are summarized in the following discussions for each alternative. The locations of BMO target wells were obtained from the 2011 Paso Robles Groundwater Basin Management Plan (GEI, Fugro and CHG, 2011). The approximate locations where supplemental supplies are used to offset groundwater pumping and locations of proposed percolation basins are shown on figures that are specific for each alternative.

5.4 Description of Predictive Model Runs

5.4.1 Updated Baseline with Growth

In order to assess the overall benefit of the revised and recalibrated Basin Model (described in Section 4.0), the previous 2014 baseline with growth scenario (Baseline) was rerun. The Baseline examines the response of the Basin to NWP deliveries, municipal wastewater supplies, water demands, and a growth rate of 1% per year projected 29 years into the future (i.e., 2012-2040). Following submittal and receipt of Stakeholder's comments on the Draft July 2016 TM, it was identified that projected future supply and demands for the City of Paso Robles had been interpreted incorrectly. Following discussions between District, City and GEOSCIENCE staff, the Baseline was rerun using the verified projected water supplies.

Assumptions for Municipal Treated Wastewater Supplies

Except for the City of Paso Robles, treated wastewater supplies by the City of Atascadero, Templeton CSD, San Miguel CSD and Camp Roberts are based on actual 2011 values plus an assumed 1% annual growth over the 29 year predictive period. For the period 2025-2040, it was assumed the City of Paso Robles would reallocate 430 acre-ft/yr of treated wastewater to offset municipal groundwater pumping (Todd Engineers, 2011)[20]. Annual projected municipal wastewater supplies are provided in Table 2.

Assumptions for NWP Supplies

Projected NWP supplies for AMWC and Templeton CSD are assumed to be used for groundwater replenishment via existing percolation basins. For the City of Paso Robles, it was assumed all NWP supplies are either delivered to their water treatment plant or discharged into the Salinas River and

[20] Although the City of Paso Robles 2015 Urban Water Management Plan has been completed, the assumptions for treated wastewater supplies were developed prior to its release.

completely recovered downstream by the City's dedicated NWP well; therefore, the City's projected NWP supplies were not included as a basin inflow. The average annual NWP supply for the period 2012-2040 is 1,241 acre-ft. Assumptions for projected annual NWP deliveries to AMWC and Templeton CSD are provided in Table 2.

Assumptions for Groundwater Pumping

A 1% annual increase in demand was also applied to municipal, private domestic and small commercial[21] pumping. Table 3 summarizes annual municipal pumping by the AMWC, City of Paso Robles, San Miguel CSD and Templeton CSD within the Atascadero Sub-Basin and Estrella Sub-Area projected for the period 2012-2040.

Assumptions for Agricultural Pumping

For agricultural water demands, the 2011 acreages for all non-vineyard crops (e.g., alfalfa) were kept steady into the future, which is reasonable given the relatively flat historical trends. For vineyards in 2012, actual acreages were applied directly. Forecasts of future vineyards were developed by agricultural members of the PBAC Computer Model Subcommittee using complete vineyard coverage from 2013 through 2017 by combining projections of vineyards to be planted by July 2013, 2014, and 2017 from the San Luis Obispo Agricultural Commissioner's Office with the 2012 vineyard coverage. Thereafter, a 1% growth rate in vineyard acreage was assumed from 2018 to 2040, with the growth applied spatially over the 2017 vineyard coverage. Table 5-5 of the 2014 Basin Model Update provides the estimated annual irrigated crop acreages within the groundwater basin for the period 2012-2040.

It should be noted that prior to running the Baseline, the previous concern raised by the PBAC Computer Modeling Subcommittee regarding the use of somewhat older land use data for projected vineyard acreages was evaluated by District staff. In coordination with the Subcommittee, the Agricultural Commissioner's Office and representatives of the agricultural community, staff reviewed vineyard coverage through November 2015 and the 2017 projections. Based on their assessment, vineyard coverage have advanced slightly quicker than the rates input into the Basin Model; however, since any new vineyard plantings through 2020 will be water neutral, the vineyard coverage will be back in line with the projected acreages used for the Basin Model. Since the differences were considered to be insignificant for modeling purposes, the District advised that the work continue forward for the predictive model runs without making any modifications to the forecasts for vineyard coverage.

Model results for the updated Baseline are provided in Section 5.5.1.

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[21] Pumping by a golf course is accounted for under the Commercial/Industrial category.

5.4.2 Alternative 1 – Demand Reduction

Alternative 1 is a demand management scenario that evaluates the benefit of reducing agricultural and municipal pumping applied to the projected annual 1% increase in demand. The approach to this alternative was not revised following submittal and review of the draft July 2016 TM. It should be noted that Alternative 1 does not include supplementing the Basin with any new water supplies. An iterative process was used to determine the percent reduction for both agricultural and municipal pumping, and in order to determine whether maximum benefit is achieved by reducing water demand uniformly across the Basin or only in certain area(s) (i.e., Estrella, Creston, Shandon and San Juan Sub-Areas).

Since baseline water levels are shown to be relatively stable in the Atascadero Sub-Basin and Shandon Sub-Area, pumping reductions were only simulated for the Estrella, Creston and San Juan Sub-Areas. Assumptions for average reductions for these three sub-areas are provided in Table 4. As shown, municipal pumping was reduced by 65% in the Estrella Sub-Area, while agricultural pumping was reduced by 65%, 25% and 40% in the Estrella, Creston and San Juan Sub-Areas, respectively. Model results for Alternative 1 are provided in Section 5.5.2.

5.4.3 Alternative 2 – Salinas River Recharge

This scenario evaluates the benefit of recharging NWP supplies via percolation basins at two locations within the Atascadero Sub-Basin. In response to Stakeholder's comments on the draft July 2016 TM, the percolation basin used to simulate recharge of NWP supplies for run 2A was revised. Recharge is simulated at the existing AMWC Nacimiento recharge facility and a proposed new 90-acre percolation basin located adjacent to the Salinas River in an area between the cities of Templeton and Paso Robles. The locations of both percolation basins are shown on Figure 33. Assumptions for NWP supplies used for artificial recharge are provided in Table 5. As shown, Alternative 2A simulates an annual average discharge of 2,190 acre-ft/yr NWP into the existing AMWC Nacimiento percolation basin. This volume is equivalent to the average NWP Allocation minus the average projected NWP use by AMWC (see Table 5 footnotes). An infiltration rate of 5.2 ft/d was assumed for AMWC's existing facility based on the capacity of the basin (1.7 acres) and a maximum NWP water delivery 3,244 acre-ft over a period of one year (i.e., 365 days). Model run 2B simulates the additional discharge of 2,942 acre-ft/yr NWP into a proposed new 90-acre percolation basin. Total combined average annual recharge of NWP under run 2B is 5,132 acre-ft/yr (i.e., 2,190 acre-ft/yr plus 2,942 acre-ft/yr). The location and size of the proposed new percolation basin was provided by the Supplemental Water Supply Options Feasibility Study team. Model results for runs 2A and 2B are provided in Section 5.5.3.

5.4.4 Alternative 3 – Offset Pumping with Recycled Water

Alternative 3 evaluates the benefit of transferring RW that is normally discharged into the Salinas River by the City of Paso Robles to a selected area within the Estrella Sub-Area. The approach for this alternative was not revised following submittal and review of the draft July 2016 TM. The method selected for this scenario simulates the direct delivery of an average of 4,059 acre-ft/yr RW from a turnout at the Paso Robles WWTP to offset agricultural pumping demands; it does not include adding new water supplies to the Basin. The area (shown on Figure 34) was determined by selecting enough cells in the Basin Model where the RW available to offset pumping did not exceed 50% of the total combined annual agricultural pumping demand. The purpose of limiting the amount of offset pumping to 50% is to represent the approximate blend ratio needed for providing an appropriate water quality, as the RW has higher levels of salts than is desired for irrigation applications. Assumptions for RW supplies to offset agricultural pumping for the period 2012-2040 are provided in Table 6. Model results for Alternative 3 are provided in Section 5.5.4.

5.4.5 Alternative 4 – Offset Demand in Estrella Sub-Area

Alternative 4 is designed to determine how much of the available supplemental water supplies are needed to stabilize declining groundwater levels in portions of the Estrella Sub-Area. In response to Stakeholder's comments on the draft July 2016 TM, a second model run was added to include enough additional recharge to achieve Estrella Sub-Area BMOs. This alternative simulates combining offset agricultural pumping with RW delivered from the Paso Robles WWTP and recharging NWP supplies at two proposed new percolation basins. Assumptions for available RW to offset pumping and NWP supplies for artificial recharge are summarized in Table 7. As shown, an average 4,059 acre-ft/yr of RW is simulated for Alternatives 4A and 4B. NWP supplies are assumed to range from 16,436 acre-ft/yr (Alternative 4A) to 21,915 acre-ft/yr (Alternative 4B). This amount of NWP water represents the maximum capacity of the proposed new recharge facility, and it should be noted is in excess of the actual allocation. The area selected for offset pumping in the Estrella Sub-Area is shown on Figure 35, which is the same area used for Alternative 3. As with Alternative 3, it was assumed annual volumes of RW did not exceed 50% of the total combined annual agricultural pumping demand with the selected area for the purpose of maintaining acceptable water quality for irrigation applications. The locations of both proposed new percolation basins are provided on Figure 36. Each percolation basin was located in area that provided the greatest potential to recharge the deeper aquifer system of the Estrella Sub-area. Model results for Alternatives 4A and 4B are provided in Section 5.5.5.

5.4.6 Alternative 5 – Huer Huero Creek Recharge

Alternative 5 evaluates the potential benefit of artificially recharging all three supplemental water supplies (RW, NWP and SWP) at four individual locations along the Huer Huero Creek within the Estrella and Creston Sub-Areas (see Figure 37). In response to Stakeholder's comments on the draft July 2016 TM, additional recharge at two new percolation basins was simulated in order to achieve Estrella Sub-Area BMOs. Assumptions for available RW, NWP and SWP supplies for artificial recharge are summarized in Table 8. As shown, Run 5A1 simulates discharging an average of 4,059 acre-ft/yr RW and 12,377 acre-ft/yr of NWP supplies into a proposed new 90-acre percolation basin. Run 5A2 adds an average of 10,958 acre-ft/yr of NWP recharge at two new percolation basins, for a total of 27,394 acre-ft/yr (i.e., 16,436 acre-ft/yr + 10,958 acre-ft/yr) of recharge within the Estrella Sub-Area. Run 5B1 simulates recharge under Alternative 5A1 plus an average of 3,203 acre-ft/yr of SWP recharged at a proposed new 35-acre percolation basin located in the Creston Sub-Area, for a total annual average of 19,639 acre-ft of recharge. Run 5B2 is a combination of 5A2 and 5B1, simulating a total average recharge of 30,597 acre-ft/yr. The size of the proposed new percolation basins for runs 5A2 and 5B1 were determined using an iterative process to achieve Estrella Sub-Area and Creston Sub-Area BMOs. All simulated deliveries of supplemental water to the proposed percolation basins were assumed to be via non-existing pipelines. Model results for runs 5A1, 5A2, 5B1 and 5B2 are provided in Section 5.5.6.

5.4.7 Alternative 6 – Estrella River Recharge

Alternative 6 is similar to Alternative 5, in that it evaluates the potential benefit of using RW, NWP and SWP water supplies for artificial recharge. In response to Stakeholder's comments on the draft July 2016 TM, additional recharge at two new percolation basins was simulated in order to achieve Estrella Sub-Area BMOs. Locations of the six proposed percolation basins used for Alternative 6 are provided on Figure 38. Assumptions for available RW, NWP and SWP supplies for artificial recharge are summarized in Table 9. As shown, run 6A simulates a total recharge of 16,436 acre-ft/yr (i.e., 4,059 acre-ft/yr RW plus 12,377 acre-ft/yr NWP). The water supplies for run 6A are delivered to three proposed new 30-acre basins located in the Estrella Sub-Area. Run 6B adds to run 6A an average of 16,436 acre-ft/yr SWP delivered to a proposed new 90-acre percolation basin located adjacent to the Estrella River in the Shandon Sub-Area. Run 6C adds to run 6A a total of 32,873 acre-ft of NWP supplies delivered to two new proposed percolation basins located in the Estrella Sub-Area, for a total recharge of 49,309 acre-ft/yr. Sizes of proposed new percolation basins for run 6C were determined using an iterative process to achieve Estrella Sub-Area BMOs. All simulated deliveries of supplemental water to the proposed percolation basins were assumed to be via non-existing pipelines. Model results for runs 6A, 6B and 6C are provided in Section 5.5.7.

5.4.8 Alternative 7 – Offset Pumping in Creston Sub-Area

Alternative 7 is designed to use NWP and SWP water supplies to offset pumping, and SWP supplies to artificially recharge the Creston Sub-Area. The approach for this alternative was not revised following submittal and review of the draft July 2016 TM. Within the selected area for Alternative 7A, there is an average of 3,062 acre-ft/yr of agricultural pumping. Using an assumed maximum offsetting percentage of 50%, 1,531 acre-ft/yr of NWP water was simulated to offset pumping under Alternative 7A (see Table 10). The assumed pumping reduction of 50% was recommended by the Supply Options Study team, and is considered to be reasonable based upon available NWP and SWP supplies, infrastructure requirements and potential customer participation. For Alternative 7B, which is in addition to Alternative 7A, the selected area to offset pumping includes approximately 5,100 acre-ft/yr of agricultural pumping. After iterative model runs were performed, it was determined that 20% of the selected agricultural pumping would be replaced by approximately 1,020 acre-ft/yr SWP water. Alternative 7B also includes a proposed new 10-acre percolation basin with an assumed infiltration rate of 0.5 ft/day. This resulted in an additional 1,826 acre-ft/yr of SWP water to recharge the groundwater system in Creston Sub-area (see Table 10). Locations of the two areas to offset pumping in the Creston Sub-Area and the proposed new percolation basin are provided on Figure 39. The two areas for offset pumping and the proposed new percolation basin were provided to GEOSCIENCE by the Supply Options Study team. Model results for runs 7A and 7B are provided in Section 5.5.8.

5.4.9 Alternative 8 – Offset Pumping in Shandon Sub-Area

In the original scope of work, Alternative 8 was established to evaluate the benefits of both direct use of SWP to offset pumping and recharging SWP in Shandon Sub-Area. However, results of updated Baseline indicated that the BMO objective for Shandon Sub-Area is already met without any further effort. It was also noticed that the San Juan Sub-Area needed some level of either operational reductions and/or new supplemental water supply in order to meet its BMO objective. Therefore, GEOSCIENCE performed a sensitivity model run, based on the original scope of work, by offsetting pumping with SWP supplies and artificial recharge of SWP supplies delivered to a proposed new percolation basin located in the south portion of Shandon Sub-Area. The results showed benefits to either the Shandon or San-Juan Sub-Areas would be minimal. After discussing the results, the District and Supply Options Study team decided to remove Alternative 8 from the Study. Therefore, results for this alternative are not included in this TM.

5.5 Modeling Results

The benefits of Alternatives 1 through 7 were measured in terms of increases in groundwater levels and storage compared to projected Baseline conditions. The ranges of BMOs identified in Section 4.4 of the

2011 Basin Management Plan were used for the purposes of groundwater level stabilization targets established for the Basin sub-areas. Results of the predictive model runs will be used by the Supply Options Study team to develop a prioritized list of the most beneficial and viable options for the Basin.

Water budgets (i.e., inflow and outflow terms) for each alternative were compiled in order to assess the potential impacts that each 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, revised deep percolation of streambed seepage, revised subsurface inflow, Nacimiento Water Project supplies, deep percolation of discharged treated wastewater effluent, and deep percolation of urban water and sewer pipe leakage. The outflow terms are comprised of groundwater pumping, evapotranspiration by riparian vegetation, groundwater discharge to rivers and subsurface outflow. The difference between the total inflow and total outflow equals change in groundwater storage. The annual values for these inflow and outflow flux terms and change in storage are provided for Alternatives 1 through 7, which are discussed in the following subsections.

5.5.1 Updated Baseline with Growth

5.5.1.1 Updated Baseline – Change in Groundwater Levels

The composite BMO hydrographs for the Estrella Sub-Area, Atascadero Sub-Basin, and Creston, Shandon and San Juan Sub-Areas with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 40 through 44, respectively.

- As shown on the Estrella BMO hydrograph (Figure 40), the differences in average annual change in groundwater elevations are predicted to range from approximately -5 ft to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to initially improve by approximately 10 ft and then steadily depart a total of approximately 70 ft below the minimum BMO range by year 2040.
- For the Atascadero Sub-Basin, average annual change in groundwater elevations shown on Figure 41 are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to improve immediately and remain relatively stable through year 2040 at approximately 20 to 30 ft above the BMO range.
- In the Creston Sub-Area, average annual change in groundwater elevations shown on Figure 42 are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average

annual change in groundwater elevations is shown to improve by approximately 10 ft two times during the 29-year predictive period; however, after year 2029, the cumulative departure steadily declines a total of approximately 30 ft (20 ft below the minimum BMO range) by year 2040.

- For the Shandon Sub-Area, average annual change in groundwater elevations shown on Figure 43 are predicted to range from less than -5 ft to approximately 5 ft. The cumulative departure of average annual change in groundwater elevations is shown to remain relatively stable and within the BMO range throughout the entire 29-year predictive period.
- For the San Juan Sub-Area, average annual change in groundwater elevations shown on Figure 44 are predicted to range from less than -5 ft to 5 ft. The cumulative departure of average annual change in groundwater elevations is shown to be initially within the BMO range, followed by a departure of approximately 20 ft by year 2022. For the subsequent years, the cumulative departure is predicted to remain fairly stable but approximately 10 ft below the BMO range by year 2040.

Based on these results for the Updated Baseline, BMOs for the Atascadero and Shandon Sub-Areas are met, but not for the Estrella, Creston and San Juan Sub-Areas.

5.5.1.2 Updated Baseline – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for the Updated Baseline are provided in Table 11. As shown in the table, groundwater storage in the Basin declines an average of approximately 32,844 acre-ft/year during the 29-year predictive period. This is approximately 6,685 acre-ft/yr more than for the previous Baseline run (Scenario 2) performed for the 2014 Basin Model update. This difference is primarily a reflection of the improvements made to the refined Basin Model in regards to the fate of water which enters the groundwater basin from the surrounding watershed, and shows that the previous model slightly underestimated the predicted amount of average annual change in storage.

5.5.2 Alternative 1 – Demand Reduction

Alternative 1 evaluates the benefit of reduction in water demand on the groundwater basin (ranging from 25% to 65%, depending on the area) applied to the projected annual 1% increase in demand. An iterative process was required to determine whether maximum benefit is achieved by reducing water demand uniformly across the groundwater basin or only in certain area(s) of the groundwater basin (i.e., Estrella, Creston, and San Juan Sub-Areas). Pumping reductions were not simulated for either the

Atascadero Sub-Basin or the Shandon Sub-Area since the BMOs were already achieved under Updated Baseline conditions. In order to stabilize water levels by 2040 within each targeted Basin sub-area, the following table summarizes average annual percent reductions in pumping required:

Basin Sub-Area	Assumed Pumping Reduction	
	Municipal	Agricultural
Estrella	65%	65%
Creston	-	25%
San Juan	-	40%

Based on these values used for Alternative 1, municipal pumping was reduced by approximately 997 acre-ft/yr and agricultural pumping was reduced by approximately 31,790 acre-ft/yr, for a combined total of 32,787 acre-ft/yr reduced pumping.

5.5.2.1 Alternative 1 – Change in Groundwater Levels

The composite BMO hydrographs for the Estrella Sub-Area, Atascadero Sub-Basin, and Creston, Shandon and San Juan Sub-Areas with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 45 through 49, respectively.

- As shown on the Estrella BMO hydrograph (Figure 45), average annual change in groundwater elevations are predicted to range from approximately less than -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, improved immediately by approximately 10 ft and remained stable and within the BMO range through year 2040.
- For the Atascadero Sub-Basin, average annual change in groundwater elevations shown on Figure 46 are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to improve immediately after year 2012 and remain relatively stable through year 2040 at approximately 20 to 30 ft above the BMO range.
- In the Creston Sub-Area, average annual change in groundwater elevations shown on Figure 47

are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to fluctuate by approximately ±10 ft but always remaining above or within the BMO range during the 29-year predictive period.

- For the Shandon Sub-Area, average annual change in groundwater elevations shown on Figure 48 are predicted to range from less than -5 ft to approximately 5 ft. The cumulative departure of average annual change in groundwater elevations is shown to remain relatively stable and within the BMO range throughout the entire 29-year predictive period.
- For the San Juan Sub-Area, average annual change in groundwater elevations shown on Figure 49 are predicted to range from less than ±5 ft. The cumulative departure of average annual change in groundwater elevations is shown to remain fairly stable and within the BMO range through year 2040.

Based on these results, water surface elevations under Alternative 1 conditions meet the BMOs for the Atascadero Sub-Basin and the Estrella, Creston, Shandon and San Juan Sub-Areas. Model-predicted changes in groundwater elevations between Alternative 1 and Updated Baseline conditions for model layers 1-4 are provided on Figures 50 through 53. As shown, groundwater elevations are predicted to improve by as much as 30 ft in all four layers, across the majority of the Estrella, Creston and San Juan Sub-Areas where pumping was reduced. Figures 52 and 53 include hydrographs for individual sub-area BMO target wells which show the water level response to Alternative 1 within the deeper aquifer (i.e., layers 3 and 4).

5.5.2.2 Alternative 1 – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 1 are provided in Table 12, and are summarized as:

- Groundwater storage in the Basin is predicted to decline an average of approximately 2,612 acre-ft/year during the 29-year predictive period. Compared to the average change in storage under no project conditions (i.e., Updated Baseline), an average annual reduction of 32,787 acre-ft/yr in total combined municipal and agricultural pumping would provide a net benefit of approximately 30,233 acre-ft/yr to the Basin.

Since Alternative 1 represents a conservation method, which effectively reduces demand on the groundwater system (thereby allowing water levels to recover and stabilize), and does not include supplementing the Basin with any new water supplies, expressing the benefit in terms of efficiency does not apply. However, the effectiveness of this amount of reduced pumping can be expressed based on the substantial amount of water predicted to remain in the Basin on an average annual basis. Results for Alternative 1 show that total outflow from the Basin are predicted to be approximately 31,455 acre-ft/yr less than under Updated Baseline conditions.

5.5.3 Alternative 2 – Salinas River Recharge

Both the AMWC and City of Paso Robles have annual NWP allocations. Within the past few years, AMWC began reallocating a portion of their allocation for discharge into a new percolation facility. The facility is designed to recharge the aquifer system within the Atascadero Sub-Basin. Likewise, the City of Paso Robles uses a portion of their NWP allocation for similar benefits. The amount of NWP supplies available to discharge into the existing AMWC Nacimiento recharge facility (i.e., Alternative 2A) and the proposed new percolation basin (i.e., Alternative 2B) were estimated by subtracting projected total annual NWP allocations from projected use. As shown in Table 5, total annual NWP allocations are projected during the 29-year predictive period (WYs 2012-2040) to range from approximately 2,000 to 3,244 acre-ft/yr for the AMWC and approximately 4,000 to 6,488 acre-ft/yr for the City of Paso Robles. Except for in 2015, actual NWP used by either AMWC or the City of Paso Robles for recharge is projected to be less than these total annual allocated amounts. NWP supplies available for recharge under run 2A range from zero to approximately 3,244 acre-ft/yr, with an average of 2,190 acre-ft/yr over WYs 2012-2040. NWP supplies available for recharge under run 2B ranges from zero to approximately 4,528 acre-ft/yr, with an average of 2,942 acre-ft/yr. Since run 2B is a combination of recharge at both percolation basins, the combined annual average NWP water available to recharge under run 2B is 5,132 acre-ft/yr.

5.5.3.1 Alternative 2A – Change in Groundwater Levels

The composite BMO hydrographs for Atascadero Sub-Basin and Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 54 and 55, respectively. The results for Alternative 2A are summarized as:

- For the Atascadero Sub-Basin, average annual change in groundwater elevations shown on Figure 54 are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to improve immediately and remain relatively stable through year 2040 at <u>approximately 20 to 30 ft above the BMO range</u>.
- For the Estrella Sub-Area, predicted changes in groundwater elevations are shown on Figure 55 to be predominately less than zero ft, ranging from approximately -1 to -5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the

BMO range at the beginning of the 29-year simulation period, is shown to initially improve by approximately 10 ft and then steadily depart a total of approximately 70 ft below the minimum BMO range by year 2040. This is essentially the same as under Updated Baseline conditions.

Based on these results for Alternative 2A, the BMO for Atascadero Sub-Basin continues to be met (as it is under the Updated Baseline conditions), but the Estrella Sub-Area BMO is not achieved based on the composite hydrograph. Additional NWP was not simulated until the BMO was achieved because it would have exceeded the maximum capacity of AMWC's existing percolation basin, which the evaluation criteria did not allow. However, based on model-predicted changes in groundwater elevations between Alternative 2A and the Updated Baseline for model layers 1-4 (see Figures 56 through 59), groundwater elevations are predicted to improve by as much as 10 ft in all four layers—although limited to an area which only extends approximately 4 miles downstream of the discharge point (i.e., existing AMWC Nacimiento percolation basin). Hydrographs for individual BMO sub-area wells are provided on Figures 58 and 59, which show only slight improvements for water levels within the deeper aquifer (i.e., layers 3 and 4) to occur under Alternative 2A conditions.

5.5.3.2 Alternative 2A – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 2A are provided in Table 13, and are summarized as:

- Groundwater storage in the Basin declines on average 32,105 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Updated Baseline), change in storage under Alternative 2A conditions improve by approximately 740 acre-ft/yr.

Review of the model output data indicates the additional recharge quickly maximizes the capacity of the Salinas River alluvium (i.e., model layer 1), resulting in the majority of the delivered NWP supplies to discharge downstream into the Salinas River channel. As shown in Table 13, groundwater discharge to rivers increases an average of 1,205 acre-ft/yr under Alternative 2A.

5.5.3.3 Alternative 2B – Change in Groundwater Levels

Alternative 2B combines the recharge under 2A with additional recharge at a new percolation basin. The composite BMO hydrographs for Atascadero Sub-Basin and Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 60 and 61, respectively. Results for Alternative 2B are essentially identical to Alternative 2A, which can be summarized as:

- For the Atascadero Sub-Basin, average annual change in groundwater elevations shown on Figure 60 are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to improve immediately and remain relatively stable through year 2040 at approximately 20 to 30 ft above the BMO range.
- For the Estrella Sub-Area, predicted changes in groundwater elevations are shown on Figure 61 to be predominately less than zero ft, ranging from approximately -1 to -5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to initially improve by approximately 10 ft and then steadily depart a total of approximately 70 ft below the minimum BMO range by year 2040. This is essentially the same as under Updated Baseline conditions.

Based on these results for Alternative 2B, the BMO for Atascadero Sub-Basin continues to be met, but the Estrella Sub-Area BMO is not achieved by 2040. However, based on model-predicted changes in groundwater elevations between Alternative 2B and the Updated Baseline for model layers 1-4 (see Figures 62 through 65), groundwater elevations are predicted to improve by as much as 30 ft in the vicinity of the proposed 2B percolation basin and 10 ft in the vicinity of the existing AMWC Nacimiento percolation basin for all four model layers. However, increases in groundwater elevation are limited to an area which extends a maximum of approximately 3 miles upstream of the proposed new percolation basin and 1 mile both up and downstream of the existing AMWC percolation basin.

Hydrographs for individual BMO sub-area wells are provided on Figures 64 and 65, show that adding the second percolation basin would improve deeper aquifer water levels by less than 10 ft by year 2040 in the Atascadero area (i.e., well 27S/12E-22M01) and southern-most area of the Estrella Sub-Area (well 27S/12E-02FO2). The remaining hydrographs show no benefit will occur in the majority of the Estrella Sub-Area.

5.5.3.4 Alternative 2B – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 2B are provided in Table 14, and are summarized as:

- Groundwater storage in the Basin declines an average of 30,870 acre-ft/year during the 29-year predictive period under Alternative 2B conditions.
- Compared to the average change in storage under no project conditions (i.e., Updated Baseline), change in storage under Alternative 2B conditions improve by approximately 1,975 acre-ft/yr.

As previously described for Alternative 2A, the overall benefit of adding more recharge to this area of the Basin is likely to be minimal due to rejected recharge of surplus NWP water. Review of the model output data indicates the additional recharge quickly maximizes the capacity of the Salinas River alluvium (i.e., model layer 1), resulting in much of the recharged NWP to discharge down-gradient into the Salinas River. As shown in Table 14, groundwater discharge to rivers under Alternative 2B conditions is approximately 2,266 acre-ft/yr more than it is under Updated Baseline conditions.

5.5.4 Alternative 3 – Offset Pumping with Recycled Water

Alternative 3 evaluates the benefit of offsetting agricultural pumping in a selected area with approximately 4,059 acre-ft/yr RW from the Paso Robles WWTP.

5.5.4.1 Alternative 3 – Change in Groundwater Levels

The composite BMO hydrograph for the Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figure 66. The results are summarized as:

- Change in groundwater elevations are predicted to range from approximately -5 ft to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to initially improve by approximately 10 ft and then steadily depart a total of approximately 55 ft below the minimum BMO range by year 2040. This is an improvement of approximately 15 ft less total departure from year 1981 compared to Updated Baseline conditions.

Based on these results, Alternative 3 does not meet the water level criteria based on the composite BMO hydrograph for the Estrella Sub-Area. However, based on model-predicted changes in groundwater elevations between Alternative 3 and the Updated Baseline for model layers 1-4 (see Figures 67 through 70), groundwater elevations are predicted to improve by as much as 30 ft. The greatest improvements occur within the area designated for offset groundwater pumping. Hydrographs for individual Estrella Sub-Area BMO targets which represent the deeper aquifer (i.e., layers 3 and 4) are included on Figures 69 and 70. As shown, the locations of the BMO targets generally do not coincide with the area where water levels improve the most. Therefore, the reason Alternative 3 did not meet the Estrella Sub-Area BMO is in part because the target wells used to develop the composite BMO hydrograph are located on the margins, or even outside the area where water levels improved the most (see hydrographs for wells 26S/12E-07F02 and 26S/13E-34B01shown on Figures 69 and 70, respectively).

5.5.4.2 Alternative 3 – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 3 are provided in Table 15, and are summarized as:

- Basin groundwater storage declines on average 30,809 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), an average pumping offset of 4,059 acre-ft/yr in the Estrella Sub-Area would provide a net benefit of 2,035 acre-ft/yr to the Basin.

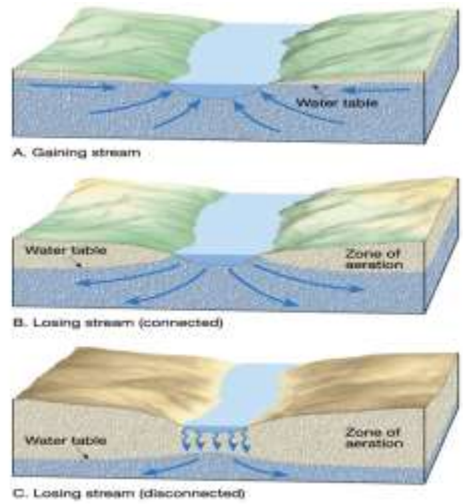
This alternative is similar to Alternative 1 in that no new water supplies were simulated to replenish the Basin; however, Alternative 3 is unique in that it transfers an existing water supply (i.e., RW) from one area of the Basin to another. This water transfer benefits the Basin in three ways:

1. Reduced pumping improves groundwater levels more effectively than the recharge gained from discharging RW into the Salinas River;
2. Lower water levels within the channel alluvial aquifer results in increased deep percolation of streambed seepage (an inflow term) and decreased groundwater discharge to rivers (an outflow term); and
3. Direct delivery of RW to irrigation users has a higher efficiency (essentially 100%) than the current method of discharging the supply into the Salinas River and recapturing downstream.

The main difference between discharging the RW into the Salinas River (i.e., Baseline conditions) and using the supply to offset groundwater pumping is the fate of the supply water. Discharging the RW into the Salinas River does provide a supply to downstream wells, but it also potentially subjects a portion of it to outflow from the Basin. This is primarily due to seasonal and hydrologic factors (e.g., rainfall, streamflow and groundwater elevations). These factors result in the majority of RW discharged into the Salinas River to: (1) remain within the Salinas River system and eventually leave the Basin; (2) percolate into the river alluvium aquifer system and eventually captured by downstream extraction wells; or, (3) recharge the deeper aquifer system and remain within the Basin. In contrast, delivering the RW directly to end users to offset agricultural pumping will subject nearly 100% of the supply to crop consumption, with only a minimal amount going towards deep percolation (return flow from applied irrigation).

Aside from the obvious benefit in lieu pumping provides, another way Alternative 3 benefits the Basin is most evident by comparing specific inflow and outflow terms with those under Baseline conditions. As shown in Table 15, deep percolation of streambed seepage is predicted to increase by approximately

730 acre-ft/yr and groundwater discharge to rivers is predicted to decrease by approximately 1,325 acre-ft/yr for Alternative. Streambed seepage is the condition when surface water within a river channel percolates into the subsurface. This condition which is commonly referred to as a "losing stream" may contribute to groundwater recharge, which is illustrated by examples B and C in the diagram shown. In contrast, a "gaining stream" is the condition when groundwater seeps (or discharged) into a river channel, contributing to surface flow (see example A in the diagram). Model results for Alternative 3 indicate when RW is not discharged into the Salinas River water levels in the alluvial aquifer (model layer 1) decrease by as much as 30 ft along a significant portion of the river (see Figure 67). This represents a losing stream condition and allows for more native streamflow percolating and recharging the Basin aquifers. Additionally, when RW is discharged into the Salinas River, it may create a gaining stream condition whereby native streamflow cannot percolate into the underlying aquifers.



Images obtained fromwww.studyblue.com

This difference supports the idea that a portion of RW discharged into the Salinas River will be lost to surface flow which leaves the Basin. Therefore, for purposes of providing a measurable benefit to be used for the ongoing Supply Options Study, the effectiveness of Alternative 3 is expressed in terms of how much water remains in the Basin compared to the Baseline. Combined with the predicted improvement of water levels within the deeper aquifers in the Estrella Sub-Area and the overall decrease in water leaving the Basin, Alternative 3 benefits the Basin more than discharging the RW into the Salinas River.

5.5.5 Alternative 4 – Offset Demand in Estrella Sub-Area

Alternative 4 is similar to Alternative 3 in that it evaluates the benefit of offsetting agricultural pumping in a selected area with approximately 4,059 acre-ft/yr RW. The difference is Alternative 4 combines the offset pumping with recharging on average approximately 16,436 acre-ft/yr (run 4A) and 5,479 acre-ft/yr (run 4B) of NWP supplies at two proposed new percolation basins, for a maximum total combined recharge of 21,915 acre-ft/yr. The area for the offset pumping is identical to Alternative 3 (compare Figures 34 and 35). The proposed new percolation basins are shown on Figure 36.

5.5.5.1 Alternative 4A – Change in Groundwater Levels

The composite BMO hydrograph for Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) is provided as Figure 71. The results for Alternative 4A are summarized as:

- Change in groundwater elevations within the Estrella Sub-Area are predicted to range from approximately less than -5 ft to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to remain stable but below the minimum BMO threshold (i.e., -60 ft departure) throughout the entire model simulation period.

Based on these results, Alternative 4A does not meet the water level criteria based on the composite BMO hydrograph for the Estrella Sub-Area. However, based on model-predicted changes in groundwater elevations between Alternative 4A and the Baseline for model layers 1-4 (see Figures 72 through 75), groundwater elevations are predicted to improve significantly (by as much as 30 ft or more) within the majority of the sub-area. Hydrographs for individual BMO targets which represent the deeper aquifer (i.e., layers 3 and 4) included on Figures 74 and 75 show this alternative would improve water levels by approximately 120 ft in the area where recent water level declines are greatest (e.g., well 26S/13E-05D01 shown on Figure 74). Despite these improvements, the BMO for the Estrella Sub-Area was not met under Alternative 4A because: (1) initial groundwater levels are so low, and (2) the area of improved groundwater levels did not extend to all BMO targets (i.e., well 26S/12E-07F02 shown on Figure 75).

5.5.5.2 Alternative 4A – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 4A are provided in Table 16, and are summarized as:

- Basin groundwater storage is predicted to decline on average of 15,889 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), an average pumping offset of 4,059 acre-ft/yr using RW and recharging 16,436 acre-ft/yr NWP within the Estrella Sub-Area water would provide a net benefit of 16,955 acre-ft/yr to the Basin.

5.5.5.3 Alternative 4B – Change in Groundwater Levels

The composite BMO hydrograph for Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) is provided as Figure 76. The results for Alternative 4B are summarized as:

- Change in groundwater elevations within the Estrella Sub-Area are predicted to range from approximately less than -5 ft to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to remain stable within the BMO range for the remaining model simulation period.

Based on these results, Alternative 4B meets the water level criteria based on the composite BMO hydrograph for the Estrella Sub-Area. Additionally, based on model-predicted changes in groundwater elevations between Alternative 4B and the Baseline for model layers 1-4 (see Figures 77 through 80), groundwater elevations are predicted to improve significantly (by as much as 30 ft or more) in the same manner as they did under Alternative 4A. The primary reason Alternative 4B is able to meet the BMO goal is because the additional recharge resulting from the proposed 30-acre percolation basin improves groundwater levels in the western portion of the sub-area. As shown in the hydrograph for well 26S/12E-07F02 (see Figure 80), water levels are predicted to improve by as much as 50 ft under Alternative 4B. In contrast, water level improvements at this well were minimal under Alternative 4A.

5.5.5.4 Alternative 4B – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 4B are provided in Table 17, and are summarized as:

- Basin groundwater storage is predicted to decline on average of 11,990 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), an average pumping offset of 4,059 acre-ft/yr using RW and recharging an average of 21,915 acre-ft/yr NWP supplies within the Estrella Sub-Area would provide a net benefit of 20,855 acre-ft/yr to the Basin.

5.5.6 Alternative 5 – Huer Huero Creek Recharge

As described in Section 5.4.6, two more model runs were added to Alternative 5 following receipt of comments on the Draft July 2016 TM. The purpose of the added runs was to increase the amount of recharge so the Estrella Sub-Area BMO was achieved. The four model runs (5A1, 5A2, 5B1 and 5B2) were conducted in order to evaluate the benefits to water levels and groundwater storage in the Estrella and Creston Sub-Areas by recharging RW, NWP and SWP through proposed new percolation basins along the Huer Huero Creek (see Figure 37). Table 8 provides a summary of assumed total supplemental supplies available for recharge, and shows average annual recharge amounts are 16,436 acre-ft/yr, 27,394 acre-ft/yr, 19,639 acre-ft/yr and 30,597 acre-ft/yr for runs 5A1, 5A2, 5B1 and 5B2, respectively. An infiltration rate of 0.5 ft/day was assumed for all proposed new recharge basins.

5.5.6.1 Alternative 5A1 – Change in Groundwater Levels

The composite BMO hydrograph for the Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure of 1981 water levels for the 29-year predictive period (WYs 2012-2040) is shown on Figure 81.

- Change in groundwater elevations within the Estrella Sub-Area are predicted to range from approximately less than -5 ft to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to remain below the minimum BMO threshold (i.e., -60 ft departure) throughout the entire model simulation period.

Based on these results, Alternative 5A1 does not meet the water level criteria based on the composite BMO hydrograph for the Estrella Sub-Area. However, based on model-predicted changes in groundwater elevations between Alternative 5A1 and the Baseline for model layers 1-4 (see Figures 82 through 85), groundwater elevations are predicted to improve significantly (by as much as 30 ft or more) within the majority of the sub-area. Hydrographs for individual BMO targets which represent the deeper aquifer (i.e., layers 3 and 4) included on Figures 84 and 85 show this alternative would improve water levels by approximately 100 ft in the area where recent water level declines are greatest (e.g., well 26S/13E-15N01 shown on Figure 85). Despite these improvements, the BMO for the Estrella Sub-Area was not met under Alternative 5A1 because: (1) initial groundwater levels are so low, and (2) the area of improved groundwater levels did not extend to all BMO targets (i.e., well 26S/12E-07F02 shown on Figure 85).

As shown on Figure 82, using the RW for artificial recharge in lieu of discharging into the Salinas River will effectively lower the shallow aquifer water levels by approximately 10 to 20 ft. The area of decline extends across an approximate 1 to 2 mile section of the river channel.

5.5.6.2 Alternative 5A1 – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 5A1 are provided in Table 18, and are summarized as:

- Basin groundwater storage is predicted to decline on average 24,953 acre-ft/year during the

29-year predictive period.

- Compared to the average change in storage under no project conditions (i.e., Baseline), a combined (RW, NWP and SWP supplies) average annual recharge of 16,436 acre-ft/yr at one percolation basin would provide a net benefit of 7,891 acre-ft/yr to the Basin.

5.5.6.3 Alternative 5A2 – Change in Groundwater Levels

The composite BMO hydrograph for the Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) is shown on Figure 86.

- Change in groundwater elevations within the Estrella Sub-Area are predicted to range from approximately less than -5 ft to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to improve and remain within the BMO range for the remaining model simulation period.

Based on these results, Alternative 5A2 meets the water level criteria established by the composite BMO for the Estrella Sub-Area. In addition, based on model-predicted changes in groundwater elevations between Alternative 5A2 and the Baseline for model layers 1-4 (see Figures 87 through 90), groundwater elevations are predicted to improve within the majority of the Estrella Sub-Area and about a third of the Creston Sub-Area. Hydrographs for some of the individual BMO wells which represent the deeper aquifer (i.e., layers 3 and 4) included on Figures 89 and 90 show the alternative would improve water levels significantly (i.e., approximately 200 ft) in the area where recent water level declines are greatest (e.g., well 27S/12E-02F02 shown on Figure 89).

As shown on Figure 87, using the RW for artificial recharge in lieu of discharging into the Salinas River will effectively lower the shallow aquifer water levels by as much as 10 ft. The area of decline extends across an approximate 1 mile section of the river channel.

5.5.6.4 Alternative 5A2 – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 5A2 are provided in Table 19, and are summarized as:

- Basin groundwater storage is predicted to decline on average 17,059 acre-ft/year during the 29-year predictive period.

- Compared to the average change in storage under no project conditions (i.e., Baseline), a combined (RW and NWP supplies) average annual recharge of 27,394 acre-ft/yr at three percolation basins located within the Estrella Sub-Area would provide a net benefit of 15,785 acre-ft/yr to the Basin.

5.5.6.5 Alternative 5B1 – Change in Groundwater Levels

The composite BMO hydrographs for the Estrella and Creston Sub-Areas with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 91 and 92, respectively. The results for Alternative 5B1 are summarized as:

- For the Estrella Sub-Area, predicted changes in groundwater elevations shown on Figure 91 are predominately less than zero ft, ranging from approximately -1 to -5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to initially improve by approximately 10 ft and then steadily depart a total of approximately 25 ft below the minimum BMO range by year 2040.
- In the Creston Sub-Area, average annual change in groundwater elevations shown on Figure 92 are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to fluctuate by approximately ±10 ft while always remaining above or within the BMO range during the 29-year predictive period.

Based on these results, Alternative 5B1 meets the BMO for Creston Sub-Area but the Estrella Sub-Area BMO is not met. However, based on model-predicted changes in groundwater elevations between Alternative 5B1 and the Updated Baseline for model layers 1-4 (see Figures 93 through 96), it appears that BMO for Estrella is not met because the area which shows improved groundwater elevations does not extend out to some BMO targets. In fact, groundwater elevations in the Estrella Sub-Area are predicted to increase from approximately zero to 110 ft (see individual hydrographs provided on Figures 95 and 96).

As shown on Figure 93, using the RW for artificial recharge in lieu of discharging into the Salinas River will effectively lower the shallow aquifer water levels by approximately 10 to 20 ft. The area of decline extends across an approximate 1 to 2 mile section of the river channel.

5.5.6.6 Alternative 5B1 – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 5B1 are provided in Table 20, and are summarized as:

- Basin groundwater storage is predicted to decline on average 21,859 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), a combined (RW and NWP supplies) average annual recharge of 19,639 acre-ft/yr at two percolation basins would provide a net benefit of 10,985 acre-ft/yr to the Basin.

5.5.6.7 Alternative 5B2 – Change in Groundwater Levels

The composite BMO hydrographs for Estrella Sub-Area and Creston Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 97 and 98, respectively. The results for Alternative 5B2 are summarized as:

- As shown on the Estrella BMO hydrograph (Figure 97), average annual change in groundwater elevations are predicted to range from approximately less than -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, improved immediately by approximately 10 ft and remained stable and within the BMO range through year 2040.
- In the Creston Sub-Area, average annual change in groundwater elevations shown on Figure 98 are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to fluctuate by approximately ±10 ft while always remaining above or within the BMO range during the 29-year predictive period.

Based on these results, the water level criteria established by the composite BMOs is met for the Estrella and Creston Sub-Areas under Alternative 5B2 conditions. In addition, based on model-predicted changes in groundwater elevations between Alternative 5B2 and the Baseline for model layers 1-4 (see Figures 99 through 102), groundwater elevations are predicted to improve significantly throughout much of both sub-areas. Hydrographs for individual BMO targets included on Figures 101 and 102 show water levels in the deeper aquifer (i.e., layers 3 and 4) are predicted to increase by as much as 200 ft (see hydrograph for well 27S/12E-02F02 on Figure 101).

As shown on Figure 99, using the RW for artificial recharge in lieu of discharging into the Salinas River will effectively lower the shallow aquifer water levels as much as 10 ft. The area of decline extends across an approximate 1 mile section of the river channel.

5.5.6.8 Alternative 5B2 – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 5B2 are provided in Table 21, and are summarized as:

- Basin groundwater storage is predicted to decline on average 13,966 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), a combined (RW, NWP and SWP supplies) average annual recharge of 30,597 acre-ft/yr at four percolation basins would provide a net benefit of 18,878 acre-ft/yr to the Basin.

5.5.7 Alternative 6 – Estrella River Recharge

As described in Section 5.4.7, a third model run was added to Alternative 6 following receipt of comments on the Draft July 2016 TM. The purpose of the added run was to increase the amount of artificial recharge in order to achieve the BMO for the Estrella Sub-Area. The three model runs (6A, 6B and 6C) were conducted in order to evaluate the benefits to water levels and groundwater storage in the Estrella and Creston Sub-Areas by recharging RW, NWP and SWP through proposed new percolation basins along the Estrella River (see Figure 38). Table 9 provides a summary of assumed total supplemental supplies available for recharge. An infiltration rate of 0.5 ft/day was assumed for all proposed new recharge basins.

5.5.7.1 Alternative 6A – Change in Groundwater Levels

The composite BMO hydrograph for the Estrella Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) is shown on Figure 103.

For the Estrella Sub-Area, predicted changes in groundwater elevations are shown to be predominately less than zero ft, ranging from approximately -5 to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to initially improve by approximately 10 ft and then steadily depart a total of approximately 40 ft below the minimum BMO range by year 2040.

Based on these results, Alternative 6A does not meet the BMO for the Estrella Sub-Area. However, based on model-predicted changes in groundwater elevations between Alternative 6A and the Baseline for model layers 1-4 (see Figures 104 through 107), groundwater elevations are predicted to improve (by as much as 30 ft or more) within the majority of the Estrella Sub-Area. The hydrograph for well 26S/13E-05D01 shown on Figure 106 indicates water levels in the deeper aquifer could significantly increase (i.e., approximately 100 ft) by the end of the model predictive period. However, Alternative 6A did not meet the BMO for Estrella Sub-Area in part because the composite BMO hydrograph includes target wells that are located outside the area where water levels improved the most (e.g., wells 27S/12E-02F02, 26S/13E-34B01 and 26S/12E-07F02).

As shown on Figures 104 through 107, using the RW for artificial recharge in lieu of discharging into the Salinas River is predicted to lower groundwater levels in the shallow aquifer by 10 to 30 ft and up to approximately 10 ft in the deeper aquifer. The area of water level decline in the shallow aquifer is significant, extending across a 9 mile section of the Salinas River channel. Water level decline in the deeper aquifer is slightly less profound because it is recharged by the NWP supplies under Alternative 6A.

5.5.7.2 Alternative 6A – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 6A are provided in Table 22, and are summarized as:

- Basin groundwater storage is predicted to decline on average 23,291 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), a combined (RW and NWP supplies) average annual recharge of 16,436 acre-ft/yr at three percolation basins would provide a net benefit of 9,554 acre-ft/yr to the Basin.

5.5.7.3 Alternative 6B – Change in Groundwater Levels

The composite BMO hydrographs for Estrella and Shandon Sub-Areas with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 108 and 109, respectively. The results for Alternative 6B are summarized as:

- For the Estrella Sub-Area, predicted changes in groundwater elevations are shown to be predominately less than zero ft, ranging from approximately -5 to 5 ft. The cumulative departure of average annual change in groundwater elevations, which was already below the BMO range at the beginning of the 29-year simulation period, is shown to initially improve by approximately 10 ft and then steadily depart a total of approximately 40 ft below the minimum BMO range by year 2040.
- For the Shandon Sub-Area, average annual change in groundwater elevations are predicted to range from less than -5 ft to approximately 5 ft. The cumulative departure of average annual change in groundwater elevations is shown to remain relatively stable and within the BMO range throughout the entire 29-year predictive period.

Based on these results for Alternative 6B, the BMO for the Shandon Sub-Basin is met (as it is under Updated Baseline conditions), but the Estrella Sub-Area BMO is not achieved. Model-predicted changes in groundwater elevations for model layers 1-4 provided on Figures 110 through 113 show conditions in the Estrella Sub-Area will remain relatively unchanged when compared to results for Alternative 6A. This suggests that adding recharge in the Shandon Sub-Area along the Estrella River results in minimal improvement to groundwater levels in the Estrella Sub-Area.

The areas of water level decline shown on Figures 110-113 are due to using RW supplies for artificial recharge in lieu of discharge into the Salinas River under Alternative 6A (see Section 5.5.7.1 for a full description).

5.5.7.4 Alternative 6B – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 6B are provided in Table 23, and are summarized as:

- Basin groundwater storage is predicted to decline on average 19,825 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), a combined (RW, NWP and SWP supplies) average annual recharge of 32,872 acre-ft/yr at four percolation basins would provide a net benefit of 13,019 acre-ft/yr to the Basin.

5.5.7.5 Alternative 6C – Change in Groundwater Levels

The composite BMO hydrographs for Estrella and Shandon Sub-Areas with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) are shown on Figures 114 and 115, respectively. Results for Alternative 6C are summarized as:

- For the Estrella Sub-Area, model-generated water surface elevations are shown to range from approximately -5 ft to 5 ft. The cumulate departure, which was already below the accepted BMO target of 60 ft at the beginning of the 29-year simulation period, following an initial 10 ft increase remains stable within the BMO range through the end of the modeling period.
- For the Shandon Sub-Area, average annual change in groundwater elevations shown are predicted to range from less than -5 ft to approximately 5 ft. The cumulative departure of average annual change in groundwater elevations is shown to remain relatively stable and within the BMO range throughout the entire 29-year predictive period.

Based on these results, Alternative 6C meets the water level criteria based on the composite BMO hydrographs for the Estrella Sub-Area and Shandon Sub-Area (same as under Updated Baseline conditions). Based on model-predicted changes in groundwater elevations between Alternative 6C and the Baseline for model layers 1-4 (see Figures 116 through 119), groundwater elevations are predicted to improve by as much as 30 ft in the western area of the Shandon Sub-Area and within the majority of the Estrella Sub-Area. Hydrographs for some of the individual BMO wells which represent the deeper aquifer (i.e., layers 3 and 4) included on Figures 118 and 119 show the alternative would improve water levels significantly (i.e., by as much as 120 ft) in the area where recent water level declines are greatest (e.g., well 26S/13E-05D01 shown on Figure 118).

The areas of water level decline shown on Figures 116-119 are due to using RW supplies for artificial recharge in lieu of discharge into the Salinas River under Alternative 6A (see Section 5.5.7.1 for a full description).

5.5.7.6 Alternative 6C – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 6C are provided in Table 24, and are summarized as:

- Groundwater storage in the Basin declines an average of 10,038 acre-ft/year during the 29-year predictive period under Alternative 6C conditions.
- Compared to the average change in storage under no project conditions (i.e., Baseline), the additional recharge of 49,309 acre-ft/yr of supplemental water (i.e., RW and NWP supplies) at five proposed percolation basins located along the Estrella River would provide a net benefit of

approximately 22,806 acre-ft/yr to the Basin.

5.5.8 Alternative 7 – Offset Pumping in Creston Sub-Area

Alternative 7 uses two model runs to evaluate the benefit to water levels and groundwater storage in the Creston Sub-area by offsetting pumping (run 7A) and introducing supplemental supplies through a proposed new percolation basin (run 7B). Alternative 7A uses NWP as the new water source to offset agricultural pumping in the Creston Sub-area. Alternative 7B included the approach used by Alternative 7A, plus SWP as an additional new source to offset agricultural pumping and artificially recharge the Creston Sub-Area at a proposed new percolation basin. Figure 39 shows the locations of selected areas to offset pumping for Alternatives 7A and 7B, and the location of the proposed new 10-acre percolation basin for Alternative 7B. Assumptions for available NWP and SWP supplies are summarized in Table 10.

5.5.8.1 Alternative 7A – Change in Groundwater Levels

The composite BMO hydrograph for the Creston Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) is shown on Figure 120.

- Average annual change in groundwater elevations for the Creston Sub-Area is predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to improve by approximately 10 ft two times during the 29-year predictive period but steadily declines to <u>approximately 20 ft below the minimum BMO range</u> by year 2040.

Based on these results, <u>Alternative 7A does not meet the water level criteria</u> based on the composite BMO hydrograph for the Creston Sub-Area. Model-predicted changes in groundwater elevations for between Alternative 7A and the Baseline are provided on Figures 121 through 124. Groundwater elevations in layers 3 and 4 are predicted to improve by as much as 30 ft in the northwest portion of the sub-area. Hydrographs for individual BMO wells which represent the deeper aquifer (i.e., model layer 4) shown on Figure 124 are located outside of the area predicted to improve, which contributes to the inability for Alternative 7A to achieve the BMO based on the composite hydrograph.

5.5.8.2 Alternative 7A – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 7A are provided in Table 25, and are summarized as:

- Groundwater storage in the Basin declines an average of 31,328 acre-ft/year during the 29-year predictive period.
- Compared to the average change in storage under no project conditions (i.e., Baseline), an average pumping offset of 1,531 acre-ft/yr using NWP in the Creston Sub-Area would provide a net benefit of 1,516 acre-ft/yr to the Basin.

5.5.8.3 Alternative 7B – Change in Groundwater Levels

The composite BMO hydrograph for the Creston Sub-Area with model-generated water surface elevation difference and cumulative departure for the 29-year predictive period (WYs 2012-2040) is shown on Figure 125. The results for Alternative 7B are summarized as:

- In the Creston Sub-Area, average annual change in groundwater elevations shown are predicted to range from approximately -5 ft to 10 ft. The cumulative departure of average annual change in groundwater elevations is shown to fluctuate by approximately ±10 ft while always remaining above or within the BMO range during the 29-year predictive period.

These results show that by adding a second area to offset groundwater pumping and artificial recharge, Alternative 7B is predicted to meet the water level criteria based on the composite BMO hydrograph for the Creston Sub-Area. Improvements to water levels in the deeper aquifer are shown to occur based on model-predicted changes in groundwater elevations between Alternative 7B and the Baseline (see Figures 126 through 129). Groundwater elevations in model layers 3 and 4 are predicted to improve by 10-20 ft in most of the aquifer and as much as 30 ft in the portions which underlie each area of offset pumping and proposed new percolation basin. Hydrographs for individual BMO targets which represent the deeper aquifer (model layer 4) provided on Figure 129 also show the improved water levels are widespread.

5.5.8.4 Alternative 7B – Water Budgets and Change in Groundwater Storage

Results for predicted annual groundwater budgets and change in storage for Alternative 7B are provided in Table 26, and are summarized as:

- Groundwater storage in the Basin declines an average of 28,788 acre-ft/year during the 29-year predictive period.

- Compared to the average change in storage under no project conditions (i.e., Baseline), an average total combined pumping offset of 2,551 acre-ft/yr using NWP and SWP supplies and recharging an average of 1,826 acre-ft/yr SWP supplies within the Creston Sub-Area would provide a net benefit of 4,057 acre-ft/yr to the Basin.

6.0 CONCLUSIONS

The overall conceptual design and computer code used for the Basin Model encourages incremental improvements so that the model can be utilized to answer a variety of water management questions. To address such uncertainty, the previous Basin Model was evaluated independently through a peer review provided by Fugro Consultants. Preceding discussions 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.

Through the cooperation from representatives of the San Luis Obispo County Flood Control and Water Conservation District, GEOSCIENCE, Todd Groundwater and Fugro Consultants, the Paso Robles Groundwater Basin Model was successfully refined and recalibrated and covers the period from October 1980 through September 2011. Model input for underflow inflow and surface water runoff entering the Basin from the watershed areas located outside of the groundwater basin are now more representative of actual conditions. Using the SFR2 Package, the Basin Model is now able to better simulate the hydraulic interaction which takes place between streams and aquifers. The horizontal and vertical hydraulic conductivity values used to recalibrate the Basin Model are reflective of values obtained from actual field parameters which were used for the original model. Results of these refinements and recalibration show the Basin Model to be a useable tool for evaluating various water supply options.

The level of improvement made to the Basin Model is supported by a relative error of 2.9%, which is well below the industry-standard recommended error of 10%. In addition, the results of model calibration indicate an acceptable match of measured and model-simulated streamflow in the Salinas River. The refined and recalibrated Basin Model is able to provide reliable predictions of change in groundwater elevations and groundwater storage for various Basin management conditions.

A total of 16 predictive model runs (including a baseline with growth scenario) were performed using the refined and recalibrated Basin Model to provide a measurable assessment of the benefits from seven (7) specific basin management actions and supplemental water supply options (i.e., Alternatives 1-7). The model runs were simulated for a period of 29 years (WY 2012-2040) with a semi-annual stress period by varying the assumptions of reduced groundwater pumping, supplemental water supplies, and recharge locations. It should be noted that assumptions of available supplemental supplies may exceed actual quantities, but it was necessary for the Supplemental Water Supply Options Study to quantify how much water is needed to stabilize the Basin by 2040. Results are compared to an assumed baseline with growth scenario to evaluate the benefit of each option.

Descriptions of each predictive model run, water supplies used, and benefits in terms of stabilized groundwater levels, change in storage are summarized in the following table.

Results of Supplemental Water Supply Options Predictive Analysis

Predictive Alternative	Model Run	Scenario[1]	Sub-Area BMO Stabilized?	Difference in Groundwater Storage from Baseline (Net Benefit)
Baseline with Growth	NA	NA	Atascadero: Yes Estrella: No Creston: No Shandon: Yes San Juan: No	NA
Demand Reduction	1	**35,094 AFY Total** (Reduction)	Atascadero: Yes Estrella: Yes Creston: Yes Shandon: Yes San Juan: Yes	30,233 AFY
Salinas River Recharge	2A	2,190 AFY NWP (Recharge)	Atascadero: Yes[2] Estrella: No	740 AFY
	2B	2,190 AFY NWP (Recharge) 2,942 AFY NWP (at New Basins) **5,132 AFY Total**	Atascadero: Yes[2] Estrella: No	1,975 AFY
Offset Pumping	3	4,059 AFY RW (Direct Delivery)	Estrella: No	2,035 AFY
Offset Demand in Estrella Sub-Area	4A	4,059 AFY RW (Direct Delivery) 16,436 AFY NWP (Recharge) **20,495 AFY Total**	Estrella: No	16,955 AFY
	4B	4,059 AFY RW (Direct Delivery) 21,915 AFY NWP (Recharge)**25,974 AFY Total**	Estrella: Yes	20,855 AFY
Huer Huero Creek Recharge	5A1	4,059 AFY RW (Recharge) 12,377 AFY NWP (Recharge) **16,436 AFY Total**	Estrella: No	7,891 AFY
	5A2	4,059 AFY RW (Recharge) 23,335 AFY NWP (Recharge) **27,394 AFY Total**	Estrella: Yes	15,785 AFY
	5B1	4,059 AFY RW (Recharge) 12,377 AFY NWP (Recharge) 3,203 AFY SWP (Recharge) **19,639 AFY Total**	Estrella: No Creston: Yes	10,985 AFY
	5B2	4,059 AFY RW (Recharge) 23,335 AFY NWP (Recharge) 3,203 AFY SWP (Recharge) **30,597 AFY Total**	Estrella: Yes Creston: Yes	18,878 AFY

(Table continues on next page)

Results of Supplemental Water Supply Options Predictive Analysis (continued)

Predictive Alternative	Model Run	Scenario[1]	Sub-Area BMO Stabilized?	Difference in Groundwater Storage from Baseline (Net Benefit)
Estrella River Recharge	6A	4,059 AFY RW (Recharge) 12,377 AFY NWP (Recharge) **16,436 AFY Total**	Estrella: No[3]	9,554 AFY
	6B	4,059 AFY RW (Recharge) 12,377 AFY NWP (Recharge) 16,436 AFY SWP (Recharge) **32,872 AFY Total**	Estrella: No[3] Shandon: Yes[2]	13,019 AFY
	6C	4,059 AFY RW (Recharge) 45,250 AFY NWP (Recharge) **49,309 AFY Total**	Estrella: Yes Shandon: Yes[2]	22,806 AFY
Offset Pumping in Creston Sub-Area	7A	1,531 AFY NWP (Direct Delivery)	Creston: No	1,516 AFY
	7B	1,531 AFY NWP (Direct Delivery) 1,020 AFY SWP (Direct Delivery) 1,826 AFY SWP (Recharge) **4,377 AFY Total**	Creston: Yes	4,057 AFY

Notes: NA – Not Applicable
[1] NWP scenario for Alternatives 4-6 is greater than the actual amount available from the Nacimiento Pipeline Project.
[2] BMO criteria already achieved under Baseline conditions.
[3] Composite BMO does not reflect improved water levels throughout the entire sub-area.

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 flow models 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.

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