A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

Technical Memorandum

PREPARED FOR:

San Bernardino Valley Water Conservation District

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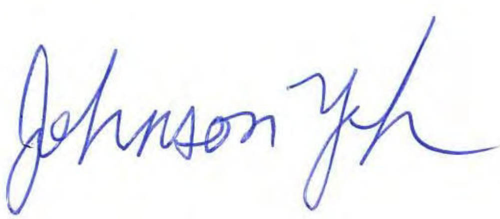

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A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912–2023

1.0 EXECUTIVE SUMMARY

The San Bernardino Valley Water Conservation District (SBVWCD) has provided continuous groundwater recharge to the San Bernardino Basin Area (SBBA) since 1912, supporting one of Southern California's most critical regional water supplies. This study quantifies the long-term effects of the District's managed aquifer recharge activities using the Integrated Santa Ana River Model (ISARM v1.1), a peer-reviewed, regional groundwater flow model calibrated for the SBBA.

Modeling results indicate that SBVWCD's diversion and recharge of over 1.7 million acre-feet of local surface water between 1912 and 2023 increased groundwater storage by an average of 7,570 acre-feet per year. This occurred during a period when groundwater pumping averaged approximately 152,626 acre-feet per year. In addition to augmenting basin storage, recharge operations have produced measurable and widespread increases in groundwater elevation across the region.

Notably, in the absence of SBVWCD recharge, groundwater levels in more than 75 square miles of the basin would be over 25 feet lower than present-day conditions. The model also shows beneficial impacts to adjacent groundwater basins. Furthermore, 188 existing production wells—including those supplying municipal, agricultural, and disadvantaged community users—would be partially or fully dewatered without the District's contributions to basin recharge.

The ISARM v1.1 model simulates key hydrologic components of the basin system, including natural recharge, underflow, pumping, and managed recharge. The analysis leveraged SBVWCD's rare, continuous historical dataset—covering over 110 years of recharge operations—to develop and compare two scenarios: one reflecting historical conditions with SBVWCD recharge, and one excluding those activities. The difference between these model runs isolates the specific impacts of managed recharge on storage and water levels. Calibration of the model against hundreds of observed well records yielded a relative error of 1.6%, substantially below the industry-accepted threshold of 10%, adding confidence to the robustness of the findings.

These results confirm that SBVWCD's long-standing investment in managed recharge has played a critical role in maintaining groundwater availability for regional use. The District's structured, data-informed approach to local groundwater stewardship provides a replicable framework for basin-scale sustainability planning under changing hydrologic and climate conditions.

2.0 INTRODUCTION

Geoscience was tasked by the SBVWCD to modify and expand the existing Integrated Santa Ana River Model (here-in referred to as ISARM v1.0), to increase the model simulation period from its existing span of 1966 through 2016 to 1912 through 2023, and incorporate and analyze groundwater recharge activities conducted by SBVWCD that occurred in the entire period. The purpose of this TM is to document the ISARM updates and scenario analysis, undertaking the following tasks:

A. Run model runs and analyze model results, including extending current model calibration from 1966-2016 to 1912-2023 and running one model run without surface water diversion for recharge,
B. Prepare draft and final technical memorandum,
C. Project management and meeting attendance (four meetings required).

3.0 UPDATE OF EXISTING INTEGRATED SAR MODEL

3.1 Background of Existing Integrated SAR Model

Geoscience constructed the ISARM v1.0 for the Upper Santa Ana Valley Groundwater Basin by integrating existing groundwater and surface water models. The ISARM v1.0 incorporated existing and updated hydrogeologic understanding of the Upper Santa Ana River Valley Groundwater Basin and new lithologic, streamflow, and evapotranspiration simulation capabilities. The Upper Santa Ana Valley Groundwater Basin incorporates the Yucaipa, San Bernardino Basin Area (SBBA)[1], Rialto-Colton, Riverside-Arlington, Chino, and Temescal Groundwater Basins. A more detailed description of the model is provided in the Integrated SAR Model Summary Report prepared by Geoscience (2020).

3.1.1 HSPF Model Components

The watershed model for the Upper Santa Ana Valley Groundwater Basin was developed using Hydrologic Simulation Program - Fortran (HSPF). HSPF is a comprehensive and physically based watershed model that can simulate all water cycle components with a time step of less than one day. Figure 1 is a schematic diagram showing the water cycle components simulated by the HSPF.

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

1 The SBBA consists of the Bunker Hill and Lytle Subbasins.

- Land surface elevations,
- Soil types,
- Land use,
- Precipitation,
- Evaporation,
- Stream Channel Characteristics,
- Discharges, and
- Streamflow.

Sources of data used for the watershed model are summarized in Section 3.2.1.

3.1.2 MODFLOW Model Components

The ISARM domain has a total of 1,642 rows and 2,243 columns, with a cell size of approximately 100 feet by 100 feet (see Figure 2). The active groundwater model area covers SBBA, Yucaipa, Rialto-Colton, Riverside-Arlington, Chino, and Temescal groundwater subbasins. The ISARM is divided vertically into five layers. In the SBBA, these layers represent the following hydrogeologic units:

- Layer 1: River Channel, Upper Confining Member, and Upper Water-Bearing
- Layer 2: Middle Confining Member
- Layer 3: Middle Water Bearing
- Layer 4: Lower Confining Member
- Layer 5: Lower Water-Bearing (upper portion)

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

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

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

3.2 Updates of the Integrated SAR Model

3.2.1 Source of Data

Data used to update the ISARM were obtained from multiple sources. The primary sources and types of data provided by each are summarized as follows:

- California Department of Water Resources (DWR): Historical streamflow diversions and production data.
- California Irrigation Management Information System (CIMIS): Evapotranspiration.
- California Integrated Water Quality System (CIWQS) database: Wastewater discharge data.
- Chino Basin Watermaster: Water levels, production data, recharge and well construction data.
- Multiple local agencies: Water levels, production data, engineered recharge, well location and well construction data.
- National Climatic Data Center (NCDC): Precipitation.
- Orange County Public Works (OCPW): Precipitation data.
- Riverside County Flood Control and Water Conservation District (RCFCWCD): Precipitation data.
- San Bernardino County Flood Control District (SBCFCD): precipitation data.
- San Bernardino Valley Water Conservation District (SBVWCD): Water levels, drainage location, locations and monthly stormwater recharge for the SAR and Mill Creek Spreading Grounds from 1912 to 2023, historical streamflow diversions.
- Santa Ana River Watermaster (2022): Wastewater discharge data.
- Stantec: Water levels, production data, anthropogenic return flow.

- State Water Resources Control Board GeoTracker: Water levels.
- Upper Santa Ana River Watershed Integrated Regional Urban Water Management Plan (2020): Production data.
- U.S. Environmental Protection Agency (US EPA): Water levels.
- U.S. Geological Survey (USGS): Streamflow and water levels.
- Watermaster Support Services (Steve Mains): Water levels.

A detailed list of sources of data used for this study is summarized in Section 7.0.

3.2.2 Extension of Model Simulation Period

The ISARM v1.1 extends the existing span from January 1966–December 2016 to January 1912–December 2023. Considering model run time and potential convergence issues, the simulation was split into two time intervals: 1912–1965 and 1966–2023. The model-calculated water levels at the end of the 1912–1965 model run were used as the initial conditions for the 1966–2023 simulation.

3.2.3 Updates to Timing and Locations for SAR Spreading Grounds

SBVWCD provided recharge area for the SAR and Mill Creek spreading grounds from 1912 through 2023 in kmz format, as shown in Figures 3 through 5. In general, over the model simulation period, the recharge footprint changes approximately every 5 to 10 years. SBVWCD began recharge operations at the SAR spreading grounds in 1912 and at the Mill Creek spreading grounds in 1922. The model cells used to simulate recharge at these locations also change over time, with selected cells falling within the recharge areas defined by SBVWCD.

3.2.4 Updates to Model Recharge and Discharge Terms

3.2.4.1 Recharge from Mountain Front Runoff

Recharge from mountain front runoff occurs along the boundaries of the groundwater basin, where the model boundary abuts the mountain front. In the updated Integrated SAR Model, recharge from mountain front runoff is simulated using the Well Package, through which specified inflows are assigned to the groundwater model domain in model layers 1 and 2 representing the shallow aquifer. In SBBA, recharge from mountain front runoff is assigned only to model layer 1. The amount of mountain front recharge assigned to the model area was based on previous modeling work and methodologies vary between existing models (refer to previous modeling reports for additional information). In SBBA, the methodology was based on a correlation with hydrology on the Santa Ana River. During the updated model calibration period from 1912 through 2023, mountain front runoff averaged 15,138 acre-ft/yr in SBBA(Figure 6).

3.2.4.2 Areal Recharge from Precipitation

Areal recharge, or direct infiltration of precipitation, was applied to the uppermost active model layer of the Integrated SAR Model using the Recharge package. The method of estimation varies by groundwater basin and is consistent with the approach used in each individual groundwater basin model. The annual average areal recharge from precipitation totaled approximately 6,385 acre-ft/yr in SBBA (Figure 7).

3.2.4.3 Streambed Percolation

Streambed percolation was simulated by the Integrated SAR Model using the Streamflow Routing Package. The Streamflow Routing Package routes tributary inflows through the stream network shown on Figure 8, and simulates streambed percolation based on streamflow, streambed conductance, and groundwater level.

Gaged inflows data in the upstream areas of the SBBA were updated based on USGS gage data and ungaged inflows in the upstream areas of the Yucaipa Basin were estimated with the watershed model. Runoff generated within the groundwater basin was also calculated by the watershed model. Recycled water discharge was updated from data from the CIWQS database. Model-calculated recharge from streambed percolation in SBBA averages 89,452 acre-ft/yr with SBVWCD diversions (Figure 9).

3.2.4.4 Engineered Recharge

Engineered recharge occurs in spreading basins throughout the Integrated SAR Model domain. Recycled, imported, and stormwater recharge data were collected based on monthly measurements and estimates from various water agencies and compiled for each spreading basin location. In the SBBA, monthly stormwater recharge at the SAR and Mill Creek Spreading Grounds was provided by SBVWCD, with recharge operations dating back to 1912. Monthly State Water Project (SWP) recharge in SBBA was provided by the San Bernardino Valley Municipal Water District, with SWP water deliveries beginning in 1973.

SBVWCD began recharge operations at the SAR spreading grounds in 1912 and at the Mill Creek spreading grounds in 1922. The locations of these two spreading grounds are discussed in Section 3.2.3. Both facilities receive recharge from stormwater and SWP supplies. These facilities do not recharge recycled water.

The total annual average stormwater recharge is 15,223 acre-ft/yr (Figure 10), and SWP recharge is 4,483 acre-ft/yr during period from 1912 through 2023 (Figure 11).

3.2.4.5 Anthropogenic Return Flow

Anthropogenic return flow refers to the amount of water that returns to the aquifer after application of water to the land surface in the form of irrigation, or from leaks in water lines, sewer lines and septic systems. Volumes of anthropogenic return flow used in the Integrated SAR Model are consistent with the methodologies used in the individual groundwater models, which vary by model (refer to previous modeling reports for additional information). In the SBBA, monthly return flow from 2017 through 2023 was provided by Stantec. The annual average return flow from applied water is approximately 16,566 acre-ft/yr from 1912 through 2023 in SBBA (Figure 12).

3.2.4.6 Underflow

In areas where the model boundary does not immediately border the mountain front, water flows into the model domain as underflow from adjacent groundwater basins. Methods for estimating underflow were based on the approaches used by the individual groundwater models.

Underflow inflow from San Timoteo and Yucaipa to SBBA occurs across the Crafton Fault. Figure 13 shows the total annual average underflow inflow to SBBA for the period from 1912 to 2023 is 11,906 acre-ft/yr. Groundwater outflow from the SBBA to Rialto-Colton occurs across the San Jacinto Fault and Barrier E. As shown on Figure 14, the annual average underflow outflow from SBBA to Rialto-Colton for the period from 1912 to 2023 is 16,858 acre-ft/yr.

3.2.4.7 Evapotranspiration

Evapotranspiration (ET) from a groundwater system generally decreases with decreasing groundwater elevation, and is at its highest in areas where groundwater elevations approach or exceed land surface. ET is simulated in the updated ISARM using the Evapotranspiration Package. Methods for estimating ET were based on the approaches used by the ISARM v1.0. The model-calculated annual average ET in SBBA for the period from 1912 to 2023 is 13,144 acre-ft/yr (Figure 15).

3.2.4.8 Groundwater Pumping

Groundwater pumping represents the largest source of discharge in the ISARM. Monthly pumping from individual wells was assigned to model cells and layers using the Well Package. For wells screened in multiple aquifers, a portion of the well's total production was apportioned to each aquifer according to the screened interval of the well and hydraulic conductivity of the screened area. Figure 16 shows the distribution of 1,769 production wells during period from 1912 to 1965 and Figure 17 shows distribution of 2,717 production wells during period from 1966 to 2023.

In SBBA, since pumping data prior to 1935 is not available, annual pumping from 1912 to 1934 was estimated based on historical land use and consumptive use for each land use type, following DWR Bulletin 104-5. Table 60 from DWR Bulletin 104-5 provides annual pumping from 1935 to 1944. Pumping records from 1945 to 1965 were obtained from the existing SBBA model (Geoscience, 2009). Active production wells prior to 1945 are assumed to be the same as 1945. Monthly pumping data during the period from 1966 to 2016 is from ISARMv1.0. Groundwater extraction quantities from 2017 to 2023 were collected from regional pumpers and compiled and provided to Geoscience by Stantec. Figure 18 shows annual groundwater pumping in SBBA for the period 1912 through 2023. As shown, annual average groundwater pumping is 152,626 acre-ft/yr.

In the Rialto-Colton Basin, since pumping data prior to 1945 is unavailable, pumping for the period from 1912 to 1944 was estimated based on the annual pumping in the SBBA, assuming that the pumping in Rialto-Colton Basin followed the same declining trend as the SBBA. Pumping records from 1945 to 1965 were obtained from the existing Rialto-Colton model (Geoscience, 2015). Active production wells prior to 1945 are assumed to be the same as 1945. Monthly pumping during the period from 1966 to 2016 is from ISARM v1.0. Groundwater extraction quantities after 2016 were based on measured pumping obtained from water agencies.

In Yucaipa, Riverside-Arlington, Chino, and Temescal basins, pumping from 1912 to 1965 was estimated using the same method as that used for the Rialto-Colton Basin. Monthly pumping during the period from 1966 to 2016 is from ISARM v1.0. Active production wells prior to 1966 are assumed to be the same as 1966. Groundwater extraction quantities after 2016 were based on measured data obtained from major water agencies.

3.3 Discussion of HSPF Model Updates, Outcomes and Uses

The Upper SAR Watershed Model was developed for SAWPA during the SAR Waste Load Allocation Model (WLAM) Update using the HSPF computer code (Geoscience, 2019). This watershed model was calibrated for the period from October 1, 2006 through September 30, 2016 (Water Year 2007 through 2016) using 2012 land use. For the ISARM v1.0, the watershed model calibration period was expanded to include the period from January 1966 through December 2016 with additional land use maps from 1963, 1984, 1994 and 2005. The watershed model was again updated and expanded by Geoscience to cover the period from

January 1912 through December 2023. Land use maps from 1963 and 2012 were used for the expanded periods: the early period from 1912 to 1965 and the later period from 2017 to 2023, respectively. Precipitation, evaporation, wastewater discharges, and streamflow data were updated based on the measured data. Sources of data were summarized in Section 3.2.1.

In order to simulate the streamflow more accurately, runoff generated from precipitation within the Upper Santa Ana Valley Groundwater Basin was calculated using the HSPF watershed model, which was then included in the Streamflow Package for the ISARM 1.1. The HSPF model was also used to provide areal recharge in the Chino and Yucaipa basins, mountain front runoff in the Yucaipa Basin, and ungaged inflows in the upstream areas of the Yucaipa Basin.

3.4 Evaluation of Model Simulation

The ISARM v1.1 calibration over the updated period was evaluated using the 'history matching' approach to determine if the model provides a reasonable match between simulated and observed groundwater system responses. The model calibration evaluation focused on the groundwater level elevations and streamflow.

3.4.1 Head Observation Targets

The ISARM v1.1 was compared against 23,015 measurements of groundwater levels in 326 calibration wells during the period from 1912 to 1965, and 144,986 measurements of groundwater levels in 935 calibration wells during the period from 1966 to 2023. The locations of water level targets for 1912 to 1965 and 1966 to 2023 are shown in Figures 19 and 20, respectively.

3.4.2 Streamflow Observation

Scatterplots of measured and model-simulated monthly streamflow for the E Street gaging station (station location shown in Figure 8) from January, 1912 through December, 2023 were plotted to evaluate the ISARM v1.1 performance (Figure 24). As shown, the ISARM v1.1 shows good performance at the E Street streamflow gage from 1912 through 2023 based on calibration performance criteria from Donigian (2002). Hydrograph of observed and model-calculated monthly streamflow is provided as Figure 25. In general, the model is able to reproduce similar streamflow dynamics seen in observed measurements.

3.4.3 Groundwater Level Simulation Validation

Figure 21 shows a scatter plot of measured versus model-calculated water levels. Most of the points are clustered about the diagonal line (representing where measured water levels match model-calculated water levels). This reflects a good match between measured and model-calculated water levels.
The relative error of the updated ISARM model is approximately 1.6%, which is within the industry standard of 10% (Spitz and Moreno, 1996; Environmental Simulations, Inc., 1999).

Figures 22 and 23 show selected hydrographs for the updated ISARM validation from 1912 through 1965 and from 1966 through 2023, respectively. In general, the model-calculated water levels match well with the measured water levels.

4.0 EVALUATION OF SURFACE WATER DIVERSIONS AND MANAGED AQUIFER RECHARGE EFFORTS

4.1 ISARM Simulation with Historic Actual SAR and Mill Creek Surface Water Diversions to Recharge

A model run, with historic actual SAR and Mill Creek surface water diversions to recharge, was conducted using the ISARM v1.1. The period from January 1912 through December 2023 was chosen as the hydrologic base period, as diversion data is available starting from 1912. Groundwater pumping, anthropogenic return flow, and engineered recharge are based on actual conditions.

4.2 ISARM Simulation without Historic SAR and Mill Creek Surface Water Diversions to Recharge

A separate simulation, without historic actual SAR and Mill Creek surface water diversions to recharge, was also conducted using the ISARM v1.1. The model assumptions are consistent with those outlined in Section 4.1, with the exception that no surface water diversions for recharge by SBVWCD were included in this model run.

4.3 Simulation Results

4.3.1 Surface Water Budget

Figure 26 shows the difference of average annual surface water budgets between two model runs, with and without SBVWCD diversions and recharge. Total surface water inflow and runoff generated within the watershed is 208,600 acre-ft/yr from 1912 to 2023. During the same period, a total of over 1.7 million acre-feet was diverted from the SAR and Mill Creek and recharged at SBVWCD's recharge basins. The engineered recharge from these diversions totals nearly 15,190 acre-feet per year, resulting in an additional 9,640 acre-feet per year of recharge, which represents the benefit to the SBBA from local diversions.

4.3.2 Groundwater Budget

Inflow terms for modeled SBBA groundwater budgets include recharge from streambed percolation, engineered recharge from diversions within the SBBA, engineered recharge of SWP water, recharge from local runoff generated by precipitation, infiltration from direct precipitation, return flow from groundwater pumping, mountain front runoff, and underflow inflow. The outflow terms comprise evapotranspiration, groundwater pumping, and underflow outflow. Inflow and outflow flux terms were identical amongst the two model runs (with and without SBVWCD diversions) except for the five flux terms shown on Figure 27, including underflow, evapotranspiration, engineered recharge and streambed percolation.

The difference of average annual water budgets between two model runs is shown on Figure 27. The increase in engineered recharge from SBVWCD diversions totals 15,190 acre-feet per year. This recharge leads to a decrease in underflow inflow of 230 acre-ft/yr from Yucaipa and an increase in underflow outflow of 750 acre-ft/yr to Rialto-Colton Basin. The changes in underflow in SBBA indicate the benefits to the Yucaipa and Rialto-Colton basins resulting from the recharge activities conducted by SBVWCD. The average annual increase in ET is about 1,090 acre-ft/yr due to high groundwater, which is beneficial for riparian vegetation. Change in groundwater storage increases 7,570 acre-ft/yr as a result of SBVWCD diversion and recharge activities.

4.3.3 Change in Water Level

The estimated change in groundwater elevation after 112 years (December 2023) was calculated as the difference between two model runs (with and without SBVWCD diversions). Figure 28 depicts the changes in groundwater elevations in the SBBA. As shown, the estimated change in groundwater elevations ranges from 0 feet to 250 feet, indicating the benefits of increased groundwater elevation throughout the basin. Water levels increased by more than 200 feet in the vicinity of the SAR and Mill Creek spreading grounds, with increases of greater than 25 feet extending over 75 square miles and increases of greater than 1 foot over an area of 107 square miles.

4.3.4 Selected Hydrographs

Groundwater level hydrographs for selected wells are provided in Figure 29. Water levels under the model run with SBVWCD diversions are displayed next to those calculated without SBVWCD diversions for wells within SBBA. As shown, the two model runs produce water levels that follow similar temporal patterns. Differences in water levels between the two model runs generally become more pronounced throughout the model simulation period, reflecting greater groundwater storage as a result of SBVWCD diversions and recharge activities.

The maximum increase in groundwater elevation at Mill Creek 2 (MC2) well is over 319 ft. At Cone Camp well, a similar trend was observed. The maximum increase in the earlier period was 105 feet, and in the later period, there was an increase of over 50 feet due to recharge activities. At the Commerce Center well, the difference between the two model runs becomes more noticeable toward the end of the simulation period due to the well located further downgradient from the spreading grounds and screened in the deep layer. The maximum increase in groundwater elevation at the Commerce Center well is nearly 52 feet. SBVWCD recharge activities beginning in 1912 initially affect the shallow layers, gradually extending to deeper layers. Near the outlet of the basin, groundwater levels rise and flow into the Rialto-Colton Basin.

5.0 SUMMARY DISUSSION

The results of this study demonstrate that a century of managed surface water recharge by the San Bernardino Valley Water Conservation District (SBVWCD) has led to substantial increases in both groundwater storage and elevation throughout the San Bernardino Basin Area (SBBA). By modeling groundwater conditions with and without recharge operations from 1912 to 2023, the analysis provides a quantitative assessment of the long-term hydrologic impacts of localized recharge management.

Under historical conditions, SBVWCD recharged more than 1.7 million acre-feet of local surface water, resulting in an average annual storage increase of 7,570 acre-feet, despite ongoing extractions averaging approximately 152,626 acre-feet per year. Modeled outcomes indicate that this recharge contributed to widespread groundwater level increases, particularly in proximity to recharge facilities. The maximum simulated rise in groundwater elevation reached 319 feet. In the absence of SBVWCD's recharge, groundwater levels in approximately 75 square miles of the basin would be at least 25 feet lower, including nearly 40 square miles with declines of 50–100 feet, 2.6 square miles with declines of 100–150 feet, and a small area exceeding 150 feet of elevation loss.

These differences have direct implications for regional water infrastructure. The analysis shows that 188 production wells—many serving public water agencies and disadvantaged communities—would have been partially or fully dewatered without SBVWCD's operations. In multiple instances, groundwater levels would have dropped below well screen intervals, compromising functionality and potentially necessitating costly interventions.

Importantly, these results were achieved using modest, low-cost facilities that are inexpensive to operate and maintain. SBVWCD's approach to managed recharge does not rely on complex or high-tech infrastructure; instead, it reflects a practical and scalable model for capturing and storing local stormwater through gravity-fed basins and strategic diversion. This demonstrates that meaningful aquifer recovery can be accomplished in a manner that is accessible to other regions and agencies seeking to enhance their own groundwater resilience.

The ability to conduct this level of analysis was made possible by SBVWCD's long-term operational data, which includes continuous recharge records from 1912 to the present. This dataset enabled high-confidence model calibration and validation. The ISARM v1.1 model incorporated distributed data on recharge, extraction, underflow, and stream-aquifer interactions, and achieved a relative error of 1.6%, well within accepted thresholds for regional groundwater modeling.

Overall, the findings underscore the effectiveness of sustained, data-informed groundwater management in enhancing aquifer reliability over decadal and century-scale timeframes. SBVWCD's recharge operations have demonstrably offset regional pumping impacts and contributed to long-term basin stability. These results highlight the critical role of locally led, cost-effective recharge programs in advancing groundwater sustainability under current and future hydrologic stressors.

6.0 MODEL LIMITATIONS AND UNCERTAINTY

The model is not intended to exactly predict water levels or streamflow beyond a level that could be reasonably anticipated from the residual statistics. As the model is applied in different applications, an assessment of the calibration and suitability for the intended purpose should be conducted prior to using the model. Sources of uncertainty in the model come from several factors. The largest source of uncertainty comes from estimations of major water budget components, as the largest components have the most influence on the overall water balance. Inflows to the groundwater basin, like mountain front runoff, areal recharge, return flow, and underflow, were estimated using various modeling techniques or assumptions correlated with hydrologic conditions. Outflows, like groundwater pumping, are subject to uncertainty due to measurement and recording error.

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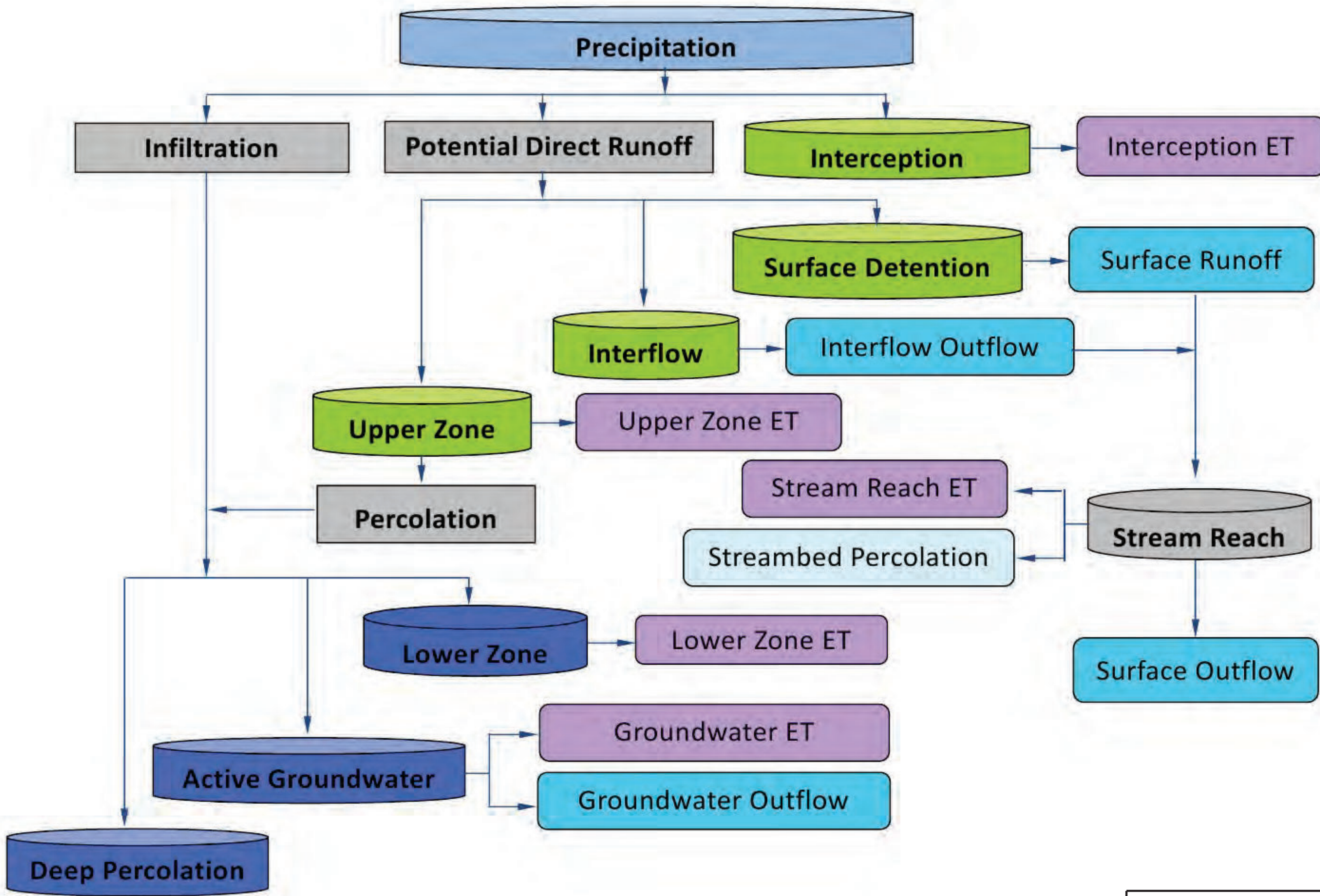
FIGURES



HSPF SCHEMATIC DIAGRAM

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Jun-2025

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

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FIGURE 1

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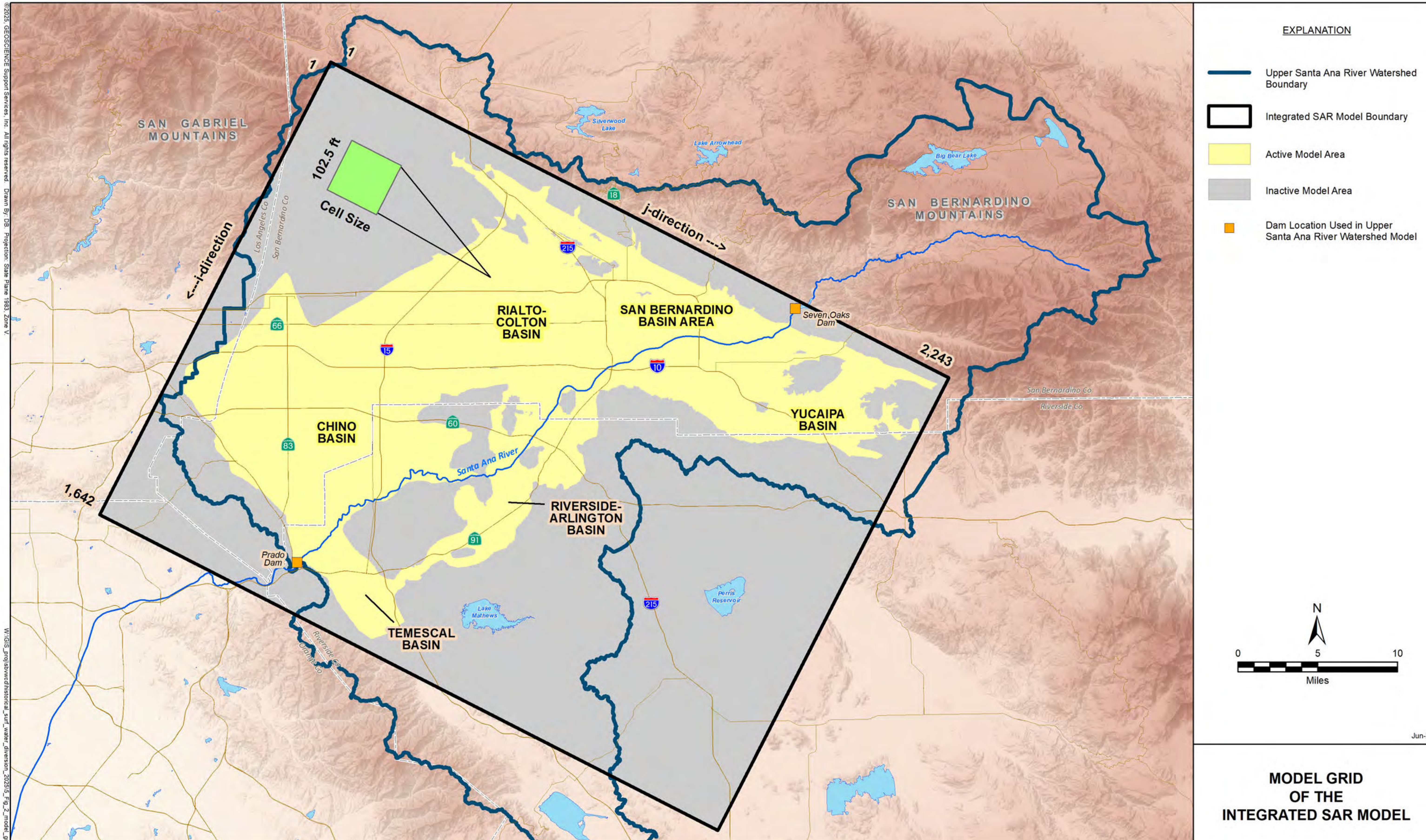

MODEL GRID OF THE INTEGRATED SAR MODEL

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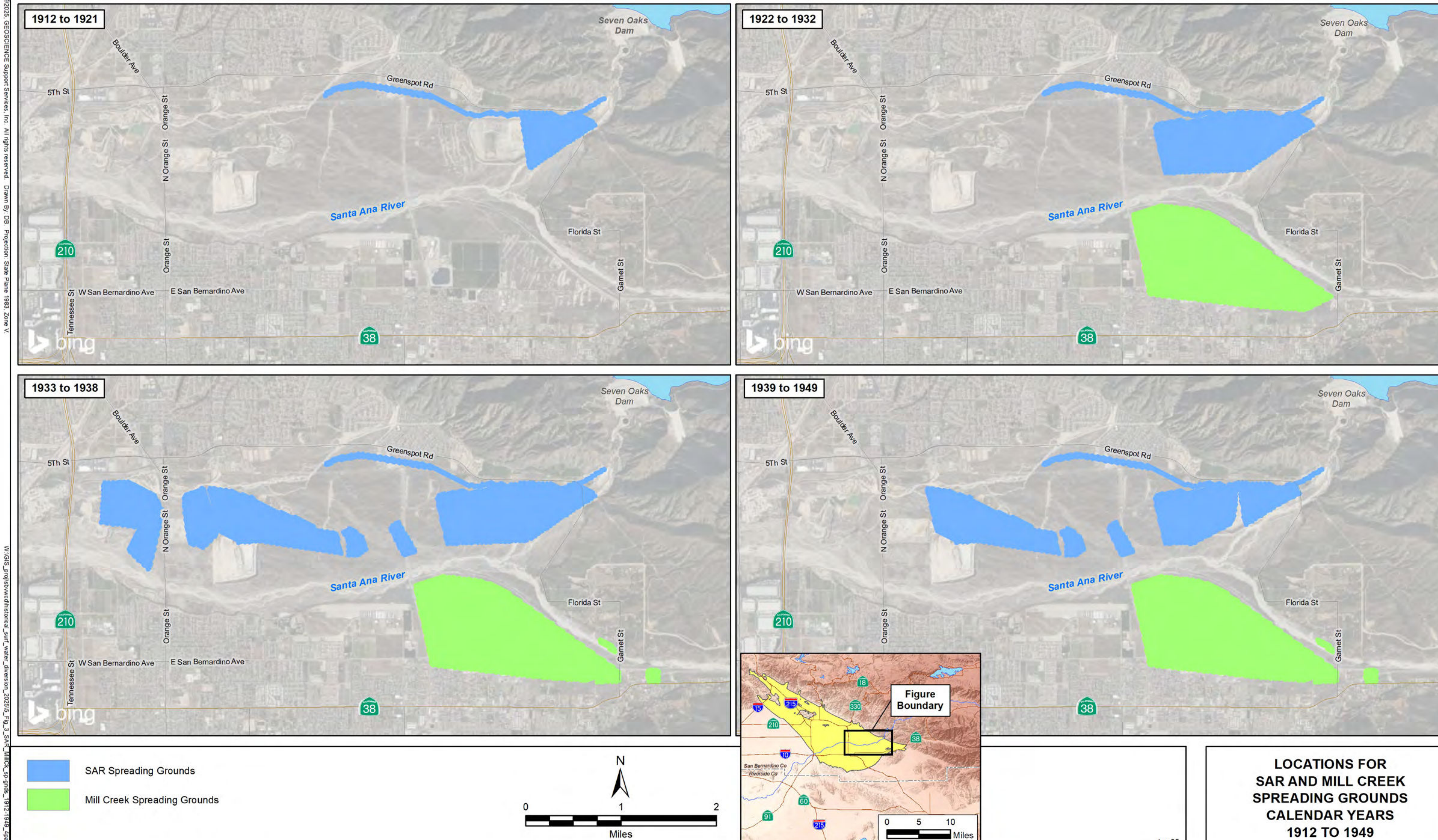
FIGURE 2



LOCATIONS FOR SAR AND MILL CREEK SPREADING GROUNDS CALENDAR YEARS 1912 TO 1949

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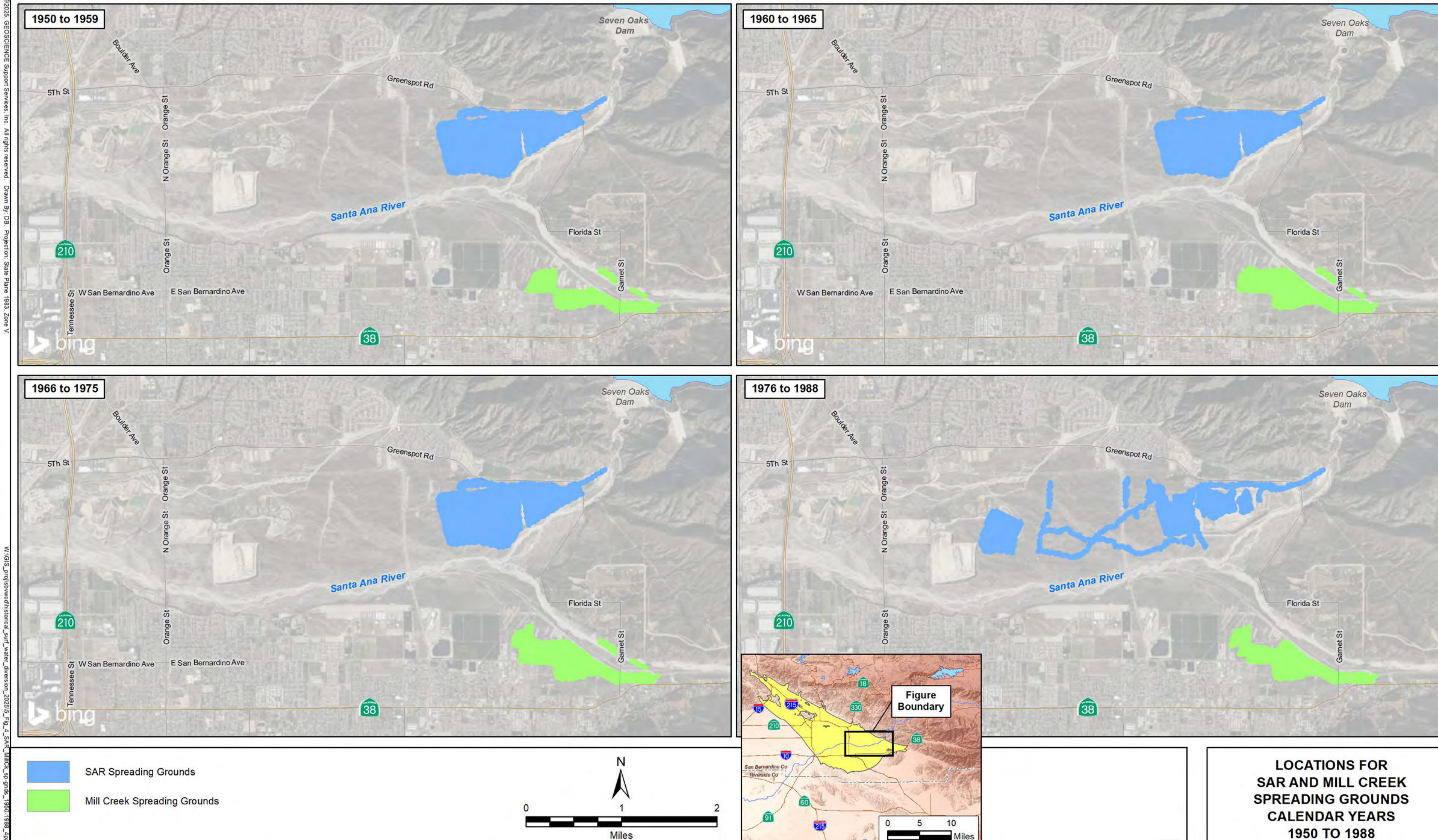
A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 3



LOCATIONS FOR SAR AND MILL CREEK SPREADING GROUNDS CALENDAR YEARS 1950 TO 1988

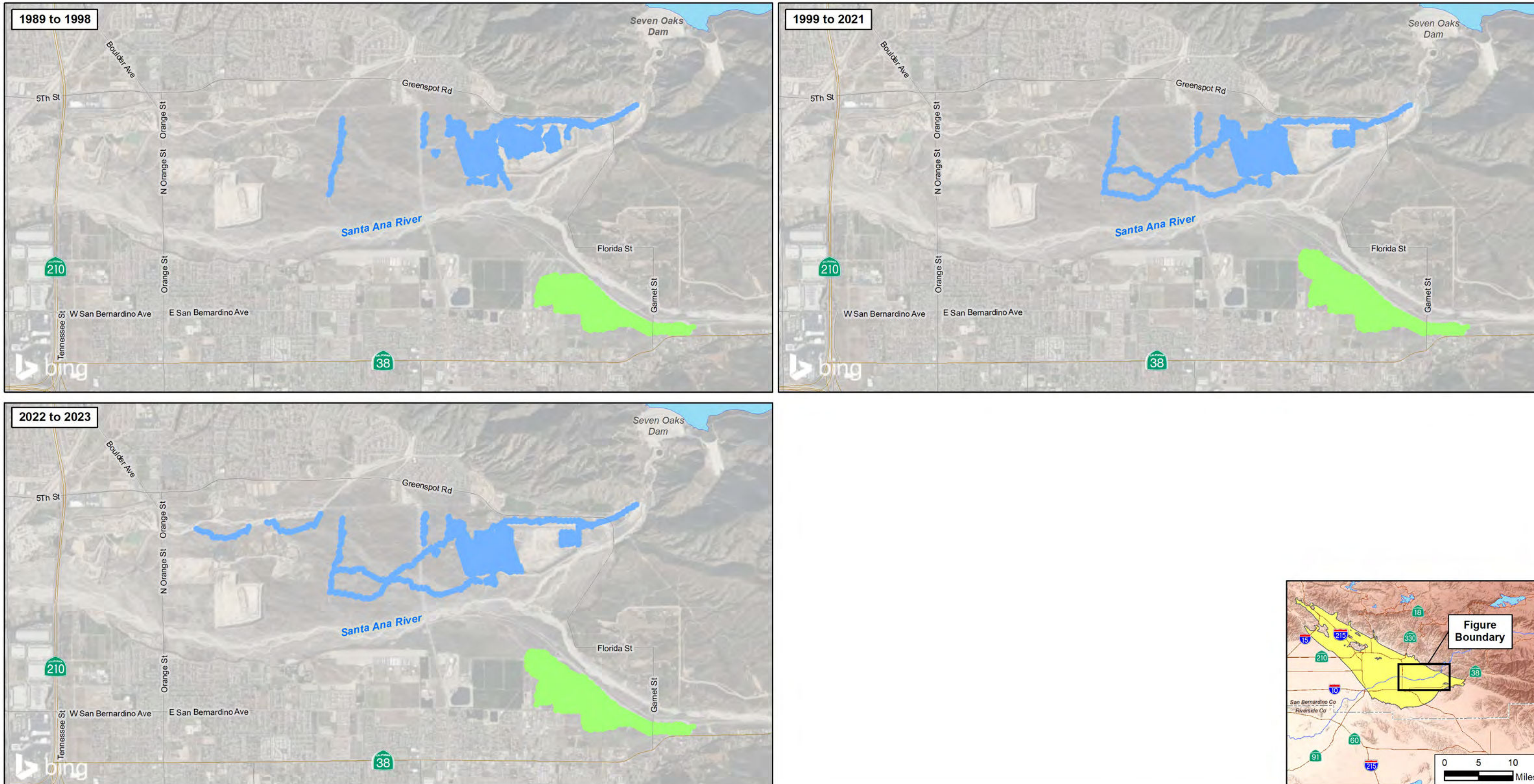
GEOSCIENCE

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 4

W:\GIS_proj\sbvwcd\historical_surf_water_diversion_202505_Fig_4_SAR_MillCk_sp-gnds_1950-1988_4panel_6-25_16x10.mxd



SAR Spreading Grounds

Mill Creek Spreading Grounds

N

0 1 2

Miles

Jun-25

LOCATIONS FOR SAR AND MILL CREEK SPREADING GROUNDS CALENDAR YEARS 1989 TO 2023

GEOSCIENCE

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 5

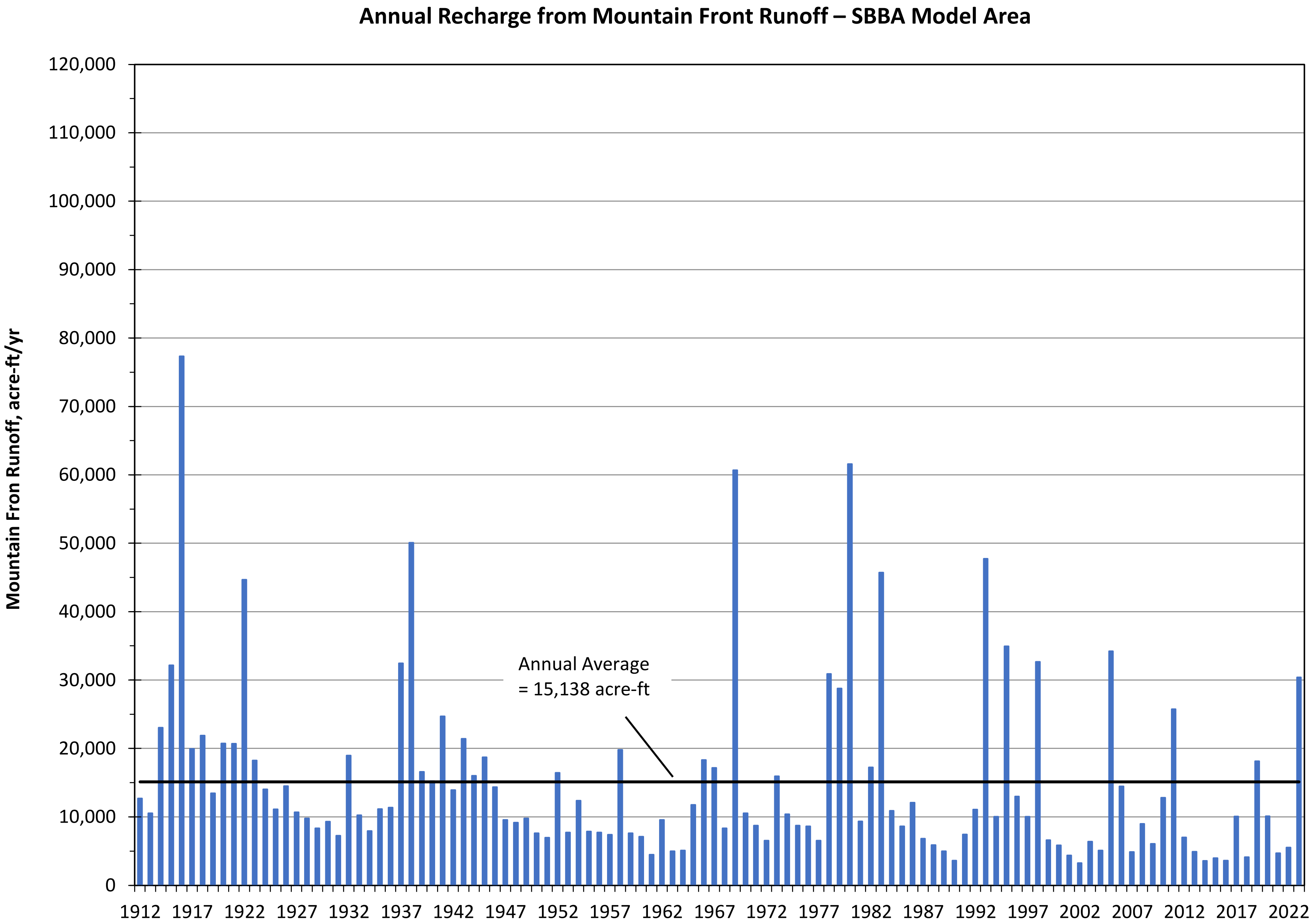

Annual Recharge from Mountain Front Runoff – SBBA Model Area
Mountain Fron Runoff, acre-ft/yr
120,000
110,000
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Annual Average
= 15,138 acre-ft
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 6

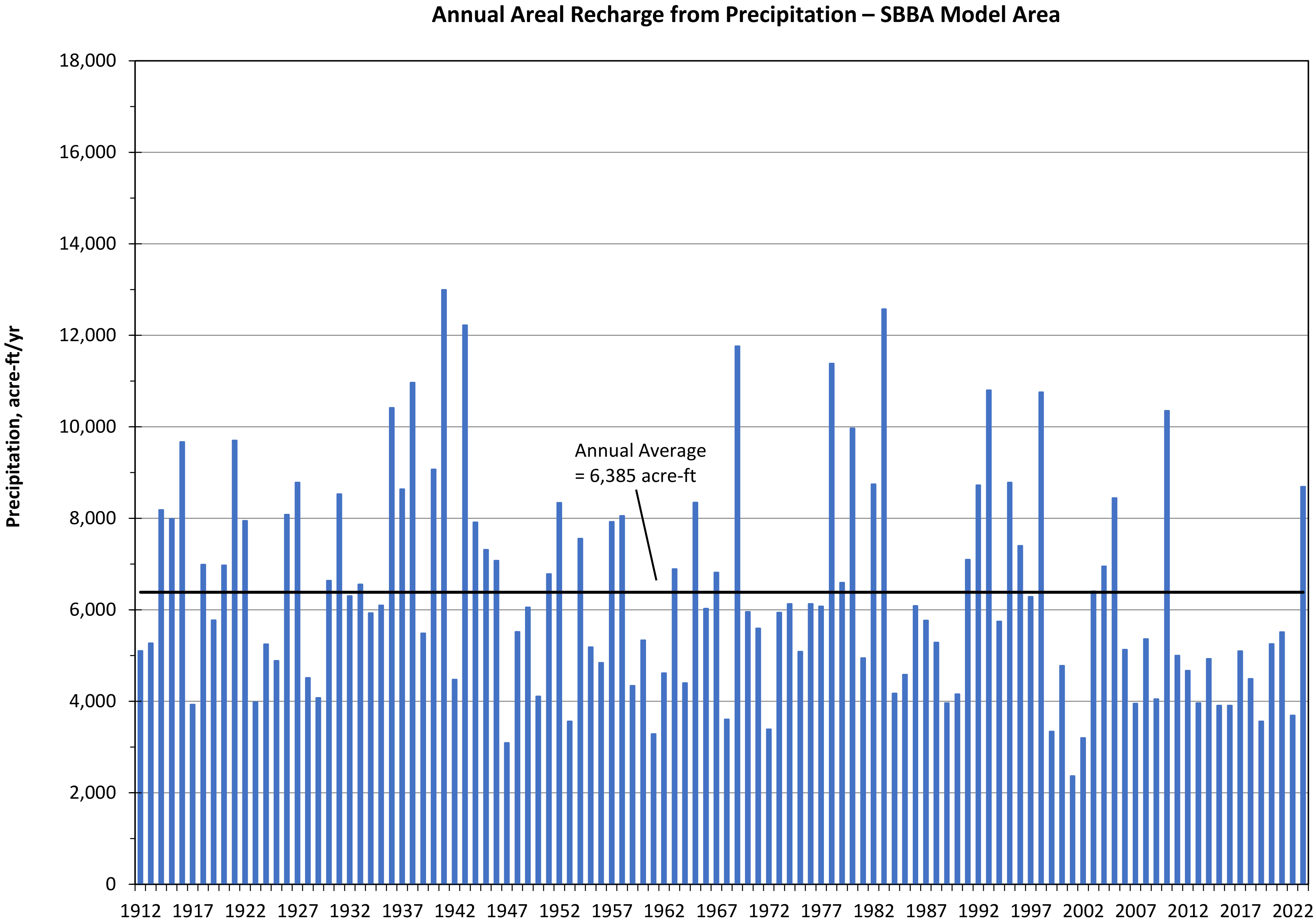
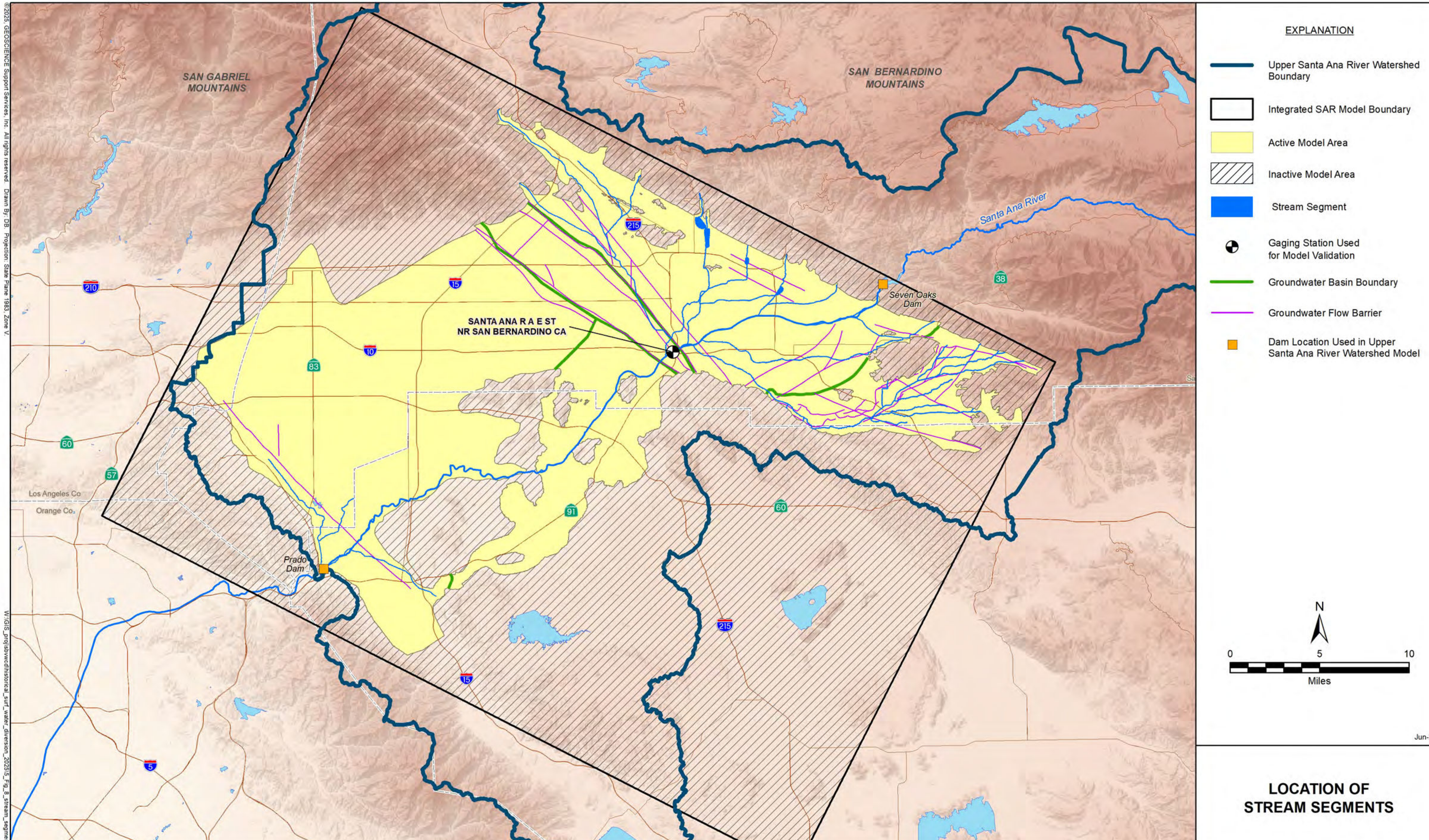

Annual Areal Recharge from Precipitation – SBBA Model Area
Precipitation, acre-ft/yr
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Annual Average
= 6,385 acre-ft
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 7



LOCATION OF STREAM SEGMENTS

GEOSCIENCE

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 8

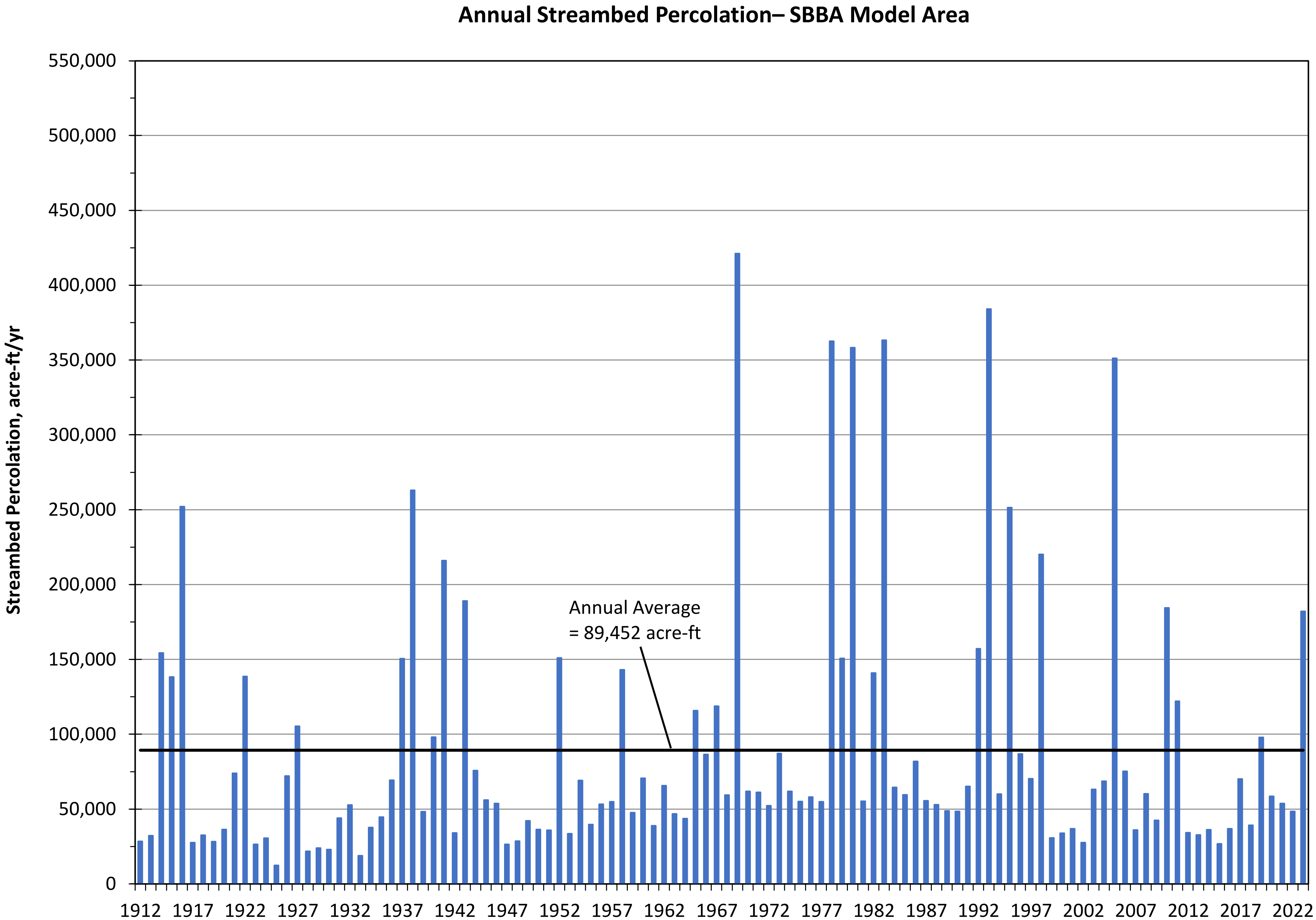

Annual Streambed Percolation– SBBA Model Area
Streambed Percolation, acre-ft/yr
550,000
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022
Annual Average
= 89,452 acre-ft

Figure 9

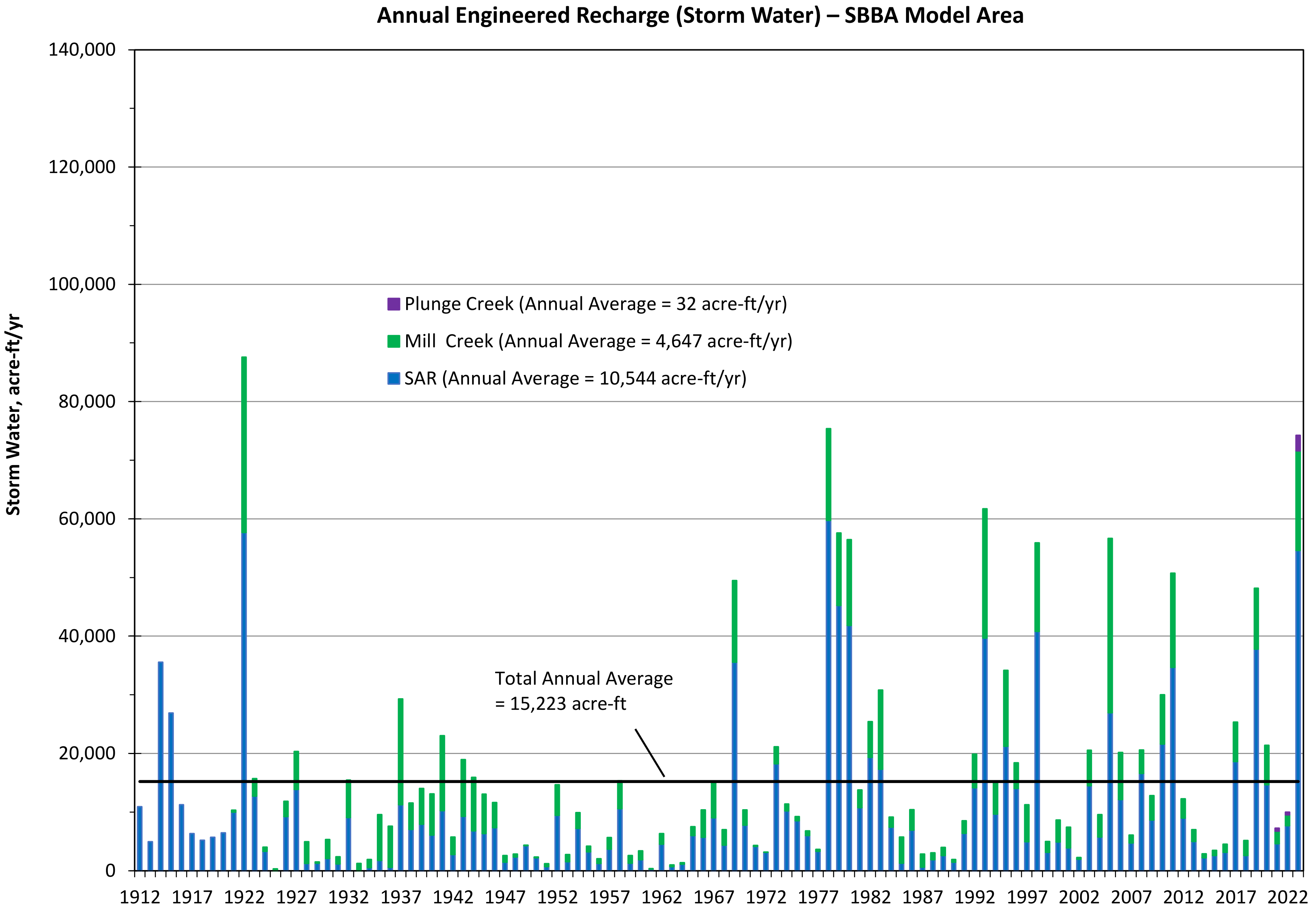

Annual Engineered Recharge (Storm Water) – SBBA Model Area
Storm Water, acre-ft/yr
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Plunge Creek (Annual Average = 32 acre-ft/yr)
Mill Creek (Annual Average = 4,647 acre-ft/yr)
SAR (Annual Average = 10,544 acre-ft/yr)
Total Annual Average
= 15,223 acre-ft
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 10

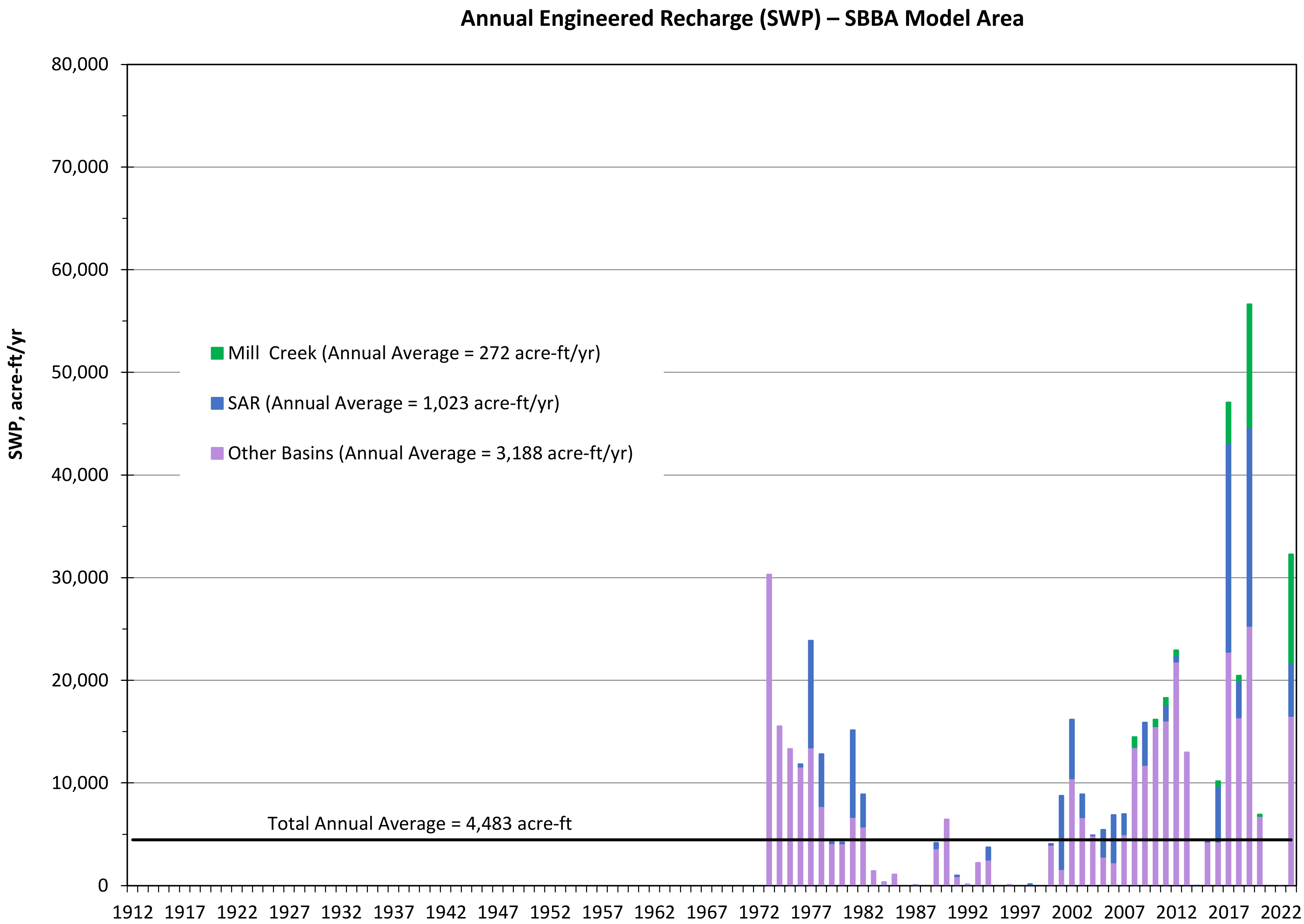

Annual Engineered Recharge (SWP) – SBBA Model Area
SWP, acre-ft/yr
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Mill Creek (Annual Average = 272 acre-ft/yr)
SAR (Annual Average = 1,023 acre-ft/yr)
Other Basins (Annual Average = 3,188 acre-ft/yr)
Total Annual Average = 4,483 acre-ft
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 11

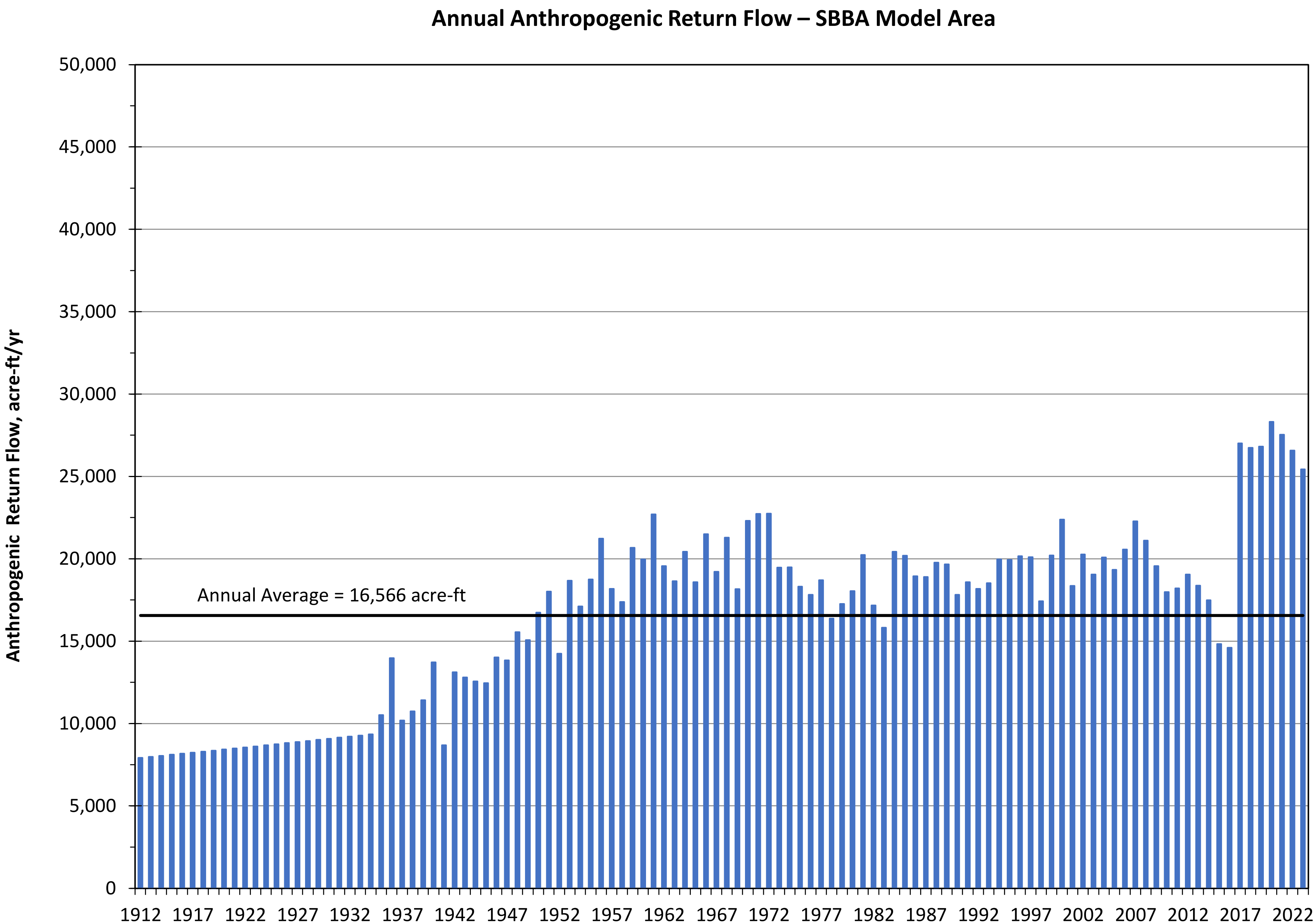

Annual Anthropogenic Return Flow – SBBA Model Area
Anthropogenic Return Flow, acre-ft/yr
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Annual Average = 16,566 acre-ft
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 12

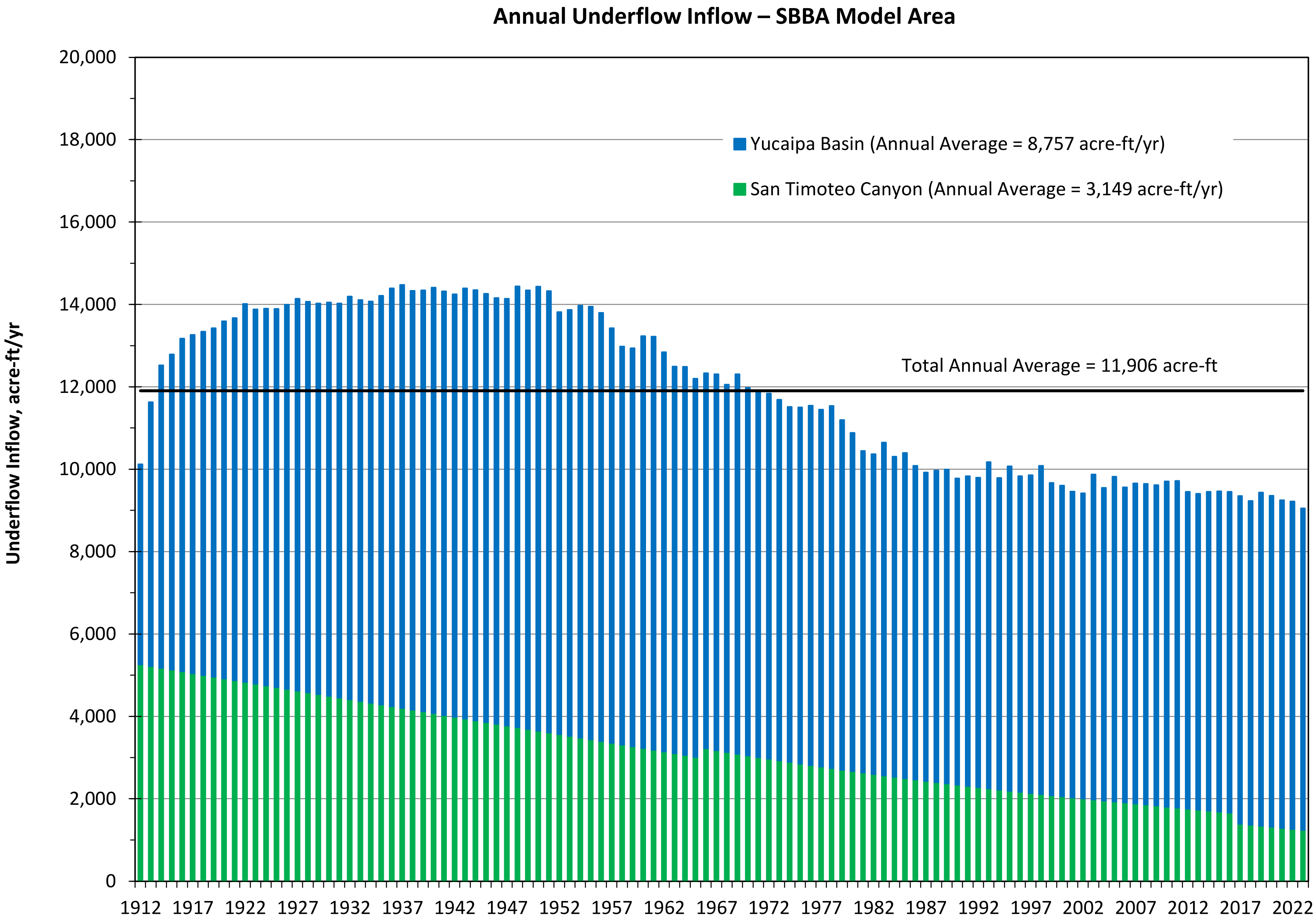

Annual Underflow Inflow – SBBA Model Area
Yucaipa Basin (Annual Average = 8,757 acre-ft/yr)
San Timoteo Canyon (Annual Average = 3,149 acre-ft/yr)
Total Annual Average = 11,906 acre-ft
Underflow Inflow, acre-ft/yr
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 13

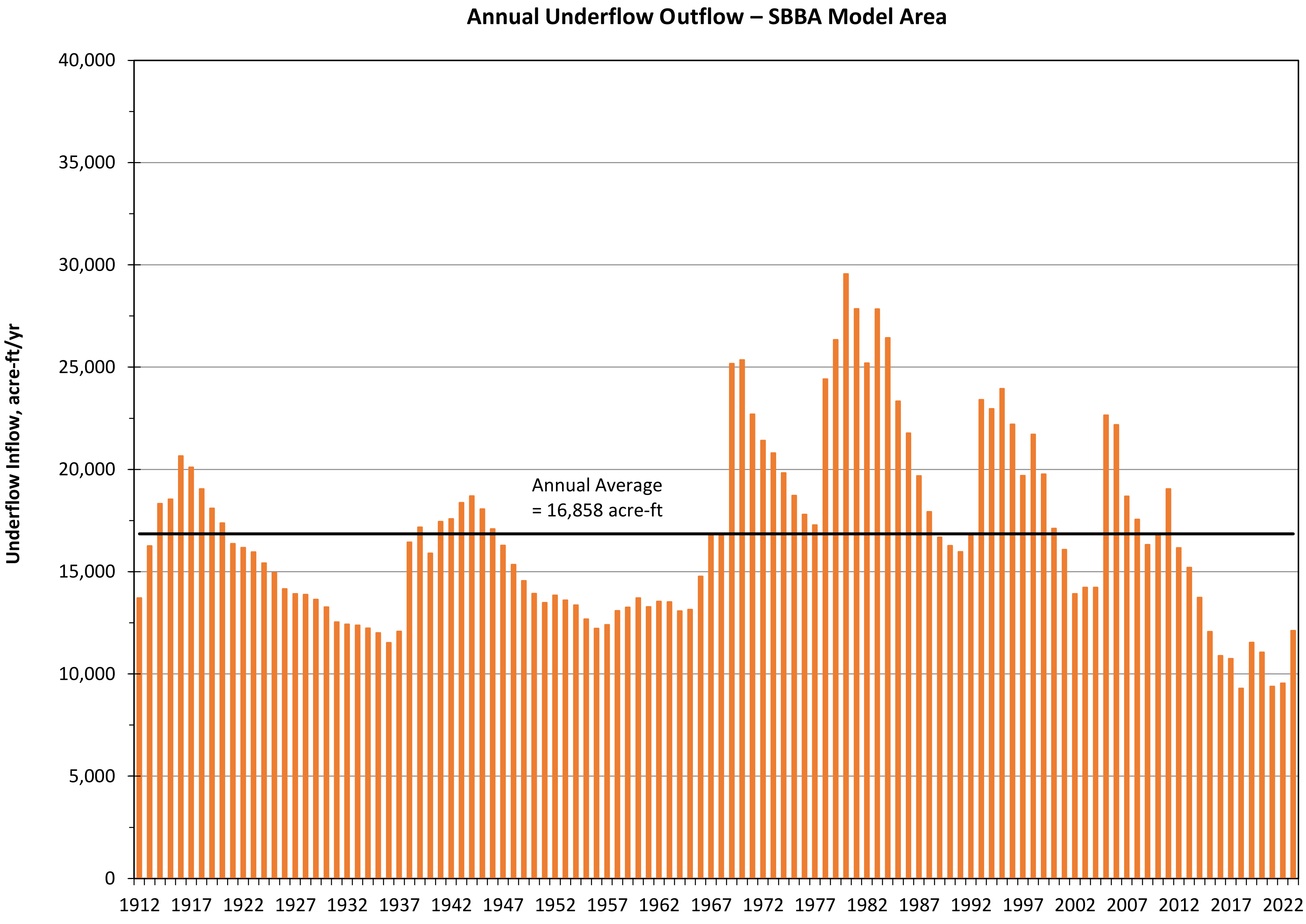

Annual Underflow Outflow – SBBA Model Area
Underflow Inflow, acre-ft/yr
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Annual Average
= 16,858 acre-ft
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 14

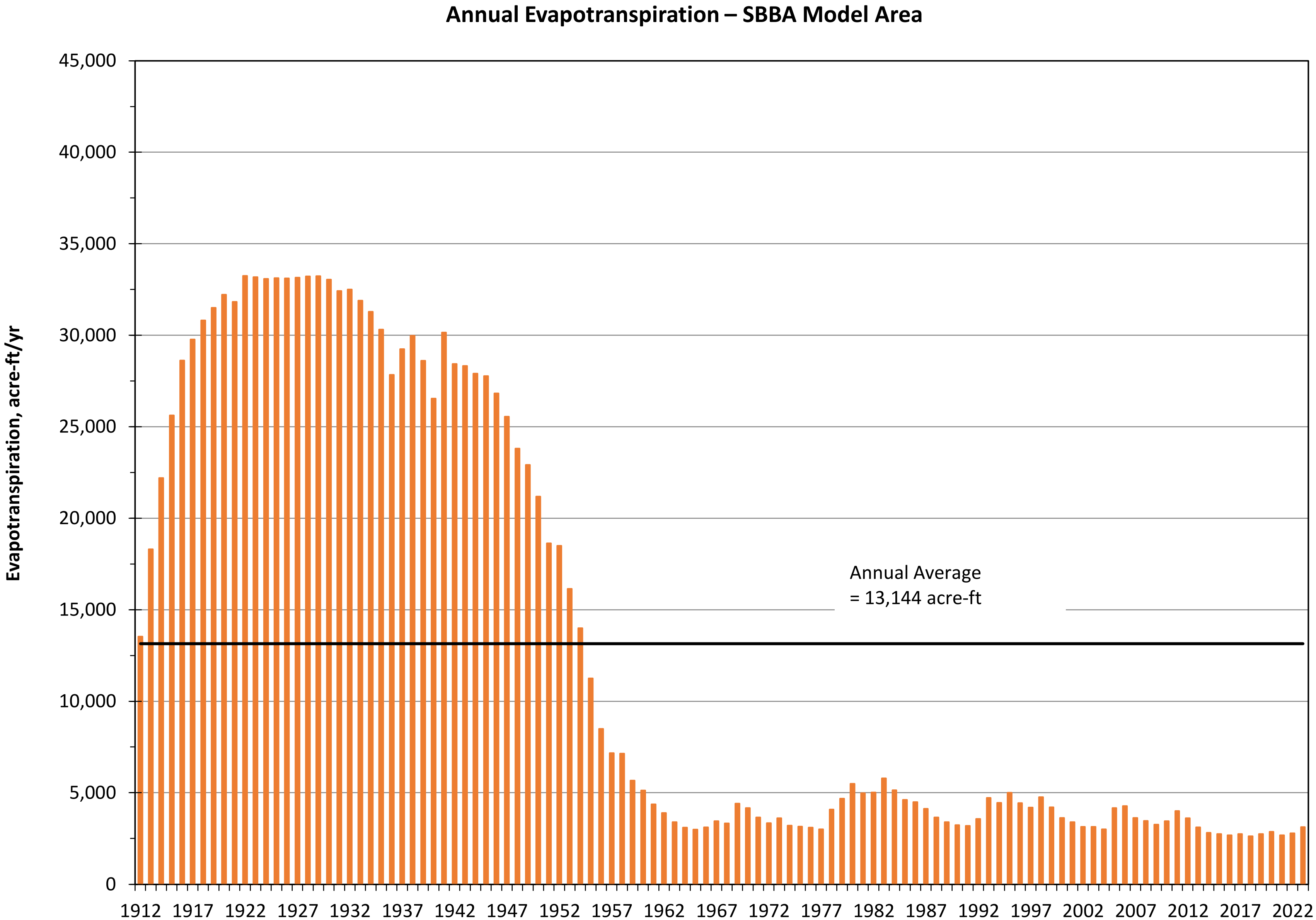
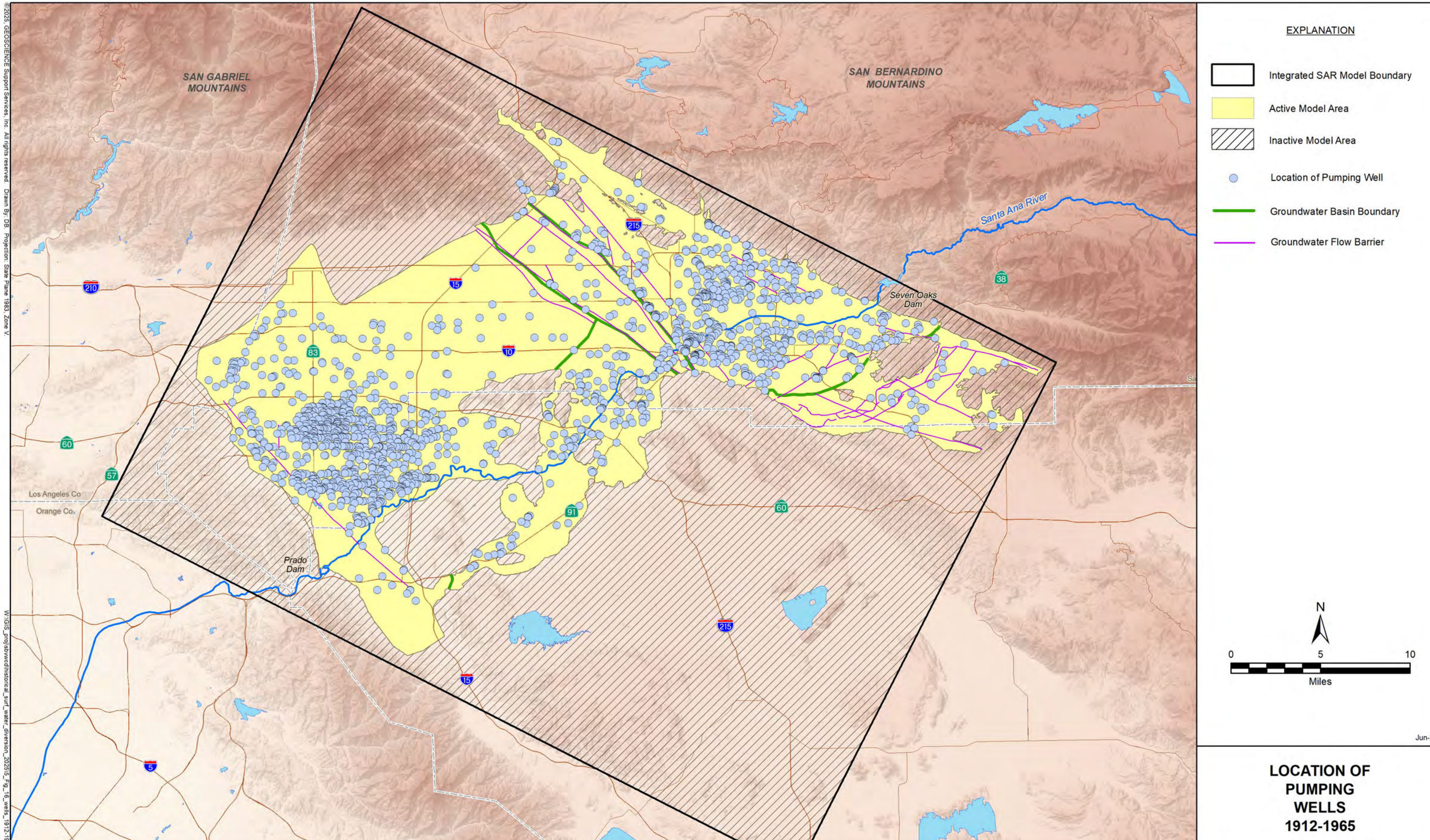

Annual Evapotranspiration – SBBA Model Area
Evapotranspiration, acre-ft/yr
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022
Annual Average
= 13,144 acre-ft

Figure 15



LOCATION OF PUMPING WELLS 1912-1965

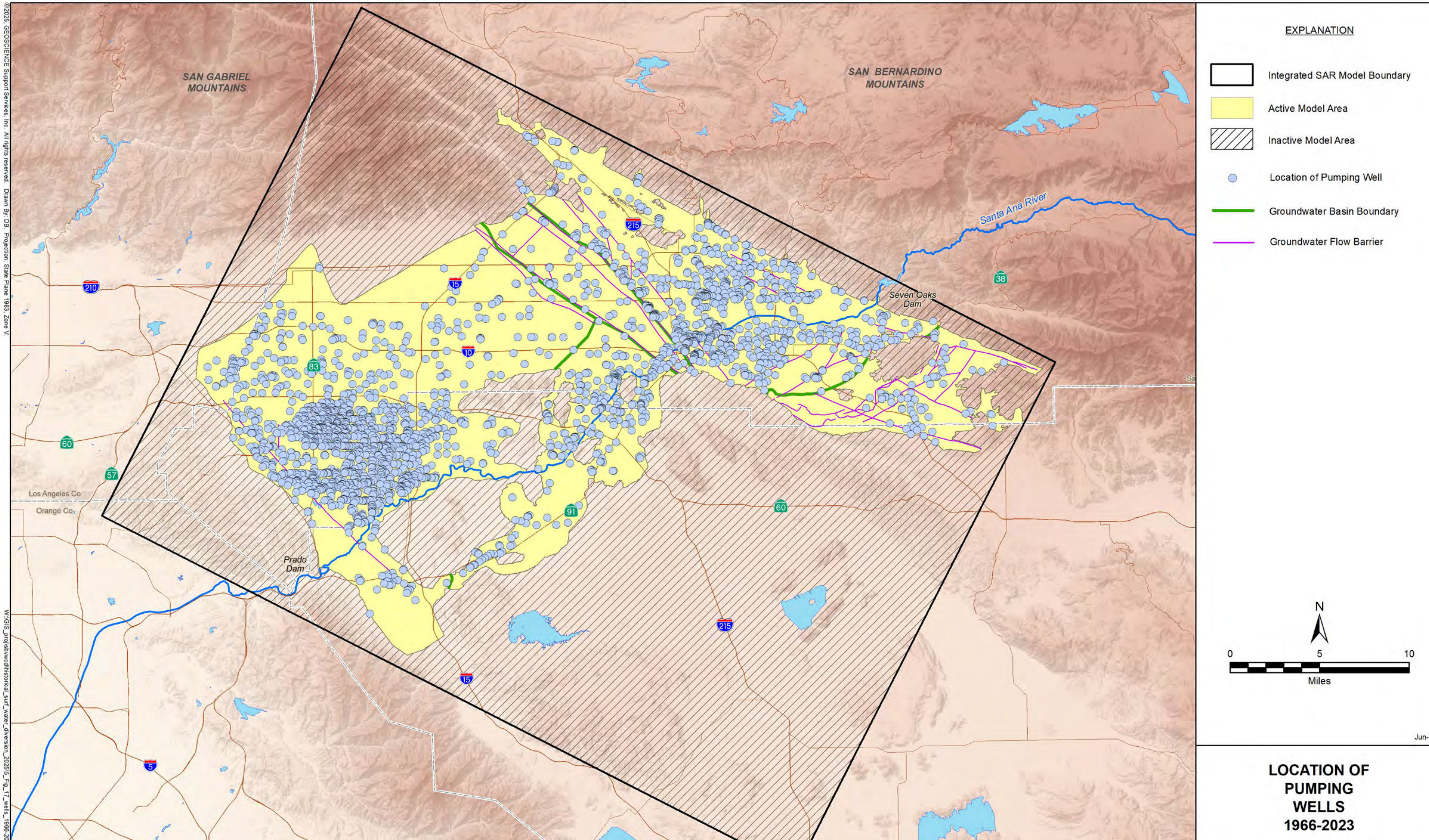
GEOSCIENCE

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 16

W:\GIS_proj\sbvwcd\historical_surf_water_diversion_202515_Fig_16_wells_1912-1965_6-25_16x10.mxd



W:\GIS_proj\sbvwcd\historical_surf_water_diversion_202515_Fig_17_wells_1966-2023_6-25_16x10.mxd

LOCATION OF PUMPING WELLS 1966-2023

GEOSCIENCE

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 17

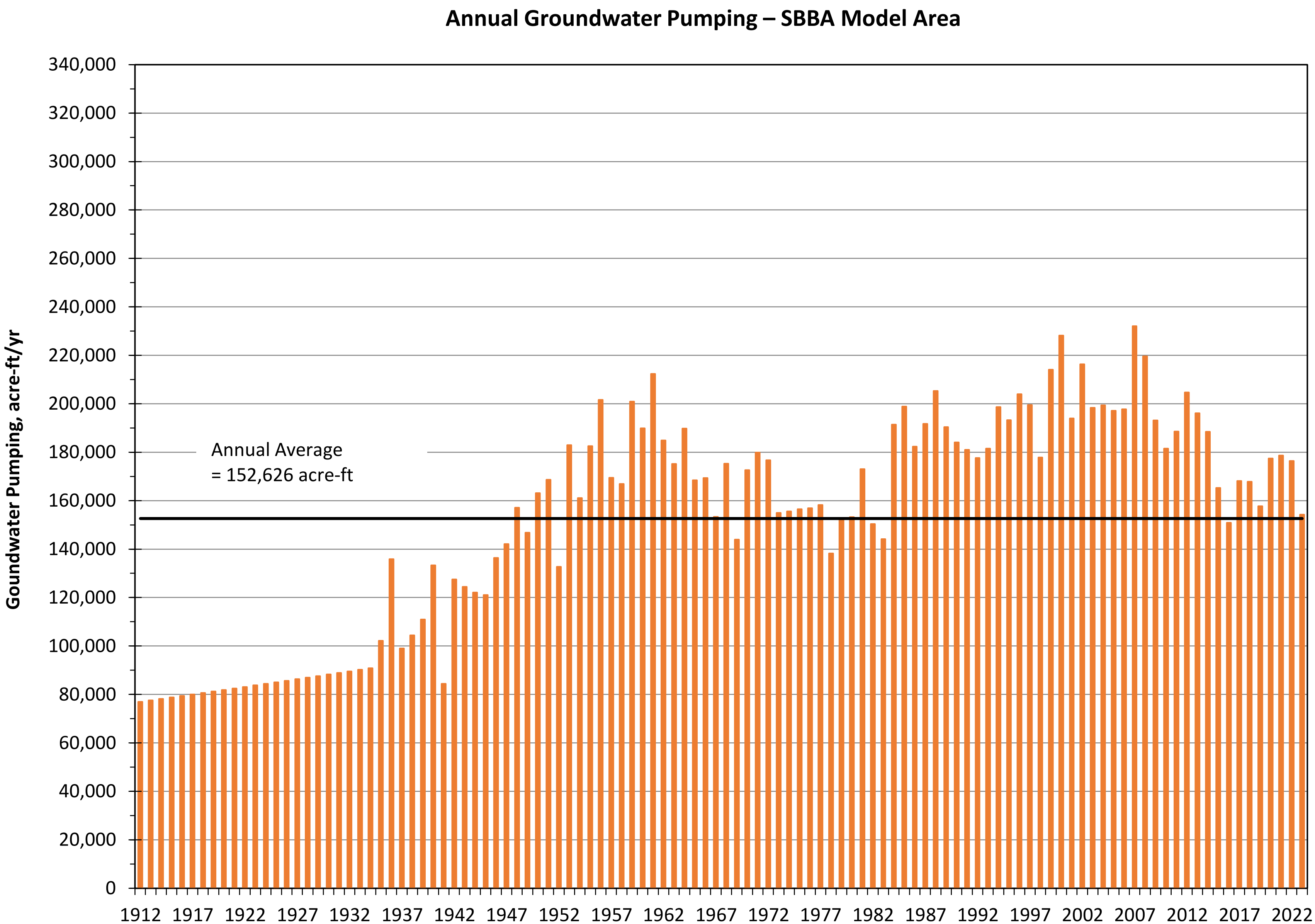
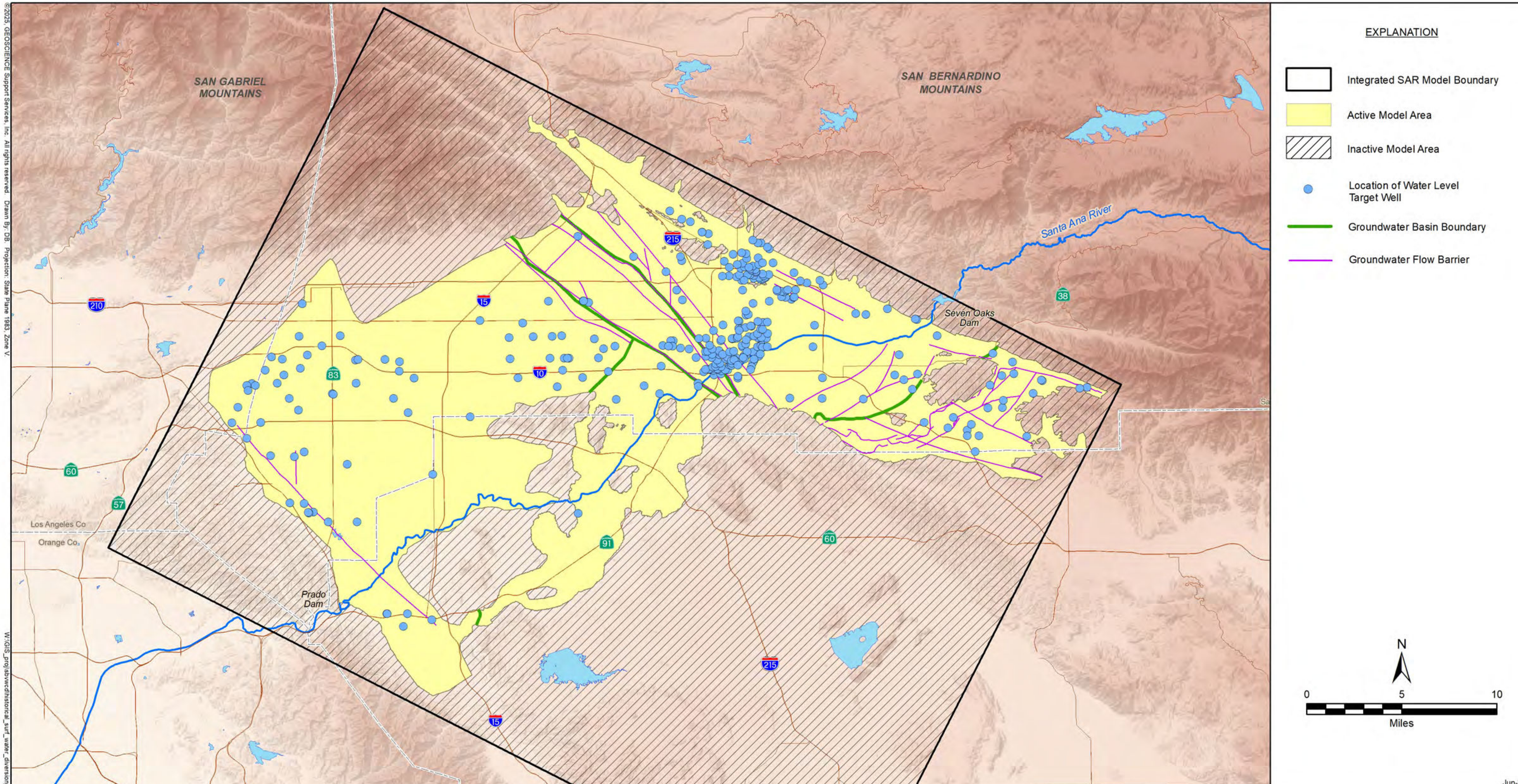

Annual Groundwater Pumping – SBBA Model Area
Goundwater Pumping, acre-ft/yr
340,000
320,000
300,000
280,000
260,000
240,000
220,000
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Annual Average
= 152,626 acre-ft
1912
1917
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 18



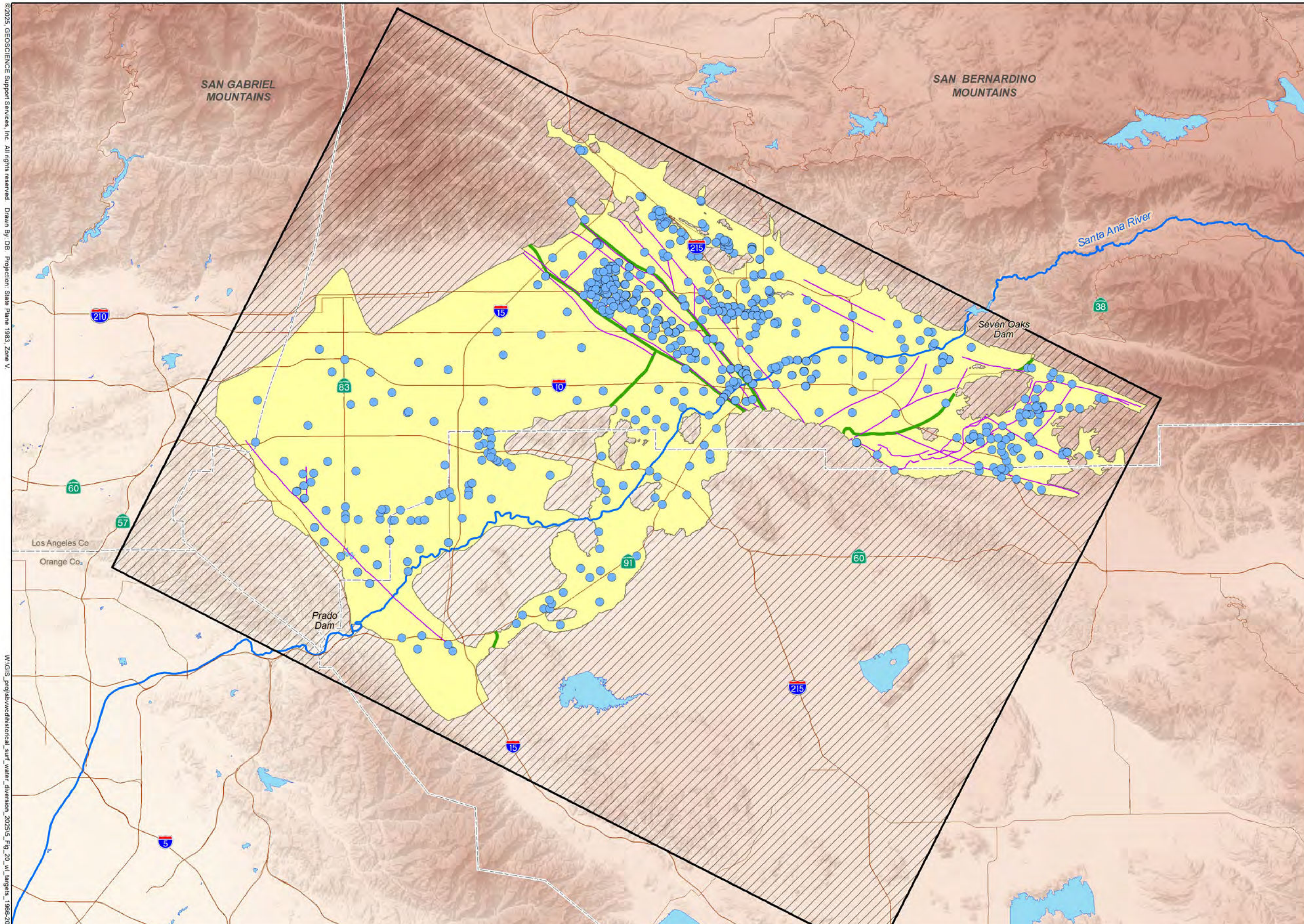
LOCATION OF WATER LEVEL TARGETS 1912-1965

GEOSCIENCE

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 19



EXPLANATION

- Integrated SAR Model Boundary
- Active Model Area
- Inactive Model Area
- Location of Water Level Target Well
- Groundwater Basin Boundary
- Groundwater Flow Barrier

N

0 5 10

Miles

Jun-25

LOCATION OF WATER LEVEL TARGETS 1966-2023

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SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 20

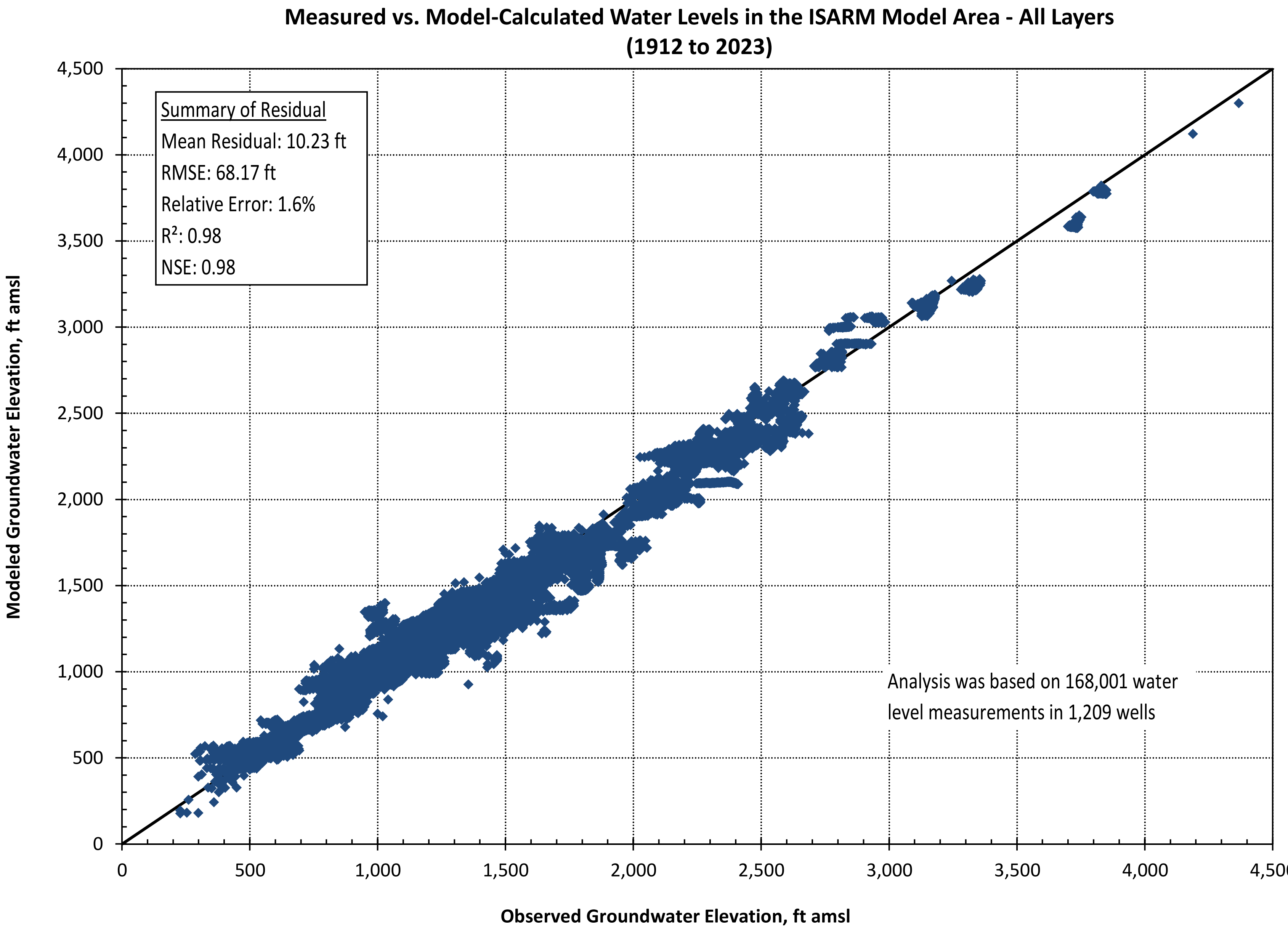
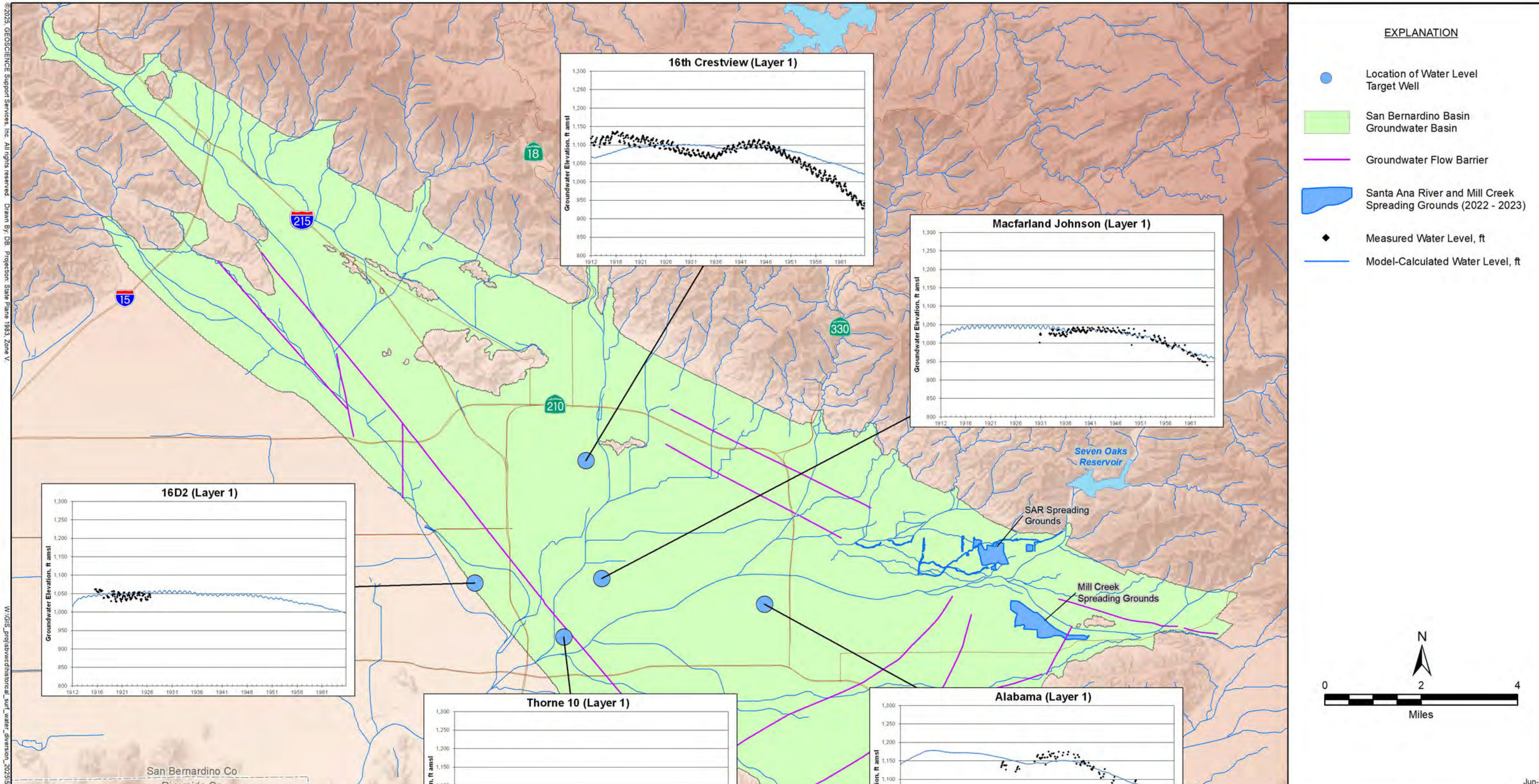

Measured vs. Model-Calculated Water Levels in the ISARM Model Area - All Layers
(1912 to 2023)
Summary of Residual
Mean Residual: 10.23 ft
RMSE: 68.17 ft
Relative Error: 1.6%
R²: 0.98
NSE: 0.98
Analysis was based on 168,001 water level measurements in 1,209 wells
Modeled Groundwater Elevation, ft amsl
Observed Groundwater Elevation, ft amsl
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500

Figure 21



SELECTED HYDROGRAPHS IN THE SBBA MODEL AREA 1912-1965

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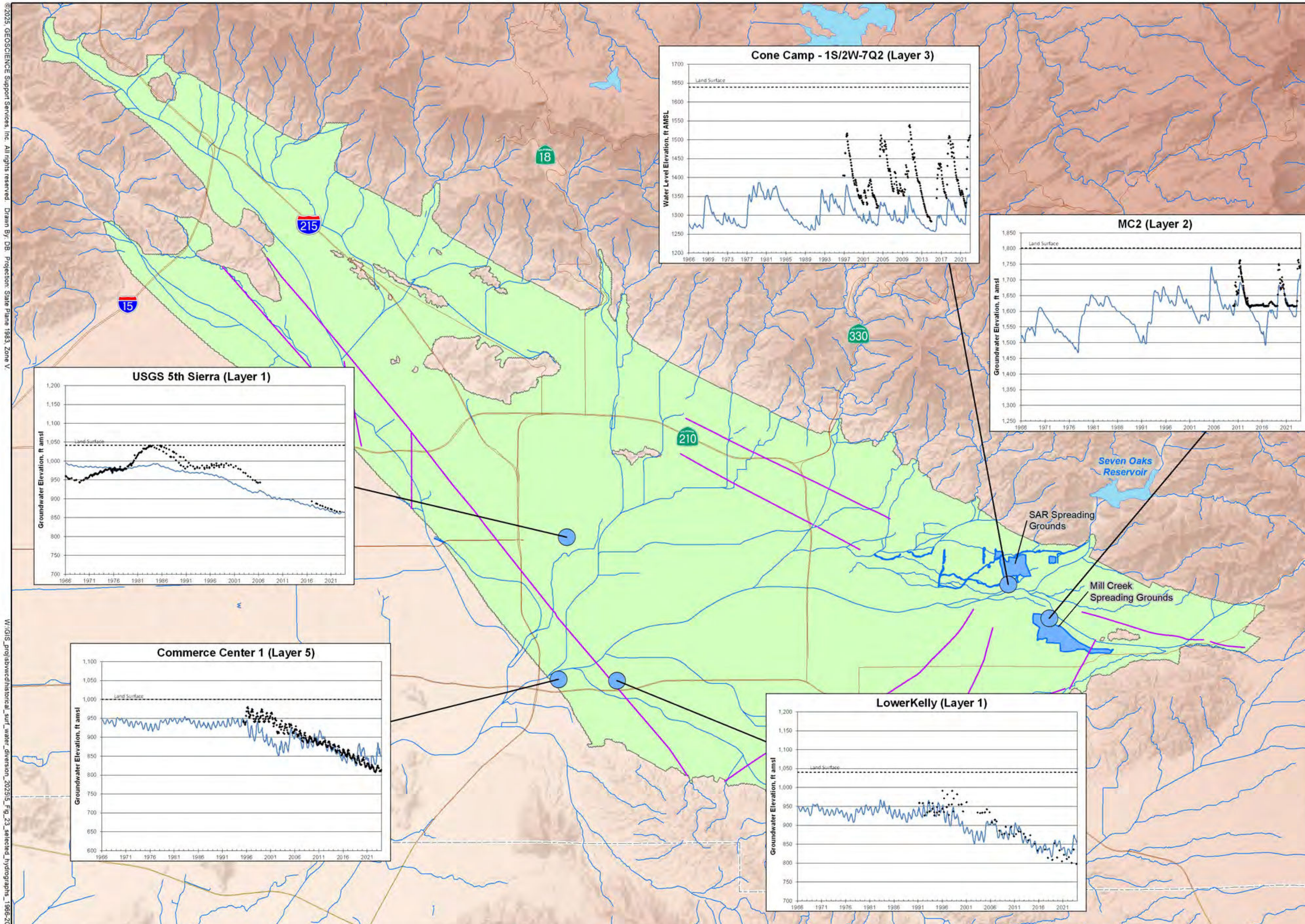
SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 22



SELECTED HYDROGRAPHS IN THE SBBA MODEL AREA 1966-2023

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SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 23

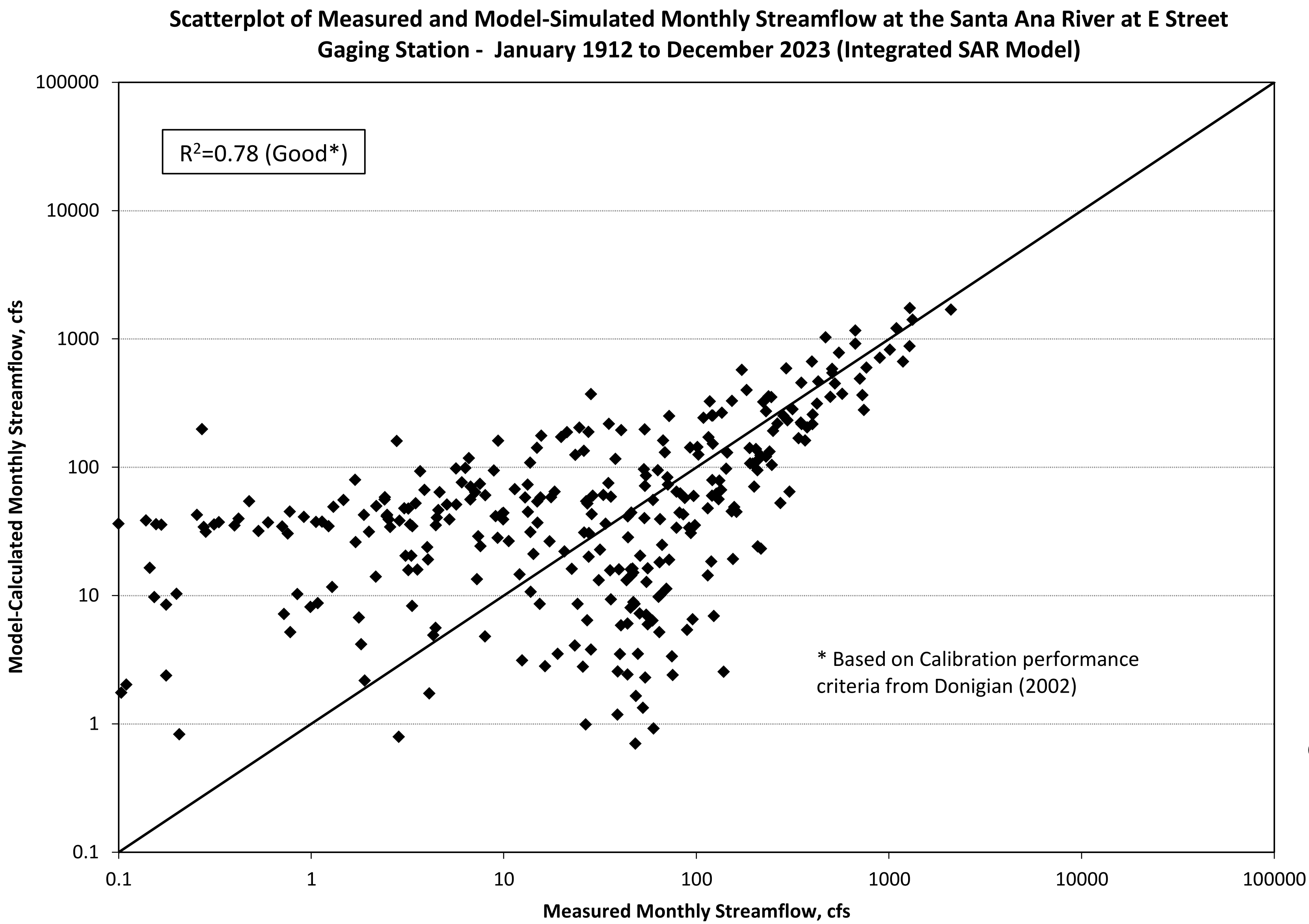

Scatterplot of Measured and Model-Simulated Monthly Streamflow at the Santa Ana River at E Street Gaging Station - January 1912 to December 2023 (Integrated SAR Model)
R²=0.78 (Good*)
100000
10000
1000
100
10
1
0.1
Model-Calculated Monthly Streamflow, cfs
0.1
1
10
100
1000
10000
100000
Measured Monthly Streamflow, cfs
* Based on Calibration performance criteria from Donigian (2002)

Figure 24

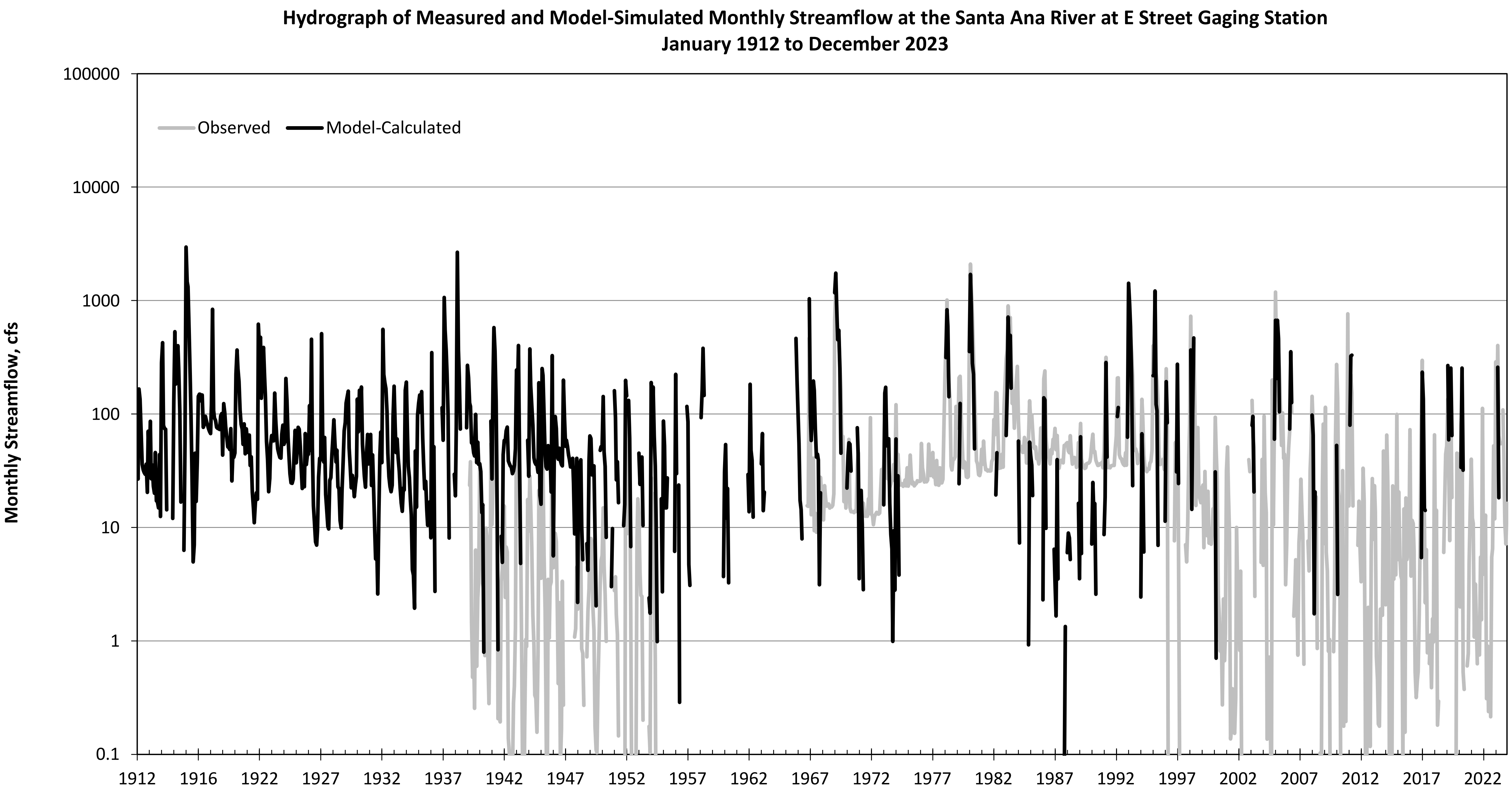
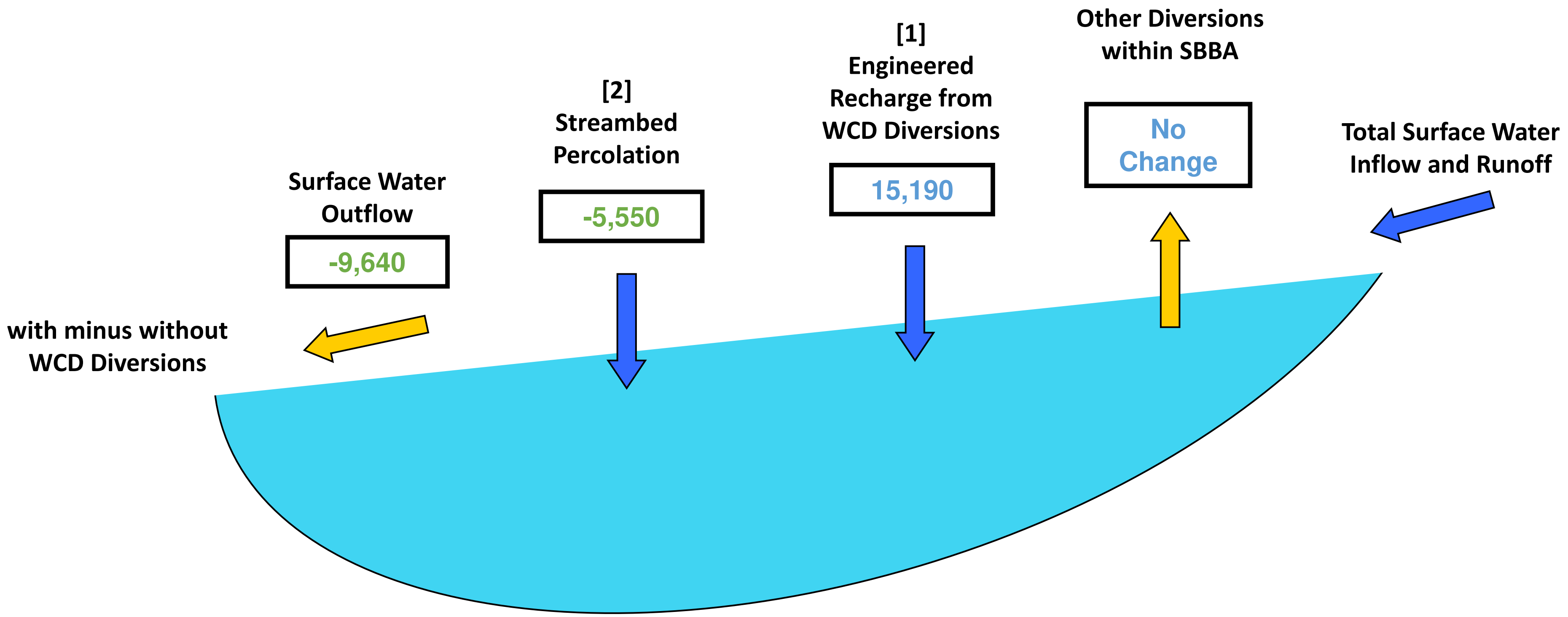

Hydrograph of Measured and Model-Simulated Monthly Streamflow at the Santa Ana River at E Street Gaging Station
January 1912 to December 2023
Observed
Model-Calculated
Monthly Streamflow, cfs
100000
10000
1000
100
10
1
0.1
1912
1916
1922
1927
1932
1937
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
2022

Figure 25

Diversions from 1912 to 2023 total over 1.7 million acre-ft.



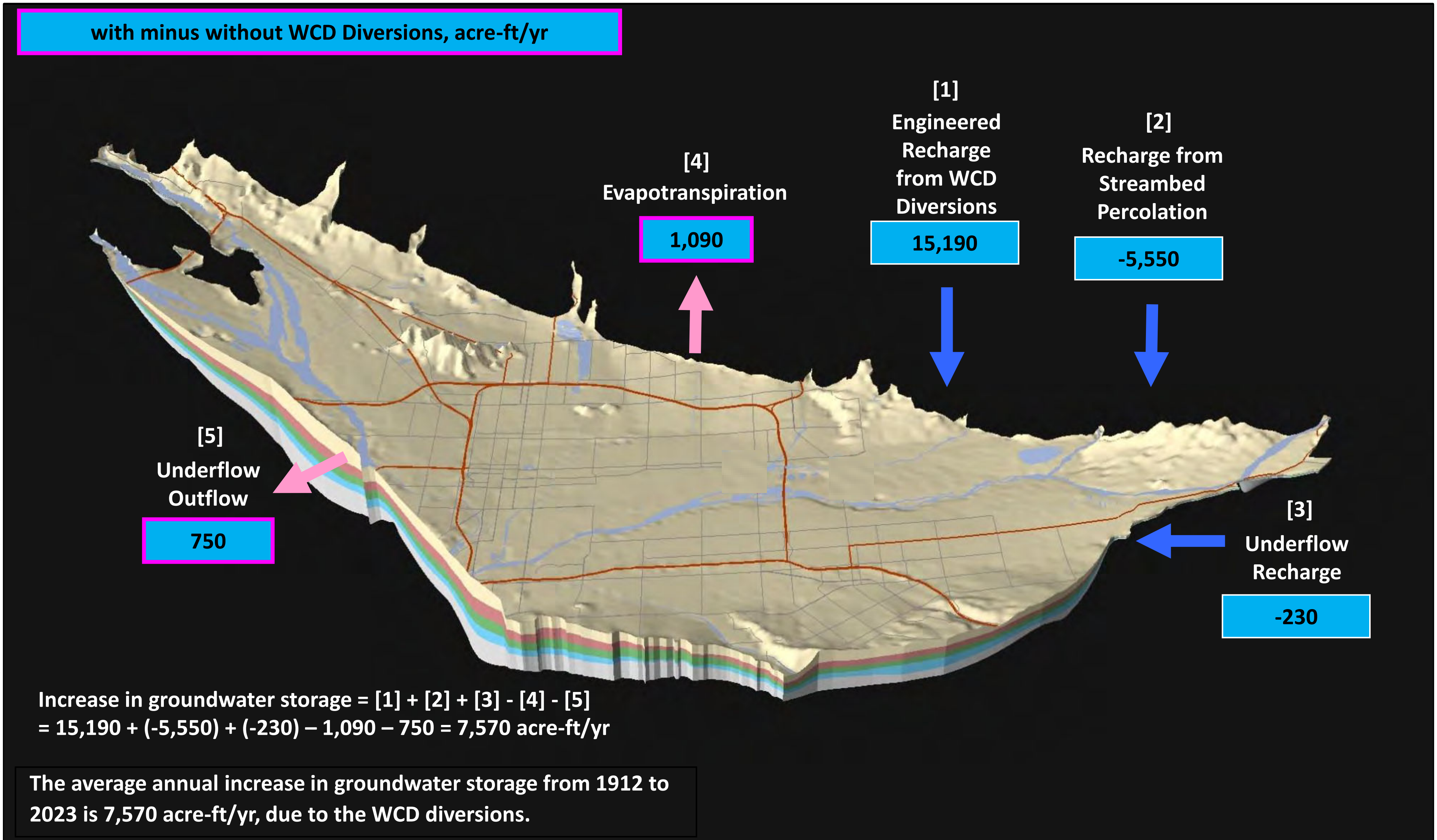
All values in acre-ft/yr

Total Surface Water Inflow and Runoff = 208,600 acre-ft/yr
Total Diversions (with WCD Diversions) = [1] = 15,190 acre-ft/yr
Difference of Annual Average Streambed Percolation (with minus without WCD Diversions) = [2] = -5,550 acre-ft/yr
Additional Recharge = [1] + [2] = 15,190 + (-5,550) = 9,640 acre-ft/yr

Note: Negative (-) denotes outflow/decrease
Positive (+) denotes inflow/increase

ANNUAL AVERGAGE SURFACE WATER BUDGET (1912 TO 2023)

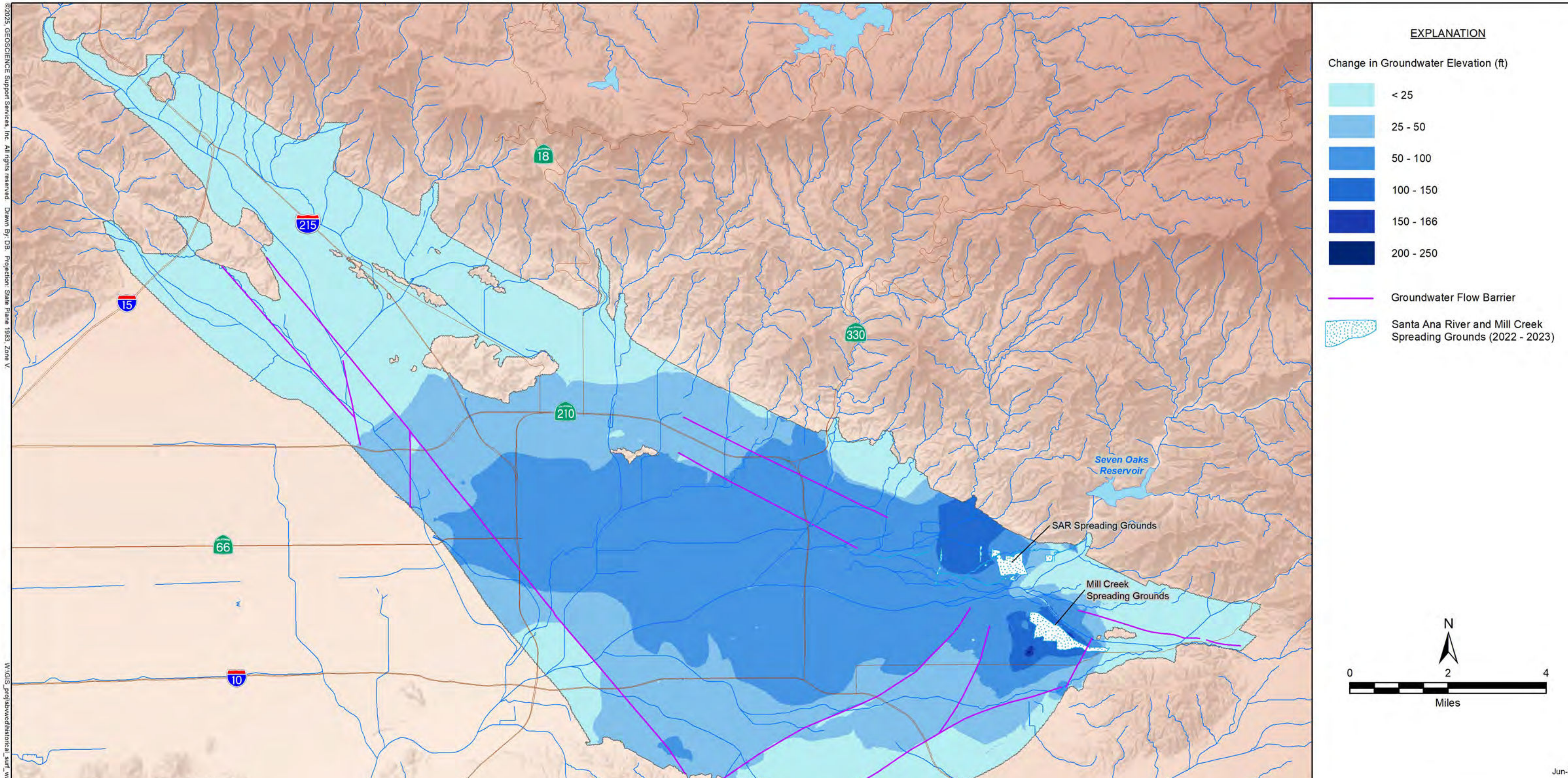
Jun-25



ANNUAL AVERAGE INCREASE IN GROUNDWATER STORAGE (1912 TO 2023)

X:\Projects\San Bernardino Valley Water Conservation District\(4)Historical Surface Water Diversion\(5)TM\Final\Figures\

Jun-25



CHANGE IN GROUNDWATER ELEVATION AFTER 112 YEARS - DEC 2023 (WITH WCD MINUS WITHOUT WCD)

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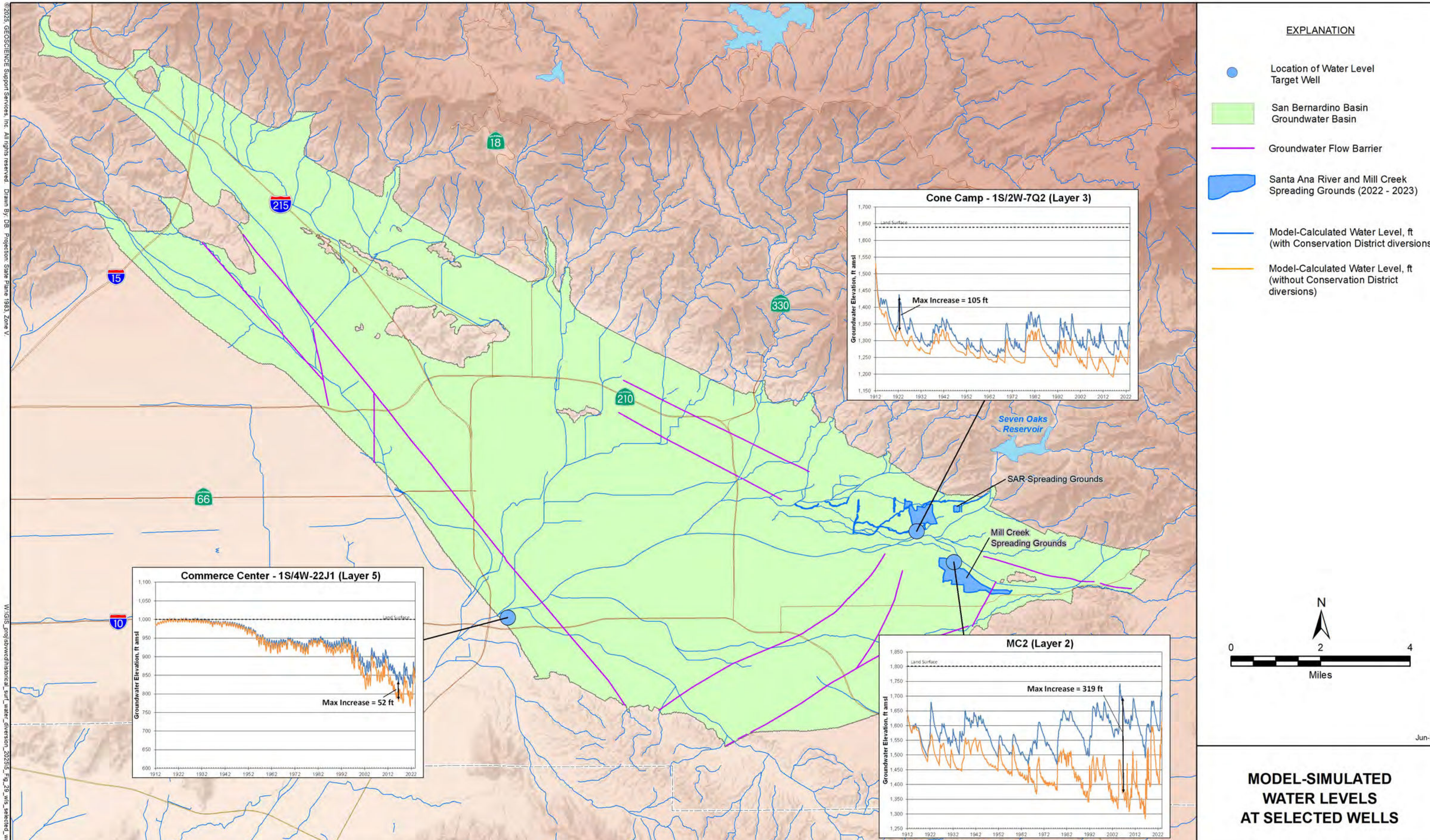
SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 28



MODEL-SIMULATED WATER LEVELS AT SELECTED WELLS

GEOSCIENCE

SAN BERNARDINO VALLEY WATER CONSERVATION DISTRICT

A CENTURY OF STEWARDSHIP: MODELING THE EFFECTS OF MANAGED RECHARGE ON THE SAN BERNARDINO BASIN AQUIFER FROM 1912-2023

FIGURE 29

W:\GIS_projs\sbvwcd\historical_surf_water_diversion_2025_Fig_29_wls_selected_wells_6-25_16x10.mxd

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P.O. Box 220, Claremont, CA 91711 | P: 909.451.6650 | F: 909.451.6638 | www.gssiwater.com