State Water Resources Control Board

Prepared for

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TMDL and Nonpoint Source Unit
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MODEL DOCUMENTATION REPORT FOR THE GROUNDWATER-SURFACE WATER MODEL FOR THE VENTURA RIVER WATERSHED

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[1] Tables 2.1 through 2.37 are not embedded in this document. All tables found in Section 2 tables are presented in a companion Microsoft Excel spreadsheet file. The spreadsheet is included in the zip folder for this model report and is available for download on the State Water Board’s California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/

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[2] Appendices A through F are not embedded in this document. The appendices are presented in companion files. Appendix A is a Microsoft Excel spreadsheet. Appendices B through F are compiled in two additional PDF files. The appendices are include in the zip folder for this model report and are available for download on the State Water Board's California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/

LIST OF ACRONYMS AND ABBREVIATIONS

AAEE	absolute average estimation error
AET	actual evapotranspiration
AF	acre-feet
AFY	acre-feet per year
APP ID	application identification number
ASTM	American Society for Testing and Materials
CDFW	California [3]Department of Fish and Wildlife
cfs	cubic feet per second
CGS	California Geological Survey
CHD	MODFLOW Constant Head Boundary
CIMIS	California Irrigation Management Information System
CMWD	Casitas Municipal Water District
DBS&A	Daniel B. Stephens & Associates
DWR	Department of Water Resources
ET	evapotranspiration
eWRIMS	electronic Water Rights Information Management System
EVT	MODFLOW evapotranspiration package
ft-amsl	feet above mean sea level
Geosyntec	Geosyntec Consultants
GHB	MODFLOW General-Head Boundary
gpcd	gallons per capita per day
gpm	gallons per minute
GSFLOW	Groundwater and Surface-water Flow
GSWC	Golden State Water Company
GW-SW	groundwater-surface water
HEC-RAS	Hydrologic Engineering Center – River Analyses System
HFB	MODFLOW horizontal flow barrier
HRU(s)	hydrologic response unit(s)
HSPF	Hydrological Simulation Program in Fortran
IHM	Integrated Hydrologic Model
K	hydraulic conductivity
km	kilometer
Kx	horizontal hydraulic conductivity
Kz	vertical hydraulic conductivity
L	length of the boundary
LAK	MODFLOW Lake Package
lidar	light detection and ranging

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LIST OF ACRONYMS AND ABBREVIATIONS (continued)

M	distance from the cell to the boundary
MAE	mean absolute error
ME	mean error
MNW2	MODFLOW Multi-Node Well Package
MODFLOW	MODular finite-difference ground-water FLOW model
MOWD	Meiners Oaks Water District
MWC	Mutual Water Company
NAVD	North American Vertical Datum
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NRCS	National Resources Conservation Service
NSME	Nash-Sutcliffe model efficiency
NWT	Newton Formulation
OBGM	Ojai Valley Basin Groundwater Model
OBGMA	Ojai Basin Groundwater Management Agency
OVSD	Ojai Valley Sanitation District
OWS	Ojai Water System
OWTS	onsite wastewater treatment systems
PAEE	percent average estimation error
PET	potential evapotranspiration
POD ID	point of diversion identification number
POI	points of interest
PRISM	Parameter-elevation Relationships on Independent Slopes Model
PRMS	Precipitation-Runoff Modeling System
R	correlation coefficient
RMMWC	Rancho Matilija Mutual Water Company
RMS	root-mean-square
RMSE	root-mean-square error
SCMWC	Senior Canyon Mutual Water Company
SFR	MODFLOW Streamflow Routing Package
SFR_K	streambed hydraulic conductivity
SGMA	Sustainable Groundwater Management Act
SSURGO	Soil Survey Geographic Database
SWRCB	State Water Resources Control Board
Sy	specific yield
TAC	Technical Advisory Committee
TMDL	total maximum daily load
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

USFS	U.S. Forest Service
USGS	U.S. Geological Survey
UVRGA	Upper Ventura River Groundwater Agency
UZF	MODFLOW Unsaturated-Zone Flow
VCAC	Ventura County Agricultural Commissioner
VCWPD	Ventura County Watershed Protection District
VKS	unsaturated zone vertical hydraulic conductivity
VRW	Ventura River Watershed
VRWD	Ventura River Water District
VSWHM	Ventura Surface Water Hydrology Model
W	width of the boundary
WWTP	wastewater treatment plant
WY	water year

1 INTRODUCTION

Geosyntec Consultants (Geosyntec) and Daniel B. Stephens & Associates, Inc. (DBS&A) developed this Model Documentation Report to describe the overall approach that was taken to develop the groundwater-surface water (GW-SW) model for the Ventura River watershed (VRW) for the State Water Resources Control Board (State Water Board) and the Los Angeles Regional Water Quality Control Board (LA Regional Water Board).

1.1 Background

Since 1997, Southern California Steelhead (*Oncorhynchus mykiss;* steelhead), an anadromous fish, have been listed under the federal Endangered Species Act as an endangered species. The listing was most recently renewed in May 2023. In 2024, the California Fish and Game Commission listed steelhead as endangered under the California Endangered Species Act.

The State Water Board is working on various efforts to establish minimum flows that support threatened and endangered fisheries species with consideration of other uses of water. Governor Edmund G. Brown Jr.'s California Water Action Plan was published in 2014 and amended in 2016. The Water Action Plan identified various actions, including the need to "Protect and Restore Important Ecosystems", and directed that:

> *The State Water Resources Control Board and the Department of Fish and Wildlife will implement a suite of individual and coordinated administrative efforts to enhance flows statewide in at least five stream systems that support critical habitat for anadromous fish. These actions include developing defensible, cost-effective, and time-sensitive approaches to establish instream flows using sound science and a transparent public process. When developing and implementing this action, the State Water Resources Control Board and the Department of Fish and Wildlife will consider their public trust responsibility and existing statutory authorities such as maintaining fish in good condition.*

In response to Governor Gavin C. Newsom's Executive Order N-10-19, issued on April 29, 2019, the California Natural Resources Agency, the California Environmental Protection Agency, and the California Department of Food and Agriculture developed the California Water Resilience Portfolio. The Water Resilience Portfolio was finalized in July 2020 and directs state agencies to "Protect and Enhance Natural Systems." Specifically, Proposal Nine (9) directs state agencies to:

- *Help regions better protect fish and wildlife by quantifying the timing, quality, and volume of flows they need…*
    - *Conduct and utilize instream flow analyses to further develop instream flow recommendations for ecologically important streams to protect public trust values.*
    - *Bring together regulators, tribes, water users, public water agencies, non-governmental organizations, and other stakeholders to develop innovative, voluntary solutions to water supply, water quality, and ecosystem protection.*
    - *Work with universities, tribes, public water agencies, and non-governmental organizations to develop new tools for identifying functional ecosystem flows.*
    - *Develop analytical modeling tools that can be used to rapidly assess streamflow depletion tied to groundwater pumping.*

Governor Newsom's California Salmon Strategy for a Hotter Drier Future (Salmon Strategy) was published in 2024 and provides ongoing direction. Action three (3) directs the State Water Board to partner with Tribal Nations, California Department of Fish and Wildlife (CDFW) and others to "Protect Water Flows and Water Quality in Key Rivers at the Right Times to Support Salmon". Specifically, Action 3.12 directs the State Water Board and CDFW to, "by 2026, complete instream flow analysis for all streams identified in the 2014 California Water Action Plan, which includes the Ventura River…" and other watersheds.

As part of its responsibilities under the Water Action Plan, Water Resilience Portfolio, and Salmon Strategy, the State Water Board is working to ensure the reasonable protection of beneficial uses in priority watersheds. The State Water Board and CDFW are working to identify potential actions that may be taken to enhance and establish instream flows for steelhead in the VRW. The VRW GW-SW Model provides a better understanding of water supply, water demand, and instream flow in the VRW.

Additionally, in 2012, the LA Regional Water Board adopted a total maximum daily load (TMDL) for algae, eutrophic conditions, and nutrients in the VRW (LARWQCB 2012a, 2012b). At the time of TMDL development, LA Regional Water Board staff did not possess the data or modeling tools to evaluate the contributions of nutrients in groundwater to surface water impairments. The VRW GW-SW Model described in this report has been used as the basis to develop a VRW Nitrogen Transport Model (Nitrogen Model) to help inform the TMDL process in the VRW. The VRW Nitrogen Model will be documented in a separate report.

1.2 Public Outreach

To support development of the VRW GW-SW Model and VRW Nitrogen Model, the Water Boards have used a rigorous public engagement process that has included seven public and Technical Advisory Committee (TAC) comment solicitation periods covering most aspects of model development. The project team has used in-person and virtual public meetings, TAC meetings, site visits, and coordination with individual parties to share information, obtain feedback, and follow-up on specific issues. The project team thanks the public and TAC for their continued engagement. The public and TAC outreach has improved development of the two models. The timeframe and description of significant document and model releases and outreach events are summarized as follows:

- 2017: *Draft Study Plan* to solicit comments on the proposed methodologies that would be used to develop the VRW GW-SW Model and VRW Nitrogen Model (Geosyntec and DBS&A, 2017).

- 2018: *Draft Geologic Analysis* of the VRW to solicit comments on the team's analysis of geologic features that are relevant to model development (DBS&A, 2018).

- 2019: *Final Study Plan* to describe how the proposed methodologies for the VRW GW-SW Model and VRW Nitrogen Model were modified in response to project changes, comments, and the 2017-2018 Thomas Fire (Geosyntec and DBS&A, 2019).

- 2020:
  - Revised *Geologic Analysis* of the Ventura River Watershed to describe how the geologic analysis was modified in response to comments and project changes (DBS&A, 2020).[4]
  - *Draft Data Compilation Report* to solicit comments on the proposed data to be used for the VRW GW-SW Model and VRW Nitrogen Model (Geosyntec and DBS&A, 2020a). Modifications in response to comments are reflected in this report.

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[4] The geologic analysis has since been updated and is included in Appendix C of this report.

  - *Draft VRW GW-SW Model Sensitivity Analysis Approach Memo* to solicit comments on the methodology that would be used to conduct a sensitivity analysis of the VRW GW-SW Model (Geosyntec and DBS&A, 2020b). Modifications in response to comments are reflected in this report.

- 2021:
  - VRW Modeling Webinar Series to update the public and TAC on model development progress and solicit comments on new revisions to the geologic analysis, an early representation of water demand, and early calibration results (SWRCB et al., 2021 a,b,c). Modifications in response to comments are reflected in this report.
  - Release of a *Preliminary Draft VRW GW-SW Model*, which included model files, simulation results for the calibration and validation simulation (existing conditions), simulation results for the unimpaired flow scenario, and a user manual (Geosyntec and DBS&A, 2021a).
  - VRW GW-SW Model: Scenarios Methodology Webinar to present information and solicit comments on the methodology and selection of scenarios that will be evaluated using the VRW GW-SW Model (SWRCB et al., 2021d).
  - *Draft VRW GW-SW Model and Report* to solicit comments on methodology, datasets, and results (Geosyntec and DBS&A, 2021b). The Draft VRW GW-SW Model included model files, simulation results for the calibration and validation simulations (existing conditions) and unimpaired flow scenario simulation, a data visualization tool for model results, and a user manual. Modifications in response to comments are reflected in this report.
- 2022:
  - Overview Webinar and two-part Technical Training webinar to support the comment solicitation period for the *Draft VRW GW-SW Model and Report* (SWRCB et al., 2022 a,b,c). Modifications in response to comments are reflected in this report.

1.3 <u>Watershed Description</u>

A comprehensive description of the VRW is available in the Ventura River Watershed Management Plan (Walter, 2015). A brief description is included here.

The VRW is located predominantly in Ventura County in southern California (Figure 1.1) and borders the Pacific Ocean to the South, the Santa Clara River watershed to the north and east, and the Rincon Creek watershed to the west. Watershed boundaries are defined by mountain ridges in the Topa Topa and

Santa Ynez Mountains within the Transverse Ranges Geomorphic Province (CGS, 2002). All watershed tributaries drain to the Ventura River and ultimately the Pacific Ocean. A schematic of the watershed and many of the hydrological and geohydrological processes is provided in Figure 1.2 and discussed in more detail in the following text.

The California Department of Water Resources (DWR) official publication on the occurrence and nature of groundwater in California (DWR, 2016a) includes four delineated groundwater basins within the VRW ("groundwater basins"), and these are displayed on Figure 1.3. Groundwater basins include the Upper Ventura River Valley Basin (Upper Ventura River Basin), Lower Ventura River Valley Basin (Lower Ventura River Basin), Ojai Valley Basin (Ojai Basin), and Upper Ojai Valley Basin (Upper Ojai Basin). The groundwater basins contain relatively thick and continuous aquifers and are surrounded by mountainous bedrock units.

Major streams within the VRW include Matilija Creek and Matilija Creek North Fork that drain the mountain bedrock areas north of the Upper Ventura River Basin, the Ventura River that flows from north to south through the Upper Ventura and Lower Ventura River Basins, San Antonio Creek that flows from northeast to southwest in the Ojai Basin to a confluence with the Ventura River, and Lion Canyon Creek that flows from east to west from the Upper Ojai Basin to a confluence with San Antonio Creek (Figure 1.3).

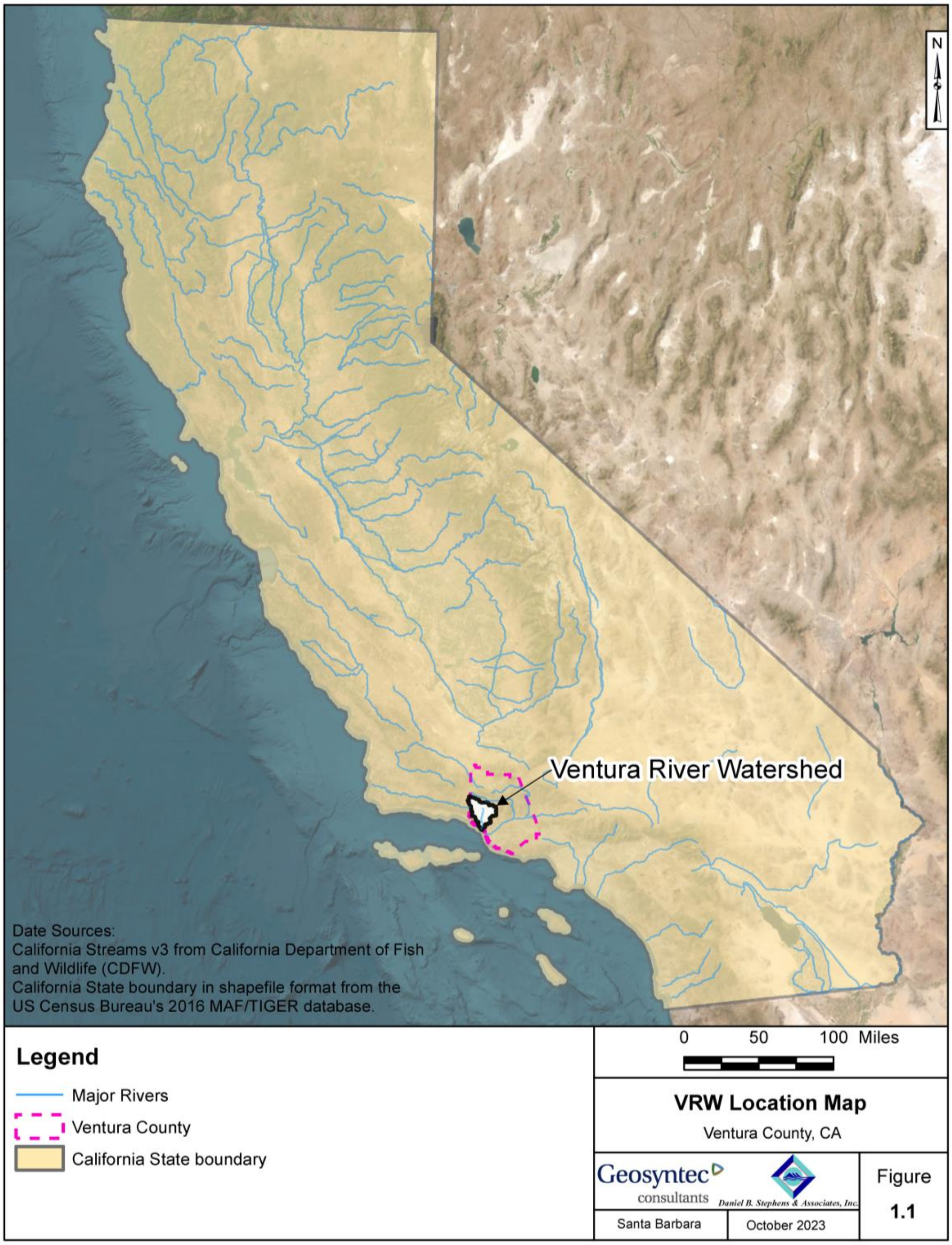

Figure 1.1 VRW Location Map

Source: Daniel B. Stephens & Associates, 2010

Ventura River Watershed Hydrologic Cycle Ventura County, CA		
Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure **1.2**
Santa Barbara	December 2021	

Figure 1.2 Ventura River Watershed Hydrologic Cycle.
Note: Some components of the hydrologic cycle, such as evaporation from lakes, are not represented.

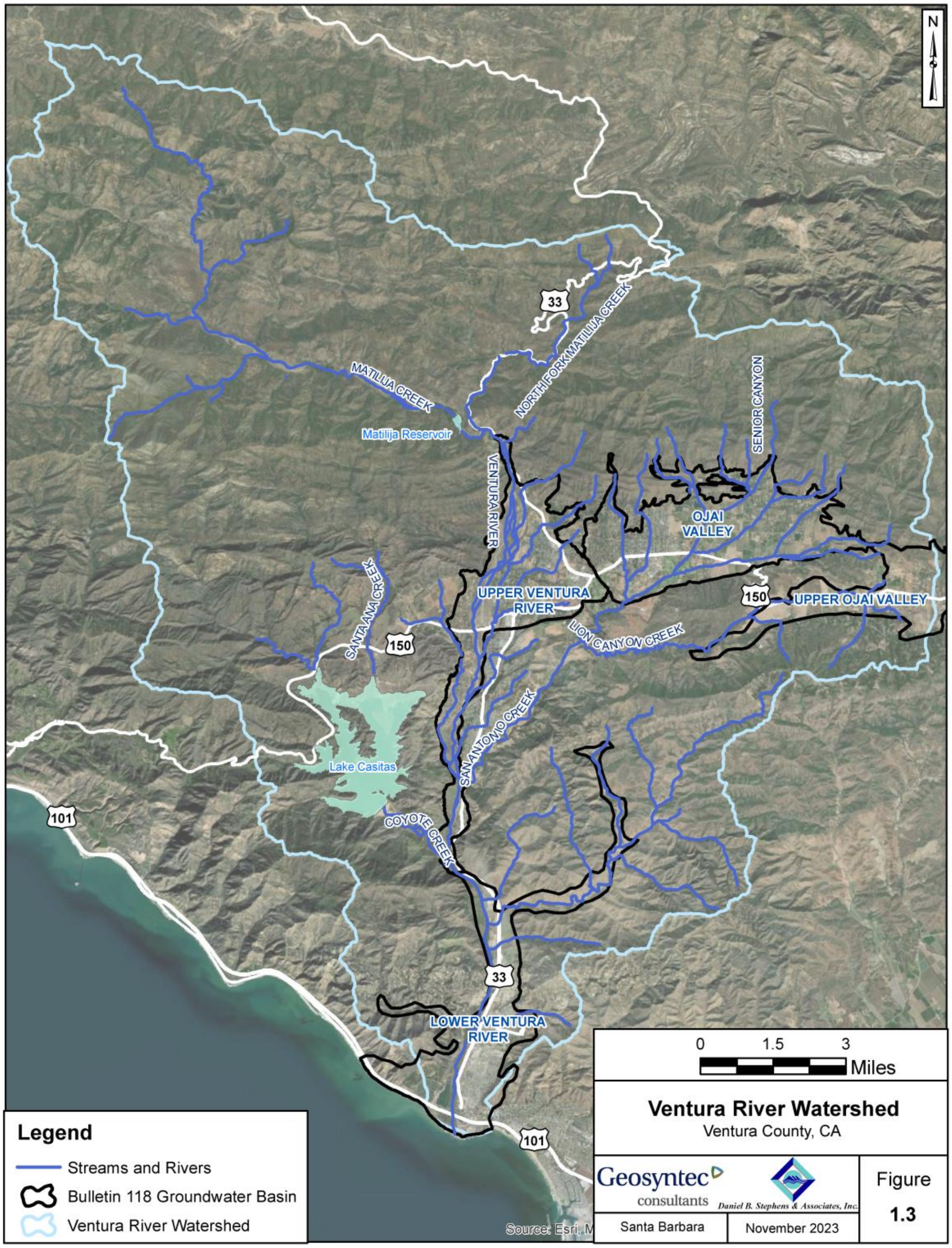

Figure 1.3 Ventura River Watershed

Lake Casitas was created by damming a portion of Coyote Creek, which flows into the Ventura River. Matilija Reservoir (also referred to as Lake Matilija) is also present due to a dam that is present on Matilija Creek. The VRW has a relatively steep topographic grade, ranging from sea level to a maximum of approximately 6,000 feet above mean sea level (ft amsl) over a span of approximately 22 miles from the coast to the highest mountain ridge on the northwestern watershed boundary.

The VRW has a Mediterranean climate with a cool winter-spring wet season and a long summer-fall dry season without measurable rain. Annual rainfall is highly variable (Figure 1.4) and largely dependent on relatively few large storm events. The steep topography enhances orographic effects with annual average rainfall ranging from approximately 15 inches at the coast, to approximately 20 inches in the Ojai valley, and upwards of 40 inches on mountain peaks. Snow occurs occasionally but the snowpack is typically short lived and does not play a significant role in the water cycle.

Demand for water in the VRW is dominated by residential use and agriculture. Excluding the City of Ventura, part of which is in the lower part of the watershed, the total population in the VRW is approximately 30,000 (see Section 2). These include the population centers of Ojai, Oak View, Meiners Oaks, Mira Monte, and Casitas Springs. There are approximately 6,700 acres of agriculture in the watershed, including a wide variety of crops (Figure 1.5). The crops are grown predominantly in the regions overlying the groundwater basins.

Substantial portions of the VRW are unsewered with more than 3,000 parcels having onsite wastewater treatment systems (OWTS) (Figure 1.6). Effluent from the OWTS passes through the unsaturated zone to the groundwater and is a source of recharge for the groundwater.

Effluent from the Ojai Valley Sanitation District (OVSD) wastewater treatment plant (WWTP) discharges to the lower Ventura River (Figure 1.7) and can contribute a significant portion of the flow in the river during the dry season.

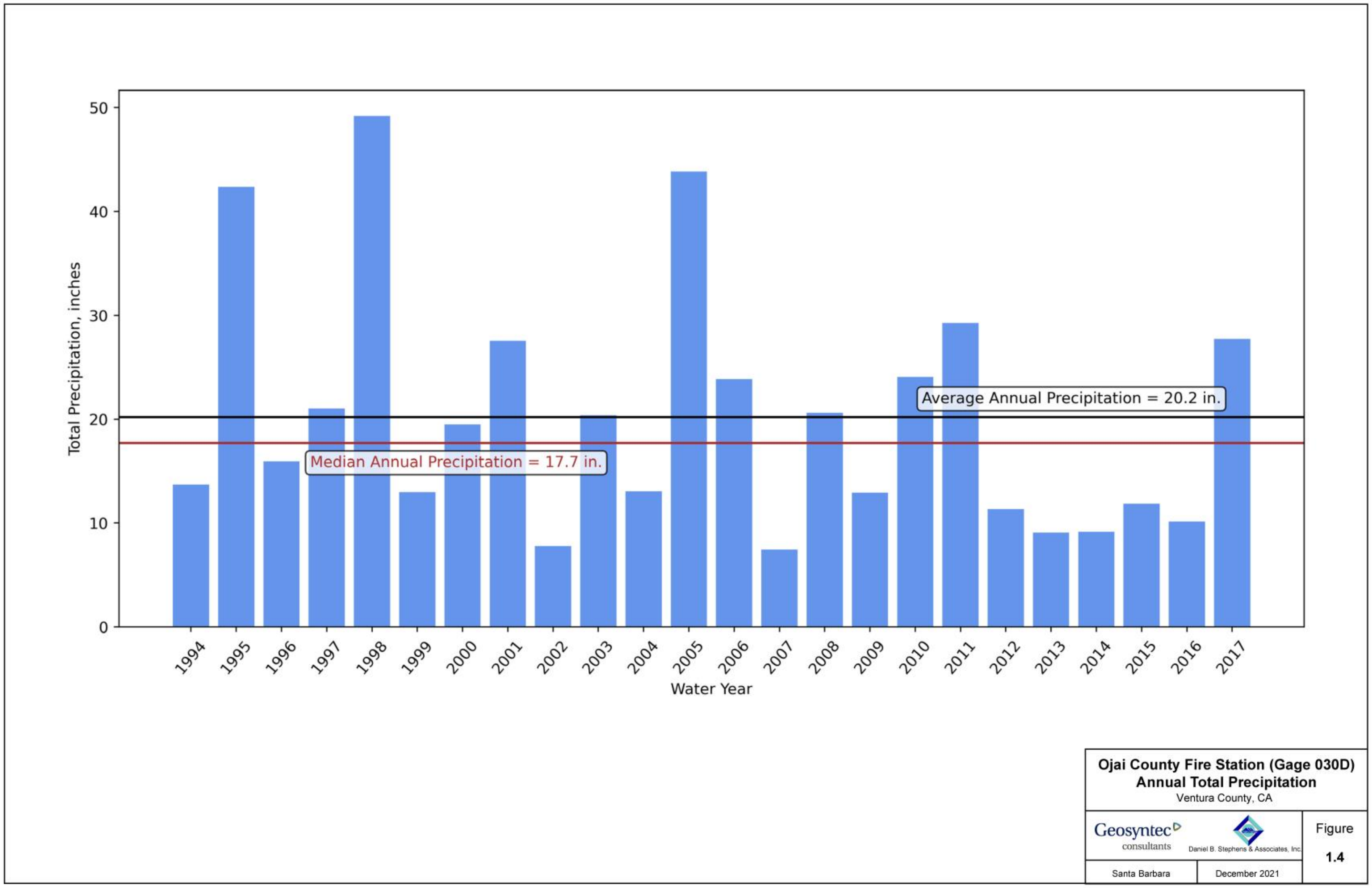

Figure 1.4 Ojai County Fire Station (Gage 030D) Annual Total Precipitation

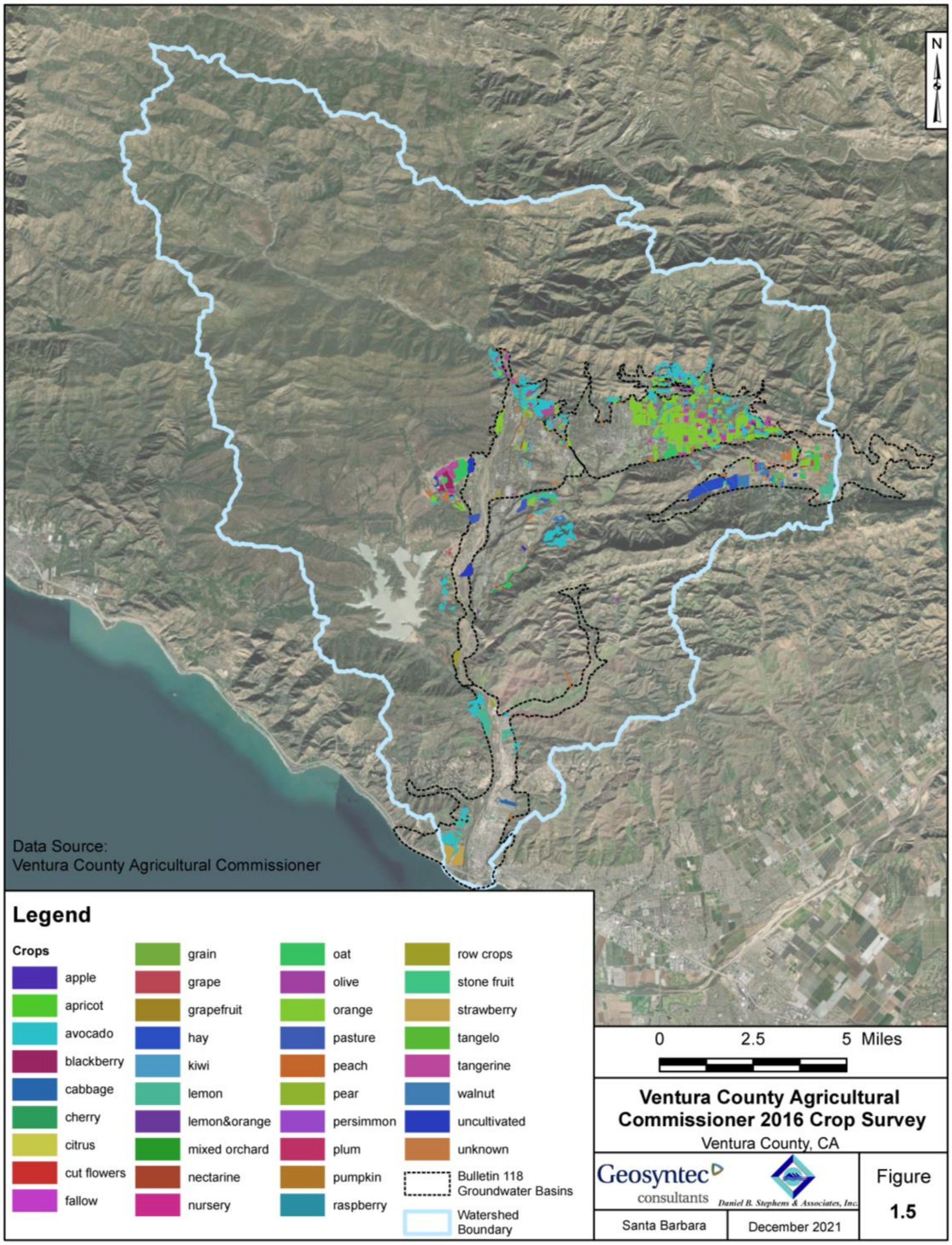

Figure 1.5 Ventura County Agricultural Commissioner 2016 Crop Survey

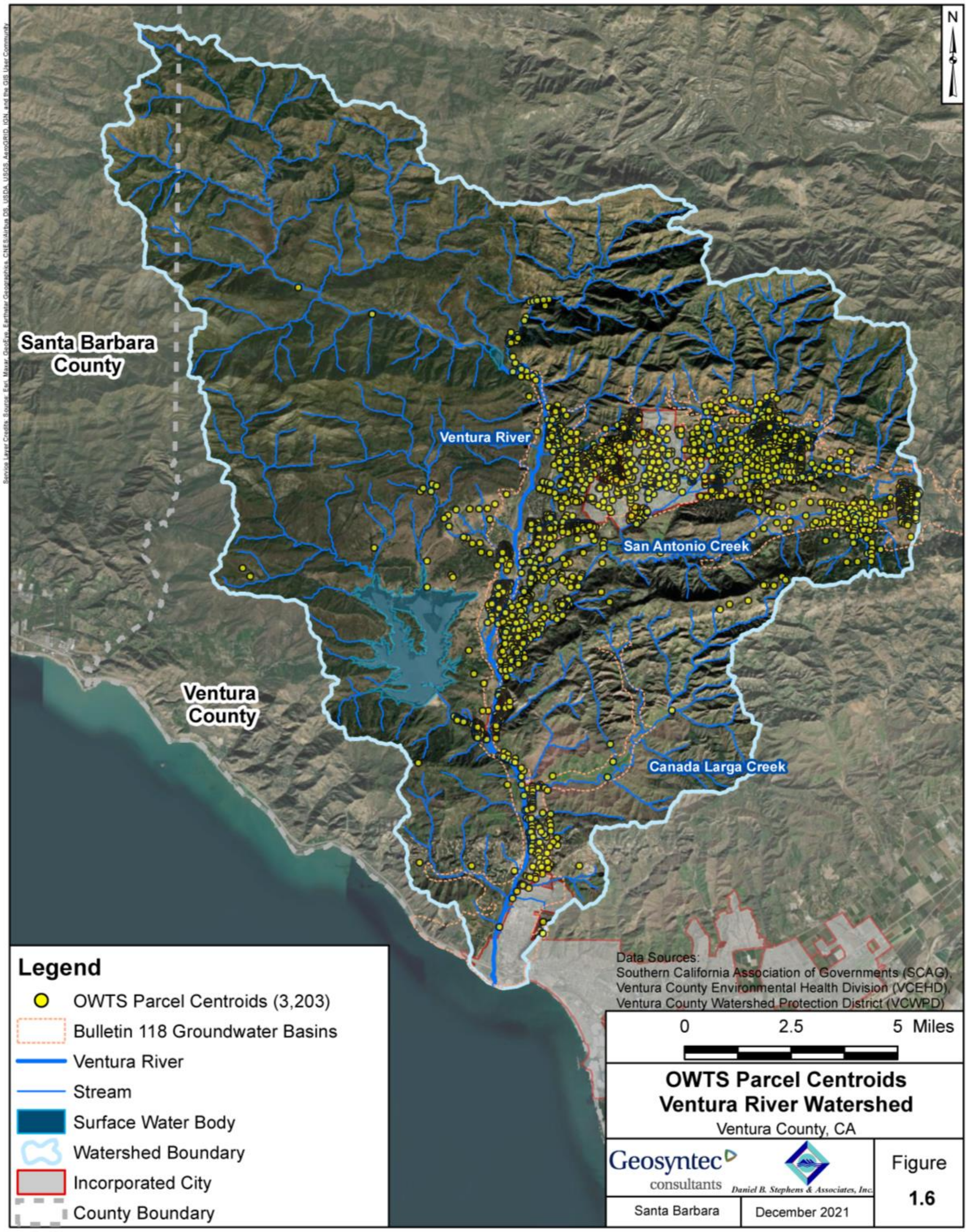

Figure 1.6 OWTS Parcel Centroids Ventura River Watershed

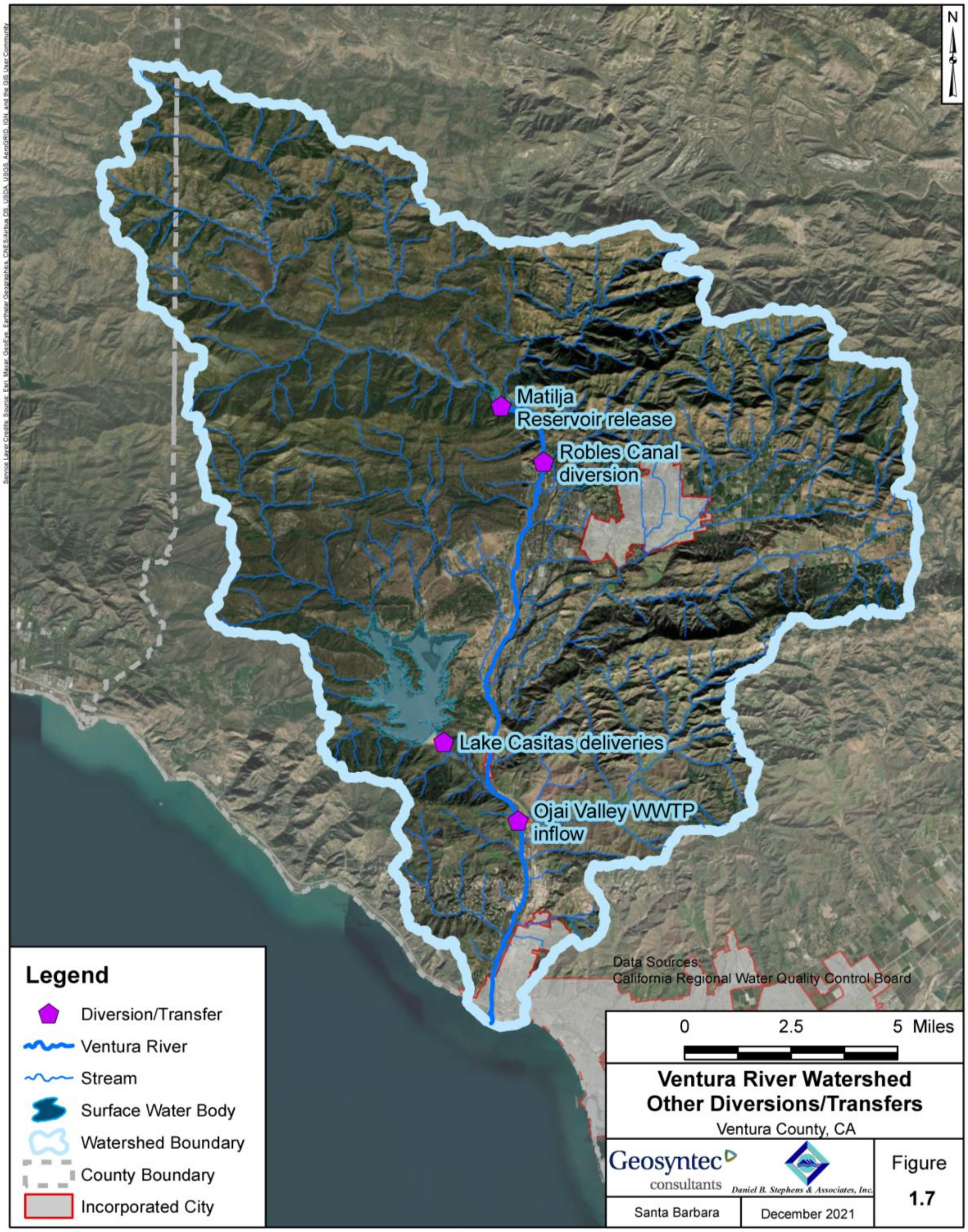

Figure 1.7 Ventura River Watershed Other Diversions/Transfers

Effluent from the WWTP and effluent discharged into OWTS are sources of nitrogen that are considered in the TMDL, together with nitrogen loads from agriculture and ranching. This will be further discussed in the separate documentation of the VRW Nitrogen Model that is under development.

Water supply in the VRW is predominantly from groundwater pumping and surface water deliveries from Lake Casitas (Figure 1.6). There are several local surface water diversions that make up a relatively small fraction of the total supply.

Deliveries from Lake Casitas are provided by the Casitas Municipal Water District (CMWD). Lake Casitas is filled by the surrounding watershed with the major inflows being Santa Ana and Coyote creeks. The lake also receives water from the Robles Canal Diversion (Figure 1.7) that diverts water from the Ventura River during periods of high flow. Historically Ventura River flows were affected by Matilija Reservoir operations (Figure 1.7). The CMWD distribution system can deliver water throughout the watershed, including to the major population centers and agricultural regions (Figure 1.8).

Groundwater is pumped from wells within each of the groundwater basins and from certain areas outside of the groundwater basins. Most groundwater pumping in the VRW is from alluvial aquifers within the groundwater basins. “Alluvial,” or “alluvium,” refers to unconsolidated layers of clay, silt, sand, or gravel and mixtures thereof. Outside the groundwater basins, groundwater is pumped from thin alluvial aquifers near stream channels and fractured bedrock geologic formations (“bedrock aquifers”). Figure 1.9 displays well locations and depths. Wells extend to a maximum depth of approximately 920 feet; however, most wells are shallower, with maximum depths ranging from 50 to 600 feet below ground. Numerous oil and gas wells are present in the VRW, but are typically much deeper (2,000 to 14,000 feet deep) than the model domain and were not represented in the GW-SW Model that focuses on the groundwater basins and bedrock aquifers used for domestic and agricultural water supply.

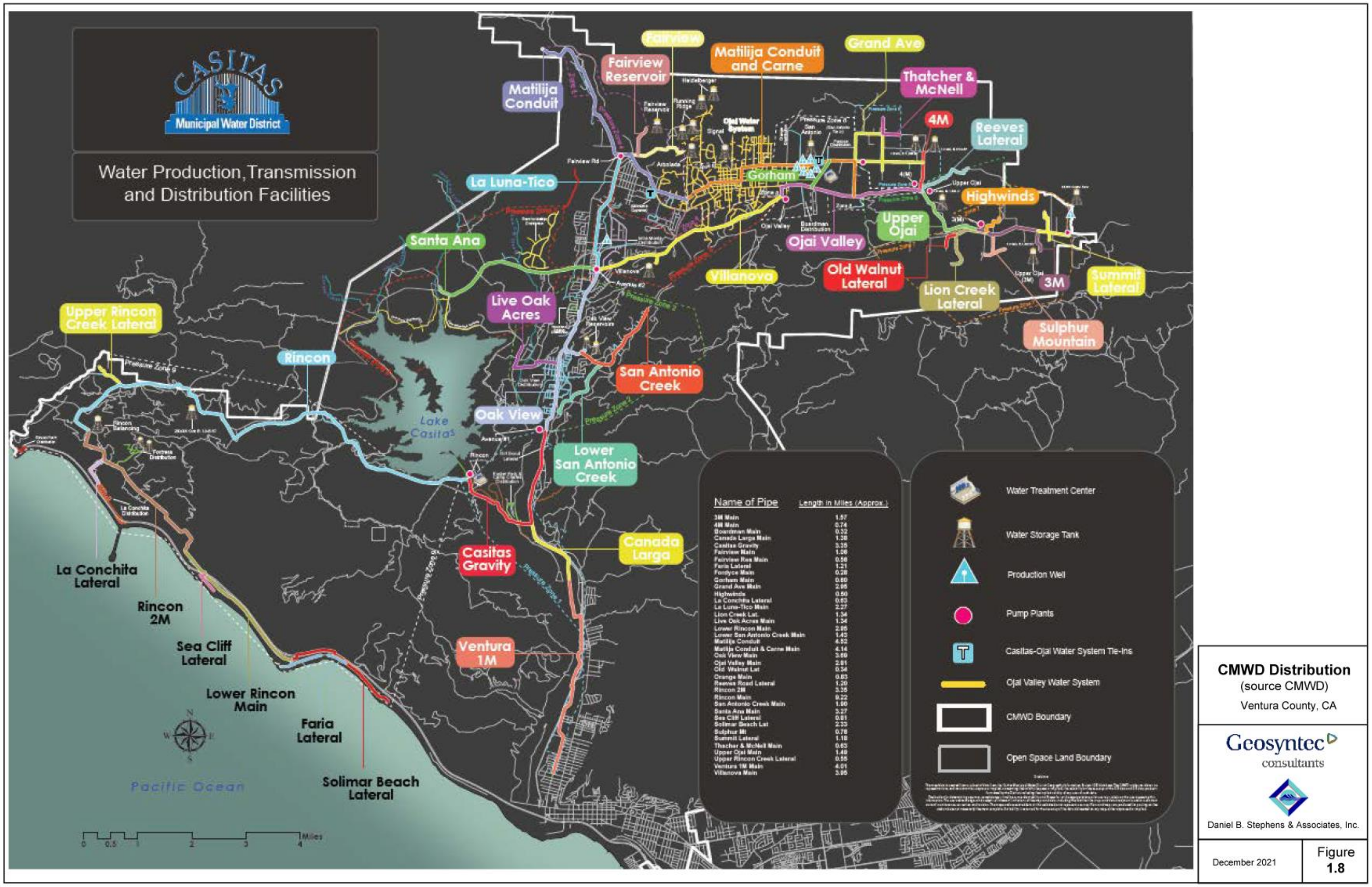

Figure 1.8 CMWD Distribution (source CMWD)

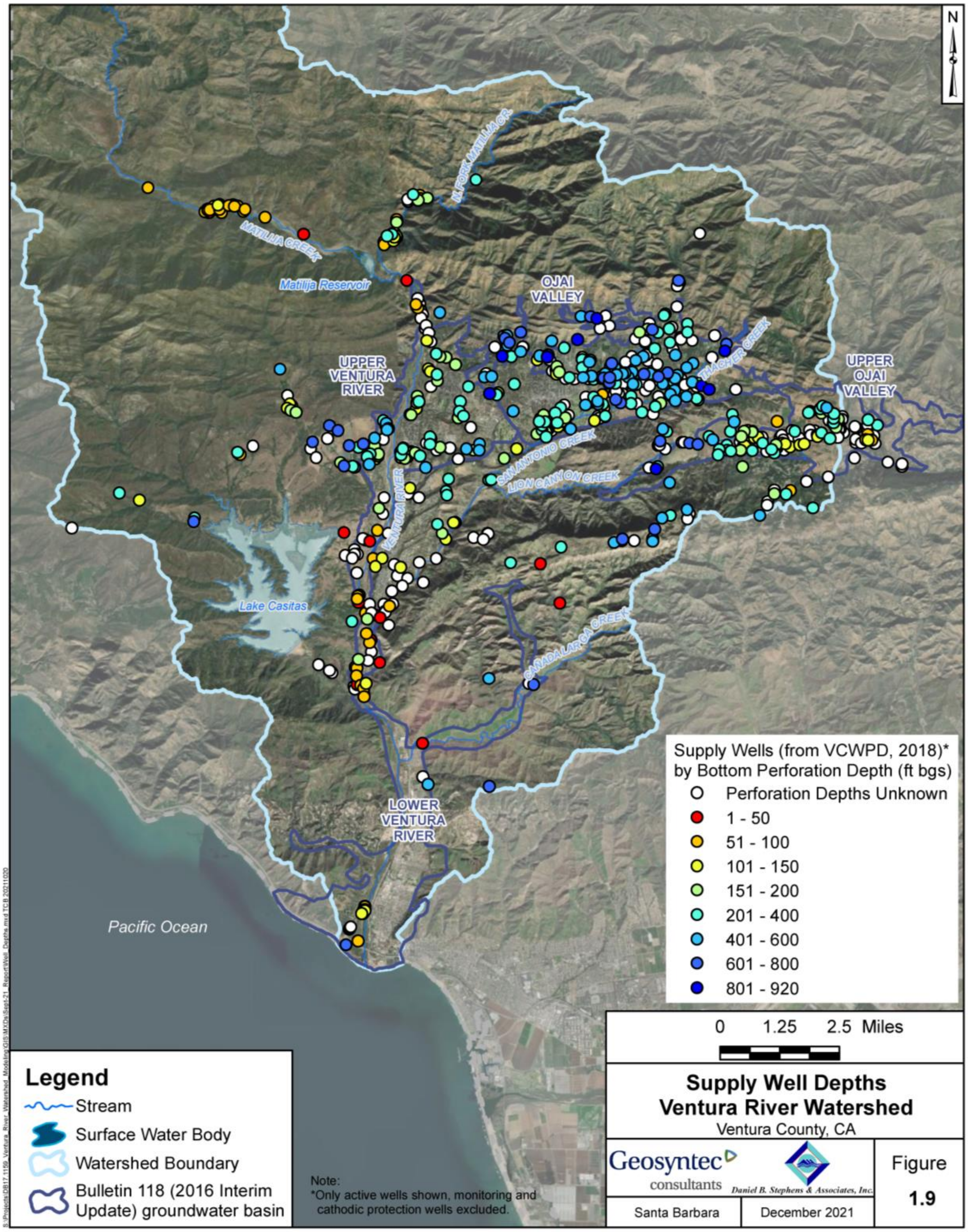

Figure 1.9 Supply Well Depths – Ventura River Watershed

1.4 Goals and Objectives of the Project

The overall goal of developing the VRW GW-SW Model and VRW Nitrogen Model is to provide scientifically defensible, cost-effective, time-sensitive, and publicly transparent tools that can be used to support the State Water Board and LA Regional Water Board instream flow and TMDL efforts, respectively. The models will be used to meet the following specific project objectives:

- Estimate existing instream flows at multiple points of interest (POI) throughout the entire VRW.
- Evaluate how water use affects the water balance and instream flows;
- Simulate groundwater pumping and GW-SW interactions to understand groundwater effects on instream flows;
- Have a model simulation period long enough to reasonably capture the variability of the full range of water year (WY) types from drought to flood years;
- Simulate nitrogen transport to inform nitrogen source assessment and load/wasteload allocations for the TMDL (per the VRW Nitrogen Model that is currently under development);
- Simulate unimpaired flow at each POI that would occur with no water diversions, pumping, or storage;
- Simulate the effects of the December 2017-January 2018 Thomas Fire on hydrology, groundwater levels, and instream flows;
- Simulate the effects of climate change, Matilija Dam removal, and other scenarios on hydrology, groundwater levels, and instream flows.

1.5 GSFLOW

During the initial project phase, available GW-SW modeling platforms were researched and evaluated for their ability to meet project needs. The project *Final Study Plan* (Geosyntec and DBS&A, 2019) describes the code selection process. Model selection criteria included:

- Capability to accurately model essential GW-SW functions, including rainfall-runoff relationships, streamflow accumulation, surface water hydrology, variable groundwater elevations, groundwater discharge to surface water, and precipitation and irrigation-related recharge to groundwater;

- Perceived credibility, for instance, as demonstrated by citation in peer-reviewed literature;
- Ability to model nitrogen fate and transport in groundwater and track sources through groundwater to surface water;
- Meets DWR Sustainable Groundwater Management Act (SGMA) public domain requirements;
- Ability to model recharge from irrigation and septic systems;
- Ability to meet project requirements within the defined scope and budget;
- Longevity of model, availability of support/updates;
- Transparency;
- Degree of leveraging previous models Ojai Valley Basin Groundwater Model (OBGM) and Ventura Surface Water Hydrology Model (VSWHM); and
- Proven use for similar applications.

U.S. Geological Survey (USGS) Groundwater and Surface-water Flow (GSFLOW) software platform was selected as the code for the VRW GW-SW Model because it has the advantages of high level of credibility and transparency, online training availability, widespread use, and thorough public documentation. The VRW GW-SW Model is also referred to as the VRW GSFLOW Model.

GSFLOW is a coupled groundwater and watershed flow model based on integration of the USGS Precipitation-Runoff Modeling System (PRMS) watershed model and Modular Finite-Difference Ground-water Flow model (MODFLOW). GSFLOW was developed to simulate coupled groundwater-surface water flow in one or more watersheds by simultaneously simulating flow across the land surface, within subsurface saturated and unsaturated materials, and within streams and lakes (Figure 1.10). As detailed in the GSFLOW documentation (Markstrom et al., 2008), additional model components were

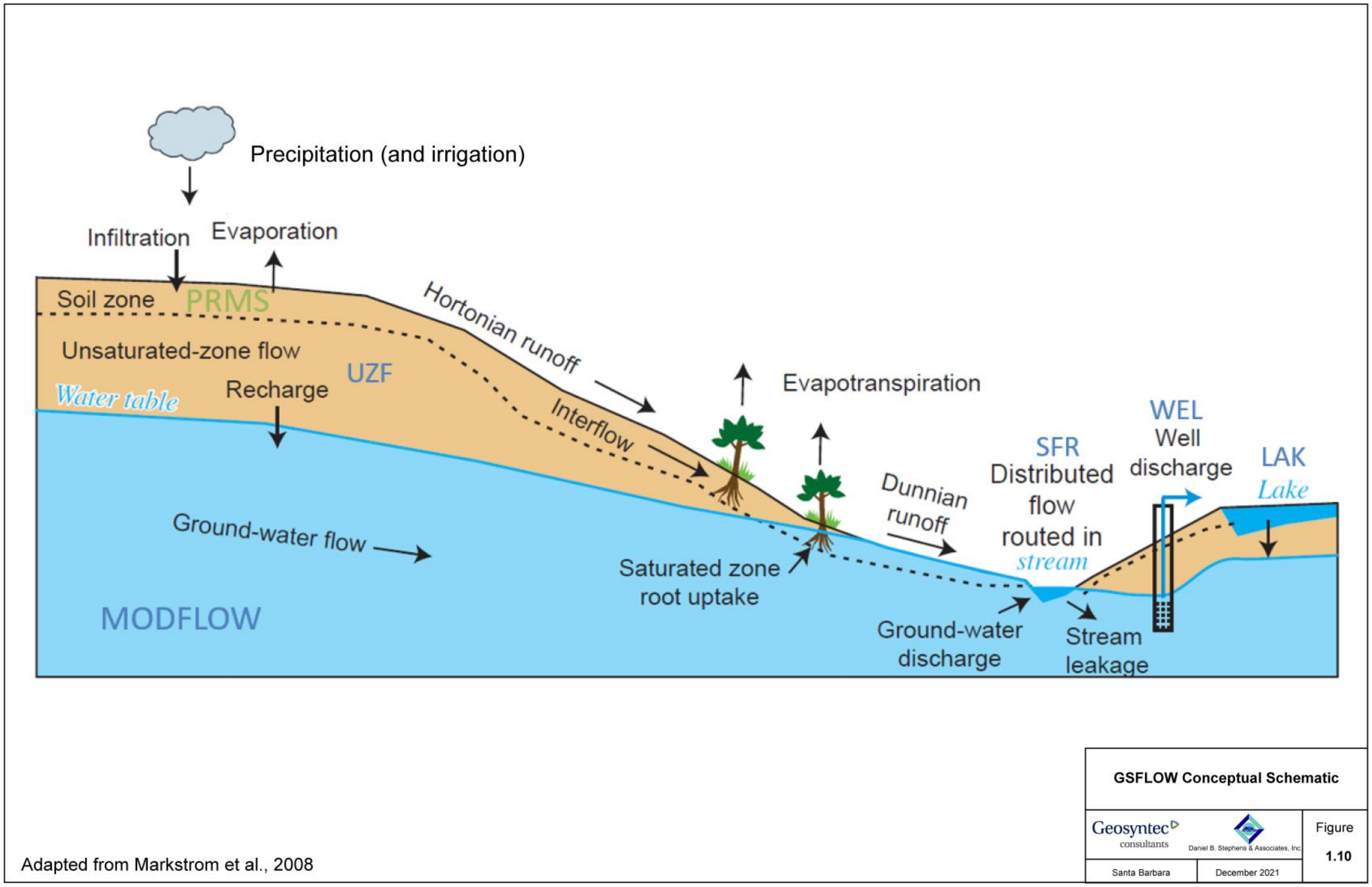

Figure 1.10 GSFLOW Conceptual Schematic

developed, and existing components were modified, to facilitate integration of the models.

GSFLOW does not directly allow for simulation of nitrogen transport.
A separate MODFLOW model will be developed for the purpose of linking to the transport model MT3D-USGS and running transport simulations. The MODFLOW model will be developed from the calibrated GSFLOW flow model (i.e., the flow rates for exchange between surface water and groundwater will be determined from the calibration of the integrated GSFLOW model; Geosyntec and DBS&A, 2019). The VRW Nitrogen Model is under development and will be presented in a separate report.

GSFLOW runs on a daily time step. Methods were developed to route flow among the PRMS hydrologic response units (HRU)s and between the HRUs and the MODFLOW finite-difference cells. An important aspect of the integrated model design is its ability to conserve water mass and to provide comprehensive water budgets for a location of interest. In addition to running integrated simulations, GSFLOW can also be run in PRMS-only or MODFLOW-only modes.

GSFLOW is conceptualized as three regions with exchanges of flow between them (Figure 1.11). The first region includes the plant canopy, snowpack, impervious storage, and soil zone, and is simulated with the PRMS modules. The second region consists of streams and lakes and is simulated using the MODFLOW-Newton Formulation (NWT) packages. The third region, or subsurface, is beneath Regions 1 and 2 and consists of the unsaturated and saturated zones. It is also simulated using MODFLOW-NWT packages.

Region 2 does not simulate surface flow hydraulics, such as flow depths and velocities. Hydraulics depend upon the nature of specific braids and flood plains, which usually change over the modeling period. For the VRW, Region 3 includes both alluvial deposits and bedrock geologic units used for water supply.

The functionality and flows between the three regions are well described in the USGS GSFLOW report (Markstrom et al., 2008), for example:

> *Specified inputs of precipitation and temperature and specified inputs or model-estimated potential solar radiation are distributed to each HRU to compute energy budgets, flow, and storage within Region 1. A portion of the water entering Region 1*

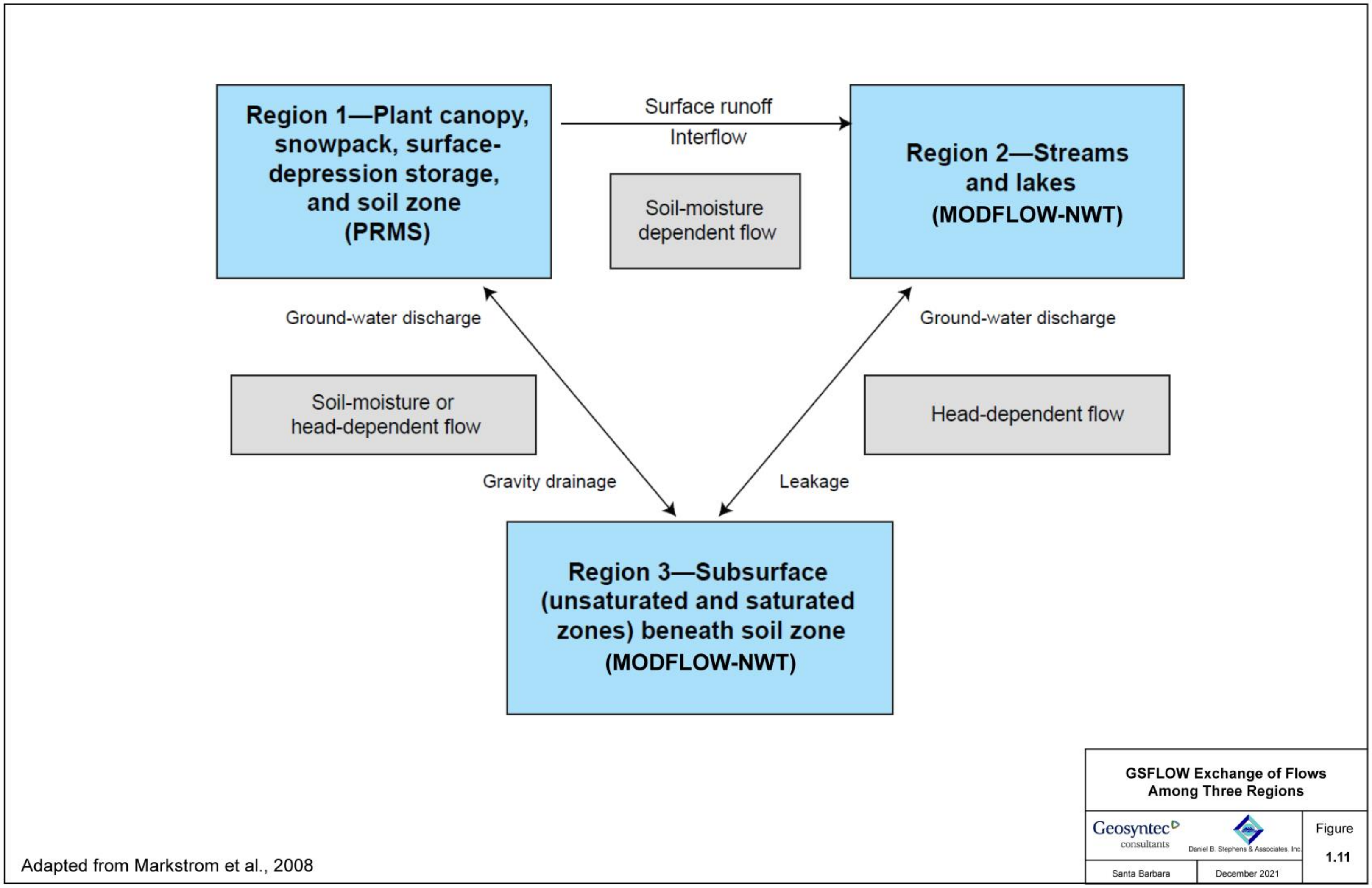

Figure 1.11 GSFLOW Exchange of Flows Among Three Regions

> *infiltrates into the soil zone, where it is evaporated and transpired back to the atmosphere, flows to streams and lakes (Region 2), and (or) drains to the deeper unsaturated and saturated zones (Region 3).*
>
> *The rate at which water flows from the soil zone to streams and lakes is dependent on: (1) the rate at which water is added to the land surface by snowmelt and rain; (2) the rate of infiltration into the soil zone; and (3) the antecedent soil-zone storage. Water that flows from the soil zone to the unsaturated and saturated zones (Region 3) is called gravity drainage.*
>
> *Gravity drainage is dependent on the vertical hydraulic conductivity of the unsaturated zone and the volume of water stored in the soil zone. Additionally, gravity drainage ceases as the water table rises into the soil zone. Water also can flow from the saturated zone into the soil zone as ground-water discharge; the rate of discharge is dependent on the hydraulic conductivity and ground-water head relative to the altitude of the soil-zone base. Flow between the unsaturated and saturated zones to streams and lakes is dependent on the ground-water head in relation to the stream- or lake-surface altitude, the hydraulic properties of the streambed and lakebed sediments, and the hydraulic properties of the unsaturated and saturated zones.*

Additional descriptions of the GSFLOW Model platform, including detailed descriptions of PRMS and MODFLOW and how they are integrated, the equations and order of calculations, modeling assumptions and limitations, and data input requirements are provided in the GSFLOW report (Markstrom et al., 2008).

1.6 Organization of Documentation Report

This report documents the development of the VRW GW-SW Model using the GSFLOW model platform. The VRW Nitrogen Model will be documented in a separate report. An overview of this report is provided below.

Section 2 provides details of comprehensive supply and demand analyses that were primarily used to estimate non-measured groundwater pumping volumes throughout the VRW.

Details of development of the surface water portion of model and the groundwater portion of the model are provided in Sections 3 and 4, respectively. This includes details of the model layout, spatial and temporal discretization of the model, and model input parameters.

Section 5 presents the calibration and validation of the coupled VRW GW-SW Model. This includes the calibration approach, the final values of the model input parameters, assessment of model fit, discussion of results and water budgets, and model limitations.

Section 6 presents details and results of the sensitivity analyses whereby key model input parameters were systematically varied to evaluate the sensitivity of the model calibration to these key model input parameters.

The unimpaired flow scenario is presented in Section 7. This includes details of the scenario and how it was implemented, presentation of results, and discussion of the changes in streamflow and groundwater elevations. The remaining scenarios to be evaluated as part of this project will be presented in later reports.

2 SUPPLY AND DEMAND ANALYSES

Within the VRW, agricultural and domestic wells do not typically have reported measurements or estimates of pumping volumes. The exception is within the Ojai Basin where quarterly or semi-annual reports are required to be submitted to the Ojai Basin Groundwater Management Agency (OBGMA). In other parts of the watershed, it is necessary to develop estimates for pumping volumes for all wells to be used as inputs into the VRW GSFLOW Model. This was achieved by performing detailed supply and demand analyses, as described in this section.

This section first provides an overview of the approach, a summary of the data sources and information used, and descriptions of the methods used to estimate demands and supplies. Results and additional details of the analyses are presented as a series of tables and are then cross-checked against other data sources. Finally, a brief description of how results are implemented into the VRW GSFLOW Model is provided.

2.1 Approach

Figure 2.1 presents a map of supply wells within the VRW. Color coding indicates the average annual pumping rates for the modeling period (WY1994-WY2017) per reported estimates and measurements available from OBGMA (diamond symbols) and municipal water providers (circles). Locations of wells without known pumping volume information are shown as white squares and are primarily domestic wells (i.e., typically used to supply single family residences) or agricultural wells (i.e., used to irrigate crops). Primary well use was determined based on well data provided by the Ventura County Watershed Protection District (VCWPD).

For the domestic wells a rate of 0.5 gallons per minute (gpm) (0.8 acre-feet per year [AFY]) was assumed, based on an assumed average of 3.5 people per household and a typical per capita use of approximately 200 gallons per capita per day (gpcd) (see Section 2.3.1). The supply and demand analyses were developed to provide estimates for the agricultural wells for which there are no reported pumping volumes. The analyses required inclusion of residential supplies and demands, due to some larger water providers supplying both agricultural and residential supplies.

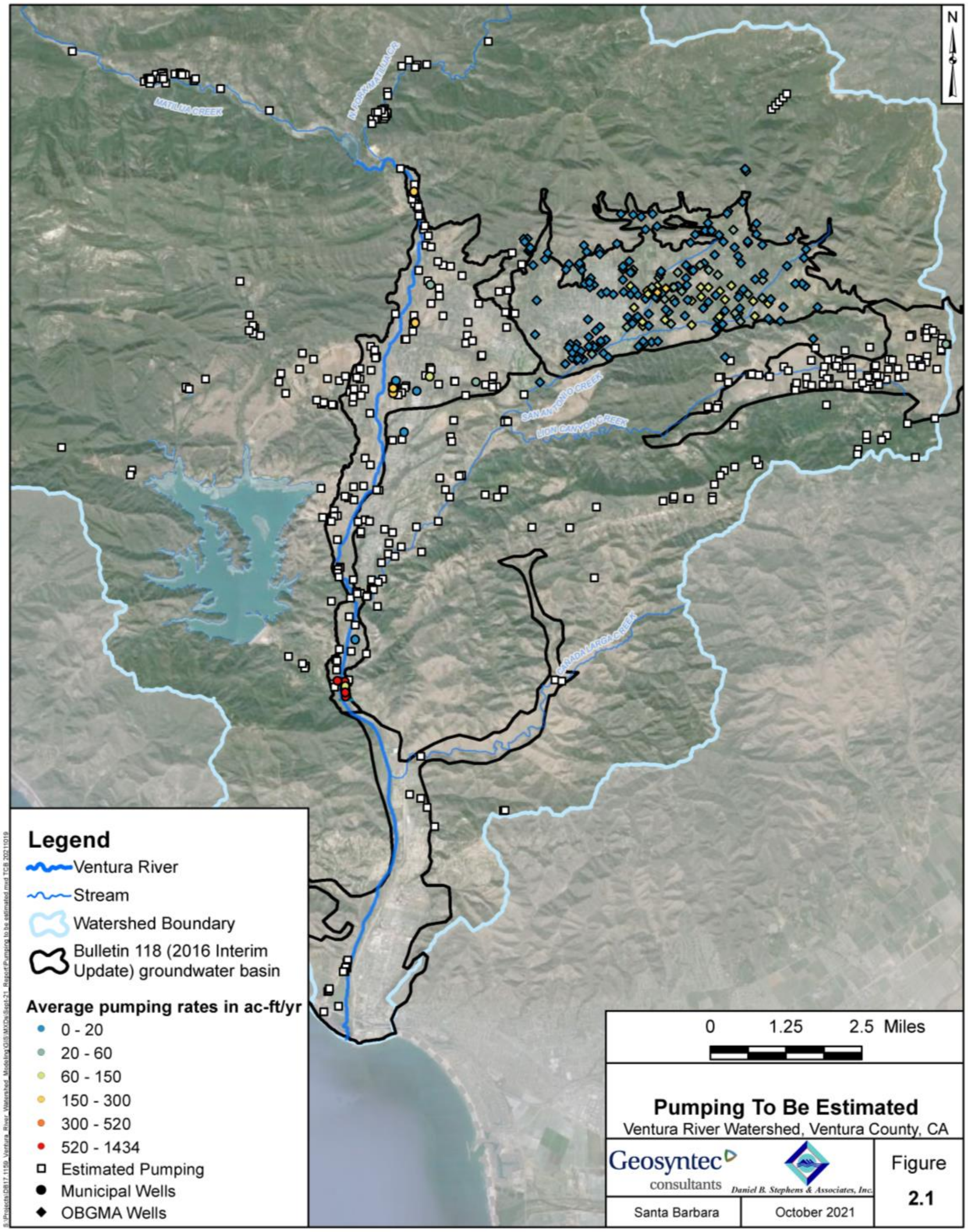

Figure 2.1 Pumping to Be Estimated

The supply and demand analyses balanced estimated water demands with known water supplies, and then used the difference (i.e., deficit in supply) to calculate the unknown pumping volumes. To develop realistic estimates in and around the four groundwater basins, and ideally within smaller subregions in each basin, there is a need to understand spatial differences in the distributions of both supply and demand. Annual water balances within the water provider boundaries for 14 water providers that have service areas in the watershed (Figure 2.2)[5] were developed. This provided the required spatial resolution and enabled information (e.g., urban water management plans) and data particular to those providers to be used where available. Surrounding the water provider service areas, the CMWD distribution area within the watershed was divided into five regions (Figure 2.2) to enable additional water balances to be developed at a reasonable spatial scale.

Region 4 was selected to mostly coincide[6] with the OBGMA boundary, within which all pumpers are required to report measurements or estimates of pumping volumes on a quarterly or semi-annual basis. Therefore, pumping estimates were not required to be developed for Region 4 for the purpose of assigning pumping rates in the VRW GSFLOW Model. Instead, the Region 4 balance was conducted to assess the accuracy of the approach and provide a check on assumptions and estimates that are made for other parts of the VRW.

The remaining regions were determined based upon CMWD pressure zones, as described further in Section 2.4.2. Region 1 includes the Lower Ventura River Basin and the southern portion of the Upper Ventura River Basin, with the northern delineation corresponding to the extent of the CMWD gravity-fed zone. Regions 2 and 3 encompass the remainder of the Upper Ventura River Basin, and Region 5 encompasses the Upper Ojai Basin.

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[5] Figure 2.2 includes the former Golden State Water Company (GSWC) service area that comprised 11 municipal wells in the Ojai Basin. Operation of these wells transferred to CMWD in 2017 and is now referred to as Ojai Water System (OWS). Since most of the data and information obtained during the modeling period is from GSWC, the terminology used herein is "former GSWC."

[6] Region 4 also included the following regions not within the OBGMA boundary: western portion of former GSWC service area, northern portions of Hermitage Mutual Water Company and Senior Canyon Mutual Water Company (SCMWC) service areas.

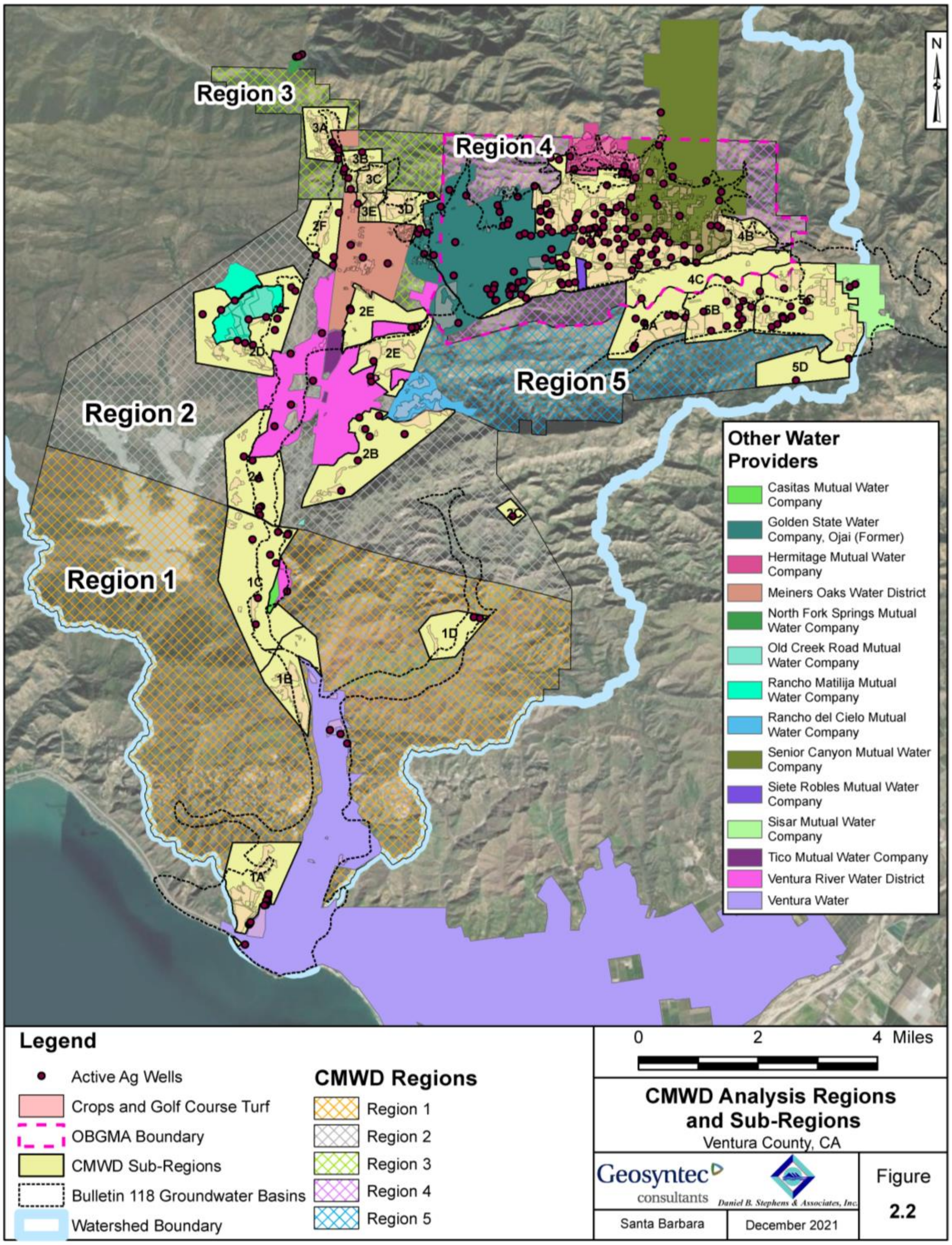


Figure 2.2 CMWD Analysis Regions and Sub-Regions

Annual water budgets were developed for each region and water provider service areas by considering supplies (i.e., CMWD deliveries from Lake Casitas, reported pumping volumes, estimated domestic well pumping volumes, local surface water diversions) and demands (i.e., residential, agricultural, and golf courses), and then calculating the difference to estimate the non-reported pumping volumes. These volumes then had to be distributed to the agricultural wells, which was generally done by assigning groups of wells to nearby crop areas, as indicated by the Sub-Regions (e.g., 1A, 1B, etc.) in Figure 2.2.

2.2 Data Sources

The supply and demand analyses involved a comprehensive review of reports, data, and information related to water use and supply within the VRW. These sources are summarized in Table 2.1. The table indicates how the sources were used and for which specific model years (if applicable). Additional descriptions are provided in the following sections.

2.3 Demands

Demands considered in the analyses include residential, agricultural, and golf courses. The industrial and commercial demands make up a small fraction of the total watershed demand and were generally neglected for the purpose of developing water budgets to estimate pumping rates.

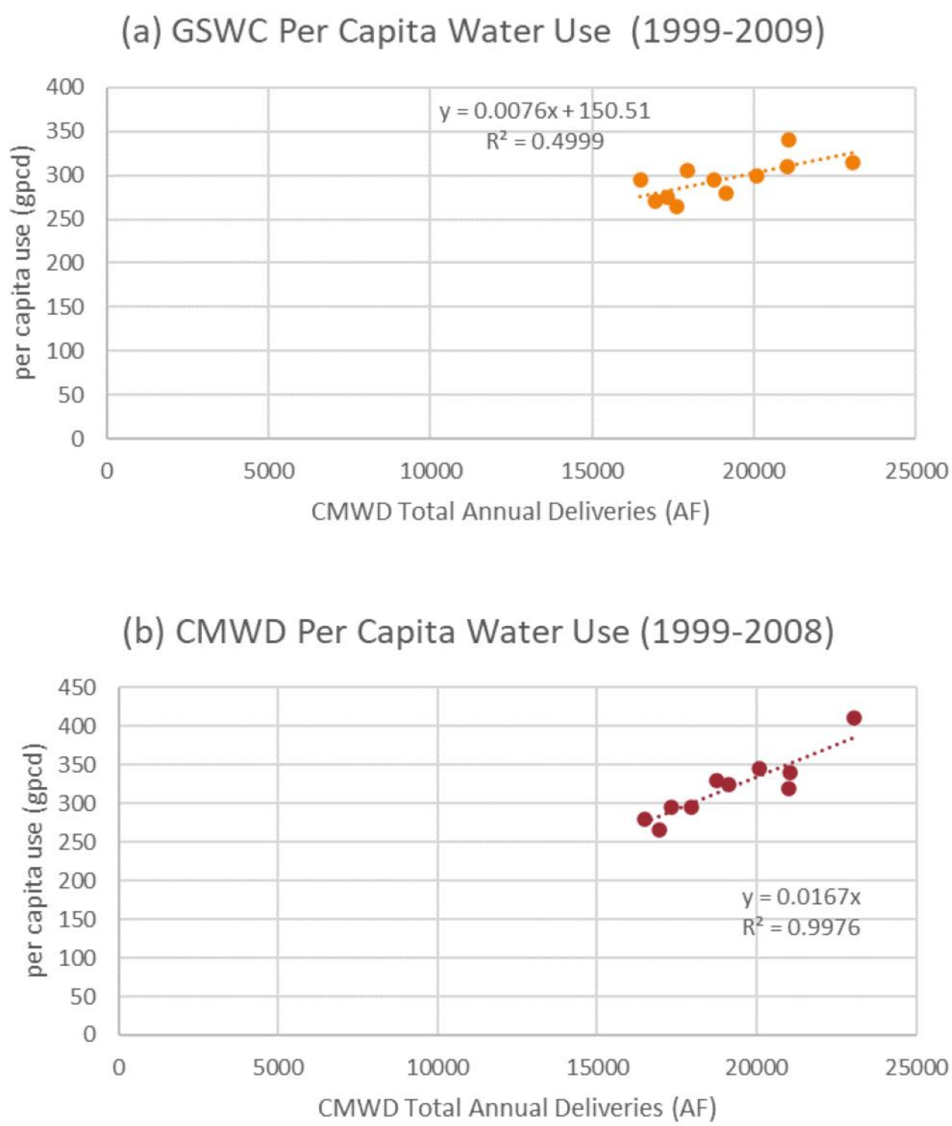
2.3.1 Residential

Residential demands were estimated based upon human populations (USCB, 2010) within each region and service area (Table 2.2), and per capita use estimates. Table 2.2 also indicates the per capita use rate information that was assumed for each region or service area. In general, the Ventura River Water District (VRWD) rates were used in the southern portion of the watershed where marine influence and property size and type result in lower per capita rates. CMWD rates were used in remaining areas of the watershed where warmer temperatures and generally larger property sizes result in higher per capita rates. Per capita rates from the former Golden State Water Company (GSWC) were only used within the former GSWC[7] service area.

[7] The former GSWC service area that comprised 11 municipal wells in the Ojai Basin was transferred to CMWD in 2017 and is now referred to as Ojai Water System (OWS).

Per capita use estimates were derived based on information obtained from former GSWC, CMWD, and VRWD[8] as summarized in Table 2.3. Regressions of per capita use estimates for former GSWC (WY1999 – WY2009) and CMWD (WY1999 – WY2008) with CMWD delivery volumes[9] were developed (Figure 2.3) and used to extrapolate to years with no information. The regression for former GSWC was not strong (Figure 2.3(a)). It is noted that analyses within former GSWC (and the entire Region 4) are only conducted as a check on the method, because pumping volumes in these regions are available from reports to OBGMA. The regression for CMWD is strong (Figure 2.3(b)), which is likely a result of direct correlations between the CMWD deliveries and CMWD demands.

[8] The VRWD per capita use estimates were based on scaling of the CMWD per capita use as explained in Table 2.3.
[9] See Section 2.4.2 and Table 2.6 for details on CMWD delivery volumes.



Per capita use data are from Figure 3.4.3.1.3 of Ventura River Watershed Management Plan (Walter, 2015)

Per Capita Water Use Regressions Ventura County, CA		
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Figure 2.3 Per Capita Water Use Regressions

The annual per capita water use estimated from the regressions are shown in Figure 2.4. The figure also includes the data points used to make the regressions as well as the final GSFLOW model input. Where data existed, they were used in preference to the regression. The per capita use rates within the CMWD were modified during the multi-year drought to account for conservation measures that were implemented. Per capita use was estimated as the 5-year WY2009-WY2013 average reduced by 20% in WY2014 and WY2015 and by 30% in WY2016 and WY2017. These reductions were based on guidance in the Meiners Oaks Water District (MOWD) Drought Contingency Plan (MOWD, 2016) and storage levels in Lake Casitas. While this guidance may not apply watershed wide, the assumptions are anticipated to be reasonable. The guidance gives reasonable results, as indicated in Section 2.5. Modifications were not made to the former GSWC per capita rates since these values were only used within the former GSWC service area rather than throughout the watershed (see Table 2.2).

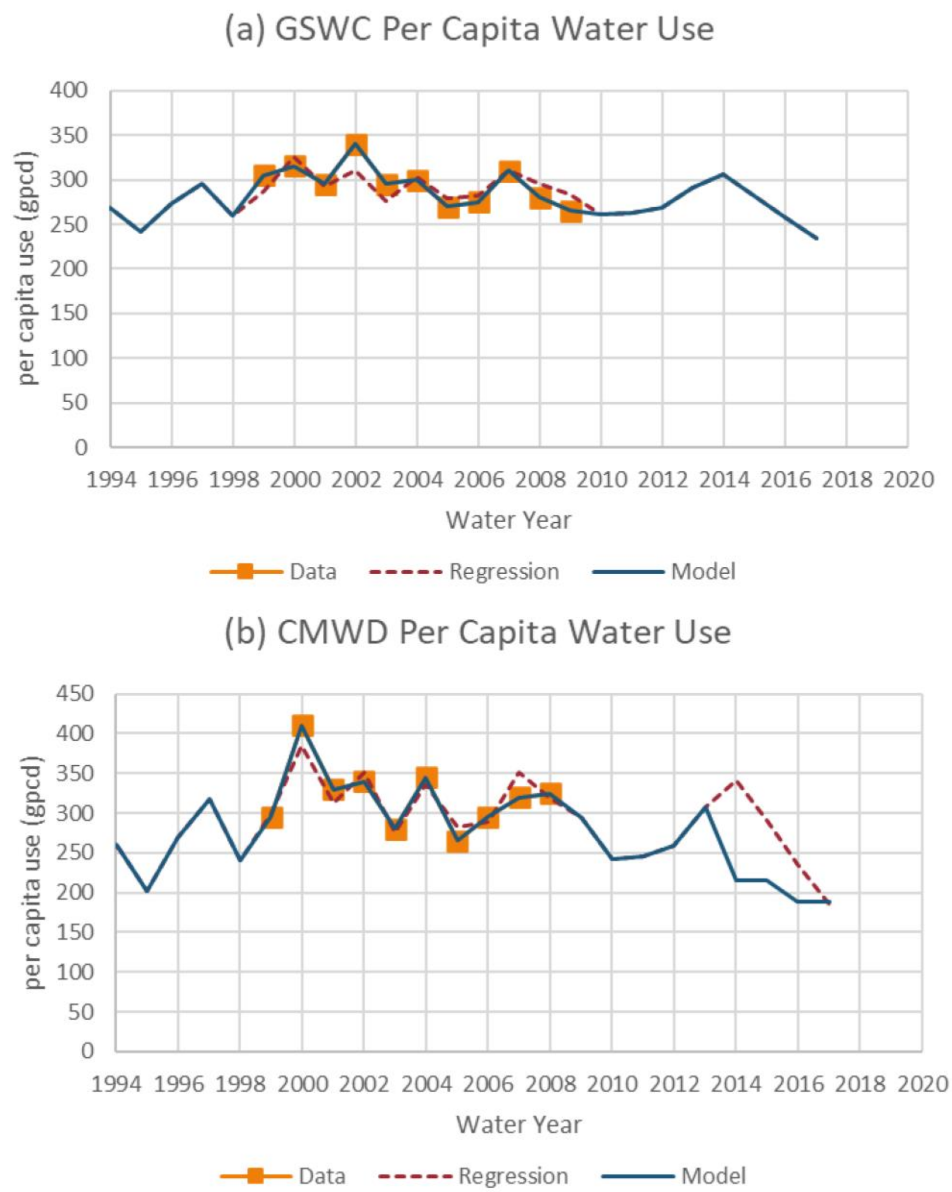
The analyses provide total residential demands within each region and service area for each year. Results are provided in tables within Section 2.5.

2.3.2 Agriculture and Golf Courses

Agricultural areas in the VRW were represented in the VRW GSFLOW Model using spatial crop data from the 2016 Ventura County Agricultural Commissioner (VCAC) dataset (VCAC, 2016). Three major crop types were assumed for the purposes of applying irrigation rates – citrus, avocado, and "other," as indicated in Figure 2.5.

A range of sources for irrigation rates of these crops were evaluated as summarized in Table 2.4. The DWR Applied Water data (DWR, 2020) provide estimates specific to each year from 1998 through 2015 (i.e., 18 of the 24 model years), whereas most other sources did not. Those data indicate interannual trends that are in general agreement with available water supply data. Assuming a constant rate from year to year would result in imbalances in the analyses and potentially inaccurate pumping estimates. Therefore, the DWR data were used in the analyses.

To develop estimates of applied water prior to 1998 and after 2015, regressions based on annual rainfall totals were developed (Figure 2.6). There was a weak regression (Figure 2.6(a)) for avocado and citrus, and this was used to extrapolate the data to other years. The regression for "other" crops was not



Per capita use data are from Figure 3.4.3.1.3 of Ventura River Watershed Management Plan (Walter, 2015)

Per Capita Water Use by Water Year

Ventura County, CA

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Figure 2.4 Per Capita Water Use by Water Year

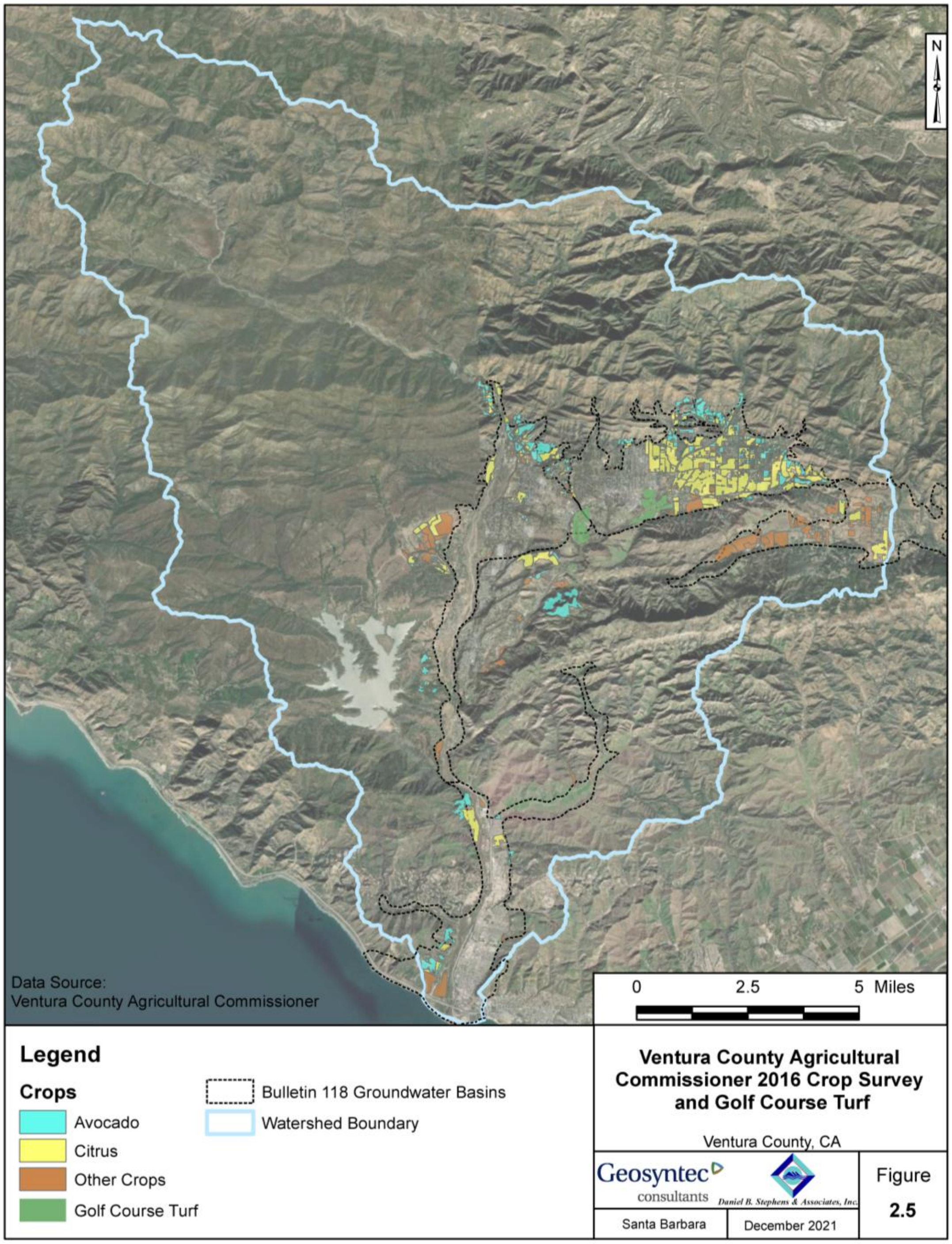
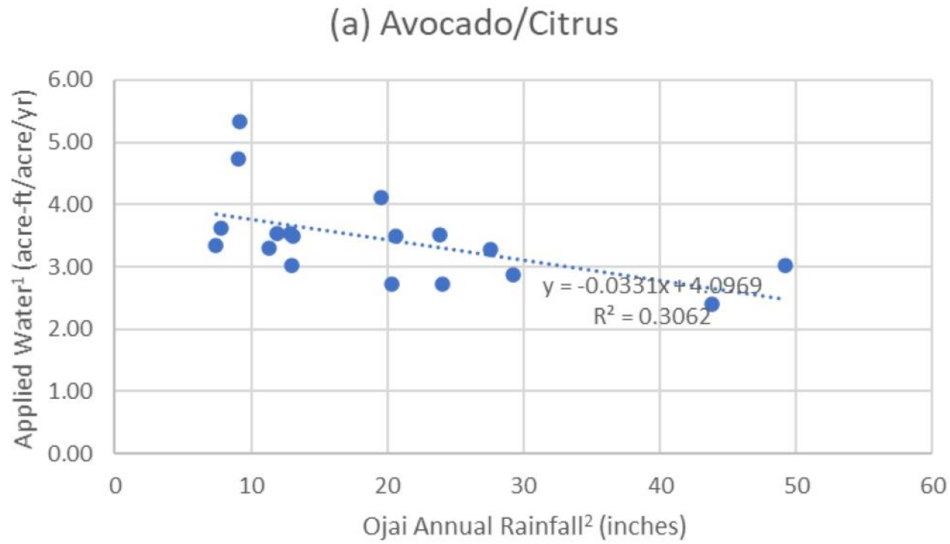


Figure 2.5 Ventura County Agricultural Commissioner 2016 Crop Survey and Golf Course Turf



1. URL: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates/
2. Ojai – County Fire Station, Gage 030D

Applied Water Regressions Ventura County, CA		
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Figure 2.6 Applied Water Regressions

meaningful (Figure 2.6(b)) and instead the average value for years 1998 through 2015 was used to extrapolate. Resulting annual crop irrigation rates are plotted in Figure 2.7 and tabulated in Table 2.5.

The DWR Applied Water rates are developed based upon demands considering weather conditions, and do not consider availability of actual supplies. During drought years, analyses within the OBGMA (Region 4) indicated that the full agricultural demands were not met and adjustments were made throughout the watershed by multiplying the agricultural demands by a drought adjustment factor (see Section 2.5.1).

There are two golf courses within the watershed (Ojai Valley Inn and Soule Park Golf Course). The courses' spatial areas were delineated manually using aerial imagery to estimate acreages (see Figure 2.5). The courses were assigned a separate irrigation rate of 4 AF/acre/year based on typical values for turf.

The analyses provide total agricultural demands, including golf courses, within each region and service area for each year. Results are provided in tables within Section 2.5.

2.3.3 Summary of Demands

The annual average residential, agricultural, and total demands by region are summarized in Figure 2.8. The analyses indicate approximately half the agricultural demands are within the Ojai Basin (Region 4), followed by the Upper Ventura River Basin (Regions 2 and 3 combined), then the Upper Ojai Basin (Region 5) and the Lower Ventura River Basin (Region 1). The residential demands are mostly in the Upper Ventura River Basin (Regions 2 and 3 combined), followed by the Ojai Basin (Region 4), with substantially lower demands in the Lower Ventura River Basin (excluding demand from City of Ventura) (Region 1) and the Upper Ojai Basin (Region 5).

2.4 <u>Supplies</u>

The supplies of water in the VRW include groundwater, deliveries by CMWD (primarily from Lake Casitas), and local surface water diversions. These are described in the following.

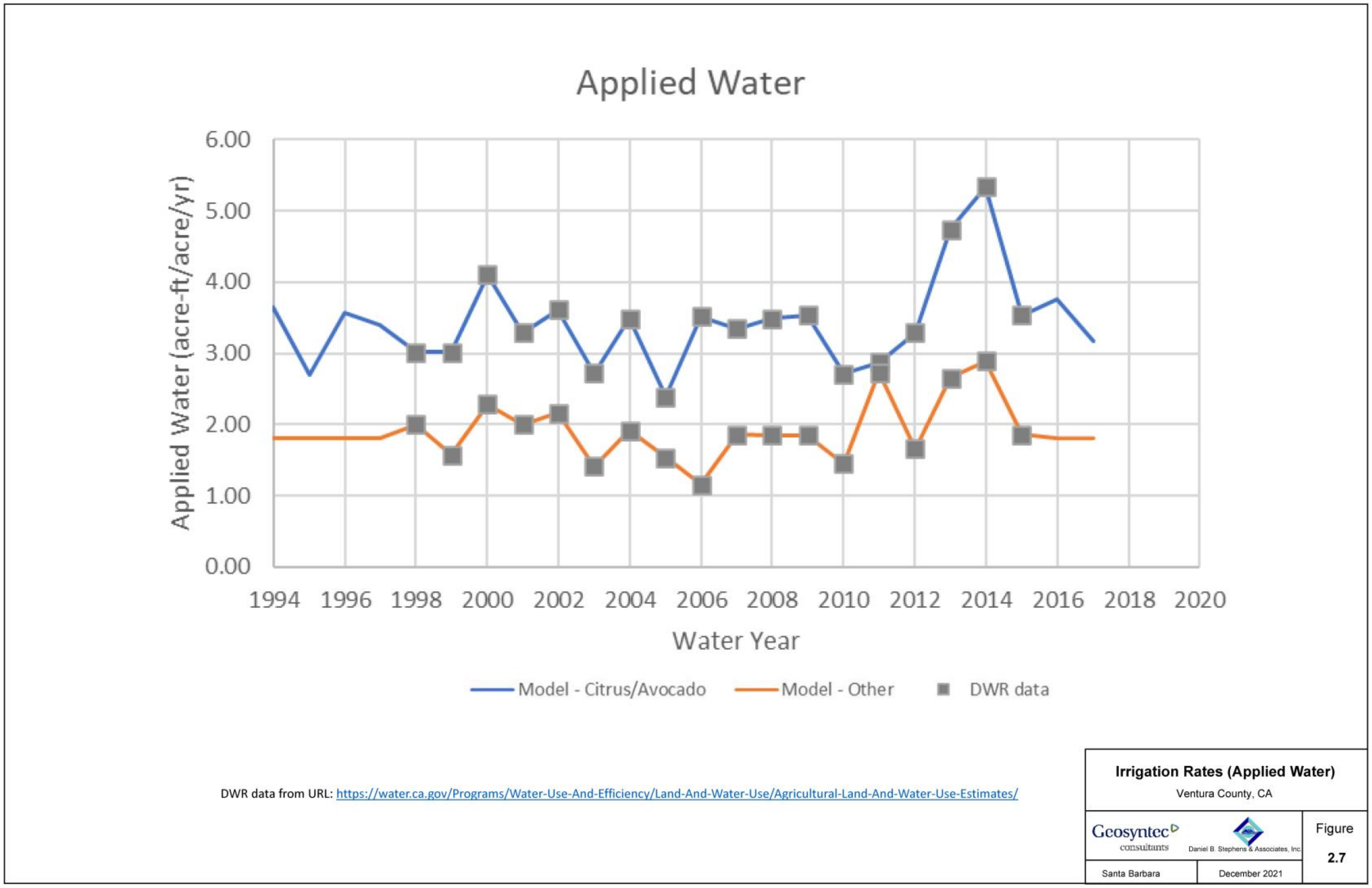

Figure 2.7 Irrigation Rates (Applied Water)

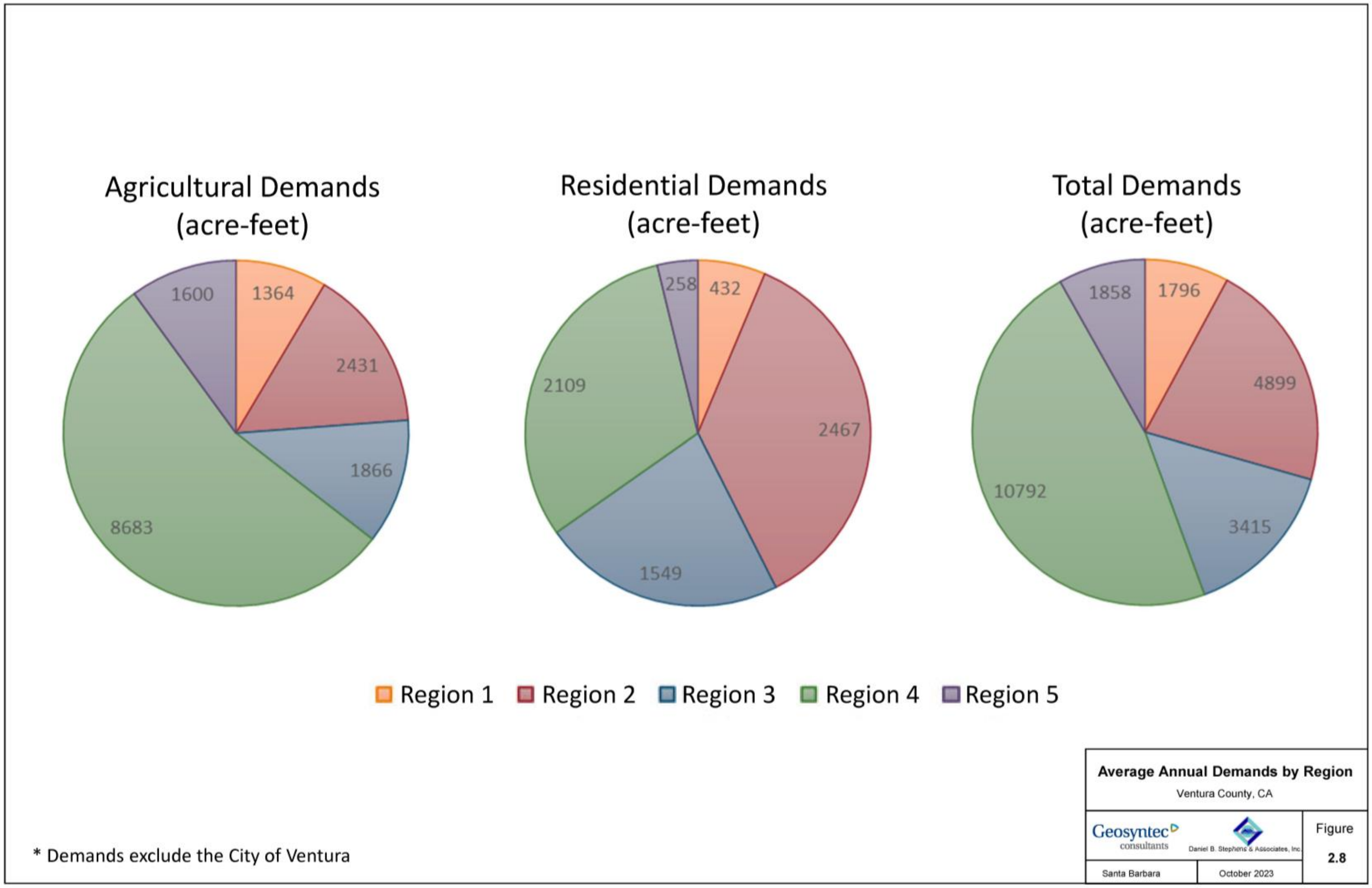

Figure 2.8 Average Annual Demands by Region

2.4.1 Groundwater

Groundwater pumping primarily consists of municipal wells, agricultural wells, and domestic wells. Within the OBGMA boundary, municipal providers and pumpers directly measure or estimate groundwater pumping volumes. These data are presented in Appendix A[10] and are used directly in the supply and demand calculations. Non-measured domestic wells were assumed to have a pumping rate of 0.5 gpm (0.8 AFY) as discussed in Section 2.1.

Measured or estimated annual volumes were aggregated by spatial region or service area (see Figure 2.2) for use in the supply and demand analyses. The aggregated volumes are presented in the tables within Section 2.5 and are ultimately used together with the estimates for CMWD delivery volumes and local surface water volumes to develop estimates for the pumping from non-measured agricultural wells. Further details and results are provided in Section 2.5.

2.4.2 CMWD Deliveries

CMWD provides a major component of the water supply to the VRW. Total annual deliveries are available from CMWD reports and are presented in Table 2.6. CMWD deliver throughout much of the watershed through their distribution facilities (Section 1.3) and the spatial distribution of the deliveries has a substantial bearing on the spatial estimates of pumping volumes. Additional information was available from other reports to provide estimates for CMWD deliveries specific to the former GSWC service area and the OBGMA (excluding the former GSWC service area) for most model years (Table 2.6). Estimating the delivery volumes to the remainder of the CMWD service area is a key part of the analyses and is described below.

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[10] Appendices A through F are not embedded in this document. The appendices are presented in companion files. Appendix A is a Microsoft Excel spreadsheet file. The appendices are include in the zip folder for this model report and are available for download on the State Water Board's California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/

The CMWD delivery system comprises multiple pressure zones, as illustrated in Figure 2.9. This includes deliveries outside the watershed (Zone 9), deliveries by gravity (Zone 1), and deliveries pumped to higher elevations into different regions of the watershed (Zones 2, 3, 4, 5, 6, 7, and 8). CMWD provided volume data for deliveries to each of these Zones from 2015 through 2020. The volumes were plotted for each WY by zone as stacked bar charts (Figure 2.10). The plot indicates that the fractional split of deliveries across zones is generally consistent from year to year. This result was used to estimate the spatial distribution of the remainder of the CMWD deliveries (i.e., excluding those to former GSWC and within the OBGMA boundary) in each WY.

As described in Section 2.1 the CMWD service area was divided into five regions based on the CMWD pressure zones (Figure 2.2). The relation between the regions and pressure zones are summarized in Table 2.7. Some provider service areas may receive CMWD water from multiple regions. Specifically, MOWD can receive CMWD water from both Regions 2 and 3, and the former GSWC service area can receive CMWD water from both Regions 3 and 4 (see CMWD distribution map in Figure 1.7).

Data and estimated CMWD deliveries to the Ventura Water Service Area (presented in Section 2.5.3) indicate volumes that represent a large fraction of deliveries to Zone 1, and additionally volumes that are historically variable. Full year CMWD pressure zone data are only available in WY2016 and WY2017 during the modeling period, and in these years the CMWD deliveries to Ventura Water were relatively low. To account for historically higher deliveries, and to obtain reasonable results in the analyses, the CMWD deliveries to the Ventura Water Service Area were subtracted from the Zone 1 CMWD deliveries. The resulting volumes in WY2016 and WY2017 (excluding Ventura Water) were then used to calculate average splits of CMWD deliveries to Region 1 (excluding Ventura Water), and Regions 2, 3, 4, and 5. These splits are summarized in Figure 2.11 and were used in the analyses together with the volumes in Table 2.6 to provide annual estimates of CMWD deliveries to each region, as presented in Figure 2.12. The CMWD deliveries to the former GSWC service area were assumed to occur from Region 3, based upon the overall balance in Region 4 (i.e., if deliveries to former GSWC were instead assumed to occur from Region 4 there would be a large shortage of supply within Region 4 (see Section 2.5.1)).

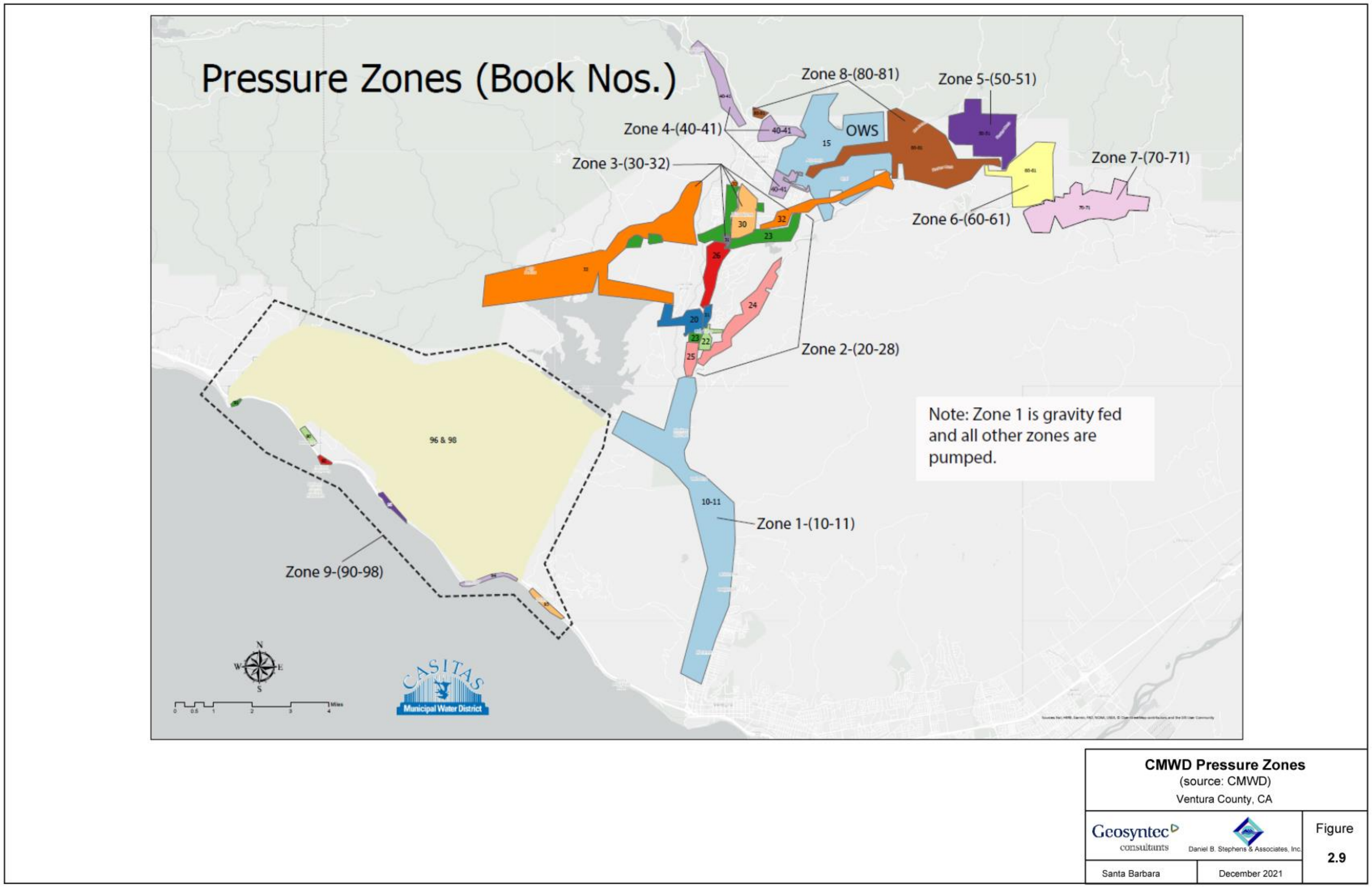


Figure 2.9 CMWD Pressure Zones

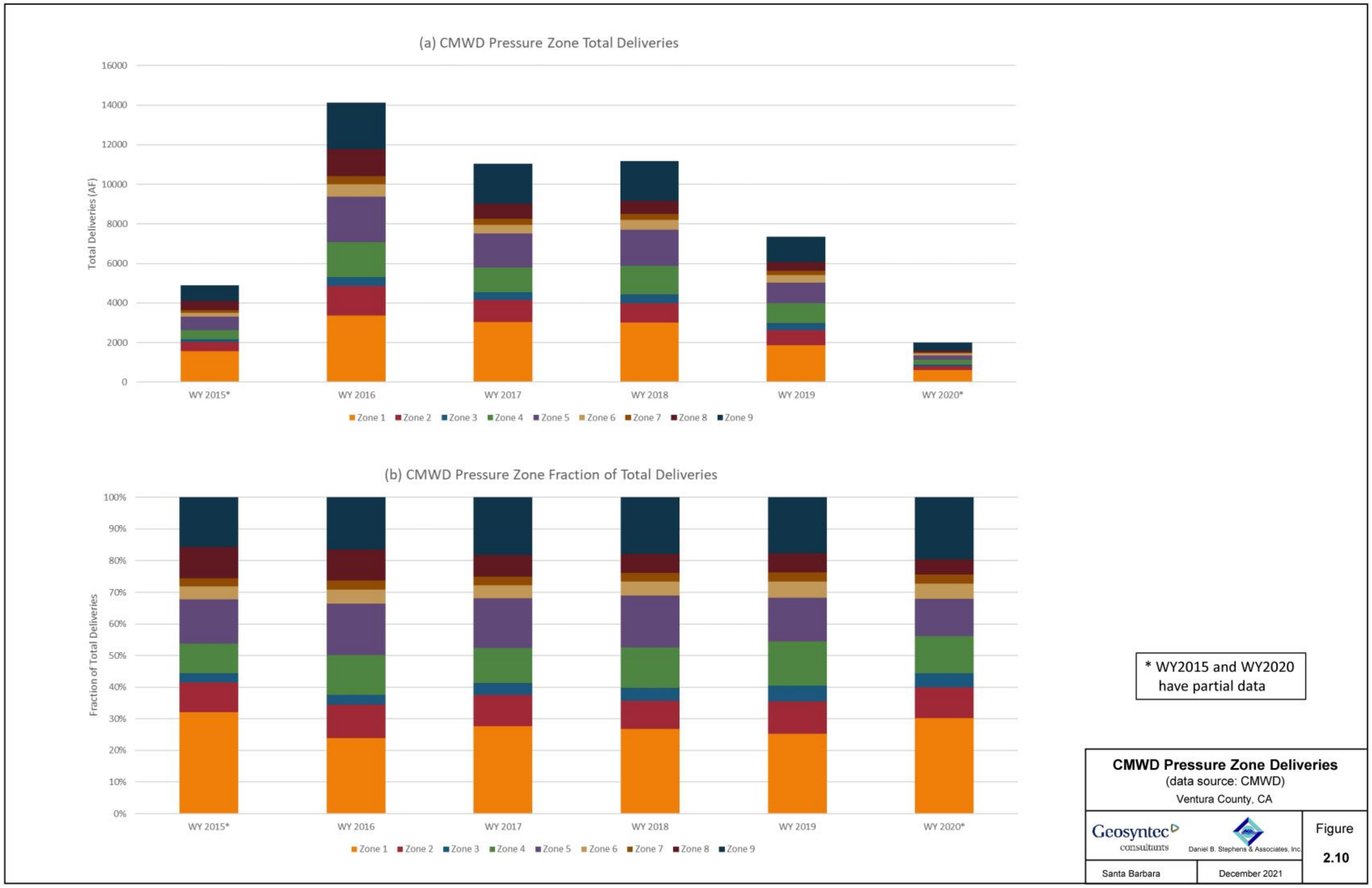


Figure 2.10 CMWD Pressure Zone Deliveries

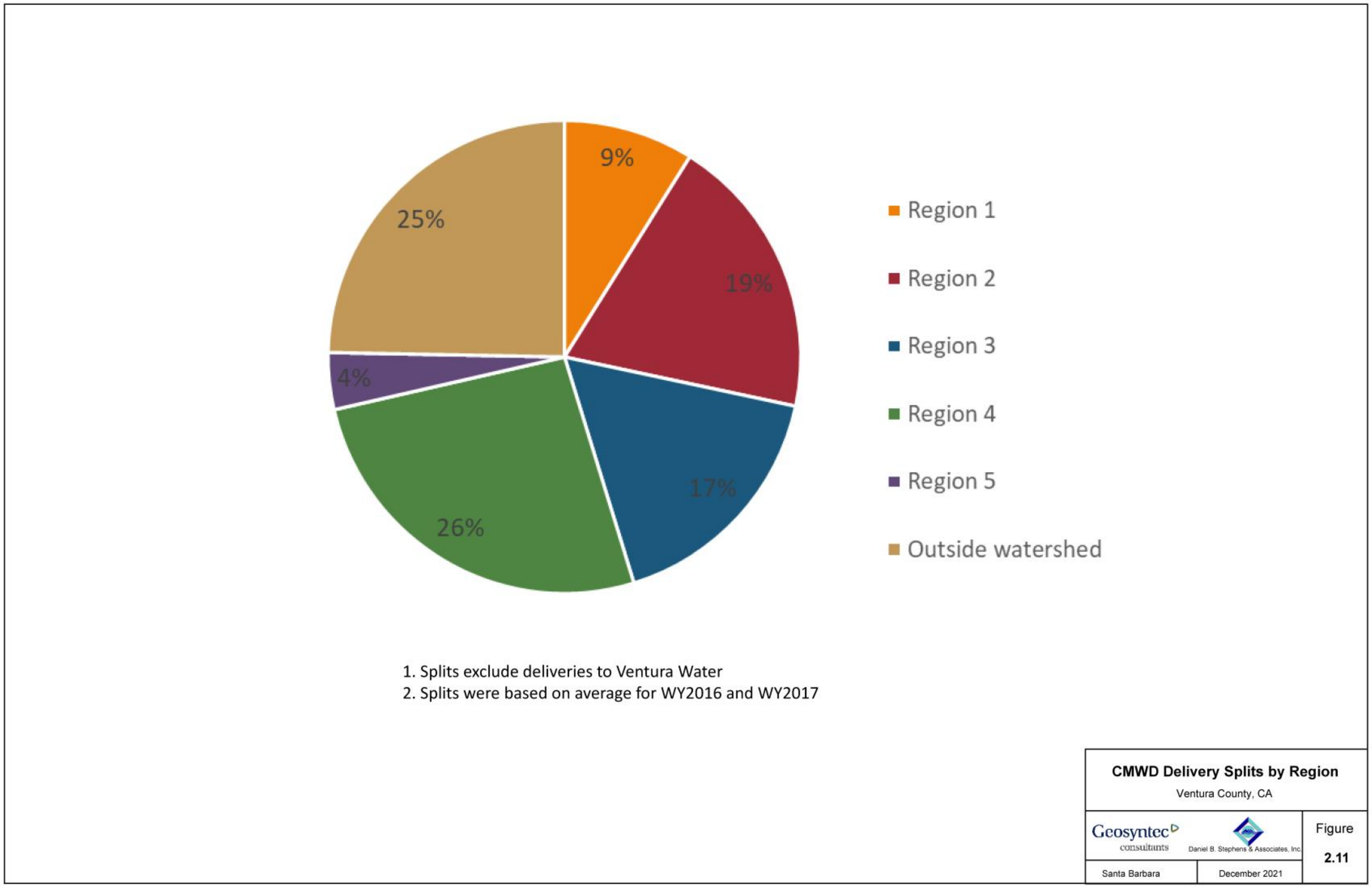
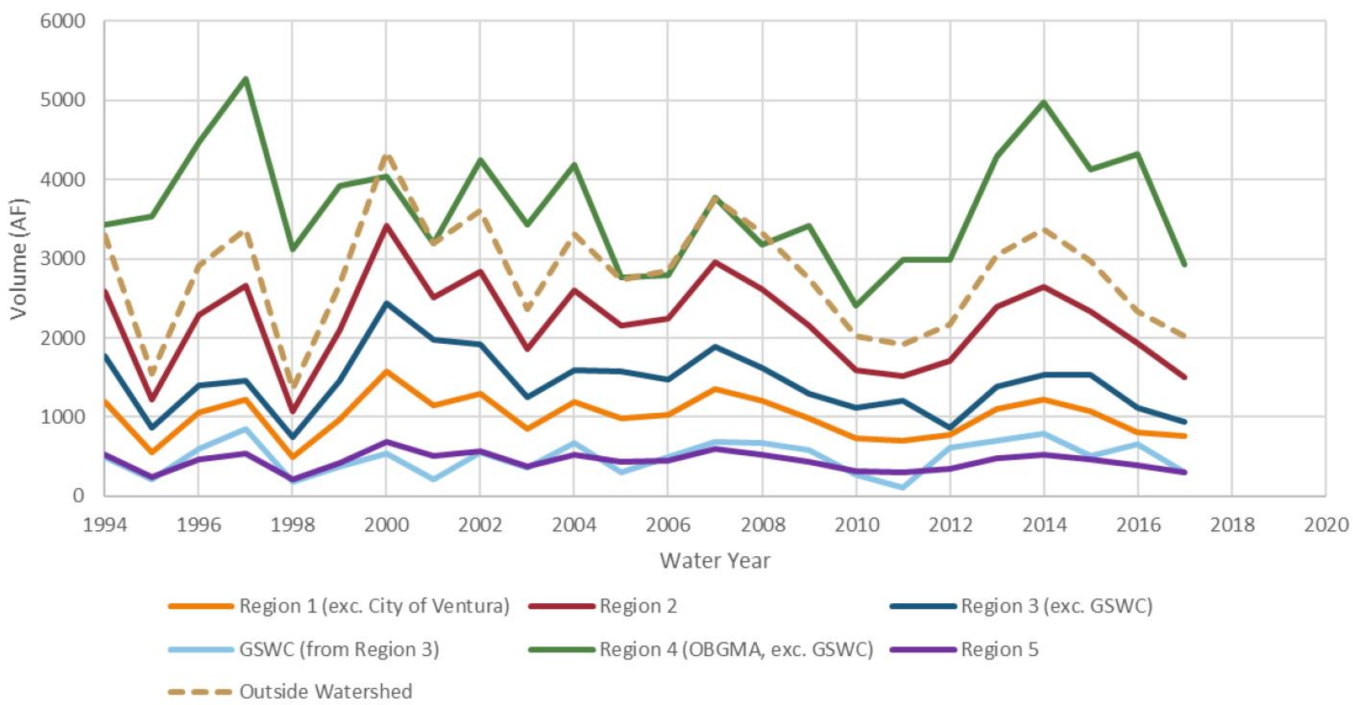


Figure 2.11 CMWD Delivery Splits by Region



CMWD Deliveries by Region Ventura County, CA		
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Figure 2.12 CMWD Deliveries by Region

2.4.3 Local Surface Water Diversions

There are more than 20 surface water diversions throughout the VRW, as indicated in Figure 2.13. Information on maximum allowable diversion rates and historical volumes from 2010 onwards are available in the SWRCB electronic Water Rights Information Management System (eWRIMS) computer database[11]. A screening analysis excluded several diversions that had no or zero diversion volumes reported, and also identified minor diversions with small volumes that were neglected in the supply and demand analyses[12].

The remaining diversions were included in the supply and demand analyses and included two diversions within Region 3 and four diversions within Region 4. Three of the four diversions in Region 4 are owned by Senior Canyon Mutual Water Company (SCMWC), including the SCMWC water tunnel, and additional information and volume estimates for these diversions were obtained directly from SCMWC. The remaining diversions used estimates for annual volumes based upon the eWRIMS data. These estimates are provided in the tables of the results in the following sections.

The Robles Canal diversion from the Ventura River was not included directly in the supply and demand analyses since the water is diverted to Lake Casitas and is already accounted for as a supply by the CMWD deliveries from Lake Casitas. Similarly, the releases from Matilija Reservoir are not included directly in the supply and demand analyses since these releases end up moving downstream into the Ventura River and the Robles Canal diversion, rather than going directly to use. The Matilija releases and Robles Canal diversion are physically represented in the VRW GSFLOW Model, as described in Sections 3.5.1 and 3.5.2, to correctly model the flows in the Ventura River.

An infiltration gallery in the upper Ventura River to the Rancho Matilija Mutual Water Company (RMMWC) service area is also not included in this surface water analyses, but is instead modeled as a pumping well due to diversion occurring from pipes within the streambed material.

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[11] A public version of the eWRIMS database is available at URL: https://ciwqs.waterboards.ca.gov/ciwqs/ewrims/EWPublicTerms.jsp
[12] The diversions were still included in the GSFLOW model as described in Section 3.5.

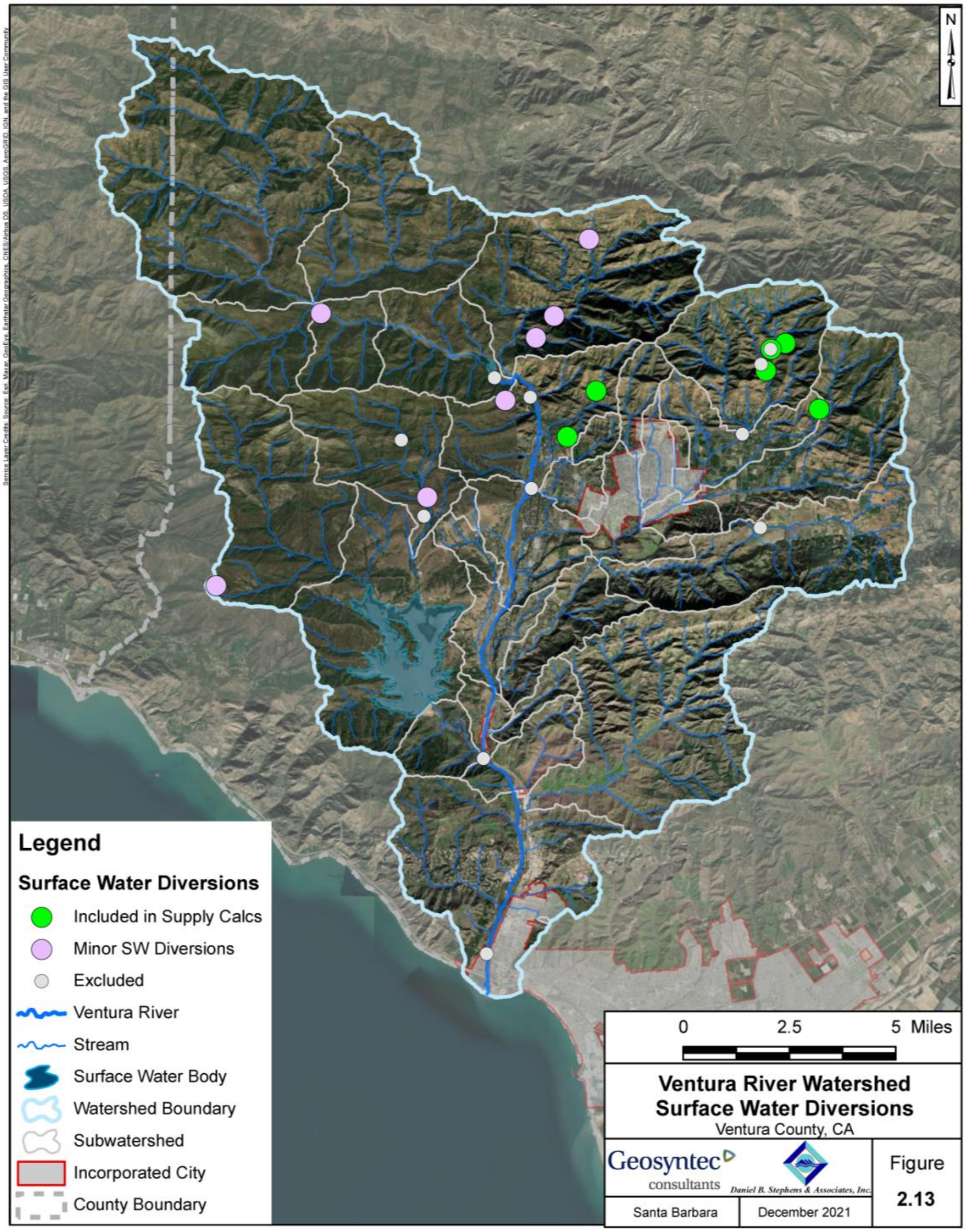


Figure 2.13 Ventura River Watershed Surface Water Diversions

2.5 Results

The results of the analyses are presented and discussed in the following sections. Region 4 results are presented first, since the pumping volumes are reported within this region, and the analyses is performed primarily as a check on the method and assumptions, and to inform the analyses in other regions. Region 5 results are presented next since it is the least complex of the regions. Subsequently, results for Regions 1 through 3 are presented in numerical order.

2.5.1 Region 4

The Region 4 results are presented as a series of tables of annual volumes for different supplies and demands for each service area and the remainder of Region 4. Specifically, the results for the former GSWC service area (Table 2.8), Hermitage Mutual Water Company (MWC) service area (Table 2.9), SCWMC service area (Table 2.10), and the remainder of Region 4 (Table 2.11) are provided. Data sources, assumptions, and or calculation methods for each column are provided in the table footnotes.

Each of the tables includes columns for deliveries from CMWD, pumping from domestic, municipal, and private wells (if applicable), and local surface water diversions (SCWMC, Table 2.10, only). These supplies are summed to calculate the total supply. The CMWD deliveries are also broken down into estimated deliveries to residential and agricultural use. Estimates for residential and agricultural demand are also provided and summed to calculate the total demand.

The total supply, total demand, and breakdown of demand into residential and agricultural are plotted for each of the service areas and remainder of Region 4 in Figure 2.14 through Figure 2.17. The former GSWC service area (Figure 2.14) comprises mostly residential demand and in general the total demand and total supply show reasonable agreement. Notably, over the entire period (i.e., WY1994-2017) the total supply and the total demand differ by only 4%.

The remaining areas in Region 4 (Figure 2.15, Figure 2.16, and Figure 2.17) are dominated by agricultural demand, and generally indicate total supply is less than total demand, particularly during the drought years (i.e., WY2013-2017). Excluding the drought years, the total supply within the entire Region 4 is 11% less than the total estimated demand. This is comparable to the reported accuracy of +/-10% for the metered/estimated reported extractions for the OBGMA that were used in the analyses (Table 1, OBGMA 2019), and

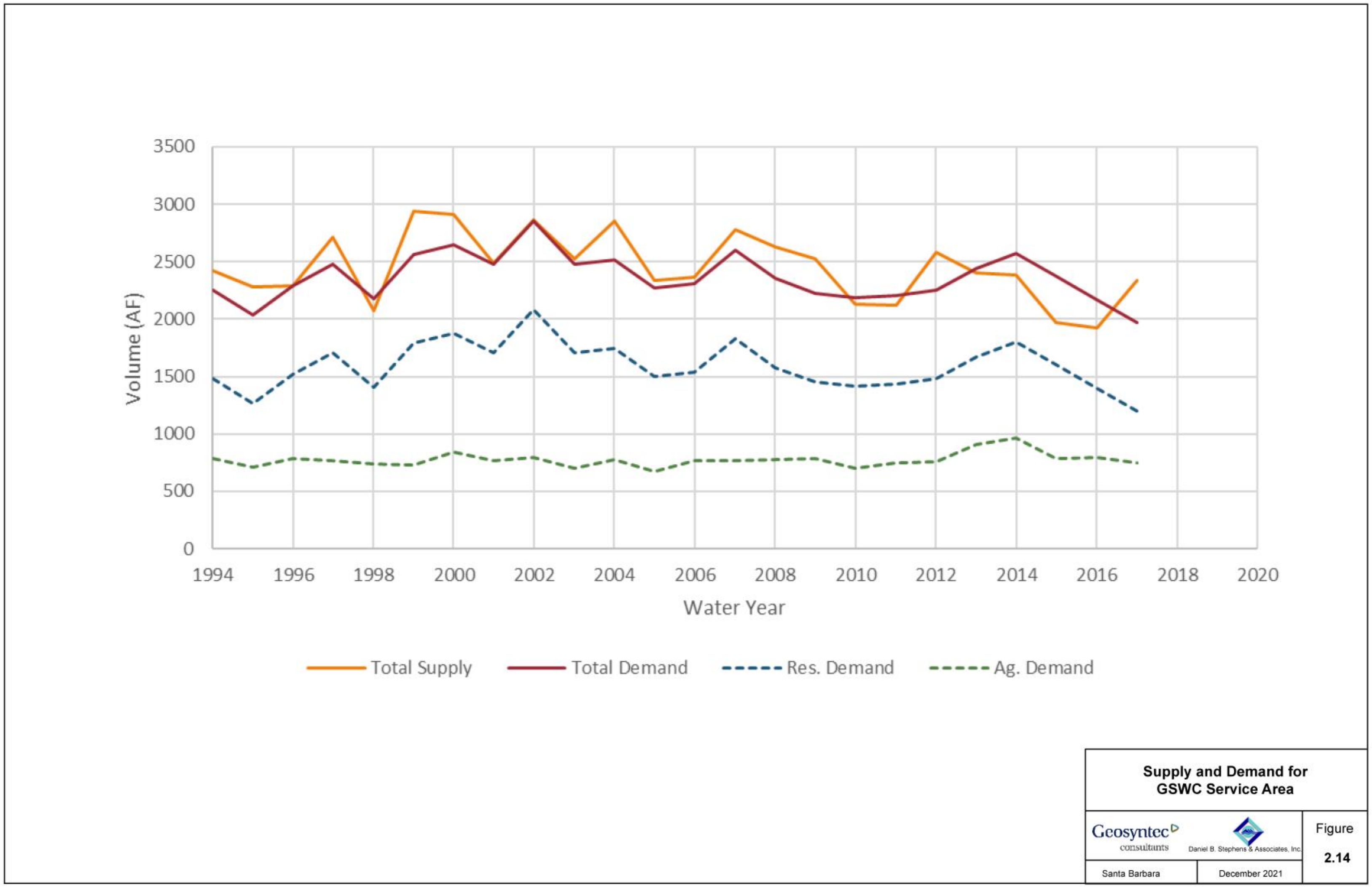


Figure 2.14 Supply and Demand for GSWC Service Area

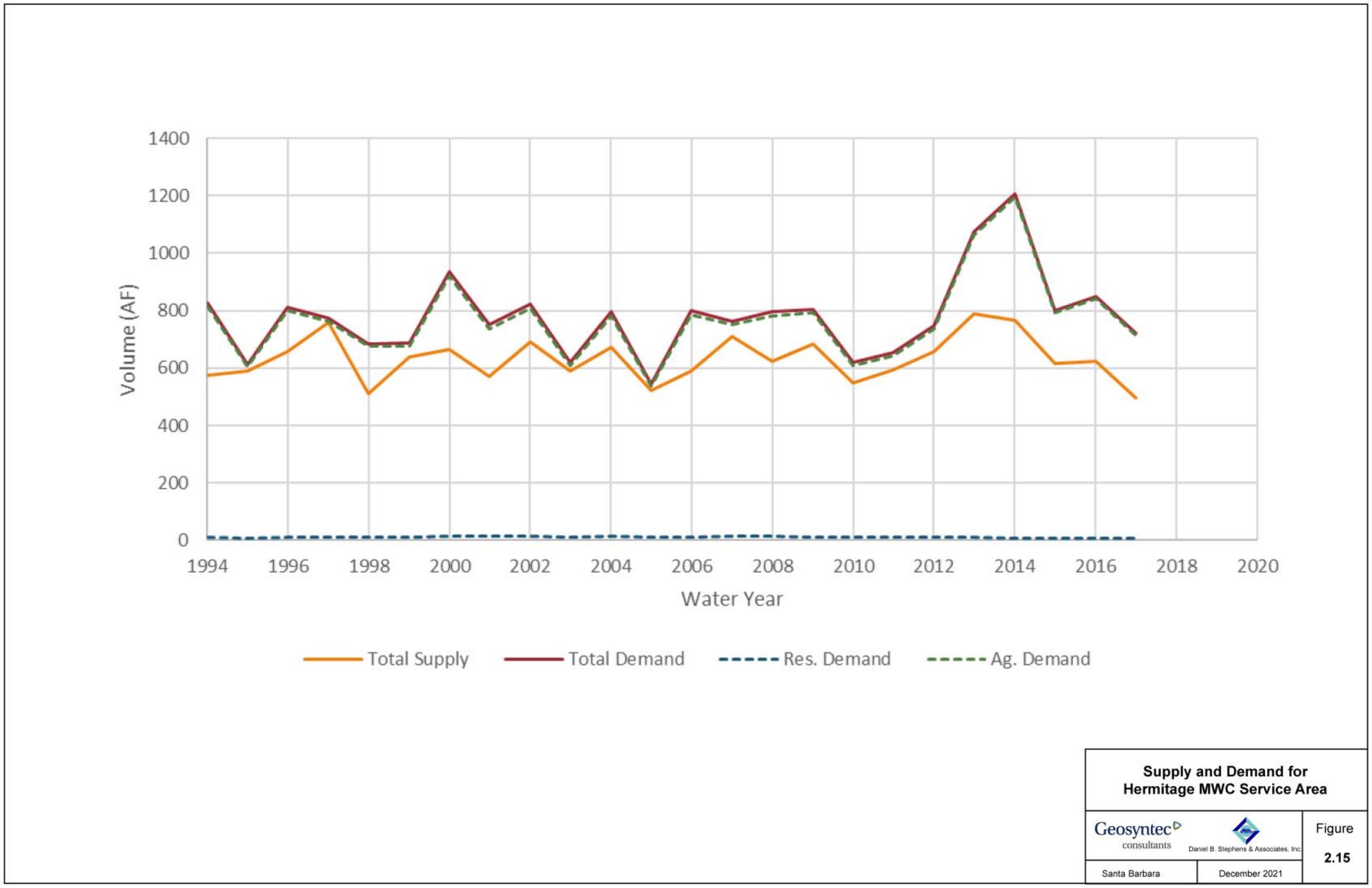


Figure 2.15 Supply and Demand for Hermitage MWC Service Area

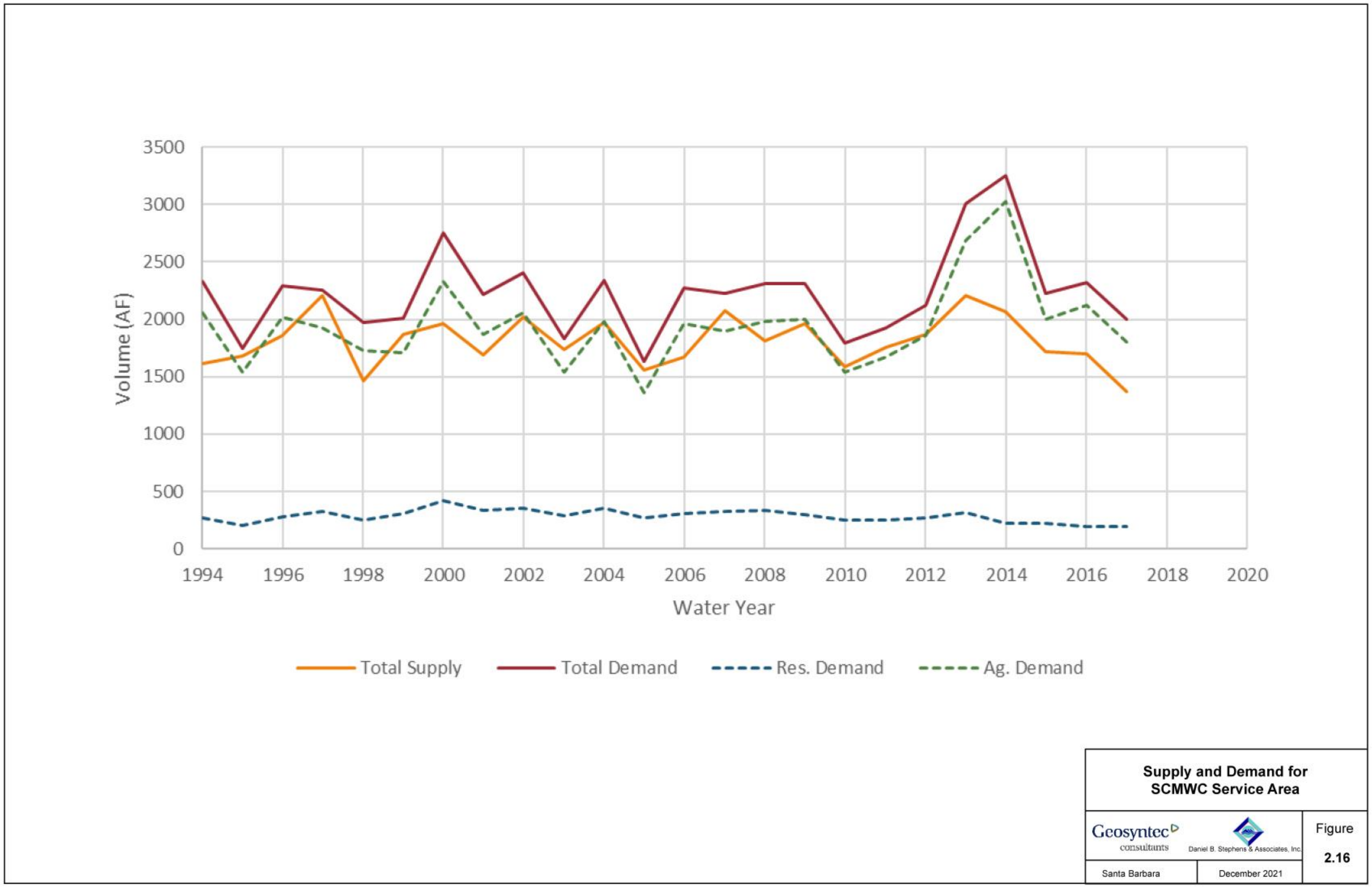


Figure 2.16 Supply and Demand for SCMWC Service Area

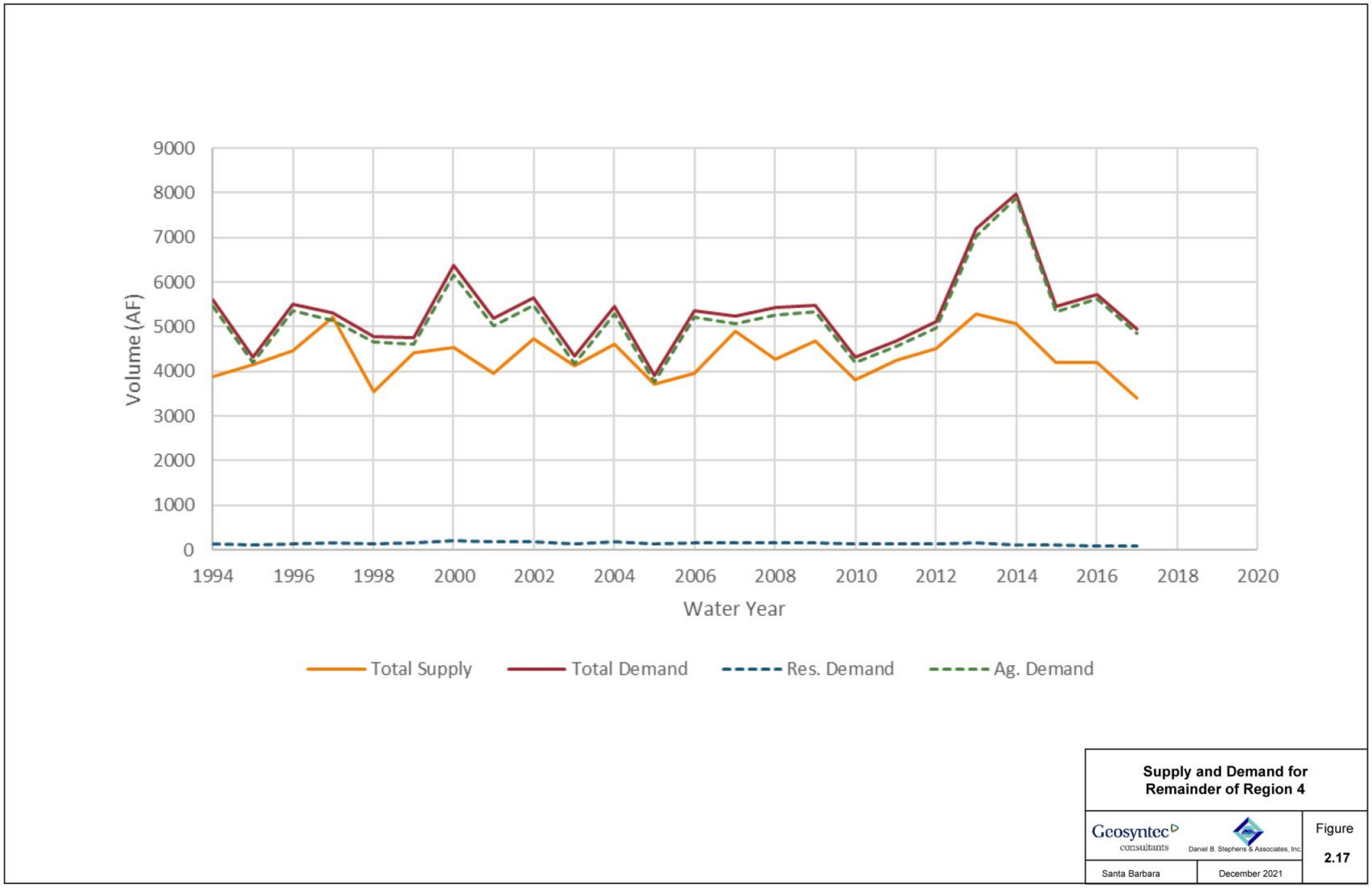


Figure 2.17 Supply and Demand for Remainder of Region 4

therefore supports the approach and assumptions used in the analyses.

During the drought years there were high agricultural demands that were not met (Figure 2.15, Figure 2.16, and Figure 2.17). This is likely due to a combination of water conservation measures implemented in the watershed and exceedingly high DWR applied water rates (e.g., more than 5 AF/acre/year in WY2014, Table 2.5). The imbalance in the drought years does not affect the model input in Region 4, since the OBGMA reported pumping is used directly in the model.

However, in Regions 1, 2, 3, and 5 many of the pumping volumes are not reported and are instead calculated as part of this analyses. If the same approach and assumptions are used in these regions and it is assumed that all agricultural demands are met, then the resulting calculated pumping will likely be overestimated during the drought years. To account for this, a drought adjustment factor was developed and applied to the estimated agricultural demands in the drought years for Regions 1, 2, 3, and 5. Table 2.12 presents the assumed adjustment factors used in the analyses for Regions 1, 2, 3, and 5. The adjustment factors are comparable to the factors calculated for Region 4 (Table 2.12), indicating this is a reasonable approach and will result in drought deficits in Regions 1, 2, 3, and 5 being similar to Region 4.

2.5.2 Region 5

Region 5 results are presented in tables similar to those for Region 4. Specifically, the results for Sisar MWC service area are presented in Table 2.13 and the results for the remainder of Region 5 are presented in Table 2.14. Unlike Region 4, the pumping from private wells to be used for agriculture are not typically measured and are not reported in Region 5, and the goal of these analyses is to estimate unknown pumping volumes.

The approach assumed that the CMWD deliveries to Region 5 as plotted in Figure 2.12 (see Section 2.4.2) were first used to meet residential demand (i.e., make up the difference between the residential demands and other supplies for residential uses, comprising domestic and municipal groundwater). The remaining CMWD deliveries were then assumed to be used for agriculture. The private agricultural groundwater pumping volumes were then calculated such that the total agricultural demand was met in each year, except for during the drought years (i.e., WY2013-2017) where the drought adjustment factors (Table 2.12) were applied to the estimated agricultural demands. Therefore, the Difference columns in Tables 2.13 and 2.14 indicate zeros (i.e., demands are met) for WY1994-2012, and negative values (i.e., demands are not fully met) for WY2013-2017.

Results of the analyses are plotted in Figure 2.18 and Figure 2.19 for Sisar MWC service area and the remainder of Region 5, respectively. The plots show the match of supply and demands until the drought period, at which point the supplies do not meet the demands. This is particularly the case for the remainder of Region 5 (Figure 2.19), which is dominated by agriculture. The trends in Figure 2.19 are qualitatively similar to the those in the agriculture dominated areas of Region 4 (i.e., Figure 2.15, Figure 2.16, and Figure 2.17) indicating that the use of the drought adjustment factors are appropriate.

The private agricultural groundwater volumes estimated in Table 2.14 are the total volumes pumped for the remainder of Region 5. Within Region 5 there are numerous agricultural wells and crops as illustrated in Figure 2.2. To better resolve the spatial scale of the pumping volumes for the VRW GSFLOW Model input, the remainder of Region 5 (as well as other regions) were subdivided into Sub-Regions based on groups of agricultural wells and crops (Figure 2.2). The estimated agricultural volumes were then distributed to each of these Sub-Regions. This required assessing whether each of the Sub-Regions could receive agricultural water from CMWD, since the volumes of CMWD water used for agriculture within each Sub-Region has a direct effect on the volumes that would come from groundwater. The CMWD delivery infrastructure (Figure 1.7) and pressure zones (Figure 2.9) indicate that most crops within Region 5 can receive deliveries from CMWD. Based on this, it was assumed that both the CMWD deliveries to agriculture, and the agricultural groundwater pumping, were distributed to each Sub-Region in relative proportion to the agricultural demands.

Results are presented for the CMWD deliveries in Table 2.15 and for groundwater pumping in Table 2.16. When implementing the groundwater pumping volumes into the model the total pumping volume within each Sub-Region is assumed to be split evenly between the agricultural wells within the Sub-Region.

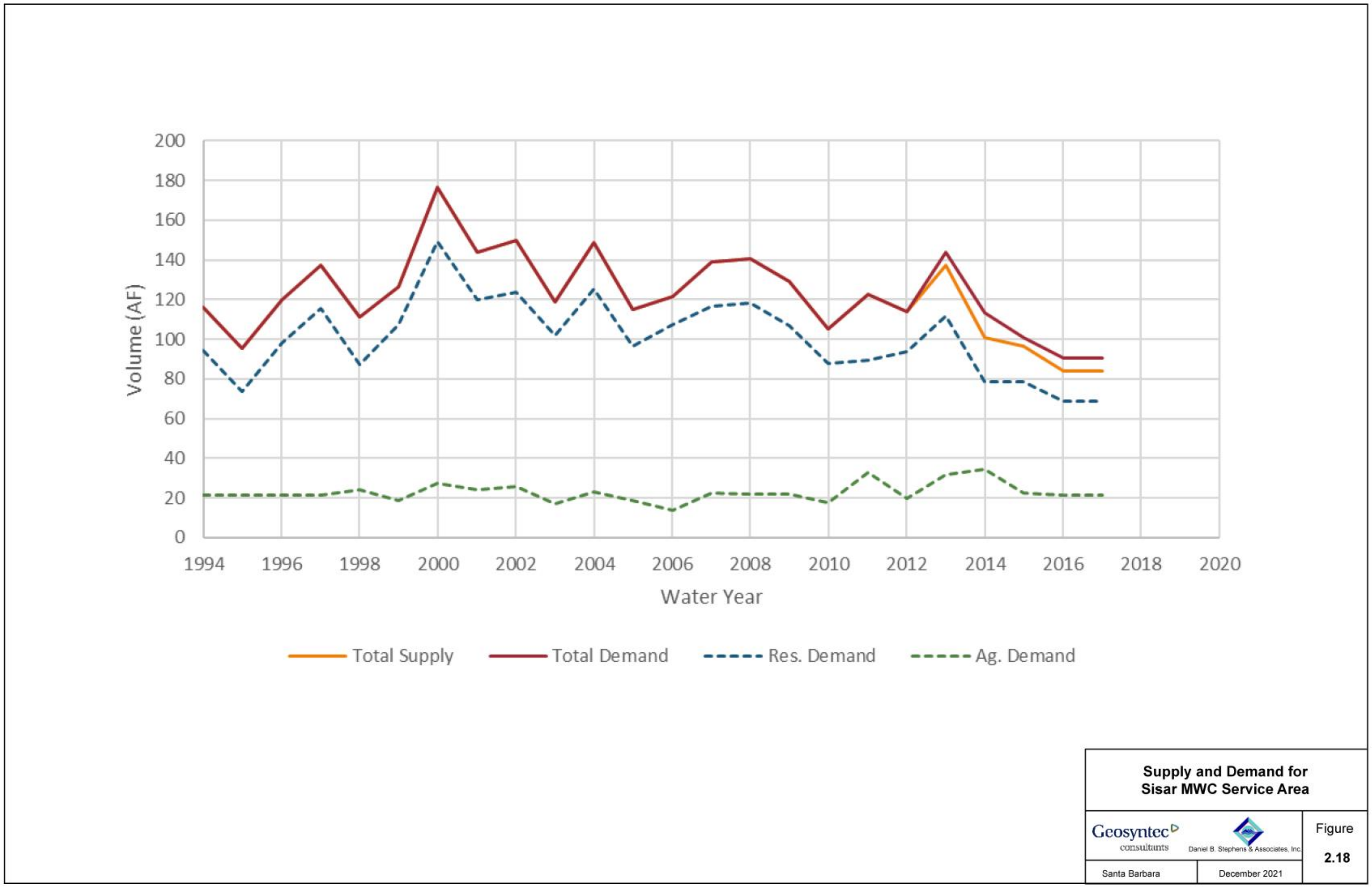
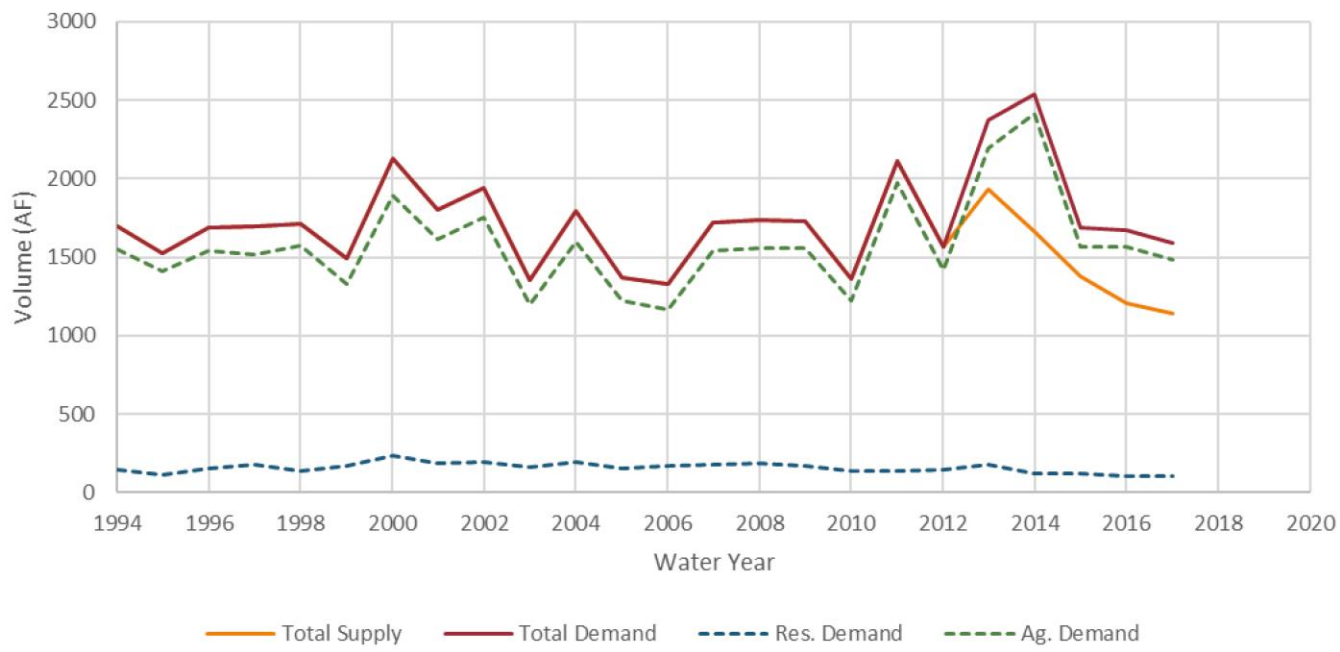


Figure 2.18 Supply and Demand for Sisar MWC Service Area



Supply and Demand for Remainder of Region 5		
Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure 2.19
Santa Barbara	December 2021	

Figure 2.19 Supply and Demand for Remainder of Region 5

2.5.3 Region 1

The estimated fraction of CMWD deliveries to within Region 1 excluded deliveries to Ventura Water service area based on analyses of historical deliveries and pressure zone data (see Section 2.4.2). To be consistent with this approach, and simplify the analyses, it was assumed that the crops in the Ventura Water service area and within the VRW (see Figure 2.2) were irrigated with locally pumped groundwater unless information was available indicating otherwise. Additionally, it was assumed that domestic wells were pumped at a rate of 0.5 gpm (0.8 AFY). Results for the Ventura River service area that is within the VRW are provided in Table 2.17.

The estimated CMWD deliveries to Region 1 as plotted in Figure 2.12 (see Section 2.4.2) were distributed within the region by considering service areas and defining Sub-Regions around crops (Figure 2.2). Since the Casitas MWC service area did not contain agricultural demands a separate balance was first calculated for the residential demand and other supplies. It was assumed the CMWD deliveries were used to make up the shortfall as indicated in Table 2.18. The small fraction of VRWD service area within Region 1 was neglected in this part of the analyses, and instead included within the Region 2 calculations.

The distribution of the CMWD deliveries to the remainder of Region 1 were made by first assuming that CMWD water was used to meet shortfalls in residential demands, and then used for agriculture. However, Sub-Region 1D is not adjacent to CMWD distribution lines (Figure 1.7 and Figure 2.9) and it was assumed this Sub-Region could not receive CMWD deliveries. Instead, it was assumed the agricultural demand within this Sub-Region was met solely by pumping from agricultural wells.

Conversely, Sub-Region 1B does not contain nearby agricultural wells, and it was assumed that demand was met from CMWD deliveries. Therefore, distribution of the CMWD deliveries within Region 1 were prioritized to meet the agricultural demands within Sub-Region 1B. In some years there were not enough estimated CMWD deliveries to meet these demands, and in those years it was further assumed that there was not enough CMWD water to fully meet the residential demand within Region 1. The CMWD deliveries were assigned such that the fraction of demand met within Sub-Region 1B and in residential areas relying on CMWD deliveries were the same.

The additional complexity of the analyses required the overall supply and demand calculations, and the breakdown of CMWD deliveries to the Sub-

Regions and resulting pumping volumes within each Sub-Region to be carried out in parallel. Results are presented in Table 2.19 (remainder of Region 1), Table 2.20 (CMWD deliveries to agriculture for the Sub-Regions), and Table 2.21 (groundwater pumping to agriculture for the Sub-Regions).

Per the assumptions, Table 2.20 indicates zero CMWD deliveries to Sub-Region 1D, and the highest CMWD deliveries to Sub-Region 1B. The remainder of the CMWD deliveries were split between Sub-Regions 1A and 1C in proportion to the agricultural demand within each Sub-Region. Similarly, Table 2.21 indicates zero groundwater pumping within Sub-Region 1B. Within each of the other Sub-Regions the groundwater volumes were calculated such that the total agricultural demand was met in each year, except for during the drought years (i.e., WY2013-2017) where the drought adjustment factors (Table 2.12) were applied to the estimated agricultural demands.

Results of the analyses are plotted in Figure 2.20 and Figure 2.21 for Casitas MWC service area and the remainder of Region 1, respectively. Figure 2.20 indicates that the demands within Casitas MWC service area are met every year due to the assumption that CMWD deliveries always make up the shortfall. By contrast, the demands within the remainder of Region 1 (Figure 2.21) are not always met, due to the use of drought adjustment factors in WY2013-2017 and due to assumed shortfall in CMWD deliveries to Sub-Region 1B in some of the other years. The shortfalls are largest in WY1995 and WY1998 (Figure 2.21) which were both wet years. It is possible that the assumptions regarding the overall split of CMWD deliveries to the Regions that were based on data from WY2015-2020 may not hold in wetter years. Nonetheless, the results for the remainder of Region 1 (Figure 2.21) are qualitatively similar to the those in the agriculture dominated areas of Region 4 (i.e., Figure 2.15, Figure 2.16, and Figure 2.17) indicating that the overall approach is reasonable.

2.5.4 Region 2

Region 2 contains several municipal service areas, including VRWD, Rancho del Cielo MWC, RMMWC, Old Creek Road MWC, and Tico MWC (Figure 2.2). Additionally, part of MOWD is within the northern portion of Region 2 with the remainder being within Region 3 (Figure 2.2). For these analyses the MOWD

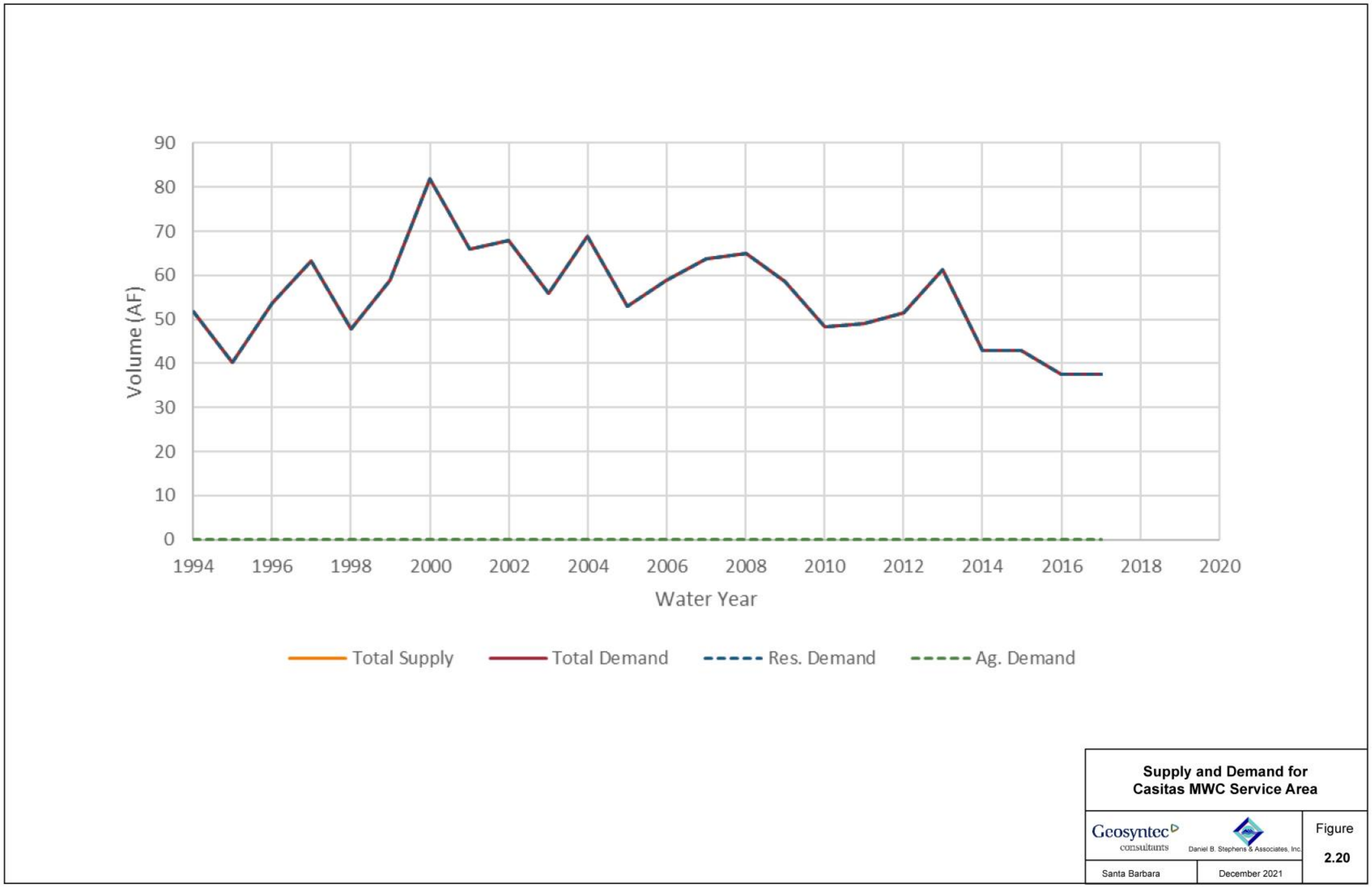


Figure 2.20 Supply and Demand for Casitas MWC Service Area

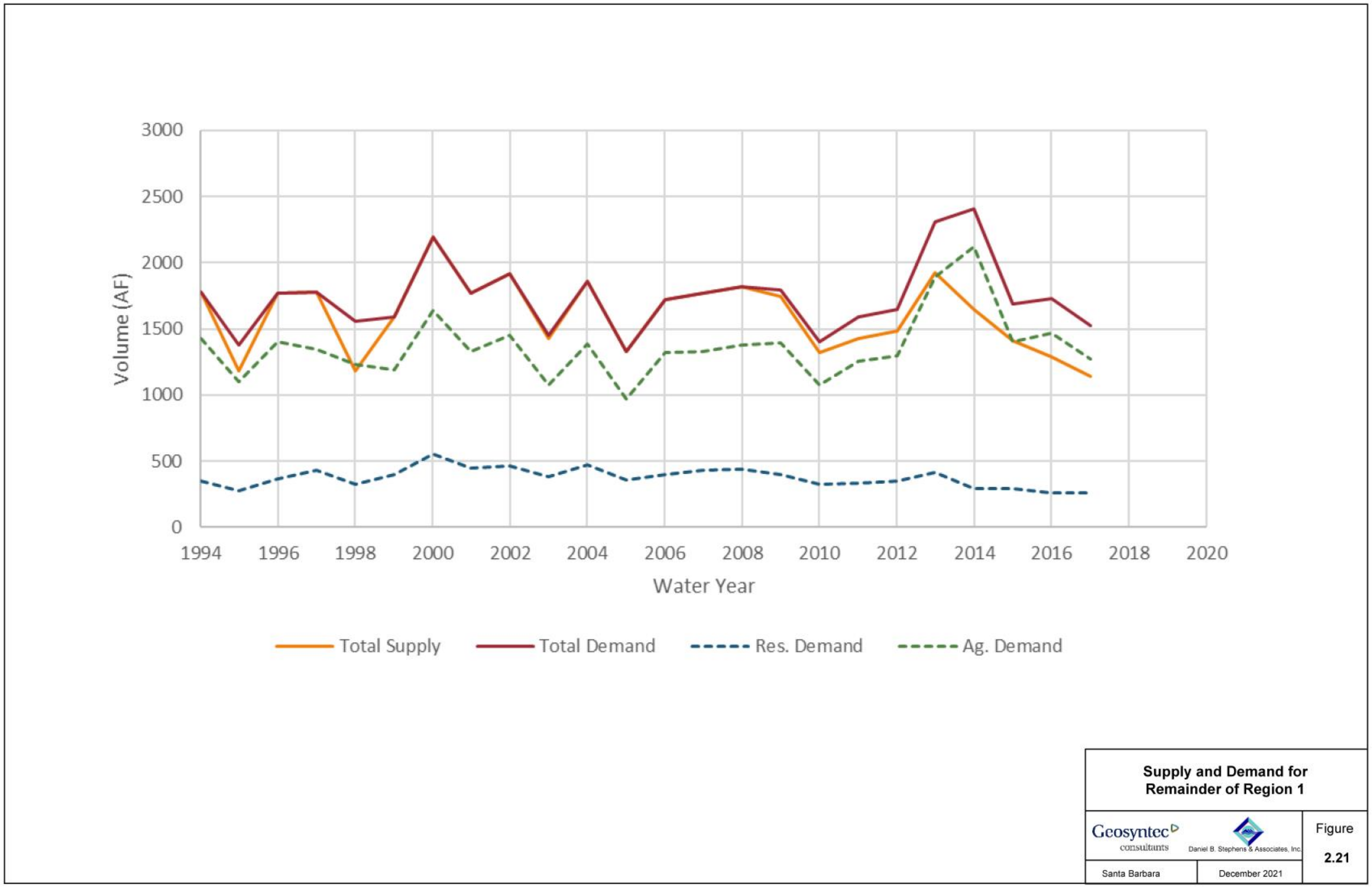


Figure 2.21 Supply and Demand for Remainer of Region 1

was primarily included within Region 3, but in some years estimates of CMWD deliveries to Regions 2 and 3 were adjusted, as described shortly.

Similar to the approach in other regions, the remainder of Region 2 was divided into Sub-Regions based on groups of crops and wells (Figure 2.2). The methodology described for Region 1 was applied to Region 2 with the noted assumptions specific to Region 2:

- RMMWC service area does not receive CMWD deliveries (Walter, 2015) and demands are met by groundwater pumping including from:
    - An infiltration gallery[13] in the Ventura River located in Region 3, Sub-Region 3A
    - Two additional wells[14] located in Region 2, Sub-Region 2F
- Rancho del Cielo service area only receives CMWD deliveries (i.e., no agricultural wells)
- Sub-Region 2C does not receive CMWD deliveries and demands are met by groundwater pumping

Results of the analyses are tabulated for VRWD service area (Table 2.22), Rancho del Cielo MWC service area (Table 2.23), RMMWC service area (Table 2.24), Old Creek Road MWC service area (Table 2.25), Tico MWC service area (Table 2.26), and the remainder of Region 2 (Table 2.27). The delivery volumes of CMWD water to agriculture for the service areas and Sub-Regions are provided in Table 2.28, and the groundwater pumping volumes to agriculture are provided in Table 2.29.

The analyses for Region 2 presented above assumed slightly different splits of CMWD deliveries in Regions 2 and 3 in some years, which was required to produce reasonable results in both regions. The adjustments are provided in Table 2.30 and indicate shifts of water from Region 3 to Region 2 in two wet years (WY1998 and WY2005) and shifts of water from Region 2 to Region 3 during the drought (WY2014-2017). The magnitude of the overall shifts were small (generally less than 2.0% of the total CMWD deliveries) and can be thought of as adjustments to the assumptions made in Section 2.4.2.

Results of the analyses for the five service areas and the remainder of Region 2 are plotted in Figure 2.22 through Figure 2.27. The plots for the agriculture dominated areas of Region 2 (i.e., Figure 2.23, Figure 2.24, and Figure 2.27) are qualitatively similar to the those in the agriculture dominated areas of

[13] Recorded as State Well number 05N23W33G03S.
[14] State Well numbers 04N23W04Q01S and 04N23W09B01S.

Region 4 (i.e., Figure 2.15, Figure 2.16, and Figure 2.17) indicating that the overall approach and results are reasonable.

2.5.5 Region 3

Region 3 contains the MOWD service area, which also partly extends into Region 2. As described above the analyses for Region 3 was conducted in parallel with Region 2 and involved some small adjustments in estimated CMWD deliveries to these regions (Table 2.30). Region 3 also has local surface water diversions that supply substantial water for crop irrigation. This is accounted for by using the place-of-use for these surface water diversions as one of the Sub-Regions of Region 3. Specifically, Sub-Region 3C (Figure 2.2) was defined by using the place-of-use for the two Michael Cromer surface water diversions.

The methods used in previous regions were applied to Region 3. Results are provided for MOWD in Table 2.31 and Figure 2.28 and for the remaining of Region 3 in Table 2.32 and Figure 2.29. The delivery volumes of CMWD water to agriculture for the MOWD service area and the Sub-Regions are provided in Table 2.33, and the groundwater pumping volumes to agriculture are provided in Table 2.34.

In other regions the calculated pumping volumes within each Sub-Region (i.e., Table 2.34) were generally applied in the model equally across the agricultural wells within the Sub-Region. However, within Region 3 there were additional information relating specific wells to crop acreages in several of the Sub-Regions (UVRGA, 2020). These information were used to pro-rate the estimated pumping volumes to each well.

At the northern extent of Region 3 is the North Fork Spring MWC service area (Figure 2.2). The pumping volumes for the agricultural wells located within the service area were estimated by matching estimated agricultural demands as summarized in Table 2.35.

Figure 2.22 Supply and Demand for VRWD Service Area

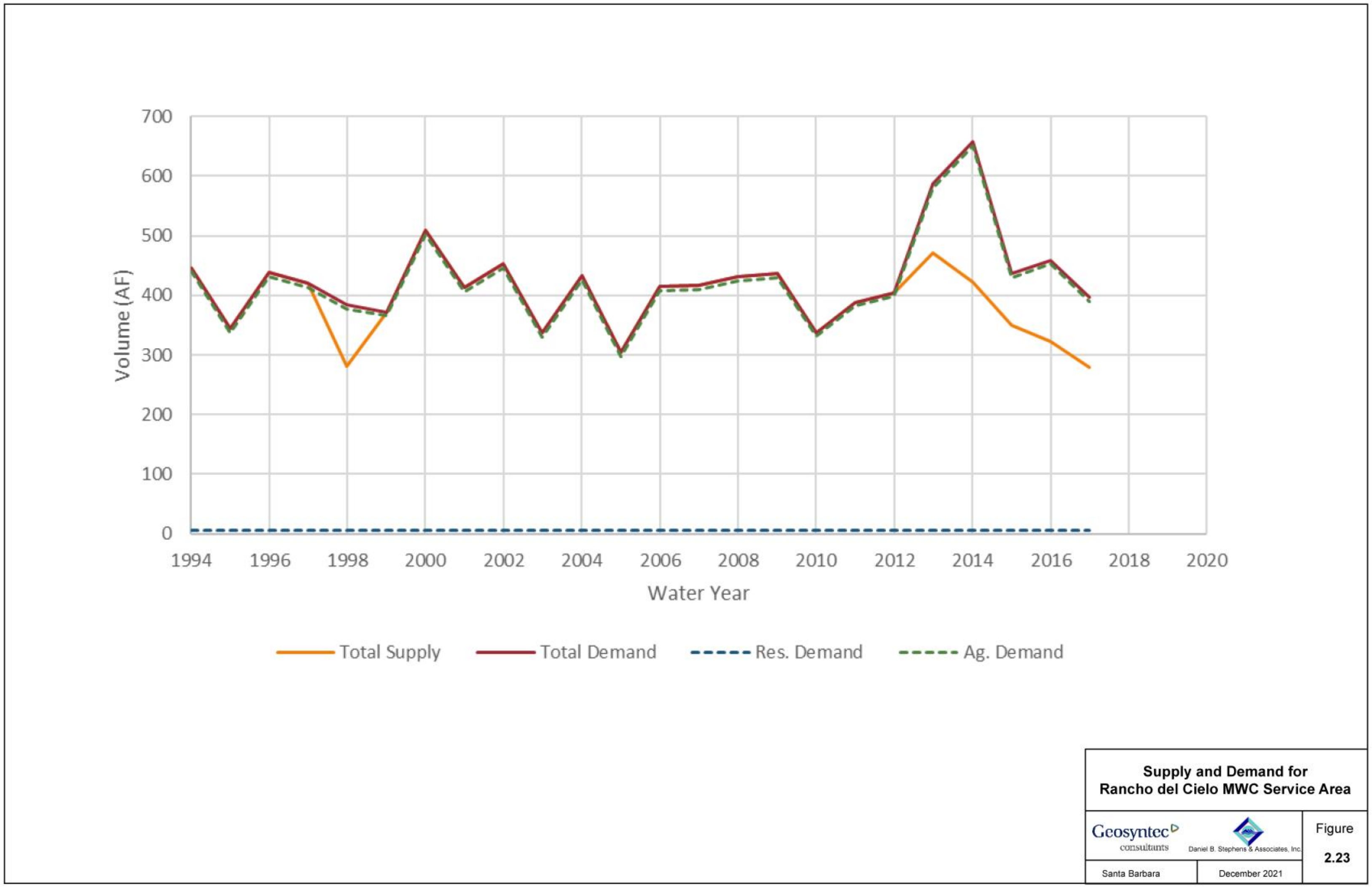


Figure 2.23 Supply and Demand for Rancho del Cielo MWC Service Area

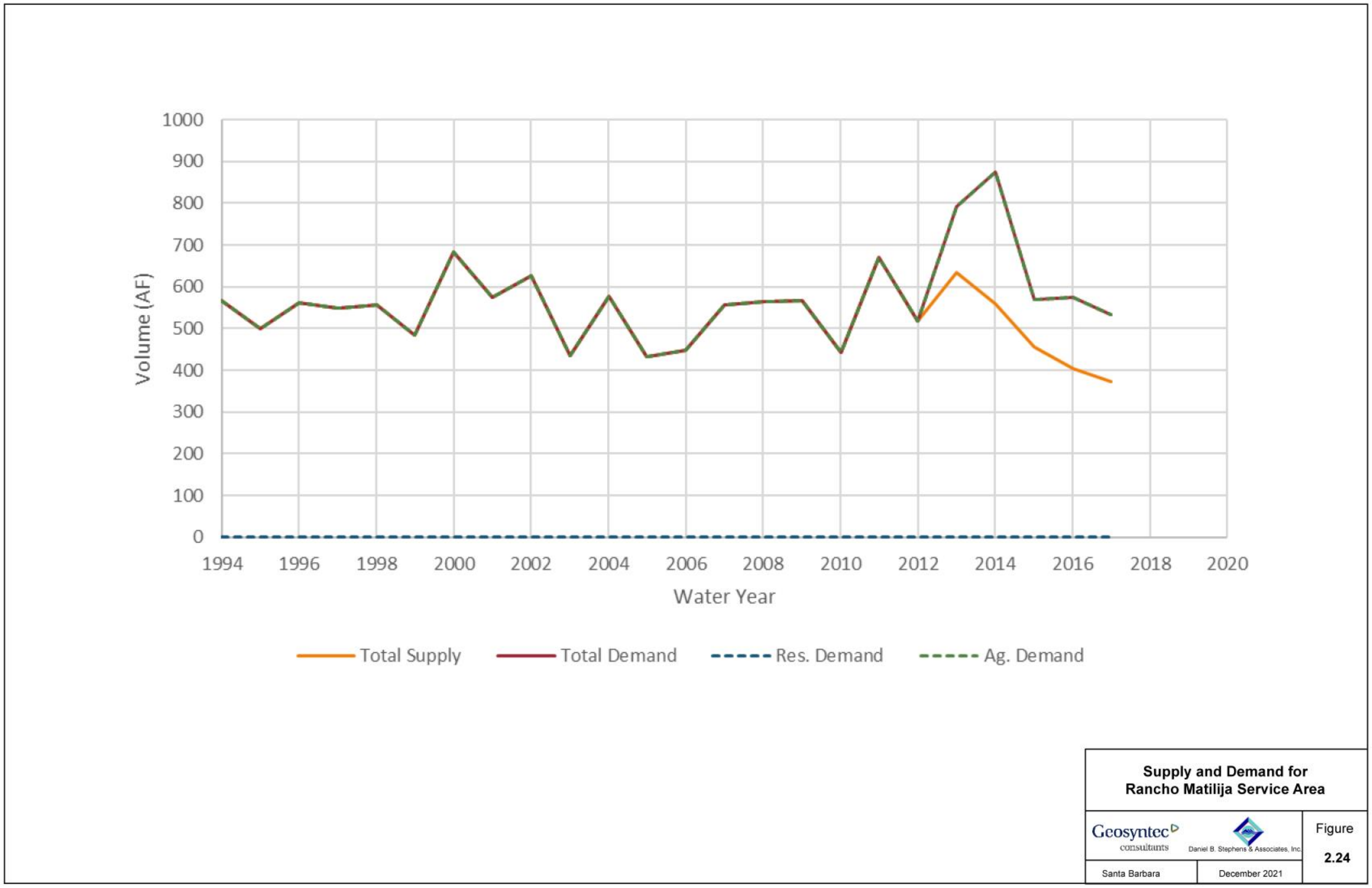


Figure 2.24 Supply and Demand for Rancho Matilija Service Area

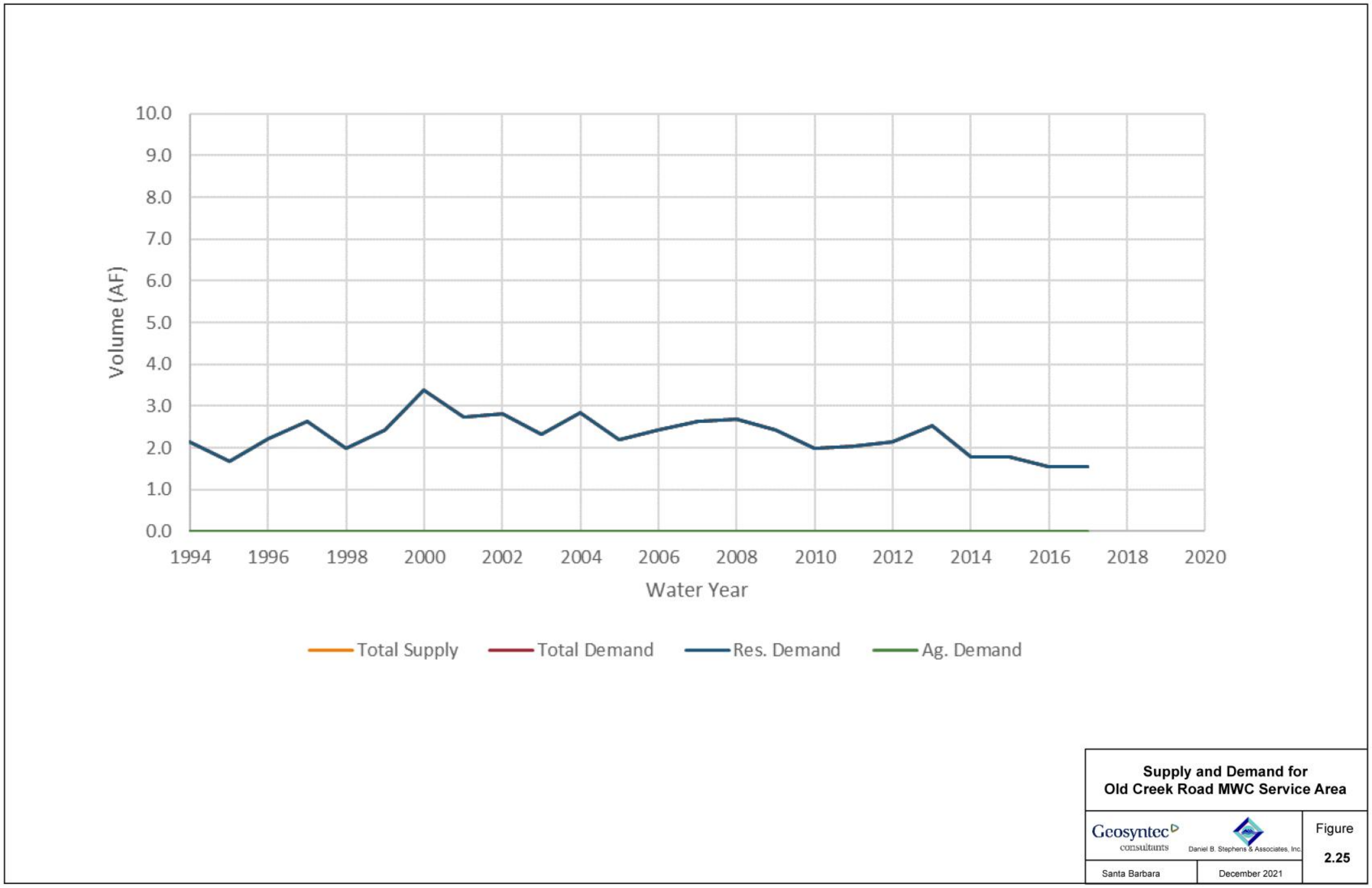


Figure 2.25 Supply and Demand for Old Creek Road MWC Service Area

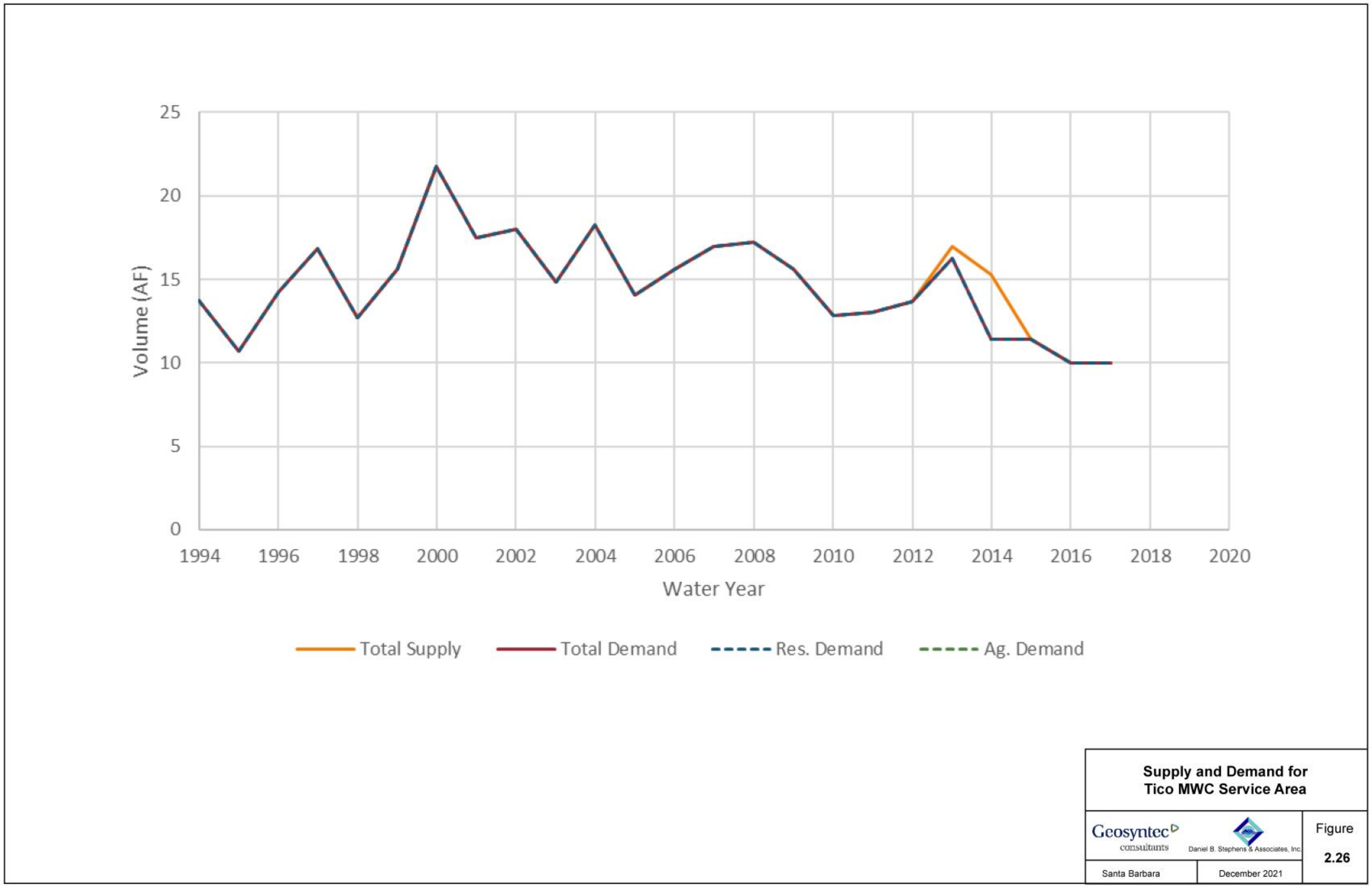


Figure 2.26 Supply and Demand for Tico MWC Service Area

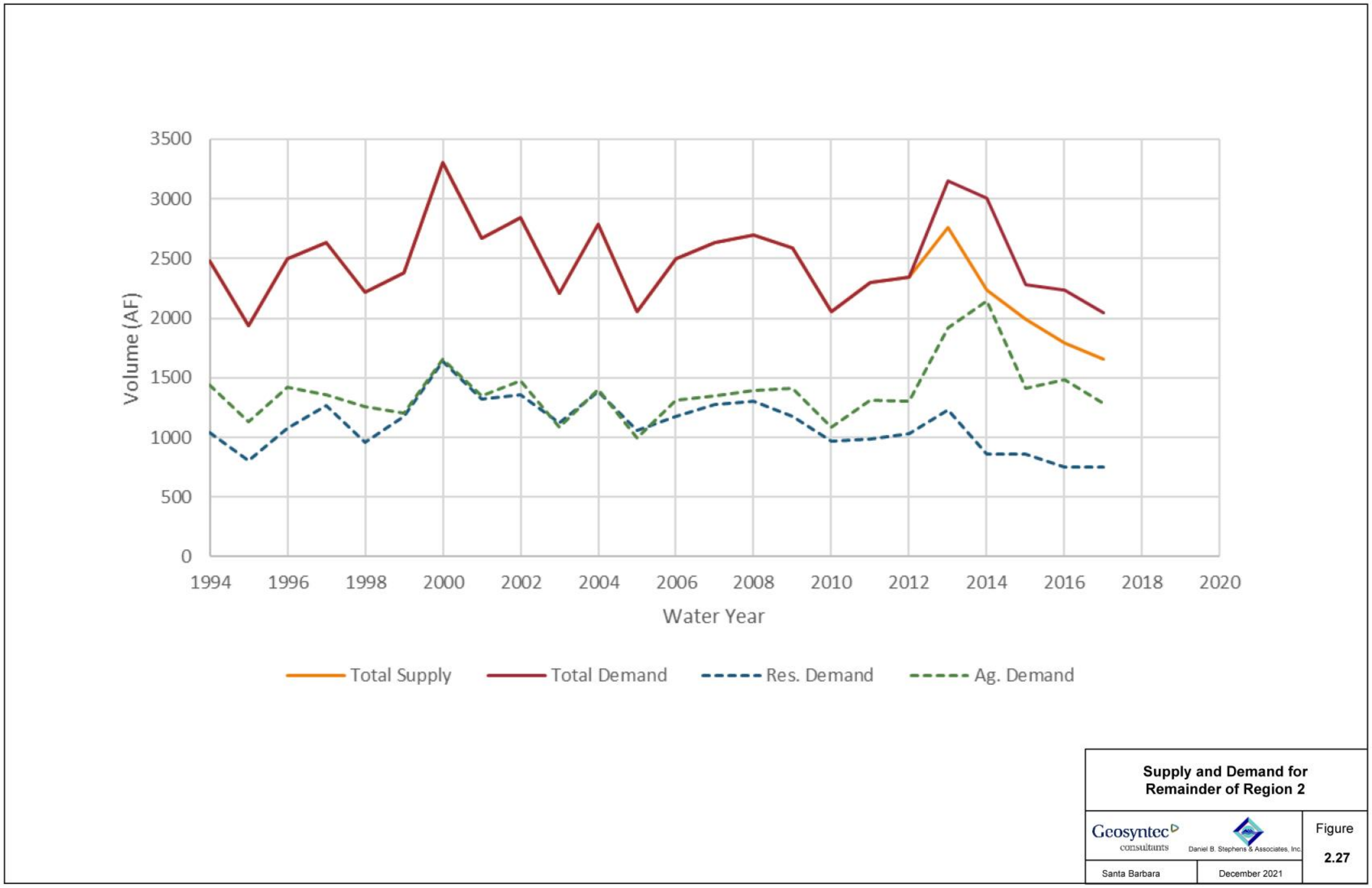


Figure 2.27 Supply and Demand for Remainder of Region 2

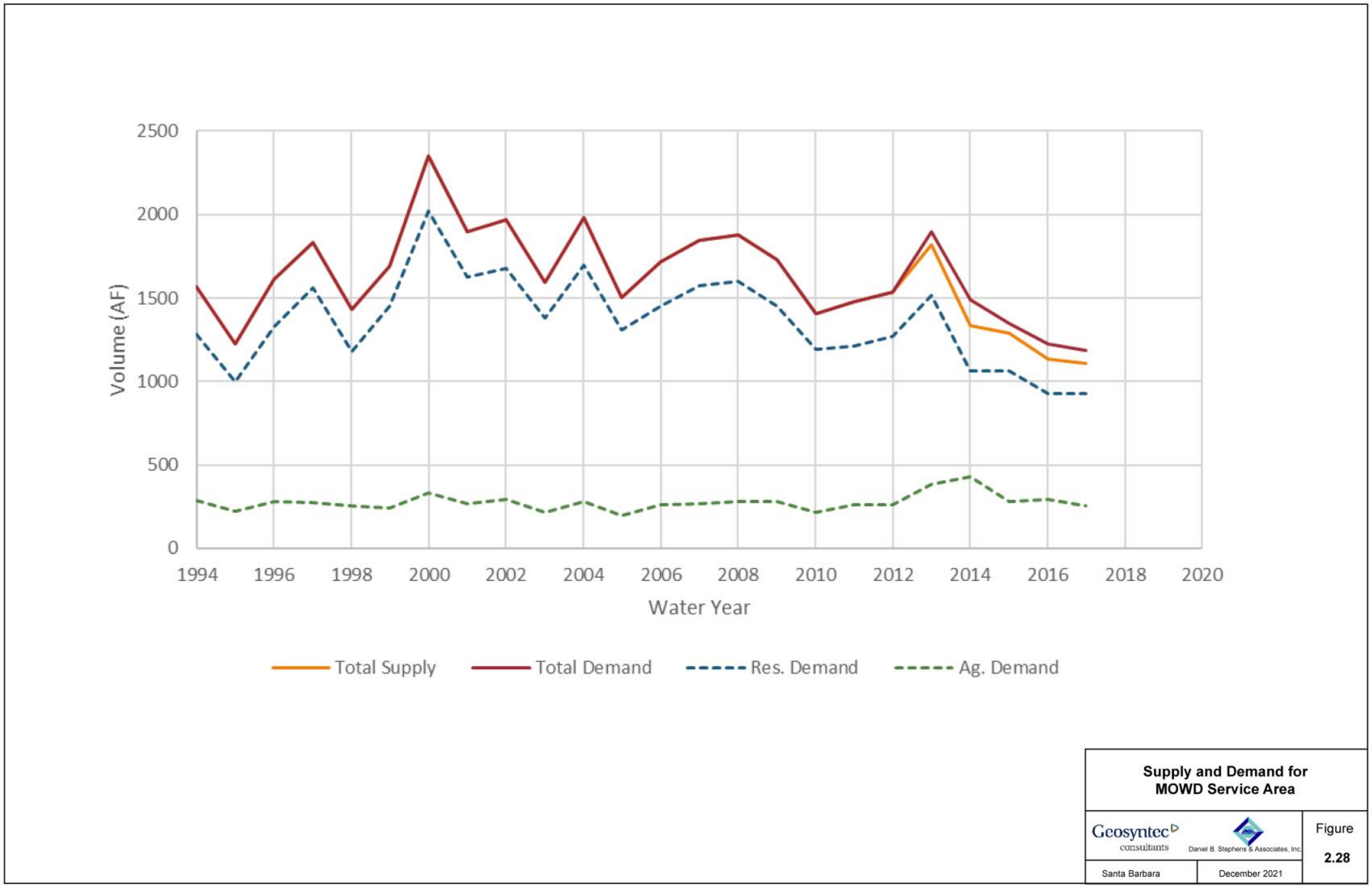


Figure 2.28 Supply and Demand for MOWD Service Area

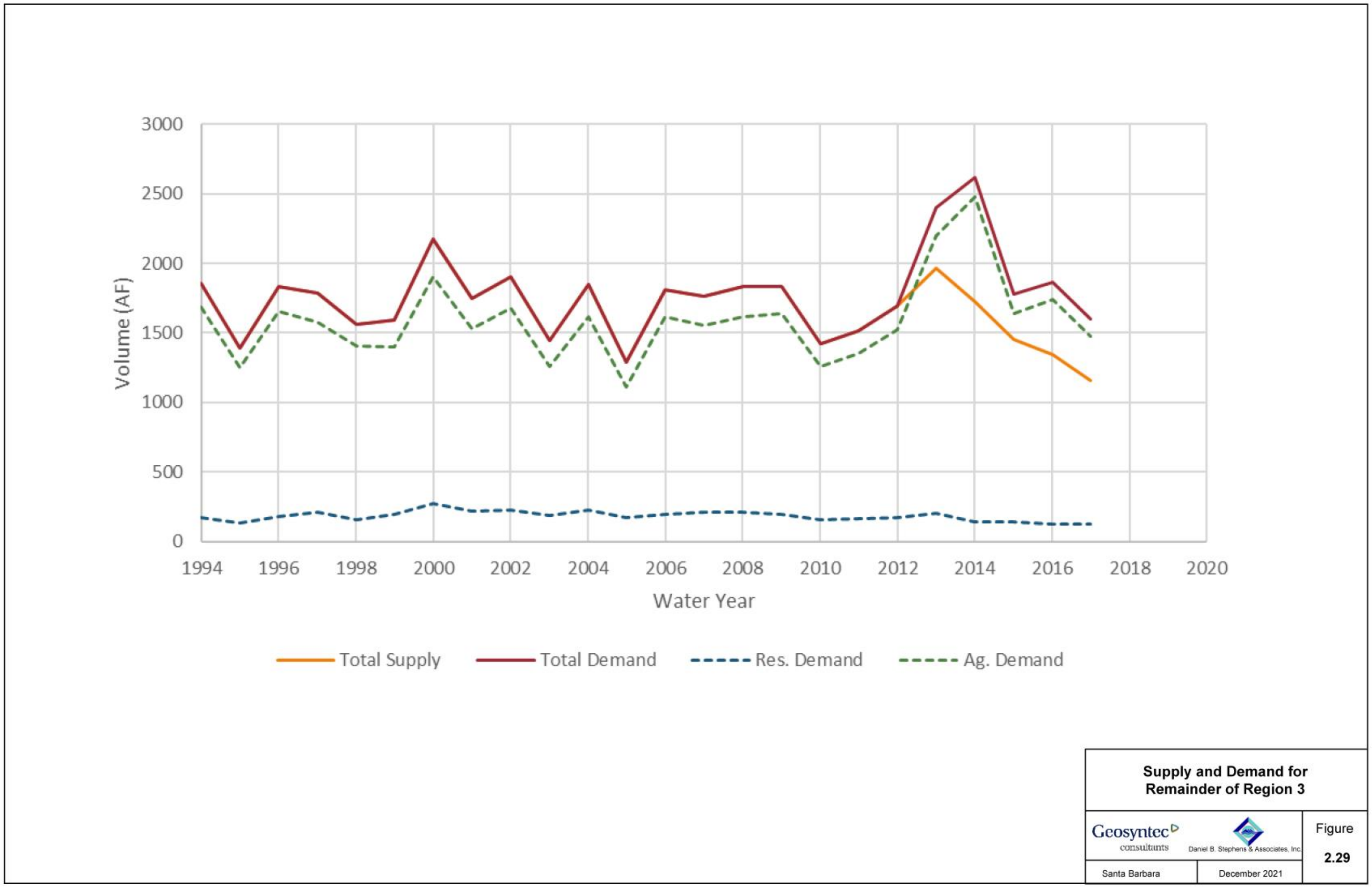


Figure 2.29 Supply and Demand for Remainder of Region 3

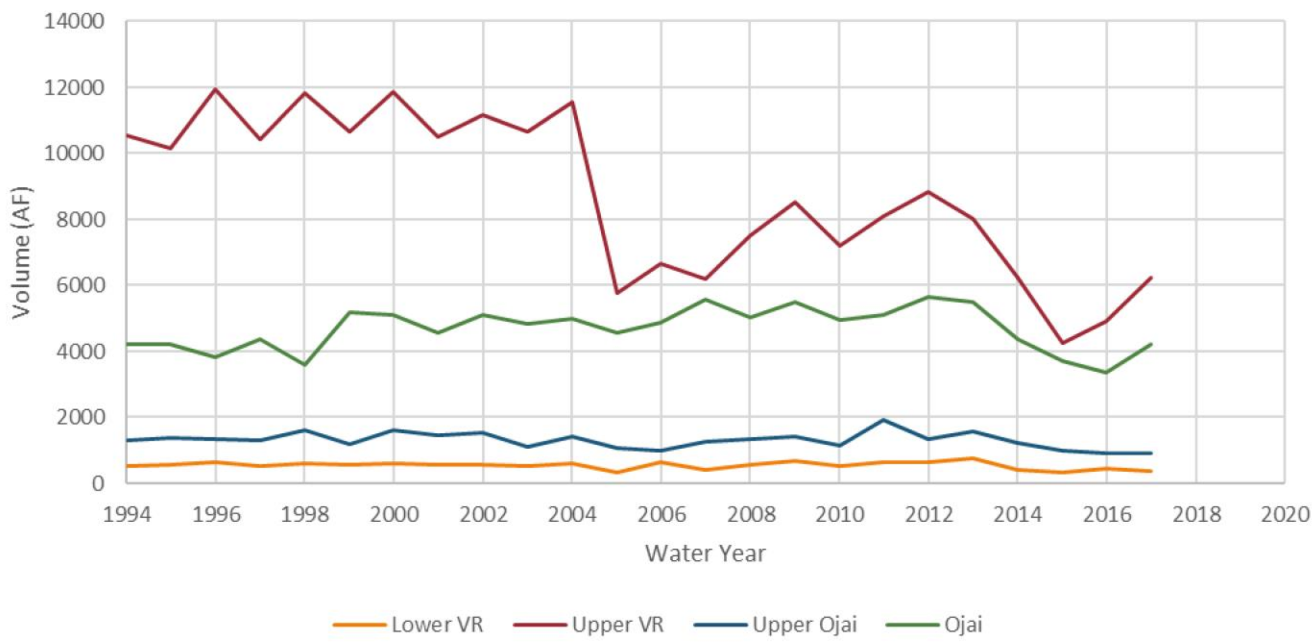
2.6 Cross Checks

Water budget analyses incorporated several assumptions to develop estimates for non-measured groundwater pumping throughout the VRW. Key assumptions included the spatial distribution of CMWD deliveries throughout the VRW, residential per capita rates and crop irrigation rates throughout the watershed, and adjustments of these rates during drought years. The analyses generally used a detailed “bottom up” approach, where assumptions and estimates were made for service areas and Sub-Regions within the watershed to enable detailed spatial estimates of pumping volumes. In the following, the results were cross-checked using a “top down” approach, by comparing to data and reports that are focused on larger spatial scales.

Results of the analyses were aggregated into total pumping volumes for each of the four Bulletin 118 groundwater basins (i.e., Lower Ventura River, Upper Ventura River, Ojai, and Upper Ojai Basins). These are plotted over the modeling period in Figure 2.30. The average pumping volumes in each basin are compared to other sources and estimates as indicated in Table 2.36. The estimates developed in the supply and demand analyses are generally within the range of the other estimates. Notably, the current analyses have a lower average estimate (8,737 AFY) for the Upper Ventura River Basin than the other cited estimates (10,392 AFY) in Table 2.36. This is likely due to the disparity in the time-span analyzed and the large decrease in pumping from Foster Park from 2005 onwards. Prior to 2005 the annual pumping rates calculated from our analyses ranged from approximately 10,000 AFY to 12,000 AFY, and therefore compare similarly to other reports.

A similar table was developed for total agricultural pumping, as shown in Table 2.37. Results of the current analyses in the Lower and Upper Ventura River basins are within the range estimated by considering agricultural demands and by assuming typical pumping rates for agricultural wells.

A key component of the supply and demand analyses was determining the spatial distribution of the CMWD deliveries, and particularly volumes that were used for agriculture, since these have direct implications on the estimates for the non-measured agricultural groundwater pumping. Total volumes for CMWD deliveries to agriculture are available through 2015 in CMWD Urban Water Management Plans (UWMP) (CMWD, 2010, 2015). These could not be used



The large drop in pumping from the Upper Ventura River Basin from 2005 was due to large storm flows damaging pumping infrastructure at Foster Park (City of Ventura Urban Water Management Plan, 2015).

Total Groundwater Pumping by Bulletin 118 Groundwater Basin		
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Figure 2.30 Total Groundwater Pumping by Bulletin 118 Groundwater Basin

Directly, because spatial information on these deliveries were not available. Instead, the results of the current supply and demand analyses were aggregated across the entire VRW and compared to the CMWD data as plotted in Figure 2.31. Results indicate general agreement between the current estimates and the CMWD delivery data. Most estimates fall below the 1:1 line, which is expected since some of the CMWD deliveries to agriculture occur to the crops outside the VRW (i.e., within pressure zone 9, per Figure 2.9).

2.7 Implementation into VRW GSFLOW Model

Results of the above analyses were used to provide specific pumping volumes for non-reported agricultural wells throughout the watershed, except for within the OBGMA area. Annual pumping volumes for each well are provided in Appendix A, Table A.12. Pumping volumes for non-measured domestic wells (based upon an assumption of 0.5 gpm [0.8 AFY]) are also provided in Appendix A, Table A.13.

Section 4.4 provides additional information on the implementation into the VRW GSFLOW Model, as well as a map of the annual average volumes for all wells that were implemented into the model.

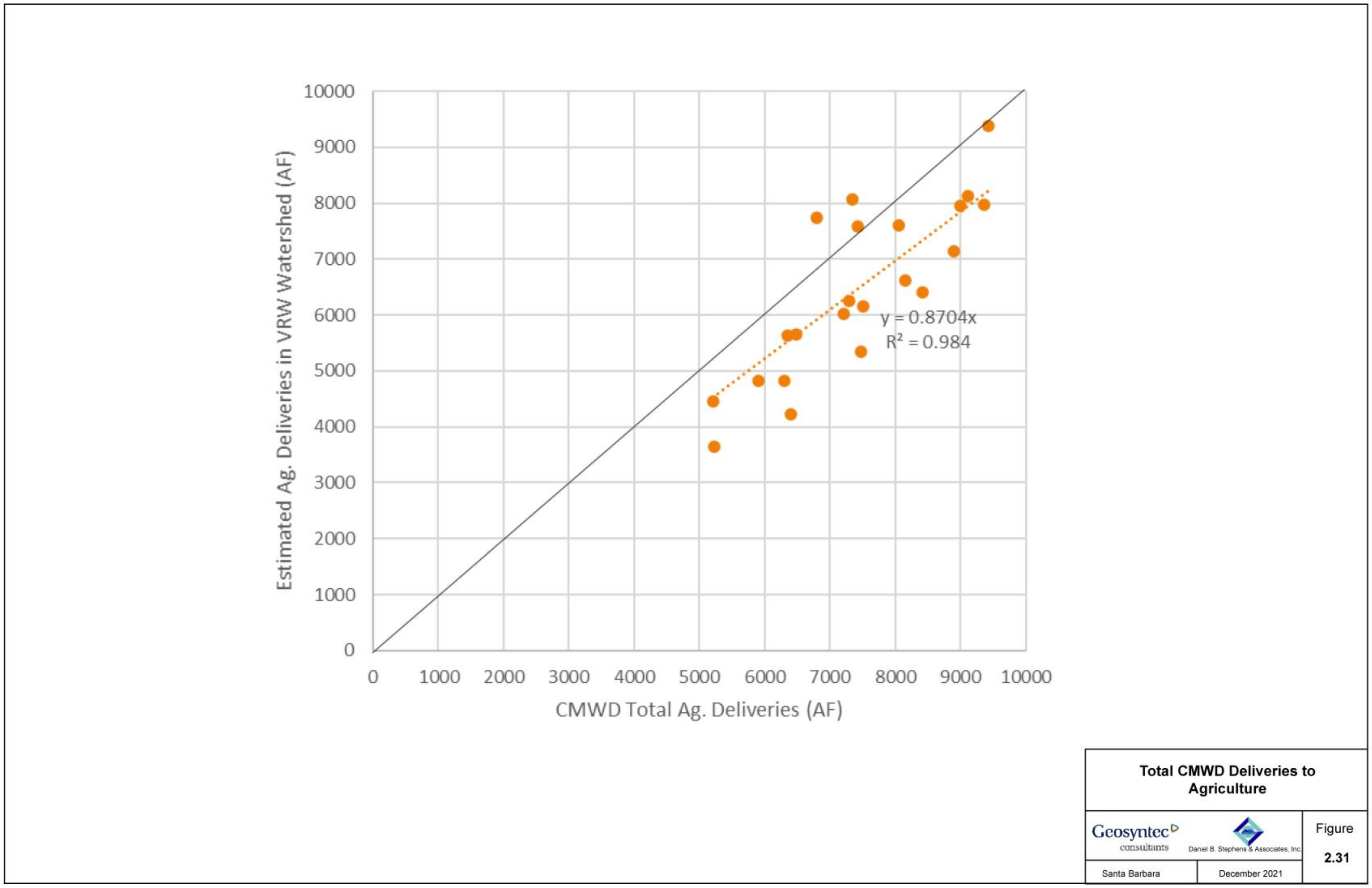

Figure 2.31 Total CMWD Deliveries to Agriculture

3 GSFLOW MODEL – SURFACE WATER

The surface water model component of GSFLOW uses the USGS PRMS Model (Markstrom et al., 2015). Of the hydrologic systems simulated in GSFLOW, PRMS simulates the hydrologic processes in plant canopy and soil zone. These processes include evaporation, transpiration, runoff, infiltration, and inter-flow. The following sections describe the layout and discretization of the PRMS model, the meteorological inputs, the implementation of lakes and reservoirs, diversions from and to streams, transfers to irrigation, and determination of PRMS model parameters.

3.1 Model Layout, Discretization, and Stream Network

The PRMS model uses gridded HRUs, rather than the more traditional polygonal based HRUs, such that the grid matches the underlying MODFLOW grid. Because HRUs and MODFLOW grid cells coincide with each other, HRUs and cells are used interchangeably throughout the document. The model grid covers the entire VRW, with approximately 114,000 model cells of 330-foot grid cell size. This includes approximately 56,000 land cells, 1,000 lake cells, and 57,000 inactive cells that are outside of the VRW. The land and lake cells are further organized into 12 sub-basins, with 10 of the sub-basin outlets corresponding to active streamflow gage locations (Figure 3.1).

The terrain dataset (Figure 3.2) used for developing the model consists of the USGS digital elevation model (USGS, 2018), supplemented with 2005 lidar (light detection and ranging) data provided by the VCWPD (VCWPD, 2005). The USGS Cascade Routing Tool (Henson et al., 2013) was used in conjunction with the terrain dataset to define the cascading surfaces for the model domain. The terrain dataset was also used to develop the model stream network shown in Figure 3.3 The stream network was edited to match the National Hydrography Dataset (NHD) Plus High Resolution (USGS, 2017) flowlines as closely as possible within the constraints of the 330-foot grid cell size.

3.2 Meteorological Inputs

Meteorological inputs to the model consist of daily precipitation and daily minimum and maximum temperature. Daily precipitation data from 23 rain gages (Figure 3.4) were processed to fill gaps. The gap-filling process for gages with missing data involved using data from the nearest available rain gage that was then scaled based upon comparison of the overlapping records

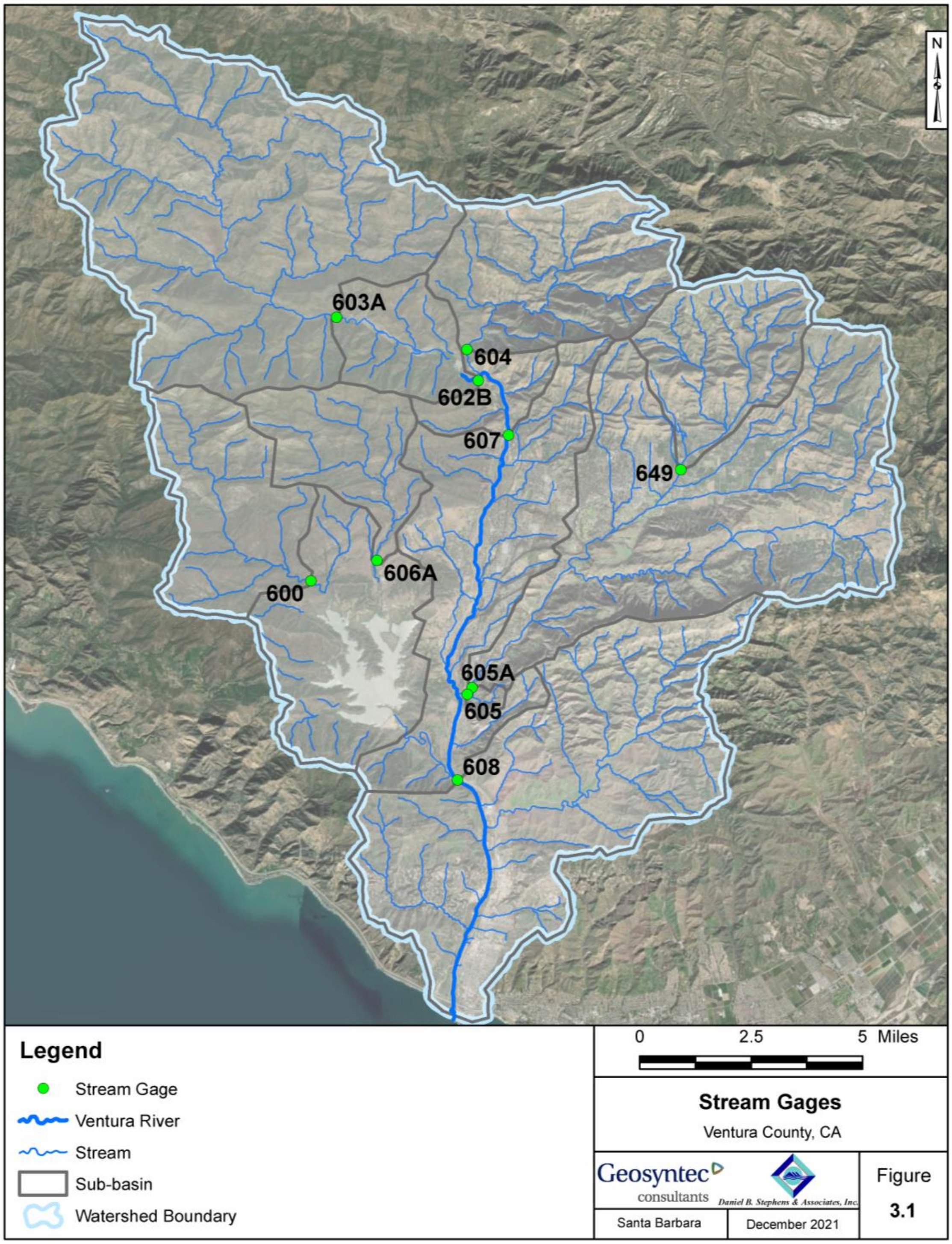

Figure 3.1 Stream Gages

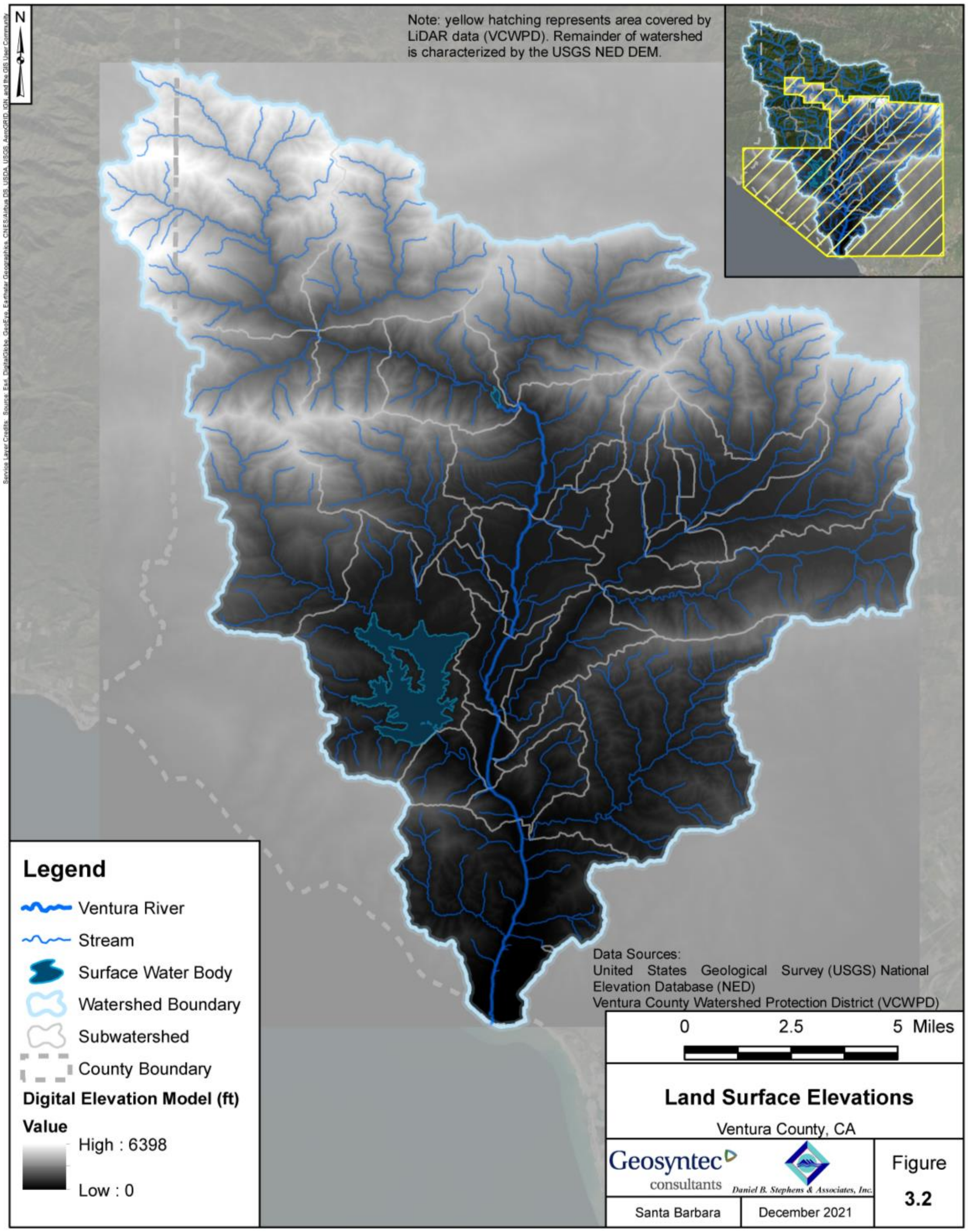

Figure 3.2 Land Surface Elevations

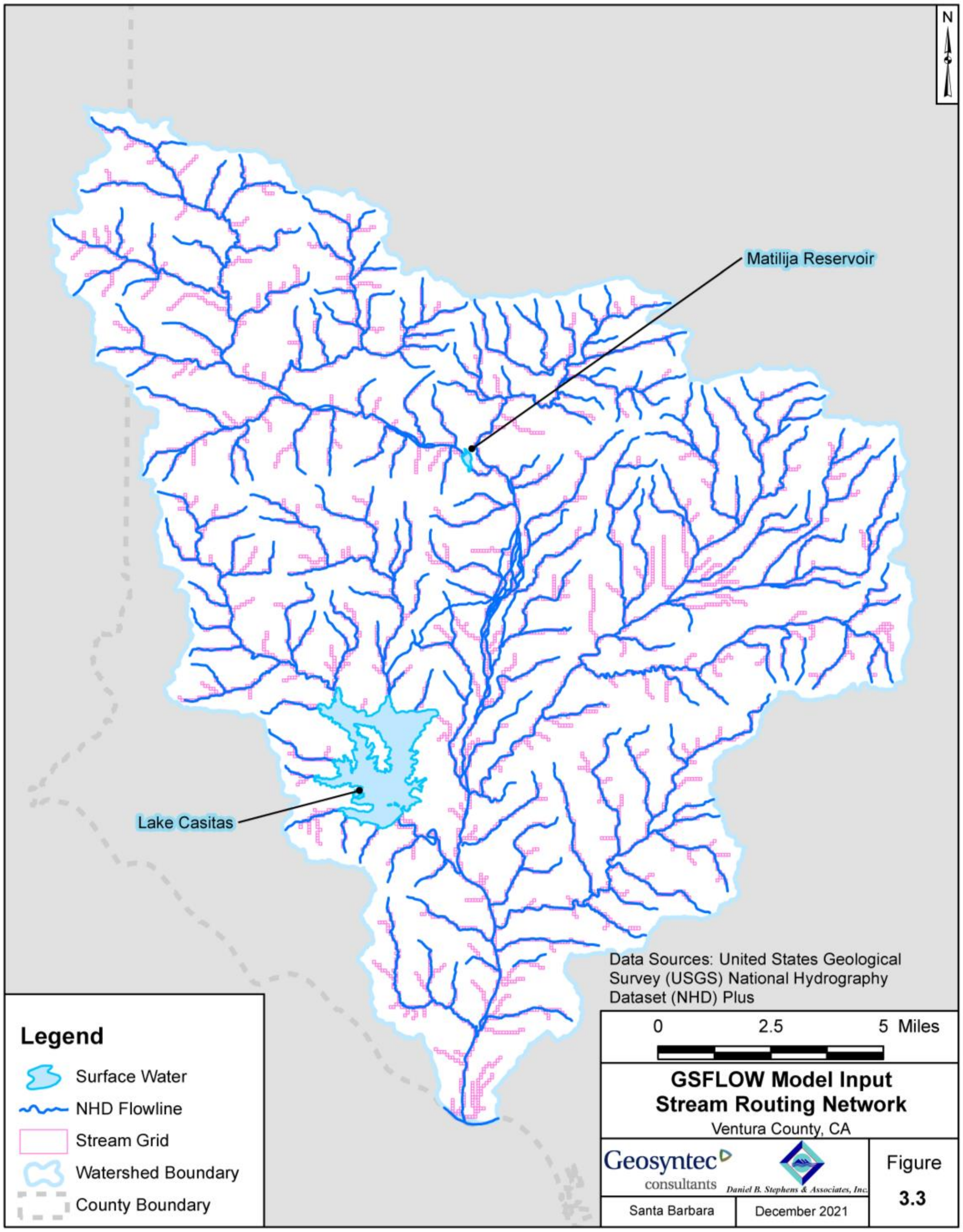

Figure 3.3 GSFLOW Model Input Stream Routing Network

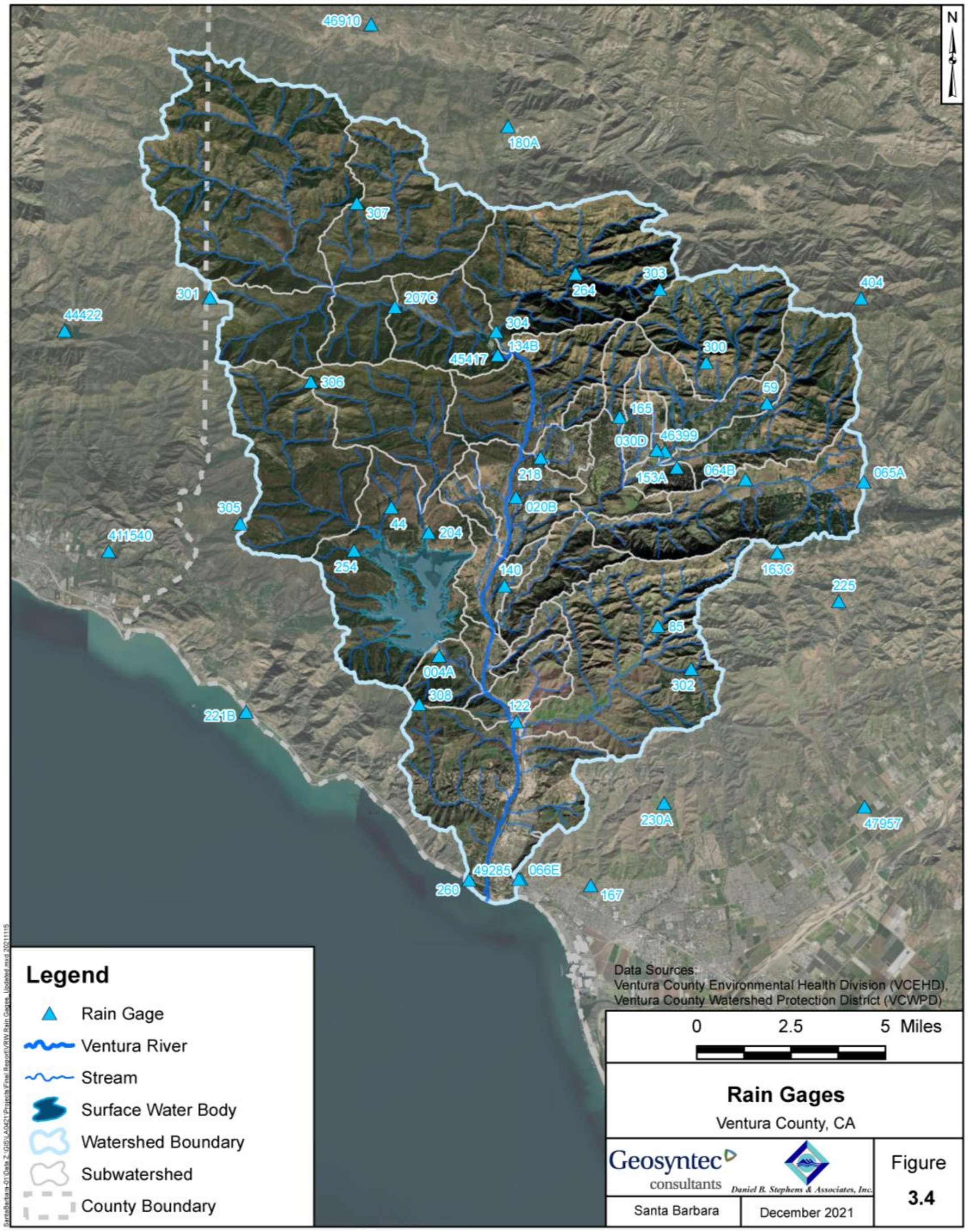

Figure 3.4 Rain Gages

between the two gages. Plots of the raw and processed data are provided in Appendix B[15].

The daily filled precipitation data were interpolated spatially onto each grid cell using Parameter-elevation Relationships on Independent Slopes Model (PRISM) dataset (PRISM, 2012). The spatial PRISM dataset includes orographic effects and provides additional detail in high-elevation regions of the watershed where there are fewer gages (Figure 3.5). The PRISM 30-year normals (1981-2010) within Thiessen polygons constructed around gage locations (Figure 3.5) were scaled on a daily basis and used as model input such that the daily rain depth at each gage location was replicated.

Temperature inputs consist of daily minimum and maximum temperature obtained from 13 weather stations in and near the VRW (Figure 3.6). The temperature data are spatially distributed onto the model grid cells using the PRMS ‘temp_dist2’ temperature distribution module. The temp_dist2 module distributes temperature from the weather stations to the model cells by computing weights based on lapse rates and the inverse of the square of the distance between the centroid of the HRU and the location of the weather stations.

3.3 Lakes and Reservoirs

Lake Casitas and Matilija Reservoir (Figure 1.3) were simulated as Lake HRUs in PRMS. Lake Casitas bathymetry was implemented into the model using data from a 2017 survey (Tetra Tech, 2017). Outflows from Lake Casitas were modeled as overflows over the dam crest into a downstream stream segment that represents the Coyote Spillway. Additional withdrawals from the lake to the CMWD distribution system were implemented as described in Section 3.5.3.

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[15] Appendices A through F are not embedded in this document. The appendices are presented in companion files. Appendices B through F are compiled in two PDF files. The appendices are include in the zip folder for this model report and are available for download on the State Water Board’s California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/

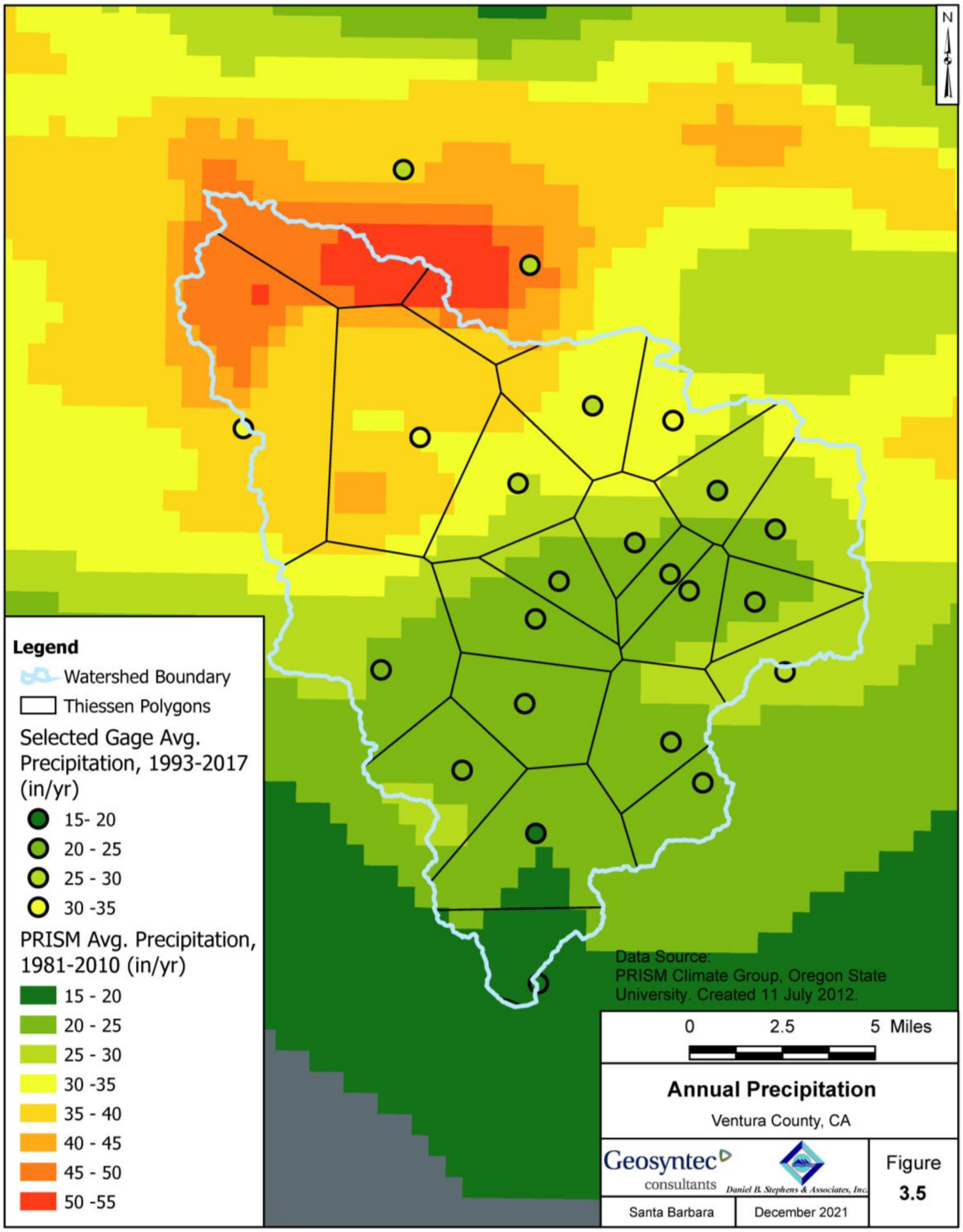


Figure 3.5 Annual Precipitation

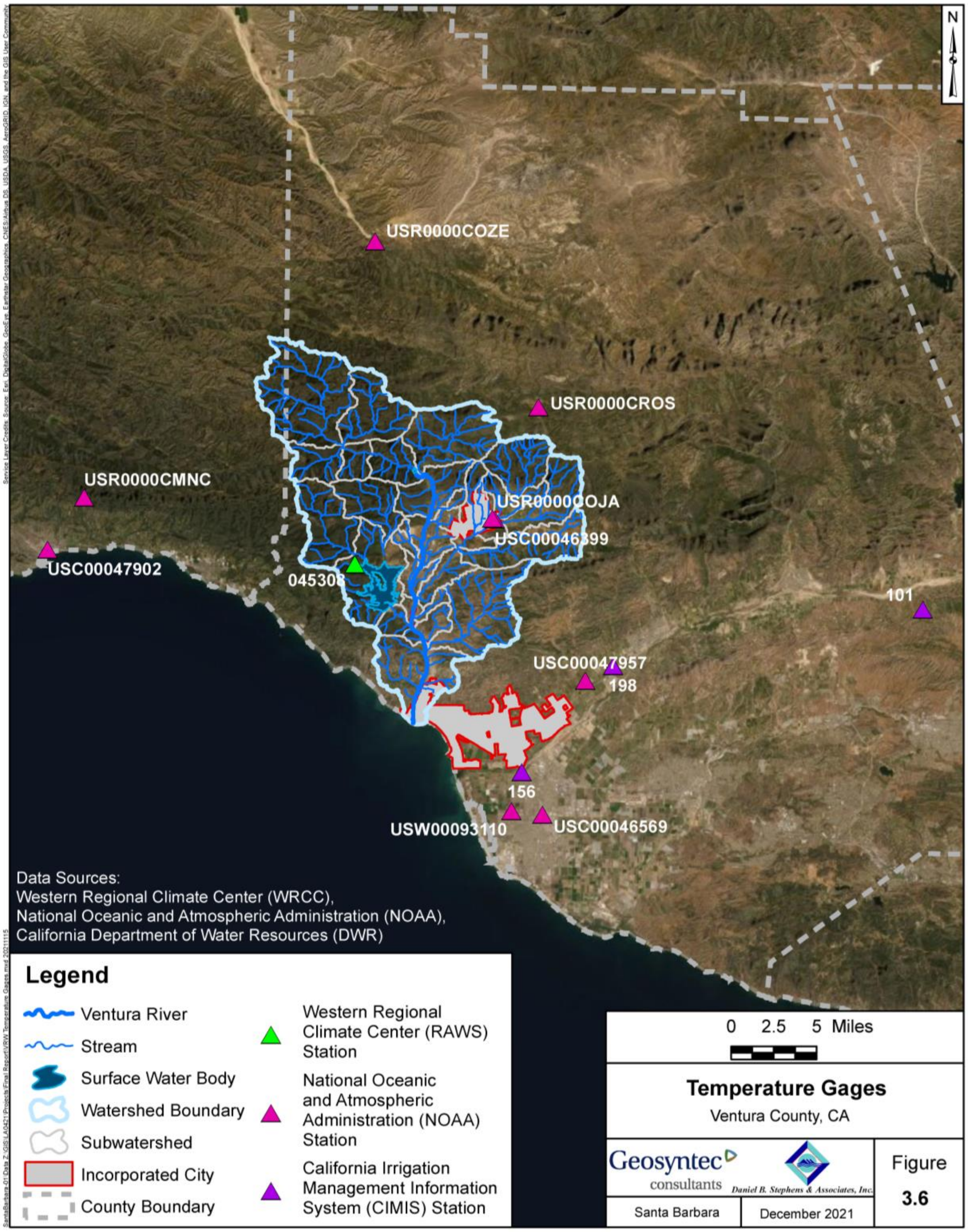


Figure 3.6 Temperature Gages

When constructed in 1947, Matilija Reservoir originally had an active storage volume of 7,000 AF. However, due to sedimentation and lowering (or 'notching') of the dam, the active volume has decreased substantially as indicated Table 3.1. Over the modeling period, the active storage volume at full pool decreased from 930 AF to 270 AF. This changing storage capacity during the modeling period is not implemented into the model. In the model, the elevations of the lake cells were lowered to create a volume of 1,503 AF with a spillway elevation of 1,095 ft based on information on from the Ventura County Watershed Protection District (VCWPD, 2019). Although this is not consistent with information in Table 3.1, the effect in the model is primarily to increase dead storage with anticipated negligible effects on streamflow.

Outflows from Matilija Reservoir were modeled as a combination of overflows over the dam crest and specified releases (Section 3.5.1), each into a downstream stream segment representing the dam spillway.

3.4 Diversions and Transfers

The following section summarizes the implementation of diversions of surface water from streams, releases from Matilija Reservoir, Robles Canal diversions, Casitas withdrawals, inflow from OVSD WWTP, and irrigation of crops.

3.5 Surface Water Diversions

Surface water diversions are located throughout the watershed as indicated in Figure 2.13. The eWRIMS self-reported volume data were analyzed to determine which of the diversions were active during the modeling period, and these were implemented into the model (Table 3.2) (SWRCB, 2018a). The SCMWC water tunnel was modeled as a series of wells in the bedrock. The remaining diversions were modeled as diversions from the streams at the maximum allowed flow rate in specified months of the year, as determined from eWRIMS and as summarized in Table 3.2. It is noted that much of the time, the streamflow rates may be less than the specified diversion rate, and that full diversions are not possible.

Table 3.1 Matilija Active Storage Volume (acre-ft)

Elevations (NAVD88)	1970	1983	1994	2002 estimated	2018	2019
1042.6	14.2	0	0	0	0	0
1047.6	93	0	0	0	0	0
1052.6	219	0	0	0	0	0
1057.6	367	0	0	0	0	0
1062.6	533	57	0	0	0	0
1067.6	724	172	0	0	0	0
1072.6	947	305	39	0	0	0
1077.6	1199	468	153	0	0	0
1082.6	1479	662	283	0	0	0
1087.6	1789	906	447	24	0.35	0
1092.6	2121	1190	666	250	138	28.75
1097.6	2473	1480	930	500	270	149.1

NAVD = North American Vertical Datum

Source: Marotto pers. comm. (2020)

Table 3.2 Surface Water Diversions[1]

POD ID	App ID	Owner	Maximum Diversion Flow Rate (cfs)	Diversion Months
22124	S015366	Senior Canyon Mutual Water Company	0.67	Jan - Dec
22125	S015367	Senior Canyon Mutual Water Company	0.67	Jan - Dec
34704	A006399	Senior Canyon Mutual Water Company	n/a[2]	Jan - Dec
3277	A006294	Topa Topa Ranch Company LLC	0.4	May - Nov
6812	A027762	Michael Cromer	0.369	Nov - Apr
37758	A006521	Michael Cromer	0.33	Jun - Oct
40619	A012557	USDA Los Padres National Forest	0.05	Jan - Dec
38032	A017929	USDA Los Padres National Forest	0.05	Jan - Dec
27287	A012297	Jerry Kenton	0.027	Jan - Dec
15438	A026086	Earl G. Holder	0.017	Jan - Dec
6903	A028074	Calvin Zara	0.0046	Dec - Mar
23428	A017621	Ernest L. Ford	0.0035	Jan - Dec
17496	A012443	Dorothy Webb Holmes	0.0023	Jan - Dec
24044	A019802	Duncan H. Abbott	0.001	Jan - Dec
41563	A019811	U.S. Forest Service, Los Padres National Forest	0.0005	Jan - Dec
8872	A014267	USDA Los Padres National Forest	0.000155	Jan - Dec

App ID = application identification number (for a water right or statement of diversion and use)
cfs = cubic feet per second
POD ID = point of diversion identification number (for a water right or statement of diversion and use)
USDA = U.S. Department of Agriculture
Source: SWRCB (2018a)
1. Surface water diversions do not include releases from Matilija Reservoir or withdrawals from Lake Casitas, which are discussed in Section 3.4.2 and 3.4.4, respectively.

2. n/a = not applicable. This diversion represents the Senior Canyon Mutual Water Company (SCWMC) water tunnel and does not have a maximum allowable flow rate. The water tunnel is modeled as a series of wells with assigned pumping rates and the resulting overall withdrawal rate depends upon hydraulic heads and conductivities in the surrounding bedrock.

3.5.1 Matilija Releases

The Matilija Reservoir was implemented in the model to pass upstream flows with a spillway at 1,095 ft elevation (Section 3.3). Historically, the CMWD would also release water from Matilija Reservoir to enable additional diversions downstream through the Robles Canal to Lake Casitas. Information on these releases is limited and had to be estimated for the modeling period.

Reservoir elevation data were available from July 2003 onwards and these were used with the stage-storage information from 2002 (Table 3.1) to estimate daily release volumes. Prior to July 2003, the releases were estimated by correlating streamflow data from Gage 602B (downstream of Matilija Reservoir) and Gage 604 (North Fork Matilija Creek, and not subject to releases) to identify periods of releases and estimate release rates. These estimates were capped at 150 cubic feet per second (cfs), based on outlet capacity. The resulting releases implemented into the model are plotted in Figure 3.7. The figure indicates minimal releases since 2011, possibly because of sedimentation.

3.5.2 Robles Canal Diversions

Diversions from Ventura River to Lake Casitas through the Robles Canal were implemented as a diversion from the relevant stream segment in SFR (see Figure 1.6 for the diversion location) to the lake. Daily diversion flow volumes are plotted in Figure 3.8.

3.5.3 Casitas Withdrawals

Annual withdrawal volumes from Lake Casitas were calculated by subtracting pumping volumes from the CMWD Mira Monte well from the total CMWD deliveries provided in Table 2.6. These volumes were further split into residential and agricultural volumes as part of the supply and demand analyses in Section 2. Monthly residential and agricultural demand factors were then applied to these annual volumes to develop monthly estimates of residential and agricultural deliveries, as plotted in Figure 3.9. These were then summed together and implemented into the model as transfers from the lake. The transfers were removed from the model, since the deliveries are represented elsewhere through applied irrigation, flows to OWTS, flows to the WWTP, and consumptive use.

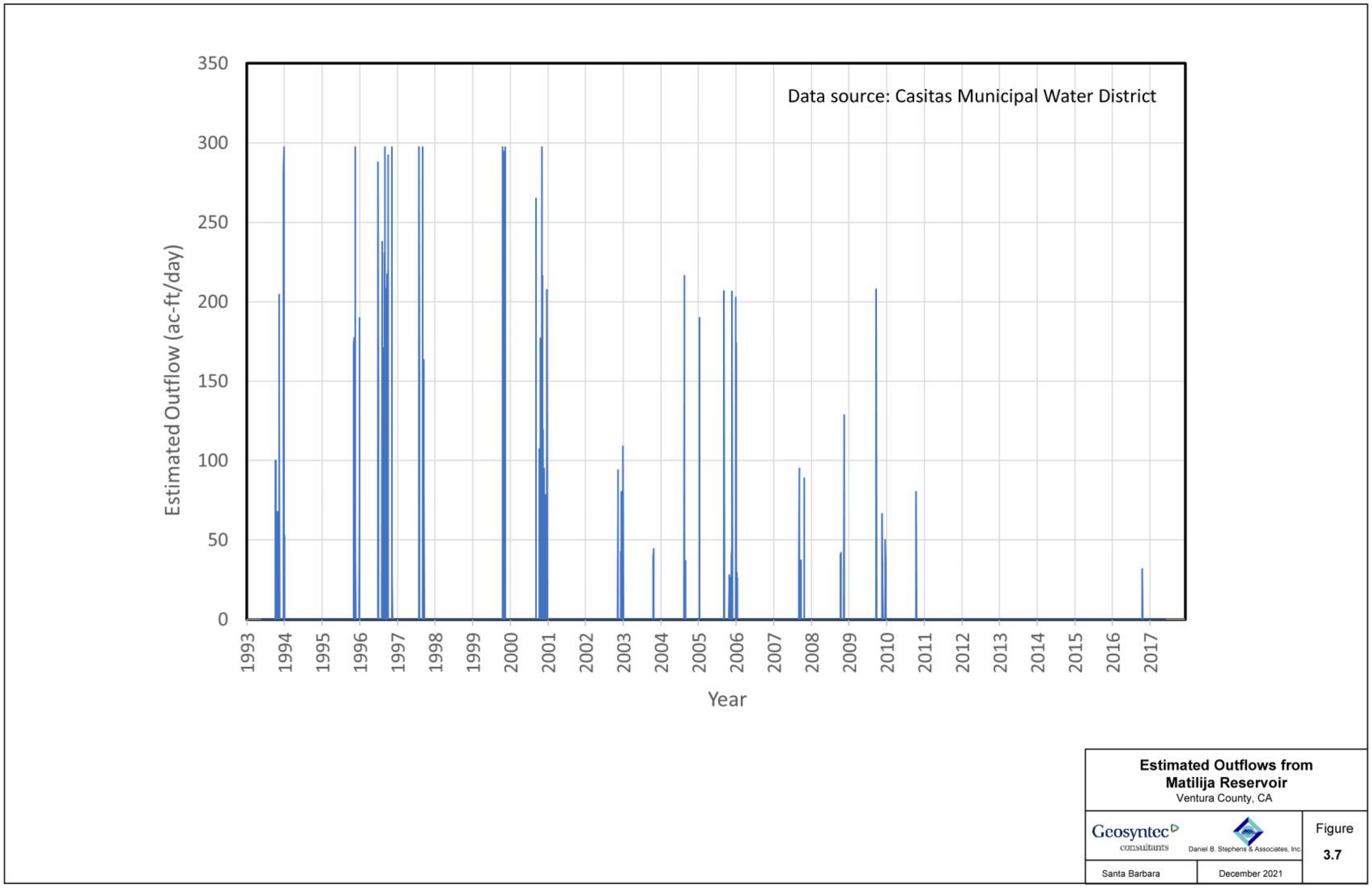


Figure 3.7 Estimated Outflows from Matilija Reservoir

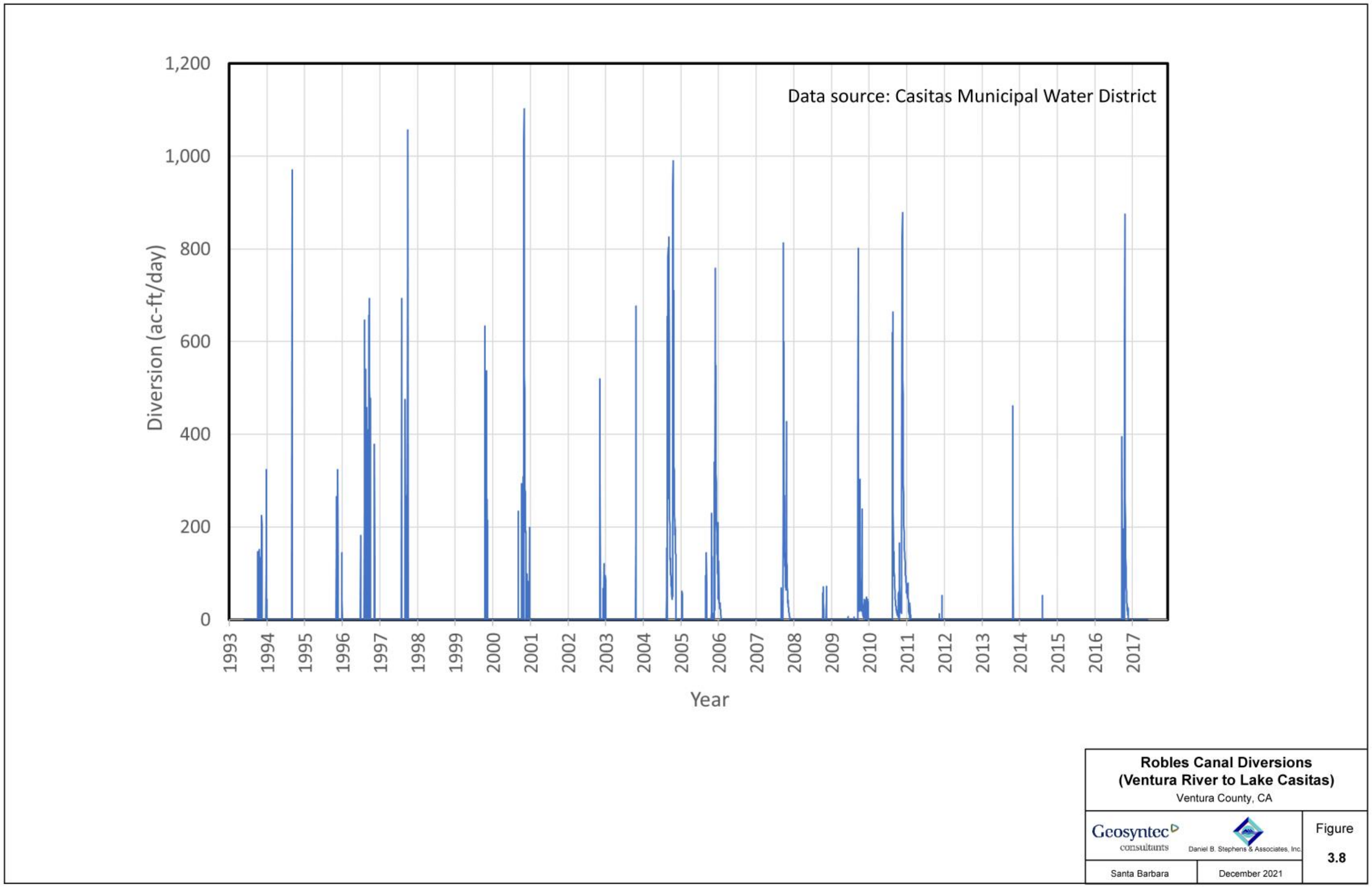
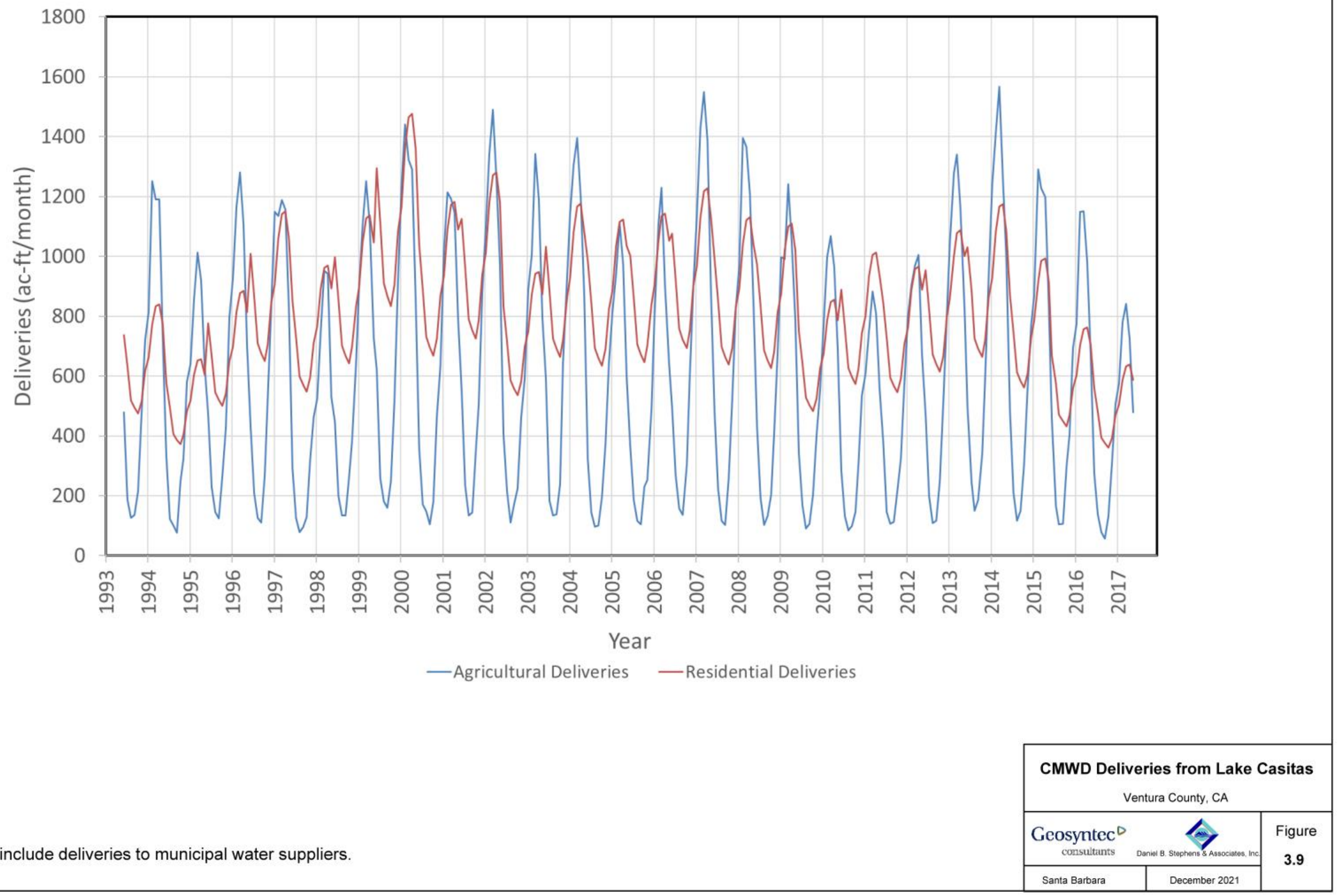


Figure 3.8 Robles Canal Diversions (Ventura River to Lake Casitas)



Note: Deliveries include deliveries to municipal water suppliers.

Figure 3.9 CMWD Deliveries from Lake Casitas

3.5.4 Ojai Valley Sanitation Discharges

Inflows to Ventura River from the Ojai Valley WWTP were implemented using SFR as inflows to the relevant stream segment (see Figure 1.6 for the inflow location). Inflow rates are plotted in Figure 3.10 and consist of available daily flow rates for 2006-2015, which were supplemented for the other years with representative monthly average flow rates calculated from the available data.

3.5.5 Irrigation

Annual estimates for irrigation rates to different crop categories and golf courses were developed in Section 2 (Table 2.5). These were split into monthly estimates using agricultural demand factors and implemented into the model using the PRMS "water_use_read" module. This module adds the capability to account for redistribution of water on the basis of water availability at storage locations internal and external to the model domain by using a time series of values (Regan and LaFontaine, 2017). Irrigation water is applied as transfer gain to the plant canopy of each model cell based on a supplied time series of transfer flow rates. Crop irrigation was applied daily, with values varying monthly and from year to year (per the estimates developed in Section 2 (Table 2.5).

Irrigation was also applied in urban areas to represent residential outdoor water use. A rate of 1.44 AF/acre/year was applied based on the average value from a study for Los Angeles (Mini et al., 2014). This was further multiplied by fractional coverages ranging from 0.33 to 0.72, depending upon the density of urban development.

The average annual[16] irrigation transfer depth (i.e., average depth of irrigated water applied in a year) is shown in Figure 3.11. The figure illustrates higher application rates where crops are located (compare to Figure 2.5), lower rates in the urban areas, and no irrigation in undeveloped areas.

[16] The average annual rates are shown for illustrative purposes only. The rates applied to crops vary annually as indicated in Table 2.5.

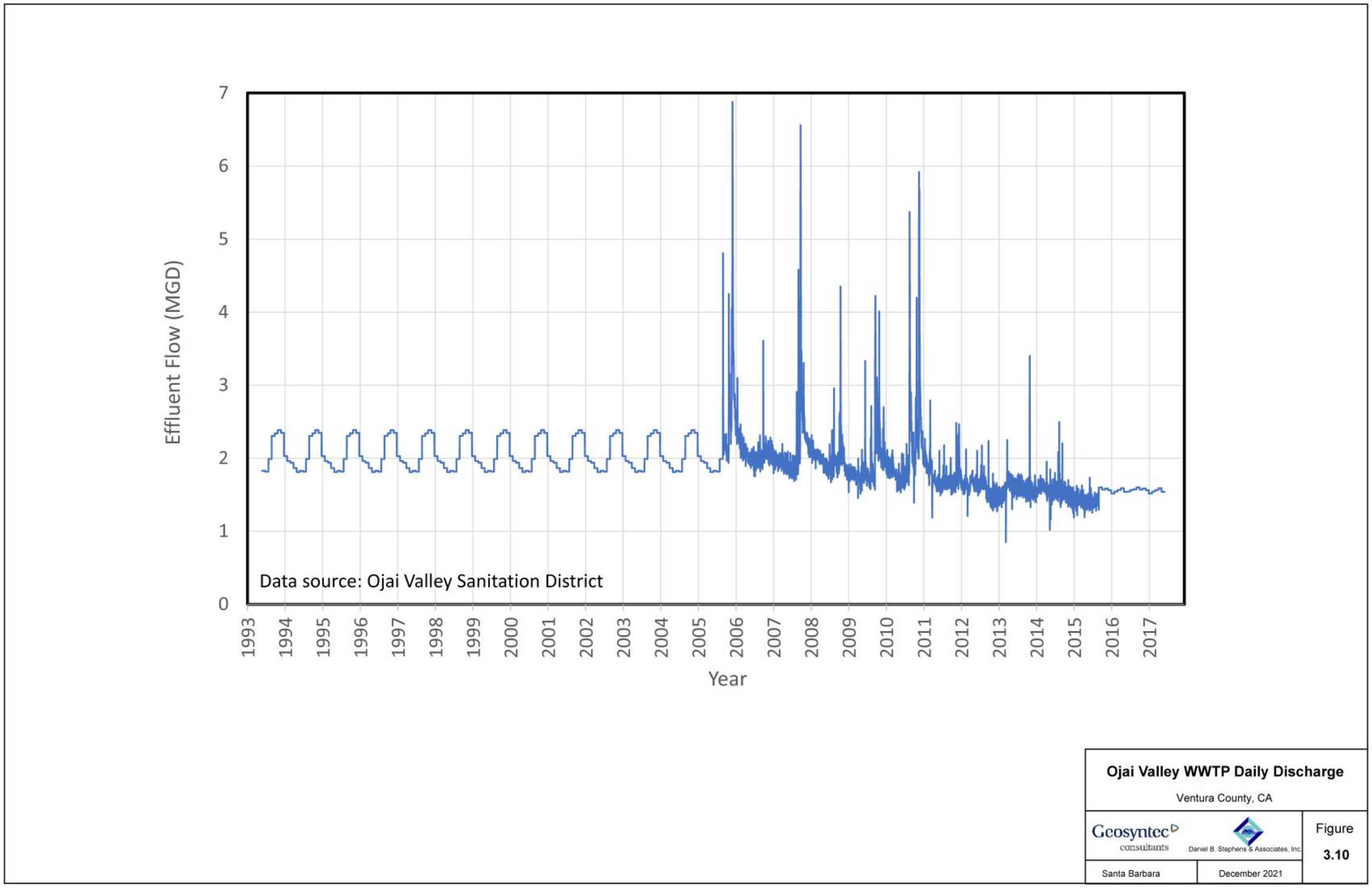


Figure 3.10 Ojai Valley WWTP Daily Discharge

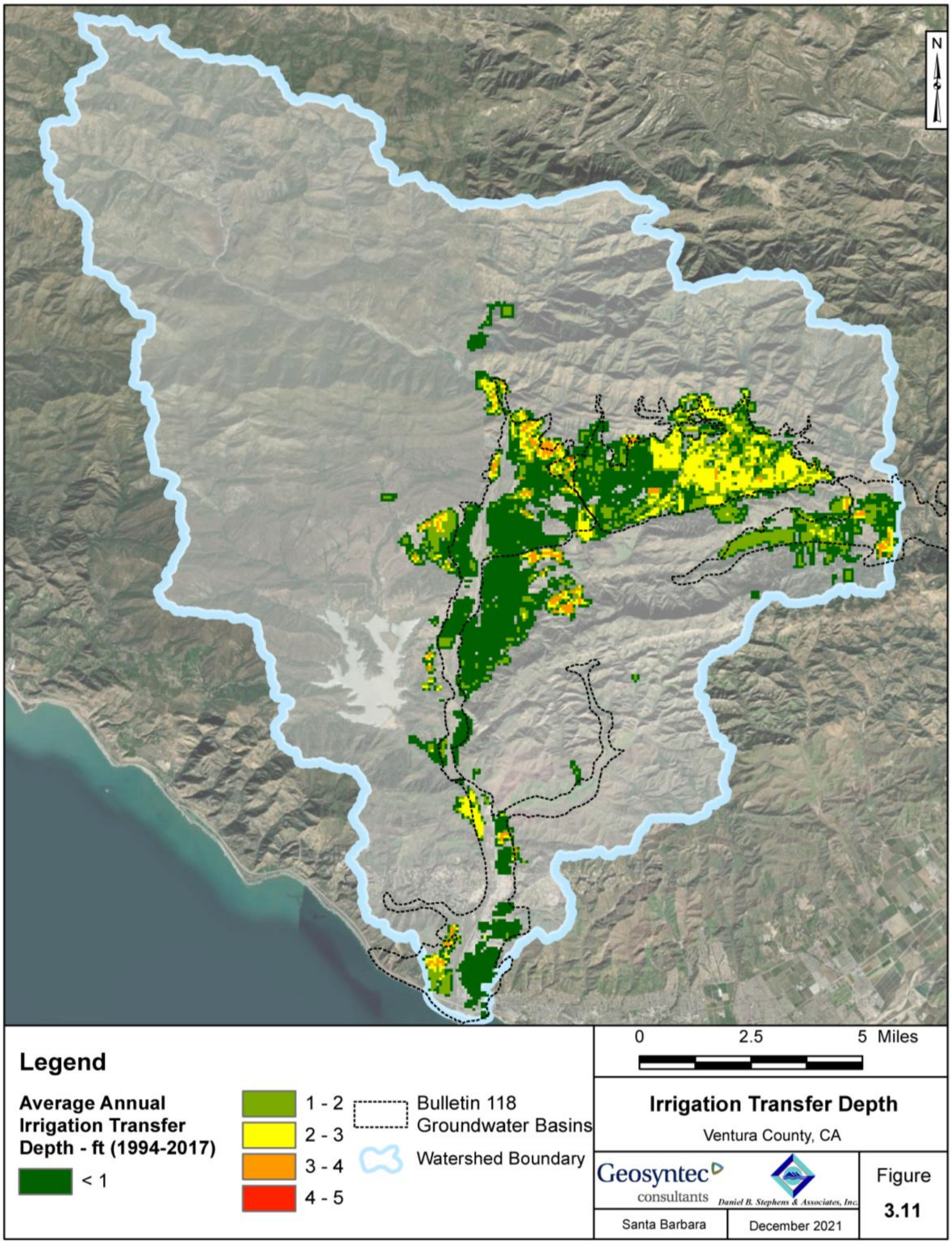


Figure 3.11 Irrigation Transfer Depth

3.6 Model Parameters

The PRMS model requires many model parameters related to soil and hydrological processes to be defined. The key parameters are presented and described briefly in Table 3.3. Additional descriptions are available in the PRMS Manual (Markstrom et al., 2015). Many of the parameters are “distributed,” meaning values are required for each grid cell within the domain.

Initial estimates for watershed model parameters were calculated using various input datasets and a Python- and ArcGIS-based toolkit, GSFLOW-Arcpy (Gardner et al., 2018). GSFLOW-Arcpy provides scripts for model parameterization, including stream network development, land coverage and meteorological distribution, and Parameter File construction. The inputs required for each parameter are summarized in Table 3.3 and include watershed-wide spatial data for percent impervious, vegetative cover, soil depth, saturated hydraulic conductivity, available water content, percent sand, percent silt, and percent clay. These datasets were obtained from the U.S. Forest Service (USFS) and USGS LANDFIRE dataset (LANDFIRE, 2014), National Land Cover Dataset (NLCD) (NLCD, 2011), and U.S. Department of Agriculture (USDA)/National Resources Conservation Service (NRCS) Soil Survey Geographic Database (SSURGO) (Soil Survey Staff, 2018). Maps of the datasets are provided in Figure 3.12 through Figure 3.19.

The initial parameter estimates developed using the GSFLOW-Arcpy scripts were then adjusted as part of the model calibration process (see Section 5.3.1).

Table 3.3 Summary of PRMS Parameters and Input Datasets

Parameter Name	Units	Description	Input Datasets
soil_moist_max	inches	Maximum available water holding capacity of capillary reservoir from land surface to rooting depth of the major vegetation type of each HRU	Maximum rooting depth, available water capacity
sat_threshold	inches	Water holding capacity of the gravity and preferential flow reservoirs; difference between field capacity and total soil saturation for each HRU	Maximum rooting depth, available water capacity
ssr2gw_rate	inches/day	Linear coefficient in equation used to route water from the gravity reservoir to the ground water reservoir for each HRU	Underlying geology[1]
carea_max	decimal fraction	Maximum possible area contributing to surface runoff expressed as a portion of the HRU area	% imperviousness
hru_percent_imperv	decimal fraction	Fraction of each HRU area that is impervious	% imperviousness
slowcoef_lin	fraction/day	Linear coefficient in equation to route gravity-reservoir storage downslope for each HRU	Saturated hydraulic conductivity, slope
slowcoef_sq	none	Non-linear coefficient in equation to route gravity reservoir storage downslope for each HRU	Saturated hydraulic conductivity, slope, % sand, maximum rooting depth, available water capacity
smidx_coef	decimal fraction	Coefficient in non-linear contributing area algorithm for each HRU	GSFLOW-Arcpy default value

Parameter Name	Units	Description	Input Datasets
smidx_exp	1/inch	Exponent in non-linear contributing area algorithm for each HRU	GSFLOW-Arcpy default value

GSFLOW = Groundwater and Surface-water Flow

HRU = hydrologic response unit

PRMS = Precipitation-Runoff Modeling System

1. Estimates for the ssr2gw_rate were determined from the underlying geological information, rather than from the GSFLOW-Arcpy scripts. Rates in more permeable zones (e.g., alluvium and beach deposits) were assigned higher rates than low permeability zones (e.g., shale and claystone). Initial estimates for rates were then adjusted during model calibration (Section 5).

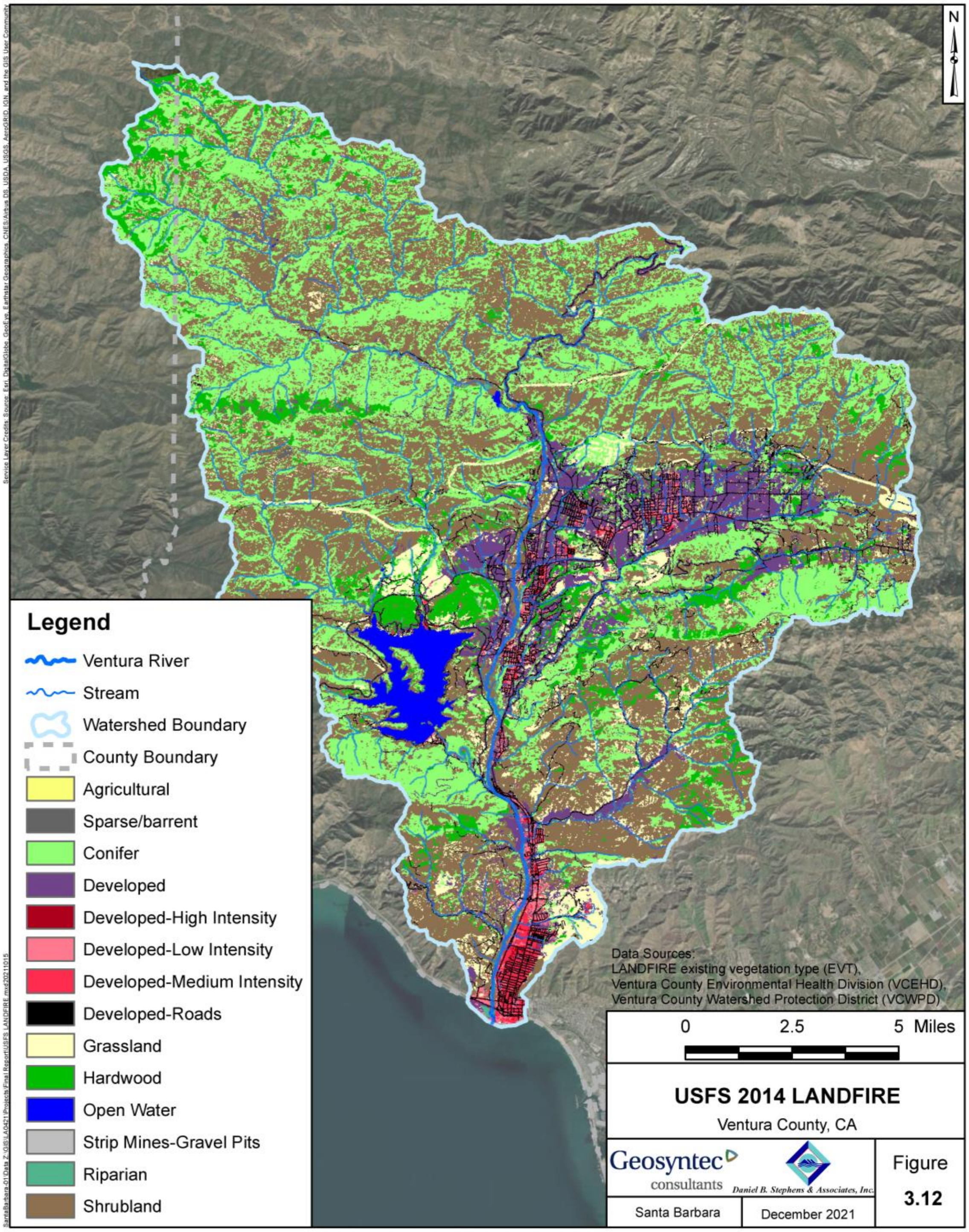


Figure 3.12 USFS 2014 LANDFIRE

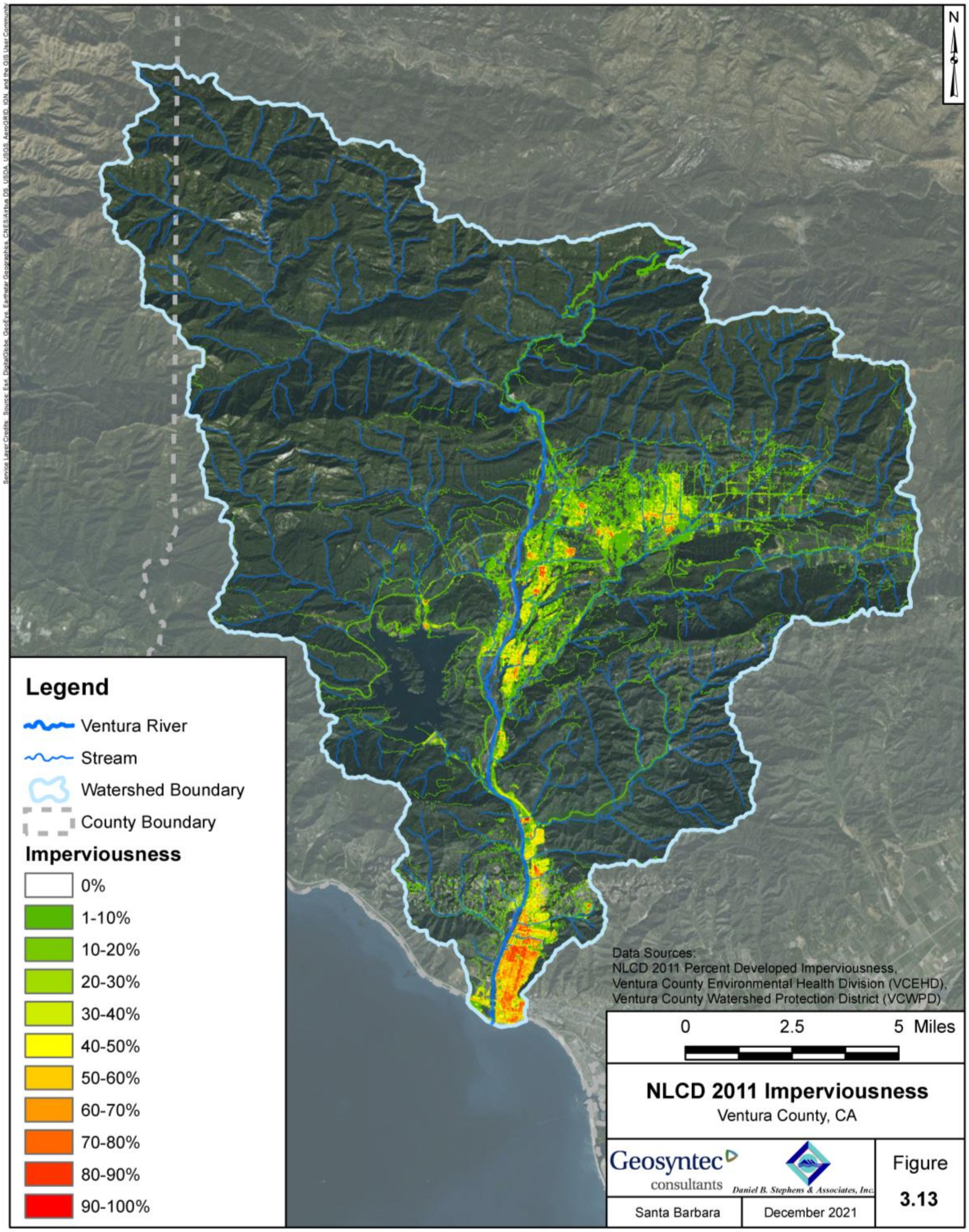


Figure 3.13 NLCD 2011 Imperviousness

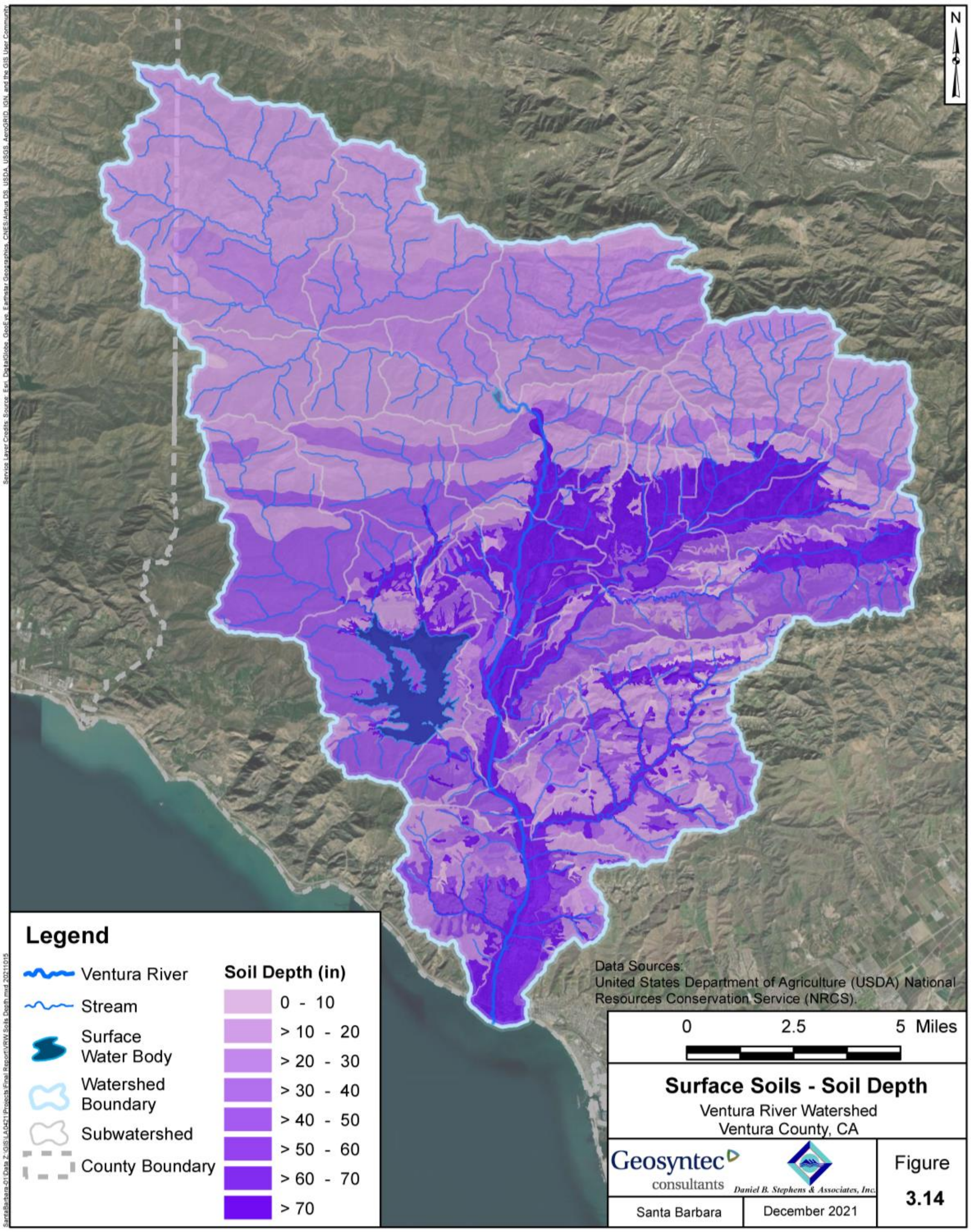


Figure 3.14 Surface Soils – Soil Depth

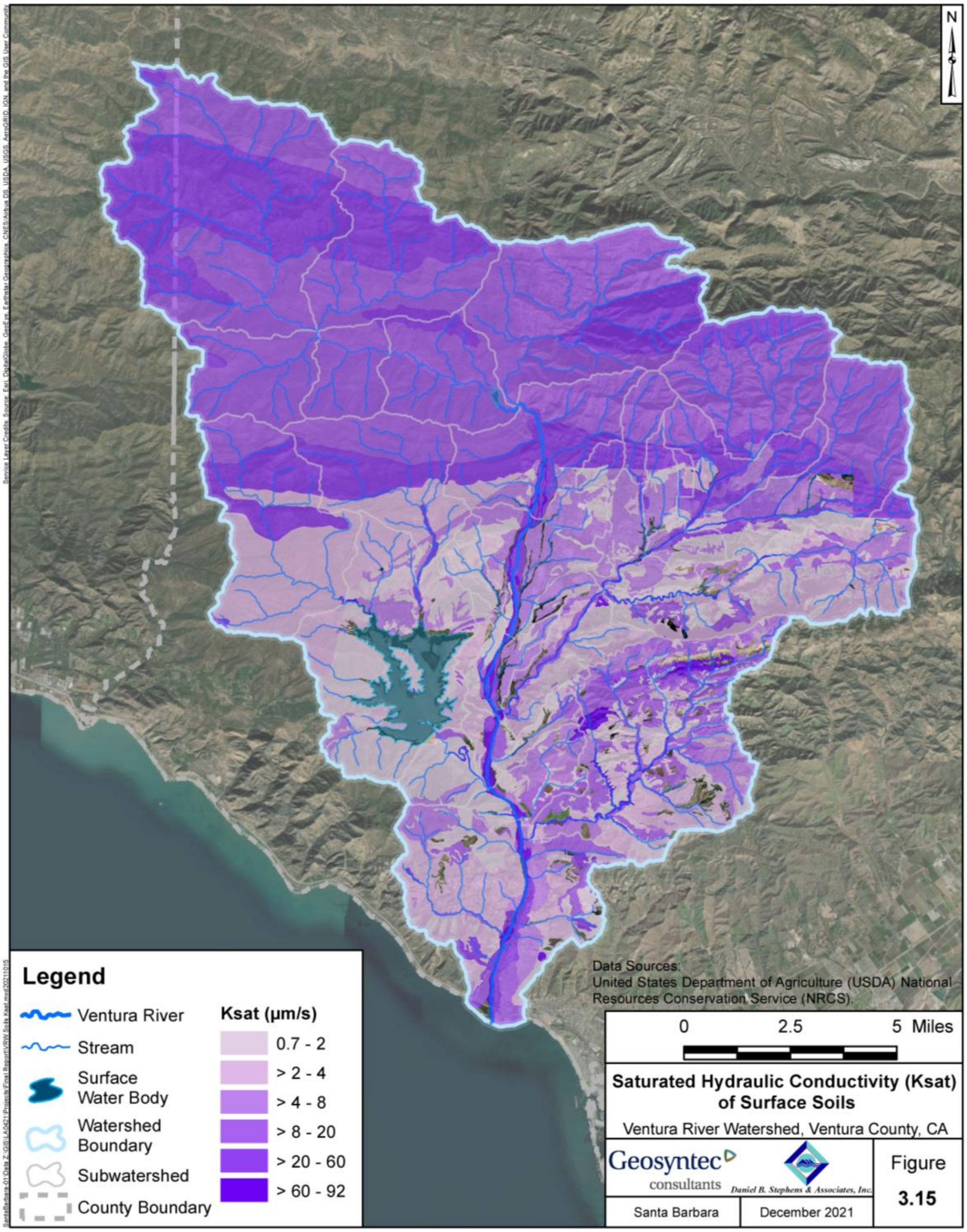


Figure 3.15 Saturated Hydraulic Conductivity (Ksat) of Surface Soils

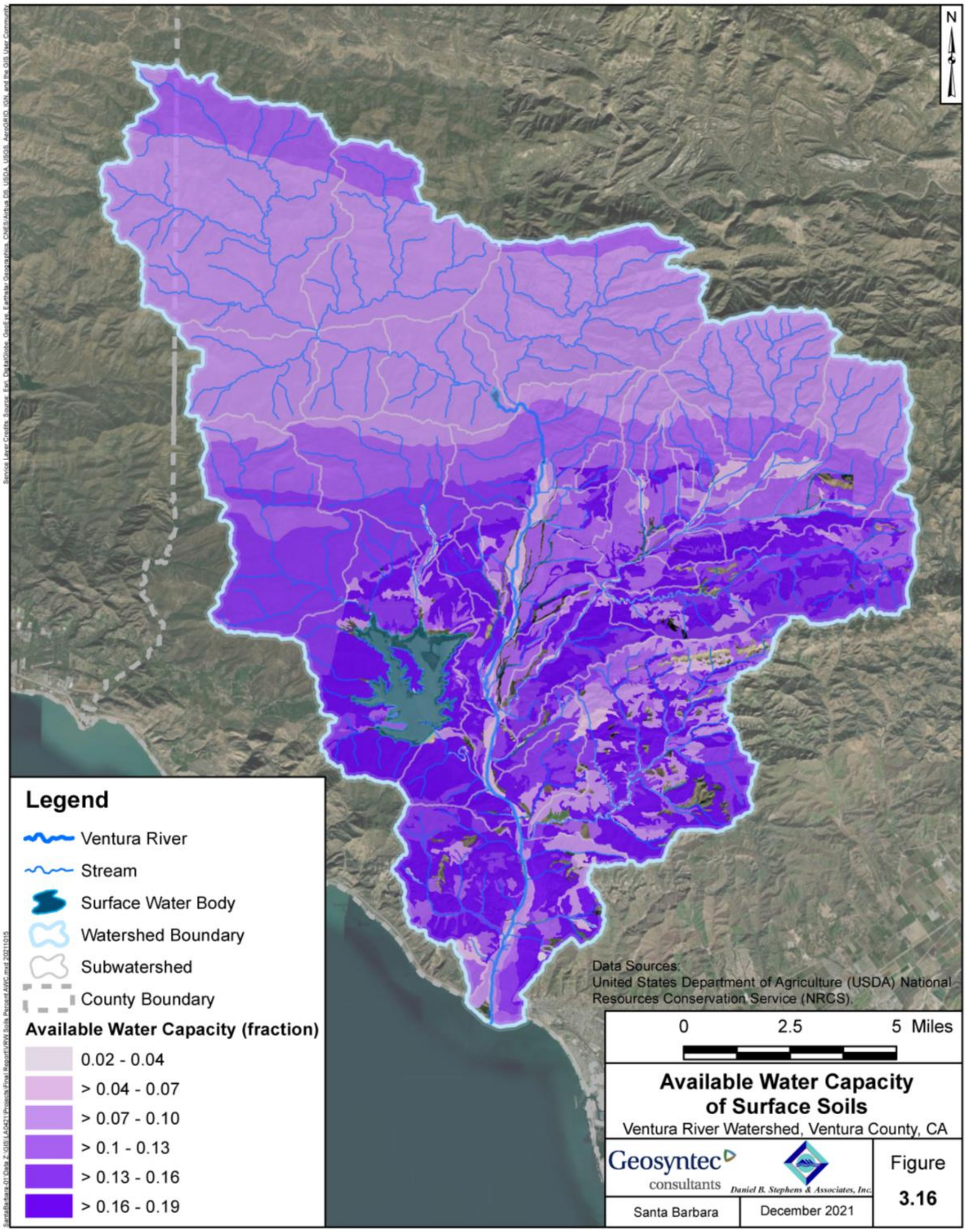


Figure 3.16 Available Water Capacity of Surface Soils

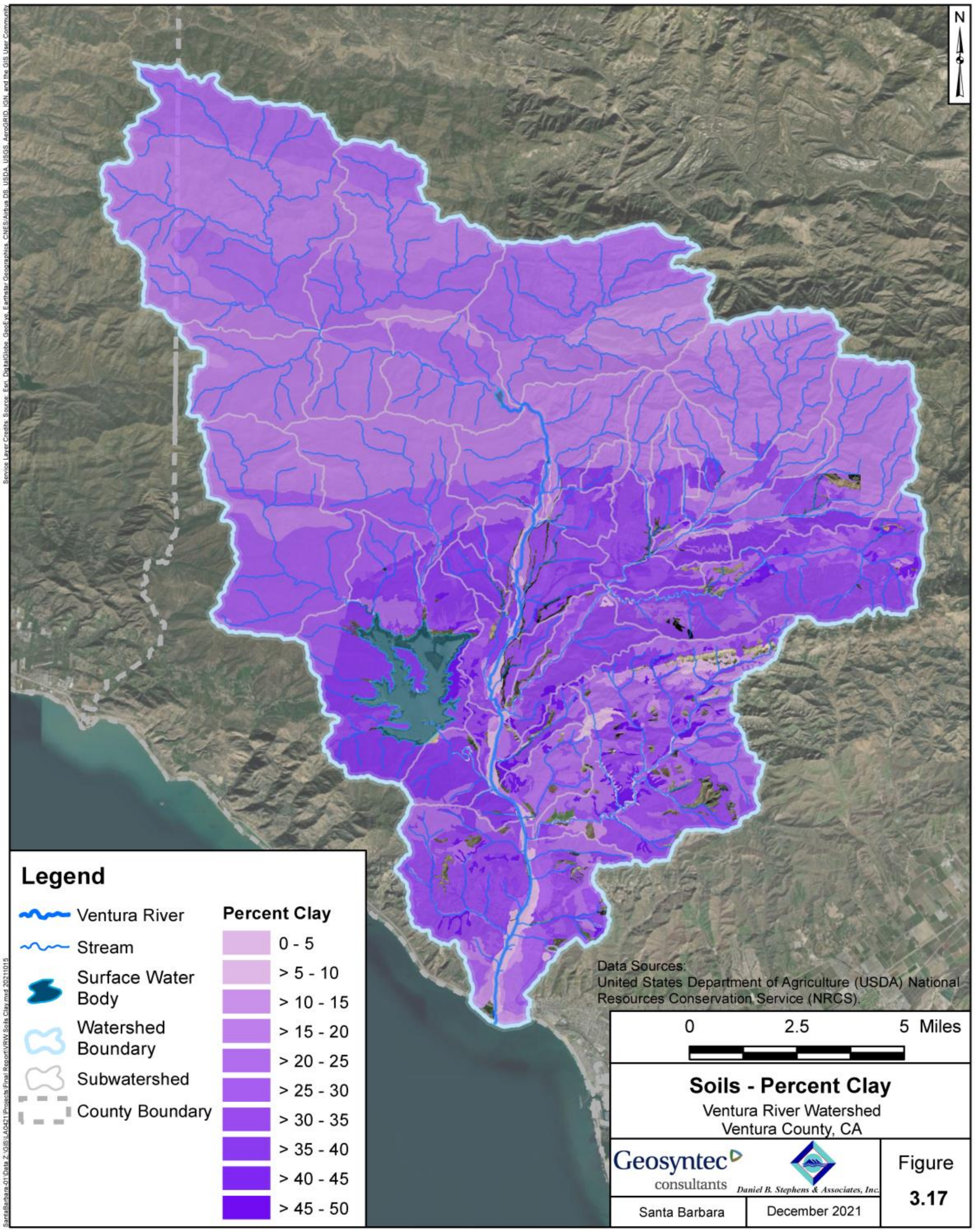


Figure 3.17 Soils – Percent Clay

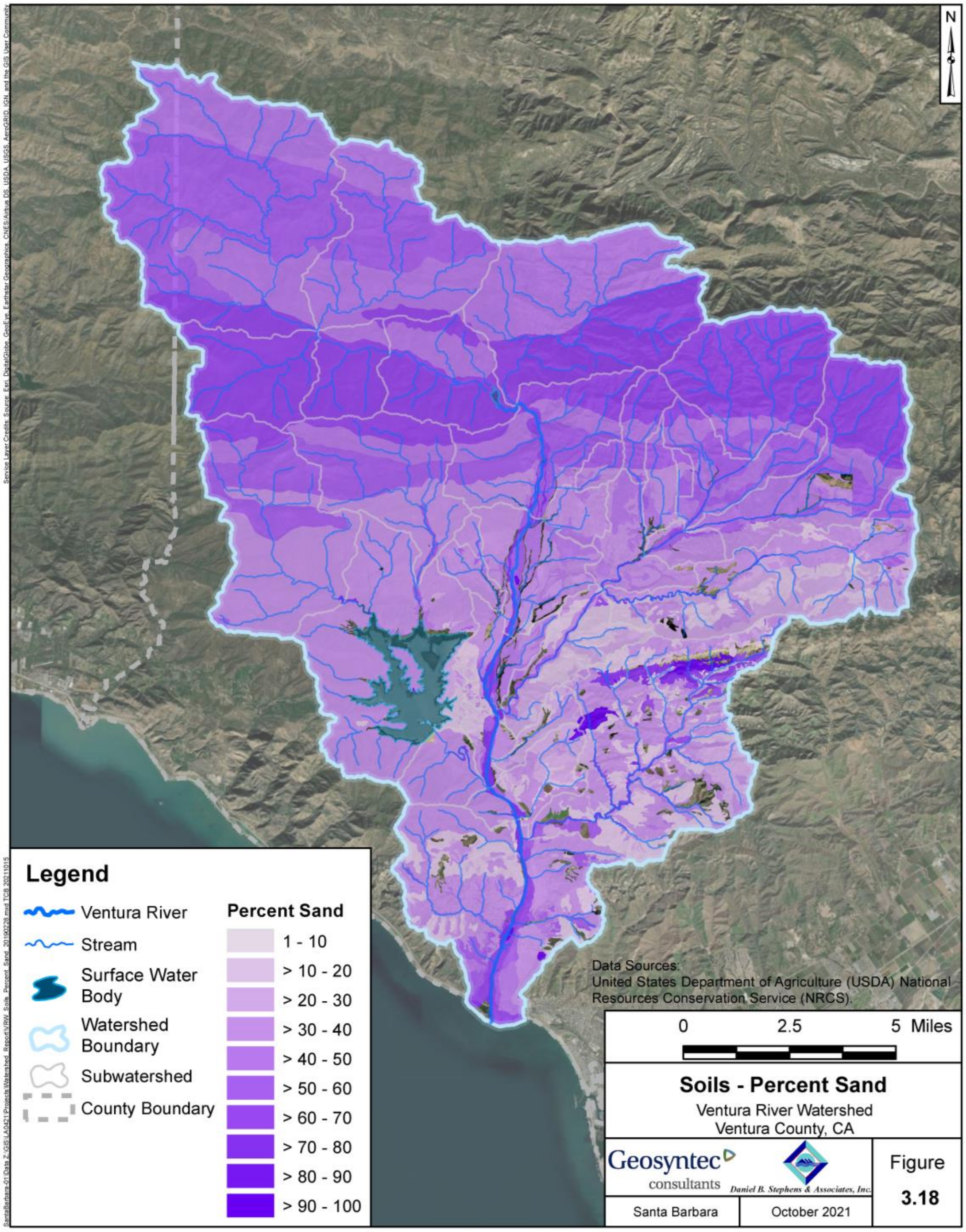


Figure 3.18 Soils – Percent Sand

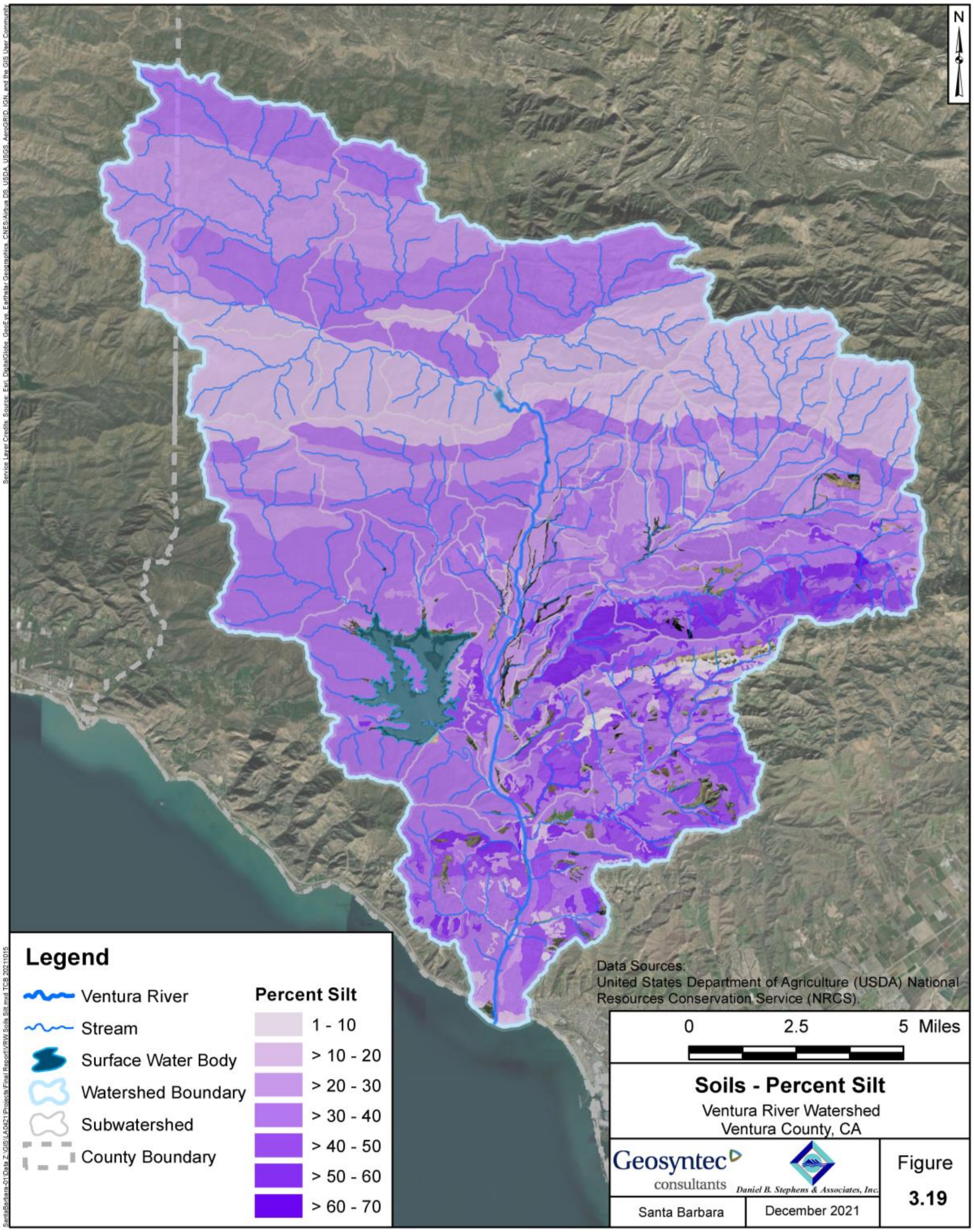


Figure 3.19 Soils – Percent Silt

4 GSFLOW MODEL – GROUNDWATER

The groundwater model component of GSFLOW uses the USGS MODFLOW modeling platform. Of the hydrologic systems simulated in GSFLOW, MODFLOW simulates the hydrologic processes in streams, lakes, and in the subsurface (i.e., below the soil zone simulated by PRMS). Flows are exchanged between PRMS and MODFLOW in many forms (e.g., groundwater recharge from soil zone to the subsurface, interflow from the soil zone to streams and lakes, and groundwater discharge from the subsurface to the soil zone) (see Section 1.5). The following sections describe the layout and discretization of the MODFLOW model, parameter inputs, boundary conditions, initial conditions, and model implementation.

4.1 Spatial Domain and Discretization

Horizontally, the active groundwater model domain extends throughout the entirety of the VRW. The groundwater model represents groundwater flow in the groundwater basins, additional areas of saturated alluvium (e.g., the area underlying San Antonio Creek south of the Ojai Basin), and the bedrock aquifers. Vertically, the full thickness of all groundwater basins is represented, and the bedrock model layer thickness is based on the depth of the majority of domestic and agricultural wells screened in the bedrock units (Figure 1.9).

As discussed in Section 3.1, the model domain is uniformly divided into grid cells 330 feet on a side, consistent with the PRMS model. Seven vertical model layers are present in the MODFLOW model, and they are numbered with 1 as the top and 7 as the bottom. The top of Layer 1 represents the bottom of soil zone (simulated by PRMS). Layers 1 through 3 are active throughout the entire VRW. Layers 4 through 7 are only active within and underneath the Ojai Basin, which has thicker alluvial deposits compared to the rest of the VRW. The layering in Ojai Basin is generally consistent with the layering of the OBGMA model (DBS&A, 2011). However, some layers in the OBGMA model (which simulated the alluvium with 10 layers) were aggregated into six layers only of alluvium in Ojai Basin of the VRW GSFLOW Model. Wherever there is alluvium within the model domain, a thick layer of bedrock of at least 200 feet was simulated underneath the alluvium.

Figure 4.1 through Figure 4.1h present maps of the distribution of the elevation of the top of each model layer and the bottom of Layer 7. Figure 4.2a through 4.2g present maps of the model layer thickness. The elevation and thickness of each model layer was based on geologic analyses and the extent of alluvium interpolated at each location, which is documented in Appendix C[17].

MODFLOW is organized in rows and columns, where row numbers refer to the vertical position within the model grid, and column numbers refer to the horizontal position within the model grid. Each model cell can be identified by its unique row, column, and layer number. Figures 4.3a through 4.3j present cross-section diagrams through specific model rows and columns, and a map displaying the cross-section locations is presented in Figure 4.4. The top of each cross-section represents the top of the groundwater model domain (bottom of the PRMS soil zone), and the bottom of each cross section represents the bottom of the model domain. Simulated groundwater potentiometric surface elevations and MODFLOW "parameter zones" are also shown on the cross-section diagrams, as discussed below in Section 4.5.

4.2 Temporal Discretization

The VRW GSFLOW Model, and its MODFLOW portion, operates with monthly stress periods and daily time steps. In MODFLOW, a stress-period defines periods of time with constant values of model stresses (e.g., pumping rates), and time steps define the period of time for which all model calculations (e.g., groundwater flow rates, streamflow discharge rates) are performed and reported. While many stresses in MODFLOW (e.g., pumping) are defined in each stress period, exchange of flows between MODFLOW and PRMS (e.g., recharge from soil zone to groundwater) occurs at the end of each time step.

4.3 Initial Conditions

Groundwater elevations must be assigned for each model cell at the beginning of the model simulation, and these are referred to as "initial conditions." Initial conditions within the groundwater basins were assigned based on interpolation

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[17] Appendices A through F are not embedded in this document. The appendices are presented in companion files. Appendices B through F are compiled in two PDF files. The appendices are include in the zip folder for this model report and are available for download on the State Water Board's California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/

of measured data for fall 1993, which is the beginning of the model calibration/validation time period. Figure 4.5 presents a map of the well measurement data and groundwater elevation interpolation for fall 1993. Streambed "wet/dry" mapping from fall-winter 2016 was also used to guide the initial conditions interpolation, with the assumption that areas of the streams that are mapped as "wet" would be generally similar in fall 1993 (no wet/dry mapping is available for fall 1993). Stream areas mapped as "wet" were assumed to be in hydraulic connection with groundwater and streambed elevations were therefore similar to groundwater elevations. As shown on Figure 4.4, "wet" streambed elevations were consistent with groundwater elevations observed from surrounding wells.

This simplifying assumption is considered to be reasonable in most parts of the VRW, but may not be true in all cases. For example, in some instances there may be an unsaturated zone beneath the streambed for a losing stream and therefore no connection. The assumption of hydraulic connection in areas mapped as wet also does not preclude areas not mapped as wet as having a hydraulic connection during the model simulations.

Initial conditions outside the groundwater basins (e.g., within the bedrock units) were assigned based on simulated values as of September 2005 from early VRW GSFLOW Model runs, noting that WY2005 had similar hydrology as WY1993. These initial conditions were updated as needed during the model calibration process to be consistent with simulated September 2005 values for each run.

Initial conditions dictate only the model conditions at the beginning of the simulation. Model testing indicated that the assumed initial conditions within the alluvium did not impact model simulations during the calibration period significantly.

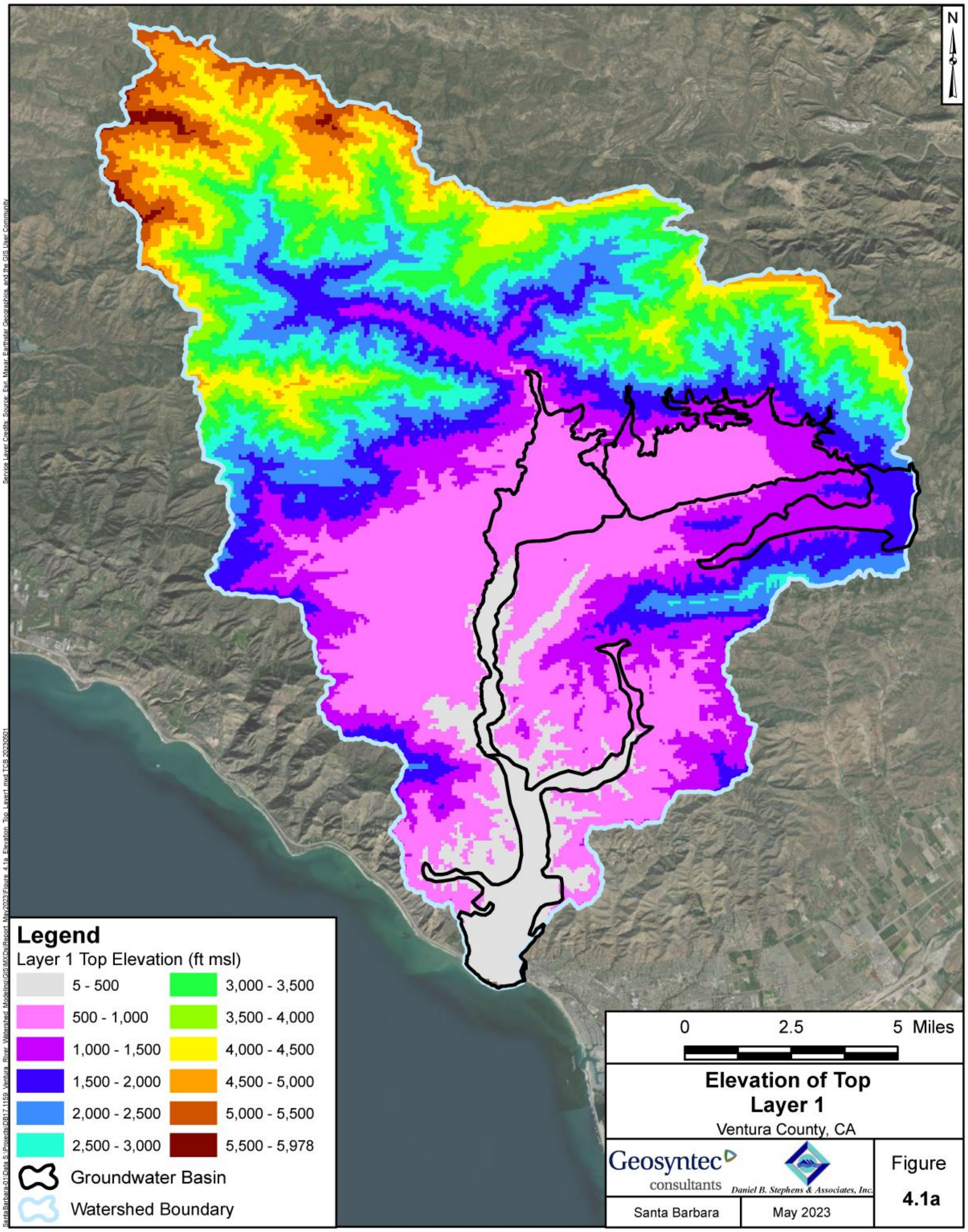

Figure 4.1a Elevation of Top Layer 1

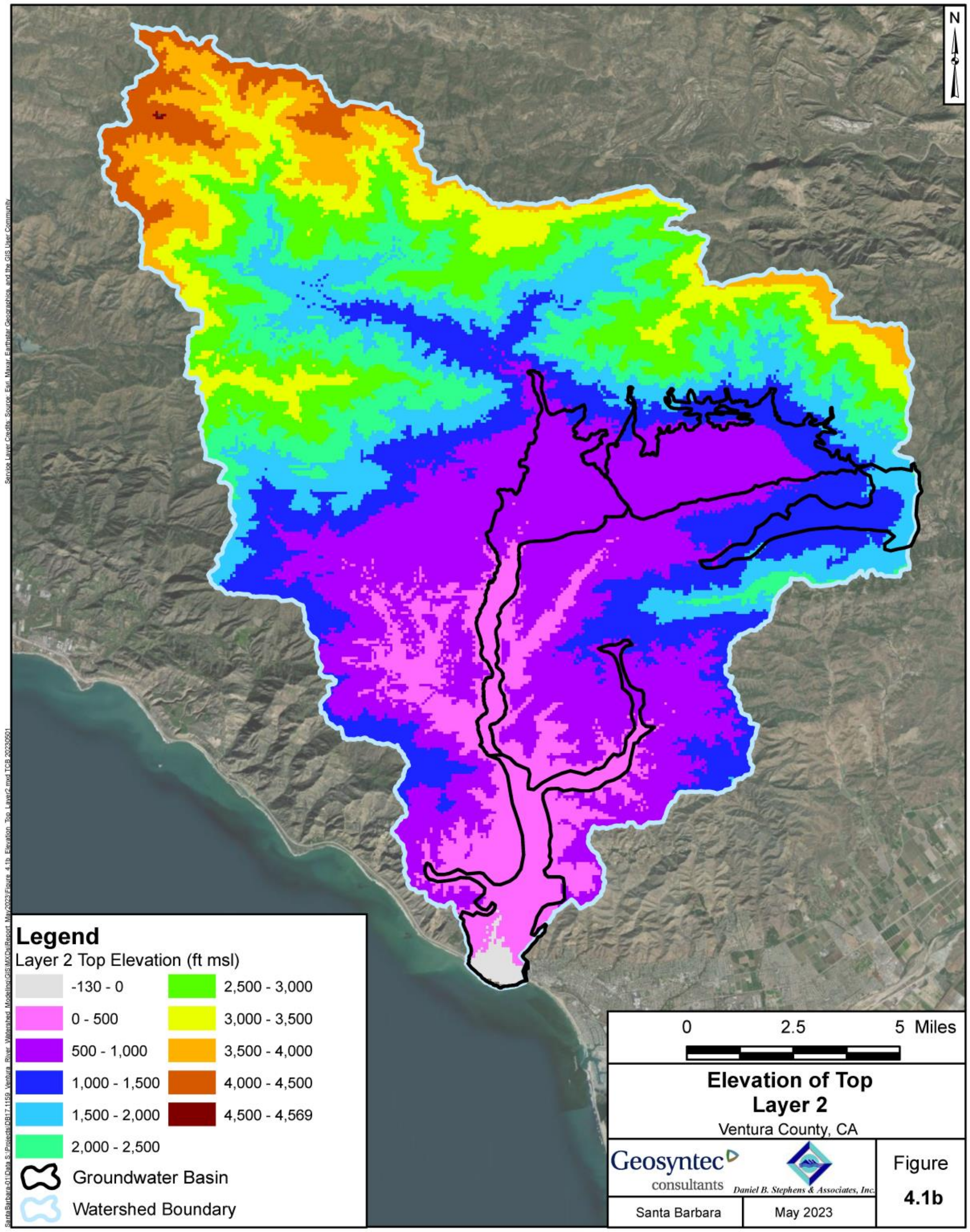

Figure 4.1b Elevation of Top Layer 2

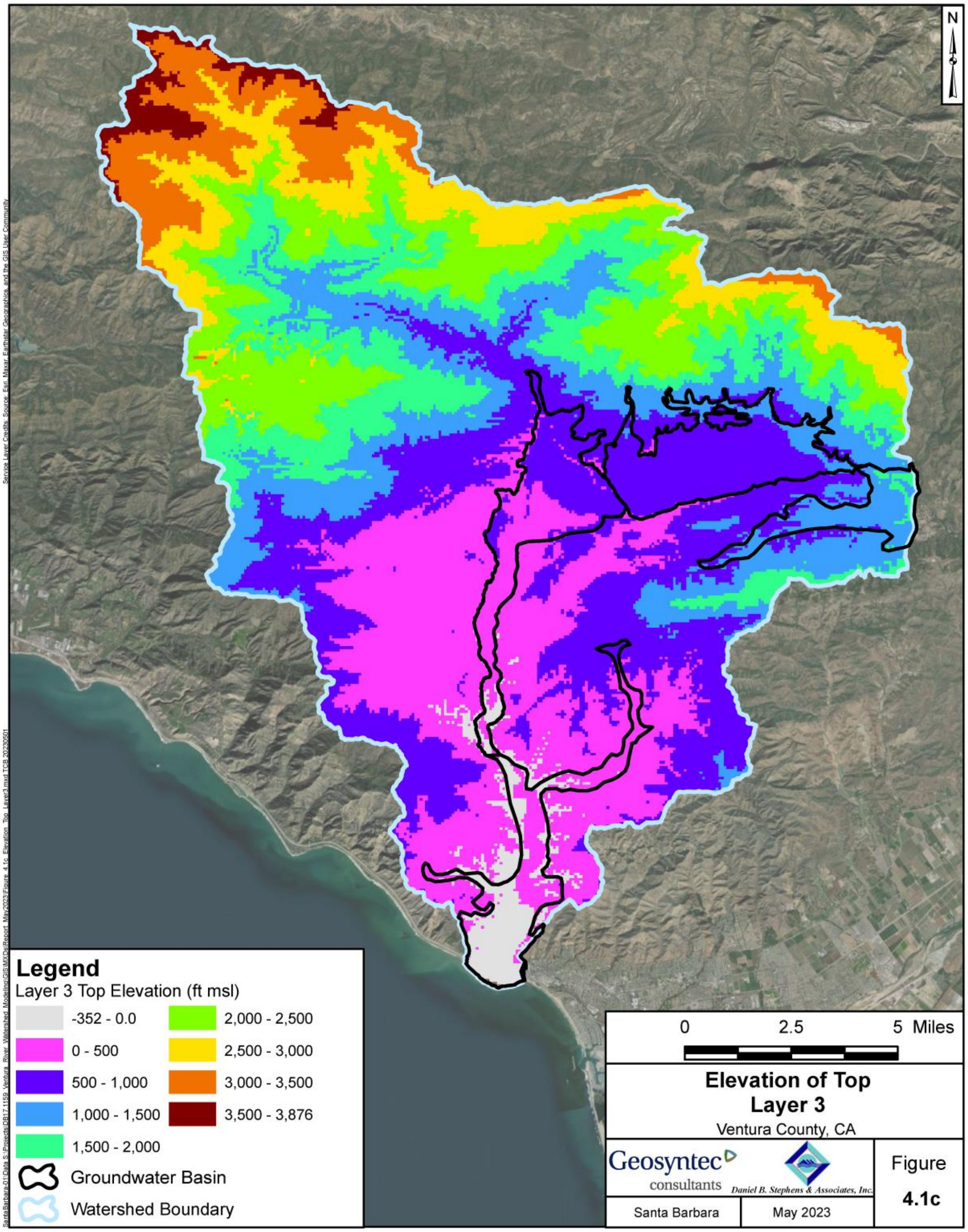

Figure 4.1c Elevation of Top Layer 3

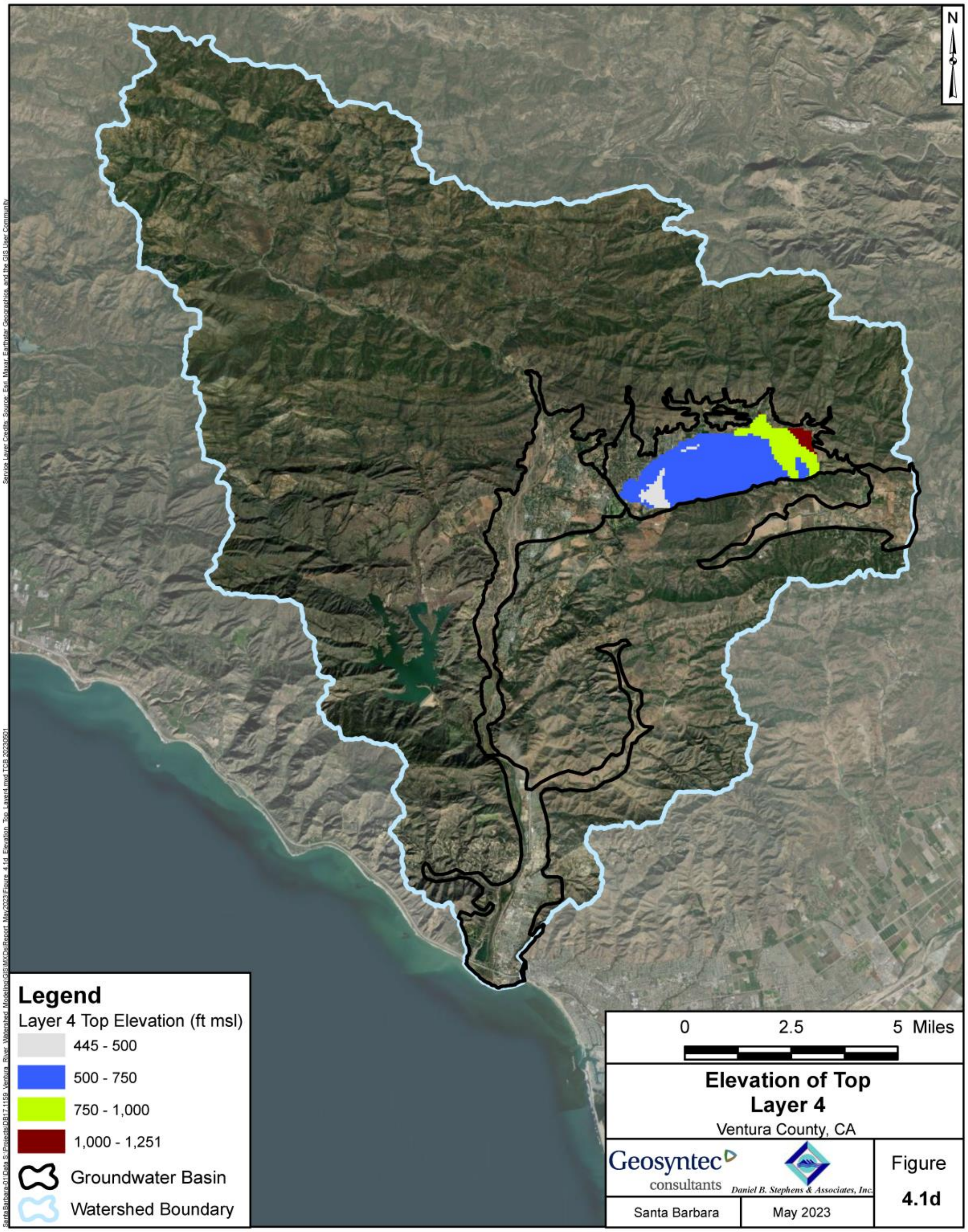

Figure 4.1d Elevation of Top Layer 4

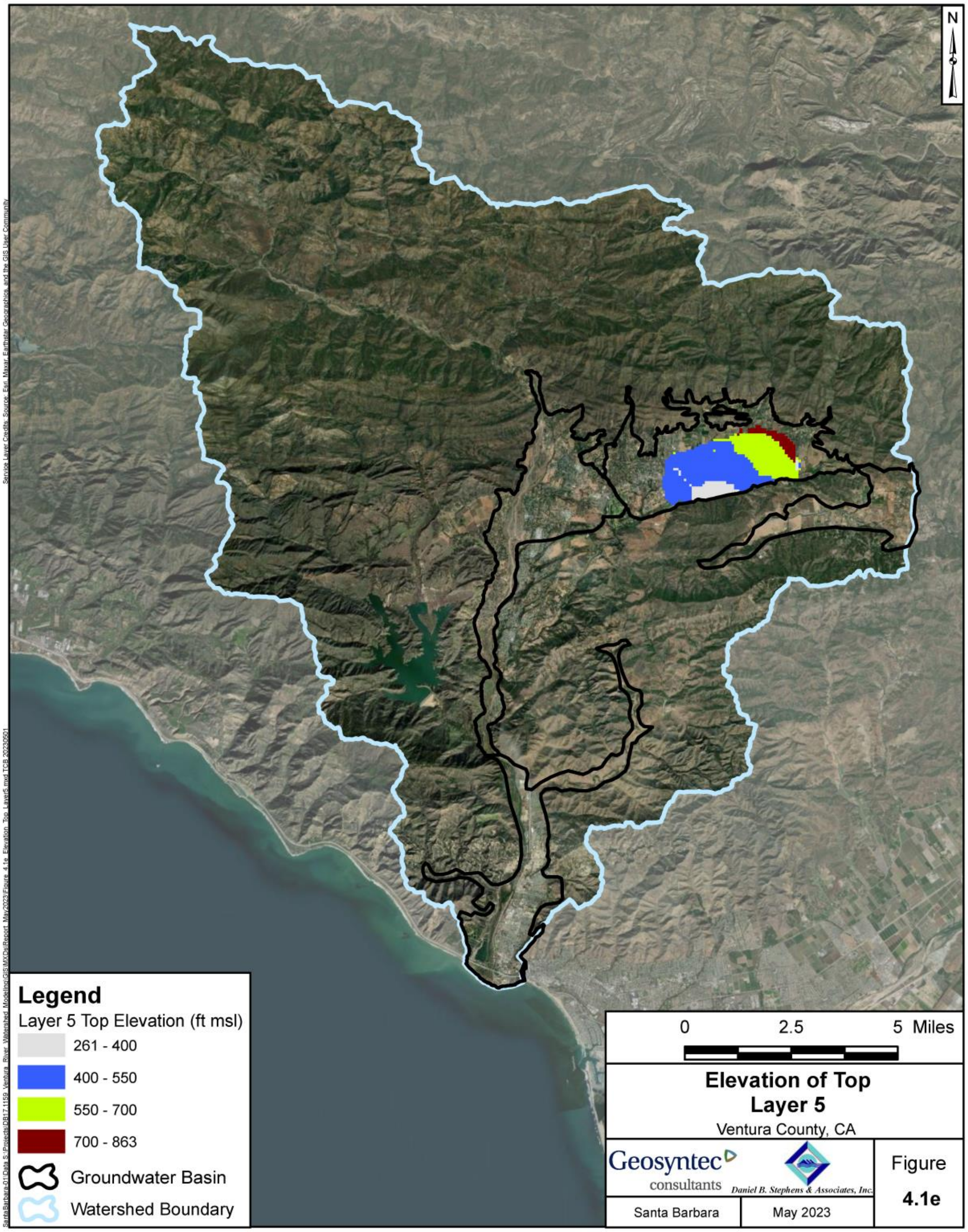

Figure 4.1e Elevation of Top Layer 5

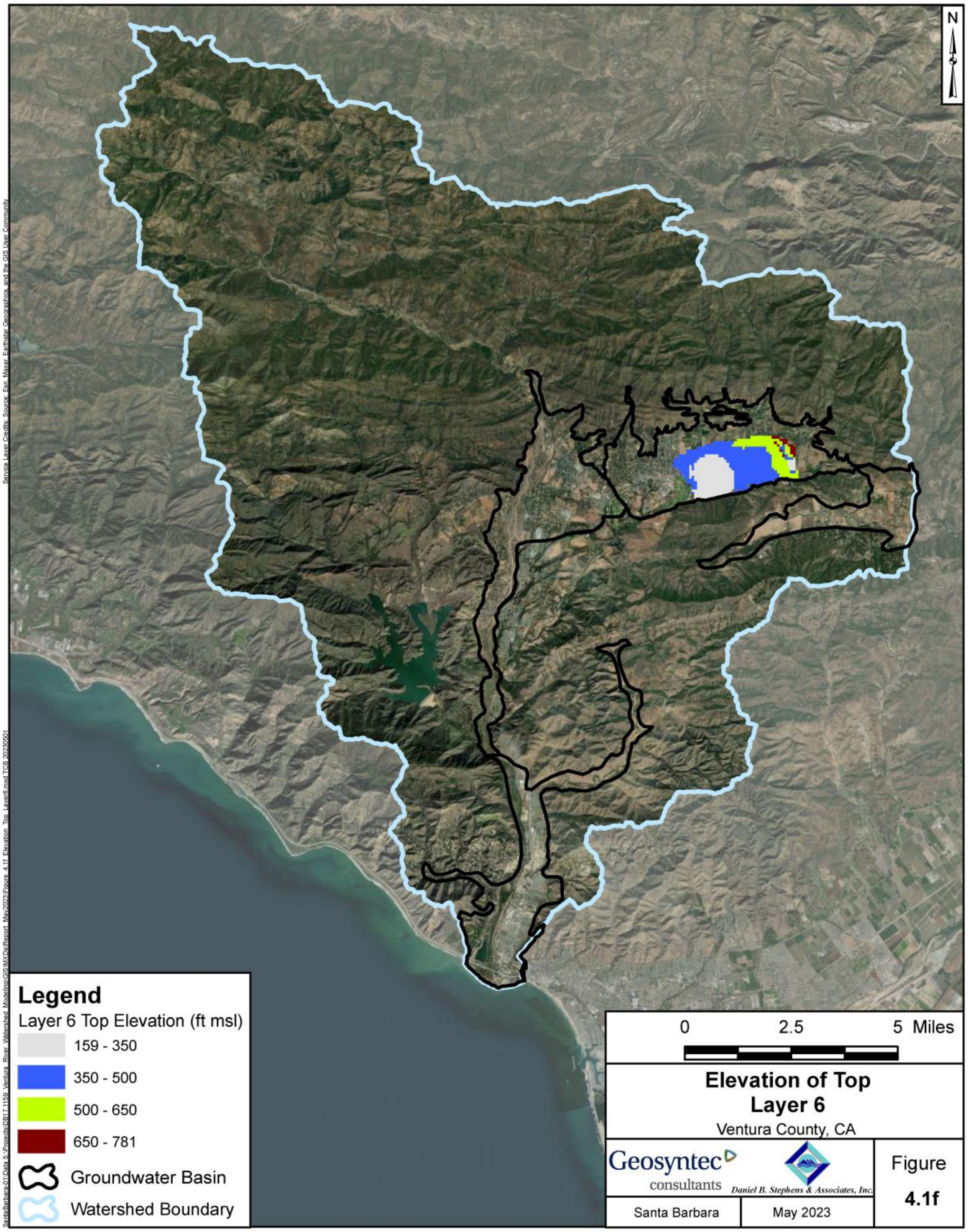

Figure 4.1f Elevation of Top Layer 6

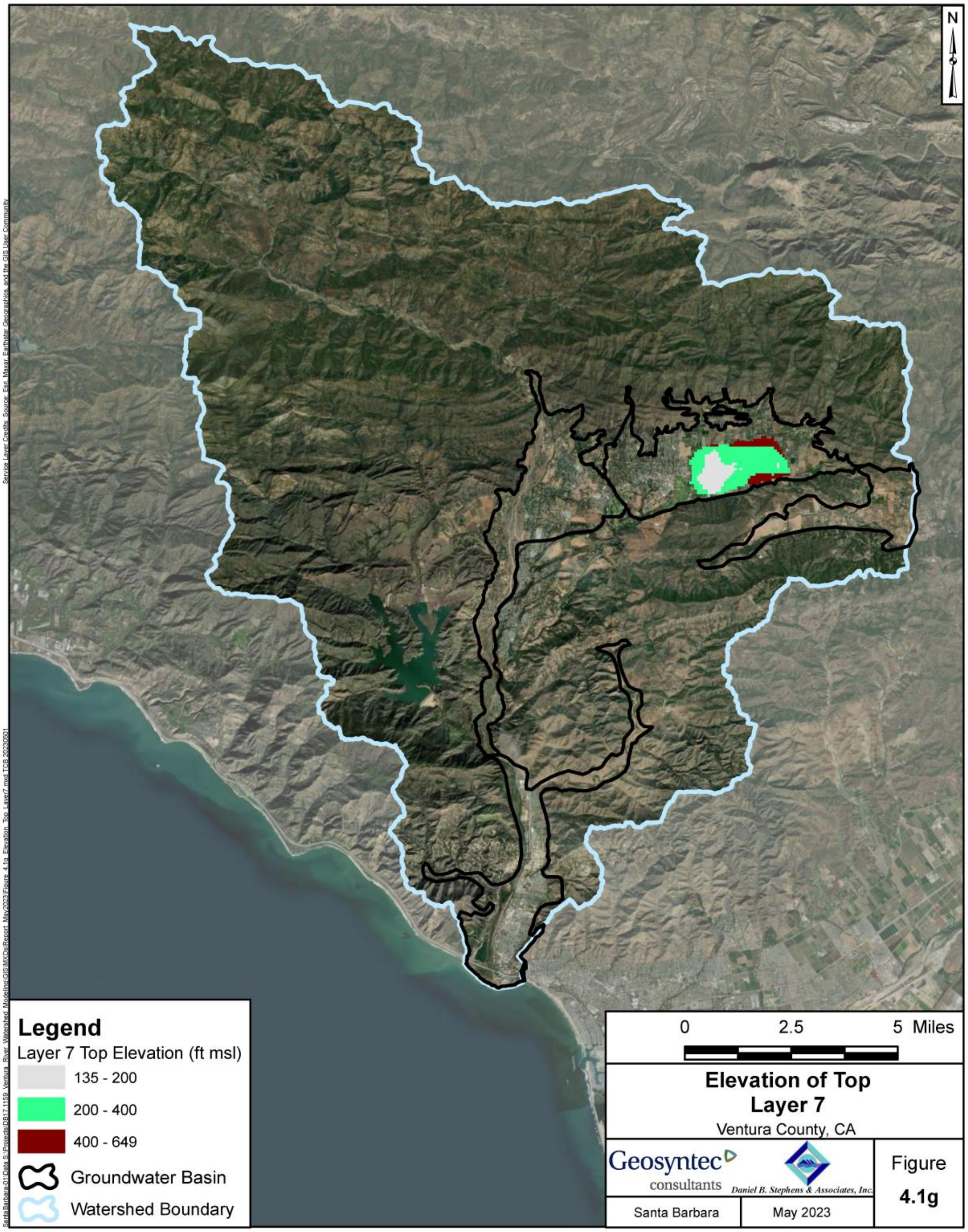

Figure 4.1g Elevation of Top Layer 7

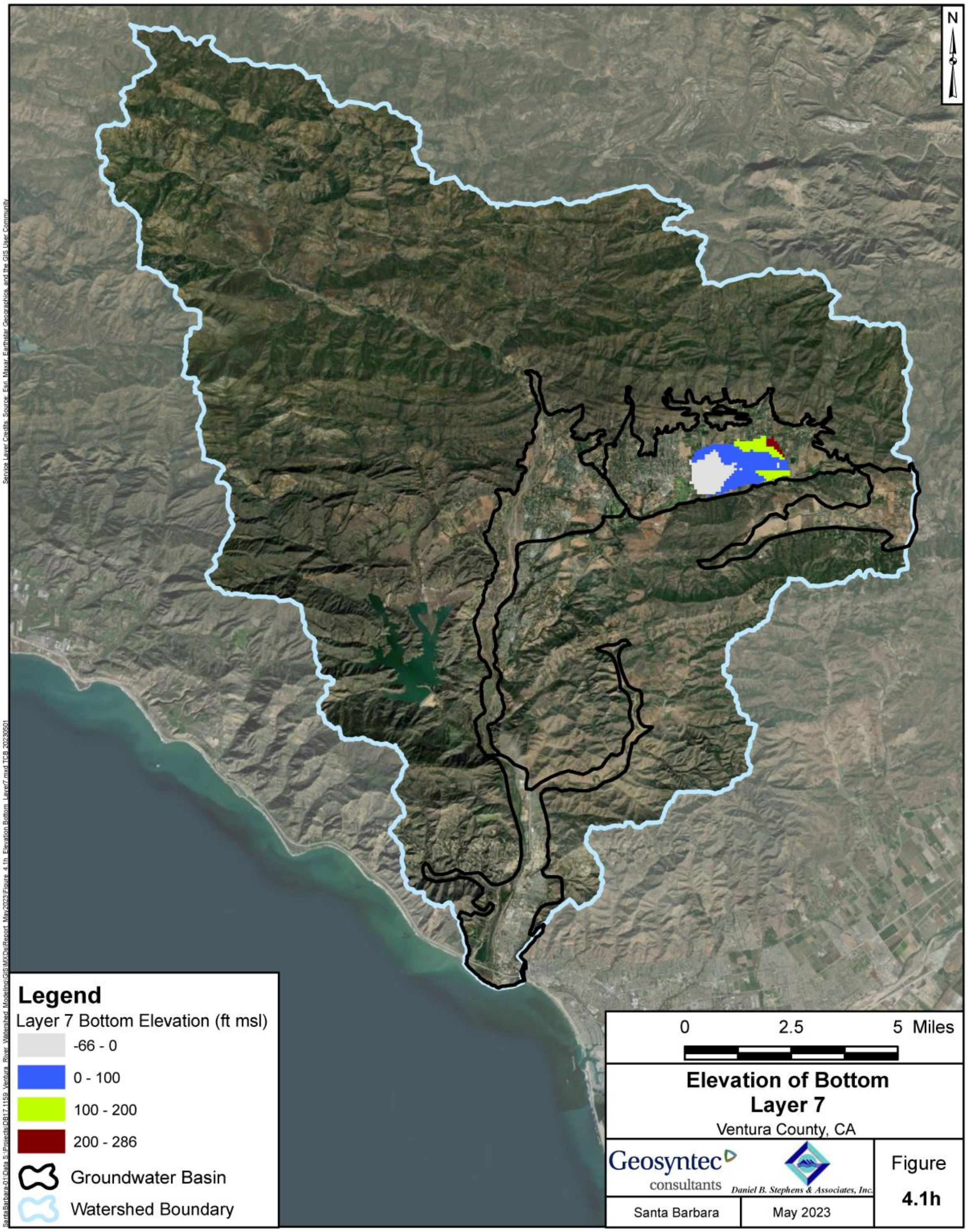

Figure 4.1h Elevation of Bottom Layer 7

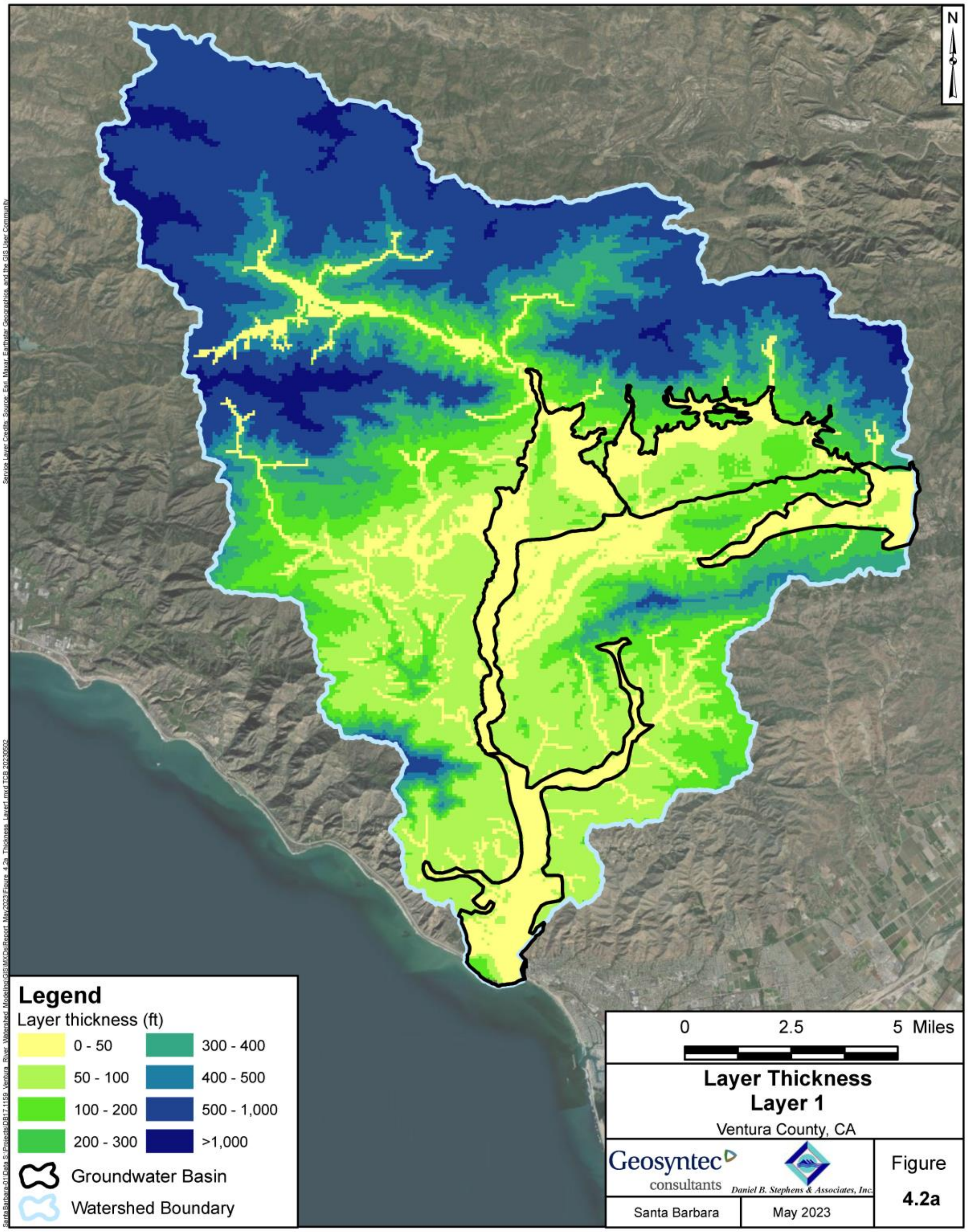

Figure 4.2a Layer Thickness Layer 1

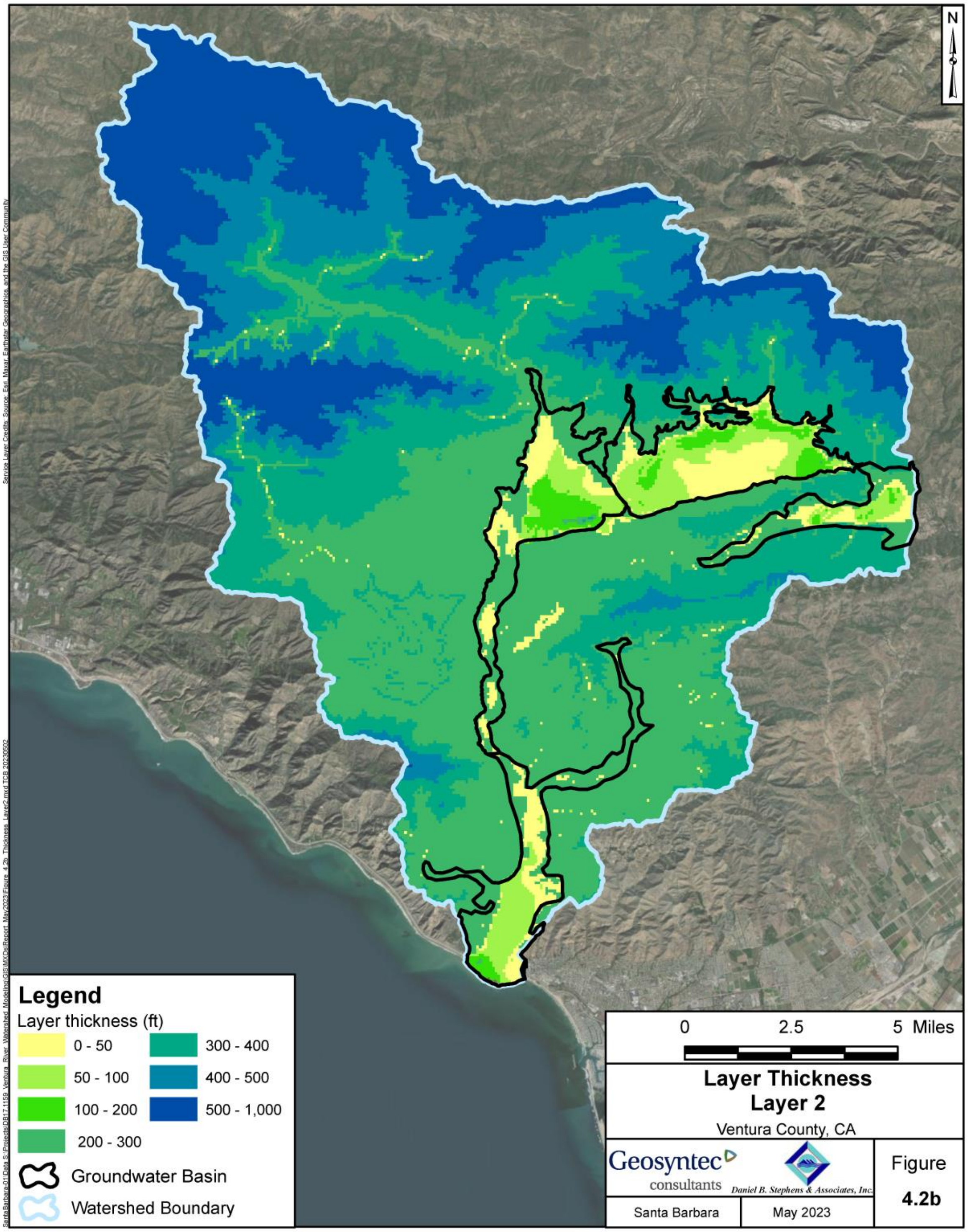

Figure 4.2b Layer Thickness Layer 2

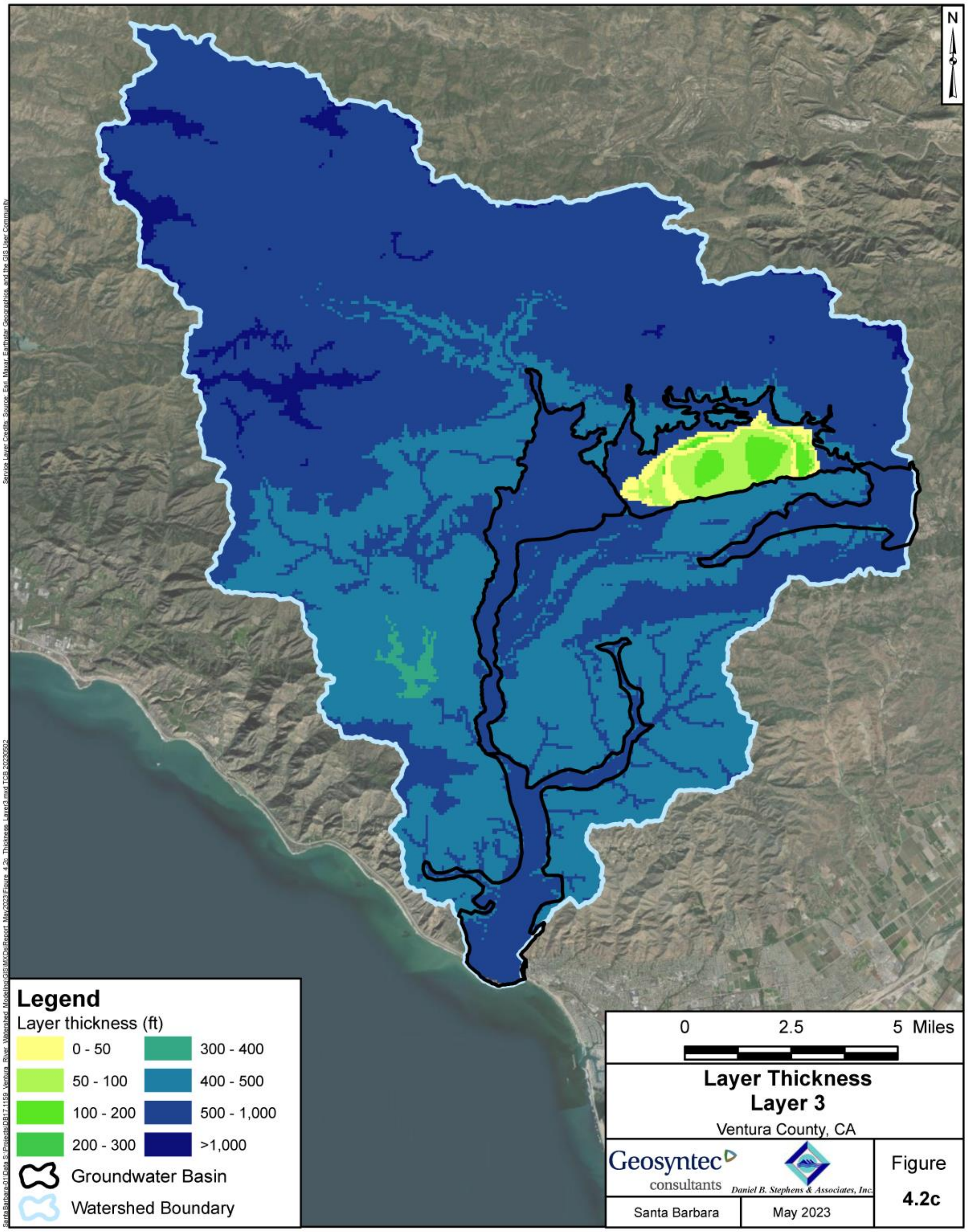

Figure 4.2c Layer Thickness Layer 3

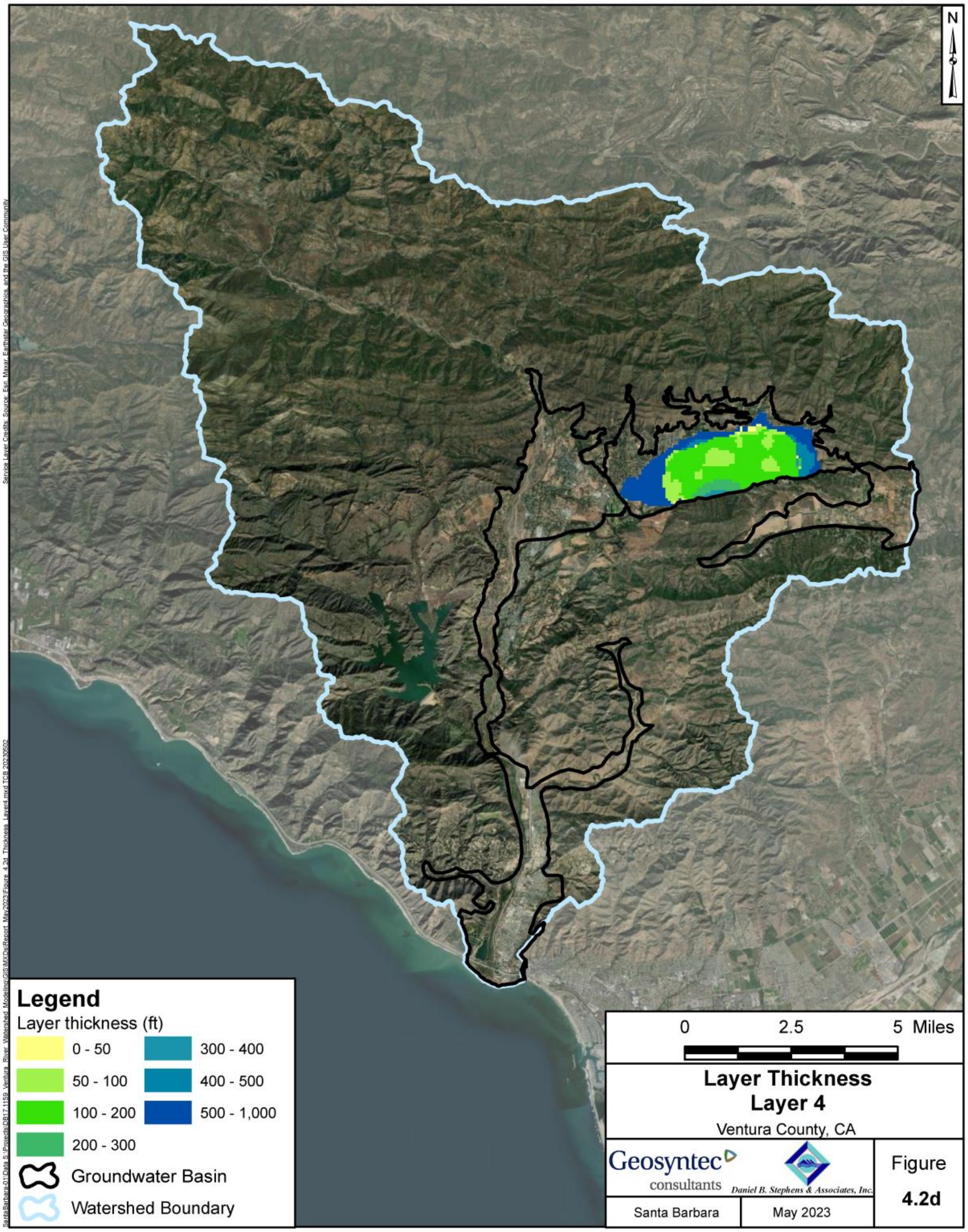

Figure 4.2d Layer Thickness Layer 4

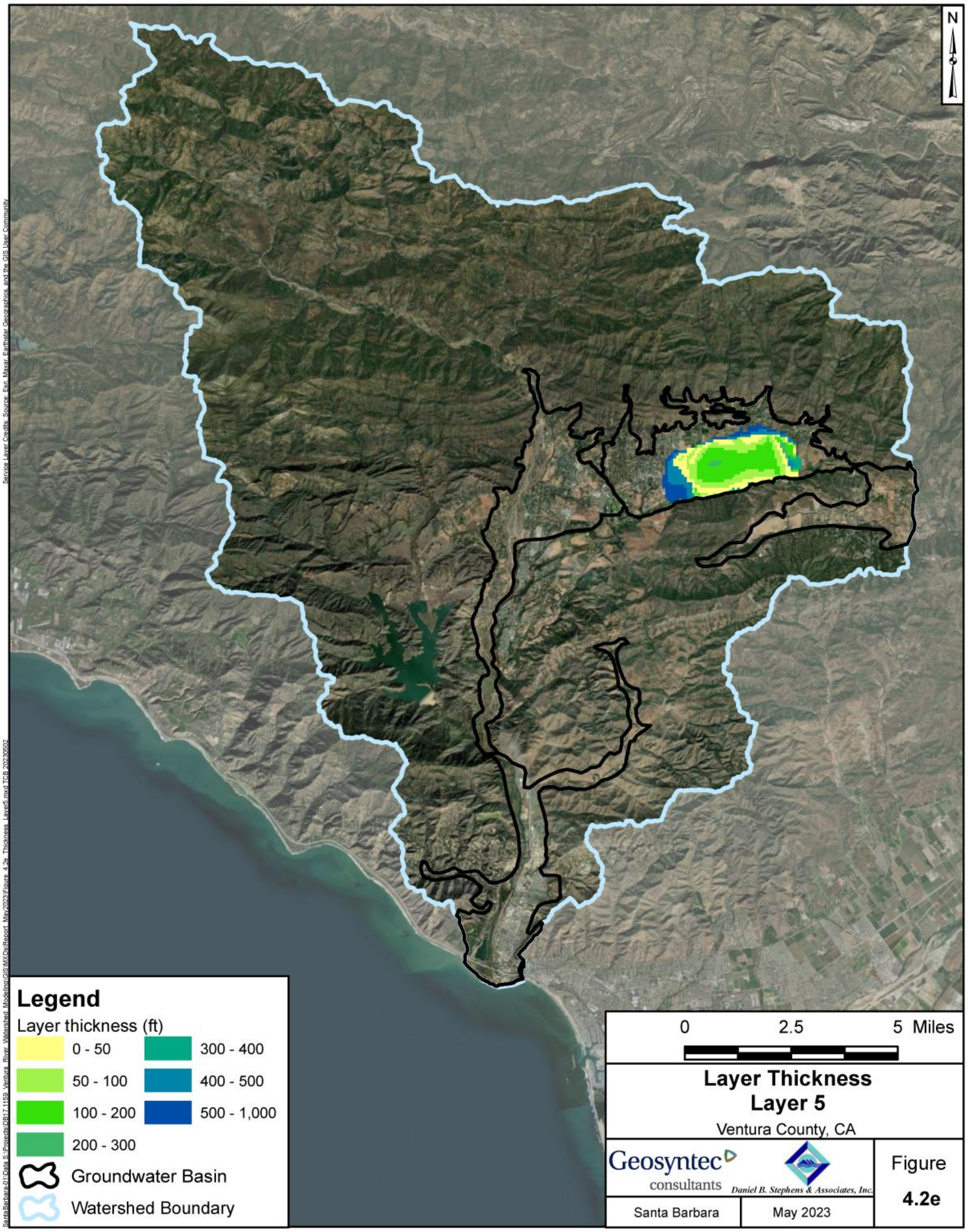

Figure 4.2e Layer Thickness Layer 5

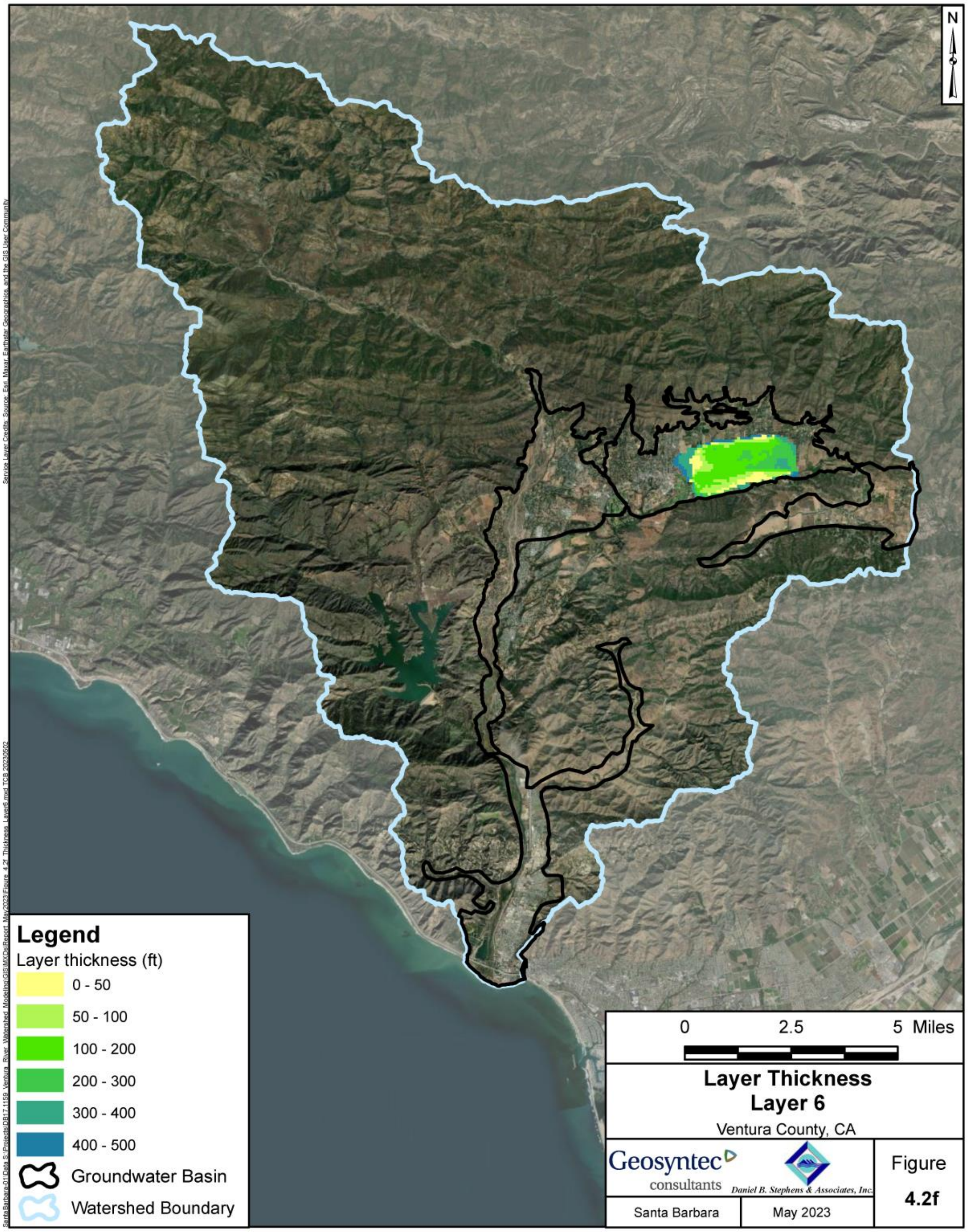

Figure 4.2f Layer Thickness Layer 6

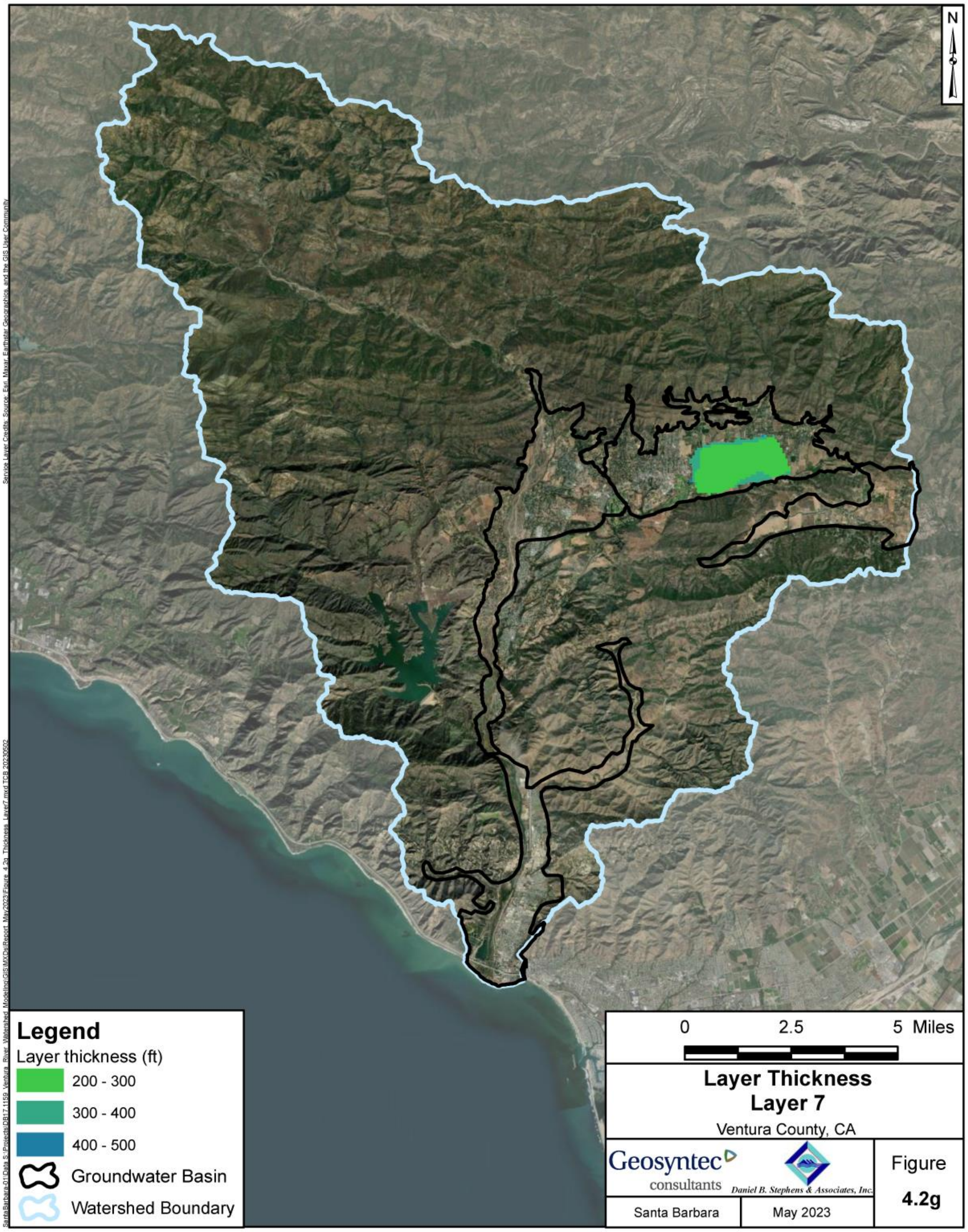

Figure 4.2g Layer Thickness Layer 7

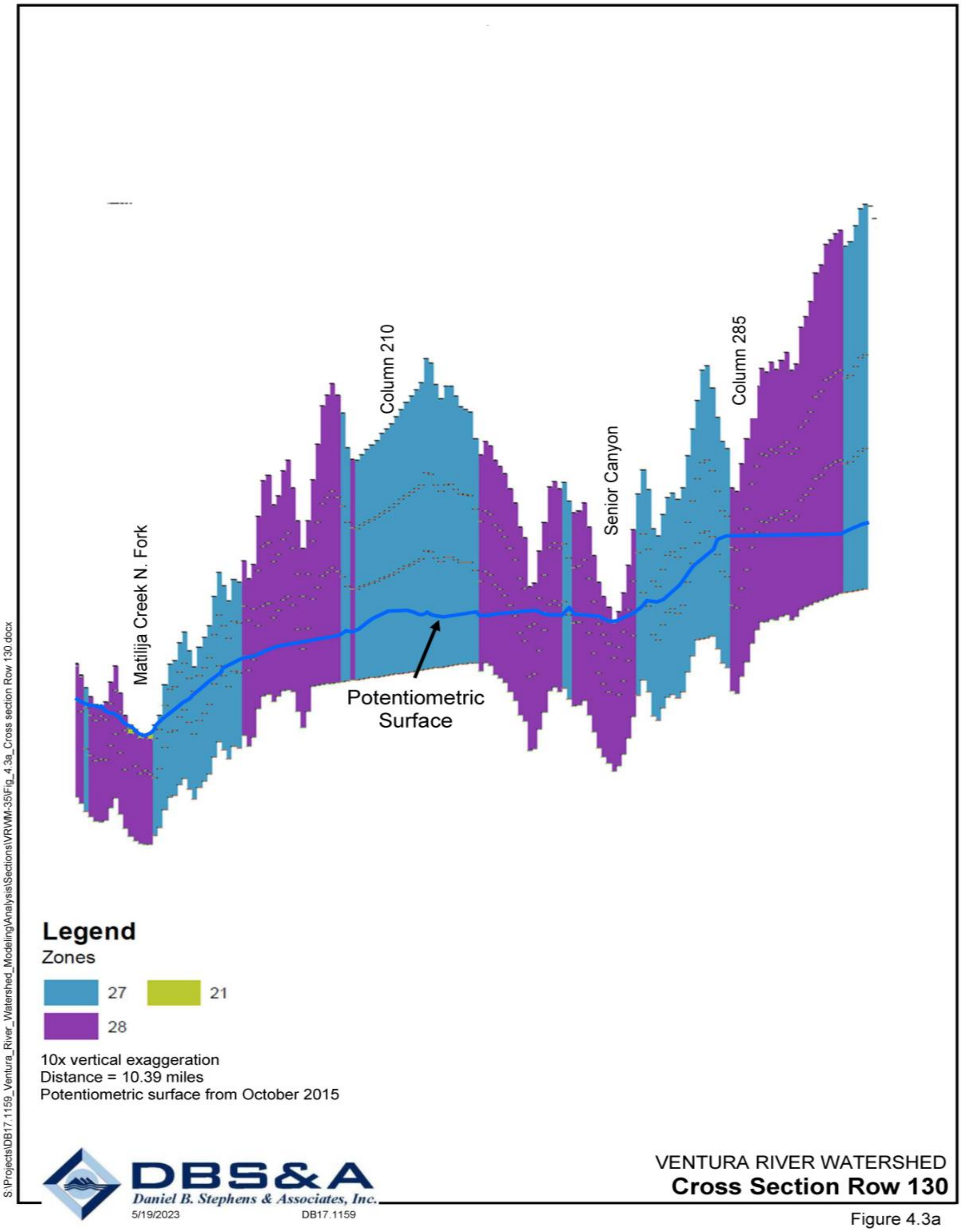

Figure 4.3a Cross Section Row 130

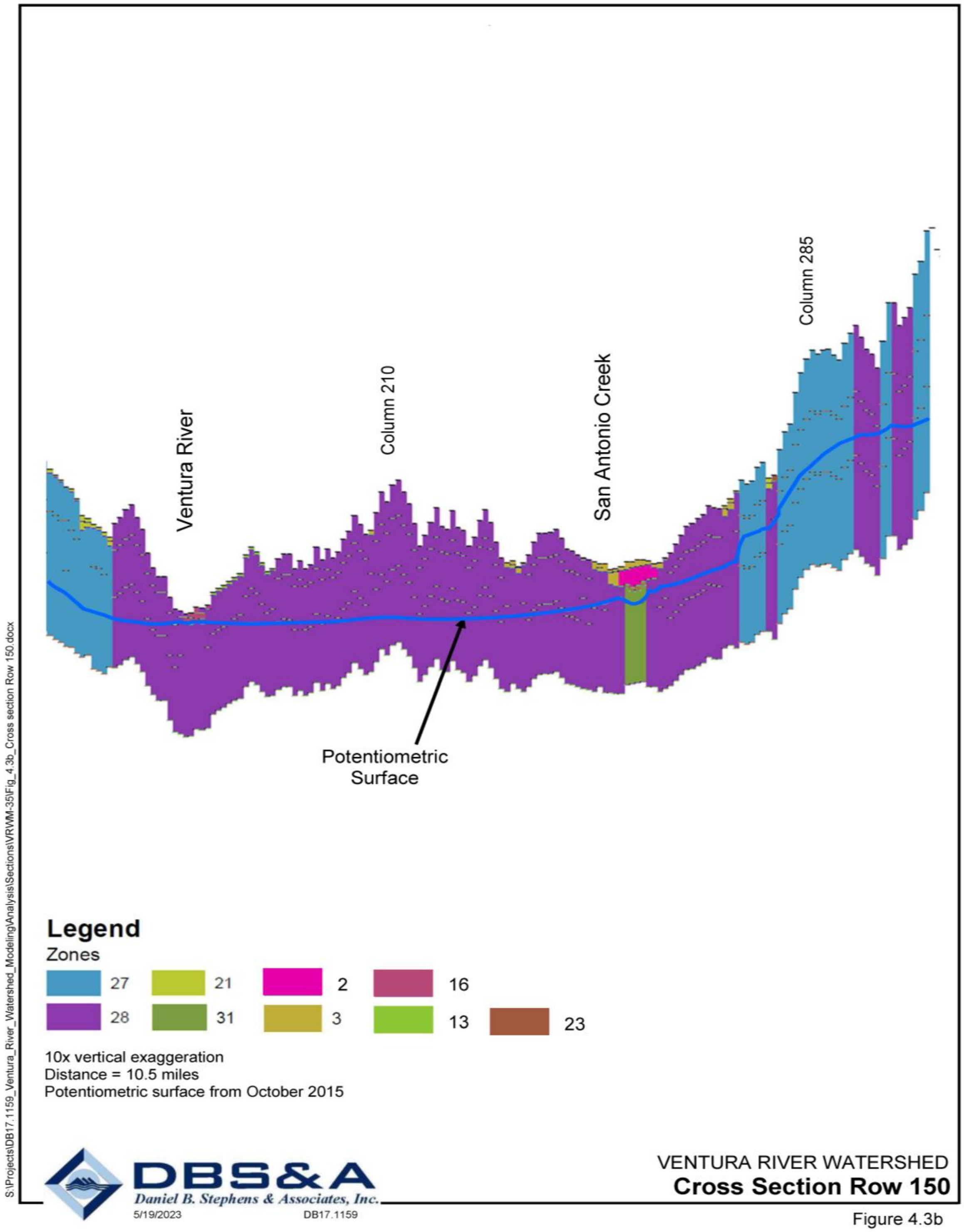

Figure 4.3b Cross Section Row 150

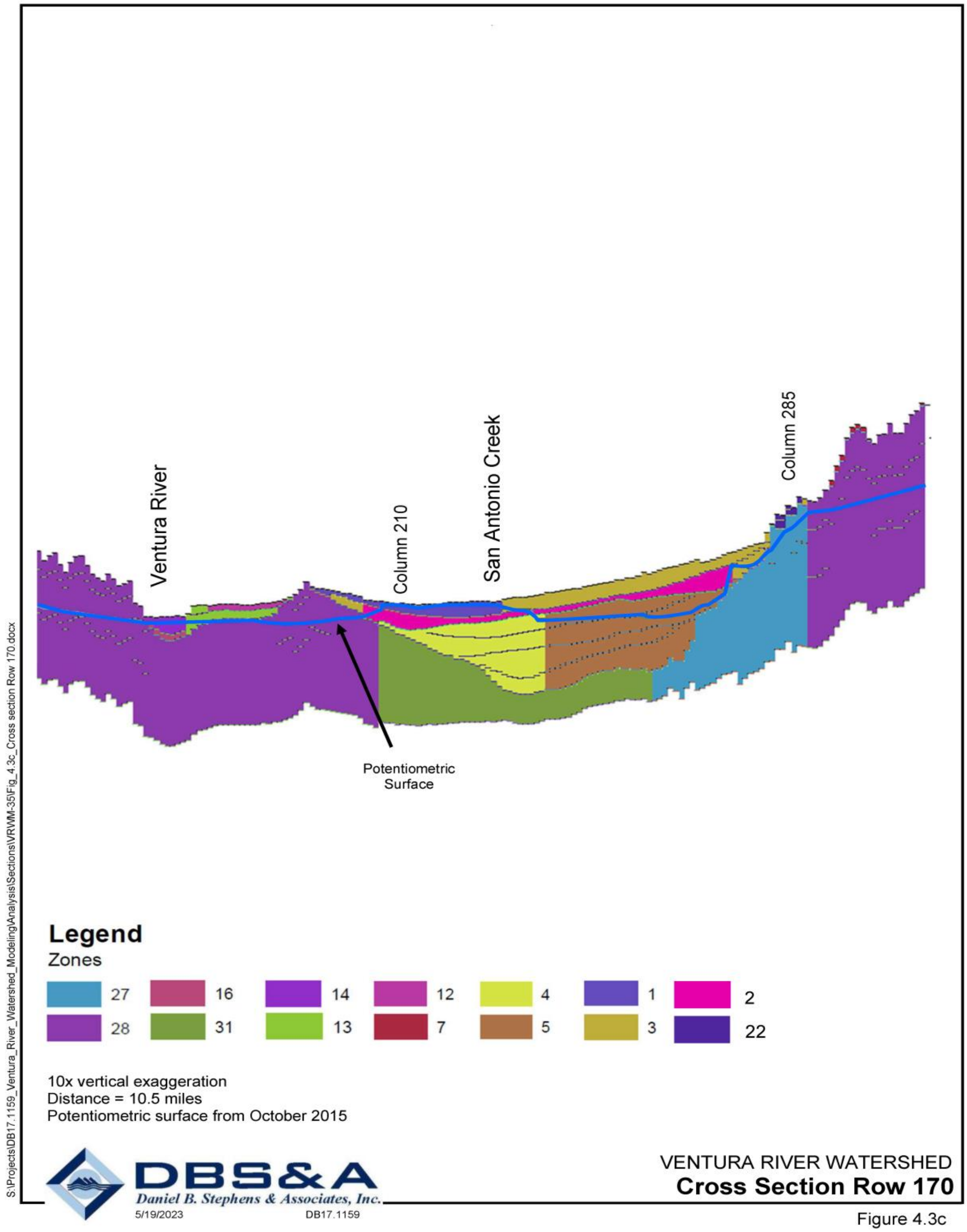

Figure 4.3c Cross Section Row 170

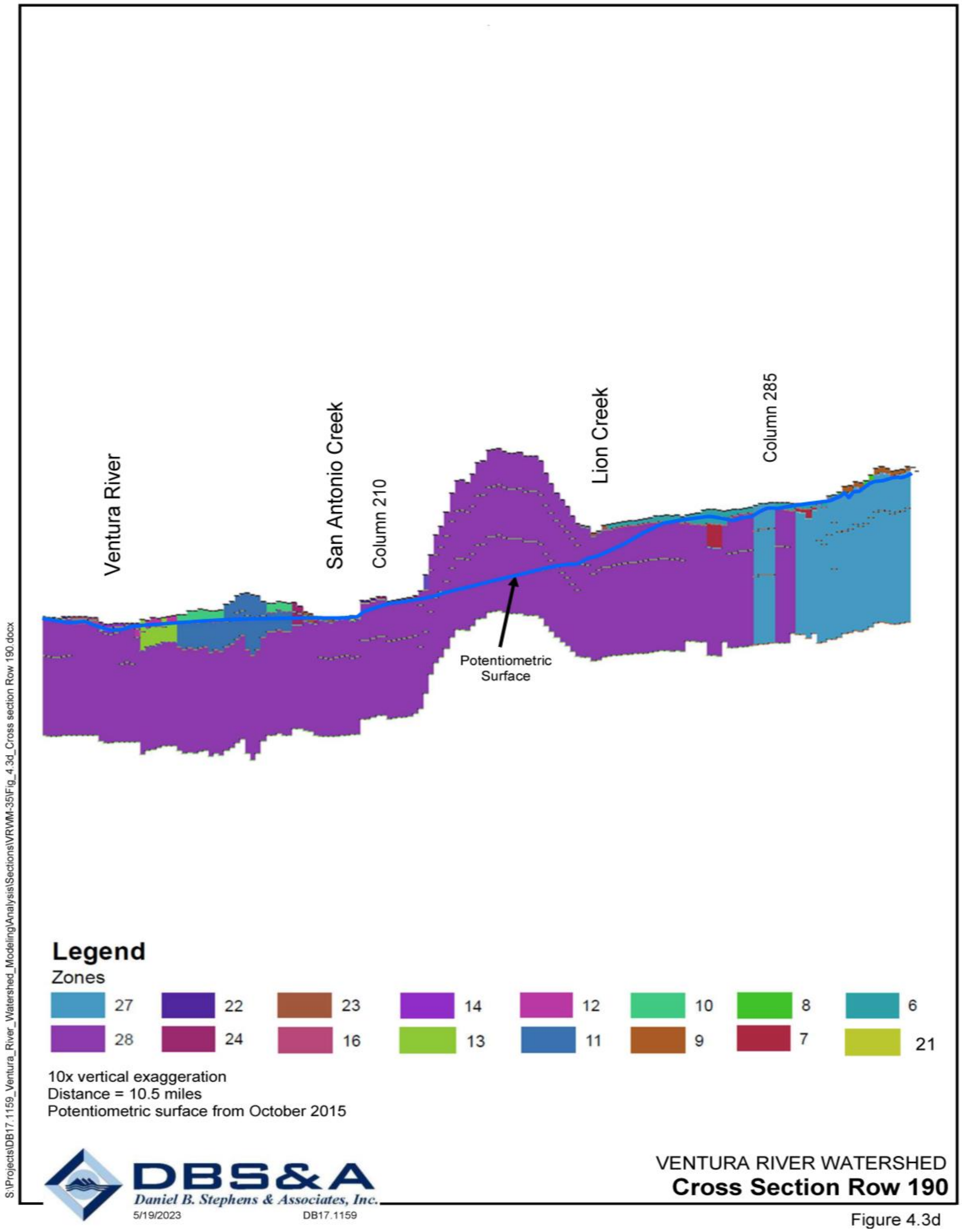

Figure 4.3d Cross Section Row 190

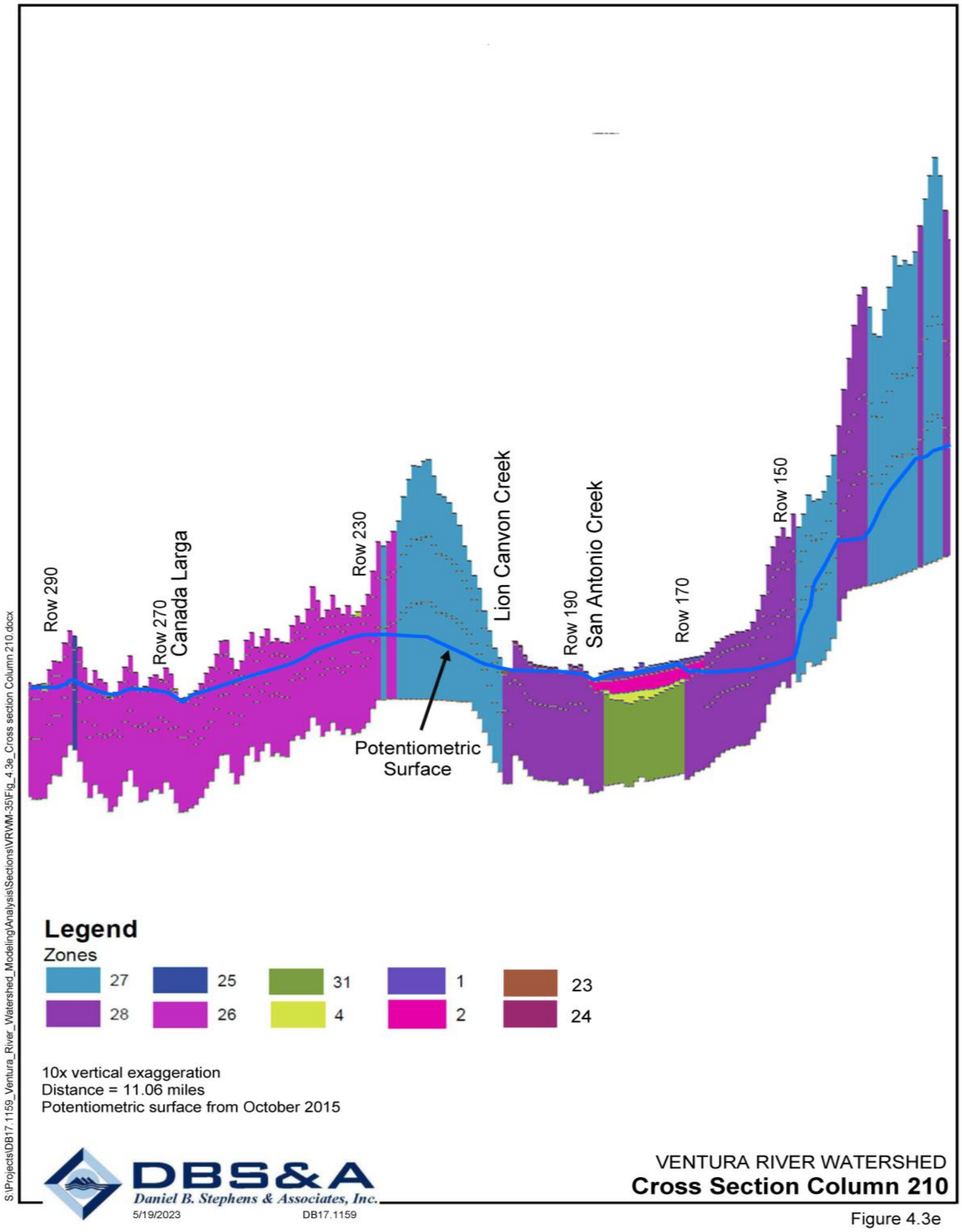

Figure 4.3e Cross Section Column 210

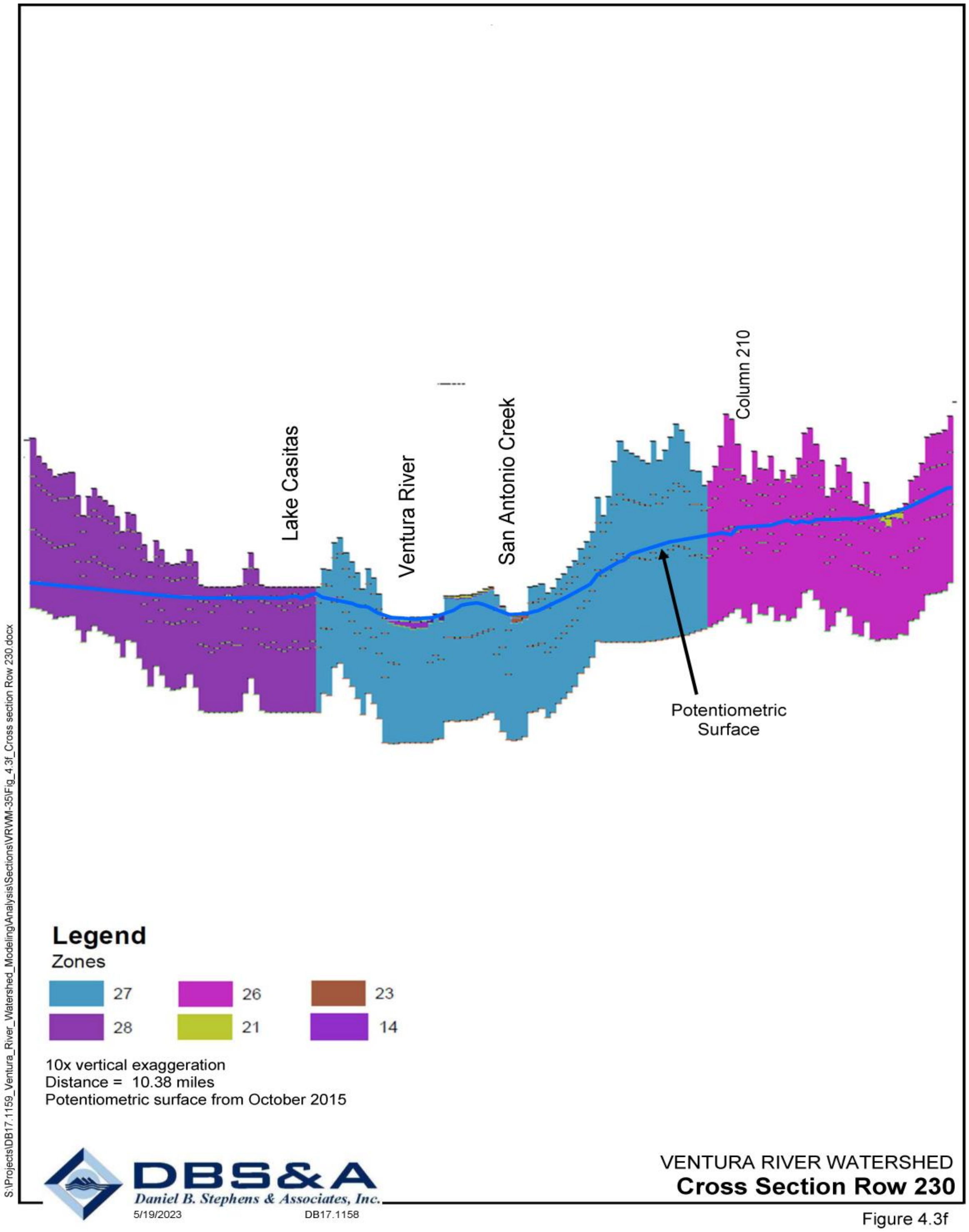

Figure 4.3f Cross Section Row 230

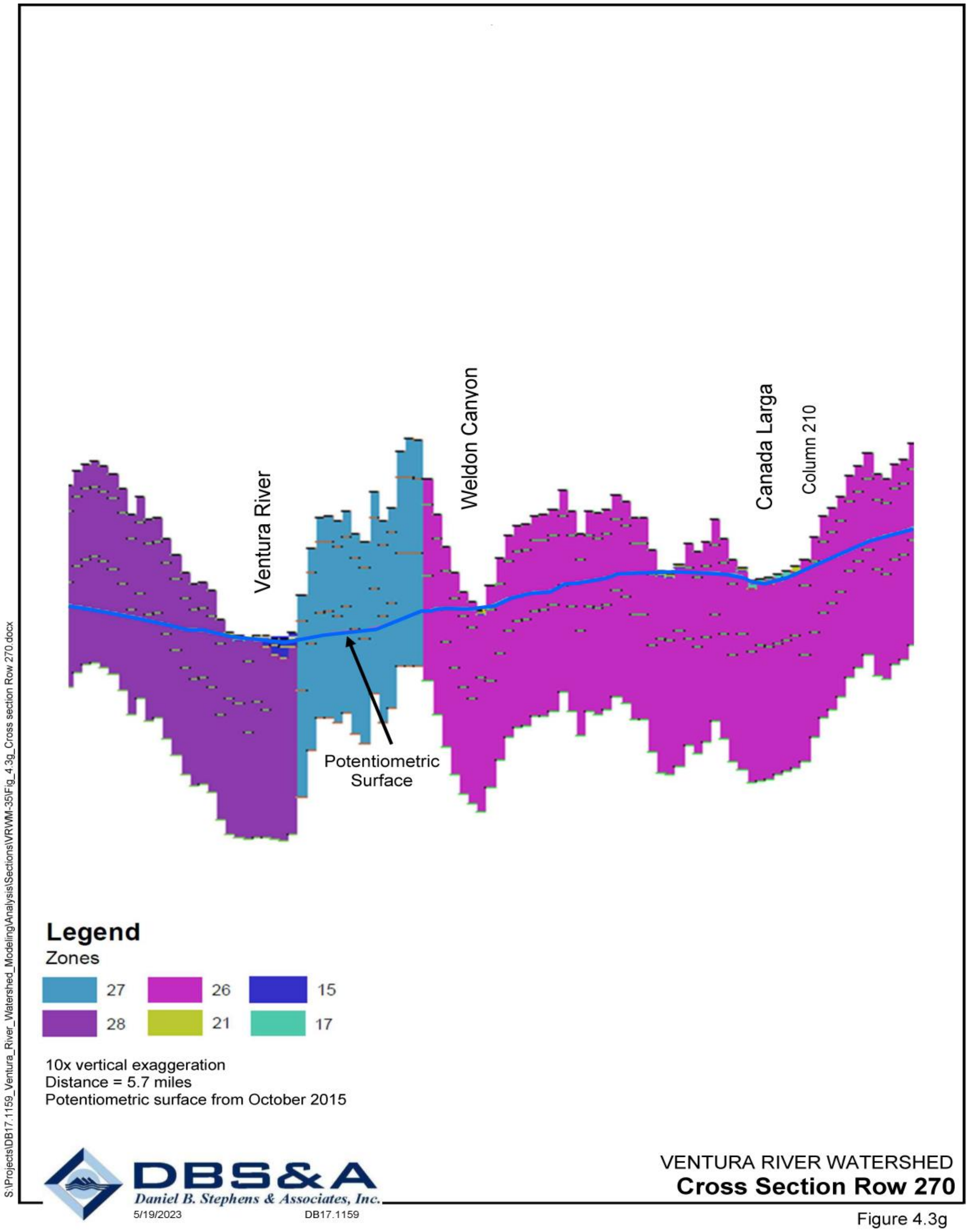

Figure 4.3g Cross Section Row 270

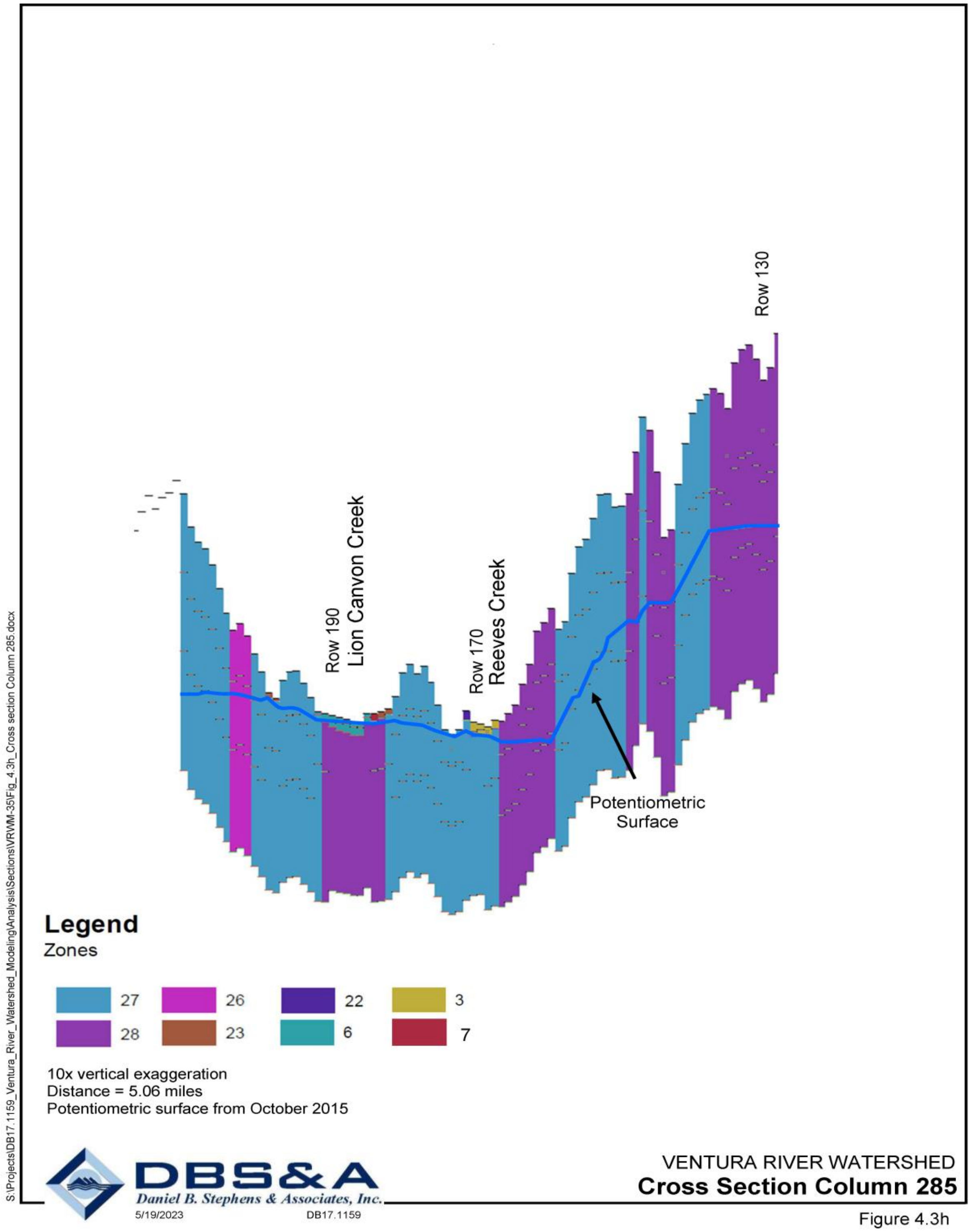

Figure 4.3.h Cross Section Column 285

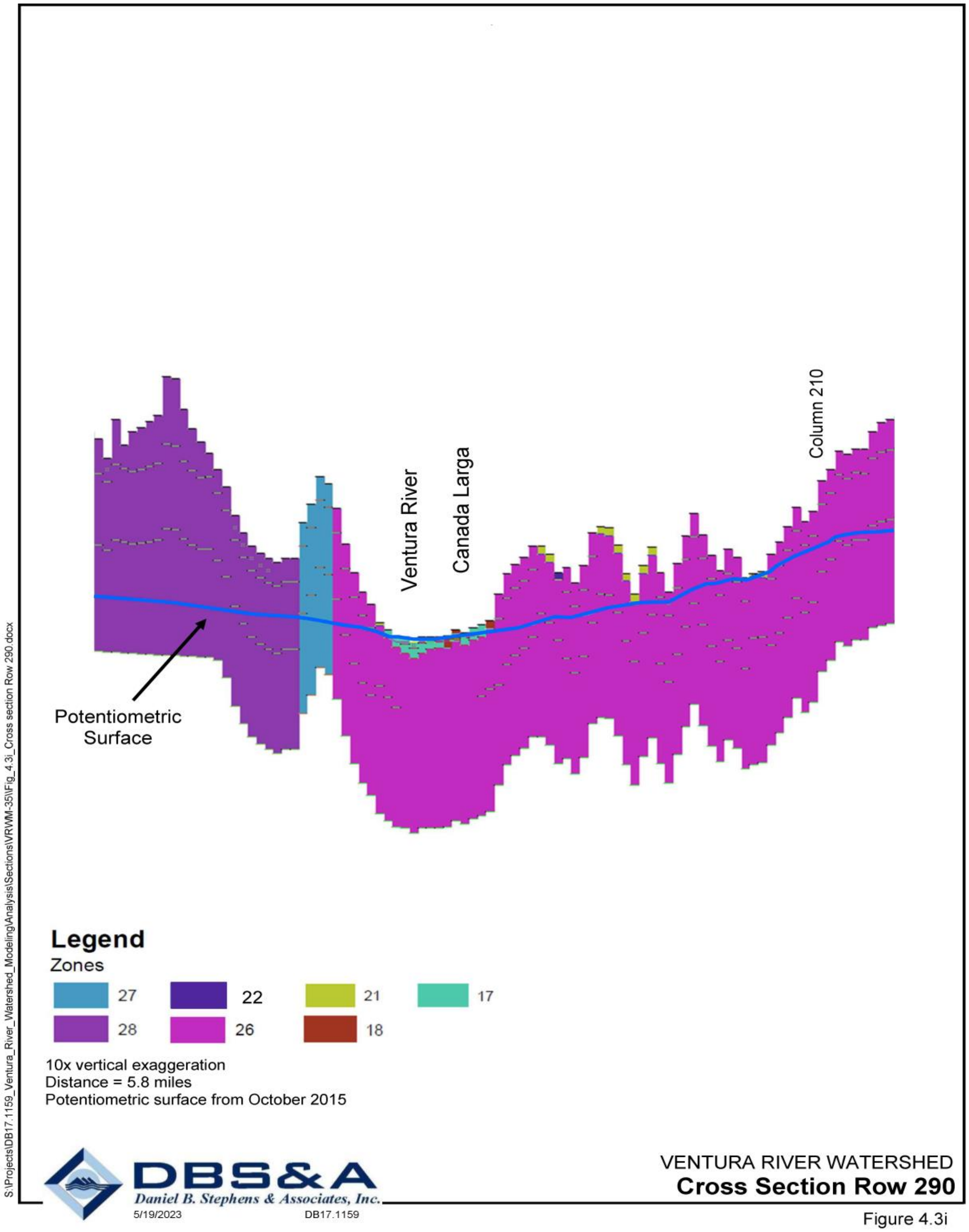

Figure 4.3.i Cross Section Row 290

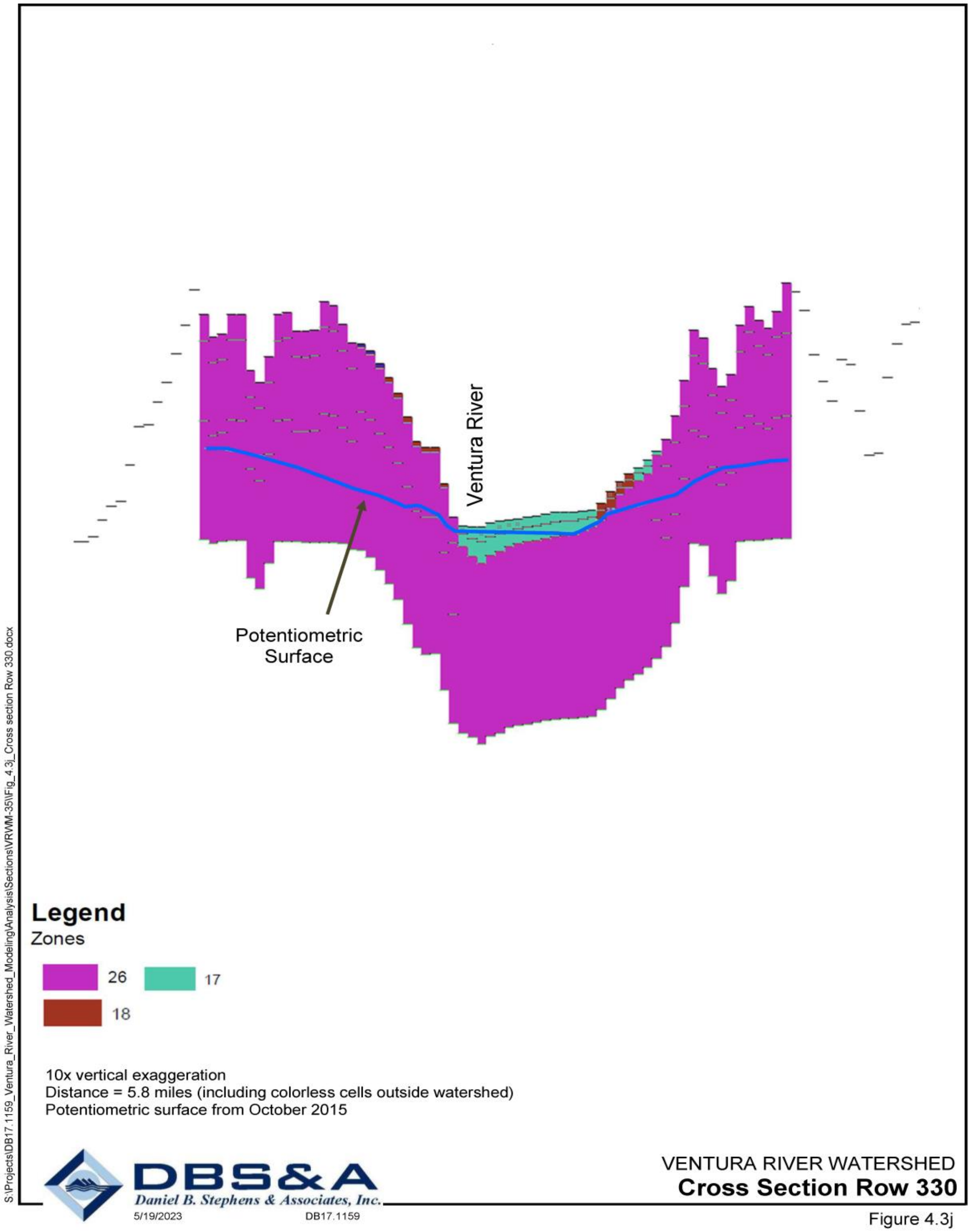

Figure 4.3j Cross Section Row 330

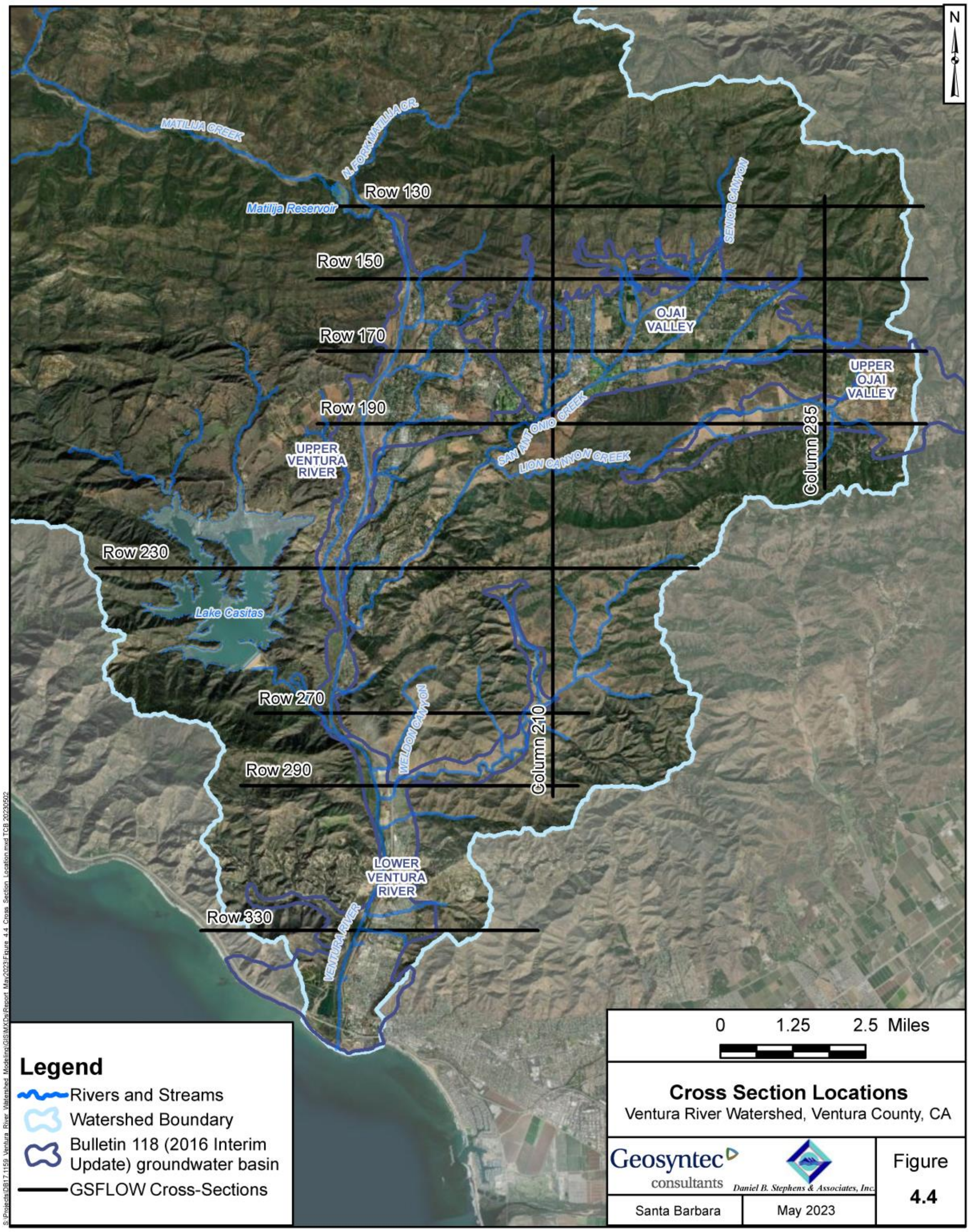

Figure 4.4 Cross Section Locations

4.4 Boundary Conditions

Groundwater model boundary conditions govern interaction of the modeled groundwater system with surrounding features that may provide inflow or outflow of water from the groundwater model domain. No-flow boundaries were assigned to the bottom model layer (representing bedrock in the entire domain). Horizontally, no-flow boundaries were also simulated for most of the active domain, except for areas east of Upper Ojai Basin (mostly representing inflow to the basin) and area at the terminus end of Lower Ventura River Basin (mostly representing outflow to the ocean). Figure 4.6 presents the model boundary conditions. MODFLOW model boundary conditions and how they are implemented are described in the following sections.

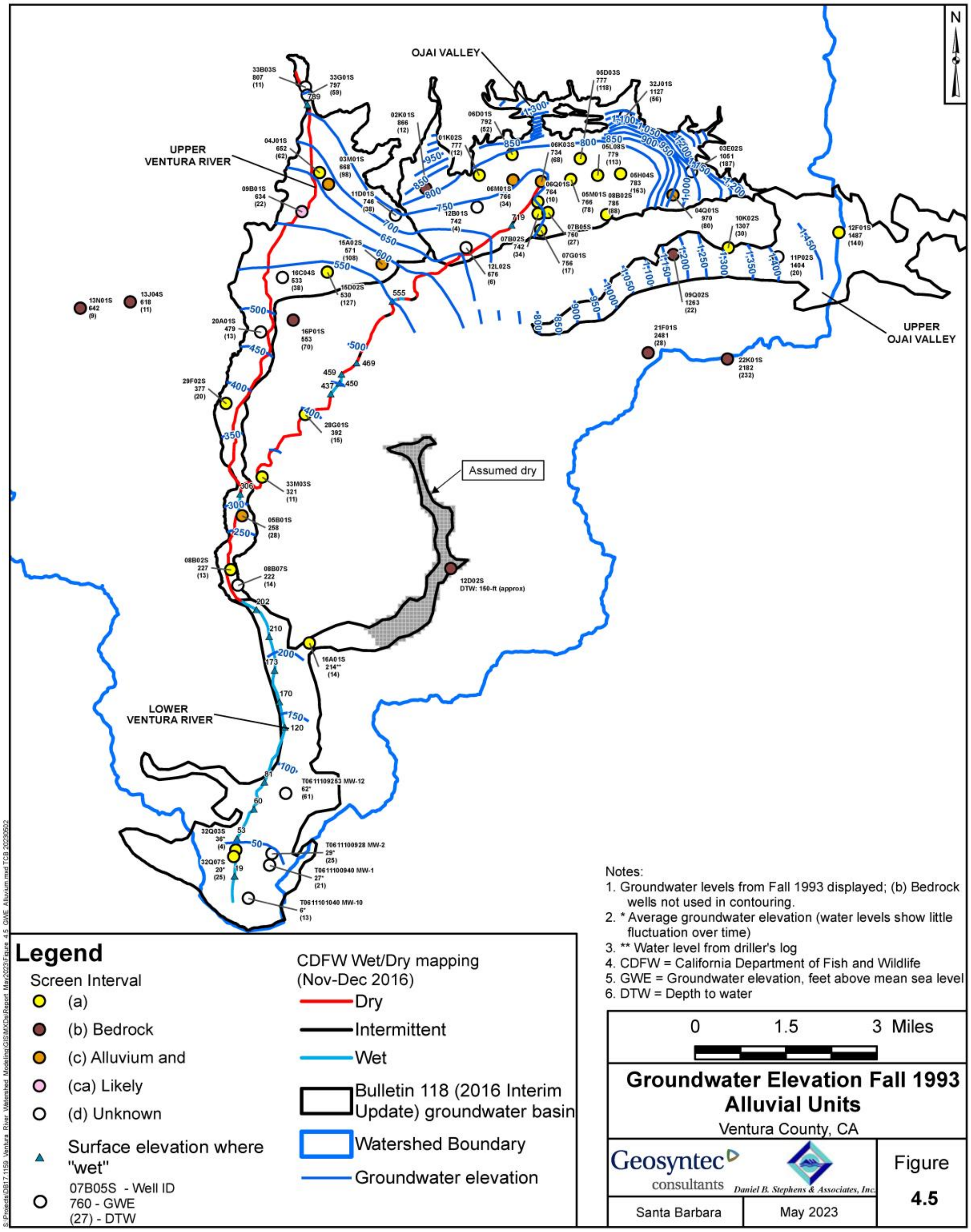

Figure 4.5 Groundwater Elevation Fall 1993 Alluvial Units

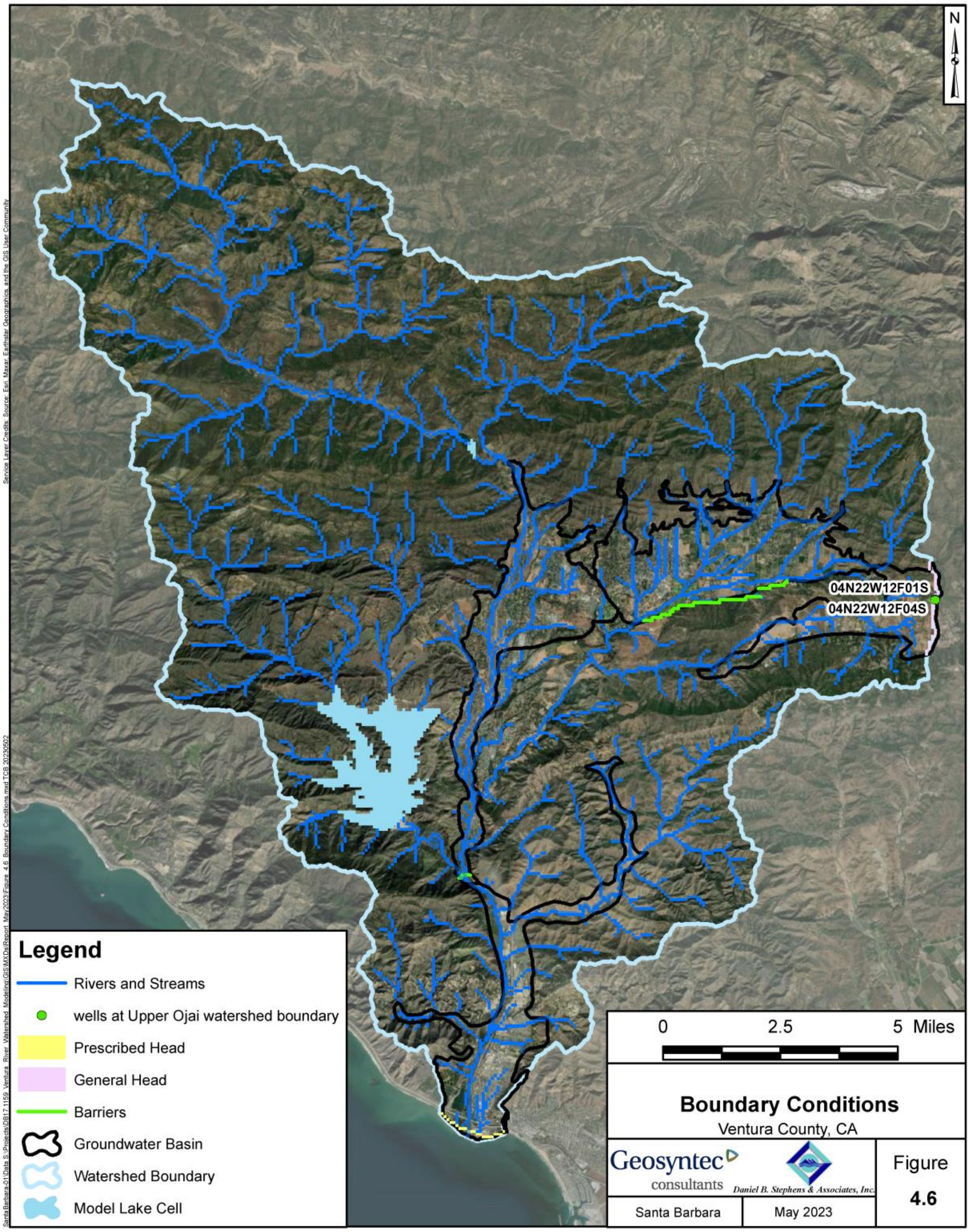

Figure 4.6 Boundary Conditions

4.4.1 Constant Head Boundary (CHD)

Groundwater outflow and/or inflow at the Pacific Ocean is represented by a Constant Head Boundary (CHD; also referred to as “Prescribed Head Boundary”), and prescribed head[18] values at the ocean boundary were based on average sea level adjusted for higher salinity (2.5 ft amsl). Prescribed head values at this location do not vary over time. CHD was applied to cells in all model active layers along that boundary.

4.4.2 General Head Boundary (GHB)

Groundwater inflow and/or outflow at the watershed boundary in the Upper Ojai Basin was represented with a General Head Boundary (GHB). GHB requires assigning a head value and a conductance term for each cell. Inflow or outflow along the boundary is calculated as the conductance term multiplied by the difference between the simulated head within the model domain and the assigned head at the boundary. Head in the GHB boundary was assigned to be constant with time and was based on observed measurements at two wells (04N22W12F01S and 04N22W1204S; see Figure 4.6). The head at the cell where the two wells are located was set at 1,500 ft amsl at all times. Each cell north and south of that cell along that boundary was assigned a head value that is 5 feet higher than the cell adjacent to it along the boundary based on the topographic grade.

In MODFLOW, the conductance is described as having units of length-squared per time (L^2/T) and is equal to KLW/M where K is hydraulic conductivity, L is the length of the boundary, W is the width of the boundary, and M is distance from that cell to the boundary. A conductance term of 1,500 ft^2/day was assigned in alluvium cells along the boundary. This is consistent with K of 150 ft/day, W of 330 ft, and assumed saturated thickness (L) of 20 ft, and distance (M) of two model cells of 660 ft. Conductance in bedrock cells was assigned an order of magnitude less conductance (150 ft^2/day).

4.4.3 Streamflow Routing (SFR)

Streams within the model are simulated by the MODFLOW Streamflow Routing (SFR) Package. The stream network is represented by 768 stream segments (Figure 4.6). Each stream segment has one or more stream reach (i.e., model

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[18] Hydraulic head (often referred to as “head”) is an indicator of the total energy available to move ground water through an aquifer, and is the elevation to which water will rise in a well.

cell). An additional 23 stream segments were added to the model to simulate diversionary segments (e.g., Robles Canal diversion and other streamflow diversions in Section 3.4), and tributary segments (e.g., WWTP inflows).

The stream widths used in the SFR package are presented in Figure 4.4. The widths were calculated using the following regression relation developed for the VSWHM (Tetra Tech, 2009),

$$\text{Width[ft]} = 1.2576 \times (\text{Drainage Area[acres]})^{0.383}$$

For the mainstem Ventura River and San Antonio Creek, as well as some storm drains, ratings tables were used for the SFR rather than an estimated stream width. These locations are also shown in Figure 4.7. The ratings tables provide a stream width and flow depth as a function of flow rate at each stream segment along the river and were obtained by running hydraulic Hydrologic Engineering Center-River Analyses System (HEC-RAS) models obtained from the VCWPD. This approach enabled more accurate estimation of the wetted stream width which is relevant for stream exchanges with groundwater in the gaining and losing reaches.

Streambed hydraulic conductivity (SFR_K) was found to be a critical parameter during model calibration. SFR_K values ranged between 0.01 ft/day to 1.5 ft/day and are discussed in Section 5.

4.4.4 Lake Package (LAK)

Lake Casitas and Matilija Reservoir (Figure 1.3) were simulated using the MODFLOW Lake Package (LAK) (Merritt and Konikow, 2000). In the Lake Package, the lakes are represented as a group of Layer 1 cells, extending downward from the upper surface of the grid to the bottom of the Lake. The Lake cells exchange water with active cells bordering the lake cell in Layer 1, and with cells in Layer 2 underneath the lake cell. Water exchange rate is determined by the difference in heads of the lake and the aquifer, multiplied by a user-specified leakance term that represents the resistance to flow through the material of the lakebed. The variations of lake stages (storage) are determined by independent water budgets computed for each lake in the model grid, which takes into consideration the lake/aquifer interaction described above, in addition to the rate of lake atmospheric recharge and evaporation, overland runoff, and the rate of any direct withdrawal from, or augmentation of, the lake volume (Merritt and Konikow, 2000).

Additional details on the bathymetries, storage, and releases from Lake Casitas and Matilija Reservoir are provided in Section 3.3.

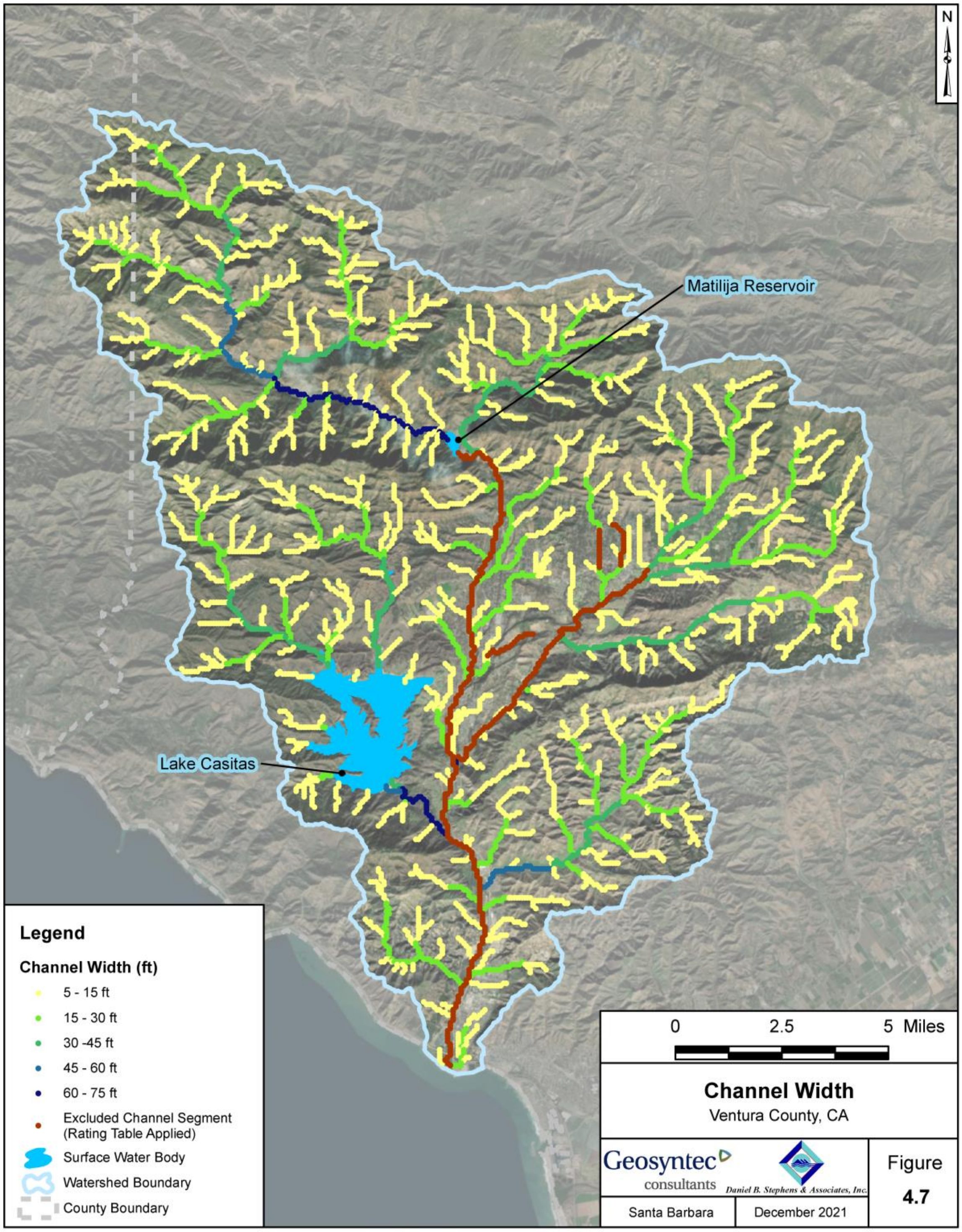


Figure 4.7 Channel Width

4.4.5 Pumping

Groundwater pumping was assigned using the MODFLOW Multi-Node Well (MNW2) package (Konikow et al., 2009). Pumping values were assigned based on measured values reported to the OBGMA in the Ojai Basin, reported values for most municipal wells, and were otherwise estimated based on the results of the water supply/demand analysis (Section 2). Pumping values for the Ojai Basin and municipal wells are presented in Appendix A. Figure 4.8 displays average simulated pumping rates for each well in the VRW implemented in GSFLOW. Pumping values at each well varied for each stress period (i.e., months) based on available pumping records, well construction/destruction dates, and the results of the supply/demand analysis.

In the MNW2 package, the pumping rate and the layers that the well is penetrating are assigned to each well. MNW2 dynamically distributes the pumping from each layer. MNW2 also shuts off the pumping, when simulated water levels are below certain user-assigned elevation (usually the bottom of the screen). When water levels rise again, pumping is resumed from the well.

4.4.6 OWTS Recharge

Domestic OWTS recharge to groundwater was represented with the Unsaturated Zone Flow (UZF) package, and a recharge rate of 200 gallons per day was assigned to each system. Figure 4.9 displays the number of OWTS per HRU.

4.4.7 Riparian ET

Riparian vegetation along rivers and creeks increase the ET from shallow groundwater, notably reducing streamflow during low flow periods. Shallow groundwater ET is represented in the model by the UZF package that includes the extinction depth as an input parameter. Extinction depth refers to how close the groundwater table to the top of model Layer 1 needs to be for shallow groundwater ET to occur. In most of the model cells an extinction depth of 1.0 foot was assigned. In areas with observed riparian vegetation the extinction depth was set between 5 and 13.5 feet to reflect the greater rooting depth, and as determined during model calibration (see Section 5).

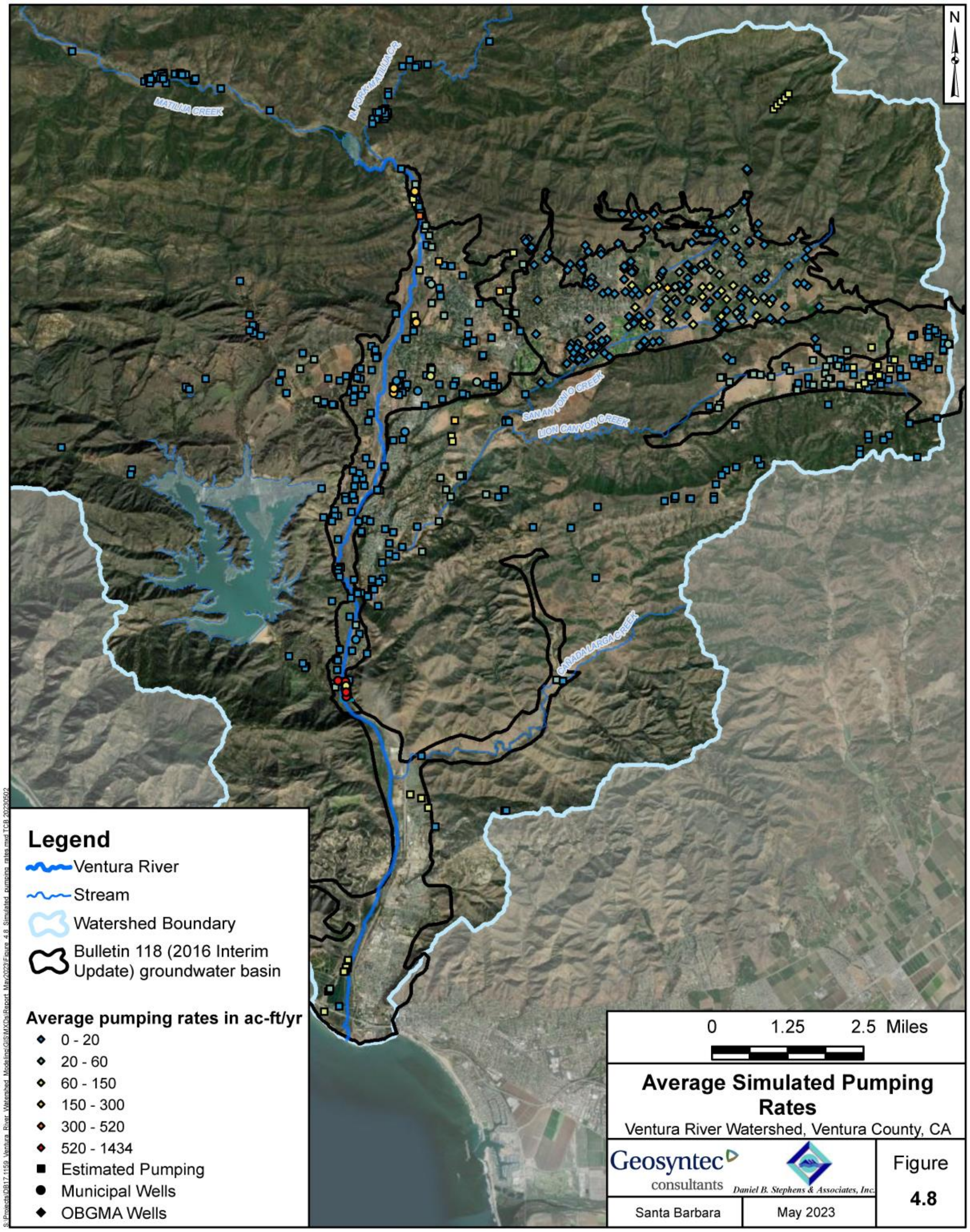


Figure 4.8 Average Simulated Pumping Rates

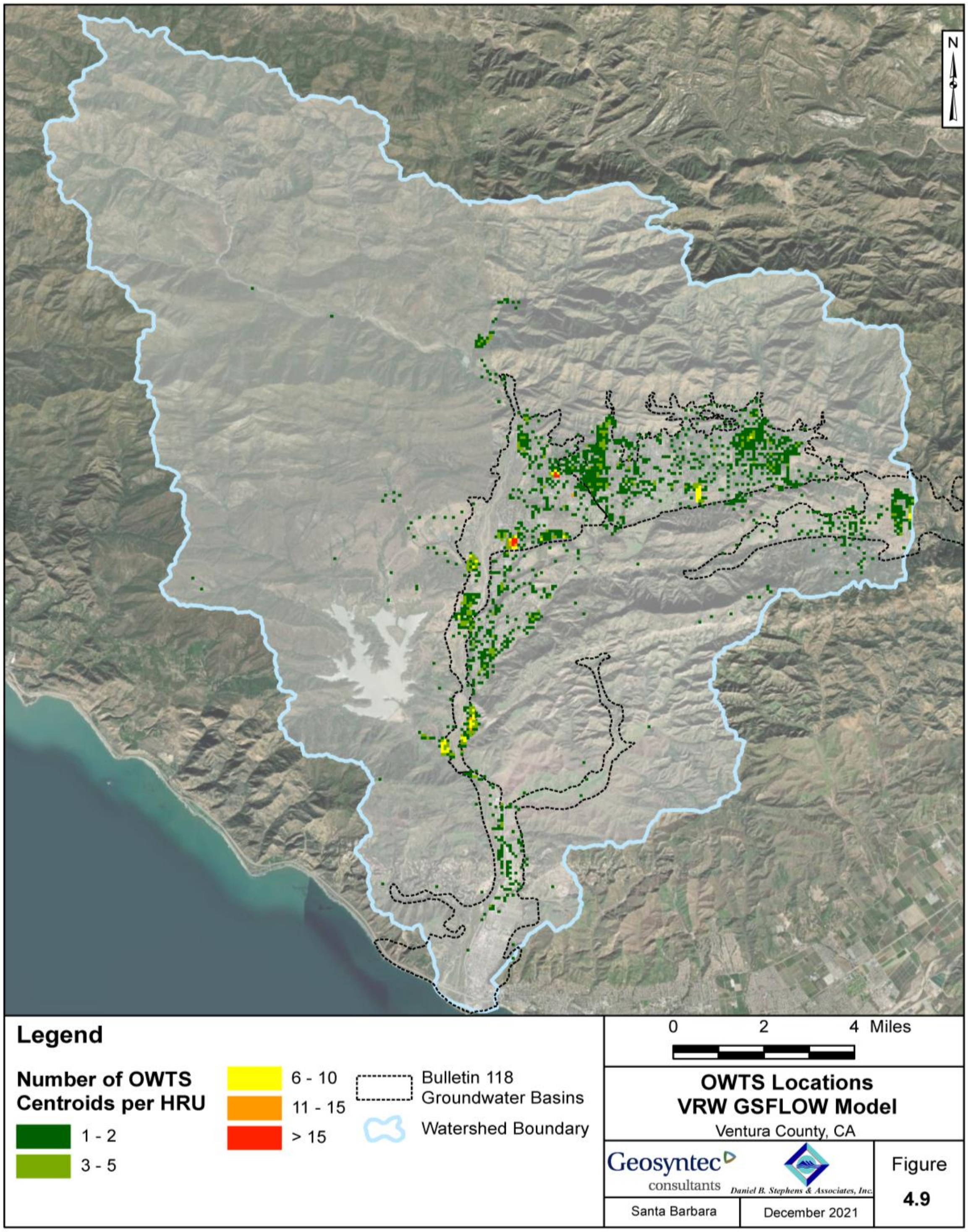


Figure 4.9 OWTS Locations VRW GSFLOW Model

Data sets used to inform where riparian vegetation existed consisted of the *Arundo donax* distribution dataset (California Invasive Plant Council, 2011), Natural Communities Commonly Associated with Groundwater dataset (Klausmeyer et al., 2018), and the National Wetlands Inventory - Riparian Areas dataset (USFWS, 2009). These data sets are mapped in Figure 4.10 Distribution of *Arundo donax*
Ventura River Watershed

, Figure 4.11 Distribution of Phreatophytic Vegetation
Ventura River Watershed, and Figure 4.12 Distribution of Riparian Vegetation
Ventura River Watershed, respectively. The *Arundo donax* dataset (Figure 4.10 Distribution of *Arundo donax*
Ventura River Watershed

) was modified to represent eradication efforts in the watershed through 2008, mostly resulting in removal in the Upper Ventura River and Matilija Creek.

Additionally, the potential evapotranspiration (PET) coefficients within PRMS were increased in cells that contained *Arundo donax* based on the fraction of coverage in the cells and assuming up to 24 feet per year of PET (California Invasive Plant Council, 2011). The PET represents ET in ideal conditions (e.g., with sufficient water and sunlight). The actual ET (AET) as simulated in the model that includes water limitation is lower.

4.4.8 Exchange of Flows between MODFLOW and PRMS

At the end of each time step (i.e., each day), flows are exchanged between PRMS and MODFLOW. While these flows are considered internal flows within the GSFLOW model, they are also boundary flows to the MODFLOW domain. These flows include:

- Groundwater recharge from the soil zone (PRMS) to the unsaturated and saturated zones (MODFLOW). This is referred to as gravity drainage in GSFLOW documentation (Markstrom et al., 2008). Gravity drainage is mostly controlled by the available water in the soil zone, by PRMS parameter ssr2gw_rate (Section 3.6), and by the MODFLOW parameter of vertical hydraulic conductivity of the unsaturated zone (VKS).

- Groundwater discharge from the saturated zone into the soil zone. The rate of discharge is dependent on the hydraulic conductivity and on groundwater elevation relative to the altitude of the soil-zone. Groundwater discharge, which is also referred to as surface leakage, is an outflow from MODFLOW and an inflow to PRMS.

- Surface runoff and interflow from PRMS to streams and lakes. In addition to flow exchange between the saturated zone and streams and lakes (both within MODFLOW as discussed in Sections 4.4.3 and 4.4.4), GSFLOW allows water to flow directly from PRMS HRUs to streams and

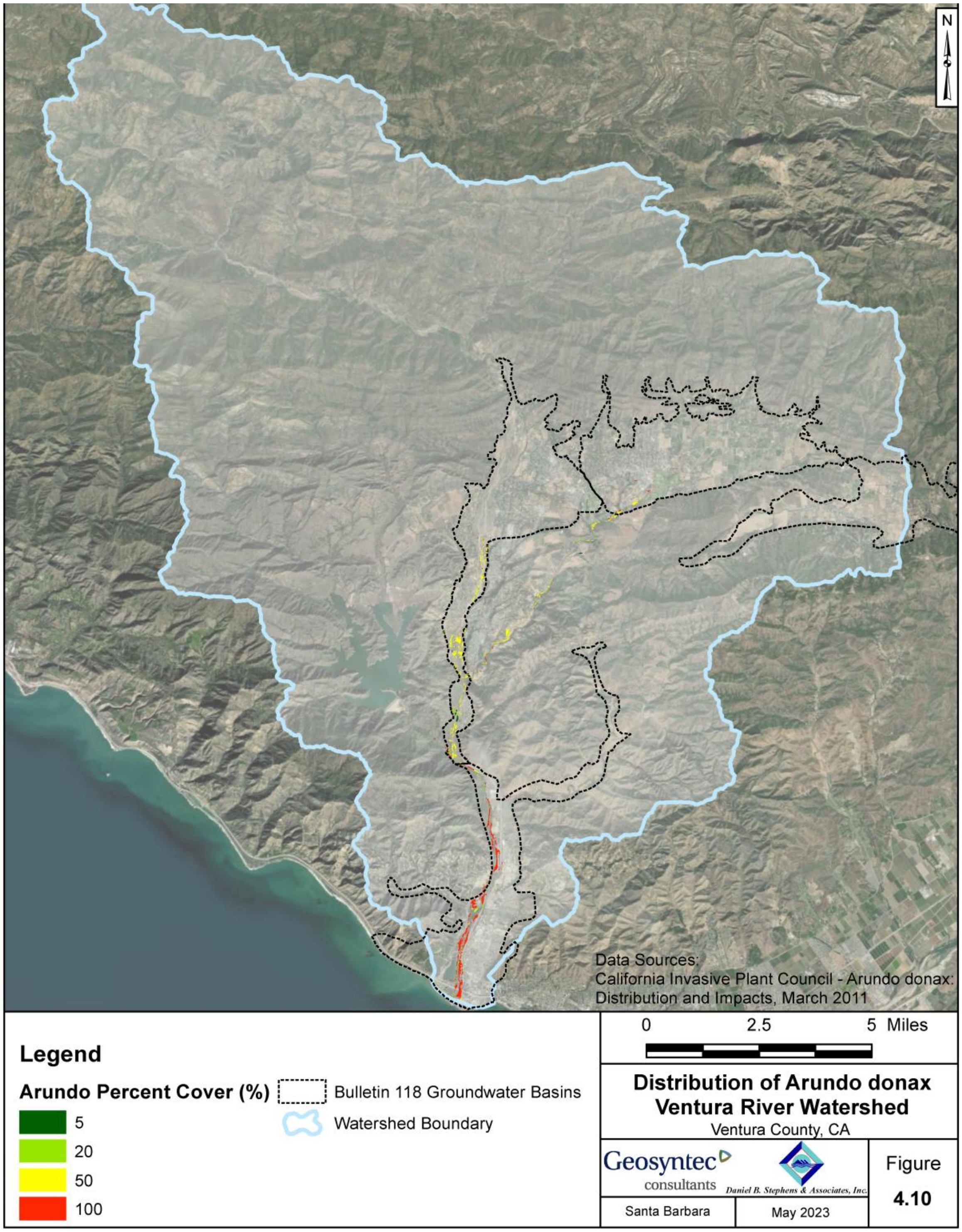


Figure 4.10 Distribution of *Arundo donax*
Ventura River Watershed

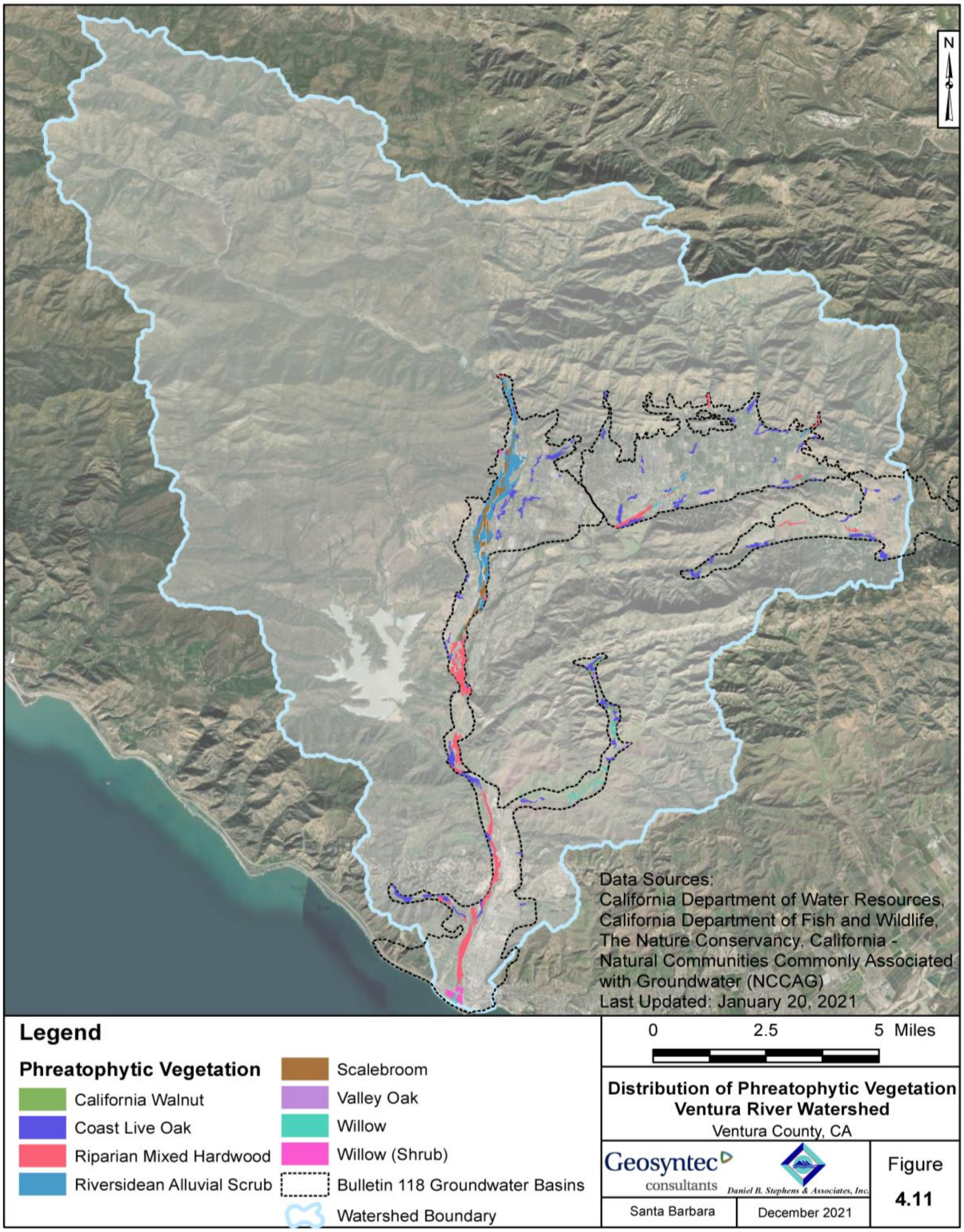


Figure 4.11 Distribution of Phreatophytic Vegetation Ventura River Watershed

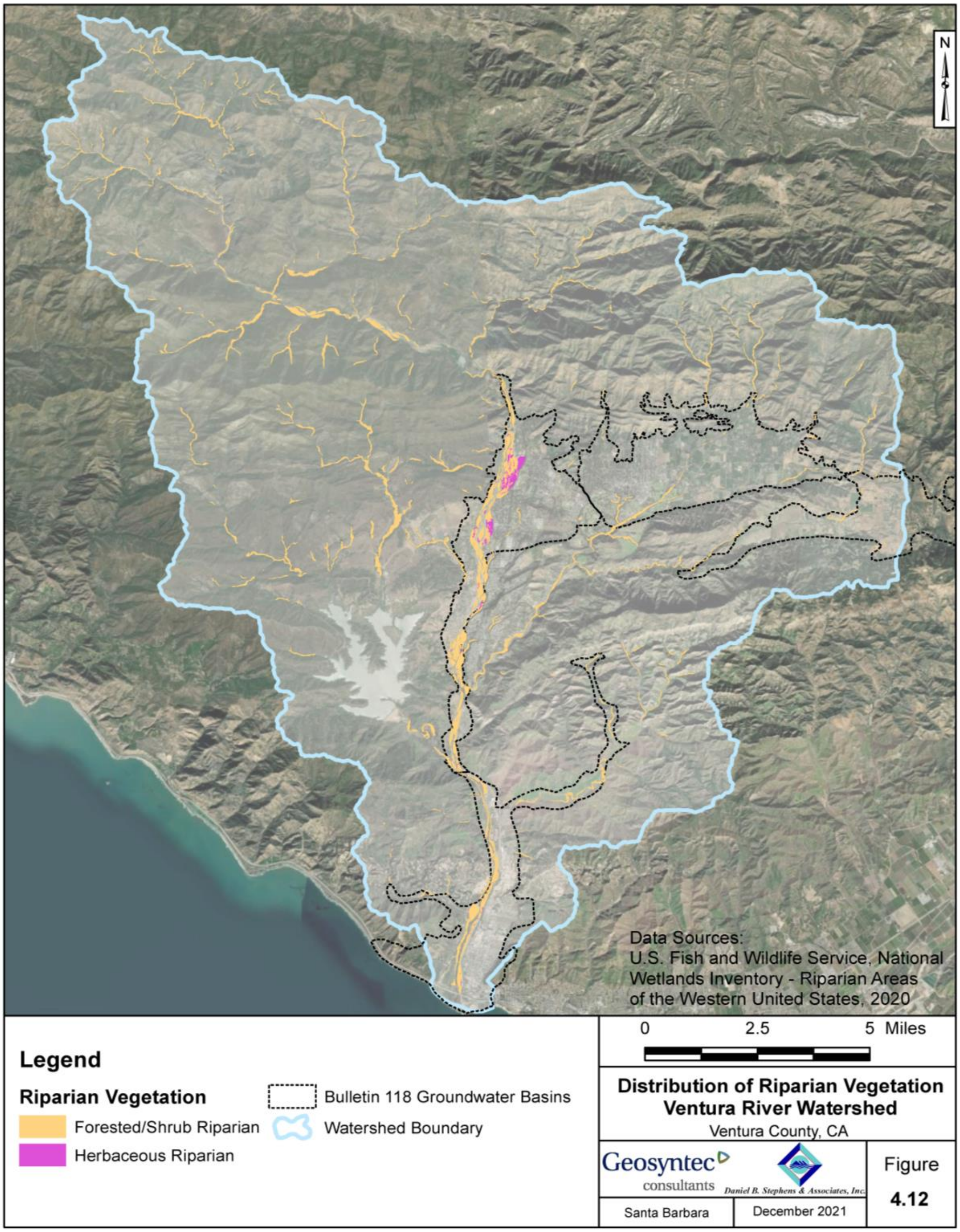


Figure 4.12 Distribution of Riparian Vegetation Ventura River Watershed

lakes. Such flows can be in the form of surface runoff and interflow. Surface runoff can be either flows in excess of infiltration capacity of the soil (Hortonian surface runoff), or water in the soil zone that is above its capacity (Dunnian surface runoff). Interflow to streams and lakes is flow from the soil zone of an HRU to a stream segment or to a lake HRU. Interflow is affected by the available water in the soil zone and by PRMS parameters slowcoef_lin and slowcoef_sq (Section 3.6).

4.5 Parameter Zones

The model domain was separated into "parameter zones," and a single value of each MODFLOW model parameter (e.g., hydraulic conductivity, specific yield) was assigned to all cells within a parameter zone. Initial model parameter zones were assigned based on geologic analyses, and model zones were refined during model calibration. Model zones for each model layer are displayed in Figure 4.13a Zones in GSFLOW Layer 1a through 4.13g and are also shown in the vertical cross sections at Figure 4.3a through 4.3j. Final assigned values of horizontal saturated hydraulic conductivity (Kx), vertical hydraulic conductivity (Kz), specific storage (Ss), specific yield (Sy), streambed hydraulic conductivity (SFR_K), and unsaturated zone vertical hydraulic conductivity (VKS) are discussed in Section 5, below.

4.6 Horizontal Flow Barriers

Certain geologic fault zones and the Foster Park submerged dam are represented with the horizontal flow barrier (HFB) MODFLOW package to reduce groundwater flow through those areas. HFB locations are shown on Figure 4.6. For HFBs, the "hydraulic characteristic" of the HFB is assigned in MODFLOW. The hydraulic characteristic represents the barrier hydraulic conductivity divided by its width. For the HFB south of Ojai (Santa Ana Fault, see Appendix C), the assigned hydraulic characteristic is $1x10^{-6}$ day^{-1}. For the submerged dam, the hydraulic characteristic is $1x10^{-7}$ day^{-1}.

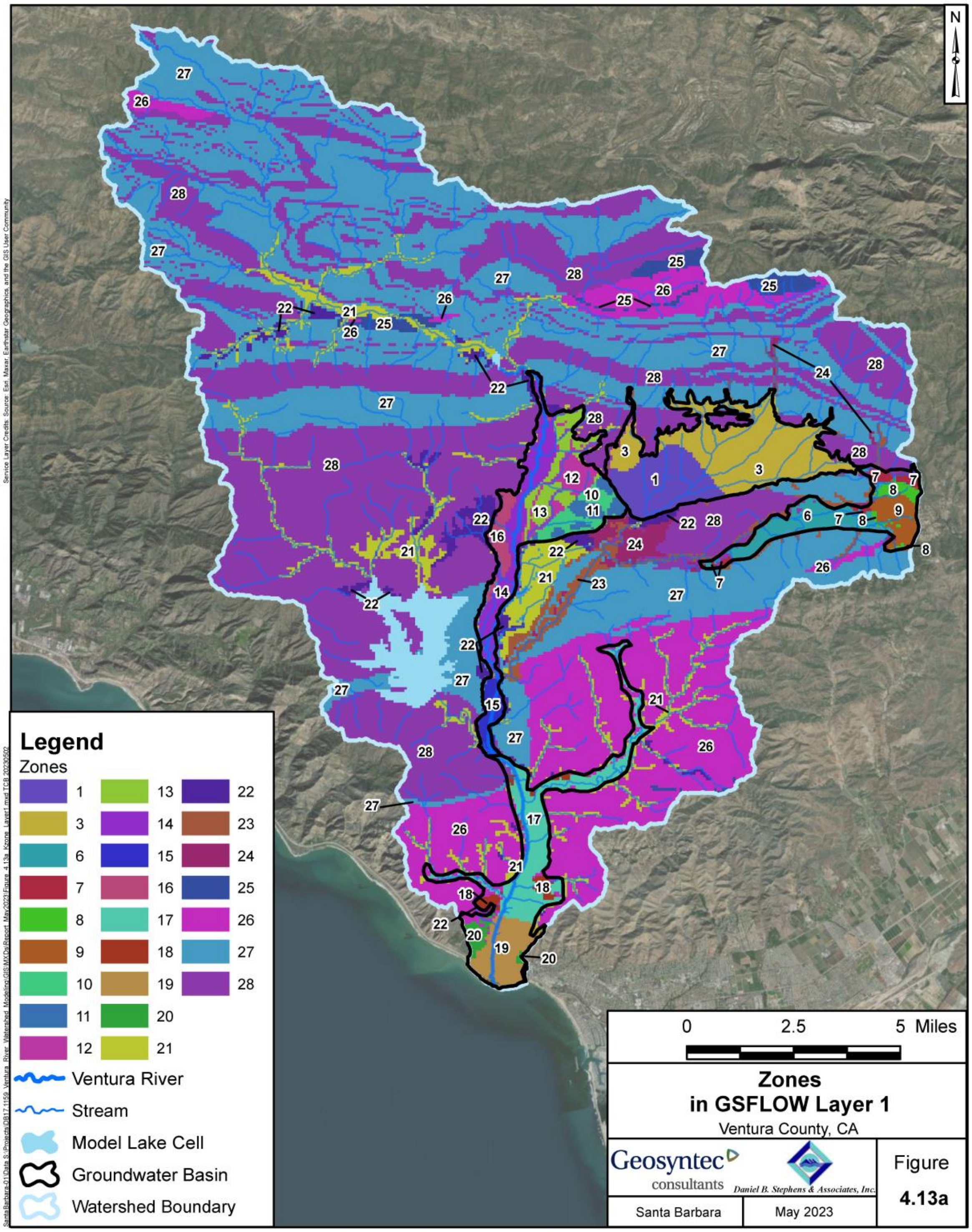


Figure 4.13a Zones in GSFLOW Layer 1

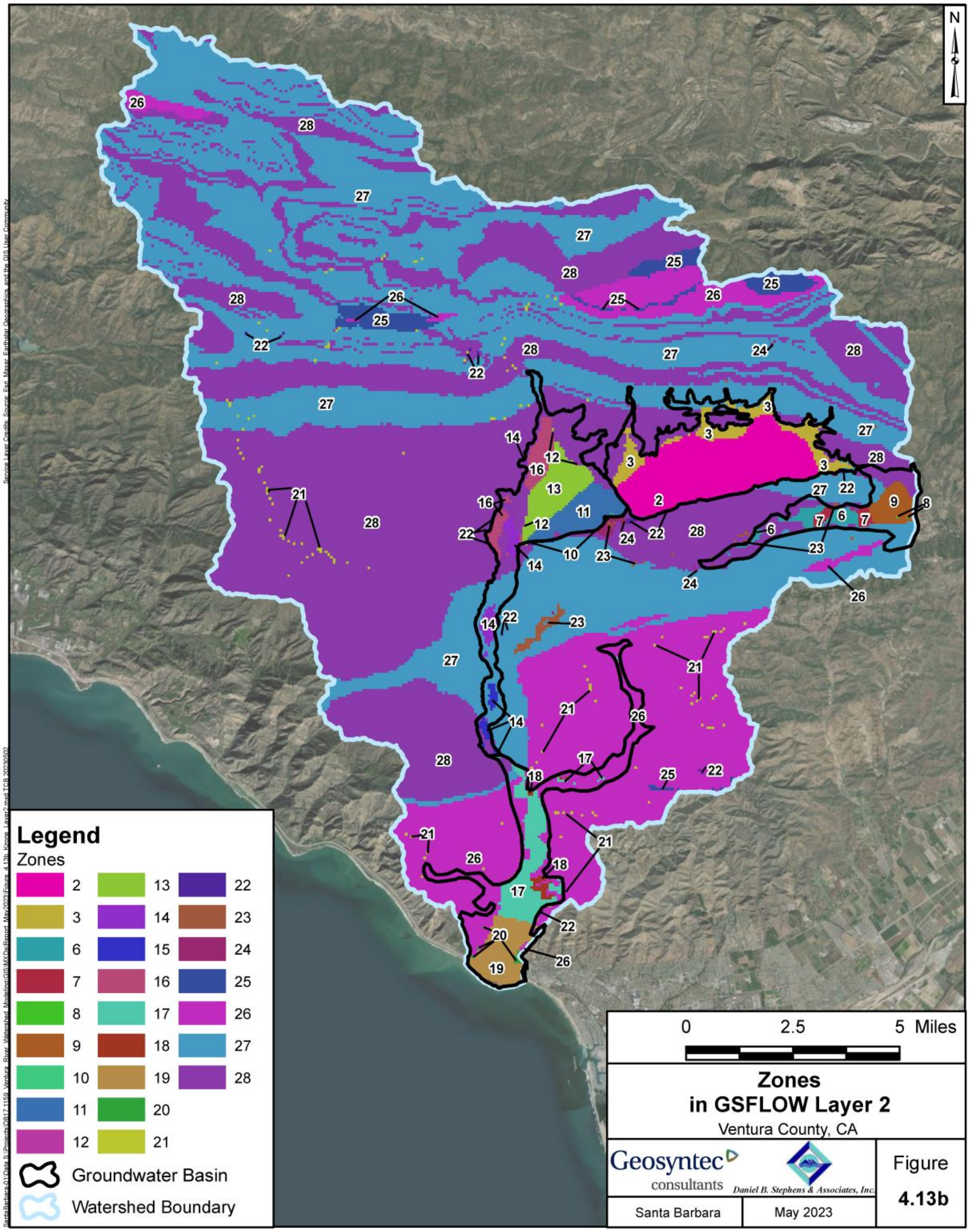


Figure 4.13b Zones in GSFLOW Layer 2

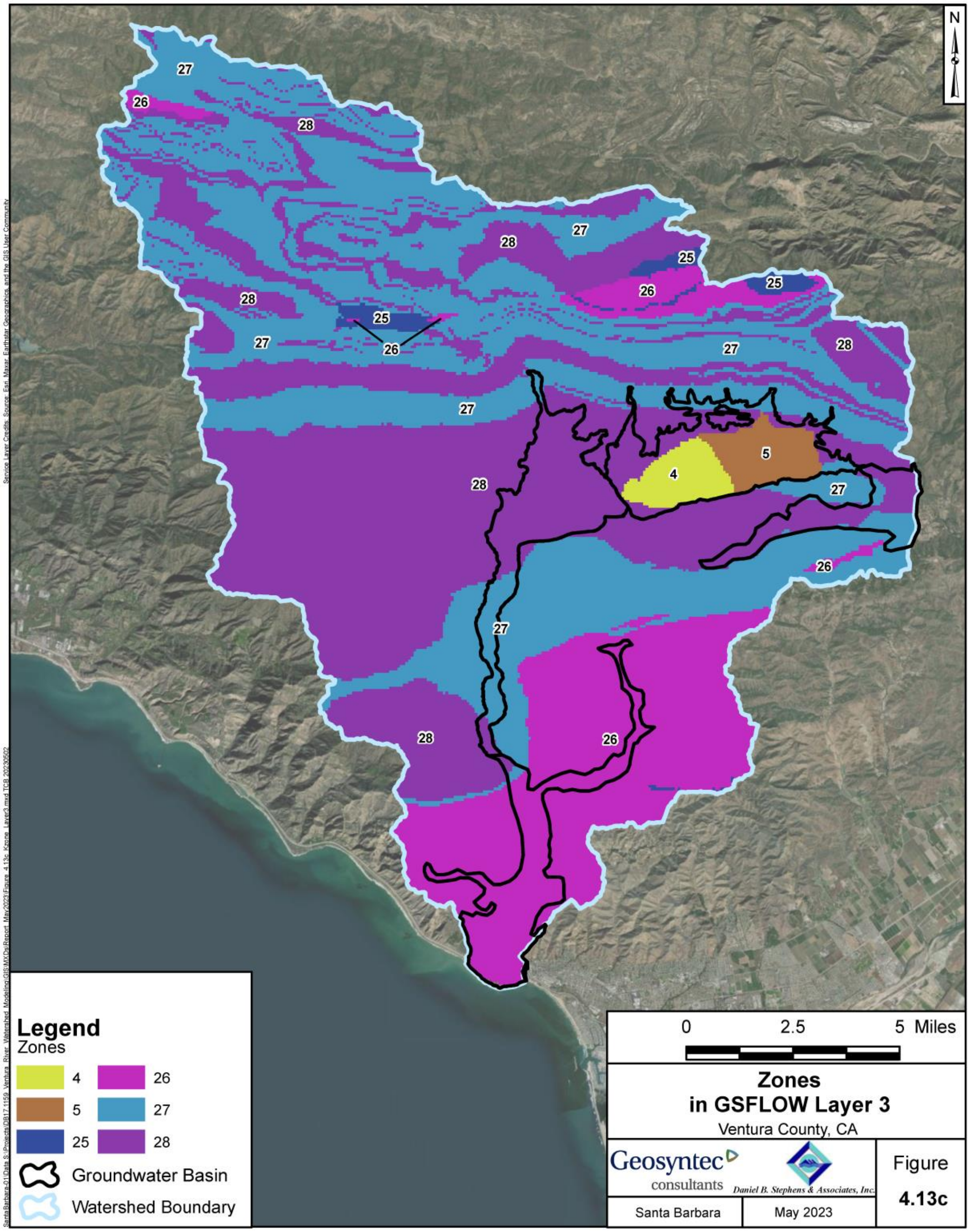


Figure 4.13c Zones in GSFLOW Layer 3

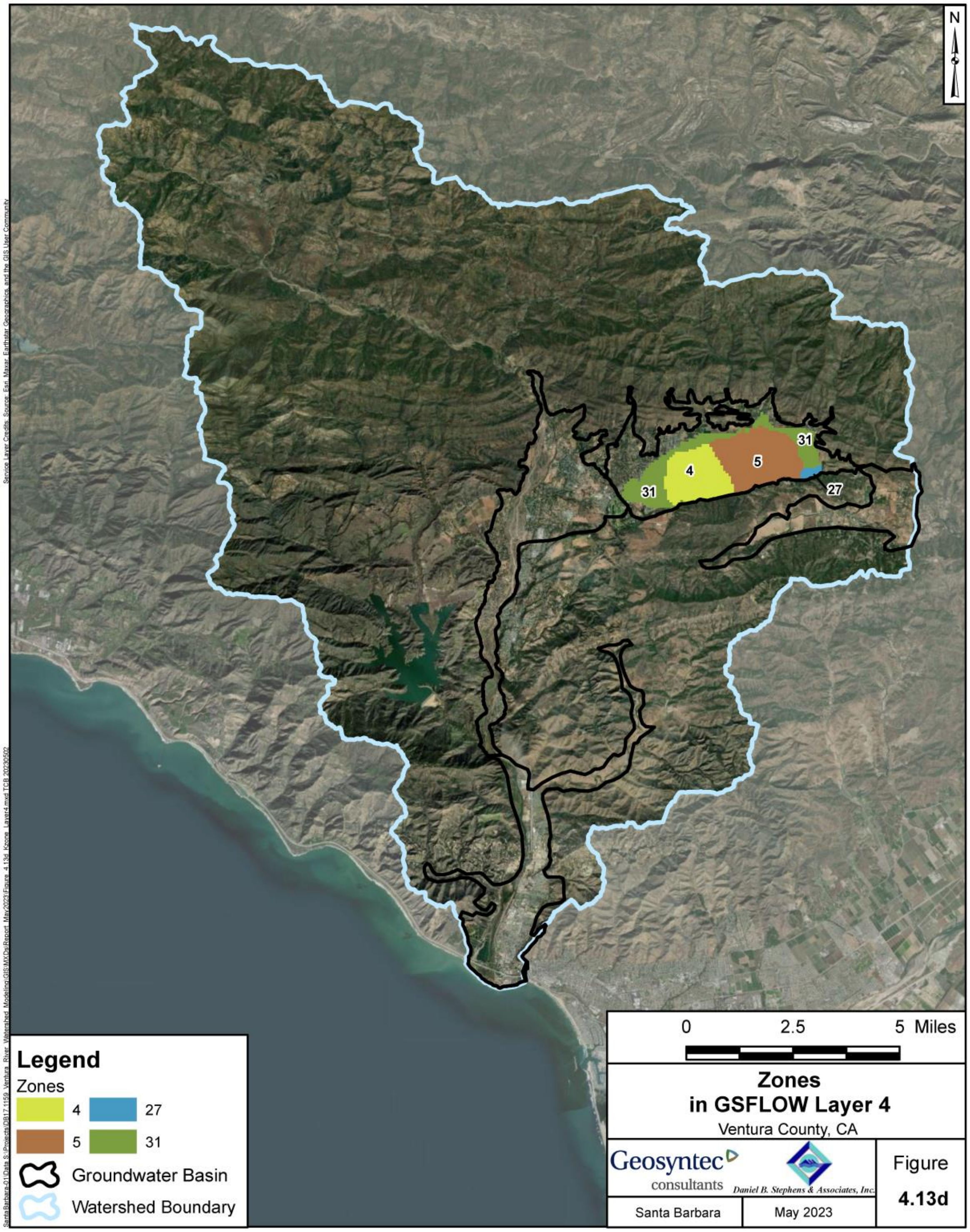


Figure 4.13d Zones in GSFLOW Layer 4

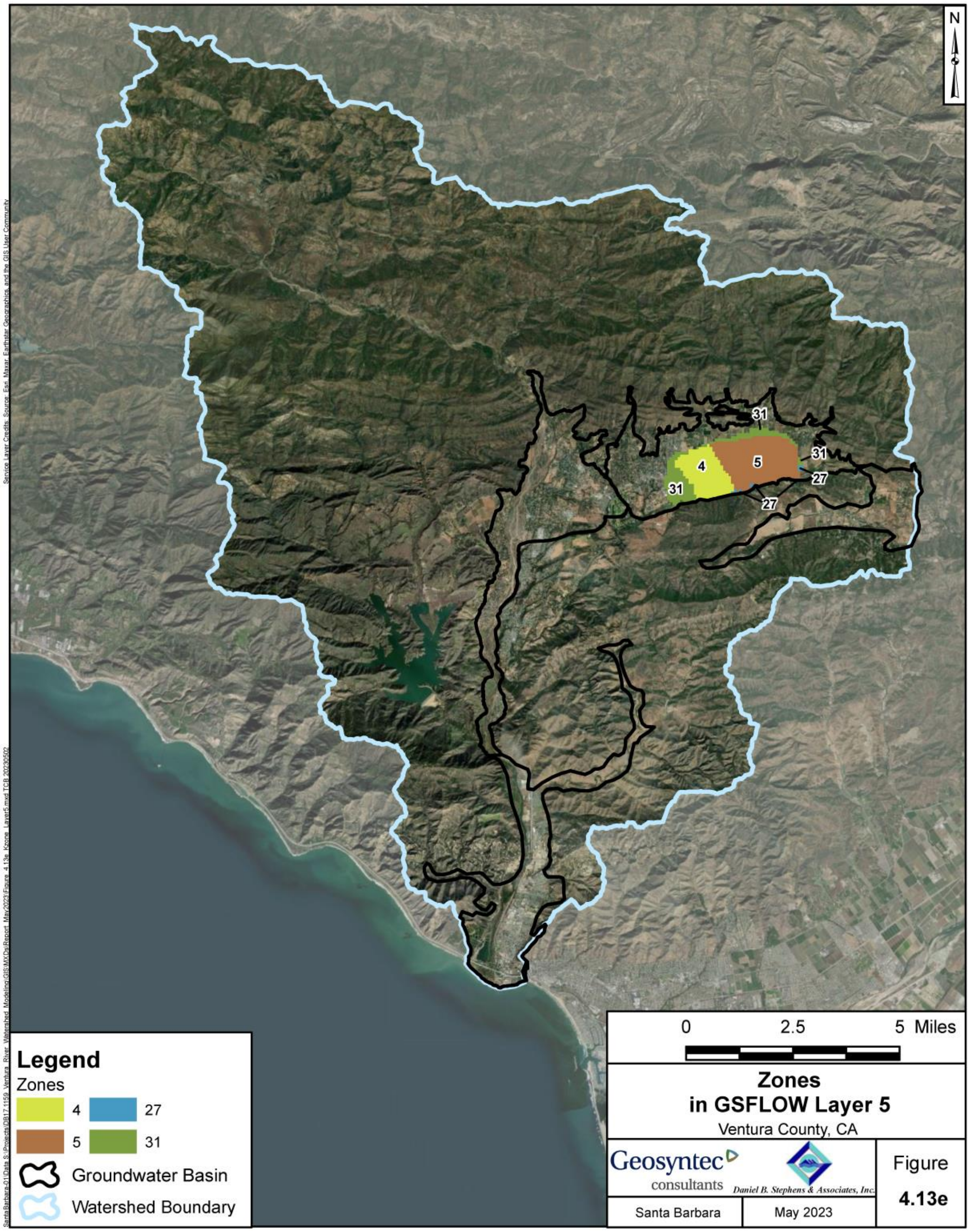


Figure 4.13e Zones in GSFLOW Layer 5

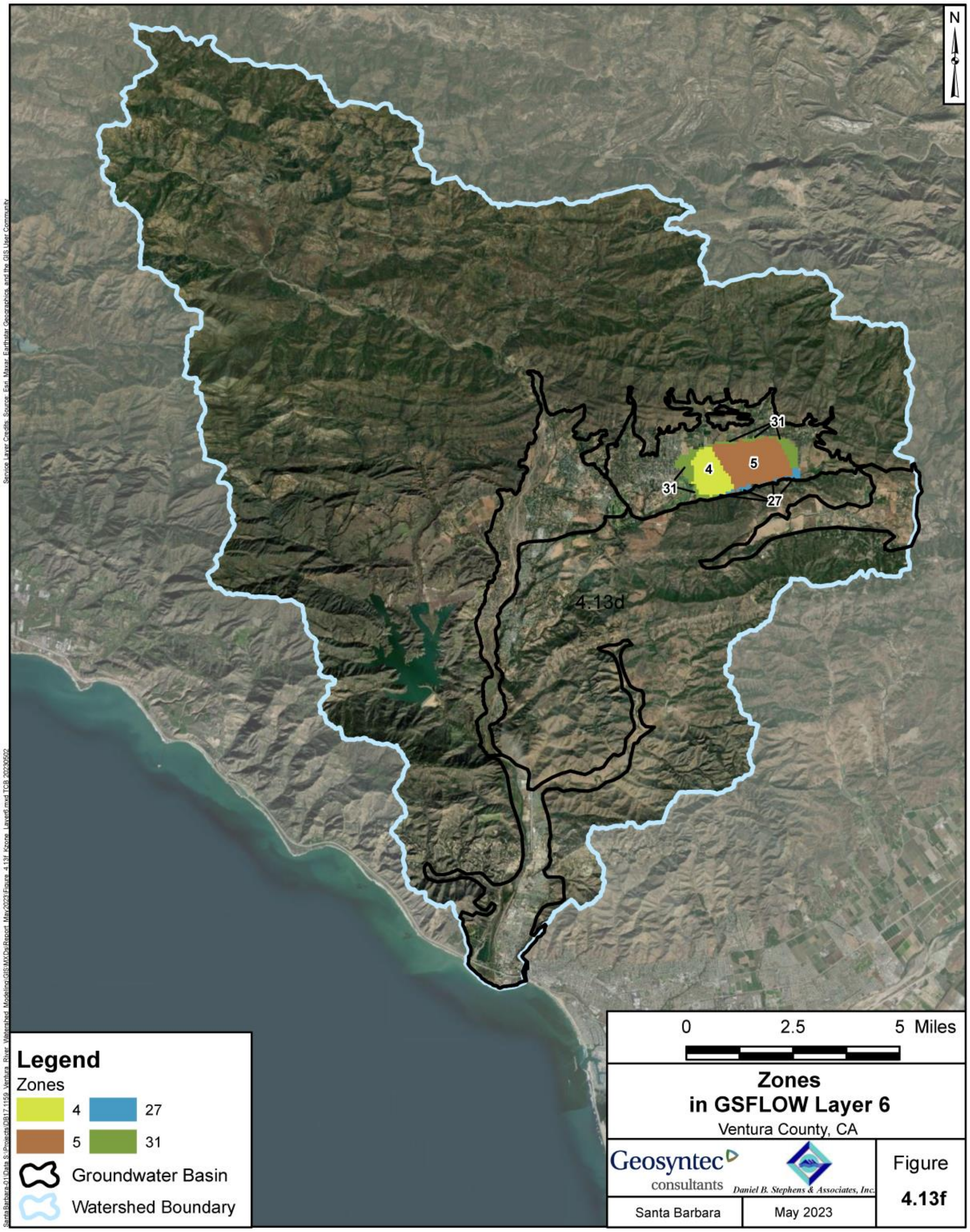


Figure 4.13f Zones in GSFLOW Layer 6

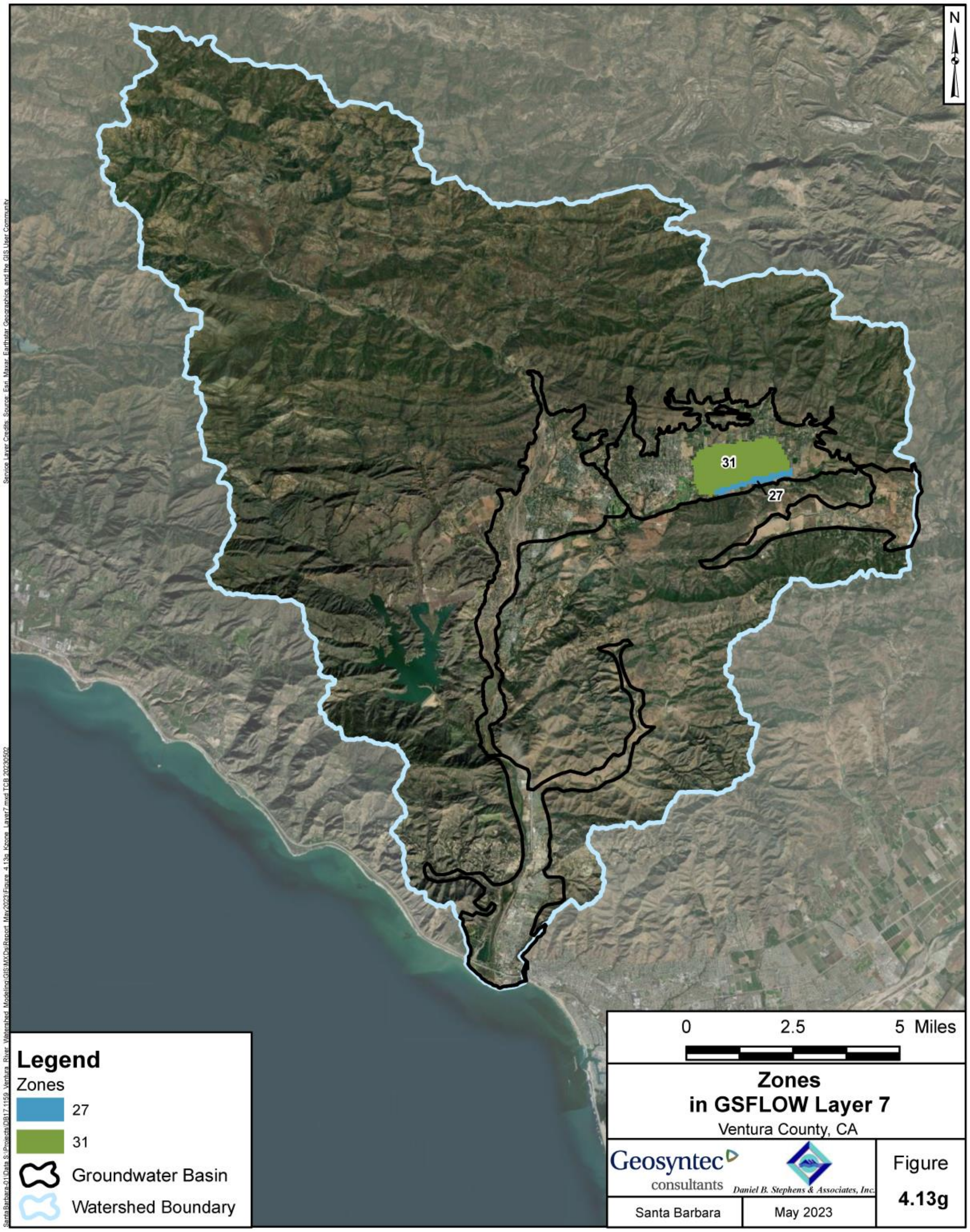


Figure 4.13g Zones in GSFLOW Layer 7

5 GSFLOW MODEL CALIBRATION AND VALIDATION

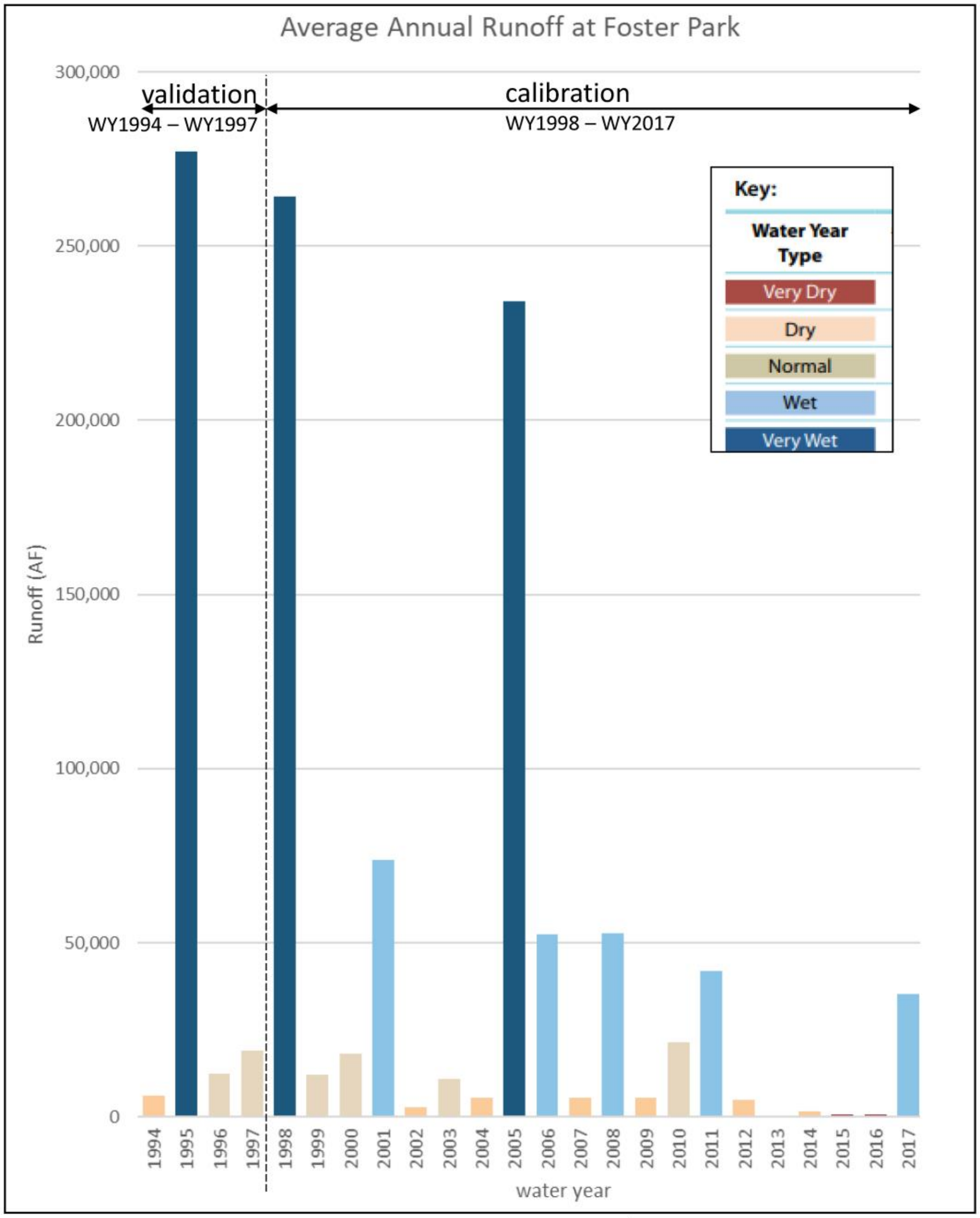
Model calibration is performed to demonstrate that the model reasonably simulates known historical conditions (DWR, 2016b). Calibration involves iterative adjustments of various model parameters until model results match historical observations within an agreed-to tolerance. Model validation is performed for a different historical time period than model calibration in order to demonstrate reasonable agreement between simulated and observed results for conditions that were not specifically used in calibration.

5.1 Calibration and Validation Periods

For the VRW GSFLOW Model, a single simulation was used for calibration and validation ("calibration/validation period") and was separated into a period used for calibration ("calibration period") and a period that was used for validation ("validation period").

The GSFLOW calibration/validation period comprises 24 years from WY1994 through WY2017 (October 1, 1993 through September 30, 2017). This period is constrained by limited groundwater pumping datasets prior to the mid-1990s and the assumption of fixed land-use (e.g., cropping types and extents) in the model. Additionally, the Thomas Fire in late 2017/early 2018 altered the watershed's hydrologic characteristics and potentially requires a different set of calibration parameters to correctly model streamflow and recharge. Therefore, using a longer modeling period (i.e., extending prior to WY1994 or after WY2017) was rejected because it would introduce additional uncertainty into many aspects of the model.

The calibration/validation period was divided into a 20-year calibration period (WY1998 through WY2017) and a four-year validation period (WY1994 through WY1997). The calibration and validation periods were altered from those outlined in the project *Final Study Plan* (Geosyntec and DBS&A, 2019) to enable both periods to include a representative mix of WY types (i.e., wet years and dry years) and to enable the historic multi-year drought (WY2012 through WY2016) to be included in the calibration period. This is illustrated in Figure 5.1.



Water year type defined by runoff volume (Walter, 2015):

Very Dry	< 1,000 AF
Dry	> 1,000 and < 6,200 AF
Normal	> 6,200 and < 24,700 AF
Wet	> 24,700 and < 100,000 AF
Very Wet	> 100,000 AF

Calibration and Validation Periods and Water Year Type

Ventura County, CA

Geosyntec consultants | Daniel B. Stephens & Associates, Inc. | Figure 5.1

Santa Barbara | December 2021

Figure 5.1 Calibration and Validation Periods and Water Year Type

5.2 Approach and Calibration Goals

Calibration of the VRW GSFLOW Model consisted of adjustment of specific parameters that govern the surface-water and groundwater portions of the model domain to match simulated groundwater elevation and streamflow values to available real-world measurements. The model calibration approach and parameters that were adjusted for the streamflow and groundwater portions of the model are summarized in the following sections. While the streamflow and groundwater model calibration are discussed in separate sections, the final calibrations were performed together in the coupled VRW GSFLOW Model.

5.2.1 Streamflow

The first step in calibrating the VRW GSFLOW Model was adjusting parameters pertaining to PET. Specifically, the 12 monthly coefficients, jh_coef, for the Jensen-Haise PET calculation (Markstrom et al., 2015) were adjusted such that the monthly modeled PET[19] averaged over the modeling period matched the monthly PET values published in the California Irrigation Management Information System (CIMIS) for Zone 10 (DWR, 2012).

Once the PET was calibrated, other PRMS model parameters described in Section 3.6, and MODFLOW parameters described below in Section 5.2.2 were adjusted iteratively to match modeled streamflow to the measured streamflow for the calibration period.

Following calibration, the model results are tested by making comparisons for the validation period (see Section 5.1).

The streamflow gages used in the model calibration process are shown in Figure 3.1 and include:

- 604, North Fork Matilija Creek;
- 603A, Matilija Creek above Reservoir;
- 602B, Matilija Creek at Matilija Hot Springs;

[19] The PET represents a maximum evapotranspiration for a reference crop under ideal conditions, while the actual evapotranspiration (AET) depends upon soil moisture storage and is calculated by PRMS.

- 607, Ventura River near Meiners Oaks;
- 605A/605, San Antonio Creek at Old Creek Road/Highway 33;
- 608, Ventura River at Foster Park;
- 600, Coyote Creek near Oak View; and
- 606A, Santa Ana Creek near Oak View.

The USGS maintains Gage 603A (USGS 11114495) and Gage 608 (USGS 11118500) and CMWD maintains Gage 607 (at the Robles diversion). The remaining gages are maintained by VCWPD.

A "weight of evidence" approach recommended for calibrating continuous output hydrological simulations (Donigian, 2002) was used whereby both qualitative graphical comparisons and quantitative statistical comparisons were made. Graphical comparisons included visual evaluation of timeseries plots and flow duration curves comparing the measured and model simulated flow rates at the above locations.

Quantitative comparison "goodness-of-fit" statistics were calculated based on guidance from a USGS GSFLOW modeling study (Woolfenden and Nishikawa, 2014). The goodness-of-fit statistics include the percent average estimation error (PAEE), the absolute average estimation error (AAEE), and the Nash-Sutcliffe model efficiency (NSME).

These metrics are calculated as follows:

$$\mathrm{PAEE} = 100\% \times \frac{\frac{1}{n}\sum_{i=1}^{n}\left(X_{sim}^{i} - X_{obs}^{i}\right)}{\frac{1}{n}\sum_{i=1}^{n} X_{obs}^{i}}$$

$$\mathrm{AAEE} = 100\% \times \frac{Abs\left[\frac{1}{n}\sum_{i=1}^{n}\left(X_{sim}^{i} - X_{obs}^{i}\right)\right]}{\frac{1}{n}\sum_{i=1}^{n} X_{obs}^{i}}$$

$$\mathrm{NSME} = 1 - \frac{\sum_{i=1}^{n}\left(X_{obs}^{i} - X_{sim}^{i}\right)^{2}}{\sum_{i=1}^{n}\left(X_{obs}^{i} - \overline{X_{obs}}\right)^{2}}$$

where n is the total number of observations (i.e., field measurements), X_{obs}^{i} is the i^{th} observation, X_{sim}^{i} is the corresponding i^{th} simulation prediction, $\overline{X_{obs}}$ is the average value of all observations, and Abs denotes absolute value.

The PAEE and AAEE measure the model bias, or systematic error, but cannot provide a definitive measure of goodness of fit alone. The NSME provides a measure of the mean square error, similar to the normalized root-mean-square error (RMSE) and can be a good indicator of the goodness of fit, but can still have substantial estimation bias. Therefore, the combination of the aforementioned statistics, in conjunction with graphical comparisons, is used to represent goodness of fit. A model that exactly matches observed results would have PAEE and AAEE values of 0, and an NSME value of 1.0 (Woolfenden and Nishikawa, 2014).

Model fit classifications based on the statistics are presented in Table 5.1. The goal adopted in this project is to achieve calibration statistics classifications of “very good” (Donigian, 2002) or better. However, errors for environmental models can vary widely depending upon the system characteristics, and the irreducible error cannot be predicted at the outset of the project (U.S. Environmental Protection Agency, 2016). Therefore, it would not be expected that calibration goals are met at every location. For example, in the USGS study by Woolfenden and Nishikawa (2014), the “very good” classification was only met or exceeded at nine of the 12 gage locations for calibration of monthly flow. For validation in the same study, the “very good” classification was only met at three of six locations for monthly flow. Other studies using GSFLOW have similar results. For example, the USGS study by Hunt et al. (2013) only achieved “very good” calibration of monthly flows at one of five gage locations (NSME = 0.86) with the NSME ranging from 0.045 to 0.57 at the other four locations. The ability to achieve desired calibration goals is dependent upon the circumstances of the specific watershed, including the accuracy of input data and flow gage measurements. Measuring streamflow in natural streams can be challenging, particularly during low flow periods, as described in the following section.

Table 5.1 Summary of Goodness of Fit Statistics for Daily or Monthly Mean Streamflow

Goodness of Fit Category	PAEE (%)	AAEE (%)	NSME
Excellent	-5 to 5	≤ 5	≥ 0.95
Very good	-10 to -5 or 5 to 10	5 - 10	0.85 - 0.94
Good	-15 to -10 or 10 to 15	10 - 15	0.75 - 0.84
Fair	-25 to -15 or 15 to 25	15 - 25	0.6 - 0.74

Goodness of fit color categories (colors also used in Table 5.4 and Table 5.5).

- Excellent (dark green)
- Very Good (green)
- Good (light green)
- Fair (tan)

AAEE = absolute average estimation error
NSME = Nash-Sutcliffe model efficiency
PAEE = percent average estimation error

5.2.1.1 Streamflow Gaging Challenges

Comparison of model results to streamflow measurements may be impacted by challenges in obtaining accurate measurement in natural channels, including;

- Stream geomorphology changing over time;
- Building of rock dams by recreational swimmers, and subsequent removal;
- Conveyance of water as groundwater beneath the streambed; and
- Stage-discharge curves that are “flat” at the low flow end, meaning small errors in stage measurement may result in large changes in discharge estimate.

The USGS provides field measurement quality ratings for their gages within the VRW (i.e., Gages 603A and 608). Gage 608 (Foster Park) is at a key location for evaluating low flows and the quality of the gaging measurements there were examined in detail. Figure 5.2 presents a bar chart of the quality of the ratings and indicates that most of the gaging measurements are either Fair or Poor.

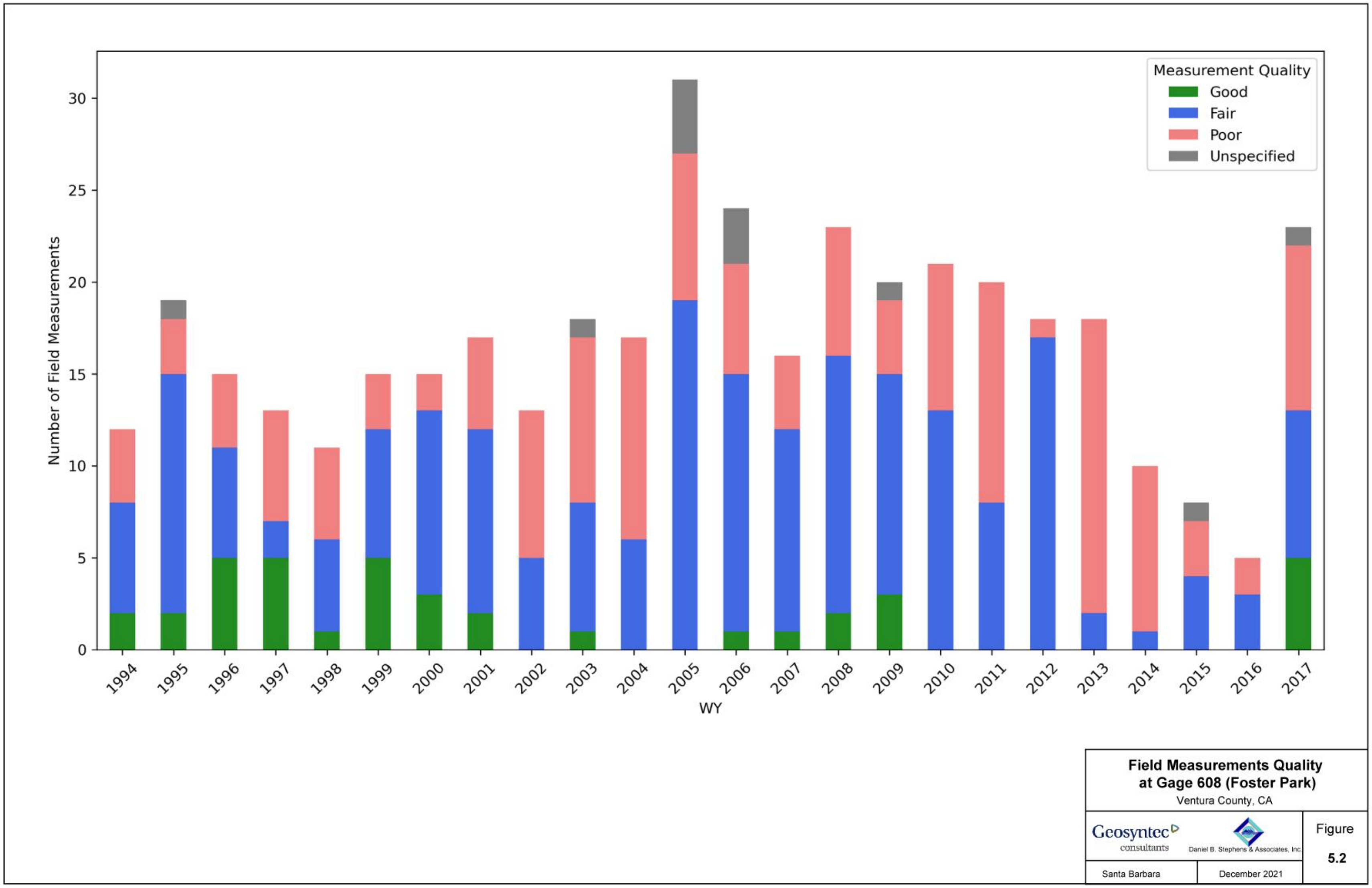


Figure 5.2 Field Measurements Quality at Gage 608 (Foster Park)

USGS guidance states a Fair rating indicates a measurement error of less than 8%, while a Poor rating indicates a measurement error of greater than 8% (USGS, 2021).

Further analyses of the field measurement quality ratings for Gage 608 indicate a higher fraction of Poor measurements at lower flow rates. Specifically, more than 60% of measurements below 5 cfs and approximately 90% of measurements below 2 cfs were of Poor quality. Therefore, many of the measurements during the low flow periods (i.e., summers) are of Poor quality with errors anticipated to be greater than 8%. These larger errors, and in particular the lack of information on an upper bound for the errors, need to be considered when comparing model results to streamflow measurements, particularly during low flow periods.

Other gages were not evaluated in as much detail as Gage 608, but it could be anticipated in general that they will have similar issues. Additionally, VCWPD Gages 600 and 606A are above Lake Casitas on private land and are noted to have access issues and may not be maintained and calibrated adequately or regularly (Marotto pers. comm., 2021). This may result in times with erroneous or inaccurate data, and this also needs to be considered when comparing model results to streamflow measurements.

5.2.2 Groundwater Elevations

GSFLOW model calibration consists of adjusting selected model parameters to minimize the difference (“residual”) between simulated groundwater level at a specific location and observed groundwater-level data from a well at that location. Groundwater-level calibration was conducted consistent with standard protocols and best practices, as defined by DWR (2016b) and ASTM (2008).

Parameters adjusted during the calibration process (i.e., calibration parameters) included hydraulic conductivity and storage coefficient of each model layer, streambed hydraulic conductivity, and unsaturated hydraulic conductivity. Values of hydraulic conductivity and storage coefficient from available aquifer tests were also used to constrain the calibration.

Groundwater level calibration results are typically presented in terms of several statistical “goodness of fit” measures, including mean error (ME), mean-absolute error (MAE), RMSE, and the correlation coefficient (R) between simulated and observed values:

- The ME is a simple average of the residual error between observed and simulated water levels, and therefore, positive values will offset negative values. A positive value of ME indicates that, on average, simulated hydraulic heads are lower than observed hydraulic heads, while a negative value indicates the opposite.

- The MAE is similar to the ME, with the important distinction that the sum of the absolute values of the residuals is calculated, thereby eliminating the offset that occurs by adding positive and negative values. The MAE, therefore, is always positive and represents the average difference between observed and simulated hydraulic head values.

- The RMSE is similar to the MAE, although negative values of the residual between observed and simulated hydraulic heads are eliminated by squaring the difference, and then the square root of the sum is determined prior to computing the average. This approach is analogous to the computation of the variance that would be conducted for a linear regression.

- The R is a measure of the linear correlation between the simulated and observed groundwater levels (DWR, 2016b). R may range from negative 1.0 (-1.0) to 1.0. A correlation of -1.0 indicates a perfect negative correlation, while a correlation of 1.0 indicates a perfect positive correlation.

These metrics are calculated as follows:

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(h_{sim}^{i} - h_{obs}^{i}\right)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n} Abs\left(h_{sim}^{i} - h_{obs}^{i}\right)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(h_{sim}^{i} - h_{obs}^{i}\right)^{2}}$$

$$\mathrm{R} = \frac{\sum_{i=1}^{n}\left(h_{obs}^{i} - \overline{h_{obs}}\right)\left(h_{sim}^{i} - \overline{h_{sim}}\right)}{\sqrt{\sum_{i=1}^{n}\left(h_{obs}^{i} - \overline{h_{obs}}\right)^{2}\sum_{i=1}^{n}\left(h_{sim}^{i} - \overline{h_{sim}}\right)^{2}}}$$

where n is the number of all water level observations measurements (at different times and locations), h_{obs}^{i} is the i^{th} observed hydraulic head, h_{sim}^{i} is the i^{th} simulated hydraulic head, $\overline{h_{obs}}$ is the average value of all observed hydraulic heads, $\overline{h_{sim}}$ is the average value of all simulated hydraulic heads, and Abs denotes absolute value.

The primary goals of model calibration are to reduce the value of the MAE and RMSE, bring the ME as close as possible to a value of zero, and bring the value of R as close as possible to 1.0, using model input values consistent with observed data or realistic estimates.

Measures of model calibration such as the MAE and the RMSE are often evaluated relative to the total head loss across the hydrogeologic system (Anderson and Woessner, 1992; ASTM, 2008). For example, the scaled RMSE is equal to the RMSE divided by the observed hydraulic head drop that occurs across the model domain.

Calibration goals for groundwater levels included:

- Scaled RMSE will be less than 10 percent for each groundwater basin (for example, if the total observed head-change in a groundwater basin is 400 feet, the RMSE will be less than 40 feet).
- R will be greater than 0.90 for each groundwater basin (DWR 2016b; Hill and Tiedeman, 2007).

Groundwater wells with available groundwater-level monitoring data used for calibration are displayed on Figure 5.3. Historical groundwater-level monitoring data are available from VCWPD (which conducts a quarterly groundwater monitoring program throughout the watershed) (VCWPD, 2017, 2018, 2020), selected GeoTracker cleanup sites (SWRCB, 2018b), and pressure-transducer data collected by OBGMA and Upper Ventura River Groundwater Agency (UVRGA) (Kear pers. comm., 2018). Sixty-one wells were used in groundwater calibration. Data from GeoTracker cleanup site monitoring wells were accessed for the Lower Ventura Basin due to the general lack of other long-term groundwater monitoring data.

In addition, data from one GeoTracker cleanup site monitoring well in the Ojai Basin were used in calibration (“Ojai Imports MW-1”) because this well is perforated exclusively in a shallow interval (3 to 23 feet below ground surface) and exhibits limited drawdown as compared to other wells with available data in the Ojai Basin. Sixty-one wells were used in groundwater calibration. Wells screened in both the alluvial and bedrock units were used for calibration. Several wells with groundwater-level data in the Ojai Basin are screened in bedrock units beneath the alluvium. Due to necessary limitations of the model grid (e.g., three active layers outside Ojai Groundwater Basin and up to seven active layers in Ojai Groundwater Basin), the VRW GSFLOW Model is not structured to simulate direct lateral flow to the deep portions of the bedrock units that underlie alluvium in the Ojai Basin (Layers 4 through 7). This is noted as a model limitation. Four wells in the Ojai Basin that were screened at least 200 feet into bedrock, and/or had at least 80 percent of their screen in bedrock (05N22W32J01S, 05N22W32P02S, 04N22W04Q01S, and 04N23W02K01S) were therefore not used for model calibration. In addition, one well that is located at the watershed boundary in a bedrock area (04N22W21F01S) was also not used in calibration.

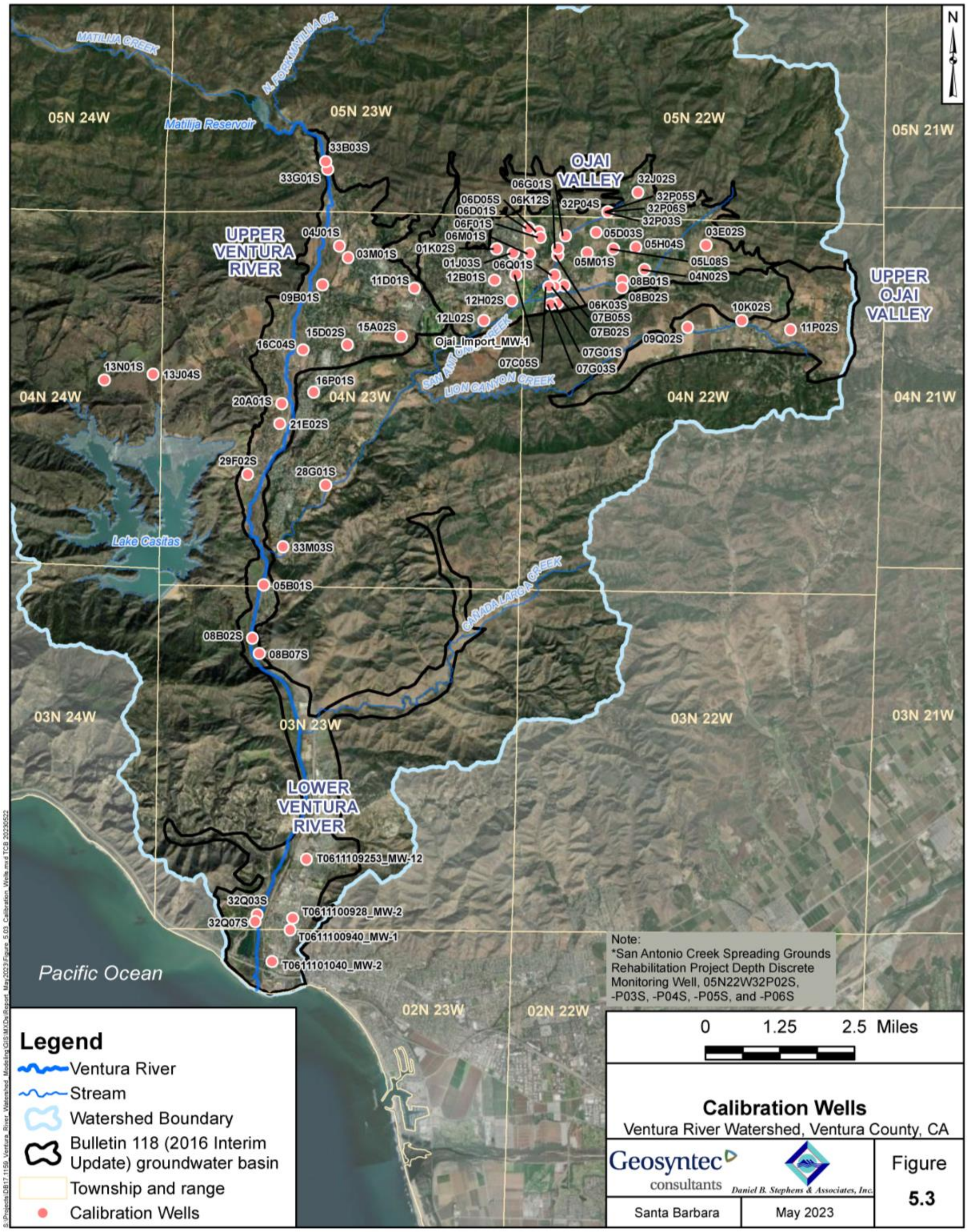


Figure 5.3 Calibration Wells

5.2.3 Wet-Dry Mapping

Wet-dry mapping data collected along the Ventura River and San Antonio Creek (Lewis pers. comm., 2017) were used to assess the ability of the model to predict the spatial distribution of gaining and losing reaches during different seasons and different WY types (e.g., wet versus dry). Output from the model was extracted to re-create the spatial and temporal information in the mapping to provide a qualitative visual (i.e., side-by-side) comparison with wet-dry observations. Additionally, the percent match between the model and the observations along each river was calculated.

The modeled wet-dry mapping is primarily a result of the groundwater level calibration coupled with streambed conductivities and widths, that together determine the extent of the gaining and losing reaches through the SFR package. During the calibration process, the wet-dry mapping was assessed and adjustments were made to the streambed conductivities to achieve better match. These adjustments were relatively minor; larger adjustments would feed back into the groundwater and surface water calibrations, requiring additional iterations.

5.3 Final Model Input

The following sections present the final model input parameters that were used for the calibrated and validated VRW GSFLOW Model.

5.3.1 PRMS Parameters

The final values of the most important PRMS model parameters are summarized in Table 5.2 and are mapped in Figure 5.4 through Figure 5.10. A description of these parameters is provided in the PRMS Manual (Markstrom et al., 2015).

5.3.2 Groundwater Model Parameters

Final calibrated hydraulic conductivity values are presented for each model layer in Figure 5.11a through Figure 5.12g and calibrated specific yield values are presented in Figure 5.12a and Figure 5.12b. Table 5.3 also presents final calibrated parameter values for each zone.

The riparian ET extinction depth[20] was also adjusted to calibrate the low flows in the dry season. Based on streamflow calibration, the extinction depth was set to 5 feet for streams and rivers within the groundwater basins where terrain is relatively flat, and 13.5 feet elsewhere in the model domain where terrain is steeper and channels may be further incised. These depths were only applied where riparian vegetation was mapped (Section 4.4.7).

5.4 Model Calibration and Validation Assessment

The following sections provide assessments of the final model calibrations to streamflow, groundwater elevations, and wet-dry mapping.

5.4.1 Streamflow Calibration Assessment

Calibration to streamflow is assessed through timeseries plots, statistic metrics, and annual stream volumes in the following sections. Comparisons are also made for lake and reservoir elevations that also depend on streamflow.

[20] The extinction depth is a MODFLOW parameter and is the depth to which shallow ET can occur in the model and is a depth below the model cell elevation that roots can reach and consume groundwater. The extinction depth is related to rooting depths for phreatophytes, but is relative to the model cell elevation that is averaged over a 330-foot cell, and therefore may be higher than the actual phreatophyte plant elevation, particularly in steep terrain with incised stream channels. Therefore, the assigned extinction depth may be larger than the rooting depth measured at the actual location of the plant.

Table 5.2 Summary of PRMS Parameters and Final Values

Parameter Name	Units	Description	Final Value: Average	Final Value: Maximum	Final Value: Minimum
soil_moist_max	inches	Maximum available water holding capacity of capillary reservoir from land surface to rooting depth of the major vegetation type of each HRU	7.6	23.3	0.11
sat_threshold	inches	Water holding capacity of the gravity and preferential flow reservoirs; difference between field capacity and total soil saturation for each HRU	18.6	47.5	0
ssr2gw_rate	inches/day	Linear coefficient in equation used to route water from the gravity reservoir to the groundwater reservoir for each HRU	0.029	0.25	0.004
carea_max	decimal fraction	Maximum possible area contributing to surface runoff expressed as a portion of the HRU area	0.109	0.838	0.1
hru_percent_imperv	decimal fraction	Fraction of each HRU area that is impervious	0.016	0.837	0
slowcoef_lin	fraction/day	Linear coefficient in equation to route gravity-reservoir storage downslope for each HRU	0.000155	0.00168	0
slowcoef_sq	none	Non-linear coefficient in equation to route gravity	0.000308	0.0172	0

Parameter Name	Units	Description	Final Value: Average	Final Value: Maximum	Final Value: Minimum
		reservoir storage downslope for each HRU			
smidx_coef	decimal fraction	Coefficient in non-linear contributing area algorithm for each HRU	0.01	0.01	0.01
smidx_exp	1/inch	Exponent in non-linear contributing area algorithm for each HRU	0.3	0.3	0.3

GSFLOW = Groundwater and Surface-water Flow
HRU = hydrologic response unit
PRMS = Precipitation-Runoff Modeling System

Table 5.3 Summary of MODFLOW Parameters and Final Values

Zone	Description	$K_{x,y}$ (ft/day)	K_z (ft/day)	S_s ($feet^{-1}$)	S_y (-)	SFR_K (ft/day)	VKS (ft/day)
1	Ojai Basin	0.1	0.001	1×10^{-7}	0.1	0.01	0.01
2	Ojai Basin	0.1	0.1	1×10^{-7}	0.001	--	--
3	Ojai Basin	150	15	1×10^{-7}	0.03	1.5	15
4	Ojai Basin	21	0.001	1×10^{-7}	0.03	--	--
5	Ojai Basin	45	0.001	1×10^{-7}	0.03	--	--
6	Young Alluvium Upper Ojai	25	2.5	1×10^{-6}	0.16	0.75	2.5
7	Old Alluvium Upper Ojai	25	2.5	1×10^{-6}	0.16	0.75	2.5
8	Young Alluvium Upper Ojai - East	150	15	1×10^{-6}	0.16	1.5	15
9	Old Alluvium Upper Ojai - East	150	15	1×10^{-6}	0.16	1.5	15
10	Young Alluvium Upper Ventura East	25	0.25	1×10^{-6}	0.10	0.01	0.01
11	Old Alluvium Upper Ventura East	25	0.25	1×10^{-6}	0.10	0.01	0.01
12	Young Alluvium Upper Ventura Middle	25	0.25	1×10^{-6}	0.10	0.01	0.01
13	Old Alluvium Upper Ventura Middle	25	0.25	1×10^{-6}	0.10	0.01	0.01
14	Young Alluvium Upper Ventura River Basin	1000	100	1×10^{-6}	0.16	1.5	100
15	Young Alluvium Upper Ventura - Foster Park	1250	125	1×10^{-6}	0.2	1.5	125
16	Old Alluvium Upper Ventura River Basin	500	50	1×10^{-6}	0.16	1.5	50
17	Young Alluvium Lower Ventura - North	50	5	1×10^{-6}	0.1	0.35	5
18	Old Alluvium Lower Ventura - North	50	5	1×10^{-6}	0.1	0.35	5
19	Young Alluvium Lower Ventura - South	200	20	1×10^{-6}	0.1	1	20
20	Old Alluvium Lower Ventura - South	200	20	1×10^{-6}	0.1	1	20

Zone	Description	$K_{x,y}$ (ft/day)	K_z (ft/day)	S_s (feet^{-1})	S_y (-)	SFR_K (ft/day)	VKS (ft/day)
21	Young Alluvium Outside 118 Basins (Mountains)	2.5	0.25	1×10^{-6}	0.03	0.1	0.5
22	Old Alluvium Outside 118 Basins (Mountains)	2.5	0.25	1×10^{-6}	0.03	0.1	0.25
23	Young Alluvium Outside 118 Basins (San Antonio Watershed)	2.5	0.25	1×10^{-6}	0.03	0.01	0.01
24	Old Alluvium Outside 118 Basins (San Antonio Watershed)	2.5	0.25	1×10^{-6}	0.03	0.01	0.01
25	Conglomerate	1	0.1	1×10^{-7}	0.001	0.1	0.01
26	Claystone	0.01	0.001	1×10^{-7}	0.001	0.01	0.0005
27	Shale (General)	0.01	0.001	1×10^{-7}	0.001	0.01	0.0005
28	Sandstone (General)	0.25	0.025	1×10^{-7}	0.001	0.1	0.005
29	Shale (Select Basins override)	--	--	--	--	--	--
30	Sandstone (Select Basins override)	--	--	--	--	--	--
31	Sandstone in Deep Ojai	0.01	0.001	1×10^{-7}	0.001	--	--

$K_{x,y}$ = Horizontal hydraulic conductivity
K_z = Vertical hydraulic conductivity
S_s =Specific storage
S_y = Specific yield
SFR_K = Streambed hydraulic conductivity
VKS = Unsaturated zone hydraulic conductivity

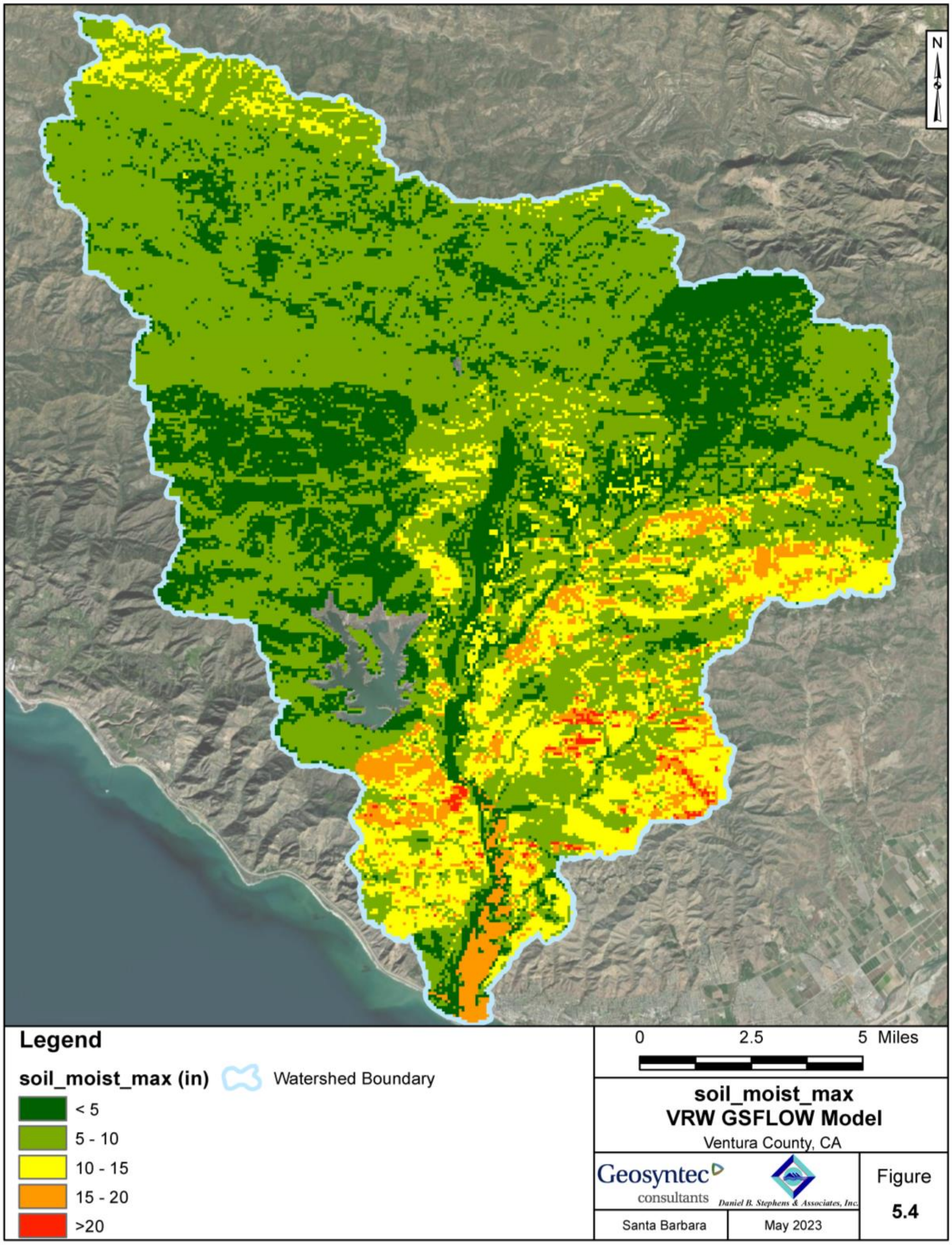


Figure 5.4 soil_moist_max VRW GSFLOW Model

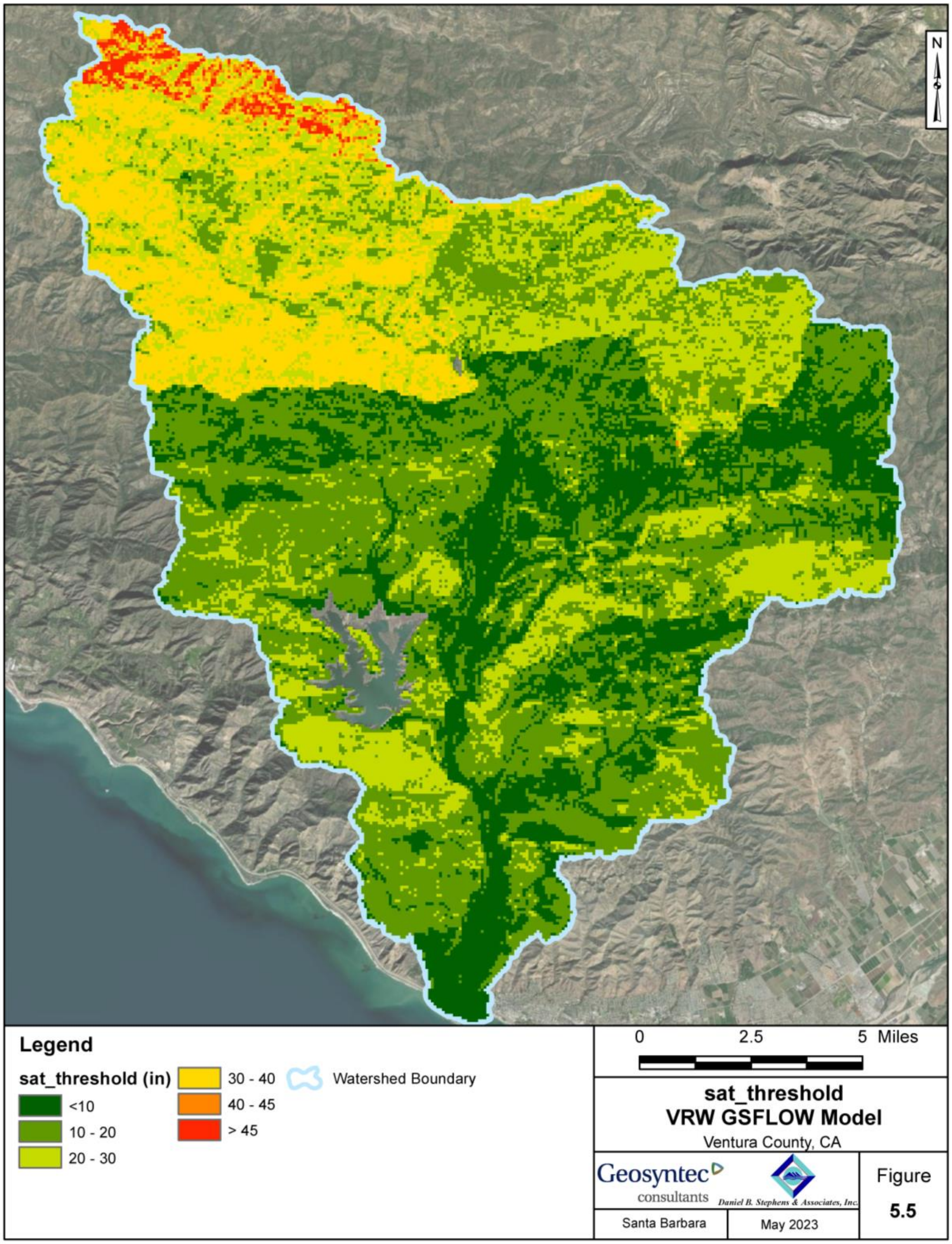


Figure 5.5 sat_threshold VRW GSFLOW Model

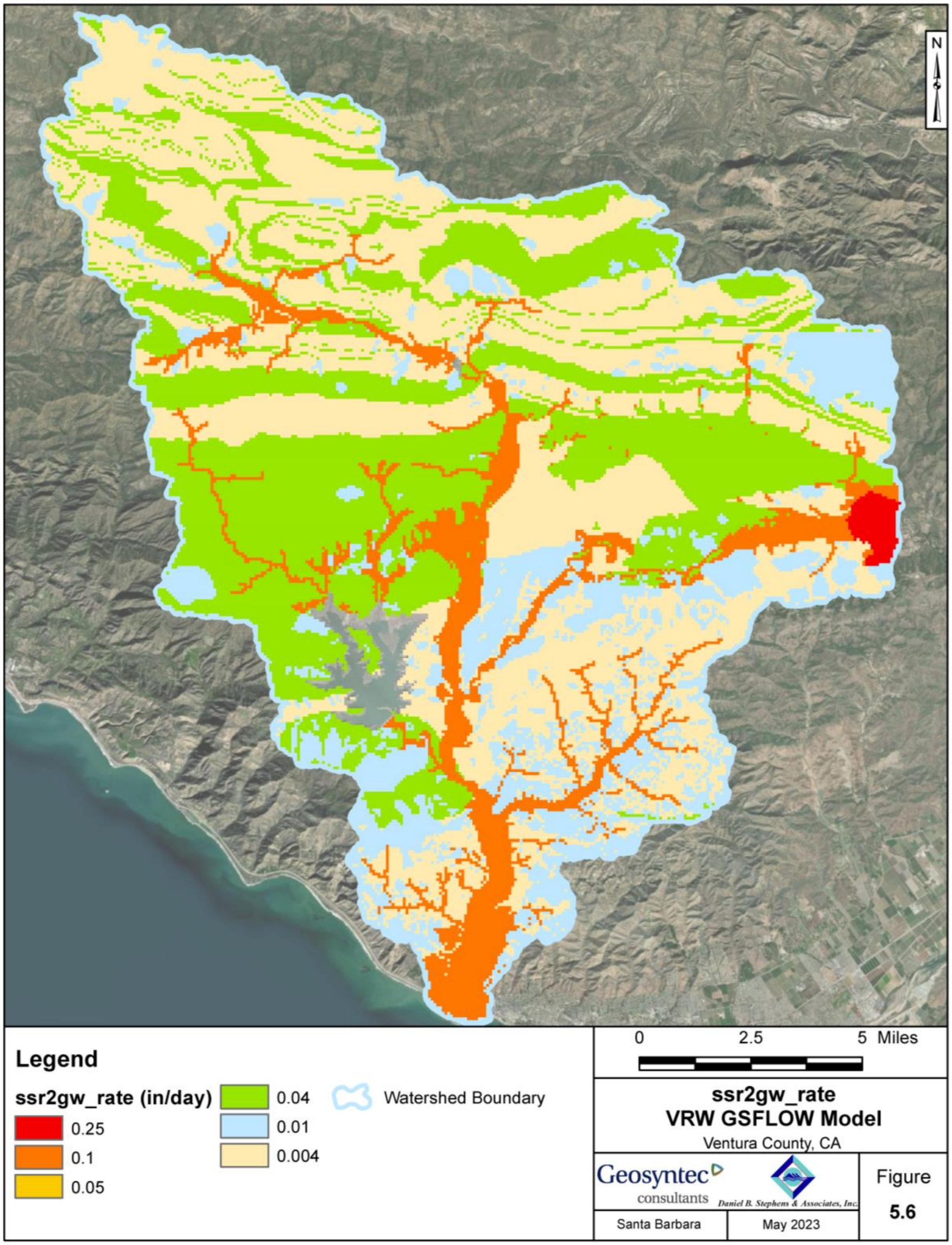


Figure 5.6 ssr2gw_rate VRW GSFLOW Model

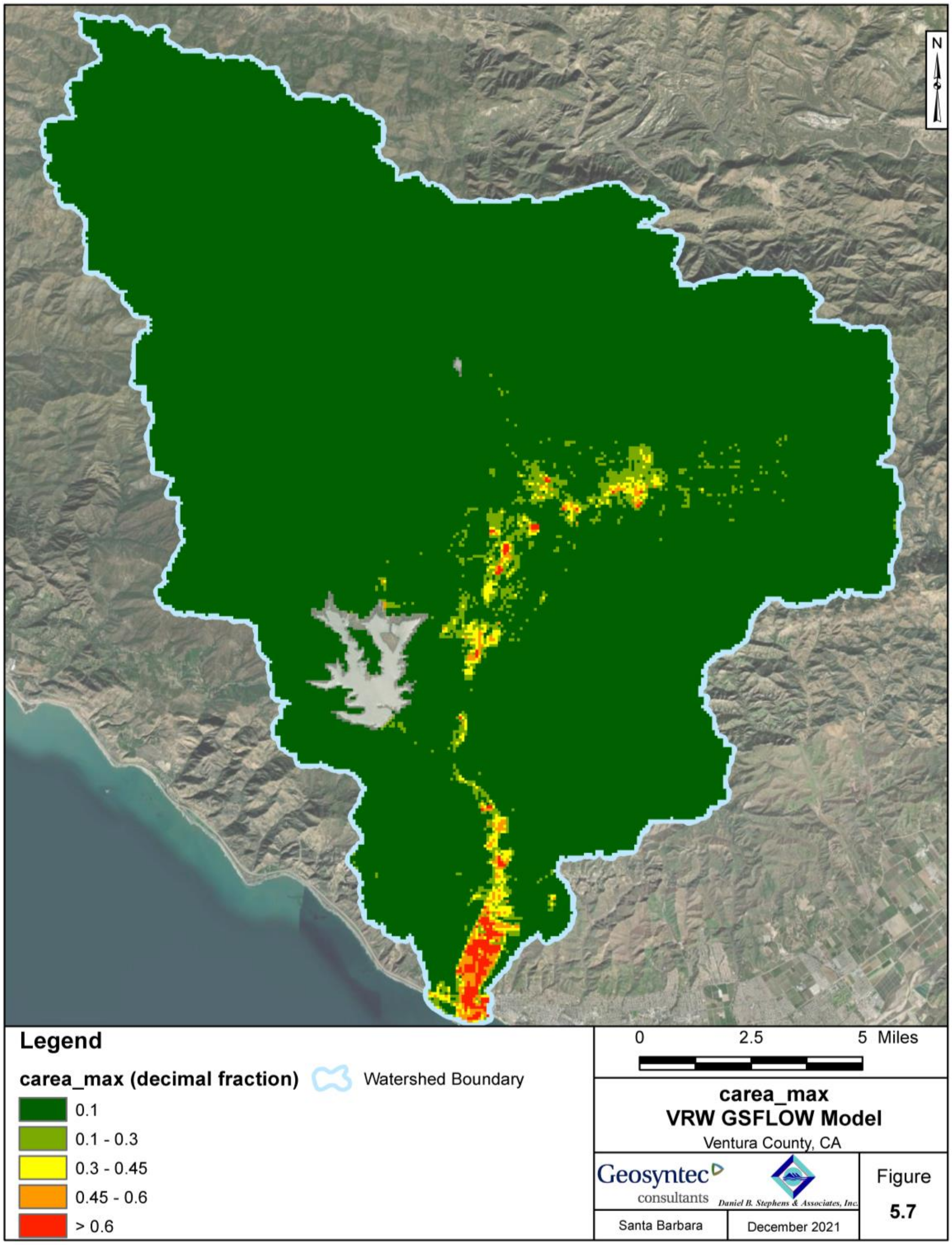


Figure 5.7 carea_max VRW GSFLOW Model

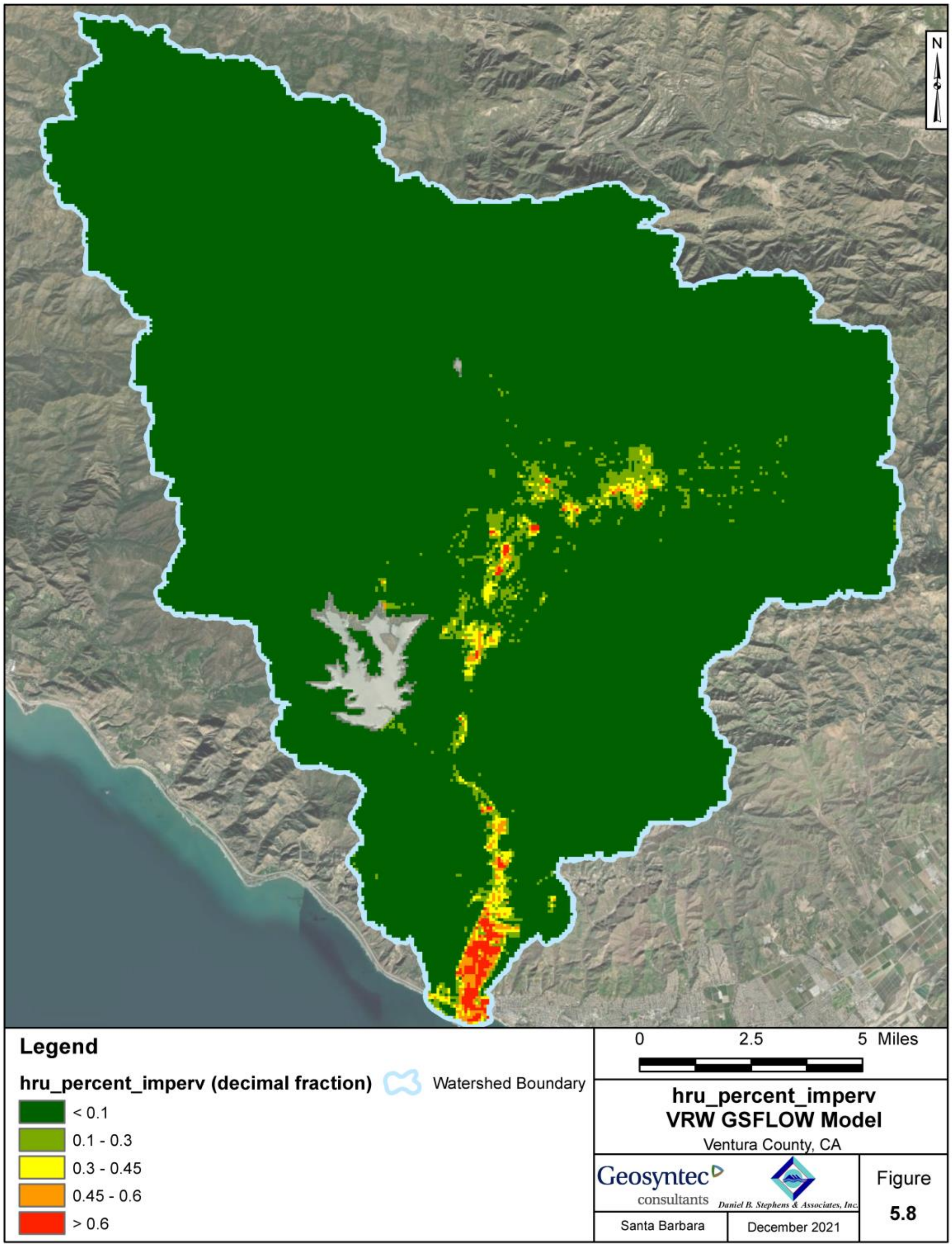


Figure 5.8 hru_percent_imperv VRW GSFLOW Model

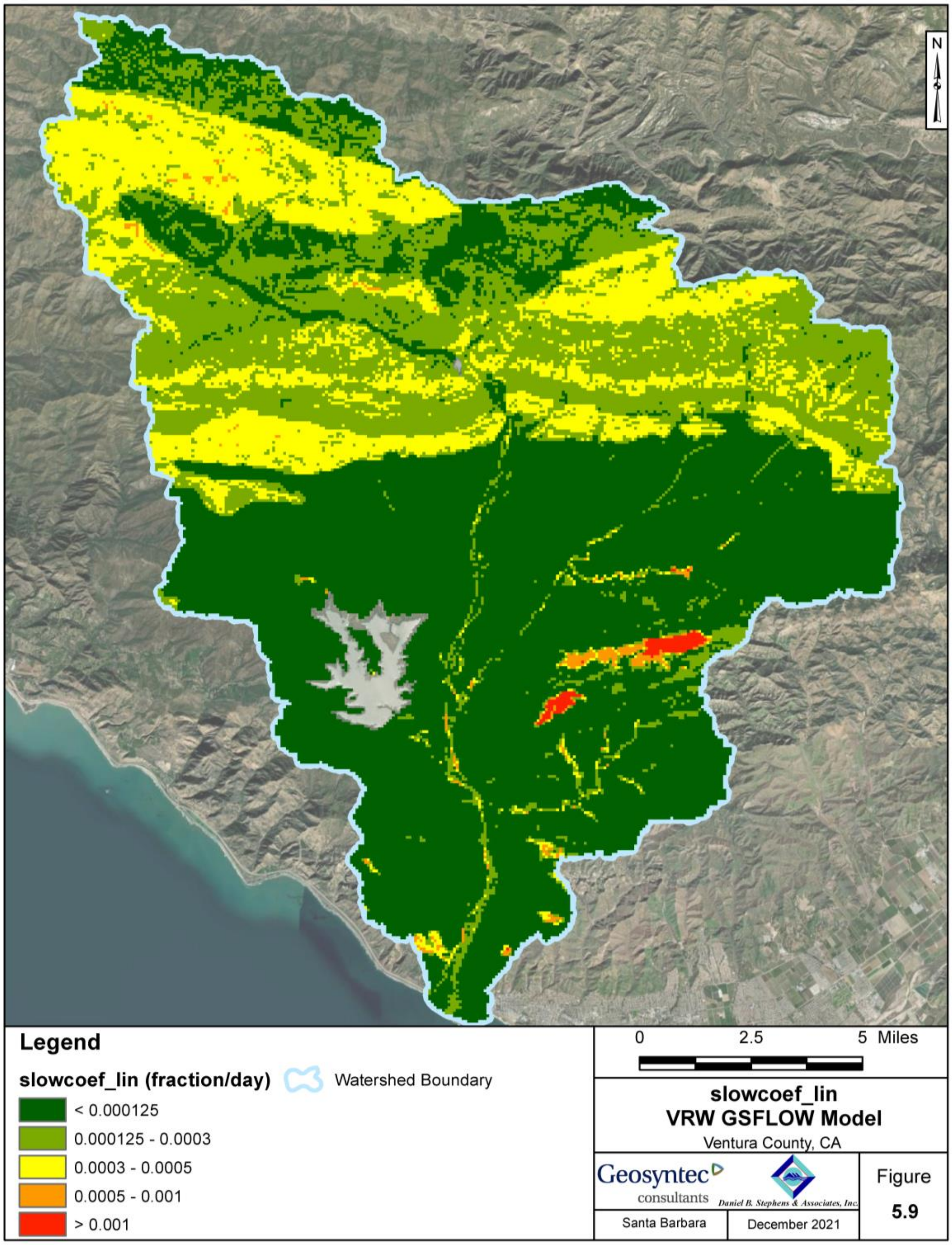


Figure 5.9 slowcoef_lin VRW GSFLOW Model

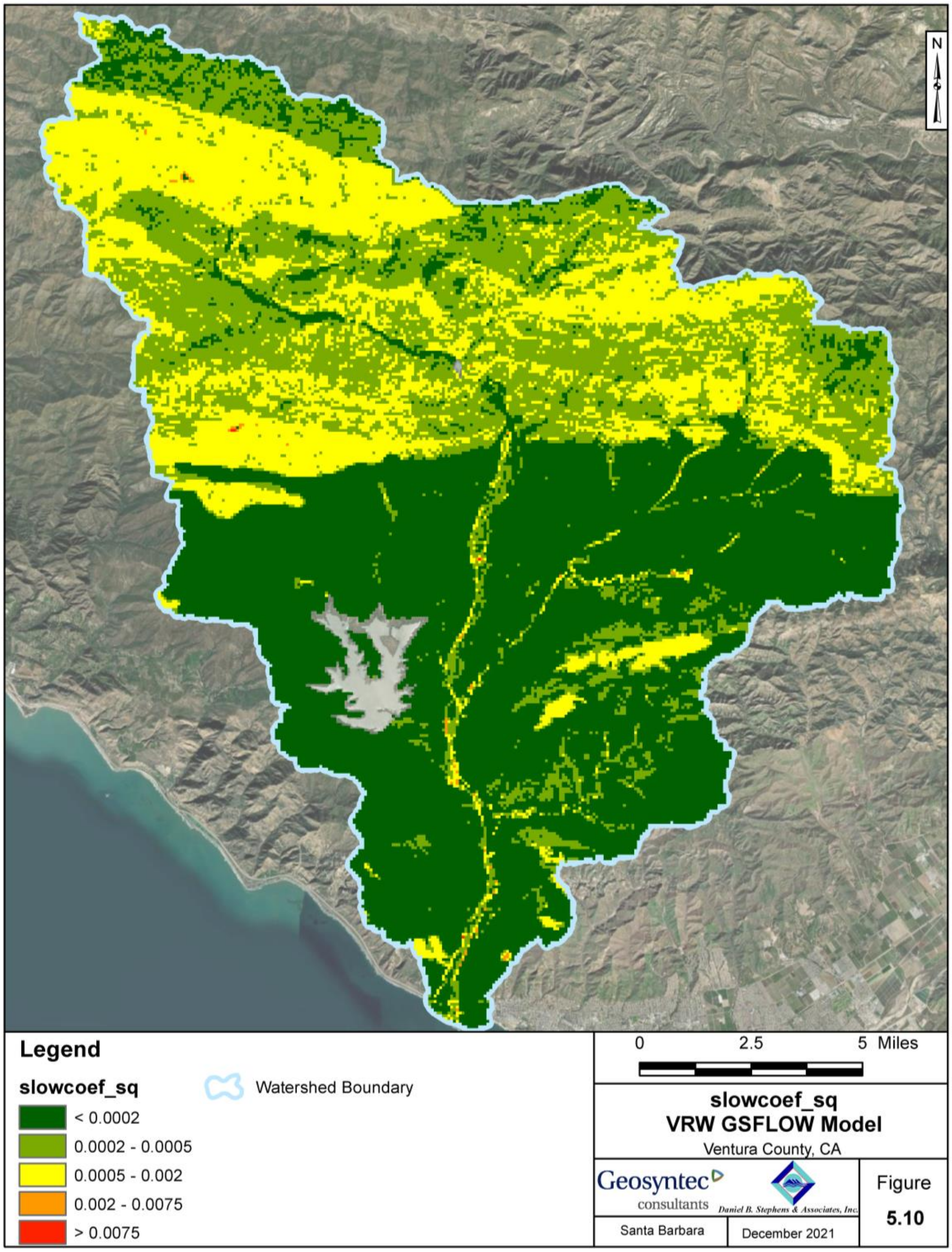


Figure 5.10 slowcoef_sq VRW GSFLOW Model

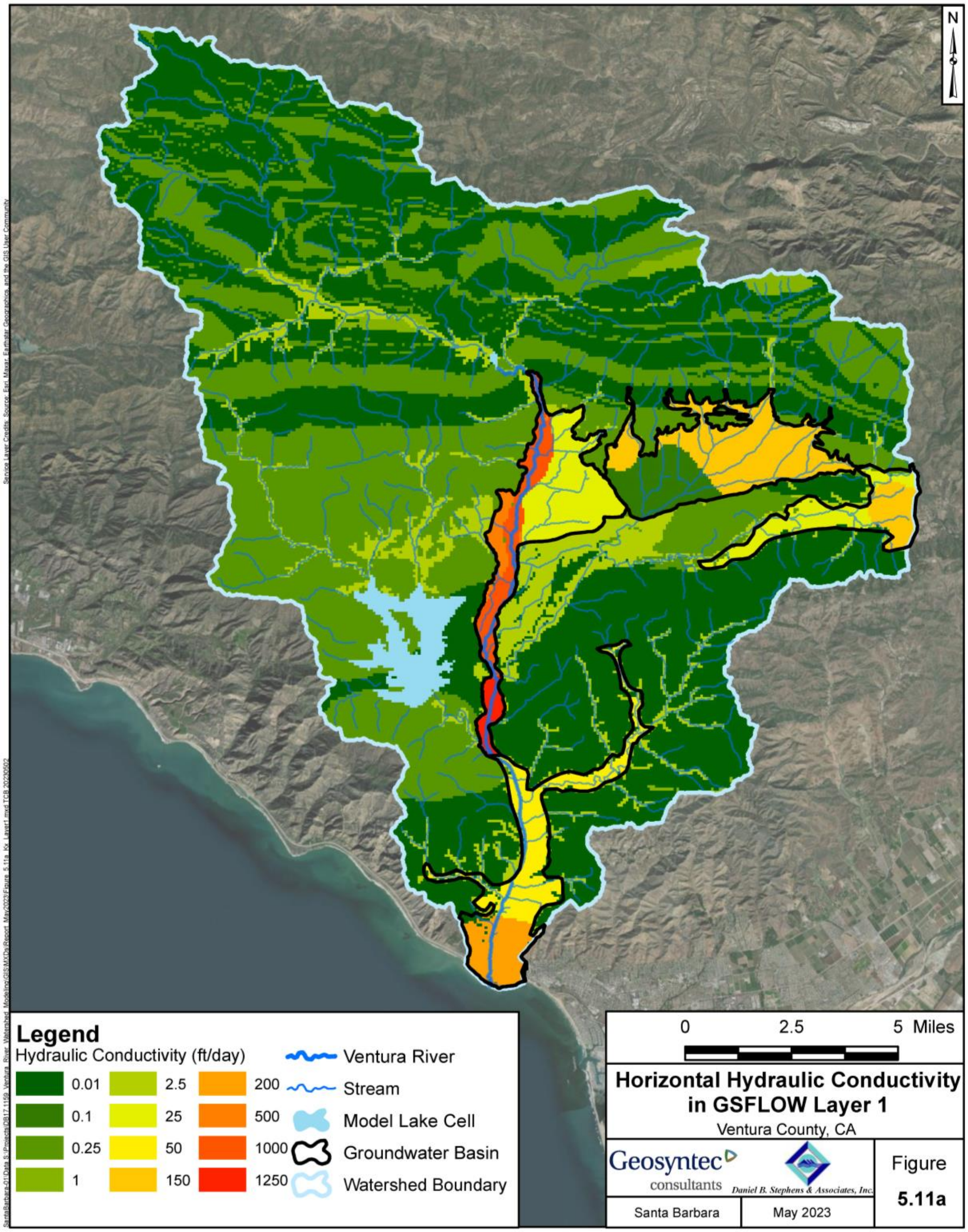


Figure 5.11a Horizontal Hydraulic Conductivity in GSFLOW Layer 1

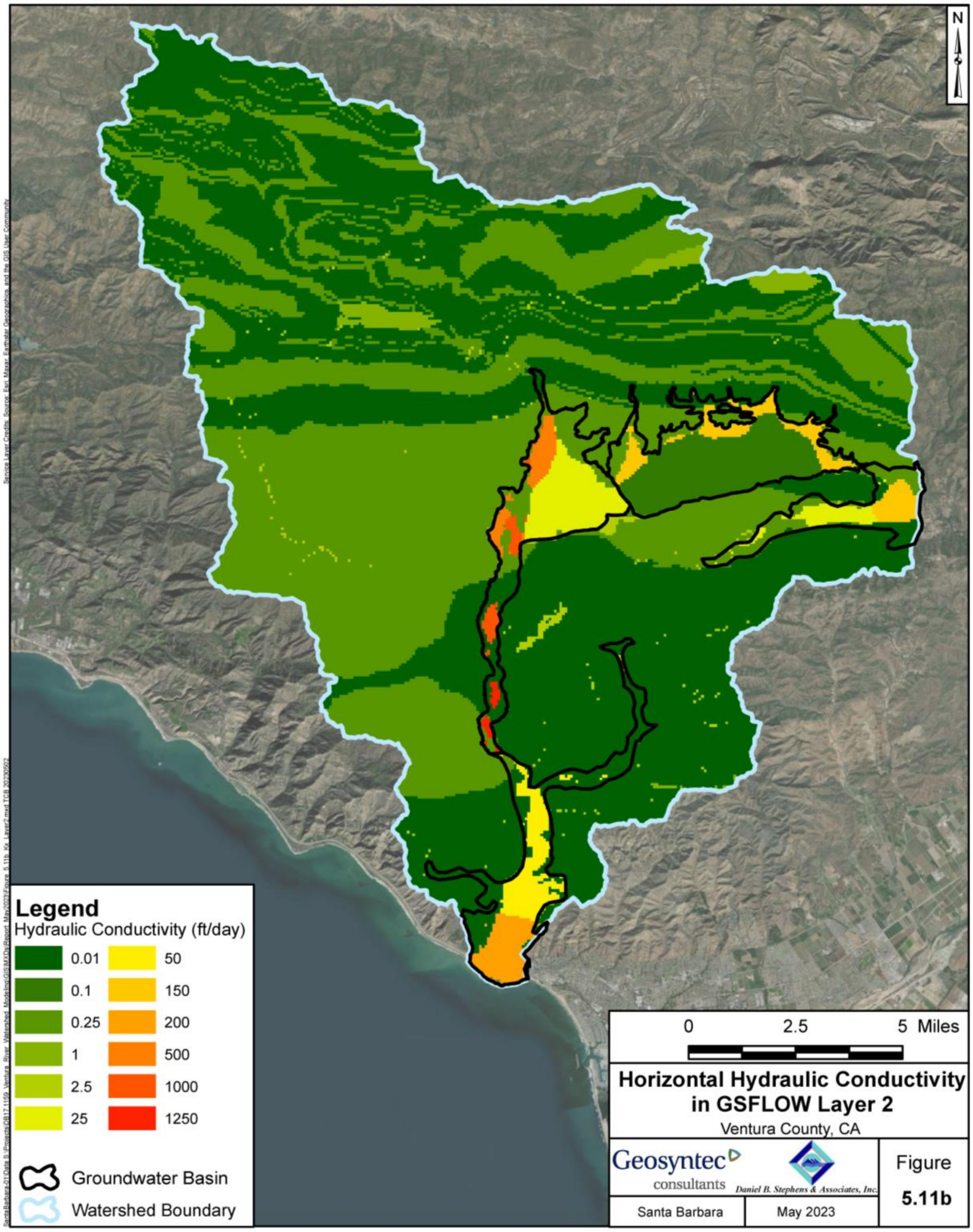


Figure 5.11b Horizontal Hydraulic Conductivity in GSFLOW Layer 2

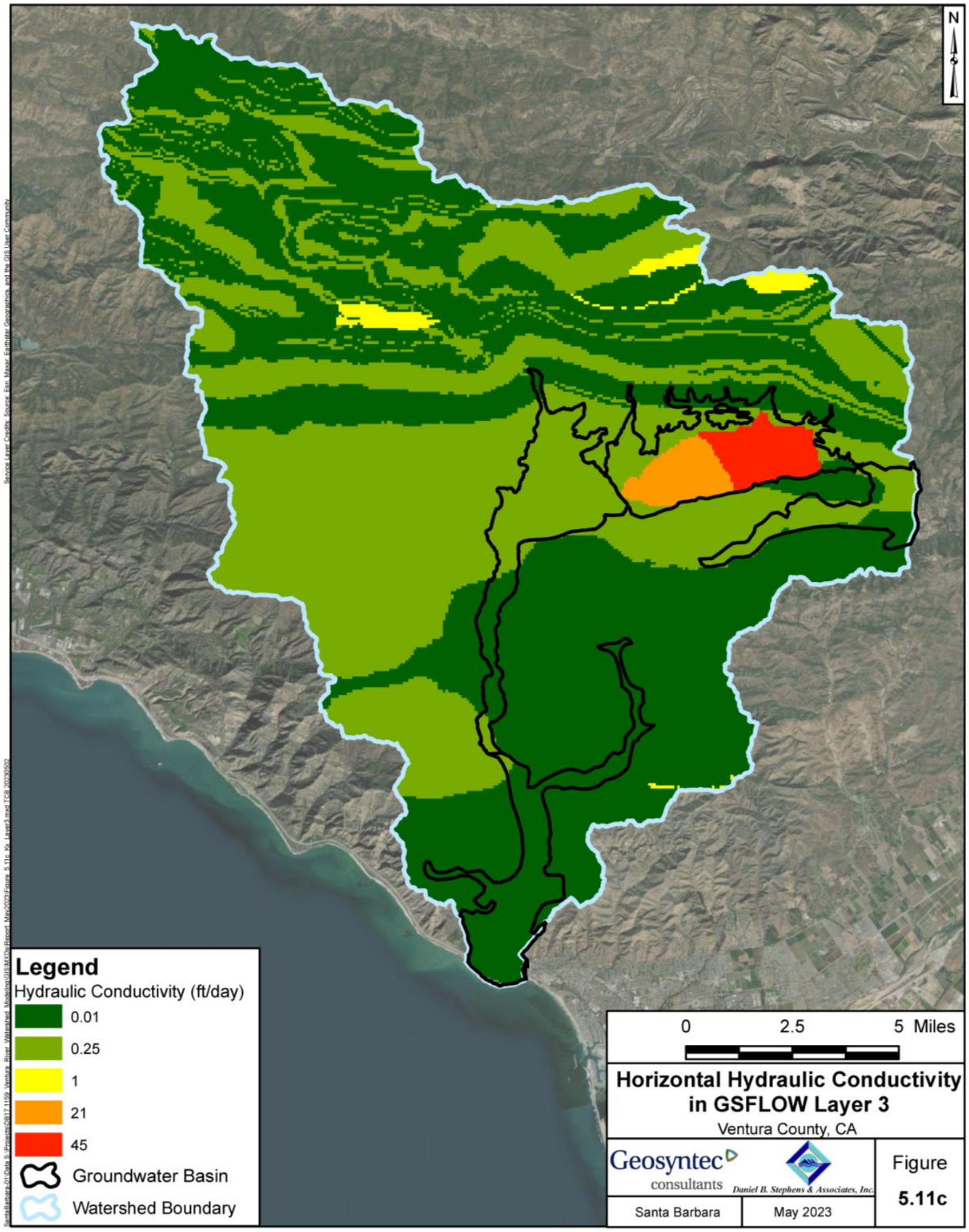


Figure 5.11c Horizontal Hydraulic Conductivity in GSFLOW Layer 3

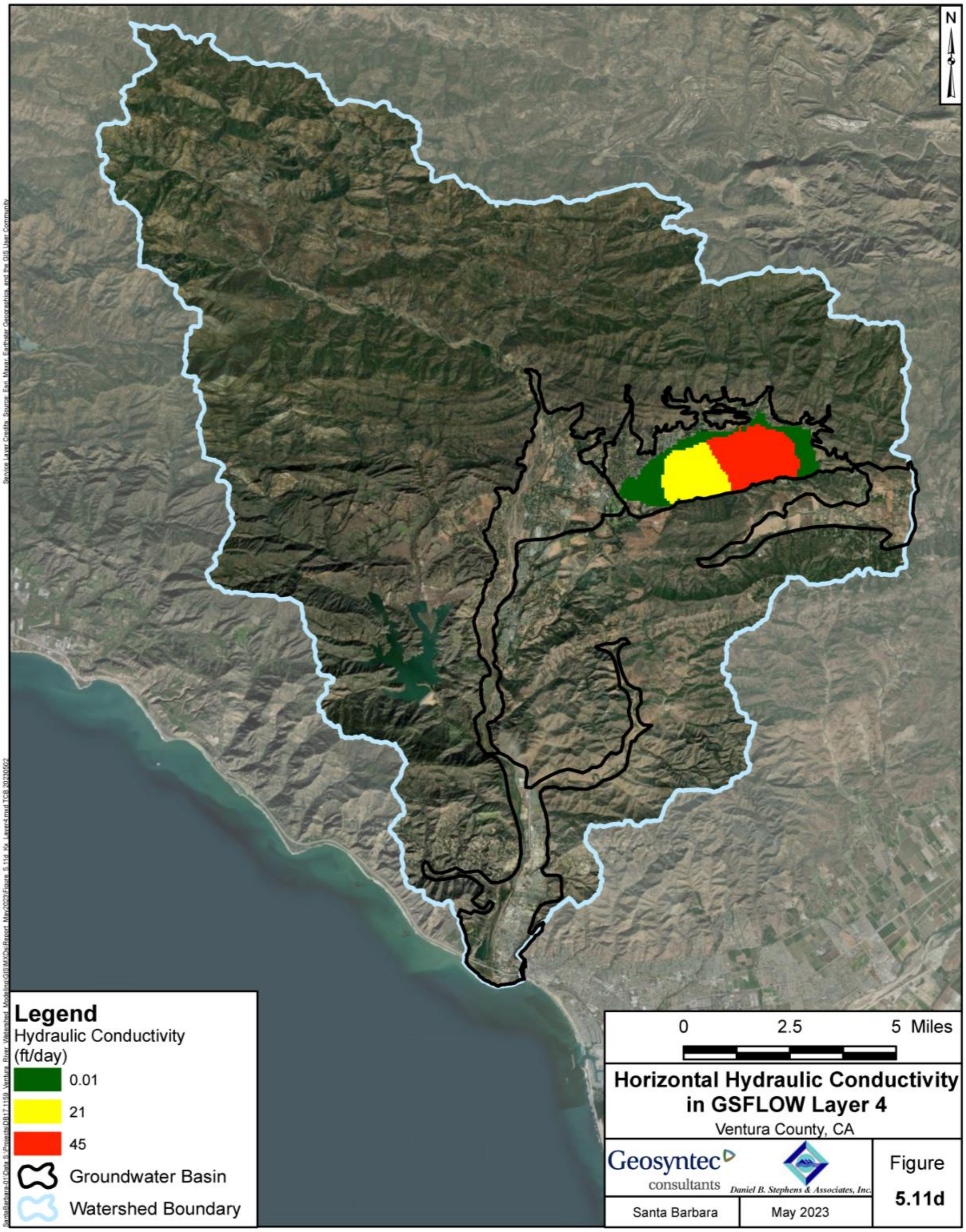


Figure 5.11d Horizontal Hydraulic Conductivity in GSFLOW Layer 4

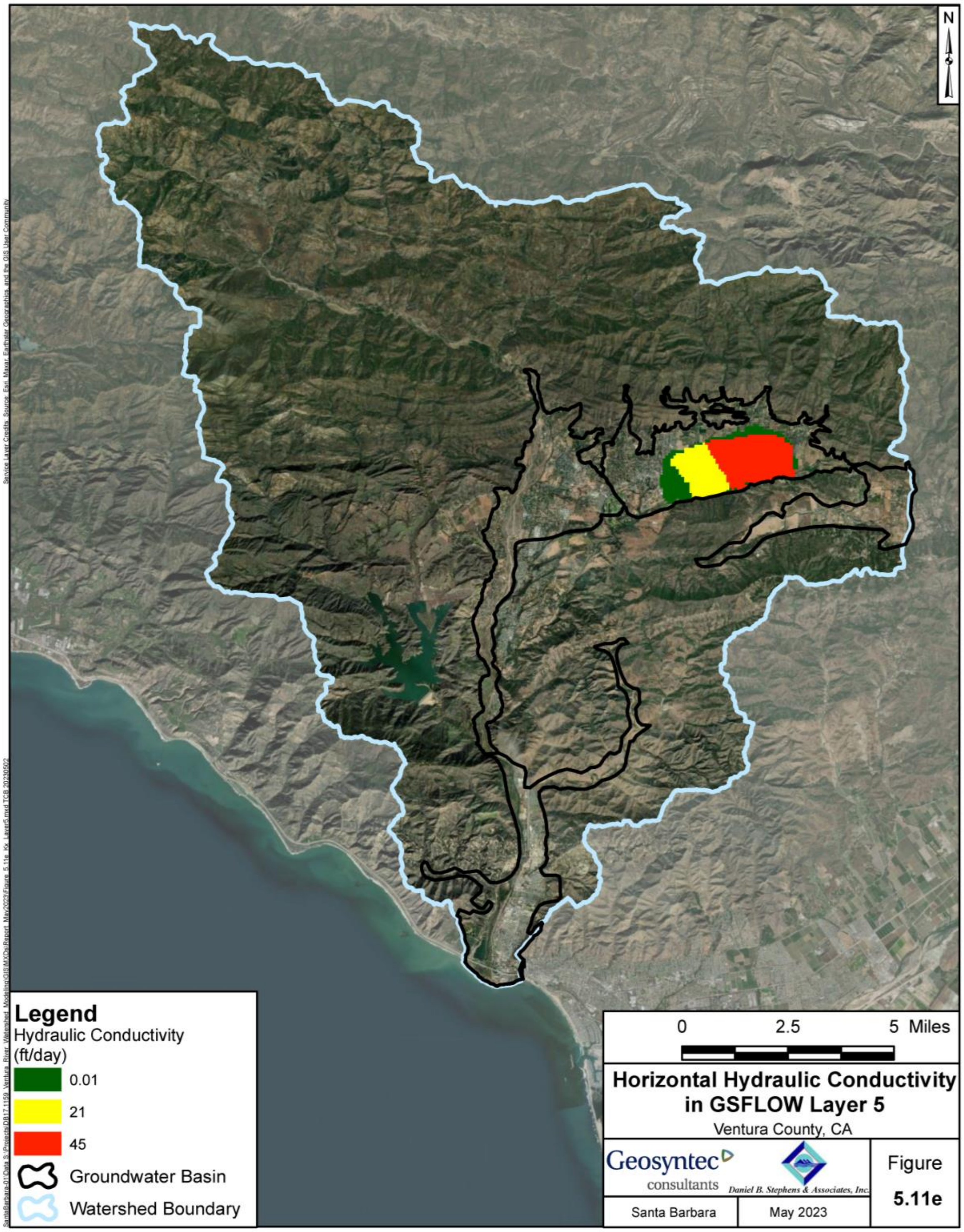


Figure 5.11e Horizontal Hydraulic Conductivity in GSFLOW Layer 5

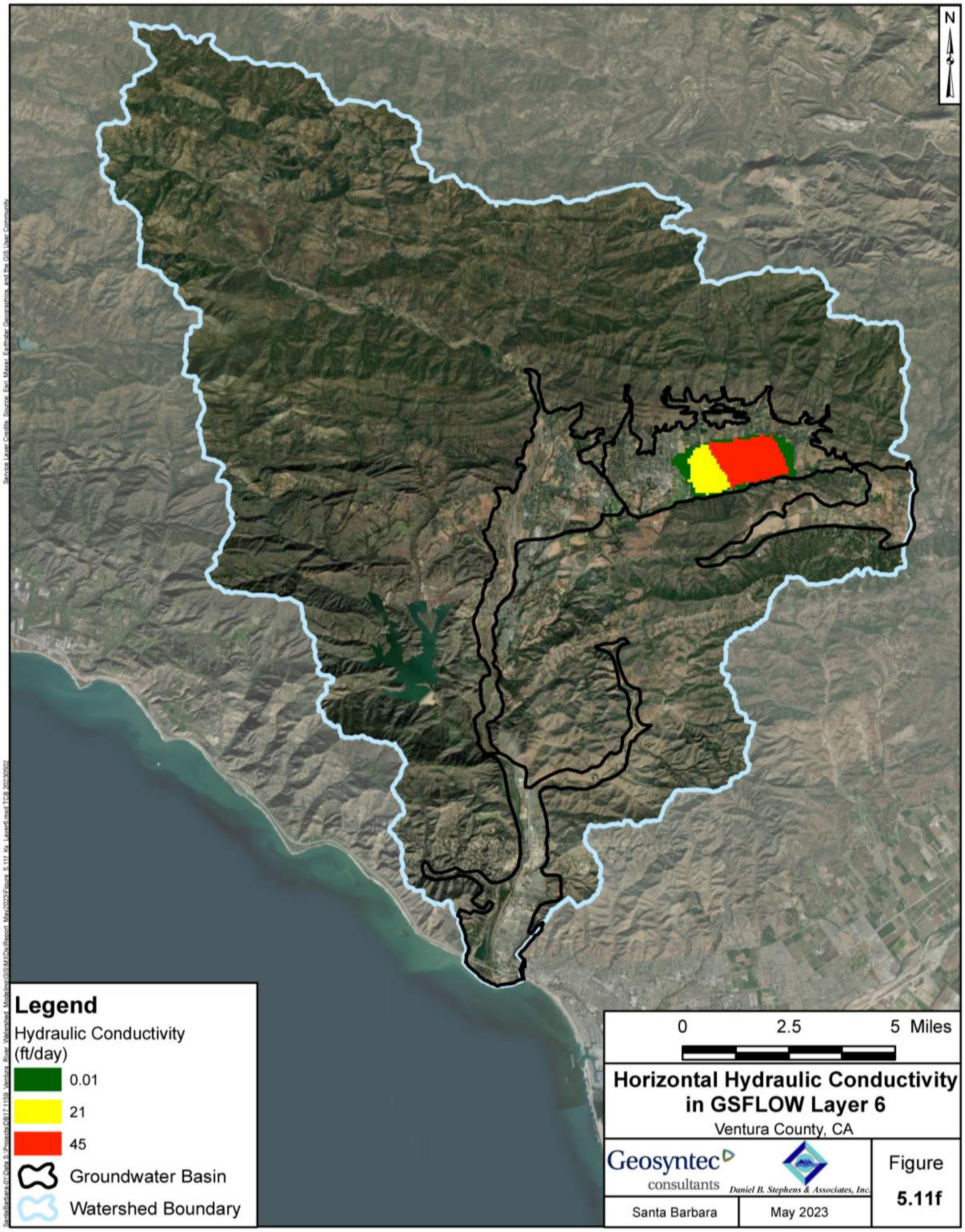


Figure 5.11f Horizontal Hydraulic Conductivity in GSFLOW Layer 6

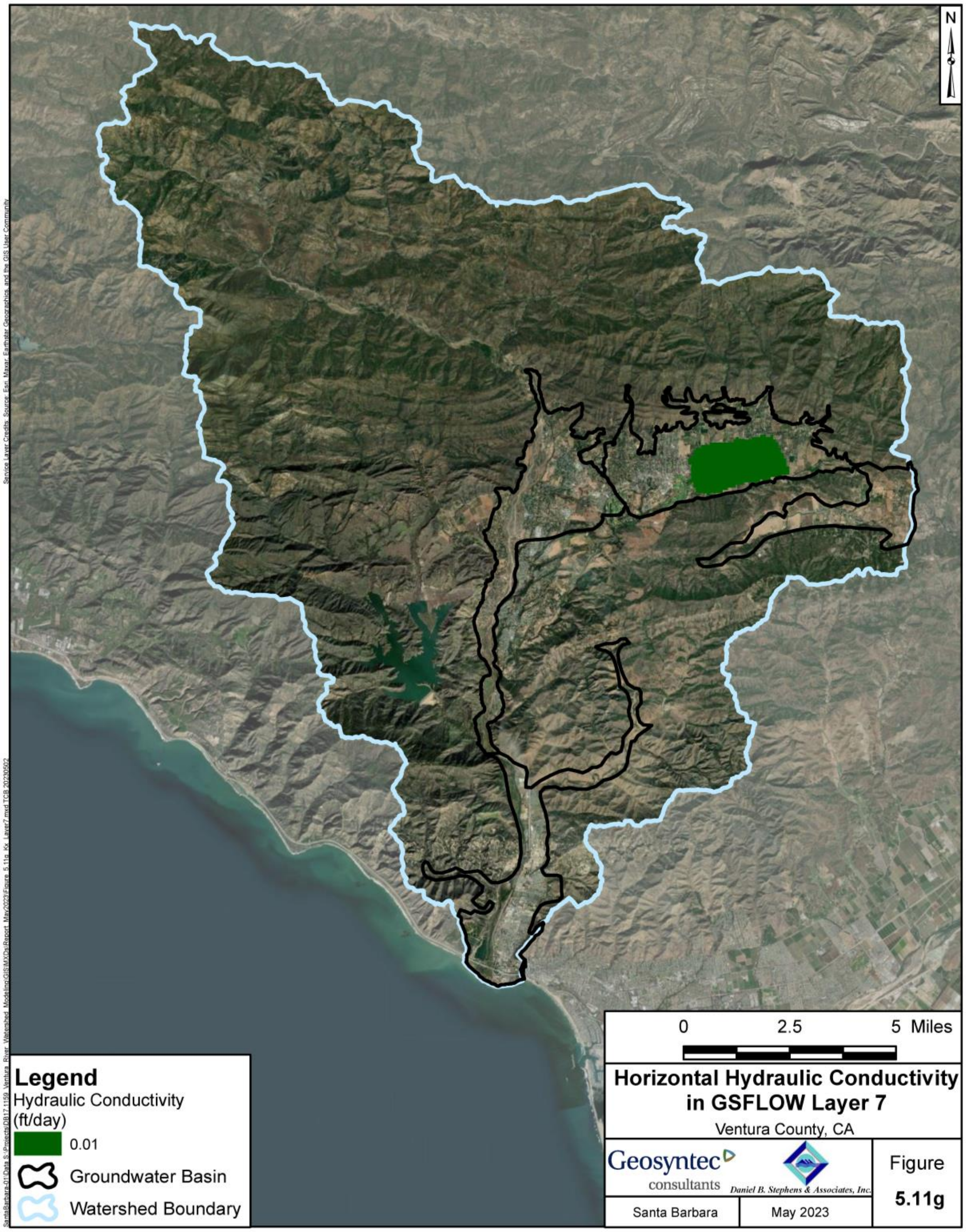


Figure 5.11g Horizontal Hydraulic Conductivity in GSFLOW Layer 7

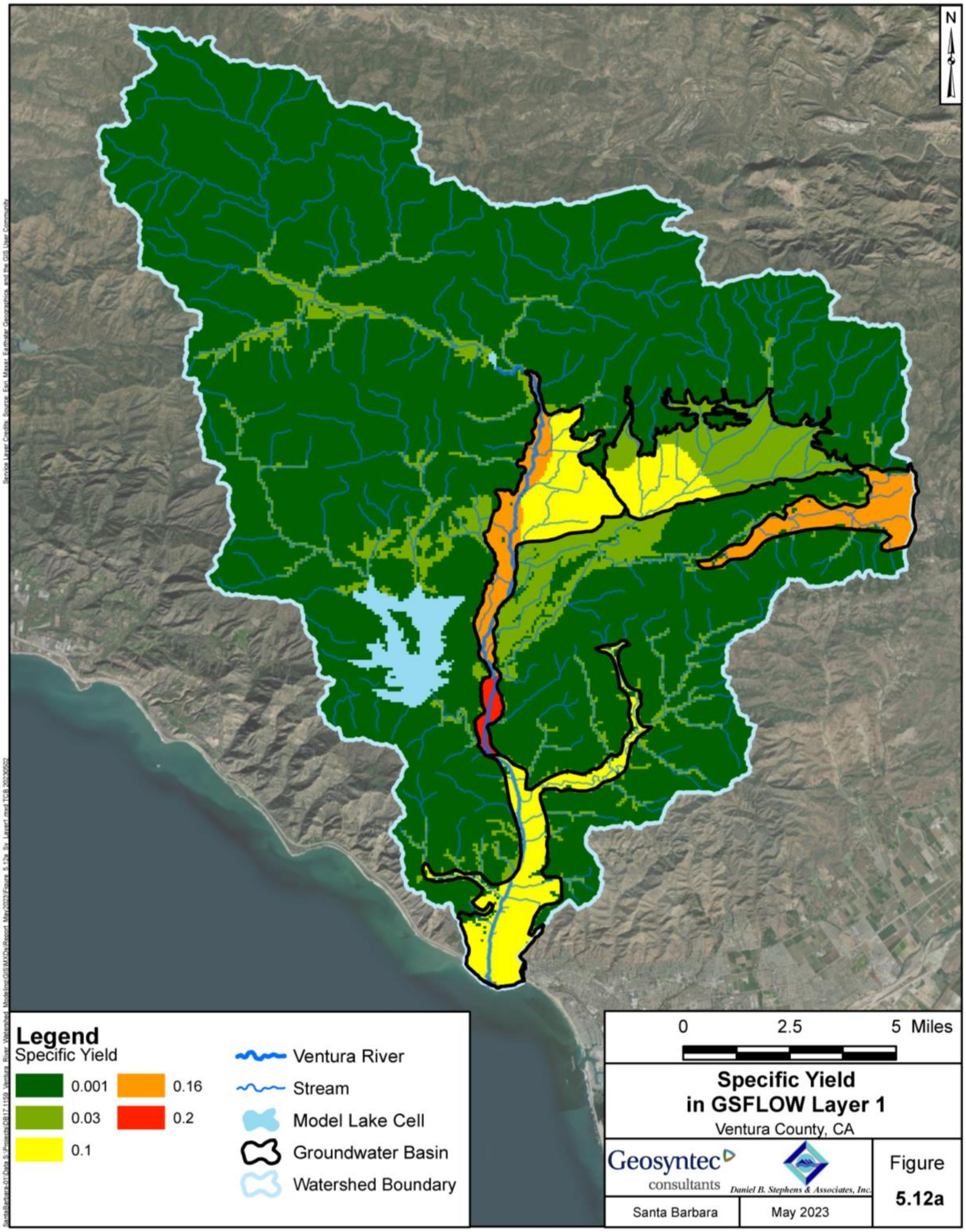


Figure 5.12a Specific Yield in GSFLOW Layer 1

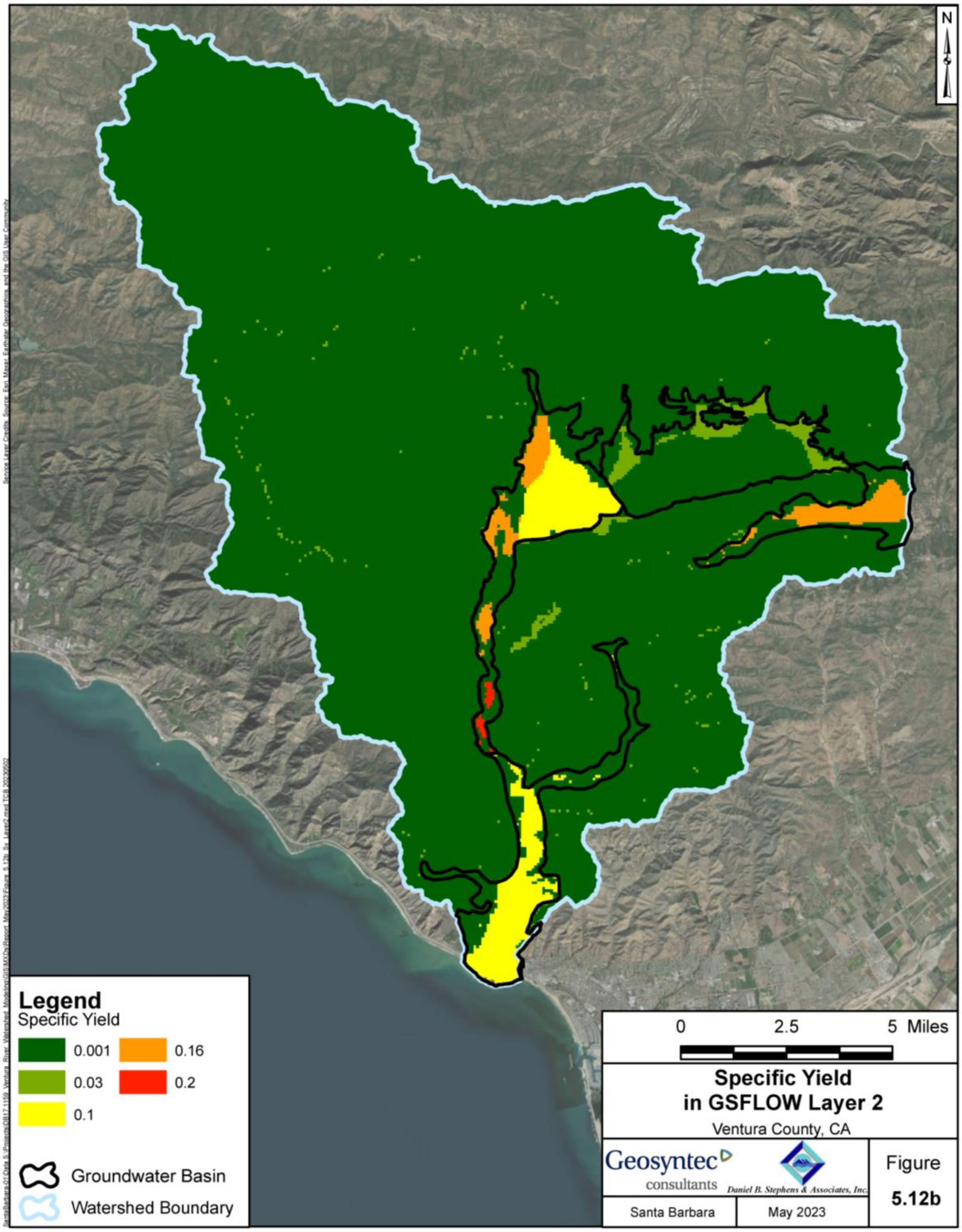


Figure 5.12b Specific Yield in GSFLOW Layer 2

5.4.1.1 Timeseries Plots

Model calibration results are presented as timeseries plots at the different gage locations in Figure 5.13 through Figure 5.20. Each plot shows a comparison of daily average flow rates (upper frame), monthly average flow rates (center frame), and flow duration curves (lower frame). The model replicates the seasonal and interannual trends in streamflow at most locations, as discussed in the following.

The model results indicate good agreement with the measured streamflow during higher flow periods (i.e., winter and spring) as best illustrated by the monthly average flow rates (center frame) and the upper end of the flow duration curves (lower frame). Notable exceptions are during certain years at Gages 600 and 606A where the measured flow rates are anomalously high (e.g., Gage 600 in years 2001, 2002, and 2011 through 2014 (Figure 5.19) and Gage 606A in 2011 (Figure 5.20). As discussed in Section 5.2.1.1, these stream gages may not be maintained and calibrated adequately or regularly and therefore have periods where streamflow rates may be in error. Despite the challenges at these streamflow gages above Lake Casitas, the model accurately matches the water surface elevations in Lake Casitas (see Section 5.4.1.4), indicating that the overall water balance in these sub-watersheds is correct.

Agreement of the model results during low-flow periods (i.e., summer and fall) is generally good, with monthly average flows being well predicted down to approximately 1 cfs at most locations. Exceptions are noted in years with higher summer flows (e.g., 1995, 1998, 2005, and 2006) where the model underpredicts the summer flows. Adjusting calibration parameters to correct these years resulted in poorer prediction of the summer flows in the more typical and lower flow years. Since the lower flows are more critical for many drivers in the watershed (e.g., fish passage), model calibration was focused on obtaining better predictions in the lower flow years. The effect of this on the summer volume errors is discussed in more detail in Section 5.4.1.2.

Model prediction of low flows and how they vary from year to year, including the multiple drought years, are particularly well captured at Gage 604 **(**Figure 5.13) and Gage 605A/605 (Figure 5.17). At Gage 603A (Figure 5.14), the reduction in low flows during the multiple drought years (2013, 2014, and 2015) are not

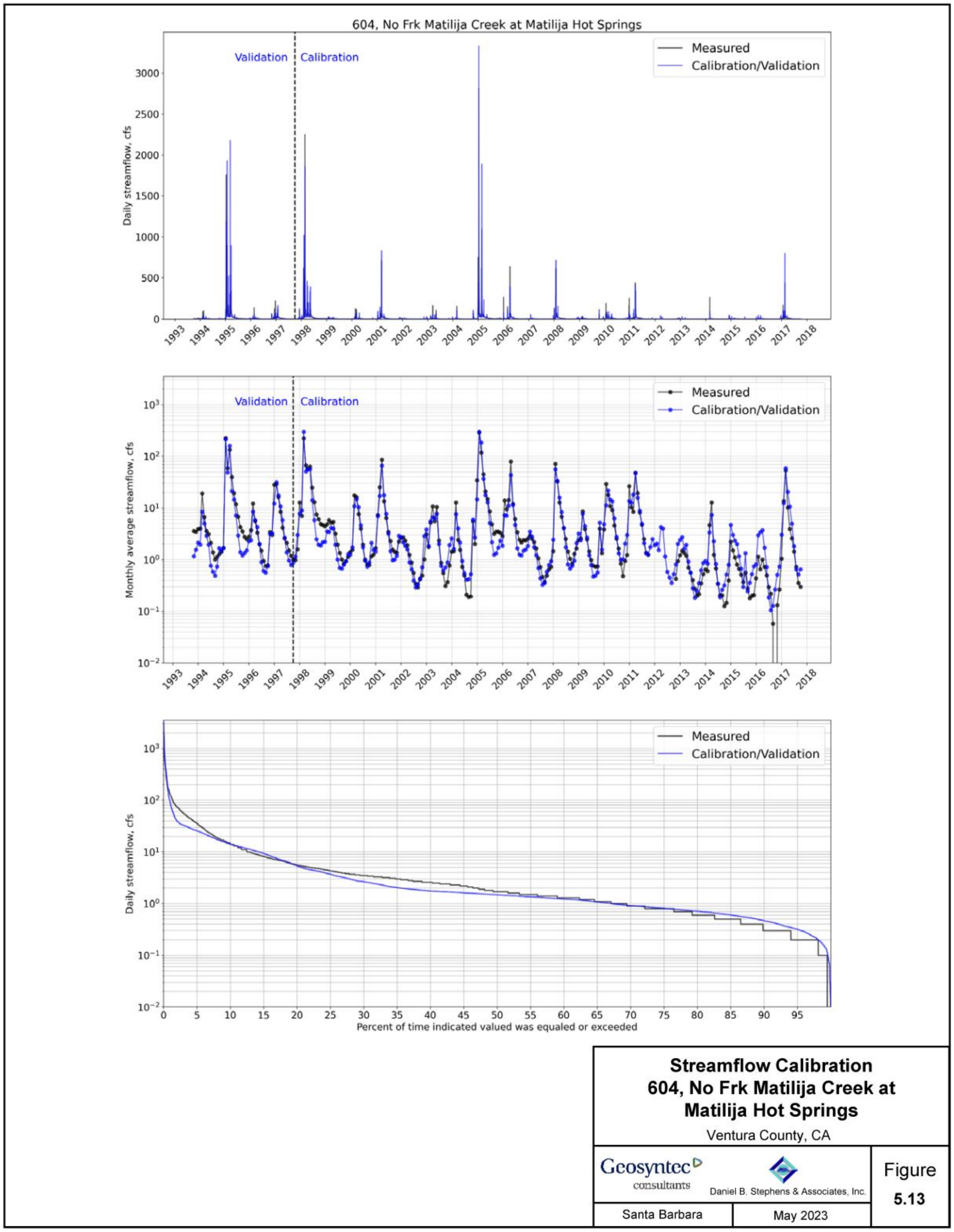
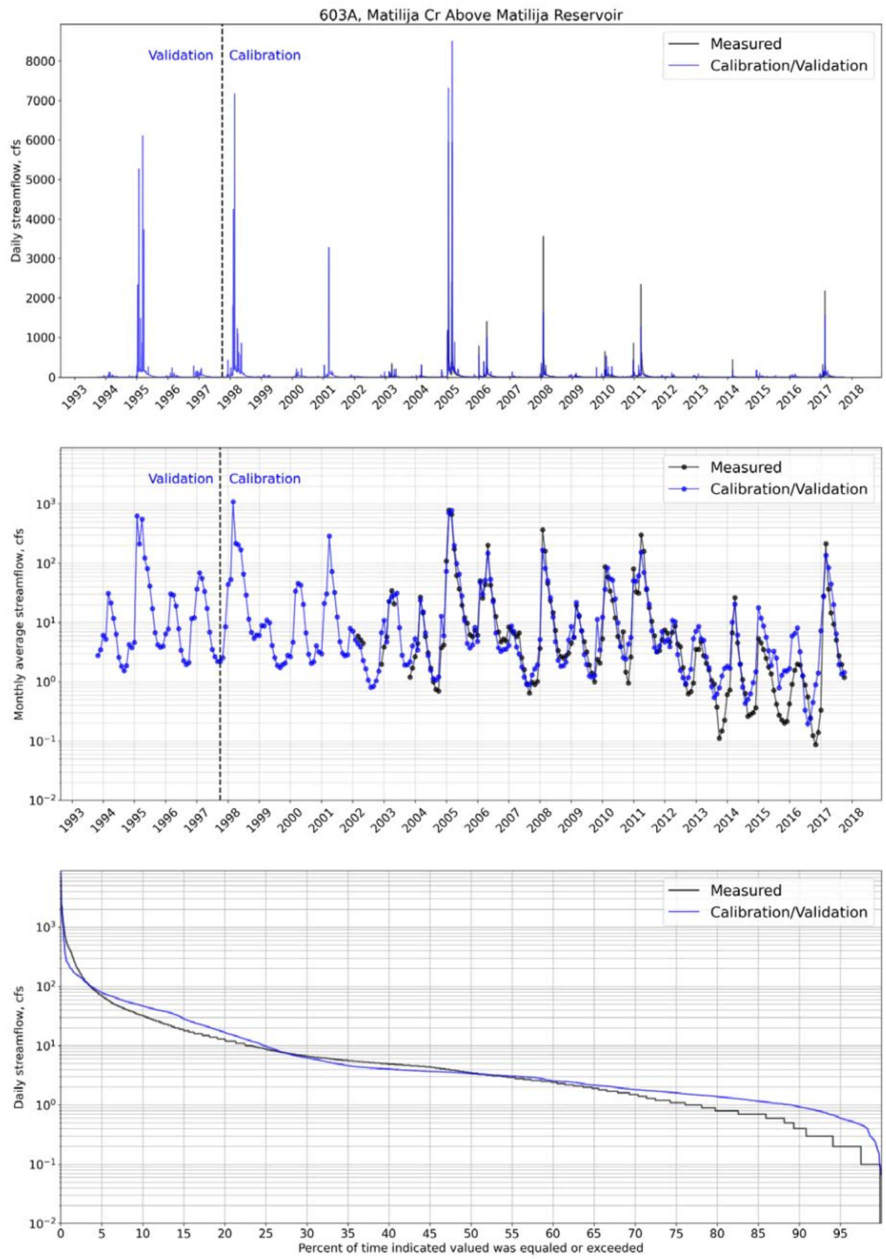


Figure 5.13 Streamflow Calibration 604, No Frk Matilija Creek at Matilija Hot Springs

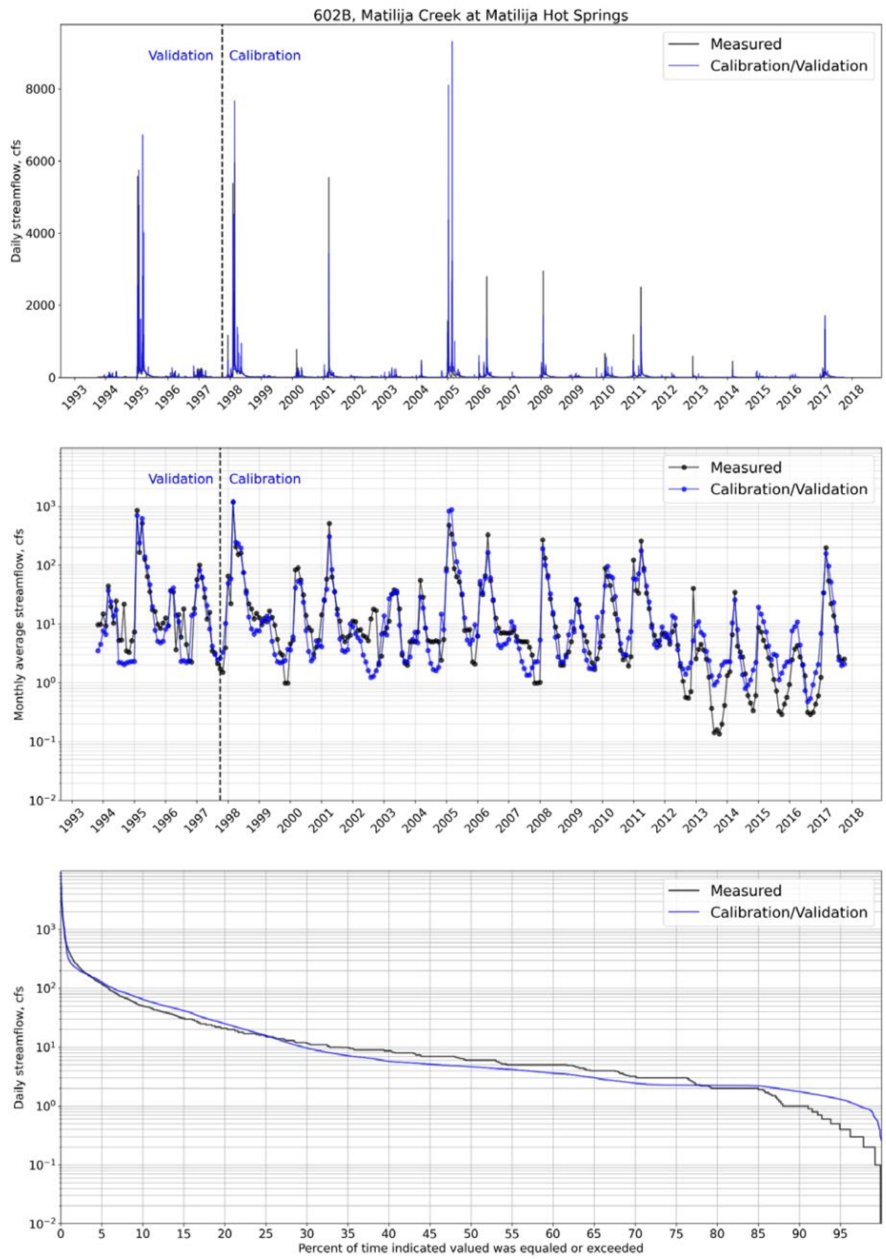


Streamflow Calibration 603A, Matilija Cr above Matilija Reservoir

Ventura County, CA

Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure 5.14
Santa Barbara	May 2023	

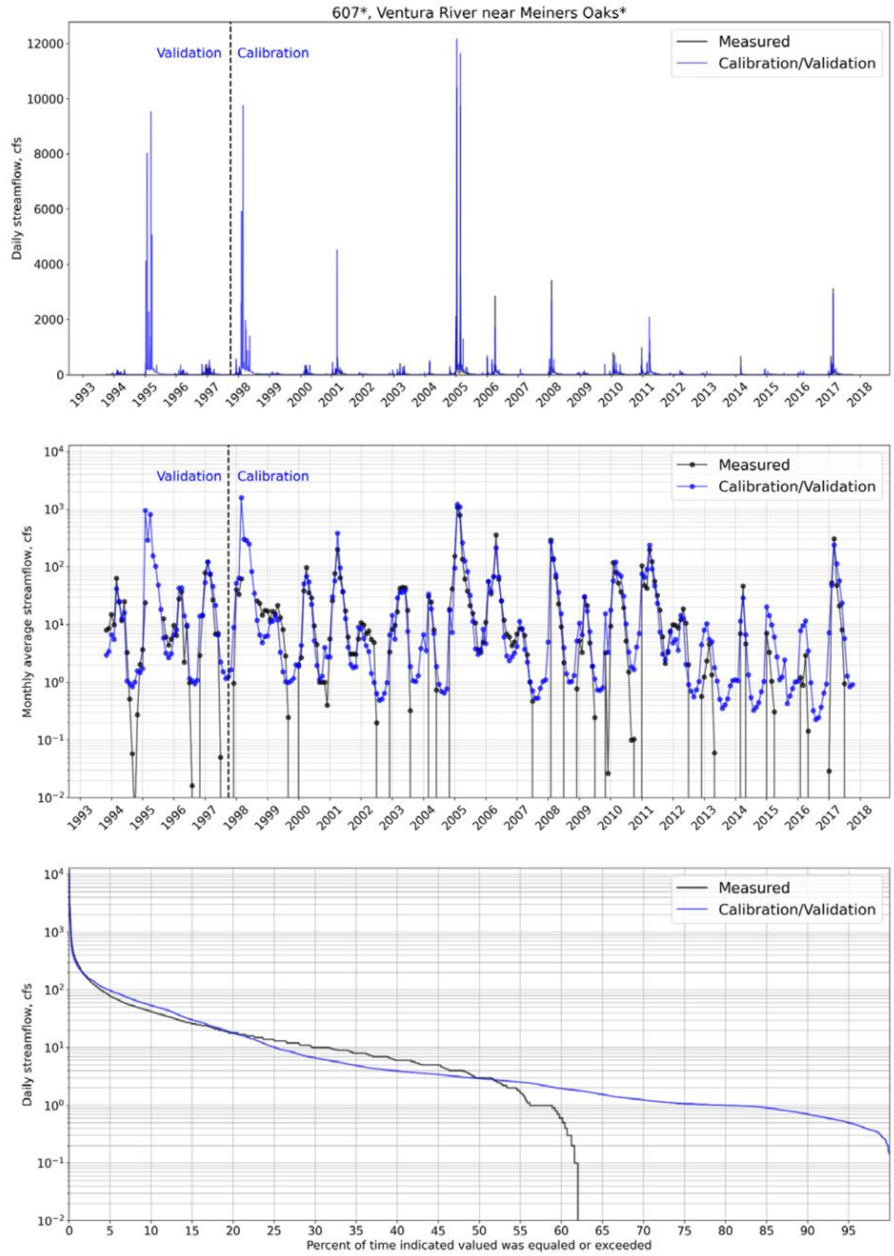
Figure 5.14 Streamflow Calibration 603A, Matilija Cr above Matilija Reservoir



Streamflow Calibration
602B, Matilija Creek at
Matilija Hot Springs
Ventura County, CA

Geosyntec consultants
Daniel B. Stephens & Associates, Inc.
Santa Barbara
May 2023
Figure
5.15

Figure 5.15 Streamflow Calibration 602B, Matilija Creek at Matilija Hot Springs



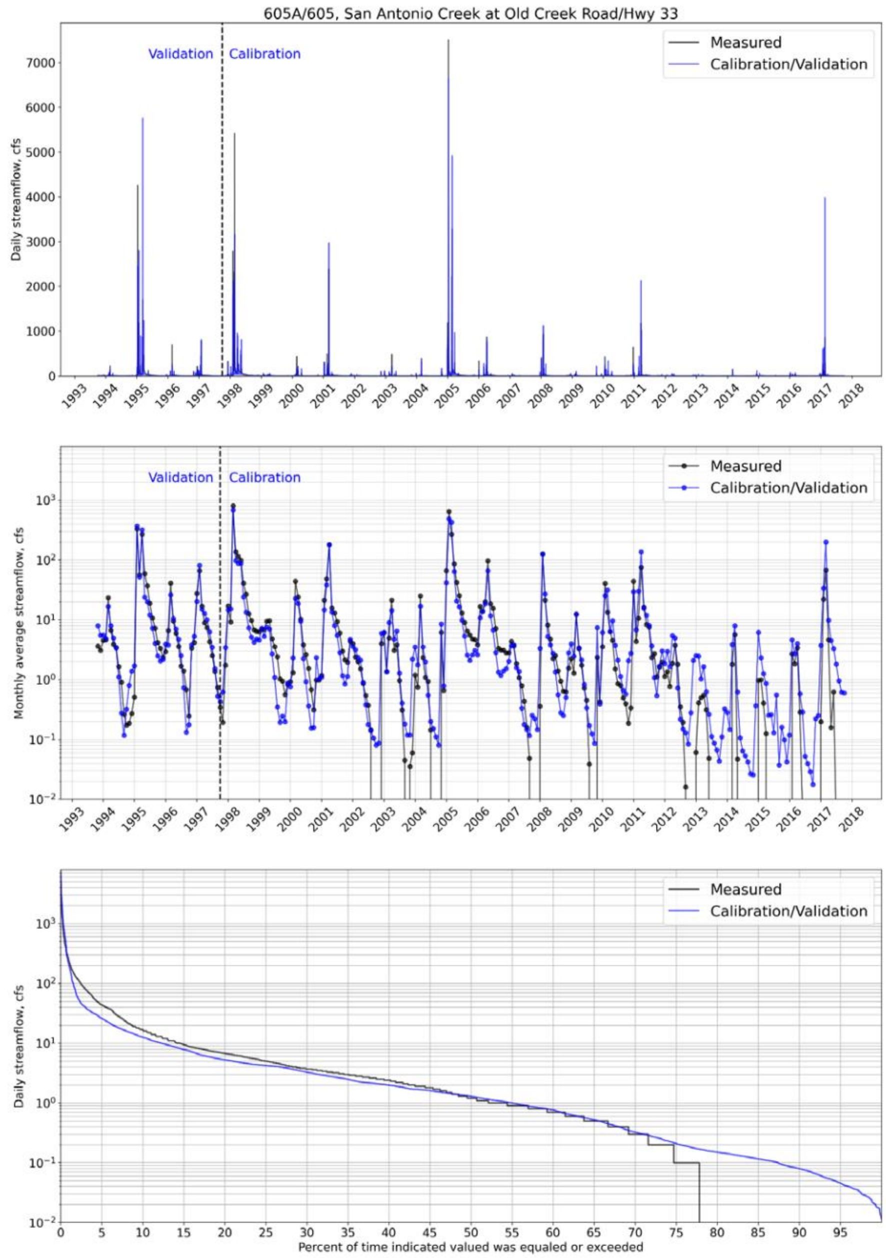
Streamflow Calibration 607*, Ventura River near Meiners Oaks*

Ventura County, CA

Geosyntec consultants | Daniel B. Stephens & Associates, Inc. | Figure 5.16

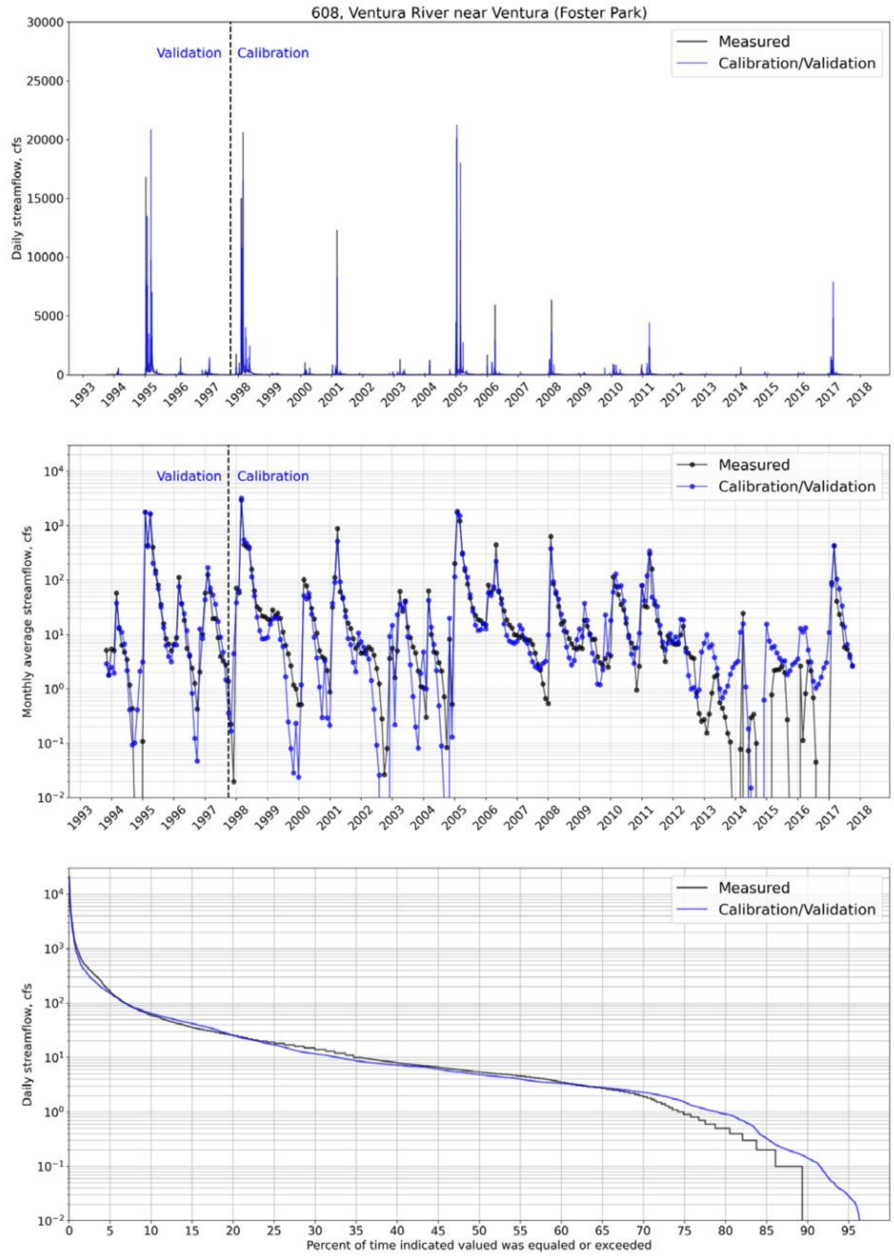
Santa Barbara | May 2023

Figure 5.16 Streamflow Calibration 607*, Ventura River near Meiners Oaks*



Streamflow Calibration 605A/605, San Antonio Creek at Old Creek Road/Hwy 33 Ventura County, CA	
Geosyntec consultants / Daniel B. Stephens & Associates, Inc.	Figure 5.17
Santa Barbara / May 2023	

Figure 5.17 Streamflow Calibration 605A/605, San Antonio Creek at old Creek Road/Hwy 33



Streamflow Calibration
608, Ventura River near Ventura
(Foster Park)

Ventura County, CA

Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure **5.18**
Santa Barbara	May 2023	

Figure 5.18 Streamflow Calibration 608, Ventura River near Ventura (Foster Park)

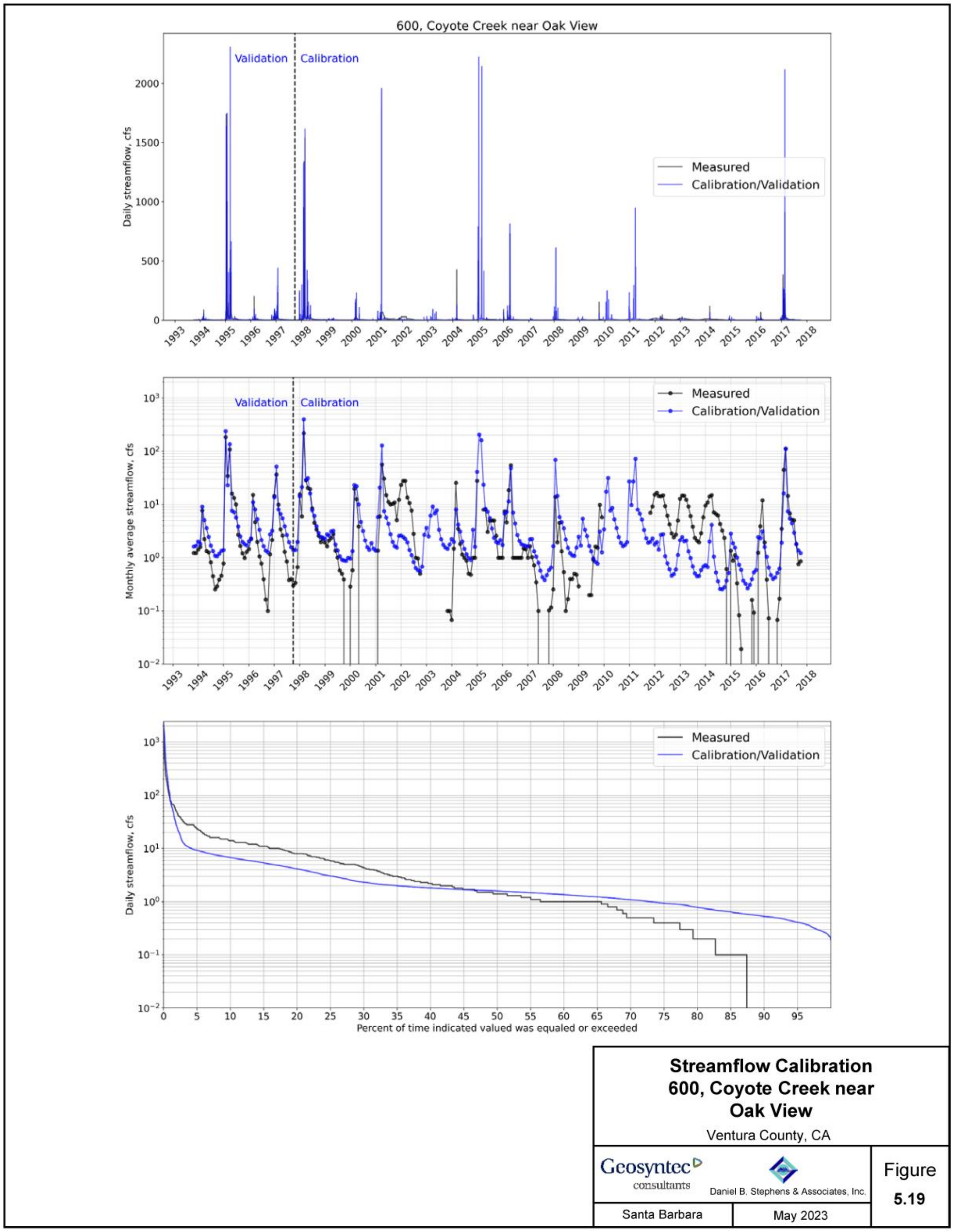
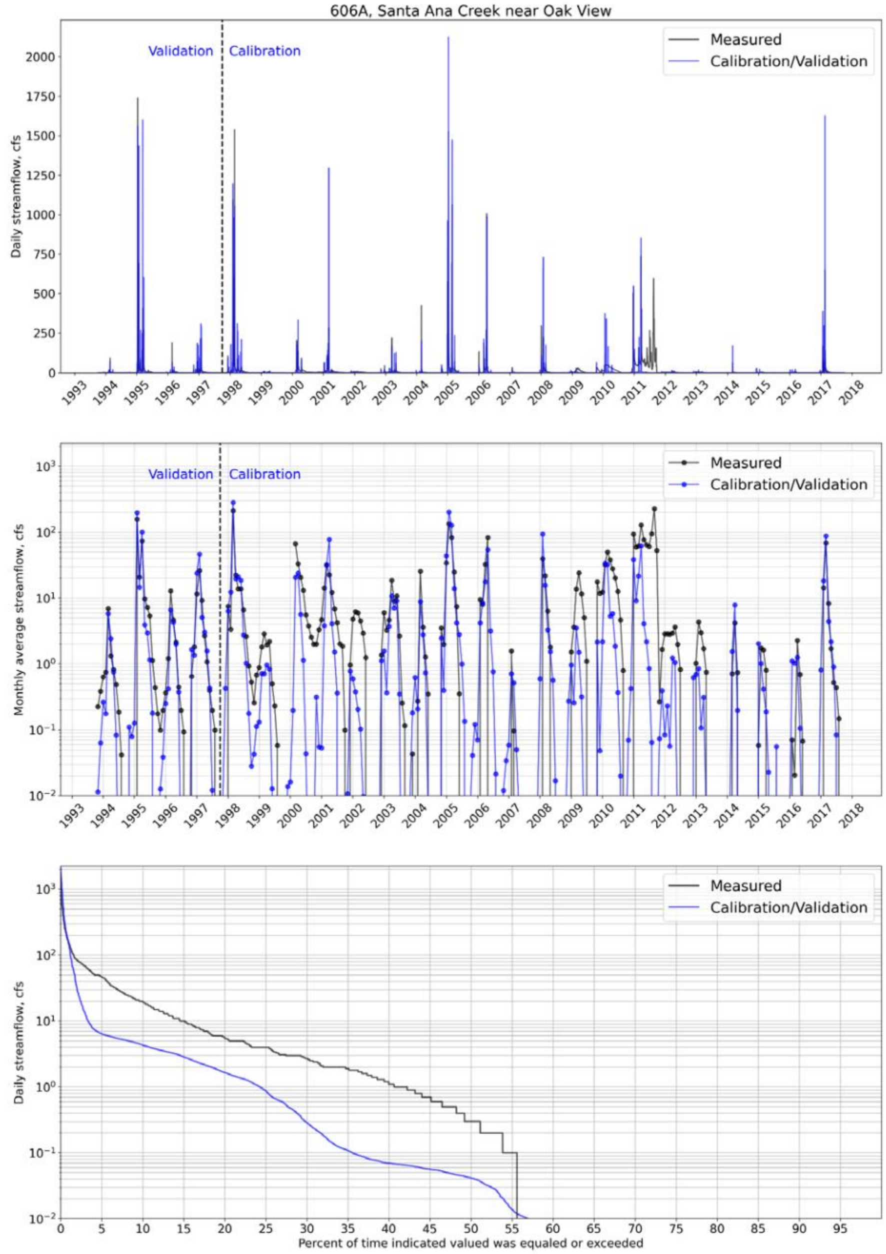


Figure 5.19 Streamflow Calibration 600, Coyote Creek near Oak View



Streamflow Calibration
606A, Santa Ana Creek
near Oak View

Ventura County, CA

Geosyntec consultants | Daniel B. Stephens & Associates, Inc. | Figure **5.20**

Santa Barbara | May 2023

Figure 5.20 Streamflow Calibration 606A, Santa Ana Creek near Oak View

predicted to the same extent as the measurements, but both model and measurements are generally less than approximately 1 cfs. These discrepancies are likely passed downstream to Gage 602B (Figure 5.15), and additional errors in the model results may result from uncertainties in estimating release volumes from Matilija Reservoir (Section 3.5.1).

At Gage 607*[21] (Figure 5.16), the measurement indicates flows decrease to zero in most years; whereas, the model typically decreases to approximately 1 cfs in most years. The discrepancy is likely due to not including details of the hydraulic structure related to the Robles diversion (i.e., the embankment and gate structure that blocks the Ventura River) in the VRW GSFLOW Model. This structure would result in pooling of water and additional streamflow losses (through infiltration) upstream of the diversion structure. While these local details are not fully captured in the VRW GSFLOW Model, the additional water passing the diversion location during low flows infiltrates and is lost from the stream shortly downstream.

At Gage 608 (Figure 5.18), the model prediction of low flows is good for the majority of the modeling period. Similar to upstream Gages 603A and 602B, the reduction in low flows at Gage 608 during the multiple drought years are not predicted to the same extent as the measurements, although both the model and the measurements are generally less than approximately 1 cfs.

5.4.1.2 Statistical Metrics

Goodness-of-fit statistics (see Section 5.2.1) for modeled streamflow are presented in Table 5.4 (calibration period) and Table 5.5 (validation period). Each table presents monthly values for the PAEE, AAEE, and NSME. Additionally, seasonal average volume errors are provided in terms of percentages for winter (January to March), spring (April to June), summer (July to September), and fall (October to December).

[21] Comparisons at Gage 607 are made for the sum of Gage 607 (which measures flow downstream of the Robles diversion) and the Robles diversion flows. This effectively is a measure of the inflow upstream of the diversion and is denoted as Gage 607* in this report. This approach has the effect of removing effects of the hydraulic details of the diversion structure from the comparison. The hydraulic details are not fully represented in the hydrological model.

Table 5.4 Streamflow Error Statistics and Seasonal Summary Volume Errors for Calibration Period (WY1998 – WY2017), VRW GSFLOW Model

Gage	Gage Name	Percent Observed Missing	Monthly PAEE (%)	Monthly AAEE (%)	Monthly NSME	Winter Volume [4] Error (%)	Spring [4] Volume Error (%)	Summer[1,4] Volume Error (%)	Fall [4] Volume Error (%)
603A	Matilija Crk above Matilija Reservoir	26.57	-5.9	5.9	0.91	-9.4	4.3	-23.5	7.8
604	No Frk Matilija Crk at Matilija Hot Springs	5.01	-1.1	1.1	0.92	4.7	-10.4	-36.2	-14.3
602B	Matilija Crk at Matilija Hot Springs	0.04	9.0	9.0	0.76	14.3	5.5	-36.0	-4.3
607[2]	Ventura River near Meiners Oaks[2]	2.67	7.3	7.3	0.91	11.1	4.1	-28.6	-8.0
608	Ventura River near Ventura (Foster Park)	0	-1.2	1.2	0.96	0.8	-5.3	-36.0	-2.4
605A/ 605	San Antonio Creek at Old Creek Road/Hwy 33	0.01	-4.7	4.7	0.92	-0.3	-21.0	-45.2	-4.4
600	Coyote Creek near Oak View	18.81	0.1	0.1	0.31	16.8	-24.4	-30.4	-31.6
606A[3]	Santa Ana Creek near Oak View[3]	1.93	-9.2	9.2	0.74	8.7	-50.2	-93.4	-41.8

Goodness of fit color categories (see Table 5.1)

- Excellent (dark green)
- Very Good (green)
- Good (light green)
- Fair (tan)

AAEE = absolute average estimation error
GSFLOW = Groundwater and Surface-water Flow
NSME = Nash-Sutcliffe model efficiency
PAEE = percent average estimation error
VRW = Ventura River Watershed
WY = water year

1. Relative summer volume errors (as percentages) are misleadingly high due to low measured flow rates and are poor metrics for assessing calibration performance for ephemeral systems that can result in a zero in the denominator. Absolute errors are provided in Table 5.6 and are more appropriate. For example, at Foster Park (Gage 608) a relative error of -33.6% corresponds to mean and root-mean-square (RMS) errors of only -2.5 cfs and 4.6 cfs, respectively. Additionally, these flow rate errors are dominated by high runoff years. Excluding the six years with >50,000 AF of run-off at Foster Park results in the mean and RMS errors decreasing to -1.0 cfs and 2.4 cfs, respectively. Furthermore, in the Very Dry and Dry years the mean and RMS errors decrease to -0.3 cfs and 1.3 cfs, respectively.
2. Includes Robles Canal diversion flows
3. Excluding WY2011
4. Winter is January to March. Spring is April to June. Summer is July to September. Fall is October to December.

Table 5.5 Monthly Streamflow Error Statistics and Seasonal Summary Volume Errors for Validation Period WY1994 – WY1997), VRW GSFLOW Model

Gage	Gage Name	Percent Observed Missing	Monthly PAEE (%)	Monthly AAEE (%)	Monthly NSME	Winter Volume [4] Error (%)	Spring [4] Volume Error (%)	Summer[1,4] Volume Error (%)	Fall [4] Volume Error (%)
603A	Matilija Crk above Matilija Reservoir	100	n/a	n/a	n/a	n/a	n/a	n/a	n/a
604	No Frk Matilija Crk at Matilija Hot Springs	0	-10.9	10.9	0.98	-1.4	-31.0	-51.2	-42.4
602B	Matilija Crk at Matilija Hot Springs	0	-0.8	0.8	0.95	1.1	15.3	-48.9	-28.6
607[2]	Ventura River near Meiners Oaks[2]	14.24	3.3	3.3	0.84	3.6	27.4	-1.8	-27.1
608	Ventura River near Ventura (Foster Park)	0	-4.2	4.2	0.99	-0.2	-25.4	-18.7	-8.6
605A/605	San Antonio Creek at Old Creek Road/Hwy 33	0	2.2	2.2	0.96	9.8	-33.1	-36.3	7.9
600	Coyote Creek near Oak View	0	22.3	22.3	0.90	22.7	0.2	153.3	26.6
606A[3]	Santa Ana Creek near Oak View[3]	0	18.4	18.4	0.89	23.6	-53.1	-90.8	75.4

Goodness of fit color categories (see Table 5.1)

- Excellent (dark green)
- Very Good (green)
- Good (light green)
- Fair (tan)

AAEE = absolute average estimation error
GSFLOW = Groundwater and Surface-water Flow
NSME = Nash-Sutcliffe model efficiency
PAEE = percent average estimation error
VRW = Ventura River Watershed
WY = water year

1. Relative summer volume errors (as percentages) are misleadingly high due to low measured flow rates and are poor metrics for assessing calibration performance for ephemeral systems that can result in a zero in the denominator. Absolute errors are provided Table 5.6 and are more appropriate. For example, at Foster Park (Gage 608) a relative error of -33.6% corresponds to mean and root-mean-square (RMS) errors of only -2.5 cfs and 4.6 cfs, respectively. Additionally, these flow rate errors are dominated by high runoff years. Excluding the six years with >50,000 AF of run-off at Foster Park results in the mean and RMS errors decreasing to -1.0 cfs and 2.4 cfs, respectively. Furthermore, in the Very Dry and Dry years the mean and RMS errors decrease to -0.3 cfs and 1.3 cfs, respectively.
2. Includes Robles Canal diversion flows
3. Excludes WY2011
4. Winter is January to March. Spring is April to June. Summer is July to September. Fall is October to December.

Most of the PAEE, AAEE, and NSME statistics fall within the “Very Good” to “Excellent” categories, as defined in Section 5.2.1. Notable exceptions are Gages 600 and 606A, which are located above Lake Casitas, and have several statistical metrics in the “Good” and “Fair” categories and one metric worse than “‘Fair” (Table 5.4, NSME = 0.31 at Gage 600). These particular stream gages have access issues and may not be maintained and calibrated adequately or regularly, as discussed above. Excluding Gages 600 and 606A, all the PAEE and AAEE metrics and all but one of the NSME metrics meet the stated calibration goal of “Very Good” or better (see Section 5.2.1) for the calibration period and all but one of the PAEE, AAEE, and NSME meet the calibration goal of “Excellent” for the validation period.

The seasonal volume errors are generally larger than the PAEE and AAEE. Excluding Gages 600 and 606A, the majority of the seasonal volume errors fall within the “Good” to “Excellent” categories for the calibration period (Table 5.4), except for the summer volumes that are worse than “Fair.” The volume errors are generally larger for the validation period (Table 5.5) than the calibration period, although the winter volume errors are mostly smaller.

The relative volume errors (as percentages) during low flow periods (e.g., summer) are misleadingly high due to low measured flow rates and are poor metrics for assessing calibration performance for ephemeral systems that can result in a zero in the denominator. Additionally, the quality of streamflow measurements during low flow periods is generally poor with errors in excess of 8% (see Section 5.2.1.1), and these can compound the comparison of relative volume errors. For better context, absolute errors for the summer flows are provided in Table 5.6 and are more appropriate. For example, at the Ventura River at Foster Park (Gage 608), a relative error of -33.6% corresponds to mean and root-mean-square (RMS) errors of only -2.5 cfs and 4.6 cfs, respectively.

The mean errors in Table 5.6 are negative at all gage locations, indicating a general bias in the model (i.e., a consistent underestimation of flows at all locations). Additional evaluation of the mean and RMS errors indicates that the largest summer streamflow errors are during the wet years with higher stream flows. This is a result of prioritizing the accuracy of years with lower flows during the calibration process, since the lower flow years are critical with respect to many of the project goals (e.g., evaluation of fish passage). Table 5.6 also provides mean and RMS errors for the “moderate flow” years, defined as years when the Ventura River run-off at Foster Park was less than 50,000 AF. This resulted in excluding six of the 24 model years (i.e., WY1995, 1998, 2001,

Table 5.6 Summer Streamflow Error Statistics (WY1994 – WY2017), VRW GSFLOW Model

Gage	Gage Name	Volume Error[1] (%)	Mean Error (cfs)	RMS Error (cfs)	Moderate Flow Years[2] Mean Error (cfs)	Moderate Flow Years[2] RMS Error (cfs)	Low Flow Years[3] Mean Error (cfs)	Low Flow Years[3] RMS Error (cfs)
603A	Matilija Crk above Matilija Reservoir	-23.5	-0.6	1.8	-0.1	1.2	0.2	0.6
604	No Frk Matilija Crk at Matilija Hot Springs	-39.7	-0.6	1.5	0.0	0.3	0.0	0.3
602B	Matilija Crk at Matilija Hot Springs	-39.2	-2.4	5.1	-2.1	5.2	-2.5	6.1
607[4]	Ventura River near Meiners Oaks[4]	-25.7	-0.6	3.5	0.4	1.8	0.6	0.7
608	Ventura River near Ventura (Foster Park)	-33.6	-2.5	4.6	-1.0	2.4	-0.3	1.3
605A/605	San Antonio Creek at Old Creek Road/Hwy 33	-43.4	-0.9	2.2	0.0	0.5	0.1	0.2
600	Coyote Creek near Oak View	-15.1	-0.3	2.2	0.0	1.4	-0.6	1.5
606A[5]	Santa Ana Creek near Oak View[5]	-93.2	-0.3	0.9	-0.3	1.0	0.0	0.0

cfs = cubic feet per second
GSFLOW = Groundwater and Surface-water Flow
RMS = root-mean-square
VRW = Ventura River Watershed
WY = water year

1. Relative summer volume errors (as percentages) are misleadingly high due to low measured flow rates and are poor metrics for assessing calibration performance for ephemeral systems that can result in a zero in the denominator. Absolute errors (i.e., in cfs) are more appropriate. For example, at Foster Park (Gage 608) a relative error of -33.6% corresponds to mean and root-mean-square (RMS) errors of only -2.5 cfs and 4.6 cfs, respectively. Additionally, these flow rate errors are dominated by high runoff years. Excluding the six years with >50,000 AF of run-off at Foster Park results in the mean and RMS errors decreasing to -1.0 cfs and 2.4 cfs, respectively. Furthermore, in the Very Dry and Dry years the mean and RMS errors decrease to -0.3 cfs and 1.3 cfs, respectively.
2. Excluding six years with >50,000 AF of runoff at Foster Park (i.e., excluding WY1995, 1998, 2001, 2005, 2006, 2008)
3. Only including years with < 6,200 AF of runoff at Foster Park (i.e., 'Dry' and 'Very Dry' years only; WY1994, 2002, 2004, 2007, 2009, 2012, 2013, 2014, 2015, 2016)
4. Includes Robles Canal diversion flows
5. Excludes WY2011

2005, 2006, and 2008). The mean and RMS errors at Gage 608 for this period decreased to -1.0 cfs and 2.4 cfs, respectively.

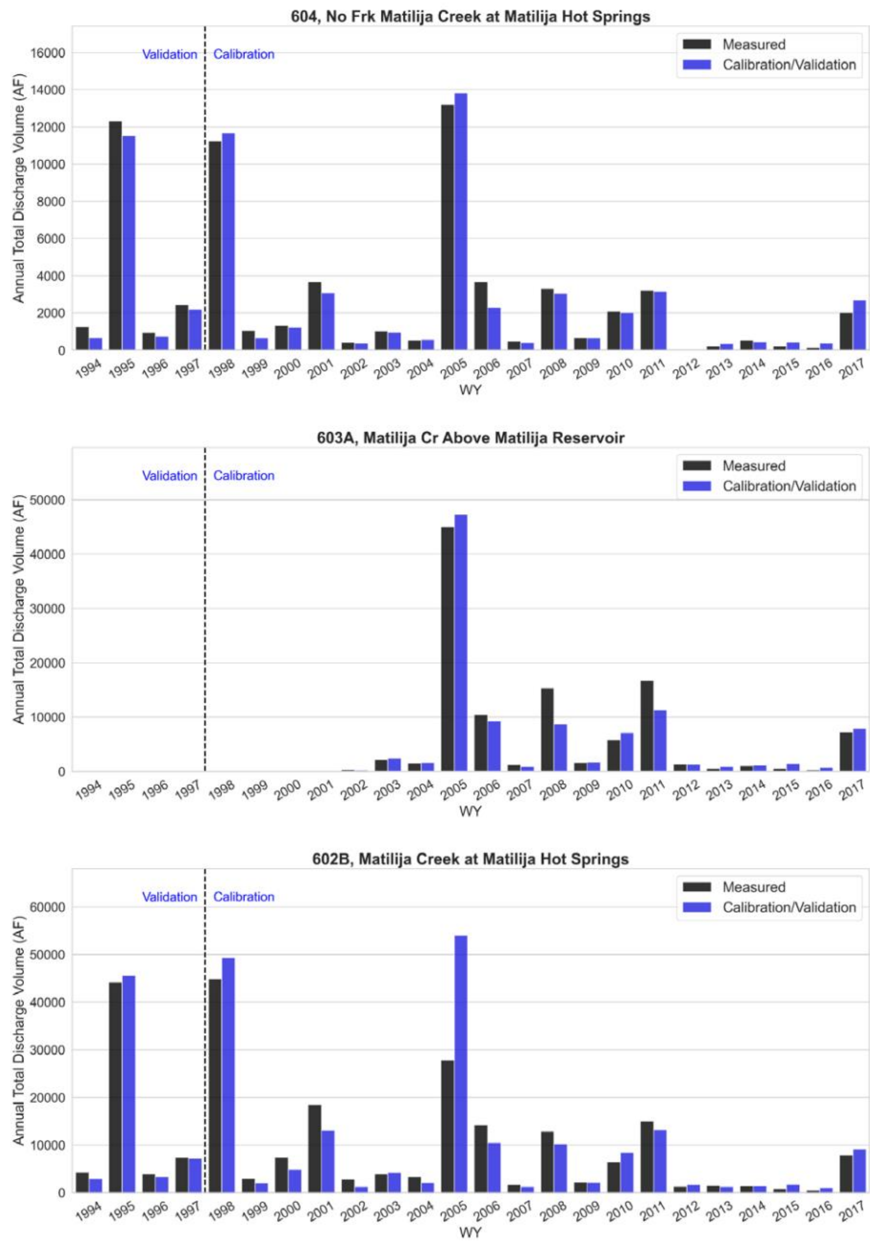
Similar decreases are observable at most other gage locations. For example, at Gage 605A/605 (a key location on San Antonio Creek), the mean and RMS errors decrease from -0.9 cfs and 2.2 cfs to 0.0 cfs and 0.5 cfs, respectively. The one notable exception is Gage 602B located immediately downstream of Matilija Dam, where the errors do not substantially improve for the moderate flow years. This may reflect some inaccuracies in the assumptions made to estimate the non-measured releases from Matilija Dam (Section 3.5.1). Notably, the mean errors for the moderate flow years across the gage locations are both positive and negative, indicating that the model is not biased for these important years.

The low flows are dependent on the groundwater model, including modeling of the fractured bedrock in the mountains. Modeling fractured bedrock is a challenging process, with flows often exhibiting stochastic behavior. It is likely that the model is missing some additional storage in the watershed and/or groundwater components that becomes active in the wetter years and sustains higher summer flows in those years. Trying to better capture the higher flow years during the calibration process resulted in substantially poorer calibration of the years with moderate or low flows.

The chosen calibration approach is justified through lower mean and RMS errors for the moderate years (Table 5.6). Additionally, in the “low flow” years (i.e., Very Dry and Dry years where Ventura River runoff at Foster Park is less than 6,200 AF) which are of critical importance, the mean and RMS errors generally further decrease. For example, the mean and RMS errors are -0.3 cfs and 1.3 cfs, respectively, at Gage 608 and 0.1 cfs and 0.2 cfs, respectively, at Gage 605A/605 (Table 5.6).

5.4.1.3 Annual Volumes

Comparisons of measured and simulated annual streamflow volumes are presented in Figure 5.21, Figure 5.22, and Figure 5.23. The plots illustrate the ability of the model to replicate the interannual trends between dry and wet years. A notable discrepancy is in WY2005 at Gage 602B (Figure 5.21) where missing field measurements during high flow periods resulted in much lower measured annual volumes. Additionally, the previously discussed issues with the measurements at Gage 600 in WY2012, 2013, 2014 and at Gage 606A in WY2011 are clearly illustrated in Figure 5.23.



Annual Volume Plots for Gages 604, 603A, and 602B

Ventura County, CA

Geosyntec consultants / Daniel B. Stephens & Associates, Inc.		Figure 5.21
Santa Barbara	May 2023	

Figure 5.21 Annual Volume Plots for Gages 604, 603A, and 602B

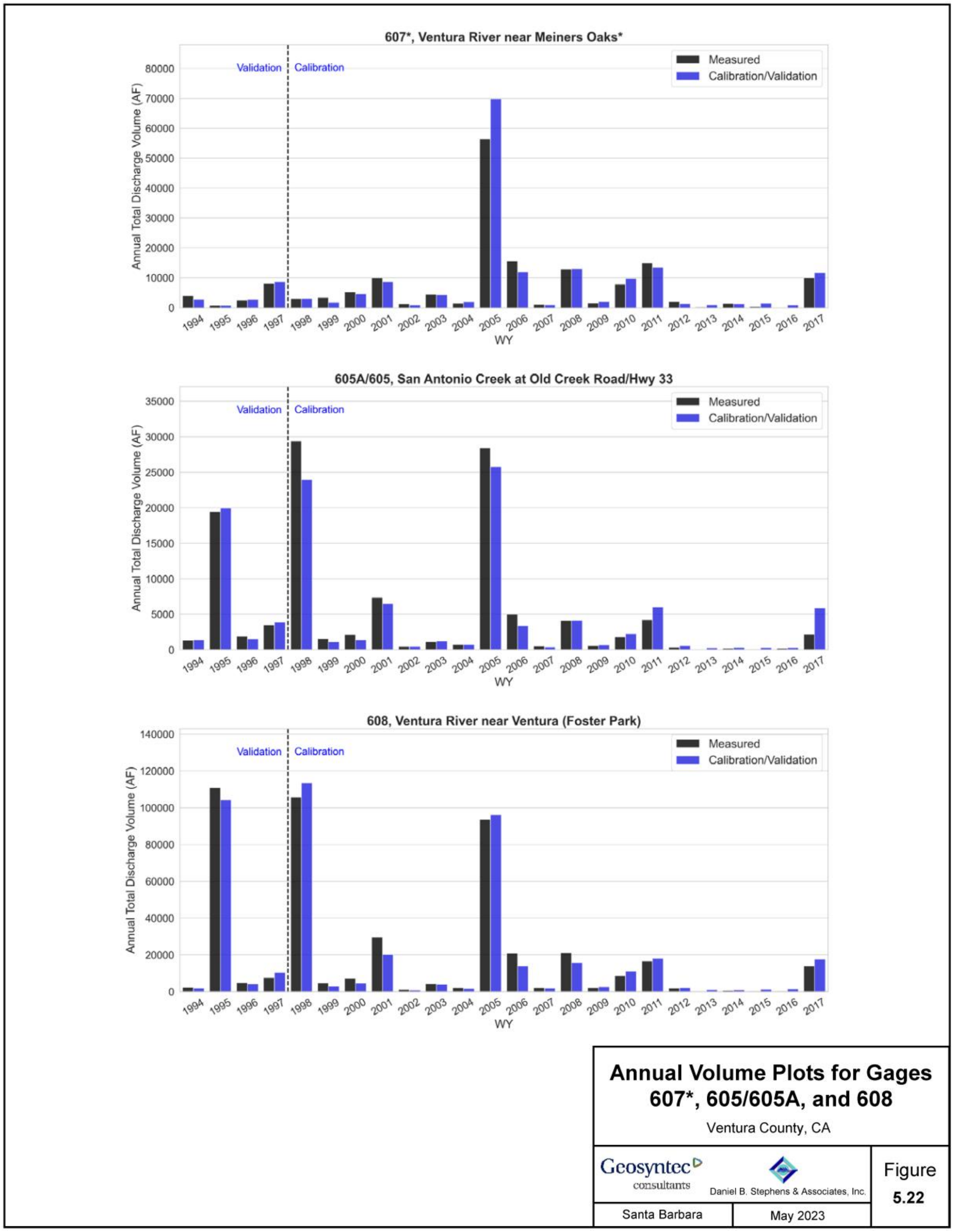


Figure 5.22 Annual Volume Plots for Gages 607*, 605/605A, and 608

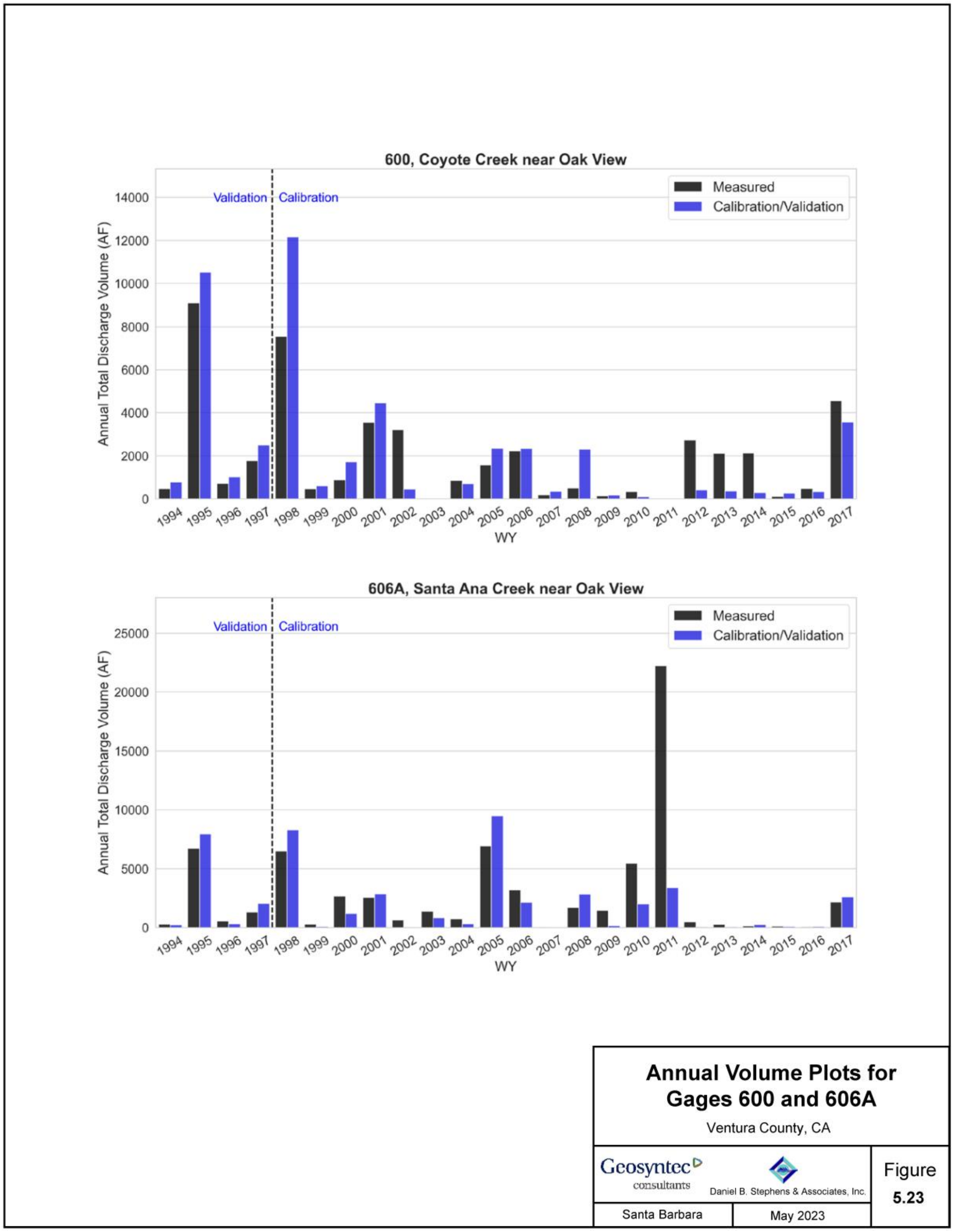


Figure 5.23 Annual Volume Plots for Gages 600 and 606A

5.4.1.4 Lake and Reservoir Elevations

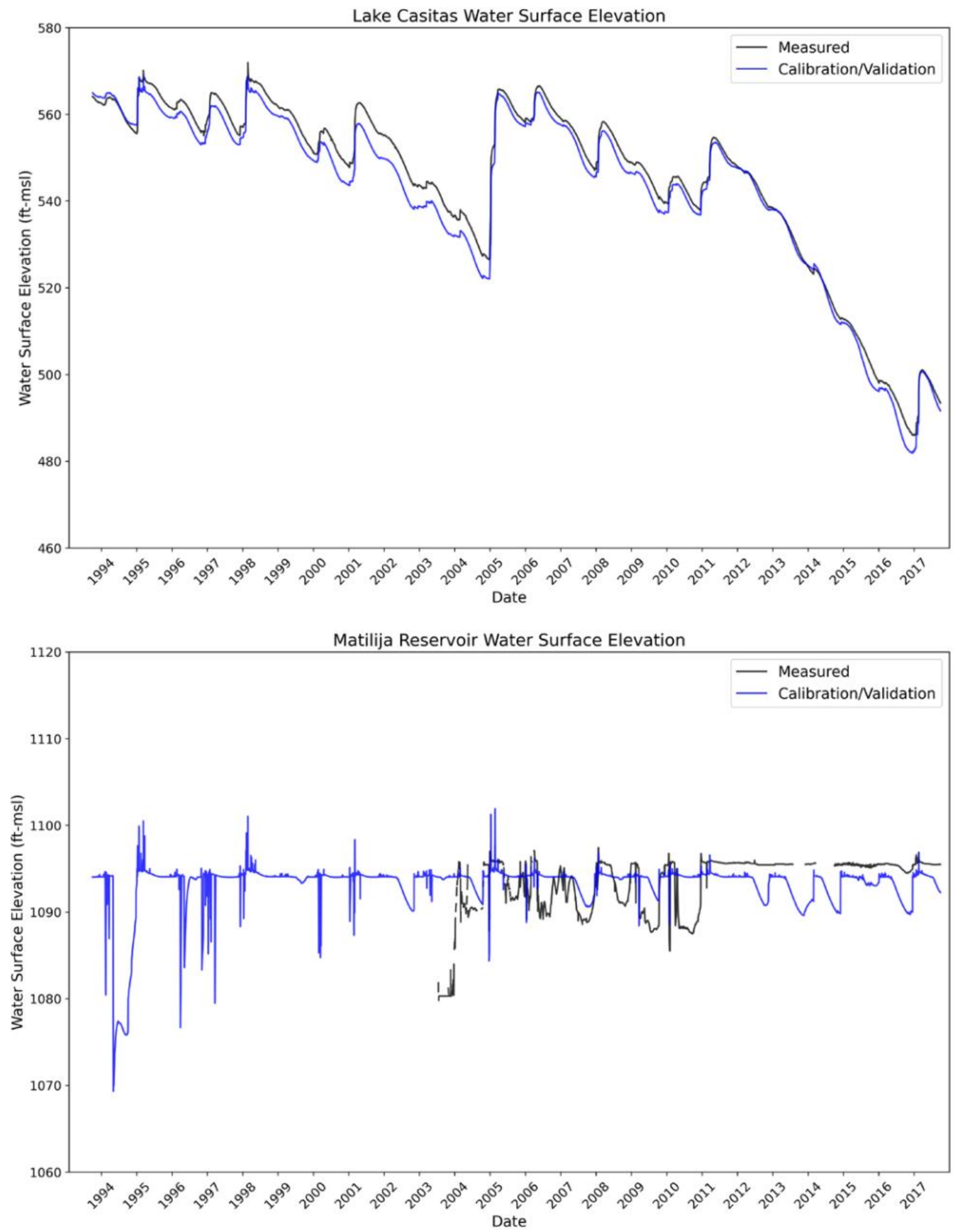
Comparisons of measured and simulated elevations for Lake Casitas and Matilija Reservoir are provided in Figure 5.24. The model well replicates the seasonal drawdowns in Lake Casitas as well as the longer-term drawdowns during the dry years in the early 2000's, the refill in 2005, and the larger drawdowns in the multi-year drought (WY2012 to WY2015).

The trends for Matilija Reservoir are less discernable with the measurements indicating seasonal drawdowns of approximately 8 feet from 2003 through 2010, followed by a more constant elevation from 2011. The model does not fully capture these relatively small changes, which may be a result of difficulties estimating release volumes and the use of a fixed stage-storage relation in the model that does not account for the reservoir filling with sediment over time.

5.4.2 Groundwater Elevation Calibration Assessment

Appendix D[22] presents comparison of simulated and observed groundwater elevations at each well location. Goodness-of-fit statistics are summarized for the calibration and validation time periods in Table 5.7 and Table 5.8, respectively. The calibration goals of scaled-RMSE less than 10 percent and R greater than 0.90 were met during the calibration period for each groundwater basin, the area outside the groundwater basins, and for the model as a whole. During the validation period all statistical measures were met, with the exception of R in the Ojai Valley, which was 0.887 as compared to the goal of 0.90.

[22] Appendices A through F are not embedded in this document. The appendices are presented in companion files. Appendices B through F are compiled in two PDF files. The appendices are include in the zip folder for this model report and are available for download on the State Water Board's California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/



Note: Water Surface Elevation shown is output from GSFLOW at a daily time step

Lake Casitas and Matilija Reservoir Water Surface Elevation Ventura County, CA		
Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure 5.24
Santa Barbara	May 2023	

Figure 5.24 Lake Casitas and Matilija Reservoir Water Surface Elevation

Table 5.7 Goodness of Fit Statistics for Groundwater Elevations, Calibration Period (WY1998 – WY2017), VRW GSFLOW Model

Group No.	No. of Points	Area	RMSE (feet)	Range (feet)	Scaled RMSE	R	Mean Error (feet)
1	148	Lower Ventura Basin	4.3	62.2	6.98%	0.980	–1.09
2	1,372	Upper Ventura Basin	27.0	595.3	4.53%	0.991	11.21
3	1,881	Ojai Basin	34.2	601.1	5.69%	0.948	–0.16
4	300	Upper Ojai Basin	7.3	171.7	4.26%	0.994	–2.63
5	476	outside basins	6.8	334.3	2.04%	0.999	4.23
	4,123	All	27.9	1414.0	1.97%	1.00	3.86

GSFLOW = Groundwater and Surface-water Flow
RMSE = root-mean-square error
R = correlation coefficient
VRW = Ventura River Watershed
WY = water year

Table 5.8 Goodness of Fit Statistics for Groundwater Elevations, Validation Period (WY1994 – WY1997), VRW GSFLOW Model

Group No.	No. of Points	Area	RMSE (feet)	Range (feet)	Scaled RMSE	R	Mean Error (feet)
1	0	Lower Ventura Basin	NA	NA	NA	NA	NA
2	217	Upper Ventura Basin	23.1	587.9	3.93%	0.993	6.31
3	364	Ojai Basin	52.4	666.4	7.87%	0.887	8.18
4	53	Upper Ojai Basin	8.4	155.9	5.40%	0.993	-3.51
5	75	outside basins	4.7	322.6	1.46%	1.000	2.63
	709	All	39.8	1191.3	3.34%	0.99	6.15

GSFLOW = Groundwater and Surface-water Flow
NA = Not applicable, no observed data during this period
RMSE = root-mean-square error
R = correlation coefficient
VRW = Ventura River Watershed
WY = water year

Figure 5.25 presents a “1:1 line chart” that compares the simulated and observed groundwater elevation lines in a scatter plot. Simulated and observed groundwater elevation values that are similar to each other will plot near the line posted on the figure. Consistent with the statistical measures, review of the 1:1 line plot indicates adequate model calibration. In conjunction with meeting the streamflow statistical measures described above, based on these results, it was determined that the GSFLOW model is sufficiently calibrated and validated.

Table 5.9 presents a comparison of available aquifer test data within the watershed and simulated values of transmissivity and hydraulic conductivity. Aquifer test results are available for several areas of the Ojai Basin, from Foster Park in the Upper Ventura River Basin, and at Taylor Ranch in the Lower Ventura River Basin. In general, values of these parameters in the model should be similar but not necessarily identical to field observations. As stated in ASTM (2008):

> *When estimates of hydraulic parameters are available for the regions of the modeled physical hydrogeologic system, the corresponding values of those parameters in the model should be similar, but do not have to be identical. There are two reasons for this. First, the estimates themselves have associated errors, often of an order of magnitude. Second, when these estimates are based on hydraulic tests, the volume of soil or rock stressed by the test is often smaller than the volume in the model for which the parameter applies. In that case, the input hydraulic conductivity or transmissivity required to calibrate the model is often larger than the measured value due to the scale effect.*

The aquifer tests reported that transmissivity values range from 462 ft^2/day to 62,466 ft^2/day, with the largest values along the Ventura River at Foster Park. A range of values is reported for most aquifer tests that reflects the uncertainty of the analysis and heterogeneity. For example, at Foster Park reported values range from 8,021 to 62,466 ft^2/day (Table 5.9). Assigned transmissivity values in the VRW GSFLOW Model are generally consistent with aquifer test results. For example, the VRW GSFLOW Model transmissivity value at Foster Park is 55,400 ft^2/day, which within the range of the aquifer test results. For several of the comparisons, the VRW GSFLOW Model transmissivity is somewhat larger than the range reported from aquifer tests. As discussed above, larger transmissivity values in groundwater models as compared to aquifer-testing results is common due to the larger spatial area being represented by the model as compared to what is stressed during the field test.

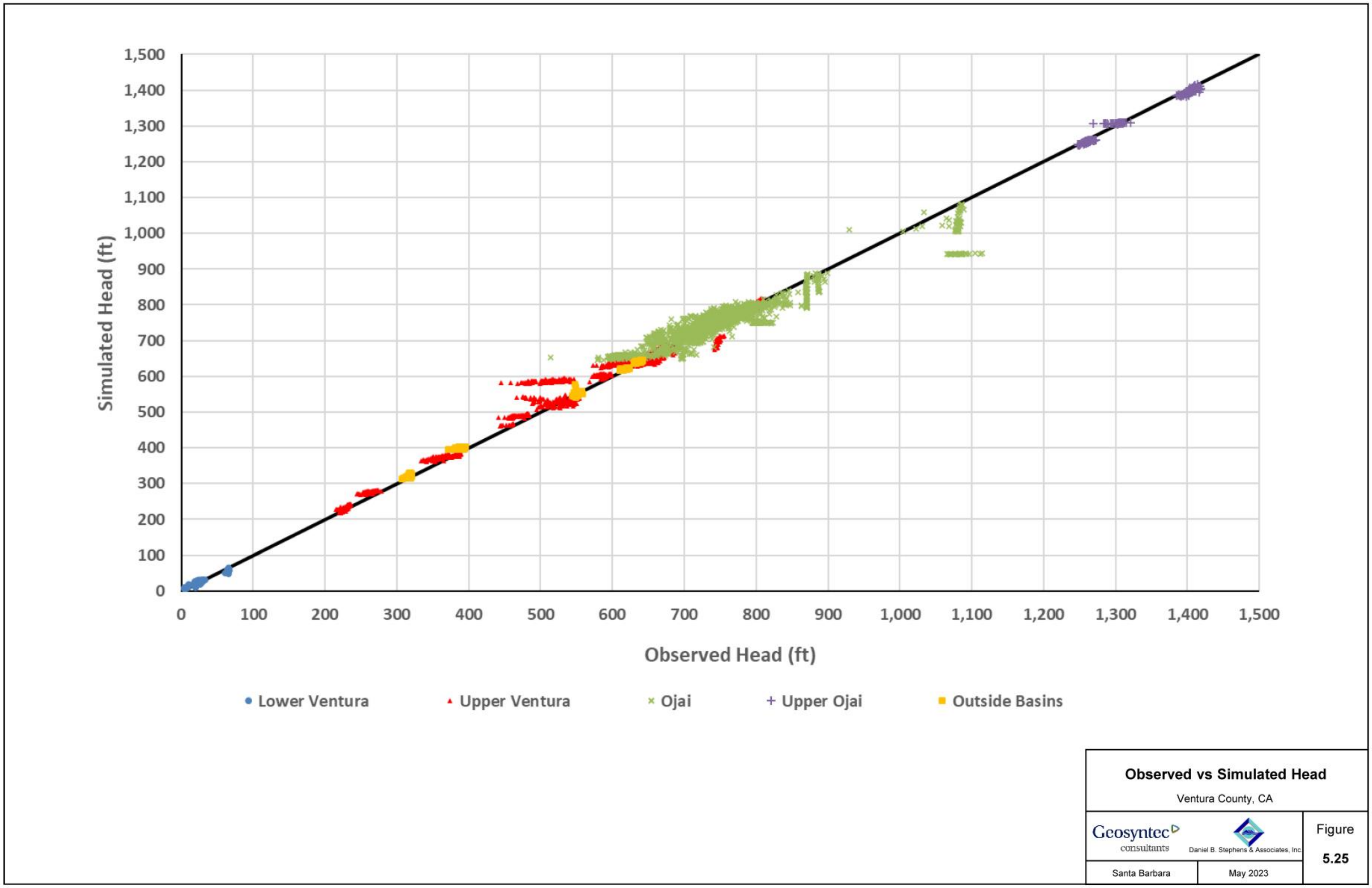


Figure 5.25 Observed vs Simulated Head

Table 5.9 Aquifer Test Comparison

Region	Well/Location	Source	Aquifer Test Reported T (ft²/d) Minimum	Aquifer Test Reported T (ft²/d) Maximum	Aquifer Test Reported K (ft/d) Minimum	Aquifer Test Reported K (ft/d) Maximum	Model Zone(s)	Model Row	Model Column	Model Layers	Model Alluvial Thickness (feet)	Model Minimum K (ft/d)	Model Maximum K (ft/d)	Model Calculated T (ft²/d)
Ojai Basin	04N22W04L01	Kear, 2005	6,264	7,171	NR	NR	5	167	261	3–6	318	45	45	14,300
Ojai Basin	04N22W05Q01	Kear, 2005	4,162	12,182	NR	NR	5	172	249	3–6	351	45	45	15,800
Ojai Basin	04N22W06E06	Kear, 2005	462	2,275	NR	NR	2, 4, 31	160	226	2–4	362	0.01	21	2,570
Ojai Basin	04N22W06K11	Kear, 2005	1,829	3,188	NR	NR	2, 4, 31	165	231	2–7	487	0.01	21	8,950
Ojai Basin	04N22W06K13	Kear, 2005	1,555	1,555	NR	NR	4	167	233	4–6	370	21	21	7,770
Upper Ventura River Basin	Foster Park[1]	HGC, 2007	8,021	62,466	398	1,875	15	268	150	1–2	44	1250	1250	55,400
Lower Ventura River Basin	Taylor Ranch[2]	Numeric Solutions, 2018	12,546	21,329	307	485	19	345	150	1–2	71	200	200	14,100

Note: Alluvial thickness is saturated alluvial thickness based on water level elevation in initial condition (stress period 1 time step 31).
T = Transmissivity
ft²/d = Square feet per day
K = Hydraulic conductivity
ft/d = Feet per day
NR = Not reported

1. Values given for all wells tested at Foster Park, location of Nye #7 (03N23W08B01S) used for model thickness value for T comparison.
2. Values given for all wells tested at Taylor Ranch, location Taylor 7 (03N23W32Q09S) used for model thickness value for T comparison.

5.4.3 Comparison to Wet-Dry Mapping

Comparisons of the model to wet-dry mapping conducted by CMWD along the Ventura River and San Antonio Creek are presented in Figure 5.26. Each frame plots color-coded classifications as a function of time (horizontal axis) and distance along the river (vertical axis). The classifications for the field observations (upper frames) are wet (surface flow), dry (subsurface flow), or intermittent (i.e., regions alternating between surface and subsurface flow on a small spatial scale on a specific day). The classifications for the model output (lower frames) are flow depth greater than 0.1 feet (corresponding to “wet”) and flow depth less than 0.1 feet (corresponding to “dry”). The representation of the dynamic streambed terrain in the model as being fixed in time and the 330-foot grid resolution does not enable the model to predict regions with alternating wet and dry reaches on a small spatial scale that were defined as “intermittent” in the CMWD mapping.

The visual comparisons illustrate that the VRW GSFLOW Model can represent both the spatial and temporal wetting and drying for both the Ventura River (left frames) and San Antonio Creek (right frames). Assuming that the “intermittent” classification in the field observations on a particular day corresponds to predominantly dry conditions, the overall match between the model and the data were 87 percent for the Ventura River and 84 percent for San Antonio Creek.

The ability of the model to accurately capture the variations in the wet-dry mapping illustrates the quality of both the surface water and groundwater calibrations.

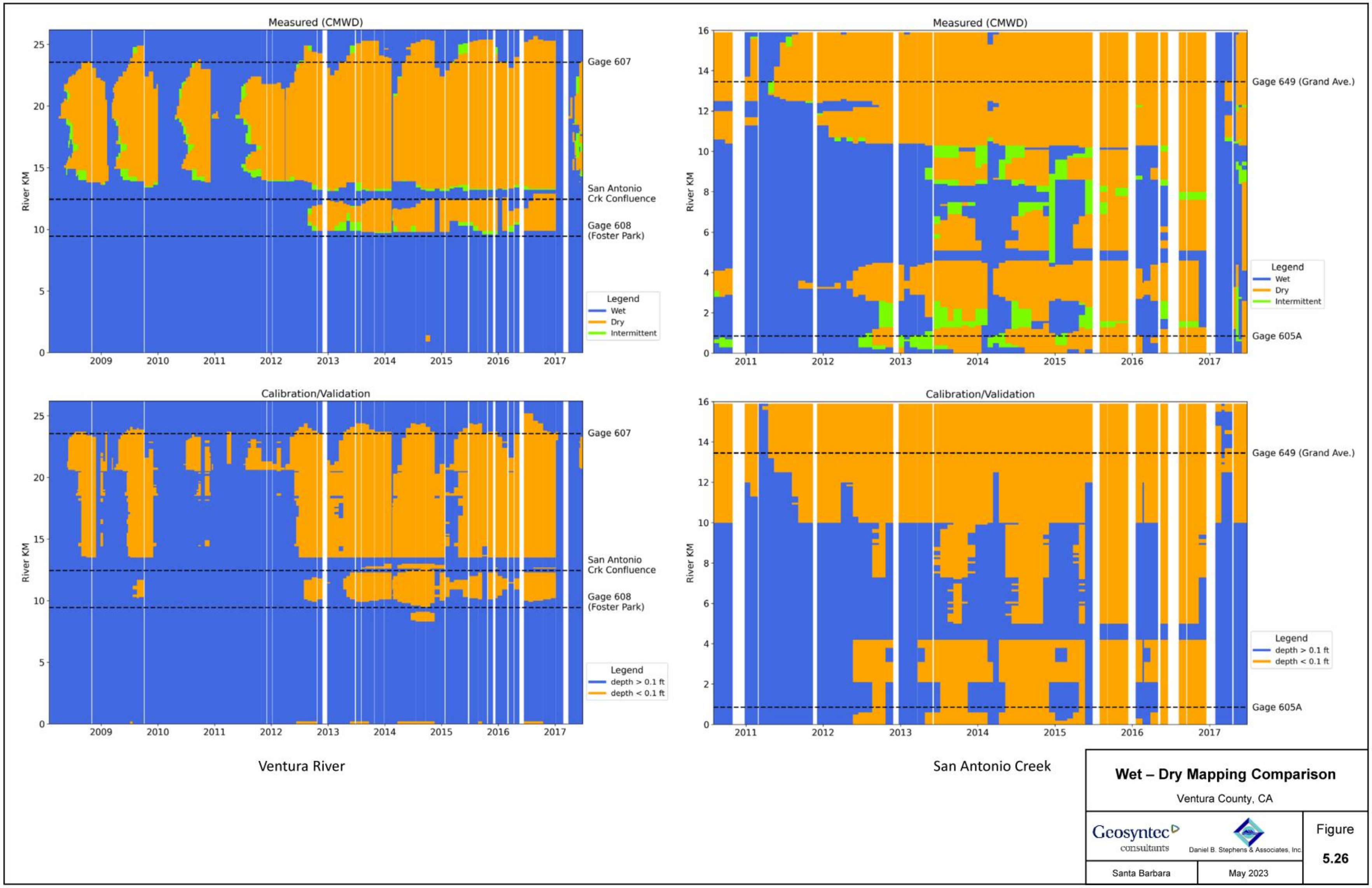


Figure 5.26 Wet – Dry Mapping Comparison

5.5 Model Results and Water Budgets

Figure 5.27 and Figure 5.28 display simulated groundwater potentiometric surface contours corresponding to March 31, 2006 (a relatively wet period) and September 30, 2015 (a dry period), respectively. Groundwater flows perpendicular to potentiometric contour lines. Potentiometric contours indicate groundwater flow generally towards Matilija Creek in the northern portion of the watershed during both wet and dry periods. Hydraulic gradient decreases in the southern portion of the watershed, including in the groundwater basins, which is consistent with the larger hydraulic conductivity values in those areas. Simulated groundwater flow direction generally follows topographic trends and surface water flow directions in the remainder of the watershed, with flow from north to south towards the Pacific Ocean.

Areas of the watershed with simulated perennial groundwater discharge to surface water (potentiometric surface elevations greater than streambed elevations, including during dry periods; see Figure 5.28) include Matilija Creek and North Fork Matilija Creek, Senior Canyon north of the Ojai Basin, San Antonio Creek near the Ojai Basin terminus, the Ventura River at Foster Park and the northern area of the Lower Ventura River Basin, and portions of Coyote Creek north of Lake Casitas. These results are generally consistent with the results of wet-dry mapping, as discussed above.

Figure 5.29 displays a map of the average precipitation and irrigation recharge to groundwater over the 24-year calibration and validation period in each VRW GSFLOW Model cell. Recharge includes deep percolation of precipitation and irrigation both within stream channels and outside of stream channels. Areas of greatest recharge include streambed channels in the higher elevations of the Ojai Basin, the main stem of the Ventura River, in the southern area of Lake Casitas, and portions of San Antonio Creek and Lion Canyon Creek. Recharge rates are generally larger in areas of alluvium within the groundwater basins and stream channels outside of the Basins, and simulated rates also reflect surficial geology outside the groundwater basins with higher rates in the sandstone units versus the shale. Lower recharge rates are also simulated in the more urbanized areas, such as the City of Ventura in the Lower Ventura River Basin, reflecting more impervious surface coverage.

Figure 5.30 plots annual watershed water budgets for the modeling period, including volumes for precipitation, total ET, outflow from streams and lakes (i.e., Lake Casitas deliveries, stream diversions, and outflow to the Pacific

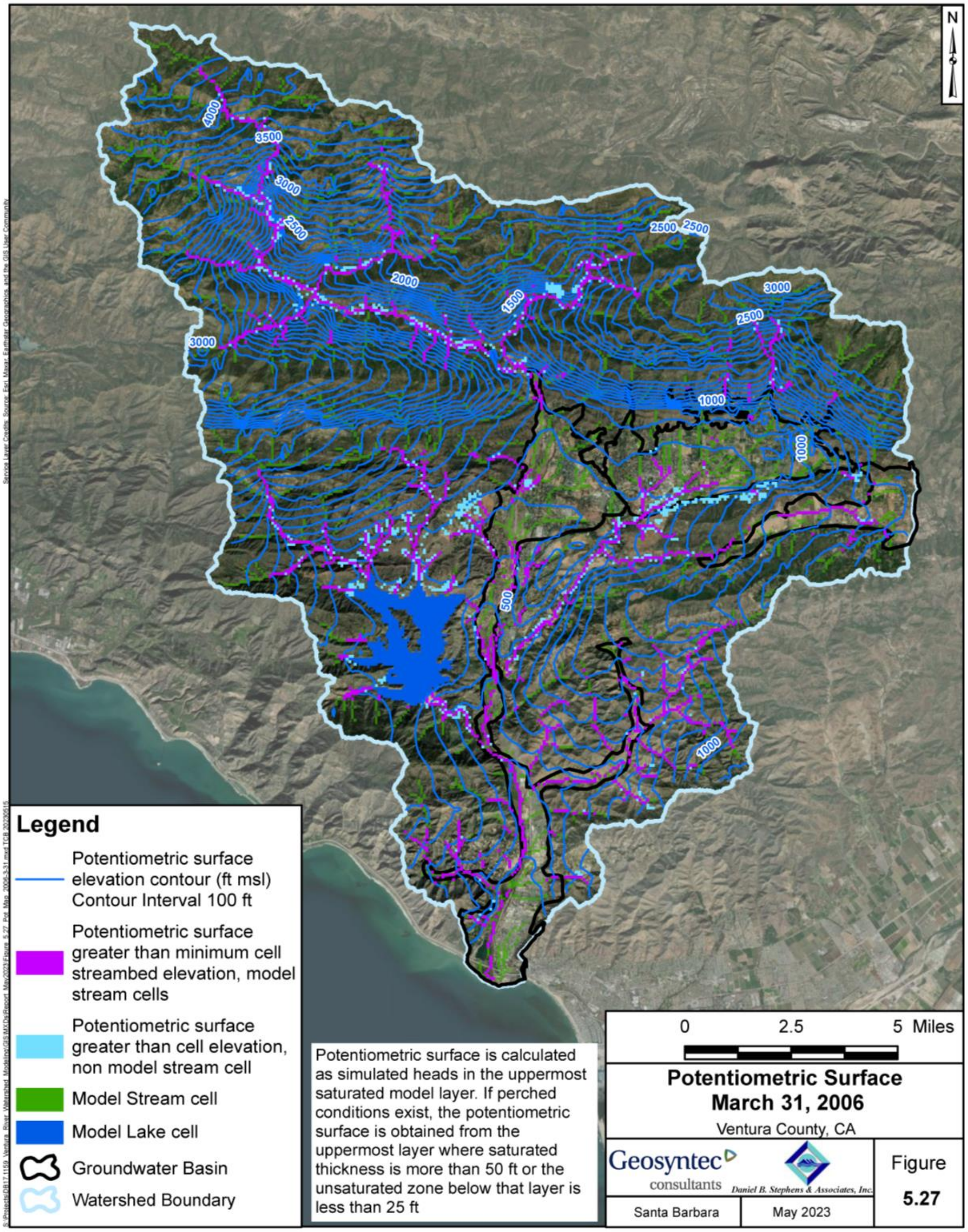


Figure 5.27 Potentiometric Surface – March 31, 2006

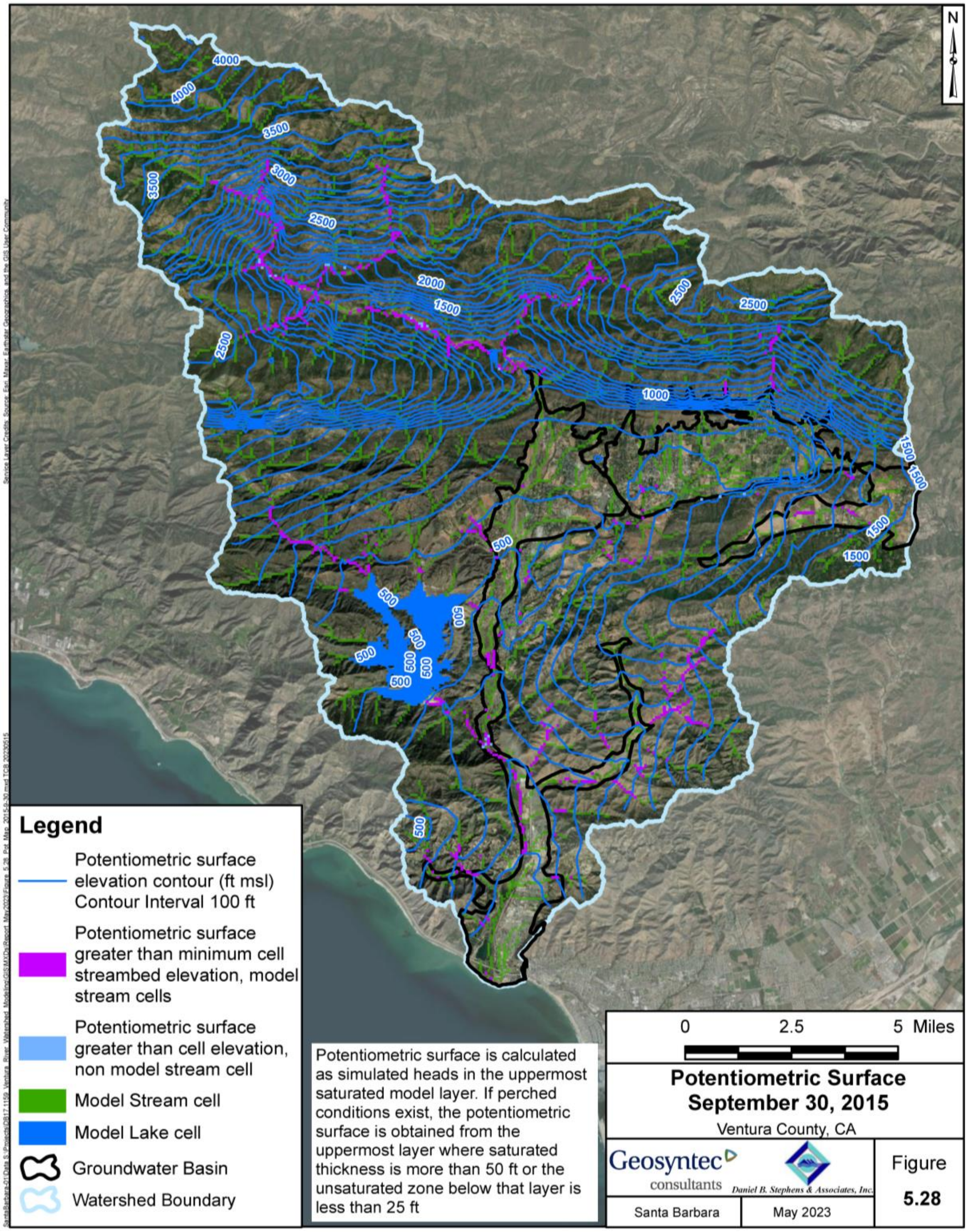


Figure 5.28 Potentiometric Surface – September 30, 2015

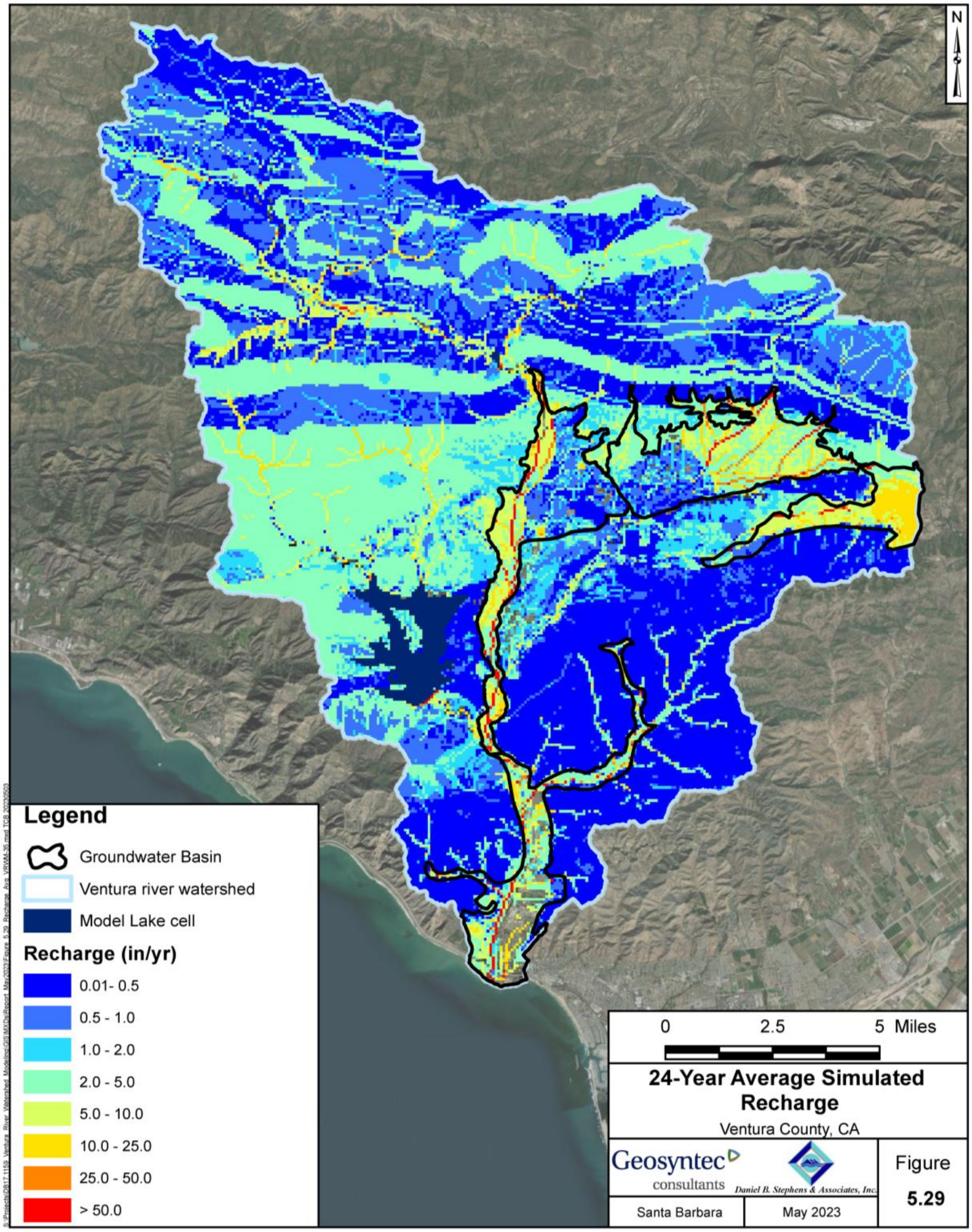


Figure 5.29 24-Year Average Simulated Recharge

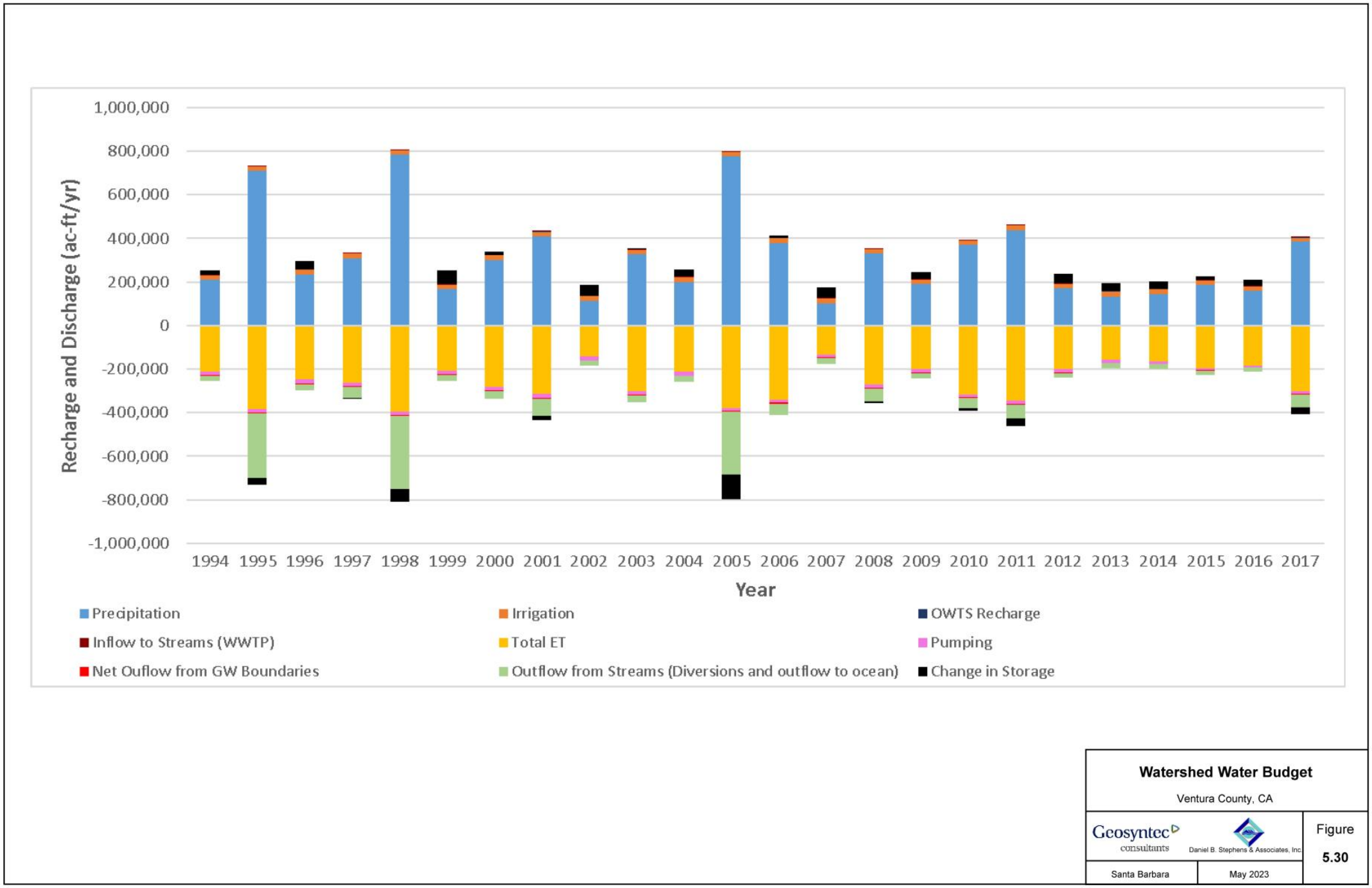
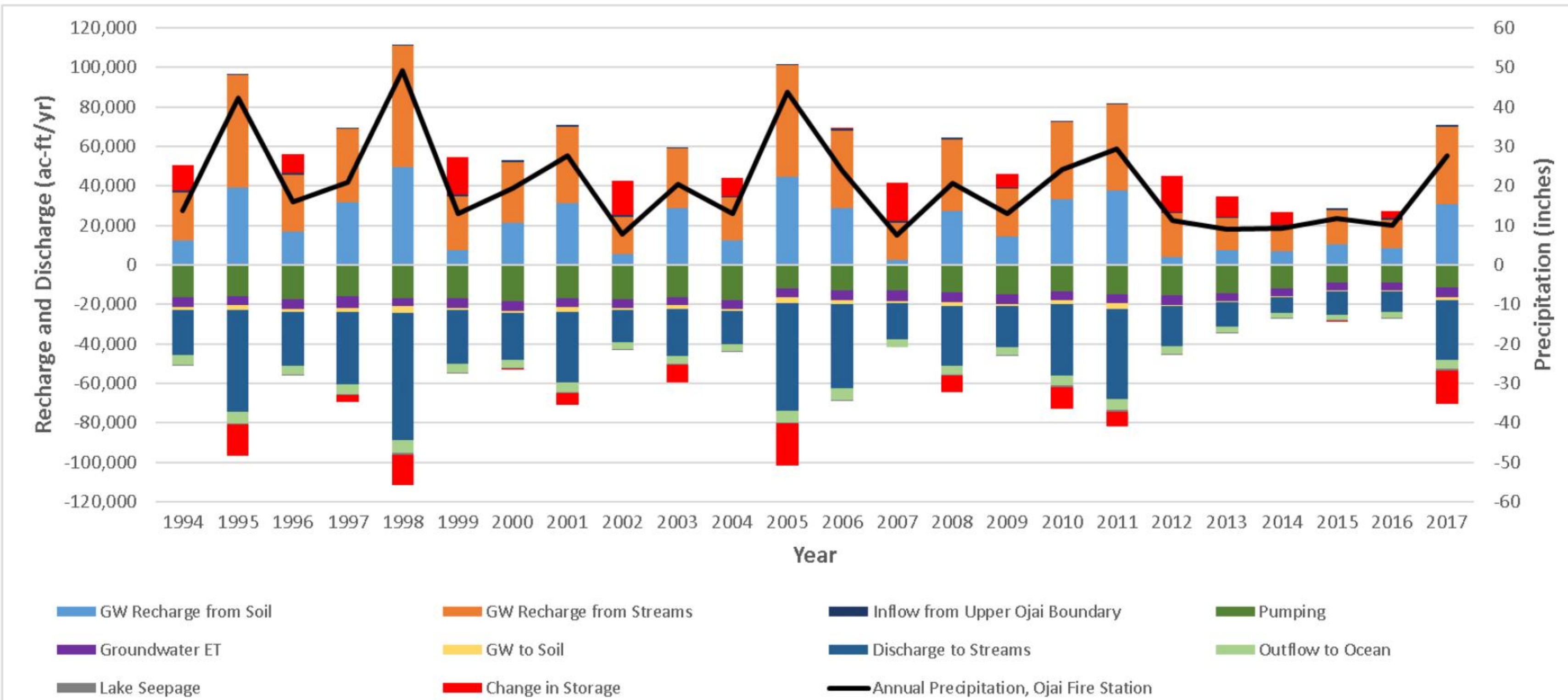


Figure 5.30 Watershed Water Budget

Ocean), and net outflow from groundwater boundaries (difference between the inflow in the Upper Ojai Basin and the outflow to the Pacific Ocean from the Lower Ventura River Basin). The plot illustrates that in lower precipitation years, most of the precipitation is lost to ET with relatively small outflow volumes from streams and groundwater. During higher precipitation years, the outflow from streams (primarily to the Pacific Ocean) increases substantially, while ET generally increases slightly. The net groundwater outflow to the Pacific Ocean also increases slightly, but remains a small part of the overall budget.

Figure 5.31 displays simulated water budget information for the groundwater portion of the domain only, and also plots observed annual precipitation at the Ojai Fire Station for comparison. Flows from groundwater storage are also shown, where positive values of flow from groundwater storage correspond to declining groundwater elevations over the course of that year. During wet years (e.g., 1998, 2005), there is significant recharge from precipitation within streams and outside the streams (“groundwater recharge from streams” and “groundwater recharge from soil”, respectively) and a corresponding increase in groundwater discharge into streams and increase of groundwater in storage (i.e., rising water levels). During dry years (e.g., 2012 through 2016), recharge from precipitation is lower, along with groundwater discharge into streams, and there is a net loss of groundwater in storage (declining water levels). Simulated pumping rates average approximately 15,000 AF/yr and are relatively constant from year to year, other than drought years 2014 through 2016, where simulated pumping rates average approximately 10,000 AF/yr.

Analyses of the potentiometric surface contours, precipitation/irrigation recharge map and water budgets, along with the calibration/validation analysis and wet-dry comparisons above, confirm that the VRW GSFLOW Model simulates watershed processes consistent with accepted conceptual models of the VRW.



Groundwater Budget		
Ventura County, CA		
Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure 5.31
Santa Barbara	May 2023	

Figure 5.31 Groundwater Budget

5.6 Model Limitations

All environmental models and model results are subject to uncertainty, including model framework uncertainty due to incomplete scientific understanding of the system and necessary system simplifications, and model input uncertainty due to data measurement errors and data gaps (EPA, 2009). However, the California DWR (2016b) states:

> *While models are, by definition, a simplification of a more complex reality, they have proven to be useful tools over several decades for addressing a range of groundwater problems and supporting the decision-making process. Models can be useful tools for estimating the potential hydrologic effects of proposed water management activities.*

The following model limitations are noted for the VRW GSFLOW Model. These limitations are typical of regional-scale hydrologic models. The dynamic and linked functionality of GSFLOW resolves several limitations of earlier groundwater-only models that treated surface water processes in a simplistic manner and likewise surface-water only models that treated the groundwater processes in a simplistic manner (e.g., Tetra Tech, 2009; DBS&A, 2010).

5.6.1 Surface Water Model Limitations

The model limitations for the surface water (PRMS) portion of the VRW GSFLOW Model, include:

- GSFLOW uses a daily rainfall input and a daily time-step that makes it difficult to resolve the details of individual storm events, including the rate of recession, in the relatively small watershed. This limitation would not appreciably affect dry season low-flow periods.
- The model assumes that land use is fixed in time, including urban development and crop types and extents. This does not account for times in the past where crops may have been fallowed and may have resulted in overestimation of applied water and overestimation of groundwater pumping in some regions during those times.
- The model assumes that the extent of riparian vegetation is fixed in time. This neglects the temporal effects of Arundo eradication efforts, reduction in vegetation following storm events in wet years, and potentially increased ET following wet years as vegetation reestablishes. This limitation would primarily affect dry season low-flow periods.

- The model assumes that the channel cross-sections are fixed in time, whereas natural geomorphic processes are constantly occurring. For this reason, the model is better used as a hydrologic tool than a hydraulic one. Reach-specific hydraulic models may use this model's hydrologic output for different locations and points in time to better predict flow depths, velocities, and shear stresses, such as needed for fish passage assessment.

- The model assumes a fixed stage-storage relation for Matilija Reservoir. However, the storage relation has changed over time as the reservoir fills with sediment. This may impact the ability to model the releases and downstream flow from the reservoir during low flows. The primary effect in the model is to increase dead storage, with anticipated negligible effects on streamflow.

- Uncertainty from the MODFLOW portion of the simulation will propagate and influence groundwater discharge to surface water estimates.

5.6.2 Groundwater Model Limitations

The model limitations for the groundwater (MODFLOW) portion of the VRW GSFLOW Model include:

- Most observation wells also are actively pumped; therefore, observed water levels may be influenced by active pumping and are lower than the adjacent aquifer.

- Pumping rates are mostly estimated based on a large-scale water balance.

- Well screen intervals (for pumping and observation wells) are often unknown and must be assumed.

- Month-long model stress periods require averaging of boundary flux rates (e.g., model pumping rates) that are assumed constant throughout a month.

- Uncertainty in geologic analysis and model layering and necessary simplifications.

- Homogenous hydraulic properties are assumed within the MODFLOW property zones. 330-ft model grid cells require generalization over fairly broad areas (e.g., assumed equal topographic surface throughout the cell).

- GHB and CHD boundaries are set at the watershed boundary within the Upper Ojai Basin and at the Pacific Ocean, respectively. Predictive simulation results are inherently more uncertain in the vicinity of GHB and CHD (Anderson and Woessner, 1992). The Upper Ojai GHB is likely within the vicinity of a groundwater divide as it is the location of a surface water divide. However, the VRW GSFLOW Model simulates groundwater flow into the VRW along the boundary. Surface water and groundwater divides are not necessarily at the same location in arid climates, and the divide location is influenced by pumping on both sides of the divide (Fetter, 2001). The location of the groundwater divide between the Ventura River and Santa Clara River watersheds is not well defined and is identified as a current data gap.
- Due to necessary limitations of the model grid, the VRW GSFLOW Model is not structured to simulate lateral flow to the deep portions of the bedrock units that underlie the alluvial Ojai groundwater basin (Layers 4 through 7).
- Uncertainty from PRMS-portion of the simulation will propagate and influence groundwater recharge estimates.
- Limited aquifer test data is available to constrain model assumed hydraulic conductivity and storage values; future data collection may focus on additional aquifer tests.
- Initial conditions were assigned based on several simplifying assumptions (see Section 4.3); however, the impact of initial conditions on model simulations and results are minor based on model testing.
- No groundwater elevation data has been identified within the Lower Ventura River Basin during the validation period.

6 SENSITIVITY ANALYSIS

As discussed in the *Draft Sensitivity Analysis Approach Memo* (Geosyntec and DBS&A, 2020a), a model sensitivity analysis is the systematic variation of model inputs to enable quantitative evaluation of their effects on model outputs, to support both model calibration and uncertainty analysis. A sensitivity analysis measures the effects of changing a model input on the outputs or performance of the model. Results from the sensitivity analysis (e.g., identification of most sensitive inputs) should not necessarily be interpreted as a determination of the primary sources of model uncertainty. For example, a model may be sensitive to an input for which accurate and robust measurement data exist and contain relatively little uncertainty.

The goal of the sensitivity analysis is to understand the response of the model to adjustments in model inputs, parameters, and/or assumptions. Extensive informal sensitivity analysis was conducted as part of the model calibration process; whereby, model inputs are varied to obtain a match with observed streamflow volume and groundwater elevation data. The formal sensitivity analysis detailed herein followed completion of calibration. The sensitivity analysis is not an exhaustive study of all model inputs and instead focused on the key inputs, as determined through literature review of similar GSFLOW modeling studies, watershed-specific experience gained during the model development and preliminary calibration, and the current project's focus on low-flow periods.

6.1 Approach

A model sensitivity analysis typically involves repeatedly running a calibrated model with systematic variation of model inputs, followed by graphical and statistical assessments of changes in model outputs. The specifics of the model and the characteristics of the watershed influence which model inputs are varied, and the variation magnitude. In addition, the outputs of focus or concern are also important to consider during a sensitivity analysis and will influence which input parameters are varied. For example, if the model is focused on groundwater supplies, a different sensitivity analysis would be conducted compared to a model that is focused on surface water flows. Here, the focus is primarily on the low-flow periods, which depend upon both surface water and groundwater components of the model.

6.1.1 Inputs Varied

The key GSFLOW model inputs that were varied are presented in Table 6.1. The inputs selected for sensitivity analysis were multiplied by the factors presented in the table to increase and decrease from the original calibrated values. While these inputs generally vary spatially throughout the watershed, the adjustment factors were applied uniformly. Results from past studies guided the magnitude of the adjustment factors, while also maintaining parameter and input values within physically realistic bounds.

6.1.1.1 Soil and surface water inputs

Soil and surface water inputs that were varied as part of the sensitivity analysis were selected based on observations during the initial PRMS calibration procedure, conclusions drawn from the existing literature, public and TAC comments, and prior experience. These included:

- Soil zone storage parameter, soil_moist_max, affects multiple soil zone processes, including Hortonian surface runoff, ET, direct recharge, and flow to the gravity reservoir. It is included in the sensitivity analysis along with another important soil zone parameter, sat_threshold. These parameters represent storage of water within the soil.

- Interflow parameter, slowcoef_sq, controls slow interflow from the gravity reservoir and was important for post-storm recession flows during calibration. Therefore, slowcoef_sq is included in the sensitivity analysis.

- ET parameter, jh_coef, was calibrated using CIMIS reference ET data (Section 5.2.1). The jh_coef is included in the sensitivity analysis due to the relative coarseness and potential uncertainty of the CIMIS data (DWR, 2012) and the importance of ET to the overall water balance. It is noted that the climate change scenario that will be evaluated with the VRW GSFLOW Model, as part of this study, will likely include increases in ET as a result of increased air temperatures. Additionally, the Post-Thomas Fire scenario will likely include decreases in ET due to loss of burned vegetation.

- The extinction depth[23] is included in the sensitivity analyses. This depth controls the degree of shallow ET from riparian vegetation (Section

[23] The extinction depth is a MODFLOW parameter, but has a strong effect on surface water during low-flow periods.

5.3.2) and was found to be important for low flows during the calibration process.

- The ssr2gw_rate (Section 3.6) controls the rate at which water from the PRMS portion of the model enters the groundwater portion of the model. During the calibration process, it was found to be important both for low flows and for groundwater elevations and is, therefore, included in the sensitivity analyses.

- Streambed hydraulic conductivity is included in the sensitivity analysis. Streambed hydraulic conductivity is a key input in influencing the groundwater- surface water exchange, which is of critical importance in this study.

Table 6.1 GSFLOW Model Inputs to be Varied in Sensitivity Analysis

Model Input	Description	Multipliers	Notes
soil_moist_max	Maximum available water holding capacity of capillary reservoir from land surface to rooting depth of the major vegetation type of each hydrologic response unit (HRU) [1]	0.8, 1.2	Affects Hortonian surface runoff, evapotranspiration (ET), direct recharge, and flow to gravity reservoir
sat_threshold	Water holding capacity of the gravity and preferential flow reservoirs [1]	0.8, 1.2	Difference between field capacity and total soil saturation for each HRU
slowcoef_sq	Non-linear coefficient in equation to route	0.8, 1.2	Controls slow interflow from gravity reservoir. The linear coefficient in

Model Input	Description	Multipliers	Notes
	gravity reservoir storage downslope for each HRU [1]		the equation had less effect than the non-linear term and is not included in the sensitivity analysis.
jh_coef	Monthly (January to December) air temperature coefficient used in Jensen-Haise potential ET computations [1]	0.8, 1.2	Will directly affect ET and overall water balance
extinction depth	Depth to which ET can occur from groundwater	0.5, 2.0	Only applied to regions with riparian vegetation
ssr2gw_rate	Rate at which water from the soil zone enters the groundwater	0.5, 2.0	Affects both surface water and groundwater
Streambed hydraulic conductivity	Hydraulic conductivity of streambed	0.25, 4.0	Affects groundwater-surface water exchange
Horizontal Hydraulic conductivity	Hydraulic conductivity, broken out for each model layer within each basin and the bedrock areas	0.25, 4.0	Affects rate of groundwater movement
Specific yield	Broken out for each unconfined model layer within each basin and the bedrock areas	0.3, 2 (subject to specific yield not less than 0.02 or greater than 0.3)	Affects the amount of groundwater held in storage

Model Input	Description	Multipliers	Notes
Storage coefficient	Broken out for each model layer within each basin and the bedrock areas	0.1, 10	Affects the amount of groundwater held in storage
Vertical anisotropy	Broken out for each model layer within each basin and the bedrock areas	0.1, 3	Affects rate of vertical groundwater movement
Horizontal-flow barrier conductance	Hydraulic conductivity for faults that intersect alluvial basins	0.1, 10	Affects the rate of groundwater movement across fault zones
General-head boundary (GHB) conductance	GHB where assigned (e.g., at Pacific Ocean, at watershed boundary in Upper Ojai Basin).	0.1, 10	Affects the rate of groundwater flow in cells assigned a GHB condition
Unsaturated-Zone Vertical Hydraulic Conductivity	Saturated vertical hydraulic conductivity of the vadose zone, broken out for each Basin and the bedrock areas	0.1, 10	Affects rate of subsurface water movement above the level of groundwater
Various	Assumptions used in the water supply/use calculations	Vary groundwater pumping volumes up to +/- 20%	Will affect groundwater elevations and low flows

ET = evapotranspiration
GHB = General-head boundary
HRU = hydrologic response unit

[1] PRMS-IV Techniques and Methods 6–B7 (Markstrom et al., 2015)

Some PRMS parameters identified in literature as important are not included in the sensitivity analysis. For example, precipitation inputs are included as sensitivity parameters in some studies (e.g., Tian et al., 2015) that have limited meteorological stations. The VRW has more than 20 precipitation measurement stations, and PRISM data were used to augment the observed precipitation data (Section 3.2). Therefore, it is expected that resultant precipitation inputs are reliable and are not included in the sensitivity analysis.

Other parameters are not included due to relatively small effects being noted during calibration processes. These include the estimated stream widths and the surface water diversion volumes. The surface runoff parameter, carea_max, the maximum possible fractional area contributing to surface runoff, is varied in some sensitivity studies (e.g., Tian et al., 2015; Markstrom et al., 2016). However, during initial calibration of the VRW GSFLOW Model in PRMS-only mode (i.e., not coupled to groundwater) for this study, carea_max showed very small impacts on output variables. Many prior PRMS sensitivity studies utilized PRMS models that were developed using a lumped parameter approach; whereas, the VRW GSFLOW Model is a gridded parameter model. For example, the Regan et al. (2018) PRMS model for the Continental U.S. has approximately 50 HRUs in the VRW. In comparison, the VRW GSFLOW Model has over 100,000 smaller gridded HRUs (Section 3.1). Responses of the empirical equations for model parameters assigned on a much finer scale may be different to those assigned in the lumped-parameter approach.

6.1.1.2 Groundwater Inputs

SGMA guidance (DWR, 2016b) suggests sensitivity analyses be conducted for input parameters that are both highly sensitive and poorly constrained. Groundwater and unsaturated-zone input parameters that were varied are listed in Table 6.1. Horizontal hydraulic conductivity, vertical anisotropy (i.e., the ratio of vertical to horizontal hydraulic conductivity), and storage coefficient were varied sequentially for each model layer within each basin and the bedrock areas. Unsaturated-zone vertical hydraulic conductivity was also varied for each basin and the bedrock areas. Horizontal-flow barrier conductance representative of faults that transect the alluvial basins, and general-head boundary conductance (assigned at the watershed boundary within the Upper Ojai Basin) were also included in the sensitivity analysis.

The amount that each input parameter was varied during sensitivity analysis is specified in Table 6.1. Hydraulic conductivity-related parameters were varied by 0.25 and 4. Specific storage was varied one-order-of-magnitude. Specific yield was varied from a factor 0.3x to 2x with the constraint that the values used in the sensitivity analyses were within the typical range of 0.02 to 0.3 (i.e., not less than 0.02 or greater than 0.3; see Fetter, 2001).

6.1.1.3 Water Supply and Use Assumptions

There are limited data related to groundwater pumping and surface water supplies in many parts of the watershed. Analysis of available water use data, consumption reports, groundwater pumping data from the water agencies that serve the region, as well as information on surface water diversions, were used to estimate these unavailable volumes (Section 2). Assumptions on the supplies and demands (e.g., assumed irrigation rates) were made to complete these estimates. There are inherent uncertainties within these assumptions.

These assumptions, including the distribution of water supply from groundwater pumping versus surface water diversions, were evaluated and varied as part of the sensitivity analysis. This was accomplished by varying assumed groundwater pumping rates by 20% (Table 6.1). It is known that groundwater levels within certain areas of the groundwater basins are highly dependent on the quantity of groundwater pumping. The assumptions were varied to obtain an anticipated reasonable range in groundwater pumping rates, which may be as high as +/- 20% in some regions, but could be lower in other regions (e.g., in the Ojai Basin, where data reporting is mandated).

6.1.2 Outputs Evaluated

Key model outputs were selected to assess and quantify model sensitivity. Streamflow results were analyzed at the following four gage locations:

1. Gage 604: North Fork Matilija Creek at Matilija Hot Springs;
2. Gage 607: Ventura River near Meiners Oaks (downstream of Robles diversion);
3. Gage 605/605A: San Antonio Creek at Old Creek Road/Highway 33 (upstream of confluence with Ventura River); and
4. Gage 608: Ventura River near Ventura (Foster Park).

The PAEE and the NSME were calculated over the entire modeling period at each above-gage location. In addition, the PAEE was calculated separately for low- and high-flow periods (i.e., different seasons), per recommendations of Ely and Kahle (2012).

Groundwater-related outputs that were analyzed include statistical measures of the difference between the model-simulated groundwater elevation and observed results for all calibration wells. These error statistics included the ME and RMSE for all groundwater wells used in model calibration.

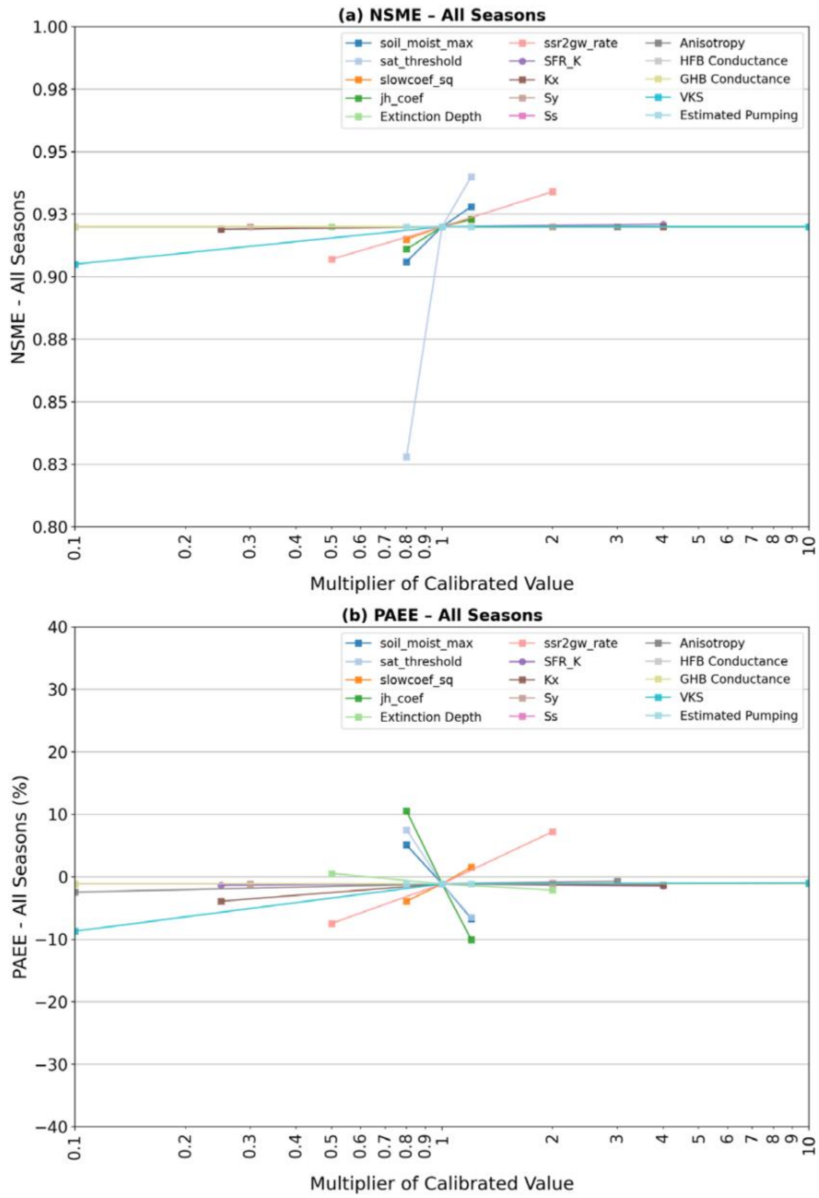
6.2 Results

Results are primarily evaluated through spider plots that show various model errors as a function of the scaling factors applied to the model inputs. These are discussed below for the streamflow and groundwater.

6.2.1 Streamflow

Timeseries plots and flow duration curves of the sensitivity analyses model results are provided in Appendix E[24]. Spider plots are provided for the four locations specified above in Figure 6.1 through Figure 6.4. Each figure spans three pages and plots (a) NSME for all seasons, (b) PAEE for all seasons, (c) PAEE for winter, (d) PAEE for spring, (e) PAEE for summer, and (f) PAEE for fall.

[24] Appendices A through F are not embedded in this document. The appendices are presented in companion files. Appendices B through F are compiled in two PDF files. The appendices are include in the zip folder for this model report and are available for download on the State Water Board's California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/



Streamflow Sensitivity
Gage 604
Ventura County, CA

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Figure 6.1a,b Streamflow Sensitivity – Gage 604

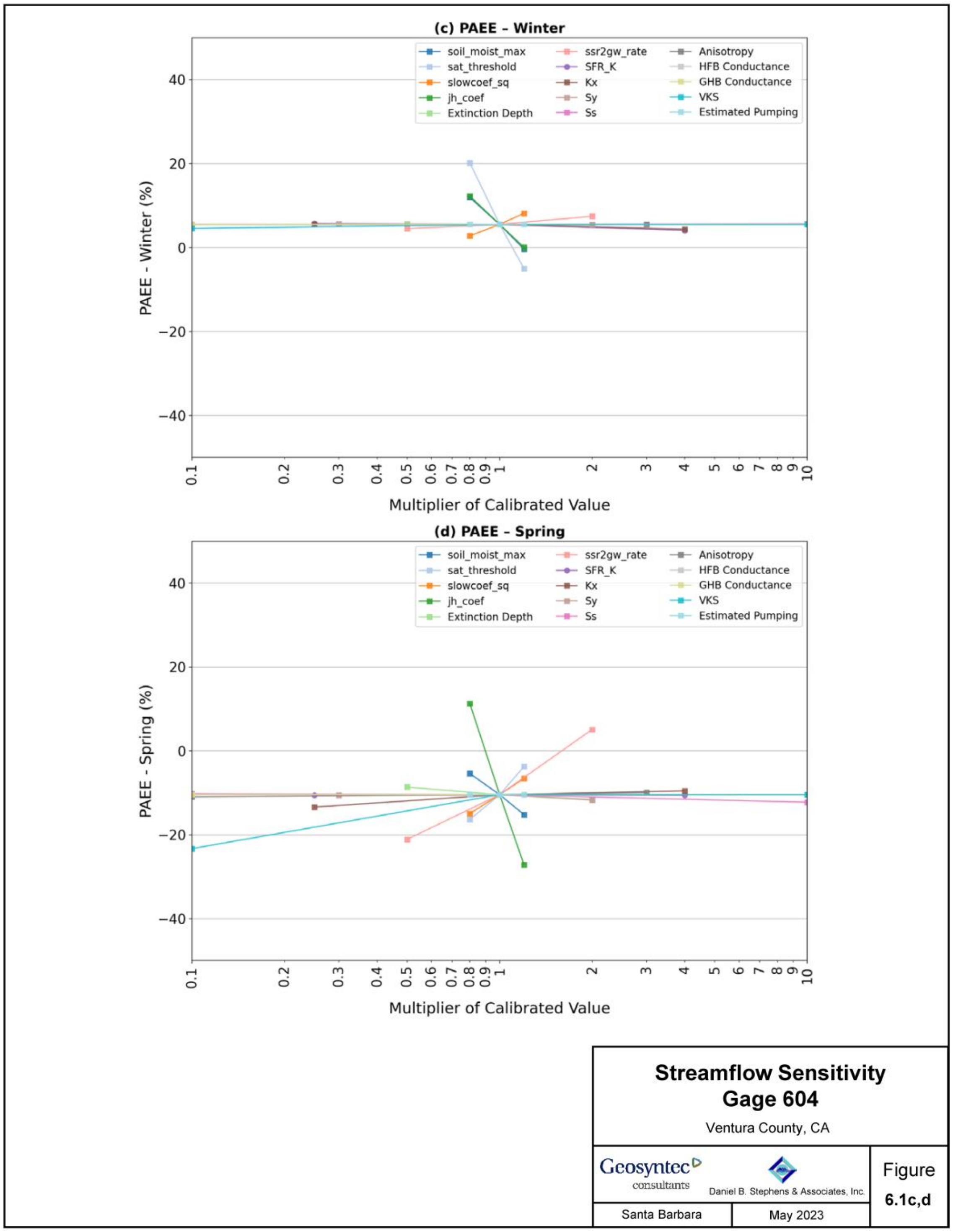


Figure 6.1c,d Streamflow Sensitivity – Gage 604

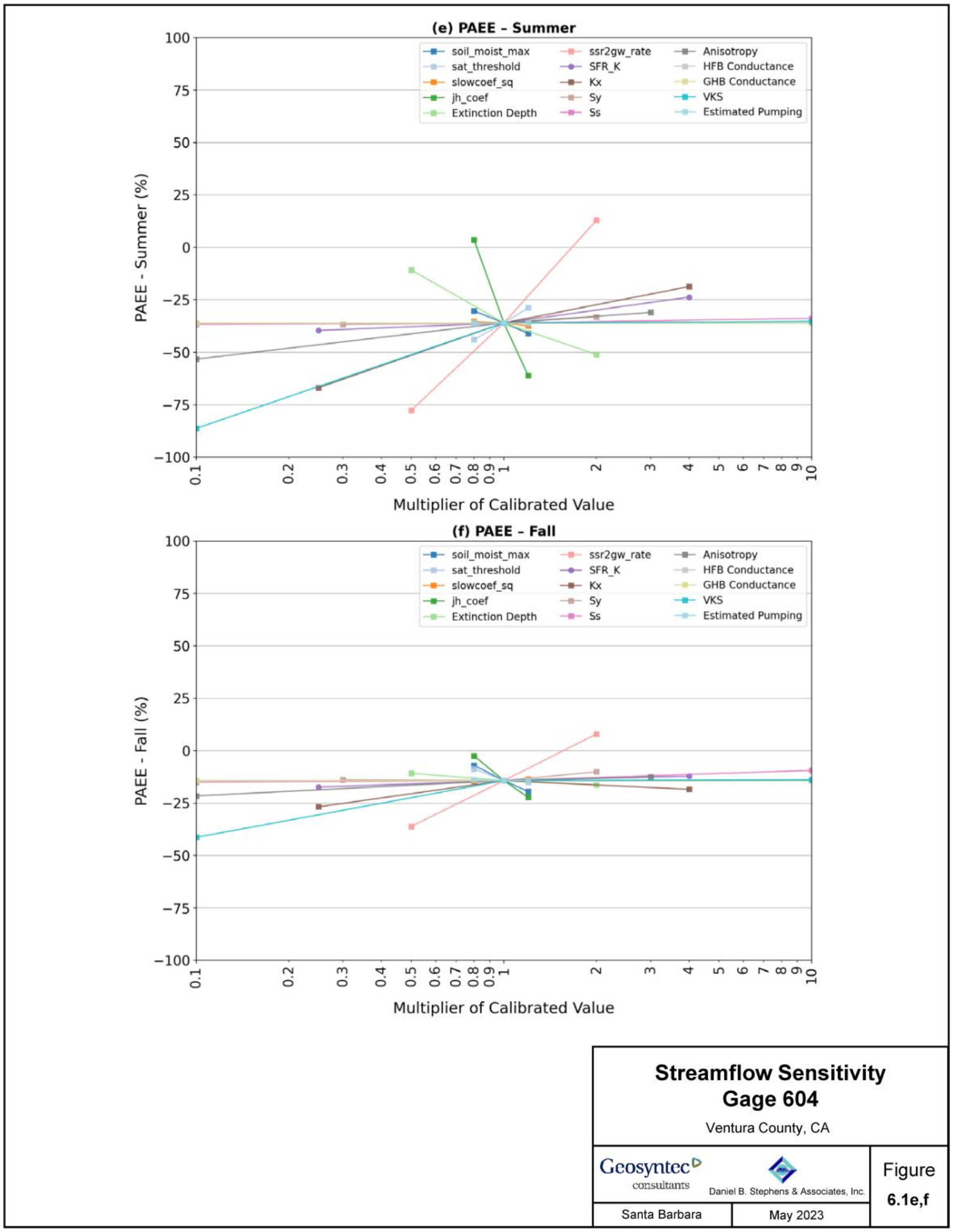


Figure 6.1e,f Streamflow Sensitivity – Gage 605

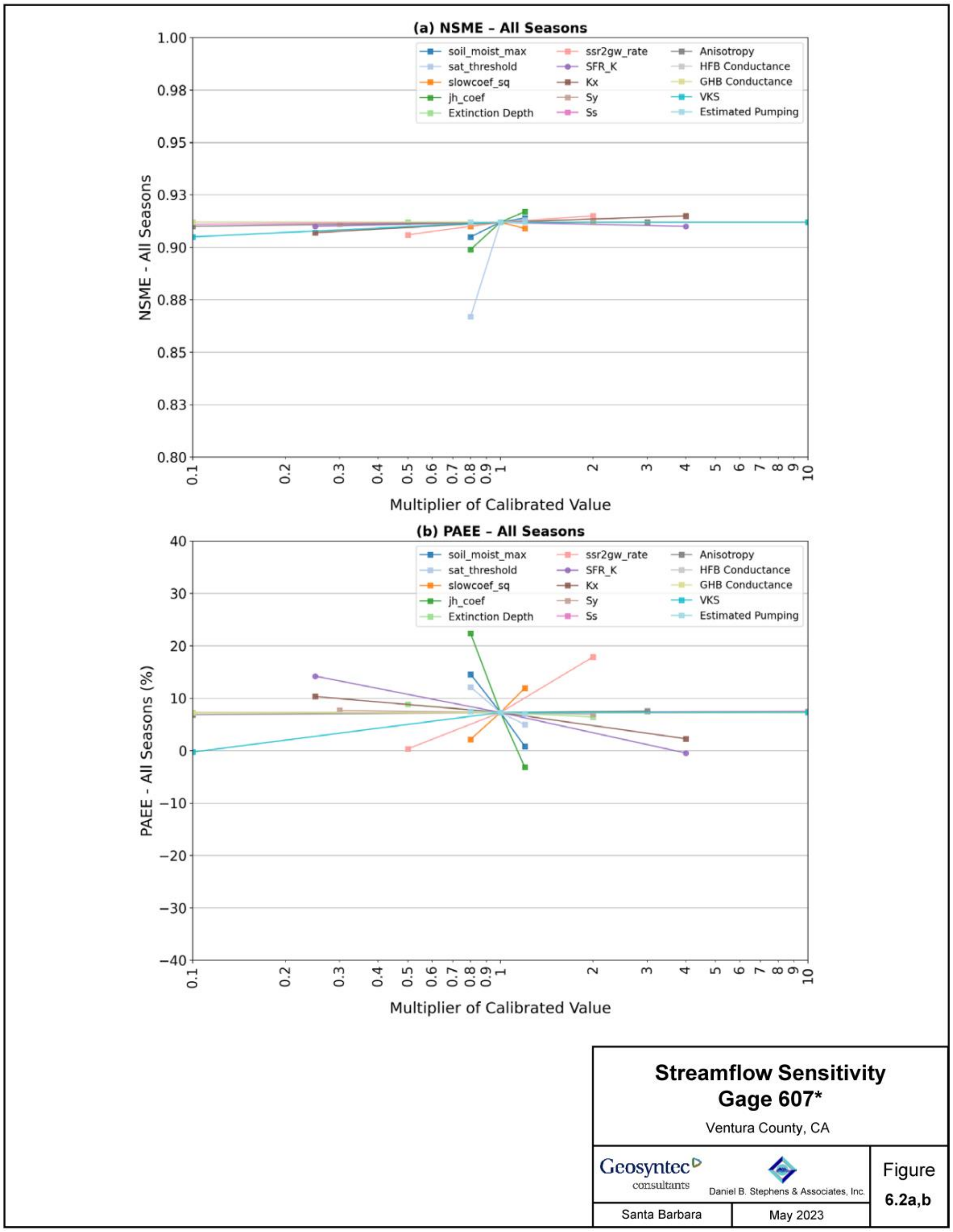


Figure 6.2a,b Streamflow Sensitivity – Gage 607*

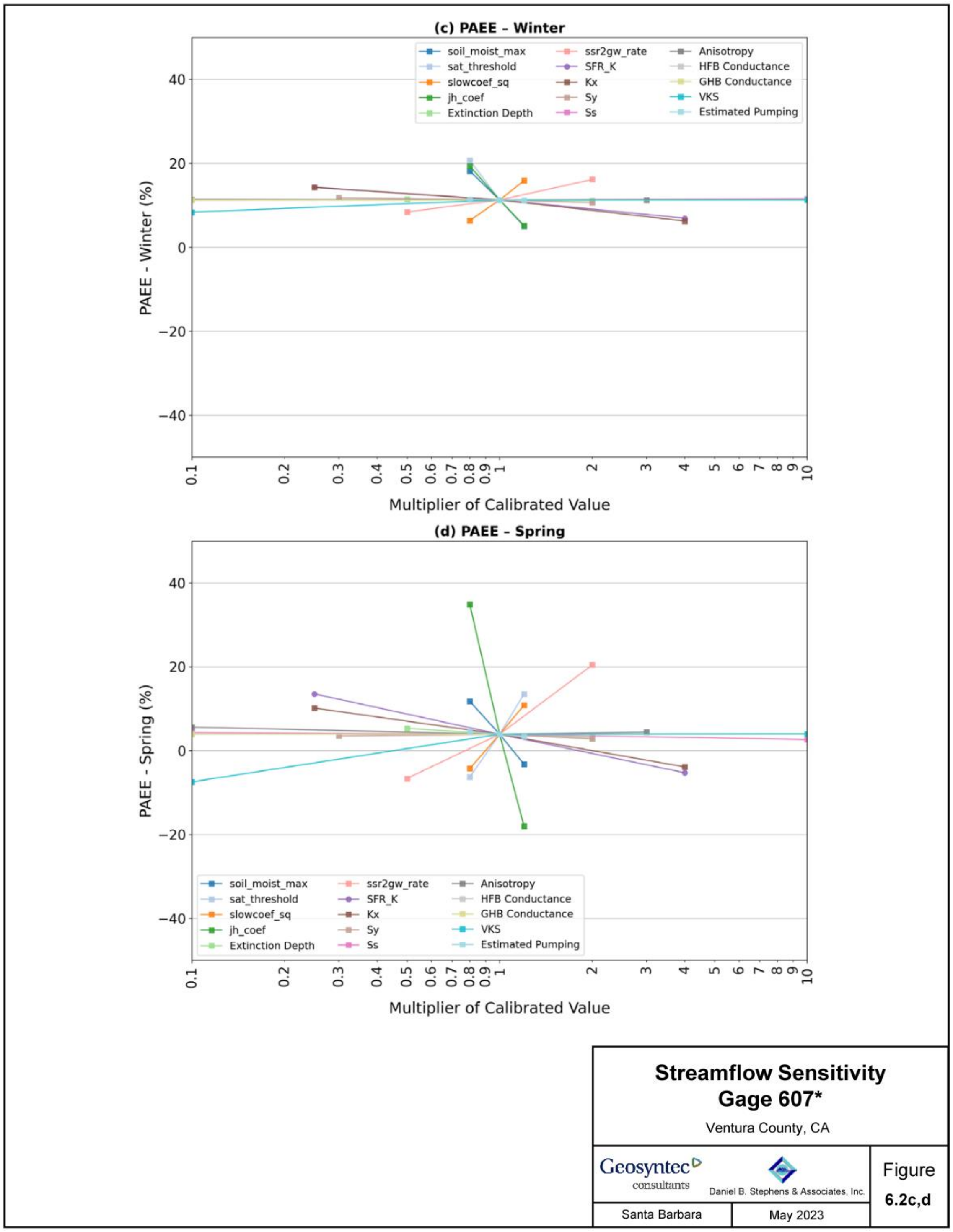
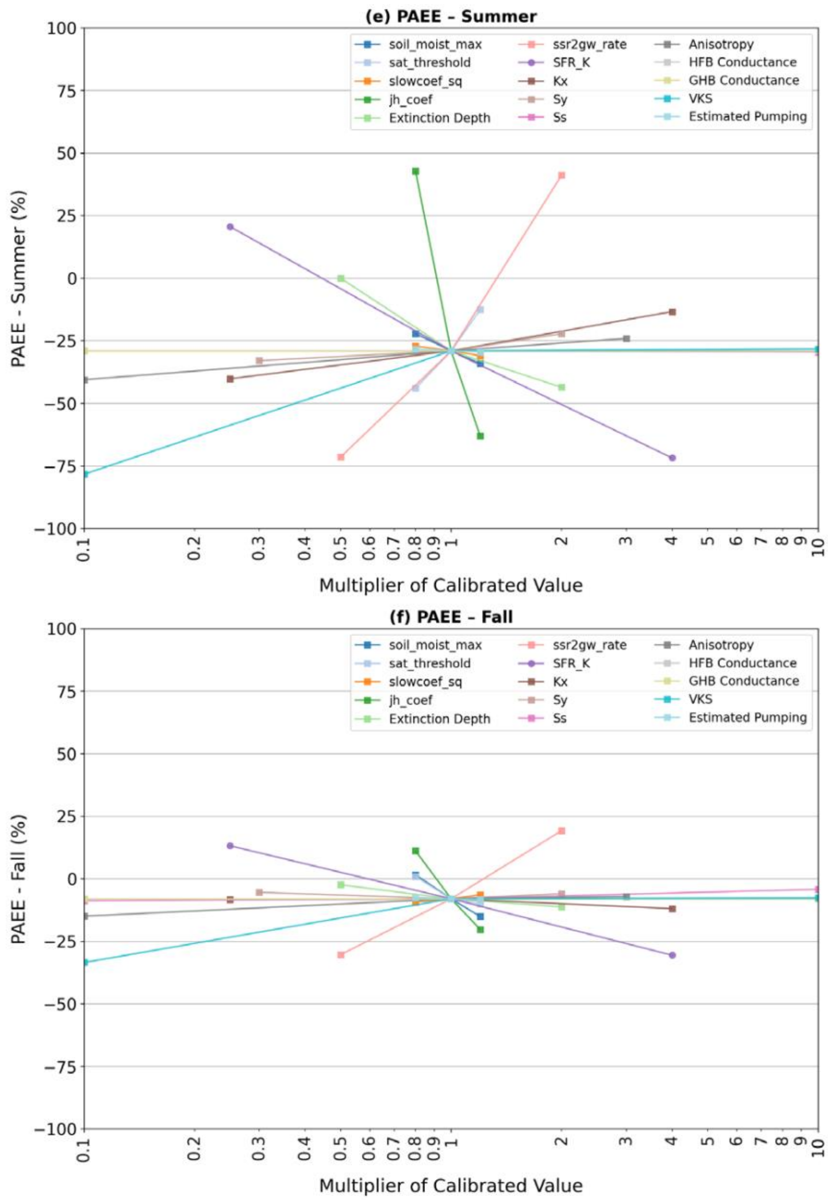
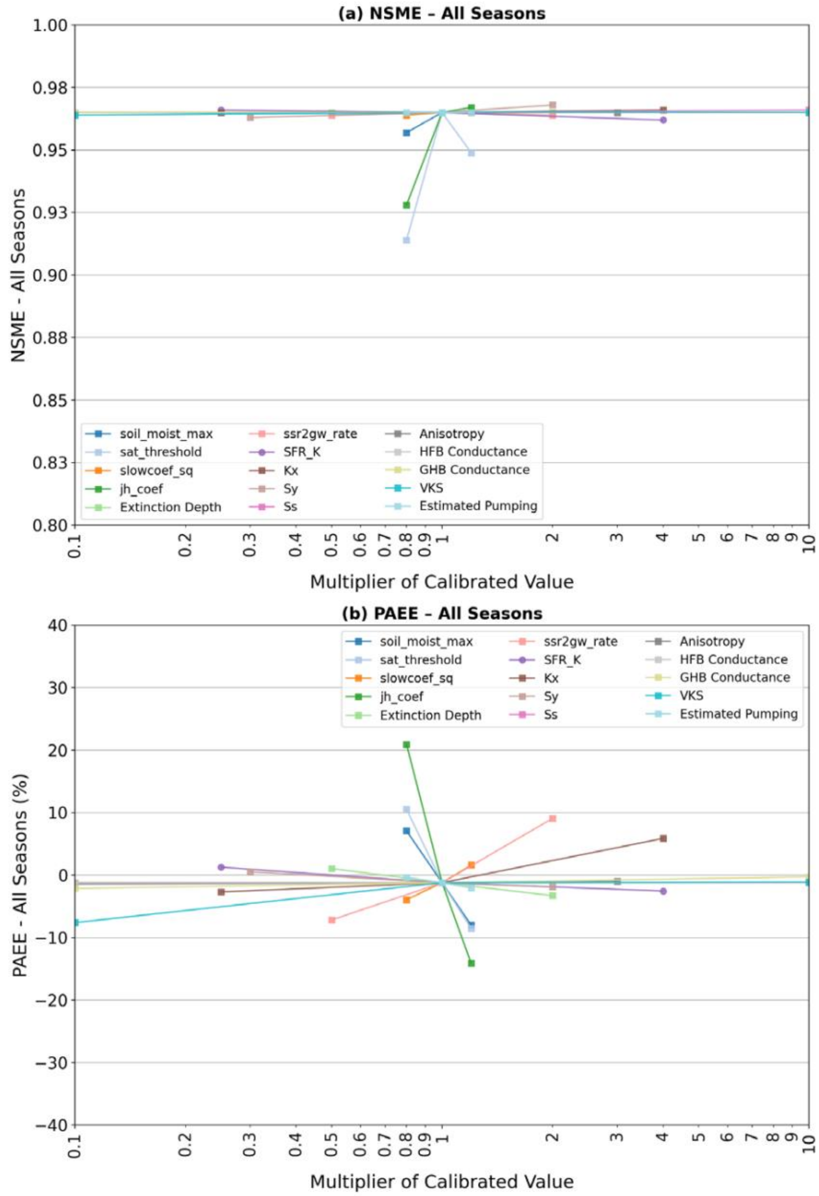


Figure 6.2c,d Streamflow Sensitivity – Gage 607*



Streamflow Sensitivity Gage 607* Ventura County, CA		
Geosyntec consultants / Daniel B. Stephens & Associates, Inc.		Figure 6.2e,f
Santa Barbara	May 2023	

Figure 6.2e,f Streamflow Sensitivity – Gage 607*



Streamflow Sensitivity Gage 608 Ventura County, CA		
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Santa Barbara	May 2023	

Figure 6.3a,b Streamflow Sensitivity – Gage 608

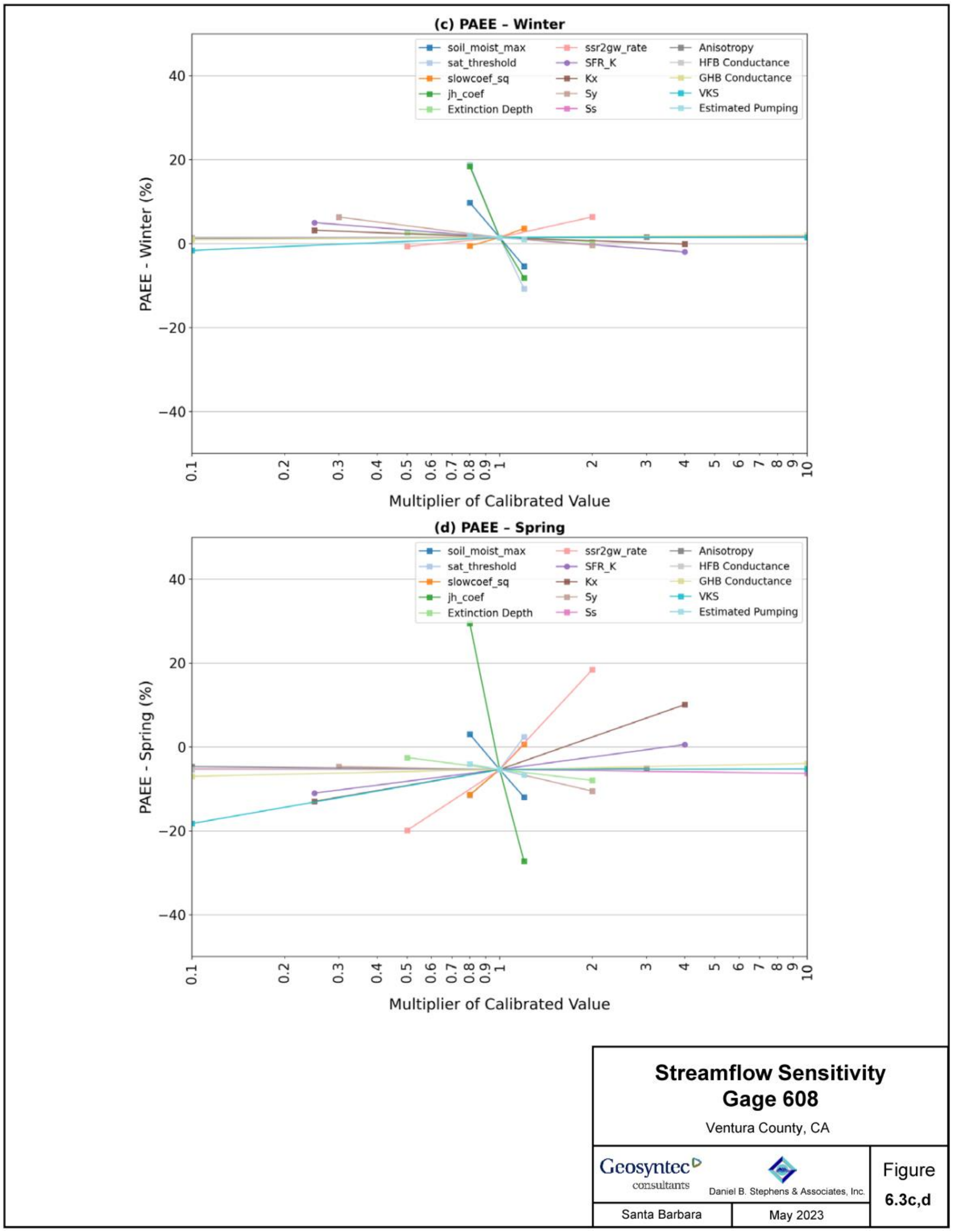
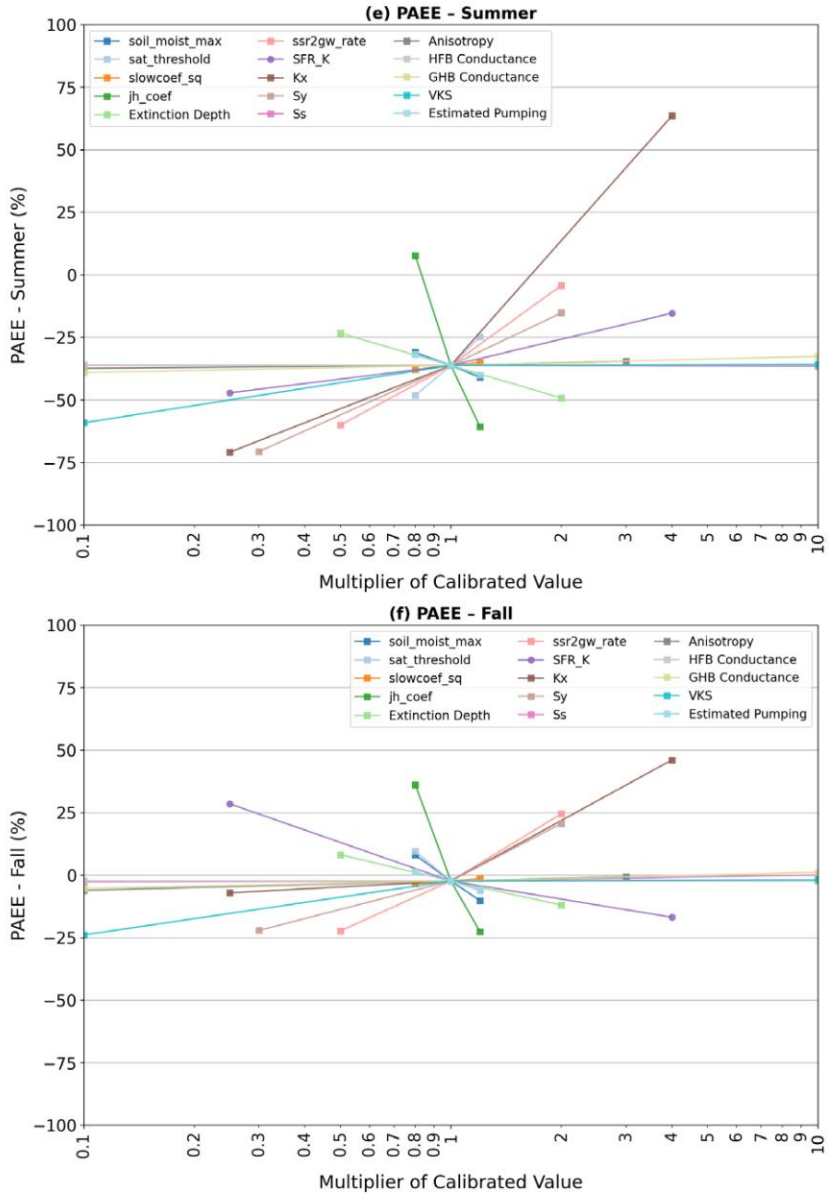


Figure 6.3c,d Streamflow Sensitivity – Gage 608



Streamflow Sensitivity
Gage 608
Ventura County, CA

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Figure 6.3e,f Streamflow Sensitivity – Gage 608

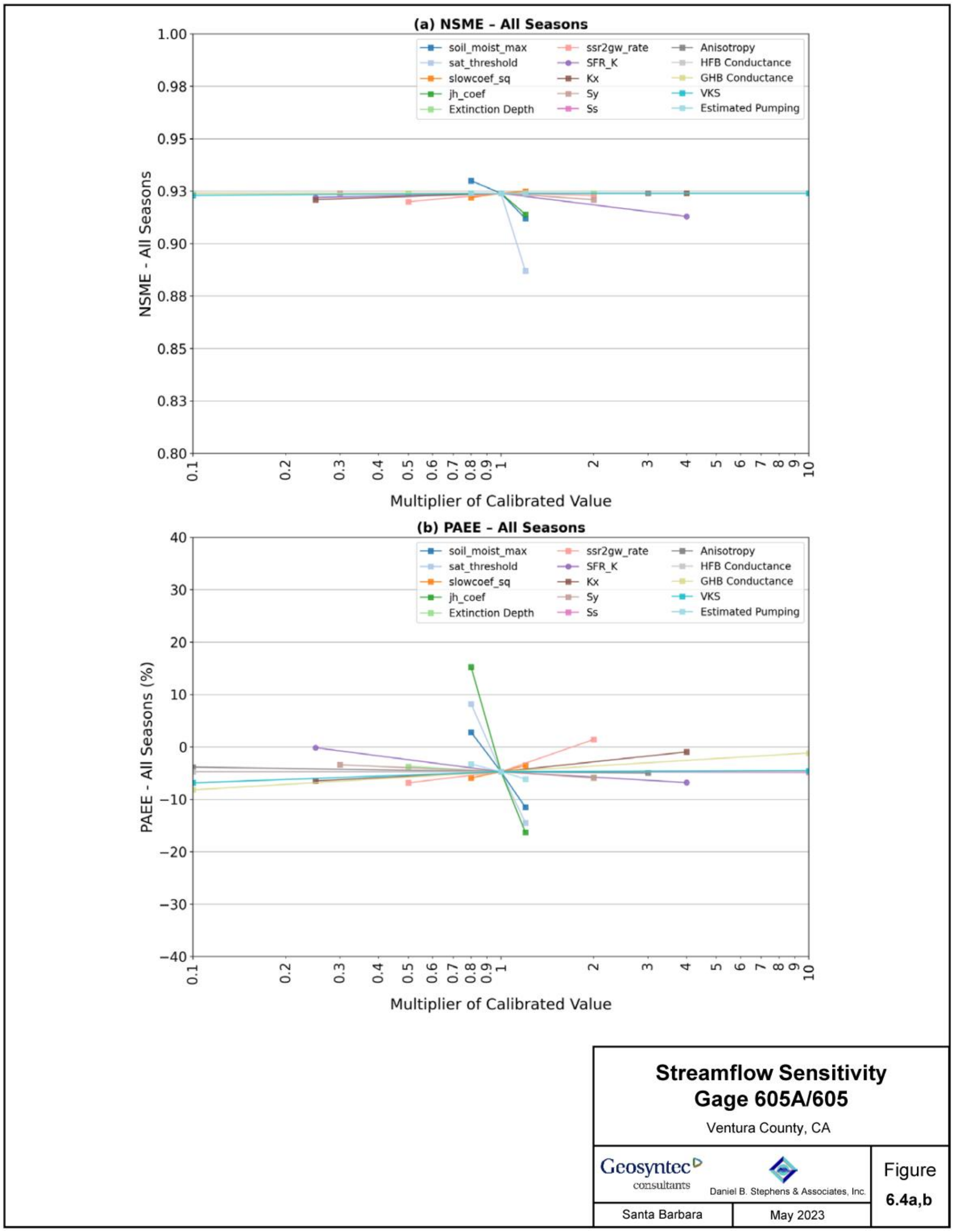


Figure 6.4a,b Streamflow Sensitivity – Gage 605A/605

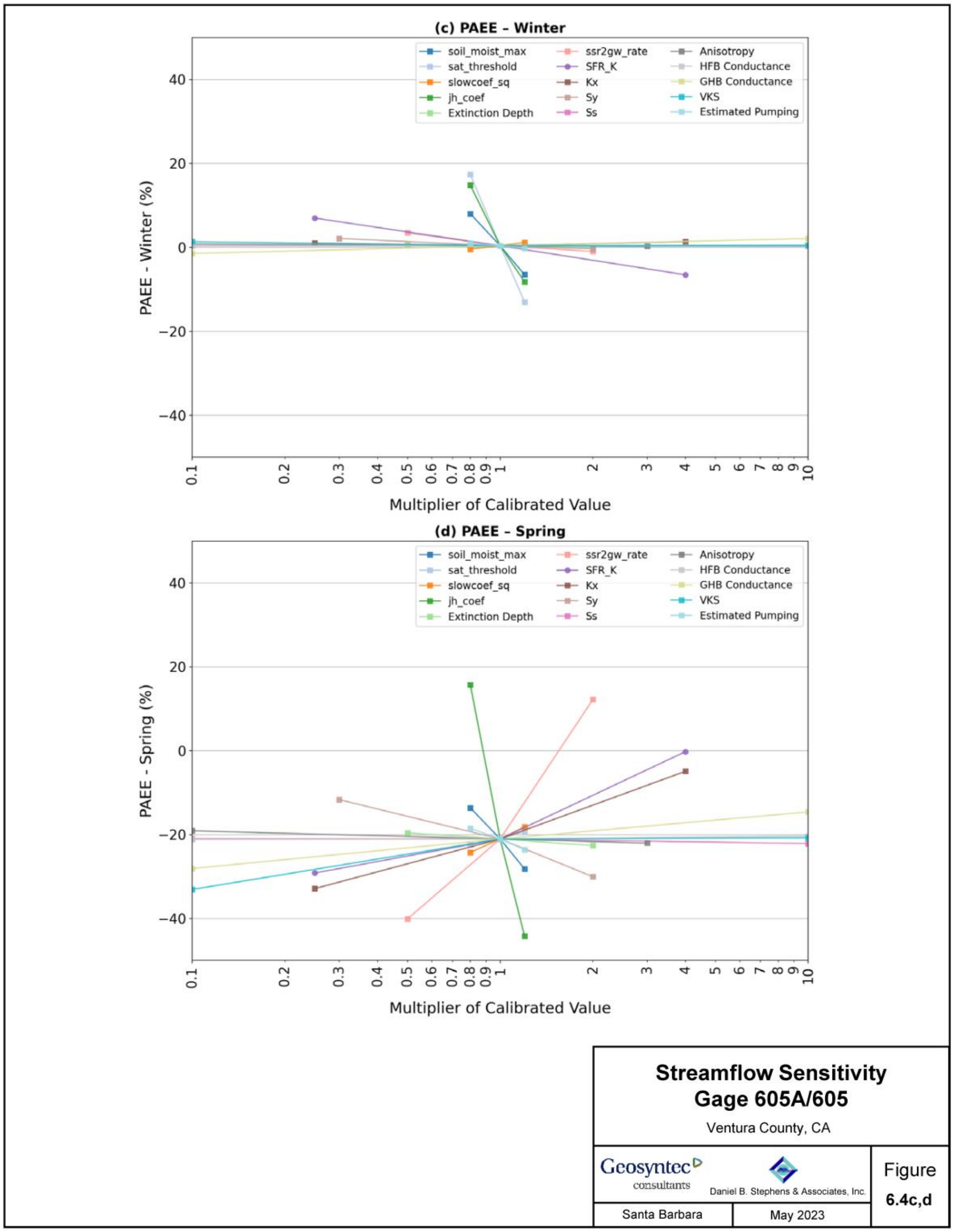
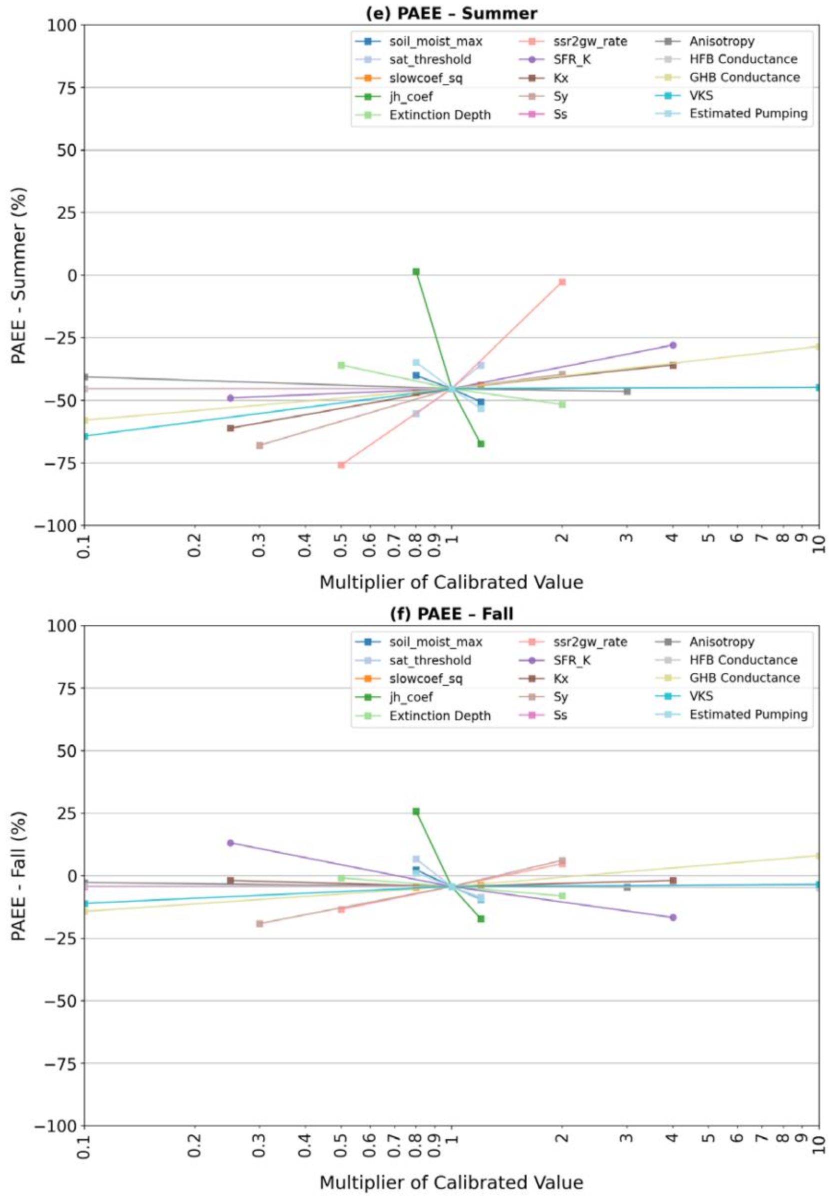


Figure 6.4c,d Streamflow Sensitivity – Gage 605A/605



Streamflow Sensitivity Gage 605A/605 Ventura County, CA		
Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure 6.4e,f
Santa Barbara	May 2023	

Figure 6.4e,f Streamflow Sensitivity – Gage 605A/605

Most sensitive parameters (highest slope on the spider plot) across all seasons and locations included parameters related to soil storage (soil_moist_max and sat_threshold) and ET (jh_coef). Results across all locations were also sensitive to the parameter controlling the interflow rate (slowcoef_sq) in the winter and spring, the rate of infiltration to groundwater (ssr2gw_rate) in the spring, summer, and fall, and riparian ET (extinction_depth) in the summer. At all locations, the summer flows were sensitive to groundwater parameters, including horizontal conductivity (Kx) and VKS.

At the locations in the Ventura River (Figure 6.2, Gage 607* and Figure 6.3, Gage 608) and San Antonio Creek (Figure 6.4, Gage 605A/605) groundwater parameters were important in the spring, summer, and fall. These parameters included, VKS and Kx (mentioned above), and the streambed conductivity (SFR_K) that governs the rate of flow between the streams and groundwater. The sensitivity to these parameters illustrates the importance of the groundwater during the dry seasons at these locations.

6.2.2 Groundwater Elevations

Figure 6.5 displays spider plots for groundwater ME and RMSE for each varied parameter. Most sensitive parameters (highest slope on the spider plot diagrams) included parameters that govern the amount of groundwater recharge from precipitation and irrigation (jh_coef, ssr2gw_rate), SFR_K that governs the amount of flow between the groundwater system and stream network, Kx that governs the rate of groundwater flow, and Sy that governs the amount of water that is stored or expelled from storage when groundwater elevations rise or fall in unconfined aquifers. In most cases, varying parameter values did not result in ME values closer to 0 or smaller RMSE values, and all RMSE values were fairly similar. RMSE decreased compared to the base case value of 27.9 feet for the sensitivity run with the increased soil_moist_max value, however surface-water results were poorer for that run (i.e., PAEE value further from 0, see Figure 6.1 through Figure 6.4).

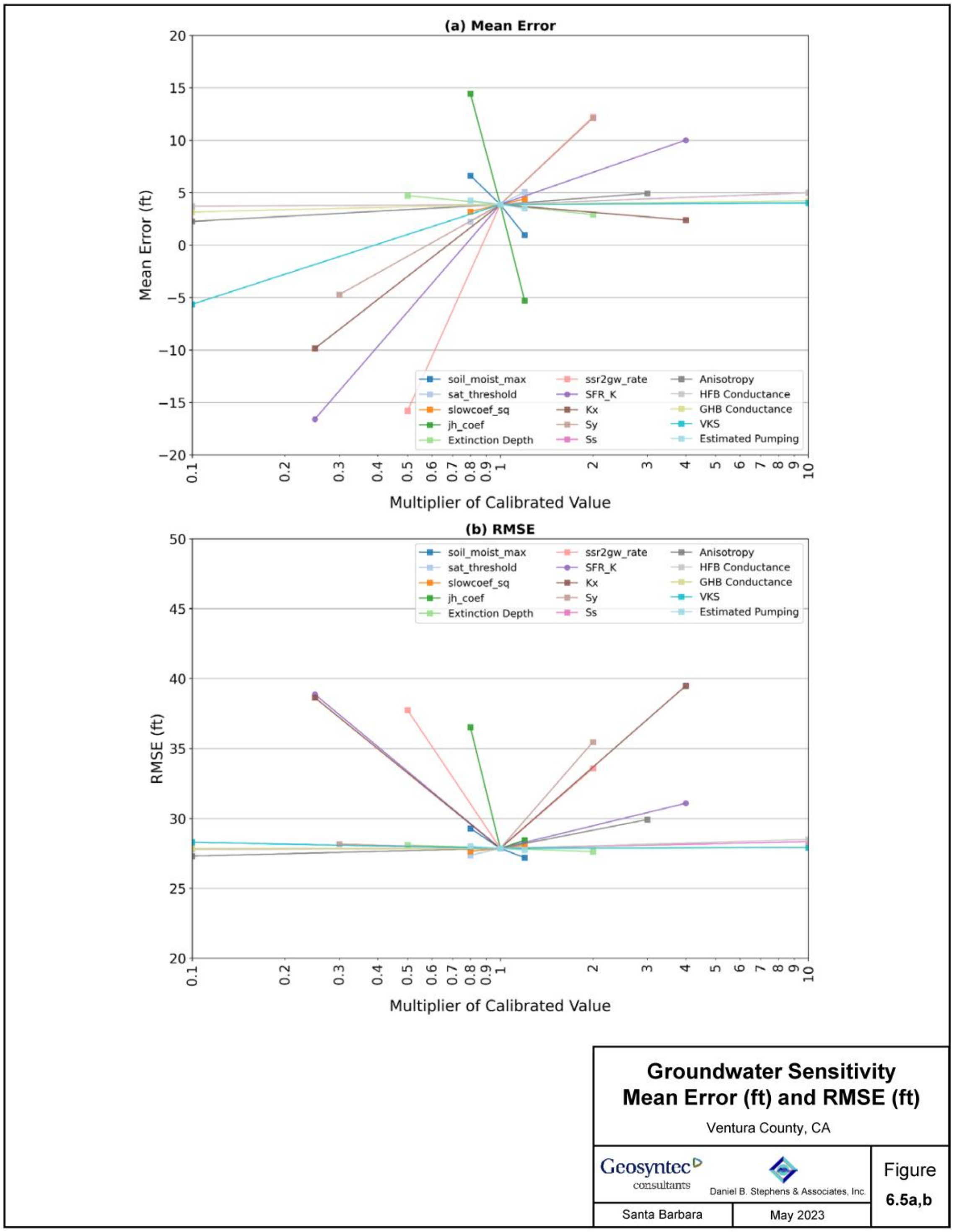


Figure 6.5a,b Groundwater Sensitivity Mean Error (ft) and RMSE (ft)

7 UNIMPAIRED FLOW SCENARIO

This section describes and presents results from the unimpaired flow scenario that was evaluated using the VRW GSFLOW Model. This scenario is one of eight scenarios that will be evaluated as part of this project. The other scenarios include Matilija Dam removal, climate change, impacts from the 2017-2018 Thomas Fire, and four additional scenarios that are to-be-determined. These other scenarios are under development.

7.1 Definition of Unimpaired Flow

The purpose of an unimpaired flow scenario is to estimate the total quantity of water available in a watershed that may be put to a reasonable and beneficial use for human and ecosystem needs.

The precise definition of unimpaired flow may vary depending upon the intended use of the results and other characteristics of the watershed. The following definition of unimpaired flow from Chapter 2 of the Staff Report for the Sacramento/Delta update of the Bay-Delta Plan (SWRCB, 2017) was used as a starting point to develop the unimpaired flow scenario for the Draft VRW GSFLOW Model:

> *Unimpaired hydrology or unimpaired flow represents an index of the total water available to be stored or put to any beneficial use within a watershed under current physical conditions. Stated another way, unimpaired flow represents the flow that would be present in a river or stream under current land use patterns in the absence of diversions, storage, releases from storage, water transfers, or other hydrologic modifications. Unimpaired flow is different than the "natural flow" that would have occurred absent human development of land and water supply. The use of unimpaired flows as an index is often misunderstood, owing in part to uncertainty regarding the relationship between unimpaired and natural flows and their intended use from a regulatory perspective.*

7.2 Key Assumptions for the VRW Unimpaired Flow Scenario

This section lists key assumptions and modelling parameters used for the unimpaired flow scenario that was evaluated with the VRW GSFLOW Model.

- Evaluate the same historical time period used for model calibration and validation, WY1994 to WY2017;
- All diversions from surface water are set to zero;

  - Reservoirs are set to zero storage, zero evaporation, and zero leakage. Water flows through existing reservoir locations with no impediment (e.g., no dam);

- All pumping from groundwater is set to zero;
- All other water infrastructure (e.g., levees, channelization, imperviousness, flood bypasses, etc.) functions consistent with existing conditions:
  - The effects of water infrastructure, excluding dams, on stream routing, infiltration, floodplain connectivity, etc. are retained;
- Land use is consistent with existing conditions:
  - Agricultural, municipal, and industrial land uses are retained;
  - Existing vegetation is retained; and
  - Vegetation types (agriculture, natural, domestic) are retained, but not irrigated. Therefore, vegetation consumes only water available from precipitation and/or shallow groundwater;
- Water discharges to OWTS and from wastewater treatment plants are set to zero.

7.3 Implementation into Model

The VRW GSFLOW Model was modified to reflect the assumptions described above. This required several relatively straightforward modifications described below as well as more complex changes to remove the effects of the lakes, as described in the following section.

The simplest changes to the model were implemented by:

- Setting all surface water diversions (Section 3.5), including the Robles diversion (Section 3.5.2), to zero;
- Removing the Matilija Reservoir releases (Section 3.5.1) and Lake Casitas withdrawals (Section 3.5.3);
- Setting the OVSD discharge (Section 3.5.4) to zero;
- Setting the OWTS recharge (Section 4.4.6) to zero; and

- Turning off the irrigation (Section 3.5.5).

7.3.1 Removal of Lakes

Removing Lake Casitas and Matilija Reservoir required replacing the lake cells with land and stream cells and modifying some elevations of stream cells to allow streamflow to pass through the former lakes unimpeded.

To achieve this, the stream networks through both lakes were created and connected to the existing stream network through modifications to the SFR package. The stream networks were created manually by extending existing streams through the former lake regions while following the low points in the bathymetry. The elevations of the cells through the dams also had to be modified to enable continuous downslope streamflow. This was done by assuming the grade between topography upstream and downstream of the dams was approximately constant. The stream widths were assumed to stay constant within the newly created network, and other values such as streambed conductivity were also kept the same.

The newly created land cells were assigned PRMS parameters that were estimated based on the average values of the hydrologic basins surrounding the lakes.

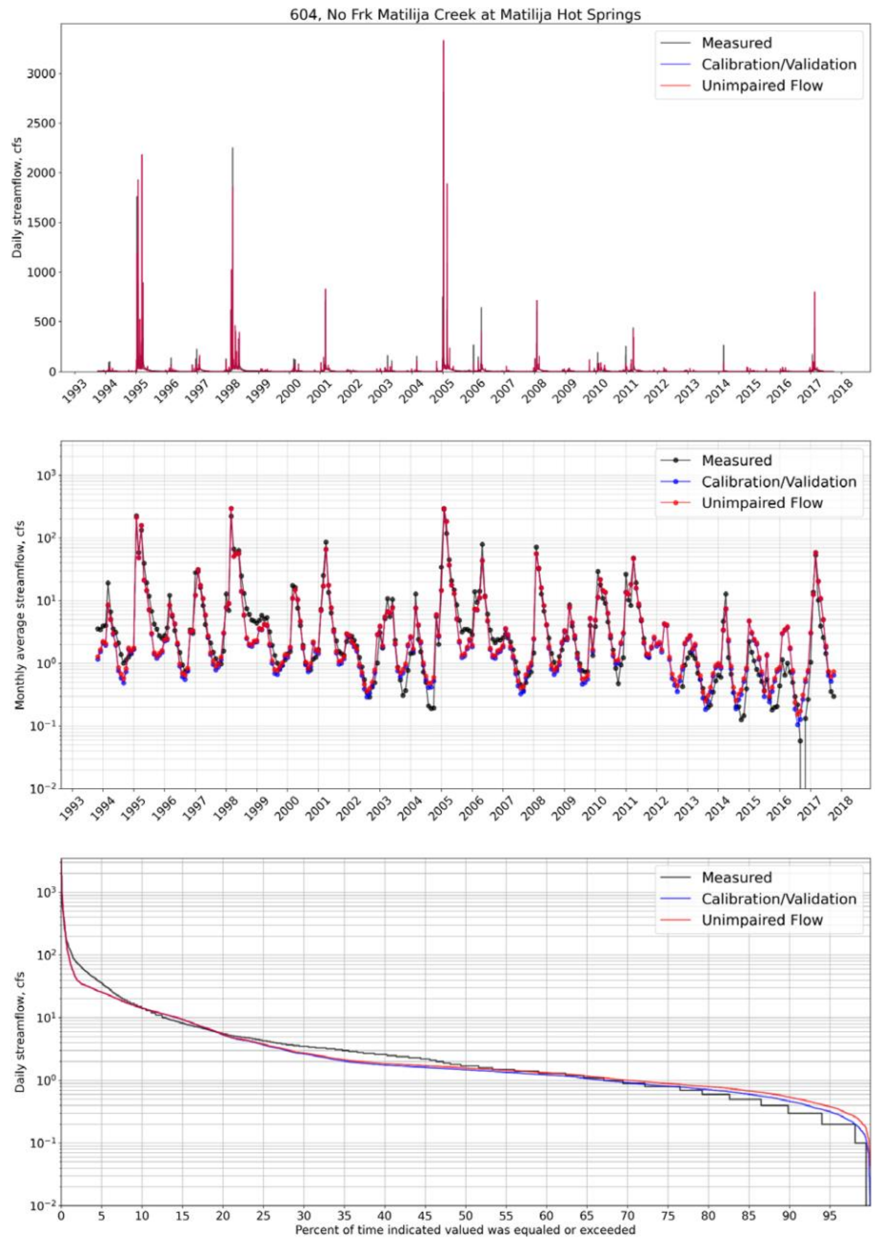
7.4 Results

Results of the unimpaired flow scenario are compared to the model calibration/validation in the following sections.

7.4.1 Surface Water Results

Timeseries plots and flow duration curves at Gage 604, Gage 607*, Gage 605A/605, and Gage 608 are provided in Figure 7.1 through Figure 7.4. The figures indicate generally higher streamflow for the unimpaired flow scenario compared to the calibration/validation. The amount of difference between the unimpaired flow scenario and the calibration/validation depends strongly upon location.

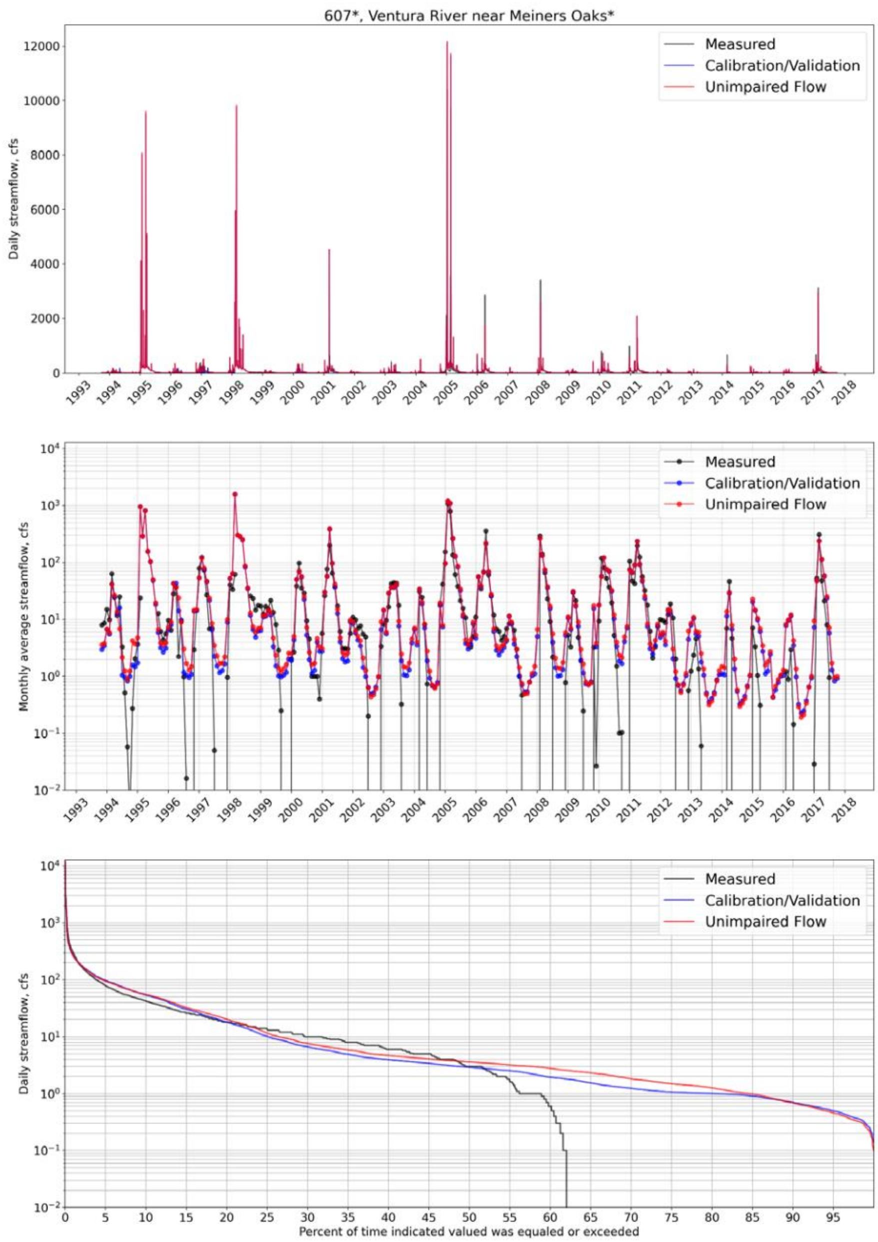
Monthly averaged streamflow is summarized statistically by season in box and whisker plots in Figure 7.5 through Figure 7.8. These clearly illustrate smaller



Unimpaired Flow Scenario
604, No Frk Matilija Creek at Matilija Hot Springs
Ventura County, CA

Geosyntec consultants | Daniel B. Stephens & Associates, Inc. | Figure 7.1
Santa Barbara | May 2023

Figure 7.1 Unimpaired Flow Scenario 604, No Frk Matilija Creek at Matilija Hot Springs

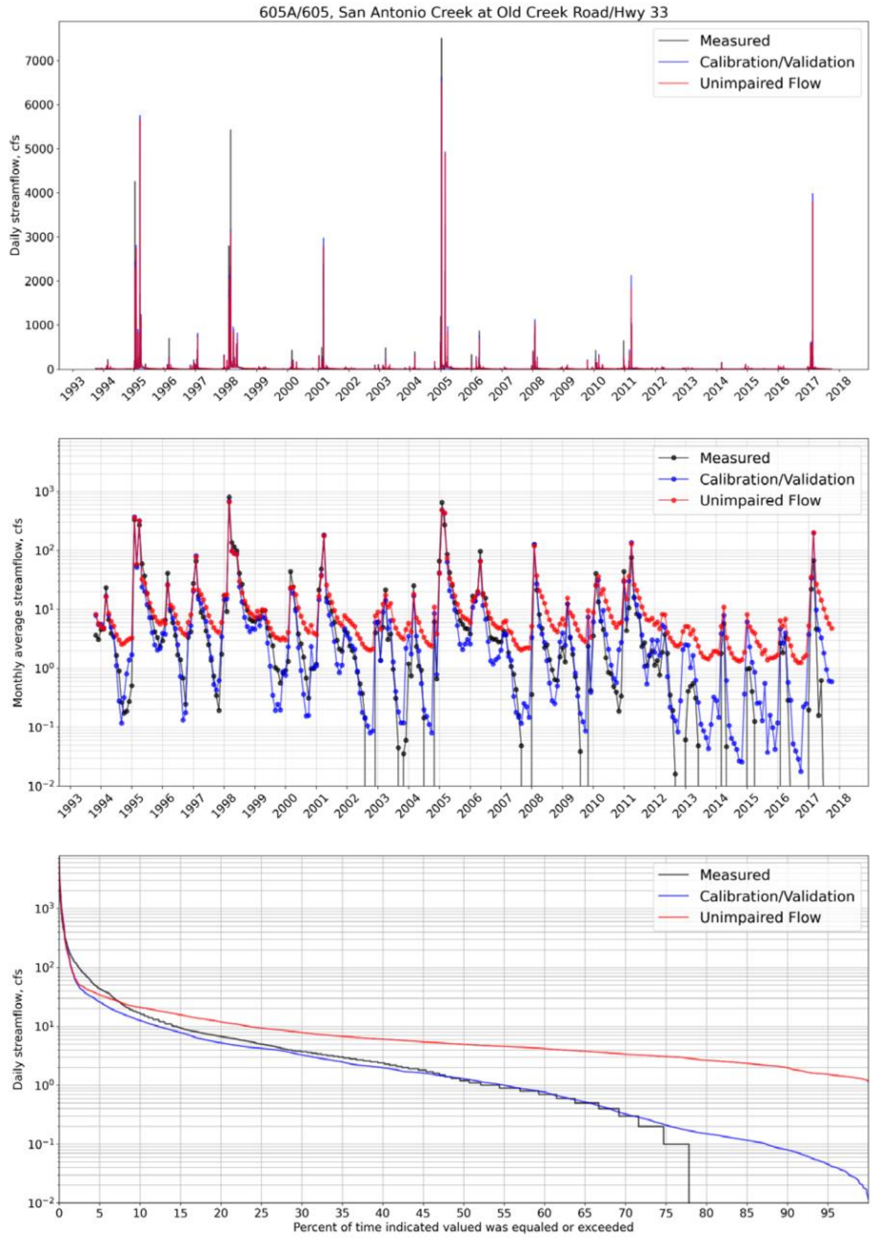


Unimpaired Flow Scenario 607*, Ventura River near Meiners Oaks*

Ventura County, CA

Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	Figure 7.2
Santa Barbara	May 2023	

Figure 7.2 Unimpaired Flow Scenario 607*, Ventura River near Meiners Oaks*



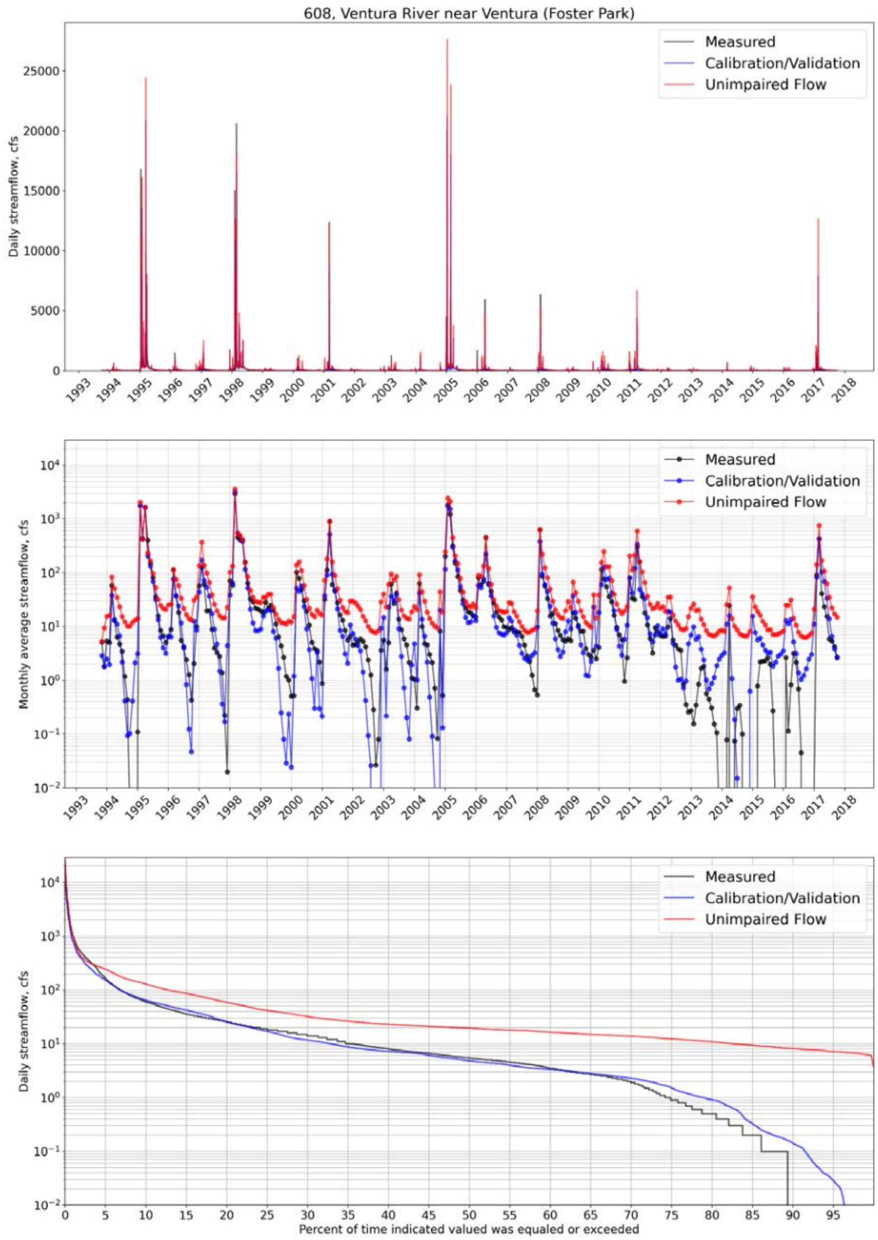
Unimpaired Flow Scenario 605A/605, San Antonio Creek at Old Creek Road/Hwy 33

Ventura County, CA

Geosyntec consultants | Daniel B. Stephens & Associates, Inc. | Figure 7.3

Santa Barbara | May 2023

Figure 7.3 Unimpaired Flow Scenario 605A/605, San Antonio Creek at Old Creek Road/Hwy 33



Unimpaired Flow Scenario
608, Ventura River near Ventura
(Foster Park)

Ventura County, CA

Geosyntec consultants

Daniel B. Stephens & Associates, Inc.

Figure **7.4**

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Figure 7.4 Unimpaired Flow Scenario 608, Ventura River near Ventura (Foster Park)

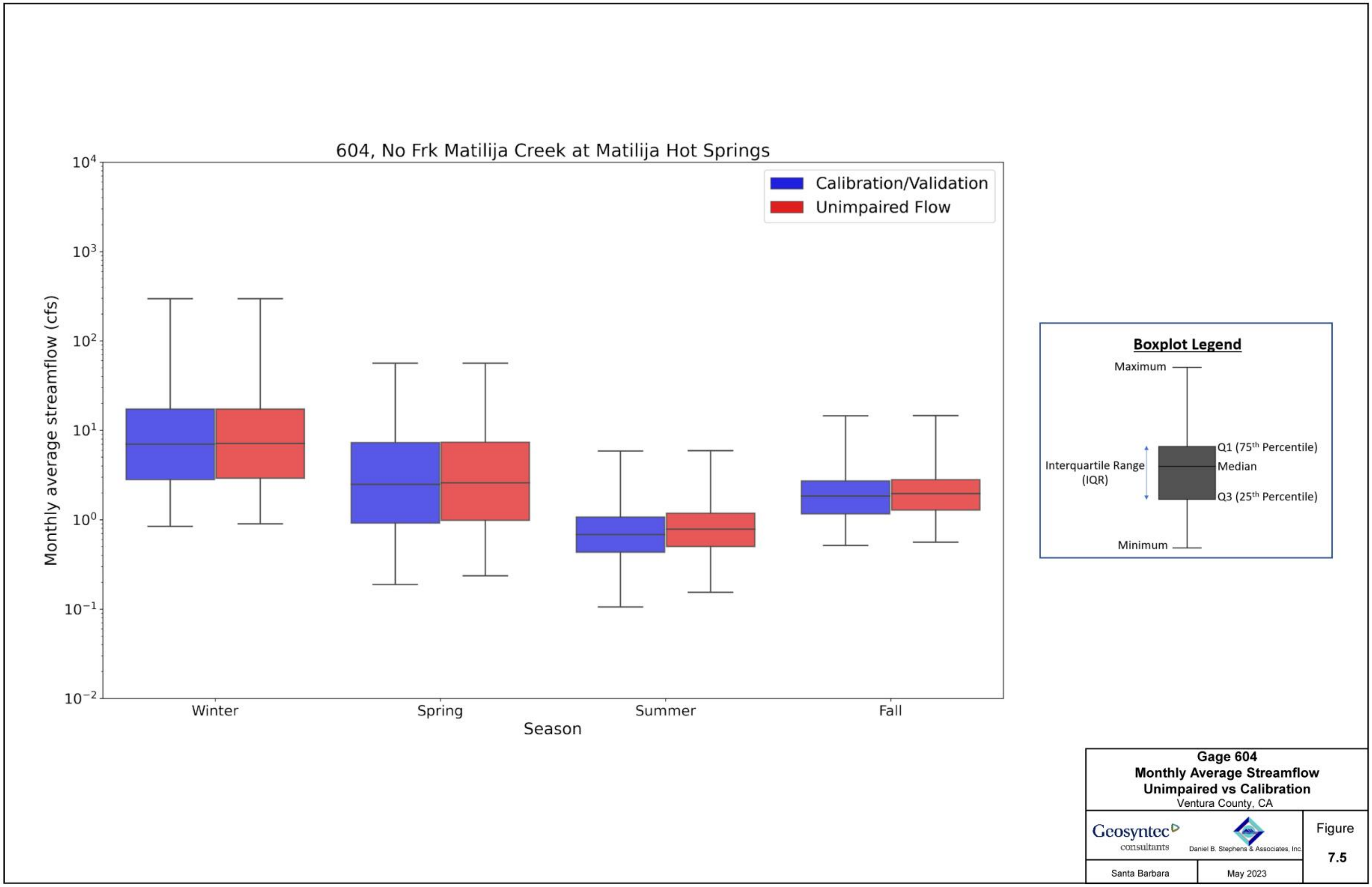


Figure 7.5 Gage 604 – Monthly Average Streamflow Unimpaired vs Calibration

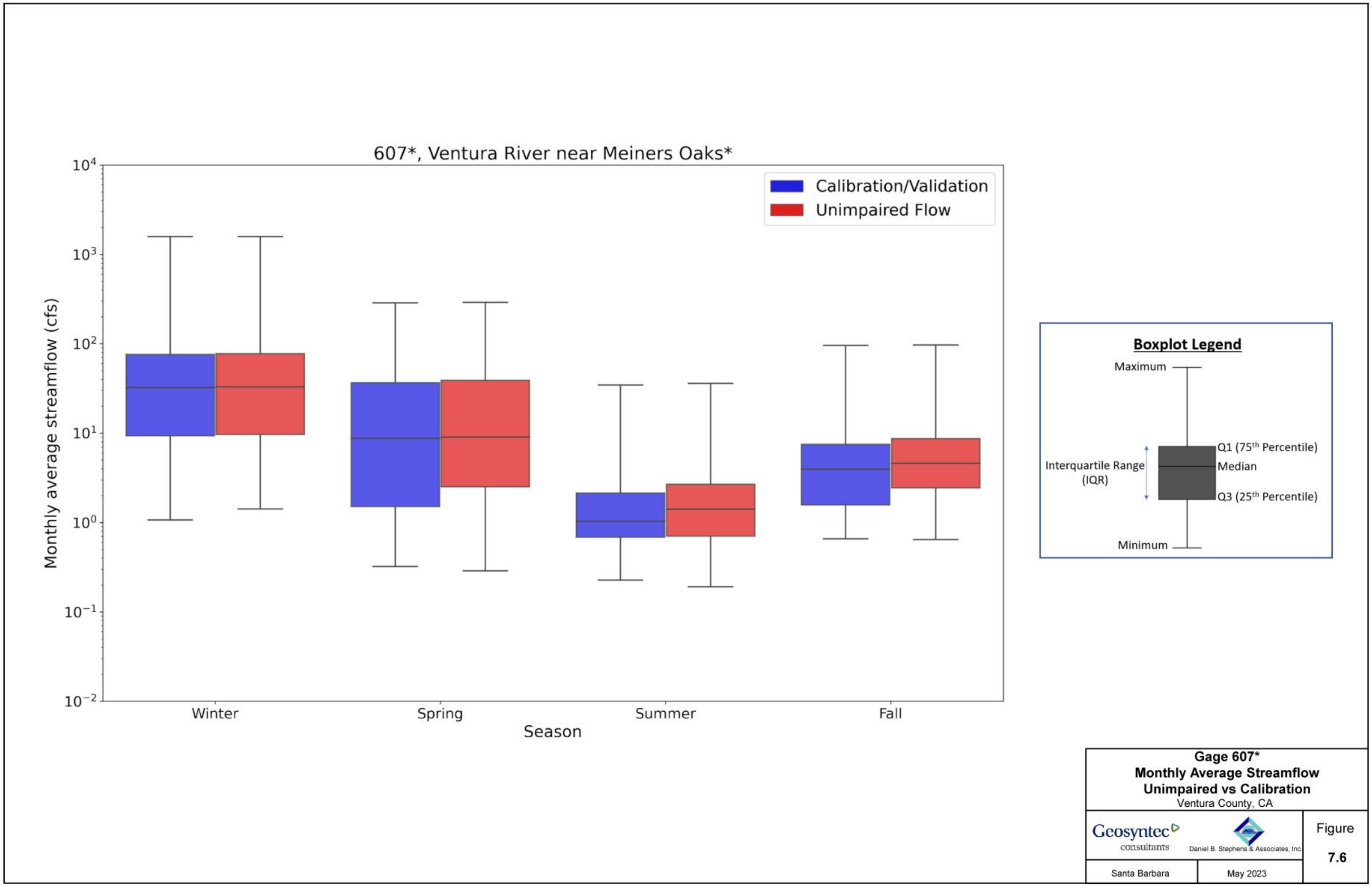


Figure 7.6 Gage 607* – Monthly Average Streamflow Unimpaired vs Calibration

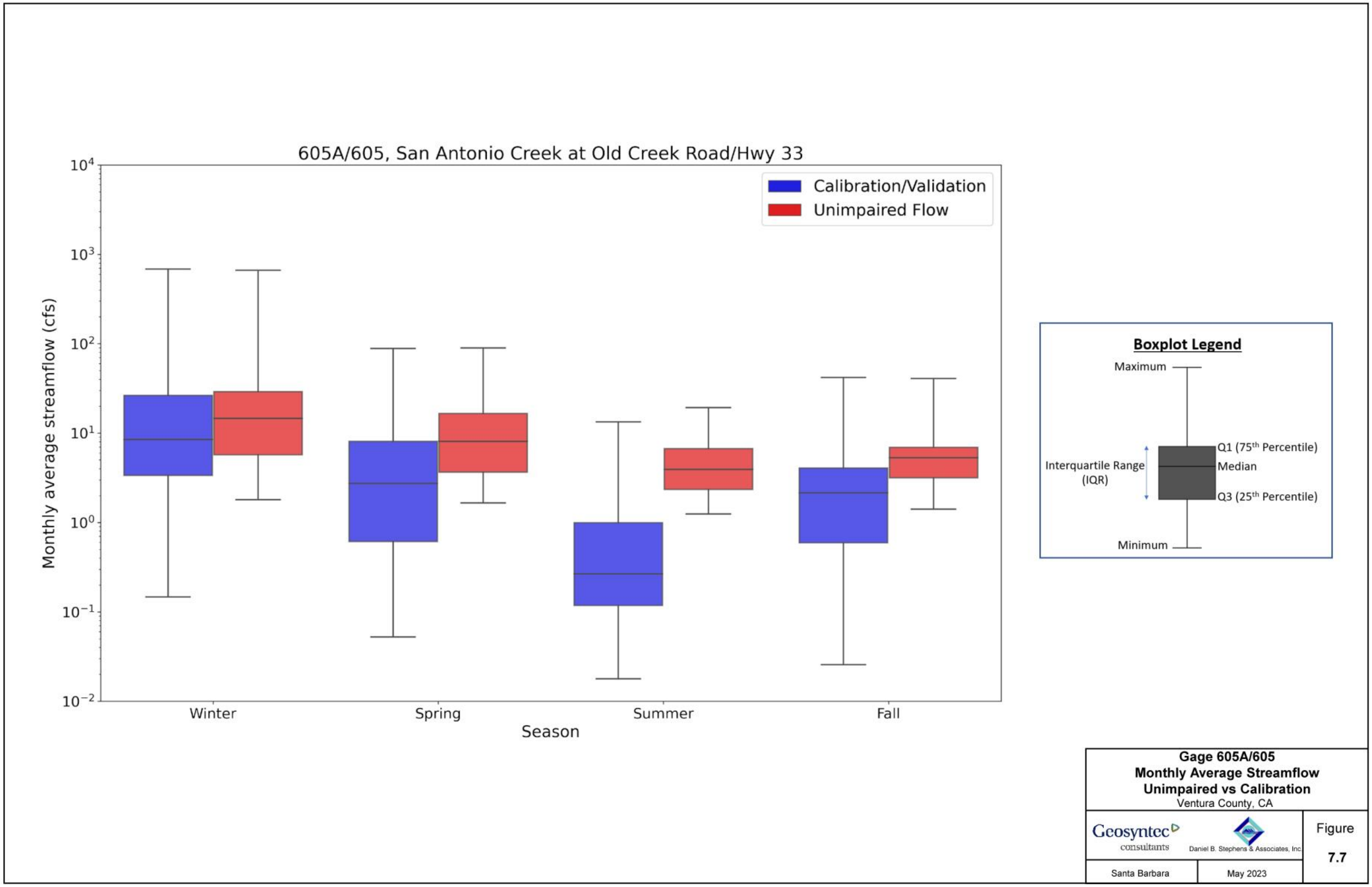
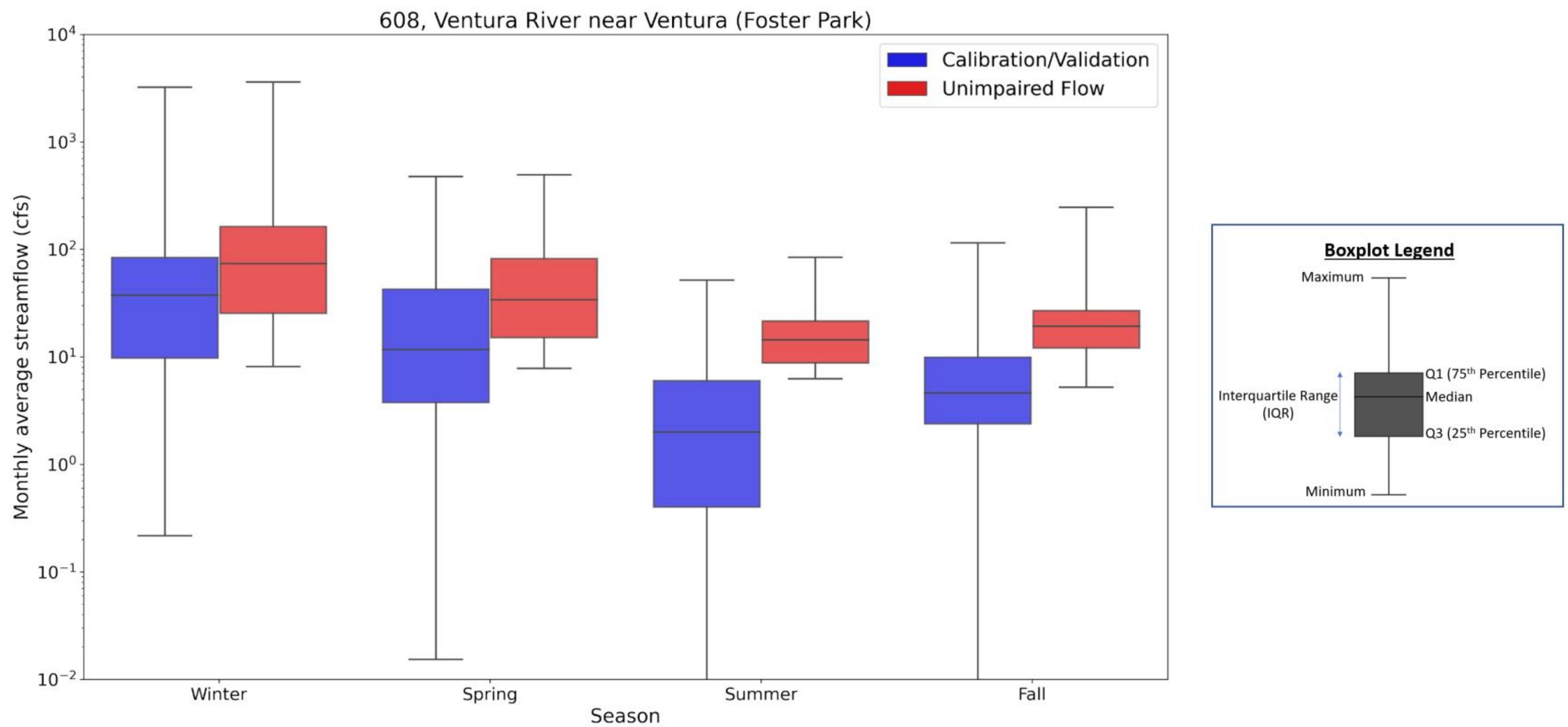


Figure 7.7 Gage 605A – Monthly Average Streamflow Unimpaired vs Calibration



Gage 608 Monthly Average Streamflow Unimpaired vs Calibration Ventura County, CA		Figure 7.8
Geosyntec consultants	Daniel B. Stephens & Associates, Inc.	
Santa Barbara	May 2023	

Figure 7.8 Gage 608 – Monthly Average Streamflow Unimpaired vs Calibration

differences between the calibration/validation and the unimpaired flow scenario at Gage 604 (Figure 7.5) and Gage 607* (Figure 7.6), and larger differences at Gage 605A/605 (Figure 7.7) and Gage 608 (Figure 7.8).

7.4.2 Groundwater Results

Appendix F[25] presents a comparison of groundwater hydrographs at each well used in calibration, showing the measured data, calibration/validation, and unimpaired flow scenario results. Well locations are shown on Figure 5.3. As expected, groundwater elevations are generally higher for the unimpaired flow scenario as compared to the calibration/validation. Groundwater elevation fluctuation is also smaller, as some fluctuation is driven by pumping cycles and there is no pumping in the unimpaired scenario. More significant increases in groundwater elevation for the unimpaired scenario are typically observed at wells further from the stream network. Streambed elevation often governs groundwater elevations observed at nearby wells. The amount of groundwater elevation increase is also influenced by the assumed specific yield at the well location (or specific storage in confined aquifers), which influences the amount of groundwater elevation change due to change in groundwater storage. The largest groundwater elevation increases for the unimpaired scenario are observed in the Ojai Basin, and relatively minor increases are observed in the Lower Ventura Basin.

Figure 7.9 and Figure 7.10 display potentiometric surface maps of the watershed for the unimpaired flow scenario for a relatively wet period (March 2006) and dry period (September 2015). Model cells with groundwater elevations greater than surface elevation (indicating groundwater discharge to surface water, flooding, and wetlands) are also shown. Corresponding diagrams for the calibration/validation are presented in Figure 5.27 and Figure 5.28. Compared to the calibration/validation, the unimpaired scenario has larger areas of groundwater discharge to surface water and wetlands, particularly for the dry time period (compare Figure 7.10 and Figure 5.28). More extensive areas of groundwater elevations greater than surface elevations are shown for the unimpaired flow scenario particularly near the terminus of the

[25] Appendices A through F are not embedded in this document. The appendices are presented in companion files. Appendices B through F are compiled in two PDF files. The appendices are include in the zip folder for this model report and are available for download on the State Water Board's California Water Action Plan website. URL: https://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/cwap_enhancing/

Ojai Basin and Upper Ventura River Basin and along portions of Lion Canyon Creek in the Upper Ojai Basin.

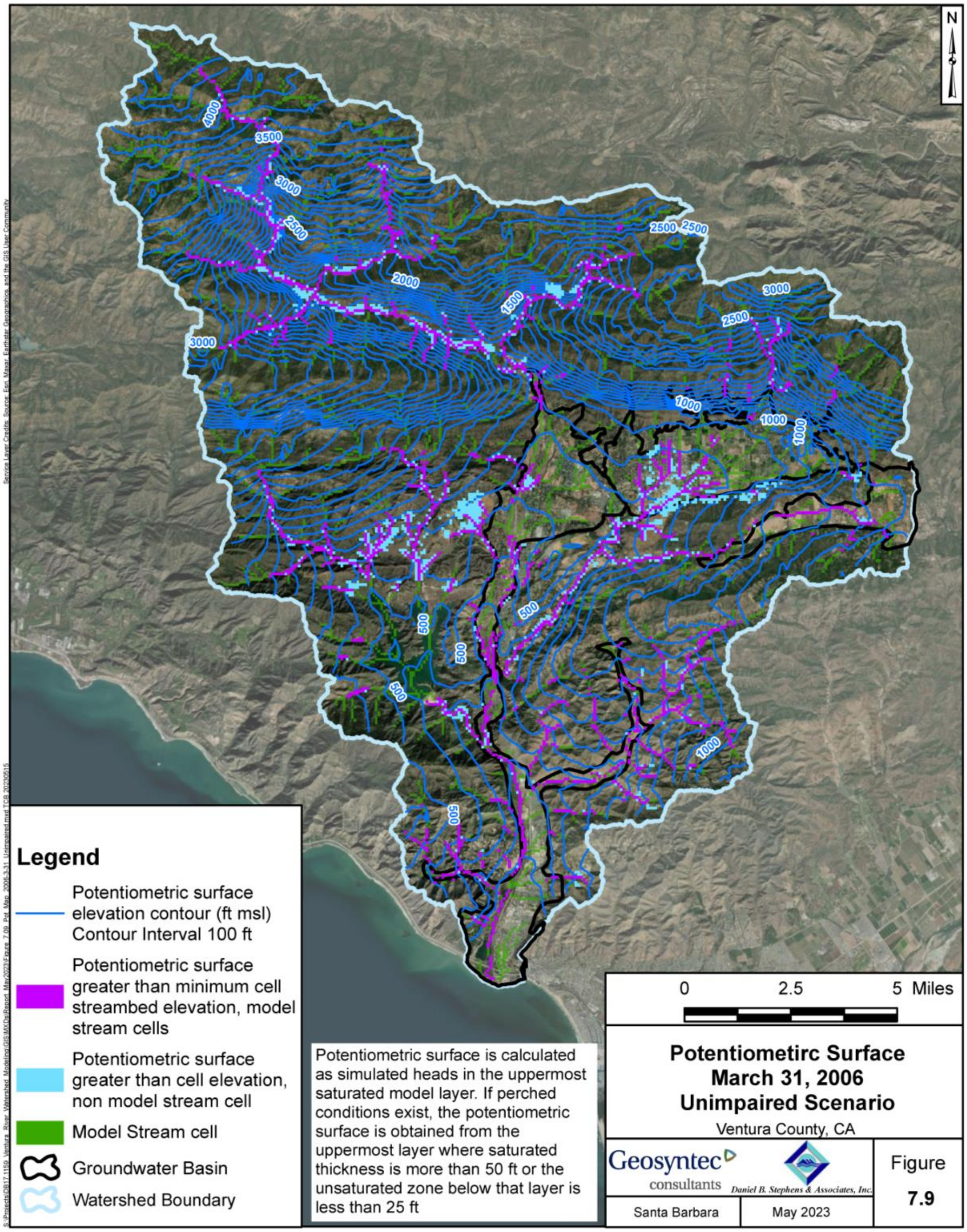


Figure 7.9 Potentiometric Surface – March 31, 2006 Unimpaired Scenario

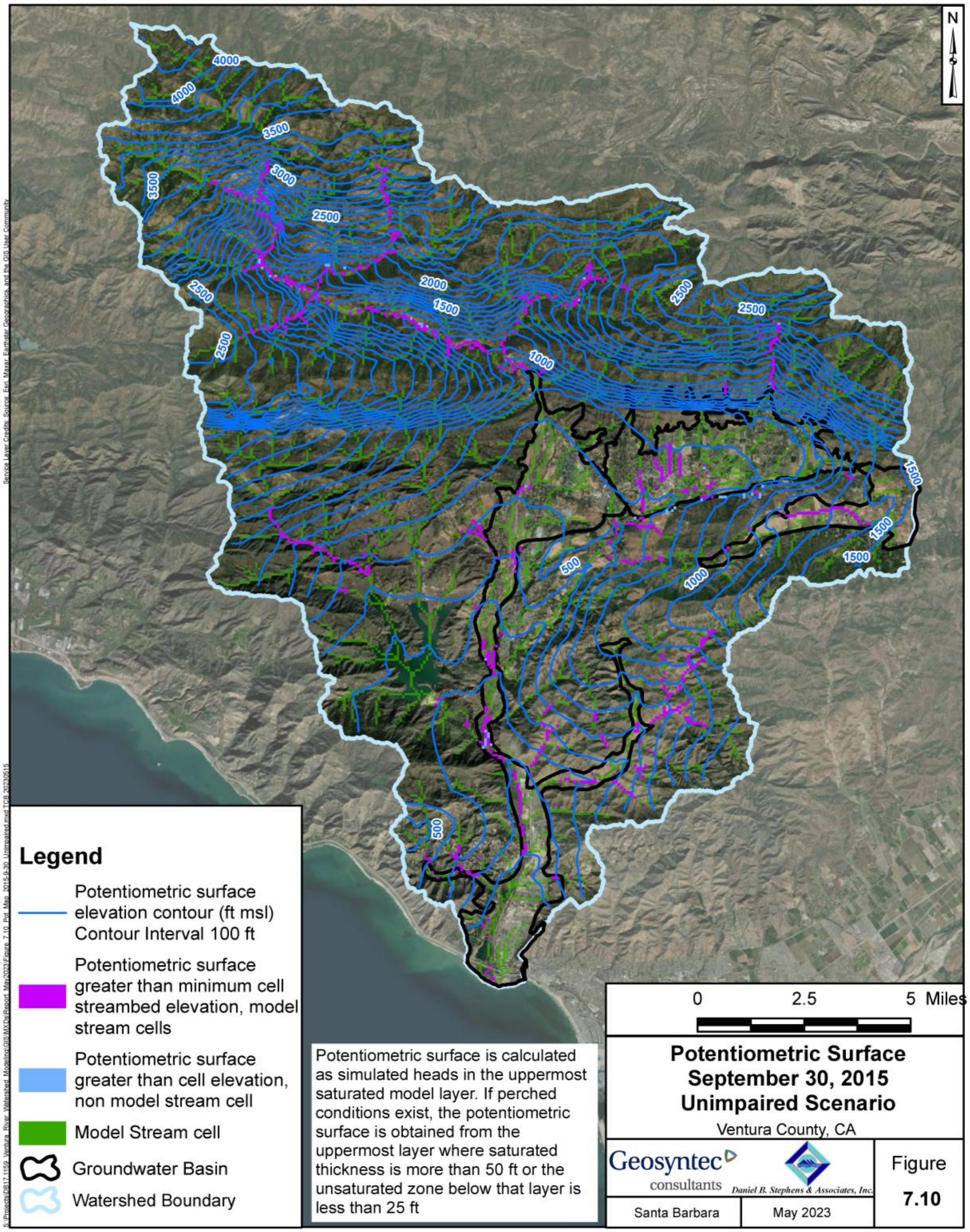


Figure 7.10 Potentiometric Surface – September 30, 2015 Unimpaired Scenario

7.4.3 Wet-Dry Mapping

Figure 7.11 compares wet-dry model predictions for the calibration/validation (upper frames) and the unimpaired flow scenario (lower frames). Each frame plots color-coded classifications as a function of time (horizontal axis) and distance along the river (vertical axis). The classifications are the same as used in the model predictions in Figure 5.26. The plot includes the full range of the simulation (i.e., WY1994 through WY2017), whereas Figure 5.26 only included the time period for which CMWD wet-dry mapping was available.

The model predictions indicate less drying for the unimpaired flow scenario, particularly in the mid-regions (river km 8 to 20) of the Ventura River (left frames) and the lower reaches (below river km 12) of San Antonio creek.

7.4.4 Water Budgets

Figure 7.12 plots annual watershed budgets for the unimpaired flow scenario. Compared to the calibration/validation (Figure 5.30) the plot for the unimpaired flow scenario does not have volumes for pumping, irrigation, OWTS recharge, and WWTP inflow to streams, because these were all removed for this scenario. The precipitation volumes are the same for the unimpaired flow scenario as the calibration/validation, while there is decreased total ET, higher outflows from streams, and smaller changes in storage.

Figure 7.13 plots annual water budget volumes for the groundwater portion of the model domain for the unimpaired flow scenario. Compared to the calibration/validation (Figure 5.32) the plot for the unimpaired flow scenario does not have volumes for pumping and lake seepage, since these were removed from the model for this scenario. The unimpaired flow scenario generally has increased discharge to streams, and higher groundwater ET.

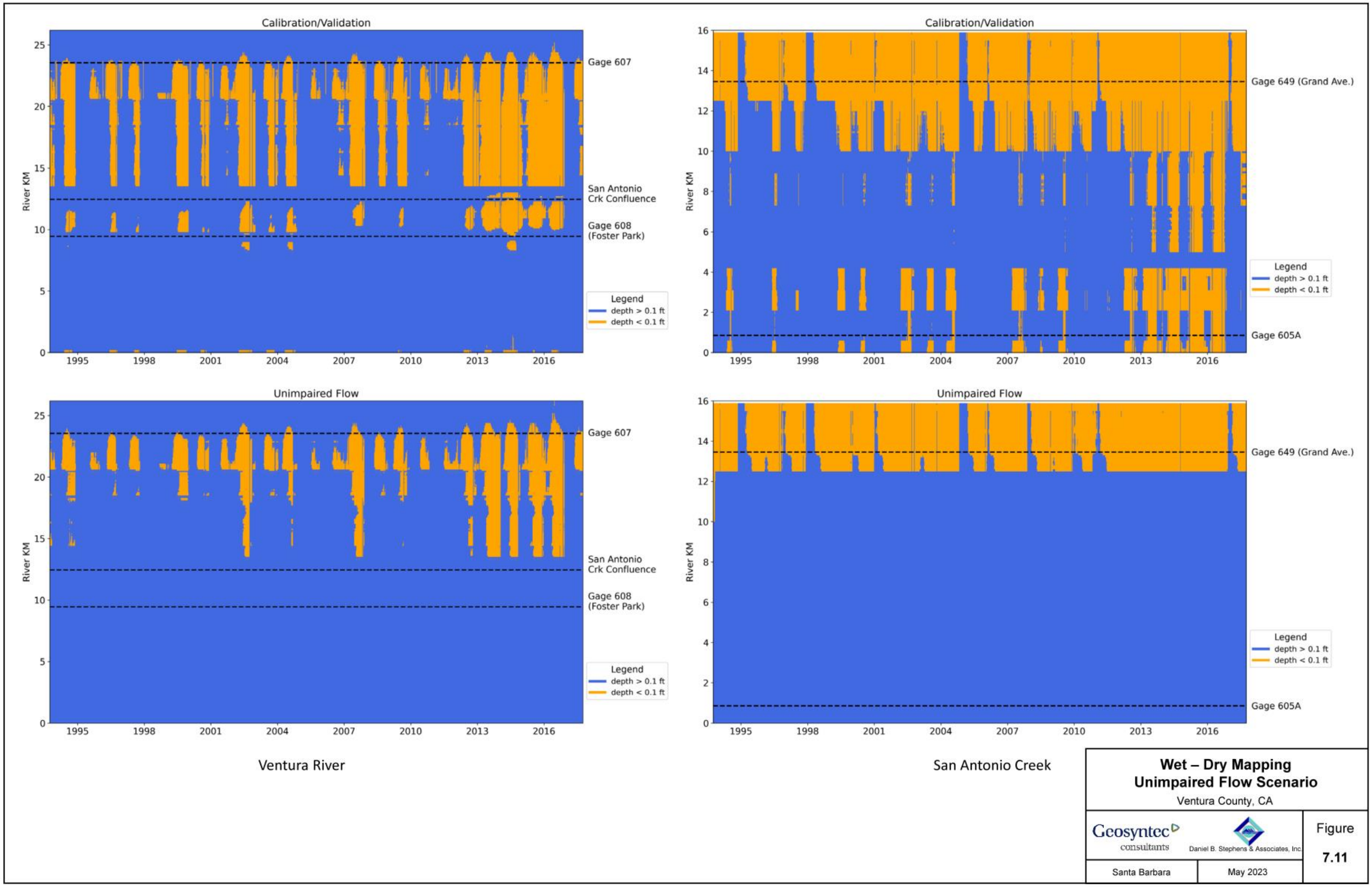


Figure 7.11 Wet – Dry Mapping Unimpaired Flow Scenario

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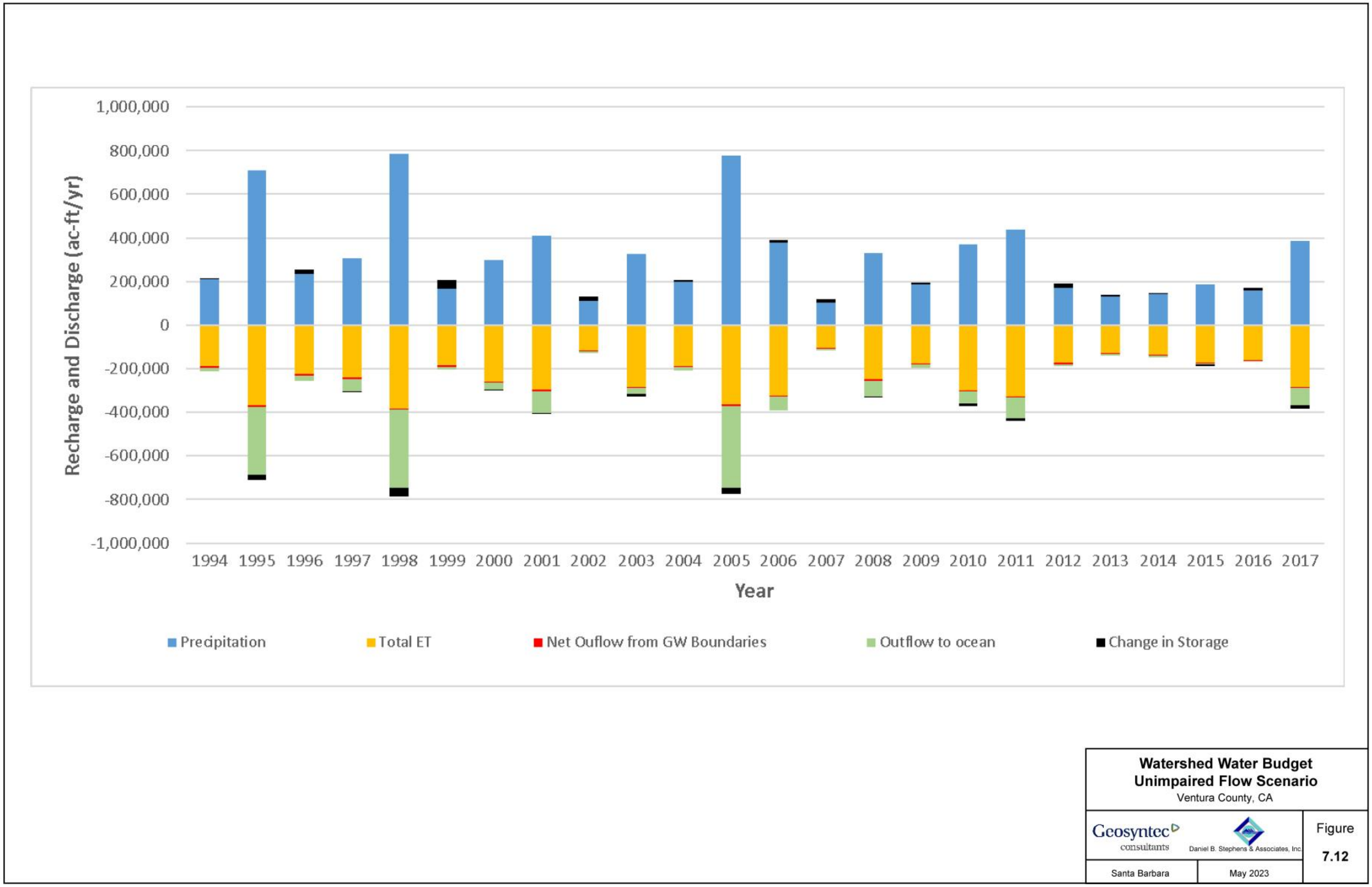

Figure 7.12 Watershed Water Budget Unimpaired Flow Scenario

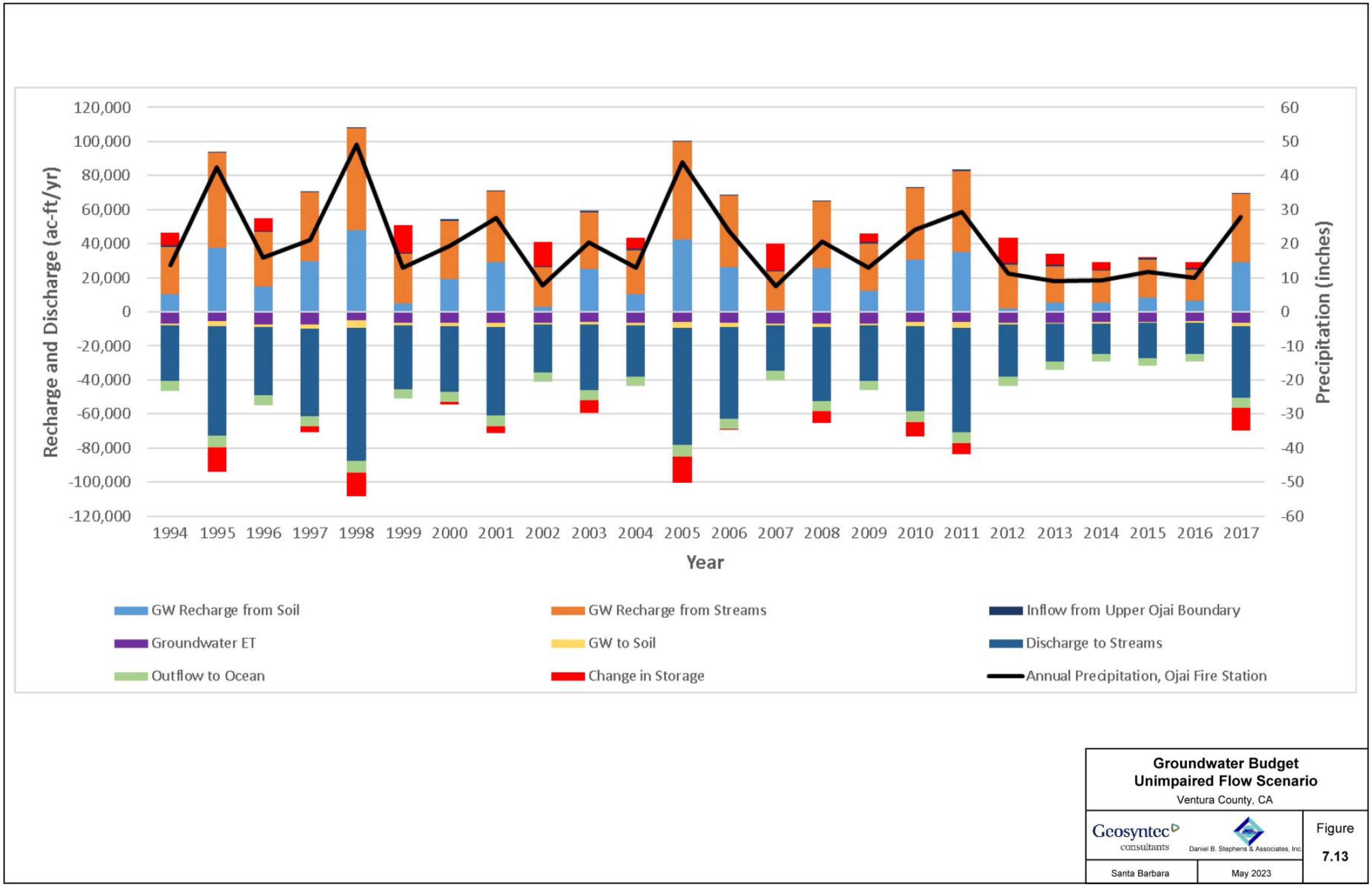

Figure 7.13 Groundwater Budget Unimpaired Flow Scenario

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