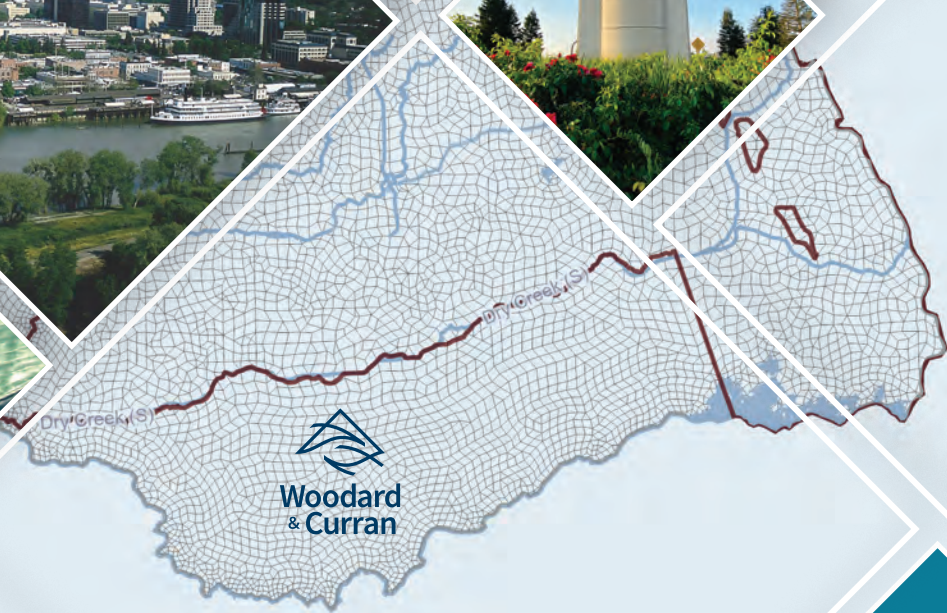


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Prepared for



**Woodard
& Curran**

CoSANA MODEL UPGRADE AND REFINEMENT
FOR
NORTH AMERICAN GROUNDWATER SUBBASIN (NASB)

MARCH 2026

ACKNOWLEDGEMENT OF STATE FUNDING

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APPENDICES

Appendix A: Baseline Conditions Sample Hydrograph

ABBREVIATIONS

2070CT	2070 Central Tendency
2070HD	2070 Hot and Dry
AEM	Airborne Electromagnetic
AFY	acre-feet per year
ARBS	American River Basin Study
ASR	aquifer storage and recovery
AWMP	Agricultural Water Management Plan
C2VSimFG	California Central Valley Groundwater-Surface Water Simulation Model
Cal Am	California American Water Company
CDEC	California Data Exchange Center
CIMIS	California Irrigation Management Information System
CoSANA	Cosumnes-South American-North American Integrated Water Resources Model
CoSb	Cosumnes Subbasin
CSD	Community Services District
CWD	community water district
DEM	digital elevation model
DWR	California Department of Water Resources
ET	evapotranspiration
ET _o	reference ET
ET _c	crop coefficient
GSA	groundwater sustainability agency
GSP	groundwater sustainability plan
GWMP	City of Sacramento's 2017 Groundwater Master Plan
ID	irrigation district; identifier
IDC	IWFM Demand Calculator
IWFM	Integrated Water Flow Model
NASb	North American Subbasin
PCWA	Placer County Water Agency
PET	Potential Evapotranspiration
PRISM	Precipitation-Elevation Regressions on Independent Slopes Model
Reclamation	United States Bureau of Reclamation
RMSE	root mean square error
RWA	Regional Water Authority
SacIWRM	Sacramento Area Integrated Water Resources Model
SAFCA	Sacramento Area Flood Control Agency
SASb	South American Subbasin
SCGA	Sacramento Central Groundwater Authority
SCWA	Sacramento County Water Agency
SGA	Sacramento Groundwater Authority
SGMA	Sustainable Groundwater Management Act
SSCAWA	Southeast Sacramento County Agricultural Water Authority
SSURGO	Soil Survey Geographic Database
SVSim	Sacramento Valley Groundwater-Surface Water Simulation Model
USGS	United States Geological Survey
UWMP	Urban Water Management Plan
WA	water agency
WC	water company
WD	water district
WY	water year

EXECUTIVE SUMMARY

The Cosumnes-South American-North American Integrated Water Resources Model (CoSANA) was developed in 2021, by the Sacramento Groundwater Authority (SGA) in collaboration with the North American Subbasin (NASb or Subbasin), South American Subbasin (SASb), and the Cosumnes Subbasin (CoSb). This collaborative, three-subbasin approach produced a comprehensive integrated numerical modeling tool. The tool has since served the Groundwater Sustainability Agencies (GSAs) in all the three subbasins during development of their respective Groundwater Sustainability Plans (GSPs), analysis and assessments of groundwater conditions for the GSP Annual Reporting to the Department of Water Resources (DWR), and other regional and local projects. These efforts include the Sacramento Regional Water Bank (SRWB) impacts analysis, and evaluation of conjunctive use program implementation over the historical period, also known as the Previously Banked Water evaluation.

This report documents the feature refinements and data upgrades performed to the CoSANA model in the NASb area to improve the representation of the model for historical hydrologic period, land and water use, and water supply data, as well as update of assumptions for the current and projected baseline conditions, including climate scenarios.

Major features and data enhancements implemented for the CoSANA model are:

- Hydrologic period of record to latest records, adding additional wet and critically dry conditions.
- Hydrogeologic and model layering, especially the use of the Airborne Electromagnetic (AEM) data from the DWR surveys, which helped refine the shallow alluvium, enhancing stream-aquifer interaction capabilities.
- Land use and cropping patterns, reflecting latest published land use surveys and crop mixes in the agricultural areas.
- Refinement and extension of evapotranspiration (Crop ET) data, and modifications to soil moisture parameters, enhancing crop water use estimation.
- Agricultural and irrigation water demand and water supply data based on Agricultural Water Management Plans and local agricultural entity data.
- Urban water demand using latest Urban Water Management Plans.
- Municipal water operations and supplies, including updates to surface water delivery system and groundwater pumping wells.
- Wastewater collection system from urban water use and treatment plant discharge to appropriate river locations.
- Refinements to the remediation operation data.
- Improvements to the geometry of major streams channels and rating tables, which helps better represent stream-aquifer interaction.
- Updates and refinements to the assumptions for Baseline Conditions, including Current (Existing) Conditions, and Projected (Future) Conditions.
- Updates of climate change scenarios, which reflects the project's state of the groundwater subbasin under Central Tendency and Hot and Dry climate change conditions.

The feature enhancements and data upgrades are significant and have resulted in a superior model with improvements in predictive capabilities in the following areas:

- Evaluation of the historical conditions of the NASb surface water and groundwater system.
- Enhanced predictive capabilities and accuracy of the model for analysis of current and future water demand and supply conditions.
- Analysis of sustainability of the groundwater basin.
- Evaluation of GSP projects and management plans.
- Assessment of regional programs and projects, such as the SRWB, including environmental permitting process.
- Analysis of impacts of local projects by municipal and agricultural entities.
- Evaluation of groundwater substitution and transfer programs.
- Assessment of GSP sustainability indicators.
- Estimation of changes to the groundwater storage and impact on changes in groundwater levels and groundwater flow conditions.

ACKNOWLEDGEMENTS

The Cosumnes-South American-North American Integrated Water Resources Model (CoSANA) was developed in a collaborative effort with representatives of the North American Subbasin (NASb), South American Subbasin (SASb), and the Cosumnes Subbasin (CoSb). This collaborative approach spanning three subbasins improves the ability for local water managers and stakeholders to use CoSANA for a range of regional planning efforts.

The original CoSANA model was developed in 2021 and the model development, calibration, and analysis of Baseline scenarios, including climate change scenarios were documented in the report by Woodard & Curran, Inc. (W&C, 2021).

The Sacramento Groundwater Authority (SGA), on behalf of the NASb received funding from the Department of Water Resources (DWR) to upgrade and refine the model features, including hydrology, hydrogeology, land use, and water supply data, and recalibrate the model for the updated information. Although the model upgrade was focused on the NASb Subbasin area, the model data sets and calibration for other Subbasins (SASb and CoSb) remained intact.

The NASb model upgrades were conducted in close coordination with the SGA and Regional Water Authority (RWA) staff, as well as the NASb GSAs and the water purveyors and agricultural interests within the NASb.

Participation by representatives of regional water agencies and GSA representatives, including SGA, RWA, municipal water purveyors, agricultural entities and interests, and the Sacramento Water Forum, allowed for incorporation of information related to stakeholders within those organizations and beyond. Further progress was shared at meetings associated with development of Groundwater Sustainability Plans (GSPs) to gain additional input and information, and to ensure model data, assumptions and results accuracy and reasonableness.

The model refinement and upgrade project was led by SGA and supported by input and efforts of many entities and their consultants, including:

- RWA/SGA
 - Trevor Joseph
 - Raiyna Villasenor
 - Monica Garcia
- Each GSA within the North American Subbasin and their representatives
- Many other water purveyors and remediation site representatives provided information to better represent their areas and operations.

Woodard & Curran was the consultant for the CoSANA model refinement and upgrade project for SGA. The Woodard & Curran project team included:

- Ali Taghavi
- Jingnan Zhou
- Sercan Ceyhan
- Emily Haan
- Adrien Camille
- Devin Hunt
- Reza Namvar
- Brian Van Lienden

The CoSANA team is grateful for the many entities that provided assistance or data to characterize the groundwater and surface water systems in the NASb, including many urban water purveyors, agricultural entities, environmental groups, GSA representatives, managers of contamination remediation operations, project proponents, private domestic and rural residential well owners. The team also appreciates the California Department of Water Resources (DWR) for their assistance in refinement and upgrade of the CoSANA model on the Integrated Water Flow Model (IWFM) platform.

1. INTRODUCTION

This section presents the list of model data used in the upgrade of the NASb area of CoSANA model. **Section 2** presents the source and analysis of input data, including spatial and temporal information for hydrologic, hydrogeologic, water use, water supply, and operations data sets included in the model.

1.1 Model Data Update

Updated data used in the upgrade of the NASb area of the CoSANA model are presented in **Table 1-1** along with the report sections where the model data and data sources are described.

Table 1-1: Updated CoSANA Data

Major Data Category	Minor Data Category	Data Source	Report Section
Hydrogeological Data	Geologic Stratification	AEM Surveys, DWR well logs	2.9, 2.10
Stream Data	Stream Inflow	CDEC and USGS stream gages	2.11
	Stream Geometry Update	CoSANA 2021, CDEC, USGS, CVFED, Google Earth	2.11
Hydrological Data	Precipitation	PRISM	2.1
Agricultural Water Demand	Land Use	LandIQ Land Use, NASb GSAs, CropScape	2.2, 2.7
Wastewater Collection	Discharge volume and location	Regional San	2.3
Urban Water Demand	-	Local Municipal Water Purveyors	2.6
Water Supply	Groundwater Pumping	Local Municipal Water Purveyors	2.5
	Surface Water Deliveries	Local Municipal Water Purveyors	2.5, 2.6, 2.7
Groundwater Level Records	-	DWR	3.1

1.2 Simulation Period Extension

The simulation period of CoSANA model was extended by six years from 1970-2018 to 1970-2024. Monthly data were used as model input, and the model simulation uses a monthly time step. Model output can be reported on a monthly or annual basis.

1.3 Report Organization

This report is organized as follows:

- **Section 1** is this introductory section.
- **Section 2** describes model input data updates for time series and spatial data.

-
- **Section 3** describes the calibration updates of CoSANA for the NASb area.
 - **Section 4** describes the baseline models updates, including the Current Conditions Baseline and Projected Conditions Baseline.
 - **Section 5** presents a summary of the report.
 - **Section 6** presents a list of references used in the report.

2. DATA UPDATES

This section presents the source and analysis of input data used in the upgrade and refinement of the NASb area of the CoSANA model. This includes spatial and temporal information for hydrologic, hydrogeologic, water use, water supply, and operations data sets included in the model.

2.1 Hydrology Update – Precipitation

Monthly rainfall data for the model area were extended from October 1, 2018, to September 30, 2024. **Figure 2-1** shows the annual rainfall in the model area. For the 2019-2024 extended period, the minimum precipitation was in 2021 with 8.5 inches, while the maximum occurred in 2023 with 27.9 inches. The average annual precipitation over the 1970-2024 period was 19.9 inches.

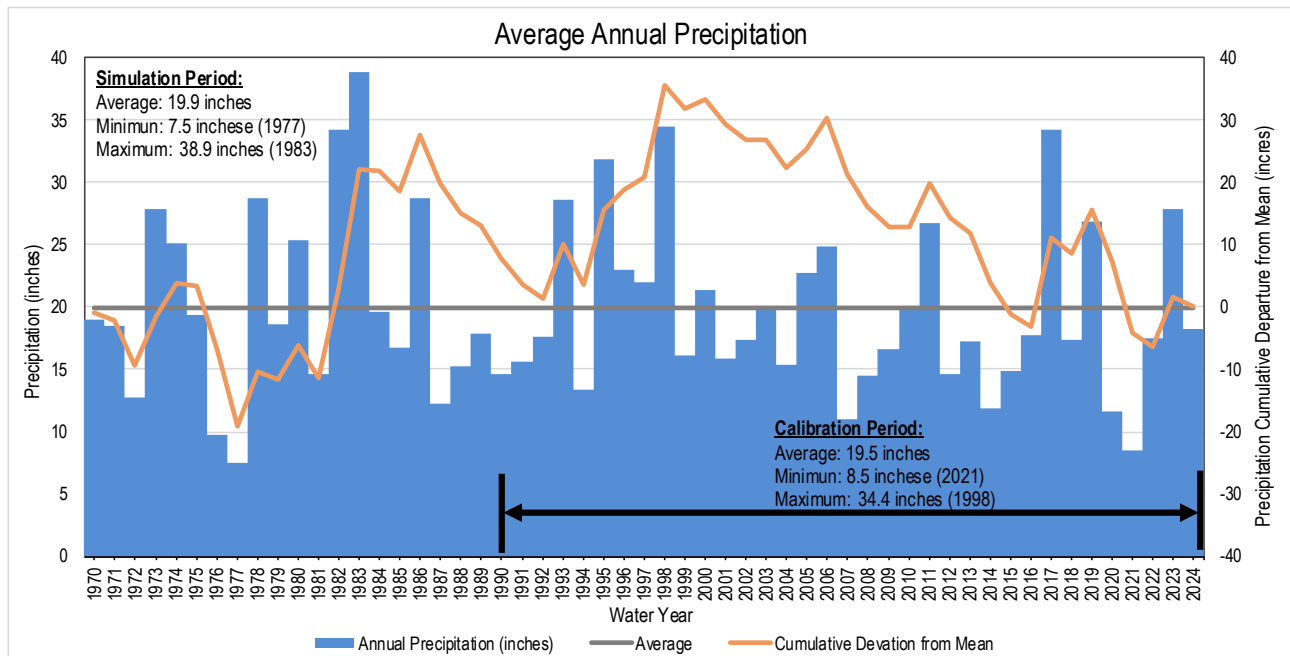


Figure 2-1: CoSANA Average Annual Precipitation

2.2 Land Use Update

Land use and cropping patterns are major data sets that are used to estimate water demand for agricultural water use, rainfall runoff, and deep percolation conditions throughout the model area. Based on land use surveys, CoSANA land use information was used to develop four general land use types and 20 irrigated crop categories (Table 2-5, W&C, 2021), which were then mapped to each of the model elements. This allowed estimation of water demands on a monthly time step. To develop land use information for CoSANA prior to 2015, three primary datasets were used: DWR county land use surveys, DWR Statewide Crop Mapping, and USDA CropScape. These datasets were used to assign land use information to each model element for each year. Three land use snapshot years were assumed to represent conditions in 1995, 2005, and 2015, using data from years close to each snapshot year (W&C, 2021). Linear interpolation was used to represent land use for years between snapshot years.

NASb land use was updated for the CoSANA extension by using LandIQ annual land use data for the 2016 to 2023 period. Annual LandIQ land use data were verified by five NASb GSAs (Reclamation District 1001, Sacramento Groundwater Authority, South Sutter Water District, Sutter County, West Placer County). The LandIQ survey dataset primarily focuses on agricultural crop classification and provides limited coverage within urban areas. In contrast, the

USDA CropScape dataset offers more detailed and comprehensive land use information for urban areas. Therefore, to better represent detailed land use conditions in urban areas, CropScape data were used to replace the LandIQ coverage of urban areas. **Figure 2-2** through **Figure 2-8** show the spatial distribution of the land use coverages for the NASb for 2016 to 2024. **Figure 2-9** shows the annual cropping patterns for the Subbasin.

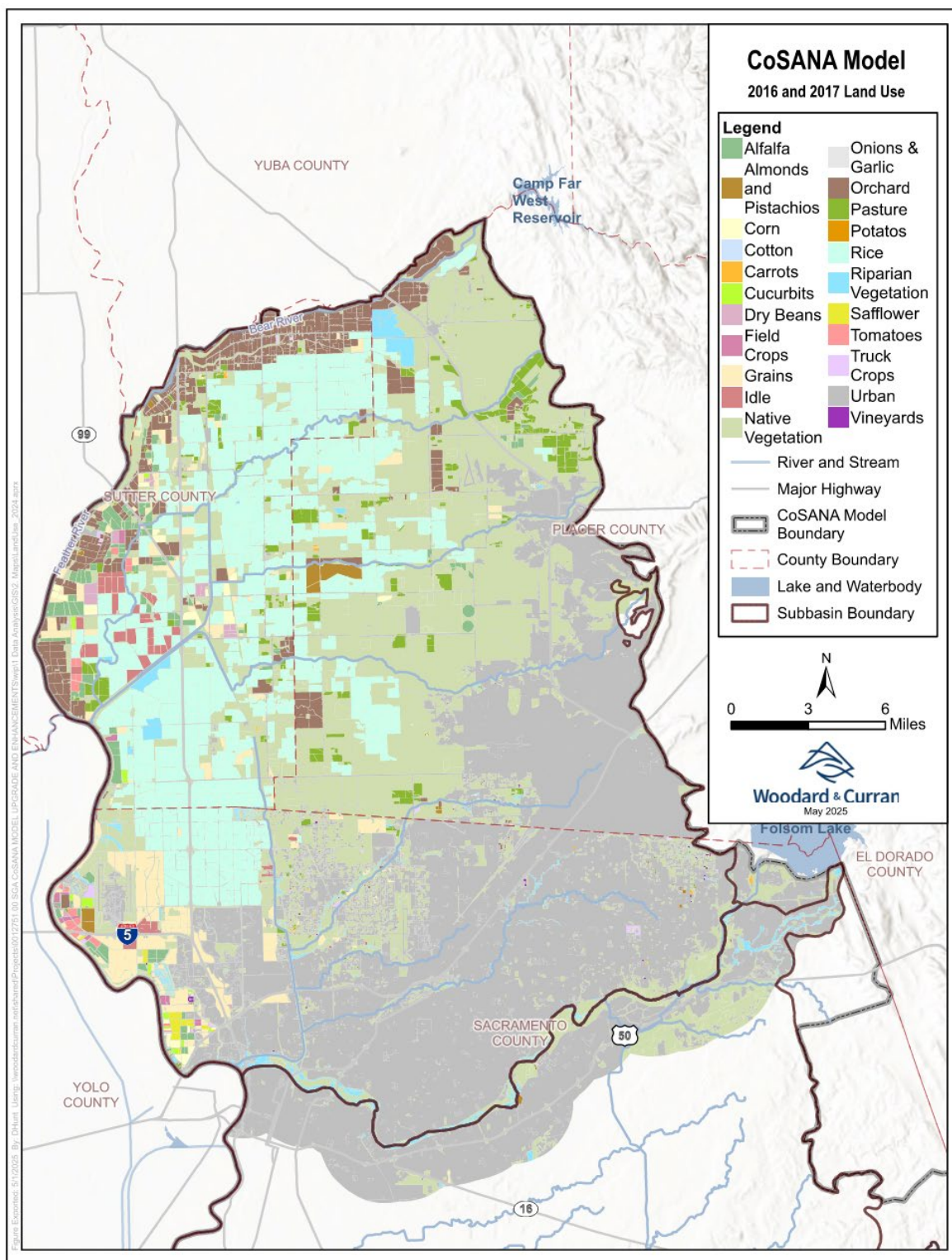


Figure 2-2: 2016 and 2017 Land Use Coverage for NASb

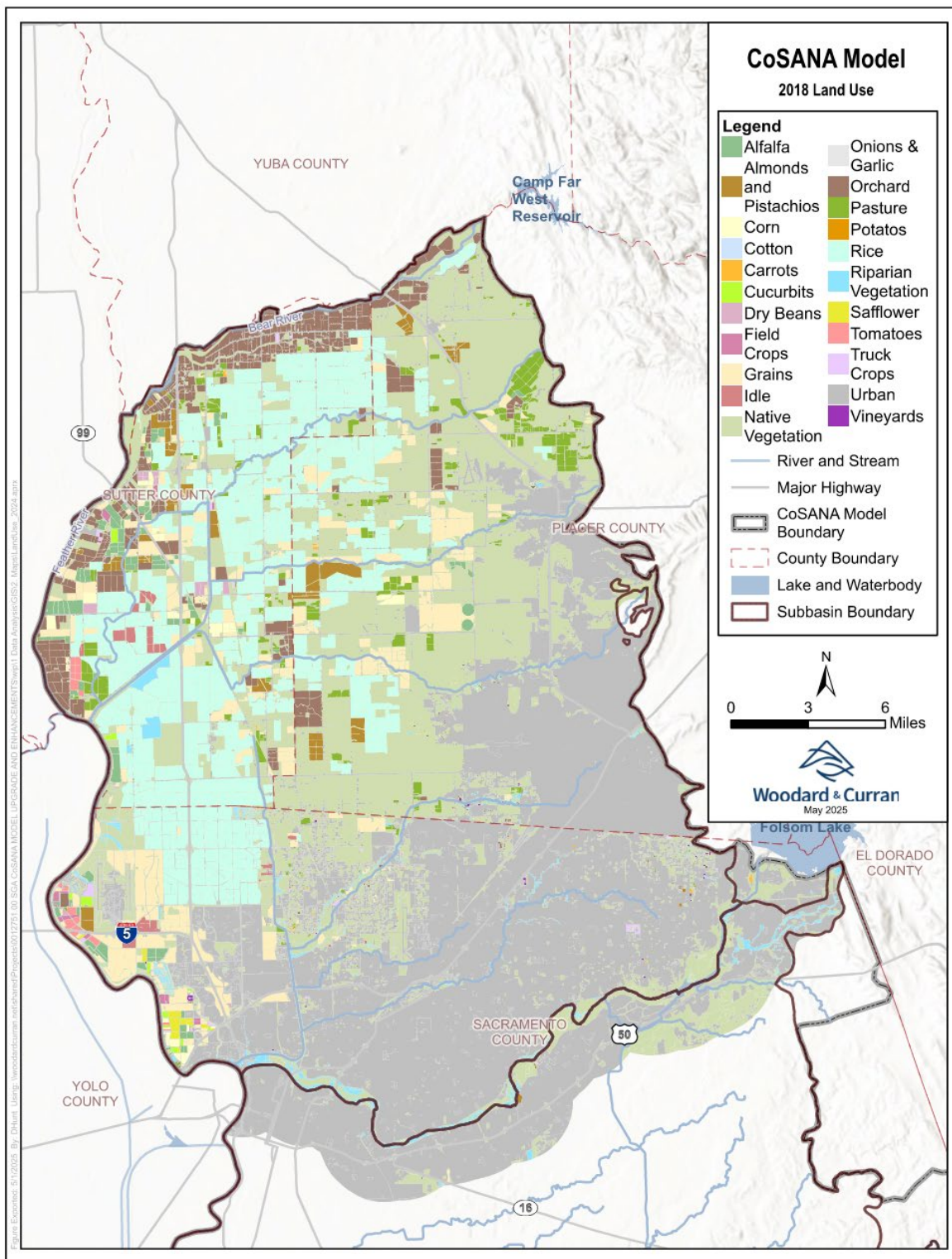


Figure 2-3: 2018 Land Use Coverage for NASb

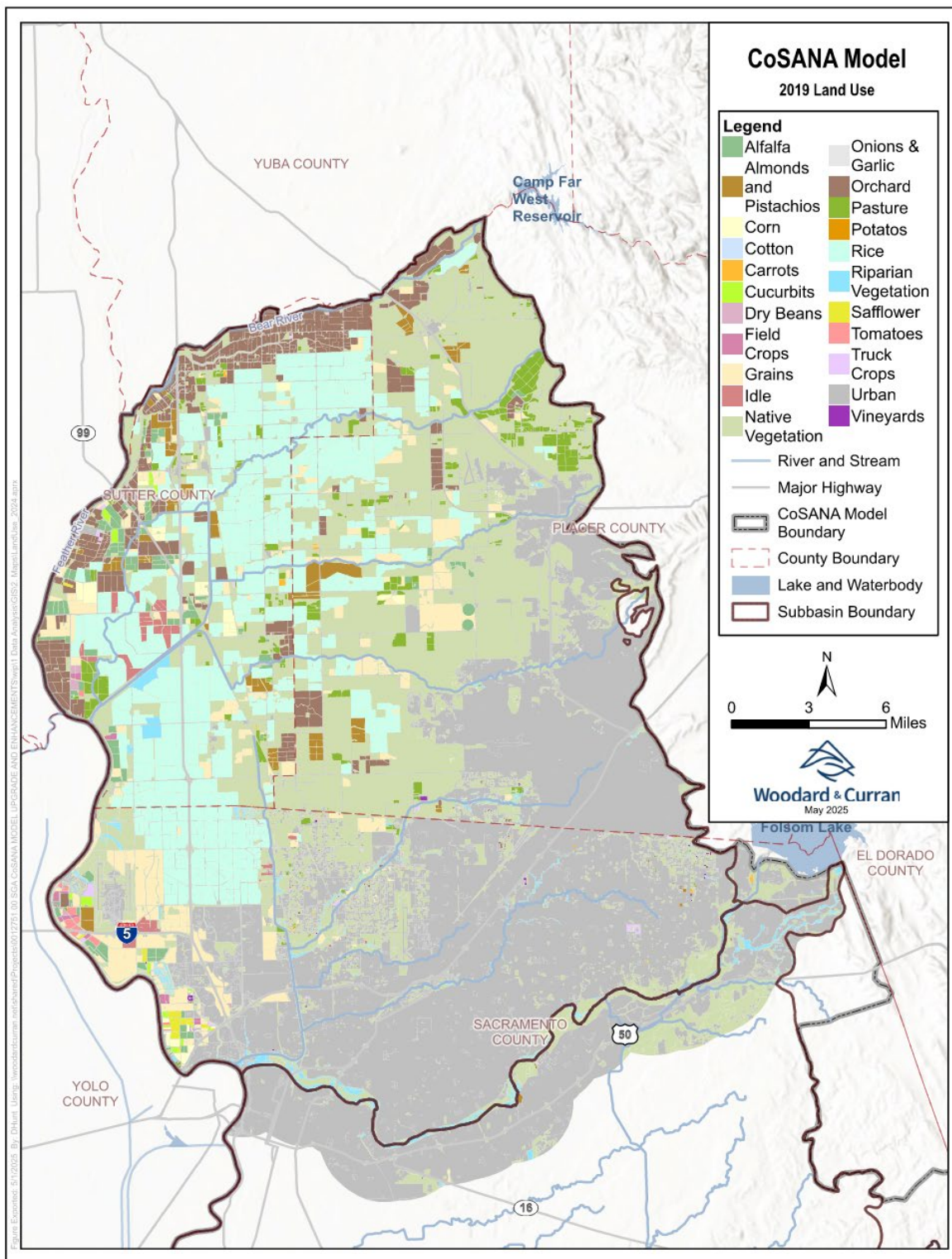


Figure 2-4: 2019 Land Use Coverage for NASb

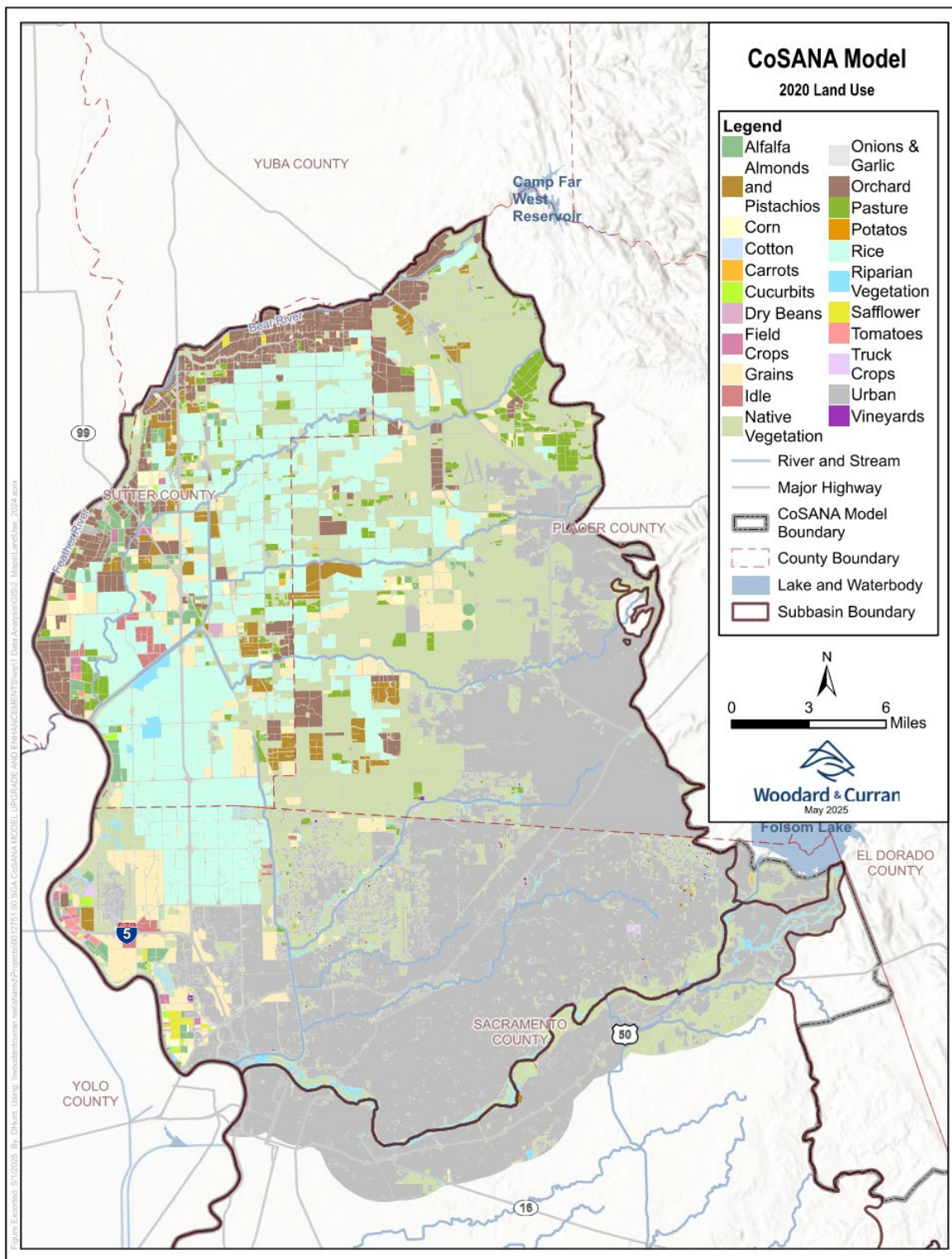


Figure 2-5: 2020 Land Use Coverage for NASb

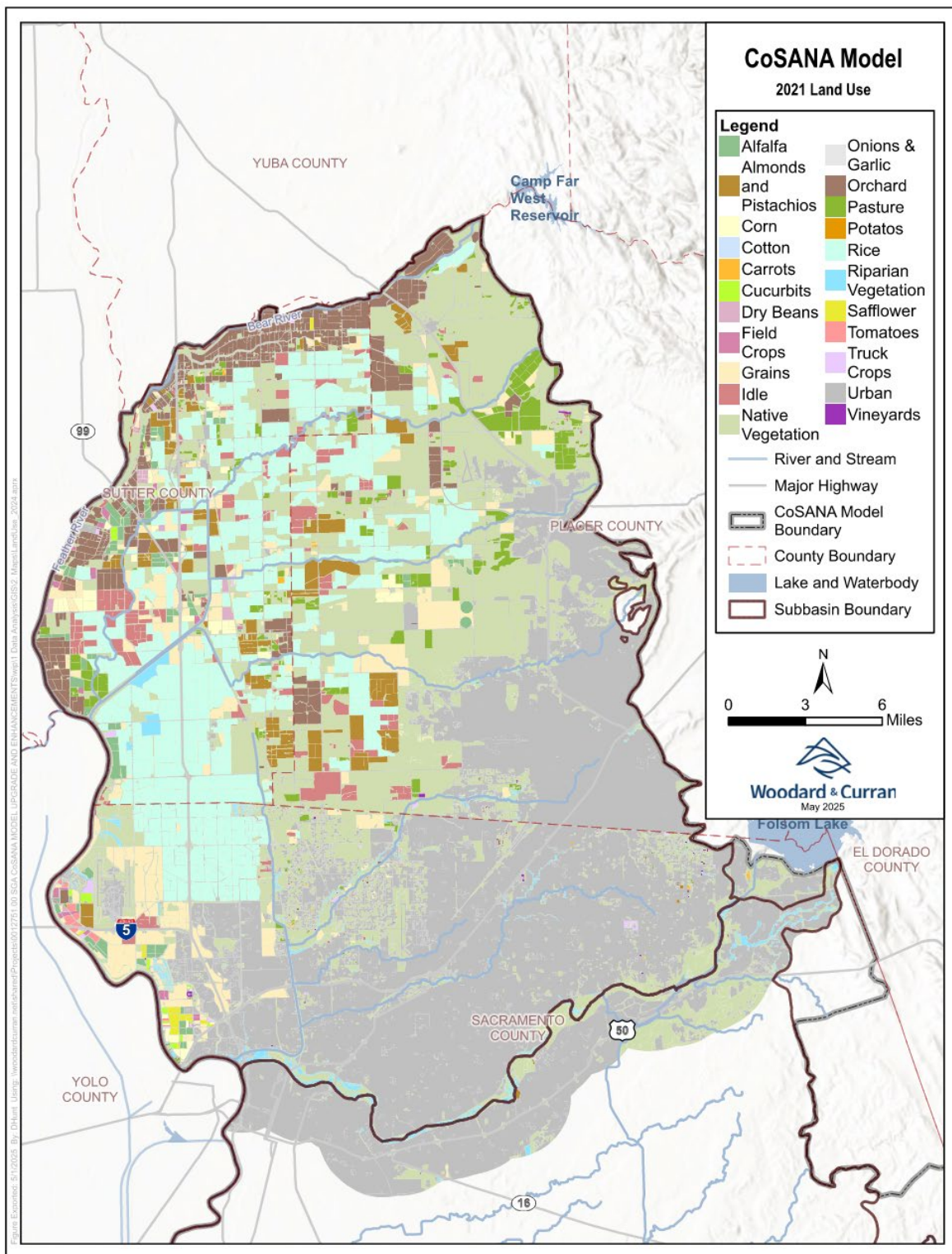


Figure 2-6: 2021 Land Use Coverage for NASb

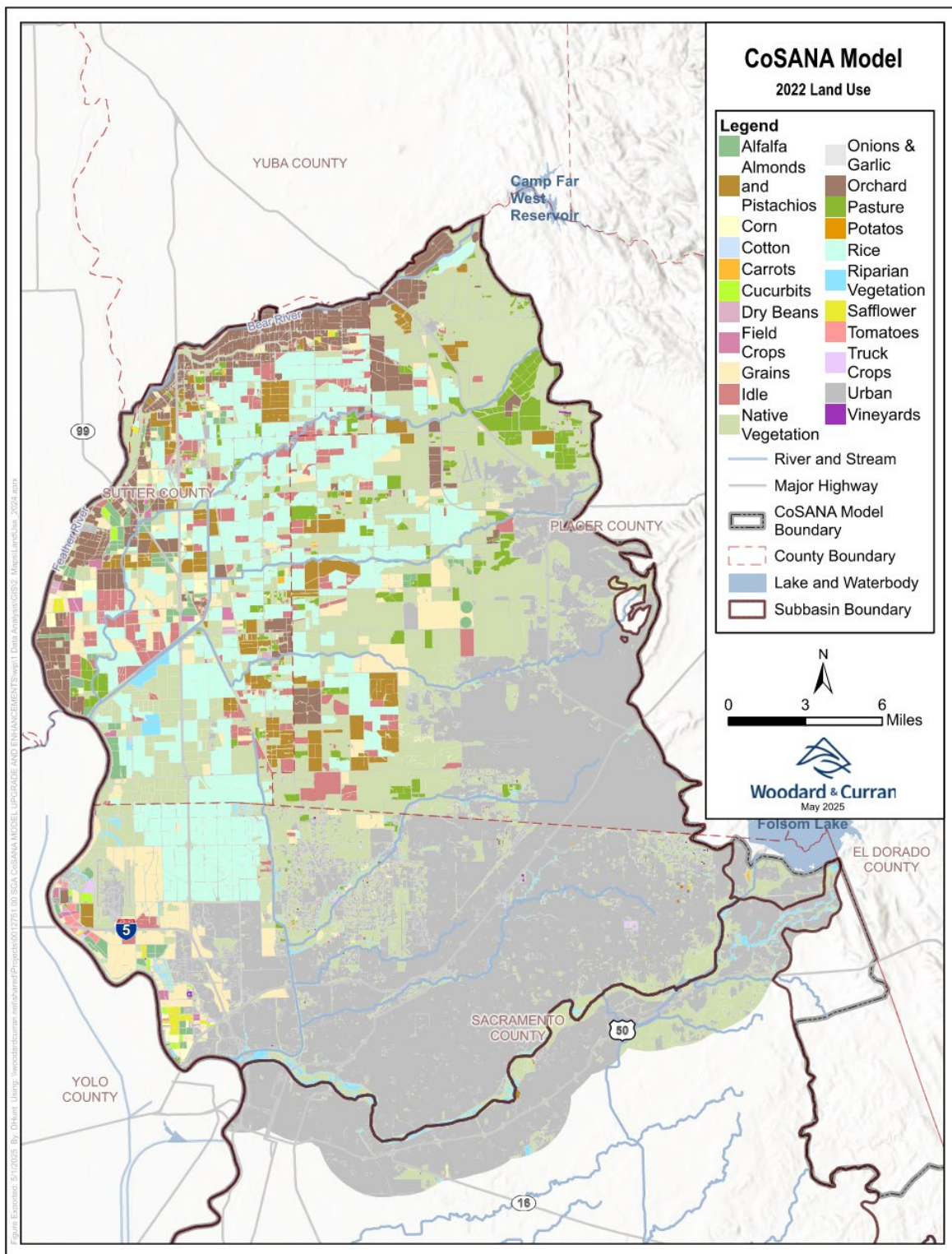


Figure 2-7: 2022 Land Use Coverage for NASb

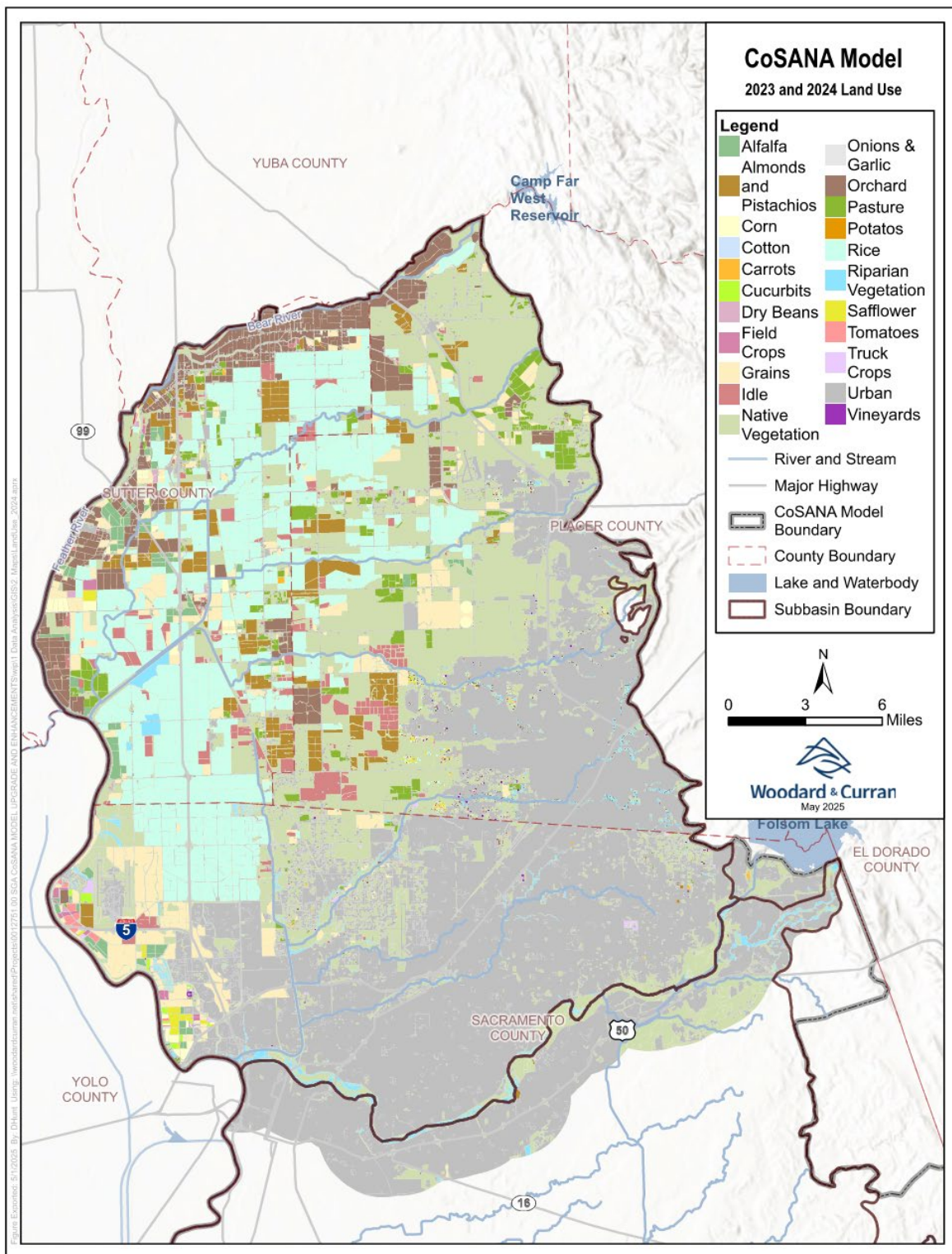


Figure 2-8: 2023 and 2024 Land Use Coverage for NASb

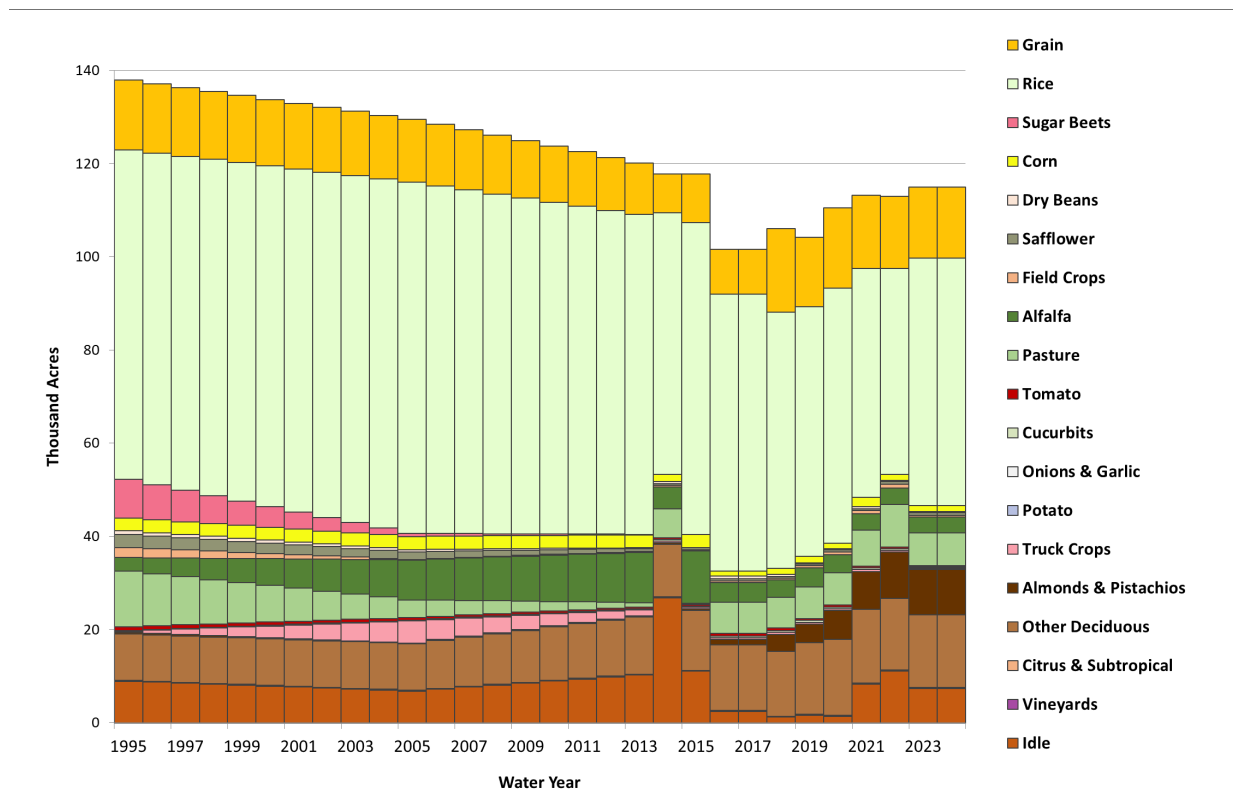
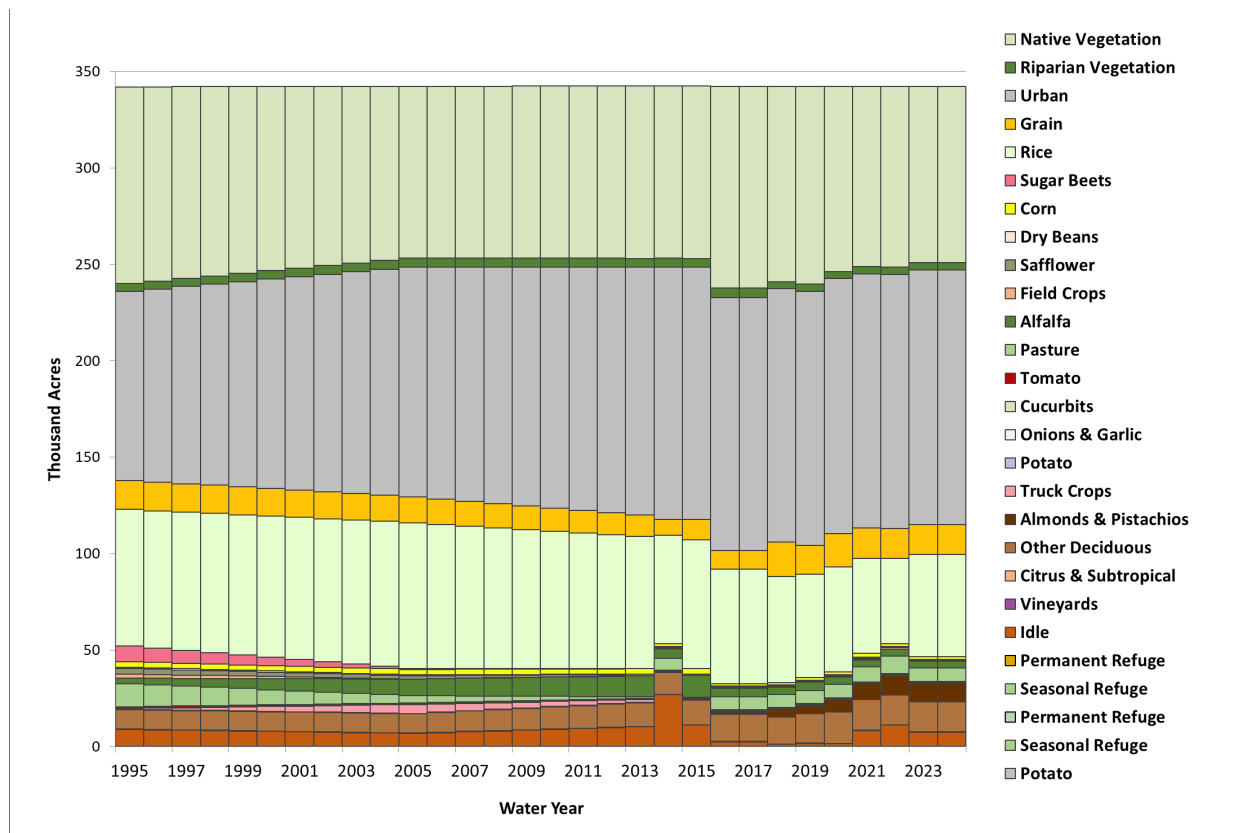


Figure 2-9: Annual Land Use for NASb

2.3 Upgrade Simulation of Wastewater Collection Network

During the CoSANA model upgrade and refinement project, a new version of the Integrated Water Flow Model (IWFM) code (v2024.1.1594) was released that provides the capability to separate out the urban stormwater discharge point from the indoor wastewater discharge point. This feature was implemented in the CoSANA model as described below.

Large urban areas within CoSANA are serviced by the Sacramento Regional County Sanitation District (Regional San or SRCSD). The service area of Regional San, 387 square miles (approximately 250,000 acres), is shown in **Figure 2-10**. Regional San's wastewater treatment plant processes the wastewater generated by all of Sacramento County and the City of West Sacramento in Yolo County, totaling about 135 million gallons each day or 151,000 acre-feet per year. Regional San discharges treated wastewater to the Sacramento River near Freeport.

In the CoSANA Model, indoor water uses in Regional San's service area along with other return flows (e.g., outdoor return flow, agricultural surface flow) were directed to several nearby stream nodes. Using the new IWFM code, the indoor water use within Regional San's service area is now routed to the wastewater treatment plant discharge point (**Figure 2-10**).

West Sacramento urban indoor return flow is also treated at Regional San's wastewater treatment plant and discharged to the Sacramento River. As part of the NASb upgrade, West Sacramento urban indoor return flow was added as inflow to the Regional San's wastewater treatment plant discharge location in the Sacramento River.

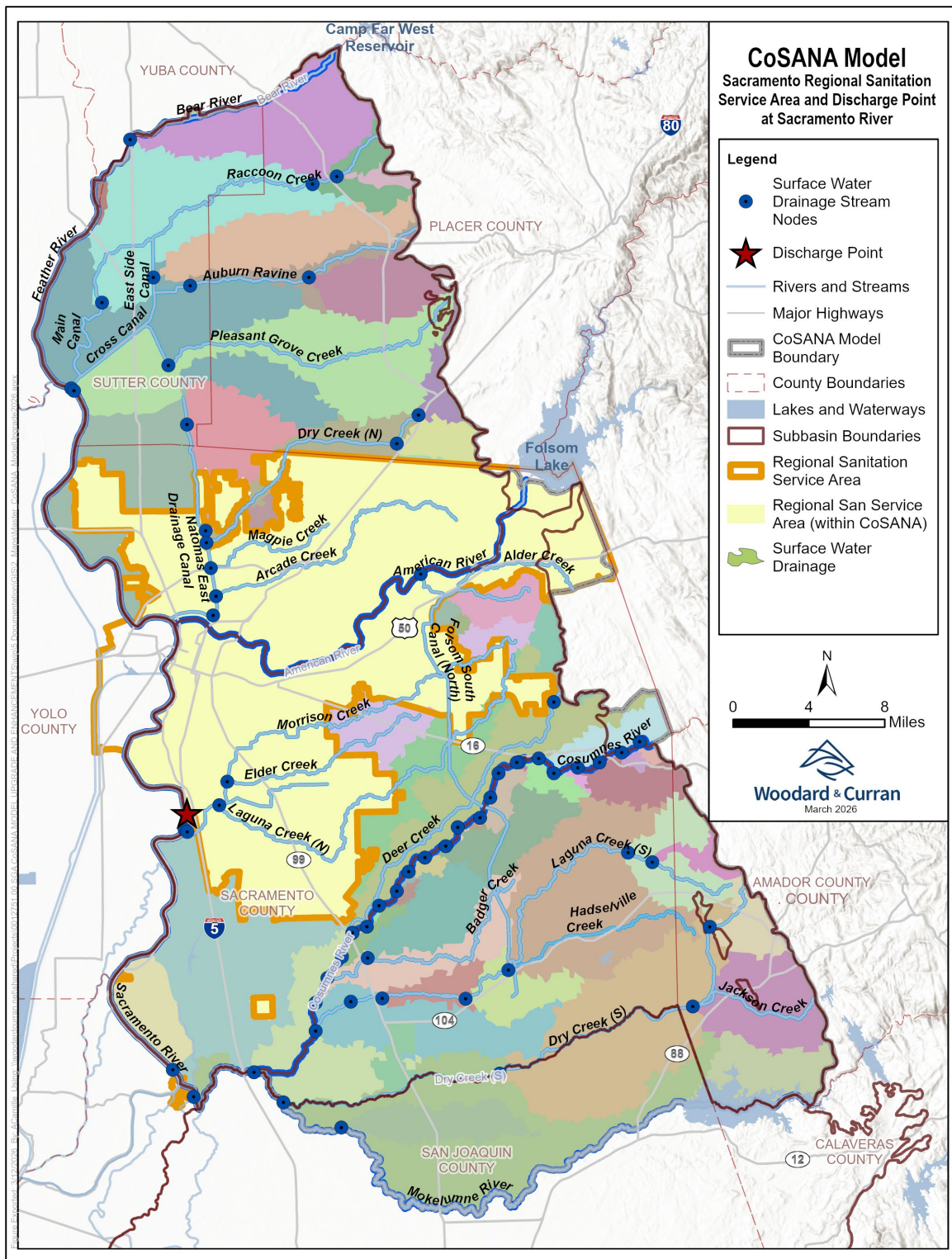


Figure 2-10: Sacramento Regional Sanitation Service Area and Discharge Point at Sacramento River

2.4 Update Stream Flow Data

Stream configuration and network are the same as the CoSANA 2021 model. Stream inflow data were updated for the extension period based on the sources identified in Table 2-4 of the CoSANA report (W&C, 2021).

2.5 Water Supply

Urban water demands and agricultural water demands in the CoSANA model are met primarily through surface water diversions and groundwater pumping, with additional supplies from other sources, including recycled water, remediated (reuse) water, and precipitation.

2.5.1 Surface Water Supply

Surface water supply is simulated as stream diversions or imports in the CoSANA model. Diversions are either assigned to a stream node near the point of diversion or they are treated as imports if the point of diversion is outside the model area. Surface water delivery data were obtained from several sources as provided in Appendix A of the CoSANA report (W&C, 2021). These sources include gage data, water rights reports, Urban Water Management Plans (UWMPs), Agricultural Water Management Plans (AWMPs), and other sources. Surface water supply data for the NASb area for the simulation extension period were obtained from local municipal water purveyors.

2.5.2 Groundwater Pumping

Groundwater pumping for water supply in the CoSANA model is represented through pumping from wells and pumping assigned at the model-element level. Pumping by wells is based on agency-operated wells that deliver groundwater to the public water supply systems and contamination remediation groundwater pumping. Pumping by elements include estimated agricultural and domestic groundwater pumping. Groundwater pumping data for the NASb area for the simulation extension period were obtained from local municipal water purveyors.

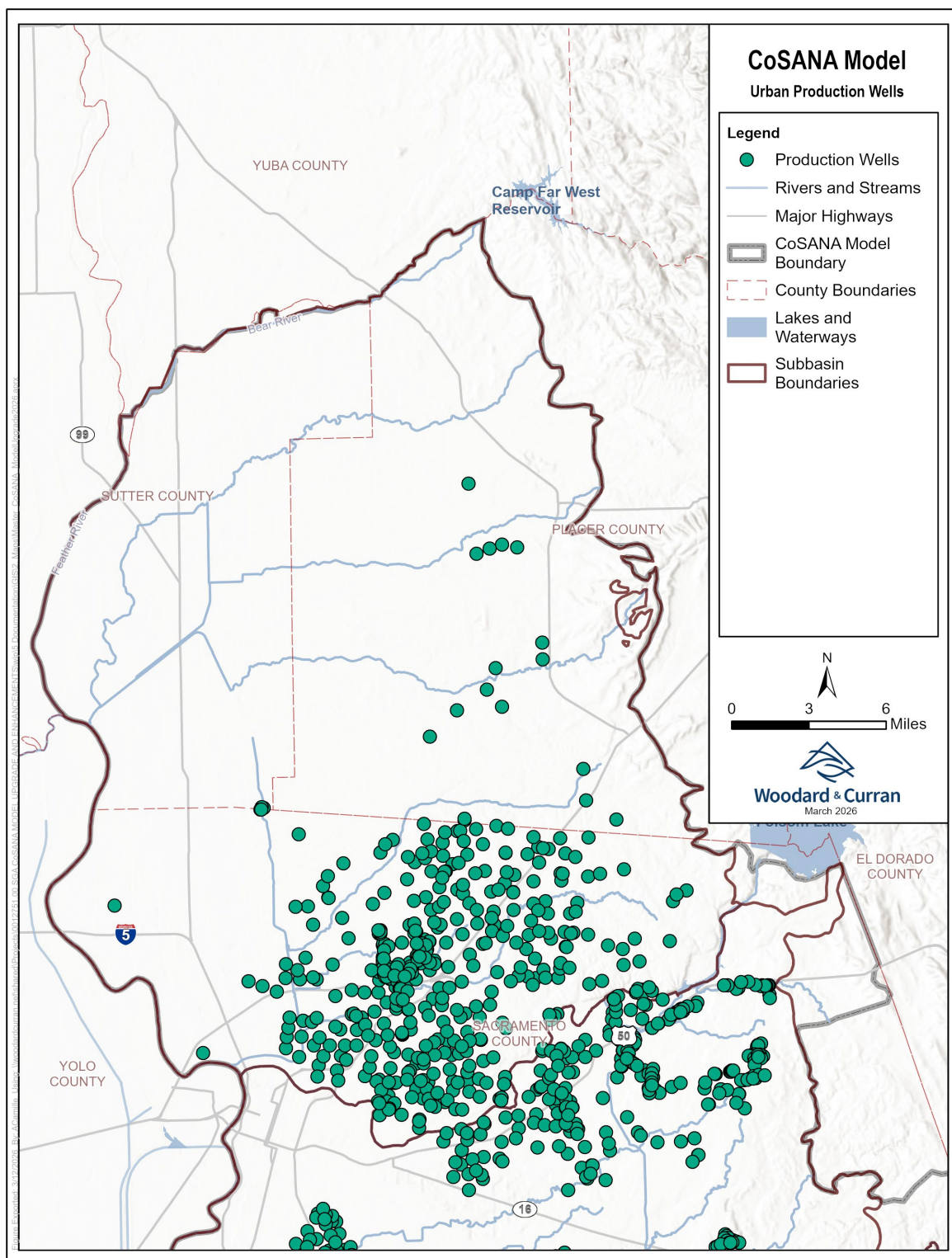
2.6 Urban Water Demand and Supply

Monthly urban water demands are provided by the urban water purveyors for the historical model period. It is assumed that an annual average of 60% of urban water is used indoors and 40% is used outdoors, as discussed in Section 3.2 of the CoSANA report (W&C, 2021). **Table 2-1** lists the number of wells by purveyors included in the NASb and their average annual municipal pumping. The locations of these wells are provided in **Figure 2-11**.

The following sections provide a brief description of urban demand and water supply used in historical CoSANA for each of the urban water purveyors in the NASb. Averages presented are for the calibration period, WY 1990-2024.

Table 2-1: Summary of Well Pumping by Urban Purveyors in NASb

Purveyor	Number of Municipal Pumping Wells	Average Annual Municipal Pumping (WY 1990-2024, acre-feet)
California American Water Company (Antelope, Arden, Lincoln Oaks, and West Placer)	64	16,267
Carmichael Water District	17	4,205
Citrus Heights Water District	14	998
City of Lincoln	6	601
City of Roseville	10	61
City of Sacramento	70	20,764
Del Paso Manor Water District	10	1,503
Fair Oaks Water District	13	1,304
Golden State Water Company (Arden)	9	1,126
Orange Vale Water Company	2	0
Rio Linda/Elverta Community Water District	14	2,947
Sacramento Suburban Water District	122	32,556
Sacramento County Water Agency (Arden and Northgate)	19	5,001
Total Average Annual Pumping (acre-feet)		85,341



2.6.1 California American Water Company (Antelope)

California American Water Company (Cal Am) Antelope mostly uses groundwater with an average of 5,200 acre-feet per year (AFY). Cal Am also received an average of 190 AFY of surface water via an intertie with the Sacramento Suburban Water District (SSWD). Data for the 2019-2024 period were provided by Cal Am.

2.6.2 California American Water Company (Arden)

Cal Am Arden primarily uses groundwater with an average of 2,789 AFY. It also receives approximately 3 AFY of surface water from the City of Sacramento. Data for the 2019-2024 period were provided by Cal Am.

2.6.3 California American Water Company (Lincoln Oaks)

Cal Am Lincoln Oaks, similar to Cal Am Arden, uses groundwater with an average of 8,278 AFY. It also receives an average of 249 AFY of surface water via an intertie with SSWD. Data for the 2019-2024 period were provided by Cal Am.

2.6.4 California American Water Company (West Placer)

Cal Am West Placer water supply includes 684 AFY of surface water from Placer County Water Agency (PCWA). Data for the 2019-2024 period were provided by Cal Am.

2.6.5 Carmichael Water District

Carmichael Water District uses an average of 6,806 AFY of surface water from the American River and 4,205 AFY of groundwater from district wells. Data for the 2019-2024 period were provided by Carmichael Water District and SGA.

2.6.6 Citrus Heights Water District

Citrus Heights Water District supply includes 15,236 AFY of surface water from San Juan Water District and 998 AFY of groundwater from district wells. Data for the 2019-2024 period were provided by Citrus Heights Water District and SGA.

2.6.7 Del Paso Manor Water District

Water supply for Del Paso Manor Water District is entirely groundwater pumping from district wells and averages 1,503 AFY. Data for the 2019-2024 period were provided by Del Paso Manor Water District and SGA.

2.6.8 Fair Oaks Water District

Fair Oaks Water District water supplies include an average of 10,948 AFY of surface water received from San Juan Water District and 1,304 AFY of groundwater from district wells. Data for the 2019-2024 period were provided by Fair Oaks Water District and SGA.

2.6.9 Golden State Water Company (Arden)

Golden State Water Company Arden water supply consists of an average of 1,126 AFY of groundwater pumping from WC wells. Data for the 2019-2024 period were provided by Golden State Water Company.

2.6.10 City of Lincoln

City of Lincoln's water supplies include an average of 6,176 AFY of surface water supplied by PCWA and Nevada Irrigation District and 601 AFY of groundwater pumping from city wells. Data for the 2019-2024 period were provided by the City of Lincoln and GEI Consultants.

2.6.11 Orange Vale Water Company

Orange Vale Water Company receives an average of 4,163 AFY of surface water from San Juan WD. Data for the 2019-2024 period were provided by Orange Vale Water Company and SGA.

2.6.12 Placer County Water Agency (City of Rocklin Retail Service Area)

PCWA serves the City of Rocklin for retail customers. Remaining portions of PCWA's service area within the model are served by other retail water purveyors or are self-supplied by groundwater. Water supply to the City of Rocklin is an average of 3,936 AFY of surface water. Data for the 2019-2024 period were provided by PCWA and GEI Consultants.

2.6.13 Rio Linda/Elverta Community Water District

Rio Linda/Elverta Community Water District water supply primarily includes 2,947 AFY of groundwater pumping and 4 AFY of surface water from an intertie with the City of Sacramento. Data for the 2019-2024 period were provided by Rio Linda/Elverta Community Water District and SGA.

2.6.14 City of Roseville

The City of Roseville receives an average of 26,696 AFY of surface water from Folsom Reservoir and 61 AFY of groundwater pumping from city wells. City of Roseville data includes details of groundwater injections as part of the city's aquifer storage and recovery (ASR) program. Data for the 2019-2024 period were provided by the City of Roseville and GEI Consultants.

2.6.15 Sacramento Suburban Water District

Sacramento Suburban Water District water supply includes 32,556 AFY of groundwater production from district wells and 8,876 AFY from surface water via intertie with PCWA and the City of Sacramento. Data for the 2019-2024 period were provided by Sacramento Suburban Water District and SGA.

2.6.16 City of Sacramento

The City of Sacramento water supply consists of an average of 95,716 AFY of surface water from their water treatment plants on the American and Sacramento Rivers and 20,764 AFY of groundwater production from city wells. Data for the 2019-2024 period were provided by the City of Sacramento and SGA.

2.6.17 Sacramento International Airport

The Sacramento International Airport receives 286 AFY of water from the City of Sacramento and the remaining demand of 916 AFY is met by groundwater. Data for the 2019-2024 period were provided by the City of Sacramento and SGA.

2.6.18 San Juan Water District

San Juan Water District water demand within the model area is met entirely by 4,974 AFY of surface water from Folsom Lake. It is assumed that 37% of the district's retail service area is within the CoSANA boundary. Data for the 2019-2024 period were provided by San Juan Water District and SGA.

2.6.19 Sacramento County Water Agency (Arden Park Vista)

Demand for the Sacramento County Water Agency (SCWA) Arden Park Vista service area of 3,795 AFY is met by groundwater pumping from district wells. Data for the 2019-2024 period were provided by SCWA.

2.6.20 Sacramento County Water Agency (Northgate)

Water supply for SCWA Northgate consists of 1,206 AFY of groundwater pumping from district wells. Data for the 2019-2024 period were provided by SCWA.

2.7 Agricultural Water Demand and Supply

Agricultural water demand is the amount of irrigation water that is required to satisfy the crop evapotranspiration requirement and meet other irrigation practices. The IWFM Demand Calculator (IDC) component of the CoSANA model estimates the agricultural water demand for each model element through consumptive use methodology. IDC calculates crop water demand at each model time step based on factors including crop type, crop evapotranspiration, rainfall, hydrologic soil type, and irrigation practices. IDC calculations rely on model input data for historical crop acreage, irrigation practices, soil moisture requirements, effective rainfall, crop ET, and localized soil parameters. Appropriate data as needed were updated for input in CoSANA upgrade in the NASb area.

Private groundwater pumping volumes, location and pumping depth for agricultural water supplies are mostly unknown. Agricultural pumping in CoSANA is estimated by IWFM on an element basis. Water demand at each relevant element is used to calculate additional pumping necessary to meet the agricultural demand estimated by IDC after public water system pumping and distributed surface water.

2.7.1 Rural-Residential Pumping

Private groundwater pumping quantities on an individual well basis are largely unknown and are estimated by IWFM on an element basis. Water demands at each relevant element are used to calculate pumping necessary to meet the urban demand estimated by the model after water purveyor groundwater and surface water has been distributed. Detailed methodology for estimating rural residential pumping is explained in Section 3.3.1 of the CoSANA report (W&C, 2021). The same approach was used for estimation of rural residential pumping for the 2019-2024 period.

2.7.2 Agricultural Groundwater Substitution Transfers

Agricultural groundwater substitution transfer pumping operations occur in the western NASb and include pumping operations of Pleasant Grove Verona Mutual Water Company (PGVMWC), Natomas Mutual Water Company (NMWC). Location of transfer pumping wells and volume of groundwater pumped for 1995-2018 period are provided in Figure 3-5 and Table 3-2, respectively, in the CoSANA report (W&C, 2021). For the 2019–2024 period, PGVMWD and NMWC transfer-pumping operations occurred in 2020 and 2021.

2.8 Remediation Pumping

There are five remediation sites in CoSANA model area. Two sites of Aerojet/IRCTS (in the NASb only) and McClellan Air Force Base are in the NASb. The NASb sites operate 128 remediation wells. The locations of these sites and remediation wells as well as average annual remediation pumping rates are provided in Section 3.4 of the CoSANA report (W&C, 2021). Total average annual remediation pumping at the two remediation sites in the NASb for the 1990-2024 period is 3,253 AFY.

2.9 Available Airborne Electromagnetic (AEM) Data

AEM surveys were completed across California's high- and medium priority groundwater basins in recent years. The collected AEM data is helpful for characterizing major aquifer systems of California and managing long-term groundwater sustainability. AEM data consists of electrical resistivity profiles of the subsurface down to depths of as much as 1,000 feet. The northern half of NASb was included in DWR's survey (**Figure 2-12**).

Aquifers are typically composed of sand and gravel that have high resistivities, while aquitards are composed of silt and clays that have low resistivities. The resistivity profiles help in mapping the overall dimensions and extent of the

aquifer system. Resistivity models provide profiles indicative of areas with relatively coarser-grained (sands and gravels) and finer grained (silts and clays) material, represented by areas of higher and lower resistivities.

While there are several AEM flight lines in the northern parts of NASb, the southern parts do not have any flight lines due to interference from urban development. A mixture of AEM data and DWR compiled bore log information (**Figure 2-12**) were analyzed in order to evaluate the CoSANA model stratigraphy and improve the Hydrogeologic Conceptual Model (HCM) of the NASb. The new lithology cross sections, including well logs within a 0.5-mile buffer zone, were aligned with the AEM flight lines for continuity in interpretation. Python was used to process the data provided by DWR.

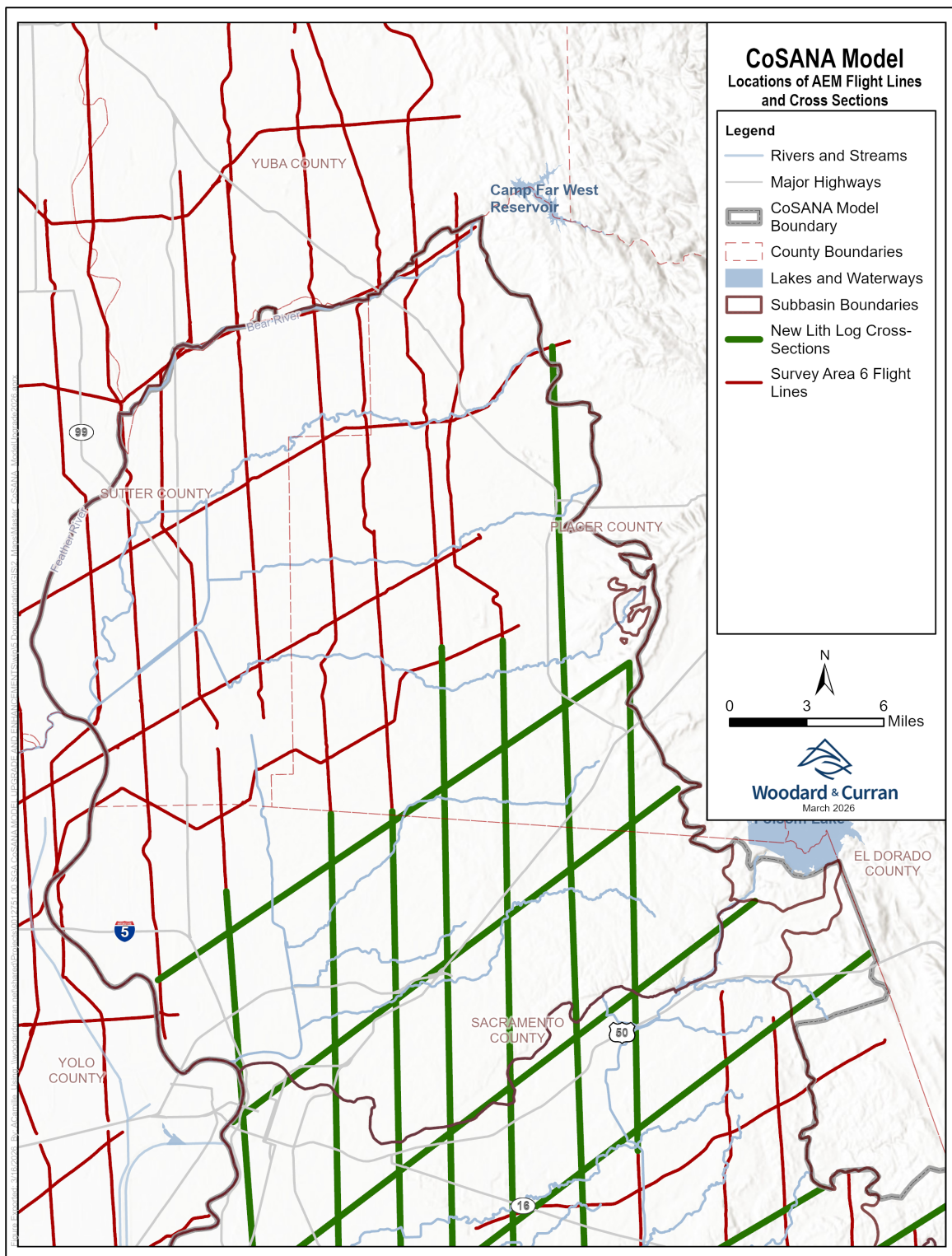


Figure 2-12: Location of Lithology Log Cross Sections and AEM flight lines in NASb

2.10 Model Layers and Stratigraphy Update

CoSANA is a five-layer model, and its stratigraphy is generally delineated by geologic formation for Layers 2 to 5. Layer 1 is designed to represent shallow alluvial deposits, where shallow groundwater interacts with surface water. A shallow Layer 1 allows isolation of shallow behavior from deeper aquifer behavior to better represent conditions in these highly dynamic zones. Layers 2, 3, 4, and 5 represent Laguna, Mehrten, Valley Springs, and Lone Formations, respectively.

Using AEM data and bore log lithology information, model layers in areas with large fluctuations in thickness were smoothed with a focus on Layers 1 and 2. The AEM data and lithology logs were used to edit Layer 1 and Layer 2 thicknesses to improve representation of shallow coarse deposits. **Figure 2-13** shows the updated thickness of CoSANA Layer 1 in the NASb and **Figure 2-14** shows the difference of Layer 1 thickness before and after stratigraphy update. Layer 1 has decreased thickness in the northern NASb and increased thickness near the American River in the southern NASb. **Figure 2-15** shows the updated thickness of CoSANA Layer 2 in the Subbasin and **Figure 2-16** shows the difference of Layer 1 thickness before and after stratigraphy update. In contrast to Layer 1 thickness changes, Layer 2 has increased thickness in the northern NASb and decreased thickness near the American River in the southern NASb.

The location of nine CoSANA stratigraphy/layers cross sections are shown in **Figure 2-17**. Updated layer thicknesses of nine CoSANA model layer cross sections in the NASb are shown in **Figure 2-18** through **Figure 2-26**.

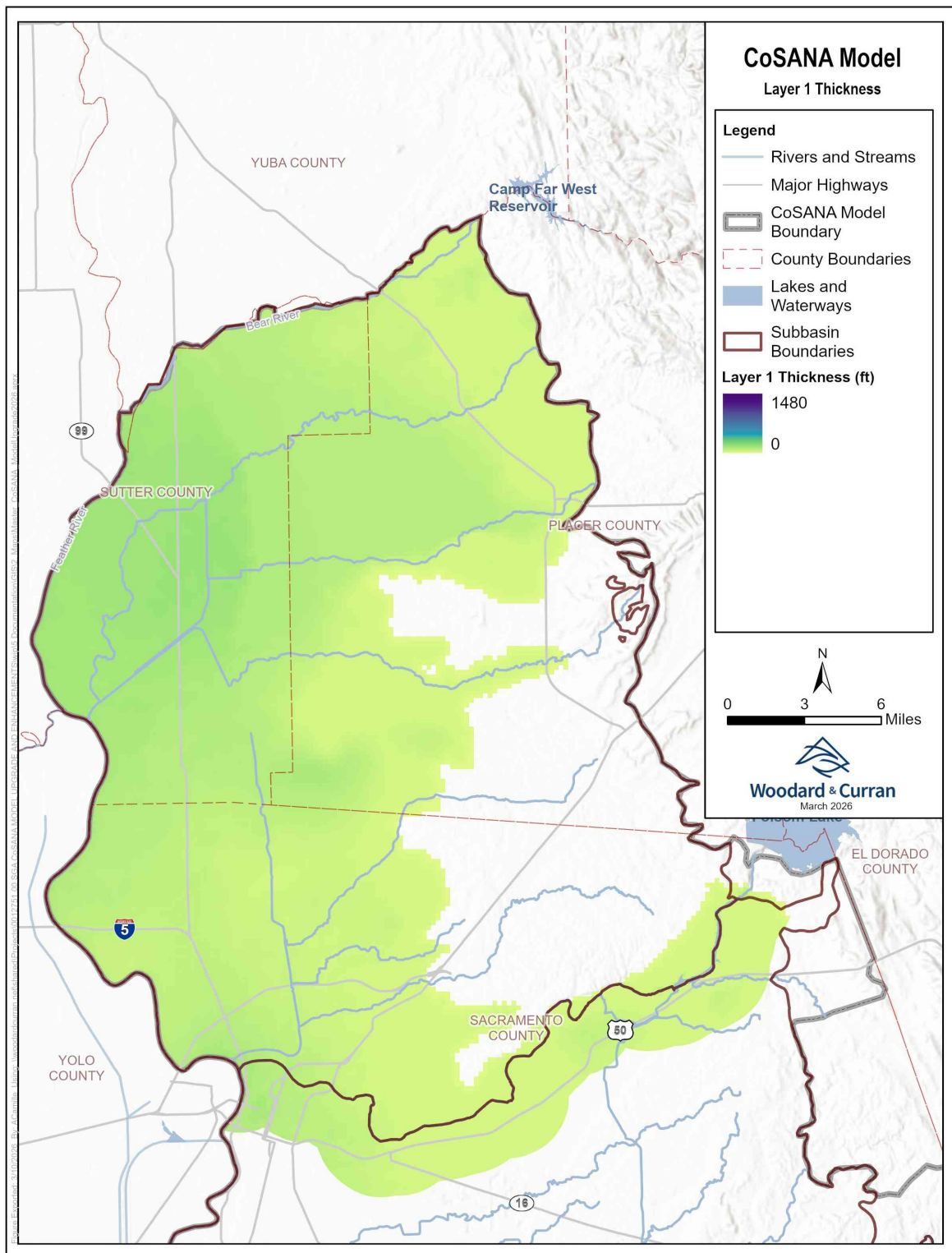


Figure 2-13: Thickness of Layer 1

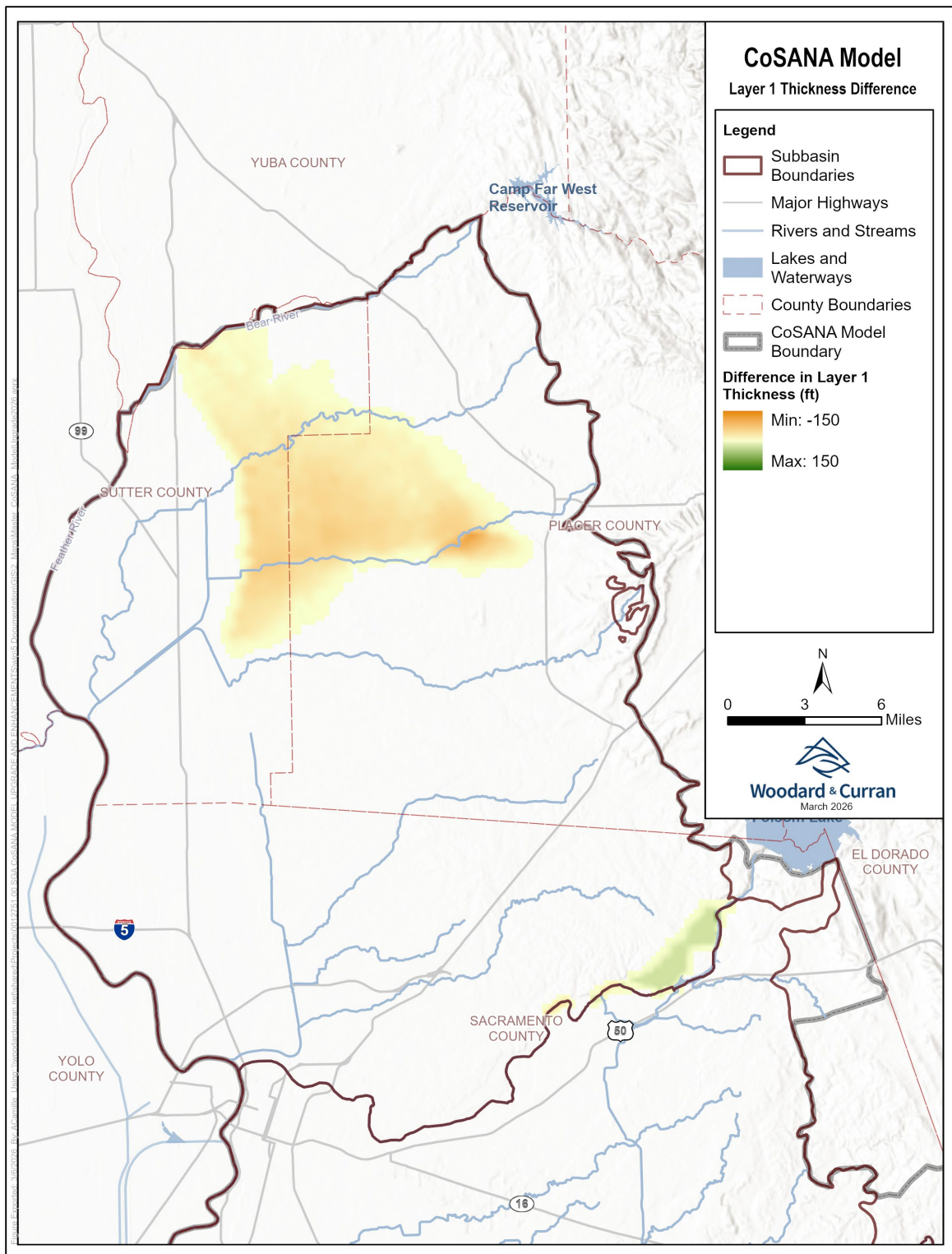


Figure 2-14 Thickness Difference of Layer 1

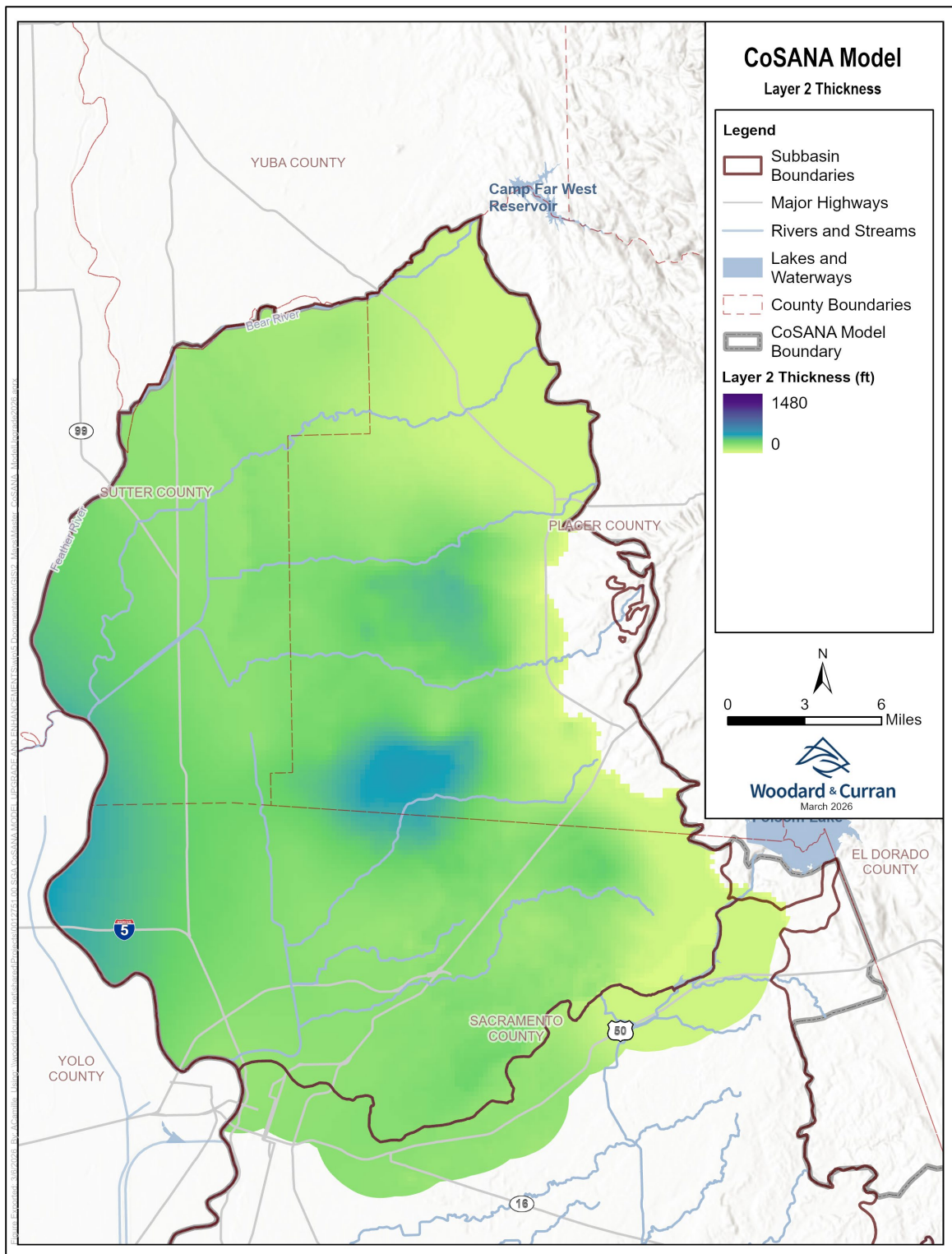


Figure 2-15: Thickness of Layer 2

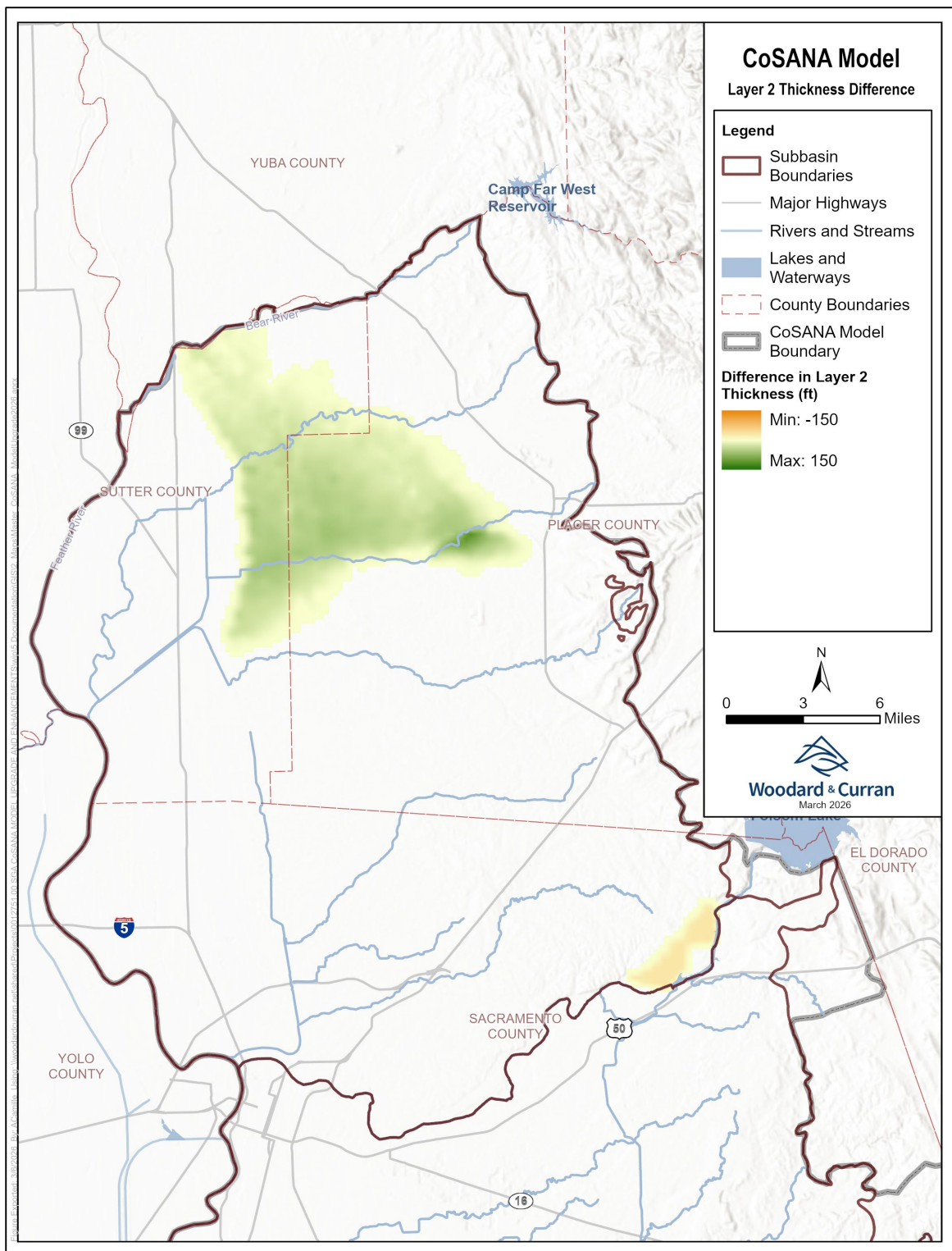
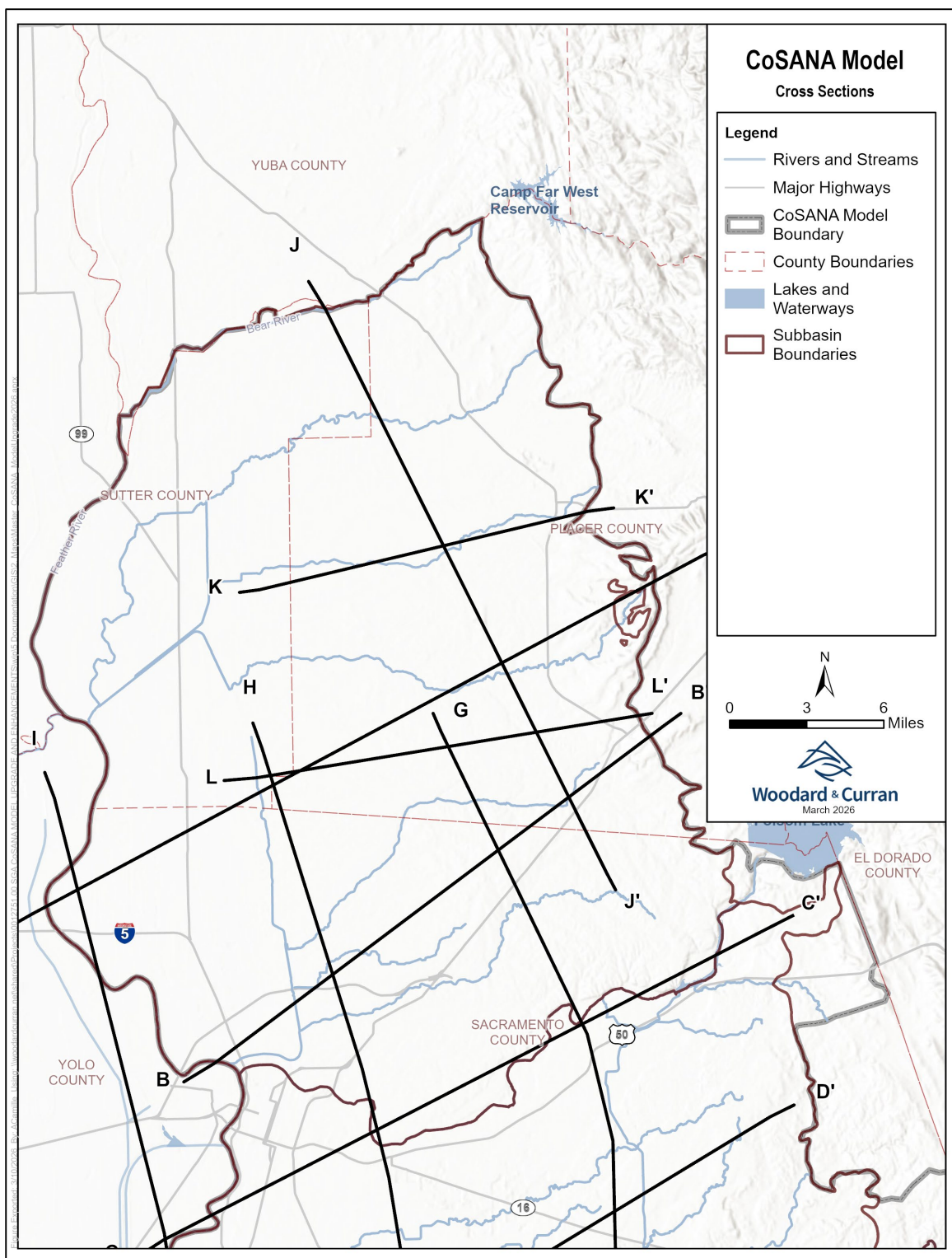


Figure 2-16: Thickness Difference of Layer 2



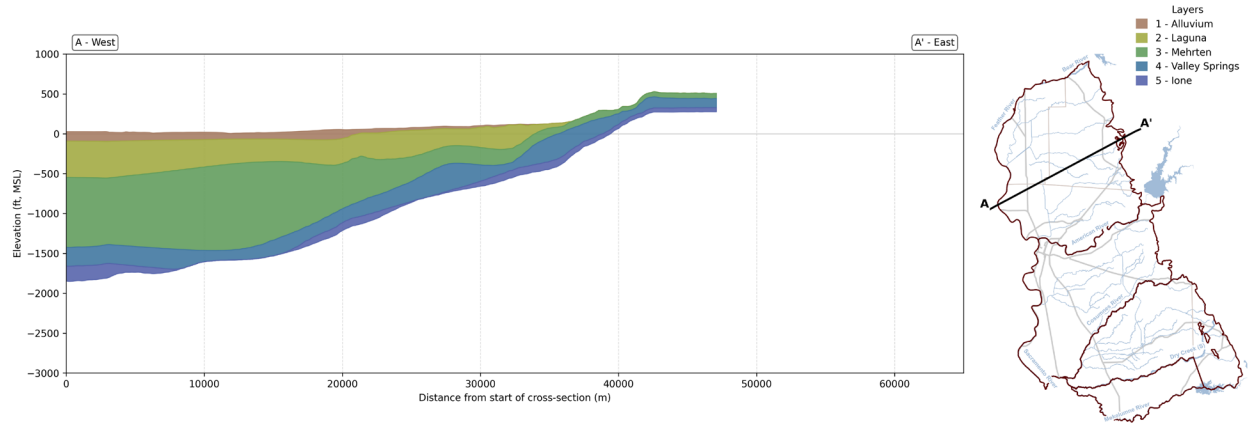


Figure 2-18: CoSANA Cross Section A-A'

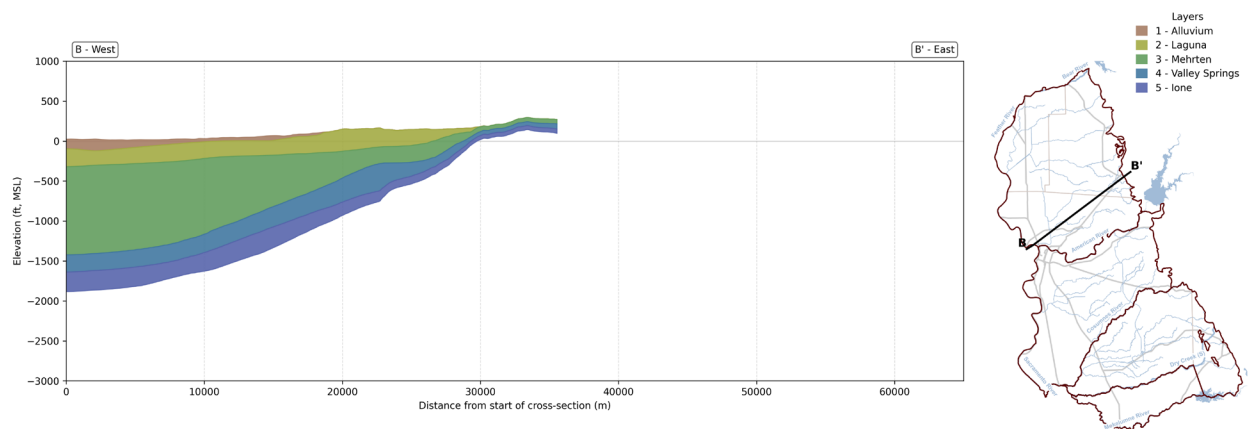


Figure 2-19 CoSANA Cross Section B-B'

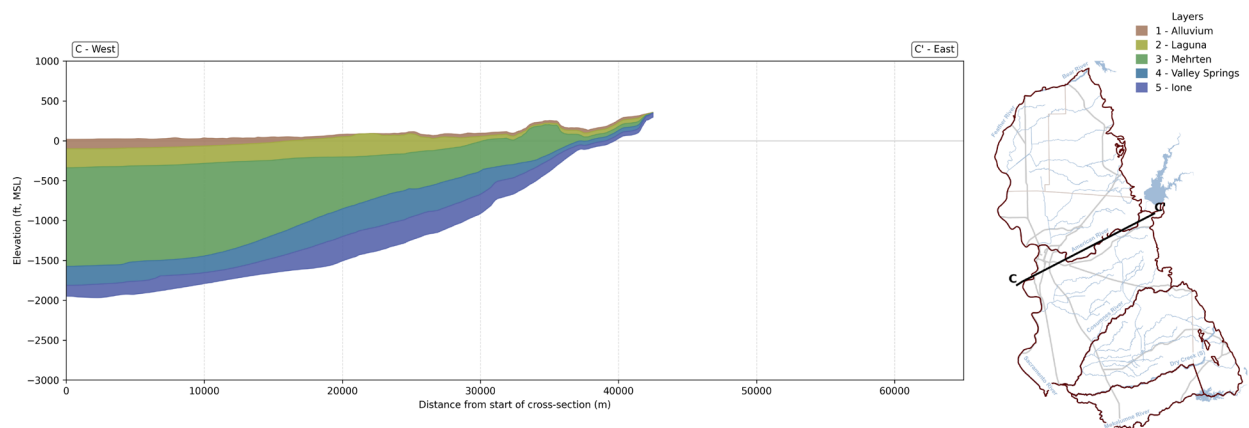


Figure 2-20: CoSANA Cross Section C-C'

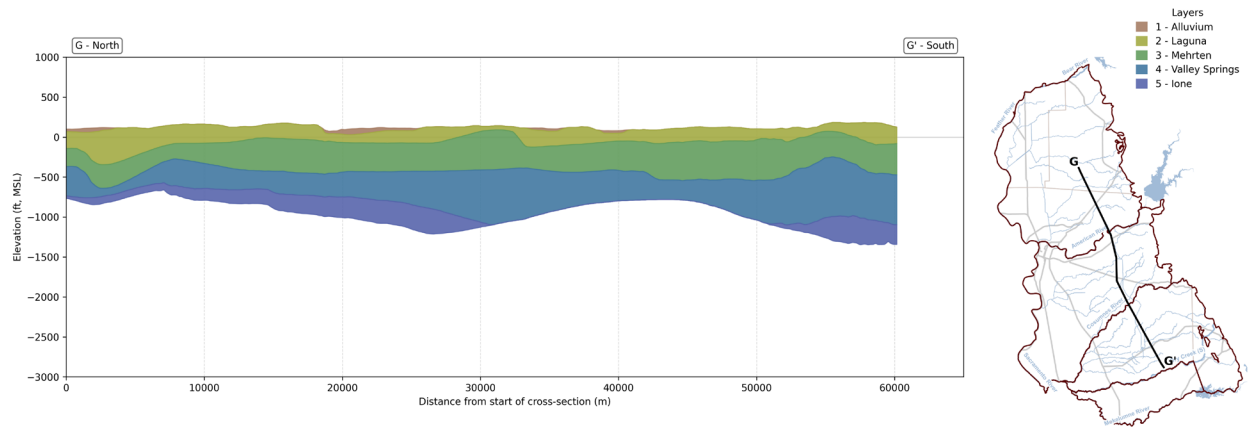


Figure 2-21: CoSANA Cross Section G-G'

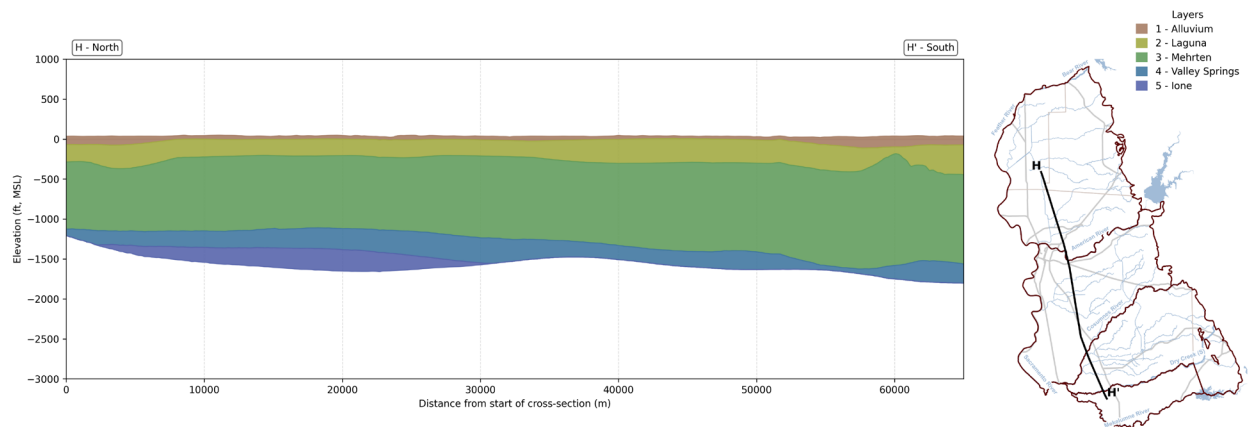


Figure 2-22: CoSANA Cross Section H-H'

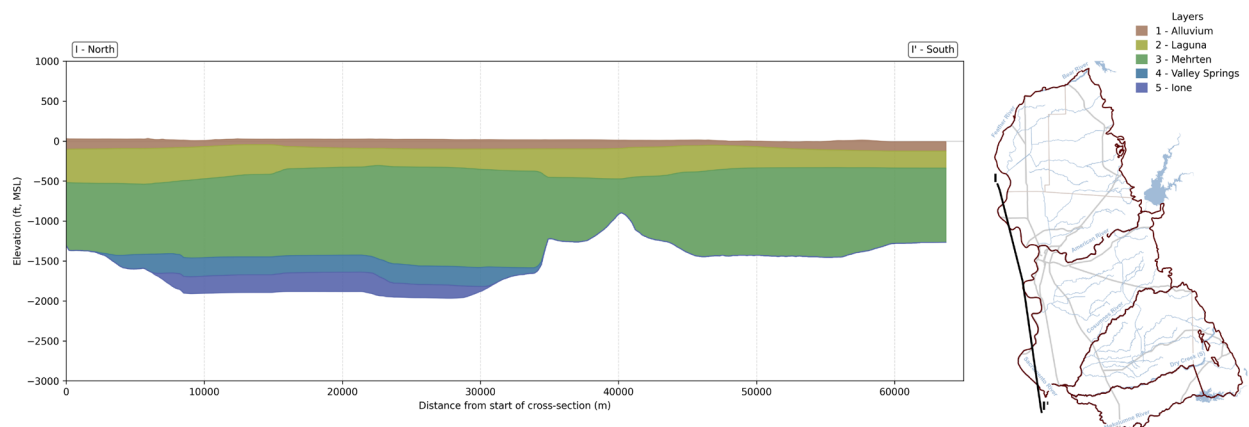


Figure 2-23: CoSANA Cross Section I-I'

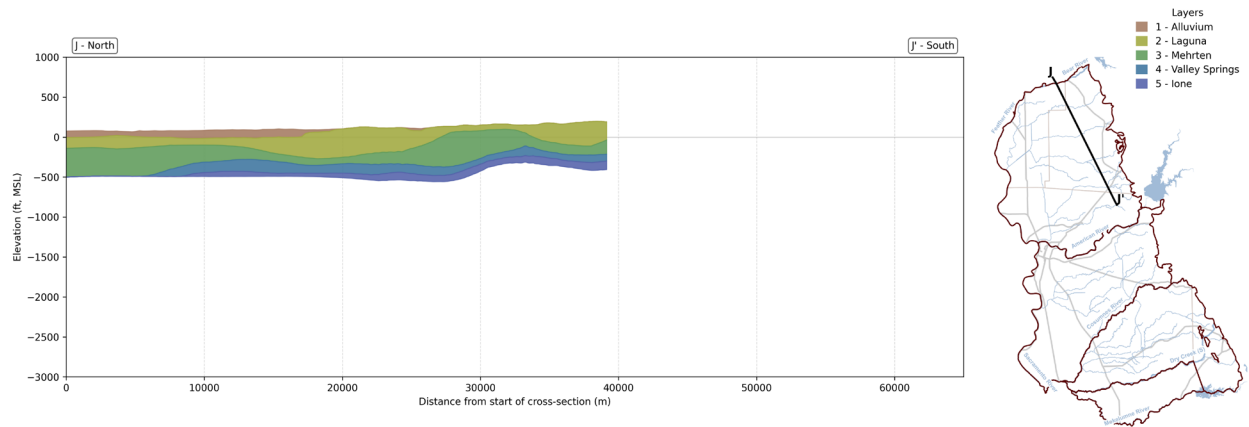


Figure 2-24: CoSANA Cross Section J-J'

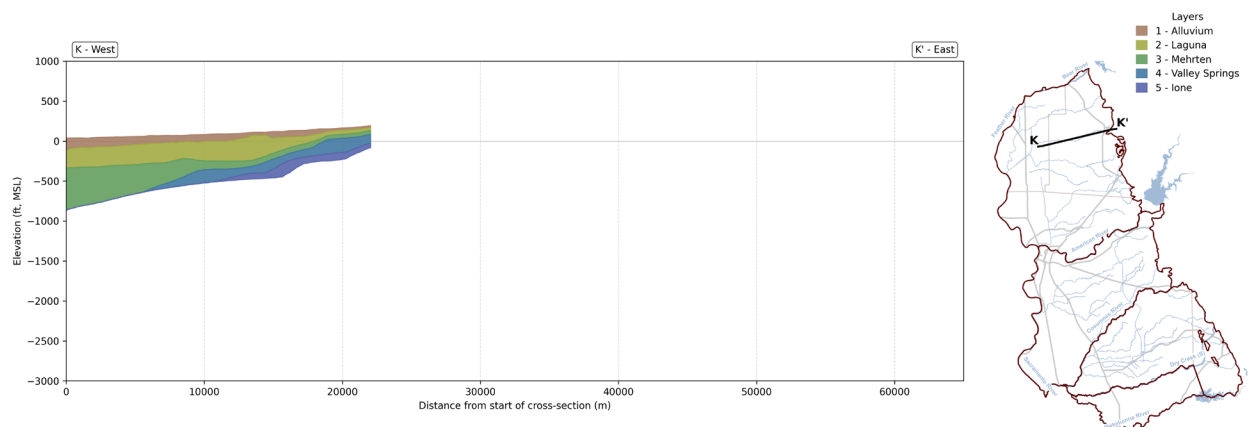


Figure 2-25: CoSANA Cross Section K-K'

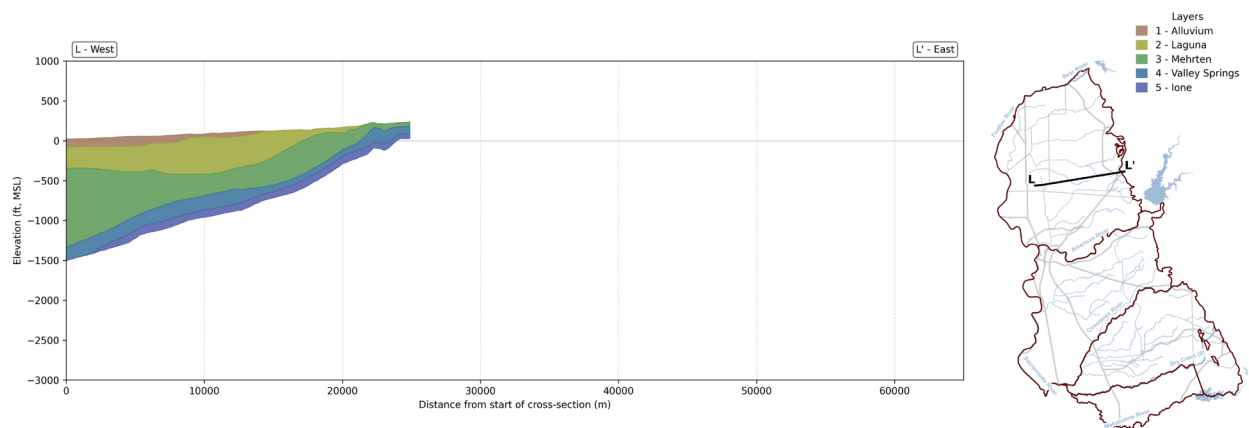


Figure 2-26: CoSANA Cross Section L-L'

2.11 Stream Physical Characteristics Update

Stream physical characteristics for four major rivers—the Sacramento, Feather, Bear, and American—were updated in the NASb area of the CoSANA model. These characteristics, including the streambed (invert) elevation, channel width, and stream flow rating tables in the NASb area, were reviewed, verified and updated as needed based on the available data from California Data Exchange Center (CDEC), USGS, and the Central Valley Floodplain Evaluation and Delineation Program (CVFED) (SVSim, 2020).

Figure 2-27 shows the streambed elevation update for the American River as an example.

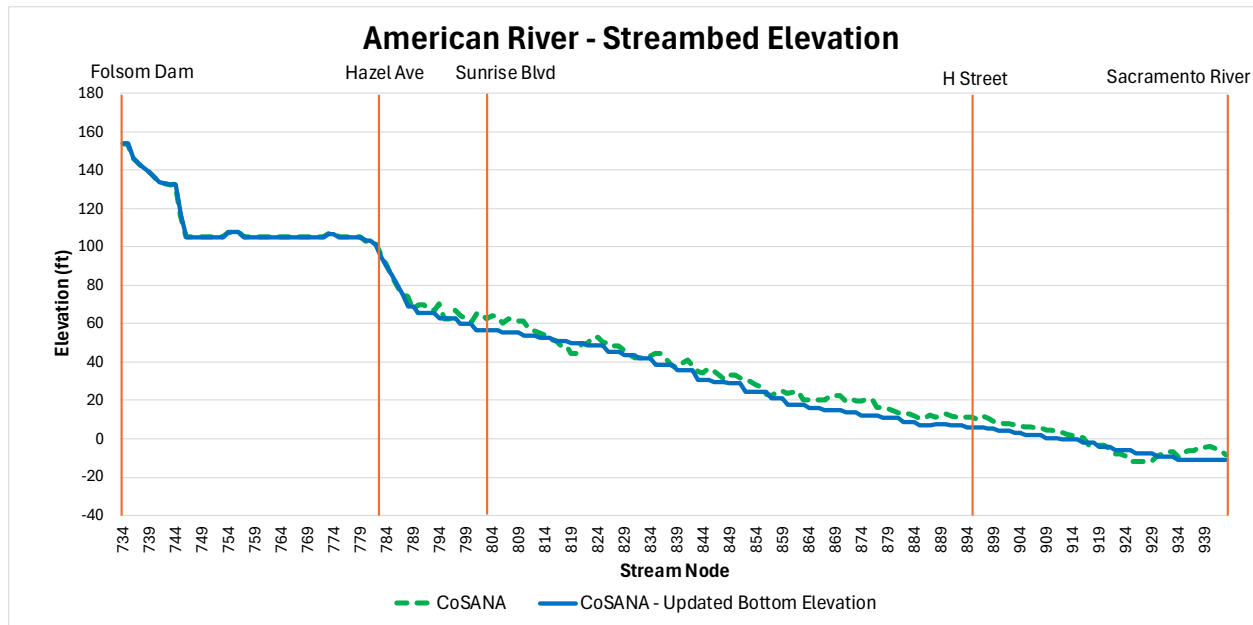


Figure 2-27: American River Streambed Elevation Update

3. CALIBRATION UPDATES

CoSANA model calibration for the NASb area was performed with several goals in mind:

- Accurate land surface water budgets representing records of water demand and supplies for the municipal water purveyors in the Subbasin, as well as estimates of water demand in the agricultural areas.
- Representative and reasonable groundwater budgets for the water use in the agricultural, urban, and undeveloped areas of the Subbasin.
- Reasonable representation of seasonal and long-term trends in groundwater levels at target calibration wells.
- Reasonable level of stream-aquifer interaction conditions.
- Proper representation of the boundary conditions and interbasin flows.

NASb calibration consisted of a hybrid approach of using a Parameter Estimation (PEST)-informed process along with expert judgement and review. Calibration targets included groundwater levels from observation wells and streamflow data from stream gauges.

3.1 Calibration Process

Calibration process included:

- Collecting data and setting calibration targets.
- Comparing simulated and observed groundwater levels.
- Developing and calibrating water budgets for land surface, groundwater, and stream systems.

The calibration process included expert involvement and automated parameter estimation process. Automated calibration was performed using PEST methodology. PEST calibration parameters included aquifer hydrogeologic and streambed parameters. Model sensitivity analysis was performed as the final step of calibration.

3.1.1 Water Budget Calibration

A water budget balances supplies, demands, and changes in storage occurring within a specific portion of hydrologic cycle. Calibration of water budgets improves the accuracy of the model to represent the hydrologic characteristics of the groundwater basin. Water budgets could be generated by the CoSANA model for various parts of the model, a single element, or any specific grouping of elements, for processes involving the surface layer, groundwater system, streams system and interaction with the groundwater system, the root zone, the unsaturated zone, and small watersheds tributary to the groundwater system. Water budgets are summarized into monthly, annual, and long-term averages.

3.1.1.1 Land and Water Use Budget

The land and water use budget represents the balance of water demands with the water supplied and includes two different versions of agricultural and urban. Both versions include the following components of the water balance:

- Demands:
 - Demand (agricultural and/or urban)
 - Surplus or shortage (if applicable)

-
- Supplies:
 - Groundwater pumping
 - Surface water deliveries (including recycled water deliveries)
 - Shortage (if applicable)

The long-term average annual water demand and supply mix used to meet the demand in the NASb for the 1990-2024 period are summarized in **Table 3-1**. The annual land and water use budgets for the calibration period are presented in **Figure 3-1** and **Figure 3-3**, showing the agricultural and urban demands and supplies in the NASb. The average annual land and water use budgets in the Subbasin are shown in **Figure 3-2** and **Figure 3-4**.

Table 3-1: Land and Water Use Budget Demand and Supply Mix

(Average Annual for the Period WY 1990-2024)

Agricultural Water Budget (AFY)				Urban Water Budget (AFY)				
Demand	Groundwater Use	Surface Water Deliveries	Surplus (-)/ Shortage (+)	Demand	Groundwater Use	Surface Water Deliveries	Recycled Water	Surplus (-)/ Shortage (+)
405,956	201,467	208,604	-4,115	210,818	91,212	119,606	0	0

Note: Small differences exist between total supplies and total demands. These shortages and surpluses are delivered and applied regardless of the demand specified in the model. Surpluses tend to result in deep percolation.

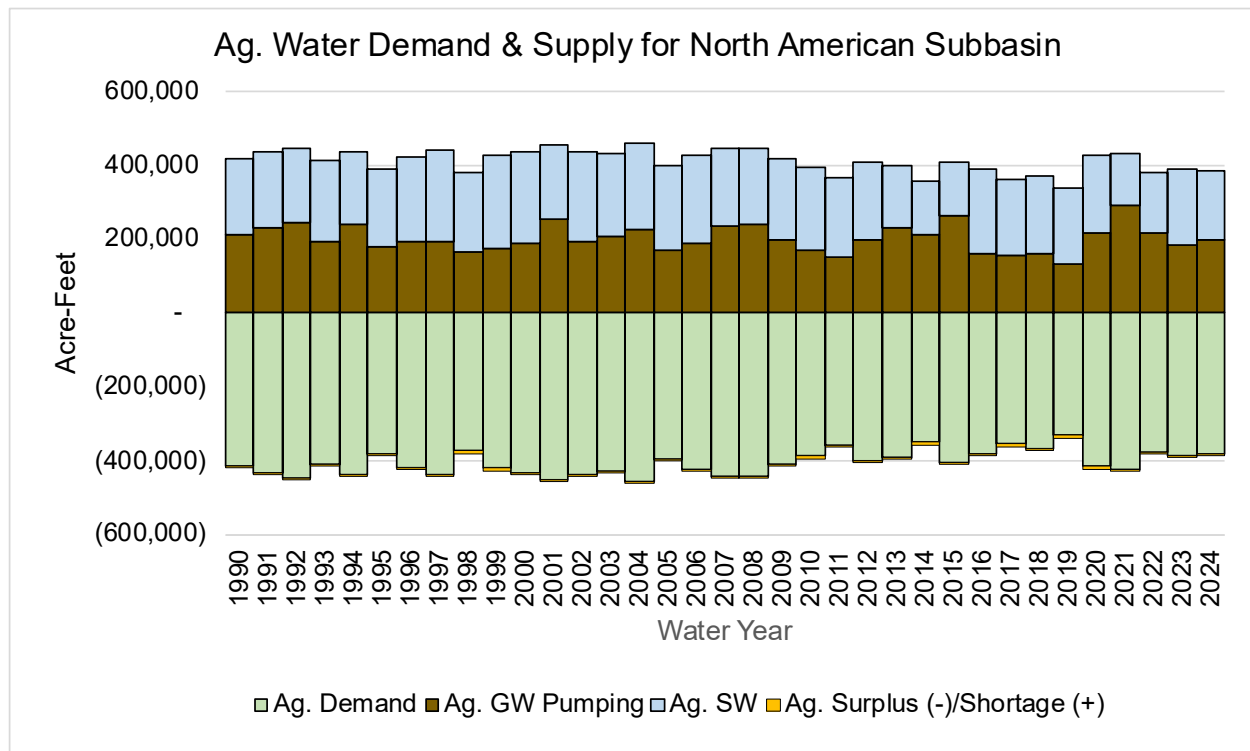


Figure 3-1: Annual Agricultural Land and Water Use Budget – NASb

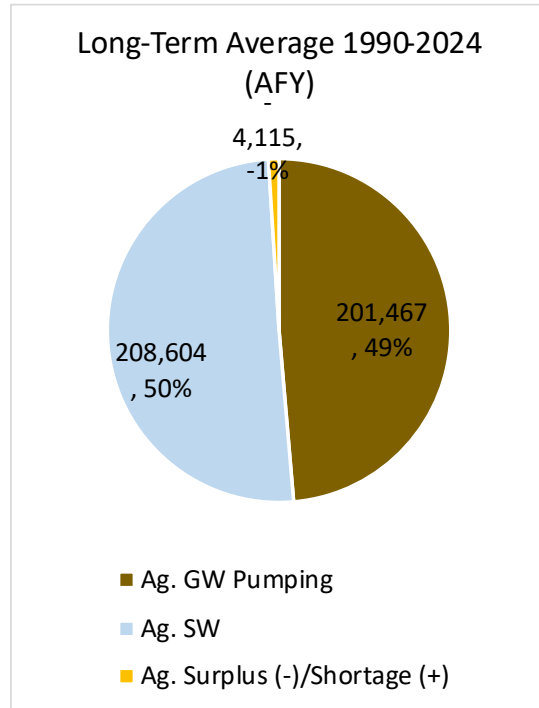


Figure 3-2: Long-term Average Agricultural Land and Water Use Budget – NASb

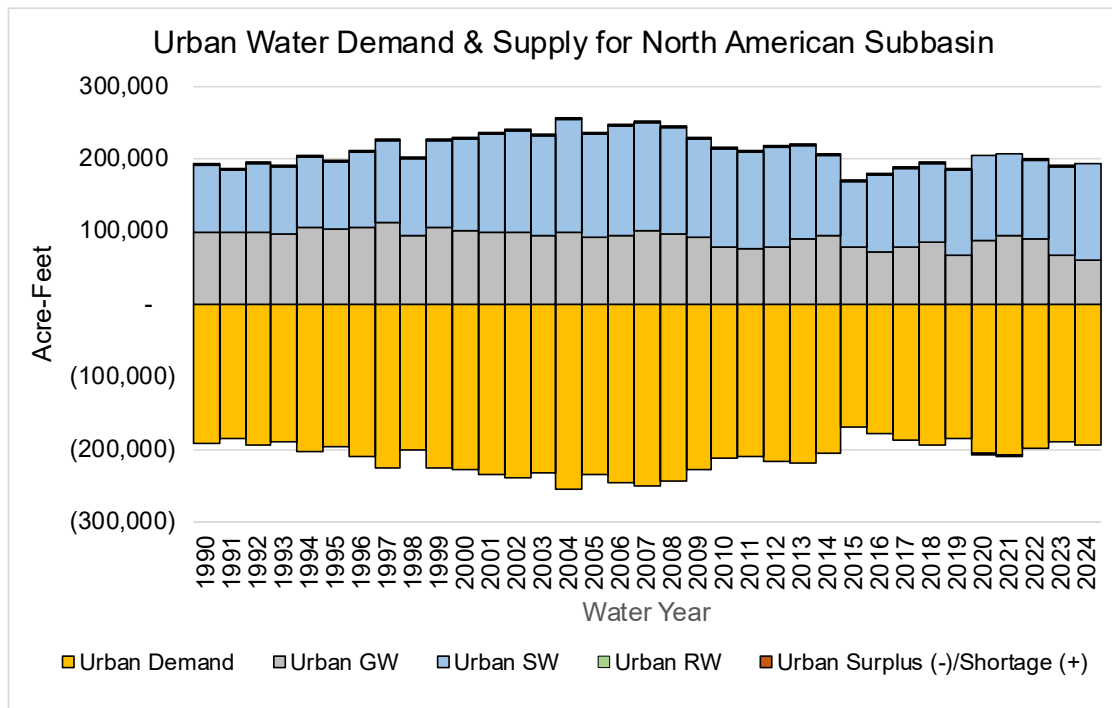


Figure 3-3: Annual Urban Land and Water Use Budget – NASb

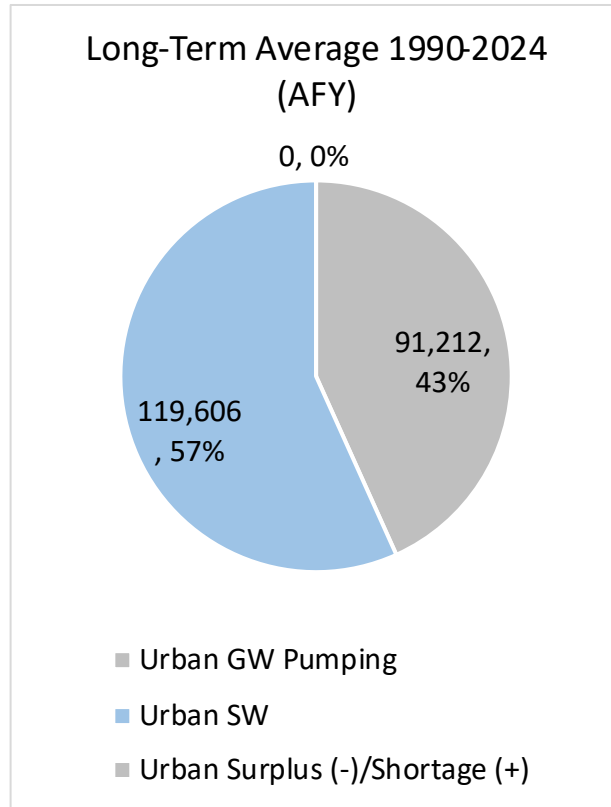


Figure 3-4: Long-Term Average Urban Land and Water Use Budget – NASb

3.1.1.2 Groundwater Budget

The groundwater budget quantifies inflows and outflows from the groundwater system. The primary components of the groundwater budget are:

- Inflows:
 - Deep percolation (from rainfall and irrigation applied water)
 - Gain from stream (recharge due to stream seepage)
 - Recharge (from other sources such as irrigation canal seepage and recharge ponds)
 - Boundary inflow (from outside the model area)
 - Net subsurface inflow (from adjacent subregions)
- Outflows:
 - Groundwater pumping
 - Loss to Stream (outflow to streams and rivers)
 - Boundary outflow (to outside the model area)
 - Subsurface outflow (to adjacent subregions)
- Change in groundwater storage
 - Positive indicates withdrawal from groundwater storage
 - Negative indicates contribution to groundwater storage

The long-term average annual groundwater water inflow and outflow components in the NASb for the WYs 1990-2024 period is summarized in **Table 3-2**. The annual groundwater budgets components for the calibration period are presented in **Figure 3-5**. The average annual groundwater budgets of net inflows, outflows, and change in storage in the NASb are shown in **Figure 3-6** and **Figure 3-7**. The cumulative change in groundwater storage for the calibration period in the long-term with annual variabilities is shown in **Figure 3-8**.

Table 3-2: Summary of NASb Groundwater Budget

(Average Annual for the Period WY 1990-2024)

Inflows (AFY)					Outflows (AFY)	Change in Storage (AFY)
Deep Percolation	Net Gain from Stream	Recharge*	Net Subsurface Inflow**	Net Boundary Flows***	Pumping	
184,676	84,396	30,366	16,685	13,273	312,413	16,978

Note:

*Recharge includes seepage through unlined irrigation supply canals.

**Net Subsurface Inflows includes inflows and outflows between the North American Subbasin and South American Subbasin and areas outside of Bulletin 118 subbasins.

***Net Boundary Flows includes inflows and outflows between areas outside of the CoSANA model domain and baseflow from small watersheds.

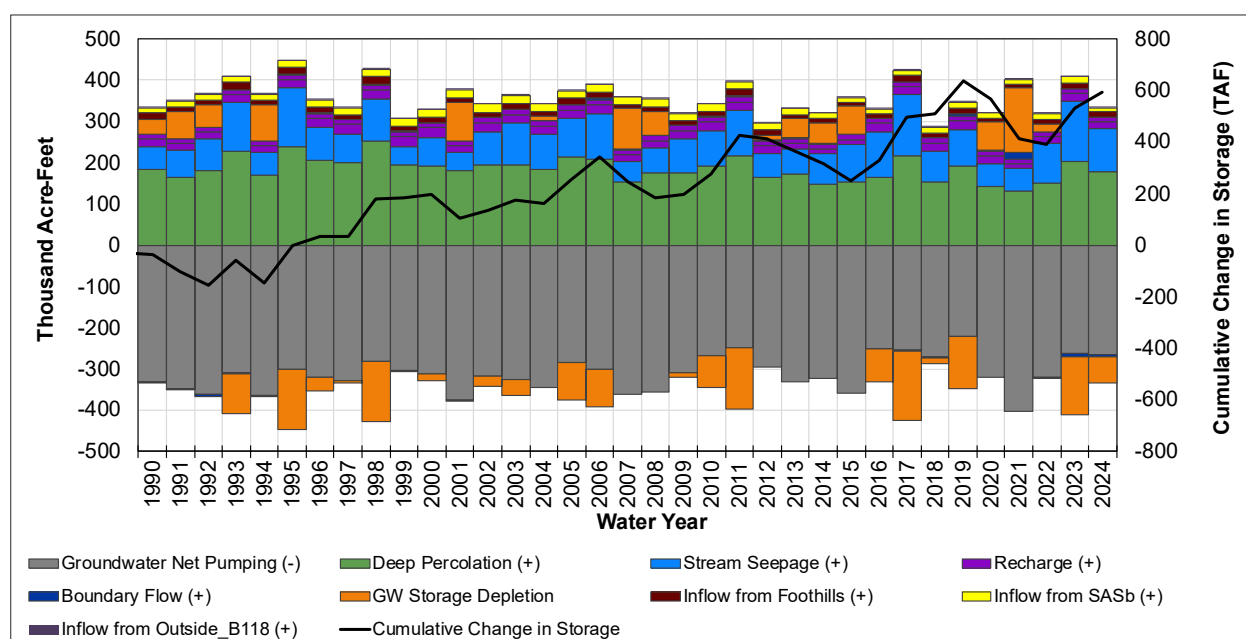


Figure 3-5: Annual Groundwater Budget – NASb

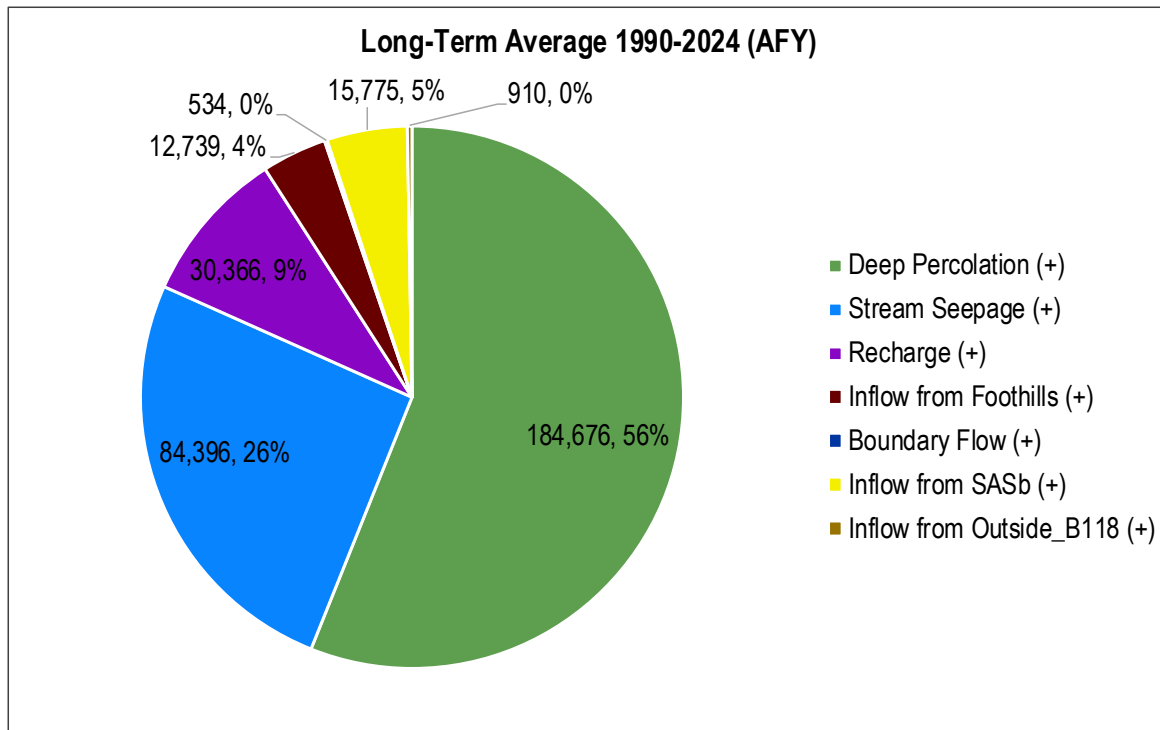


Figure 3-6: Average Annual Groundwater Budget Inflows – NASb

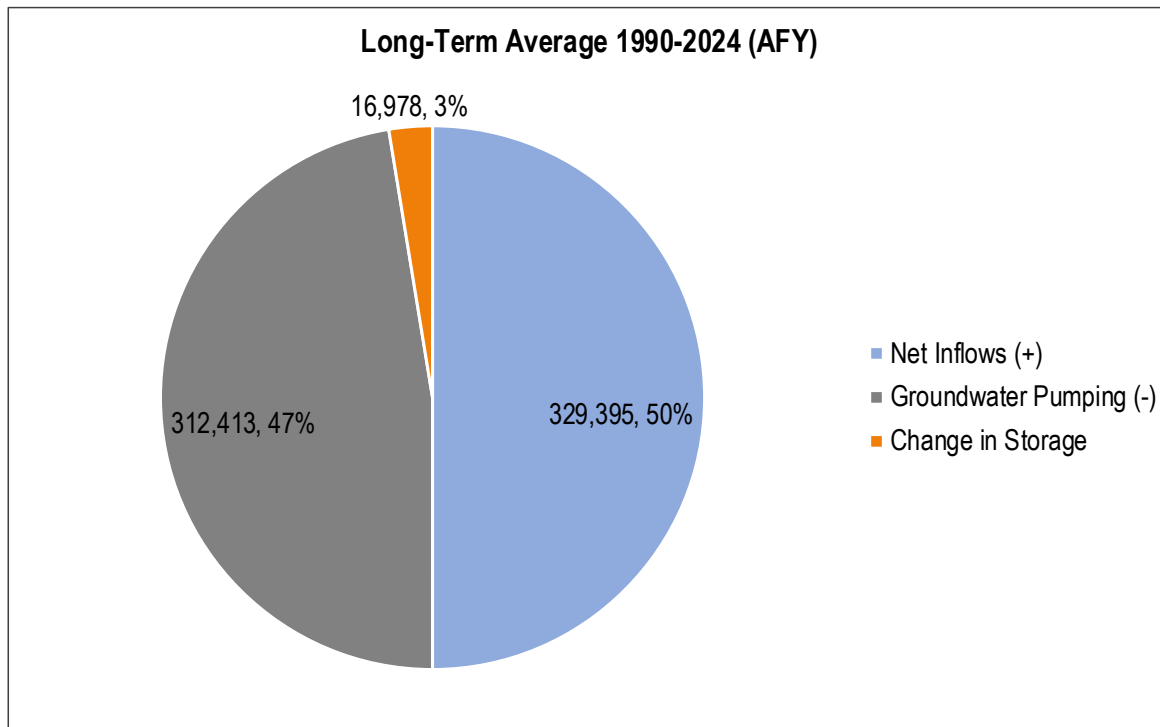


Figure 3-7: Average Annual Groundwater Budget Net Inflows & Outflows & Change in Storage – NASb

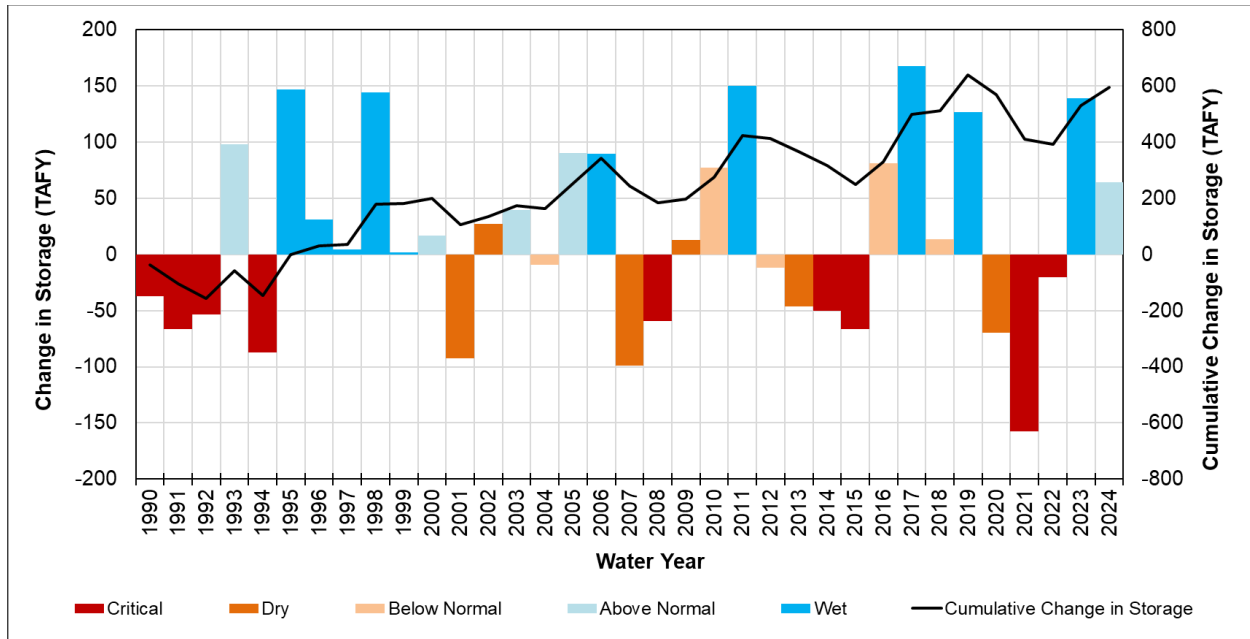


Figure 3-8: Annual Groundwater Change in Storage Budget – NASb

3.1.2 Groundwater Level Calibration

Groundwater level calibration consists of achieving acceptable agreement between the simulated and observed groundwater levels at the calibration wells. Out of CoSANA's 761 calibration wells, 400 of them are located within the NASb. These calibration wells were used to achieve CoSANA's calibration at both the Subbasin and local scale.

The groundwater level calibration process included both manual refinements to the model as well as automated calibration using the PEST software package. The set of 400 wells with associated observations was used to perform PEST calibration. The location and number of observations for the set of 400 wells are shown in **Figure 3-9**, the period of record of each of these wells is shown in **Figure 3-10**.

A preliminary manual calibration was performed to adjust the water budgets, primarily the land and water use budgets and the groundwater budgets to have a reasonable starting point for calibrating the aquifer parameters. Simulated groundwater levels were calibrated to observed levels through adjustments to the aquifer hydrogeologic parameters, including horizontal and vertical hydraulic conductivity, specific storage, and specific yield. The goal of groundwater level calibration is to achieve the maximum agreement between simulated and observed groundwater elevations at calibration wells while maintaining reasonable values for aquifer parameters.

The automated parameter estimation tool, PEST, was used to assist in refinement of aquifer parameters to improve model calibration. PEST-assisted calibration was performed to interact with CoSANA in the NASb area via input and output files and iteratively modifies parameter values to reduce an objective function representative of the model residual error. PEST-assisted calibration focused on the aquifer parameters noted above.

Simulated groundwater level contours and observed values for calibration wells are shown in **Figure 3-11**, **Figure 3-12**, and **Figure 3-13** for spring 2023, fall 2022, and fall 2024. Simulated groundwater level hydrographs and observations for selected wells (locations shown in **Figure 3-14**) are shown in **Figure 3-15** through **Figure 3-25**.

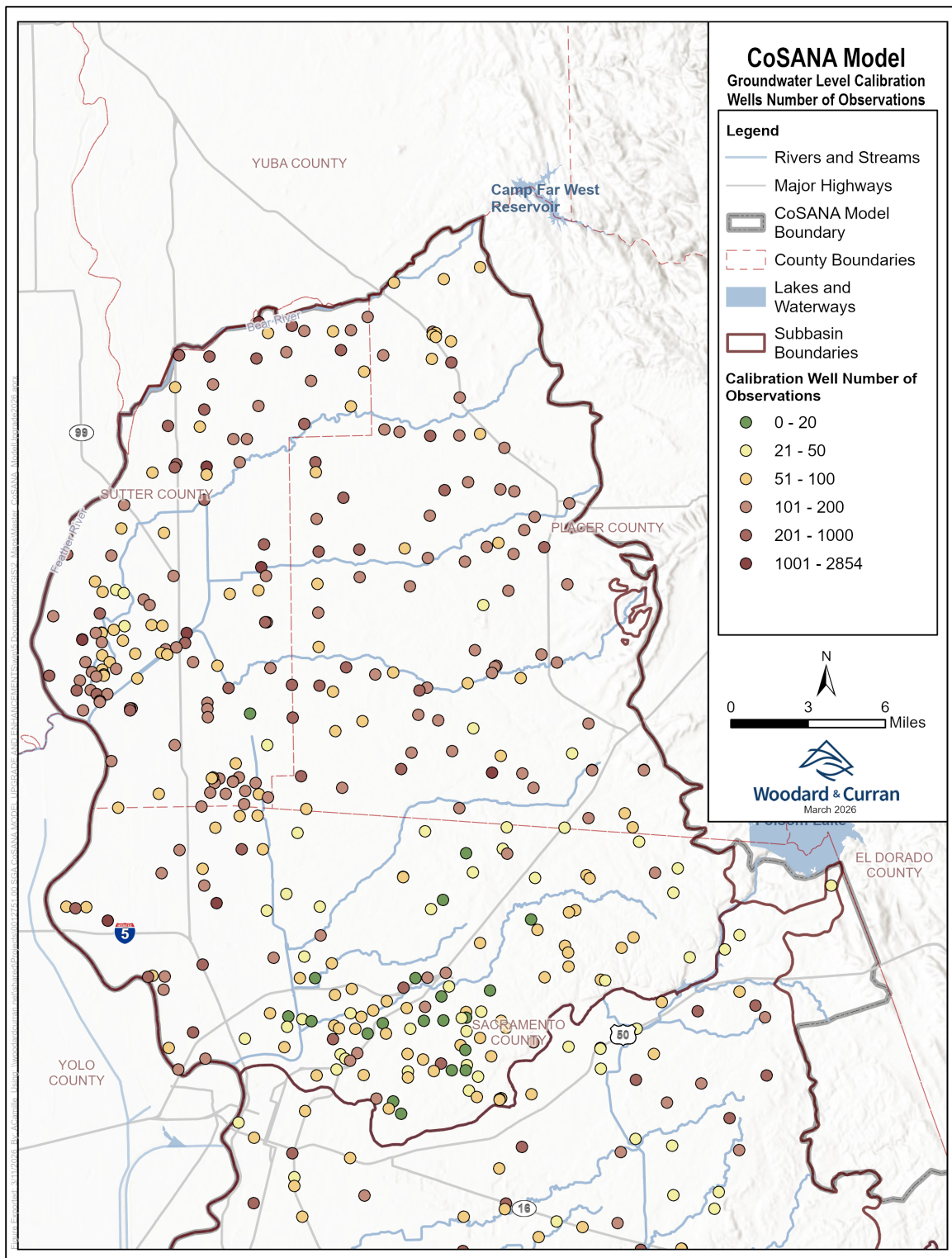


Figure 3-9: Number of Observations for Calibration Wells in NASb

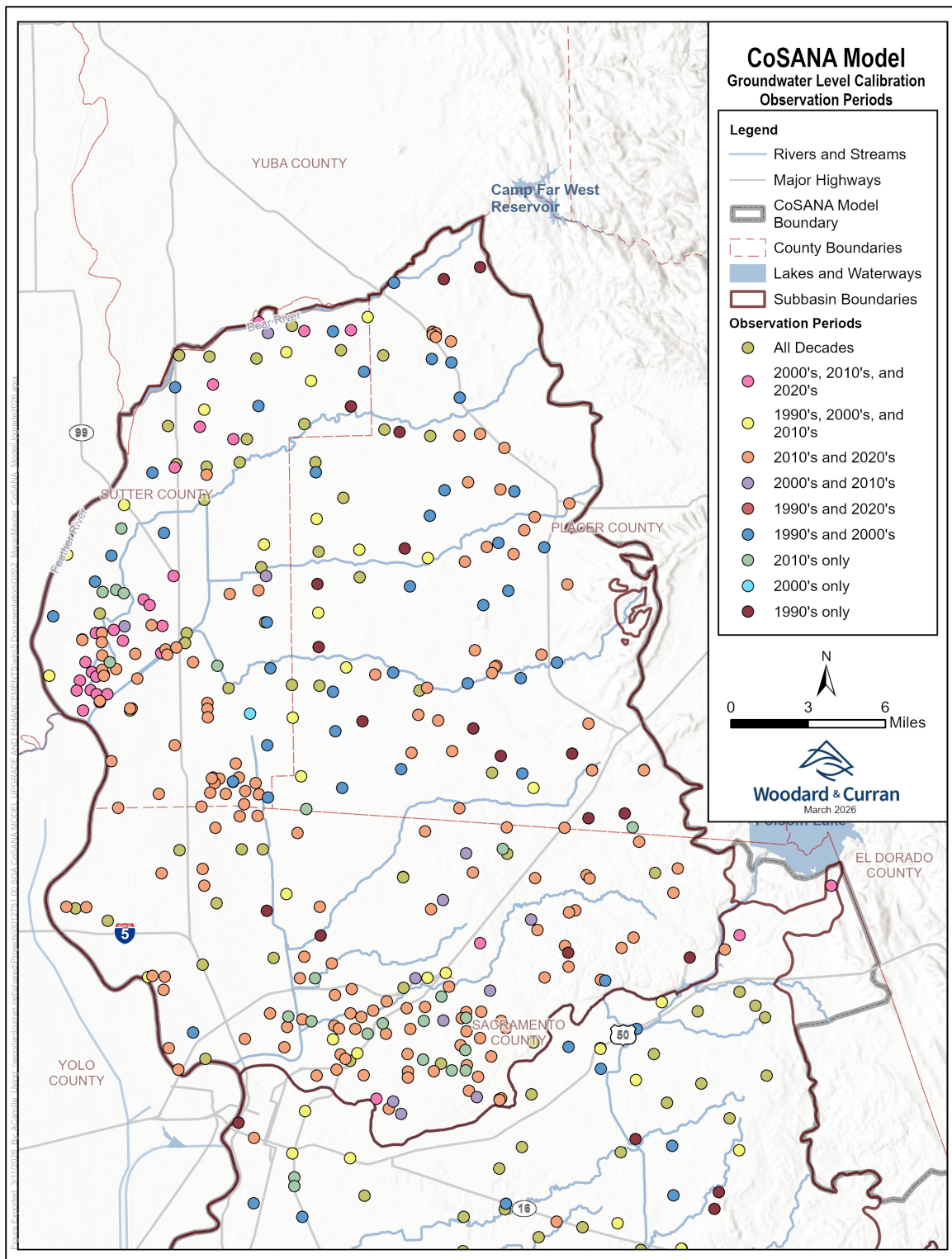


Figure 3-10: Period of Record for Calibration Wells in NASb

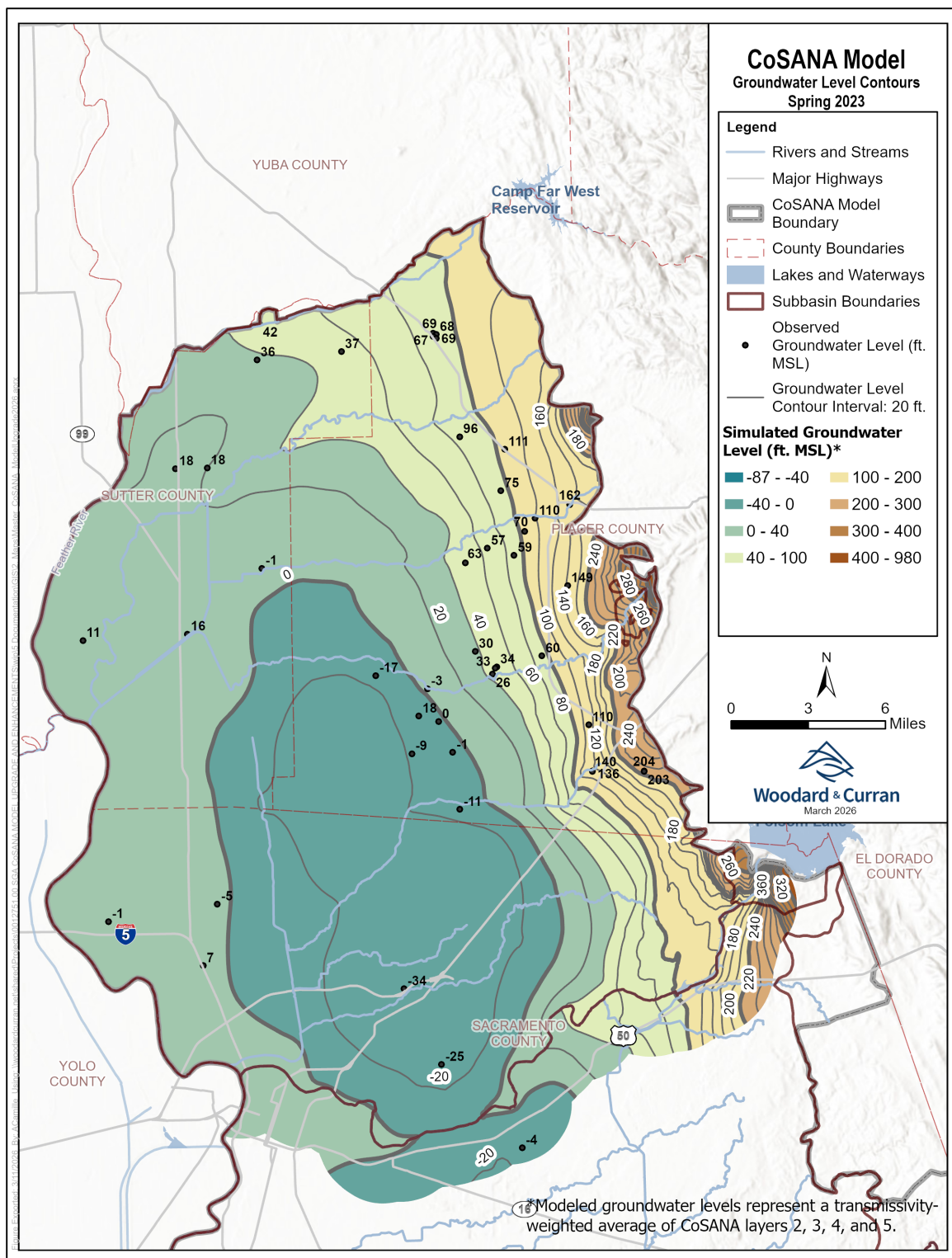


Figure 3-11: NASb Groundwater Level Contours – Spring 2023 (End of Wet Period)

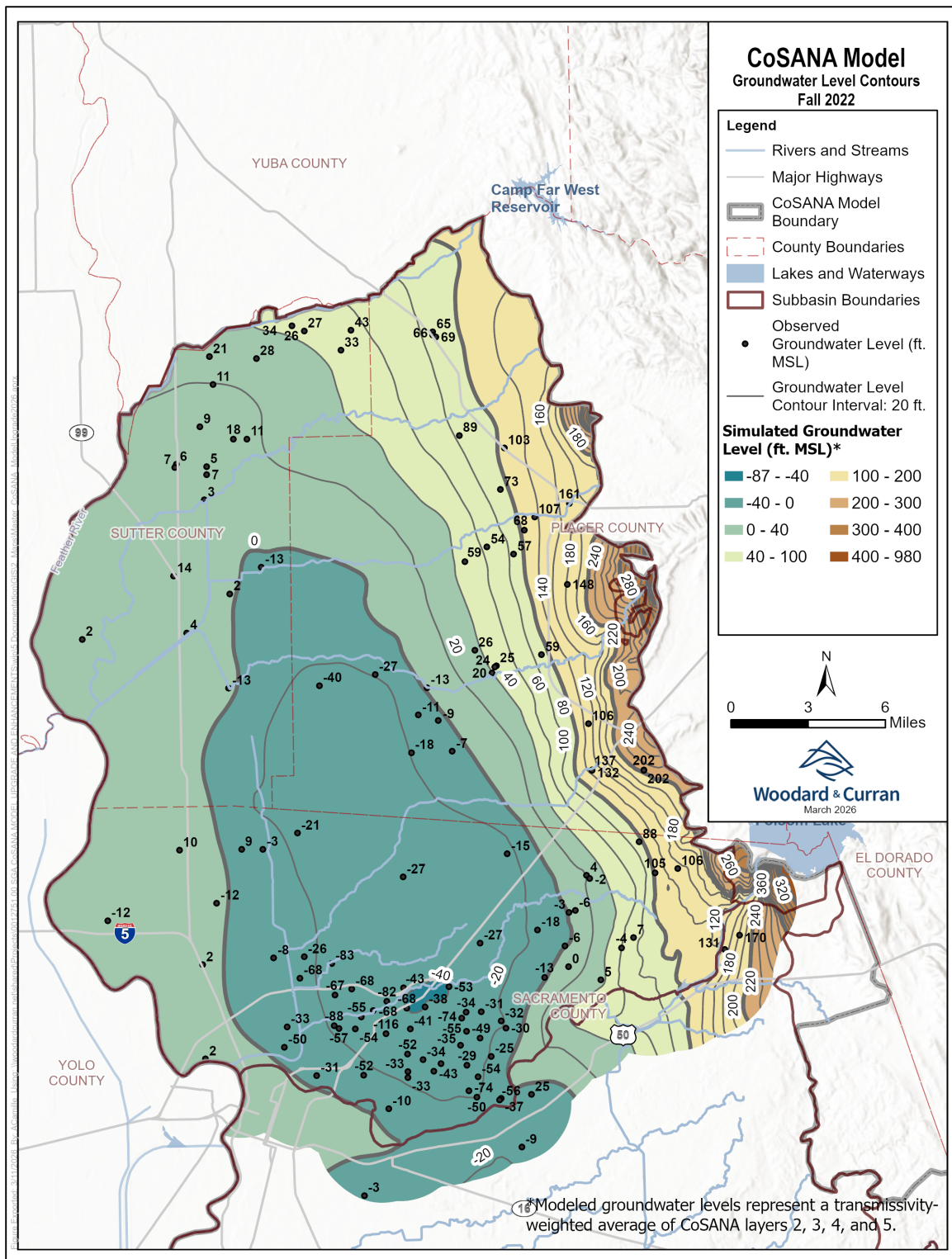


Figure 3-12: NASb Groundwater Level Contours – Fall 2022 (End of Drought Period)

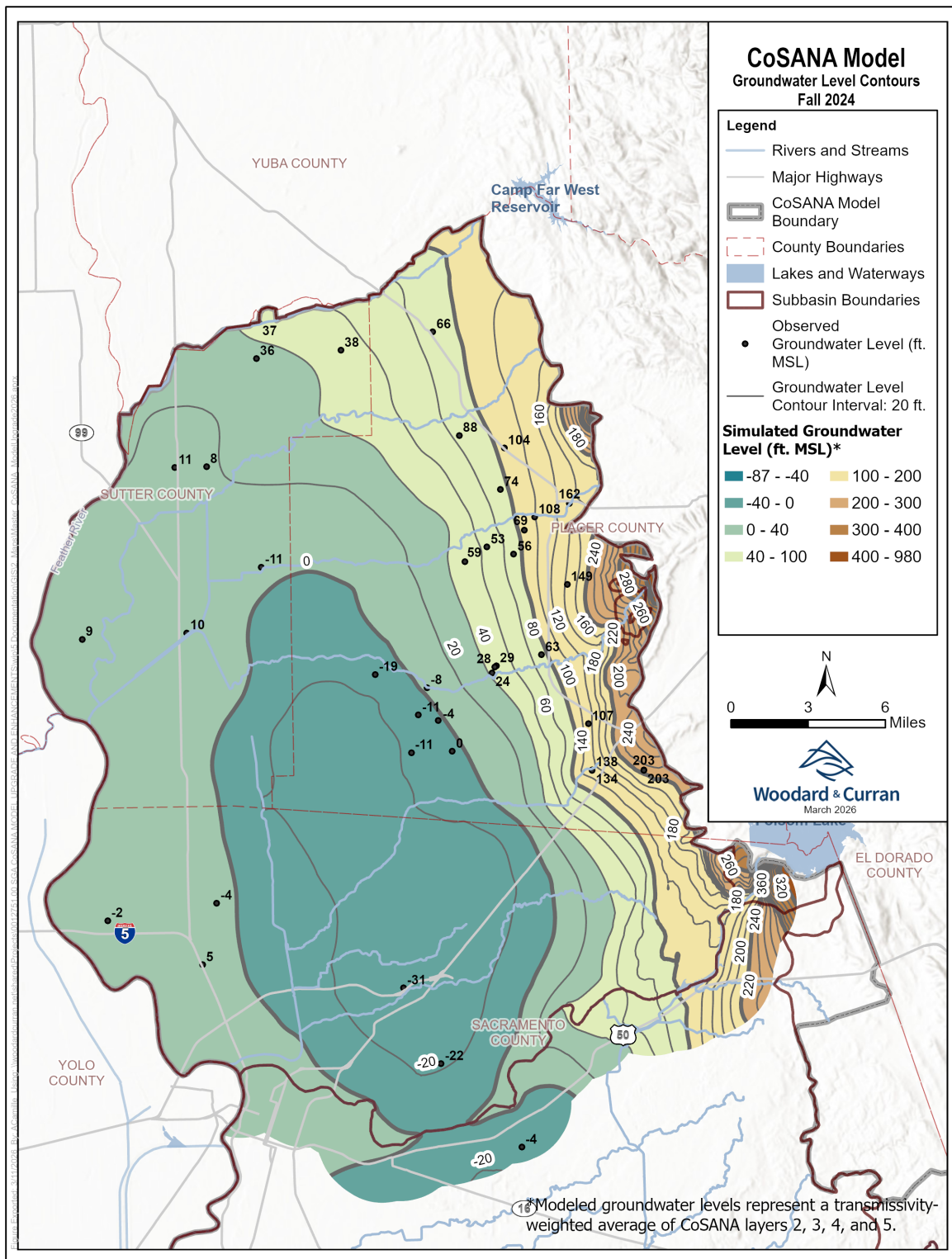


Figure 3-13: NASb Groundwater Level Contours – Fall 2024 (End of Simulation)

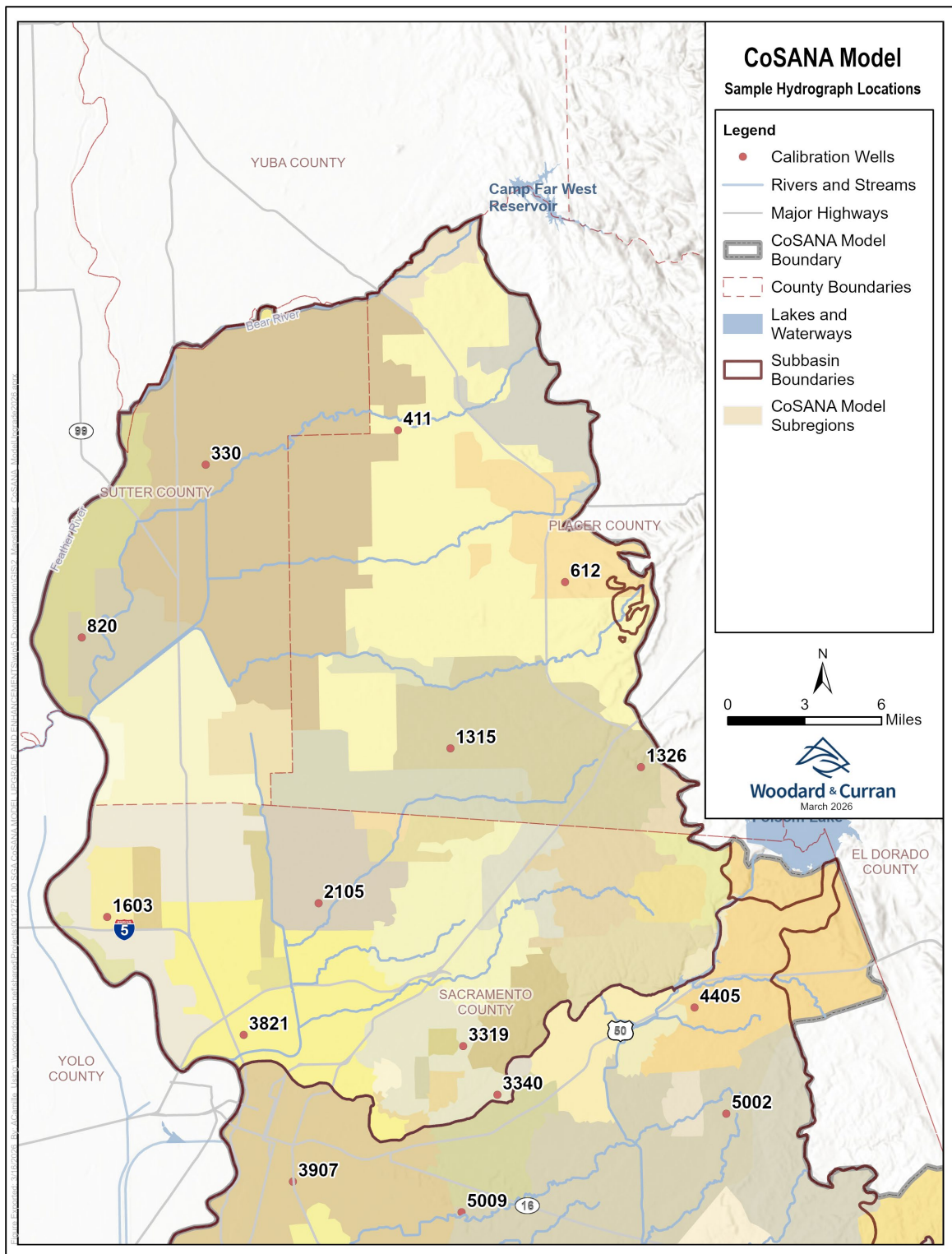


Figure 3-14: Location of Sample Hydrographs in NASb

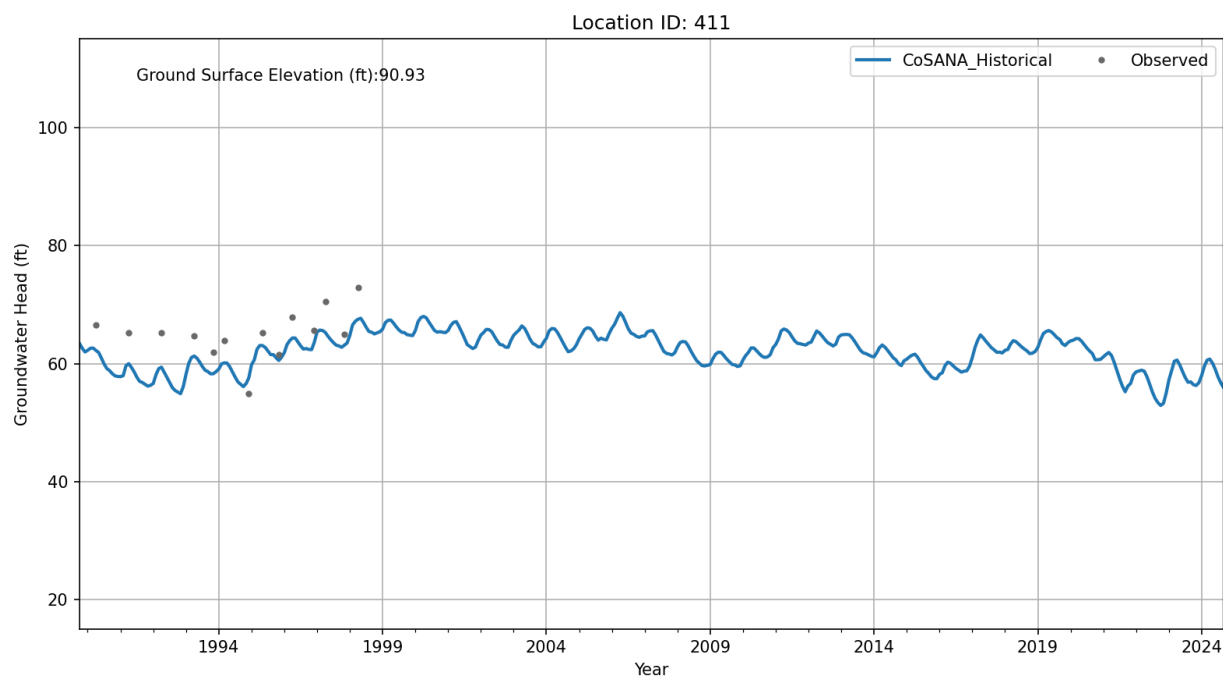


Figure 3-15: NASb Groundwater Level Hydrograph – Hydrograph #1

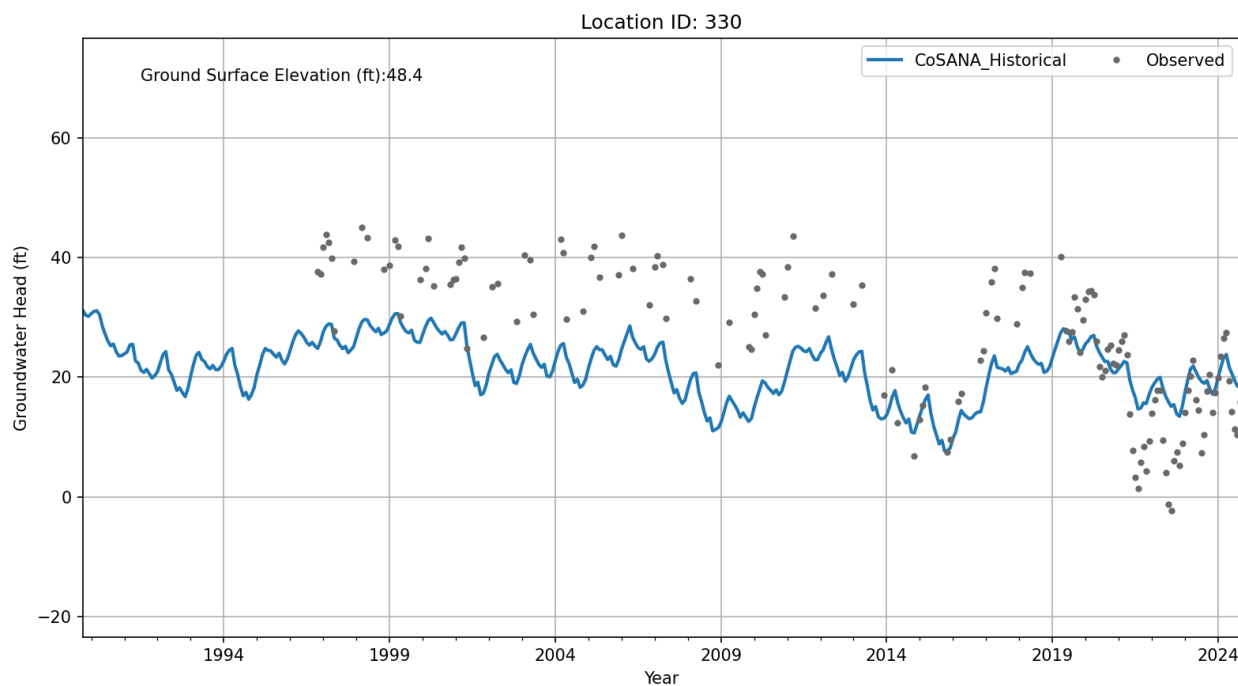


Figure 3-16: NASb Groundwater Level Hydrograph – Hydrograph #2

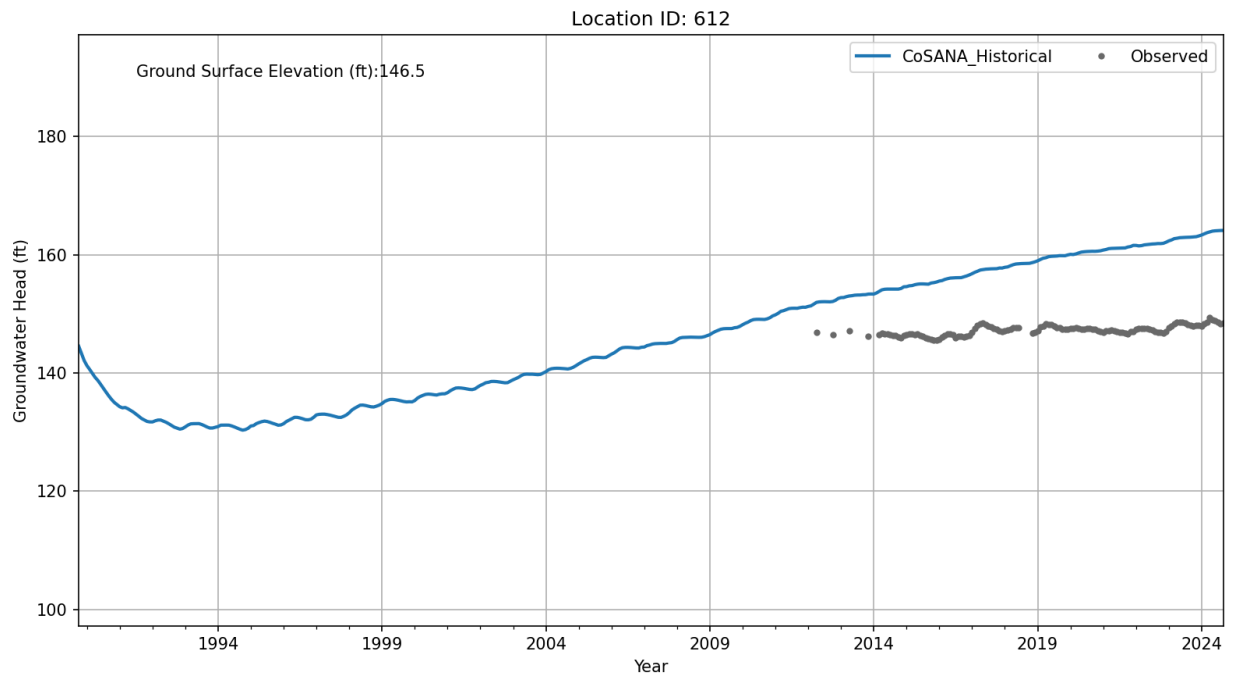


Figure 3-17: NASb Groundwater Level Hydrograph – Hydrograph #3

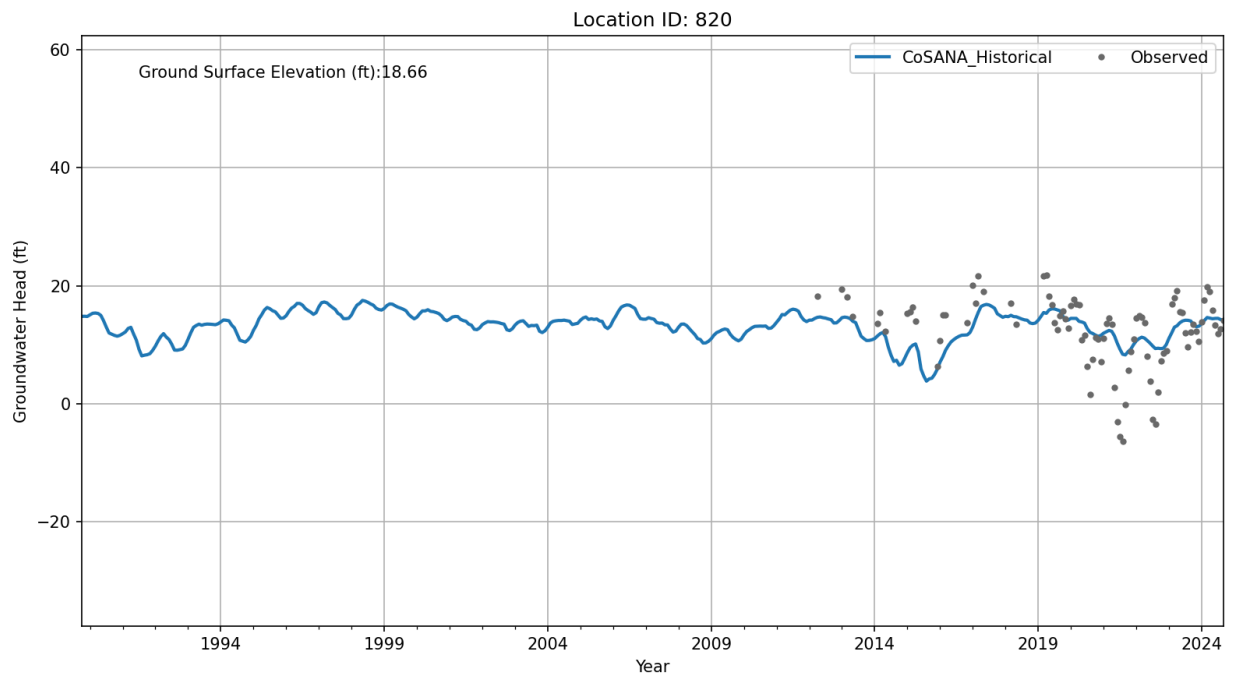


Figure 3-18: NASb Groundwater Level Hydrograph – Hydrograph #4

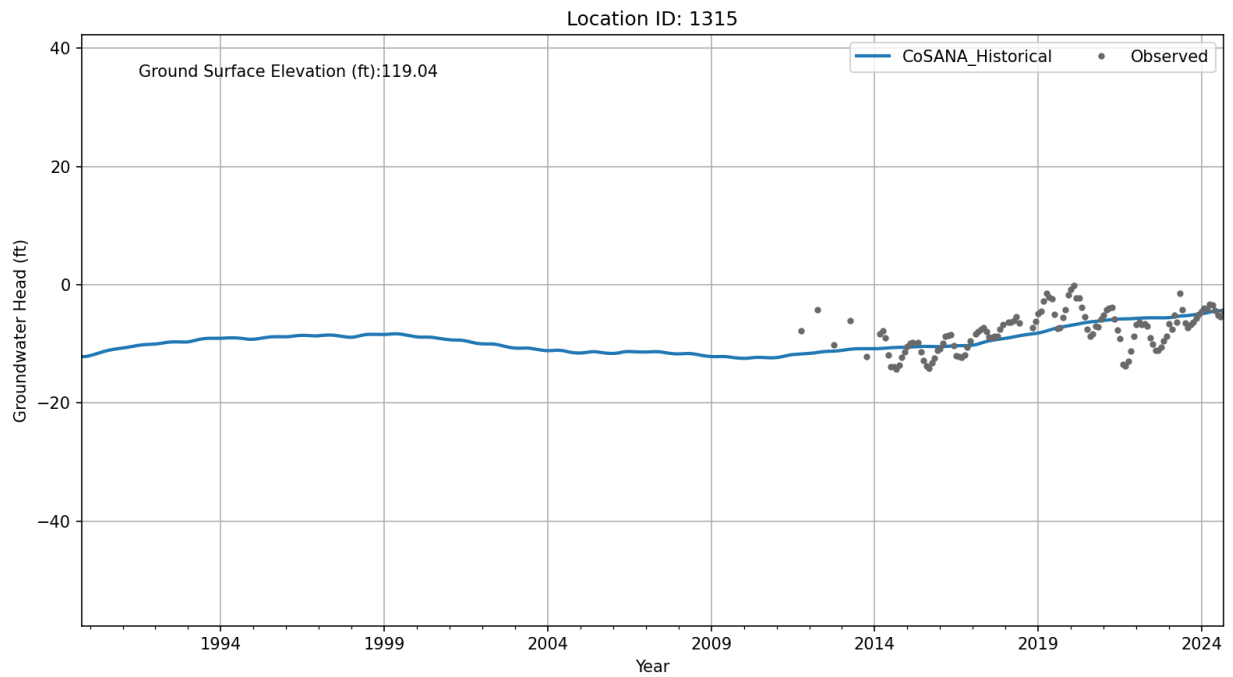


Figure 3-19: NASb Groundwater Level Hydrograph – Hydrograph #5

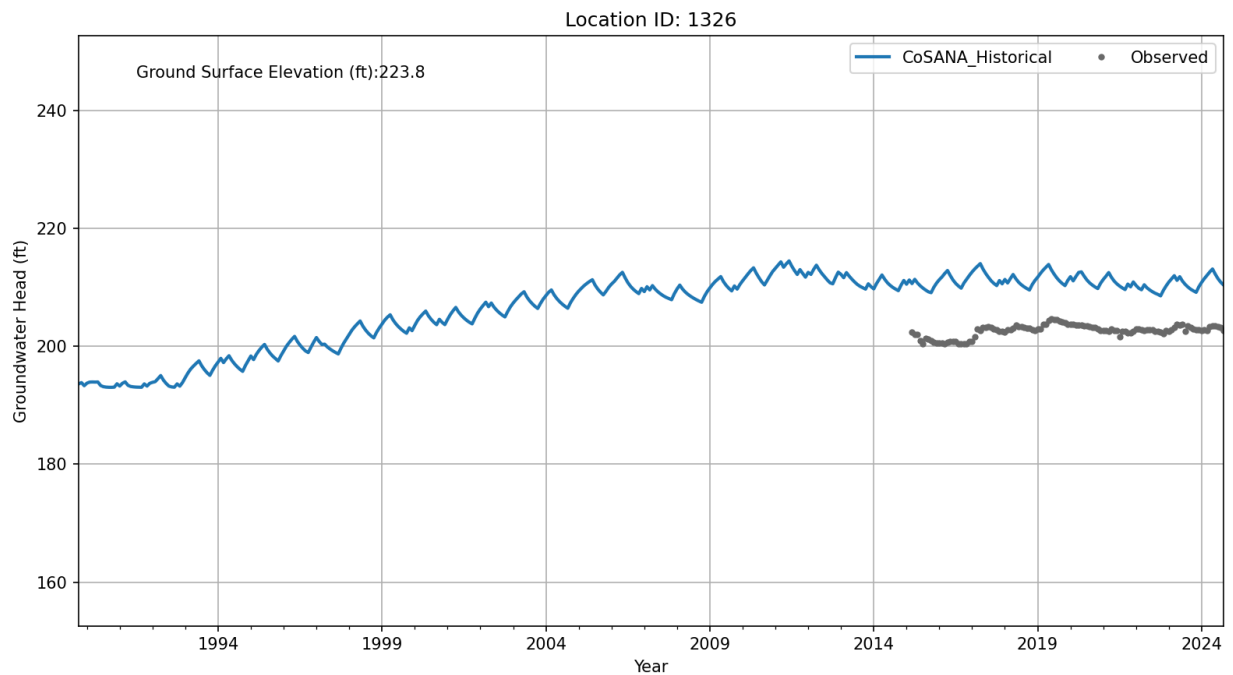


Figure 3-20: NASb Groundwater Level Hydrograph – Hydrograph #6

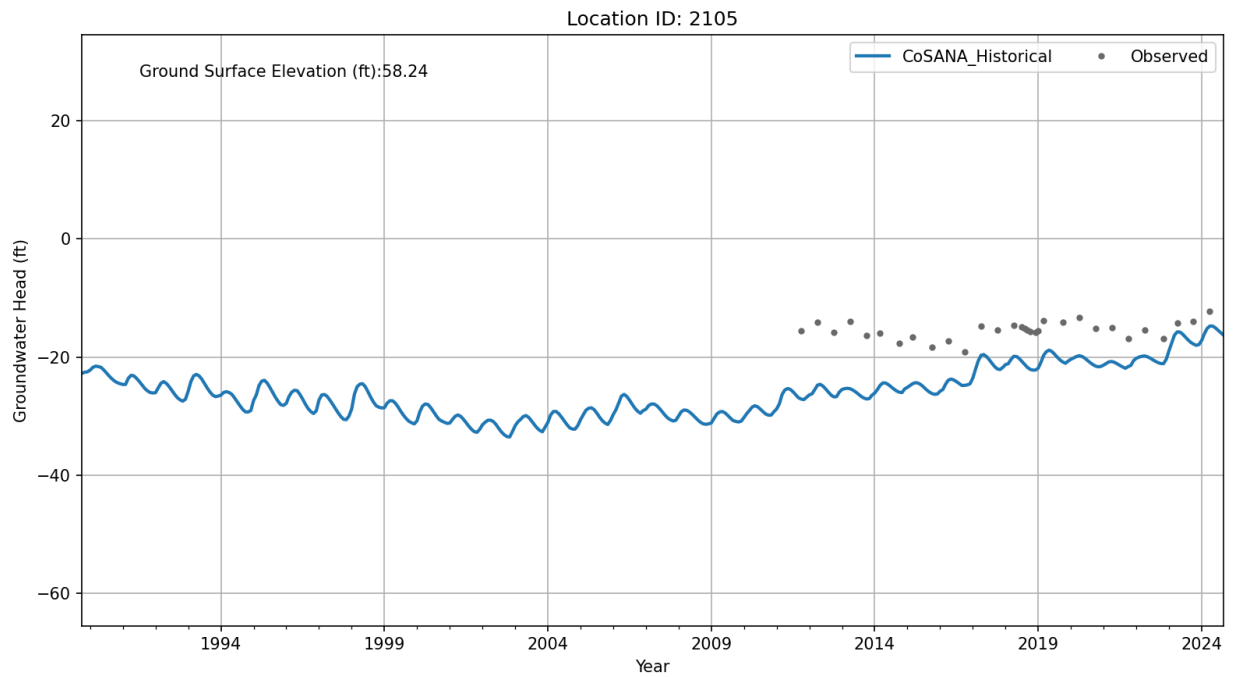


Figure 3-21: NASb Groundwater Level Hydrograph – Hydrograph #7

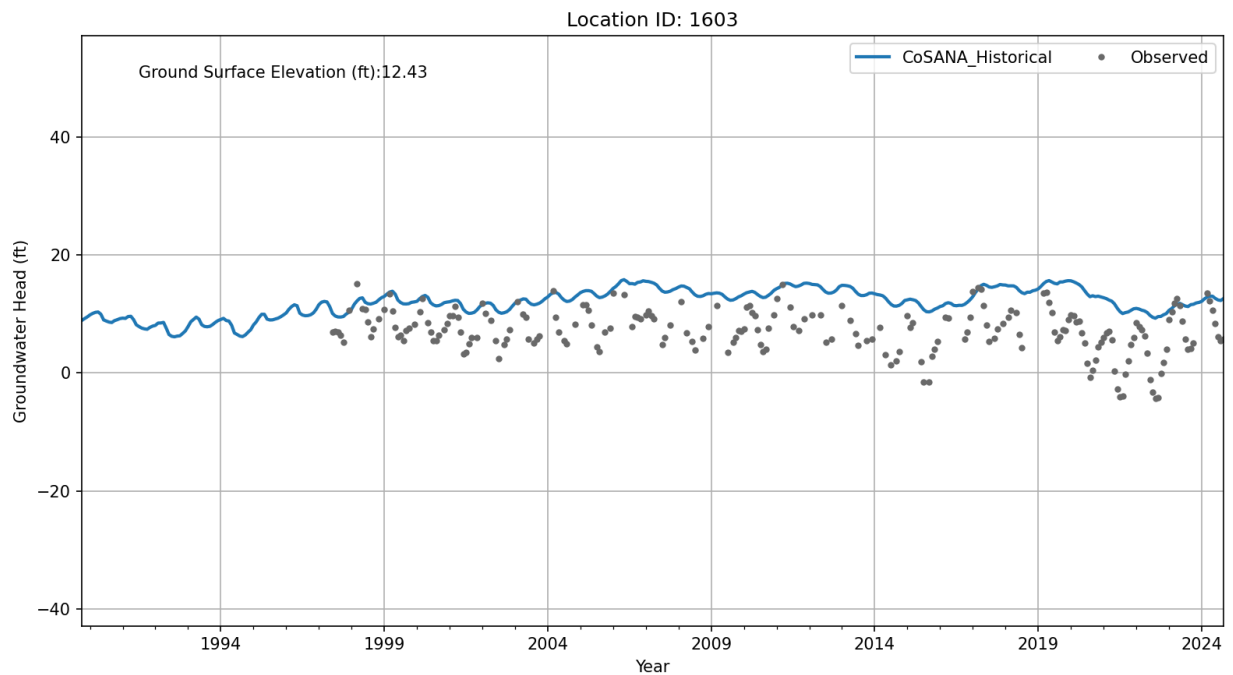


Figure 3-22: NASb Groundwater Level Hydrograph – Hydrograph #8

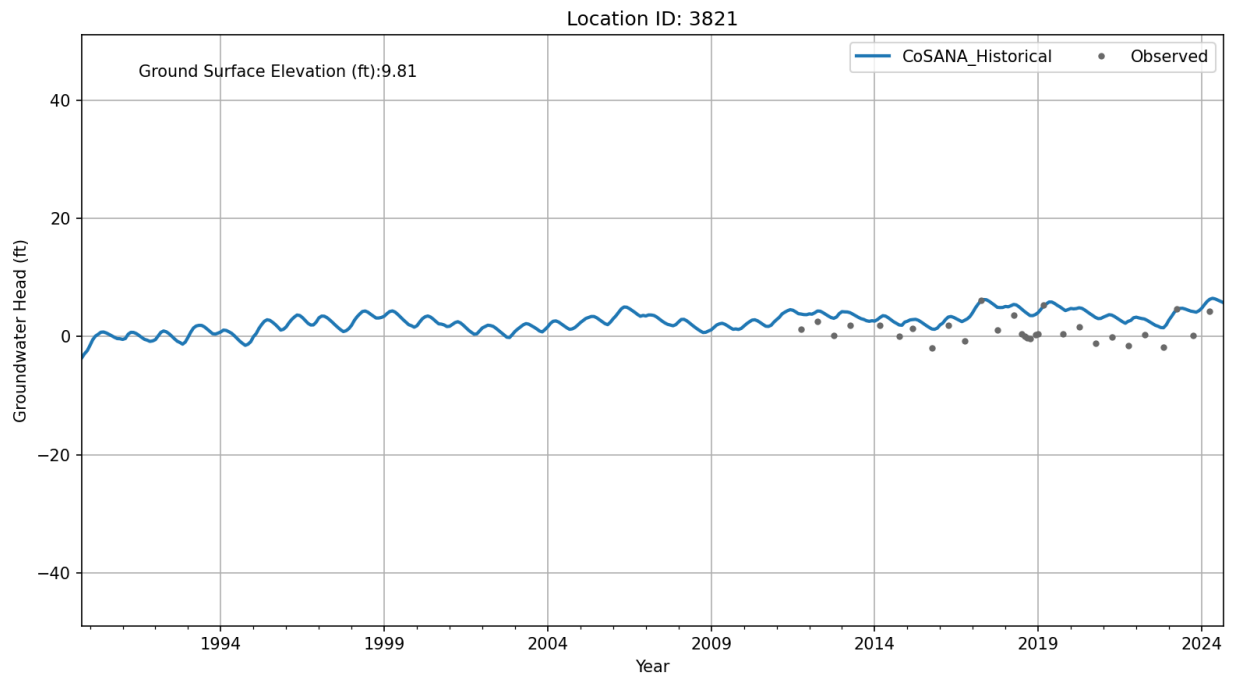


Figure 3-23: NASb Groundwater Level Hydrograph – Hydrograph #9

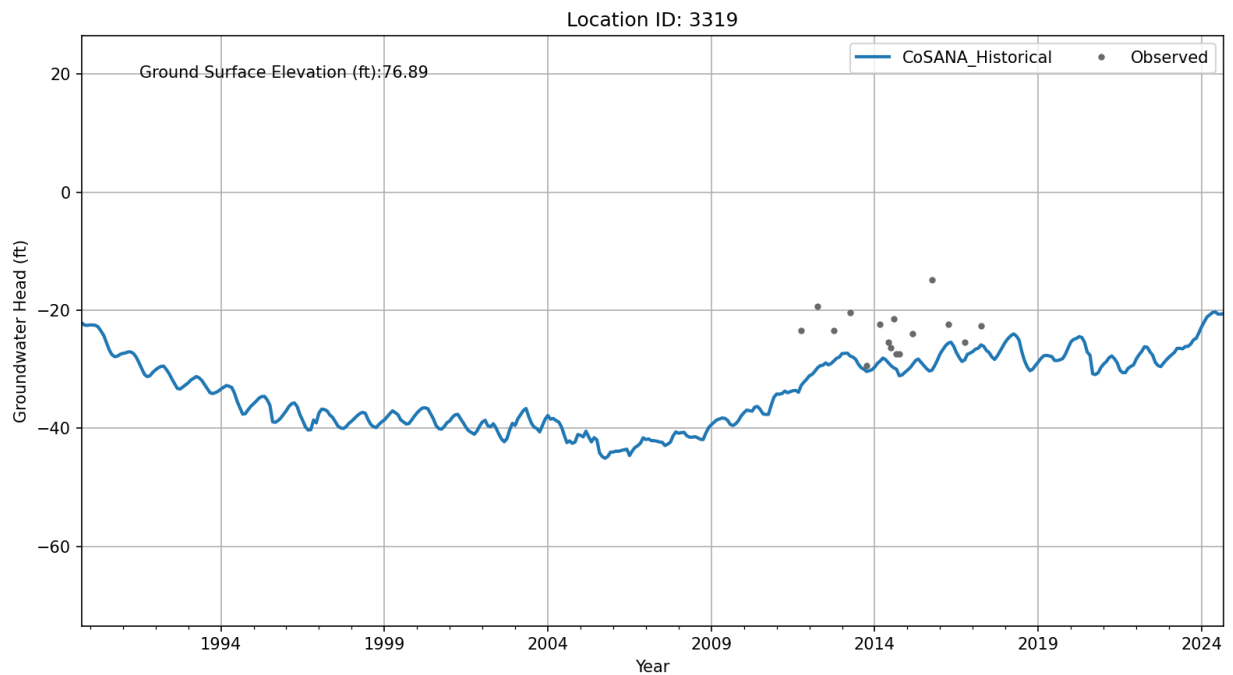


Figure 3-24: NASb Groundwater Level Hydrograph – Hydrograph #10

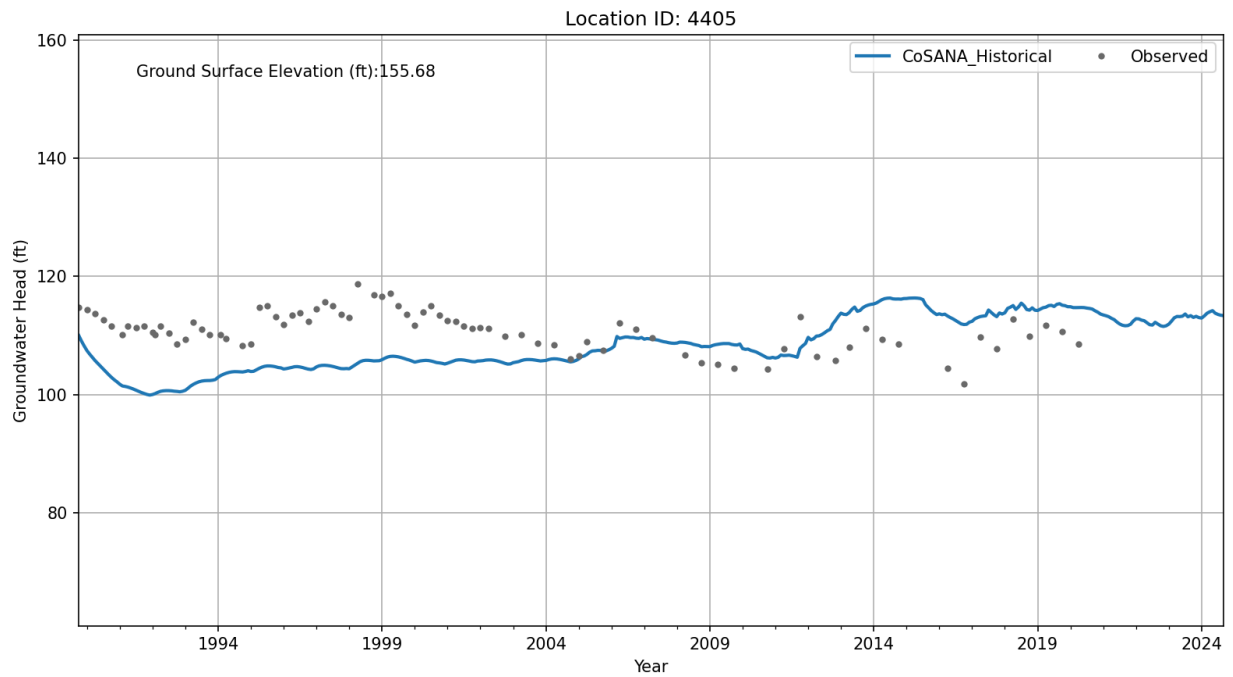


Figure 3-25: NASb Groundwater Level Hydrograph – Hydrograph #11

3.1.3 Streamflow Calibration

Similar to the process of calibration for groundwater levels, streamflows were calibrated to achieve reasonable agreement between the simulated and observed streamflows at the gaging stations. Streamflow gaging stations near the eastern boundary of the model are used for inflow data. Other streamflow gaging stations are downstream of these inflow points and associated observed streamflow data were compared to simulated streamflow in the calibration process. The comparison assisted in modifications to parameters associated with stream aquifer interaction.

Streamflow calibration is primarily performed by comparing the simulated streamflow with local data from several stream gages (Table 4-3 and Figure 4-50 of the CoSANA report [W&C, 2021]). Data for these gages came from USGS or CDEC.

Streamflow calibration, including PEST-assisted calibration, consisted of refinement of streambed thickness and hydraulic conductivity.

3.2 Calibration Statistics and Goodness of Fit

The CoSANA calibration for the NASb was primarily assessed using two metrics: groundwater level trends and the correlation between simulated and observed groundwater levels. In addition to quantifiable metrics, the calibration included comparisons and modifications to result in regional groundwater flow directions and water budgets that are consistent with available information on observed conditions.

Statistics related to the differences between simulated and observed groundwater levels were evaluated to achieve an acceptable residual (simulated head minus the observed head). The calibration exceeds the acceptable residual, as shown by the following statistics.

- 65% of observed groundwater levels are within +/- 10 feet of its respective simulated values.
- 87% of observed groundwater levels are within +/- 20 feet of its respective simulated values.
- 95% of observed groundwater levels are within +/-30 feet of its respective simulated values.

The residual histogram for the NASb area is shown in **Figure 3-26**. Additionally, a scatter plot of simulated versus observed values is shown in **Figure 3-27**.

3.3 Final Calibration Parameters

The parameters resulting from the calibration process are listed in **Table 3-3**. The spatial distribution of horizontal hydraulic conductivity is presented in **Figure 3-28** through **Figure 3-32**.

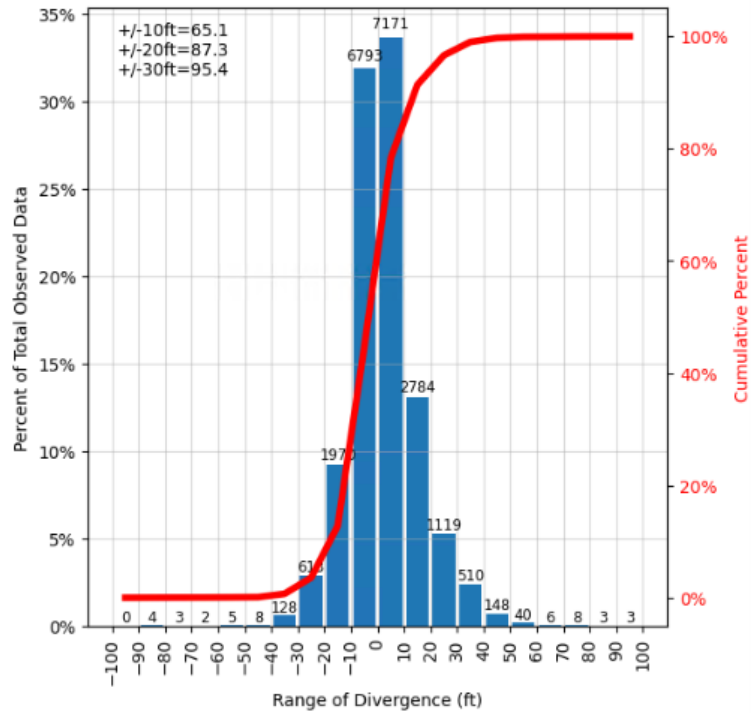


Figure 3-26: Residual Histogram for the NASb Area

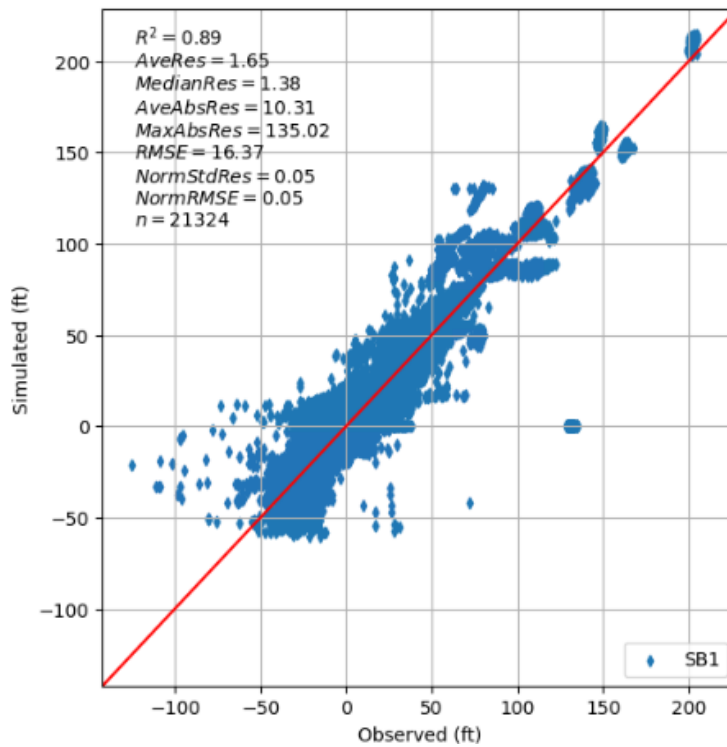


Figure 3-27: Scatter Plot of NASb Simulated versus Observed Values

Table 3-3: Range of Aquifer Parameters Values in NASb

Data		Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Horizontal Hydraulic Conductivity (ft/day)	Minimum	5.9	4.5	3.35	0.34	0.21
	Average	40.9	23.8	13.6	13.1	9.1
	Maximum	93.3	63.7	38.8	37.5	33.8
Vertical Hydraulic Conductivity (ft/day)	Minimum	0.104	0.0799	0.06043	0.0188	0.0139
	Average	1.51	0.89	0.50	0.46	0.39
	Maximum	4.2	2.7	1.8	1.9	1.7
Specific Storage (unitless)	Minimum	2.67×10^{-6}	1.88×10^{-6}	1.54×10^{-6}	1.15×10^{-6}	9.80×10^{-6}
	Average	6.30×10^{-5}	6.40×10^{-5}	5.95×10^{-5}	6.09×10^{-5}	7.52×10^{-5}
	Maximum	4.73×10^{-4}	4.59×10^{-4}	4.68×10^{-4}	4.91×10^{-4}	4.96×10^{-4}
Specific Yield (unitless)	Minimum	0.060	0.063	0.052	0.078	0.045
	Average	0.13	0.13	0.14	0.14	0.11
	Maximum	0.22	0.22	0.23	0.21	0.21
Transmissivity (ft ² /day)	Minimum	183.33	234.607	175.868	2.99	3.30
	Average	3,332	5,032	6,988	2,282	1,747
	Maximum	13,639	21,982	36,023	6,584	4,856

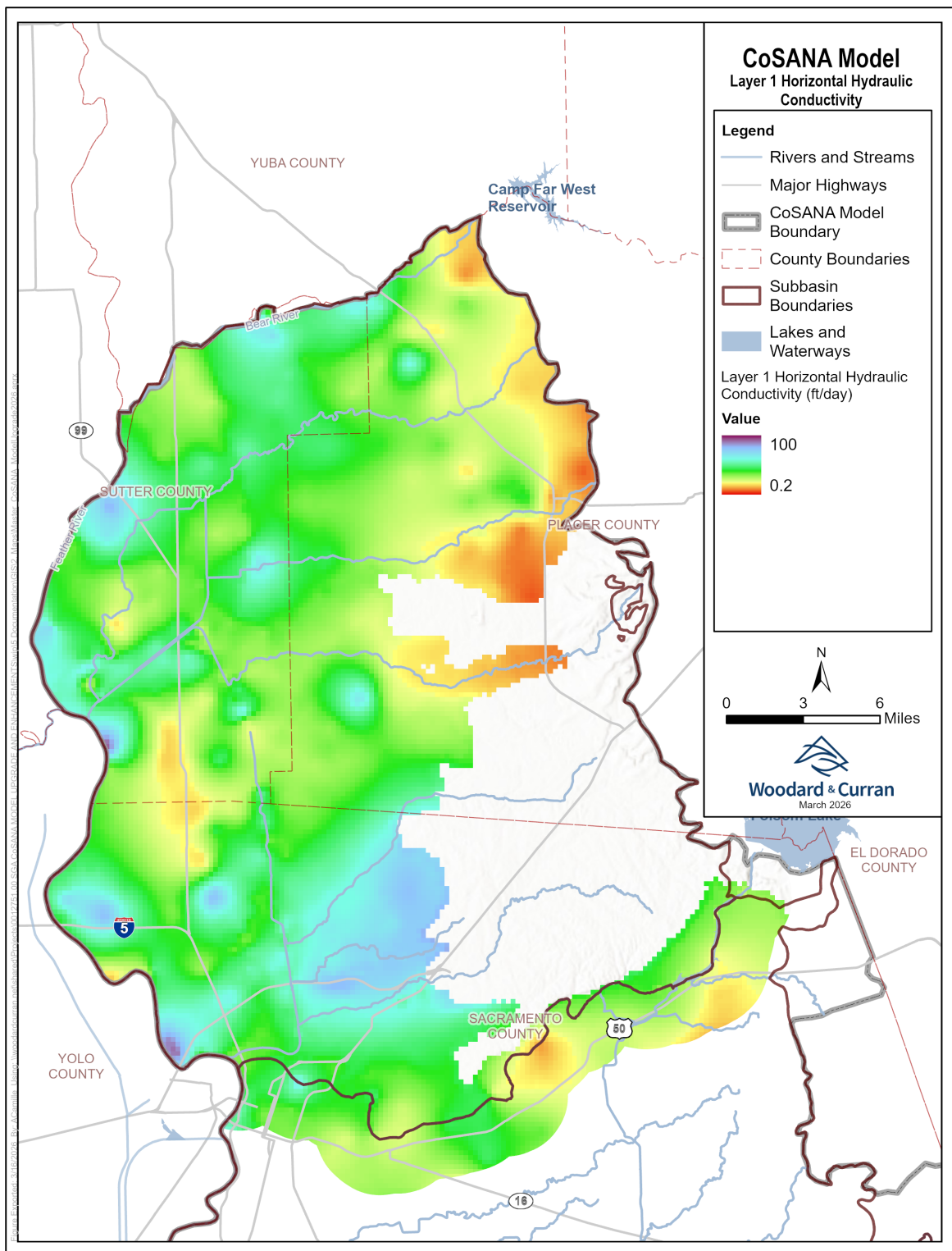


Figure 3-28: Distribution of NASb Layer 1 Horizontal Hydraulic Conductivity (K_H)

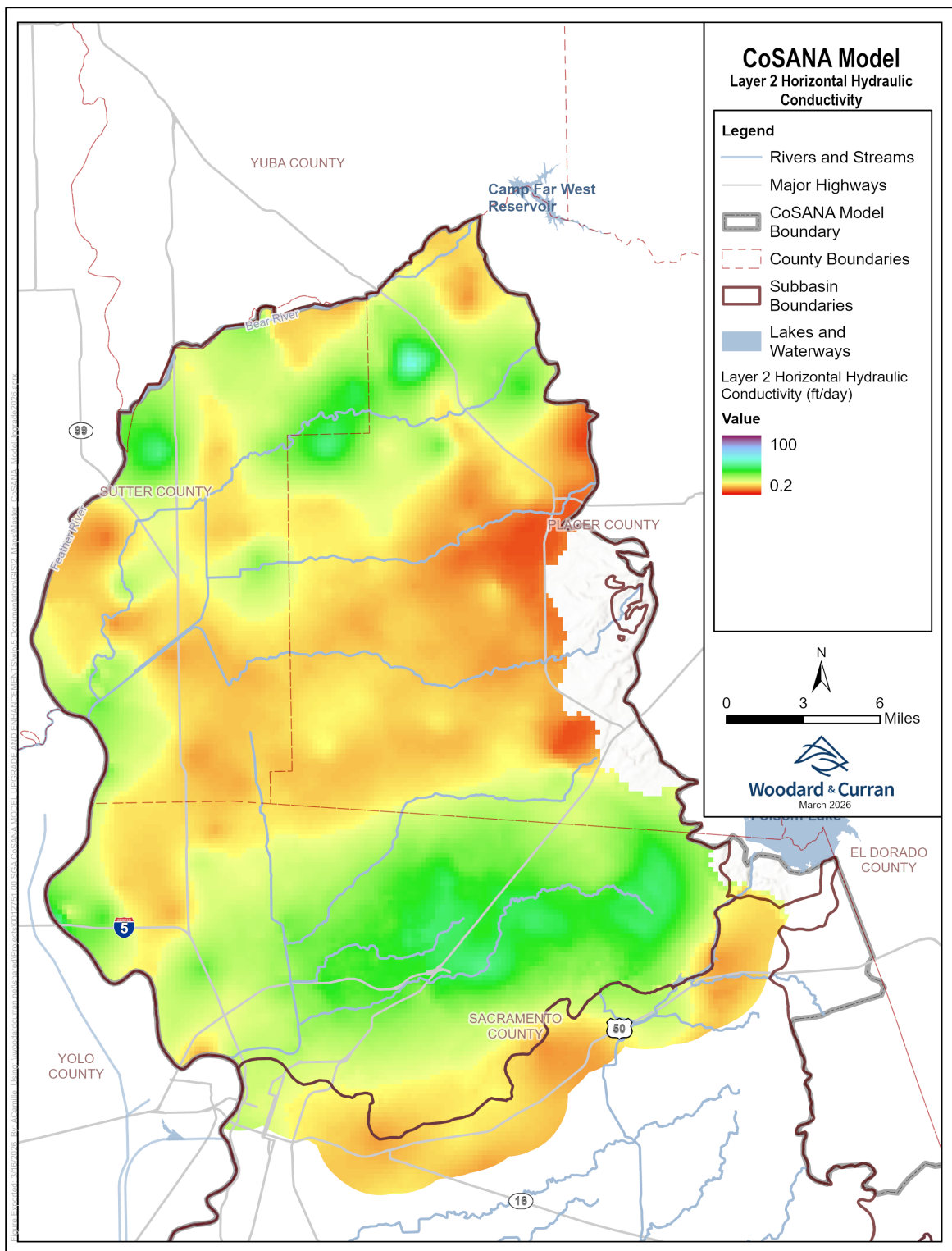


Figure 3-29: Distribution of NASb Layer 2 Horizontal Hydraulic Conductivity (K_H)

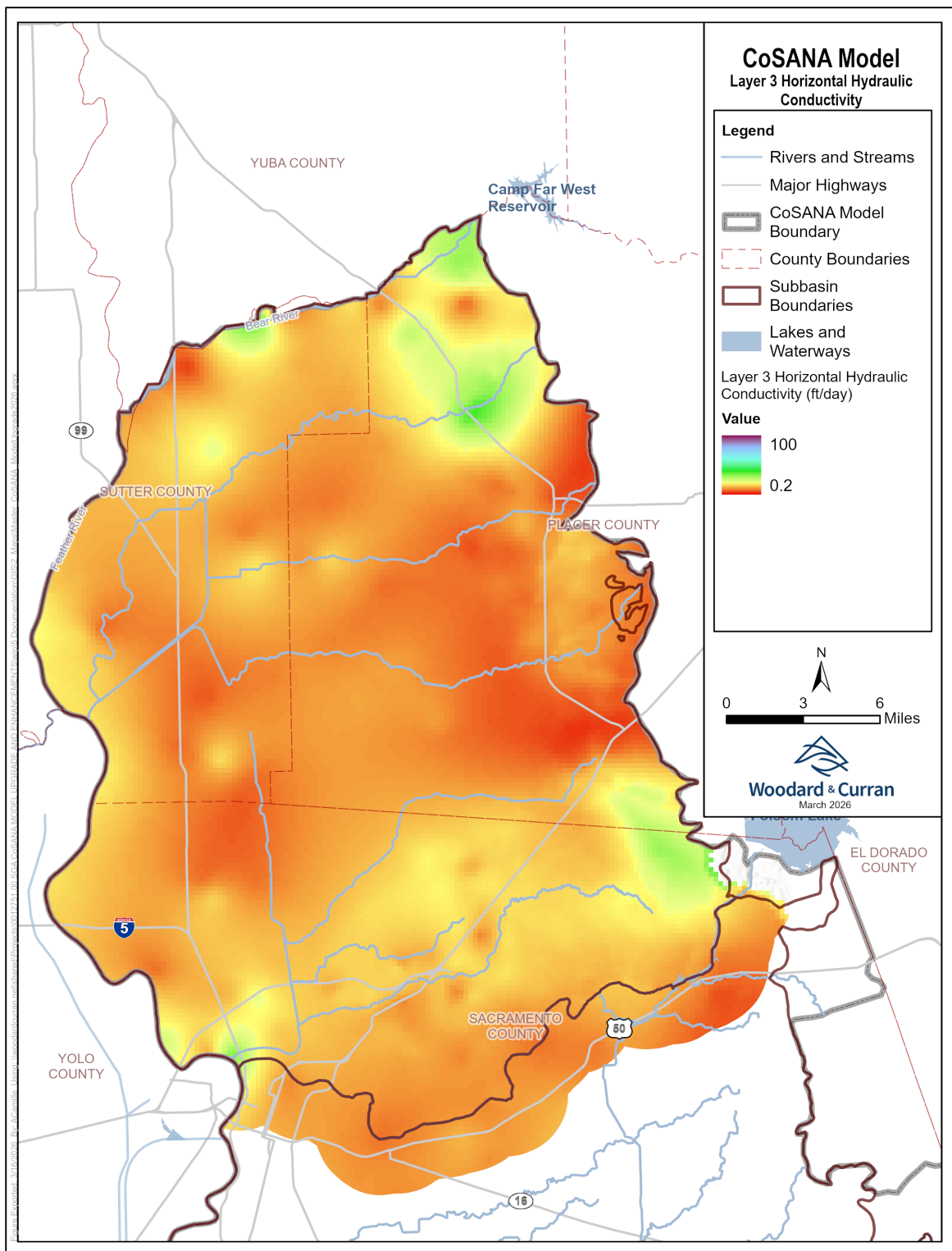


Figure 3-30: Distribution of NASb Layer 3 Horizontal Hydraulic Conductivity (KH)

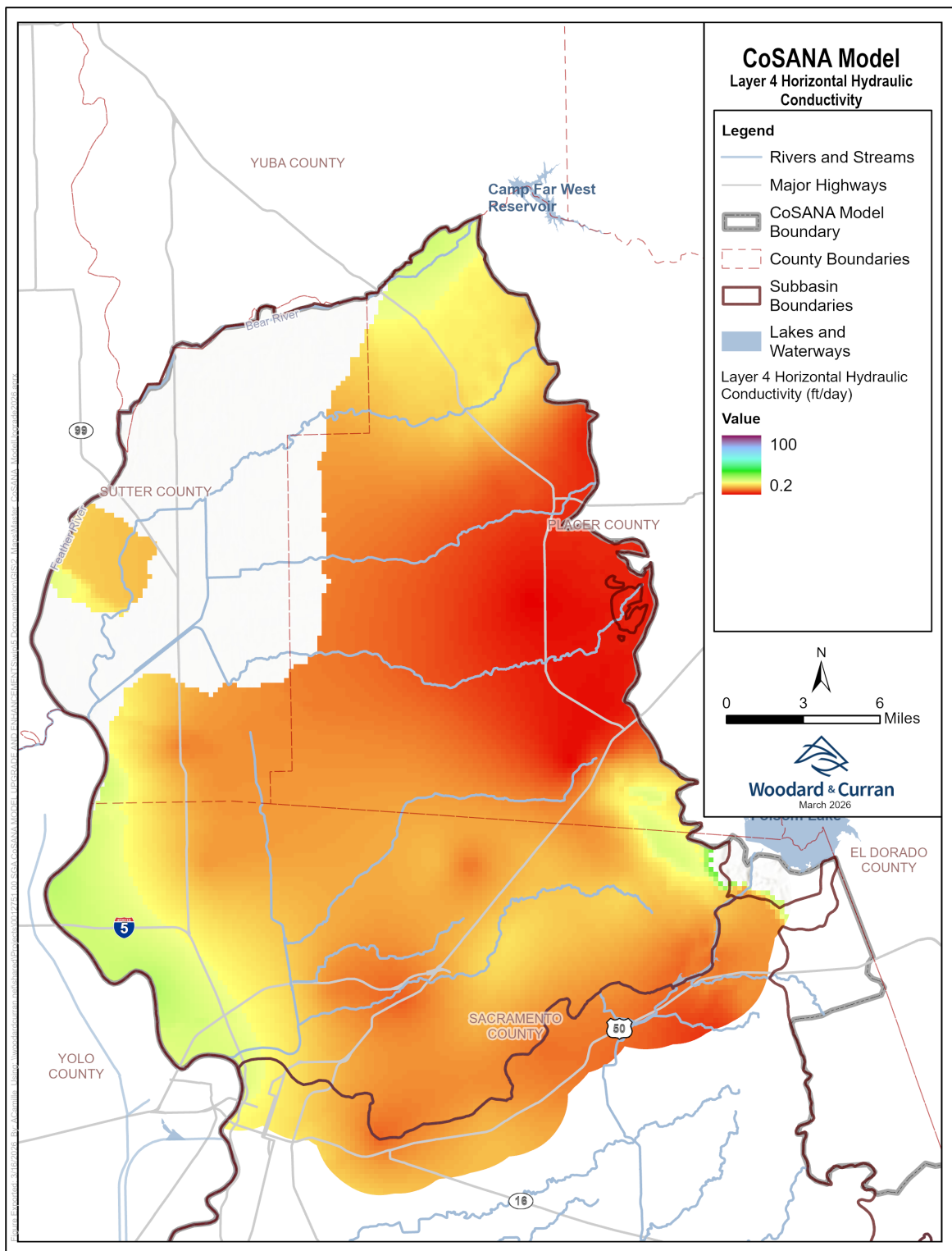


Figure 3-31: Distribution of NASb Layer 4 Horizontal Hydraulic Conductivity (K_H)

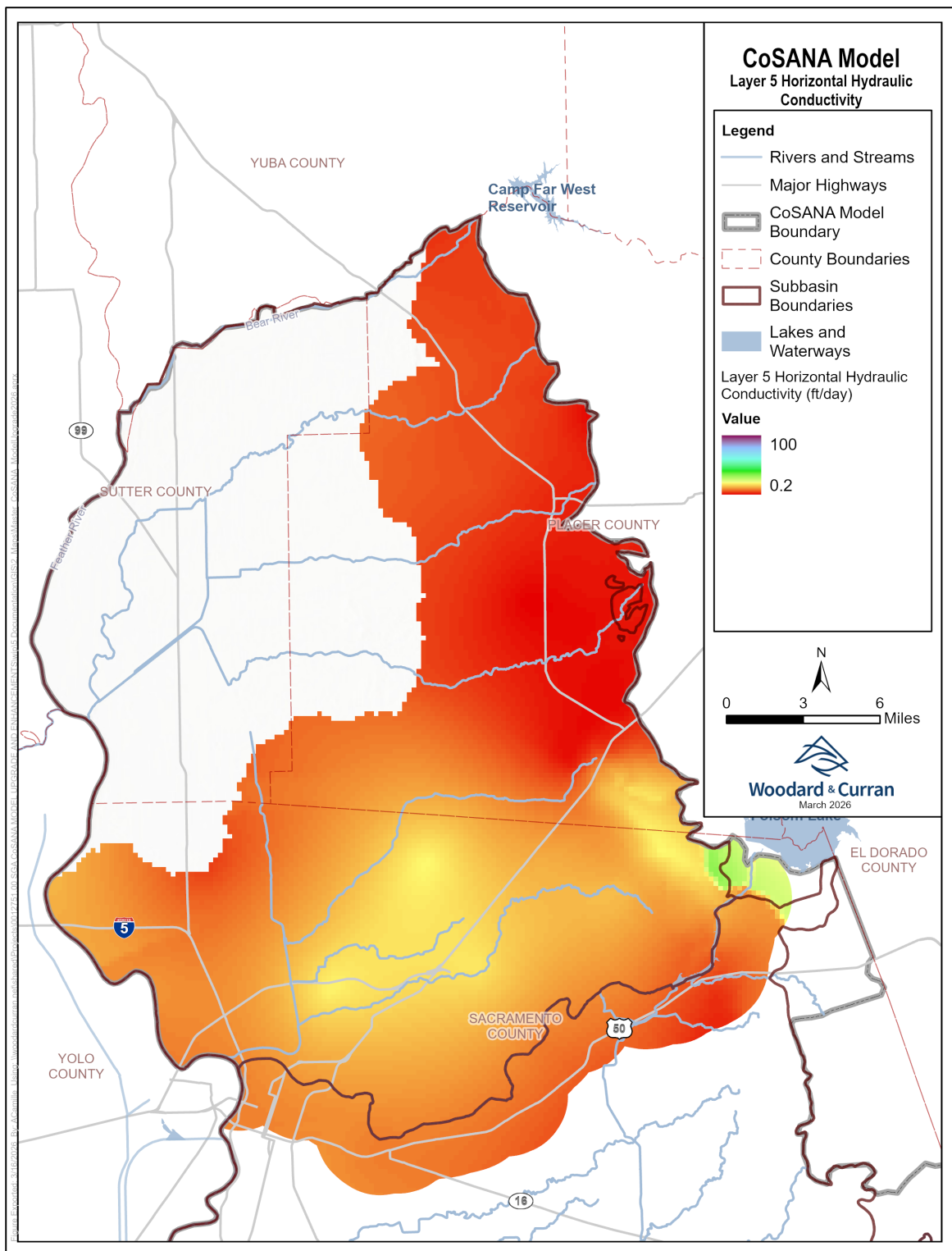


Figure 3-32: Distribution of NASb Layer 5 Horizontal Hydraulic Conductivity (K_H)

4. BASELINE MODELS UPDATES

Integrated hydrologic and water resources models are used to evaluate effects, benefits, and impacts of projects and management action scenarios under a set of baseline conditions. These baseline conditions can represent a set of pre-established hydrologic, land and water use, water demand, water supply, and basin operational conditions (W&C, 2021). As part of the development of the NASb GSP, three sets of baseline conditions have been defined for the CoSANA model. These represent the current, projected, and projected under climate change baseline conditions.

Following are descriptions of the assumptions and results for each of these baseline scenarios.

4.1 Current Conditions Baseline (CCBL) Model

The CoSANA Current Conditions Baseline (CCBL) is a representation of long-term average conditions assuming that a recent level of development and water demand persists over a long-term period of hydrologic conditions. Initial groundwater levels and soil conditions in the CCBL represent those at the end of WY 2018, which is consistent with those used in the 2022 GSP CCBL as documented in the CoSANA report (W&C, 2021).

4.1.1 Hydrology

The CCBL uses a 55-year historical hydrology from water year (WY) 1970 through 2024 (October 1, 1969, through September 30, 2024) for precipitation, evapotranspiration, and streamflow.

4.1.1.1 Precipitation

The baseline conditions assume that the historical hydrology is repeated. As such, the precipitation records for WYs 1970-2024 are used for baseline. This is consistent with the statewide planning approach used by DWR. Precipitation for the historical hydrologic record, discussed in **Section 2.1** is based on the PRISM database for the entire period of record. The average precipitation across the entire model area is 19.9 inches, with a minimum of 7.5 inches in WY 1977 and a maximum of 38.9 inches in WY 1983.

Figure 4-1 graphically illustrates the cumulative departure of the spatially averaged rainfall within the CoSANA model area. The figure includes bars displaying annual precipitation for each water year from WY 1970 through 2024 and a horizontal line representing the long-term mean precipitation of 19.9 inches. The colors of the bars correspond to the three water year types (wet, normal, and dry) represented in the baseline simulations. A detailed description of the water year types of assumptions is provided in **Section 4.1.1.4**. The cumulative departure from mean precipitation is displayed as a line that highlights wet periods with upward slopes (positive departure) and dry periods with downward slopes (negative departure). More severe events are shown by steeper slopes and greater changes (W&C, 2021).

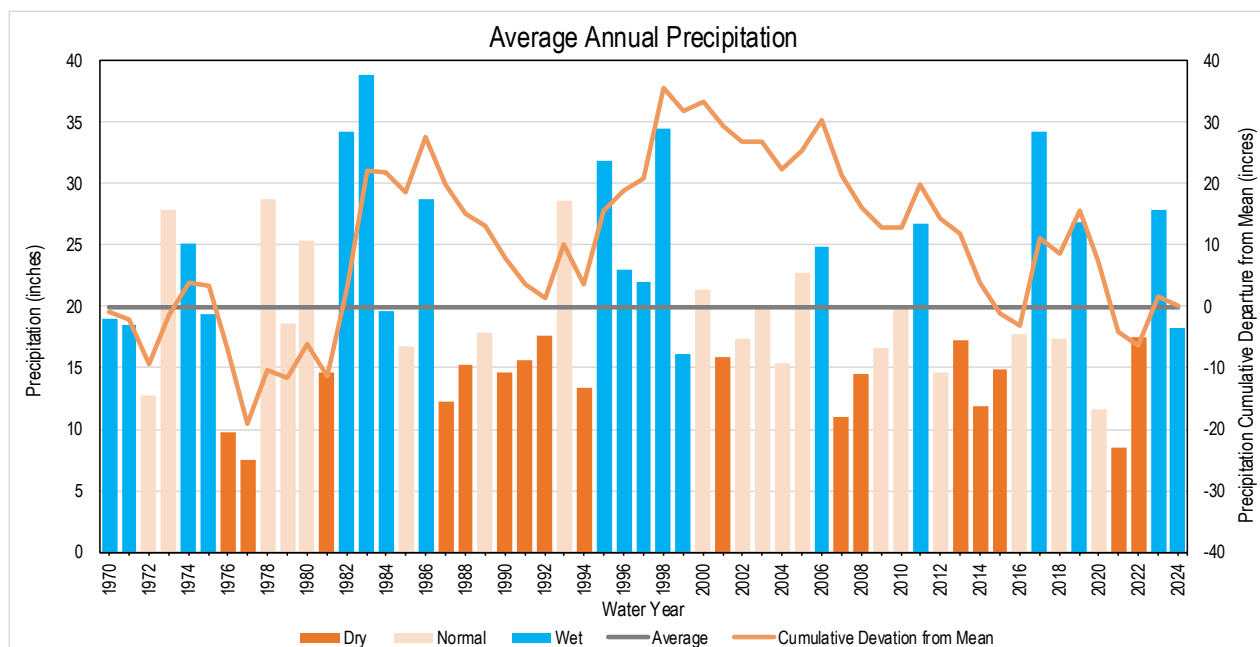


Figure 4-1: 55-Year Historical Precipitation and Cumulative Departure from Mean Precipitation

4.1.1.2 Evapotranspiration (ET)

The crop ET requirement is based on values from regional modeling (C2VSimFG) and associated California Irrigation Management Information System (CIMIS) Zones 12 and 14. The ET used in the historical simulation was extended through WY 2024 for use in the CCBL.

4.1.1.3 Stream Inflow

Stream inflows are from stream gaging stations at the upstream area of CoSANA river reaches. As the CCBL uses the historical hydrologic conditions as the basis for planning the baseline conditions, the stream inflows used in the historical simulation were extended through WY 2024 for use in the CCBL.

4.1.1.4 Hydrologic Year Types

The 55 years of the CCBL, from WY 1970 through 2024, represent a range of hydrologic conditions, as identified by the water year types in both the Sacramento Valley Water Year Hydrologic Classification and the Water Forum Agreement Year Type.

The Sacramento Valley Water Year Hydrologic Classification classifies water years 1901 through 2024 as Wet (W), Above Normal (AN), Below Normal (BN), Dry (D), and Critical (C) based on inflows to major reservoirs or lakes. A description of how this index is calculated and the specific data used to calculate this index is available online from CDEC at <http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST>. In the 55 years of hydrology used in the CCBL, there are 12 Critical years, 11 Dry years, 6 Below Normal years, 8 Above Normal years, and 8 Wet years.

The Water Forum Agreement (WFA) outlines specific year types for water management based on the amount of unimpaired inflow to Folsom Lake during the March–November period. The “Water Year Types as Defined by Water Forum Agreement” published by SGA provides explicit thresholds for four WFA Year Types for Wet (No Restrictions), Average (Hodge Year), Drier (Wedge Year), and Driest (Conference Year) years. This one-page document is available online at <https://www.sqah2o.org/wp-content/uploads/2017/02/Water-Year-Types-as-Defined-by-Water-Forum->

[Agreement.pdf](#). In the 55 years of hydrology used in the CCBL, there are 2 Driest years, 13 Drier years, 12 Average years, and 28 Wet years.

To facilitate assumptions for baseline water supplies and demands, these water year types were simplified into three water year types, as shown in **Table 4-1**. These three baseline water year types are used in the remainder of the CCBL data development and results discussion.

Table 4-1: Hydrologic Water Year Types

Baseline Year	Water Year	Sacramento Valley Water Year Hydrologic Classification	Water Forum Agreement Year Type	Baseline Year Type	Baseline Year	Water Year	Sacramento Valley Water Year Hydrologic Classification	Water Forum Agreement Year Type	Baseline Year Type
1	1970	Wet	Average	Wet	29	1998	Wet	Wet	Wet
2	1971	Wet	Wet	Wet	30	1999	Wet	Wet	Wet
3	1972	Below Normal	Average	Normal	31	2000	Above Normal	Wet	Normal
4	1973	Above Normal	Wet	Normal	32	2001	Dry	Drier	Dry
5	1974	Wet	Wet	Wet	33	2002	Dry	Average	Normal
6	1975	Wet	Wet	Wet	34	2003	Above Normal	Wet	Normal
7	1976	Critical	Drier	Dry	35	2004	Below Normal	Average	Normal
8	1977	Critical	Driest	Dry	36	2005	Above Normal	Wet	Normal
9	1978	Above Normal	Wet	Normal	37	2006	Wet	Wet	Wet
10	1979	Below Normal	Wet	Normal	38	2007	Dry	Drier	Dry
11	1980	Above Normal	Wet	Normal	39	2008	Critical	Drier	Dry
12	1981	Dry	Drier	Dry	40	2009	Dry	Average	Normal
13	1982	Wet	Wet	Wet	41	2010	Below Normal	Wet	Normal
14	1983	Wet	Wet	Wet	42	2011	Wet	Wet	Wet
15	1984	Wet	Average	Wet	43	2012	Below Normal	Average	Normal
16	1985	Dry	Average	Normal	44	2013	Dry	Drier	Dry
17	1986	Wet	Wet	Wet	45	2014	Critical	Drier	Dry
18	1987	Dry	Drier	Dry	46	2015	Critical	Driest	Dry
19	1988	Critical	Drier	Dry	47	2016	Dry	Wet	Normal
20	1989	Dry	Wet	Normal	48	2017	Wet	Wet	Wet
21	1990	Critical	Drier	Dry	49	2018	Below Normal	Wet	Normal
22	1991	Critical	Average	Dry	50	2019	Wet	Wet	Wet
23	1992	Critical	Drier	Dry	51	2020	Dry	Average	Normal
24	1993	Above Normal	Wet	Normal	52	2021	Critical	Drier	Dry
25	1994	Critical	Drier	Dry	53	2022	Critical	Average	Dry
26	1995	Wet	Wet	Wet	54	2023	Wet	Wet	Wet
27	1996	Wet	Wet	Wet	55	2024	Above Normal	Wet	Wet
28	1997	Wet	Average	Wet					

4.1.2 Initial Conditions

The initial conditions for the 55-year CCBL, similar to CoSANA 2021 model version (W&C, 2021), are defined as the groundwater, surface water, and hydrologic conditions of end of WY 2018. This is retained for the sake of consistency at this stage of analysis and for the current version of CCBL. The initial conditions can be updated for other upcoming projects, such as the analysis needed for the SRWB to reflect the conditions needed for analysis of impacts.

4.1.3 Boundary Conditions

CCBL boundary conditions are based on an average for each baseline water year type (normal, wet, and dry) during the last 15 years of the historical simulation (WYs 2010-2024). This averaging is applied to the constrained head

boundary conditions that represent Lake Camanche in the southeast corner of the model, and the general head boundary conditions that represent groundwater levels to the north, south, and west of the model boundary. Water year type averaging is not applied to the small watersheds from the eastern boundary of the model, as these are driven by hydrology (precipitation and evapotranspiration).

4.1.4 Land Use

The land use conditions reflecting the CCBL are similar to that used in the W&C 2021 model report and CoSANA 2021 model version. This is primarily due to the need for consistency to be able to compare the updated model results with those reported in 2021. However, for upcoming projects, such as the SRWB, the land use conditions prevailing in the subbasin can be analyzed and adapted in the model to reflect the current conditions.

A spatial representation of the current version of CCBL land use is shown in **Figure 4-2**. The time-series of land use for the CCBL in the NASb is shown in **Figure 4-3**, highlighting the constant nature of land and water use in the baseline conditions.

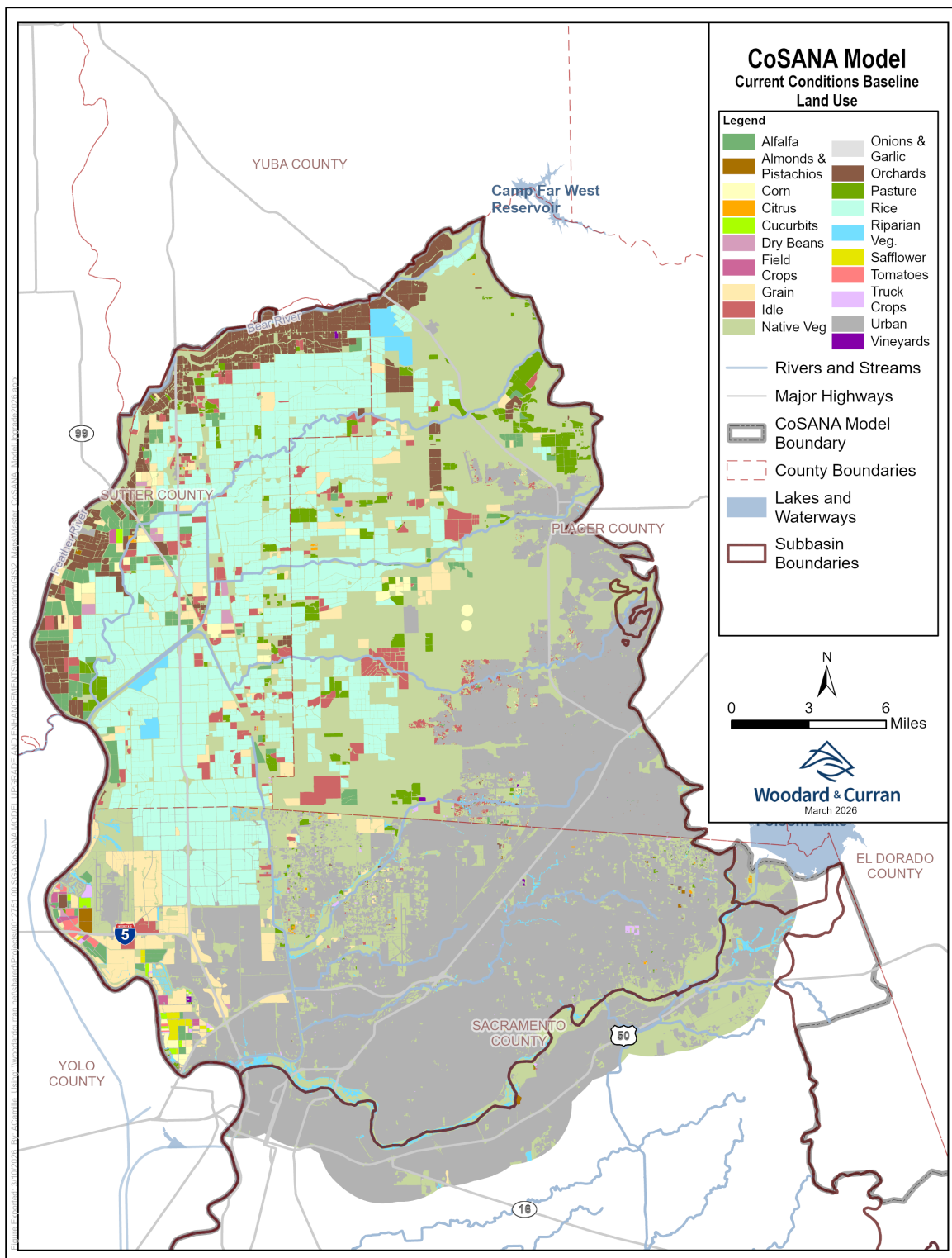


Figure 4-2: Current Conditions Baseline Land Use

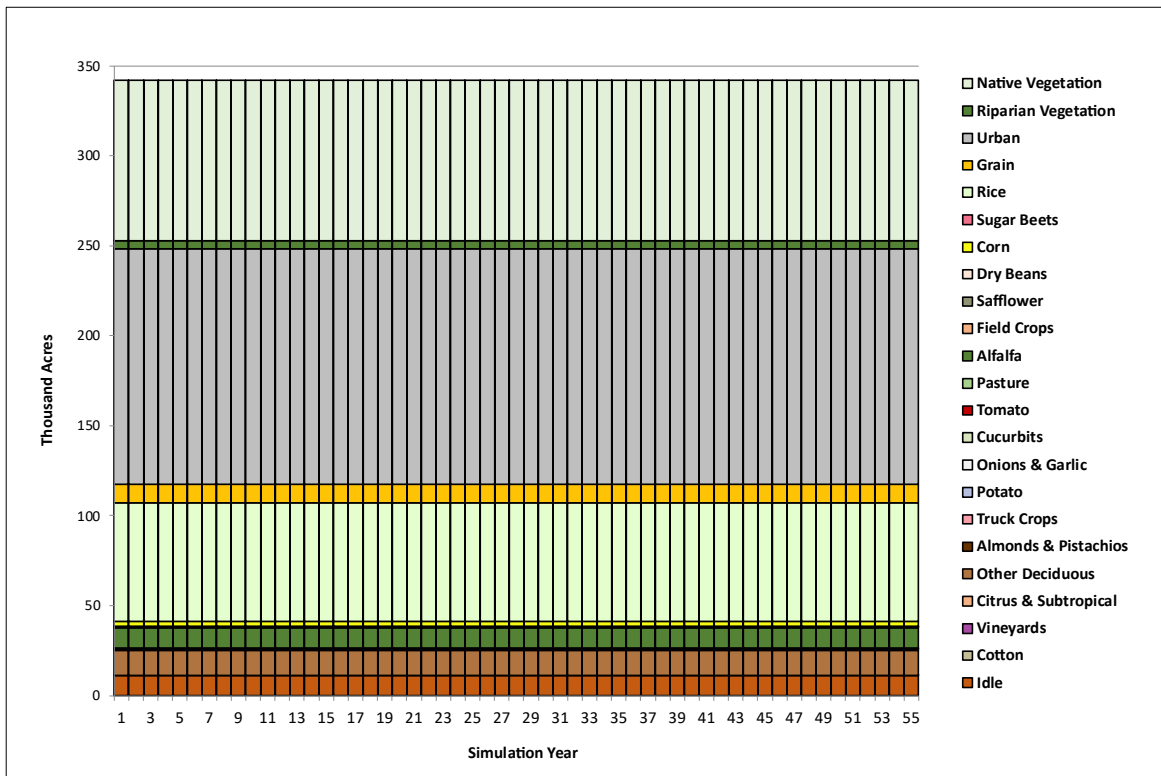
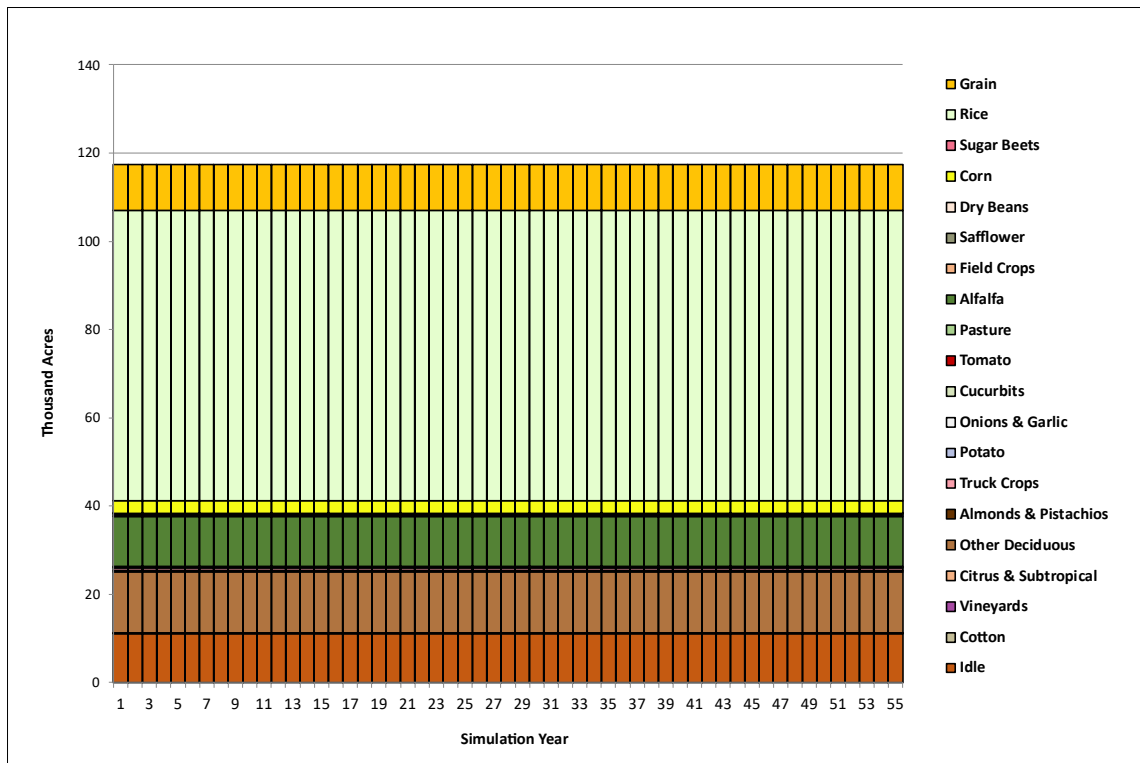


Figure 4-3: Current Conditions Baseline Land Use for NASb

4.1.5 Urban Demand and Supply

Urban water demand assumptions in the CCBL are based on the 2020 conditions from the 2020 Urban Water Management Plans (UWMPs) for purveyors in the NASb.

Urban water supply in the CCBL, including surface water deliveries and groundwater pumping, are calculated using the method described below, unless exceptions are listed in the individual purveyor sections that follow. To estimate CCBL water supply, the information for the last 15 years of the historical simulation (WYs 2010 through 2024) was averaged by the three baseline water year types (normal, wet, and dry) described in **Section 4.1.1.4** WY 2010 through 2024 contains five normal years (2010, 2012, 2016, 2018, and 2020); five wet years (2011, 2017, 2019, 2023, and 2024); and five dry years (2013, 2014, 2015, 2021 and 2022). The water supply conditions for these three baseline year types were applied to the 55 years of hydrology within the CCBL. The surface water deliveries and groundwater pumping supplies were calculated using the proportional averages developed from the last 15 years of the historical simulation to meet the urban demand for each purveyor. For the purpose of the modeling, supply was assumed to meet the demand with no surplus or shortage.

Average pumping by baseline year type was distributed in the CCBL to all active wells by purveyor based on their proportion of the historical simulation purveyor totals. Active wells are defined as those wells that have been in operation during the period covering WYs 2022-2024.

The CCBL urban demand and supply assumptions are summarized in **Table 4-2**. Additional explanations of the urban demand and supply assumptions for individual purveyors, and for purveyors not utilizing the methodology described above, are provided in the following subsections.

Table 4-2: Current Conditions Baseline Urban Demand and Supply

Purveyor	Service Area	Purveyor Type	2020 UWMP Demand (TAF)	Wet Year Water Use (TAF)			Normal Year Water Use (TAF)			Dry Year Water Use (TAF)		
				GW	SW	RW	GW	SW	RW	GW	SW	RW
California American Water Company	Antelope	GW Reliant	4.5	3.7	0.7	0.0	4.0	0.5	0.0	4.5	0.0	0.0
	Arden	GW Reliant	1.3	1.3	0.0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
	Lincoln Oaks	SW-GW	5.7	4.8	0.9	0.0	5.1	0.6	0.0	5.7	0.0	0.0
	West Placer	SW Reliant	1.1	0.0	1.1	0.0	0.0	1.1	0.0	0.0	1.1	0.0
Carmichael WD	-	SW-GW	9.2	2.8	6.4	0.0	2.8	6.4	0.0	3.6	5.6	0.0
Citrus Heights WD	-	SW-GW	12.5	0.8	11.7	0.0	0.8	11.7	0.0	1.8	10.7	0.0
City of Lincoln	-	SW-GW	10.6	1.1	9.5	0.0	1.1	9.4	0.0	0.7	9.9	0.0
City of Roseville	-	SW Reliant	32.0	0.0	32.0	0.0	0.0	32.0	0.0	0.8	31.2	0.0
City of Sacramento	-	SW-GW	101.6	15.6	86.1	0.0	21.6	80.0	0.0	44.3	57.3	0.0
Del Paso Manor WD	-	GW Reliant	1.2	1.2	0.0	0.0	1.2	0.0	0.0	1.2	0.0	0.0
Fair Oaks WD	-	SW-GW	10.5	2.4	8.0	0.0	1.6	8.8	0.0	2.3	8.2	0.0
Golden State WC	Arden	GW Reliant	1.5	1.5	0.0	0.0	1.5	0.0	0.0	1.5	0.0	0.0
Orange Vale WC	-	SW Reliant	4.2	0.0	4.2	0.0	0.0	4.2	0.0	0.0	4.2	0.0
Rio Linda Elverta CWD	-	GW Reliant	2.8	2.8	0.0	0.0	2.8	0.0	0.0	2.8	0.0	0.0
San Juan Retail	-	SW Reliant	11.8	0.0	11.8	0.0	0.0	11.8	0.0	0.0	11.8	0.0
Sacramento Suburban WD	North	GW Reliant	24.0	13.2	10.8	0.0	15.1	9.0	0.0	22.0	2.0	0.0
	South	GW Reliant	15.9	10.6	5.3	0.0	10.6	5.3	0.0	10.6	5.3	0.0
Sacramento County WA	Arden	GW Reliant	3.2	3.2	0.0	0.0	3.2	0.0	0.0	3.2	0.0	0.0
	Northgate	GW Reliant	2.0	2.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0

4.1.5.1 City of Sacramento (in both NASb and SASb)

City of Sacramento's water demand is based on the 2020 UWMP. The City of Sacramento's current supplies include groundwater pumping and surface water supplies that vary by five water year types (wet, normal, drier, drier & critical, and driest years) based on the City of Sacramento's 2017 Groundwater Master Plan (GWMP) (City of Sacramento, 2017). Groundwater pumping assumptions for the CCBL are consistent with the Existing Conditions Baseline developed in the 2017 GWMP for wet and normal years. For simplicity, the groundwater pumping assumptions for dry years in the CCBL use the average of drier, drier & critical, and driest years in the 2017 GWMP under the Existing Conditions Baseline. Remaining demand not met by groundwater pumping is assumed to be supplied by surface water. The groundwater pumping and surface water supplies for wet, normal, and dry years are provided in **Table 4-2**.

The City of Sacramento also has specific wells that supply certain larger parks and green areas within the city. These irrigation wells are simulated using six representative irrigation wells that pump 2,400 AFY. Based on the locations of the irrigated parks and green areas, approximately half of the irrigation pumping is estimated in the NASb and the remaining half in the SASb.

4.1.5.2 City of Rocklin

- **Demand:** Demand was estimated based on the average of the last 15 years of the historical simulation (WYs 2010 through 2024) in the CCBL.
- **Supply:** All CCBL demand was assumed to be met by surface water.

4.1.5.3 Sacramento International Airport

- **Demand:** Demand was estimated based on the average of the last 15 years of the historical simulation (WYs 2010 through 2024) in the CCBL.
- **Supply:** Demand was assumed to be met by surface water and groundwater supply, proportional to the volumes in the last 15 years of the historical simulation.

4.1.6 Groundwater Substitution Transfers for Municipal Entities

The Groundwater Substitution Transfer schedule is developed based on the South-of-Delta (SOD) Demand and the Jones and Banks Pumping Plants export capacity, which together determine the availability of conveyance for north-to-south transfer water. Under hydrologic and regulatory conditions that limit Delta exports, only select years provide sufficient SOD pumping capacity to accommodate groundwater substitution transfers.

Within the CCBL modeling period (WYs 1970–2024), the years identified as having available transfer capacity include: 1976, 1977, 1981, 1987, 1988, 1990, 1991, 1992, 1994, 2001, 2008, 2013, 2014, 2015, 2021, and 2022.

The allocation of transfer volumes among purveyors participating in the Groundwater Substitution Transfer program is based on their historical groundwater transfer contributions, specifically using records from 2018, 2020, and 2022 (T & Y, Inc. 2019 and 2021, and RWA, 2023). These historical volumes establish a proportional distribution that reflects each purveyor's demonstrated groundwater production capability and past participation levels, ensuring that modeled transfer amounts are grounded in observed operational data.

For purveyors in the NASb, groundwater substitution transfers were estimated using the following assumptions:

- Sacramento Suburban Water District Transferable Water: 5.3 TAF
- City of Sacramento/Sacramento Suburban Water District Intertie Water: 0.8 TAF
- City of Sacramento Transferable Water: 3.0 TAF
- City of Sacramento/Sacramento County Water District Intertie Water: 1.4 TAF
- Carmichael Water District Transferable Water: 1.1 TAF
- Carmichael Water District/Fair Oaks Water District Intertie Water: 0.2 TAF
- Fair Oaks Water District Transferable Water: 1.2 TAF
- Citrus Heights Water District Transferable Water: 1.2 TAF

4.1.7 Agricultural Demand and Supply

Agricultural water demand in the CCBL is estimated within the model using land use, evapotranspiration, precipitation, and other hydrologic and irrigation practices information.

Agricultural water supply in the CCBL is made up primarily of surface water deliveries and groundwater pumping. Surface water deliveries are based on water year type (normal, wet, and dry) averages calculated using the last 15 years of the historical simulation (WYs 2010-2024). Remaining water demand not met by surface water is assumed to be met by groundwater pumping. Agricultural water demand and supply calculation are performed at model element scale. Since information on wells used for agricultural water supplies is very limited, groundwater pumping to meet agricultural water demand is calculated at each model element, rather than physical location of wells.

4.1.7.1 Rural-Residential Pumping

Rural residential pumping for the current conditions baseline is assumed to be the same as the historical model for WY 2024.

4.1.7.2 Groundwater Substitution Transfers for Agricultural Entities

Pumping associated with agricultural water transfers occurs in three entities in the North American Subbasin: Natomas Mutual Water Company (NMWC), Pleasant Grove-Verona Mutual Water Company (PGVMWC), and South Sutter Water District. NMWC and PGVMWC participate in groundwater substitution transfers under certain conditions. South Sutter Water District is different from the other two, as they transfer water based on a hybrid approach. The water made available is released from storage in Camp Far West Reservoir. Generally, a similar volume of groundwater is pumped by private well owners within the district. This volume is not directly measured and is assumed to be slightly less than the amount released from storage. This is represented in the CCBL by delivering less surface water during dry years than normal or wet years, with averages calculated using the data from the last 15 years of the historical simulation. The groundwater pumping is calculated internally in the model and therefore automatically adjusts for years with less or more surface water (W&C, 2021).

For NMWC and PGVMWC, historical groundwater substitution transfer pumping data were provided for water years 2020 and 2021 (2019 was not a transfer year). For the CCBL estimates of groundwater substitution transfer pumping, dry year averages were calculated using historical data for WYs 2010-2024. During this 15-year period, all groundwater substitution transfer pumping occurs in the five dry years (2013, 2014, 2015, 2021, and 2022). The estimated dry year transfer pumping for NMWC and PGVMWC was distributed among all transfer wells in the same proportion as in the historical pumping records. The surface water deliveries to NMWC and PGVMWC in the CCBL are adjusted based on the amount of dry year transfer pumping.

4.1.8 Remediation Operations

Remediation operations in the NASb, including both McClellan Air Force Base and Aerojet remedial extraction systems, are held constant at the WY 2024 level of pumping for the entire CCBL. The number and location of the remediation wells is assumed to remain the same as in the historical simulation. McClellan Air Force Base remediation pumping is set at 2,166 AFY and Aerojet remediation pumping in the NASb is set at 851 AFY.

4.1.9 Results

This section provides a summary of the NASb CCBL results.

4.1.9.1 Land and Water Use Budget

The land and water use budget provides details on the urban and agricultural demand and the water supply meeting the demand (groundwater pumping, surface water deliveries, recycled water, or remediation pumping). Average annual CCBL model results by groundwater subbasin are shown in **Table 4-3**. Annual agricultural water demand and supply in the NASb are shown in **Figure 4-4**. Average annual agricultural water supply in the NASb is shown in **Figure 4-5**. Annual urban demand and supply by subbasin are shown in **Figure 4-6**. Average annual urban water supply in the NASb is shown in **Figure 4-7**.

Table 4-3: CCBL Average Annual Land and Water Use Budget

Agricultural Water Budget (AFY)				Urban Water Budget (AFY)				
Demand	Groundwater Use	Surface Water Deliveries	Surplus (-)/ Shortage (+)	Demand	Groundwater Use	Surface Water Deliveries	Recycled Water	Surplus (-)/ Shortage (+)
402,493	210,135	195,295	-2,937	209,628	90,328	119,300	-	0

Note: Small differences exist between total supplies and total demands. These shortages and surpluses are delivered and applied regardless of the demand specified in the model. Surpluses tend to result in deep percolation.

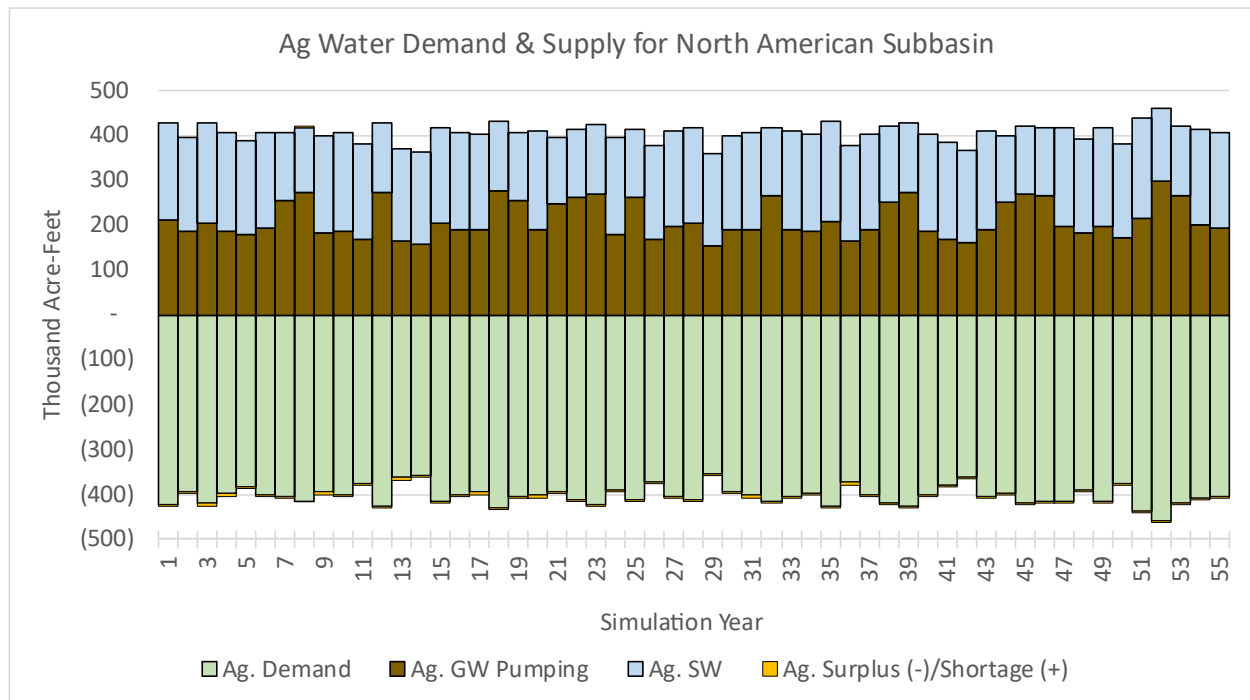


Figure 4-4: Annual Agricultural Water Demand and Supply – NASb, CCBL

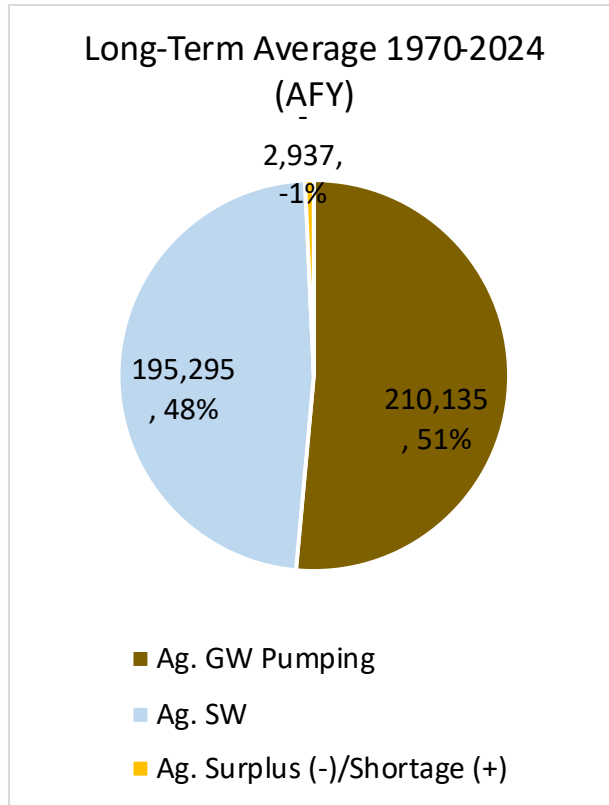


Figure 4-5: Average Annual Agricultural Water Supply – NASb, CCBL

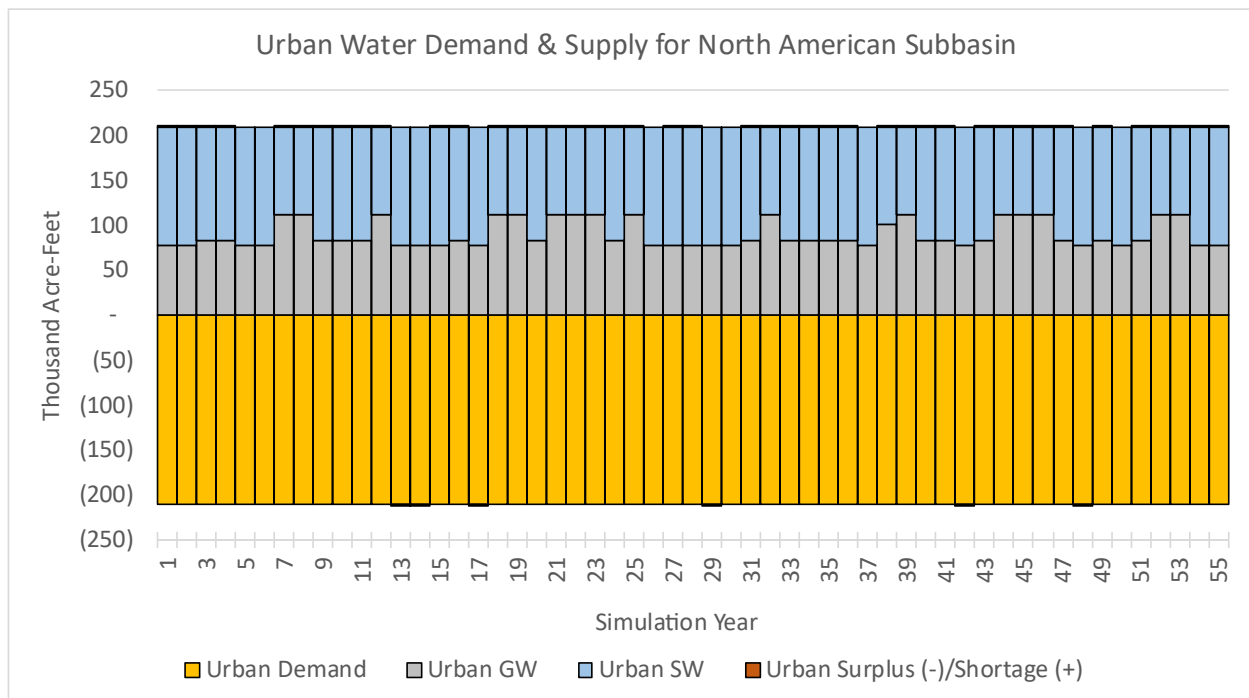


Figure 4-6: Annual Urban Water Demand and Supply – NASb, CCBL

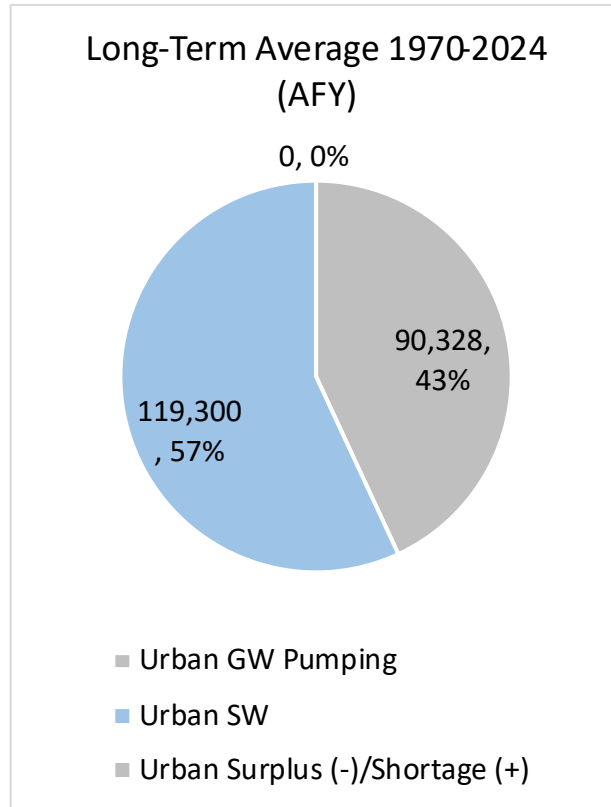


Figure 4-7: Average Annual Urban Water Supply – NASb, CCBL

4.1.9.2 Groundwater Budget

The groundwater budget provides all inflows and outflows to the groundwater aquifer system. Average annual CCBL model results for the NASb are shown in **Table 4-4**. Annual groundwater budgets with cumulative change in storage in the NASb are shown in **Figure 4-8**. The average annual groundwater budgets of net inflows, outflows, and change in storage in the NASb are shown in **Figure 4-9** and **Figure 4-10**. The cumulative change in groundwater storage in the long-term with annual variabilities is shown in **Figure 4-11**. **Appendix A** includes a set of sample hydrographs for the baseline models.

Table 4-4: CCBL Average Annual Groundwater Budget

Inflows (AFY)					Outflows (AFY)	Change in Storage (AFY)
Deep Percolation	Net Gain from Stream	Recharge*	Net Subsurface Inflow**	Net Boundary Flows***	Pumping	
182,462	92,711	28,835	10,782	14,673	319,461	9,997

Note:

*Recharge includes seepage through unlined irrigation supply canals.

**Net Subsurface Inflows includes inflows and outflows between the North American Subbasin and South American Subbasin and areas outside of Bulletin 118 subbasins.

***Net Boundary Flows includes inflows and outflows between areas outside of the CoSANA model domain and baseflow from small watersheds.

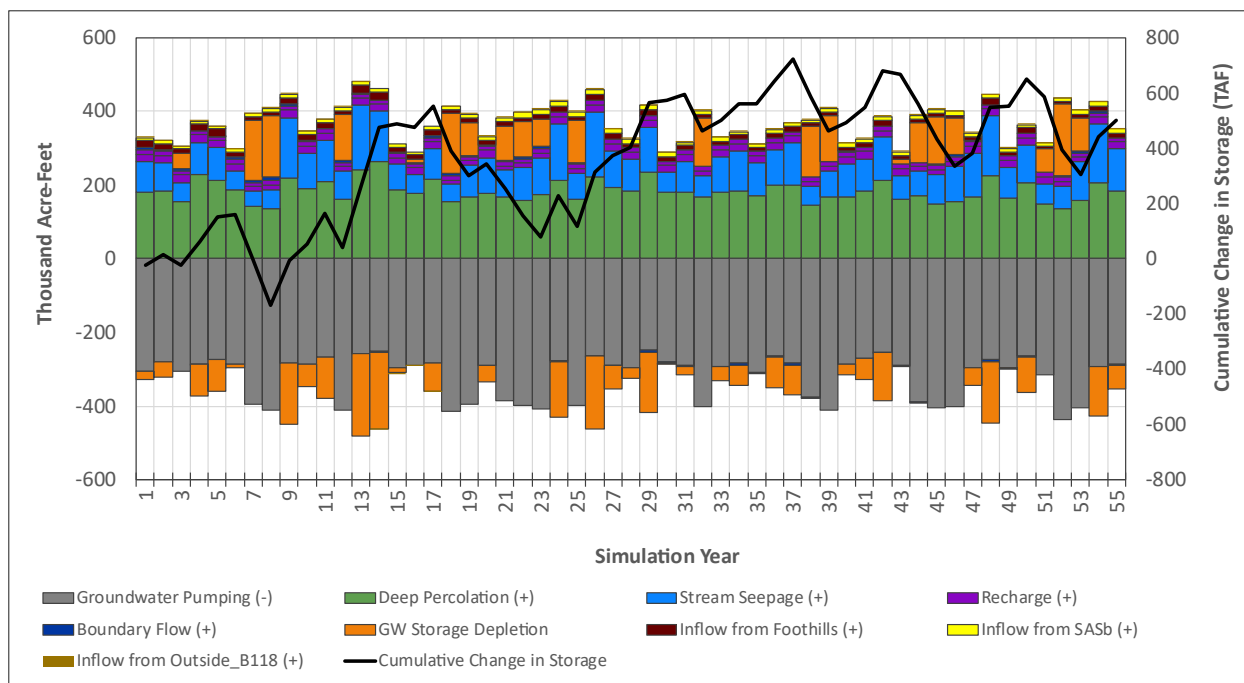


Figure 4-8: Annual Groundwater Budget and Cumulative Change in Storage – NASb, CCBL

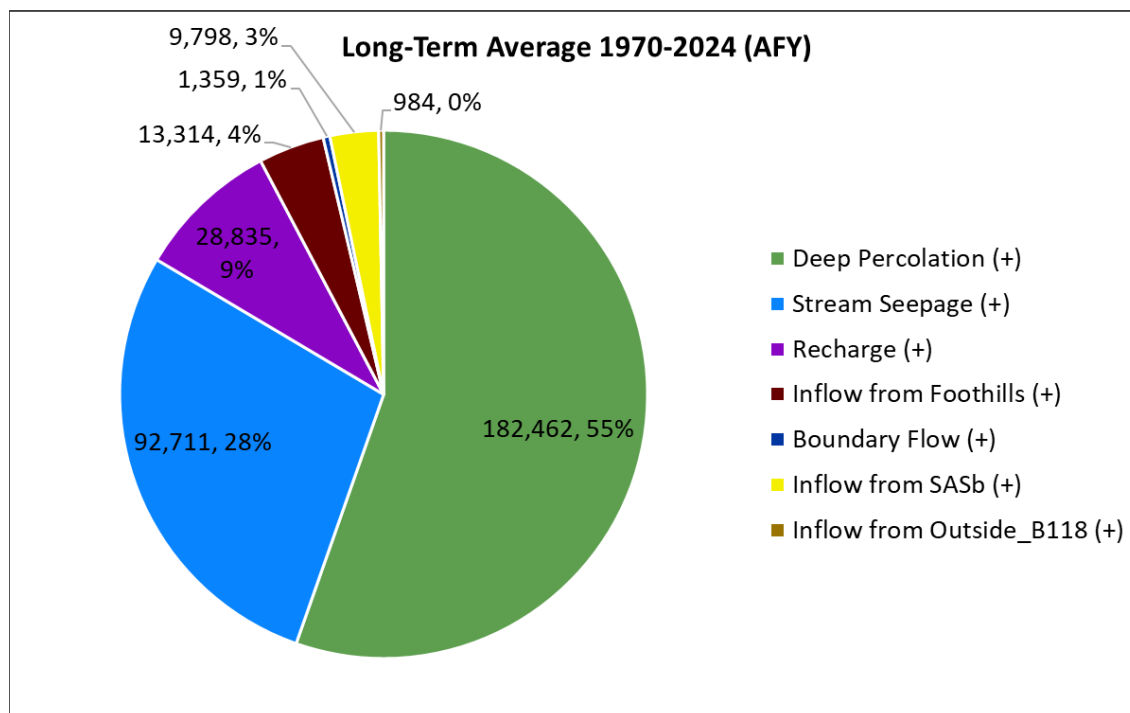


Figure 4-9: Average Annual Groundwater Budget Inflows – NASb, CCBL

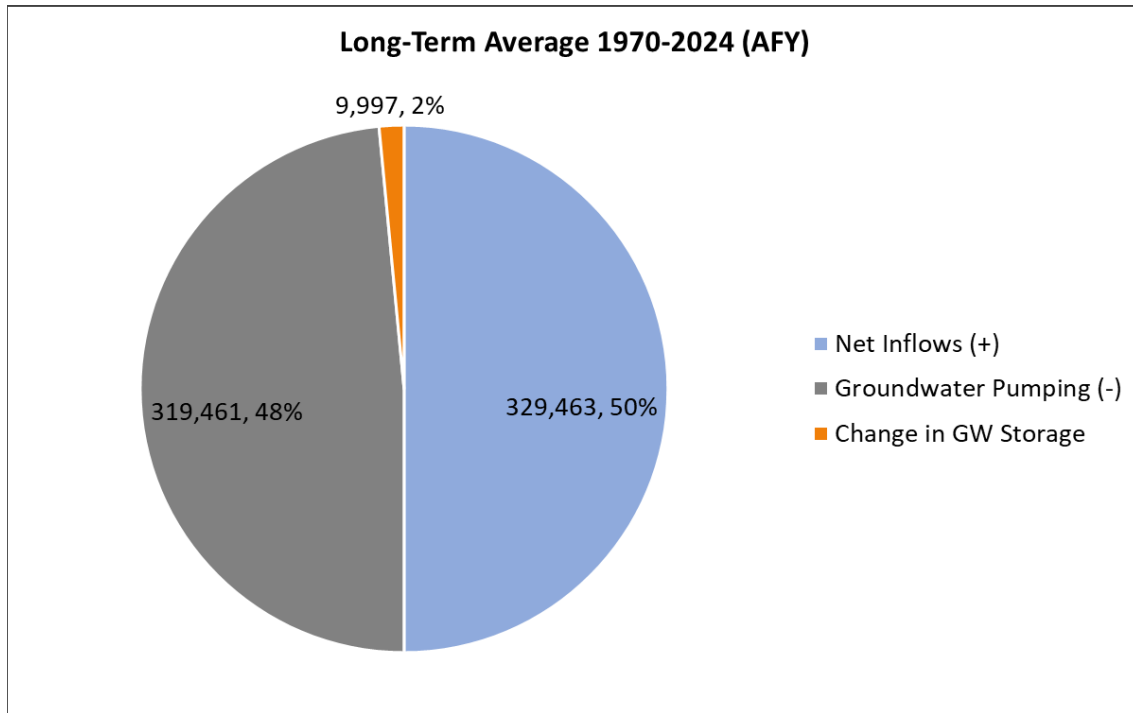


Figure 4-10: Average Annual Groundwater Budget Net Inflows & Outflows & Change in Storage – NASb, CCBL

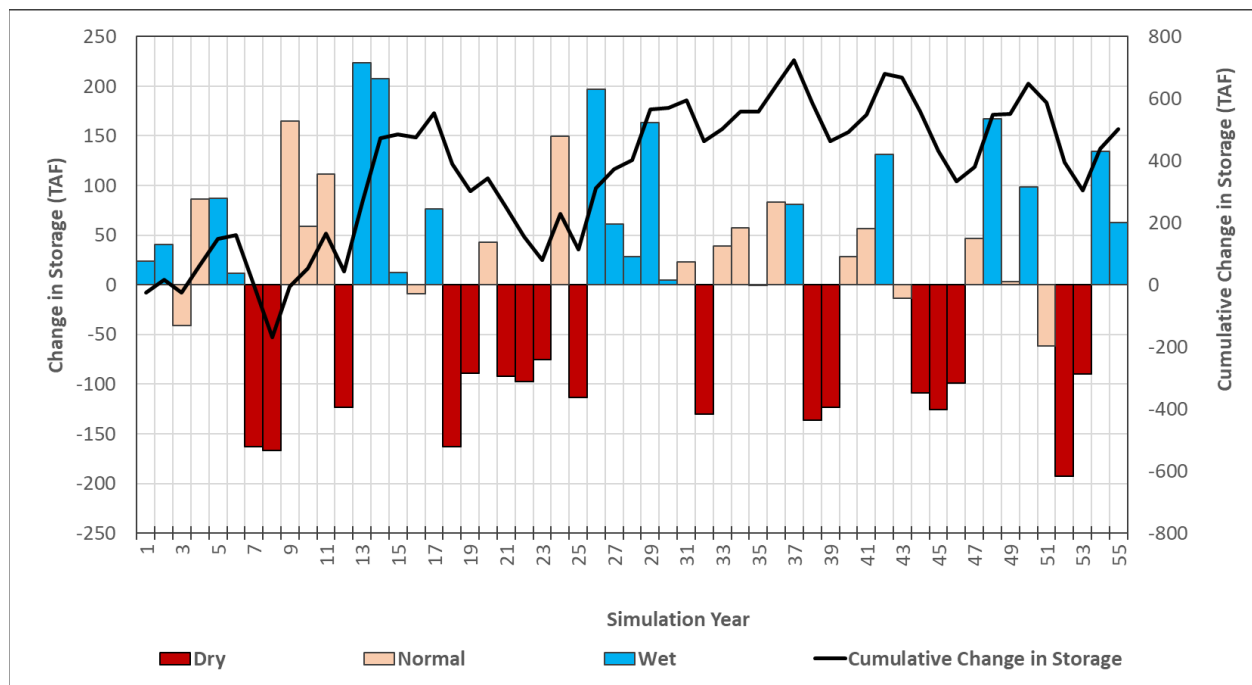


Figure 4-11: Annual Groundwater Budget Change in Storage – NASb, CCBL

4.2 Projected Conditions Baseline (PCBL) Model

The CoSANA Projected Conditions Baseline (PCBL) is a representation of the projected land and water use conditions of 2040, or the closest information available from planning documents. This section presents the key data sources and assumptions used to develop the PCBL and provides the model results. Initial groundwater levels and soil conditions in the PCBL represent those at the end of WY 2018, which is consistent with those used in the 2022 GSP PCBL as documented in the CoSANA report (W&C, 2021).

4.2.1 Hydrologic Period

The PCBL uses the 55-year historical hydrology from WYs 1970 through 2024 (October 1, 1969, through September 30, 2024) for precipitation, evapotranspiration, and streamflow. This is the same as for the CCBL, discussed in **Section 4.1**. The hydrologic year types discussed in **Section 4.1.1.4** are used in the PCBL to develop projected water demands and supplies.

4.2.2 Land Use

The PCBL incorporates the proposed new developments to reflect the 2040 land use conditions or the closest data available from planning documents. The land use conditions reflecting the PCBL are similar to that used in the W&C 2021 model report and CoSANA 2021 model version, with an updated urban footprint based on the latest information received on the urban development area. This is primarily due to the need for consistency to be able to compare the updated model results with those reported in 2021. However, for upcoming projects, such as the SRWB, the land use conditions to be used for projection at buildout for agricultural areas, cropping mix and extent of urban development in the subbasin can be analyzed and adapted in the model to reflect the current conditions.

Table 4-5 lists the proposed new developments incorporated into the PCBL. A total of 34 proposed new developments were identified in the NASb, urban land was expanded around existing developed areas, as projected in planning documents.

As documented in CoSANA report (W&C, 2021), the main data source for identifying the new developments in Sacramento County was information and Geographic Information System (GIS) files provided by the Sacramento County Office of Planning and Environmental Review (T. Smith, personal communication, October 2020). In addition, public information available from the Sacramento Area Council of Governments (SACOG) was also collected and reviewed for identifying and confirming the developments within Placer and Sutter Counties. Placer County also reviewed the list of the new developments and provided inputs (J. Byous, personal communication, December 2020). Information was also available for many of the developments in Sutter and Placer Counties (R. Shatz, personal communication, December 2020).

The majority of the new developments in the NASb are located in Placer County near the City of Rocklin (Sunset Ranchos and Clover Valley); City of Lincoln (SUD A, SUD B, SUD C, Village 1, Village 2, Village 3, Village 4, Village 5, Village 6, and Village 7); City of Roseville (Amoruso Ranch, Creekview, HP Campus Oaks, North Area, Northwest Roseville, Sierra Vista, Sun City Roseville [or Del Webb] and West Roseville Specific Plans); and Cal Am West Placer (Placer Vineyards Specific Plans East and West and Riolo Vineyards). Other proposed developments include the Placer Ranch and Regional University in Placer County, Sutter Pointe in Sutter County; and Grandpark Specific Plan, Elverta, Greenbrier, Panhandle, Northborough, and Upper Westside in Sacramento County.

The proposed new developments and future land use conditions in the NASb are shown in **Figure 4-12**. The time-series of land use for the PCBL in the NASb is shown in **Figure 4-13**, highlighting the constant nature of land and water use in the baseline conditions.

Table 4-5: Proposed New Developments in NASb

Proposed Development Name	ID		Proposed Development Name	ID
Village 4	1		Sun City Roseville	18
SUD A	2		HP Campus Oaks	19
Village 3	3		Sierra Vista Specific Plan	20
Village 5	4		North Area Specific Plan 2	21
SUD B	5		Northwest Roseville Specific Plan	22
Village 2	6		Sutter Pointe	23
Village 1	7		Regional University	24
Village 6	8		Riolo Vineyards	25
Village 7	9		Placer Vineyards Specific Plan (east)	26
SUD C	10		Placer Vineyards Specific Plan (west)	27
Sunset Ranchos	11		Dry Creek-West Placer Community Plan	28
Amoruso Ranch	12		Grandpark Specific Plan	29
Clover Valley	13		Elverta Specific Plan	30
Placer Ranch	14		Northborough Boundary	31
Creekview	15		Greenbriar	32
West Roseville	16		Panhandle	33
North Area Specific Plan	17		Upper Westside	34

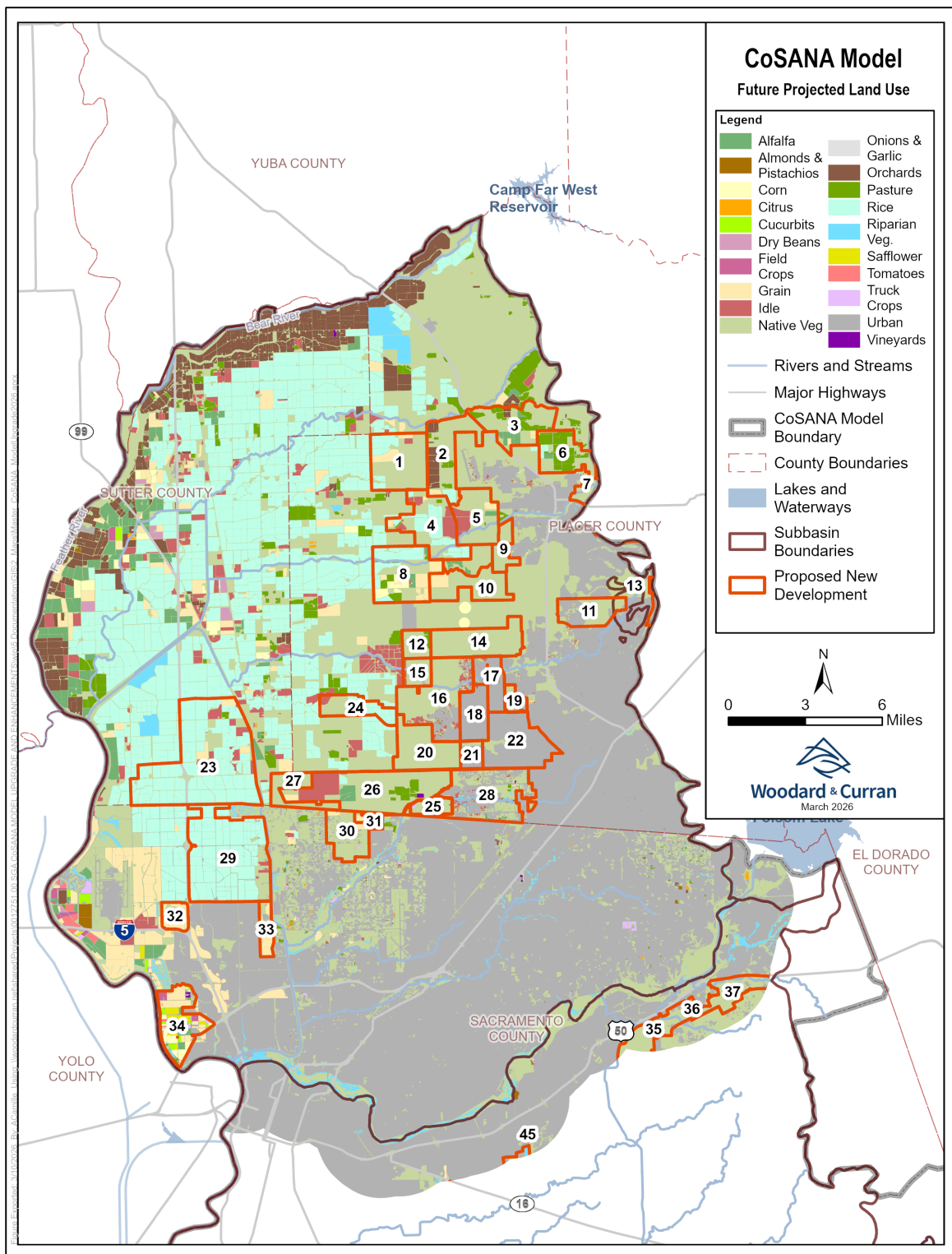


Figure 4-12: Projected Land Use and Proposed New Developments in NASb

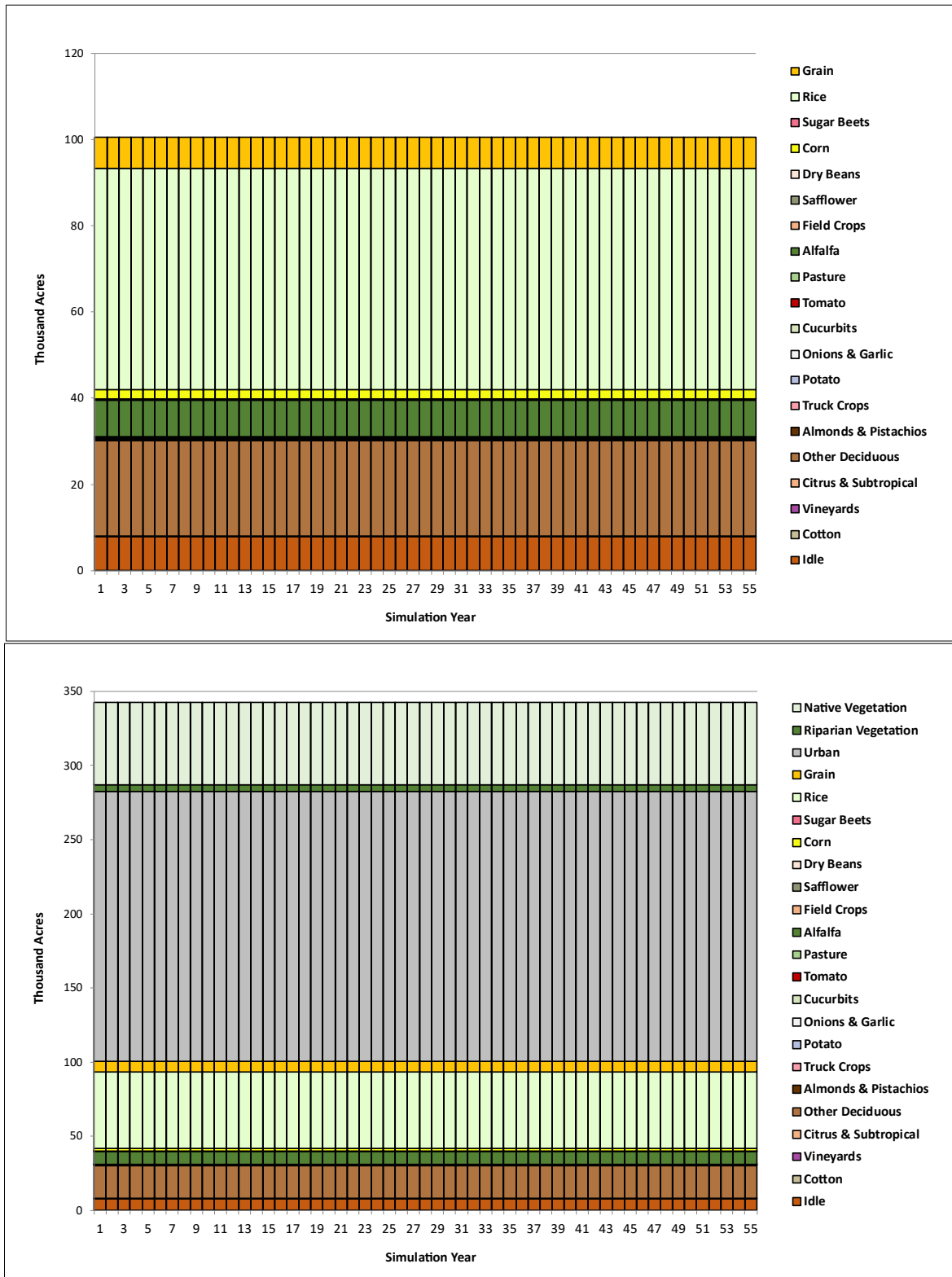


Figure 4-13: Projected Conditions Baseline Land Use for NASb

4.2.3 Urban Demand and Supply

Urban water demand assumptions in the PCBL are based on the 2040 conditions from the 2020 Urban Water Management Plans (UWMPs) for purveyors in the NASb.

Urban water supply in the PCBL, including surface water deliveries, groundwater pumping and recycled water, are calculated based on the purveyor type. In general, for groundwater reliant purveyors, surface water supply was the same as they are in the CCBL, and groundwater supply was used to meet urban demand under the 2040 conditions. For surface water reliant agencies, groundwater supply was the same as they are in the CCBL, and surface water supply was used to meet the urban demand under the 2040 conditions. For purveyors using both surface water and groundwater supplies, the assumptions were similar to groundwater reliant purveyors. For purveyors that include recycled water as their supply, the recycled water was simulated as part of the surface water supply in the model.

The PCBL urban demand and supply assumptions are summarized in **Table 4-6** Additional explanations of the urban demand and supply assumptions for individual purveyors, and for purveyors not utilizing the methodology described above, are provided in the following subsections.

Table 4-6: Projected Conditions Baseline Urban Demand and Supply

Purveyor	Service Area	Purveyor Type	2040 UWMP Demand (TAF)	Wet Year Water Use (TAF)			Normal Year Water Use (TAF)			Dry Year Water Use (TAF)		
				GW	SW	RW	GW	SW	RW	GW	SW	RW
California American Water Company	Antelope	GW Reliant	4.7	4.0	0.7	0.0	4.2	0.5	0.0	4.7	0.0	0.0
	Arden	GW Reliant	1.4	1.4	0.0	0.0	1.4	0.0	0.0	1.4	0.0	0.0
	Lincoln Oaks	SW-GW	6.0	5.1	0.9	0.0	5.4	0.6	0.0	6.0	0.0	0.0
	West Placer	SW Reliant	3.6	0.0	3.6	0.0	0.0	3.6	0.0	0.0	3.6	0.0
Carmichael WD	-	SW-GW	9.2	2.8	6.4	0.0	2.8	6.4	0.0	3.6	5.6	0.0
Citrus Heights WD	-	SW-GW	12.9	0.8	12.1	0.0	0.8	12.1	0.0	1.8	11.1	0.0
City of Lincoln	-	SW-GW	19.9	2.9	13.8	3.2	3.0	13.7	3.2	2.8	13.9	3.2
City of Roseville	-	SW Reliant	62.9	0.0	58.0	4.9	0.0	58.0	4.9	6.9	51.1	4.9
City of Sacramento	-	SW-GW	116.5	24.3	91.1	1.0	35.9	79.6	1.0	68.7	46.8	1.0
Del Paso Manor WD	-	GW Reliant	1.2	1.2	0.0	0.0	1.2	0.0	0.0	1.2	0.0	0.0
Fair Oaks WD	-	SW-GW	10.8	2.4	8.4	0.0	1.6	9.2	0.0	2.3	8.5	0.0
Golden State WC	Arden	GW Reliant	1.5	1.5	0.0	0.0	1.5	0.0	0.0	1.5	0.0	0.0
Orange Vale WC	-	SW Reliant	3.9	0.0	3.9	0.0	0.0	3.9	0.0	0.0	3.9	0.0
Rio Linda Elverta CWD	-	GW Reliant	3.1	3.7	0.0	0.0	3.7	0.0	0.0	3.7	0.0	0.0
San Juan Retail	-	SW Reliant	11.4	0.0	11.4	0.0	0.0	11.4	0.0	0.0	11.4	0.0
Sacramento Suburban WD	North	GW Reliant	23.2	12.4	10.8	0.0	14.3	9.0	0.0	21.2	2.0	0.0
	South	GW Reliant	15.4	10.1	5.3	0.0	10.1	5.3	0.0	10.1	5.3	0.0
Sacramento County WA	Arden	GW Reliant	3.2	3.2	0.0	0.0	3.2	0.0	0.0	3.2	0.0	0.0
	Northgate	GW Reliant	2.0	2.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0

4.2.3.1 City of Sacramento (in both NASb and SASb)

City of Sacramento's water demand is based on the 2020 UWMP. The City of Sacramento's current supplies include groundwater pumping and surface water supplies that vary by five water year types (wet, normal, drier, drier & critical, and driest years) based on the City of Sacramento's 2017 Groundwater Master Plan (GWMP) (City of Sacramento, 2017). Groundwater pumping assumptions for the CCBL are consistent with the Future Conditions Baseline scenario developed in the 2017 GWMP for wet and normal years. For simplicity, the groundwater pumping assumptions for dry

years in the PCBL are using the average of drier, drier & critical, and driest years in the 2017 GWMP under the Future Conditions Baseline scenario. Demand after groundwater pumping is assumed to be supplied by surface water. The groundwater pumping and surface water supplies for wet, normal, and dry years are provided in **Table 4-6**.

The City of Sacramento also has specific wells that supply certain larger parks and green areas within the city. These irrigation wells are simulated using six representative irrigation wells that pump 2,400 AFY. Based on the locations of the irrigated parks and green areas, approximately half of the irrigation pumping is estimated in the NASb and the remaining half in the SASb.

4.2.3.2 City of Rocklin

- **Demand:** The City of Rocklin's future demand was based on the Placer County Water Agency's 2020 UWMP (PCWA, 2021) with a partial demand estimated and incorporated into the PCBL to represent the portion of the City of Rocklin within the model domain. It is estimated that approximately 33% of the City of Rocklin's demand was within the model area.
- **Supply:** All PCBL demand was assumed to be met by surface water.

4.2.3.3 City of Roseville

- **Demand:** The 2040 demand projection was based on the 2020 UWMP (City of Roseville, 2022).
- **Supply:** Demand was assumed to be met by 4,933 AFY of recycled water in all years, based on the 2020 UWMP; the remaining demand was assumed to be met by surface water and the city's ASR program. The PCBL incorporated the ASR program, which is consistent with those used in the 2022 GSP CCBL, at buildout with 15 ASR wells operating and included well information (well IDs, well locations, and well screens) and annual extraction and injection schedules provided by the City of Roseville. With the ASR program, the city assumes no net take on groundwater supply over the long-term, based on the following ASR operations by water year types:
 - During dry years, the City of Roseville's ASR wells extract 6,907 AFY of groundwater.
 - During wet years, the City of Roseville recharges groundwater through injection of 6,200 AFY of surface water into aquifer.
 - During normal and wet years, ASR wells pump a small volume of 25 AFY for maintenance.

4.2.3.4 Sacramento International Airport

- **Demand:** Because no updated urban demand or supply data were available after 2019, urban demands were estimated using the values from the CCBL to maintain consistency and preserve variability across wet, normal, and dry hydrologic years.
- **Supply:** Demand was assumed to be met by surface water and groundwater supply, consistent with the assumptions used in the CCBL.

4.2.3.5 Sutter Pointe

- **Demand:** A demand projection of 15,786 AFY was assumed, based on the Phase 2+B proposed water supply program from the *Supplement to the Water Supply Assessment for Lakeside at Sutter Pointe* (Golden State Water Company, 2020) (W&C, 2021).

-
- **Supply:** Demand was assumed to be met by a mixture of groundwater pumping and surface water. Groundwater pumping is assumed to meet 10,919 AFY of demand, and surface water is assumed to meet the remaining 4,867 AFY of demand (W&C, 2021).

4.2.3.6 Grandpark

- **Demand:** A demand projection of 12,030 AFY was assumed, based on build out projections for the project (K. Giberson, pers comm. Feb 14, 2019) (W&C, 2021).
- **Supply:** Demand was assumed to be met by a mixture of groundwater pumping and surface water. Groundwater pumping is assumed to meet 2,407 AFY of demand during normal and wet years, and 3,007 AFY of demand during dry years. Surface water is assumed to meet 9,623 AFY of demand during normal and wet years, and 9,395 AFY of demand during dry years (W&C, 2021).

4.2.4 Groundwater Substitution Transfers for Municipal Entities

The PCBL modeling applied the same Groundwater Substitution Transfer assumptions as those established for CCBL to maintain methodological consistency. See **Section 4.1.6**.

4.2.5 Agricultural Water Demand and Supply

Agricultural demand and supply in the PCBL are similar to the discussion in the CCBL (**Section 4.1.7**), with demand being driven by the land use changes in the PCBL discussed in **Section 4.2**. and much of the supply being internally calculated within the model or based on the last 15 years of the historical simulation.

4.2.5.1 Rural Residential

Rural residential demand in the PCBL version of CoSANA accounts for the urbanization of areas that would lead to a decrease in the rural residential population. It is assumed that the projected urbanization of areas previously used for agricultural purposes would result in a decline in rural residential population and the associated demand. These areas are subsequently served by an urban water purveyor.

4.2.5.2 Groundwater Substitution Transfers for Agricultural Entities

As discussed for the CCBL (**Section 4.1.7.2**), two purveyors engage in agricultural groundwater substitution transfer pumping in the NASb are NMWC and PGVMWC. The agricultural groundwater substitution transfer pumping in two purveyors is assumed to be the same as in the CCBL.

4.2.6 Remediation Operations

Information about future remediation operations is not available, so remediation operations in the PCBL are the same as in the CCBL, discussed in **Section 4.1.8**.

4.2.7 Results

This section provides a summary of the NASb PCBL results.

4.2.7.1 Land and Water Use Budget

The land and water use budget provides details on the urban and agricultural demand and the water supply meeting the demand (groundwater pumping, surface water deliveries, recycled water, and remediation pumping). Average annual PCBL model results by groundwater subbasin are shown in **Table 4-7** Annual agricultural water demand and supply in the NASb are shown in **Figure 4-14**. Average annual agricultural water supply in the NASb is shown in **Figure**

4-15. Annual urban demand and supply by subbasin are shown in **Figure 4-16**. Average annual urban water supply in the NASb is shown in **Figure 4-17**.

Table 4-7: PCBL Average Annual Land and Water Use Budget

Agricultural Water Budget (AFY)				Urban Water Budget (AFY)				
Demand	Groundwater Use	Surface Water Deliveries	Surplus (-)/ Shortage (+)	Demand	Groundwater Use	Surface Water Deliveries	Recycled Water	Surplus (-)/ Shortage (+)
357,583	202,603	157,083	-2,103	294,510	107,129	187,381	-	0

Note: Small differences exist between total supplies and total demands. These shortages and surpluses are delivered and applied regardless of the demand specified in the model. Surpluses tend to result in deep percolation.

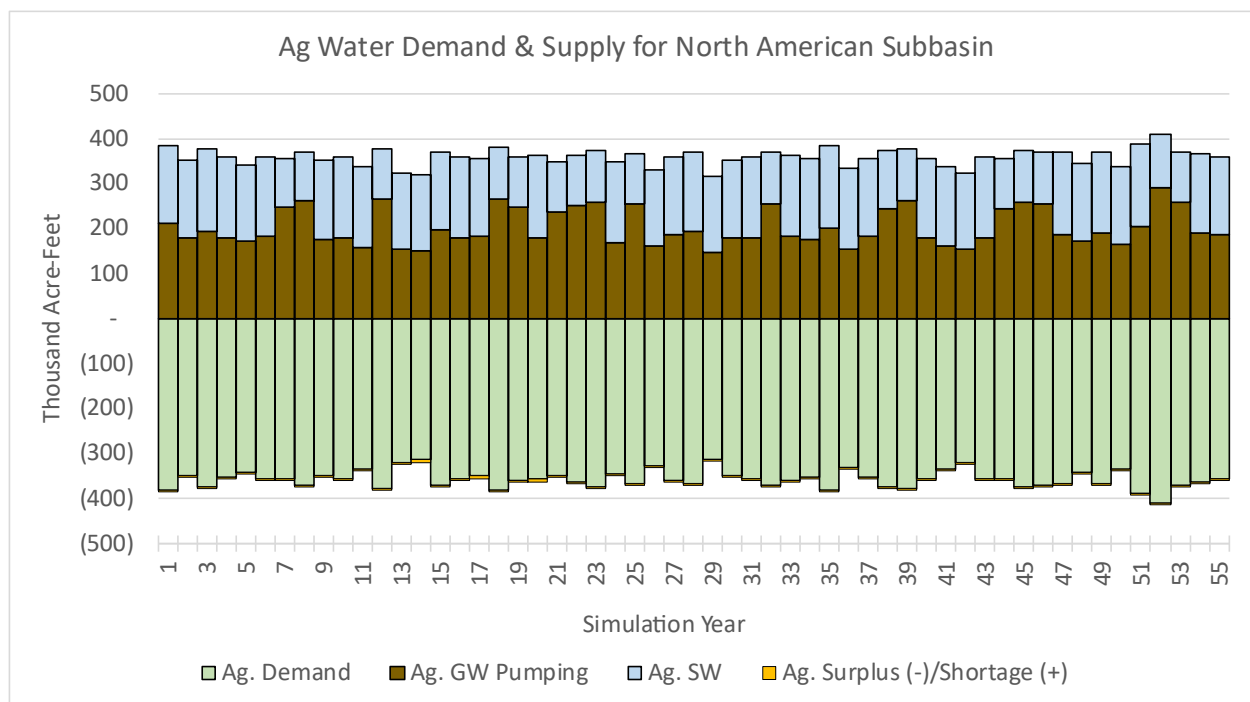


Figure 4-14: Annual Agricultural Water Demand and Supply – NASb, PCBL

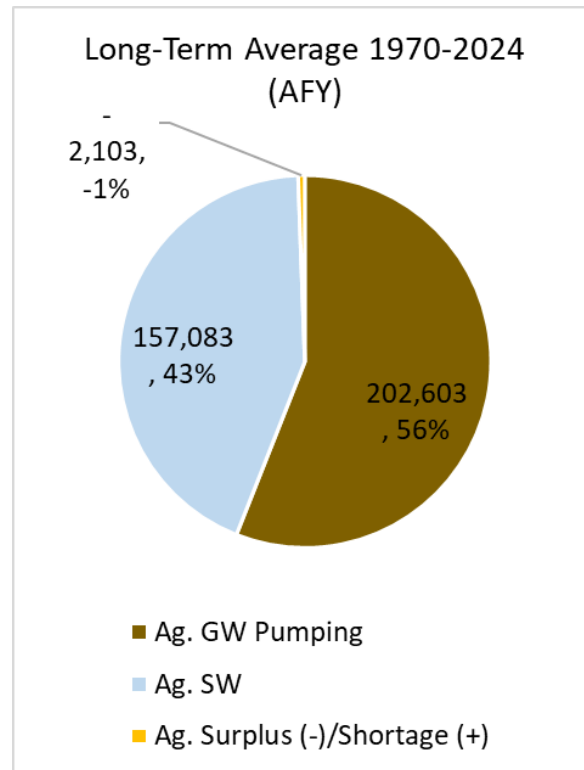


Figure 4-15: Average Annual Agricultural Water Supply – NASb, PCBL

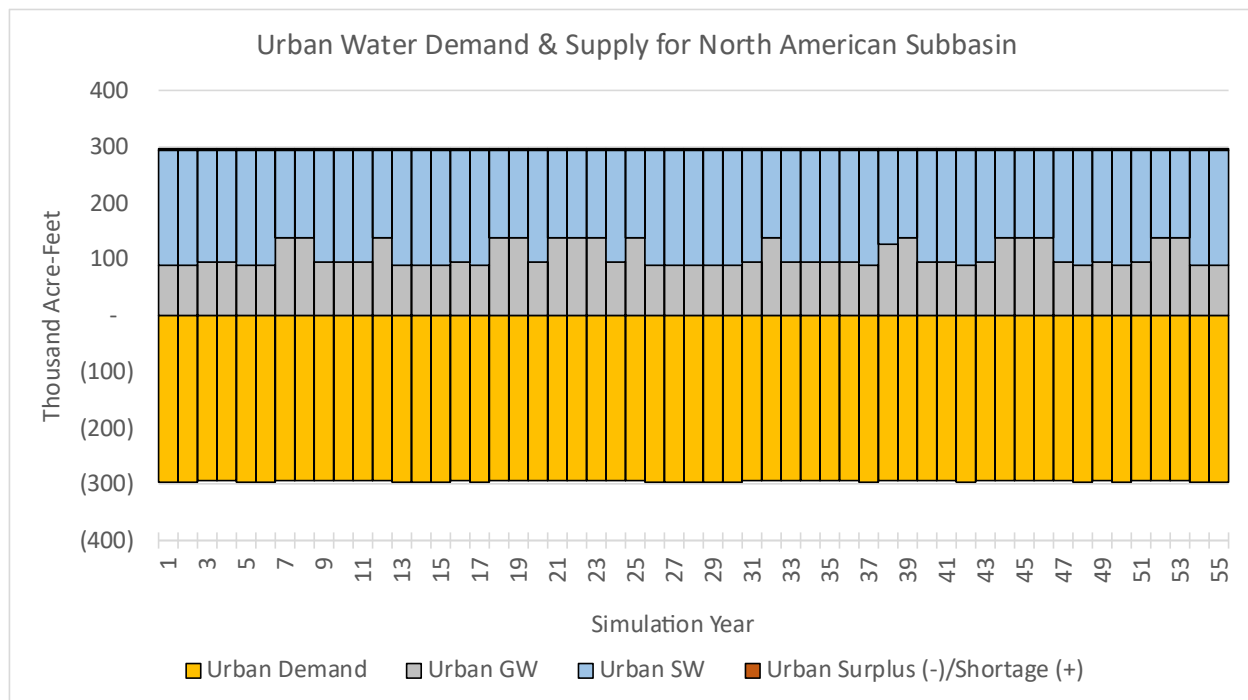


Figure 4-16: Annual Urban Water Demand and Supply – NASb, PCBL

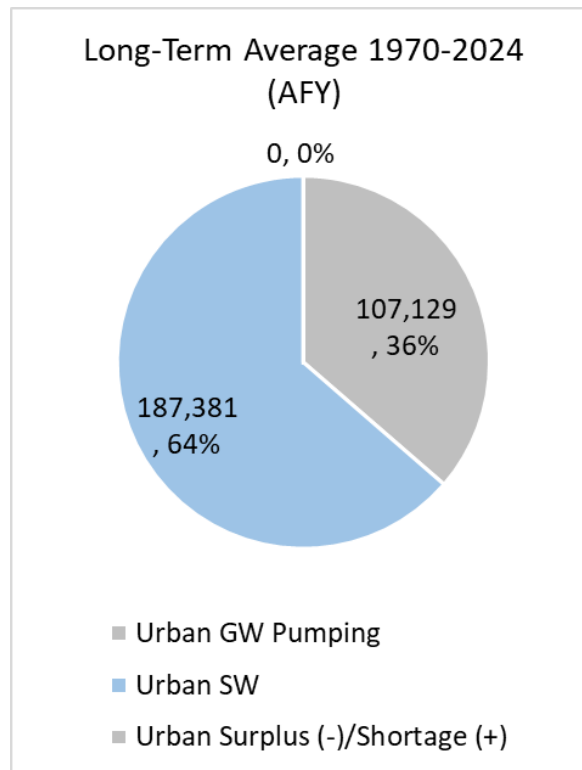


Figure 4-17: Average Annual Urban Water Supply – NASb, PCBL

4.2.7.2 Groundwater Budget

The groundwater budget summarizes all inflows and outflows to the groundwater aquifer system. Average annual PCBL model results by groundwater subbasin are shown in **Table 4-8**. Annual groundwater budgets with cumulative change in storage in the NASb are shown in **Figure 4-18**. The average annual groundwater budgets of net inflows, outflows, and change in storage in the NASb are shown in **Figure 4-19** and **Figure 4-20**. The cumulative change in groundwater storage in the long-term with annual variabilities is shown in **Figure 4-21**. **Appendix A** includes a set of sample hydrographs for the baseline models.

Table 4-8: PCBL Average Annual Groundwater Budget

Inflows (AFY)					Outflows (AFY)	Change in Storage (AFY)
Deep Percolation	Net Gain from Stream	Recharge*	Net Subsurface Inflow**	Net Boundary Flows***	Pumping	
164,180	110,496	28,451	4,245	15,971	318,251	5,074

Note:

*Recharge includes seepage through unlined irrigation supply canals.

**Net Subsurface Inflows includes inflows and outflows between the North American Subbasin and South American Subbasin and areas outside of Bulletin 118 subbasins.

***Net Boundary Flows includes inflows and outflows between areas outside of the CoSANA model domain and baseflow from small watersheds.

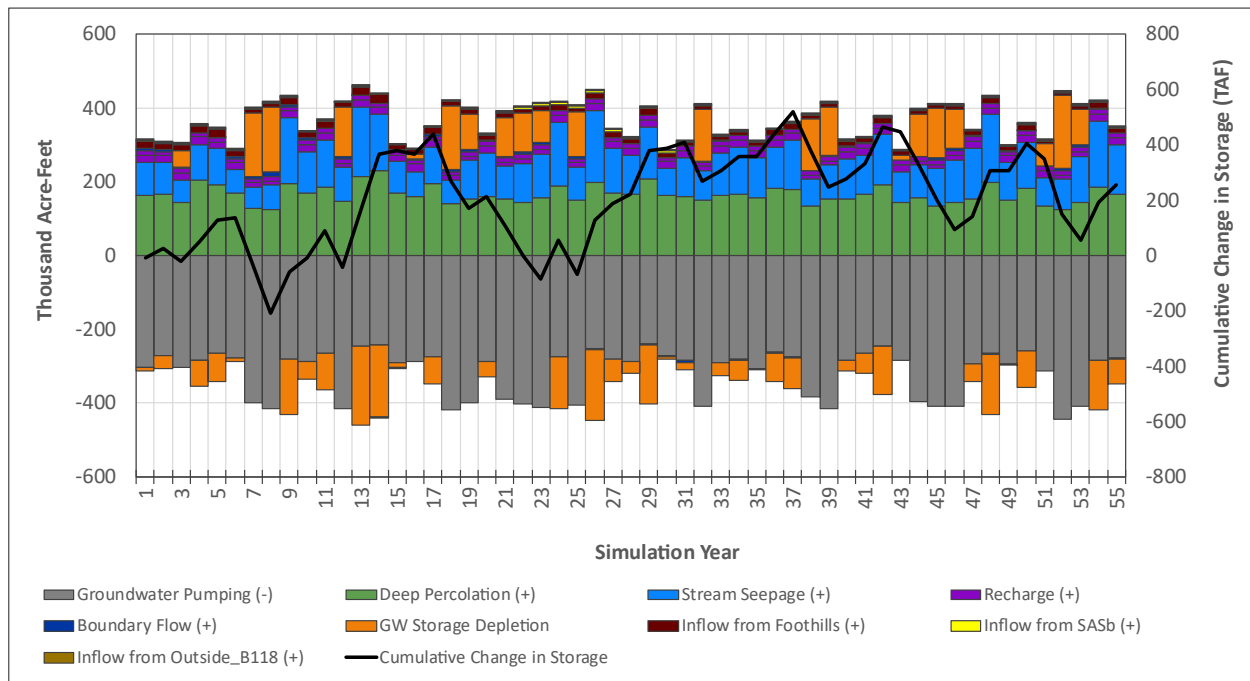


Figure 4-18: Annual Groundwater Budget and Cumulative Change in Storage – NASb, PCBL

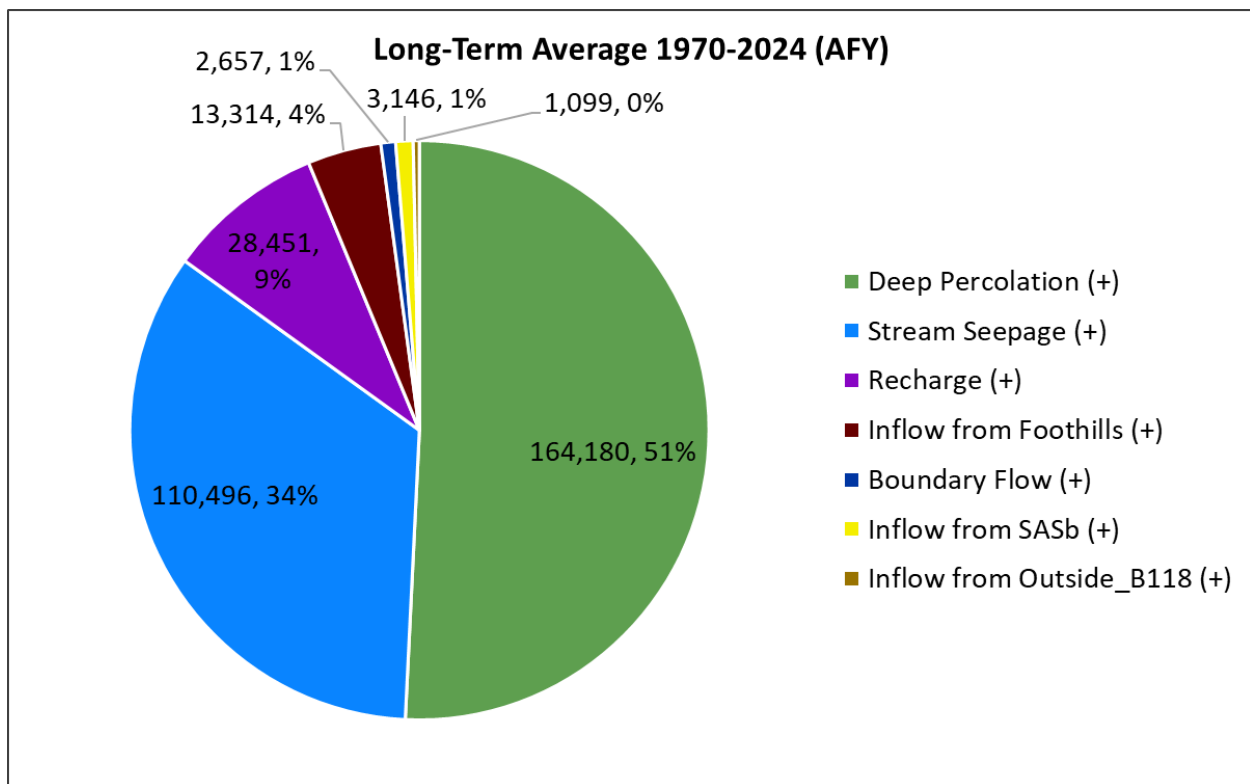


Figure 4-19: Average Annual Groundwater Budget Inflows – NASb, PCBL

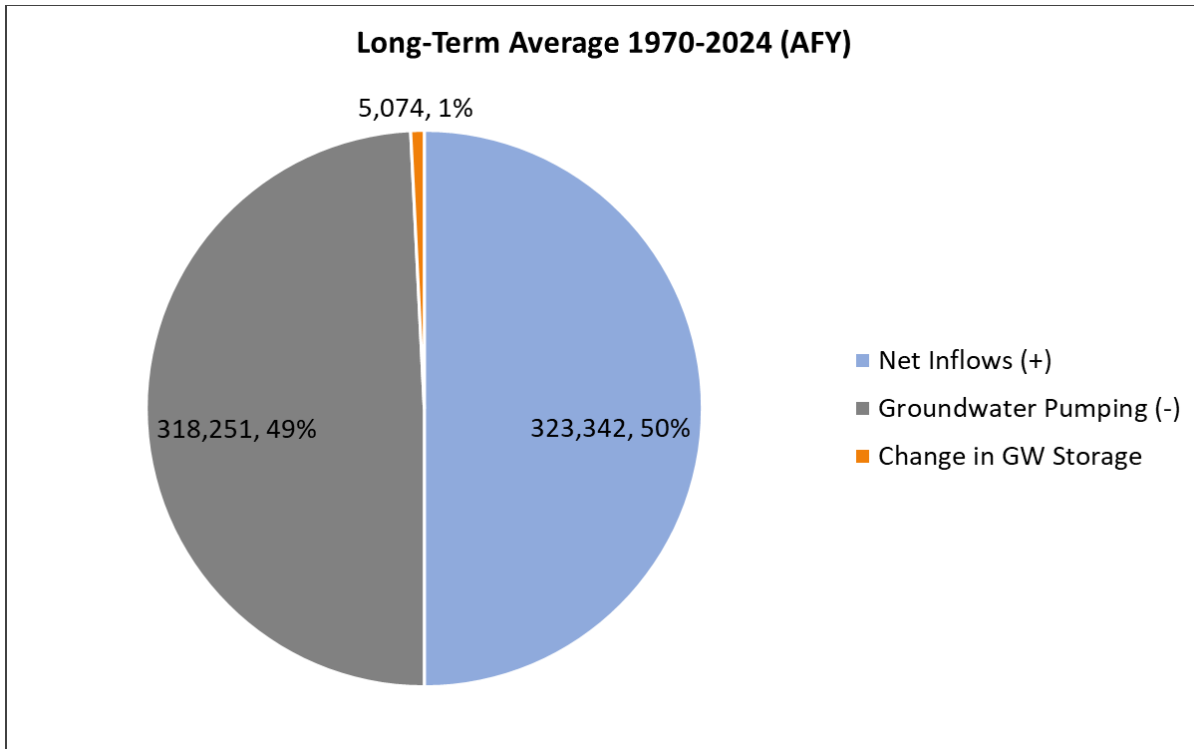


Figure 4-20: Average Annual Groundwater Budget Net Inflows & Outflows & Change in Storage – NASb, PCBL

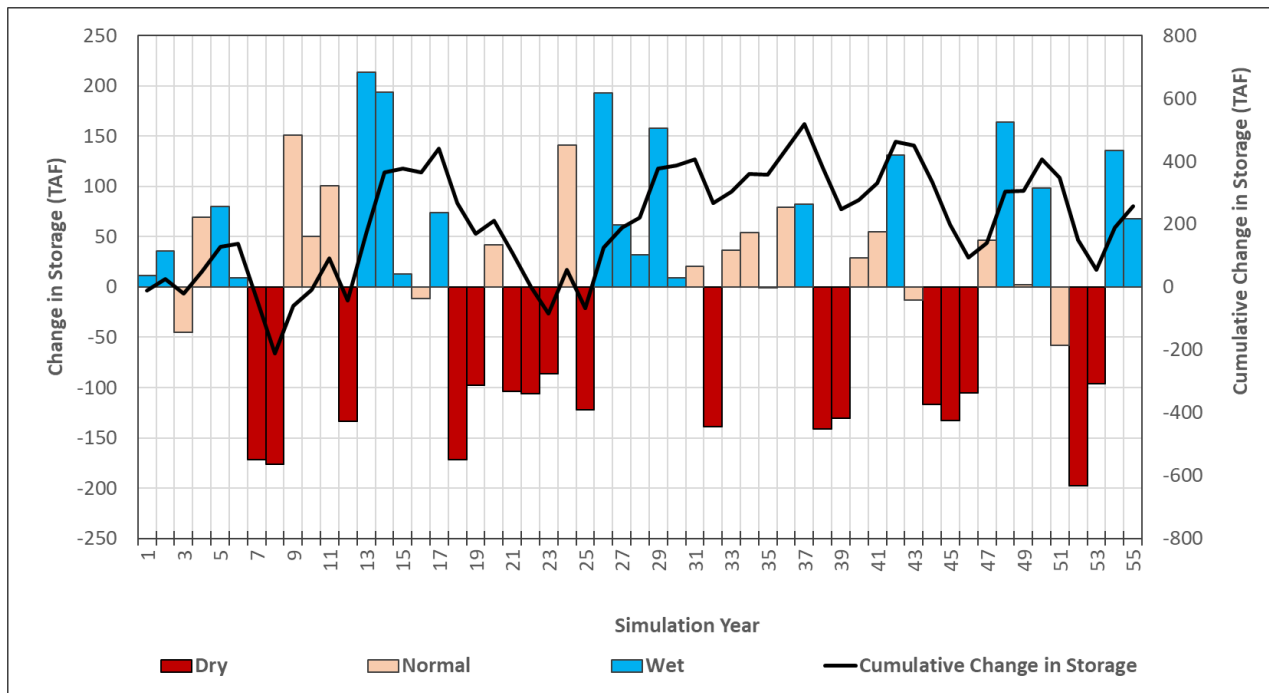


Figure 4-21: Annual Groundwater Budget Change in Storage – NASb, PCBL

4.3 Projected Conditions Baseline with Climate Change

The CoSANA Projected Conditions Baseline with Climate Change (PCBL with Climate Change) shares many of the same inputs as the PCBL, but with additional factors to incorporate potential climate change conditions. These conditions affect the hydrologic cycle as changes in precipitation and temperature. In the CoSANA model files, the change in precipitation is incorporated by the precipitation rate and stream inflow inputs while the change in temperature is reflected by the change in evapotranspiration rate and stream inflow inputs. Changes in water use are incorporated by estimation of agricultural water demands within CoSANA based on changes in precipitation and evapotranspiration. Urban water use is assumed to remain unchanged, based on assumed changes in conservation and landscape choices (W&C, 2021).

4.3.1 Hydrologic Period

The hydrologic period used for the projected conditions baseline with climate change is the same as the PCBL (WYs 1970 to 2024), modified according to the methodology explained below to incorporate climate change conditions.

4.3.1.1 Methodology

The PCBL with climate change conditions continue using the American River Basin Study (ARBS) as the methodology to update and extend the precipitation, stream inflow, and evapotranspiration time series data from the PCBL.

ARBS remains the most appropriate basis for representing future climate conditions in the CoSANA groundwater model upgrade because it provides a basin-specific, publicly available, and fully documented set of climate and hydrologic scenarios tailored to the American River system. ARBS employs an ensemble-informed framework with a Central Tendency case for general planning and a Hot-Dry stress case, both developed using recognized downscaling methods and propagated through basin-relevant operations and temperature models. These features yield decision-relevant inputs (e.g., shifts in runoff timing, seasonal storage, and river temperature) that integrate directly with CoSANA's groundwater-surface water processes. Continuing to use ARBS, therefore ensures methodological continuity with prior CoSANA applications, traceability and transparency for stakeholder review, and a stable, reproducible foundation for evaluating baseline, stress, and adaptation scenarios, while preserving compatibility should newer global projection datasets be benchmarked against ARBS in future updates.

The detailed methodology and climate change scenarios selection can be found in Section 5.3.1.1 of the CoSANA report (W&C, 2021). A summary comparison table of the ARBS historical baseline hydrology and percent changes to different system components in the 2070 Central-Tendency (2070CT) and 2070 Hot and Dry (2070HD) is shown in **Table 4-9** (Table 5-7 of the CoSANA report, [W&C, 2021]).

Table 4-9: Percent Change in Annual Climatic and Hydrologic Indicators in the American River Basin Study*

Climate Scenario	Precipitation	Temperature (average)	Potential Evapotranspiration	Runoff
Historical Observations (1915-2015 average)	38.2 inches	54.8°F	42.8 inches	1,458,000 AFY
2070 Central-Tendency	-3%	+11%	+10%	-6%
2070 Hot and Dry	-9%	+14%	+12%	-13%

* The values are for the entire American River Basin Study area and are based on Table 2-4 in the study report.

4.3.1.2 Precipitation

Annual precipitation near Sacramento International Airport and within the small watershed areas for the climate-change scenarios in the PCBL was extended from 2019 through 2024. The extended precipitation time series for WYs 2019–2024 was derived using the long-term average water-year-type distribution from WYs 1970–2018 under the 2070CT scenario, as documented in the CoSANA report (W&C, 2021).

4.3.1.3 Stream Inflow

Major streamflow inputs to the CoSANA domain were adjusted to reflect climate-change conditions consistent with the 2070CT scenario. Annual American River releases from Folsom Reservoir for the PCBL climate-change scenarios were extended through WYs 2019–2024. The extended streamflow time series for this period was developed using the long-term average distribution of water-year types from WYs 1970–2018 under the 2070CT scenario, as documented in the CoSANA report (W&C, 2021).

4.3.1.4 Evapotranspiration

Potential Evapotranspiration (PET) time series data for each land cover type in CoSANA were modified to accommodate climate change according to 2070CT conditions. Because the 2070CT scenario projects higher temperatures relative to historical conditions, corresponding increases in potential evapotranspiration rates were applied. Annual potential evapotranspiration values were extended through WYs 2019–2024, and the extended PET time series for this period was developed using the long-term average distribution of water-year types from WYs 1970–2018 under the 2070CT scenario, as documented in the CoSANA report (W&C, 2021).

4.3.2 Land Use

The PCBL with Climate Change land use is the same as the PCBL, described in **Section 4.2.2**.

4.3.3 Urban Demand and Supply

The PCBL with Climate Change urban demand and supply is the same as the PCBL, described in **Section 4.2.3**. It is noted that water demands for urban landscape will increase with increasing ET under climate change; however, demand and supply remain unchanged in the baseline due to likely changes in ordinances and likely changes in landscaping practices.

4.3.4 Groundwater Substitution Transfers for Municipal Entities

The PCBL with Climate Change Groundwater Substitution Transfers for municipal entities is the same as the PCBL, described in **Section 4.2.4**.

4.3.5 Agricultural Demand and Supply

The PCBL with Climate Change agricultural demand and supply is based on the PCBL, described in **Section 4.2.5**. The agricultural demand under the climate change conditions is impacted by the effect of climate change on hydrology, notably evapotranspiration, which increases demand. The increased supply needed to meet this demand is typically met by additional groundwater pumping.

4.3.6 Remediation Operations

Information about future remediation operations is not available, so remediation operations in the PCBL with Climate Change are the same as in the CCBL, discussed in **Section 4.2.6**.

4.3.7 Results

This section provides a summary of the CoSANA PCBL with Climate Change results.

4.3.7.1 Land and Water Use Budget

The land and water use budget provides details on urban and agricultural demand and the water supply meeting the demand (groundwater pumping, surface water deliveries, recycled water, and remediation pumping). Average annual PCBL with Climate Change model results by groundwater subbasin are shown in **Table 4-10**. Annual agricultural water demand and supply in the NASb are shown in **Figure 4-22**. Average annual agricultural water supply in the NASb is shown in **Figure 4-23**. As discussed in **Section 4.3.3**, urban demand and supply for the PCBL with Climate Change are the same as the PCBL; refer to **Figure 4-16** and **Figure 4-17** for urban land and water use budgets.

Table 4-10: PCBL with Climate Change Average Annual and Water Use Budget

Agricultural Water Budget (AFY)				Urban Water Budget (AFY)				
Demand	Groundwater Use	Surface Water Deliveries	Surplus (-)/ Shortage (+)	Demand	Groundwater Use	Surface Water Deliveries	Recycled Water	Surplus (-)/ Shortage (+)
378,022	219,501	159,858	-1,337	294,510	107,129	187,381	-	0

Note: Small differences exist between total supplies and total demands. These shortages and surpluses are delivered and applied regardless of the demand specified in the model. Surpluses tend to result in deep percolation.

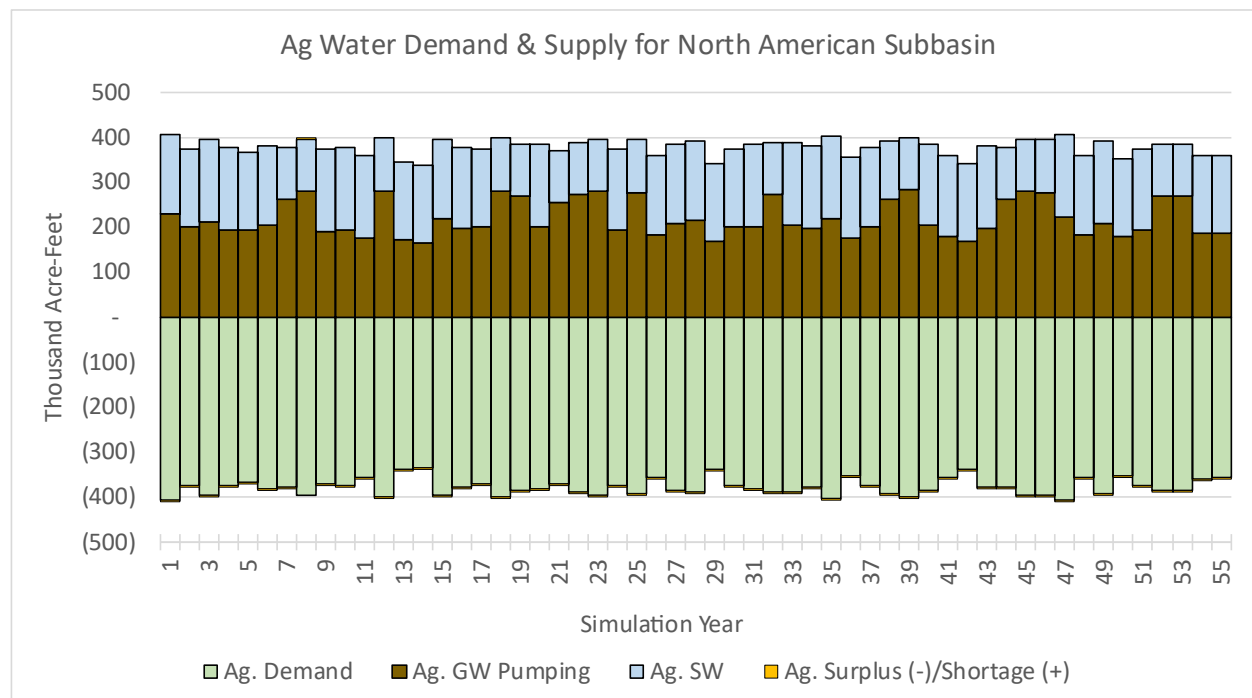


Figure 4-22: Annual Agricultural Water Demand and Supply – NASb, PCBL with Climate Change

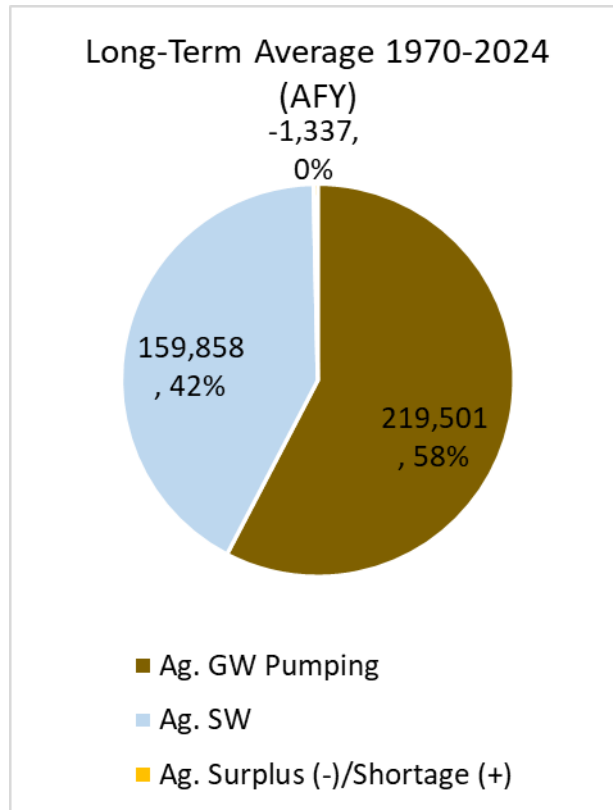


Figure 4-23: Average Annual Agricultural Water Supply – NASb, PCBL with Climate Change

4.3.7.2 Groundwater Budget

The groundwater budget provides all inflows and outflows to the groundwater aquifer system. Average annual PCBL with Climate Change model results by groundwater subbasin are shown in **Table 4-11**. Annual groundwater budgets with cumulative change in storage by subbasin are shown in **Figure 4-24**. The average annual groundwater budgets of net inflows, outflows, and change in storage in the NASb are shown in **Figure 4-25** and **Figure 4-26**. The cumulative change in groundwater storage in the long-term with annual variabilities is shown in **Figure 4-27**. **Appendix A** includes a set of sample hydrographs for the baseline models.

Table 4-11: PCBL with Climate Change Average Annual Groundwater Budget

Inflows (AFY)					Outflows (AFY)	Change in Storage (AFY)
Deep Percolation	Net Gain from Stream	Recharge*	Net Subsurface Inflow**	Net Boundary Flows***	Pumping	
159,875	125,151	28,513	4,960	17,106	335,148	440

Note:

*Recharge includes seepage through unlined irrigation supply canals.

**Net Subsurface Inflows includes inflows and outflows between the North American Subbasin and South American Subbasin and areas outside of Bulletin 118 subbasins.

***Net Boundary Flows includes inflows and outflows between areas outside of the CoSANA model domain and baseflow from small watersheds.

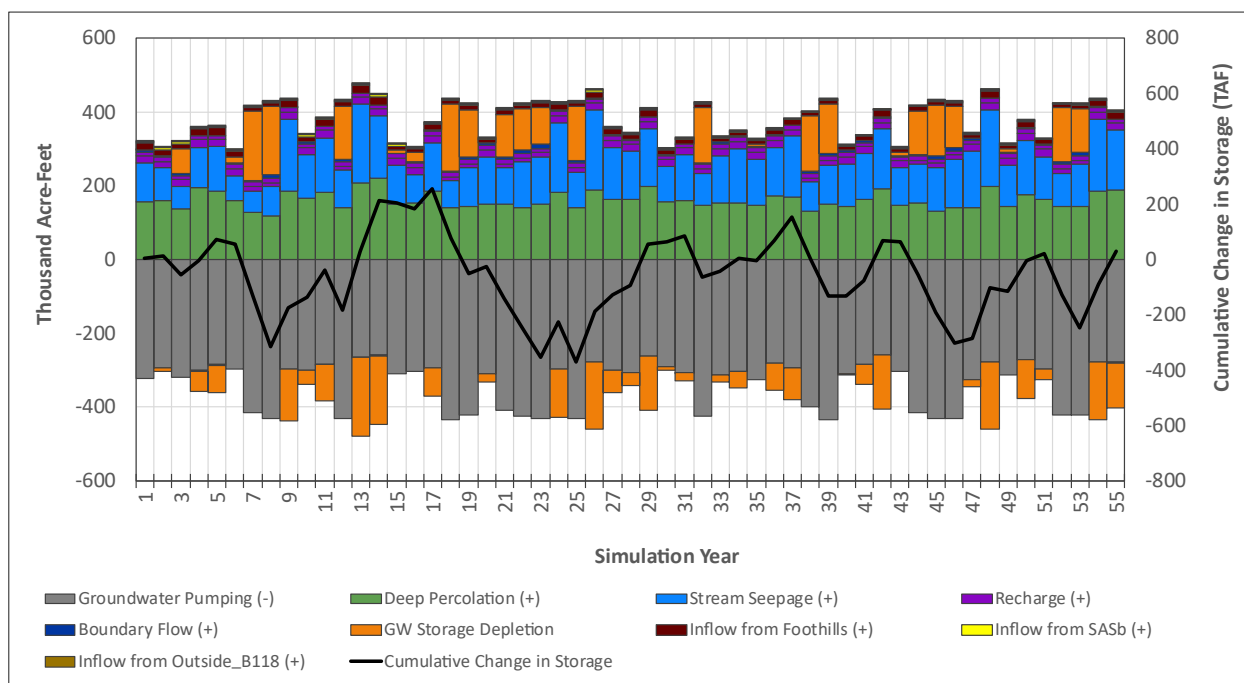


Figure 4-24: Annual Groundwater Budget and Cumulative Change in Storage – NASb, PCBL with Climate Change

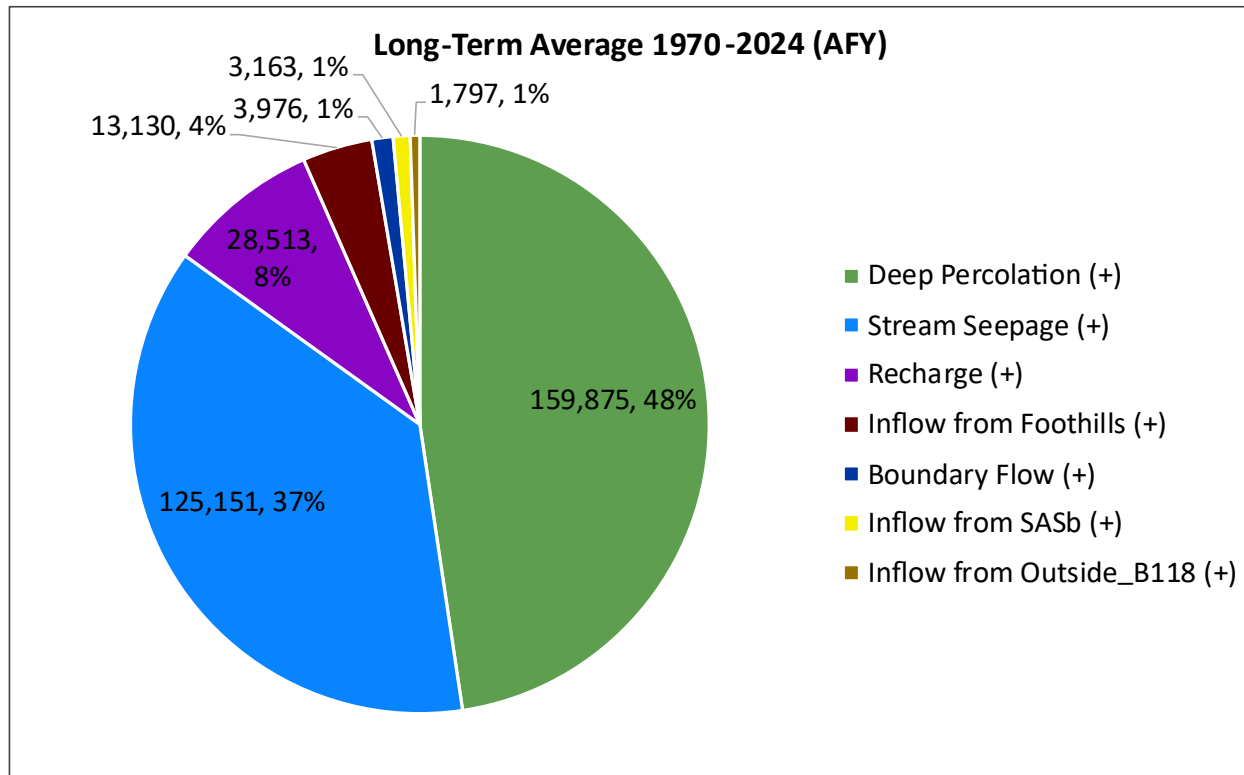


Figure 4-25: Average Annual Groundwater Budget Inflows – NASb, PCBL with Climate Change

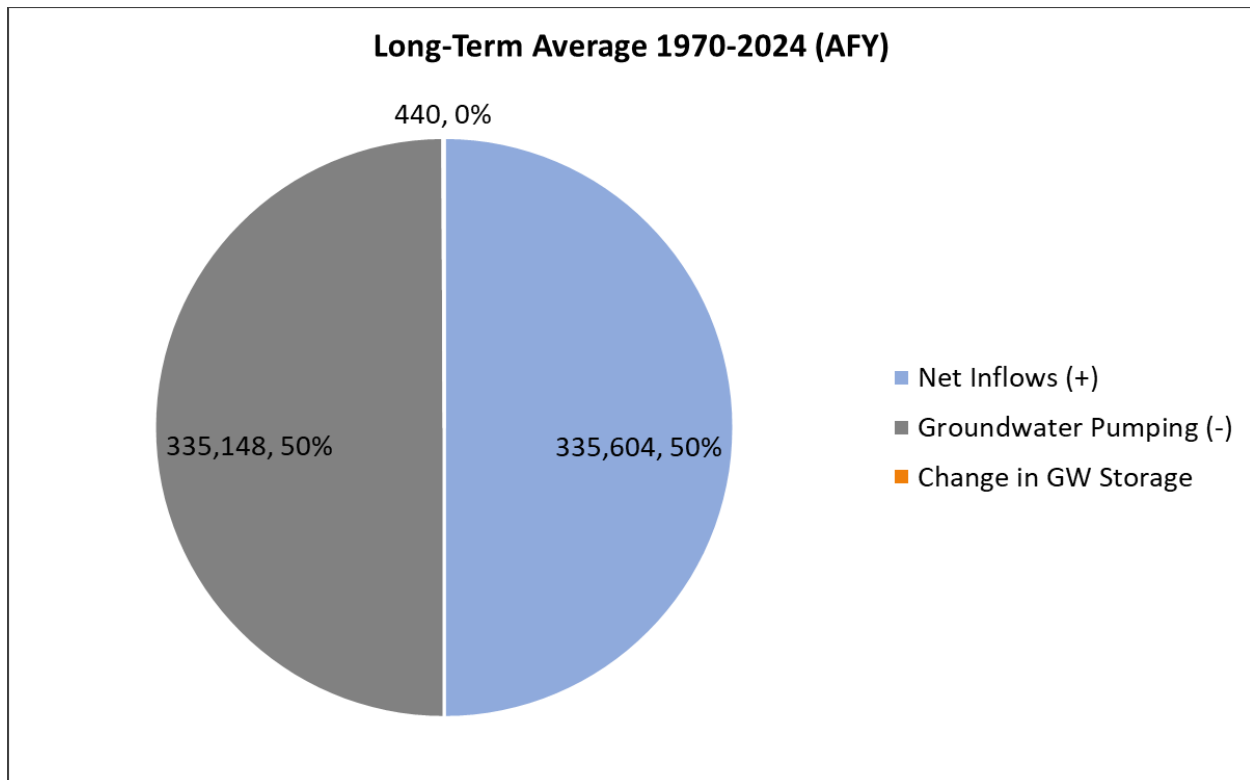


Figure 4-26 Average Annual Groundwater Budget Net Inflows & Outflows & Change in Storage – NASb, PCBL with Climate Change

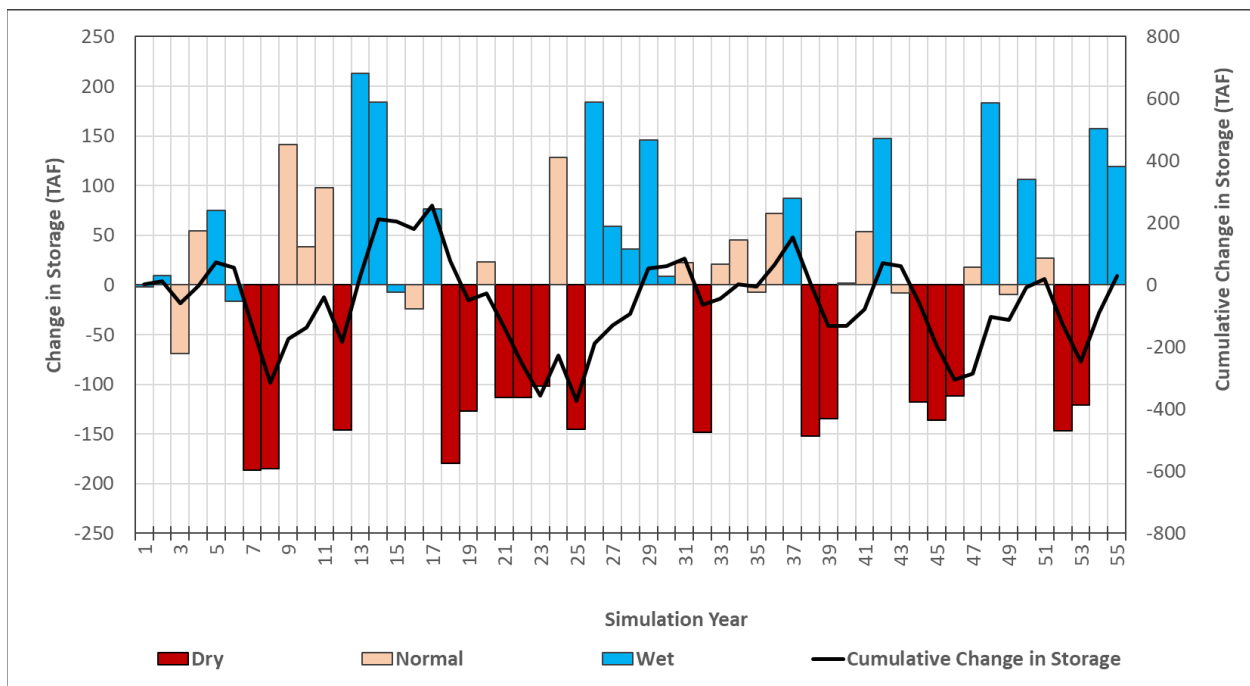


Figure 4-27: Annual Groundwater Budget Change in Storage – NASb, PCBL with Climate Change

4.3.8 Hot and Dry Scenario

The 2070HD scenario is analyzed as an extreme case to determine the potential effects of the 2070HD scenario on the groundwater and surface water systems. Although there is additional updated climate change projection information developed by DWR available, the version of climate change and especially the Hot and Dry scenario is used in this context to evaluate the sensitivity of the hydrologic and groundwater system to the extreme climate change scenarios. It is understood that Climate Science is an evolving one and more potentially accurate information is developed as science evolves. Therefore, this model scenario and results are assumed to provide reasonable scale of impacts for planning purposes at this point in time.

2070HD simulates lower overall precipitation, and higher temperature, than the 2070CT. A comparison of the NASb groundwater budgets for PCBL, PCBL with 2070CT, and PCBL with 2070HD are shown **Table 4-12** below.

Table 4-12: Comparison of NASb Groundwater Budgets of CoSANA Climate Change Models to the PCBL

Model Version	Inflows (AFY)					Outflows (AFY)	Change in Storage (AFY)
	Deep Percolation	Net Gain from Stream	Recharge*	Net Subsurface Inflow**	Net Boundary Flows***	Pumping	
PCBL	164,180	110,496	28,451	4,245	15,971	318,251	5,074
PCBL+CC (2070CT)	159,875	125,151	28,513	4,960	17,106	335,148	440
PCBL+CC (2070HD)	154,495	131,920	28,521	5,215	18,120	344,148	-5,894

Note:

*Recharge includes seepage through unlined irrigation supply canals.

**Net Subsurface Inflows includes inflows and outflows between the North American Subbasin and South American Subbasin and areas outside of Bulletin 118 subbasins.

***Net Boundary Flows includes inflows and outflows between areas outside of the CoSANA model domain and baseflow from small watersheds.

As shown in **Table 4-12** the 2070HD scenario leads to an overall increase in pumping of approximately 3% above the 2070CT, this is largely due to increased evapotranspiration causing an increase in agricultural demand. Decreases in deep percolation are largely attributable to decreasing precipitation. Increases in stream seepage, subsurface flows, and boundary flows are all due to lower groundwater levels being observed in the 2070HD scenario.

5. SUMMARY AND RECOMMENDATIONS

5.1 Summary

The CoSANA model is a robust, comprehensive, defensible model for assessing water resources conditions in the Sacramento region through integrated modeling of land surface, groundwater, and surface water conditions using detailed local and regional data and the DWR-supported IWFM modeling platform. This includes simulation under historical, current, projected, and projected with climate change conditions. The efforts documented in this report reflect upgrades and refinements to the CoSANA model for the NASb. These efforts have resulted in significant improvements to the model calibration for the NASb area. The resulting model is a much improved numerical tool that can be used for various water supply and management studies and includes flexibility for updates and refinements to meet future needs of the region, including application to regional and local projects, such as the SRWB and groundwater sustainability evaluation for the GSP.

The CoSANA model, upgraded and refined for the NASb, simulates historical hydrology for WYs 1970–2024 on a monthly time step, with a focused calibration period of WYs 1990–2024. The updated model calibration is based on water budgets, regional groundwater level and flow trends, groundwater level elevations at designated calibration wells, streamflows at selected stream gaging stations, interaction between the stream and the aquifer system along major river courses, surface runoff, and subsurface flow contributions from the tributary watersheds to the east, and subsurface flow directions and rates among the three groundwater subbasins within the model.

Three baseline scenarios are updated to support SGMA activities, including the periodic evaluation of the NASb GSP and other potential water resources planning needs, such as the SRWB. The Current Conditions Baseline, Projected Conditions Baseline, and Projected Conditions with Climate Change Baseline allow for assessment of water budgets under respective hydrologic, land and water use, and operations conditions and also facilitate analysis of future projects and management activities. The baselines incorporate 55 years of hydrology (WYs 1970–2024) to support the NASb GSP periodic evaluation, and to provide climatic change uncertainty based on the 2070 Central Tendency climate change to assess future groundwater sustainability conditions, as well as assessment of the groundwater sustainability conditions under the 2070 Hot and Dry climate conditions.

5.2 Recommendations

It is important to recognize that integrated hydrologic model development, refinement and use is an evolutionary process. Development and use of models can help identify data and information gaps and/or need to enhance and upgrade model features. A model that is put to use can always benefit from improvement over time.

The CoSANA model, as upgraded, refined, and documented in this report is a significantly improved version of the model which meets the needs of regional and local programs and projects, including GSP periodic evaluation, projects and management actions, SRWB, and other projects. During the course of model refinement, the model developers ran into data, parameters and assumptions that could contribute toward further improvements in the model. However, neither data was readily available, nor the work was scoped and budgeted for this project. These are documented herein as recommendations only for future consideration and do not reflect on major limitations or shortcomings of this version of the model:

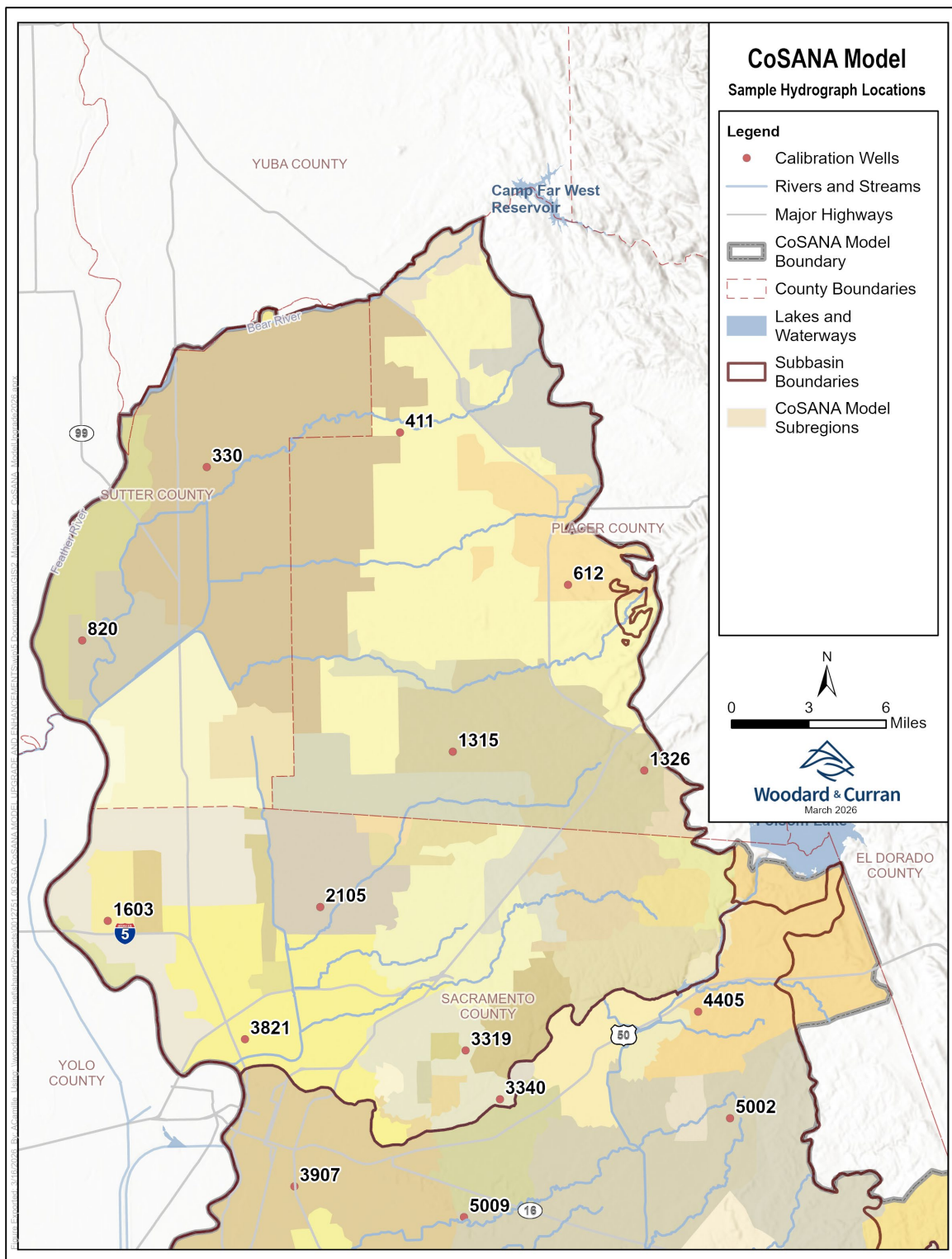
- The current model has spatial and temporal distribution of ET. However, other ET data based on satellite imagery have recently been made available that can potentially provide higher resolution spatial and temporal variability. The use of such data and analysis need to be evaluated in the context of crop types, annual crop rotations, and migration to permanent crops.
- The current model soil conditions were updated based on latest set of Soil Survey Geographic Database (SSURGO) maps. Additional field investigation and collaboration with agricultural entities and irrigation specialists can help confirm rootzone parameters to improve spatial resolution of the soil parameters.

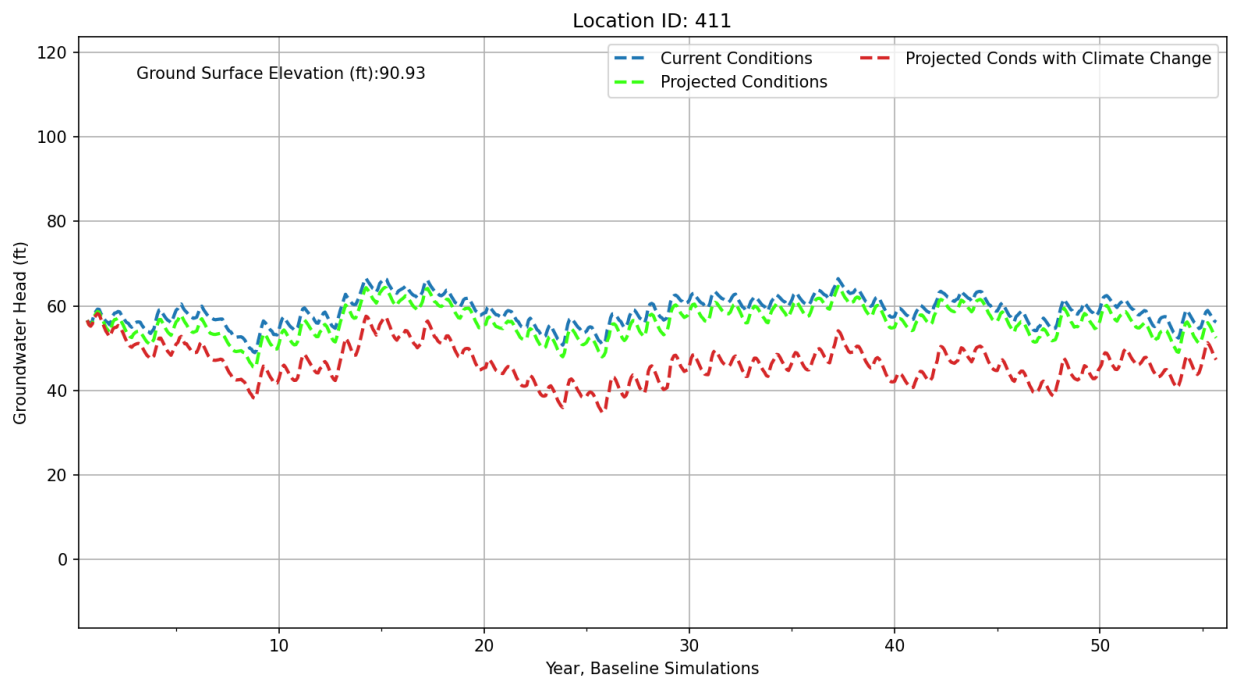
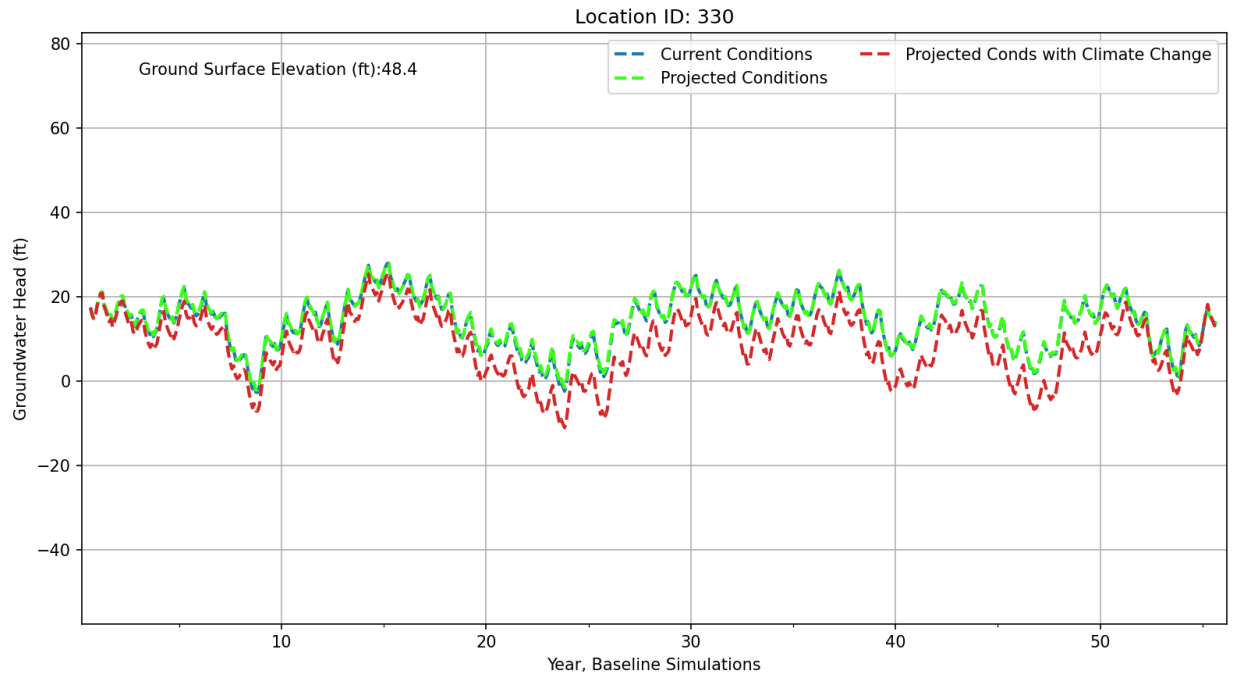
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- The tributary runoff and flows are currently estimated using the Small Watershed component of IWFM. Field data and information from the local agencies and county flood control agencies can help improve inflow estimates for tributary ungaged streams in the NASb.
 - At the time of model upgrade and refinement, LiDAR data for Auburn Ravine was not available. Once that information becomes available, the model data set can be improved to help estimate historical Auburn Ravine flows.
 - During model upgrade and refinement, some work was conducted to ensure proper location and depth of wells for groundwater use near the foothills, including those for Cities of Lincoln, Rocklin, and Roseville. Additional more detailed data and information for these areas would improve representation of the groundwater operation and activities in these areas.
 - The model currently accounts for use of recycled water as part of the overall water supply for each municipality. As recycled water use becomes more prevalent, it is recommended that recycled water be tracked separately and independent of other sources to ensure accurate accounting and effective management of future use.
 - The current analysis of climate change is based on the ARBS climate change study. It is recognized that climate science is an evolutionary process and new advances in climate change projections become available with more knowledge on the process as well as better data. The current climate change scenarios provide a reasonable understanding of the response of groundwater system to the Central Tendency and Hot and Dry climate change scenarios. Since other projections of climate change scenarios are being developed, additional analysis of groundwater system response can be evaluated in the future using updated climate change projections.
 - The baseline conditions in this report reflect current conditions using the 2015 level of development. This is consistent with the 2022 GSP assumptions. It is recommended that more updated land use data be analyzed in detail to develop a set of land use assumptions that reflect current and projected conditions for baseline evaluation. This can result in an update of the CCBL and PCBL land use assumptions for agricultural areas, cropping patterns, and extent of urban areas to reflect current land use conditions, and projected conditions with additional inputs provided from local agencies regarding planned development schedules and proposed growth areas.
 - The current groundwater level initial conditions are similar to those used in the 2022 GSP model. Depending on other assumptions for the CCBL and PCBL, an update to the initial conditions for the baseline models can be made to represent the hydrologic state under the current conditions.

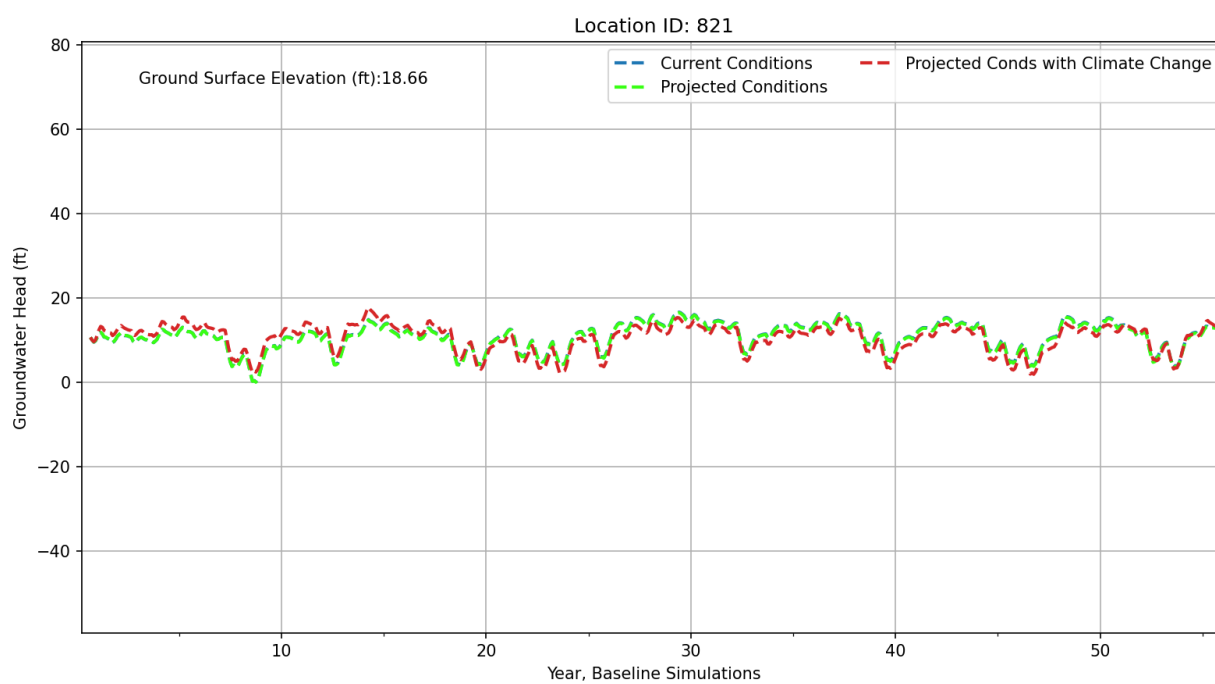
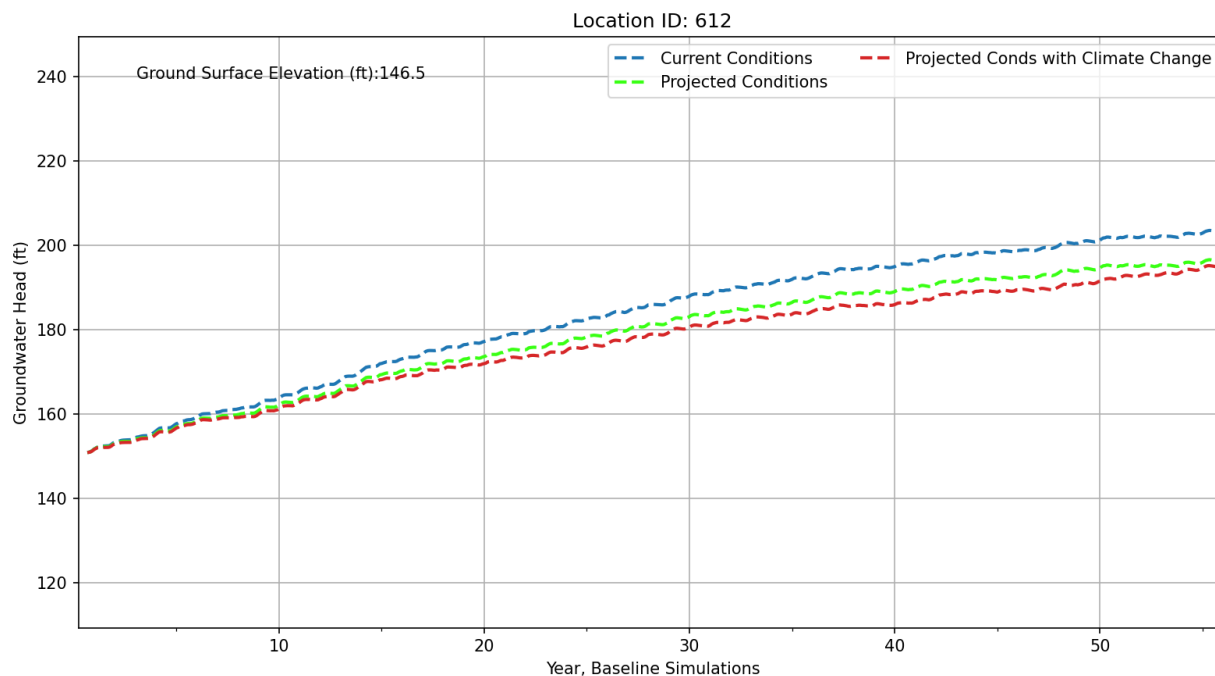
6. REFERENCES

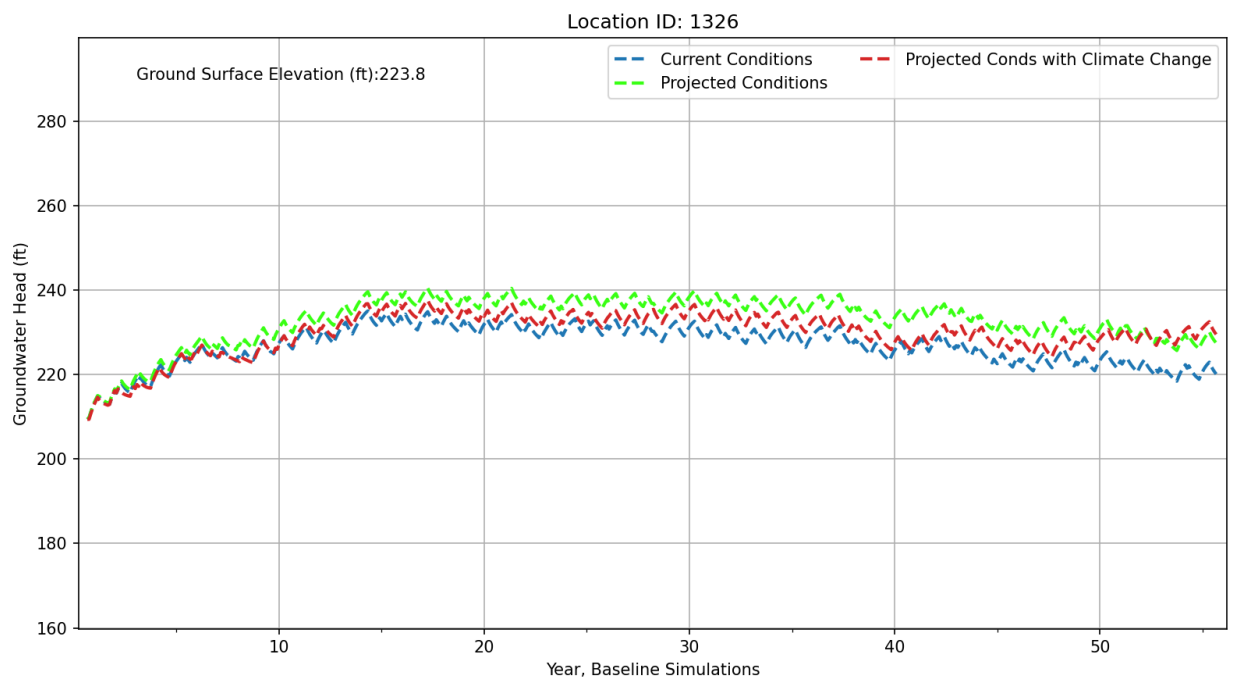
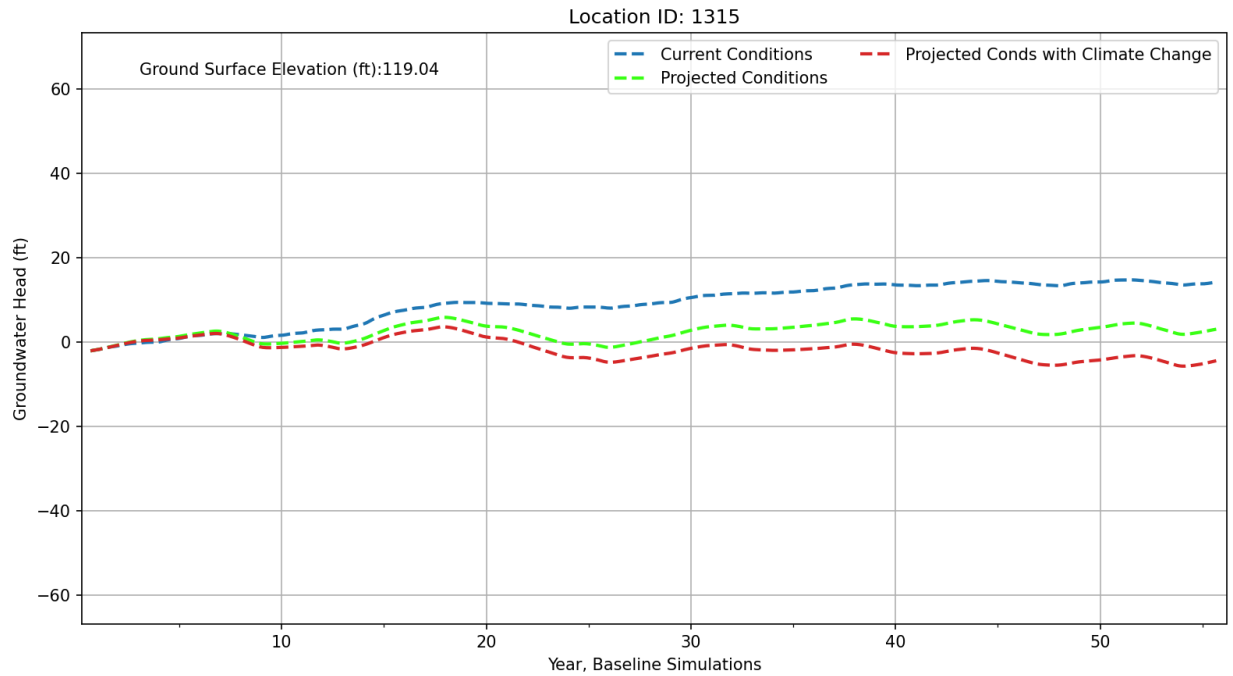
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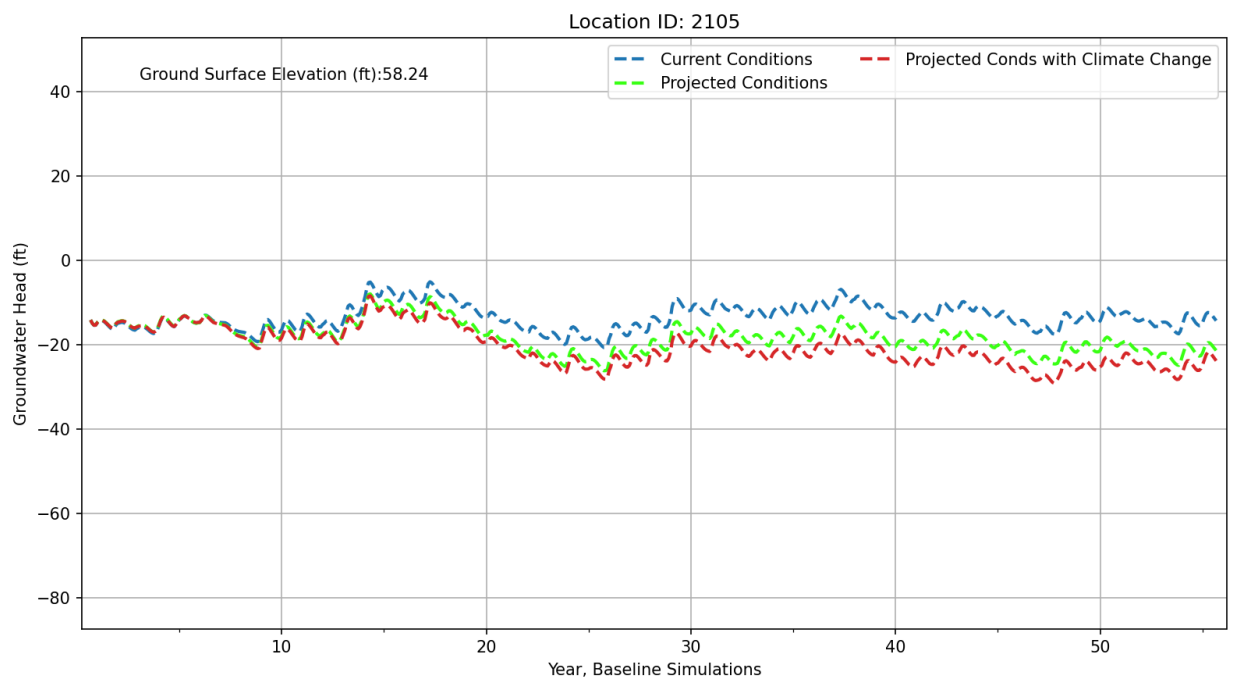
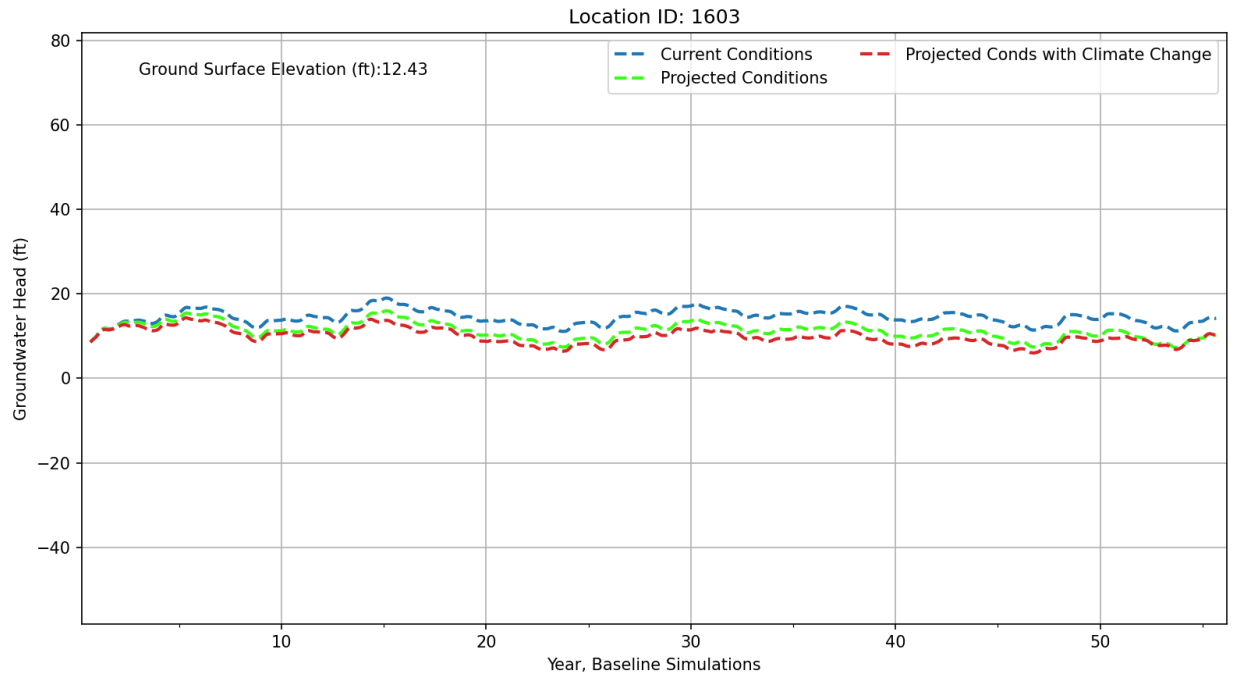
APPENDIX A: BASELINE CONDITIONS SAMPLE HYDROGRAPHS

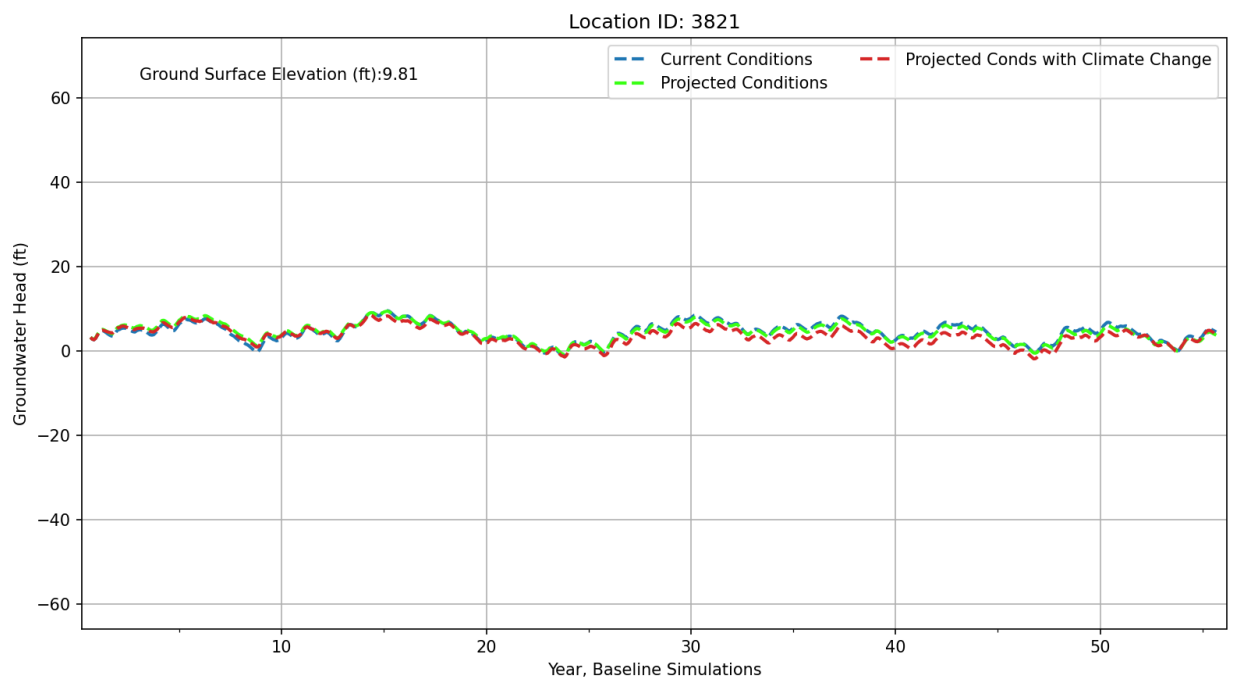
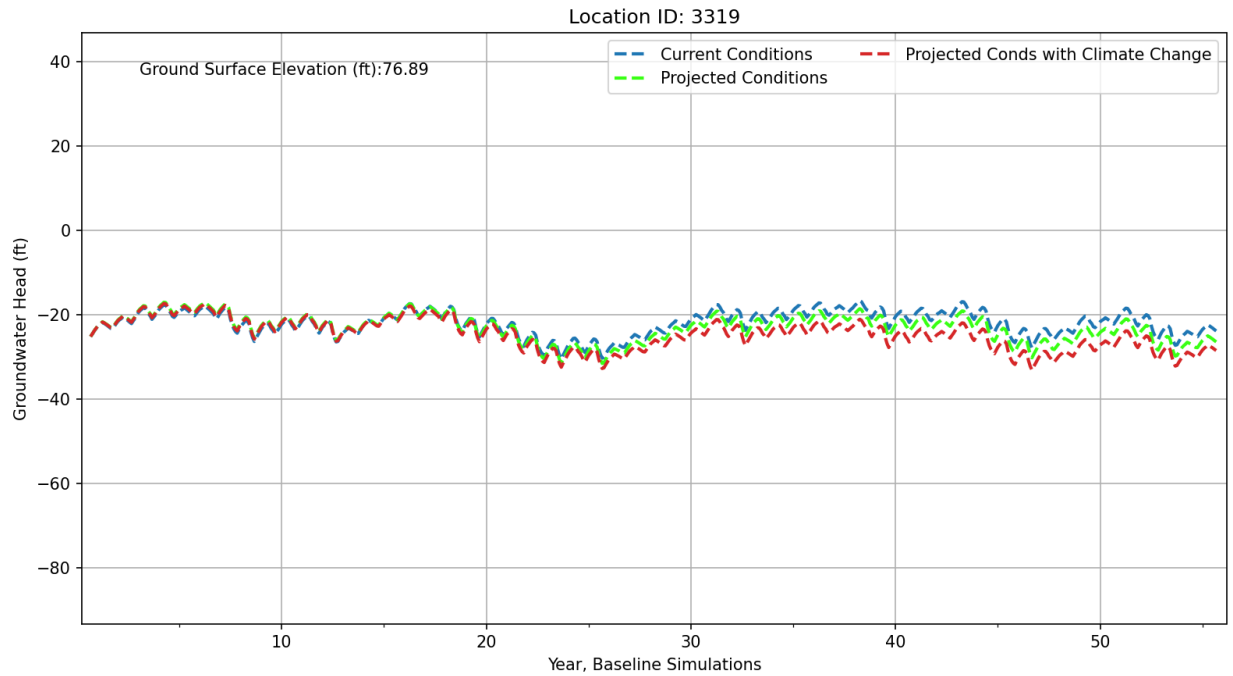


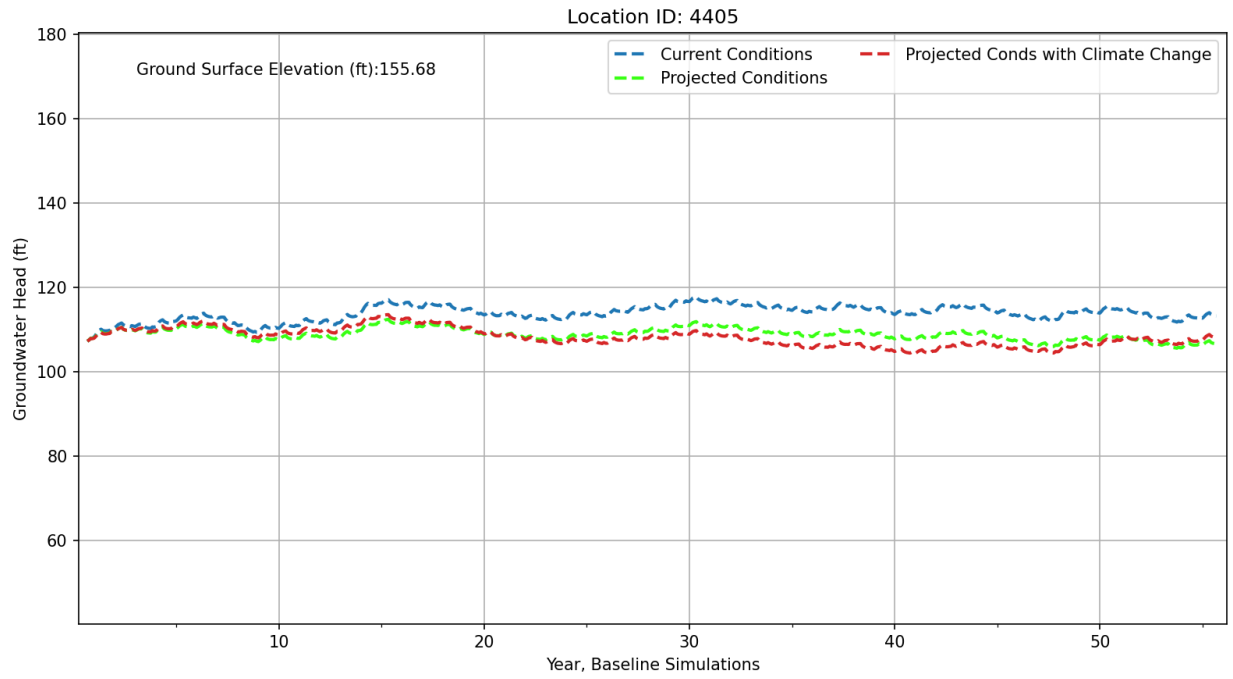












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