TECHNICAL MEMORANDUM

TO: San Pasqual Valley Groundwater Sustainability Agency

PREPARED BY: Nate Brown/Jacobs, Craig Cooledge/Jacobs, Paula Silva/Jacobs

REVIEWED BY: Sally Johnson/W&C, Christy Kennedy/W&C, Jim Blanke/W&C

DATE: August 22, 2023

RE: Project Management Action (PMA) No. 7: Initial Surface Water Recharge Evaluation, Task 5: Groundwater and Surface Water Model Simulations

---

TABLE OF CONTENTS

ACRONYMS & ABBREVIATIONS

AF	acre-feet
AFY	acre-feet per year
Basin	San Pasqual Valley Groundwater Basin
bgs	below ground surface
b_{sb}	thickness of streambed
b_t	total alluvium thickness above the water table
b_{vz}	thickness of vadose zone beneath the streambed
cfs	cubic feet per second
City	City of San Diego
cm/s	centimeter(s) per second
County	County of San Diego
DWR	Department of Water Resources
ft	foot/feet
ft/d	foot/feet per day
GCM	global circulation model
GDE	Groundwater Dependent Ecosystem
gpm	gallons per minute
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
HadGEM2-ES	Hadley Centre Global Environment Model v2-ES
K	hydraulic conductivity
$K_{v\text{-}sb}$	streambed vertical hydraulic conductivity
$K_{v\text{-}SFR}$	effective vertical hydraulic conductivity assigned to SFR package
$K_{v\text{-}vz}$	vertical hydraulic conductivity of vadose zone below the stream channel
MR	mean residual
NAVD88	North American Vertical Datum of 1988
NHDPlus	National Hydrography Dataset Plus
PMA	Project and Management Action
PT	Planning Threshold
R^2	coefficient of determination
Ramona MWD	Ramona Municipal Water District
Range	range of measured head values
RMSR	root mean squared residual
RMW	representative monitoring well
RSD	residual standard deviation
SFR	Streamflow Routing
SPV	San Pasqual Valley
SPV GSP Model	SPV GSP Integrated Groundwater/Surface Water Flow Model
TDS	total dissolved solids
TM	technical memorandum
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WY	water year

EXECUTIVE SUMMARY

This technical memorandum (TM) describes the update of the San Pasqual Valley Groundwater Sustainability Plan Integrated Groundwater/Surface Water Flow Model (SPV GSP Model) and the application of the model to evaluate four potential recharge strategies. This TM is part of a broader effort to develop a Preliminary Feasibility Study, which will contain the following components, each developed under a separate task:

- Evaluation Criteria and Ranking Process (Task 1)
- Streambed Investigation (Task 2)
- Water Sources for Recharge (Task 3)
- Potential Recharge Strategies (Task 4)
- Modeling Approach and Results (Task 5)
- Possible Benefits to Potential Groundwater Dependent Ecosystems (GDEs) (Task 6)

The SPV GSP Model was updated from the version used to support the development of the GSP to improve its representation of streams and aquifer characteristics in the SPV Groundwater Basin (Basin). This updated model incorporates more permeable stream channels, a more permeable alluvial aquifer, and more realistic streamflow behavior as compared with the previous version used to support GSP development. The SPV GSP Model updates were conducted using information obtained during the Task 2 streambed investigation and recalibrated using a combination of daily and monthly stress periods. A stress period is an interval of time during which different values of precipitation, stream inflows at the perimeter of the model, and groundwater pumping are used in the model.

This updated SPV GSP Model was used to evaluate the four recharge strategies retained from the Task 4 assessment of potential recharge strategies. The intent of the evaluation is to better understand potential benefits of the recharge strategies, should they require implementation as part of adaptive management to avoid undesirable results in the Basin. These recharge strategies are as follows:

- Strategy 1B: Enhance Streamflow Infiltration with In-stream Modifications
- Strategy 2A: Augment Santa Ysabel Creek Streamflow with Sutherland Controlled Releases
- Strategy 3A: Augment Santa Ysabel Creek Streamflow with Ramona MWD Deliveries
- Strategy 3D: Injection Wells with Ramona MWD Deliveries

Model output from these simulations was processed to establish numerical values for six of the eight criteria developed as part of Task 1. The eight evaluation criteria from Task 1 are as follows:

- Criterion 1: Reduction of Modeled Deficit in Groundwater Storage
- Criterion 2: Average Reduction of Depth to Water
- Criterion 3: Fewer Exceedances of Minimum Thresholds
- Criterion 4: Efficiency of Recharge Strategy
- Criterion 5: Average Reduction of Groundwater Total Dissolved Solids Concentration

- Criterion 6: Fewer Consecutive Days Groundwater Levels are Below 30 Feet Below Ground Surface
- Criterion 7: Costs and Monetary Benefits of Implementation and Maintenance
- Criterion 8: Feasibility of Implementation and Maintenance

Numerical values for Criteria 6 through 8 for each recharge strategy are listed in **Table ES-1**. Additional details for the modeling results are provided in Section 3.3.

Table ES-1: Summary of Results for Evaluation Criteria

Recharge Strategy	Criterion 1 Reduction of Modeled Deficit in Groundwater Storage (AF)	Criterion 2 Average Reduction of Depth to Water (feet bgs)	Criterion 3 Fewer Exceedances of Minimum Thresholds (count)	Criterion 4 Efficiency of Recharge Strategy (percent)	Criterion 5 Average Reduction of Groundwater TDS Concentration (mg/L)	Criterion 6 Fewer Consecutive Days Groundwater Levels are Below 30-feet bgs
1B–Enhance Streamflow Infiltration with In-stream Modifications	-1	0	4	110	-0.3	0
2A–Augment Streamflow with Sutherland Controlled Releases	0	1	41	84	3.1	1
3A–Augment Streamflow with Ramona MWD Deliveries	17	4	208	93	3.1	2
3D–Injection Wells with Ramona MWD Deliveries	80	10	476	97	6.7	10
Evaluation Criteria 7 (cost) and 8 (feasibility) will be presented in the draft Preliminary Feasibility Study, which will be completed in 2023. Larger positive values indicate larger benefits from implementing the recharge strategy.						

Although the simulations of recharge strategies show positive benefits toward enhancing resilience against undesirable results, the simulations also show some limitations of the recharge strategies. The maintenance of sustainable groundwater levels in the eastern portion of the Basin during extended drought periods may require implementation of more than one recharge strategy. With reduced natural aquifer replenishment due to extended droughts, recharge strategies (or demand reduction) would need to be implemented to avoid exceeding minimum thresholds and possible undesirable results. Depending on the availability of water from sources outside of the Basin and the frequency and duration of dry years, implementing more than one recharge strategy at a time, or combining a strategy with other options may be necessary to achieve sustainability. Doing so would provide the most operational flexibility to conjunctively manage the Basin's water resources. Further, modeling results suggest that the individual strategies might not be adequate to meet long-term sustainability goals.

Results from this effort will be used to help develop two additional documents: the Task 6 TM, which will use the simulation outcomes described herein to assess possible benefits to potential GDEs from implementing each of the four individual recharge strategies and the Preliminary Feasibility Study. The draft Preliminary Feasibility Study will be completed in 2023.

The following studies are recommended as part of adaptive management to provide resilience against undesirable results:

- Follow-on study of potential losses due to conveyance from Sutherland Reservoir to the Santa Ysabel Creek inflow point to the Basin, if the GSA chooses to further assess Strategy 1B
- Follow-on modeling of Sutherland Reservoir operations linked to regional system to further optimize water resources
- System-wide reservoir water supply analysis to determine alternative conjunctive-use strategies
- Pilot study to assess the viability of injection well operation, if the GSA chooses to further assess Strategy 3D
- Assessment of potential ecosystem impacts from addition of supplemental water into Santa Ysabel Creek
- Assess and update water-use agreements with water purveyors in the region to support future flexibility of recharge strategies in the Basin

1. INTRODUCTION

The San Pasqual Valley Groundwater Sustainability Agency (GSA) – composed of the City of San Diego (City) and the County of San Diego (County) – adopted the San Pasqual Valley Groundwater Sustainability Plan (GSP) and submitted it to the California Department of Water Resources (DWR) in January 2022 (City and County, 2021). The GSP provides guidance and quantifiable metrics to provide for the continued sustainable management of groundwater resources within the San Pasqual Valley Groundwater Basin (Basin) over the 20-year GSP implementation period **(Figure 1-1)**. To accomplish this, the GSP includes a hydrogeological conceptual model, monitoring requirements, sustainable management criteria, and several projects and management actions (PMAs). The PMAs included in the GSP provide opportunities to enhance water supply, reduce demands, and otherwise support sustainable groundwater management in the Basin, allowing the GSA to respond to changing conditions and help prevent undesirable results, as defined in the GSP. The Basin is currently sustainably managed, so no additional PMAs are needed to achieve sustainability. However, implementing PMAs could improve resilience against challenging future hydrologic conditions, such as extended droughts.

This technical memorandum (TM) is the fifth of six that focuses on PMA No. 7, which is an Initial Surface Water Recharge Evaluation.

- The first TM describes the evaluation criteria by which the best surface water recharge strategies for the Basin will be determined (City, 2022a).
- The second TM describes the approach and results of a streambed investigation along Santa Ysabel Creek in the eastern San Pasqual Valley (SPV) and provides recommendations for updating the SPV GSP Integrated Groundwater/Surface Water Flow Model (SPV GSP Model) (City, 2023a).
- The third TM describes the assessment of three types of water sources that could potentially be used for surface water recharge projects within the Basin, including stormwater flows in Santa Ysabel Creek in the eastern portion of the Basin, controlled releases from Sutherland Reservoir, and untreated water from Ramona Municipal Water District (Ramona MWD) (City, 2023b).
- The fourth TM describes a screening assessment of different recharge strategies, the basis for selecting the four following strategies for further assessment, and additional details about the four following strategies:
    - Strategy 1B–Enhance Streamflow Infiltration with In-stream Modifications
    - Strategy 2A–Augment Santa Ysabel Creek Streamflow with Sutherland Controlled Releases
    - Strategy 3A–Augment Santa Ysabel Creek Streamflow with Ramona MWD Deliveries
    - Strategy 3D–Injection Wells with Ramona MWD Deliveries
- This fifth TM documents the work performed as part of Task 5 of PMA No. 7, which included the following two activities: SPV GSP Model update and simulation and assessment of the four strategies retained for further assessment from Task 4 (City, 2023c).

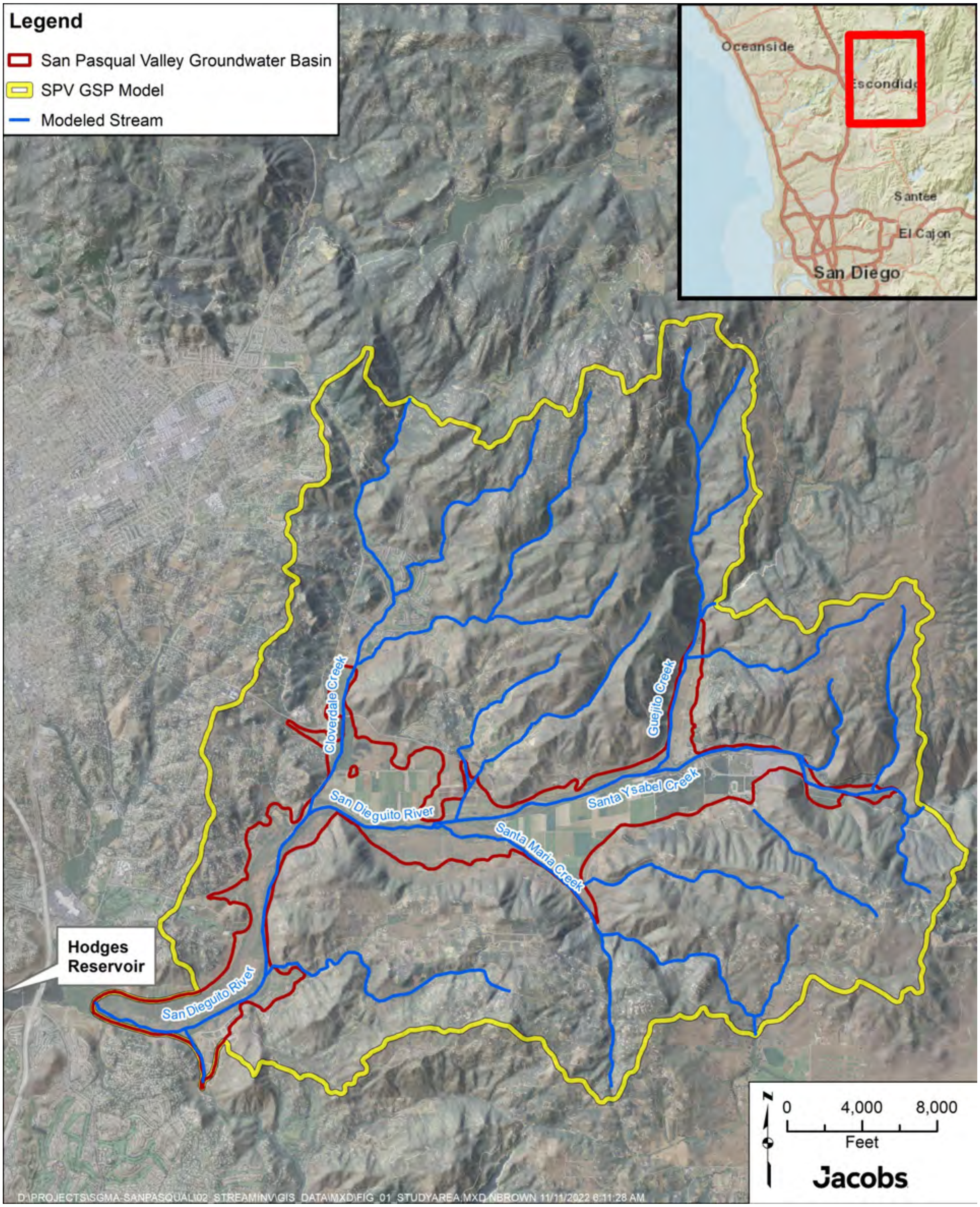


Figure 1-1: San Pasqual Valley Groundwater Basin and Model Area

The SPV GSP Model updates were conducted following the recommendations from the Task 2 streambed investigation (City, 2023a). The Task 2 streambed investigation was performed to provide site-specific data that could be used to improve the understanding of stream channel characteristics in Santa Ysabel Creek in the eastern portion of the Basin. From this point forward in this TM, the version of the SPV GSP Model used during development of the GSP (City and County, 2021) is referred to as SPV GSP Model v1.0, whereas the updated version that was used in Task 5 to evaluate the four selected recharge strategies is referred to as SPV GSP Model v2.0. The ultimate modeling objective for this Task 5 effort is to quantify potential groundwater benefits from implementing these four recharge strategies, using SPV GSP Model v2.0.

The GSA will use the Initial Surface Water Recharge Evaluation to better understand the recharge strategies, should they require implementation as part of adaptive management to avoid undesirable results, as defined in the GSP. Potential recharge areas presented in this TM have not been vetted by stakeholders or permitting agencies, so they should be viewed as conceptual for this stage of study. The Initial Surface Water Recharge Evaluation will be completed in 2023, and the resulting information will be provided in a Preliminary Feasibility Study. The Preliminary Feasibility Study will include the following sections:

- Evaluation Criteria and Ranking Process (Task 1)
- Streambed Investigation (Task 2)
- Water Sources for Recharge (Task 3)
- Potential Recharge Strategies (Task 4)
- Modeling Approach and Results (Task 5)
- Possible Benefits to Potential Groundwater Dependent Ecosystems (GDEs) (Task 6)

2. MODEL UPDATES

Updates to the SPV GSP Model v1.0 in this TM are divided into three categories: (1) Modeled streams, (2) Time discretization (how time is handled in the model), and (3) Recalibration, each of which is described here.

2.1 Modeled Streams

Streamflow and groundwater-surface water interaction along the modeled streams are simulated using the Streamflow Routing (SFR) package of the MODFLOW-OWHM software code (Boyce et al., 2020). The following subsections describe how modeled stream and runoff characteristics have been updated for the Initial Surface Water Recharge Evaluation.

2.1.1 Stream Channel Definition and Calculation Method

Cross sections used to describe the shape of the streambed in the model were updated to more closely reflect actual channel shapes in the Basin, rather than the simplified rectangular channel shapes used in the SPV GSP Model v1.0. Instead of using simple rectangular shapes to describe the stream channel, irregularly shaped cross sections were incorporated into the SPV GSP Model v2.0 using information acquired from the stream channel survey described in the Task 2 TM (City, 2023a), along with 3-meter to 10-meter digital elevation model data from the United States Geological Survey (USGS).

The SFR package in SPV GSP Model v1.0 represented modeled stream channels with simple rectangular channel shapes (City and County, 2021; City 2023a); therefore, whenever streamflow occurred in the model, the wetted width of the stream equaled the assigned rectangular stream width, regardless of the magnitudes of different streamflow events. As a result, the variations in streamflow width that occurred from storms with different intensities and durations were not as well represented in the SPV GSP Model v1.0 as they could be. Conceptually, an increase in streamflow width with higher flows would allow greater surface area for the stream to recharge the groundwater system. Because of the interest of the Initial Surface Water Recharge Evaluation in infiltration characteristics in the eastern portion of the Basin, the SPV GSP Model v2.0 was modified to use an eight-point cross section of the stream channel for each stream segment, rather than the fixed rectangular channels (**Figure 2-1**). The shapes of the different stream segments now included in the SPV GSP Model v2.0 are provided in Attachment A.

With this updated setup, stream depth and wetted perimeter (the perimeter of the cross-sectional area that is wet at a given time) are computed internally by the software code during a simulation based on the shape of the eight-point cross section, allowing the SPV GSP Model v2.0 to automatically account for wider streams that cover more of the stream channel during larger streamflow events and narrower streams that cover less of the stream channel during smaller streamflow events. This configuration of the SFR package provides the opportunity for improved representation of wetted widths of modeled streams that change through time and more accurate simulation of groundwater-surface water interactions during streamflow events of different magnitudes.

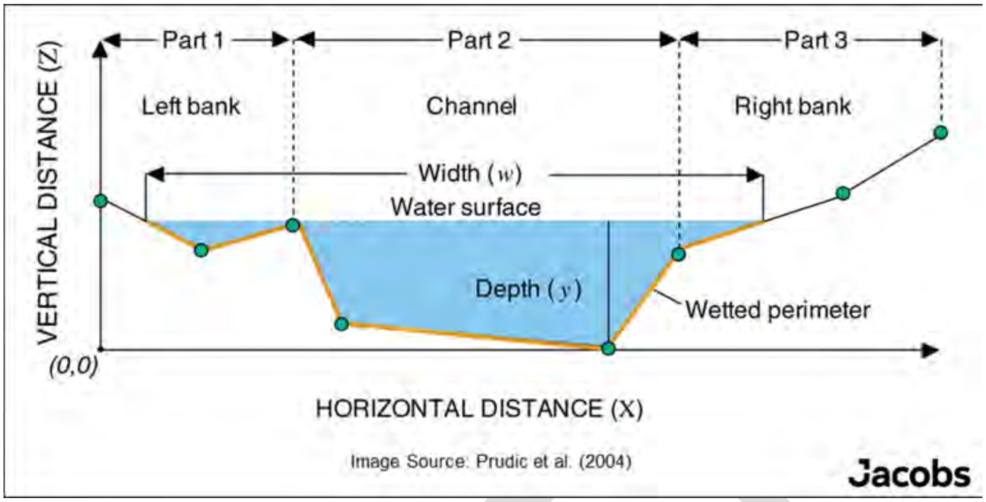


Figure 2-1: Conceptual Eight-point Cross Section

The eight-point cross section is split into the three parts shown on **Figure 2-1**, including the left bank, channel, and right bank also named Part 1, Part 2, and Part 3 correspondingly. One variable that is required with the SFR package is the Manning's roughness coefficient, which is a measure of the resistance of the stream channel to streamflow (Chow, 1959). This coefficient affects the velocity of streamflow in the modeled channel. Larger roughness coefficients have the effect of impeding modeled stream velocities, because larger values correspond to stream channels with greater resistance to streamflow. Although it is possible to assign different values of the Manning's roughness coefficient to the stream channel (Part 2) and to the stream banks (Parts 1 and 3) of the stream cross section (Prudic et al., 2004; Niswonger and Prudic, 2005), the modeling team assigned uniform roughness coefficient values in Parts 1 through 3 (**Figure 2-1**). This was done because there are no stream gauges within the Basin with long enough recording histories to calibrate the model to streamflow. Additionally, actual stream channel characteristics are quite complex and change over time. Thus, the modeling team did not want to overcomplicate the assignment of roughness coefficients to stream features in an ever-changing stream channel environment when the model simulations span multiple decades. The roughness coefficients assigned to the SFR package in the SPV GSP Model v2.0 are summarized in **Table 2-1** and are reasonable considering the types and conditions of stream channels included in the model (e.g., main channels and mountain streams) (Chow, 1959).

Table 2-1: Summary of Manning's Roughness Coefficients in SPV GSP Model v2.0

Stream	Manning's Roughness Coefficient
Santa Ysabel Creek	0.035 to 0.05
Guejito Creek	0.05 to 0.08
Santa Maria Creek	0.035 to 0.08
Cloverdale Creek	0.05 to 0.08
Sycamore Creek	0.08
Other Creeks	0.03 to 0.08
San Dieguito River	0.08

After modifying the shapes of the modeled stream channels and changing the SFR package to compute transient wetted widths of the streams during the simulations, the effective vertical hydraulic conductivity values assigned to the SFR package in the SPV GSP Model v1.0 were also updated, as is described in the following subsection.

2.1.2 Hydraulic Conductivity of Modeled Streams

Hydraulic conductivity (K) is one of the most important input parameters in a numerical groundwater flow model. It is a measure of the physical capacity of porous materials (e.g., clay, silt, sand, gravel, and rock) to allow fluids to move through them. It is a function of the interconnected pore space within the materials and the characteristics of the fluid (specifically the fluid density and viscosity) flowing through the materials. In this case, the fluid of interest is water. Porous materials can resist water flow differently in different directions. Typically, alluvial sediments like those in the Basin are deposited in such a way that the horizontal K is larger than the vertical K. In other words, water flowing vertically through the sediments is typically met with more resistance than water flowing horizontally. However, this is not necessarily true for fractured bedrock systems, where the direction of fractures and other imperfections in the rock affects the directional resistance to water flow. Regardless of the directional characteristics of K, K values are larger for sand and gravel and smaller for silt, clay, and rock. A larger K value means that water moves more easily through the material than a material with a smaller K value, which has an increased resistance to flow. Conceptual images of water flowing through materials with different vertical K characteristics are presented in **Figure 2-2**. Hypothetical water flowpaths are shown in this figure as blue flowlines moving through and around the materials presented. Note how these flowlines become less straight as the flowlines are met with more resistance along the flowpath in the lower-K materials. The blue flowlines shown for the clay in **Figure 2-2** are intended to imply that water would move very slowly through the clay and would mostly flow around it. When considering groundwater recharge strategies in a stream channel, the K value is an important parameter that limits how much streamflow can infiltrate the streambed material and recharge the underlying aquifer.

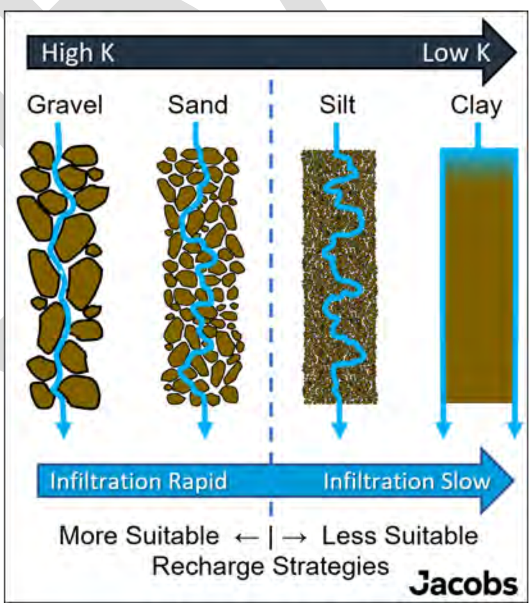


Figure 2-2: Role of Hydraulic Conductivity with Infiltration

To help put the role of streambed K values into perspective, it is important to have a general understanding of how streams and aquifers are simulated in the SPV GSP Model. With numerical groundwater models, the three-dimensional surface and subsurface region being modeled is subdivided into "mathematical boxes" known as cells. All versions of the SPV GSP Model are subdivided into 100-foot by 100-foot model cells in each model layer. The software code solves the groundwater flow equations for each model cell at each simulation time step. The result of these calculations is cell-by-cell values at a given simulation time for groundwater elevation, groundwater flow between each cell with its neighboring cells, and groundwater storage. Portions of modeled streams that are located within a model cell are known as stream reaches. Stream reaches "sit on top" of the underlying groundwater cells (**Figure 2-3**). Portions of groundwater cells above and below the water table represent the vadose zone and aquifer, respectively. The water table is depicted in **Figure 2-3** as the horizontal blue dashed line with the blue inverted triangle. The vadose zone is the subsurface interval that is only partially saturated with water above the water table, whereas the aquifer is fully saturated with water.

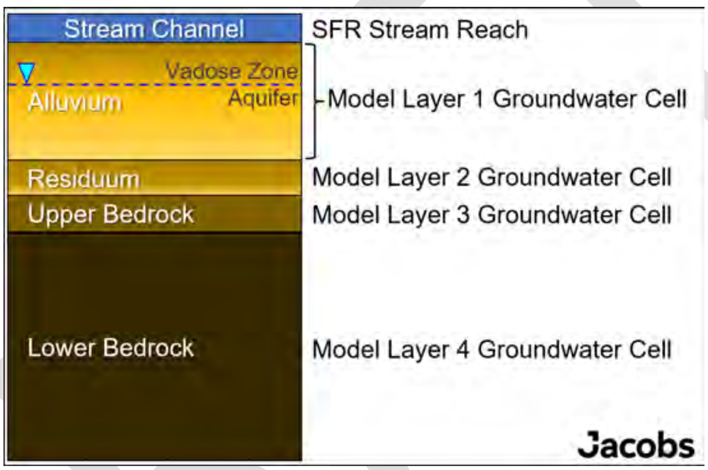


Figure 2-3: Stream Reaches and Groundwater Cells

Values for the vertical K of the streambed material derived from the Task 2 streambed investigation are representative of sediments in the stream channel and some upper portion of the vadose zone below the stream channel (**Figure 2-3**). Water that infiltrates the stream channel, moves through the vadose zone, and enters the aquifer is referred to as groundwater recharge from streams. The rate at which water infiltrates the stream channel at the surface is not necessarily the rate at which the infiltrated water enters the aquifer as groundwater recharge from the stream. This is because the vertical K of the vadose zone materials below the stream channel affects the rate of groundwater recharge from the stream.

The influence of vertical K of the vadose zone on groundwater recharge from streams must be accounted for by the modeler. The K values of the streambed materials that were derived in Task 2 (City, 2023a) are not appropriate to directly assign to the SFR package as they only account for the vertical K of the stream. To account for the K of both the streambed and underlying vadose zone, the modeling team developed a mathematical formulation as described in Attachments B and C, respectively.

2.1.3 Improved Runoff Routing

Understanding how runoff flows across a watershed is important for understanding the overall water balance. In the model, this translates into understanding how runoff flows between model cells. Runoff is examined at the subwatershed level, where a subwatershed is any of several parts of a larger watershed that drains to a specific location. Although runoff is not a major component of the water balance during most months in the model area, there are times when some runoff is generated in the model.

With the SPV GSP Model v1.0, runoff from groups of model cells called "water balance subareas" was distributed evenly across the SFR reaches that were within each water balance subarea (City and County, 2021). However, some water balance subareas spanned more than one subwatershed, so the routing of runoff in the SPV GSP Model v1.0 was not as physically realistic as it could be.

Runoff routing assignments were therefore reconfigured in the SPV GSP Model v2.0 to better account for how subwatersheds within the modeled area collect and convey runoff to streams. Subwatershed boundaries from the United States Environmental Protection Agency (US EPA) National Hydrography Dataset Plus (NHDPlus) (US EPA, 2019) repository were used to relate SFR reaches (**Figure 2-3**) to subwatersheds within the model area, rather than only to the water balance subareas. The distribution of NHDPlus subwatersheds and water balance subareas within the model area is shown in **Figure 2-4**. The runoff component of the SPV GSP Model v2.0 was reconfigured so that each SFR reach receives an equal amount of runoff generated within its subwatershed. This setup allows the runoff to flow downstream through the SFR as streamflow originating within its subwatershed.

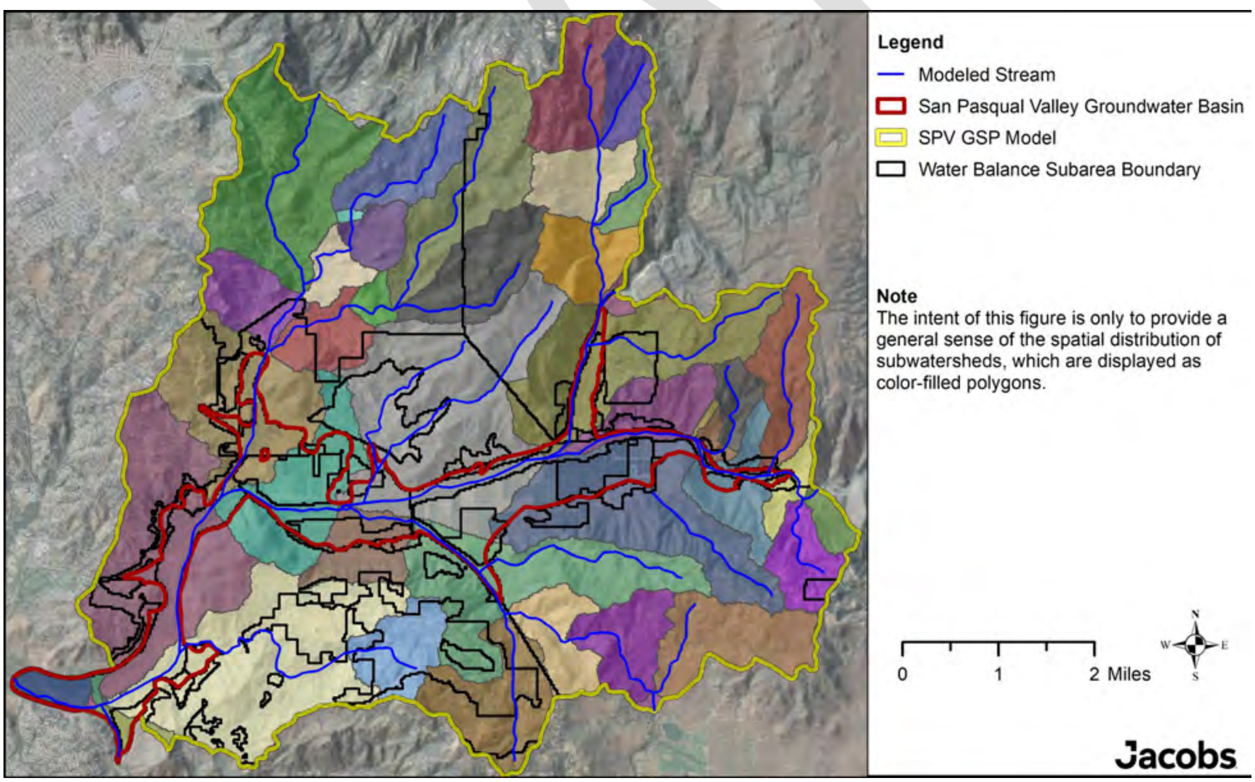


Figure 2-4: National Hydrography Dataset Plus Subwatersheds within the Model Area

2.2 Time Discretization

A computer simulation of flow that varies in time must be set up with discrete time intervals known as stress periods. A stress period is an interval of time at which different values of precipitation, stream inflows at the perimeter of the model, and groundwater pumping are used in the model (e.g., daily or monthly). The SPV GSP Model v1.0 was set up to simulate hydrologic conditions with monthly stress periods. The monthly stress periods in the SPV GSP Model v1.0 were adequate for establishing long-term water budgets and supporting the development of the GSP (City and County, 2021). However, for the current effort, the modeling team wanted to improve the ability of the model to simulate selected streamflow events that occur for durations of less than one month. Doing so provides the opportunity to better simulate selected recharge strategies that utilize the existing streambed to infiltrate intermittent Santa Ysabel Creek streamflow in the eastern portion of the Basin.

A 24-hour day is the finest practical stress period duration for a numerical integrated flow model as large as the SPV GSP Model with a simulation period that spans multiple years to decades. This is due to the practical constraints of computing resources and the need to perform multiple simulations to complete the work. If one were to replace all monthly stress periods with daily stress periods in the SPV GSP Model v2.0, runtimes would range from several days to weeks to complete a single simulation of a recharge strategy, which would substantially slow the modeling progress. Therefore, the modeling team implemented an approach of embedding daily stress periods selectively throughout the 15-year historical simulation period. The basis for selecting timeframes within the 15-year historical simulation period to embed daily stress periods is as follows. Daily streamflow measured at the USGS Santa Ysabel Creek stream gauge near Ramona (gauge number 11025500) from the 15-year historical record were processed to identify periods when continuous streamflow occurred. The modeling team evaluated different numbers of days within a month when streamflow occurred and selected seven days as the basis for embedding daily stress periods. If streamflow at the Santa Ysabel Creek stream gauge occurred for at least seven days within a given month during the 15-year historical period, then that monthly stress period was subdivided into daily stress periods. Selection of seven streamflow days per month as the basis for embedding daily stress periods provided a reasonable balance between being able to simulate more storm events at finer time scales while avoiding excessively long model runtimes. A graph illustrating the timing of the daily stress periods (blue bars) along with monthly streamflow at the Santa Ysabel Creek stream gauge are shown in **Figure 2-5**. Thus, the SPV GSP Model v2.0 incorporates a combination of daily and monthly stress periods.

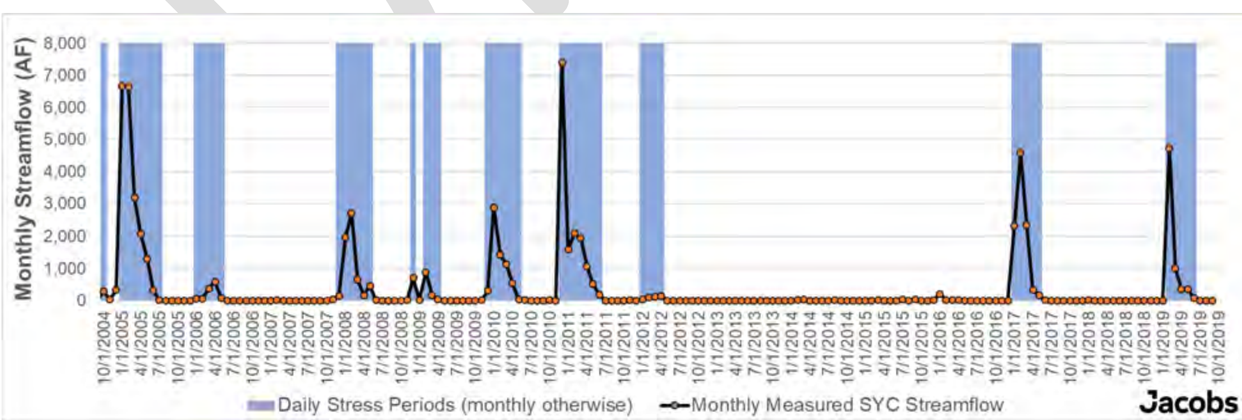


Figure 2-5: Portions of Historical Simulation with Daily Stress Periods

2.3 Recalibration

After updating the modeled stream and runoff characteristics and stress period configuration, as described in Sections 2.1 and 2.2, the 15-year historical simulation from water year (WY) 2005 through WY 2019 was run to allow for a calibration check. Model calibration is a process of adjusting selected model input parameter values within realistic ranges until modeled groundwater levels are reasonably consistent with groundwater levels measured in monitoring wells. This calibration check was done to assess whether the SPV GSP Model v2.0 could adequately replicate measured groundwater levels after the updates described above were incorporated. The outcome of that calibration check indicated that recalibration was necessary. The updates described above resulted in more permeable stream channels, a more permeable alluvial aquifer, and more realistic transient streamflow behavior, which resulted in modeled groundwater elevations being too high across the Basin as compared with measured groundwater levels.

The recalibration approach initially included reviewing the updated groundwater budget of the Basin to note the largest sources of water to the Basin relative to the groundwater outflow processes and rates. This step was done to provide guidance for how to better match groundwater levels by adjusting parameters that affect rates of groundwater inflows and outflows. Additionally, the assigned K values and groundwater storage values of the alluvial aquifer, residuum, and surrounding rock were also varied to gain insight into how modifications to these parameters could improve the fit to measured groundwater levels. The recalibration effort resulted in the SPV GSP Model v2.0, which was sufficiently recalibrated for use on this Initial Surface Water Recharge Evaluation. Additional details regarding the recalibration of the SPV GSP Model v2.0 are provided in Attachments C and D.

3. SIMULATIONS OF RECHARGE STRATEGIES

Once the SPV GSP Model v2.0 was recalibrated, it was used to simulate the four retained recharge strategies discussed in the Task 4 TM (City, 2023c). The following subsection describes the approach and assumptions for setting up and simulating the recharge strategies.

3.1 Approach for Simulating Recharge Strategies

As discussed above, the intent of this study is to better understand the recharge strategies, should they require implementation as part of adaptive management to avoid undesirable results, as defined in the GSP. The four recharge strategies retained from the Task 4 TM (City, 2023c) are described as follows:

- **Strategy 1B**–Enhance streamflow infiltration with in-stream modifications. The in-stream modification in this case is a hypothetical inflatable rubber dam constructed across the channel of Santa Ysabel Creek (white line across Santa Ysabel Creek east of Ysabel Creek Road in **Figure 3-1**).
- **Strategy 2A**–Augment streamflow where Santa Ysabel Creek flows into the model area with controlled releases from Sutherland Reservoir (light blue triangle in **Figure 3-1**).
- **Strategy 3A**–Augment streamflow at and downstream from a hypothetical outfall location in Santa Ysabel Creek with Ramona MWD deliveries (green triangle in **Figure 3-1**).
- **Strategy 3D**-Injection of Ramona MWD deliveries at three hypothetical injection wells in the eastern portion of the Basin (yellow circles in **Figure 3-1).**

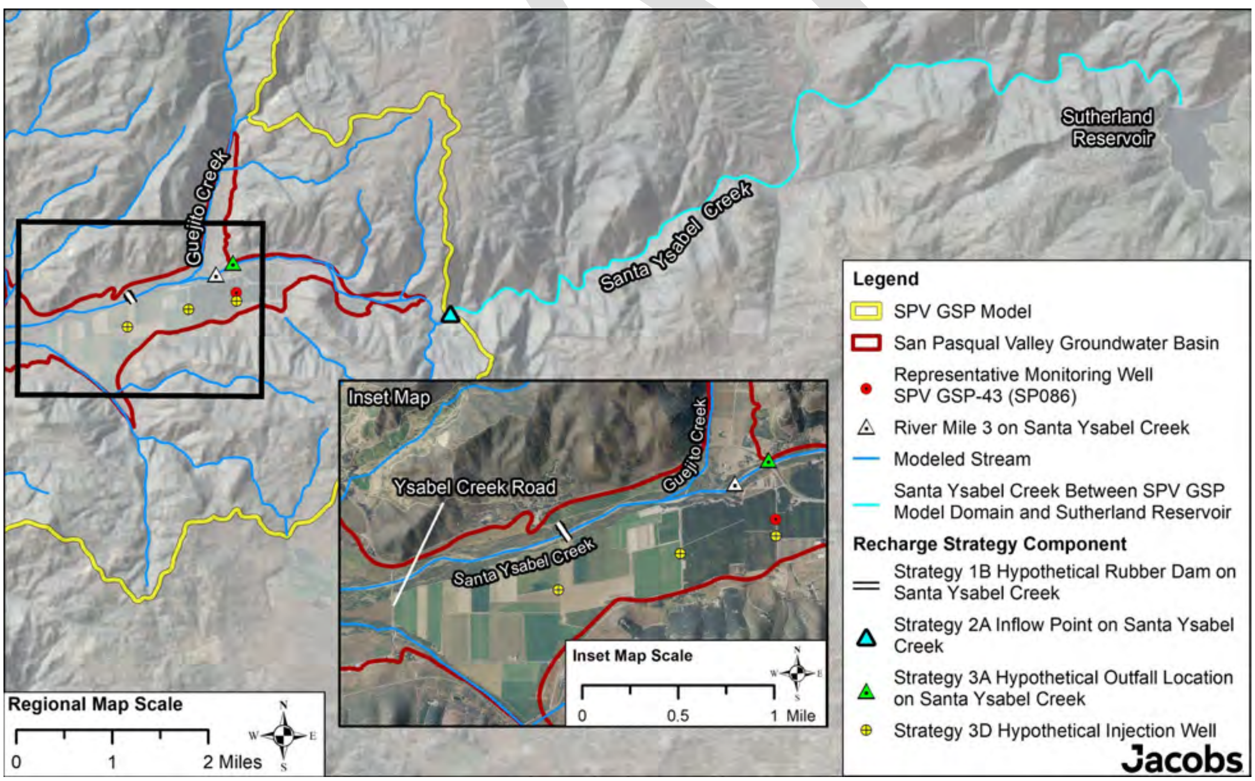


Figure 3-1: Conceptual Layout for Recharge Strategies

For this evaluation, it was assumed that the intent of implementing a recharge strategy would be to enhance resilience against undesirable results, as defined in the GSP (City and County, 2021), rather than to keep the Basin full of groundwater year after year. Therefore, determining when and how much source water is needed was critical in determining the modeling approach for simulating recharge strategies that would rely on controlled releases and deliveries from Sutherland Reservoir and Ramona MWD, respectively (Strategies 2A, 3A and 3D). For Strategy 1B, the source water would be naturally occurring stormwater in the form of streamflow in Santa Ysabel Creek (**Figure 3-1**). Thus, Strategy 1B would only be implemented under specific streamflow conditions in Santa Ysabel Creek, as described in Section 3.1.1.

The modeling approach first required establishing a simulation that did not incorporate any of the recharge strategies described above. This simulation is hereafter in this TM referred to as the Baseline simulation. The Baseline simulation was created by using the SPV GSP Model v2.0 to simulate the same hydrology, land-use, and climate conditions described in the GSP (City and County, 2021). The 15-year historical simulation period includes WYs 2005 through 2019 and the 52-year projection period includes WYs 2020 through 2071. The projection period incorporates projected changes in climate based on the Hadley Centre Global Environment Model v2-ES (HadGEM2-ES) global circulation model (GCM) with the Representative Concentration Pathway 8.5 emissions scenario. This GCM was selected during the development of the GSP for its warmer and drier tendencies. Full details regarding the assumptions associated with the projection period can be found in Section 5 of Appendix I of the GSP (City and County, 2021). Land use and the associated agricultural demand within the Basin were held constant at 2018 conditions for the entirety of the projection period. Thus, the Baseline simulation and recharge strategy simulations do not consider changes in land use that could occur in the future in response to droughts or other factors.

Preliminary SPV GSP Model v2.0 recharge simulations were conducted and compared to the Baseline simulation to get an initial sense for how streamflow in Santa Ysabel Creek and Basin groundwater levels might respond to implementation of the recharge strategies. This comparative assessment helped the modeling team consider possible operational rules or "Conditions" that would help establish the timing for when to implement Strategies 2A, 3A, and 3D in the simulations. Because the water from Sutherland Reservoir and Ramona MWD's untreated water system would have associated costs, the goal of incorporating these Conditions in the modeling process is to simulate recharge strategies that would strive for maximizing recharge benefits while minimizing excess streamflow across Ysabel Creek Road[1]. Based on these preliminary modeling simulations, the decision process shown in **Figure 3-2** was developed for Strategies 2A, 3A, and 3D.

[1] Excess streamflow across Ysabel Creek Road is defined in this TM as the streamflow across Ysabel Creek Road in a recharge strategy simulation minus the streamflow across this road in the Baseline simulation. This flow volume is considered excess in that it would occur because of implementing a recharge strategy, as opposed to what would have naturally occurred. Because this evaluation only focuses on recharge benefits to the Basin, any water flowing in Santa Ysabel Creek that, because of implementing a recharge strategy, ultimately leaves the Basin in San Dieguito River is considered a loss. (**Figure 1-1**).

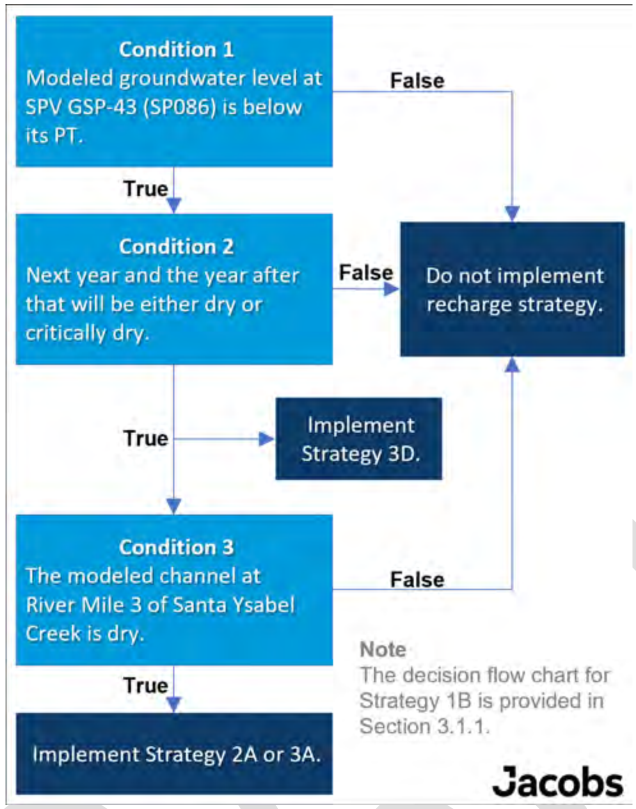


Figure 3-2: Decision Flow Chart for Recharge Strategies 2A, 3A, and 3D

The Conditions were developed to establish initial sets of rules for when to implement the recharge strategies in the model simulations. These rules would likely be modified if the GSA were to choose to implement the recharge strategies described herein. Additional details for the strategy timing are provided as follows:

- **Condition 1**: During development of the GSP, a planning threshold (PT) was established for representative monitoring wells. The intent of these PTs is to provide an early warning for planning purposes before groundwater levels at a representative monitoring well (RMW) drop below minimum thresholds. Condition 1 uses the PT elevation of 347.4 feet[2] at RMW SPV GSP-43 (SP086), which was established during the development of the GSP (City and County, 2021). This particular well is used for Condition 1 due to its location in the eastern portion of the Basin (**Figure 3-1**) and the tendency for modeled groundwater levels at this well to drop below its PT more frequently than at other RMWs in the eastern portion of the Basin. The modeled groundwater-level hydrograph for SPV GSP-43 (SP086) is shown in **Figure 3-3** along with the timing for when Condition 1 is met (see the vertical yellow bars, which coincide with times when the black line drops below the horizontal dashed yellow line). The modeled "head" in the figure legend is synonymous with the modeled "groundwater elevation". If modeled groundwater levels at SPV GSP-43 (SP086) at the end of a given month in the Baseline

[2] All elevations in this TM are presented in reference to the North American Vertical Datum of 1988 (NAVD88)

simulation are not below the PT, then additional flows associated with Strategy 2A, 3A, or 3D are not simulated. If Condition 1 is met for a given month, then Condition 2 is assessed, as described below.

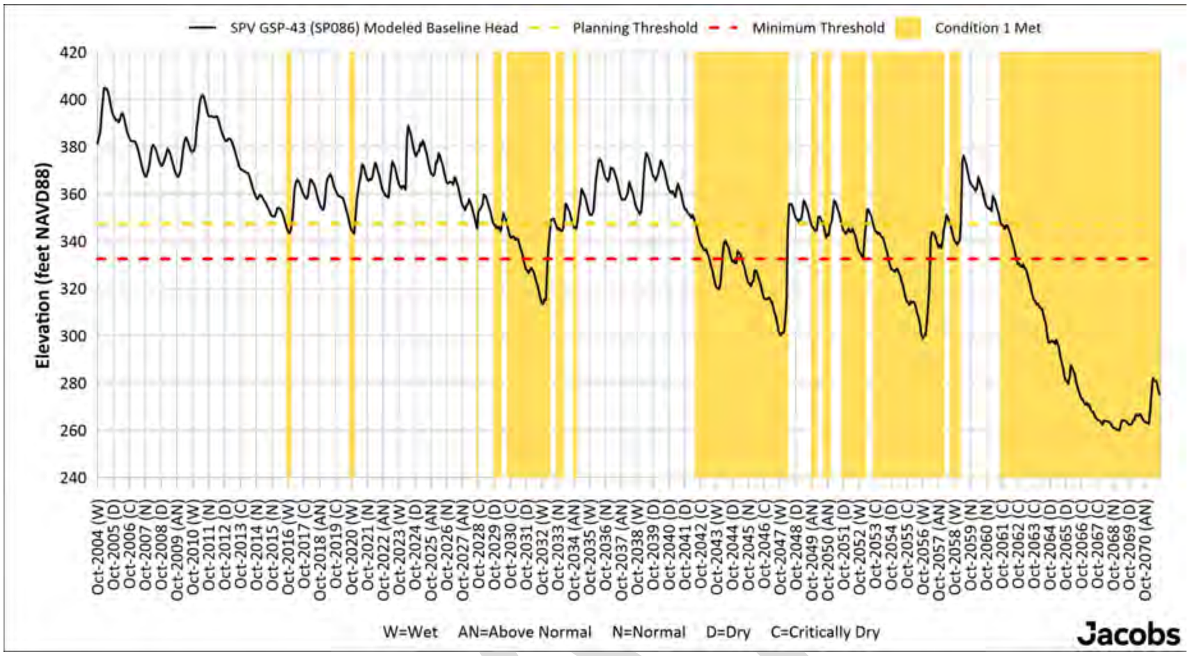


Figure 3-3. Timing for When Condition 1 is Met at SPV GSP-43 (SP086)

- **Condition 2**: A water year classification scheme was developed during GSP development to establish WY types based on annual precipitation including wet, above normal, normal, dry, and critically dry classifications. These classifications are defined for the historical and projection periods. Condition 2 is assessed if Condition 1 is met. Condition 2 incorporates a 2-year look-ahead at WY type with the Baseline simulation for the months during which Condition 1 is met. If this look-ahead indicates that two consecutive dry or critically dry years occur, then the additional flows from Sutherland Reservoir or Ramona MWD would be implemented in the recharge simulation. The timing for when Conditions 1 and 2 are met during the 67-year simulation period is illustrated in **Figure 3-4**. Condition 2 is intended to avoid controlled releases and deliveries if, after Condition 1 is met, either of the two following years has a WY type of wet, above normal, or normal. This Condition was chosen because past groundwater monitoring has demonstrated that Basin groundwater levels are able to rebound naturally to some degree during years with these WY types. For example, modeled groundwater levels in October 2020 in **Figure 3-4** drop below the PT established for SPV GSP-43 (SP086), so Condition 1 is met at that time. However, modeled groundwater levels rebounded naturally by nearly 30 feet after October 2020 during normal and above normal water years without the need to implement a recharge strategy. If Condition 2 is met, then that would mean drier conditions will occur over the two years after Condition 1 is met, which would limit the natural rebound of Basin groundwater levels. For example, Condition 2 is met in October 2029, because the two years after that are designated as critically dry and dry. If Condition 1 is met for a given month, and Condition 2 is also met, then Strategy 3D is implemented (see the timing that coincides with the vertical gray bars in **Figure 3-4**). However, the decision for implementing Strategy 2A or 3A also depends on the assessment of Condition 3, as shown in **Figure 3-2** and below.

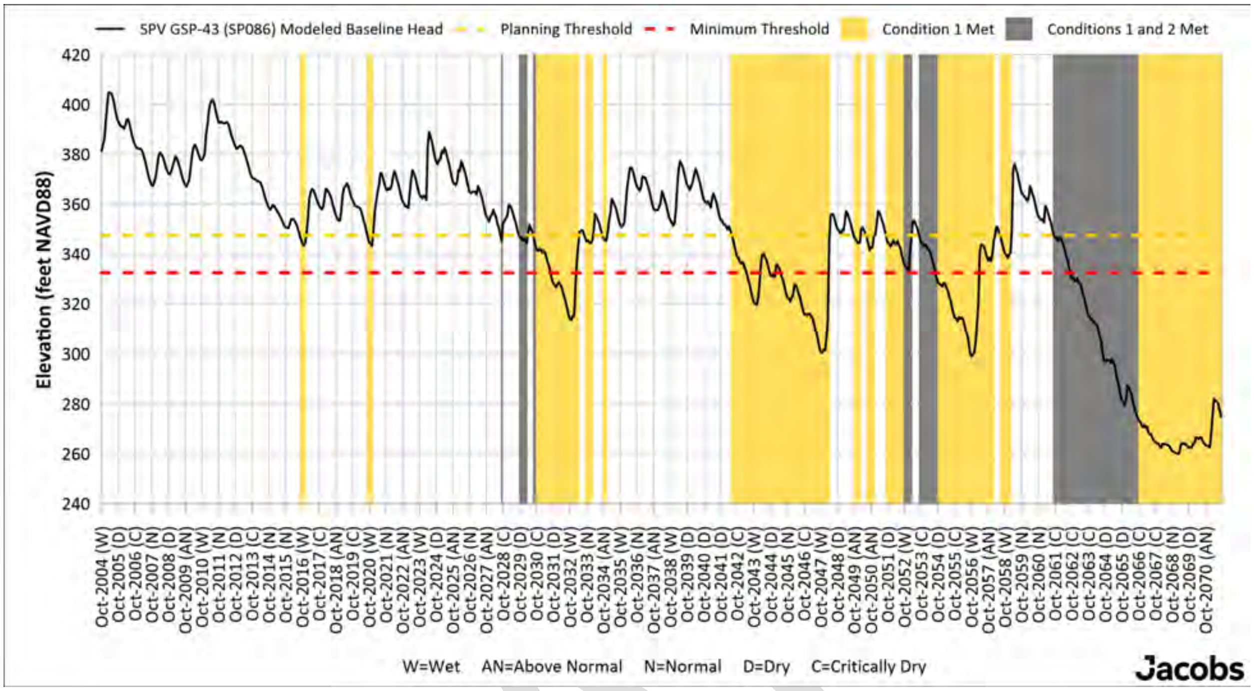


Figure 3-4: Implementation Timing for Strategy 3D (When Conditions 1 and 2 are Met)

- **Condition 3**. If modeled streamflow in Santa Ysabel Creek occurs when Conditions 1 and 2 are met, then releases or deliveries of water to the Santa Ysabel Creek at that time would have a greater chance of creating excess flows across Ysabel Creek Road in the model. Excess flow across Ysabel Creek Road is considered a loss for this study because that water would not recharge the eastern portion of the Basin. River Mile 3 shown in **Figure 3-1** was used to assess whether modeled streamflow in the Baseline simulation occurs in Santa Ysabel Creek when Conditions 1 and 2 were met. Therefore, Strategy 2A or 3A, the two recharge strategies that rely on streambed infiltration, is implemented in the recharge simulation only if streamflow does not occur in the Baseline simulation at River Mile 3 during a month when Conditions 1 and 2 are met. The timing for when all three Conditions are met and Strategy 2A or 3A is implemented is illustrated in **Figure 3-5**. Comparison of the vertical gray bars in **Figure 3-4** and **Figure 3-5** shows that inclusion of Condition 3 results in fewer months when Strategy 2A or 3A is implemented (**Figure 3-5**), as compared with Strategy 3D (**Figure 3-4**).

  Condition 3 is not assessed for Strategy 3D because injection well performance would depend on aquifer parameters rather than infiltration conditions in Santa Ysabel Creek. Thus, all three Conditions must be met for a given month in the Baseline simulation for Strategy 2A or 3A to be implemented in the recharge simulation, whereas only Conditions 1 and 2 need to be met for Strategy 3D to be implemented in the recharge simulation (**Figure 3-2** and **Figure 3-4**).

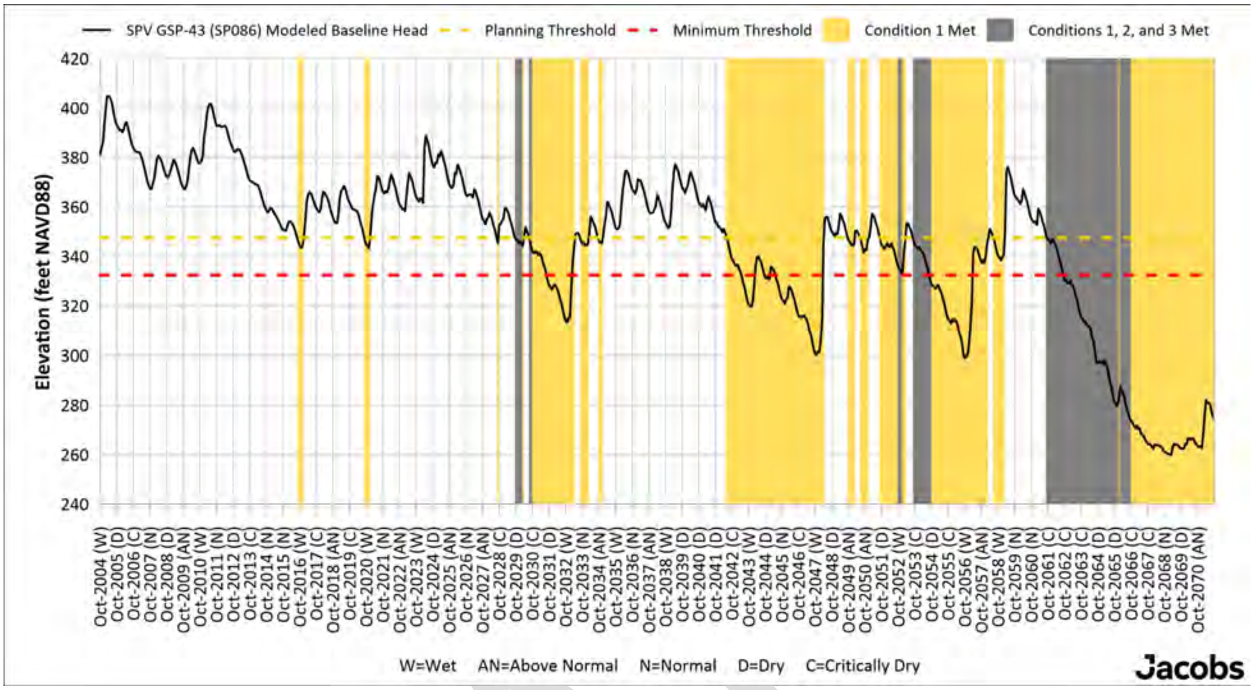


Figure 3-5: Implementation Timing for Strategy 2A or 3A (When Conditions 1, 2, and 3 are Met)

The three Conditions described above were used to decide on the timing for when to implement additional flows associated with Strategy 2A, 3A, or 3D in the recharge simulations. Implementation of these strategies in reality could require other real-time operations considerations not included herein. For example, additional time would be needed before the initial releases or deliveries to develop an agreement with the parties involved. Regardless, the types of observations and forecasts described in the three Conditions are important factors that should be incorporated into adaptive management planning.

Although the decision flow chart shown in **Figure 3-2** helps establish the timing for when to implement Strategy 2A, 3A, or 3D, flow constraints were also needed to determine the volume of source water needed during those times. These flow constraints, as well as other additional details and assumptions, are provided for each recharge strategy in the following subsections.

3.1.1 Strategy 1B–Enhance Streamflow Infiltration with In-stream Modifications

The goal of Strategy 1B is to enhance streambed infiltration along Santa Ysabel Creek through in-stream modifications (City, 2023c). A permanent, channel-spanning, inflatable rubber dam across Santa Ysabel Creek (**Figure 3-6**) was selected for further evaluation using the SPV GSP Model v2.0. Strategy 1B is the only recharge strategy considered in this TM that does not rely on controlled releases from Sutherland Reservoir or deliveries from Ramona MWD. Instead, it relies on stormwater in the form of streamflow in Santa Ysabel Creek at the location shown in **Figure 3-1**. Therefore, the decision flow chart shown in **Figure 3-2** does not apply to Strategy 1B; instead, the decision flow chart shown in **Figure 3-7** applies to Strategy 1B.

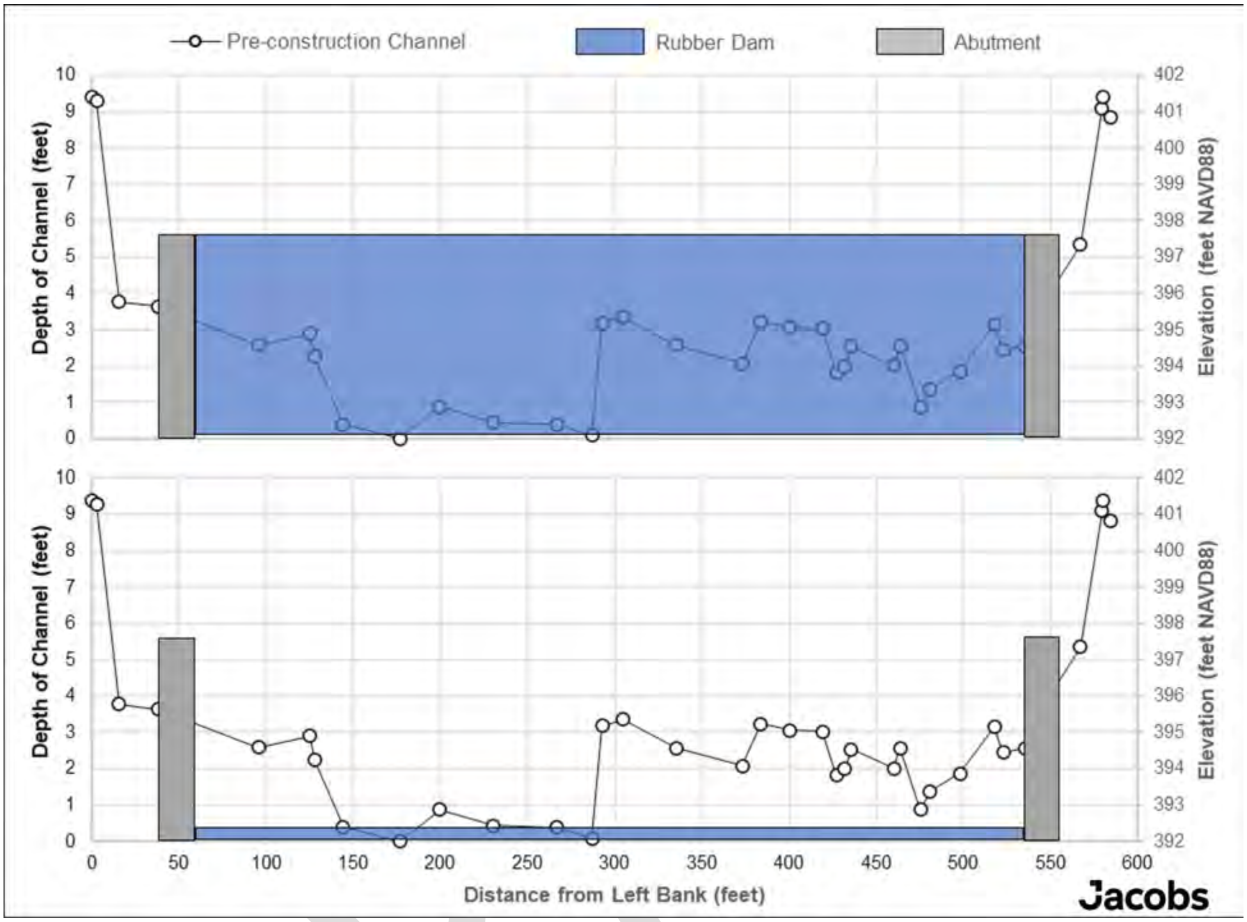


Figure 3-6: Concept for Inflatable Rubber Dam Across Santa Ysabel Creek Channel at Transect 4

Conceptually, the rubber dam would be inflated during selected periods to detain stormwater and increase the opportunity for additional infiltration and groundwater recharge behind the dam (when both Conditions A and B are met; see **Figure 3-5**) and deflated when Santa Ysabel Creek is dry or during higher-streamflow periods to allow stormwater in the creek to flow past the dam (when either Condition A or B is not met; see **Figure 3-5**). Therefore, determining the timing for inflating and deflating the dam was the first step in developing the approach for simulating Strategy 1B. The following discussion in this subsection describes the approach and assumptions for determining when to inflate the rubber dam (**Figure 3-7**).

As with the other recharge strategies, Strategy 1B is based on Baseline simulation outputs. Modeled streamflow at the hypothetical rubber dam location shown in **Figure 3-1** and **Figure 3-8** in the Baseline simulation was processed for WYs 2005 through 2071 to establish the timing for when the rubber dam would be inflated and deflated.

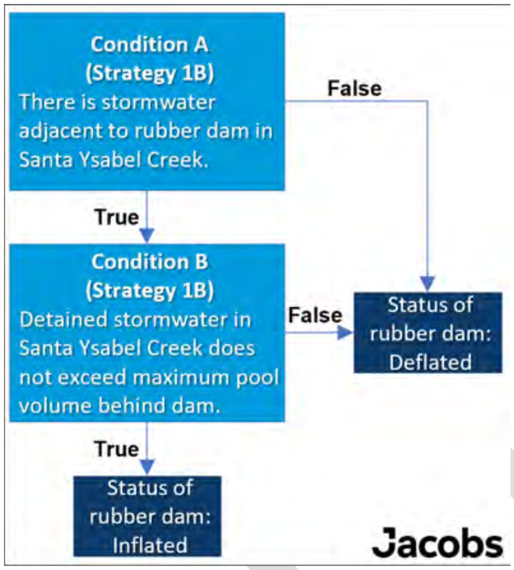


Figure 3-7: Decision Flow Chart for Strategy 1B

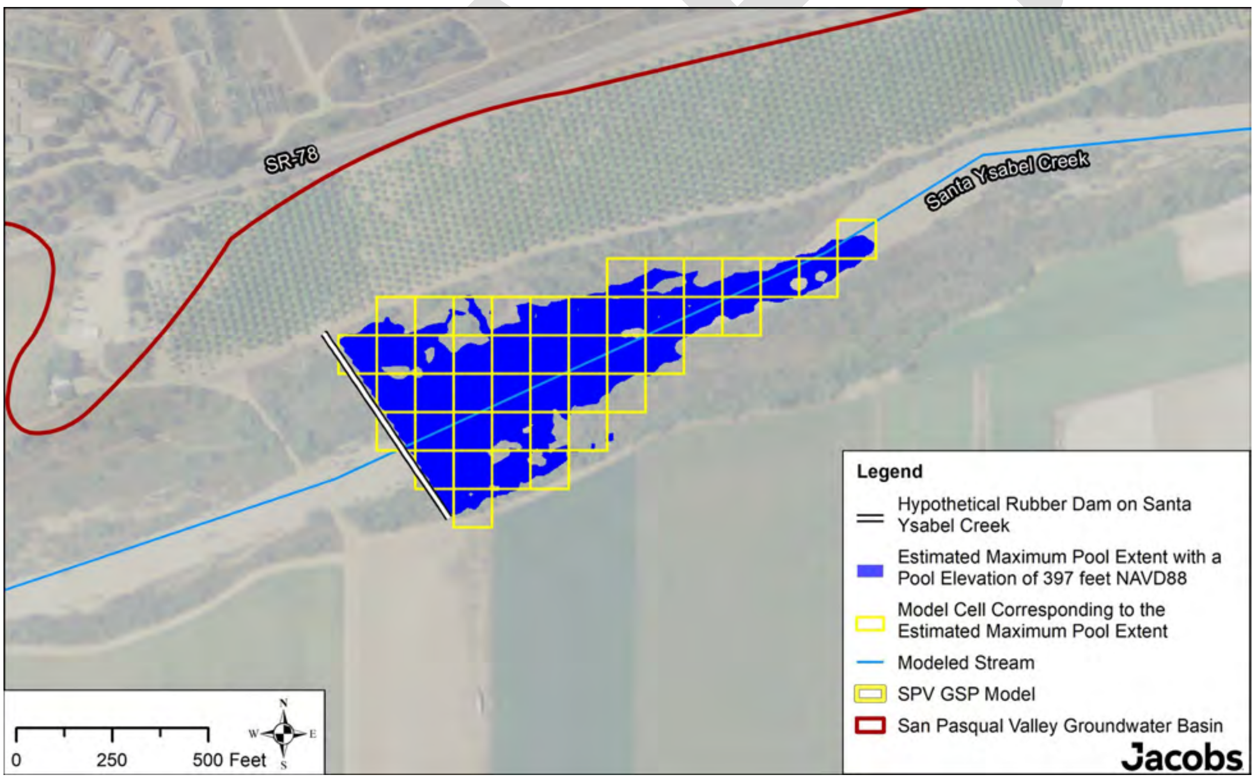


Figure 3-8: Estimated Maximum Pool Extent Behind the Hypothetical Inflatable Rubber Dam

Operation of the dam should ensure that a maximum pool volume is not exceeded, to minimize the potential for adverse flooding in upstream areas and to ensure that the pool does not overtop the dam and create erosional hazards around and downstream of the dam. Using the best available topographic data[3], a maximum pool surface elevation and extent behind the dam was estimated. This extent is shown in blue in **Figure 3-8** and is based on an assumed maximum pool depth of 5 feet behind the dam, which would be 6 inches below the top of the dam shown in **Figure 3-6**. The pool surface elevation corresponding to this 5-foot depth behind the dam is approximately 397 feet NAVD88. Once the maximum pool extent was estimated, an equation that defines the relationship between the pool volume and pool depth was established with the aid of Surfer® v23 and Excel software. The maximum pool volume of 11.3 acre-feet (AF) for a pool depth of 5 feet behind the dam was calculated using Surfer. The output data from Surfer were plotted in Excel and fit with the equation shown in **Figure 3-9**.

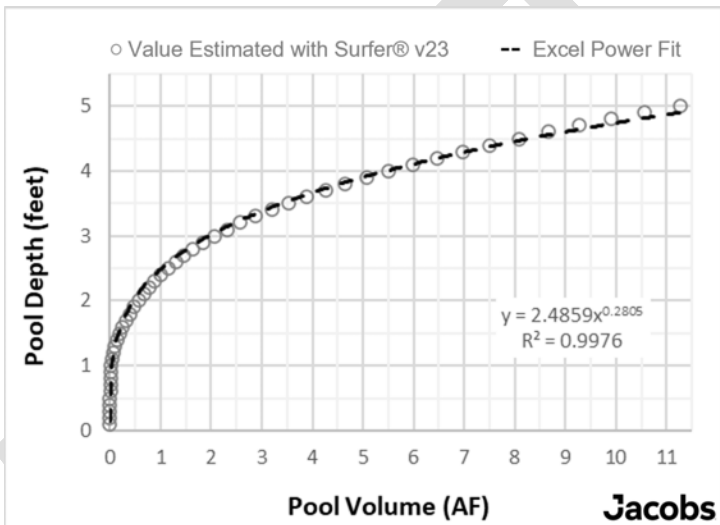


Figure 3-9: Estimated Pool Depth Versus Pool Volume

Once the maximum pool volume and the equation shown in **Figure 3-9** were developed, the modeled streamflow from the Baseline simulation at the SFR reach representing the location of the rubber dam was tabulated in an Excel spreadsheet. A daily pool-water-balance was then developed in this spreadsheet based on the tabulated streamflow from the Baseline simulation to compute time-series groundwater recharge values for the pool that reflect operation of the inflatable rubber dam. This pool-water-balance equation is provided as Equation 3-1:

$$S_t = S_{t-1} + Qin_t - Qout_t \quad (3\text{-}1)$$

[3] The best available topographic data that are continuous across Santa Ysabel Creek and the areas surrounding the modeled location of the rubber dam (**Figure 3-1** and **Figure 3-6**) are 3-meter digital elevation model data from the USGS.

where

S_t = pool storage for current daily time step (AF)
S_{t-1} = pool storage from previous daily time step (AF)
Qin_t = detained stormwater volume for current daily time step (AF)
$Qout_t = \frac{Dp_t}{\left({}^{b_{sb}}/_{K_{v-SFR}}\right)}$ = groundwater recharge from pool for current daily time step (AF)
Dp_t = pool depth for current daily time step (feet)

Equation 3-1 uses the Baseline-simulated streamflow corresponding to the location of the rubber dam to track the daily pool volume that would be detained each day behind the dam. It also accounts for the groundwater recharge from the pool each day. With this pool mass balance, the rubber dam is assumed to be inflated when the stormwater volume behind the dam plus the previous day's pool storage volume is less than the maximum pool volume of 11.3 AF. The daily pool volume is tracked to determine whether there is still available room behind the rubber dam on a particular day during the simulation to detain additional stormwater without exceeding the maximum pool volume. While the dam is inflated, the only modeled outflow from the pool is groundwater recharge from the pool (**Figure 3-10)**. Groundwater recharge from the pool is calculated based on the pool depth during the current time step, the modeled streambed thickness, and the $K_{v\text{-}SFR}$. If the detained pool volume exceeds the maximum pool volume on a given day, then the dam is deflated, and any water currently stored behind the dam is released and allowed to flow downstream (**Figure 3-10**).

The daily groundwater recharge from the pool, as estimated using Equation 3-1, was incorporated into the Strategy 1B simulation using a "boundary condition". Boundary conditions are mathematical rules coded into the modeling software that specify head (groundwater elevation) or water flux (water flow) at selected locations within the model area. The boundary condition that represents groundwater recharge from the pool is referred to as a specified-flux boundary. With this type of boundary condition, time-series groundwater recharge values associated with the detained pool are input to the software by the modeler before the simulation. During the simulation, the software incorporates the provided flow values at the intended boundary-condition cells. In this case, the intended boundary-condition cells are the 44 yellow model cells shown in **Figure 3-8** and **Figure 3-10**. The groundwater recharge values associated with the detained pool (Qout) are divided evenly across these 44 model cells through time during the simulation. The detained stormwater volume is also removed from the Santa Ysabel Creek reach representing the rubber dam to establish the Qin values for Equation 3-1 (**Figure 3-10**). When the dam is deflated due to maximum pool conditions, the detained water that is released is simulated as a stream inflow in the Santa Ysabel Creek reach immediately downstream from the rubber dam location to account for the stormwater released downstream.

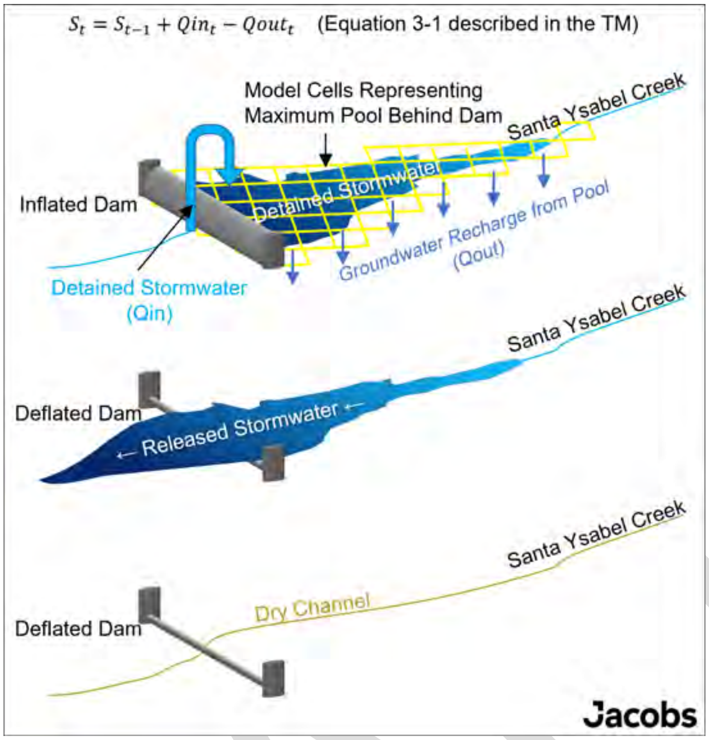


Figure 3-10: Conceptual Dam Operations and Location of Groundwater Recharge Cells for Detained Pool

Figure 3-11 shows the cumulative groundwater recharge from the pool using the daily pool mass balance approach (Equation 3-1). Over the 67-year historical and projection period, including WYs 2005 through 2071, the Strategy 1B simulation incorporated approximately 720 AF of groundwater recharge from the 44 model cells representing the detained stormwater pool (**Figure 3-8** and **Figure 3-10**), at an average of approximately 11 AFY.

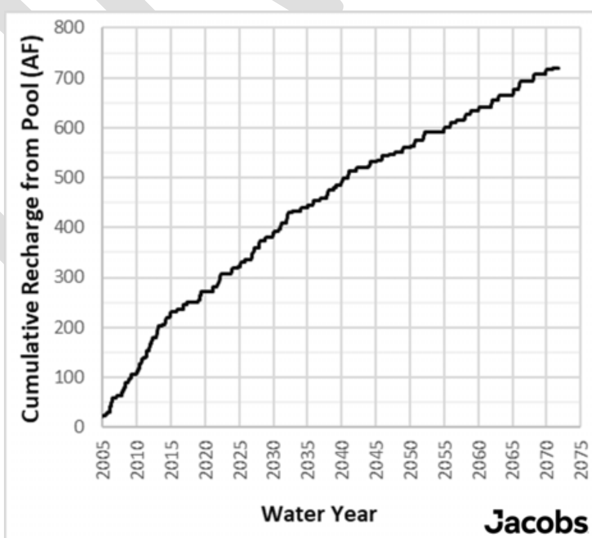


Figure 3-11: Cumulative Groundwater Recharge from Pool

Additional considerations not addressed herein would be needed if Strategy 1B were to be implemented in the Basin. Examples of such considerations include, but are not limited to, the following:

- Deposition of silt and other materials behind the dam could affect infiltration rates through time or would require removal
- Whether stormwater pooled over time could affect the stability of the banks adjacent to the nearby farm roads
- Maintenance activities could affect the timing for when Strategy 1B would be implemented
- Releases of stormwater from the dam could create problems at or downstream from the dam
- The dam should be deflated when pooled water reaches some depth greater than 5 feet

3.1.2 Strategy 2A–Augment Santa Ysabel Creek Streamflow with Sutherland Controlled Releases

The simulation of Strategy 2A included two steps:

- First, the estimation of maximum controlled releases that Santa Ysabel Creek can infiltrate in the Basin through time from Sutherland Reservoir and
- Second, the estimation of how much of these maximum controlled releases were available at the reservoir throughout the simulation period.

The following sections describe the assumptions and approach for these steps.

Estimation of Maximum Controlled Releases from Sutherland Reservoir

As discussed in the Task 4 TM (City, 2023c), the primary goal of Strategy 2A is to augment streamflow in Santa Ysabel Creek with controlled releases from Sutherland Reservoir. Strategy 2A takes advantage of infiltration in Santa Ysabel Creek as the mechanism for additional groundwater recharge but introduces a "new" source of water to the Basin. The timing of recharge strategy implementation shown in **Figure 3-4** would occur based on Conditions 1 and 2 in the decision flow chart provided in **Figure 3-2**. However, an additional consideration was made beyond these two conditions to establish the Strategy 2A implementation periods. If Conditions 1 and 2 are both met, then Condition 3 addresses whether streamflow is already occurring in Santa Ysabel Creek at River Mile 3 (**Figure 3-1** and **Figure 3-2**). To implement Strategy 2A at a given simulation time, streamflow must also be zero at River Mile 3 at that simulation time. Thus, all three Conditions shown in **Figure 3-2** must be met before Strategy 2A is implemented.

In addition to these three Conditions, limits on the controlled release volume from Sutherland were imposed. A monthly maximum streambed infiltration volume between the inflow point of Santa Ysabel Creek into the model area and Ysabel Creek Road (**Figure 3-1**) was estimated to be approximately 900 AF from the historical (WYs 2005 through 2019) Baseline simulation period. The analysis conducted to estimate this monthly maximum volume is presented in Attachment D of the Task 4 TM (City, 2023c). Additionally, an annual maximum streambed infiltration volume between the inflow point of Santa Ysabel Creek into the model area and Ysabel Creek Road (**Figure 3-1**) was estimated to be 3,000 AF based on a December through May period of the Baseline simulation.

Using the three Conditions presented in **Figure 3-2,** and the monthly and annual maximum streambed infiltration rates, monthly maximum controlled releases from Sutherland Reservoir were developed for the 67-year simulation period, including WYs 2005 through 2071. Maximum controlled releases from Sutherland Reservoir were estimated as the monthly maximum streambed infiltration volume of 900 AF minus the current month's streambed infiltration volume in the Baseline simulation. These monthly values were then uniformly reduced such that the total annual infiltration volume did not exceed the annual maximum streambed infiltration volume of 3,000 AF. The result of this calculation is an estimate of the maximum controlled release target from Sutherland Reservoir (**Figure 3-1**) and does not directly account for when water is available as a controlled release from Sutherland Reservoir. The purpose of these calculations and the monthly and annual maximum constraints was to evaluate periods when the streambed infiltration capacity along Santa Ysabel Creek is the greatest to maximize recharge benefits to the Basin, while minimizing excess streamflow[1] at Ysabel Creek Road. Excess streamflow across Ysabel Creek Road due to implementation of a recharge strategy is considered a negative outcome. However, some excess flows might be unavoidable due to the complex nature of how the Basin streams and aquifer respond to increases in streambed infiltration.

Estimation of Available Controlled Releases Using Sutherland Reservoir Operations Model

A reservoir operation model was needed to provide an estimate of the water available from Sutherland Reservoir up to the target maximum controlled releases discussed above. A reservoir operation model was developed for this effort using the GoldSim platform (**Figure 3-12**) to estimate the monthly available controlled releases to Santa Ysabel Creek for the 67-year simulation period. This GoldSim model uses a reservoir water balance approach based on the assumptions listed in **Table 3-1**. These assumptions and the reservoir operation characteristics, as described in Attachment A in the Task 3 TM (City, 2023b), are based on information provided by City staff (City, 2022b, 2022c and 2022d). A water balance is conducted at the monthly timescale to estimate the available stored water in the reservoir for controlled releases. The stored water available for release is estimated as the water stored above a minimum operation storage level and below the maximum operation level. Monthly operational targets were defined using historical records, where the operational minimum and maximum storage levels are approximately 2,350 AF and 27,300 AF respectively. For example, if the current monthly reservoir storage is 10,000 AF after evaporation and other uncontrolled releases (spills) have been accounted for, then the estimated available volume for controlled releases from the reservoir is approximately 7,650 AF to maintain a minimum storage of 2,350 AF (10,000 minus 2,350 equals 7,650). The GoldSim model allocates the available volume for releases according to the following priorities, first the existing controlled releases of San Vicente Reservoir and Ramona MWD and then the controlled releases associated with the Strategy 2A:

1. **Releases to San Vicente Reservoir.** The flow volume and timing to San Vicente are determined by conveyance constraints, such as maximum capacity releases (5 cubic feet per second [cfs] to 95 cfs, which varies depending on the storage level) and environmental restrictions like the toad breeding season. Modeled releases to San Vicente Reservoir are assumed for the projection period (WYs 2020 through 2071) to follow the assumptions indicated in Table 3-1.
2. **Releases to Ramona MWD.** Although the agreement between the City and Ramona MWD to send water to Ramona MWD's Bargar Water Treatment Plant is still in effect, the Water Treatment Plant has been offline since 2007. Historically, releases to Ramona MWD only took place in 2005, 2006 and 2007. Ramona MWD does not currently have plans for placing this water treatment plant back into service as

a source of potable water (Ramona MWD, 2021). Therefore, releases from Sutherland Reservoir to Ramona MWD are not considered for the projection period.

3. **Releases to Santa Ysabel Creek.** The flow volume and timing to Santa Ysabel Creek are determined based on the monthly maximum controlled releases estimated as described above, water in storage after San Vicente releases, and a release maximum capacity of 110 cfs of the reservoir outlet to Santa Ysabel Creek.

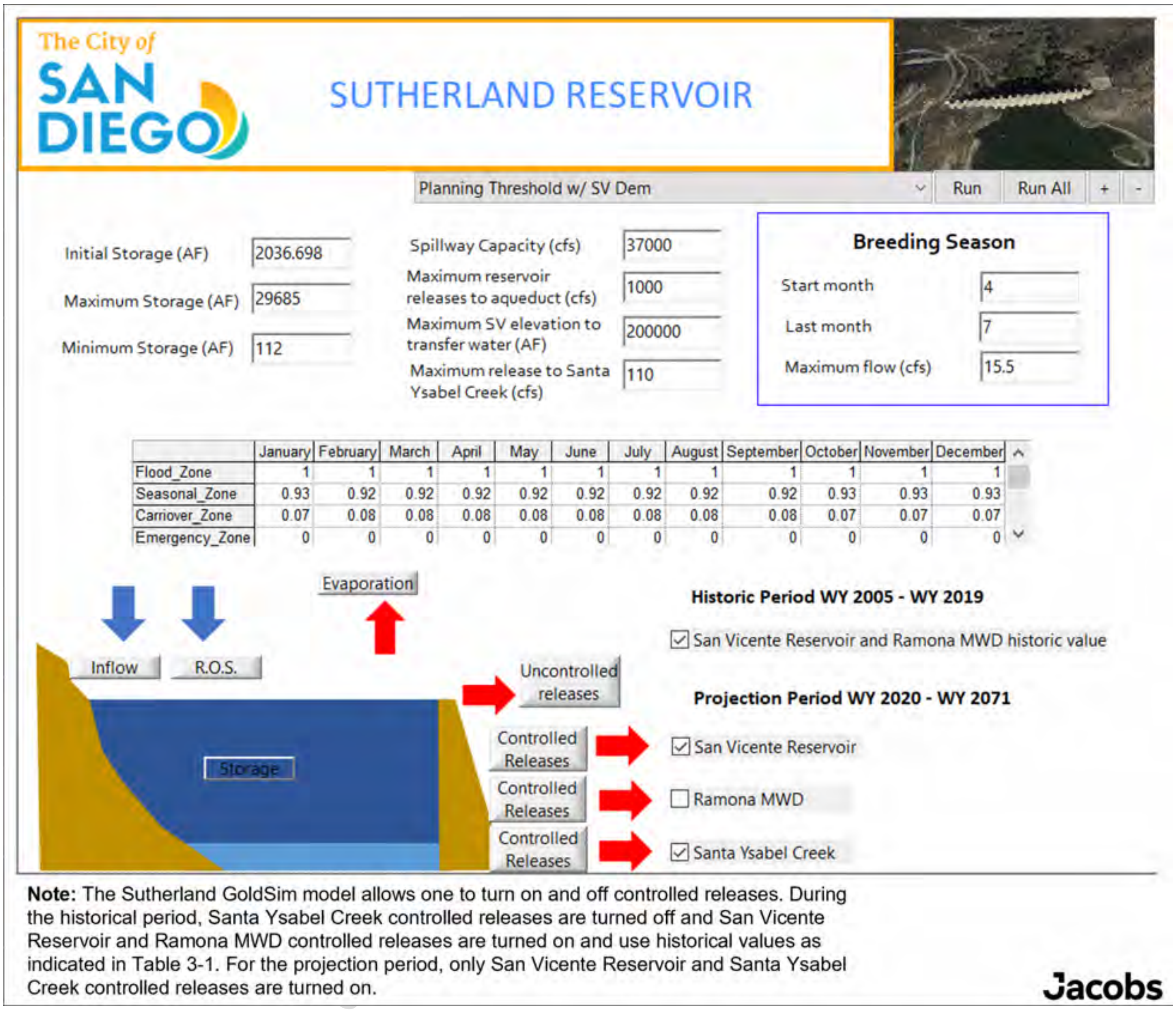


Figure 3-12: Sutherland Reservoir Operation Model Dashboard

Table 3-1: Water Balance Assumptions in GoldSim Model

<table>
<tr><th colspan="2">Water Balance Component</th><th>Historical Period Assumptions
WYs 2005 though 2019</th><th>Projection Period Assumptions
WYs 2020 though 2071</th></tr>
<tr><td rowspan="2">Inflows</td><td>Runoff</td><td colspan="2">Monthly runoff estimates from the USGS Basin Characterization Model (Flint et al., 2013; Flint and Flint, 2014) were aggregated over the contributing watershed area of Sutherland Reservoir for the 67-year simulation period. A bias-correction process was implemented to modify the simulated runoff response from the Basin Characterization Model to be consistent with the City's historical water balance information (City, 2022c). The bias-correction process was then applied to the runoff for the projection period.</td></tr>
<tr><td>Rain on surface</td><td>Monthly volume estimated based on an area versus storage relationship (to determine the surface area) and monthly historical precipitation data provided by the City.</td><td>Monthly volume estimated based on an area versus storage relationship and monthly projected precipitation developed based on projected WY type (see Section 3.1). Average precipitation by WY type were developed based on historic precipitation data.</td></tr>
<tr><td rowspan="5">Outflows</td><td>Evaporation</td><td>Monthly volume estimated based on an area versus storage relationship and evaporation data provided by the City.</td><td>Same approach as projected Rain on Surface but used average evaporation by WY type.</td></tr>
<tr><td>Uncontrolled Releases and Controlled Flood Releases</td><td colspan="2">Uncontrolled flood releases (or spills) are monthly flows estimated based on volume exceeding the maximum storage level of 29,685 AF and up to the spillway capacity of 37,000 cfs. Controlled flood releases can take place when reaching maximum operation volume of 27,000 to 27,300 AF (depending on the month).</td></tr>
<tr><td>Controlled Releases to San Vicente Reservoir</td><td>Historical releases</td><td>• Release up to the maximum outlet capacity determined by storage level (5 cfs to 95 cfs)
• During toad breeding season (April through July), releases were conservatively constrained to a maximum flow of 15.5 cfs
• Assumes San Vicente Storage has available space in the City's account to store releases from Sutherland</td></tr>
<tr><td>Controlled Releases to Ramona MWD</td><td>Historical releases</td><td>No future release</td></tr>
<tr><td>Controlled Releases to Santa Ysabel Creek</td><td>No releases</td><td>Estimated based on target maximum controlled releases and stored water availability (after San Vicente controlled releases). The maximum controlled releases to Santa Ysabel Creek are limited by an assumed maximum capacity of 110 cfs</td></tr>
</table>

The GoldSim model provides an estimate of the water available for controlled releases from Sutherland Reservoir based on the Strategy 2A implementation period and the target maximum controlled releases (see light-blue line in **Figure 3-13**). However, as shown by the orange line in **Figure 3-13**, particularly in the 2061 to 2068 time frame, no water is available for release to Santa Ysabel Creek due to limited water availability from Sutherland Reservoir during dry and critical years. Based on the conditions under which this recharge strategy was modeled, the cumulative water available for controlled releases to meet the monthly target releases is approximately 2,400 AF over the 67-year simulation period (see black line in **Figure 3-13**), or about 36 AFY. For this initial assessment, it was assumed all the water released from Sutherland as controlled releases would be available as additional inflow to the Basin. Additional considerations would need to be made to ensure that losses between Sutherland Reservoir and the Basin are minimized and that controlled Sutherland Releases would be conveyed at a time when efficient streamflow transmission to the Basin could be achieved.

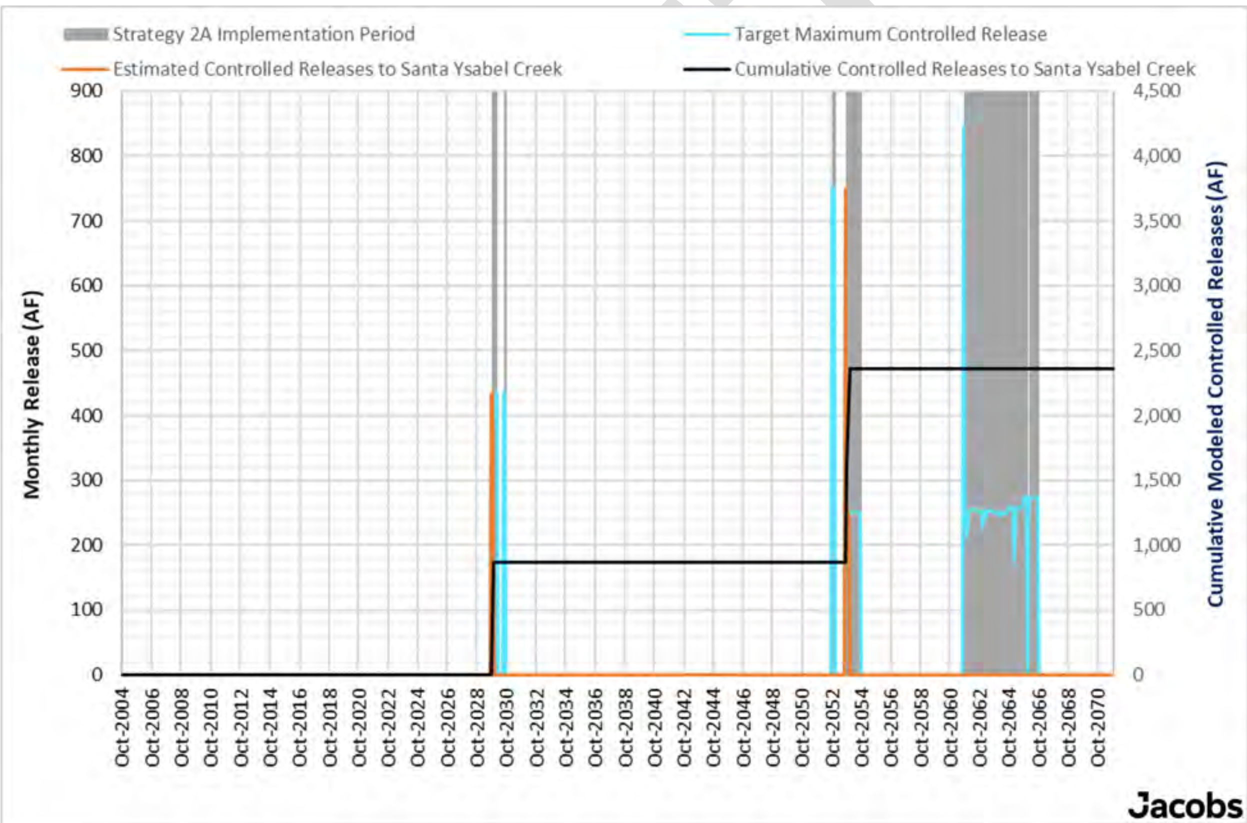


Figure 3-13: Target and Available Controlled Releases from Sutherland Reservoir

The available controlled releases from Sutherland Reservoir were incorporated into the SPV GSP Model v2.0 as additional inflow at the Santa Ysabel Creek inflow location (see blue triangle in **Figure 3-1**). Additional factors not addressed herein would need to be considered if Strategy 2A were to be implemented in the Basin. Examples of such factors include, but are not limited to, the following:

- Whether conveyance losses from the outlet of Sutherland Reservoir to the Basin inflow location could be estimated and refined to better inform the GoldSim model

- Whether the timing and volume of San Vicente Reservoir releases could be modified to make more water available during dry and critical years for controlled releases to Santa Ysabel Creek
- Whether the maximum release capacity to Santa Ysabel Creek with other operational rules not considered herein could result in greater daily controlled releases
- Whether the additional flows in Santa Ysabel Creek may hinder biological function due to the presence of flows during times when the creek would naturally be dry

3.1.3 Strategy 3A–Augment Santa Ysabel Creek Streamflow with Ramona MWD Deliveries

As discussed in the Task 4 TM (City 2023c), the primary objective of Strategy 3A is to augment Santa Ysabel Creek streamflow with deliveries from Ramona MWD. Deliveries of Ramona MWD would occur upstream of River Mile 3 near the San Pasqual Valley Road bridge (see the green triangle in **Figure 3-1**). This location was ultimately determined to maximize the potential for streambed infiltration by conveying water along a realistic hypothetical pipeline route from Ramona MWD's conveyance system to Santa Ysabel Creek and delivering the water in the eastern portion of the Basin. Deliveries from Ramona MWD district would occur based on Conditions 1 and 2 in the decision flow chart of **Figure 3-2**. However, an additional consideration was made beyond these two conditions to establish the Strategy 3A implementation periods. If Conditions 1 and 2 are both met, then Condition 3 addresses whether streamflow is already occurring in Santa Ysabel Creek at River Mile 3 (**Figure 3-1** and **Figure 3-2**). To implement Strategy 3A, streamflow must also be zero at River Mile 3 in Santa Ysabel Creek. Thus, all three conditions must be met before Strategy 3A is implemented (**Figure 3-14)**.

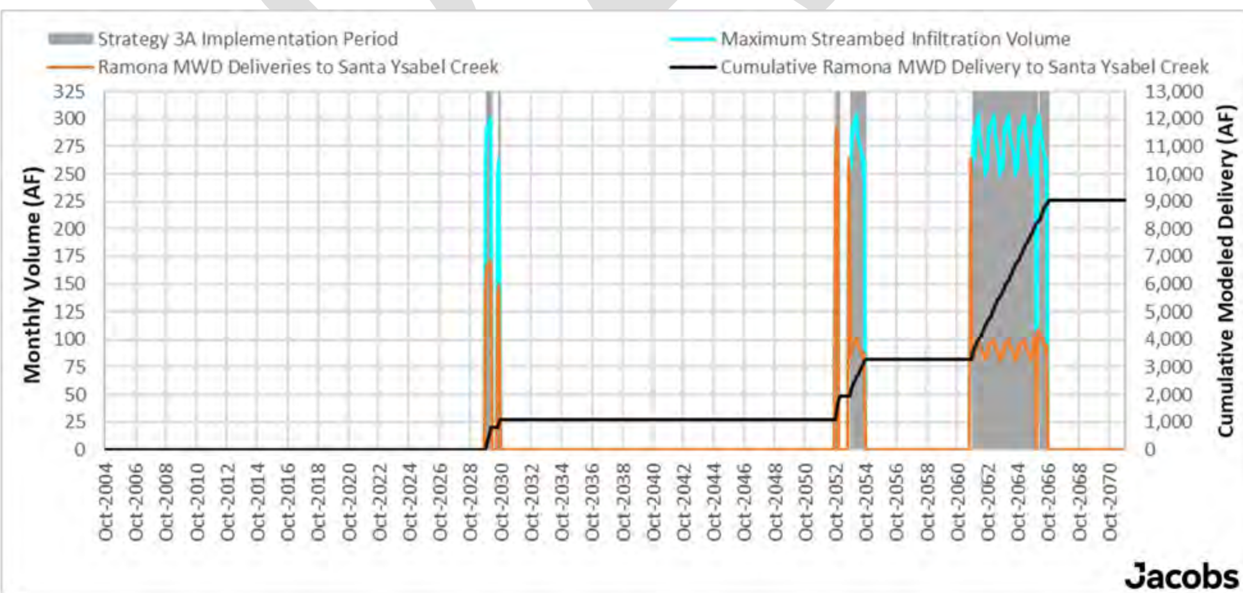


Figure 3-14: Ramona MWD Deliveries to Santa Ysabel Creek

In addition to the three conditions shown in **Figure 3-2**, limits on the deliveries to Santa Ysabel Creek from Ramona MWD were imposed. From the historical Baseline simulation, a monthly maximum streambed infiltration volume of 375 AF was determined for Santa Ysabel Creek between the proposed delivery location and Ysabel Creek Road. Additionally, an annual maximum streambed infiltration volume was determined based on the maximum December through May streambed infiltration volume of 1,100 AF for the same portion of Santa Ysabel Creek. An initial estimate of the maximum Ramona MWD deliveries that the streambed could infiltrate was calculated as the monthly maximum streambed infiltration volume (375 AF) minus the current month's streambed infiltration volume, as modeled in the Baseline simulation (see Maximum Streambed Infiltration Volume as the blue line in **Figure 3-14**). Monthly water available from Ramona MWD (**Table 3-2**) was then accounted for by taking the full amount of water available from Ramona MWD up to the determined monthly maximum streambed infiltration volume. These monthly volumes were then uniformly reduced such that the total annual volume did not exceed the annual maximum streambed infiltration volume (1,100 AF) to establish the Ramona MWD deliveries to Santa Ysabel Creek (**Figure 3-14**). The monthly and annual streambed infiltration volumes were applied to maximize recharge benefits to the Basin while minimizing excess flows across Ysabel Creek Road.

Table 3-2: Monthly Water Volume Available from Ramona Municipal Water District

Month	Available Flow Volume (acre-feet)	Available Flow Volume (gpm)
Jan	296	2,161
Feb[a]	300	2,424
March	304	2,219
April	285	2,150
May	280	2,044
Jun	271	2,044
Jul	267	1,949
Aug	248	1,810
Sep	264	1,991
Oct	255	1,861
Nov	293	2,210
Dec	287	2,095
Total	3,350	2,080[b]

[a] Value assumes a 28-day month.
[b] Value is the average of the monthly values.

The Ramona MWD deliveries developed from this analysis were included in the SPV GSP Model v2.0 as additional inflow to the SFR package at the Ramona MWD delivery location on Santa Ysabel Creek (the green triangle on **Figure 3-1**). The cumulative volume of water made available for recharge from Ramona MWD deliveries was approximately 9,000 AF (see the black line in **Figure 3-14**), or about 134 AFY.

Additional factors not addressed herein would need to be considered if Strategy 3A were to be implemented in the Basin. Examples of such factors include, but are not limited to, the following:

- Whether the conveyance capacity of the pipeline and outfall to Santa Ysabel Creek could be operated to convey the simulated Ramona MWD deliveries
- Whether permitting constraints would constrain operations of this strategy
- Whether concentrations of other constituents in Ramona MWD deliveries not evaluated herein could result in degradation of groundwater quality
- Whether the additional flows in Santa Ysabel Creek may hinder biological function due to the presence of flows during times when the creek would naturally be dry

3.1.4 Strategy 3D–Injection Wells with Ramona MWD Deliveries

As discussed in the Task 4 TM (City, 2023c), the primary goal of Strategy 3D is to recharge water from Ramona MWD directly into the Basin aquifer through injection wells. For the implementation of Strategy 3D, three hypothetical injection well locations were identified (see the yellow circles in **Figure 3-1**). These locations were ultimately determined based on the thickness of aquifer material in this area, proximity to existing agricultural pumping wells, and proximity to proposed pipeline routes from Ramona MWD's conveyance system to the eastern portion of the Basin. Deliveries to the injection wells would occur based on Conditions 1 and 2 in the decision flow chart of **Figure 3-2**. During the Strategy 3D implementation periods, the monthly water available from Ramona MWD (**Table 3-2**) would be conveyed and evenly distributed across each of the three injection wells (**Figure 3-15**).

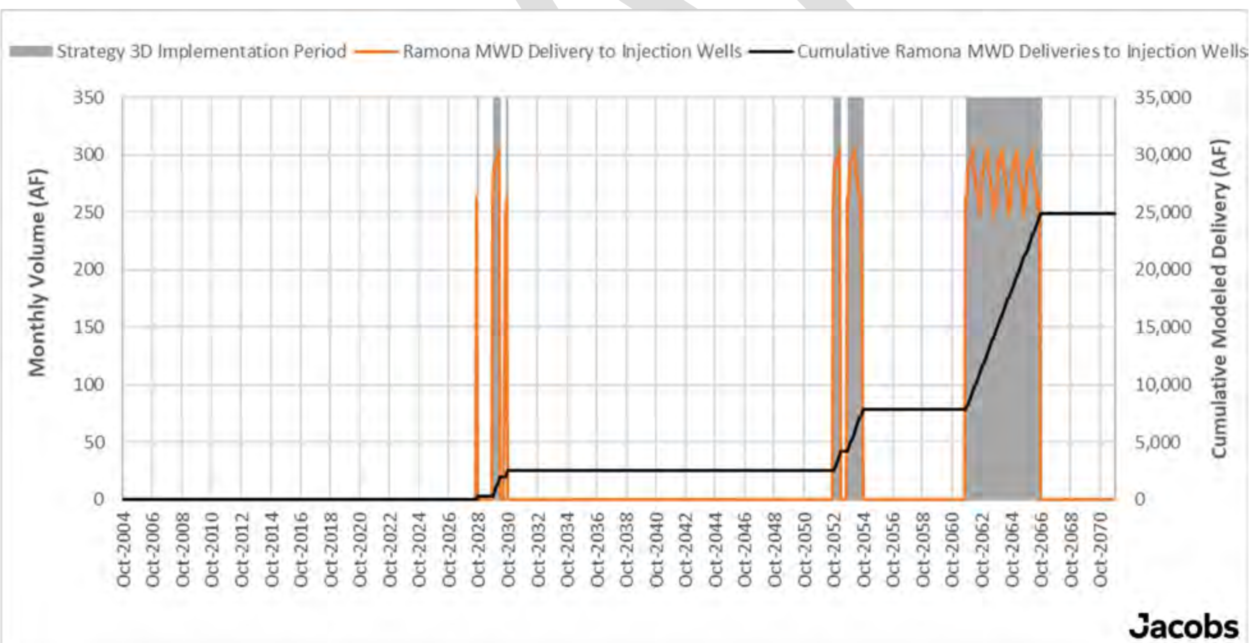


Figure 3-15: Ramona MWD Deliveries to Injection Wells

Injection wells were incorporated into the SPV GSP Model v2.0 using the Multi-Node Well package. Each injection well was assumed to be 12-inch diameter wells with a 50-foot screened interval. The bottom of the screened interval was set to coincide with the bottom of the alluvial aquifer. The Multi-Node Well package allows for constraints that limit how much water can be injected by the wells. For Strategy 3D, the injected water level inside the well was not allowed to go above the land surface. This constraint can reduce the assigned injection rate dynamically during the simulation to prevent water inside the injection well from rising above the land surface. The total surface water made available from Ramona MWD for delivery to injection wells over the 67-year simulation period is 24,874 AF (see the black line in **Figure 3-15**), or about 371 AFY.

Additional factors not addressed herein would need to be considered if Strategy 3D were to be implemented in the Basin. Examples of such factors include, but are not limited to, the following:

- Whether water treatment requirements would affect the rate at which water could be delivered to the injection wells
- Whether injection of water could negatively affect groundwater quality
- Whether injection of water with the modeled rates and locations might cause localized mounding into rooting zone depths that could hinder agricultural operations
- Whether operational considerations would cause downtime of the injection wells that may reduce the overall time that wells could be operated, reducing the volume of water that could be injected into the Basin

3.2 Approach for Evaluating Recharge Strategies

As described in Section 3.1, the modeling approach first required establishing the Baseline simulation, in which the SPV GSP Model v2.0 simulates the same hydrology, land-use, and climate conditions described in the GSP (City and County, 2021). The simulation period for all simulations described in this and later sections of this TM cover the historical period (WYs 2005 through 2019) and the projection period (WYs 2020 through 2071). This Baseline simulation does not incorporate any of the recharge strategies described above. Each recharge strategy simulation is built upon the Baseline simulation, so the effects from implementing the recharge strategy can be isolated by comparing outputs from the recharge strategy simulation against those from the Baseline simulation.

It is important to acknowledge that the western and eastern portions of the Basin have distinctly different depths to water and potential GDE characteristics (refer to Section 8 of the GSP [City and County, 2021] for more details). Therefore, to facilitate processing simulation results in a meaningful and consistent manner, the Basin was subdivided near the western edge of the confluence of Santa Ysabel Creek and Santa Maria Creek into the Western Subarea and Eastern Subarea (**Figure 3-15**). Processed outputs include groundwater budget summaries for the Eastern Subarea, groundwater-level hydrographs at RMWs, streamflow in modeled streams, and groundwater recharge from streams in the Eastern Subarea. Computing groundwater budgets for the Eastern Subarea for this Initial Surface Water Recharge Evaluation is appropriate because most stream recharge in the Basin occurs in the Eastern Subarea. Furthermore, groundwater levels at domestic and irrigation wells in the Eastern Subarea are more vulnerable to dropping below minimum thresholds during drought conditions, as compared with groundwater levels in the Western Subarea. Processing groundwater budgets for the Eastern Subarea allows for a better understanding of each strategy's benefit without inadvertently "averaging out" the modeled benefits over the entire Basin.

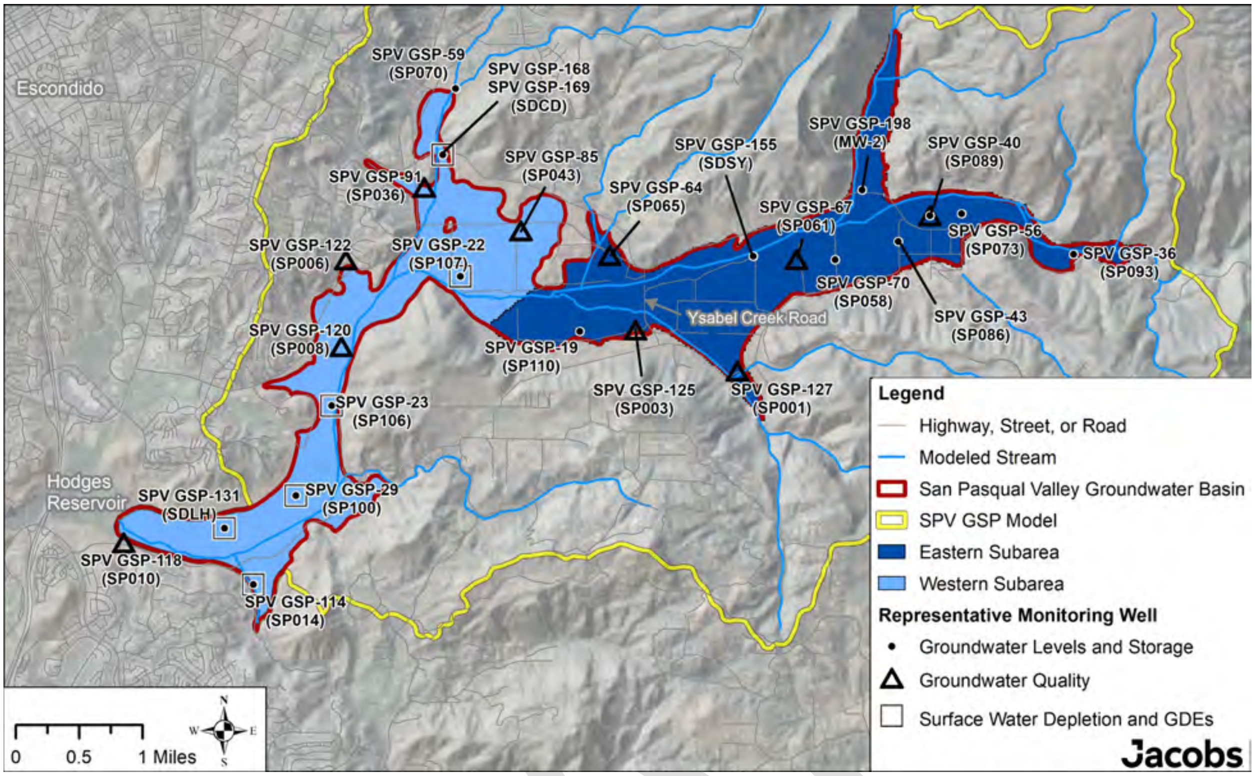


Figure 3-16: Representative Monitoring Well Locations and Basin Subareas

Model outputs were used to provide values for the metrics associated with six of the eight evaluation criteria established in the Task 1 TM (City, 2022a). Because Evaluation Criteria 7 and 8 are not individually based on simulation output, the findings for these two criteria will be presented in the draft Preliminary Feasibility Study, which will be completed in late 2023. The metrics and evaluation approach associated with the first six evaluation criteria are summarized in **Table 3-3**, along with the weighting values that were developed collaboratively with Basin stakeholders during preparation of the Task 1 TM (City, 2022a). Thus, the weighting values shown in **Table 3-3** reflect the priorities of the City and Basin stakeholders. The following subsections provide additional details for the criterion-specific evaluation approach.

Table 3-3: Evaluation Criteria Metrics and Evaluation Approach Summary

Criterion[a]	Metric	Evaluation Approach	Weighting (%)
Criterion 1: Reduction of Modeled Deficit in Groundwater Storage	Average change in modeled groundwater storage in Eastern Subarea for WYs 2005 through 2071	Average change in modeled groundwater storage in a recharge strategy simulation minus that in the Baseline simulation over the 67-year simulation period	13
Criterion 2: Average Reduction of Depth to Water	Modeled depths to water at groundwater-level RMWs[b] during extended drought periods[c]	Sum of modeled depths to water at RMWs in the Baseline simulation minus those in a recharge strategy simulation divided by the number of simulation days, divided by the number of groundwater-level RMWs	7
Criterion 3: Fewer Exceedances of Minimum Thresholds	Modeled groundwater levels at groundwater-level RMWs[b]	Number of occurrences when modeled groundwater levels at RMWs are below Minimum Thresholds in the Baseline simulation minus that in a recharge strategy simulation over the 67-year simulation period	18
Criterion 4: Efficiency of Recharge Strategy	Percentage of water made available with the recharge strategy that recharges the aquifer in Eastern Subarea for WYs 2005 through 2071	Calculated as 1 minus the loss. The loss is computed as the modeled streamflow across Ysabel Creek Road in a recharge strategy simulation minus that in the Baseline simulation divided by the total volume of surface water made available with the recharge strategy over the 67-year simulation period.	18
Criterion 5: Average Reduction of Groundwater TDS Concentration	Estimated groundwater TDS concentrations at selected RMWs[b] in Eastern Subarea for WYs 2005 through 2071	Estimated average groundwater TDS concentration in the Baseline simulation minus that in a recharge strategy simulation over the 67-year simulation period	7
Criterion 6: Fewer Consecutive Days Groundwater Levels are Below 30-feet bgs	Modeled groundwater levels at GDE RMWs[b]	Average number of consecutive days modeled depths to water occur below 30-feet below ground surface in the Baseline Simulation minus that from a recharge strategy simulation over the 67-year period	7

[a] Because Criteria 7 and 8 are not individually based on model output and are not shown in this table, the weights do not add up to 100%. The findings for these two criteria will be presented in the draft Preliminary Feasibility Study, which will be completed in late 2023.
[b] RMW locations are shown in **Figure 3-15**.
[c] Extended drought periods are defined as having three or more consecutive dry or critically dry years. Extended drought periods during the projected period include WYs 2029 through 2032, 2040 through 2043, 2054 through 2056, and 2061 through 2068.

3.2.1 Evaluation Approach for Criterion 1

The evaluation approach for Criterion 1 focuses on quantifying the reduction of the modeled deficit in groundwater storage by implementing a recharge strategy. Groundwater inflows and outflows were summarized for the Eastern Subarea and used to compute changes in groundwater storage (groundwater inflows minus groundwater outflows) for each WY. An average change in groundwater storage value was calculated for the Baseline simulation and each recharge strategy simulation over the 67-year period for use in the evaluation approach for Criterion 1.

3.2.2 Evaluation Approach for Criteria 2, 3, and 6

Criteria 2, 3, and 6 all focus on modeled groundwater levels from the recharge strategy simulations as compared with those from the Baseline simulation (**Table 3-3**). As such, modeled groundwater-level hydrographs were prepared and include modeled groundwater levels for the Baseline simulation and each of the four recharge strategy simulations over the 67-year simulation period. These groundwater-level hydrographs are discussed in Section 3.3. Groundwater-level data associated with these hydrographs were processed to obtain depth-to-water values and to evaluate groundwater levels relative to groundwater-level thresholds including Minimum Thresholds for Criterion 3 and a GDE threshold of 30-feet below ground surface (bgs) for Criterion 6.

3.2.3 Evaluation Approach for Criterion 4

Criterion 4 evaluates the efficiency of recharge associated with each recharge strategy as defined by the goal of maximizing recharge benefits to the Basin while minimizing excess streamflow at Ysabel Creek Road. The cumulative volume of surface water made available for recharge was determined during the approach for simulating recharge strategies (Section 3.1). As this volume of water is introduced to the Basin, the unintended consequence of excess streamflow leaving the eastern portion of the Basin could occur. This excess streamflow is compared to the volume of water made available for recharge as a means of determining how efficient the recharge strategy is at benefiting the Basin.

3.2.4 Evaluation Approach for Criterion 5

Criterion 5 seeks to estimate how total dissolved solids (TDS) concentrations in groundwater might change in response to implementing a recharge strategy. Other constituents such as nitrate could be assessed as part of a future evaluation, if necessary. Measured TDS concentrations at groundwater-quality RMWs east of Ysabel Creek Road and raw water TDS concentrations from Ramona MWD's untreated water system and Sutherland Reservoir were evaluated to estimate how the mixing of these source waters with Basin groundwater could affect groundwater TDS concentrations east of Ysabel Creek Road. Measured TDS concentrations for these wells and source waters are provided in **Figure 3-17**.

Groundwater TDS concentrations east of Ysabel Creek Road depend on the following:

- Volumes of surface waters and groundwater and the associated TDS concentrations in those waters entering the eastern portion of the Basin
- Volume of groundwater and the associated TDS concentrations exiting the eastern portion of the Basin across Ysabel Creek Road

Because the SPV GSP Model v2.0 is a flow model and not a transport model, it cannot be directly used to compute TDS concentrations. However, the volumes of flow computed by the SPV GSP Model v2.0 can be used along with measured TDS concentrations shown in **Figure 3-17** to perform mixing calculations in a spreadsheet. The result of these mixing calculations approximates groundwater TDS concentrations in the eastern portion of the Basin through time for the Baseline simulation and each recharge strategy simulation.

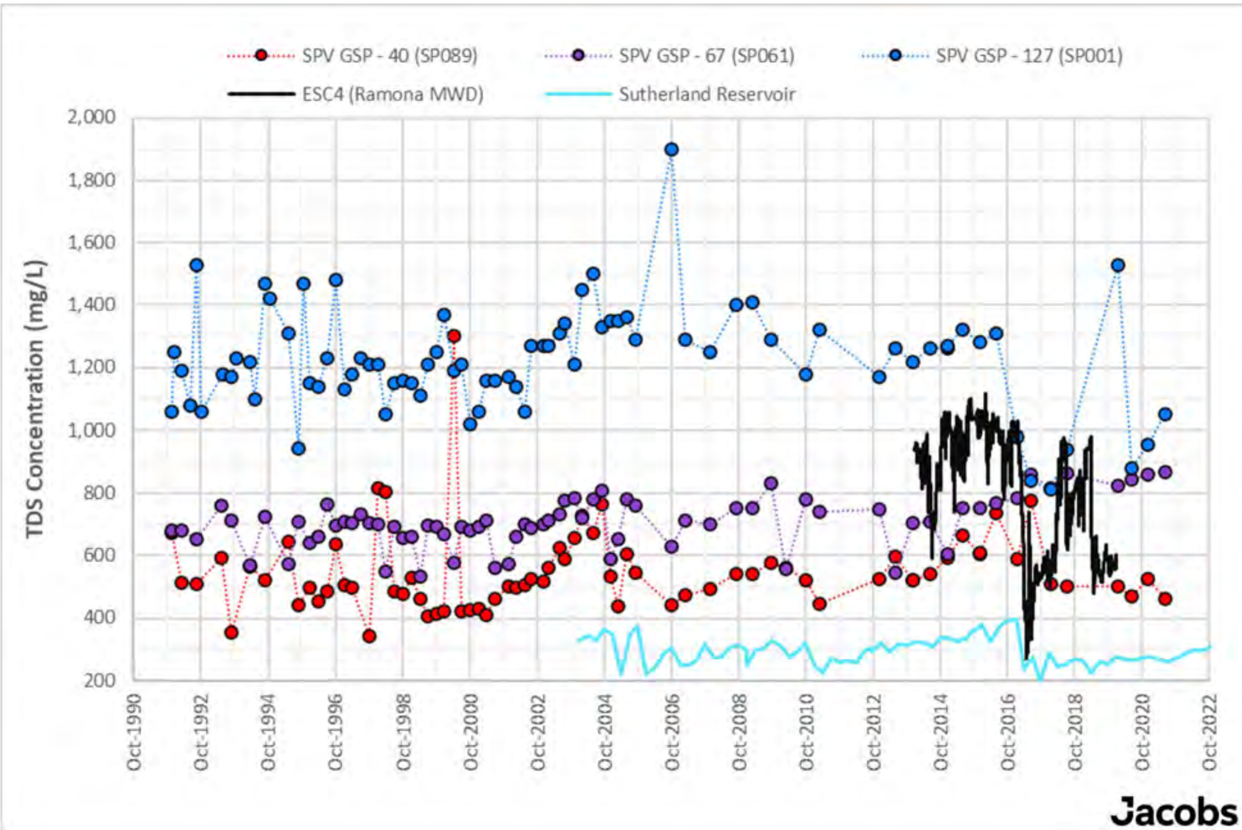


Figure 3-17: Historical TDS Concentrations in Surface Water and Groundwater

3.3 Results for Recharge Strategy Simulations

Using the approach described in Section 3.2, modeled outputs from the Baseline and recharge strategy simulations were processed to support the evaluation of the recharge strategies. Results for each criterion's metric are shown in **Table 3-4**. The larger positive values in **Table 3-4** indicate larger benefits from implementing the recharge strategy, based on simulation results. Criterion-specific details are further discussed below.

Table 3-4: Summary of Results for Evaluation Criteria

Recharge Strategy	Criterion 1 Reduction of Modeled Deficit in Groundwater Storage (AF)	Criterion 2 Average Reduction of Depth to Water (feet bgs)	Criterion 3 Fewer Exceedances of Minimum Thresholds (count)	Criterion 4 Efficiency of Recharge Strategy (percent)	Criterion 5 Average Reduction of Groundwater TDS Concentration (mg/L)	Criterion 6 Fewer Consecutive Days Groundwater Levels are Below 30-feet bgs
1B–Enhance Streamflow Infiltration with In-stream Modifications	-1	0	4	110	-0.3	0
2A–Augment Streamflow with Sutherland Controlled Releases	0	1	41	84	3.1	1
3A–Augment Streamflow with Ramona MWD Deliveries	17	4	208	93	3.1	2
3D–Injection Wells with Ramona MWD Deliveries	80	10	476	97	6.7	10
Evaluation Criteria 7 (cost) and 8 (feasibility) will be presented in the draft Preliminary Feasibility Study, which will be completed in 2023. Larger positive values indicate larger benefits from implementing the recharge strategy.						

3.3.1 Reduction of Modeled Deficit in Groundwater Storage

Criterion 1 evaluates the change in groundwater storage in the Eastern Subarea over the 67-year simulation period. The cumulative change in groundwater storage was processed for each model simulation and plotted for comparative purposes. The chart in **Figure 3-18** shows that the cumulative changes in groundwater storage for all simulations are very similar for most of the simulation period. This is supported by the small values listed in **Table 3-4** under Criterion 1. Periods in which there are larger deviations in the cumulative change in groundwater storage coincide with droughts and periods following droughts, which is consistent with the general timing for when Strategies 2A, 3A, and 3D are implemented. Note that none of the strategies stabilize long-term groundwater levels, which would appear as a line that trends horizontally as opposed to the lines in **Figure 3-18** that have long-term downward trends.

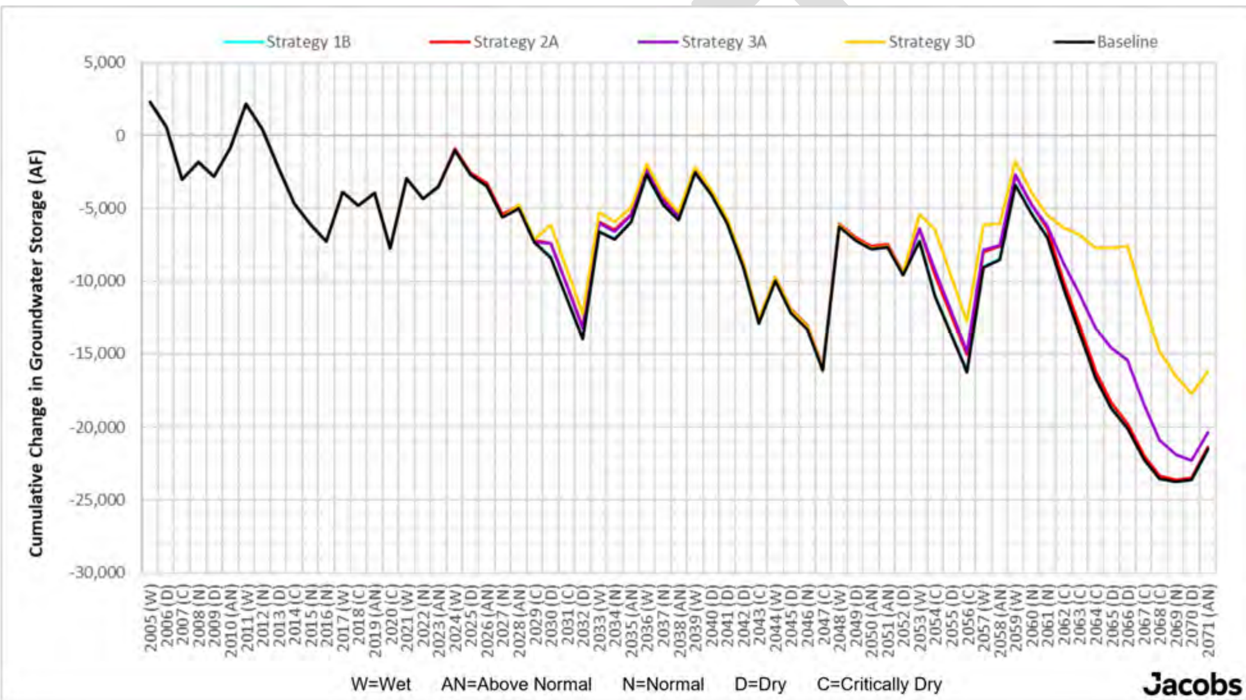


Figure 3-18: Modeled Cumulative Change in Groundwater Storage

Overall, Strategy 3D provides the greatest improvement in groundwater storage (represented as the largest reduction in the modeled deficit in groundwater storage), as compared with the Baseline simulation, followed by Strategy 3A, Strategy 2A, and then Strategy 1B (**Table 3-4**). Note that the yellow line associated with Strategy 3D in **Figure 3-18** does not drop as low during extended drought periods as the Baseline or other strategies. Because Strategy 3D would involve directly recharging the aquifer in the Eastern Subarea, it has the greatest effect on groundwater storage of the four recharge strategies. The light blue line associated with Strategy 1B is not visible in **Figure 3-18** because it is very similar to and obscured by the black line of the Baseline simulation. Overall, Strategies 3A and 3D tend to simulate the greatest reduction in the modeled deficit in cumulative groundwater storage, representing the largest benefit in groundwater storage. This is because source water availability is greatest from Ramona MWD as compared with Sutherland Reservoir under Strategy 2A.

3.3.2 Average Reduction of Depth to Water

Criterion 2 evaluates the change in depth to water at groundwater-level RMWs during four extended droughts that occur in the projection period. Groundwater-level hydrographs for the Baseline simulation and each recharge strategy simulation at all RMWs are included in Attachment E for the 67-year simulation period. These groundwater-level hydrographs were processed for use in the evaluation of Criterion 2. For Criterion 2, extended drought periods were focused on for this criterion's metric to better evaluate how the recharge strategies influence depth to water during stressed conditions in the Basin. The evaluation approach looks at the average change in depth to water across all groundwater-level RMWs as compared with Baseline conditions. As with Criterion 1, implementation of Strategy 3D would have the greatest average reduction of depths to water, representing the greatest benefit to modeled groundwater levels, and Strategy 1B would have no discernible effect on depths to water, according to the model. Note that the yellow line associated with Strategy 3D in the hydrographs in Attachment E is higher in elevation during drier conditions. Because Strategy 3D would involve directly recharging the aquifer in the Eastern Subarea, it has the greatest effect on groundwater levels of the four recharge strategies.

3.3.3 Fewer Exceedances of Minimum Thresholds

Criterion 3 evaluates the number of exceedances of minimum thresholds at groundwater-level RMWs for the Baseline simulation and each recharge strategy simulation. Although exceedances of minimum thresholds can occur without triggering undesirable results, having fewer exceedances can be viewed as having greater resilience against undesirable results. Like Criteria 1 and 2, Strategy 3D has the largest reduction in exceedances of minimum thresholds followed by Strategy 3A, Strategy 2A, and Strategy 1B (same order as Criteria 1 and 2). Strategy 3D includes twice the reduction of exceedances in minimum thresholds as compared to Strategy 3A due to the proximity of injection wells to RMWs where the response of the groundwater levels to nearby injection of water is greatest in the model (**Table 3-4**).

3.3.4 Efficiency of Recharge Strategy

Criterion 4 quantifies the efficiency of the recharge strategy based on the goal of maximizing benefits to the Basin, while minimizing excess streamflow across Ysabel Creek Road. For this criterion, the cumulative volume of surface water made available for recharge was quantified based on the implementation of each recharge strategy, as discussed in Sections 3.1.1 through 3.1.4. The modeled flows used to compute the efficiencies listed in **Table 3-4** under Criterion 4 are listed in **Table 3-5**. The initial volume of surface water made available for recharge for Strategy 3D was 24,874 AF over the 67-year simulation period. During the model simulation injection rates were automatically reduced at specific wells to avoid having water levels inside the injection wells rise above land surface, reducing the total volume of surface water made available to 23,264 AF (**Table 3-5**). The cumulative streamflow volume across Ysabel Creek Road was quantified for the Baseline simulation and each recharge strategy simulation. Each recharge strategy, except for Strategy 1B, caused an increase in streamflow across Ysabel Creek Road, as compared with the Baseline simulation. Strategy 1B simulates a reduction in streamflow across Ysabel Creek Road, as compared with the Baseline simulation, by detaining stormwater that would have otherwise crossed Ysabel Creek Road. This is why the efficiency listed in **Table 3-4** under Criterion 4 for Strategy 1B is greater than 100%. All recharge strategies achieved efficiencies greater than 80%.

Table 3-5: Summary of Modeled Flow for Criterion 4

Strategy	Cumulative Volume of Surface Water Made Available (AF)	Cumulative Streamflow Across Ysabel Creek Road (AF)	Difference in Cumulative Streamflow Across Ysabel Creek Road as Compared with Baseline Simulation (AF)
Baseline	0	587,938	-
Strategy 1B	720	587,863	-75
Strategy 2A	2,363	588,306	368
Strategy 3A	9,063	588,581	643
Strategy 3D	23,264	588,572	634

3.3.5 Average Reduction of Groundwater TDS Concentration

Criterion 5 addresses potential changes in groundwater quality conditions in the Eastern Subarea due to implementation of recharge strategies. The water quality constituent evaluated for this criterion is TDS. Using the mixing-calculation approach described in Section 3.2.4, groundwater TDS concentrations throughout the 67-year simulation period were approximated for the Baseline simulation and each recharge strategy simulation (**Figure 3-19**). Overall, groundwater TDS concentrations from each recharge strategy show minor deviations from the Baseline simulation. Improvements to groundwater TDS concentrations occur for Strategies 2A, 3A, and 3D during the periods when water is imported to the Basin for these strategies from Sutherland Reservoir and Ramona MWD's untreated water system. Strategy 2A tends to show greater improvements in TDS concentrations as compared with Strategies 3A and 3D when controlled releases from Sutherland Reservoir occur (see periods when the red line is below all other lines in **Figure 3-19**). This is a result of Sutherland Reservoir having a lower TDS concentration as compared with water from Ramona MWD (**Figure 3-17**).

3.3.6 Fewer Consecutive Days Groundwater Levels are Below 30 Feet Below Ground Surface

Criterion 6 quantifies possible benefits to potential GDEs by evaluating the number of consecutive days that modeled groundwater levels are below a 30-foot bgs threshold at GDE RMWs (locations of GDE RMWs are symbolized as open squares in **Figure 3-15**). GDE RMWs tend to be in the Western Subarea of the Basin where groundwater levels are shallower than groundwater levels in the Eastern Subarea. As a result, the implementation of recharge strategies in the Eastern Subarea has minimal influence on groundwater levels at GDE RMWs. The largest change in the number of consecutive days that groundwater levels were below 30-feet bgs occurred with Strategy 3D with 10 fewer consecutive days. Strategy 3A, followed by Strategy 2A produced the next largest change in consecutive days with Strategy 1B having no influence on water levels relative to 30-feet bgs at GDE RMWs (**Table 3-4**).

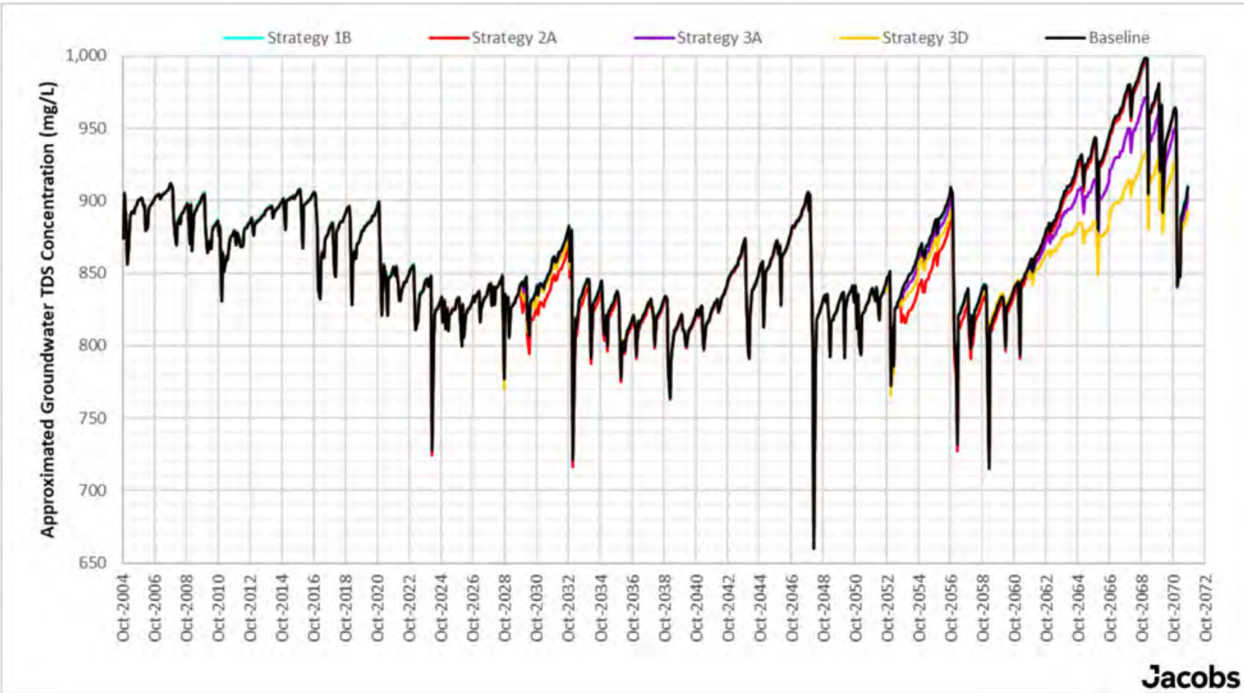


Figure 3-19: Approximated Average Groundwater TDS Concentrations

3.4 Sensitivity Analysis

According to the discussion in Section 3.3, Strategy 1B performed the worst of all four strategies because the height of the dam limits the volume of stormwater that can be detained and the area over which additional infiltration can occur, relative to the Baseline simulation. The simulation results highlight the fact that Santa Ysabel Creek has a high infiltration capacity on its own without implementing an inflatable rubber dam as an in-stream modification. The additional groundwater recharge from the detained water in the Strategy 1B simulation was small enough that considering variations of Strategy 1B any further would provide little value. However, to gain additional insights into the performances of Strategies 2A, 3A, and 3D, different operational variations were considered as part of a sensitivity analysis. The sensitivity analysis was set up to address the following question:

If Strategies 2A, 3A, and 3D had been implemented more frequently than the simulations described in Sections 3.1 through 3.3, how might that have affected the number of exceedances of minimum thresholds (Criterion 3) and the efficiency of recharge (Criterion 4)?

These two criteria were selected to summarize the results of the sensitivity analysis because they received the highest evaluation criteria weighting values (City, 2022a) (**Table 3-3**). The most efficient way to change the timing for when Strategies 2A, 3A, and 3D were implemented in the sensitivity analysis simulations was to consider a more stringent Condition 1 (**Figure 3-2**). The operational variations incorporated into the sensitivity analysis consider a change in the SPV GSP-43 (SP086) water-level trigger to include an offset of 10 feet above the PT. The PT at this well is elevation 347.4 feet. Thus, for this sensitivity analysis, Condition 1 was met when modeled groundwater levels dropped below a level that is 10 feet above the PT at well SPV GSP-43 (SP086), which equates to an elevation of 357.4 feet. This operational variation should in no way be interpreted to mean that the PT for well SPV GSP-43 (SP086) is inadequate or that the modeling team is proposing a different PT for this RMW. Implementing a vertical offset of 10 feet from the PT at this well was done purely out of mathematical convenience to incorporate the desired effect in the sensitivity analysis simulations to answer the question posed above in this section.

Sensitivity results for Criteria 3 and 4 for Strategies 2A, 3A, and 3D are presented in **Figure 3-20**. All three sensitivity analysis simulations achieved fewer exceedances of minimum thresholds (note the difference between the blue bars and orange bars in the left chart of **Figure 3-20**). For example, the sensitivity analysis simulation for Strategy 2A has 109 fewer exceedances (orange bar) than the Baseline simulation, as compared with the original Strategy 2A simulation, which had only 41 fewer exceedances (blue bar) than the Baseline simulation. Thus, as action is taken sooner and more often, more recharge water is made available to the Basin in the simulation, resulting in greater benefit to the Basin in terms of having fewer exceedances of minimum thresholds.

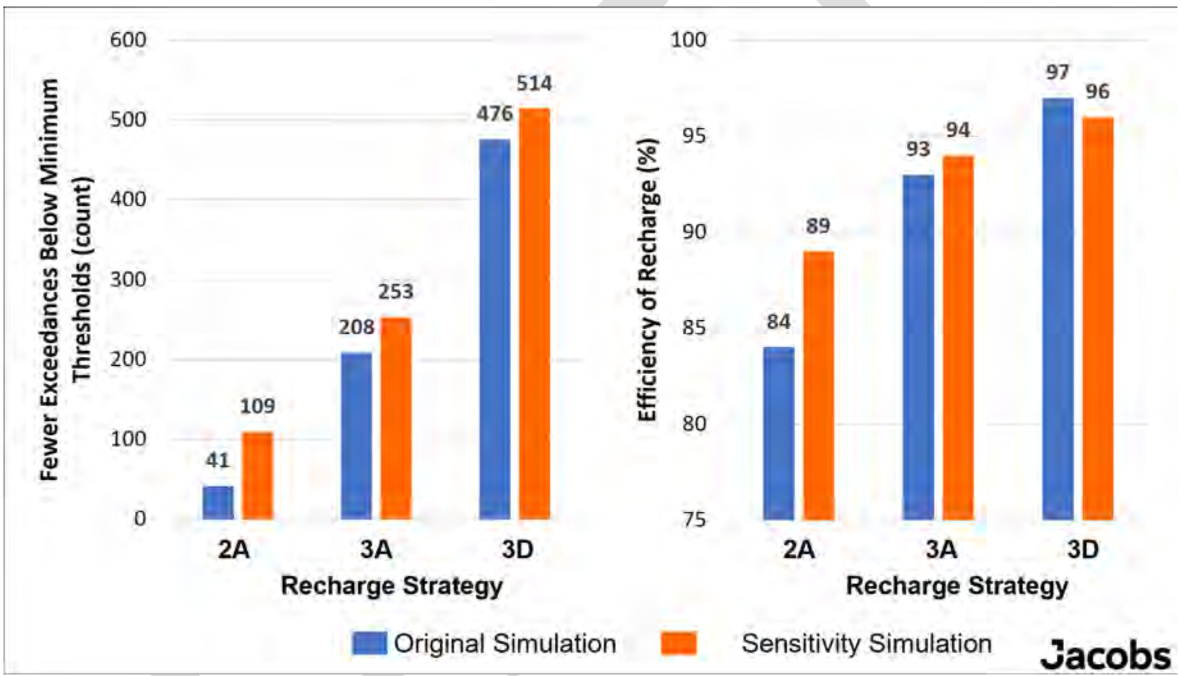


Figure 3-20: Sensitivity Analysis Results for Criteria 3 and 4

For Criterion 4, Strategies 2A and 3A both simulate an increase in the efficiency of recharge with the sensitivity analysis simulations (note the orange bars are taller than the blue bars in the right chart of **Figure 3-20** for Strategies 2A and 3A). This indicates that the additional water introduced to the Basin did not proportionally increase excess streamflow across Ysabel Creek Road. Thus, the timing and volume of releases and deliveries occurred at times when benefits to the Basin could be maximized. Strategy 3D, however, simulated a small reduction in efficiency (orange bar) as compared with the original Strategy 3D simulation (blue bar), which is a result of increasing groundwater levels enough to induce greater streamflow across Ysabel Creek Road.

3.5 Results Summary

The updated SPV Model v2.0 provided an improved understanding of groundwater changes in the Basin under Baseline conditions and if each of the four recharge strategies were implemented under the conditions described in this TM. The approach of utilizing the PT exceedance at SPV GSP-43 (SP086) and a 2-year look-ahead at WY type to determine the timing of recharge strategies helped to ensure that the recharge strategies were implemented during the most challenging periods and assessed using the similar implementation conditions. Additional considerations were made depending on the recharge strategy that aimed to maximize benefits to the Basin while minimizing excess flow across Ysabel Creek Road. Overall, each recharge strategy maintained an efficiency greater than 80% based on the recharge implementation approaches. The operational variation for recharge strategy implementation explored in the sensitivity analysis (Section 3.4) highlights that the timing of implementation of a recharge strategy is an important consideration to maximize benefits to the Basin while minimizing excess streamflow across Ysabel Creek Road.

Although the simulations of recharge strategies show positive benefits toward enhancing resilience against undesirable results, the simulations also highlight the limitations of the recharge strategies. The maintenance of modeled groundwater levels in the eastern portion of the Basin during extended drought periods will be challenging, as modeled groundwater levels under each recharge strategy show long-term declines in groundwater levels. With reduced natural aquifer replenishment due to extended droughts, recharge strategies (or demand reduction) would need to be implemented to avoid exceeding minimum thresholds and possible undesirable results. Depending on the availability of water from sources outside of the Basin and the frequency and duration of dry years, implementing more than one recharge strategy at a time, or combining a strategy with other options may be necessary to achieve sustainability. Doing so would provide the most operational flexibility to conjunctively manage the Basin's water resources. It may also be possible that selecting different conditions under which a recharge strategy is implemented could also provide additional benefits to the Basin not modeled as part of this study. As modeled, results suggest that the individual strategies alone might not be adequate to meet long-term sustainability goals.

Overall, the recharge strategies implemented in the Eastern Subarea had minimal influence on modeled groundwater levels in the Western Subarea.

Results from this effort will be used to help develop two additional documents: the Task 6 TM, which will use the simulation results described herein to assess possible benefits to potential GDEs from implementing the four recharge strategies and the Preliminary Feasibility Study. The draft Preliminary Feasibility Study will be completed in 2023.

4. NEXT STEPS

Evaluation criteria results described in Section 3.3 for each of the four recharge strategies will be used to help develop two additional documents: the Task 6 TM, which will use the simulation results described in this TM to assess possible benefits to potential GDEs from implementing the four recharge strategies and the draft Preliminary Feasibility Study, which will be completed in 2023. During the development of the Preliminary Feasibility Study the results shown in **Table 3-4** will be further evaluated and ranked. Additionally, Criteria 7 (cost) and 8 (feasibility) will also be evaluated during the ranking process.

Because long-term groundwater level trends for Baseline conditions and for each of the recharge strategies show long-term declines in groundwater levels, the following studies are recommended to better understand the recharge strategies, should they require implementation as part of adaptive management to avoid undesirable results:

- Follow-on study of potential losses due to conveyance from Sutherland Reservoir to the Santa Ysabel Creek inflow point to the Basin
- Follow-on modeling of Sutherland Reservoir operations linked to regional system to further optimize water resources.
- System-wide reservoir water supply analysis to determine alternative conjunctive-use strategies
- Pilot study to assess the viability of injection well operation, if the GSA chooses to further assess Strategy 3D
- Assessment of potential for ecosystem impacts from addition of supplemental water into Santa Ysabel Creek
- Assess and update water-use agreements with water purveyors in the region to support future flexibility of recharge strategies in the Basin

5. REFERENCES

Boyce, S.E., Hanson, R.T., Ferguson, I., Schmid, W., Henson, W., Reimann, T., Mehl, S.M., and M. Earll. 2020. *One-Water Hydrologic Flow Model: A MODFLOW based conjunctive-use simulation software: U.S. Geological Survey Techniques and Methods 6–A60*. 435 p., https://doi.org/10.3133/tm6a60.

Chow, V.T. 1959. *Open-Channel Hydraulics.* McGraw-Hill, New York.

City of San Diego (City) and County of San Diego (County). 2021. *Final San Pasqual Valley Groundwater Basin Groundwater Sustainability Plan.* Prepared by Woodard & Curran. September.

City of San Diego (City). 2022a. *Technical Memorandum. Project Management Action (PMA) No. 7: Initial Surface Water Recharge Evaluation, Task 1: Development of Evaluation Criteria.* Prepared by Woodard & Curran. May.

City of San Diego (City). 2022b. *Spillway capacity curve of Sutherland Reservoir*. Data provided in spreadsheet format by the City of San Diego Public Utilities Department of Production Engineering. File: Sutherland Spillway Capacity.xlsx.

City of San Diego (City). 2022c. *Sutherland Monthly Historic Hydrograph for the period of March 1954 – May 2022.* Data provided in spreadsheet format by the City of San Diego Public Utilities Department of Production Engineering. May.

City of San Diego (City). 2022d. *Responses to information requests on Sutherland Reservoir from the City of San Diego Public Utilities Department of Production Engineering.* Data provided by the City of San Diego Public Utilities Department of Production Engineering. File: WPD Responses_Sutherland Reservoir Information Request.pdf. July.

City of San Diego (City). 2023a. *Technical Memorandum. Project Management Action (PMA) No. 7: Initial Surface Water Recharge Evaluation, Task 2: Streambed Investigation.* Prepared by Jacobs. January.

City of San Diego (City). 2023b. *Technical Memorandum. Project Management Action (PMA) No. 7: Initial Surface Water Recharge Evaluation, Task 3: Water Sources for Potential Recharge.* Prepared by Jacobs and Woodard & Curran. January.

City of San Diego (City). 2023c. *Technical Memorandum. Project Management Action (PMA) No. 7: Initial Surface Water Recharge Evaluation, Task 4: Potential Recharge Strategies.* Prepared by Jacobs and Woodard & Curran. May.

Flint, L.E., Flint, A.L., Thorne, J.H., and R. Boynton. 2013. Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance. Ecol Process 2, 25 (2013). https://doi.org/10.1186/2192-1709-2-25.

Flint, L.E. and A.L. Flint. 2014, California Basin Characterization Model: A Dataset of Historical and Future Hydrologic Response to Climate Change, (ver. 1.1, May 2017): U.S. Geological Survey Data Release, https://doi.org/10.5066/F76T0JPB.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater.* Prentice Hall, Englewood Cliffs, New Jersey 07632. 604 p.

Johnson, A.I. 1963. *A Field Method for Measurement of Infiltration.* U.S. Geological Survey Water-Supply Paper 1544-F. URL: https://pubs.er.usgs.gov/publication/wsp1544F.

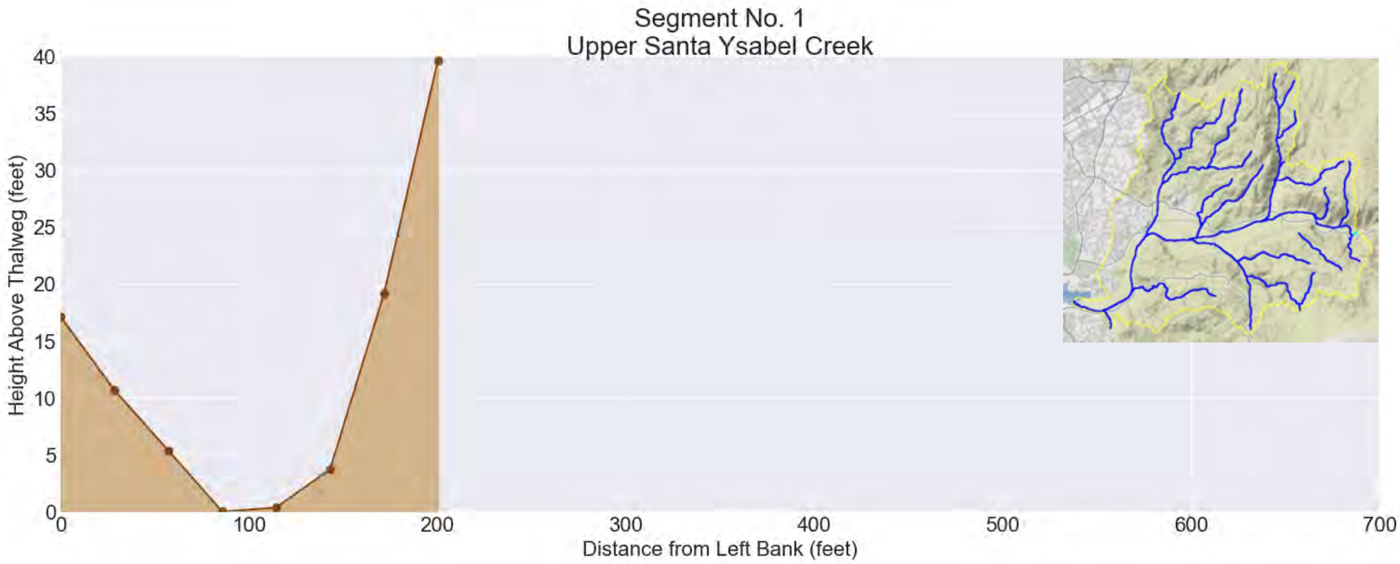
Niswonger, R.G., and D.E. Prudic. 2005. *Documentation of the Streamflow-Routing (SFR2) Package to Include Unsaturated Flow Beneath Streams—A modification to SFR1.* U.S. Geological Survey Techniques and Methods 6-A13, 50 p.

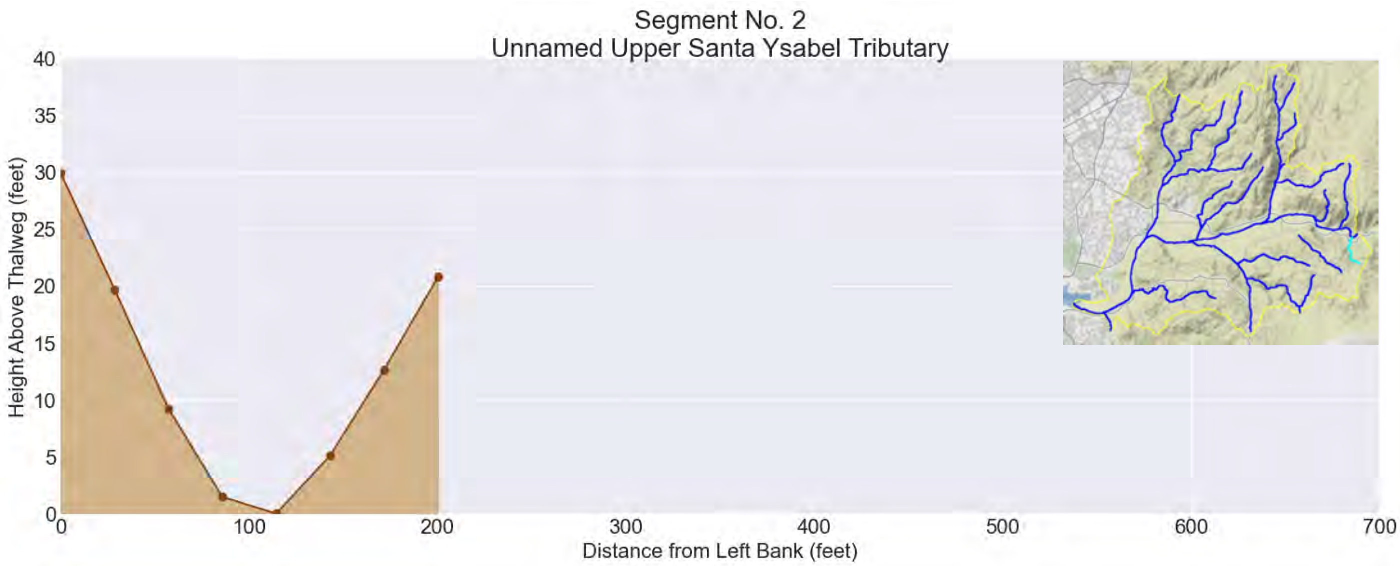
Prudic, D.E., Konikow, L.F., and E.R. Banta. 2004. *A New Streamflow-Routing (SFR1) Package to Simulate Stream-Aquifer Interaction with MODFLOW-2000.* U.S. Geological Society Open-File Report 2004-2042.

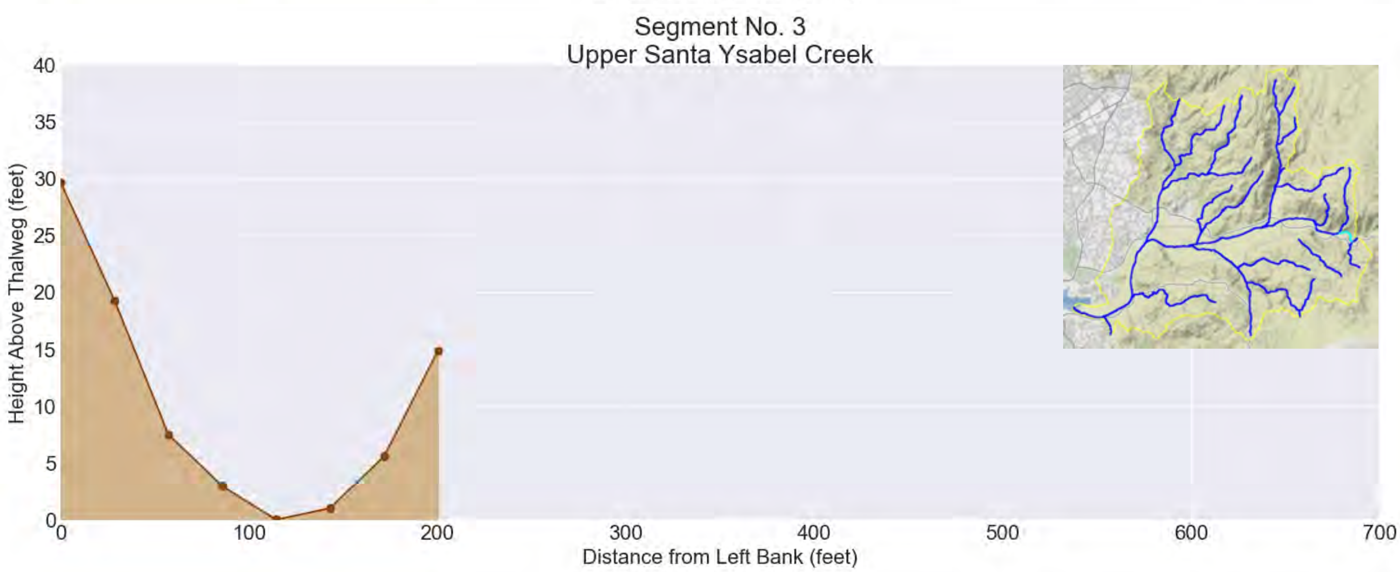
Ramona Municipal Water District (Ramona MWD). 2021. *2020 Urban Water Management Plan*. Prepared for the District by Dudek. Encinitas, California: Dudek. June.

United States Environmental Protection Agency (US EPA). 2019. *National Hydrography Dataset Plus version 2 (NHDPlusv2)*. Accessed 2022. https://www.epa.gov/waterdata/nhdplus-california-data-vector-processing-unit-18

ATTACHMENT A: MODELED EIGHT-POINT STREAM CHANNELS





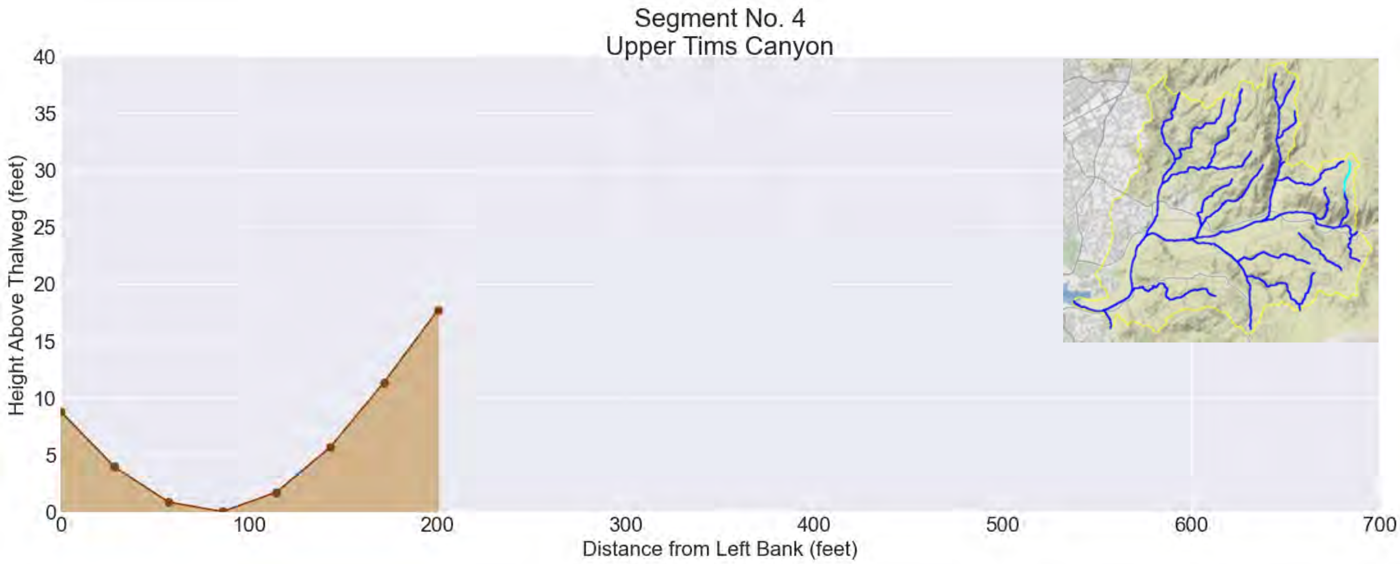


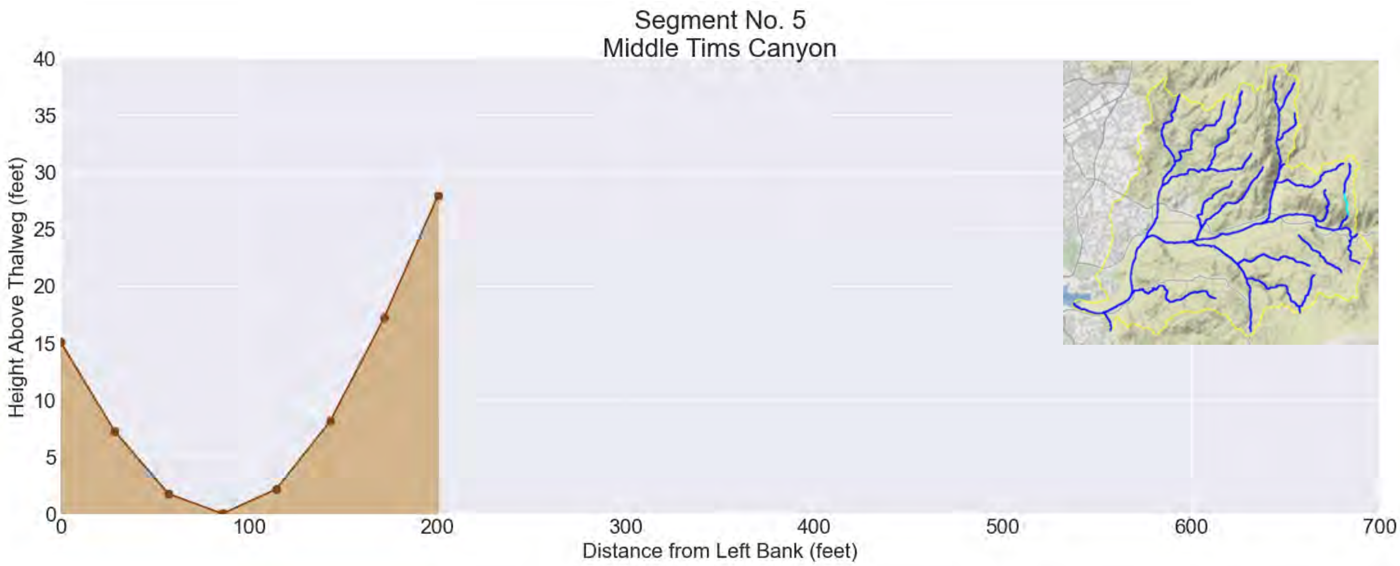
Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

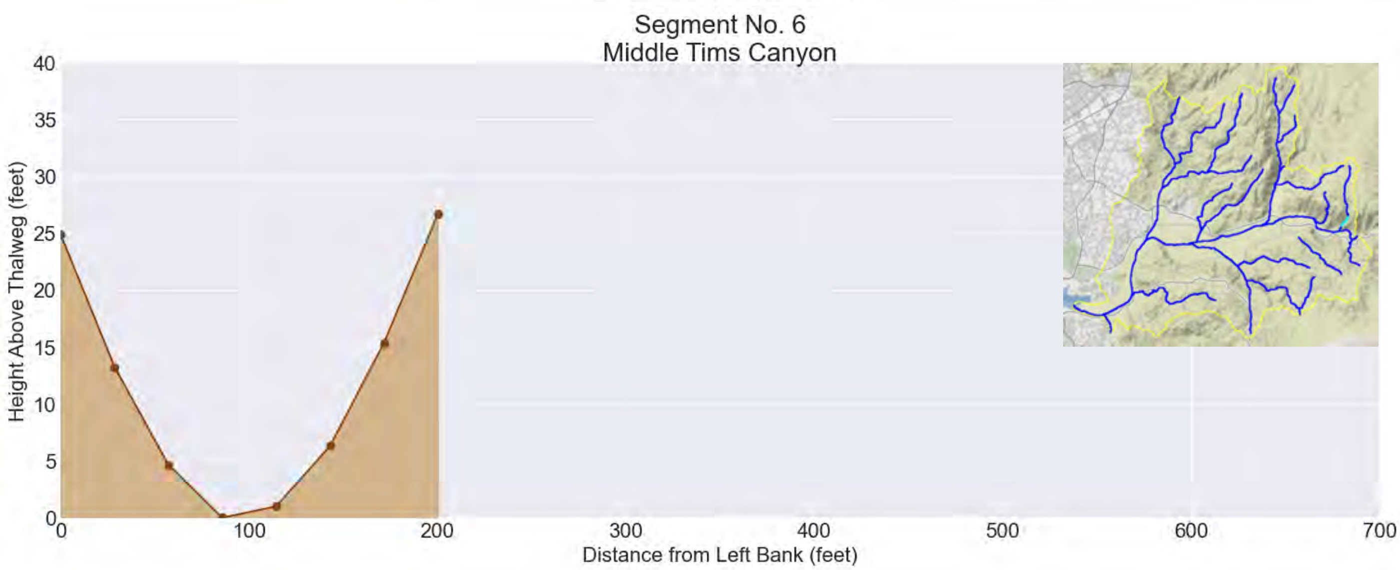
Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-1
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs







Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-2

Modeled Eight-point Stream Channels

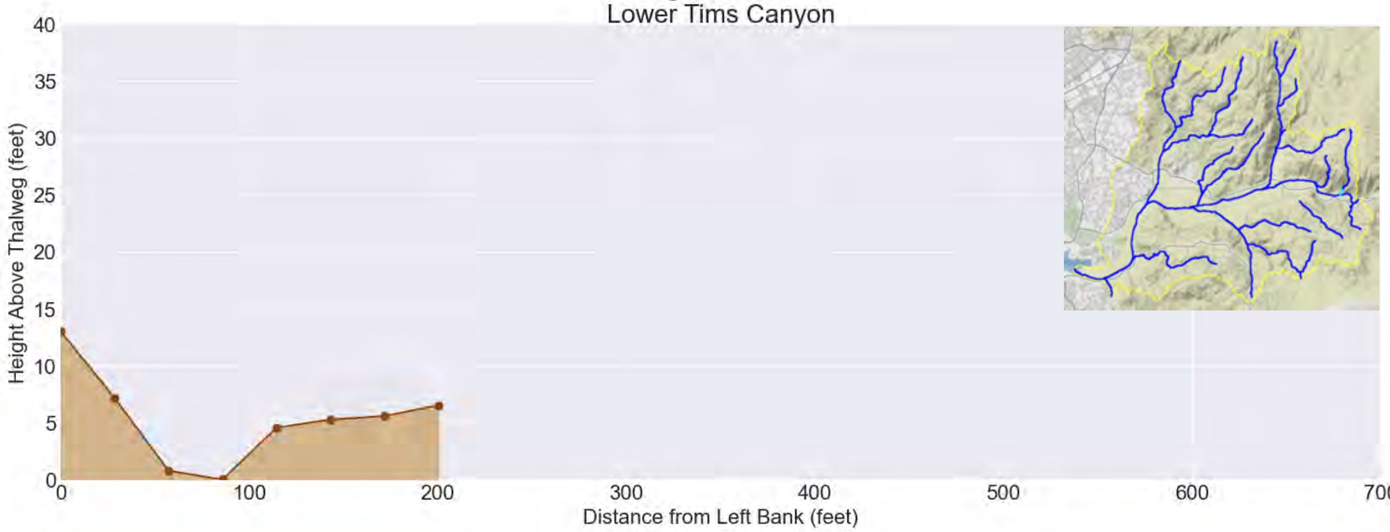
PMA7: Initial Surface Water Recharge Evaluation

Task 5 Groundwater and Surface Water Simulations

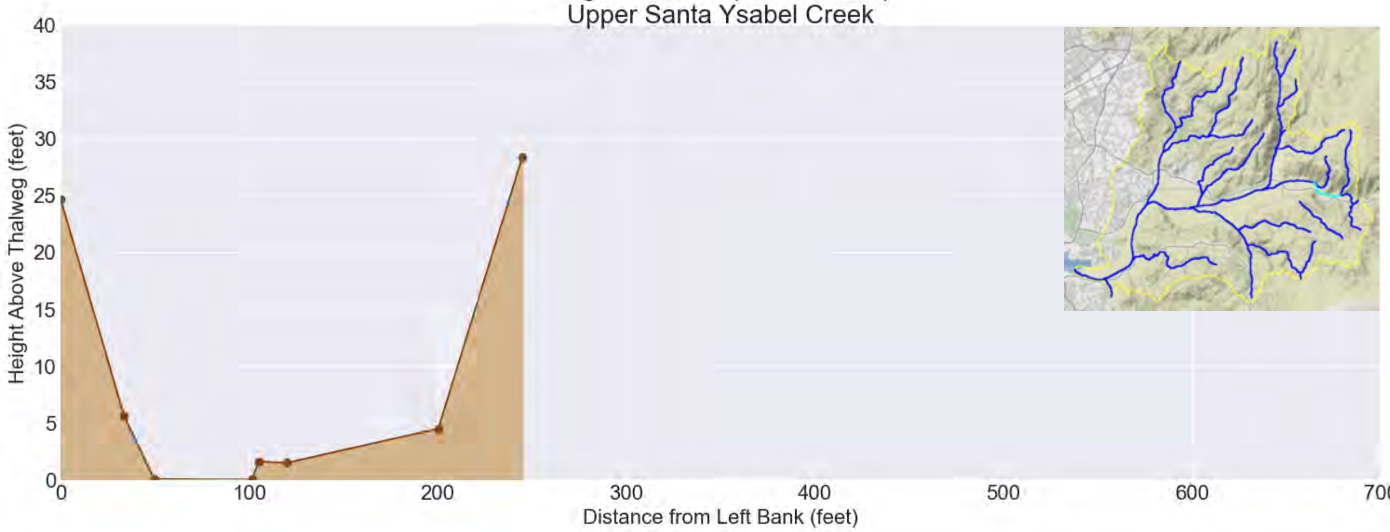
San Pasqual Valley, California

Jacobs

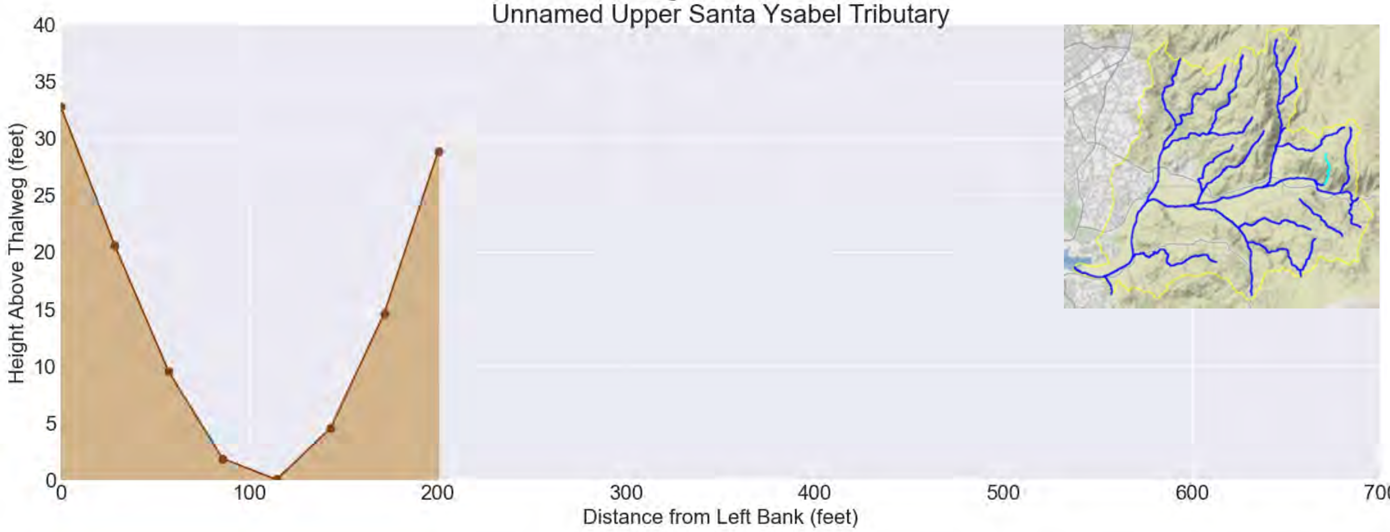
Segment No. 7
Lower Tims Canyon



Segment No. 8 (T-1 Transect)
Upper Santa Ysabel Creek



Segment No. 9
Unnamed Upper Santa Ysabel Tributary



Notes:

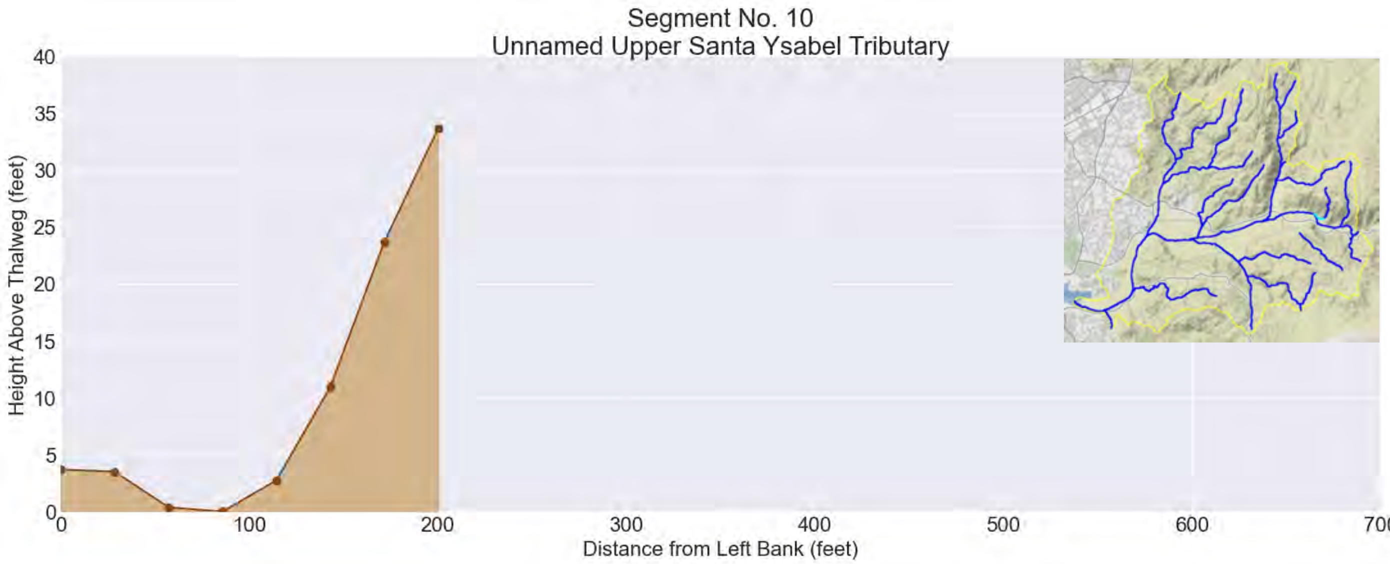
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

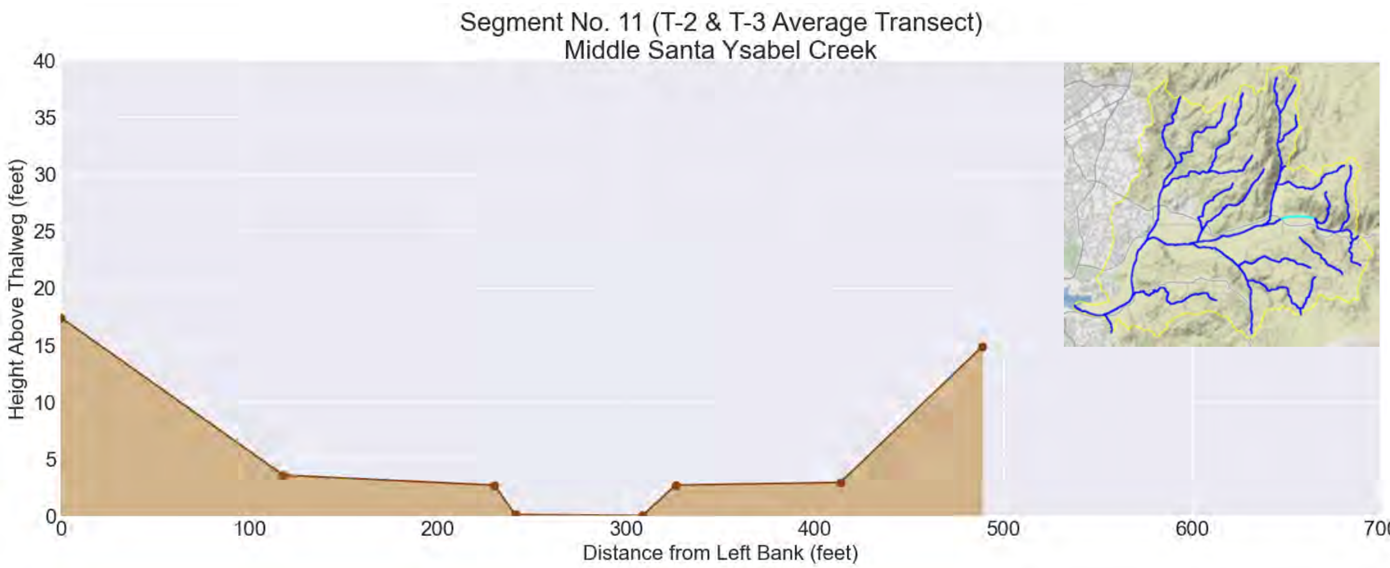
Map Legend

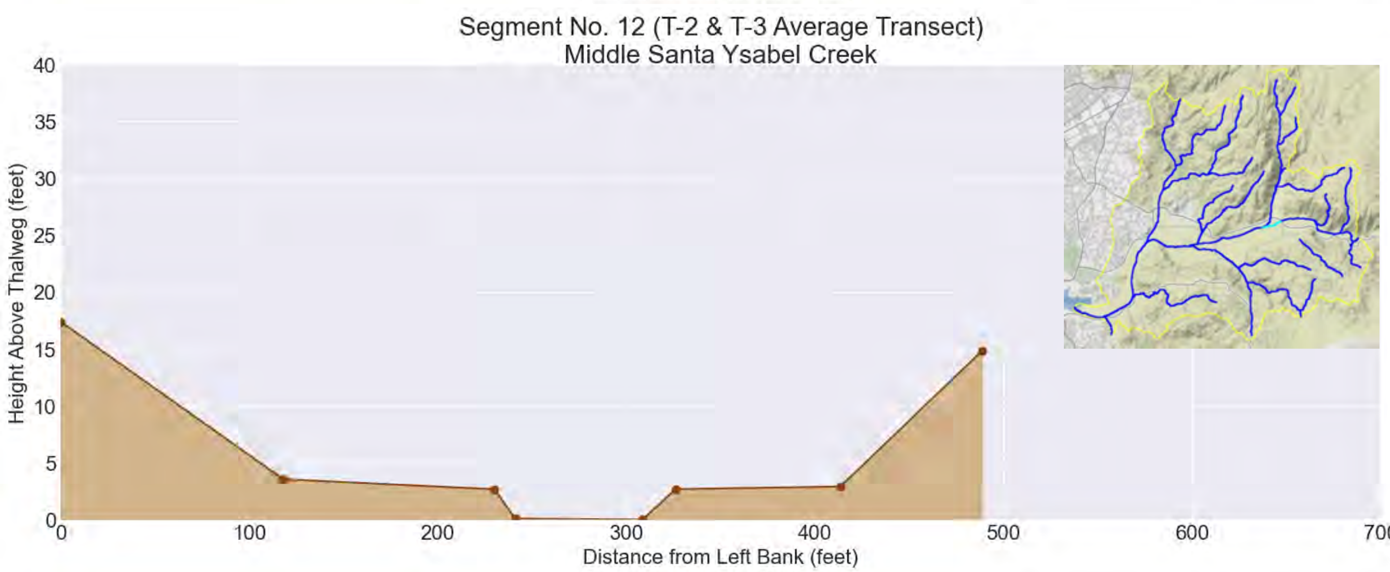
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-3
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs







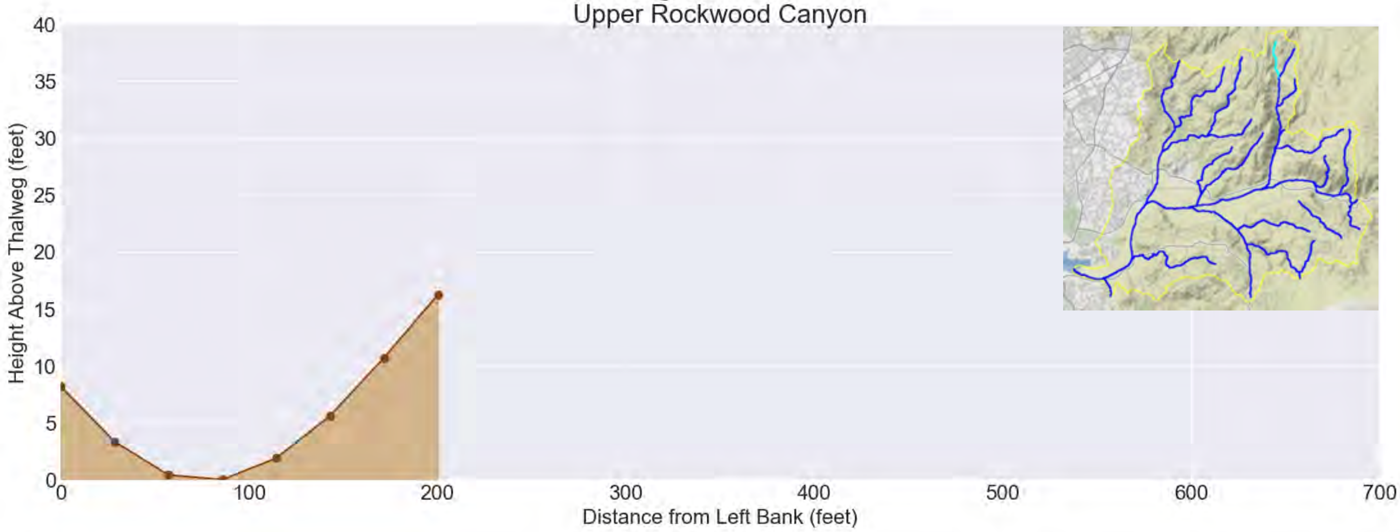
Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

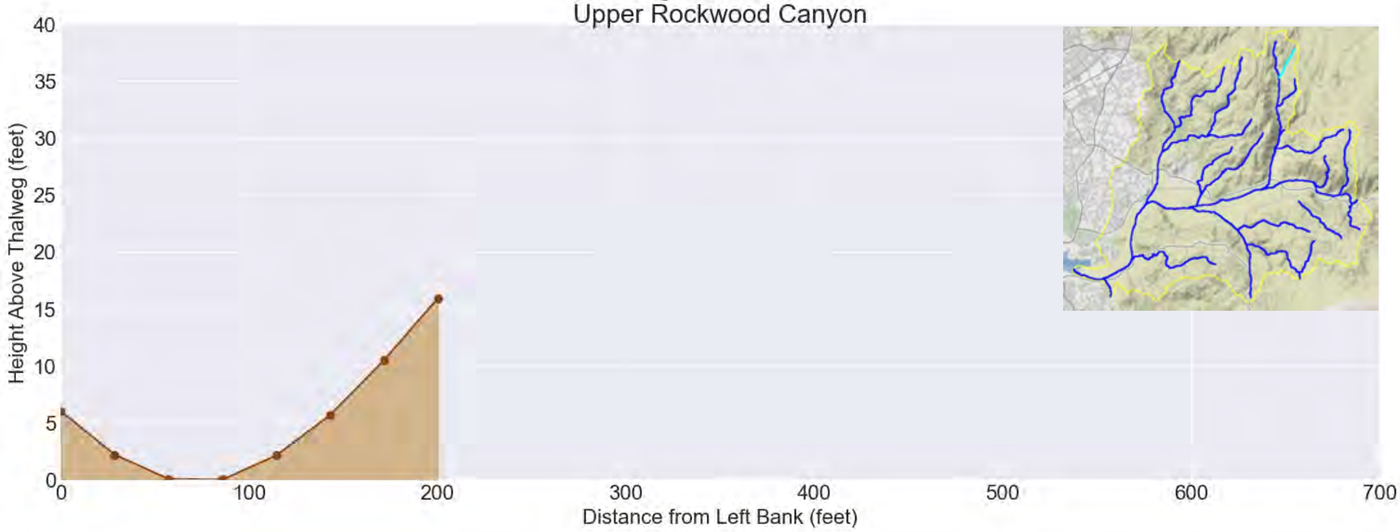
Figure A-4
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs

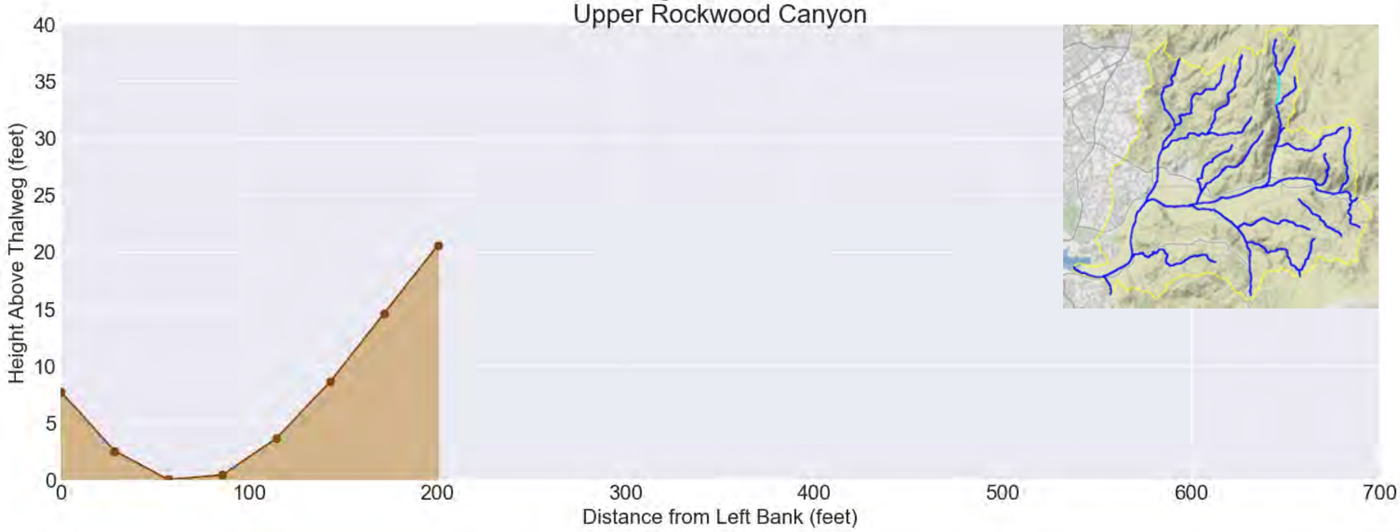
Segment No. 13
Upper Rockwood Canyon



Segment No. 14
Upper Rockwood Canyon



Segment No. 15
Upper Rockwood Canyon



Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-5

Modeled Eight-point Stream Channels

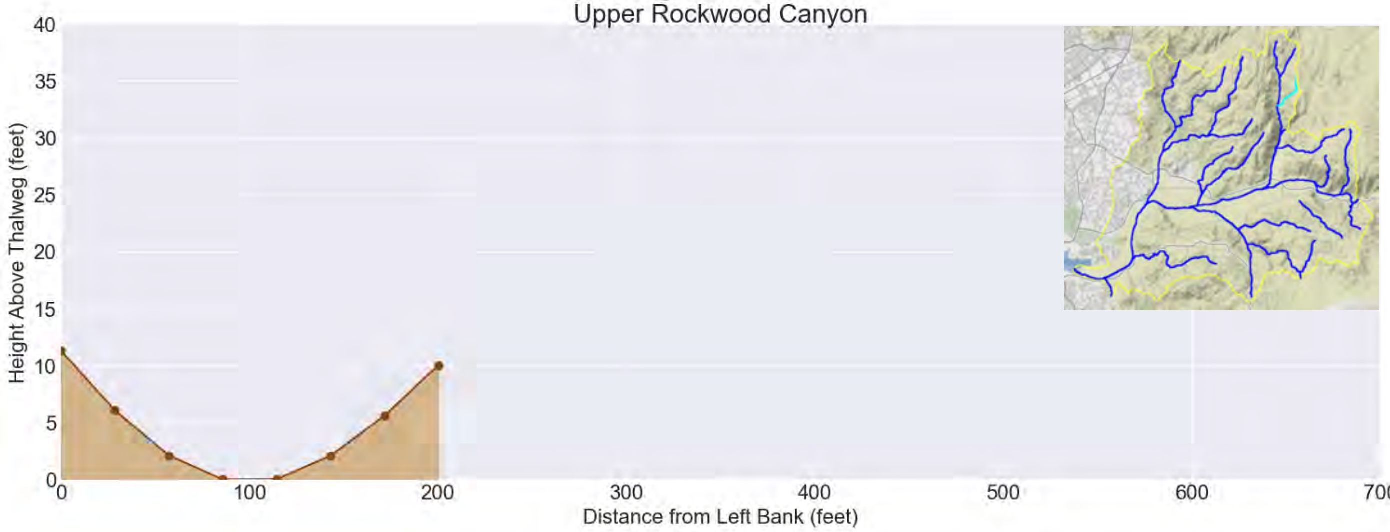
PMA7: Initial Surface Water Recharge Evaluation

Task 5 Groundwater and Surface Water Simulations

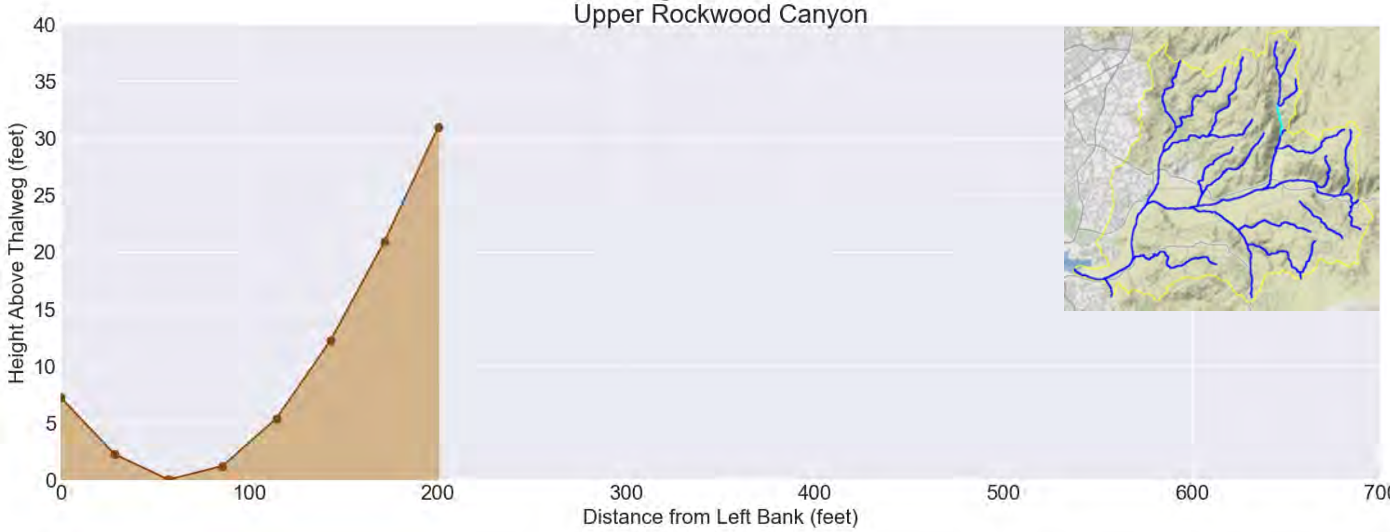
San Pasqual Valley, California

Jacobs

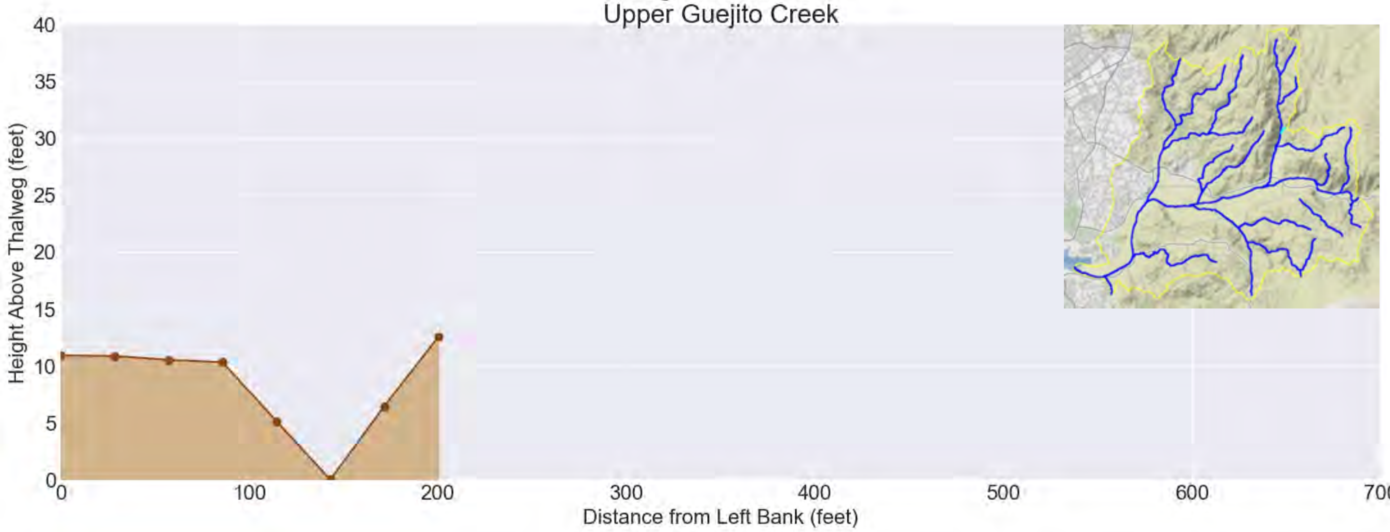
Segment No. 16
Upper Rockwood Canyon



Segment No. 17
Upper Rockwood Canyon



Segment No. 18
Upper Guejito Creek



Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

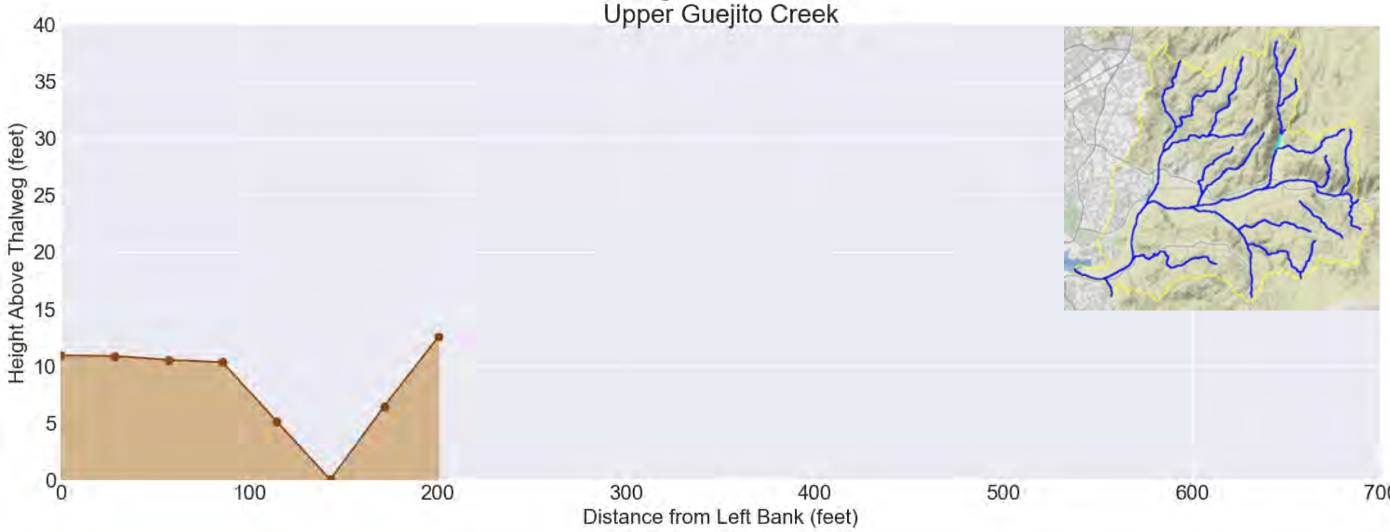
Figure A-6

Modeled Eight-point Stream Channels

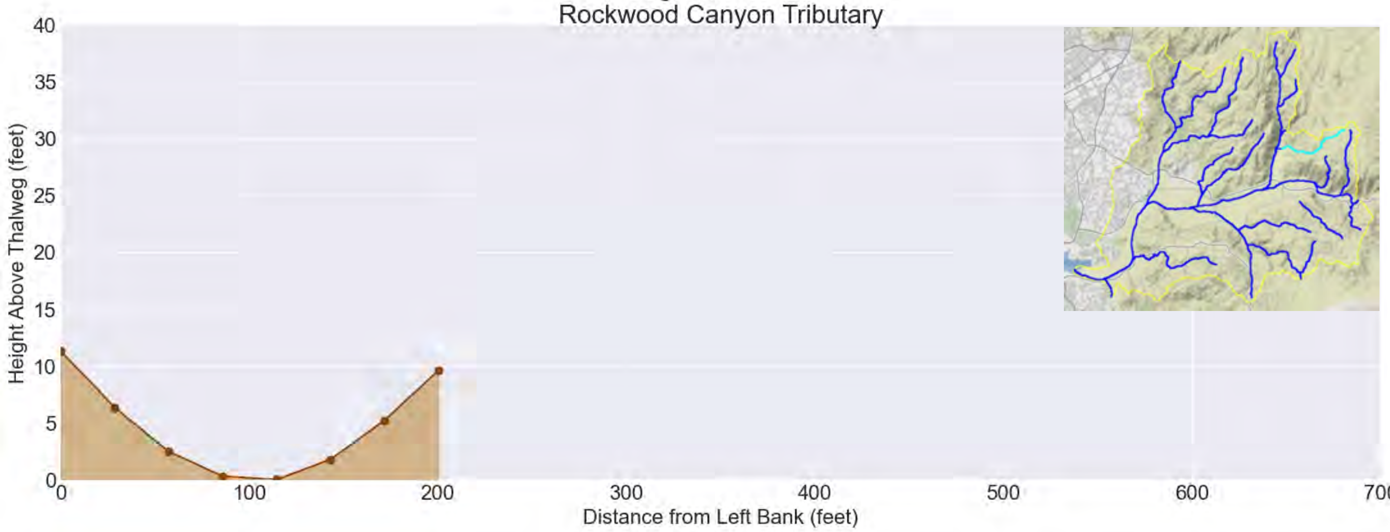
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs

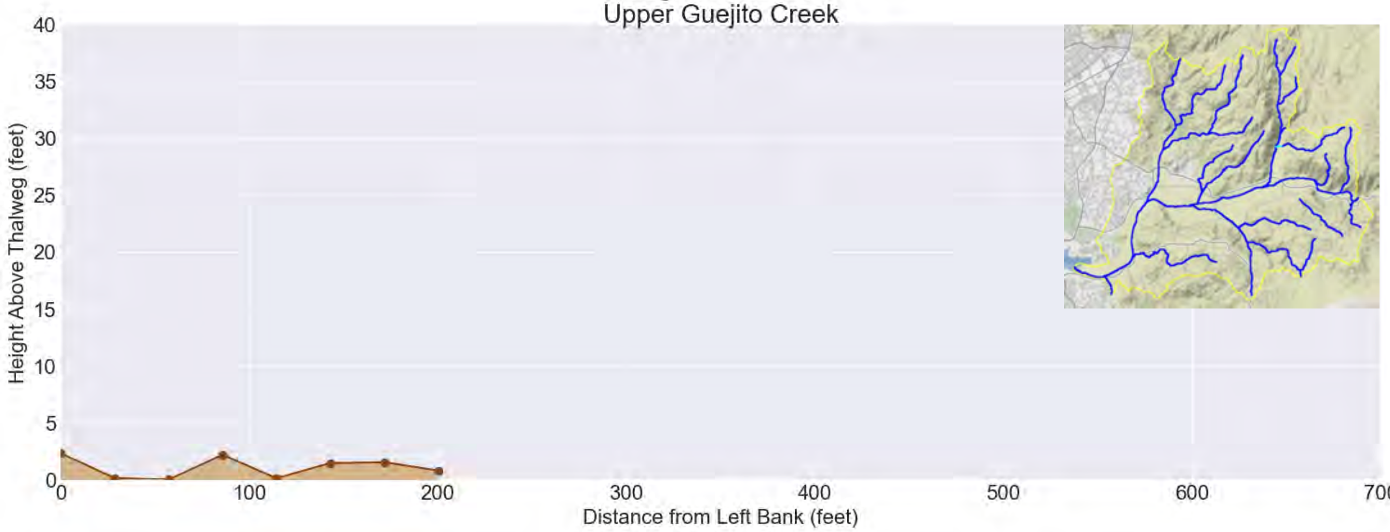
Segment No. 19
Upper Guejito Creek



Segment No. 20
Rockwood Canyon Tributary



Segment No. 21
Upper Guejito Creek

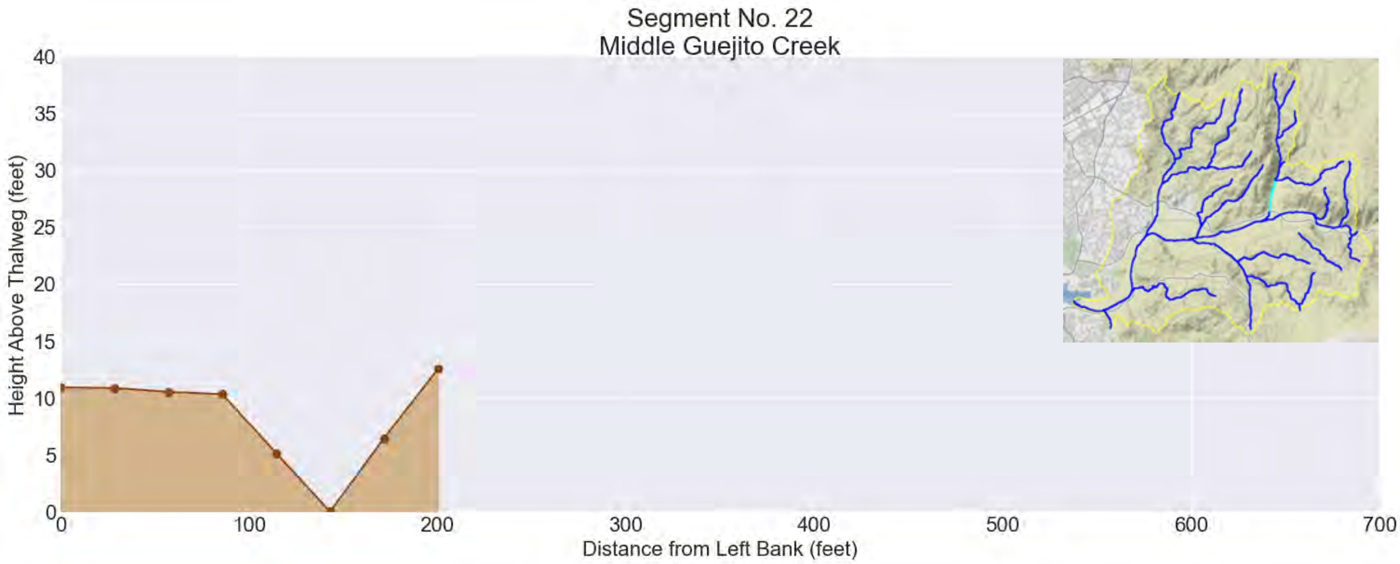


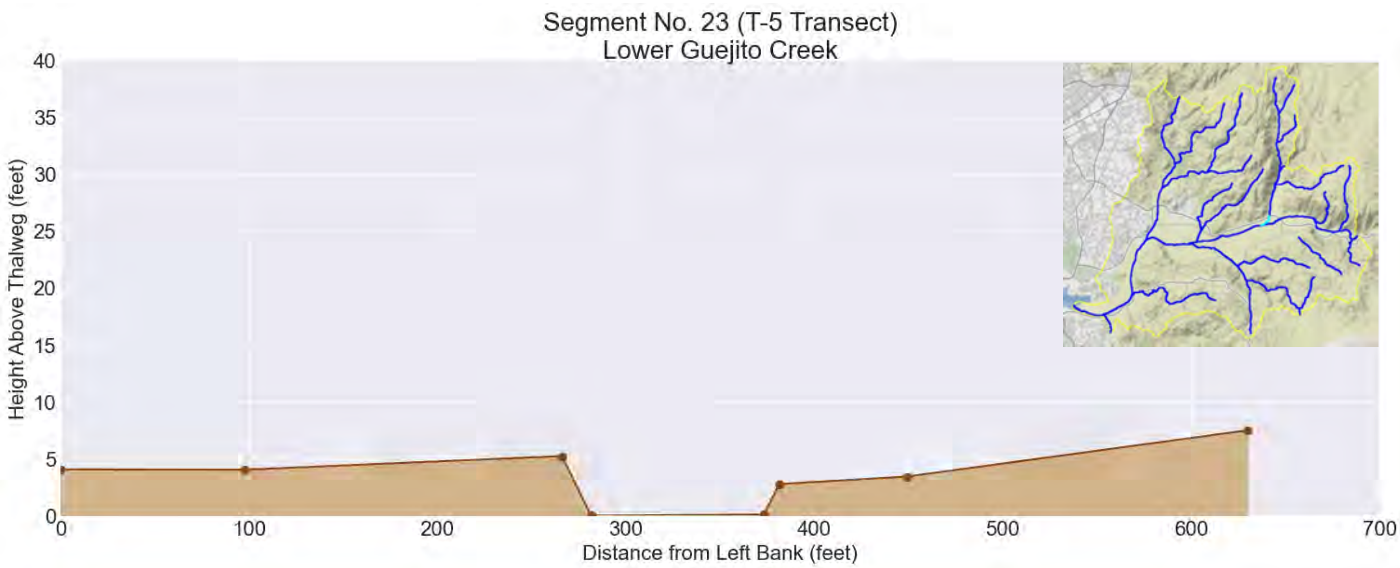
Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

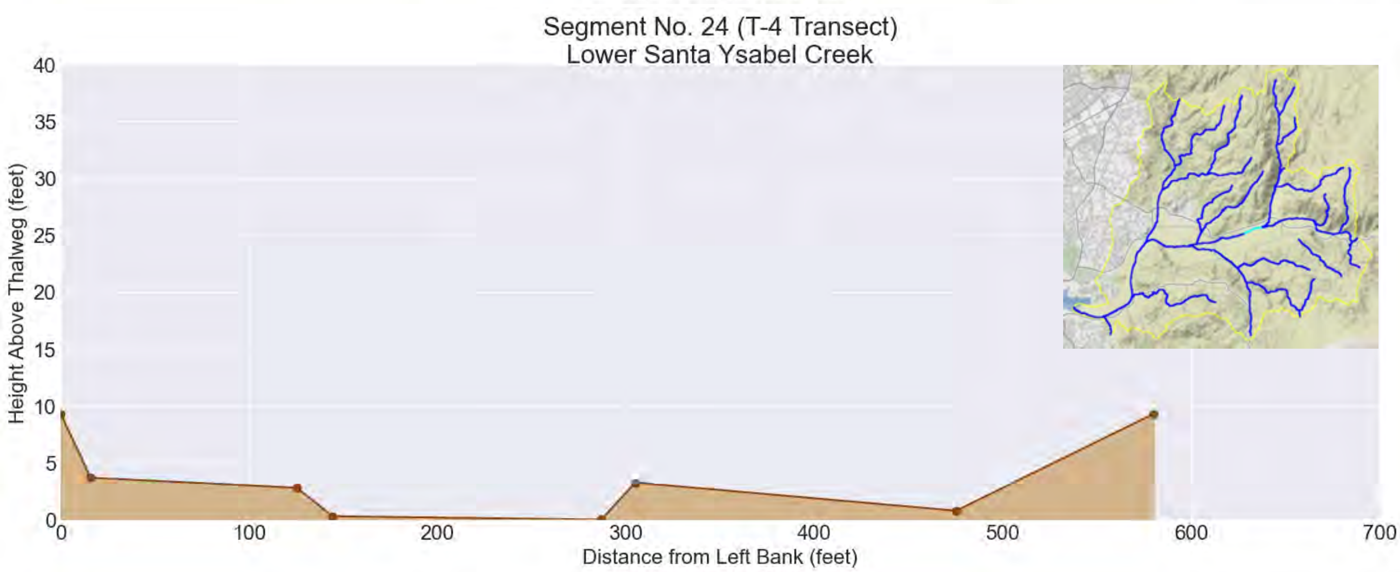
Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-7
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs







Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

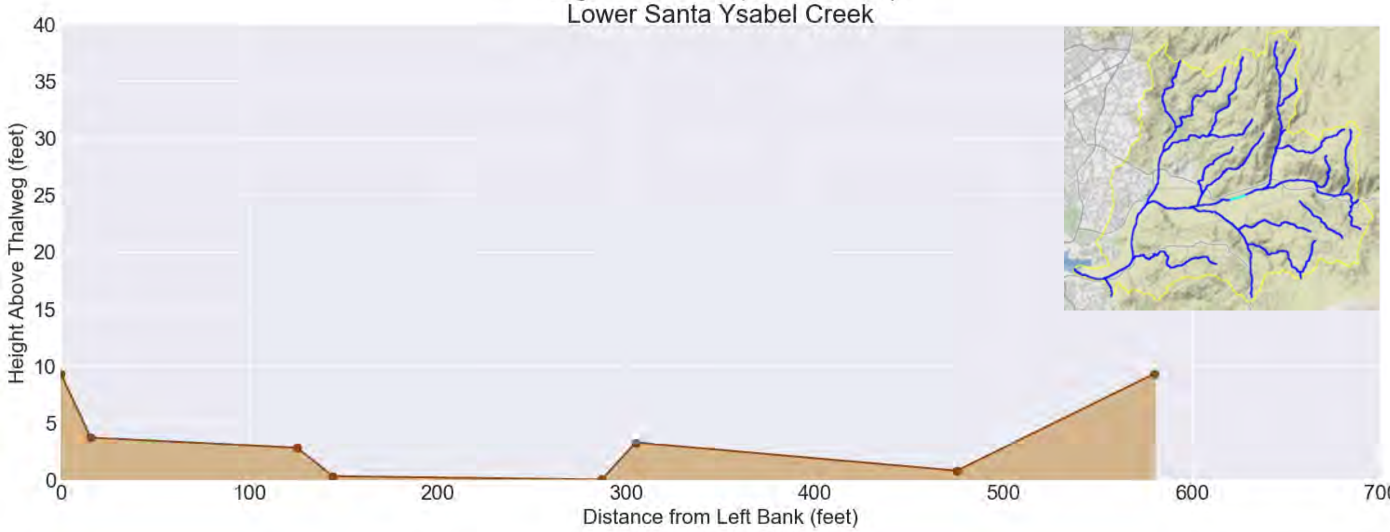
Figure A-8

Modeled Eight-point Stream Channels

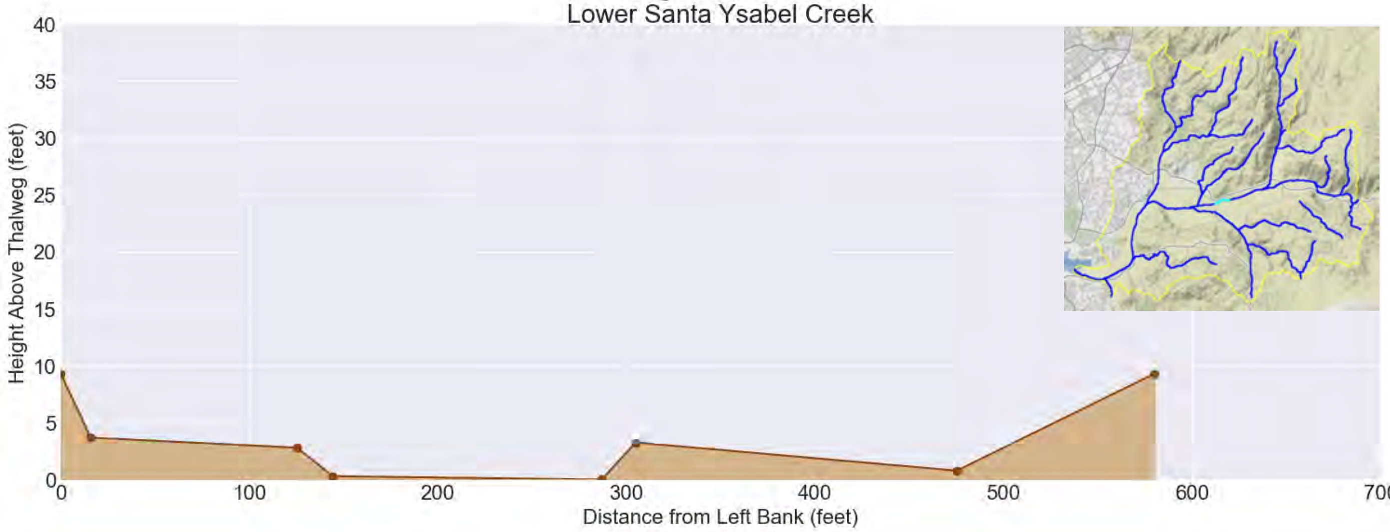
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs

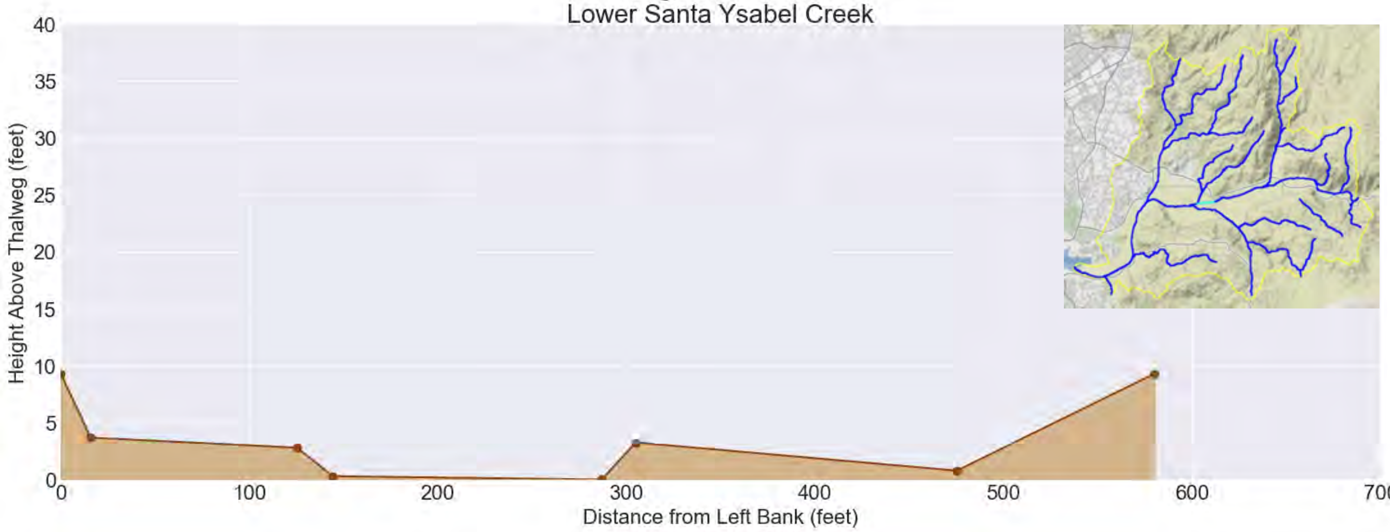
Segment No. 25 (T-4 Transect)
Lower Santa Ysabel Creek



Segment No. 26
Lower Santa Ysabel Creek



Segment No. 27
Lower Santa Ysabel Creek

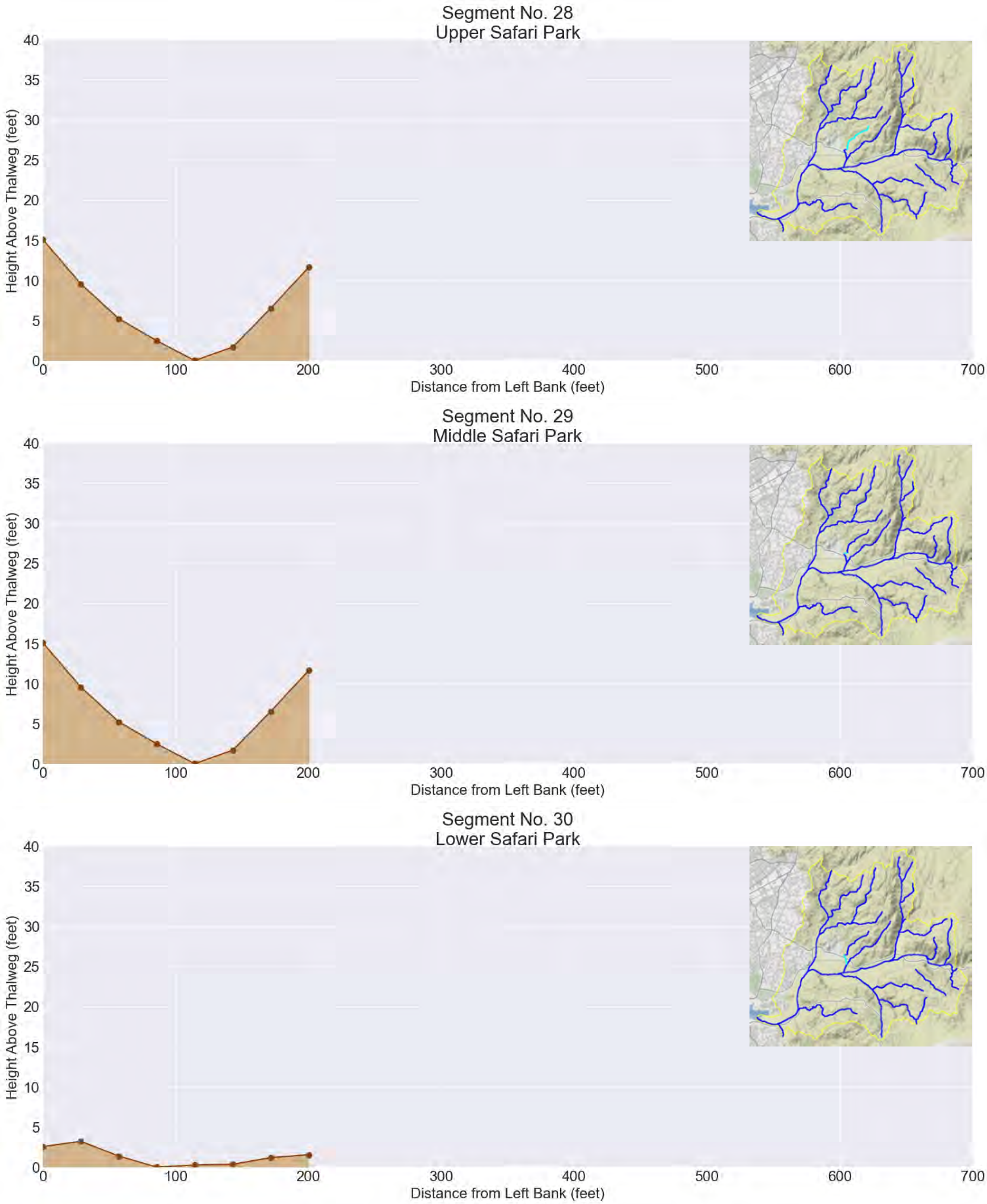


Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-9
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs



Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-10

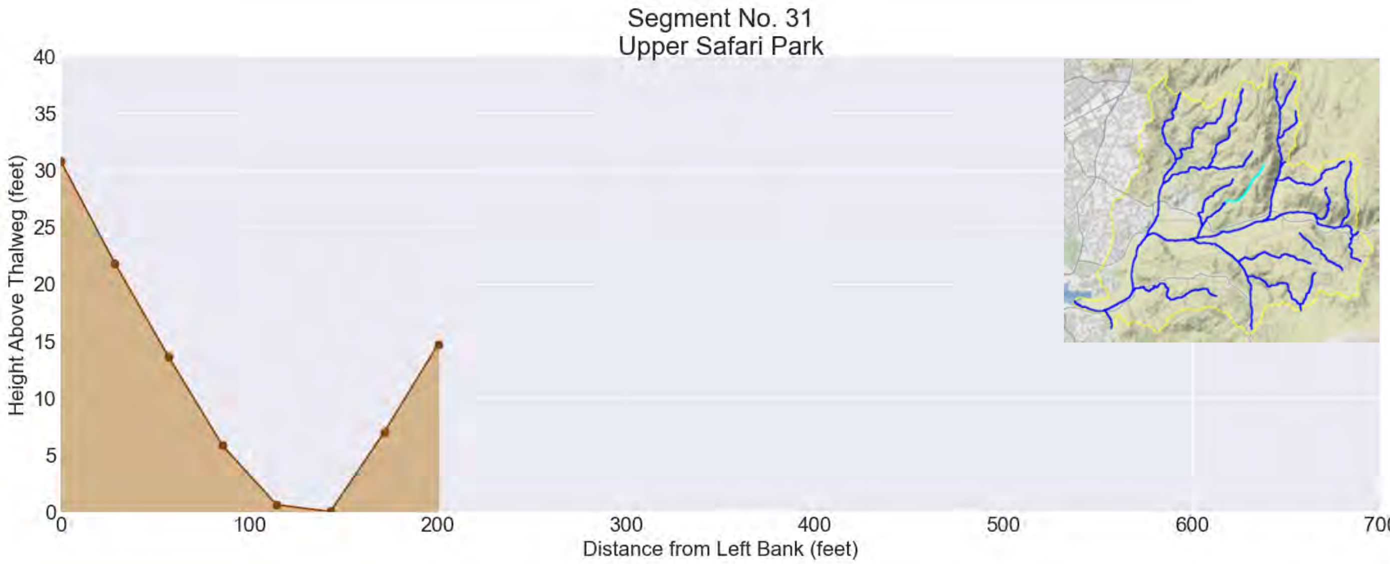
Modeled Eight-point Stream Channels

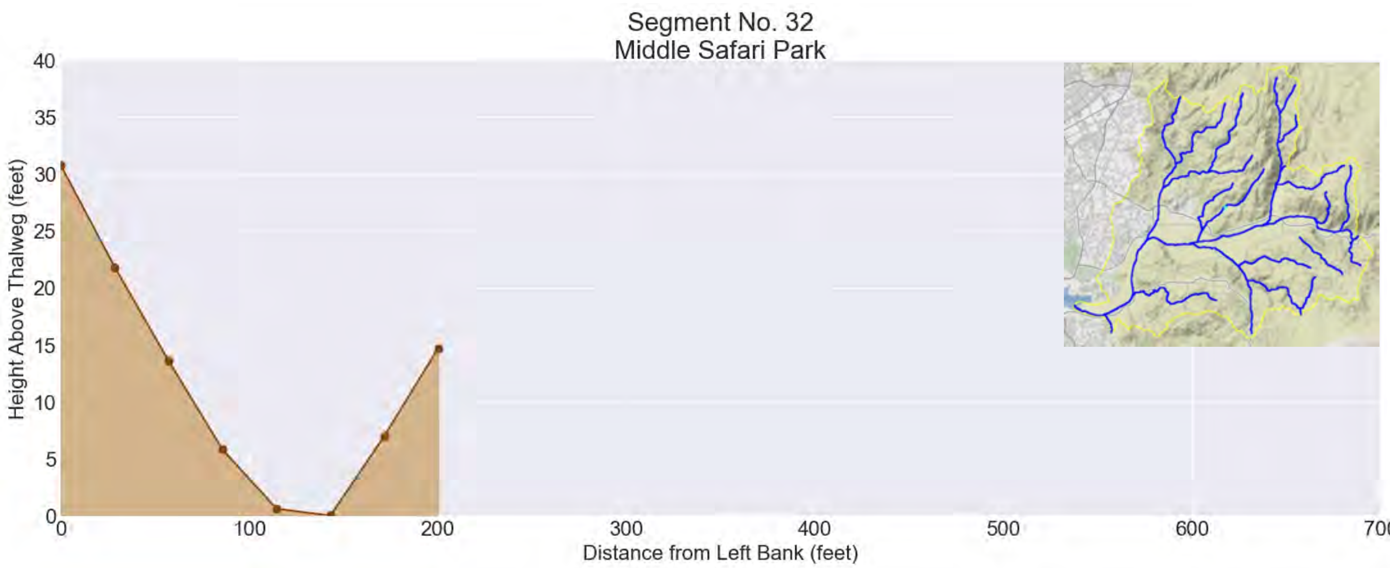
PMA7: Initial Surface Water Recharge Evaluation

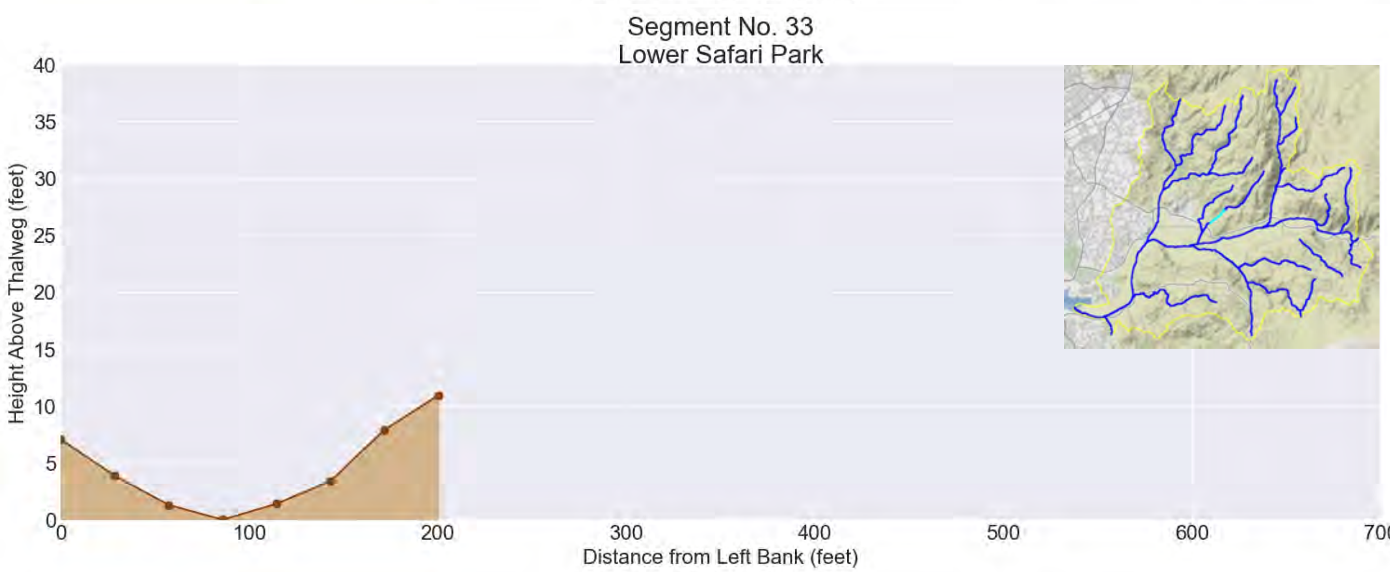
Task 5 Groundwater and Surface Water Simulations

San Pasqual Valley, California

Jacobs







Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

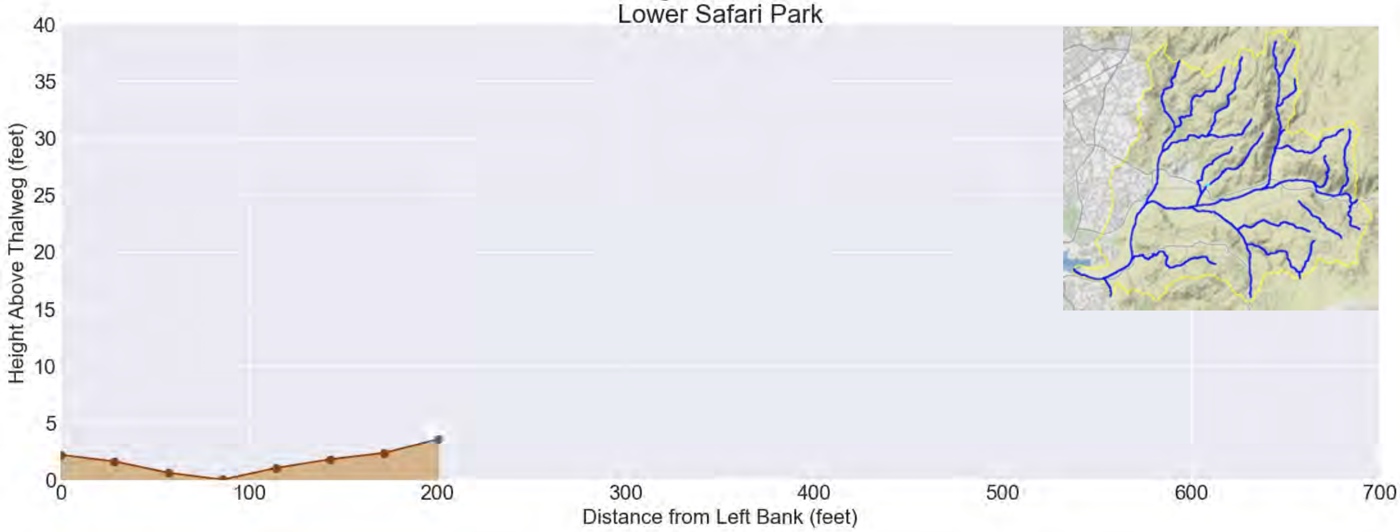
Figure A-11

Modeled Eight-point Stream Channels

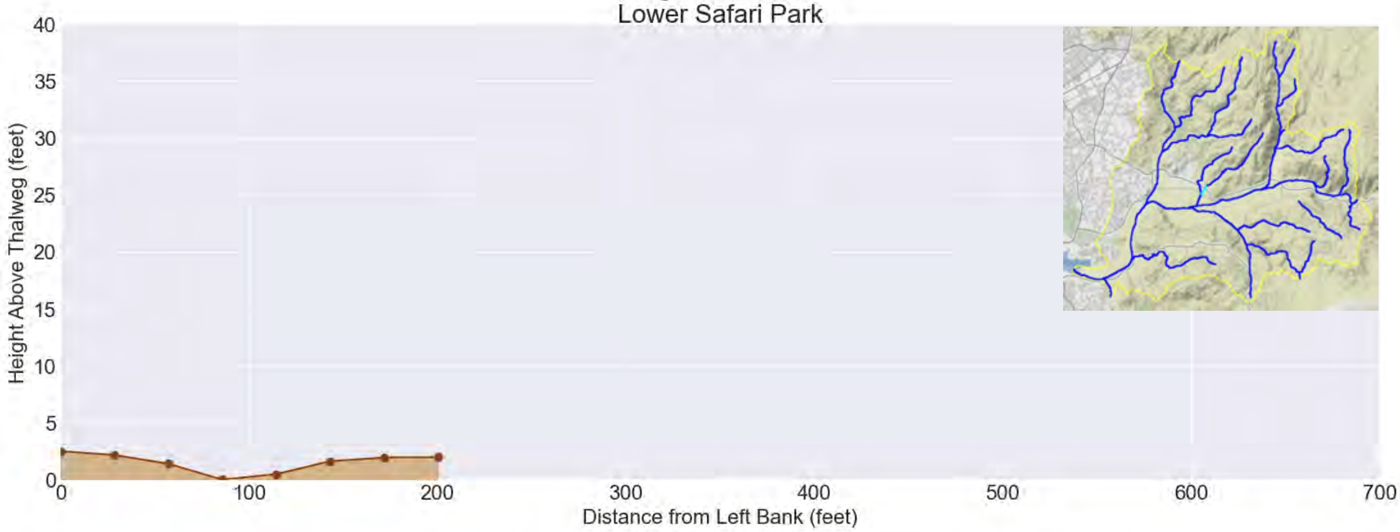
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs

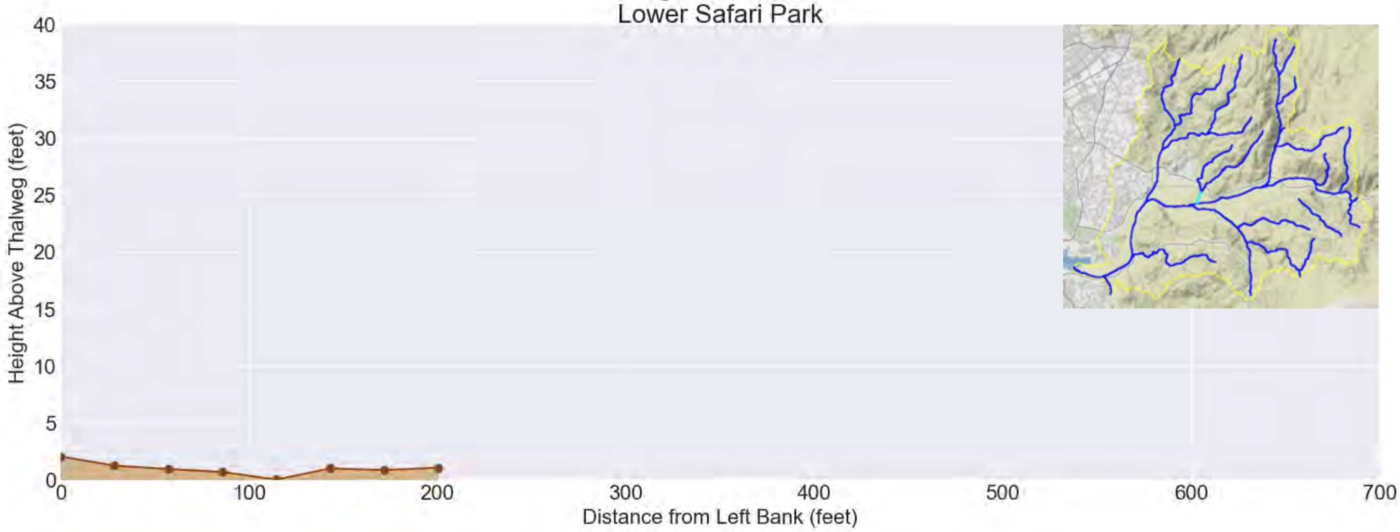
Segment No. 34
Lower Safari Park



Segment No. 35
Lower Safari Park



Segment No. 36
Lower Safari Park

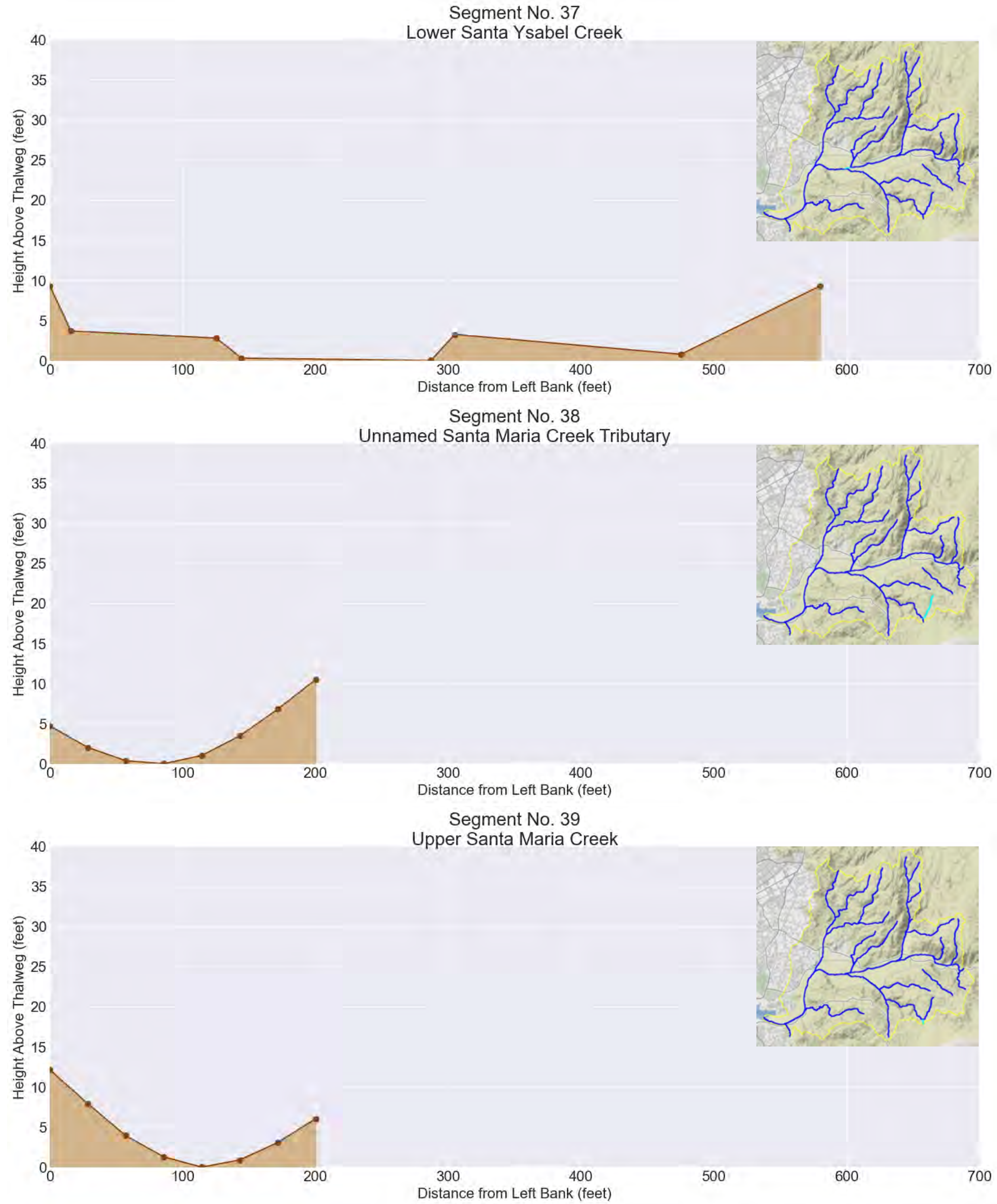


Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-12
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs

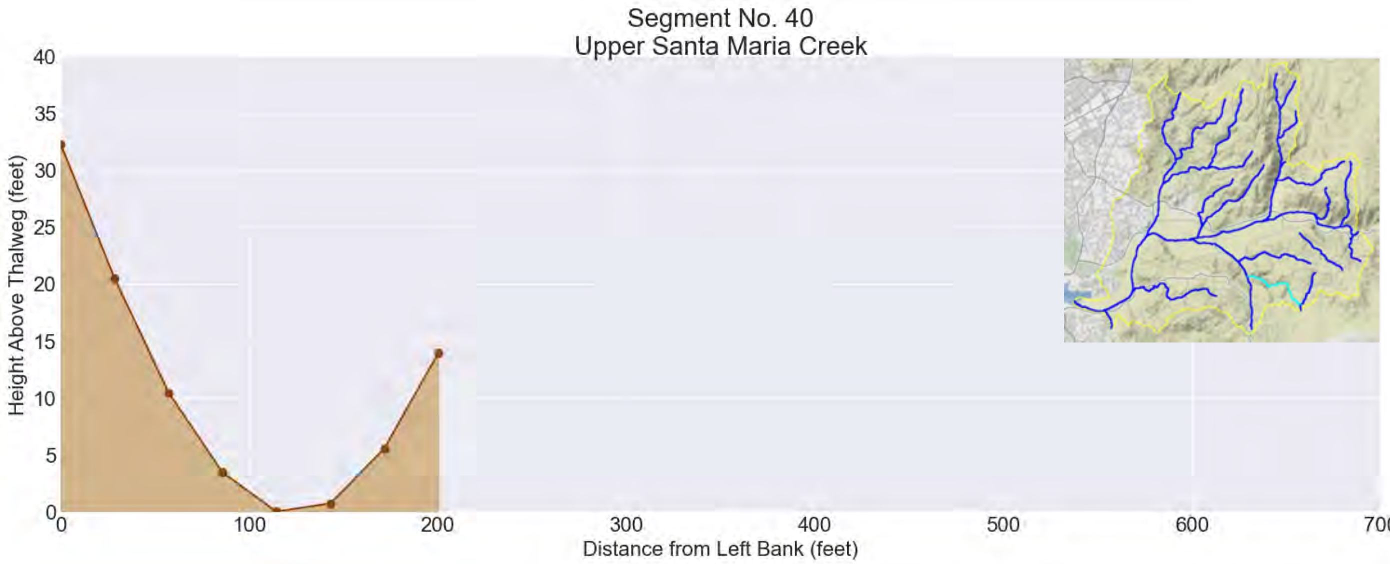


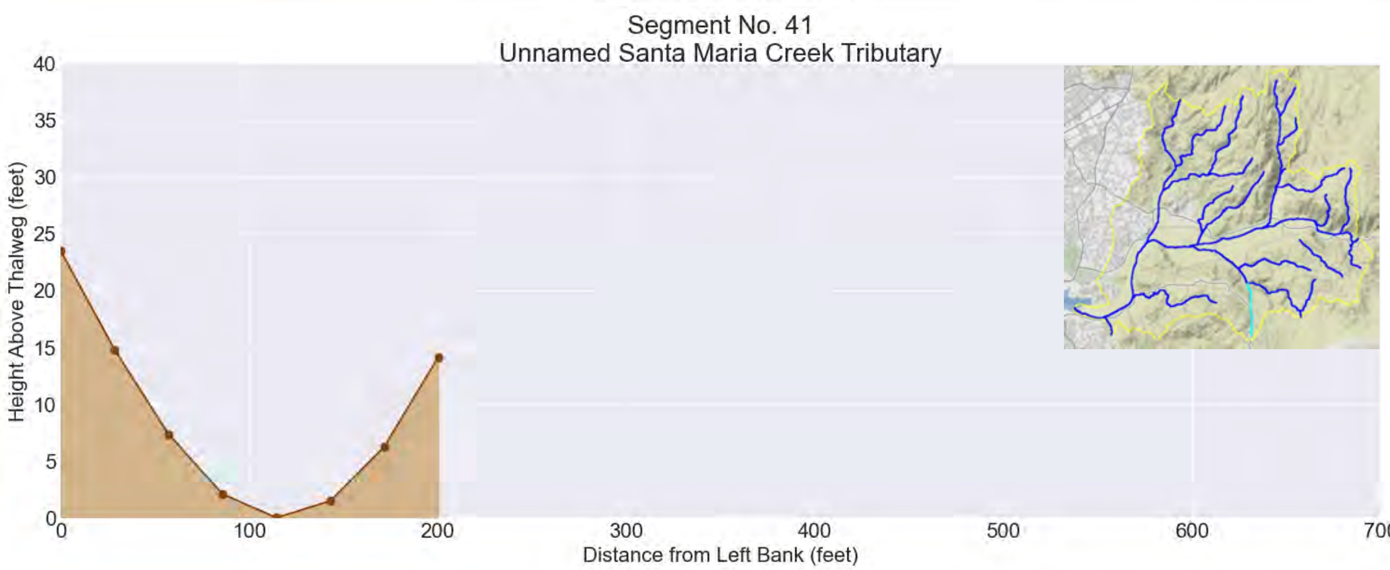
Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

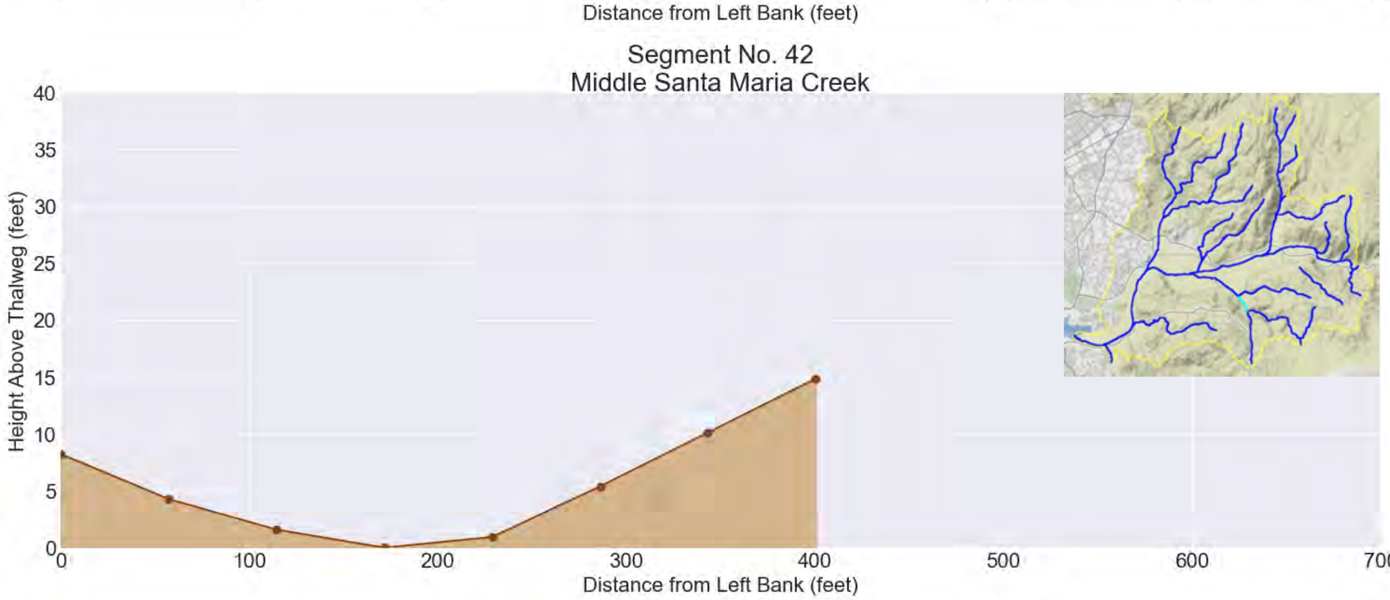
Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-13
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs





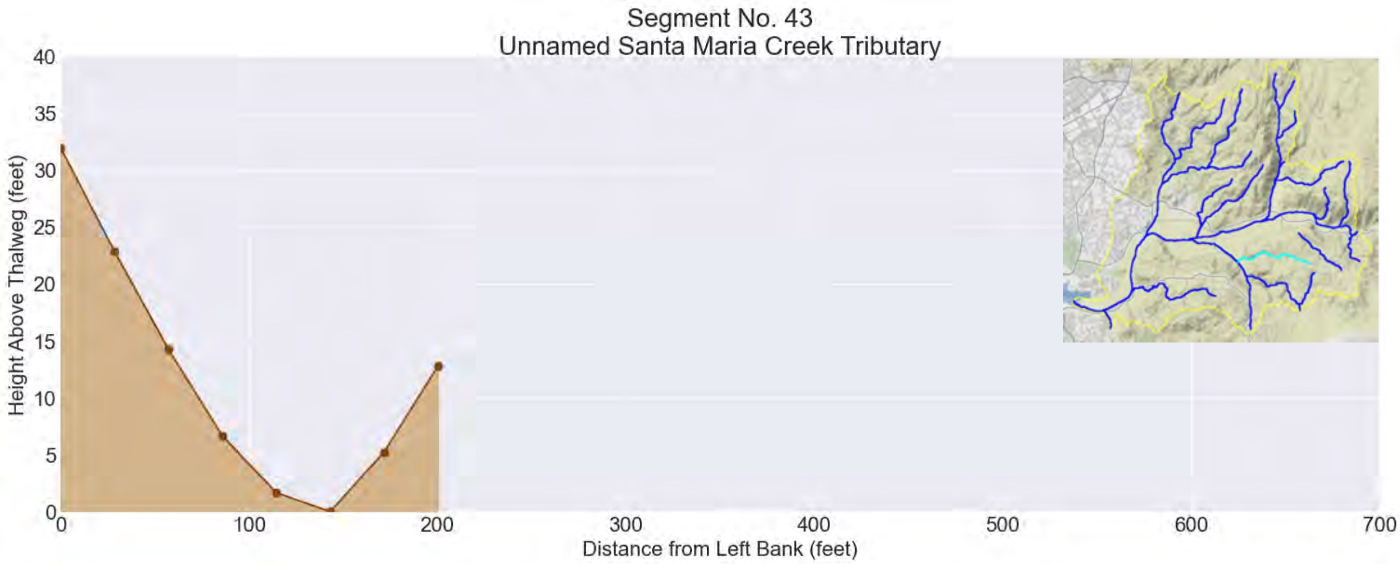


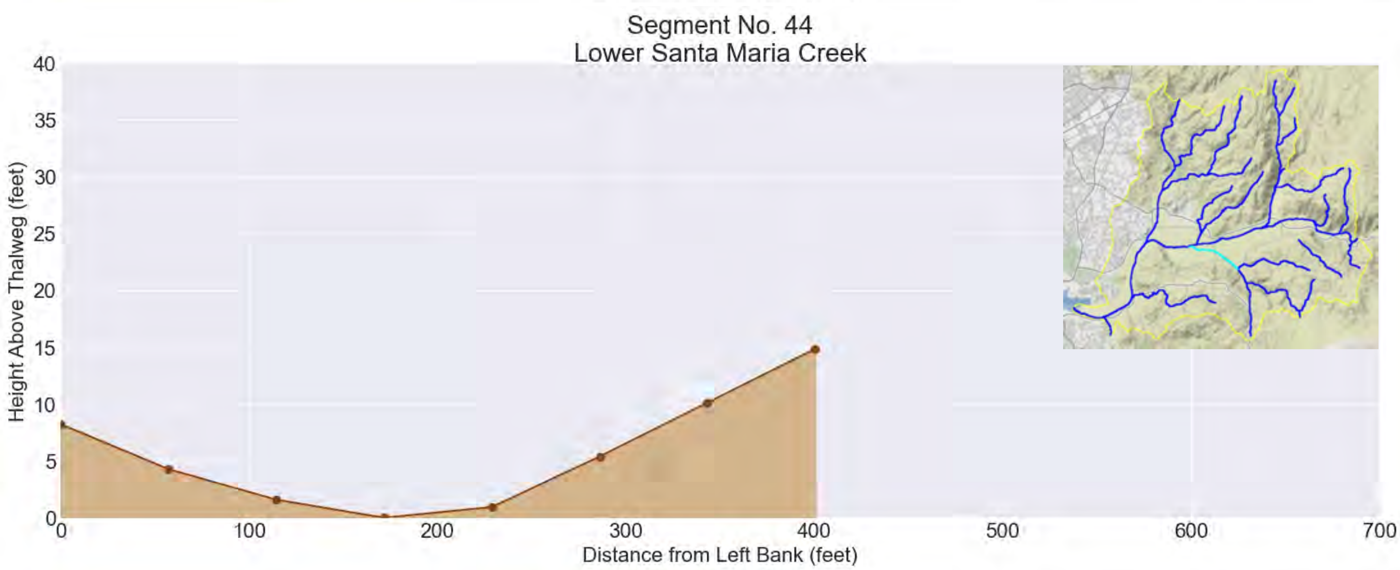
Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

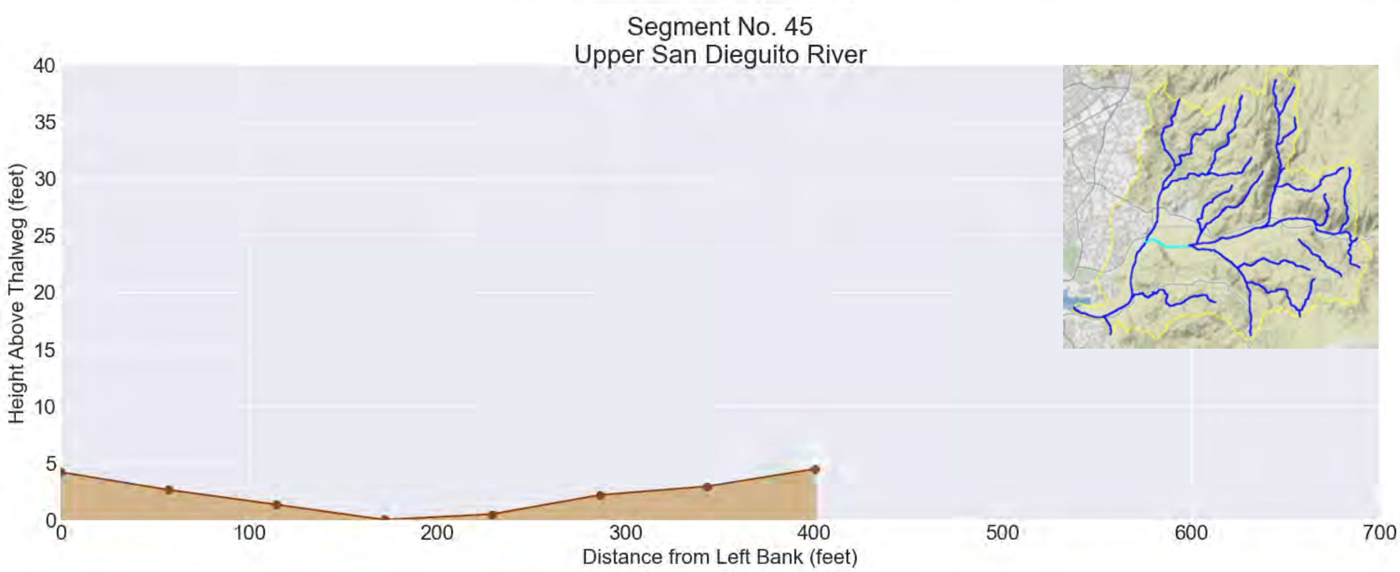
Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-14
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs







Notes:

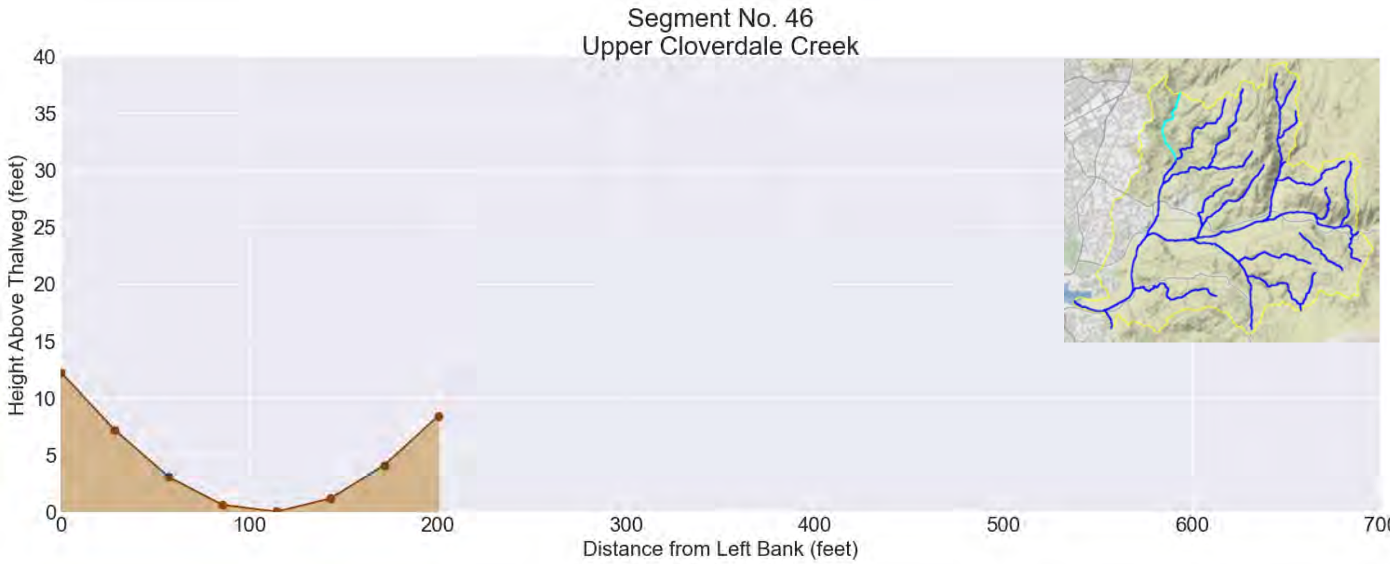
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

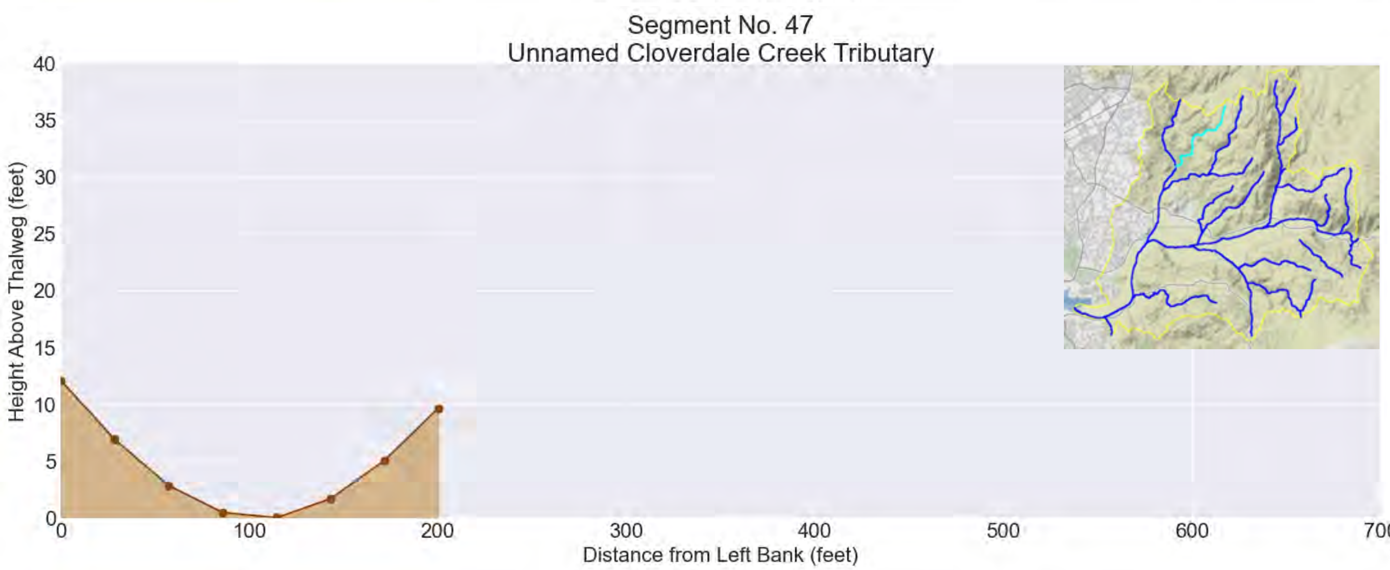
Map Legend

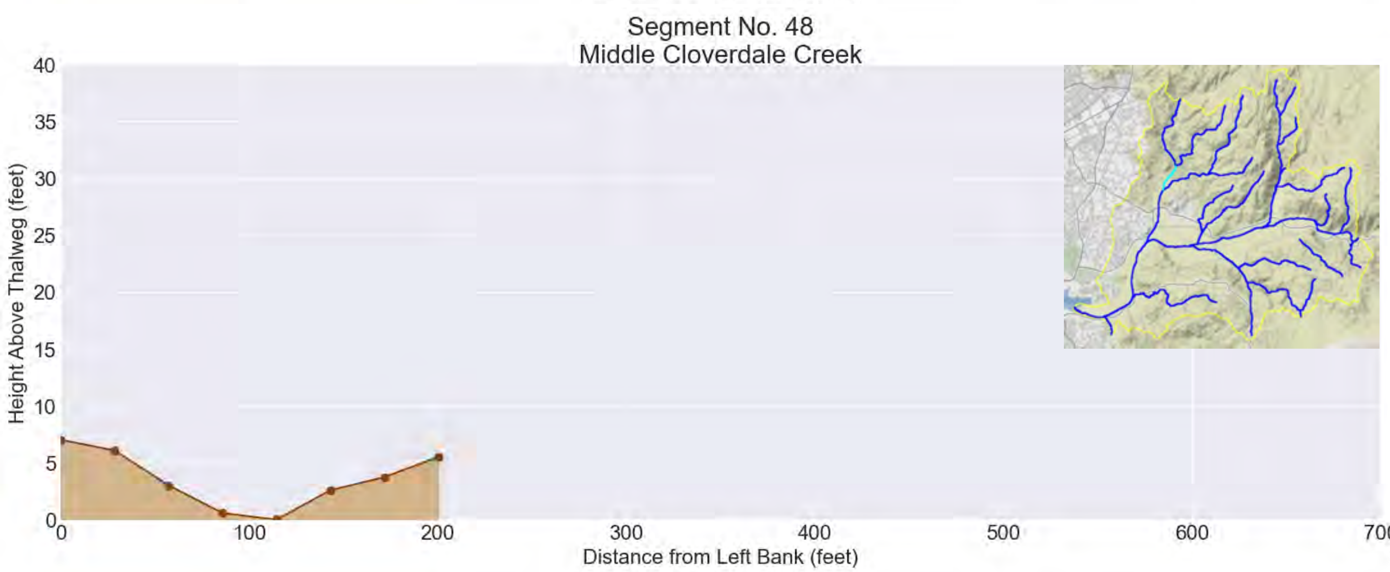
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-15
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs





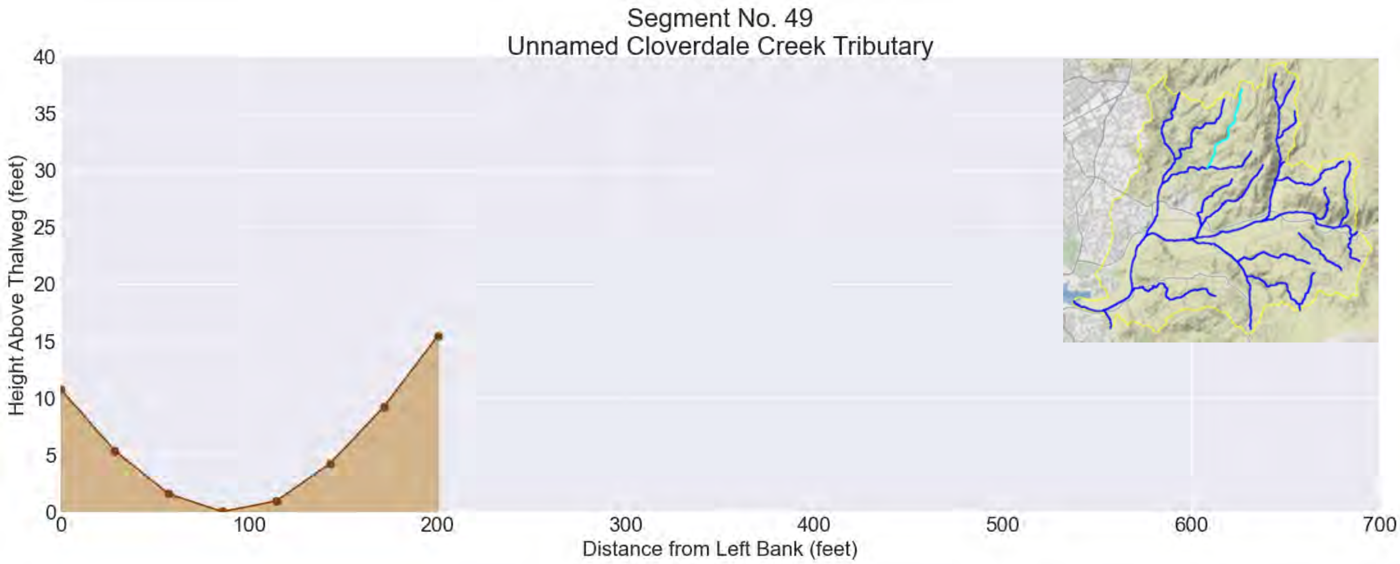


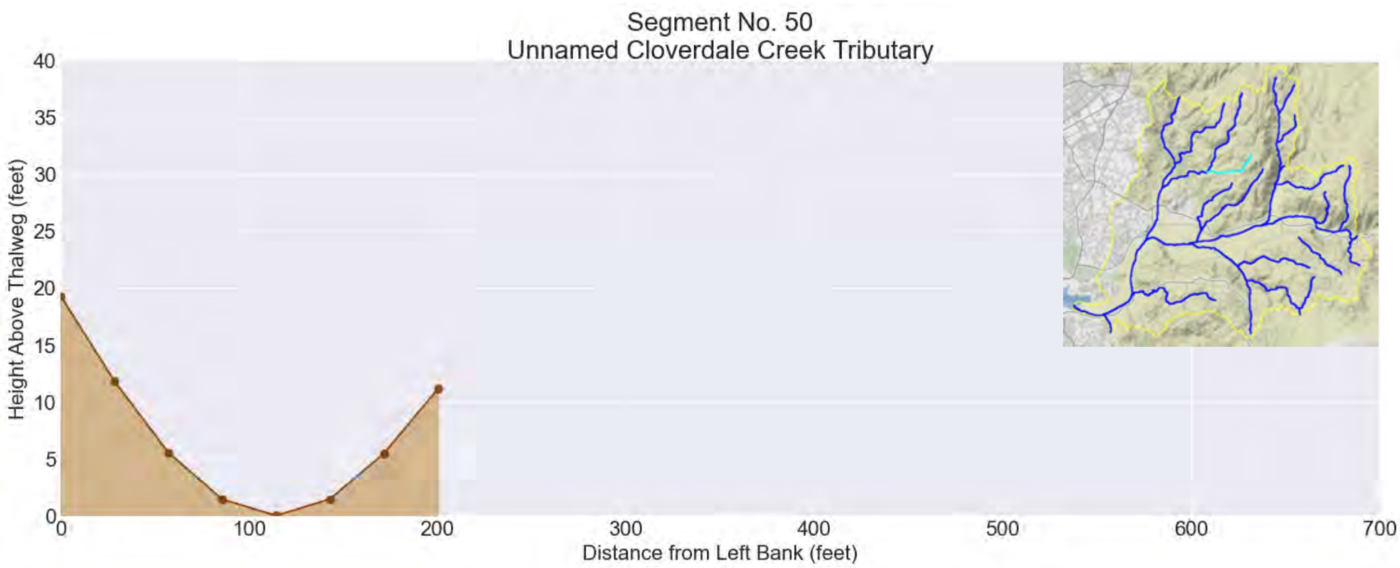
Notes:
1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

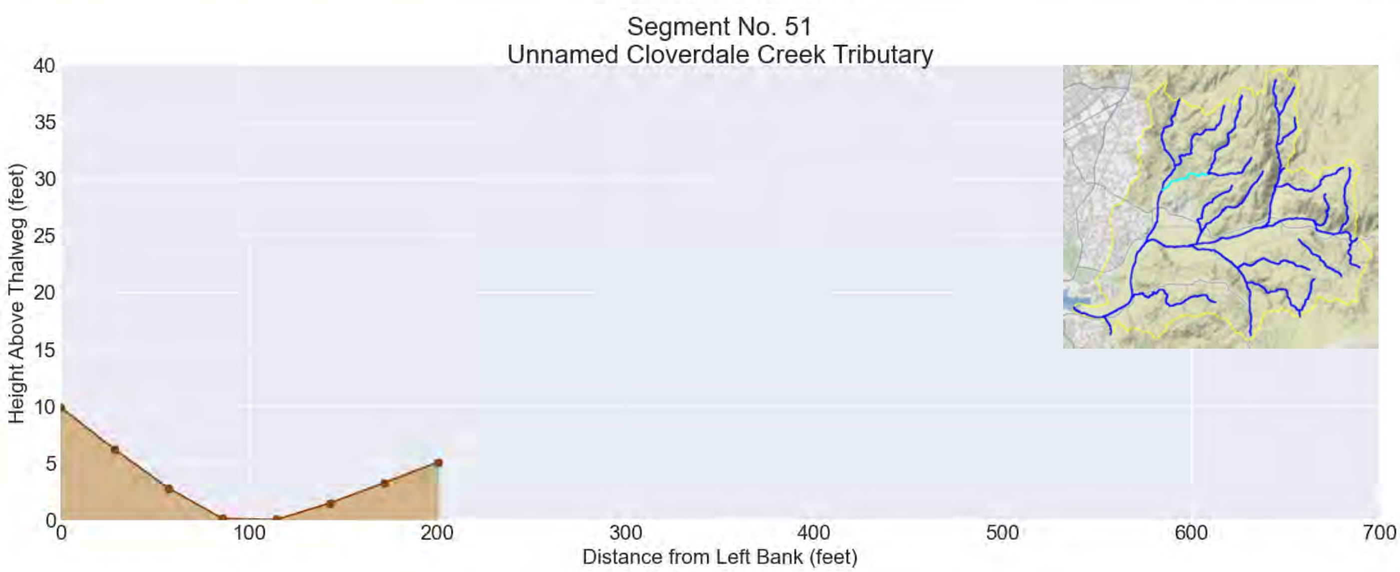
Map Legend
- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-16
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs







Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. "Left Bank" refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-17

Modeled Eight-point Stream Channels

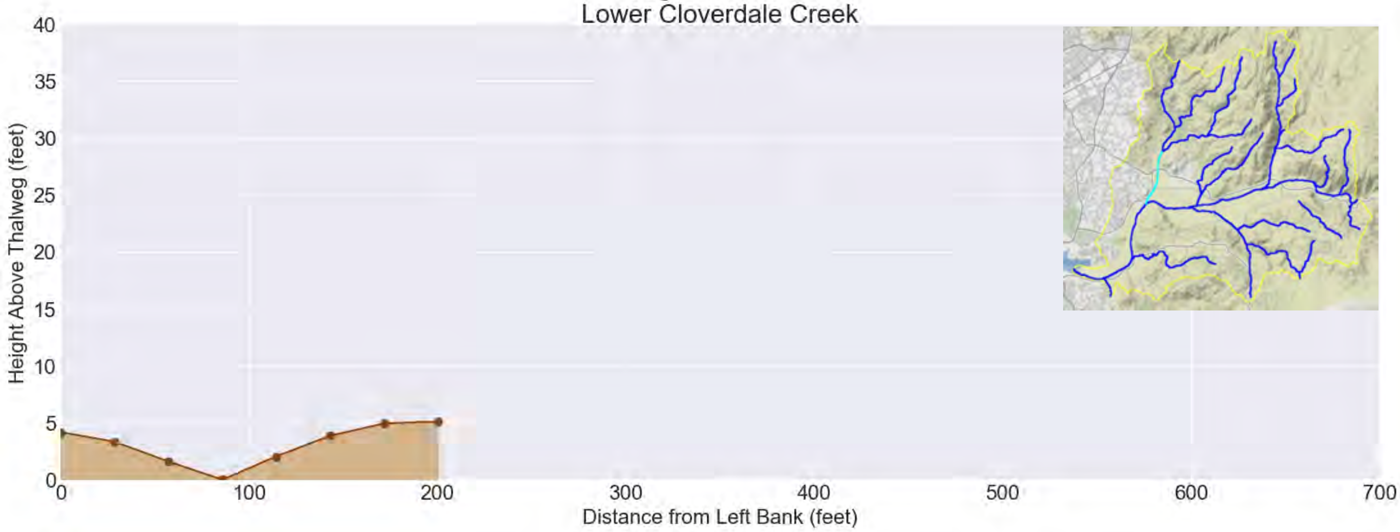
PMA7: Initial Surface Water Recharge Evaluation

Task 5 Groundwater and Surface Water Simulations

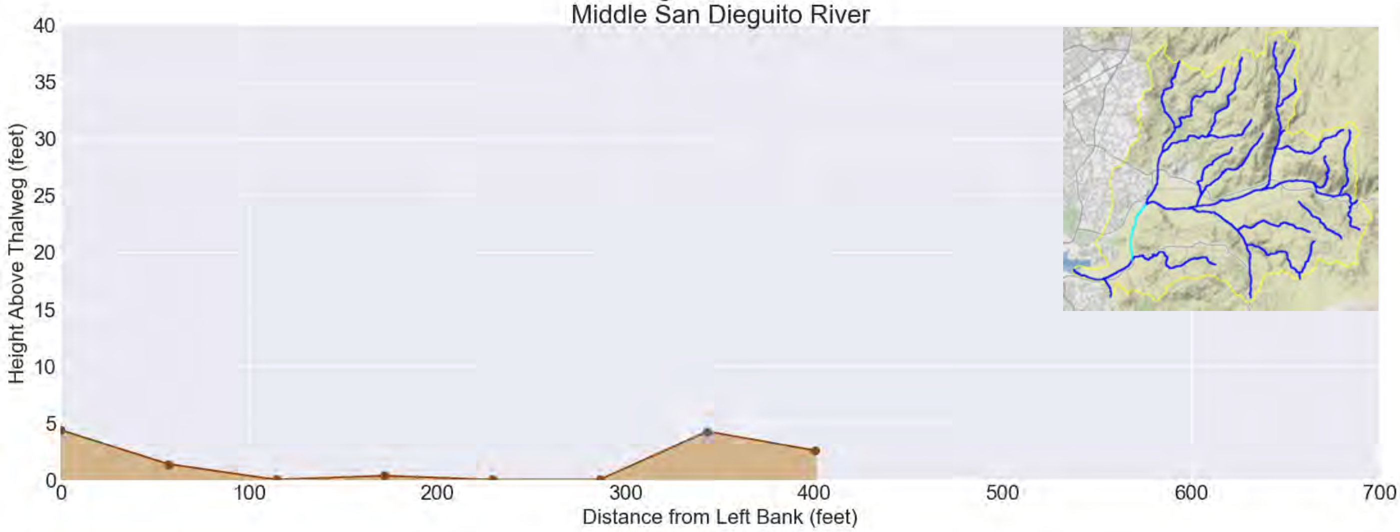
San Pasqual Valley, California

Jacobs

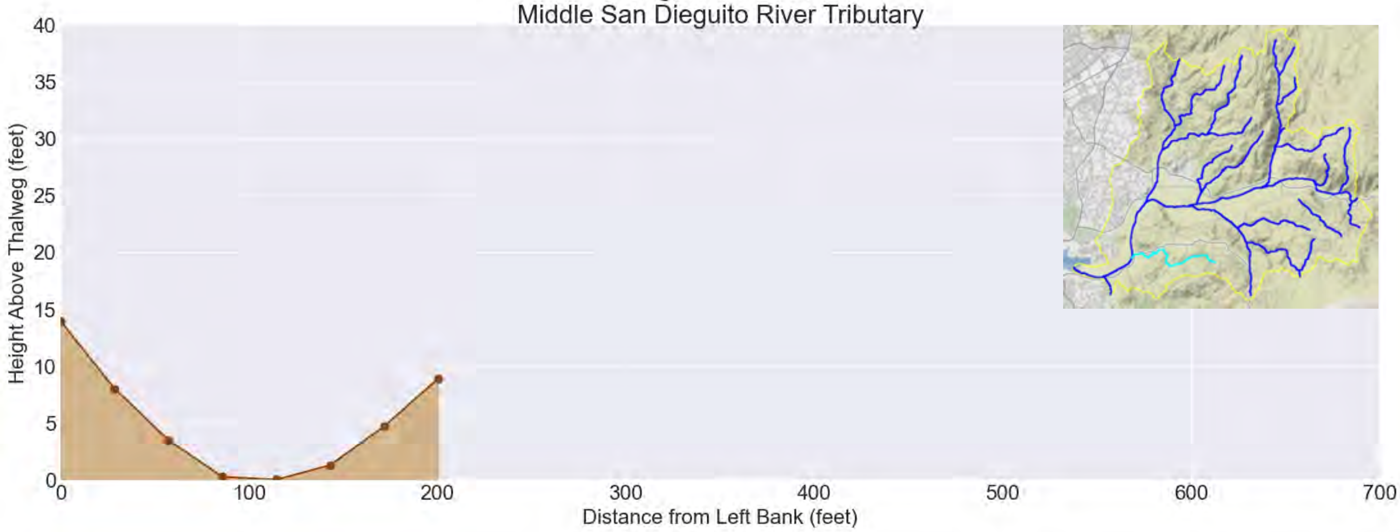
Segment No. 52
Lower Cloverdale Creek



Segment No. 53
Middle San Dieguito River



Segment No. 54
Middle San Dieguito River Tributary



Notes:

1. Vertical axes are exaggerated by 20 times the horizontal axes.
2. “Left Bank” refers to the left side of the channel when facing the downstream direction for the stream segment.

Map Legend

- Modeled Stream
- Highlighted Segment of Modeled Stream

Figure A-18
Modeled Eight-point Stream Channels
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

ATTACHMENT B: MATHEMATICAL FORMULATION FOR HYDRAULIC CONDUCTIVITY OF MODELED STREAMS

This attachment describes the mathematical formulation used to compute effective vertical K values assigned to the SFR package in the SPV GSP Model v2.0. This mathematical formulation is needed because the SFR package requires input of K values that represent the effective vertical K of the streambed and underlying materials above the water table. The K values of the streambed materials that were derived in Task 2 (City, 2023a) are not appropriate to directly assign to the SFR package as they only account for the vertical K of the stream. The following background subsection describes the basis for why the approach for assignment of vertical K in the SFR package was needed.

Background

The SPV GSP Model v1.0 was originally calibrated to groundwater levels measured over the 15-year historical period including WYs 2005 through 2019. The calibration process involves varying selected input parameter (e.g., K) values within realistic ranges until there is a reasonable match between modeled and measured groundwater levels through time, while also achieving acceptable numerical mass balances. A numerical mass balance discrepancy is computed and reported by the model for each stress period and is a measure for how well the software code[1] was able to solve the flow equations during each stress period. A stress period is an interval of time during which different values of precipitation, stream inflows at the perimeter of the model, and groundwater pumping are used in the model.

It was discovered during the calibration process of the SPV GSP Model v1.0 that the numerical mass balance discrepancy was sensitive to the effective vertical K values assigned to the SFR package ($K_{v\text{-}SFR}$). Generally, the higher the assigned $K_{v\text{-}SFR}$ values, the worse the numerical mass balance discrepancies. The modeling team corresponded with one of the software code developers on this topic and confirmed that higher $K_{v\text{-}SFR}$ values can result in higher mass balance discrepancies. Because the key model output of interest for the GSP (City and County, 2021) was the groundwater budget, achieving adequate numerical mass balances was of utmost importance. Therefore, during the development of the GSP, a compromise was made by assigning a $K_{v\text{-}SFR}$ value of 0.1 feet per day (ft/d) (3.5×10^{-5} centimeters per second [cm/s]) to achieve sufficient numerical mass balances, even though it was understood at that time that actual K values of the streambed could be greater. This compromise was deemed reasonable and appropriate during development of the GSP, especially given that streambeds in the SPV were dry most of the time during the 15-year historical calibration period and because no site-specific K data for the streambed or underlying sediments above the water table were available to confirm or refute the assigned value.

The uncertainty in site-specific K values for the Santa Ysabel Creek streambed provided the motivation for the Task 2 streambed investigation (City, 2023a). One of the key findings from this streambed investigation was a range of streambed vertical hydraulic conductivity ($K_{v\text{-}sb}$) values at eight locations along the Santa Ysabel Creek channel. The $K_{v\text{-}sb}$ values were estimated to range from 116 to 552 ft/d (4.1×10^{-2} to 1.9×10^{-1}

[1] The USGS code MODFLOW-OWHM: One Water Hydrologic Flow Model version 2 (Boyce et al., 2020) was selected for this modeling effort. Additional details on this software code can be found in Section 3.1 of Appendix I of the GSP (City and County, 2021).

cm/s) for the main Santa Ysabel Creek channel (e.g., Part 2 in **Figure 2-1**) and from 24 to 83 ft/d (8.5×10^{-3} to 2.9×10^{-2} cm/s) for the right bank (e.g., Part 3 in **Figure 2-1**). However, the software code developer indicated that the $K_{v\text{-}SFR}$ should consider not only the $K_{v\text{-}sb}$, but also the vertical K of the vadose zone below the stream channel ($K_{v\text{-}vz}$). This is because the SFR package ignores the vertical K assigned to the groundwater cell in Model Layer 1 directly beneath the SFR channel and instead uses the $K_{v\text{-}SFR}$ when computing the groundwater recharge from the stream (**Figure 2-3**). Therefore, a mathematical formulation was needed to compute $K_{v\text{-}SFR}$ values that account for both the $K_{v\text{-}sb}$ estimates from the Task 2 streambed investigation (City, 2023a) as well as the $K_{v\text{-}vz}$, because (as indicated in Section 2.1.2) the rate at which water infiltrates the stream channel at the surface is not necessarily the rate at which the infiltrated water enters the aquifer as groundwater recharge from the stream. This is because the vertical K of the vadose zone materials below the stream channel affects the rate of groundwater recharge from the stream. For this reason, it would not be appropriate to directly assign to the SFR package the K values of the streambed materials that were derived in Task 2 (City, 2023a).

Mathematical Formulation

Groundwater monitoring wells in the Santa Ysabel Creek streambed could provide information on the rate of groundwater recharge from the stream. However, none of the existing groundwater monitoring wells are located in the streambed and estimation of the vertical distribution of K in the vadose zone below the stream channel cannot be estimated solely with the infiltration testing data from the Task 2 streambed investigation (City, 2023a). This limitation is especially relevant in the eastern portion of the Basin where the water table is disconnected from and typically dozens of feet below Santa Ysabel Creek. In this hydrologic setting, the lower-K sediment intervals between the stream channel and water table are the intervals that limit the rate of groundwater recharge from streams. For example, if zone K_5 in **Figure B-1** were to have a much lower K value than the other zones below the infiltration test ring, then it would be the zone that limits the groundwater recharge from infiltration in the test ring. In other words, the zone with the lowest K value above the water table would be the limiting factor for how easily water moves through the vadose zone and enters the aquifer as groundwater recharge from streams. Shorter-term infiltration tests only provide information on the $K_{v\text{-}sb}$ and the vertical K of shallower sediments beneath the streambed, rather than the effective vertical K of all the materials (e.g., $K_{v\text{-}sb}$ and K_1 through K_7 zones in **Figure B-1**) above the water table under the stream (Johnson, 1963).

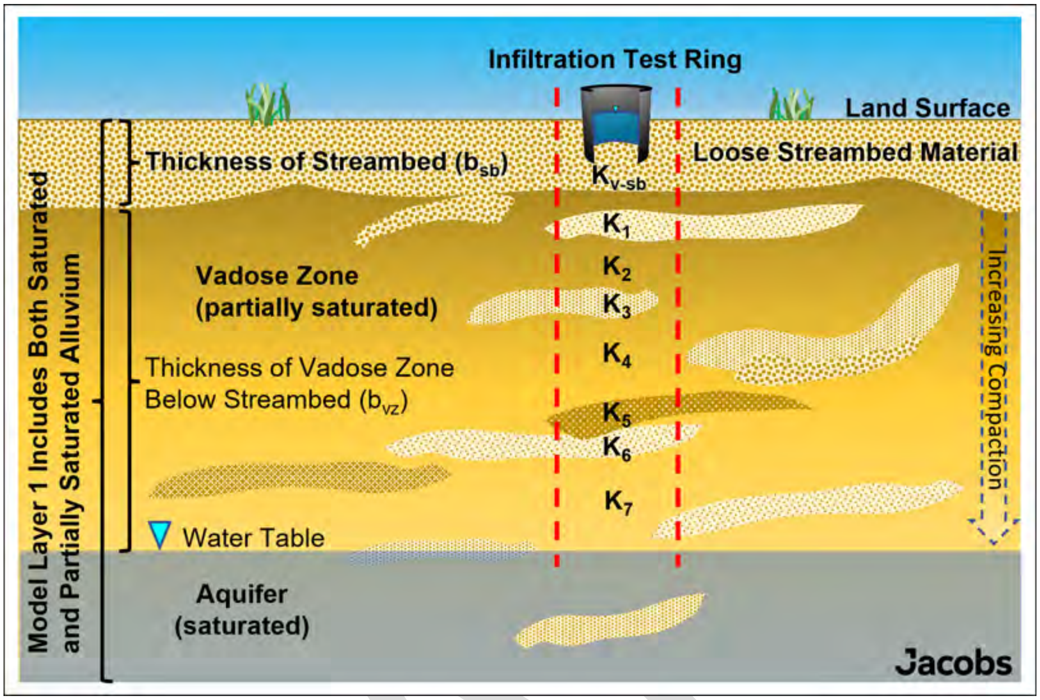


Figure B-1: Hypothetical K Zones Below a Stream Channel

As indicated above, when the water table is some distance below the modeled stream channel, the groundwater recharge rate from the stream is computed using the $K_{v\text{-}SFR}$ as the effective vertical K of the entire vadose zone below the stream; thereby ignoring the vertical K value assigned to the underlying groundwater cell in Model Layer 1 (**Figure 2-3** and **Figure B-1**). In recognition of this aspect of the SFR package, the modeling team assigned $K_{v\text{-}SFR}$ values to SFR stream reaches in the SPV GSP Model v2.0 based on the harmonic mean (Freeze and Cherry, 1979) of the $K_{v\text{-}sb}$ and vertical K assigned in the underlying groundwater cell in Model Layer 1, according to Equation B-1, as follows:

$$K_{v-SFR} = \frac{b_t}{\frac{b_{sb}}{K_{v-sb}} + \frac{b_{vz}}{K_{v-vz}}} \qquad \text{(B-1)}$$

where (see **Figure B-1)**

- $K_{v\text{-}SFR}$ = effective vertical hydraulic conductivity assigned to SFR package
- $K_{v\text{-}sb}$ = streambed vertical hydraulic conductivity
- $K_{v\text{-}vz}$ = vertical hydraulic conductivity of vadose zone below the stream channel
- b_{sb} = thickness of the modeled streambed
- b_{vz} = thickness of the interval between the bottom of the streambed and average water table elevation
- b_t = total alluvium thickness above the average water table elevation = b_{sb} + b_{vz}

The $K_{v\text{-}SFR}$ value establishes the effective resistance to flow after water infiltrates the streambed and moves downward through the vadose zone to the underlying water table (**Figure B-1**). The smaller the $K_{v\text{-}SFR}$ the greater the resistance to downward flow between the stream and underlying aquifer. The $K_{v\text{-}vz}$ values in

Equation B-1 were based on the vertical K values assigned to groundwater model cells in Model Layer 1 that underlie SFR reaches (**Figure 2-3** and **Figure B-1**). The $K_{v\text{-}vz}$ values were arrived at through the recalibration process discussed in Section 2.3 and Attachment C.

ATTACHMENT C: RECALIBRATION DETAILS

As indicated in Section 2.3, recalibration of the SPV GSP Model v2.0 was necessary after incorporating updates because modeled groundwater elevations were too high across the Basin as compared with measured groundwater levels. This attachment describes the modifications made to recalibrate the SPV GSP Model v2.0 for use on this Initial Surface Water Recharge Evaluation.

Input Parameter Modifications

In addition to the stream channel configuration update (see Section 2.1.1 and Attachment A) and the improved runoff routing (see Section 2.1.3), the following modifications were made:

- Updated $K_{v\text{-}SFR}$ values using vertical K values from Model Layer 1 and $K_{v\text{-}sb}$ values from the Task 2 streambed investigation (City, 2023a), and Equation B-1 (see Attachment B)
- Removed specified subsurface inflow along the northern, eastern, and southern boundaries of the model area
- Updated the depth to bedrock near the mouth of Rockwood Canyon
- Modified the boundary condition at the western end of the Basin to better match groundwater-level responses in the western portion of the Basin to water-level changes in Hodges Reservoir

The following subsections provide additional details regarding each of these bulleted items.

Effective Hydraulic Conductivity of Modeled Streambeds

As described in Section 2.1.2 and Attachment B, a mathematical approach was formulated to assign $K_{v\text{-}SFR}$ values to the SFR package in the SPV GSP Model v2.0. A summary of the streambed thickness (b_{sb}), streambed vertical K ($K_{v\text{-}sb}$), vadose zone thickness (b_{vz}), and effective vertical K assigned to the SFR package ($K_{v\text{-}SFR}$) by stream systems is listed in **Table C-1**.

The $K_{v\text{-}SFR}$ values shown in **Table C-1** were calculated using Equation B-1 from Attachment B, based on the assigned $K_{v\text{-}sb}$, b_{sb}, $K_{v\text{-}vz}$, and b_{vz}. SFR reaches representing stream channels located near the Task 2 streambed infiltration testing locations were assigned $K_{v\text{-}sb}$ values based on the channel-center K estimates derived during the Task 2 streambed investigation (City, 2023a) (**Table C-2)**. The rest of the SFR reaches within the Basin were assigned a $K_{v\text{-}sb}$ value of 50 ft/d (1.8×10^{-2} cm/s), whereas the SFR reaches outside of the Basin were assigned a $K_{v\text{-}sb}$ value of 0.01 ft/d (3.5×10^{-6} cm/s) **(Figure C-1**). Having lower $K_{v\text{-}sb}$ values assigned to stream reaches located outside the Basin is reasonable because these narrow reaches exist over rock and likely have stream channel material that is either very thin or nonexistent. SFR reaches within the Basin were assigned a streambed thickness value of 5 feet, whereas SFR reaches outside of the Basin were assigned a value of 1 foot. The spatial distributions of $K_{v\text{-}sb}$ and $K_{v\text{-}SFR}$ are shown in **Figure C-1** and **Figure C-2**.

Table C-1: Summary of Parameters Used to Compute Effective Hydraulic Conductivity of Modeled Streams

Stream	Streambed Thickness, b_{sb} (feet)	Streambed Vertical Hydraulic Conductivity, $K_{v\text{-}sb}$ (ft/d)[a,b]	Vadose Zone Thickness, b_{vz} (feet)	Effective Vertical Hydraulic Conductivity Assigned to Modeled Stream, $K_{v\text{-}SFR}$ (ft/d)[b,c]
Santa Ysabel Creek	1 or 5	0.01 to 552 (3.5×10^{-6} to 1.9×10^{-1})	0 to 57	0.01 to 0.71 (3.5×10^{-6} to 2.5×10^{-4})
Guejito Creek	1 or 5	0.01 to 116 (3.5×10^{-6} to 4.1×10^{-2})	0 to 50	0.01 to 0.31 (3.5×10^{-6} to 1.1×10^{-4})
Santa Maria Creek	1 or 5	0.01 to 50 (3.5×10^{-6} to 1.8×10^{-2})	0 to 50	0.01 to 0.48 (3.5×10^{-6} to 1.7×10^{-4})
Cloverdale Creek	1 or 5	0.01 to 50 (3.5×10^{-6} to 1.8×10^{-2})	0	0.01 to 0.60 (3.5×10^{-6} to 2.1×10^{-4})
Sycamore Creek	5	50 (1.8×10^{-2})	0	0.30 (1.1×10^{-4})
Other Creeks	1 or 5	0.01 to 373 (3.5×10^{-6} to 1.3×10^{-1})	0 to 46	0.01 to 0.69 (3.5×10^{-6} to 2.4×10^{-4})
San Dieguito River	1 or 5	0.01 to 50 (3.5×10^{-6} to 1.8×10^{-2})	0	0.01 to 0.60 (3.5×10^{-6} to 2.1×10^{-4})

[a] Values are from City (2023a).
[b] Values in parenthesis are expressed in units of cm/s.
[c] Values were computed using Equation B-1 (see Attachment B).

Table C-2: Summary of Task 2 Streambed Investigation Vertical Hydraulic Conductivity

Location[a]	Channel-center Vertical Hydraulic Conductivity (ft/d)[b,c]
Transect 1, T-1	373 (1.3×10^{-1})
Transect 2, T-2	552 (1.9×10^{-1})
Transect 3, T-3	116 (4.1×10^{-2})
Transect 4, T-4	158 (5.6×10^{-2})

[a] Transect locations are shown in **Figure C-1.**
[b] Values are from City (2023a).
[c] Values in parenthesis are expressed in units of cm/s.

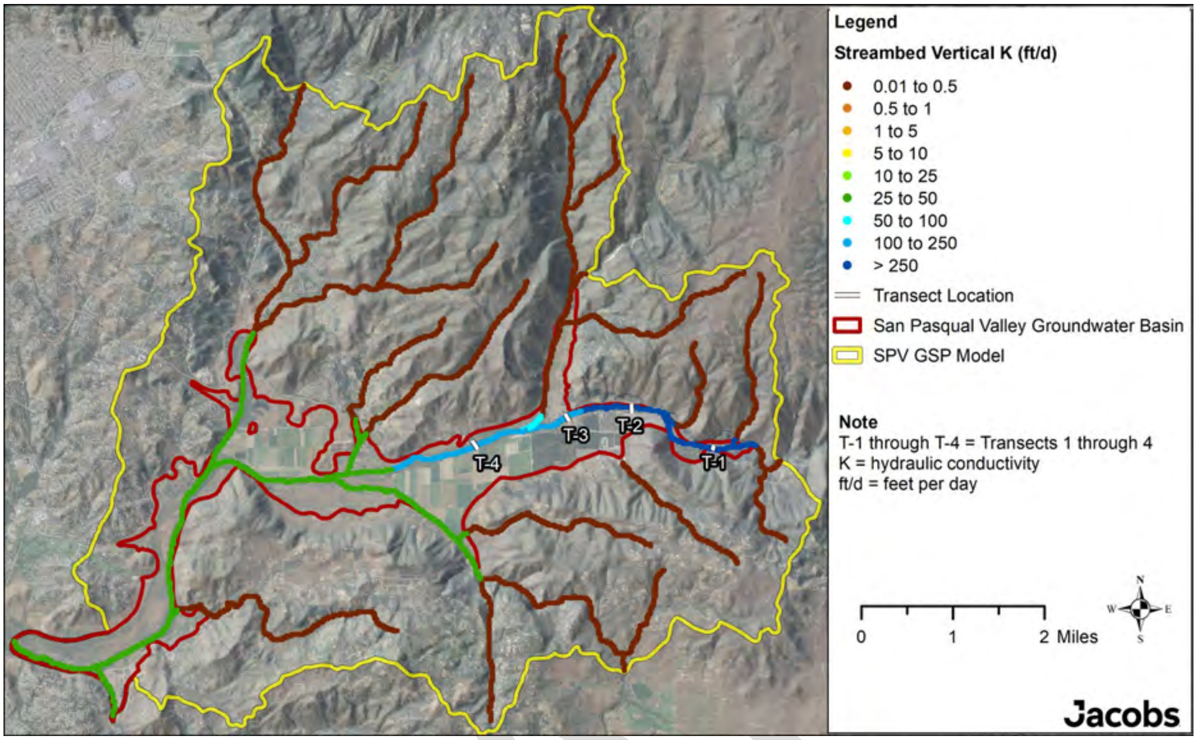


Figure C-1: Assigned Streambed Vertical Hydraulic Conductivity

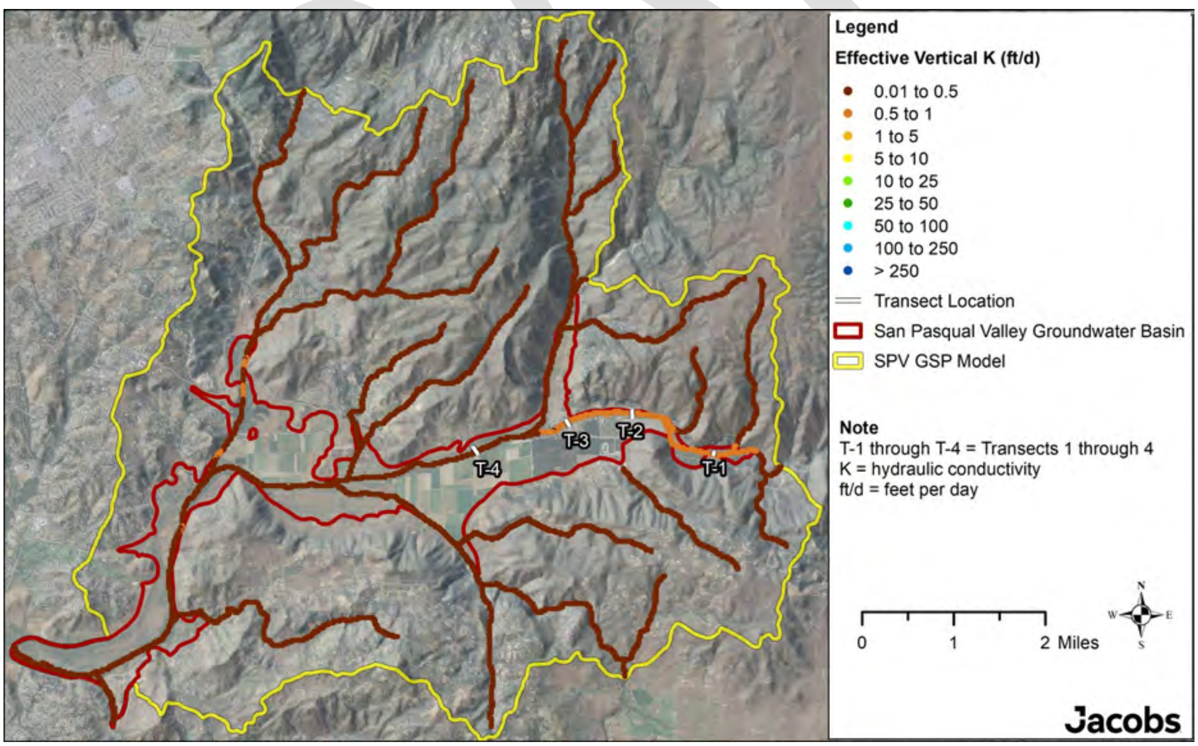


Figure C-2: Calibrated Effective Vertical Hydraulic Conductivity

Removal of Specified Subsurface Inflow

Groundwater flow entering the model area at its northern, eastern, and southern boundaries from areas adjacent to the model area was simulated in the SPV GSP Model v1.0. This term was called "subsurface inflow from contributing catchments" in the GSP (City and County, 2021). This groundwater inflow into the model area was simulated in the SPV GSP Model v1.0 using a boundary condition. Boundary conditions are mathematical rules coded into the modeling software that specify head (groundwater elevation) or water flux at selected locations within the model area. The boundary condition that represents subsurface inflow from contributing catchments is referred to as a specified-flux boundary. With this type of boundary condition, time-series subsurface inflow values are input to the software by the modeler before the simulation. During the simulation the software incorporates the provided flow values at the intended boundary-condition cells.

Throughout the recalibration process, modeled groundwater levels within the Basin were generally higher than the measured groundwater levels because of higher $K_{v\text{-}SFR}$ values allowing for greater groundwater recharge from the streams. As a result, other sources of groundwater recharge to the Basin needed to be reduced within reasonable ranges to help achieve better fits to the measured groundwater levels. Additionally, the increase in groundwater recharge from streams was causing water at the inflow point of the Basin in Santa Ysabel Creek to pond above ground surface, which is not consistent with the hydrogeologic conceptual model, suggesting that this boundary condition overestimated the subsurface contribution of water from adjacent catchments. With these considerations in mind, the specified-flux boundary condition values that represent subsurface inflow from contributing catchments in the SPV GSP Model v2.0 were reduced to a value of zero in the relevant boundary-condition cells. This change helped avoid water ponding along the eastern perimeter of the model and helped play a small part in lowering modeled groundwater levels in the Basin. Removal of these subsurface inflows does not limit the ability of the SPV GSP Model v2.0 to achieve its purpose to help quantify potential benefits from implementing the four recharge strategies described in Section 1.

Updated Depth to Bedrock

Throughout the recalibration process, modeled groundwater levels near the mouth of Rockwood Canyon were consistently too high as compared with measured groundwater levels. Inspection of detailed subarea groundwater budgets between Rockwood Canyon and the SPV revealed that groundwater was moving too easily into the mouth of Rockwood Canyon from the south. In other words, groundwater depressions that would in reality exist around the irrigation wells in the mouth of Rockwood Canyon were being replenished with some of the groundwater that was mostly flowing west down the SPV. This observation compelled the modeling team to examine the model layering within this subarea.

Cross-section D-D' is shown in **Figure C-3** and extends along the center of Rockwood Canyon to where it meets A-A' along the center of SPV. According to Cross-section D-D', which was prepared by Snyder Geologic during development of the GSP (City and County, 2021), the bedrock surface rises in elevation at LWELL16379. This higher bedrock surface means that near this well there is less thickness of alluvium, which could create a barrier effect to groundwater flow between the Rockwood Canyon and SPV (**Figure C-3**). Although the SPV GSP Model v1.0 included this bedrock high along Cross-section D-D', the modeled bedrock surface decreased in elevation east of this bedrock high creating a "saddle" or low-point in the bedrock surface between the bedrock high at LWELL16379 and the southeast corner of Rockwood Canyon, where the Basin meets the surrounding bedrock (**Figure C-4**).

Bottom elevations of Model Layers 1 and 2 were raised by a range of 2 to 60 feet at selected model cells in the vicinity of LWELL16379 to create a smoother transitional surface between the bedrock high at LWELL16379 and the Basin margin to the east (**Figure C-4**). The layer modifications in this subarea improved the fits between the measured and modeled groundwater levels at calibration wells within Rockwood Canyon by reducing the amount of groundwater flow from the south into the lower end of Rockwood Canyon.

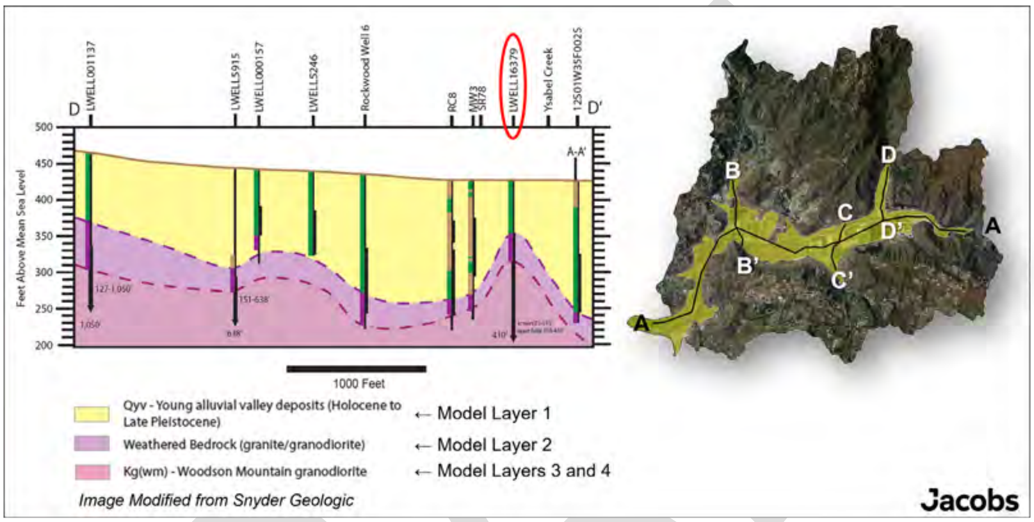


Figure C- 3: Geologic Cross Section Along Rockwood Canyon

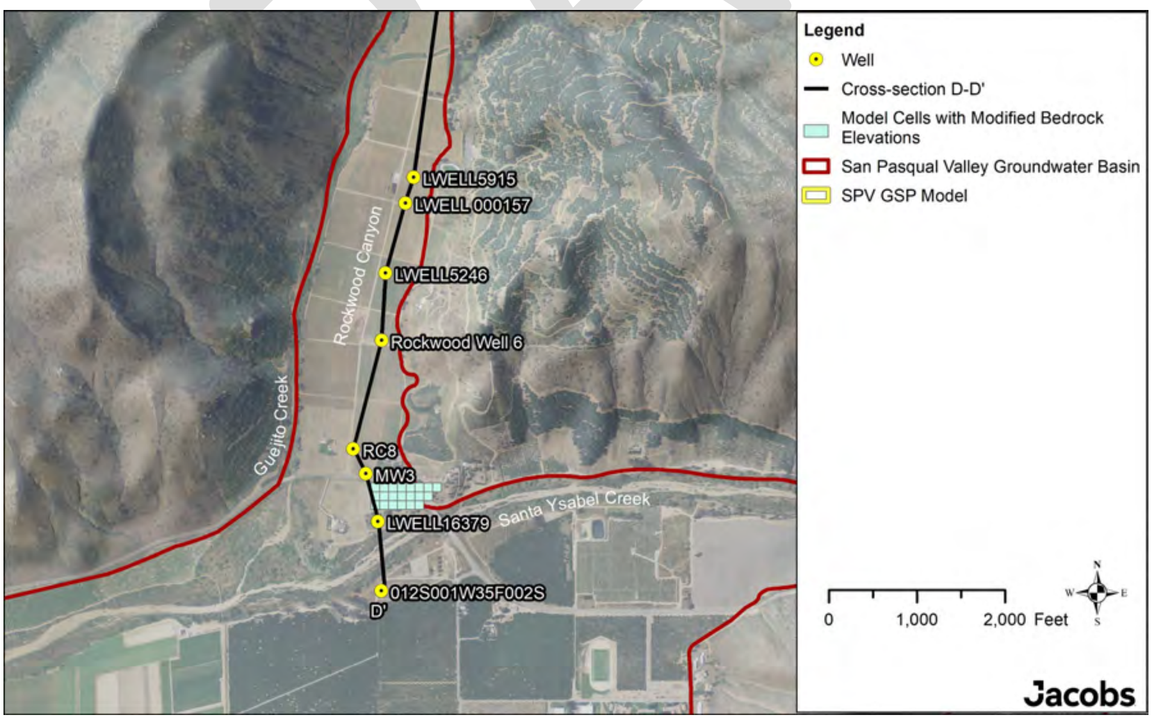


Figure C- 4 Model Cells with Modified Bedrock Elevations

Modified Flow Boundary at Basin Outlet

Groundwater flow across the western end of the Basin near Hodges Reservoir is simulated using a boundary condition (**Figure C-5**). The boundary condition assigned at the western end of the Basin is referred to as a head-dependent flux boundary. With this type of boundary condition, the head (groundwater elevation) and hydraulic-conductance values are assigned to selected model cells, and water fluxes across the boundary cells are computed automatically by the model code during a simulation. This type of boundary condition is a two-way boundary condition, meaning that groundwater can move across the boundary-condition cells into and out of the Basin. Groundwater is simulated to move from the Basin toward Hodges Reservoir when modeled heads in the western end of the Basin are higher than the head value assigned to the boundary condition cell. Groundwater is simulated to move into the Basin from the area between Hodges Reservoir and the western end of the Basin when modeled heads in the western end of the Basin are lower than the head value assigned to the boundary-condition cell. The time-series head values assigned to these boundary-condition cells is the measured surface elevation or “stage” of Hodges Reservoir through time during the simulation.

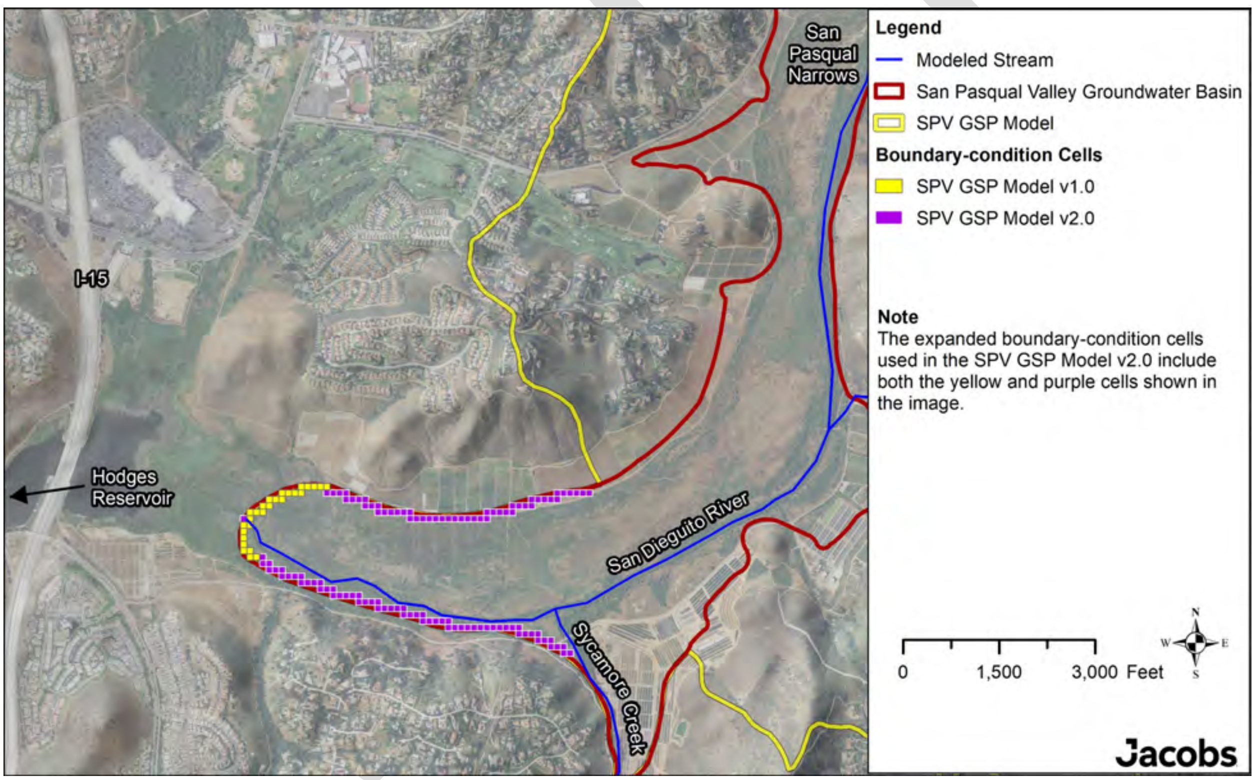


Figure C-5: Boundary-condition Cells Along Western Basin Boundary

During early stages of recalibration, it was evident that modeled groundwater levels along San Dieguito River through San Pasqual Narrows in the western end of the Basin were too high as compared with measured groundwater levels (**Figure C-5**). To help lower modeled groundwater levels, the assignment of boundary-condition cells described above was expanded eastward, thereby allowing the opportunity for greater groundwater flow exchange across the western boundary of the Basin. The conductance term assigned to each of these boundary-condition cells incorporates the distance of the cell to the Interstate-15 bridge to scale the influence of the Hodges Reservoir stages. In other words, the boundary condition cells at the western tip of the Basin are closer to Hodges Reservoir than those boundary-condition cells located farther east; therefore, groundwater flow from this location should respond more easily to stage changes in Hodges Reservoir, as compared with those boundary-condition cells farther from Hodges Reservoir. These modifications resulted in an overall better match between modeled and measured groundwater levels in the western end of the Basin.

Recalibration Results

This subsection presents the recalibration results from the modifications described in Section 2 and in the above attachments.

Calibration Statistics and Goals

The following definitions of terms are provided to support the technical discussion provided in this subsection.

- Head: Synonymous with "groundwater elevation" in this TM
- Residual: Computed as the modeled-head value minus the measured-head value that serves as the calibration target
- Mean residual (MR): Computed as the sum of all residuals divided by the number of observations.
- Residual standard deviation (RSD): Computed as the square root of the average of all squared differences of each residual from the MR. This provides a measure of the spread of the residuals around the MR.
- Root mean squared residual (RMSR): Computed as the square root of the average of all squared residuals.
- Range of measured-head values (Range): Computed as the maximum measured-head value minus the minimum measured-head value.
- RMSR/Range: A summary statistic provided to demonstrate the overall quality of the calibration. A value of less than 10% would indicate an adequately calibrated groundwater model.
- Coefficient of determination (R^2): Computed as the square of the correlation coefficient, which is a statistical measure of the strength of the linear relationship between two variables. In this case the two variables are the modeled and measured heads.

During the recalibration effort, the modeling team executed work with the following general goals:

- Minimize spatial bias of residuals in key areas of the model area.
- Minimize residuals, MR, RMSR, and RMSR/Range values.
- Strive for R^2 values as close to one as possible.

During model recalibration, it is helpful to be aware of model tendencies or inclinations referred to as bias. The modeling team evaluated two types of bias during the recalibration effort: global bias and spatial bias.

Global bias would be evident if the residual values were either all large positive or large negative values. Plotting the modeled versus measured groundwater elevations, as is presented in **Figure C-6**, is a good way to evaluate the degree to which a model exhibits global bias. It also facilitates assessing the overall ability of a model to replicate historical groundwater levels. Overall, the SPV GSP Model v2.0 does not exhibit global bias. Global bias would be evident if all the points in **Figure C-6** were either above or below the "1:1 correlation line". Most points in this figure plot along the 1:1 correlation line with some points falling above and below the line. Calibration statistics for the modeled groundwater elevations are also listed in **Figure C-6** (see definitions and acronyms of statistical terms above). The MR is small, the RMSR/Range is less than 10%, and R^2 is greater than 0.7, which indicates the modeled and measured heads are well correlated. All of the points shown in **Figure C-6** are also provided in Attachment D in the form of groundwater-level hydrographs for each of calibration target location. These hydrographs include modeled groundwater elevations from the SPV GSP Model v1.0 and the SPV GSP Model v2.0 to show how the historical simulation results differ between the two versions of the model.

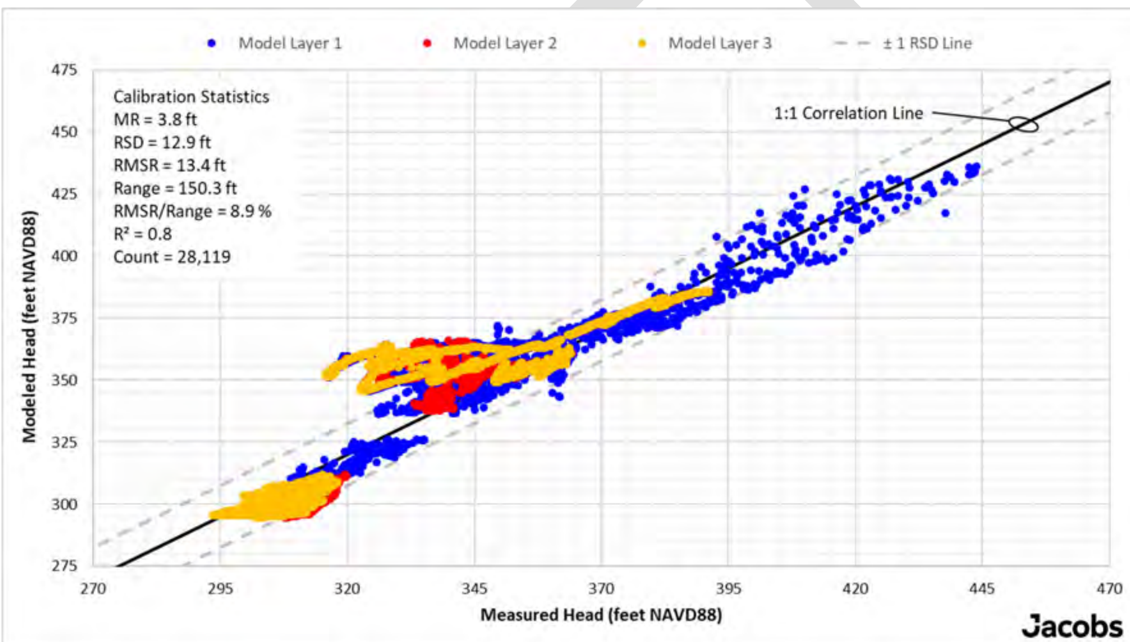


Figure C-6: Modeled Versus Target Groundwater Elevations

Although the modeled heads in the SPV GSP Model v2.0 do not exhibit global bias, it is important to also assess whether the model exhibits spatial bias. Spatial bias would be evident if there are groups of wells in specific subareas of the model with large positive or large negative residuals. A map of the MRs for each calibration well is provided in **Figure C-7.** This type of map is useful for assessing whether spatial biases are evident. Throughout most of the model area there are both positive and negative MRs at nearby wells. The exception to this is in the southern portion of the San Pasqual Narrows near the western outlet of the Basin. Although the fit to measured groundwater levels was generally improved in the SPV GSP Model v2.0 in this western end of the Basin (see **Figure D-7** and **Figure D-8** in Attachment D), as compared with the SPV GSP Model v1.0, it tends to underestimate groundwater levels in that subarea. All the calibration wells in that subarea have negative MRs, indicating some degree of spatial bias in modeled heads in that subarea. However, because the recharge strategies are focused on the eastern portion of the Basin, the spatial bias in heads in the western portion of the Basin is not of concern for this effort. Furthermore, because the simulation of each recharge strategy will be based on the same underlying “baseline model”, the spatial bias would be “washed out” when making comparisons among the simulations of recharge strategies. Overall, the degree of calibration looks sufficient for the intended purpose of the SPV GSP Model v2.0 for the Initial Surface Water Recharge Evaluation.

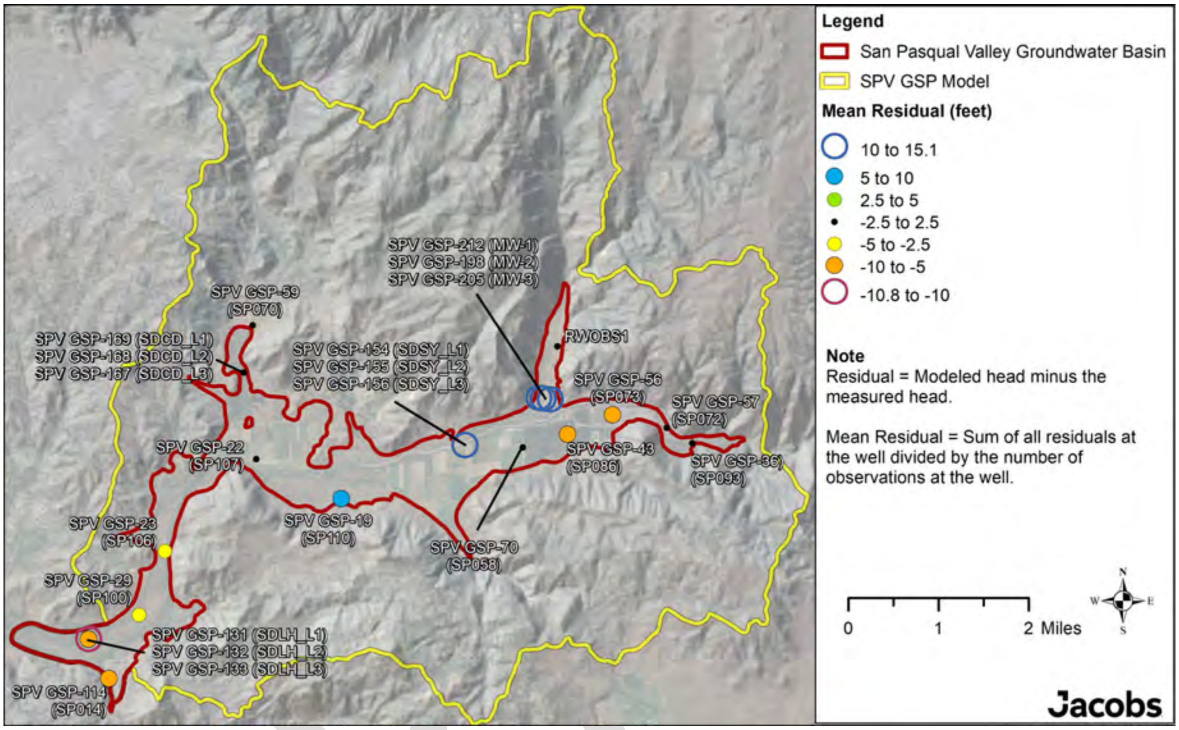


Figure C-7: Map of Mean Residuals

Recalibrated Parameters

The recalibrated horizontal and vertical K values for the subsurface materials are presented in **Figure C-8** and **Figure C-9,** respectively. Hydraulic conductivity zones in Model Layers 1 and 2 were defined to differentiate between the hydrostratigraphic units within the Basin boundary (e.g., alluvium in Model Layer 1 and residuum in Model Layer 2) and the bedrock material surrounding the Basin. Calibrated horizontal and vertical K values for the subsurface materials are summarized by hydrostratigraphic unit and model layer in **Table C-3**.

Overall, the SPV GSP Model v2.0 included multiple refinements to better reflect the dynamics of surface water dynamics and their interaction with groundwater to develop a tool that will be better suited for analyzing the recharge strategies outlined in the Task 4 TM (City, 2023c).

Table C-3: Model Calibrated Horizontal and Vertical Hydraulic Conductivity for Subsurface Materials

Hydrostratigraphic Unit	Model Layer(s)	Horizontal Hydraulic Conductivity (ft/d)[b]	Vertical Hydraulic Conductivity (ft/d)[b]
Alluvium	1	100 (3.5×10^{-2})	0.20 to 0.63 (7.1×10^{-5} to 2.2×10^{-4})
Residuum	2	2.0 to 9.0 (7.1×10^{-4} to 3.2×10^{-3})	0.04 to 0.95 (1.4×10^{-5} to 3.4×10^{-4})
Bedrock	1 through 4[a]	0.004 (1.4×10^{-6})	0.4 (1.4×10^{-4})
[a] Bedrock is represented in all four layers outside the Basin. [b] Values in parenthesis are expressed in units of cm/s.			

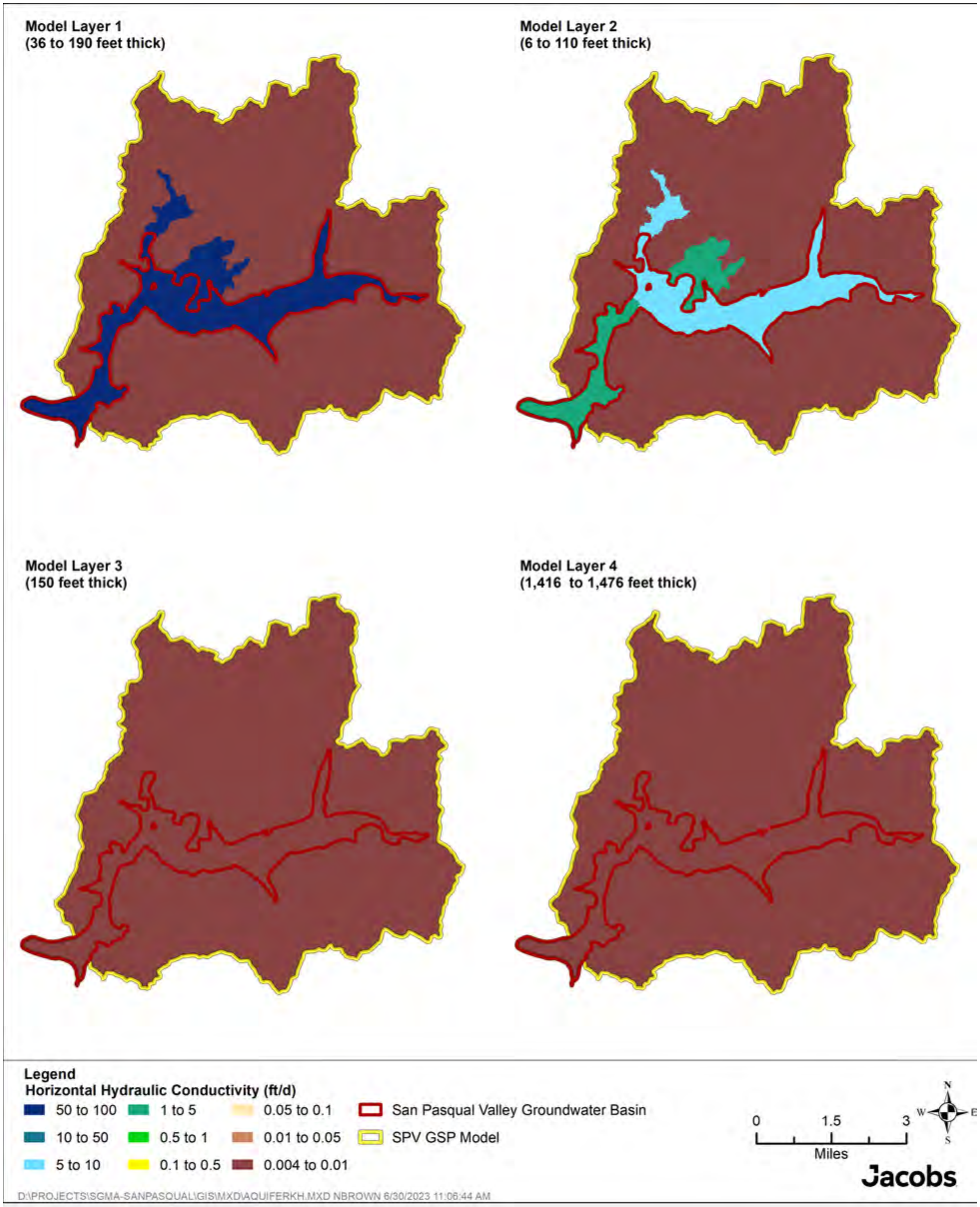


Figure C-8: Calibrated Horizontal Hydraulic Conductivity

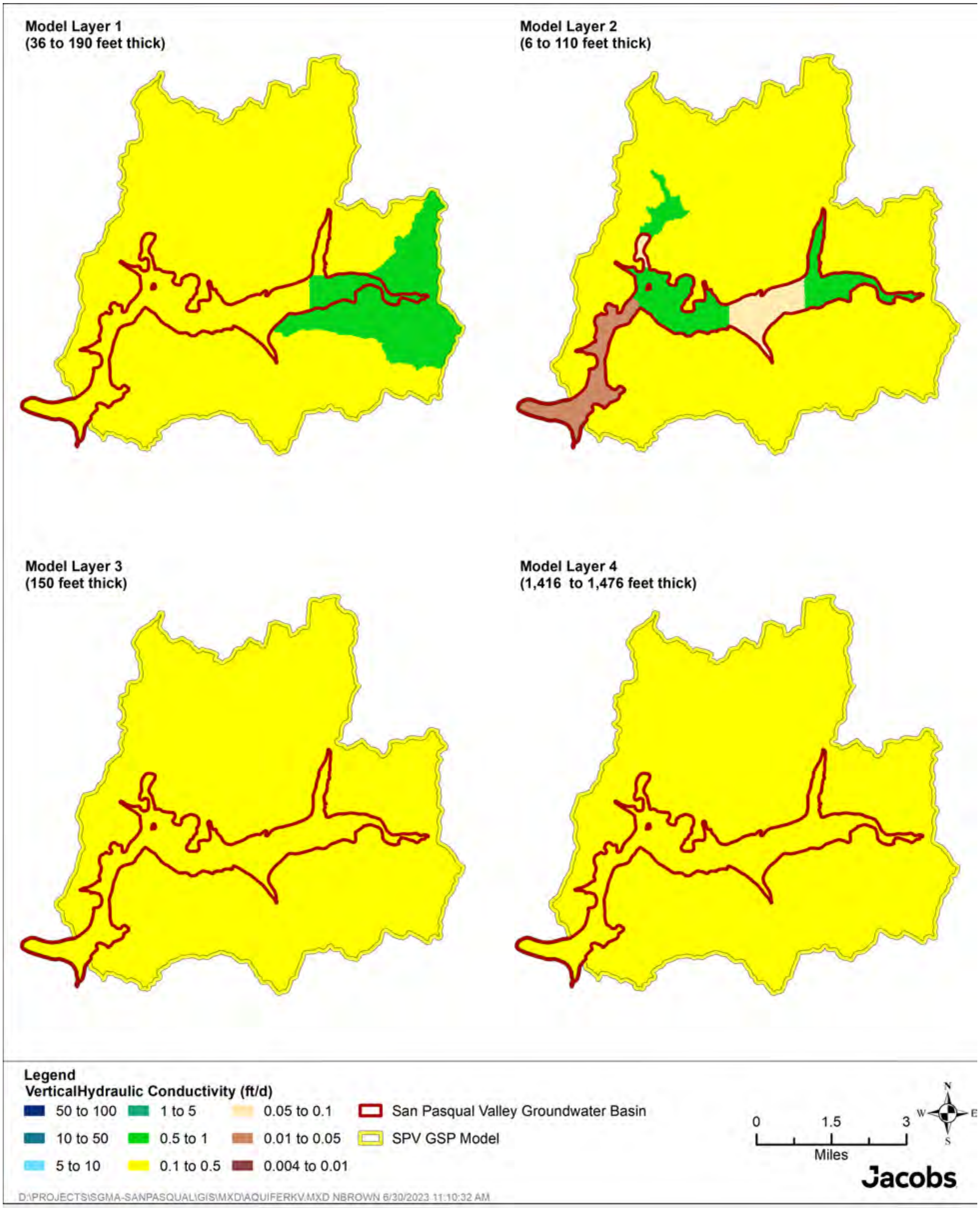
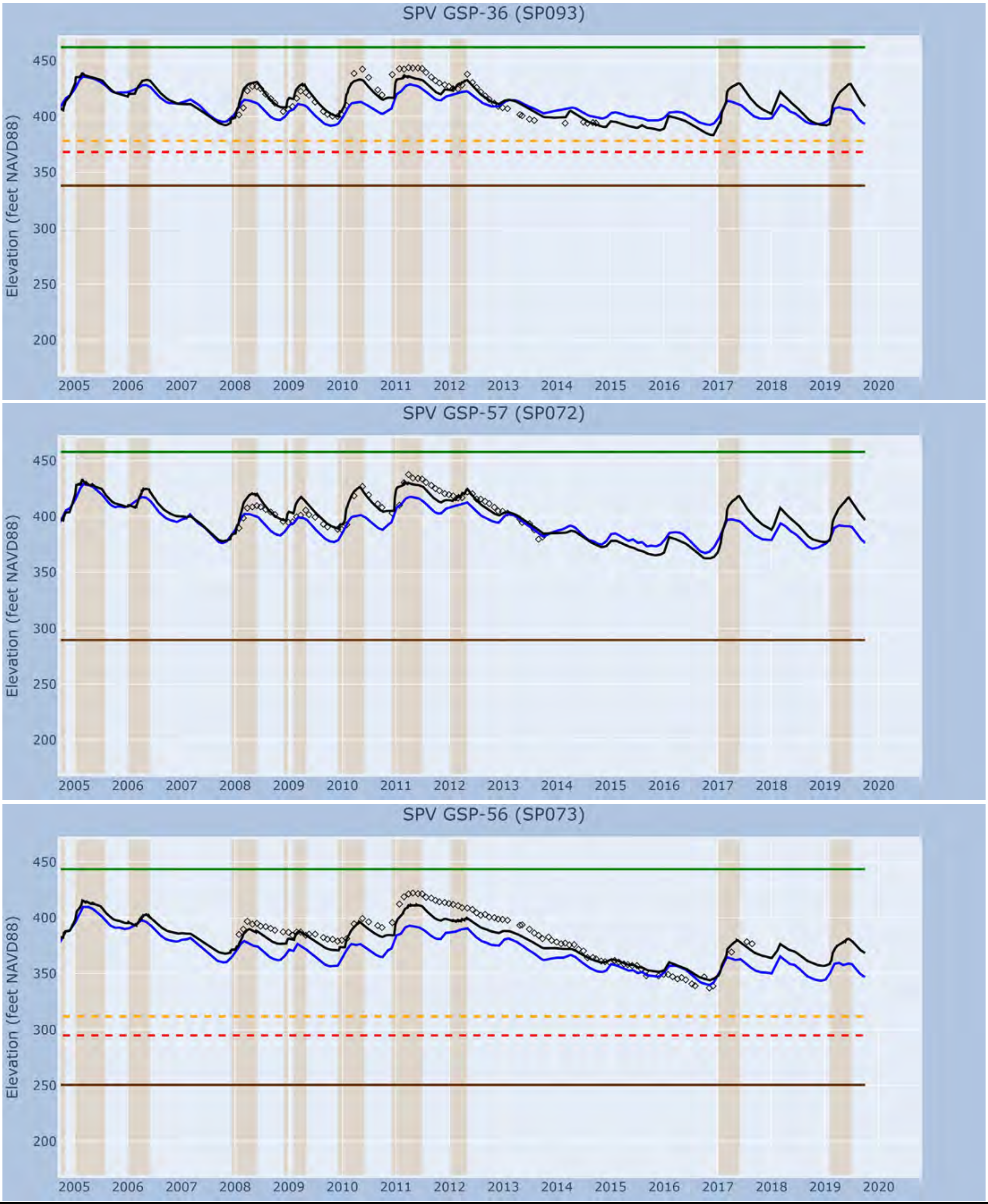


Figure C-9: Calibrated Vertical Hydraulic Conductivity

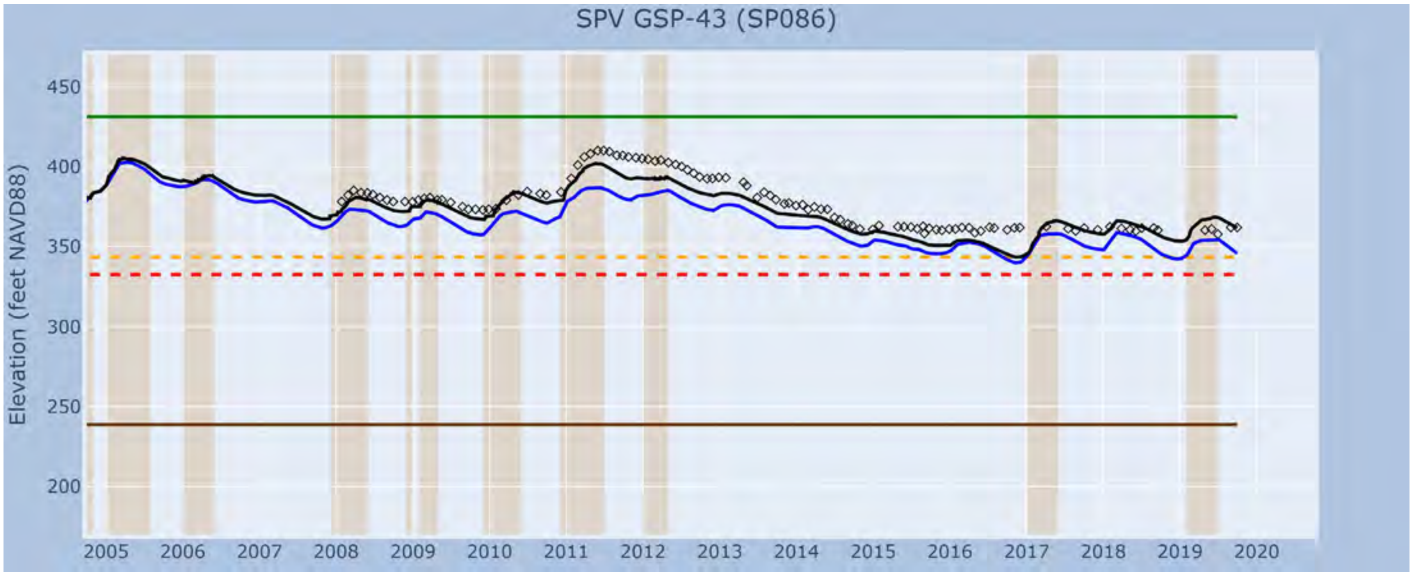
ATTACHMENT D: HISTORICAL GROUNDWATER HYDROGRAPHS

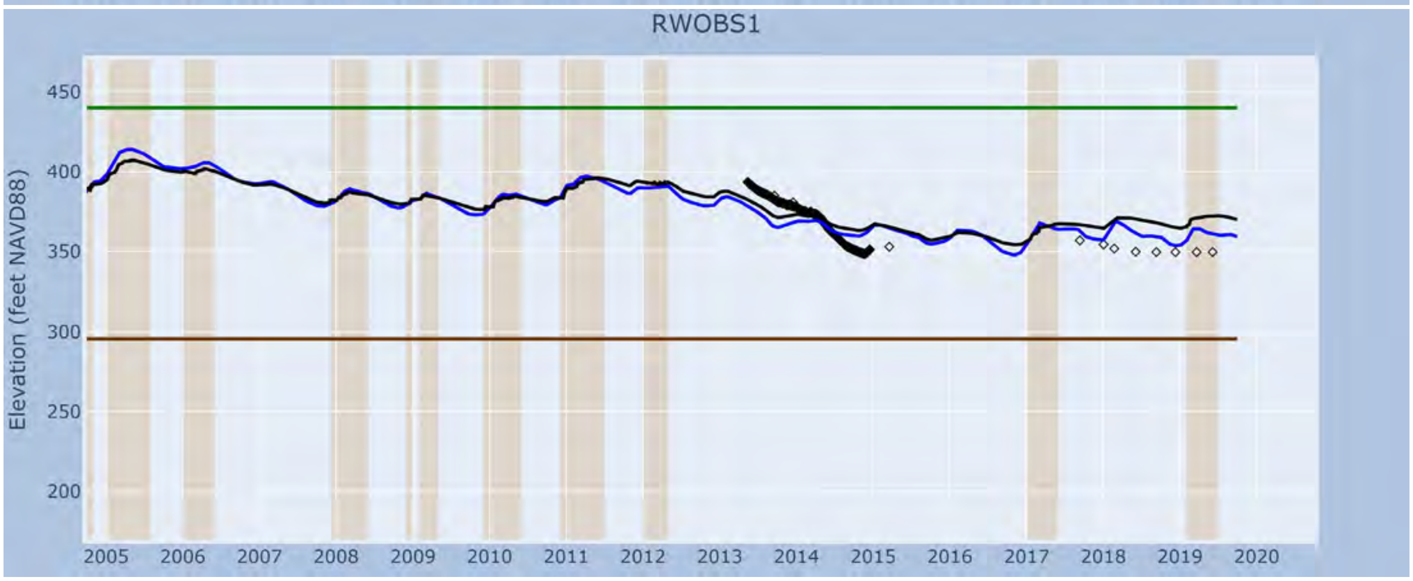


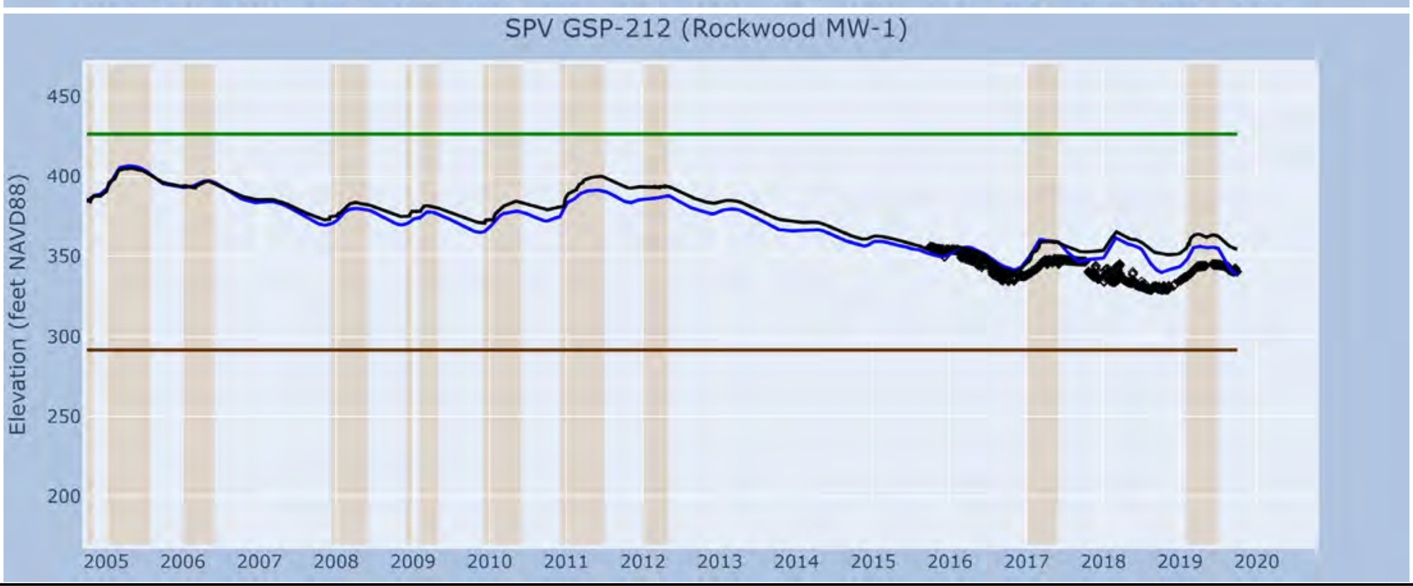
Legend
- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- Measured Groundwater Elevation (feet NAVD88)
- SPV GSP Model v1.0 Head (feet NAVD88)
- SPV GSP Model v2.0 Head (feet NAVD88)
- Daily Stress Period in the SPV GSP Model v2.0 (monthly otherwise)

Figure D-1
Modeled Versus Target Groundwater Head Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs



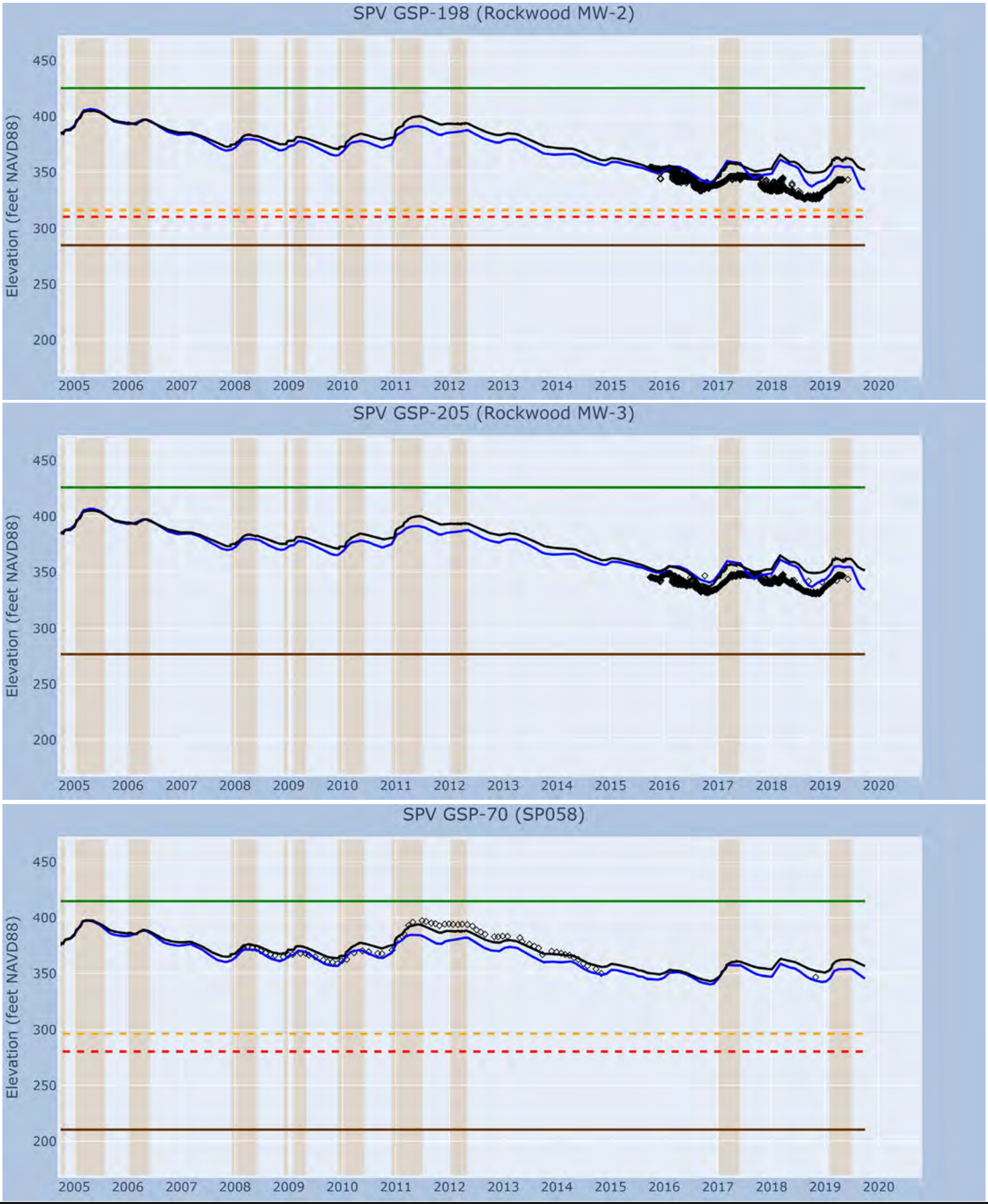




Legend
- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- Measured Groundwater Elevation (feet NAVD88)
- SPV GSP Model v1.0 Head (feet NAVD88)
- SPV GSP Model v2.0 Head (feet NAVD88)
- Daily Stress Period in the SPV GSP Model v2.0 (monthly otherwise)

Figure D-2
Modeled Versus Target Groundwater Head Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

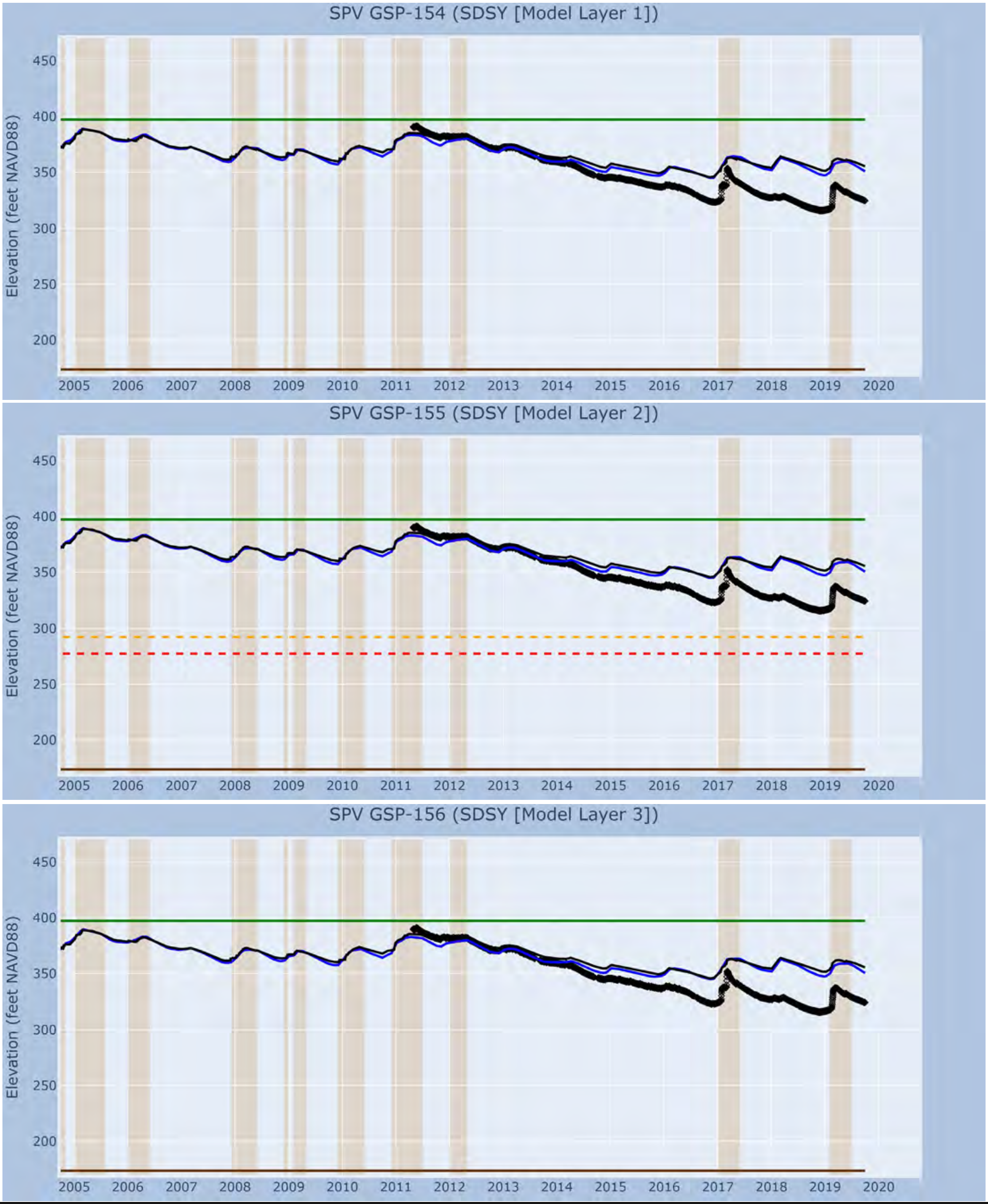
Jacobs



Legend
- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- Measured Groundwater Elevation (feet NAVD88)
- SPV GSP Model v1.0 Head (feet NAVD88)
- SPV GSP Model v2.0 Head (feet NAVD88)
- Daily Stress Period in the SPV GSP Model v2.0 (monthly otherwise)

Figure D-3
Modeled Versus Target Groundwater Head Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

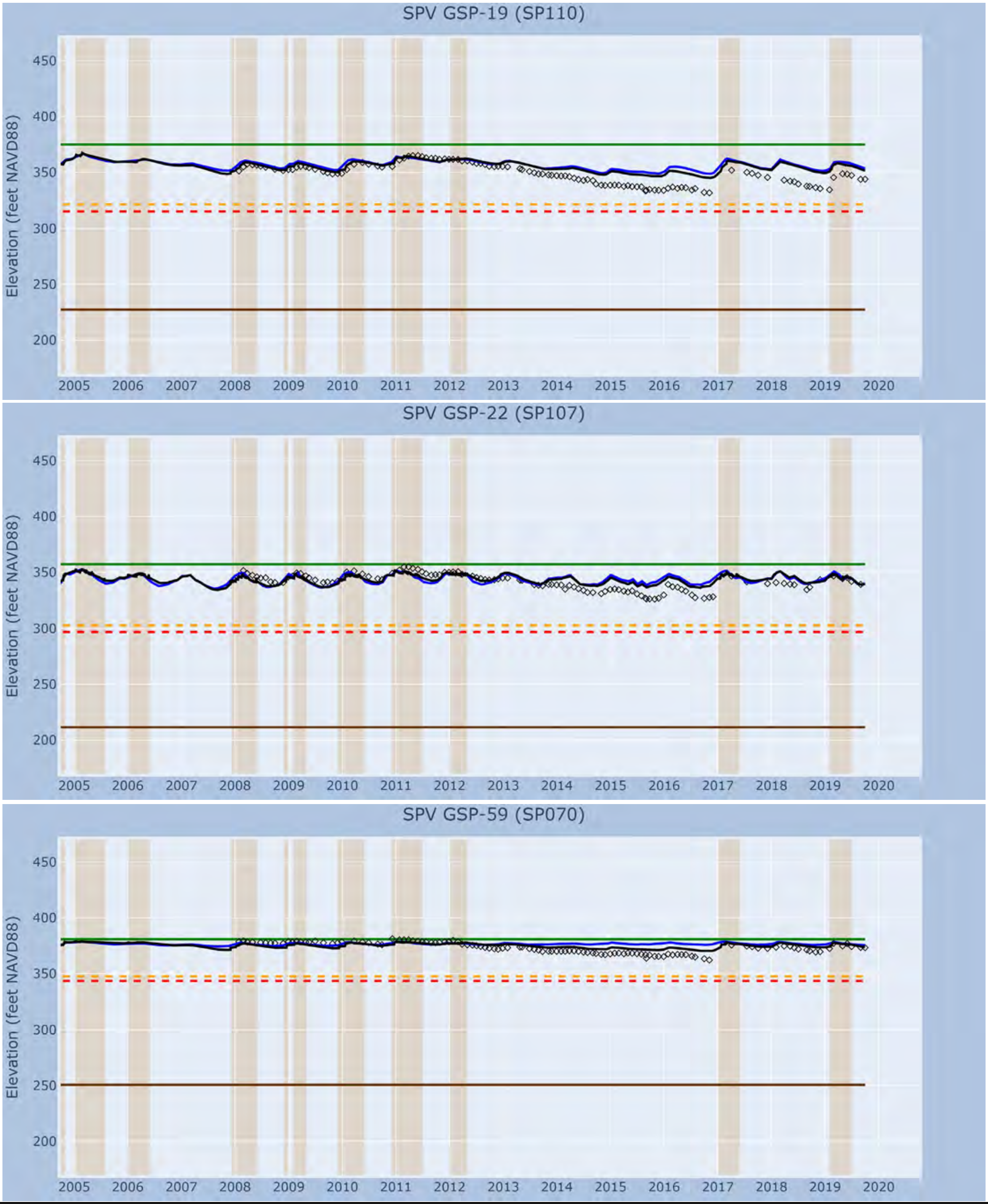
Jacobs



Legend
- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- Measured Groundwater Elevation (feet NAVD88)
- SPV GSP Model v1.0 Head (feet NAVD88)
- SPV GSP Model v2.0 Head (feet NAVD88)
- Daily Stress Period in the SPV GSP Model v2.0 (monthly otherwise)

Figure D-4
Modeled Versus Target Groundwater Head Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs



Legend
Ground Surface Elevation (feet NAVD88)
Modeled Basin Bottom Elevation (feet NAVD88)
Minimum Threshold (feet NAVD88)
Planning Threshold (feet NAVD88)
Measured Groundwater Elevation (feet NAVD88)
SPV GSP Model v1.0 Head (feet NAVD88)
SPV GSP Model v2.0 Head (feet NAVD88)
Daily Stress Period in the SPV GSP Model v2.0 (monthly otherwise)

Figure D-5
Modeled Versus Target Groundwater Head Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California

Jacobs

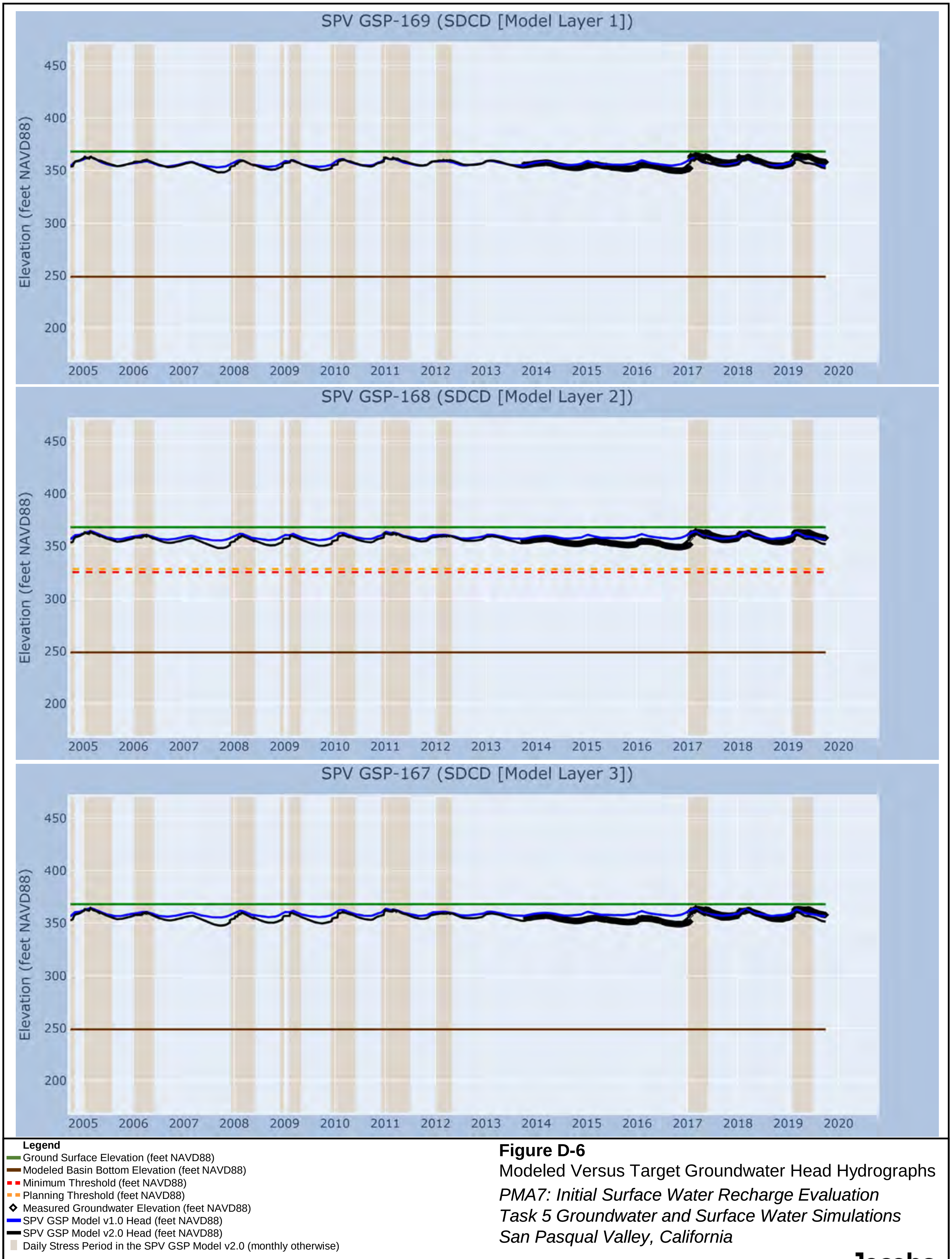
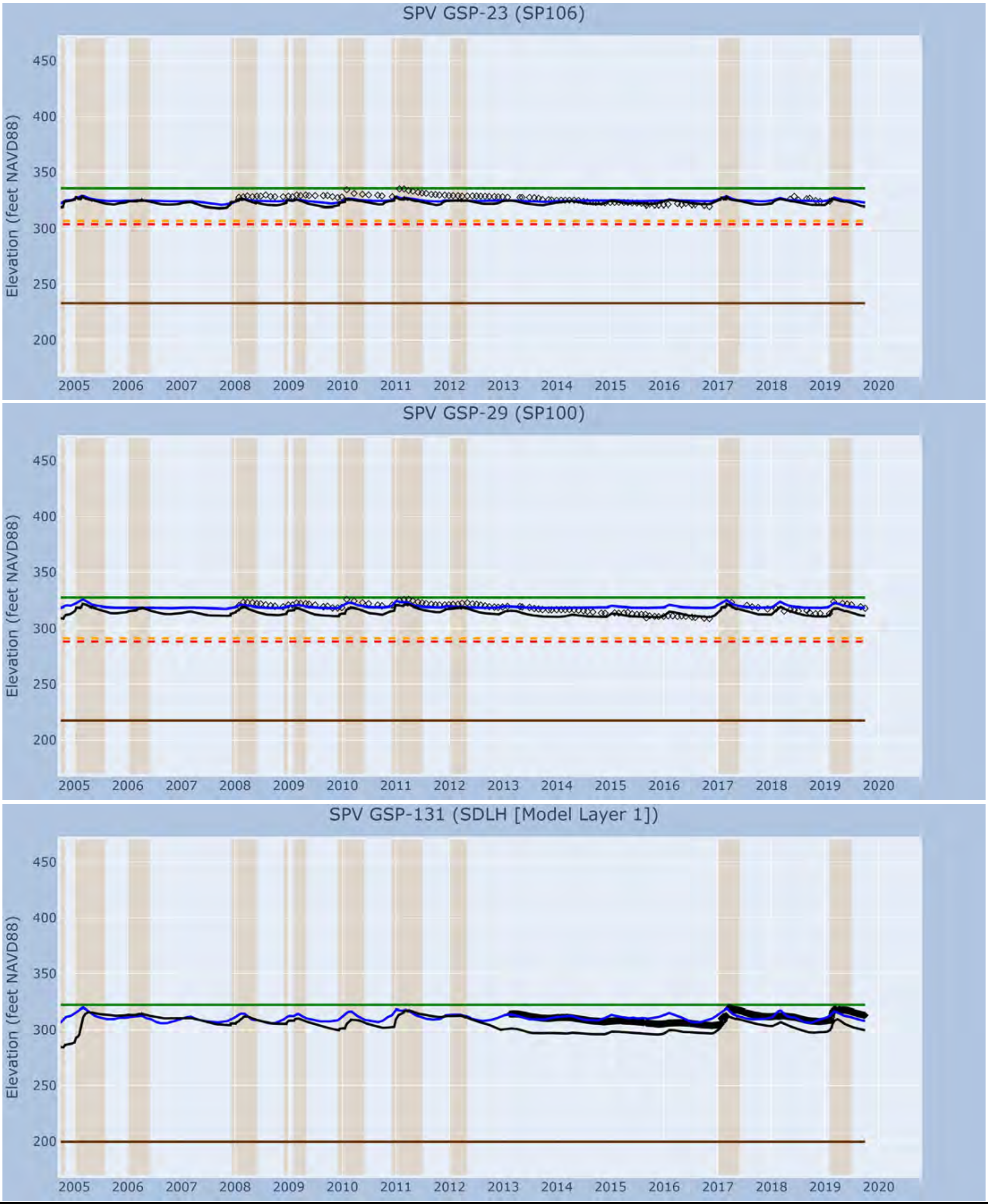
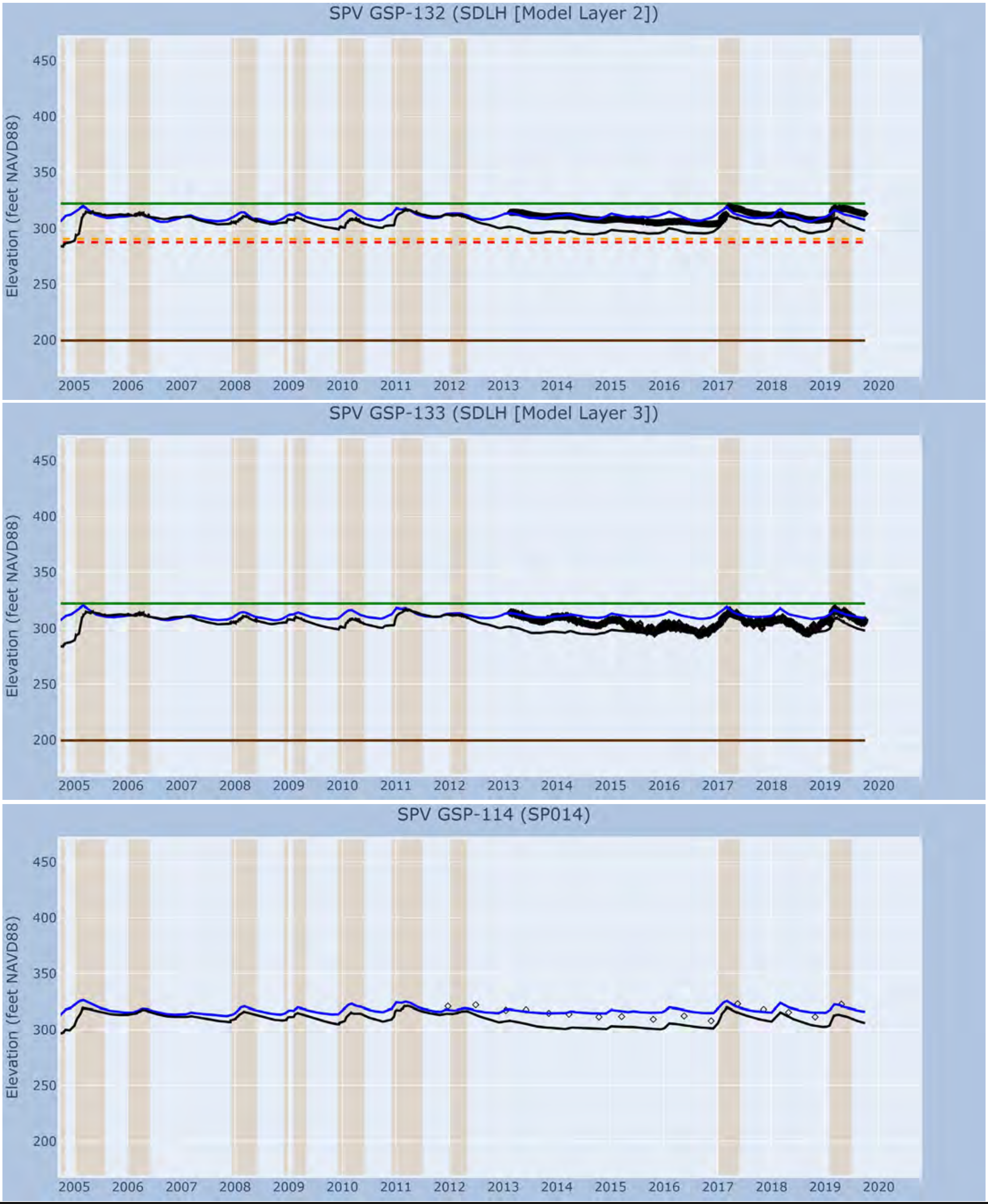


Figure D-6
Modeled Versus Target Groundwater Head Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California



Legend
Ground Surface Elevation (feet NAVD88)
Modeled Basin Bottom Elevation (feet NAVD88)
Minimum Threshold (feet NAVD88)
Planning Threshold (feet NAVD88)
Measured Groundwater Elevation (feet NAVD88)
SPV GSP Model v1.0 Head (feet NAVD88)
SPV GSP Model v2.0 Head (feet NAVD88)
Daily Stress Period in the SPV GSP Model v2.0 (monthly otherwise)

Figure D-7
Modeled Versus Target Groundwater Head Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater and Surface Water Simulations
San Pasqual Valley, California



Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- Measured Groundwater Elevation (feet NAVD88)
- SPV GSP Model v1.0 Head (feet NAVD88)
- SPV GSP Model v2.0 Head (feet NAVD88)
- Daily Stress Period in the SPV GSP Model v2.0 (monthly otherwise)

Figure D-8

Modeled Versus Target Groundwater Head Hydrographs

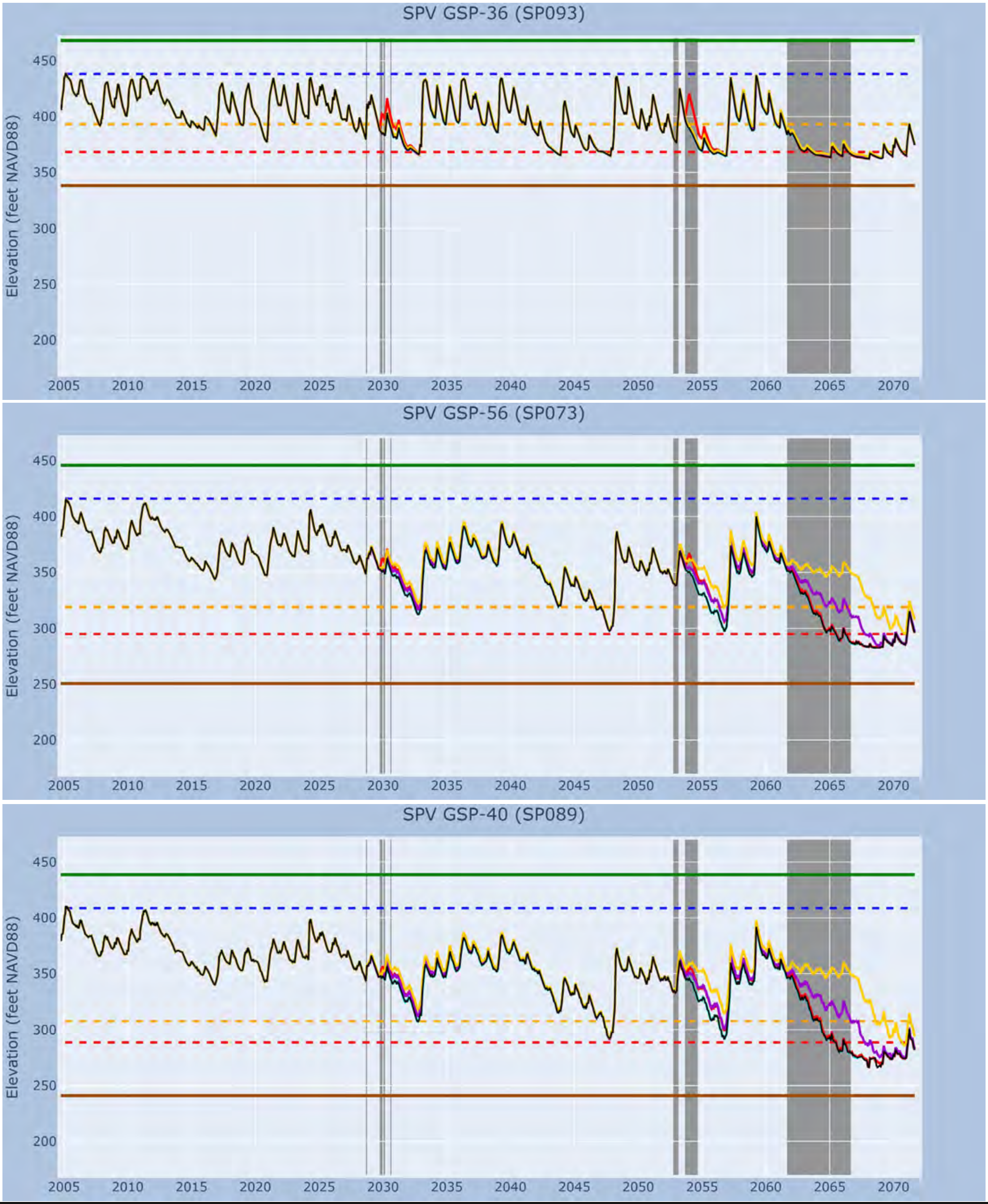
PMA7: Initial Surface Water Recharge Evaluation

Task 5 Groundwater and Surface Water Simulations

San Pasqual Valley, California

Jacobs

ATTACHMENT E: RECHARGE STRATEGY GROUNDWATER-LEVEL HYDROGRAPHS

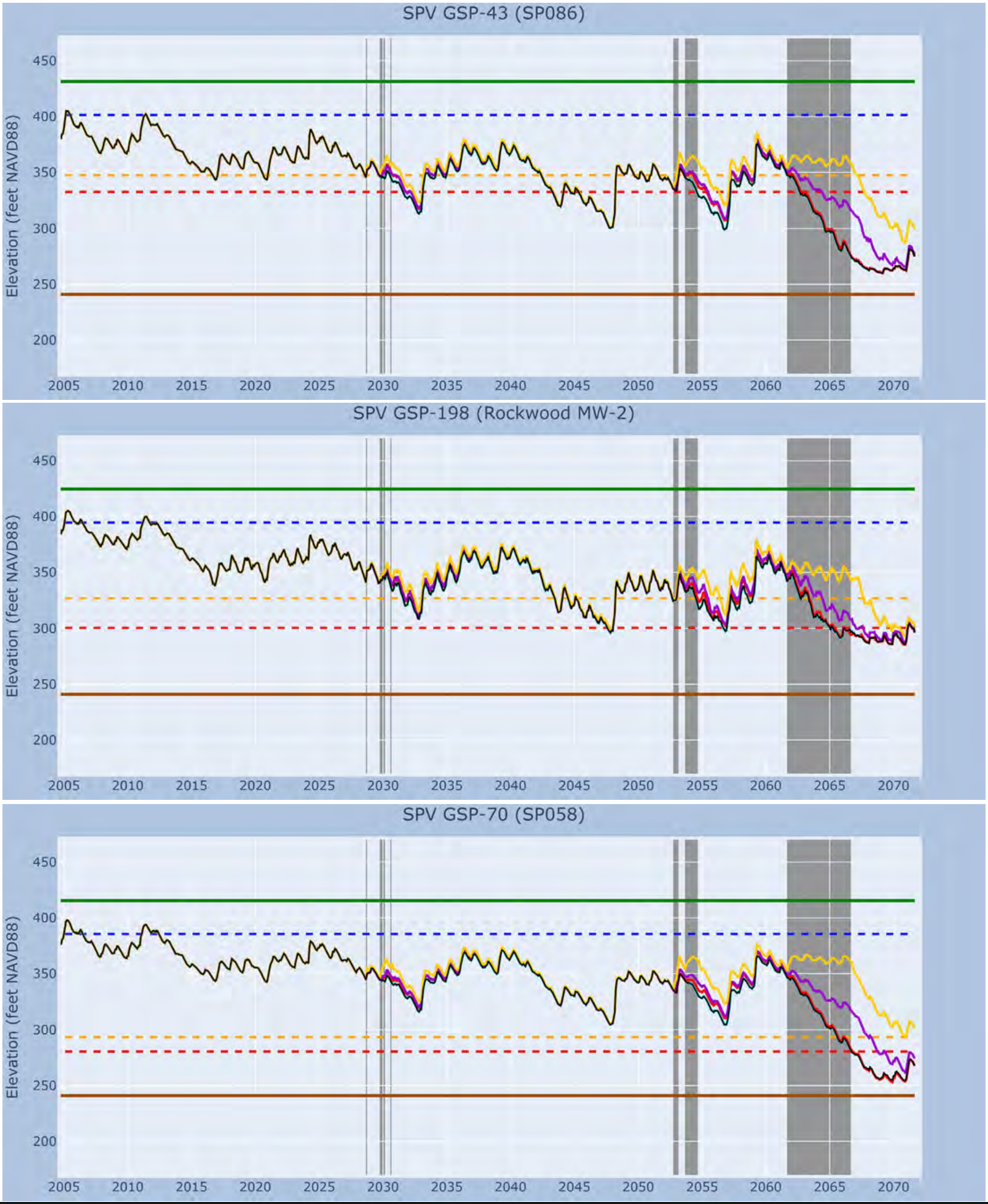


Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-1
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

Jacobs

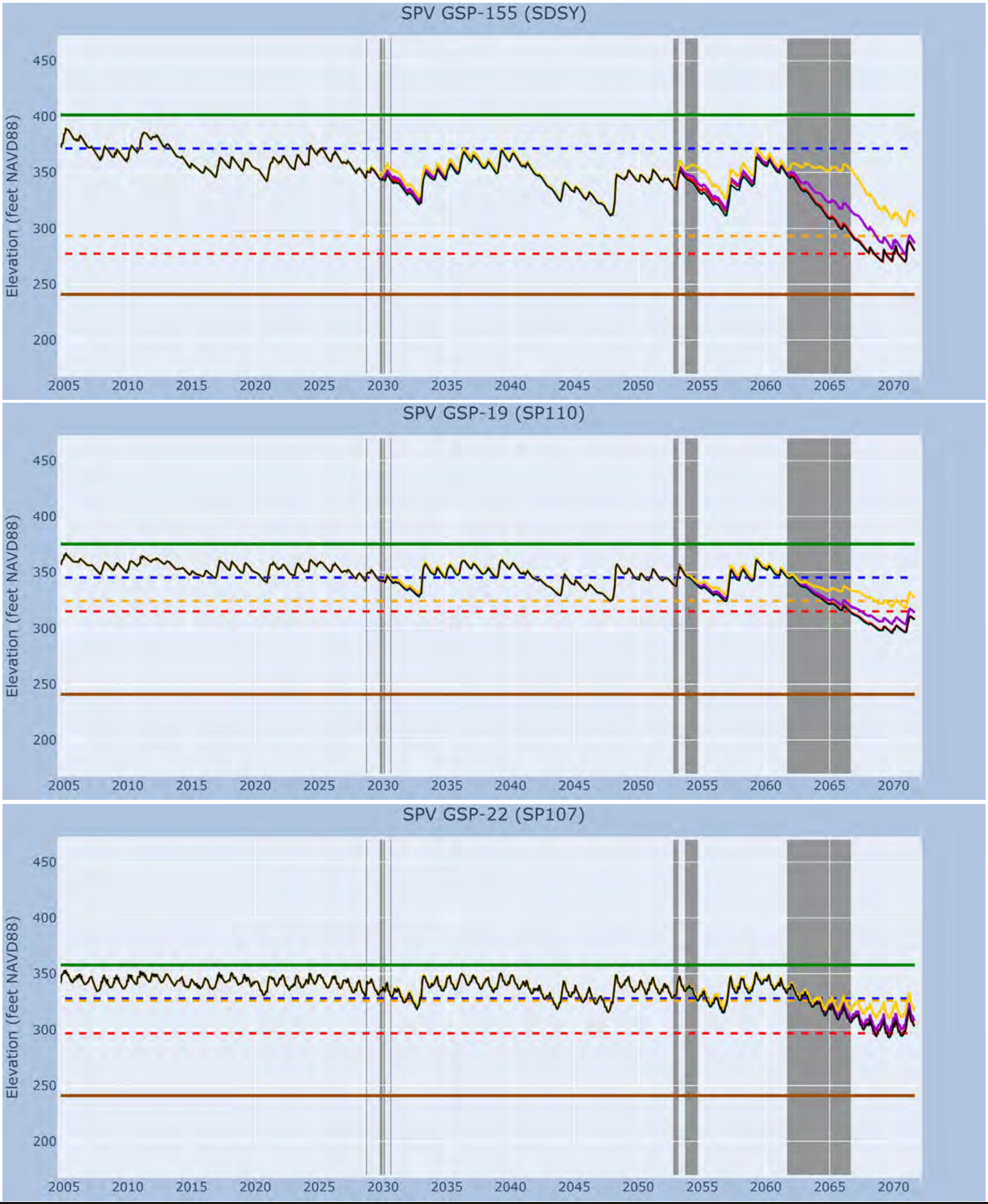


Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-2
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

Jacobs

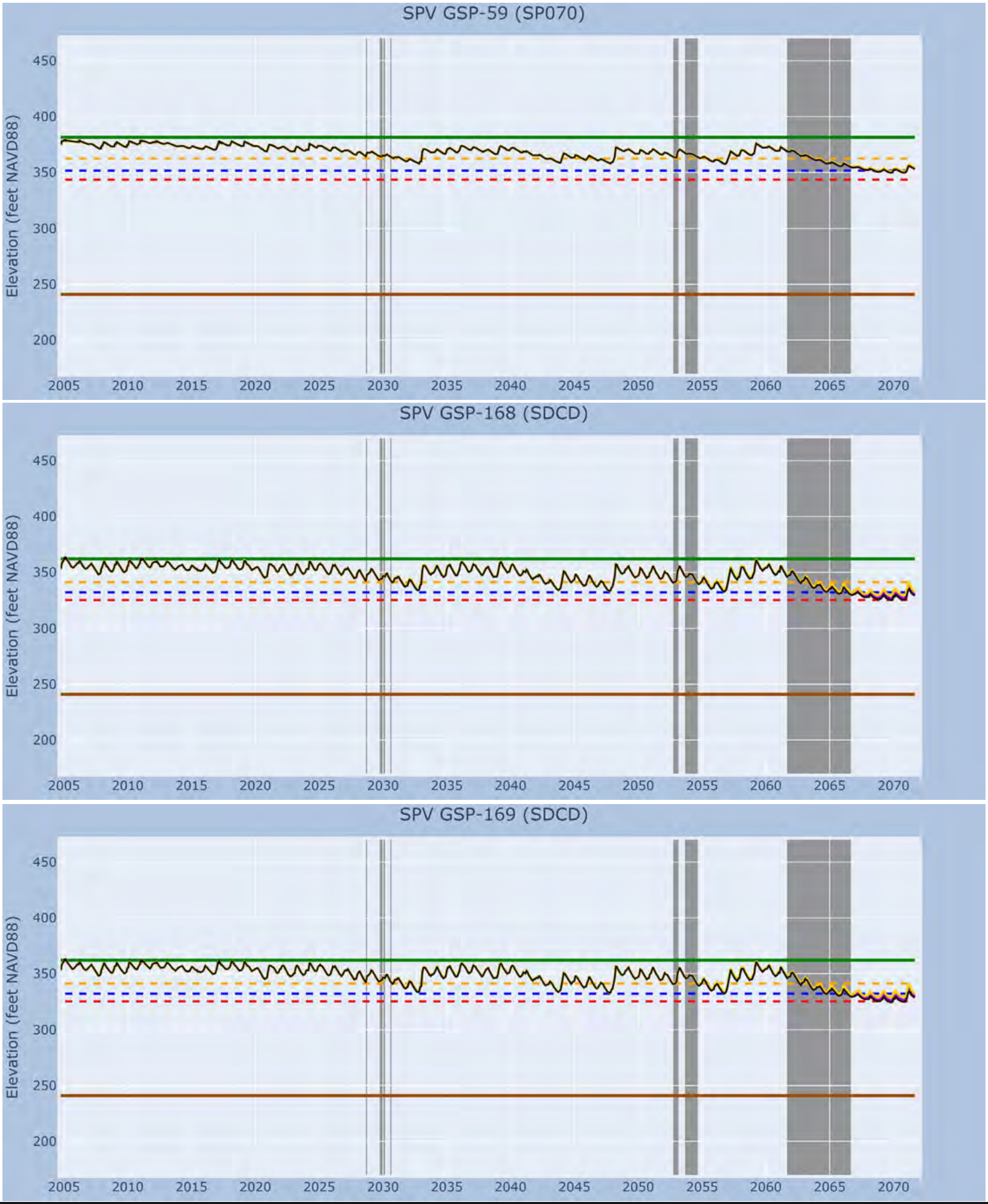


Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-3
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

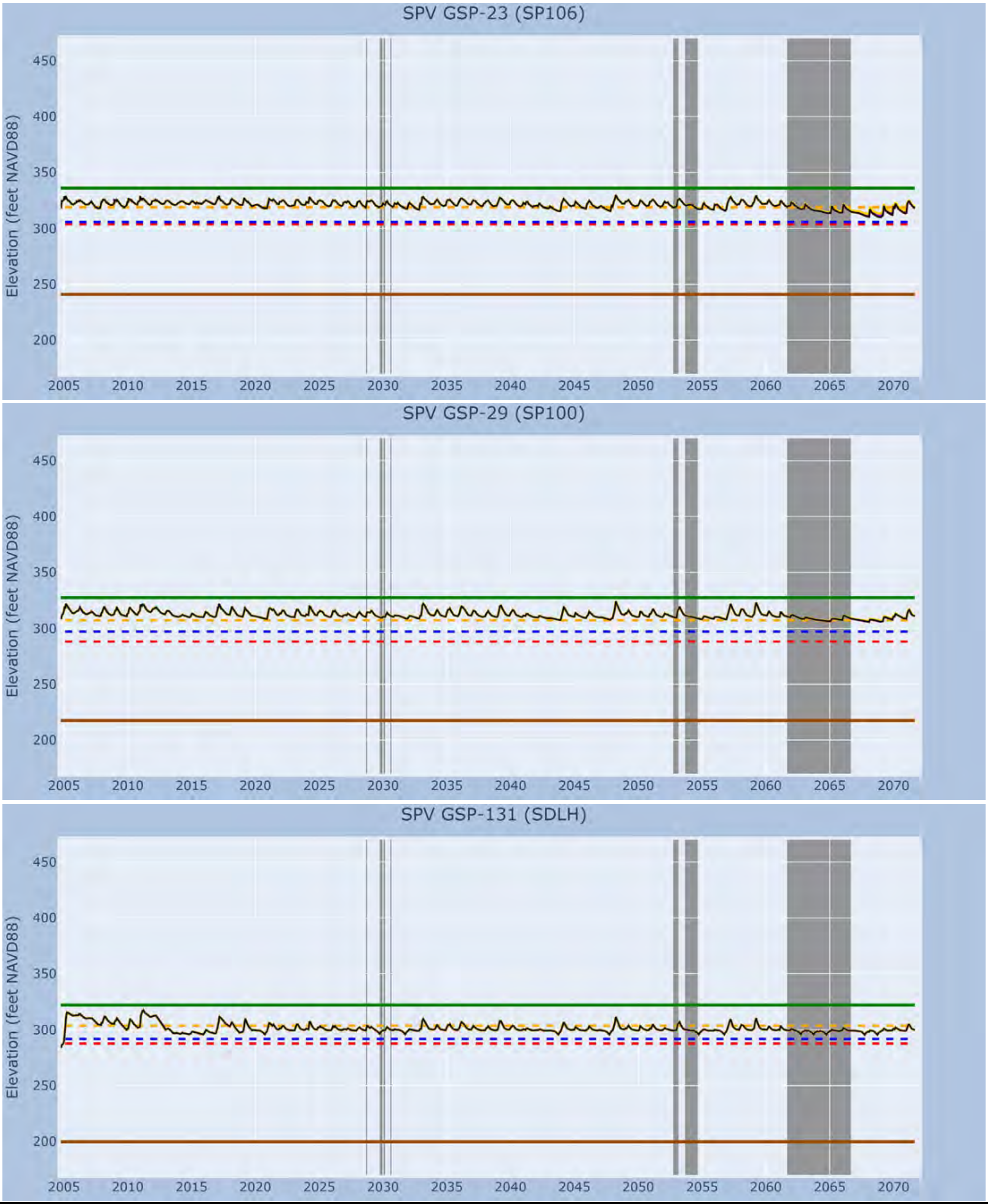
Jacobs



Legend
- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-4
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

Jacobs

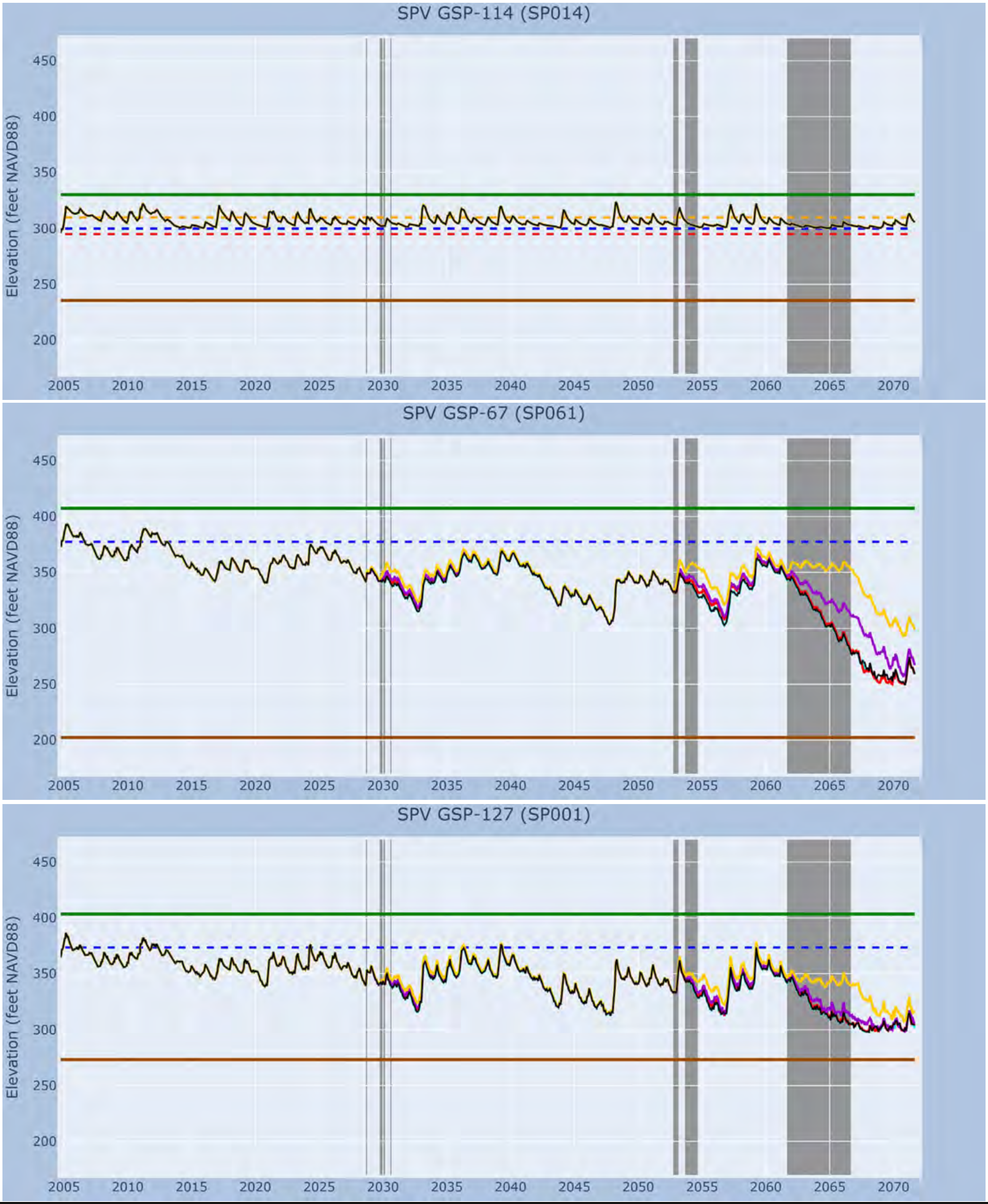


Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-5
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

Jacobs

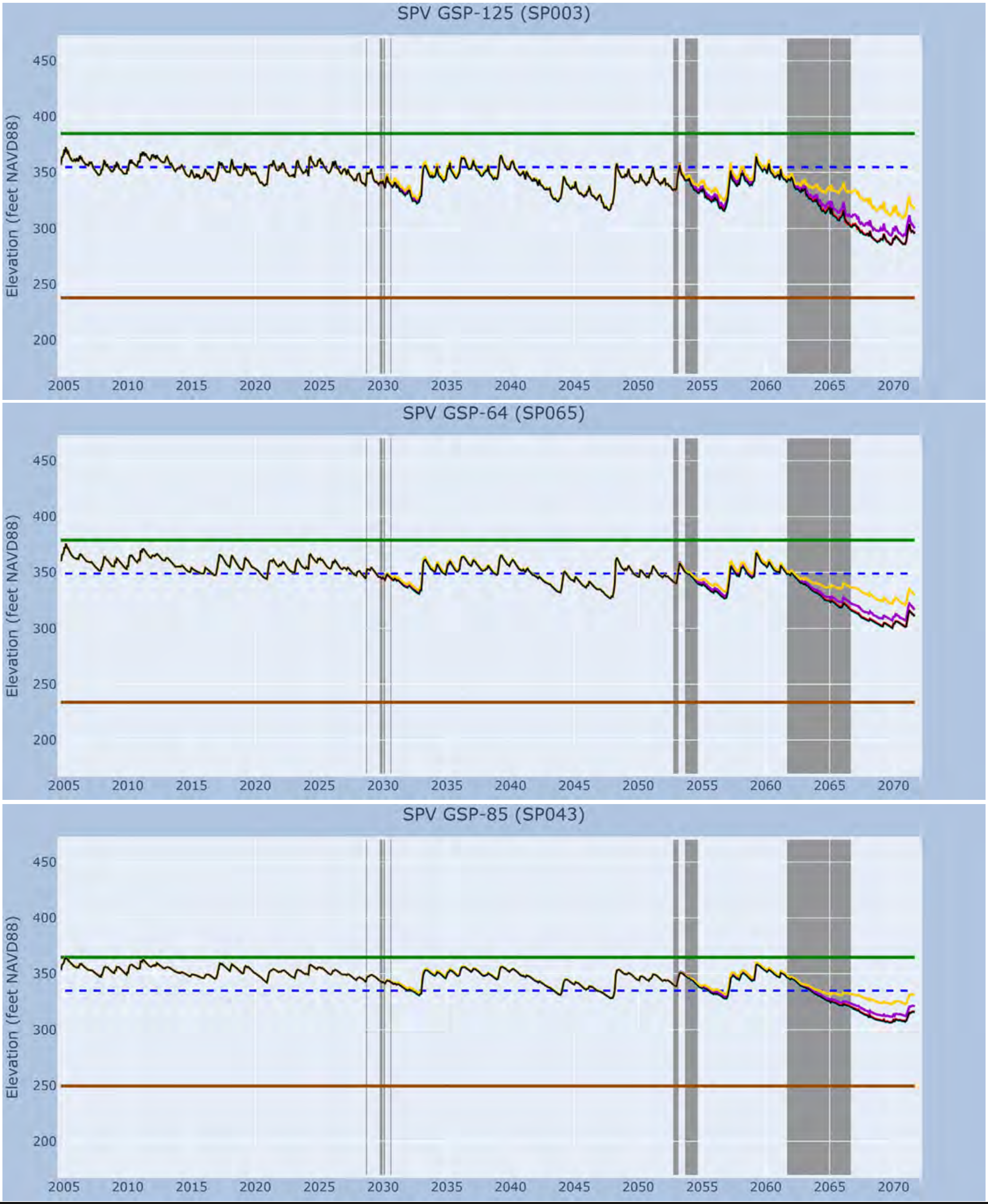


Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-6
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

Jacobs

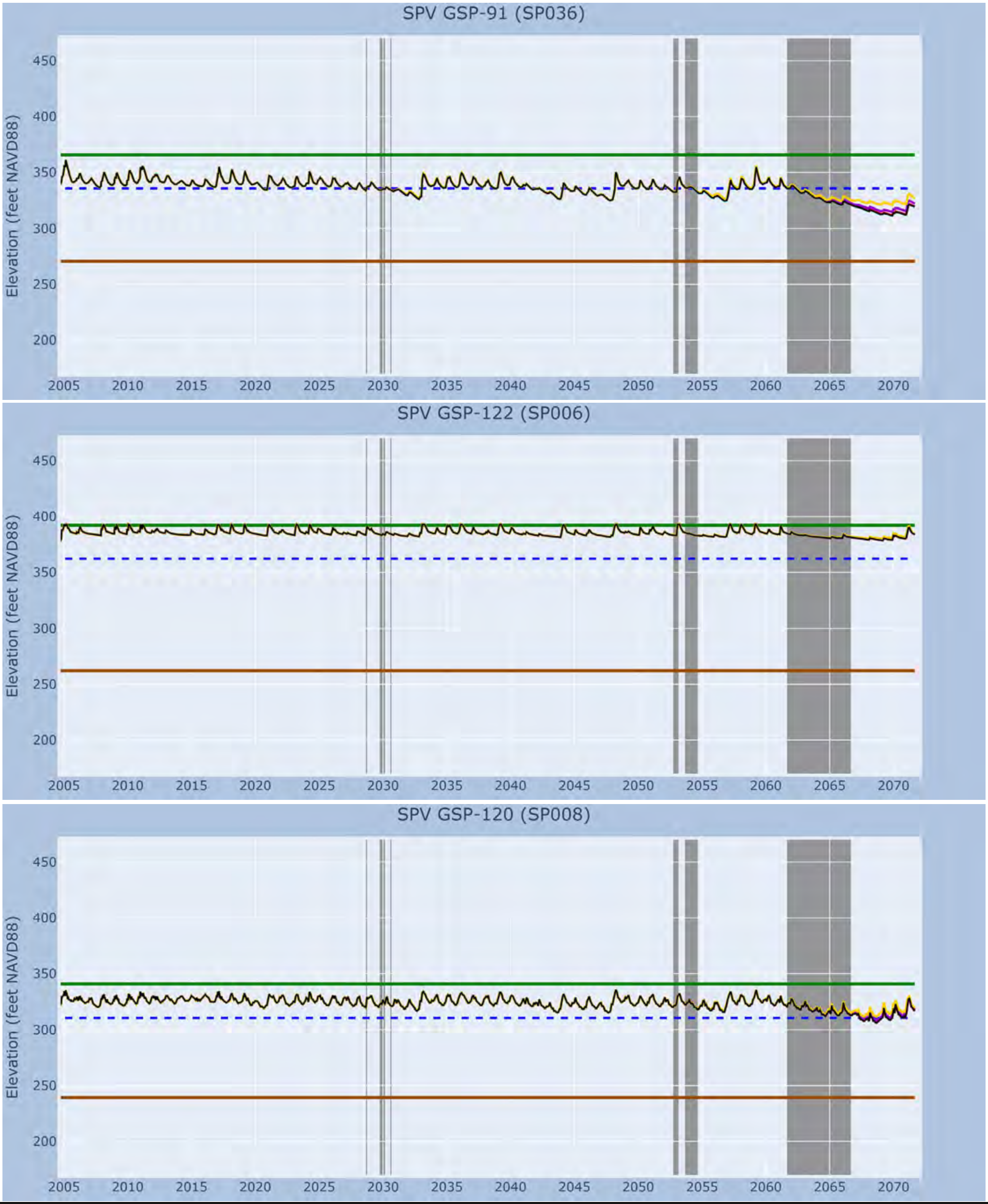


Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-7
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

Jacobs

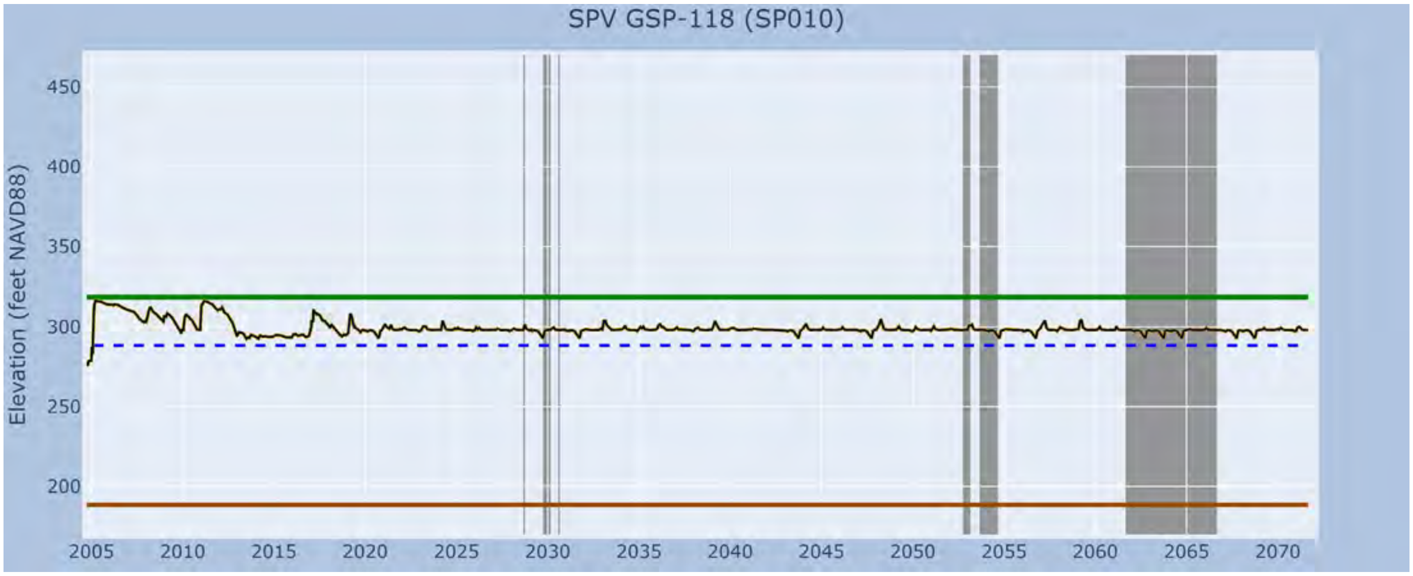


Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-8
Recharge Strategy Groundwater Level Hydrographs
PMA7: Initial Surface Water Recharge Evaluation
Task 5 Groundwater & Surface Water Simulations
San Pasqual Valley, California

Jacobs



Legend

- Ground Surface Elevation (feet NAVD88)
- Modeled Basin Bottom Elevation (feet NAVD88)
- Minimum Threshold (feet NAVD88)
- Planning Threshold (feet NAVD88)
- 30-feet below ground surface
- Recharge Implementation Timing (Condition 1 & Condition 2 met)
- Baseline Modeled Head (feet NAVD88)
- Strategy 1B Modeled Head (feet NAVD88)
- Strategy 2A Modeled Head (feet NAVD88)
- Strategy 3A Modeled Head (feet NAVD88)
- Strategy 3D Modeled Head (feet NAVD88)

Figure E-9

Recharge Strategy Groundwater Level Hydrographs

PMA7: Initial Surface Water Recharge Evaluation

Task 5 Groundwater & Surface Water Simulations

San Pasqual Valley, California

Jacobs