Prepared for

State Water Resources Control Board

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FINAL STUDY PLAN FOR THE DEVELOPMENT OF GROUNDWATER-SURFACE WATER AND NUTRIENT TRANSPORT MODELS OF THE VENTURA RIVER WATERSHED

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LIST OF ACRONYMS AND ABBREVIATIONS

AAEE	absolute average estimation error
ASTM	American Society for Testing and Materials
CEDEN	California Environmental Data Exchange Network
CDFW	California Department of Fish and Wildlife
CIMIS	California Irrigation Management Information System
CMWD	Casitas Municipal Water District
DBS&A	Daniel B. Stephens & Associates
DEM	digital elevation model
DPWM	distributed parameter watershed model
DWR	Department of Water Resources
EVT	MODFLOW evapotranspiration package
GAMA	Groundwater Ambient Monitoring and Assessment Program
GHB	MODFLOW general-head boundary
GSFLOW	Groundwater and Surface-water Flow
HRU	Hydrologic Response Unit
HSPF	Hydrological Simulation Program in Fortran
HFB	MODFLOW horizontal flow barrier package
IHM	Integrated Hydrologic Model
MAE	mean absolute error
ME	mean error
MNW	MODFLOW multi-node well package
MODFLOW	Modular Ground-Water Flow Model
MODFLOW-NWT	Modular Ground-Water Flow Model – Newton Formulation
NHD	National Hydrography Dataset
MT3D-USGS	Groundwater Solute Transport Simulator
NLCD	National Land Cover Dataset
NRCS	National Resources Conservation Service
NSME	Nash-Sutcliffe model efficiency
OBGM	Ojai Valley Basin Groundwater Model
OBGMA	Ojai Basin Groundwater Management Agency
OVSD	Ojai Valley Sanitation District
OWHM	One World Hydrologic Model
OWTS	onsite wastewater treatment systems
PAEE	percent average estimation error
PPCP	pharmaceuticals and personal care products
POI	points of interest
PRMS	Precipitation-Runoff Modeling System
R	correlation coefficient

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

RCH	MODFLOW recharge package
RMSE	root-mean-square error
SFR	MODFLOW streamflow routing package
SGMA	Sustainable Groundwater Management Act
TAC	Technical Advisory Committee
TMDL	total maximum daily load
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
UVRGA	Upper Ventura River Groundwater Agency
UZF	MODFLOW unsaturated-zone flow package
VCAC	Ventura County Agricultural Commissioner
VCAILG	Ventura County Agricultural Irrigated Lands Group
VCEHD	Ventura County Environmental Health Department
VCWPD	Ventura County Watershed Protection District
VSWHM	Ventura Surface Water Hydrology Model
WAP	Water Action Plan
WEL	MODFLOW well package
WY	water year

1. INTRODUCTION

Geosyntec Consultants (Geosyntec) and Daniel B. Stephens & Associates, Inc. (DBS&A) developed this Study Plan to describe the overall approach that will be taken to develop integrated groundwater-surface water and nutrient transport models for the Ventura River Watershed for the State Water Resources Control Board (State Water Board) and the Los Angeles Regional Water Quality Control Board (Los Angeles Regional Water Board).

1.1 Background

The Ventura River, predominantly in Ventura County, was identified as one of five priority stream systems in the California Water Action Plan (WAP) enacted in January 2014 by Governor Edmund G. Brown Jr. Action four (4) of the WAP, to "Protect and Restore Important Ecosystems," contains the following sub-action:

> *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.*

The State Water Board and California Department of Fish and Wildlife (CDFW) are currently working to identify potential actions that may be taken to enhance and establish instream flow for anadromous fish in the Ventura River Watershed (and the other four priority watersheds). The integrated groundwater-surface water model developed in this project will provide a better understanding of water supply, water demand, and instream flow in the Ventura River Watershed.

Additionally, in 2012, the Los Angeles Regional Water Board adopted a total maximum daily load (TMDL) for algae, eutrophic conditions, and nutrients in the Ventura River Watershed (Los Angeles Regional Water Board 2012a, 2012b). At the time of TMDL development, Los Angeles 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 nitrogen transport model described in this document will help inform the TMDL process in the Ventura River Watershed.

The State Water Board and Los Angeles Regional Water Board (Water Boards) recognize that local stakeholders in the Ventura River Watershed are also creating water management tools, gathering new data, and developing water management actions. The Water Boards encourage local dialogue on instream flow and water quality needs to identify solutions that protect public trust resources and best meet the needs of local stakeholders. The Water Boards are committed to developing these publicly available modeling tools that local stakeholders in the Ventura River Watershed can use to understand and manage water resources. The Water Boards are open to coordinating with interested parties to develop water management actions that enhance instream flows, protect water quality, and consider the need for resilient water supplies in Ventura River Watershed.

1.2 Goals and Objectives of the Model

The overall goal of the integrated groundwater-surface water and nutrient transport models for the Ventura River Watershed is to provide scientifically defensible, cost-effective, time-sensitive, and publicly transparent[1] tools that can be used to support the State Water Board and Los Angeles Regional Water Board instream flow and TMDL efforts, respectively. The model will specifically meet the following objectives:

- Estimate existing instream flows[2] at multiple points of interest (POI) throughout the entire Ventura River Watershed;

[1] Public transparency will be achieved through conducting multiple public outreach meetings with stakeholders, meetings with and reviews by a technical advisory committee (comprised of experts from academia, public agencies, water districts, and local consultants), development of comprehensive modeling documentation, and using an open-source, freely available modeling platform. See Section 8 of this document for additional information related to outreach and technical review opportunities.

[2] For this model, "existing instream flows" are defined as historical flow conditions simulated by the model. The model will estimate flows using the most recent and complete land and water use data available at the time of model development.

- Predict unimpaired flow[3] at each POI that would occur with no water diversions, pumping, or storage;
- Evaluate how water use affects the water balance and instream flows;
- Simulate groundwater pumping and groundwater-surface water interactions to understand groundwater effects on instream flows;
- Ensure that the model simulation period is long enough to reasonably capture the variability of the full range of water year types from drought to flood years;
- Create a nutrient transport model to inform nitrogen source assessment in the Ventura River Watershed; and
- Simulate the effects of the December 2017-January 2018 Thomas Fire on hydrology, nitrogen transport, groundwater levels, and instream flows.

When evaluating modeling platforms for the current study, the Water Boards considered other model capabilities that may support future studies and planning efforts. Although these capabilities may require future model refinements or linkages to other models, the base hydrologic modeling system will be developed in a manner that supports these potential future upgrades or linkages. Additional capabilities of interest include:

- Support assessments of habitat for important species;
- Represent the water rights priority system to evaluate water management scenarios;
- Simulate climate change and future water demands scenarios; and

[3] Unimpaired flow is the flow that would have occurred had the natural flow regime remained unaltered in rivers instead of being stored in reservoirs, imported, exported, pumped, or diverted. Unimpaired flow is a modeled flow generally based on historical gage data with factors applied to primarily remove the effects of dams, diversion, and pumping within the watersheds. Unimpaired flow differs from full natural flow in that the modeled unimpaired flow does not remove changes that have occurred such as channelization and levees, loss of floodplain and wetlands, deforestation, and urbanization. Where no diversion, storage, or consumptive use exists in the watershed, the historical gage data are often assumed to represent unimpaired flow.

- Model water temperature, other water quality characteristics, or have the ability to link the integrated groundwater-surface water model to separate water temperature or water quality models.

1.3 Overview of Report

Section 2 describes the different modeling platforms that Geosyntec and DBS&A considered. It also describes the basis for the final decision, made in consultation with the Water Boards, to use the Groundwater and Surface-water Flow (GSFLOW) model.

Section 3 provides an overview of GSFLOW and the proposed approach. Section 4 and Section 5 describe the proposed approach for the surface water model and groundwater model, respectively. These two sections also include summaries of the data sources to be used. Section 6 describes the GSFLOW model calibration process, including a discussion of the modeling simulation period and model calibration goals.

Section 7 describes the proposed approach and data sources to develop a groundwater nitrogen transport model using the Groundwater Solute Transport Simulator for Modular Ground-Water Flow Model (MODFLOW/MT3D-USGS) platform.

Section 8 describes the Water Boards' public outreach plan, including continued use of a Technical Advisory Committee (TAC). This section also includes an anticipated review approach and timeframe.

1.4 Thomas Fire

In December 2017, approximately six months after commencement of the project, the Thomas Fire broke out in the Santa Clara River Watershed adjacent to the Ventura River Watershed. The fire quickly burned west into the Ventura River Watershed. Within approximately eight weeks, the fire burned more than 440 square miles, becoming the largest wildfire in recorded California history at that time.

Much of the Ventura River Watershed was burned, affecting the physical and hydrological properties of the watershed. Properties affected included the soil infiltration capacity, soil water holding characteristics, and transpiration. Even low heat of fire can destroy soil organic matter, an important component that affects soil structure and soil water storage capacity. Collapsed soil structure can result in reduced porosity and alteration of pore size distribution. The heat of fire also vaporizes organic compounds such that they coat soil grains, resulting in water repellency (DeBano, 2000). The result of the fire-caused degradation of soil physical properties and the increased soil water repellency is a general reduction of infiltration and a general reduction in the amount of stored soil water, and reduction in percolation that recharges groundwater. The loss of stored soil water and its consequent effect on groundwater recharge is offset, to some extent, by the absence of evapotranspiration, particularly in riparian areas of a fire-denuded landscape. This can result in increased runoff during precipitation events and a change in stream baseflow (e.g., U.S. Department of Agriculture, 2005).

The Thomas Fire resulted in some modifications to the modeling approach, including shifting of the calibration and validation period to exclude 2018 (since the hydrologic properties will be substantially different post-fire), and the addition of a “Post-Thomas Fire Scenario” to model January 2018 through Spring 2020. The Post-Thomas Fire Scenario will be used to better understand the impacts of the fire on the hydrology and nitrogen fate and transport within the watershed. Additional details are provided herein.

2. MODEL METHODOLOGY SELECTION

Several model platforms are publicly or commercially available for integrated groundwater-surface water modeling. Some of these model platforms require purchase of a license while others are free to the public. This section describes the process of selecting the platform that will be used to conduct the Ventura River Watershed study and describes previous modeling efforts in this watershed.

2.1 Overview of Existing Models

Two numerical modeling efforts have previously been completed in parts of the Ventura River Watershed that can be used as the starting point for new model development: (1) the Ojai Valley Basin Groundwater Model (OBGM); and (2) Ventura Surface Water Hydrology Model (VSWHM). Each model is described below.

2.1.1 Ojai Valley Basin Groundwater Model

The OBGM was developed by DBS&A for the Ojai Basin Groundwater Management Agency (OBGMA) and was funded primarily through a California Department of Water Resources (DWR) Local Groundwater Assistance grant. The original model was finalized in 2011 (DBS&A, 2011) and subsequently updated in 2014 (DBS&A, 2014).

The model was developed using the MODFLOW-SURFACT computer code, which is an upgraded and proprietary version of the widely used U.S. Geological Survey (USGS) MODFLOW code. Because recharge from precipitation was observed to have a significant effect on groundwater elevations in the Ojai Valley Basin, a distributed parameter watershed model (DPWM) was used to estimate the transient distribution and magnitude of recharge for input to the groundwater model.

Laterally, the groundwater model covers the geographic and vertical extent of alluvial deposits in the Ojai Valley Basin (Figure 2-1). Vertically, the model extends to the estimated depth of the alluvial deposits, and vertical model discretization is based on analysis of geophysical logs from 24 wells located within the basin. The model is discretized into time periods that apply average values of recharge, extraction, and other inflows and outflows, termed “stress periods.” Stress periods of three months, corresponding to water-year quarters, were used. A model time step, the time period over which the model computes the groundwater elevation and flux solution, is different than the model stress period. A model time step is typically on the order of several days. The OBGM time step varied from one day to several days within each stress period. The model was calibrated from 1970 to 2013.

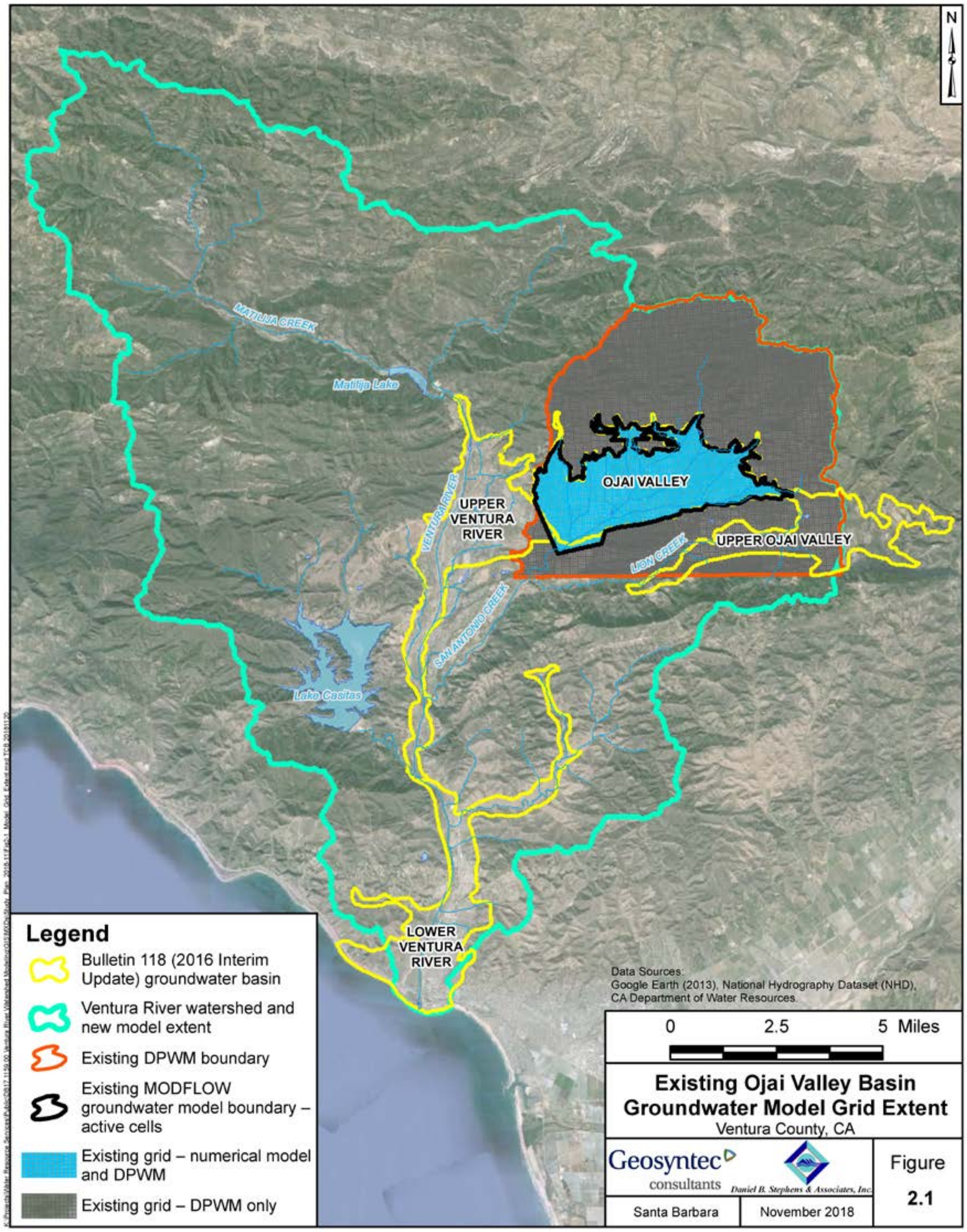

Figure 2-1 Existing Ojai Valley Basin Groundwater Model Grid Extent

The model mass balance indicated that most water inflow into the Ojai Valley Basin is from recharge from precipitation, and the primary outflows are groundwater pumping and groundwater discharge to surface streams. The model was used for several predictive simulations, including evaluation of the basin response to extended drought and wet periods, investigation of the basin safe yield, and assessment of the basin response to the San Antonio Creek Spreading Grounds Rehabilitation Project.

2.1.2 Ventura Surface Water Hydrology Model

The VSWHM is a Hydrologic Simulation Program in Fortran (HSPF) model of the entire Ventura River Watershed. The model was originally created in 2007 by Tetra Tech (2009). The model was calibrated to water year (WY[4]) 1996 through 2007 and validated to WY 1986 through 1996. In 2012, the model was updated and simplified by Ventura County Watershed Protection District (VCWPD, 2012) and calibrated for 1996 through 2005. The model uses sub-daily time steps and is geared towards predicting peak flows from large storm events for hydraulic design of flood control infrastructure. It is a lumped parameter model with sub-basin sizes ranging from approximately 100 acres to more than 6,000 acres.

Groundwater inflows and outflows from the VSWHM were estimated, and no dynamic modeling or coupling of surface water flows with groundwater was included, which limited the accuracy of the models at low flows. Improvement of the ability to accurately model low flows is one of the primary goals in the current development of a new integrated groundwater-surface water model.

2.2 Model Selection Criteria

Available integrated groundwater-surface water modeling platforms were researched and evaluated for their ability to meet project needs. It was important that the modeling approach meet DWR Sustainable Groundwater Management Act (SGMA) public domain requirements, so many models not meeting this requirement were not considered. Model selection criteria included:

- Capability to accurately model essential groundwater-surface water functions, including rainfall-runoff relationships, streamflow accumulation, surface water hydrology, variable groundwater elevations, groundwater

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[4] WY = water year, defined as October 1 through September 30. For example, WY1995 is from October 1, 1994 through September 30, 1995.

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 SGMA public domain requirements[5];
- 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 OBGM and VSWHM; and
- Proven use for similar applications.

2.3 Available Integrated Groundwater-Surface Water Models

Based on a review of available models that appear to potentially meet the requirements listed above, the following modeling options were evaluated:

1. Custom dynamic two-way local coupling of HSPF & MODFLOW/MT3D-USGS;
2. Custom dynamic two-way coupling of HSPF & MODFLOW/MT3D-USGS & DPWM;
3. GSFLOW with custom coding to link to MT3D-USGS for nitrogen transport;
4. MODFLOW-One World Hydrologic Model (OWHM)/MT3D-USGS; and
5. Integrated Hydrologic Model (IHM)/MT3D-USGS.

[5] URL to Best Management Practices for Sustainable Management of Groundwater – Modeling BMP: https://www.water.ca.gov/LegacyFiles/groundwater/sgm/pdfs/BMP_Modeling_Final_2016-12-23.pdf

2.3.1 MODFLOW/MT3D-USGS + HSPF

Dynamic two-way coupling of HSPF and MODFLOW would require that HSPF pass recharge from the active groundwater component of each hydrologic response unit (HRU) to the appropriate MODFLOW cells; MODFLOW would be required to pass hydraulic head information to HSPF for simulation of lower-zone storage processes and discharge of groundwater to stream reaches (Bent et al., 2011). The dynamic linking would also need to overcome differences in spatial and temporal discretization between the two models. A custom code to dynamically couple the models would need to be developed. The MODFLOW version used would be Modular Groundwater Flow Model Newton Formulation (MODFLOW-NWT) (Niswonger et al., 2011). The custom code would need to also handle nitrogen transport in groundwater and discharge to surface water by linking to MT3D-USGS (Bedekar et al., 2016).

This approach would bring flexibility to the project, as the team would be able to customize the dynamic linkage to provide sufficiently accurate physical representation of hydrologic processes. The approach also leverages existing models in the Ventura River Watershed and would be fully public-domain/open source. However, developing a new custom code would require significant project resources (e.g., time and budget), and the existing HSPF model may need to be revised to allow for finer discretization of HRUs to account for spatially variable processes (e.g., recharge) that impact the groundwater model.

Based on an initial review, this model option was retained for further consideration.

2.3.2 MODFLOW/MT3D-USGS + DPWM + HSPF

This approach is similar to Option #1 above, but would also make use of the DPWM, which was used in development of the OBGM to represent the temporally and spatially variable precipitation-related groundwater recharge in the Ojai Valley Basin. HSPF model results for groundwater recharge would be matched to DPWM on an HRU-scale, and then DPWM would be used to determine spatially variable recharge for input into MODFLOW.

This approach would leverage the existing OBGM DPWM and provide spatially variable groundwater recharge on a finer scale than HSPF; in addition, DPWM provides a more rigorous approach for estimation of groundwater recharge (percolation past the root zone). The DPWM executable and documentation is publicly available, has been used to provide spatially variable recharge input to numerical models developed in other California groundwater basins, and DPWM is currently being used by DBS&A in support of development of Groundwater Sustainability Plans under SGMA in the Fox Canyon Groundwater Management Area of Ventura County.

However, application of DPWM in addition to HSPF and MODFLOW will complicate dynamic coupling and introduce potential issues with differences in methodology and assumptions between HSPF and DPWM. The work required to achieve coupling will require significant project resources and time.

Given the impact that this approach would have on the project schedule and resources and considering that HSPF (and other methods described below) can provide sufficiently accurate representation of hydrologic processes, including groundwater recharge, this method was not considered further. Existing DPWM results for the OBGM can be used as a check on the new model-applied groundwater recharge values in the Ojai Valley Basin.

2.3.3 GSFLOW + MT3D-USGS

GSFLOW is a coupled groundwater and watershed flow model based on integration of the USGS Precipitation-Runoff Modeling System (PRMS) and MODFLOW. Recent updates to GSFLOW bring compatibility with the latest version of MODFLOW (MODFLOW-NWT), which is necessary for representation of variable groundwater levels in the Ojai Valley Basin. 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 (Markstrom et al., 2008; Regan et al., 2016). PRMS simulates similar hydrologic processes as compared to HSPF.

GSFLOW is a pre-existing integrated hydrologic model that is actively supported and updated by USGS and is fully publicly available. No coding by the Project Team would be required for integrated groundwater-surface water modeling.

Based on personal communication with USGS staff (Morway, 2017), GSFLOW does not currently support transport simulations. Custom coding would be required to link GSFLOW to MT3D-USGS for nitrogen transport simulations. For example, custom coding could be used to develop a separate MODFLOW model with boundary conditions assigned from GSFLOW. This MODFLOW model could then be used to develop the necessary 'linker' file required to run transport simulations with MT3D-USGS.

This approach will bring the advantages of GSFLOW, adding in the capability for nitrogen transport simulations. However, custom coding to link GSFLOW and MT3D-USGS will require significant project resources and time. Based on personal communication with USGS staff, there may be unforeseen problems in developing the linker file and implementing transport (Morway, 2017).

The approach will extract output from GSFLOW to use as flow and head boundary conditions for a separate MT3D-USGS model. This will enable the assessment of nitrogen transport from groundwater to surface water, which is consistent with the project objectives. A fully coupled (i.e., two-way) model is not required to meet these goals. Modeling results may be used to update the existing receiving water quality (QUAL2K) model used by the Los Angeles Regional Water Board.

Use of GSFLOW would leverage the existing VSWHM to a lesser extent as compared to other options that use HSPF. This option meets all project needs and was retained for further consideration.

2.3.4 MODFLOW-OWHM/MT3D-USGS

MODFLOW-OWHM (Hanson et al., 2014) has been developed by USGS to evaluate water management in a physically based supply-and-demand framework. The primary difference between MODFLOW-OWHM and GSFLOW is that GSFLOW is intended to link MODFLOW with the watershed model PRMS; whereas, MODFLOW-OWHM links MODFLOW to models of human water-resource infrastructure needed for conjunctive-use analysis. MODFLOW-OWHM does not solve the rainfall-runoff equation and does not solve the surface water problem on the scale of a watershed. Rather, time series rainfall, evaporation, and lateral flows are assigned to every surface water reach. Additional comparison between MODFLOW-OWHM and GSFLOW is provided by the USGS (USGS, 2017).

MODFLOW-OWHM offers linkages to MODFLOW packages, such as the Farm Package, that could be used to estimate agricultural pumping in areas or time periods without sufficient pumping data. MODFLOW-OWHM is primarily intended for evaluating conjunctive use scenarios and would be useful for those analyses.

MODFLOW-OWHM does not solve the rainfall-runoff equation and, therefore, does not provide sufficient physical representation of surface water hydrology necessary to build a fully integrated groundwater-surface water model. Therefore, MODFLOW-OWHM was not considered further.

2.3.5 Integrated Hydrologic Model MT3D-USGS

The IHM was previously developed to dynamically link HSPF and MODFLOW and is referenced in the scientific literature (Hosseinipour, 2006). IHM was developed as a collaborative effort, including the South Florida Water Management District (Tampa Bay Water, 2017). IHM has been used in Florida to evaluate effects of the proposed increase in pumping on nearby spring flow, streamflow, and aquifer levels (Intera, 2017). As a pre-existing linkage between MODFLOW and HSPF, IHM may offer advantages as a starting point for Ventura River Watershed model development. However, at the time of the development of the study plans, IHM does not appear to be in the public domain. Capabilities of IHM are also unclear, and user guidance and detailed model description and assumptions may be limited. It is also unclear if IHM is compatible with MODFLOW-NWT or MT3D-USGS. For these reasons, IHM was not retained for further evaluation.

2.4 Model Selection

The two options retained for further consideration were Option #1 - MODFLOW/ MT3D-USGS + HSPF and Option #3 - GSFLOW + MT3D-USGS. A selection matrix was developed as a basis for selecting the model platform (Table 2-1). For the selection matrix, a Score of 1 (worst) to 3 (best) was applied to each of the selection criteria for each model platform. In addition, weighting factors were applied to the selection criteria based on input from the Water Boards. Overall, Option #3 (GSFLOW + MT3D-USGS) received a greater score as compared to Option #1.

Table 2-1 shows that GSFLOW offers the key advantages of high level of credibility and transparency, the need for less custom coding, online training availability, widespread use, and thorough public documentation. Based on these considerations GSFLOW + MT3D-USGS was selected as the modeling platform for the project.

Table 2-1 Modeling Platform Selection Matrix

Model Criteria are scored 1 to 3, where 1=worst and 3=best

Weight (0 to 5)	Factor/ Criteria	Custom 2-way coupling of HSPF-MODFLOW with separate MT3D	GSFLOW with MT3D
5	Capability to accurately model essential groundwater-surface/watershed functions	3	3
5	Perceived credibility	2	3
5	Ability to track nitrogen sources through groundwater to surface water	3	3
5	Ability to model irrigation and septics	3	2
3	Model in public domain/ meet DWR SGMA requirements	3	3
3	Project resources required (schedule/budget)	1	2
3	Ability to model sub-daily temperature	3	2
2	Longevity of model	1	2
2	Support/Updates	1	2
	FINAL SCORE	80	84

3. OVERVIEW OF GSFLOW AND MODELING APPROACH

This section provides an overview of GSFLOW, the modeling platform chosen to develop the integrated groundwater-surface water model (Section 2), and the overall approach that will be used to develop the integrated GSFLOW model and nitrogen groundwater model.

3.1 Overview of GSFLOW

GSFLOW is an integrated hydrologic model developed by the USGS to simulate coupled groundwater and surface water resources (Markstrom et al., 2008). GSFLOW will simulate the volume of surface water and groundwater in the watershed. The model is based on the integration of the PRMS (Markstrom et al., 2015) and MODFLOW. As detailed in the GSFLOW documentation (Markstrom et al., 2008), additional model components were developed, and existing components were modified, to facilitate integration of the models. GSFLOW runs on a daily time step. Methods were developed to route flow among the PRMS HRUs 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, as illustrated in Figure 3-1. 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-NWT packages (after a recent update from MODFLOW-2005). Thus, the stream-routing modules of PRMS are not used when GSFLOW is run in coupled mode. However, the PRMS stream-routing modules are used when GSFLOW is run in PRMS-only mode (e.g., during an initial surface water model calibration prior to coupling with the groundwater model). 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. The third region, or subsurface, is beneath Regions 1 and 2 and consists of the unsaturated and saturated zones. For the purpose of the Ventura River Watershed, Region 3 includes both alluvial deposits and bedrock geologic units used for water supply. Region 3 also uses MODFLOW-NWT packages.

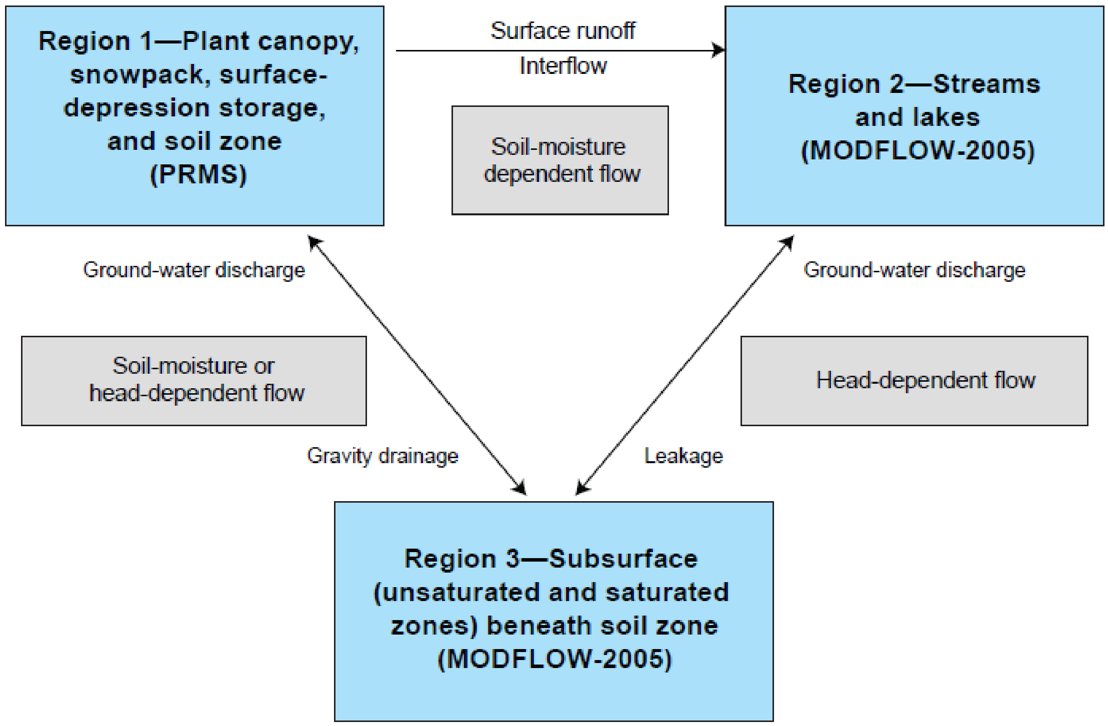

Figure 3-1 Schematic diagram of the exchange of flow among the three regions in GSFLOW (Markstrom et al. 2008). The MODFLOW-2005 packages were recently updated to MODFLOW-NWT.

The functionality and flows between the three regions depicted in Figure 3-1 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 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, including detailed descriptions of PRMS and MODFLOW and how they were integrated, the equations and order of calculations used, modeling assumptions and limitations, and data-input requirements are provided in the GSFLOW report (Markstrom et al., 2008).

3.2 Development Approach

The general approach for model development will consist of the following steps:

1. Develop PRMS model and calibrate primarily to wet-weather flow (PRMS-only);
2. Develop MODFLOW model and perform initial simulations (MODFLOW-only);
3. Integrate PRMS and MODFLOW in GSFLOW and perform comprehensive groundwater and surface water calibration; and
4. Based on GSFLOW flow output, develop a standalone MODFLOW model for nitrogen transport modeling with MT3D-USGS.

Step 1 involves the development of the PRMS-only surface water model, as detailed in Section 4. The PRMS-only model will be initially calibrated to wet-weather flow, potentially using the wet-weather calibration parameters from the VSWHM as an initial guide (see Section 2). Calibration of dry-weather flows will be delayed until integration with the groundwater model in GSFLOW (see Section 6), since the low flows inherently depend upon interaction with groundwater.

Step 2 will be carried out in parallel with Step 1 and involves the development of the MODFLOW-only groundwater model (see Section 5). The purpose of this step is to develop the groundwater model files and ensure that the model runs without errors and flow patterns are in general agreement with conceptual understanding of the basins. Full calibration of the groundwater model will be made when the model is integrated in GSFLOW.

In Step 3, the PRMS and MODFLOW models will be integrated in GSFLOW (and calibrated for dry-weather surface flows and groundwater elevations (see Section 6).

Finally, in Step 4, the groundwater model for nitrogen transport simulations will be developed with MT3D-USGS (see Section 7). This model will be a standalone model that uses flows from the GSFLOW model as one-way inputs to enable the assessment of nitrogen transport from groundwater to surface water.

4. SURFACE WATER MODEL DEVELOPMENT

This section describes how the PRMS-only surface water model will be developed, including leveraging the existing VSWHM; it will also describe the datasets and sources to be used for model inputs and calibration, including discussions of data quality evaluation and gap filling. The PRMS-only model will initially be calibrated to wet-weather flows. As described in Section 6, the PRMS-only surface water model will be integrated with the MODFLOW-only groundwater model, forming the integrated GSFLOW model. The integrated GSFLOW model will undergo full calibration and validation.

4.1 Model Grid

The surface water model will be developed to cover the entire Ventura River Watershed. The watershed will be discretized into a model grid. To facilitate pre and post-model processing, watershed and groundwater models are often discretized such that one square mile is divided into either 24, 16, 12, 8, 6, or 4 cells, corresponding to grid cell sizes of 220, 330, 440, 660, 880, or 1,320 feet respectively. Another common approach is to have a maximum of 100,000 to 150,000 grid cells total (including all layers of the GSFLOW model) to have reasonable model run times. After review of watershed features and previous modeling efforts in the watershed, it was decided that the present Ventura River Watershed modeling study will use a model-grid cell size of 330 feet. Based on a preliminary review of needed vertical model layering of the final GSFLOW model in different areas of the Ventura River Watershed, the 330-foot grid cell size will result in a total of approximately 130,000 active model cells.

A grid-cell size of 330 feet is appropriate for the regional nature of the model development, while at the same time allowing for fine enough spatial discretization to characterize the relevant watershed and surface water features. For example, the main-stem of the Ventura River is approximately 15 miles long and associated active-wash deposits have an area of approximately 126 million square feet (2,900 acres), which will be represented with approximately 1,158 cells per model layer.

The 330-foot model grid cell size is similar or smaller than comparable GSFLOW modeling studies. For example, model development of the Santa Rosa Plain Watershed by the USGS for the Sonoma County Water Agency covers an area of 20 x 21 miles with a grid-cell size of 660 feet (Woolfenden and Nishikawa, 2014).

If, during model development, it is determined that the 330-foot grid results in a model that is overly computationally intensive, requiring very long model run times, a coarser grid cell size will be considered in consultation with the Water Boards.

Future local modeling studies within the Ventura River Watershed by the Water Boards or others (outside the scope of the current study) may decide to use a finer-scale model grid. In these cases, local model-grid refinement may be used to decrease the model grid cell sizes in a particular area of interest, while still using the regional model developed for this study (see e.g., Feinstein et al., 2010; USGS, 2017).

4.2 Leveraging the Existing Ventura Surface Water Hydrology Model

The existing VSWHM (HSPF based) was developed and calibrated focusing primarily on high-flow events, in contrast to the current project, which focuses on low flows (see Section 2.1.2). However, the VSWHM still represents a substantial effort that should be leveraged as much as possible in the current modeling project. A summary of the similarities and differences between HSPF and PRMS, along with discussion of how VSWHM's calibrated input parameter values may be used to inform the initial set-up of the PRMS model, are provided below.

PRMS and HSPF are both semi-distributed parameter models (Chalise et al., 2018) that rely on attributes of different HRUs to assign parameters to control the water balance on the land surface and direct surface runoff, interflow, and active groundwater flow to downstream stream segments. The VSWHM will be a useful resource in development of the PRMS model due to the relative similarity of their inputs. For example, VHSWM may be used to inform irrigation rates applied to urban landscaped areas; diversion operations; point source discharges; stage-storage curves and operation rules of the dams, reservoirs, debris basins, and other infrastructure; as well as a useful starting point for assigning key model parameter values prior to calibration.

While similar, PRMS differs from HSPF in several respects. For example, PRMS implements soil layers and irrigation differently than HSPF. PRMS is also able to route flows from one HRU to another (instead of only to the stream). In addition, to aid in the dynamic coupling between PRMS and MODFLOW, a grid-based land representation (i.e., using the same horizontal grid as the groundwater model) will be used in PRMS rather than a polygon-bed representation. The PRMS model will also contain updated meteorological input and other data not available or not used in the VSWHM model. So, while the VSWHM will inform the development of the PRMS model, the PRMS model will be developed independently.

4.3 Datasets and Sources

The data that will be used to develop and calibrate the PRMS model are shown in Table 4-1, Table 4-2, and Table 4-3 and are described briefly in the following sections. The data will be described in more detail in an upcoming data compilation report (see Section 8 for more information).

4.3.1 Precipitation Data

Precipitation data sources are similar to those used in the VSWHM model, but periods of record will be extended through 2017 (and ultimately through 2020, see Section 4.3.9), and precipitation will be input on a daily average basis for consistency with GSFLOW daily time step. Figure 4-1 provides a map indicating the gages that were used in the VSWHM and additional rain gages that were not used previously. In general, it is anticipated that the same gages used in the VSWHM will be used in the current modeling efforts, although other gages will also be evaluated and used if deemed beneficial (e.g., to fill temporal gaps in other gages and/or to provide additional spatial resolution). It is noted that several gages were discontinued in recent years, as indicated in Figure 4-2. For example, gages 300, 301, 302, and 303 were discontinued from between 2010 and 2013. These gages are located near the perimeter of the watershed, and do not have nearby gages that can readily be used to replace them. Instead, correlations to other gages based on the period of overlapping records will be developed as necessary to fill gaps in these important gages.

Orographic effects are important in the Ventura River Watershed, with substantially higher rainfall on the peaks than in the valleys. To better account for these effects, the Parameter-elevation Relationships on Independent Slopes Model (PRISM) data[6] will be used to augment the measured rainfall data. Specifically, the methodology and Python scripts developed by USGS (Gardner et al., 2018) will be used to spatially interpolate between rain gage values on a daily basis using monthly rainfall distributions. Monthly rainfall distributions will be based on PRISM's 30-year (1981-2010) normals[7] at a spatial resolution of

[6] URL to Parameter-elevation Relationships on Independent Slopes Model (PRISM): http://www.prism.oregonstate.edu/

[7] URL to PRISM normal data: http://www.prism.oregonstate.edu/normals/

800 m. This method will result in the measured data being used directly at the gage locations, and result in realistic estimates away from the gage locations, particularly in the high elevation regions in the northwest part of the watershed where there are limited gages (Figure 4-2).

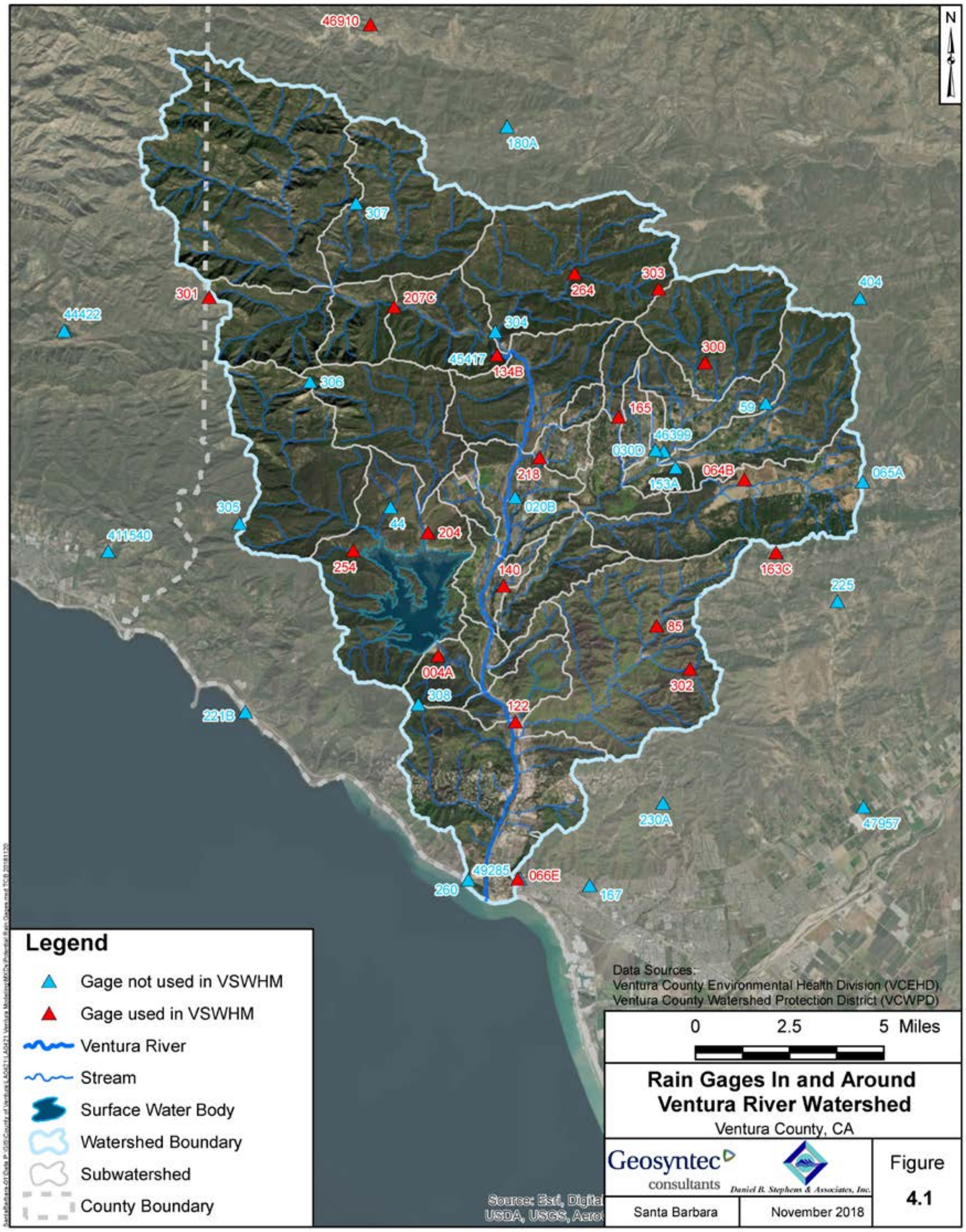

Figure 4-1 Rain Gages In and Around Ventura River Watershed

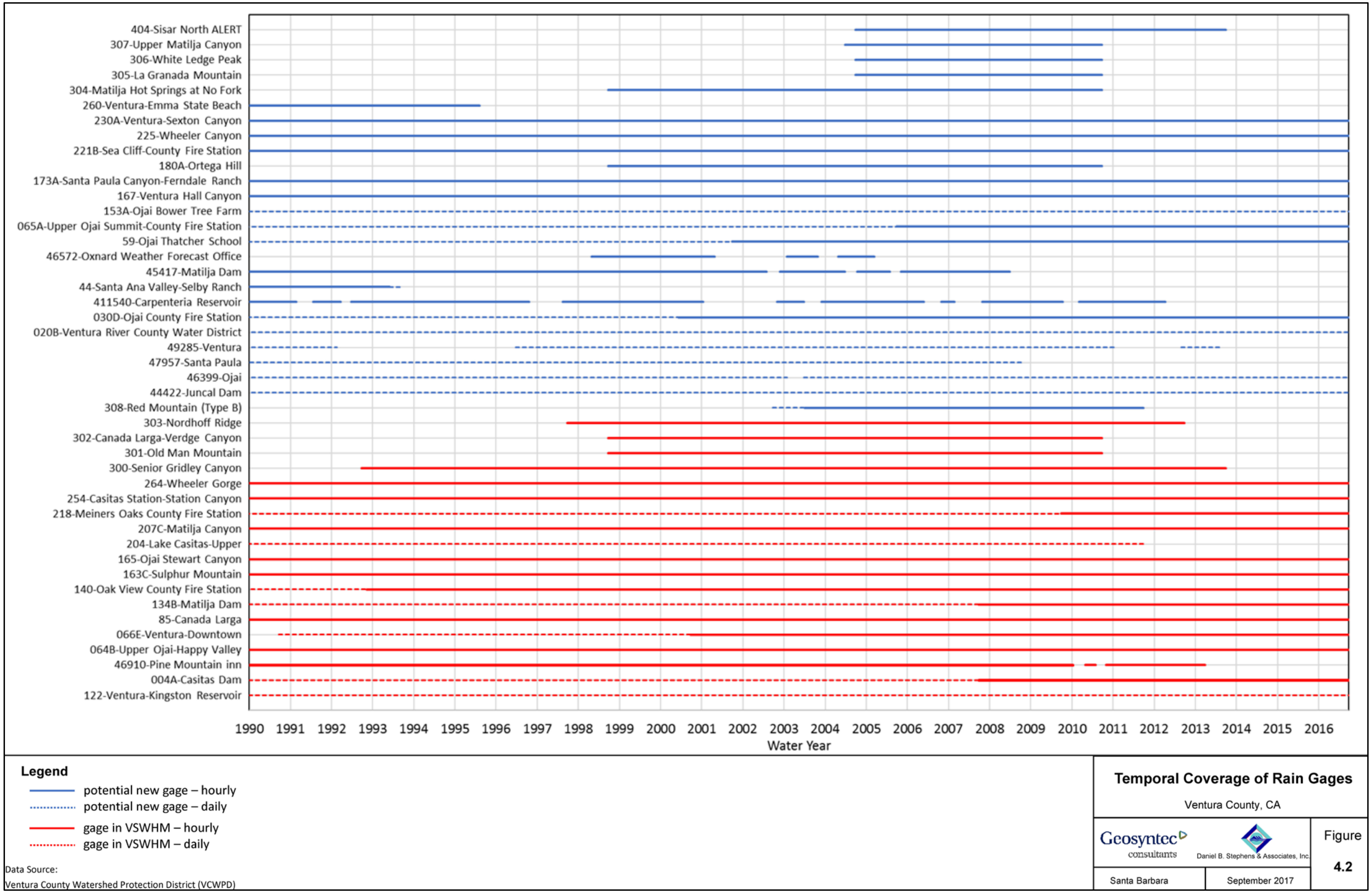

Figure 4-2 Temporal Coverage of Rain Gages

Rain gage data used as input into the USGS Python scripts will be checked for quality, consistency, and completeness. Precipitation data from VCWPD have already had all gaps filled and accumulations removed as part of the VCWPD quality assurance process. Gages used from other sources will be examined for temporal gaps and accumulations in the precipitation record. Temporal gaps will be filled by scaling data from nearby gages based on a comparison of their annual precipitation depths.

4.3.2 Potential Evapotranspiration Data

Potential evapotranspiration (PET) for natural vegetation and irrigated crops will be computed by the PRMS model (e.g., based upon air temperature using the Hamon method [Hamon, 1961]), and checked and calibrated against available data and information. Annual PET data for reference crops are available from California Irrigation Management Information System (CIMIS), and specific evapotranspiration data for different crop types within Ventura County are available from DWR. The actual evapotranspiration will be calculated in the model from the PET, while also considering land use, vegetation type, soil type, and available soil moisture.

4.3.3 Topography

The data used to determine slopes, connectivity, and elevations will come from a USGS digital elevation model (DEM), as was done for the VSWHM, and supplemented with 2005 LiDAR data provided by VCWPD where available. A grid-based land representation (rather than the more traditional polygon-based representation) will be used to aid in the dynamic coupling between PRMS and MODFLOW (Woolfenden and Nishikawa, 2014). Specifically, the same horizontal grid used in the groundwater model (Section 5) will be used to develop the PRMS model.

The DEM will be processed using the USGS Cascade Routing Tool (Henson et al., 2013) to define the cascading surfaces and subsurface flow paths for the grid-based domain. If necessary, the grid-scale DEM will be conditioned to fill unintended swales and provide continuous down-sloping HRUs.

Table 4-1 Data Anticipated to be Used to Develop PRMS Model for Creating PRMS Land Grid and Attributes

Need for PRMS Model	Anticipated Data to be Used
Precipitation	VCWPD data, National Climatic Data Center data, PRISM, and CMWD data
Potential Evapotranspiration	CIMIS ETo data for reference crop, Crop coefficients from LA County and DWR, Air temperatures from VCWPD, Western Regional Climate Center Remote Automated Weather Stations, NOAA, and CIMIS.
Land surface elevations	USGS DEM, 2005 LiDAR (VCWPD)
Soil attributes	NRCS
Land use	NLCD 2011, DWR Crop Survey, VCAC Crops Now, USFS Landfire, VCEHD parcels with OWTS (2016), Parcels from Los Angeles Regional Water Board with additional agriculture and OWTS locations
Imperviousness	NLCD 2011
Irrigation rates and attributes for urban landscaping	Previous HSPF Model, DWR annual irrigation rates
Irrigation application rates by crop type	DWR county-level annual application rates by crop, Staal, Gardner and Dunne, Inc. (1992), Fox Canyon Groundwater Management Agency (2015), VCAILG Water Quality Management Plan (2017)

CIMIS = California Irrigation Management Information System
CMWD = Casitas Municipal Water District
DEM = digital elevation model
DWR = Department of Water Resources
HSPF = Hydrological Simulation Program in Fortran
NLCD = National Land Cover Dataset
NOAA = National Oceanic and Atmospheric Administration
NRCS = National Resources Conservation Service
OWTS = onsite wastewater treatment systems
PRMS = Precipitation-Runoff Modeling System
PRISM = Parameter-elevation Relationships on Independent Slopes Model

USFS = U.S. Forest Service
USGS = U.S. Geological Survey
VCAC = Ventura County Agricultural Commissioner
VCAILG = Ventura County Agricultural Irrigated Lands Group
VCEHD = Ventura County Environmental Health Department
VCWPD = Ventura County Watershed Protection District

Table 4-2 Data Anticipated to be Used to Develop PRMS Model for Creating Stream Routing in PRMS in PRMS-only Model

Need for PRMS Model	Anticipated Data to be Used
Stream geometry and other attributes	Previous HSPF Model F-tables, USGS transects
Reservoir volumes, control curves, evaporation volumes, etc.	CMWD Hydrology Reports
Diversions and withdrawals	CMWD Hydrology Reports, CMWD UWMP-AWMP, Ventura Comprehensive Water Resources Reports, USGS 11118400 Gage, EWRIMS
Debris Basins geometry and curves	VCWPD, Previous HSPF Model
Ojai Valley WWTP discharges	Daily records from OVSD

AWMP = Agriculture Water Management Plan
EWRIMS = Electronic Water Rights Information Management System
OVSD = Ojai Valley Sanitation District
UWMP = Urban Water Management Plan
WWTP = wastewater treatment plant

Table 4-3 Data Anticipated to be Used to calibrate/validate PRMS Pre- and Post- Coupling

Need for PRMS Model	Anticipated Data to be Used
Streamflow gage data	VCWPD, USGS, CMWD Hydrology Reports
Wet-dry data	CDFW, Meiners Oaks Water District, CMWD, and OBGMA maps

CDFW = California Department of Fish and Wildlife
OBGMA = Ojai Basin Groundwater Management Agency

4.3.4 Land Use

Soil attributes will be assigned to HRUs based on the National Resources Conservation Service (NRCS) soil survey data, which was also done for the VSWHM. Land uses will be fixed (i.e., temporally static) in the PRMS baseline model to simplify comparisons with other scenarios. The National Land Cover Dataset (NLCD) 2011 dataset (Figure 4-3) is a grid-based representation of land uses in the watershed and will be used as a base land use layer. Visual comparisons between NLCD 2001 and NLCD 2011 data indicate minimal changes in land use on the watershed scale. For example, the total increase in developed land (combining low, medium, and high intensity) was 167 acres while the total increase in cultivated crops was 85 acres. These respectively correspond to 0.12 % and 0.06 % of the total watershed area. As such, the use of the 2011 data should be reasonably representative of much of the modeling period.

The NLCD 2011 land use data will be combined with spatial crop data from DWR (years 2000 and 2014, Figure 4-4 and Figure 4-5, respectively) and Ventura County Agricultural Commissioner (VCAC) (year 2016) to provide a more detailed characterization of different crop types than what is provided in the NLCD agricultural areas. These will also be cross-checked against crop information available in Ventura County Agricultural Irrigated Lands Group (VCAILG) Water Quality Management Plan (VCAILG, 2017).

The land use dataset will also be combined with the U.S. Forest Service (USFS) Landfire dataset (Figure 4-7) in natural areas to provide information on natural vegetation types that comprise approximately 90% of the watershed area.

Data reflecting the assumed locations of parcels with onsite wastewater treatment system (OWTS) (2016 data from Ventura County Environmental Health Department (VCEHD)) (Figure 4-8[8]), agricultural parcels (from Los Angeles Regional Water Board), and parcels with horses present (from Los Angeles Regional Water Board) will be used to further refine the land use dataset to the necessary HRU categories for modeling. These data will also be important in determining loading sources for the nitrogen model (Section 7). Each grid will be assigned to the dominant HRU category.

Arundo donax distribution and evapotranspiration datasets (California Invasive Plant Council, 2011) will be assessed to determine if the invasive reed can be incorporated into the model as a land use type.

[8] OWTS parcel data for the Cities of Ojai and Ventura are not included in the Figure 4-8. OWTS data/information in the City of Ojai will be assessed and included in the modeling. OWTS data/information in the City of Ventura will be assessed and included in the modeling if necessary.

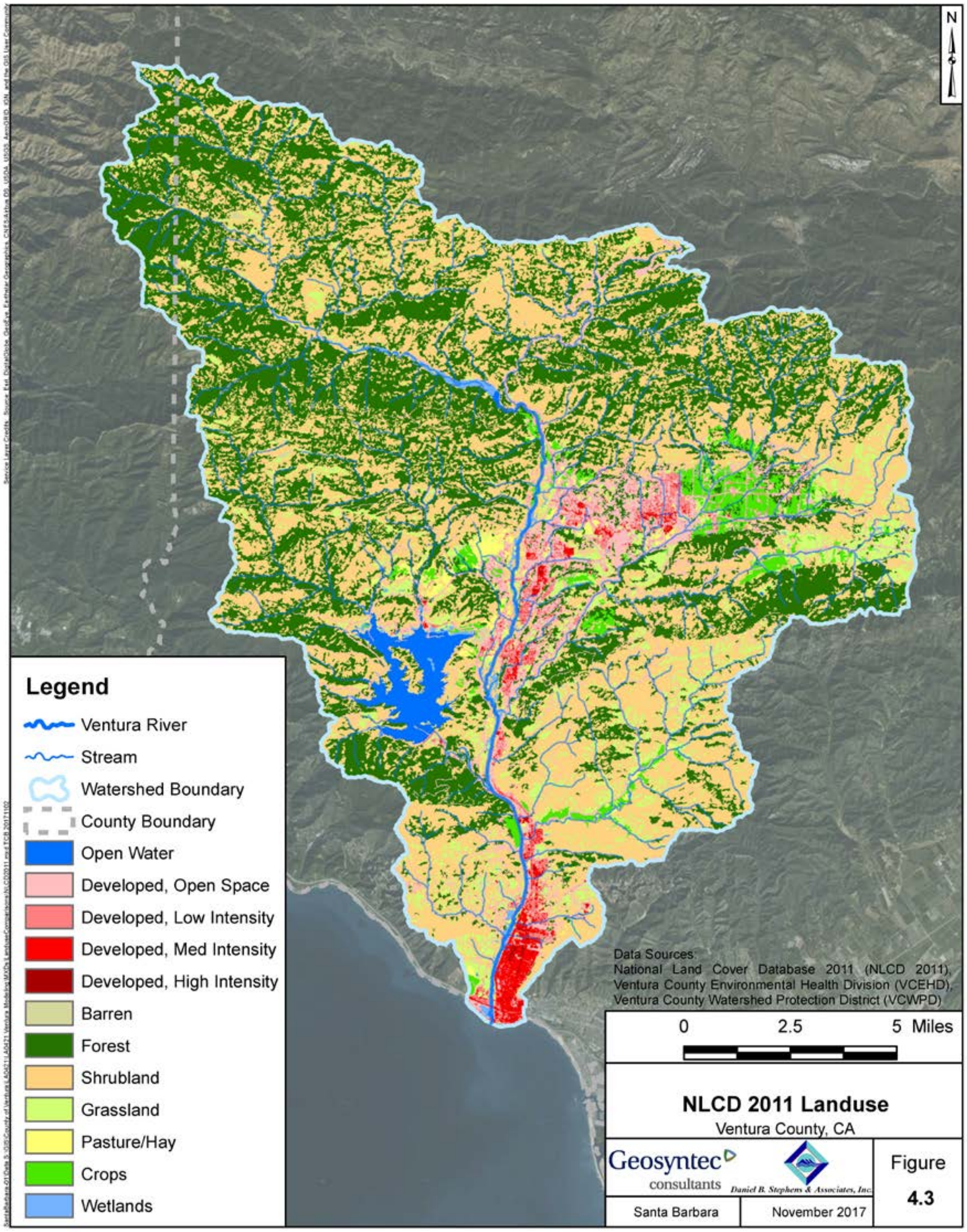

Figure 4-3 National Land Cover Dataset 2011 Landuse

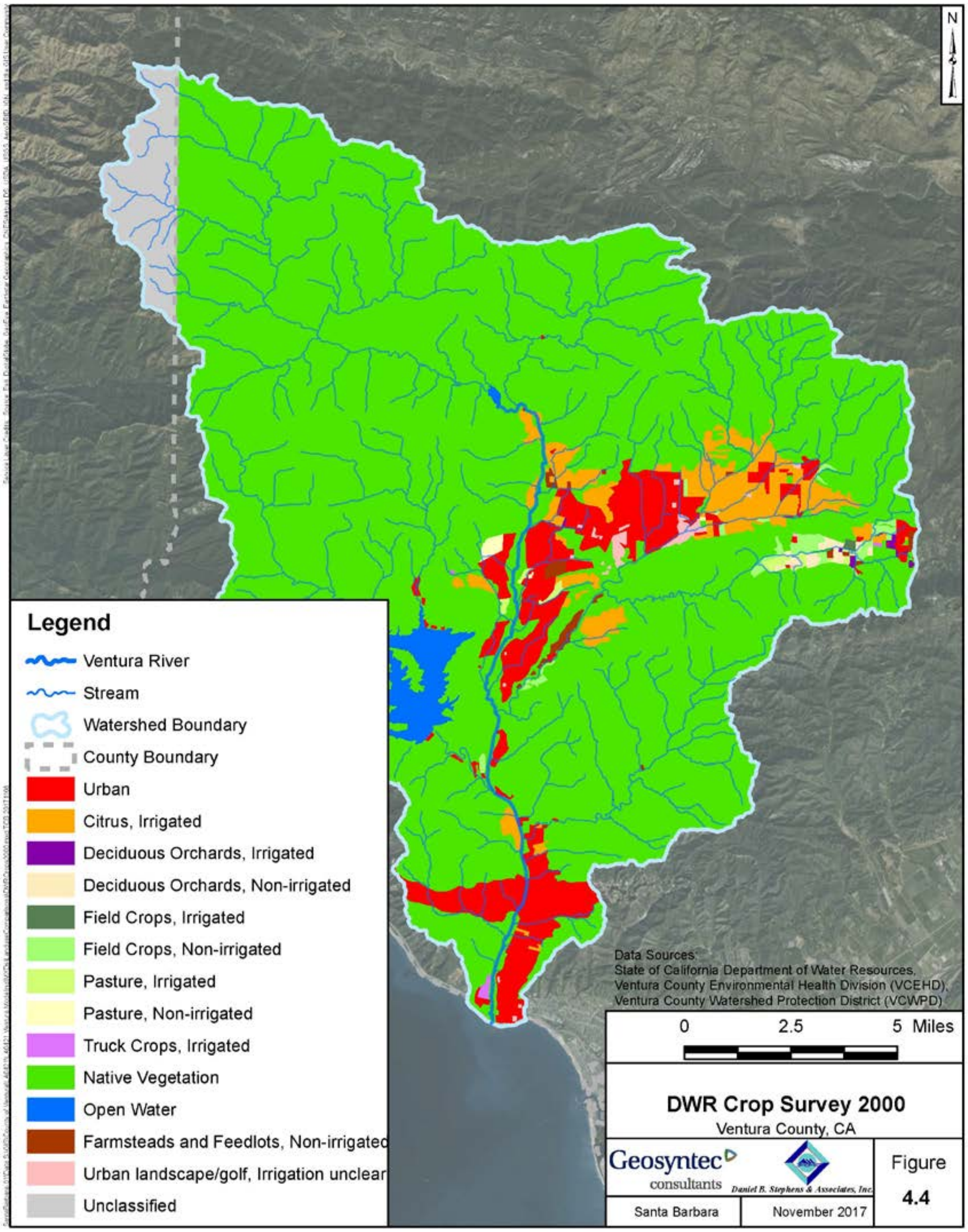

Figure 4-4 Department of Water Resources Crop Survey 2000

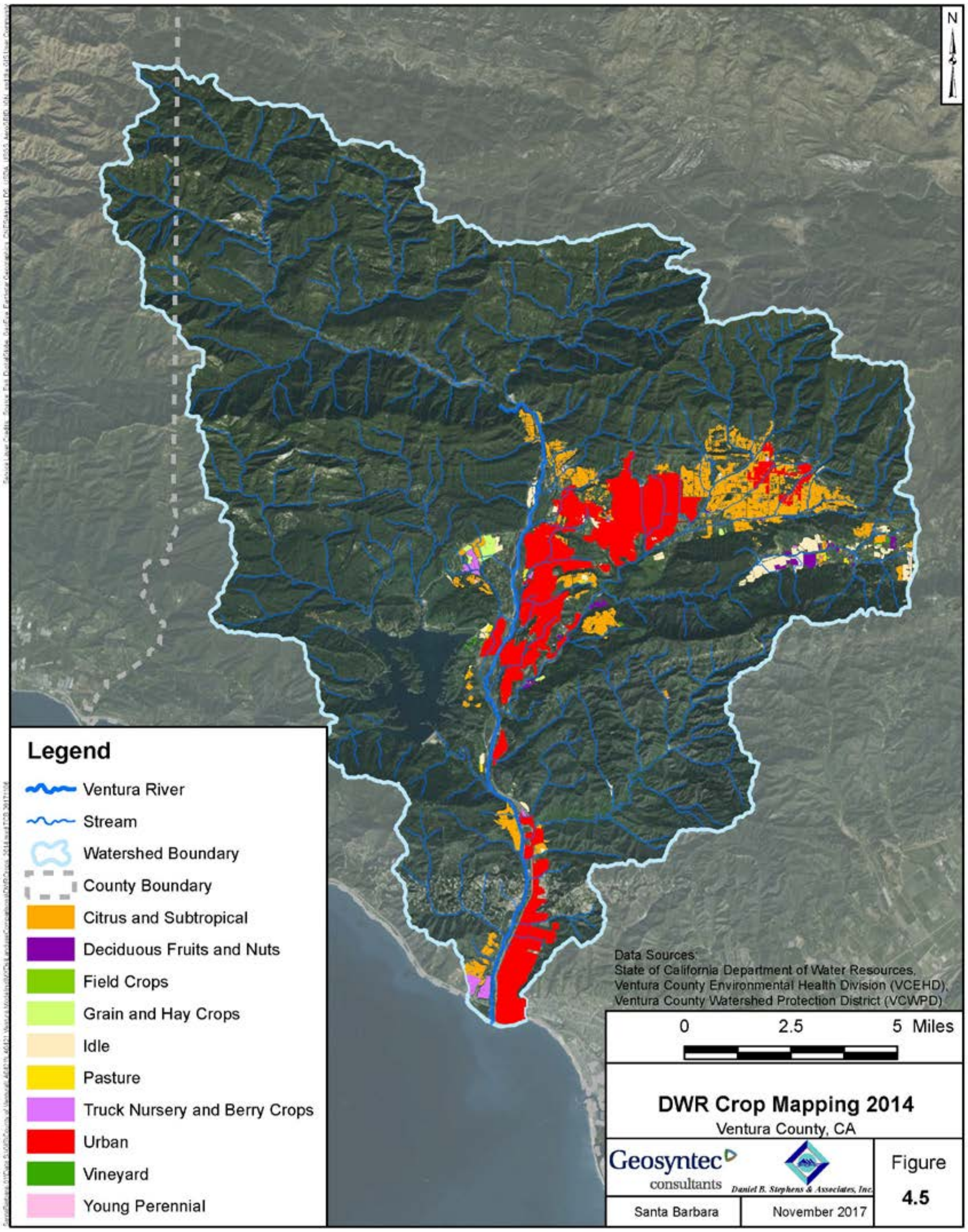

Figure 4-5 Department of Water Resources Crop Mapping 2014

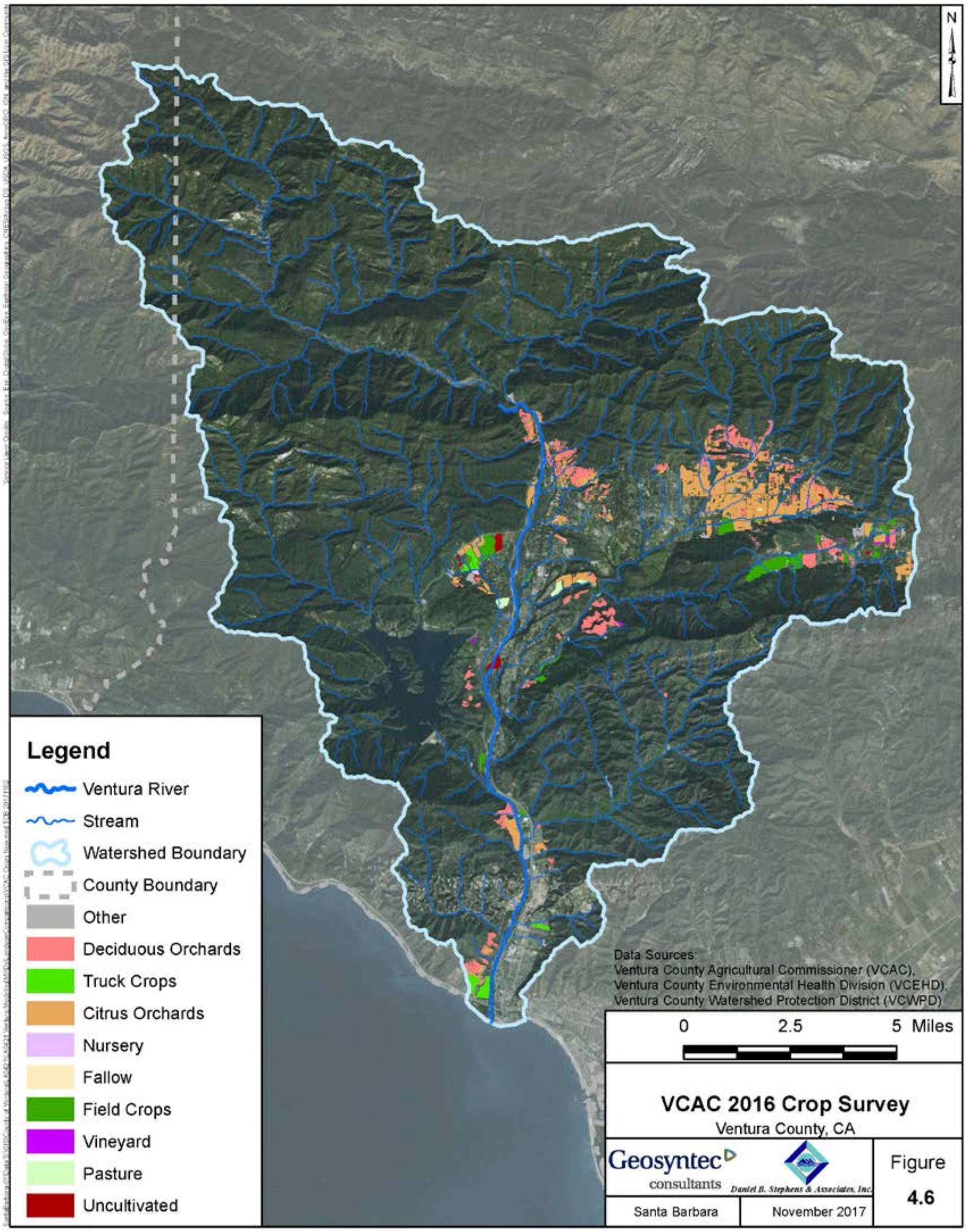

Figure 4-6 Ventura County Agricultural Commissioner 2016 Crop Survey

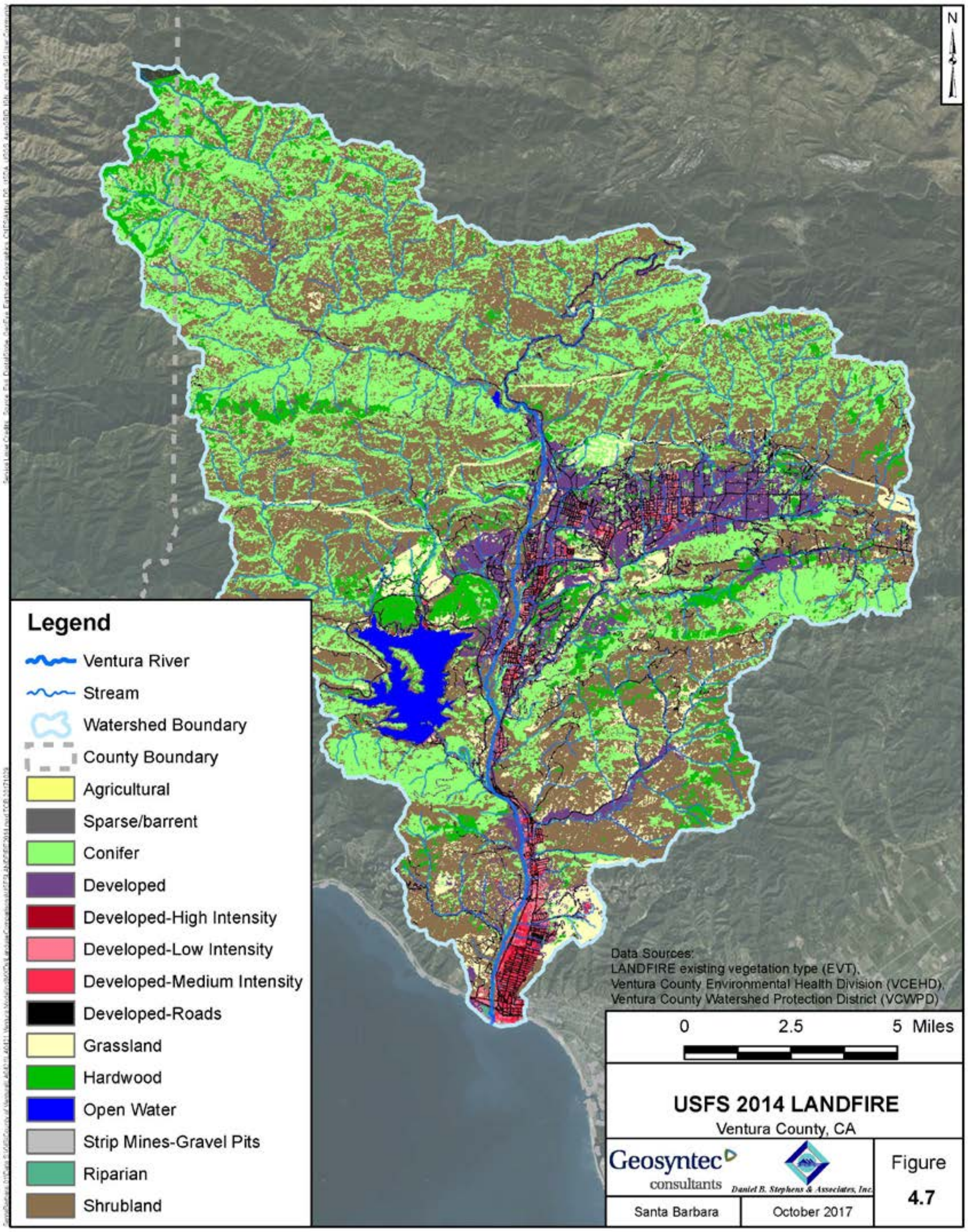

Figure 4-7 U.S. Forest Service 2014 LANDFIRE

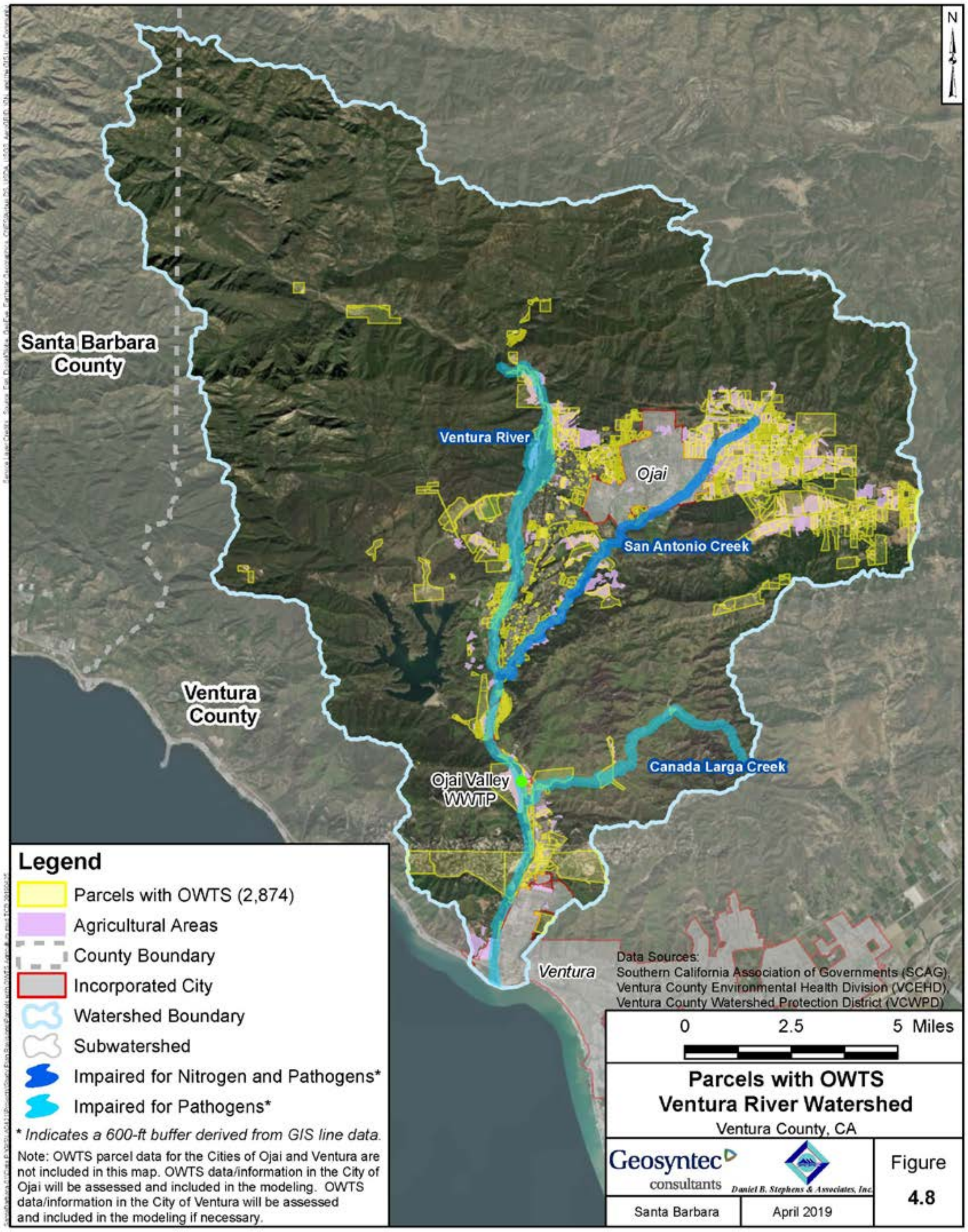

Figure 4-8 Parcels with Onsite Wastewater Treatment Systems, Ventura River Watershed

Finally, imperviousness of each grid will be determined from the NLCD 2011 dataset (Figure 4-9). Visual comparisons between NLCD 2001 and NLCD 2011 data indicate minimal changes in the watershed, at least at the scale of the watershed, as the average imperviousness of the watershed in 2001 was 1.5% and shifted slightly to 1.6% in 2011. As such, the use of the 2011 data should be reasonably representative of much of the modeling period.

4.3.5 Irrigation Data

Irrigation application rates in urban areas are less important in this watershed due to limited urban development, but irrigation in urban landscaped areas still plays a minor role in the water balance. Urban irrigation rates and attributes will be determined based on the VSWHM model and evaluation of pumping data for municipal wells and surface water diversion data (as available, see Section 5.2). Assessments of differences within the urbanized areas (e.g., traditional residential versus golf courses, ranchettes, and small urban orchards) will also be made as necessary.

Irrigation on agricultural areas (defined by the agricultural parcel data from Los Angeles Regional Water Board) is important to the water balance as well as the nitrogen model (see Section 7). Annual irrigation rates by crop type in Ventura County are available from DWR between 1998 and 2010[9]. These will be evaluated together with literature values available in Staal, Gardner and Dunne, Inc. (1992), irrigation allowance rates provided by Fox Canyon Groundwater Management Agency (2015), and information on irrigation and ground-cover practices in the VCAILG Water Quality Management Plan (2017). From these sources appropriate annual irrigation rate estimates for different crop types will be determined for model input.

Available pumping data for agricultural wells and surface water diversions will be assessed for consistency with the annual irrigation rates and to determine seasonal (e.g., monthly) variations in irrigation. Finally, the assumed irrigation rates will be consistent with those used to estimate well extraction for the purposes of the groundwater model (see Section 5.2). Additionally, the Upper Ventura River Groundwater Agency (UVRGA) has commissioned an infrared aerial imagery survey in the Upper Ventura Basin to evaluate irrigation practices. Results of this study are unlikely to be available during the data

[9] URL to DWR Agricultural Land And Water Use Estimates: https://water.ca.gov/Programs/Water-Use-And-Efficiency/Land-And-Water-Use/Agricultural-Land-And-Water-Use-Estimates

collection period, but they may be used later as a check on assigned irrigation rates.

Irrigation in the model will be applied as additional precipitation on specific parcels of land, as has been done in other GSFLOW modeling studies (e.g., Woolfenden and Nishikawa, 2014; Tian et al., 2015; and Essaid and Caldwell, 2017).

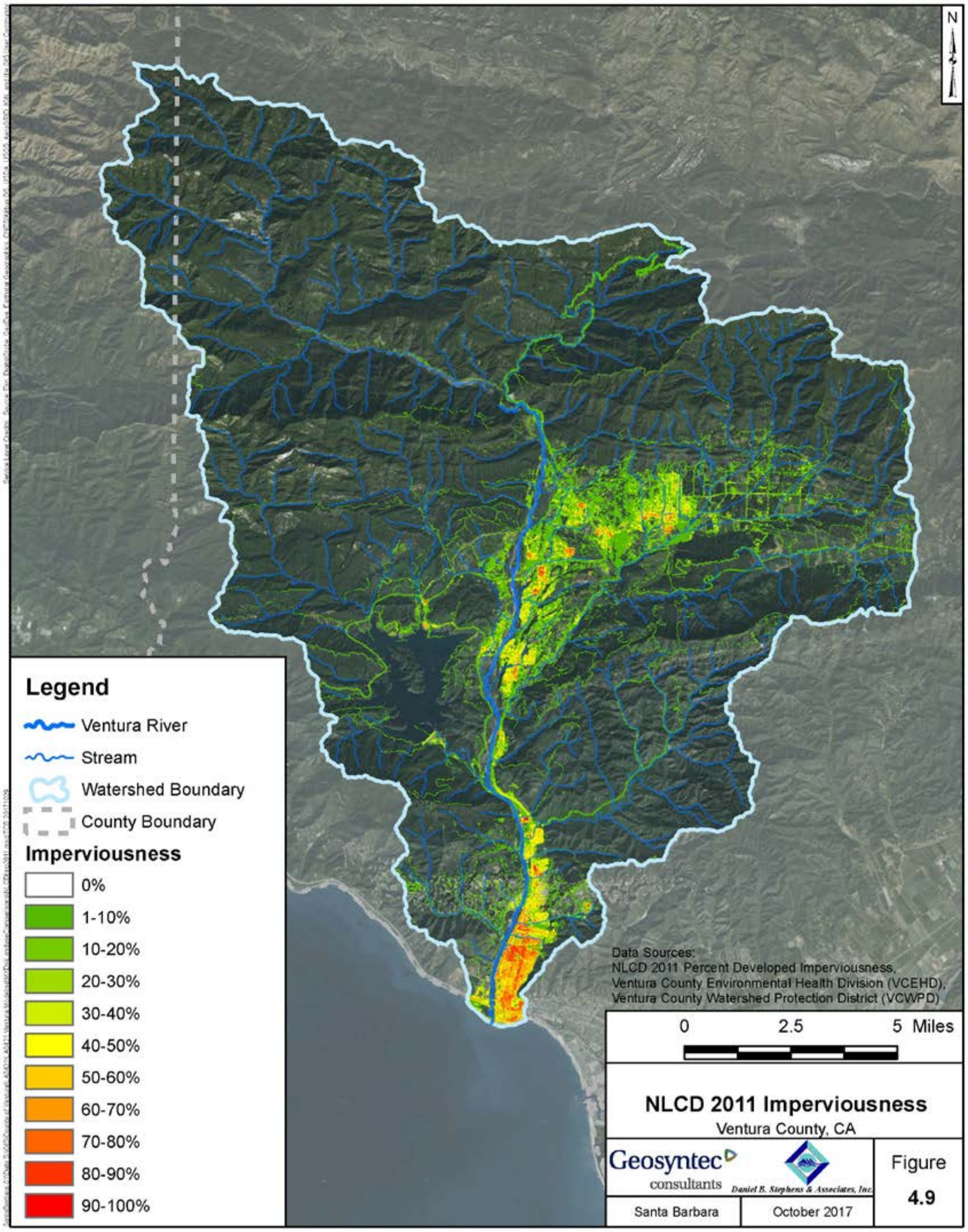

Figure 4-9 National Land Cover Dataset 2011 Imperviousness

4.3.6 Stream Network

Streamflow and routing will be handled by MODFLOW, once PRMS is coupled to MODFLOW. However, to get an initial calibration of PRMS, some stream routing is necessary. The stream network will be developed using GIS and Python scripts developed by the USGS for specific application of setting up PRMS and GSFLOW models (Gardner et al., 2018). This approach will ensure consistency with the gridded topography. The detail of the stream network is controlled by parameters input to the Python scripts and will be chosen to obtain similar detail as the VSWHM and the USGS National Hydrography Dataset (NHD) stream network (Figure 4-10). Additional information that may be used include dams, diversions, debris basins, withdrawals, and other anthropogenic changes in flow routing that will be implemented into the model using estimates derived from information and data available in the reports in Table 4-1.

4.3.7 Streamflow Gages

Model calibration will be achieved by comparing simulated flow to measured streamflow at VCWPD, Casitas MWD, and USGS gages (Table 4-1). Figure 4-11 indicates 18 streamflow gages are available to be used. The temporal coverage of these gages is illustrated in and indicates that four new gages were installed in late 2013. Specifically, Gage 605A was added to replace Gage 605 that was removed. Gages 648, 649, and 650 were added in the upper reach of San Antonio Creek (Figure 4-11), but Gages 648 and 650 were subsequently removed. These new gages (Gage 649 in particular) will be useful for calibration of the model in the upper San Antonio Creek sub-watershed. It is noted that gaging stations located in alluvium channels may be subject to changing channel morphology during large flow events, and that this may affect the accuracy of the rating curves. Past published rating curves will be reviewed to assess the degree to which they may have changed, and conclusions regarding measurement accuracy will be made at these gage locations.

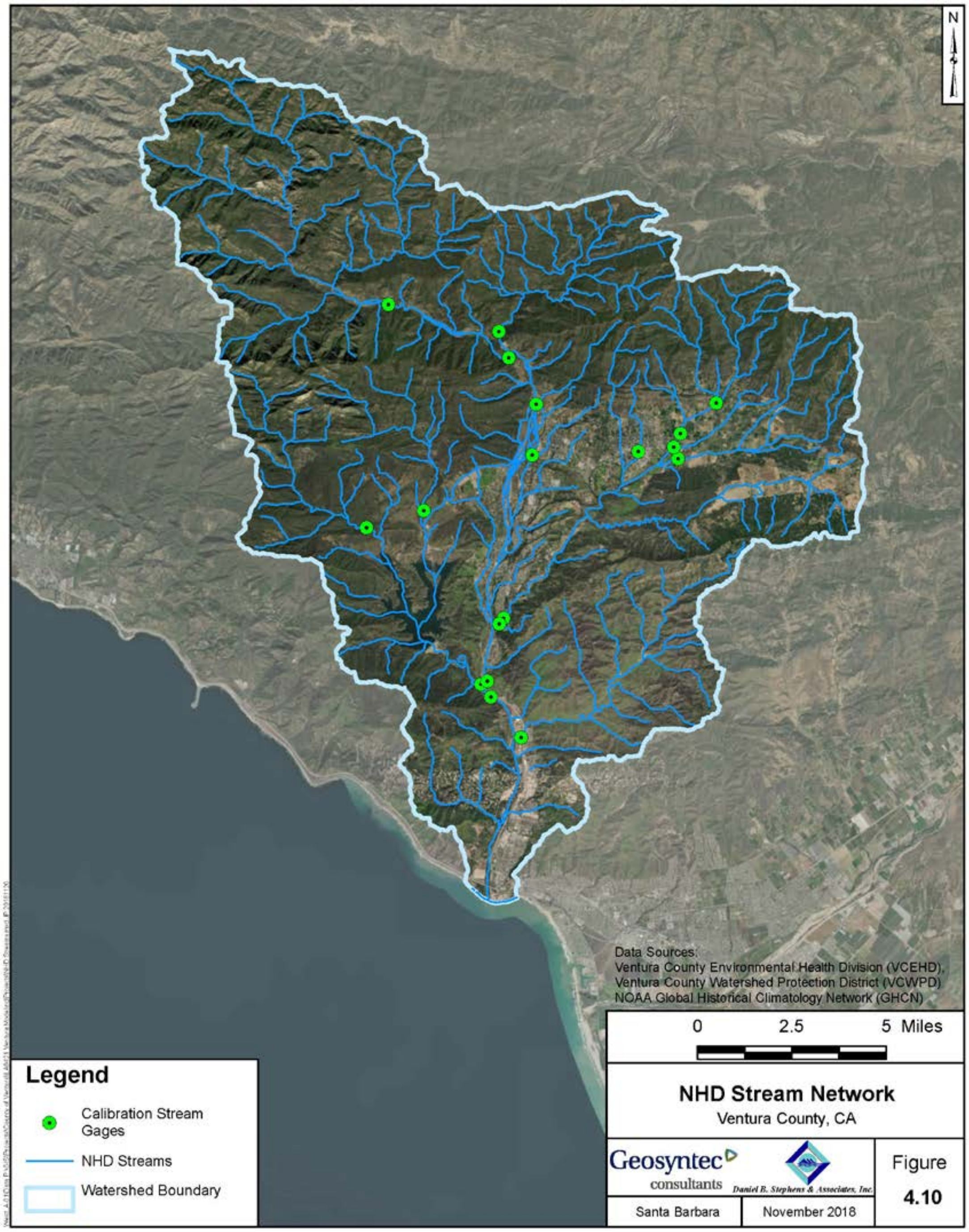

Figure 4-10 National Hydrography Dataset Stream Network

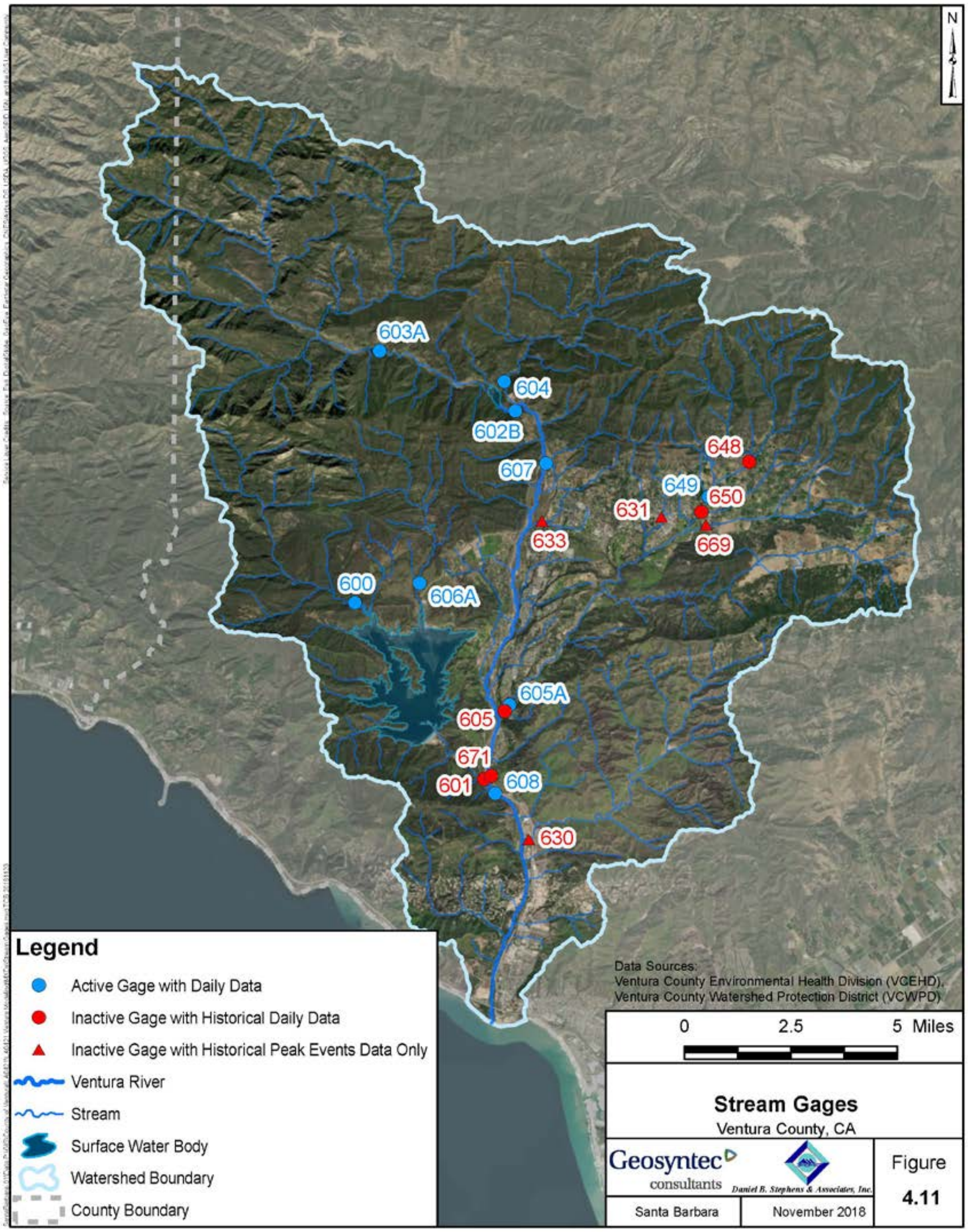

Figure 4-11 Stream Gages

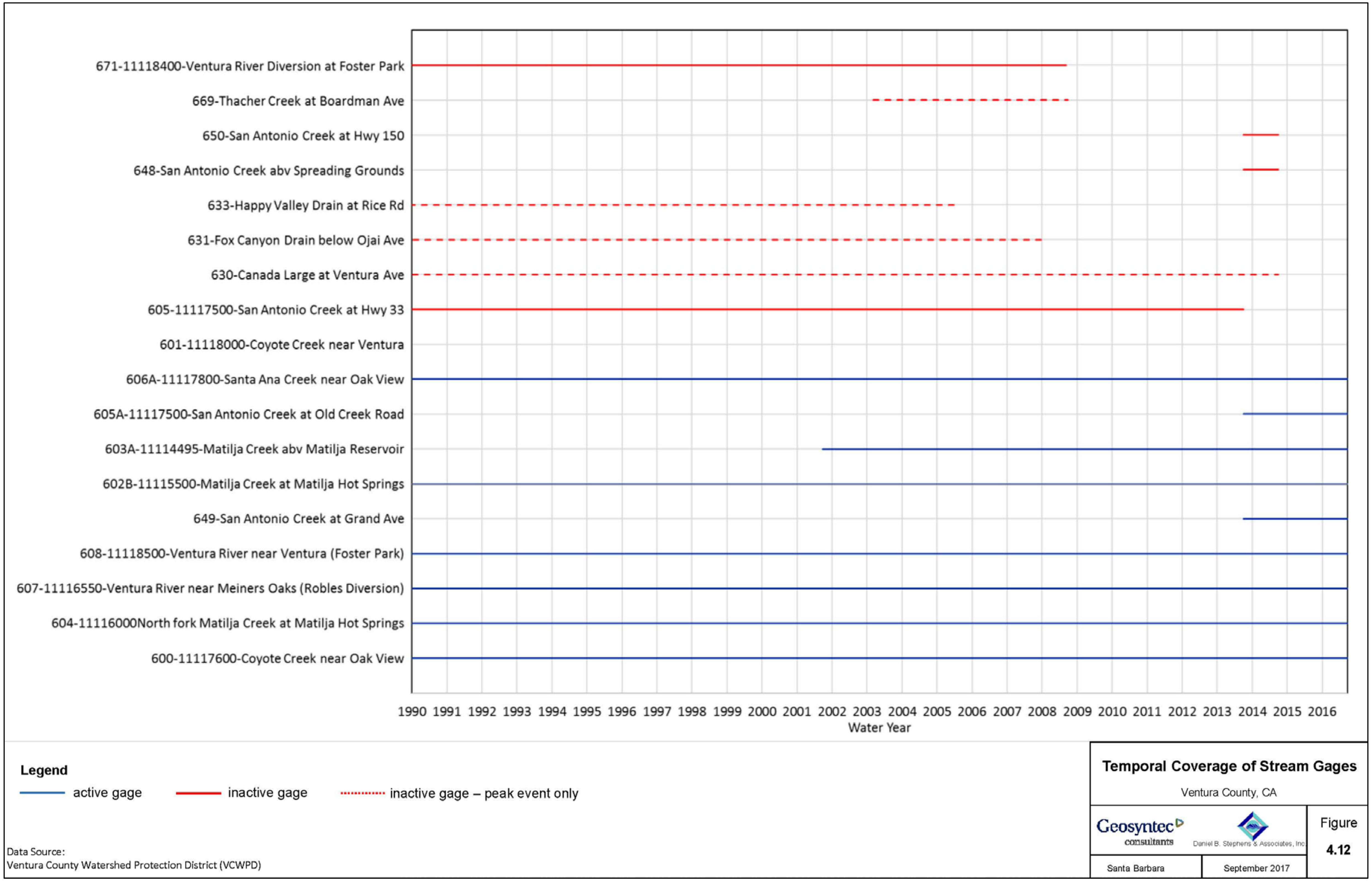

Figure 4-12 Temporal Coverage of Stream Gages

In addition to data from the existing streamflow gages, the State Water Board is working with the DWR, USGS, and VCWPD to collect additional data as follows:

- The State Water Board is working with the VCWPD on installation and maintenance of a new permanent, telemetered, streamflow gage on San Antonio Creek at Camp Comfort. VCWPD installed the new gage (VCWPD #616[10]) in Fall 2018 and began collecting stage and streamflow data. The State Water Board is funding operation and maintenance, including biweekly manual streamflow measurements to establish a rating curve, through December 2020. The new gage will help quantify streamflow downstream of the Ojai Valley Basin and will be used for calibration in the Post-Thomas Fire scenario (see Section 6.5). The State Water Board is looking for local organizations to take over funding the VCWPD to support operations and maintenance of the new gage after December 2020.
- The State Water Board worked with DWR and USGS on weekly manual streamflow measurements of Ventura River near Ventura (USGS# 11118500[11]) streamflow gage from December 2017 to October 31, 2018. The refined rating curve will improve accuracy of this gage during the Post-Thomas fire scenario (see Section 6.5).

Data collection will follow existing methodologies used by these organizations. These data will not be utilized in the historic, 1994 to 2017, model calibration, and validation periods. Instead, these data are expected to help assess model performance in the Post-Thomas Fire model scenario, as well as other potential scenarios that include time covered by the new data.

4.3.8 Wet-dry Maps

CDFW and various local water agencies (e.g., Meiners Oaks Water District, Casitas Municipal Water District (CMWD), and OBGMA) conduct observations and surveys of the river and stream channels in the Ventura River Watershed to generate wet-dry maps such as those presented in Figure 4-13. These maps can be used to verify predicted reaches as being wet, dry, or intermittent during

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[10] URL to VCWPD #616, San Antonio Creek Gage at Camp Comfort: https://www.vcwatershed.net/fws/VCAHPS/php/ahps_d3.htm?gage=616

[11] URL to USGS# 11118500, Ventura River Gage near Ventura: https://waterdata.usgs.gov/nwis/uv?site_no=11118500

periods of the model simulation. This will be done during model calibration and validation, once the PRMS model and groundwater model are integrated in GSFLOW (see Section 6).

4.3.9 Data for Post-Thomas Fire Scenario

Research studies and reports specific to the Thomas Fire will be reviewed to provide additional background and information on impacts to hydrology and nitrogen transport. Representative owners of infrastructure will be consulted as needed to understand impacts on water supply infrastructure (e.g., damage to pumps/wells and rain gages) within the Ventura River Watershed. This information will be summarized and used to inform model development for a post-fire modeling period from January 2018 through Spring 2020. Rainfall data and pumping and irrigation rates (as available) for the post-fire modeling period will be obtained, reviewed, and formatted for model input. GIS data on burn severity, if available, will be used to support the calibration of key soil input parameter values and their spatial variability. Streamflow measurements and water quality information will be reviewed to understand which storm events may have created a burned and bulked (or debris flow) effect.

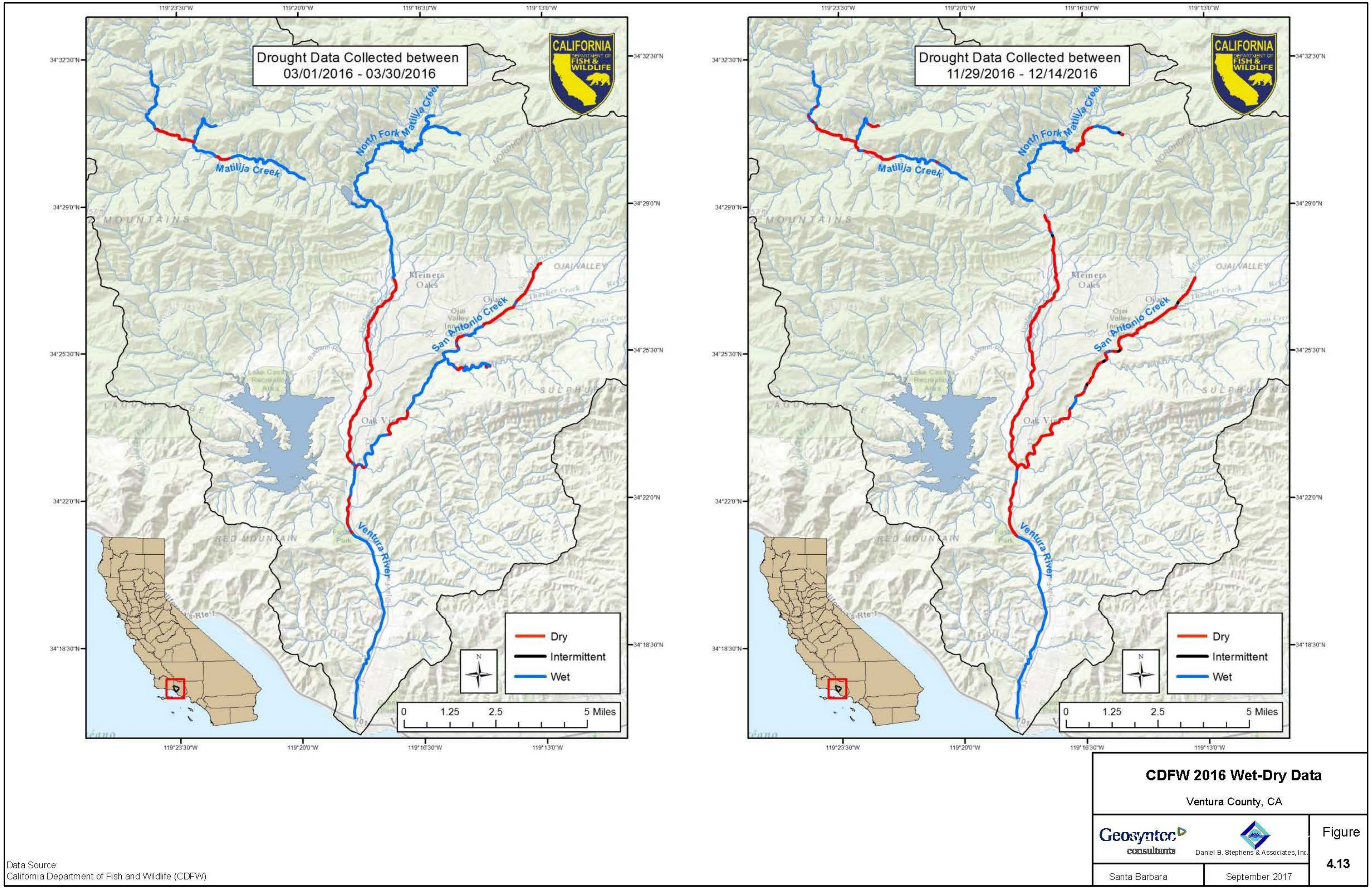

Figure 4-13 California Department of Fish and Wildlife 2016 Wet-Dry Data

5. GROUNDWATER MODEL DEVELOPMENT

This section describes how the MODFLOW-only groundwater model will be developed, including the model input data, data gaps, model domain and discretization, and boundary conditions. The goal of the MODFLOW-only model development is to ensure that the groundwater model runs without errors, and that the groundwater flow system is consistent with the understanding of groundwater flow within the Ventura River Watershed. The groundwater model will be developed to represent groundwater throughout the entire Ventura River Watershed, including the alluvial groundwater basins (i.e., Bulletin-118 groundwater basins), additional areas of saturated alluvium (e.g., the area underlying San Antonio Creek south of the Ojai Valley Basin), and bedrock geologic units currently used in the Ventura River Watershed for water supply ("bedrock aquifers").

The groundwater model will operate with monthly stress periods and daily time steps. In MODFLOW, a stress-period defines periods of time with constant values of all 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.

As described in Section 6, the MODFLOW-only groundwater model will be integrated with the PRMS-only surface water model, forming the integrated GSFLOW model. The integrated GSFLOW model will undergo full calibration and validation.

5.1 <u>Model Input Data</u>

The following input data will be used to develop the groundwater model and are broken-out by: (1) input parameters that are anticipated to remain the same before and after MODFLOW-PRMS model integration; (2) input parameters that are anticipated to come primarily from PRMS, and therefore initial placeholder values are used in the MODFLOW-only model; and (3) input parameters that are anticipated to be adjusted during calibration of the integrated model. Data will be described in more detail in an upcoming data compilation report (see Section 8 for more information). Geologic data are described in more detail in the State Water Board's Draft Geologic Analysis of the Ventura River Watershed, released in Fall 2018 with a final version forthcoming (see Section 5.4 and Section 8 for more information) (DBS&A, 2018).

Parameters that will remain the same in integrated model:

- Extent and thickness of model layers representative of alluvial and bedrock aquifers based on review of geologic maps, boring logs, existing geologic studies and cross-sections (see Section 5.2);
- Groundwater extraction from municipal wells will be based on agency pumping records, including CMWD, Meiners Oaks Water District, the City of Ventura, and Ventura River Water District, and smaller water suppliers;
- Agricultural and domestic well extraction will be based on pumping reported to OBGMA for the Ojai Valley Basin. Pumping for remaining agricultural and domestic wells throughout the Ventura River Watershed (including within the bedrock aquifers) will be estimated based on the presence of known wells (VCWPD, 2018) and assumptions regarding pumping rates as discussed in Section 5.2; and
- Recharge from OWTS systems.

Parameters that will come from PRMS:

The following parameters are estimated by PRMS, and average estimates will be applied for the purpose of the initial MODFLOW-only simulations.

- Recharge from deep percolation of precipitation (including within stream bottoms) and irrigation;
- Recharge from spreading grounds; and
- Riparian evapotranspiration of shallow groundwater.

Parameters that will be adjusted during calibration:

- Hydraulic conductivity and storage coefficient are the primary model calibration parameters and will initially be based on calibrated values for the OBGM in the Ojai Valley Basin and based on available aquifer-test and/or specific-capacity tests for remaining alluvial basins. Properties of the bedrock model layer (e.g., hydraulic conductivity) will be based on existing hydrogeologic studies (for example, DBS&A [2011] Upper and

Lower Ventura River Basin Groundwater Balance).[12] These values will be adjusted during model calibration (see Section 6).

5.2 Data Gaps

Key data gaps for the groundwater model include hydraulic parameters (e.g., hydraulic conductivity), subsurface geology, and groundwater extraction rates. Subsurface geology will be evaluated based on boring logs and references as described in Section 5.4, and hydraulic parameters will be subject to model calibration as constrained by available aquifer-test data as described in Section 6.

Groundwater extraction related data gaps include: (1) annual extraction rates for agricultural and domestic wells in the Upper Ventura, Lower Ventura, and Upper Ojai Valley basins and bedrock aquifers; and (2) monthly extraction rates for all non-municipal supply wells.

Agricultural and domestic well extraction rates have not historically been systematically collected and reported in the Ventura River Watershed outside of the Ojai Valley Basin. In the Ojai Valley Basin, extraction rates have been reported to OBGMA since 1996. Extraction rates will be estimated for wells without records. Irrigation water within the basins can be supplied from both groundwater and surface water sources (e.g., from Lake Casitas). Agricultural groundwater extraction rates will be estimated for each well based on:

- Area irrigated by the well and crop coverage, determined from surrounding land use for each well (land use coverage consistent with those used for the PRMS-model, see Section 4.3.4), and well records available from VCWPD;
- Irrigation rates determined by crop-type and available irrigation estimates consistent with those used in the PRMS-only model (see Section 4.3.5); and
- The fraction of irrigation supply sources from groundwater versus surface water (including how this varies in dry versus wet precipitation years) will be determined based on review of Casitas surface water delivery records and consultation with local growers.

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[12] Modeling of fractured bedrock systems will be conducted using the Equivalent Porous Medium approach (see e.g., Botros et al., 2008).

Figure 5-1 displays the presence of, and indicates the depth of, wells within the Ventura River Watershed based on data received from VCWPD (2018). To the extent possible, the Project Team will coordinate with the UVRGA to identify growers to interview regarding the area supplied by each well, crop coverage, and to what extent surface water supplies are used for irrigation. In addition, the Project Team will coordinate with CMWD staff to obtain data on surface water deliveries used for municipal water supply and irrigation. This effort will inform how surface water supplies stored in Lake Casitas are used. The Project Team will also evaluate how extraction rates change for wells in the Ojai Valley Basin that report to OBGMA, as another line of evidence for how the proportion of surface water versus groundwater has varied over time. Lastly, the UVRGA has commissioned an aerial crop survey and inventory of wells in the Upper Ventura Basin with meters to evaluate irrigation and groundwater extraction practices. If results of this study are available during the data collection period, they will also be used as a basis for assigning extraction rates.

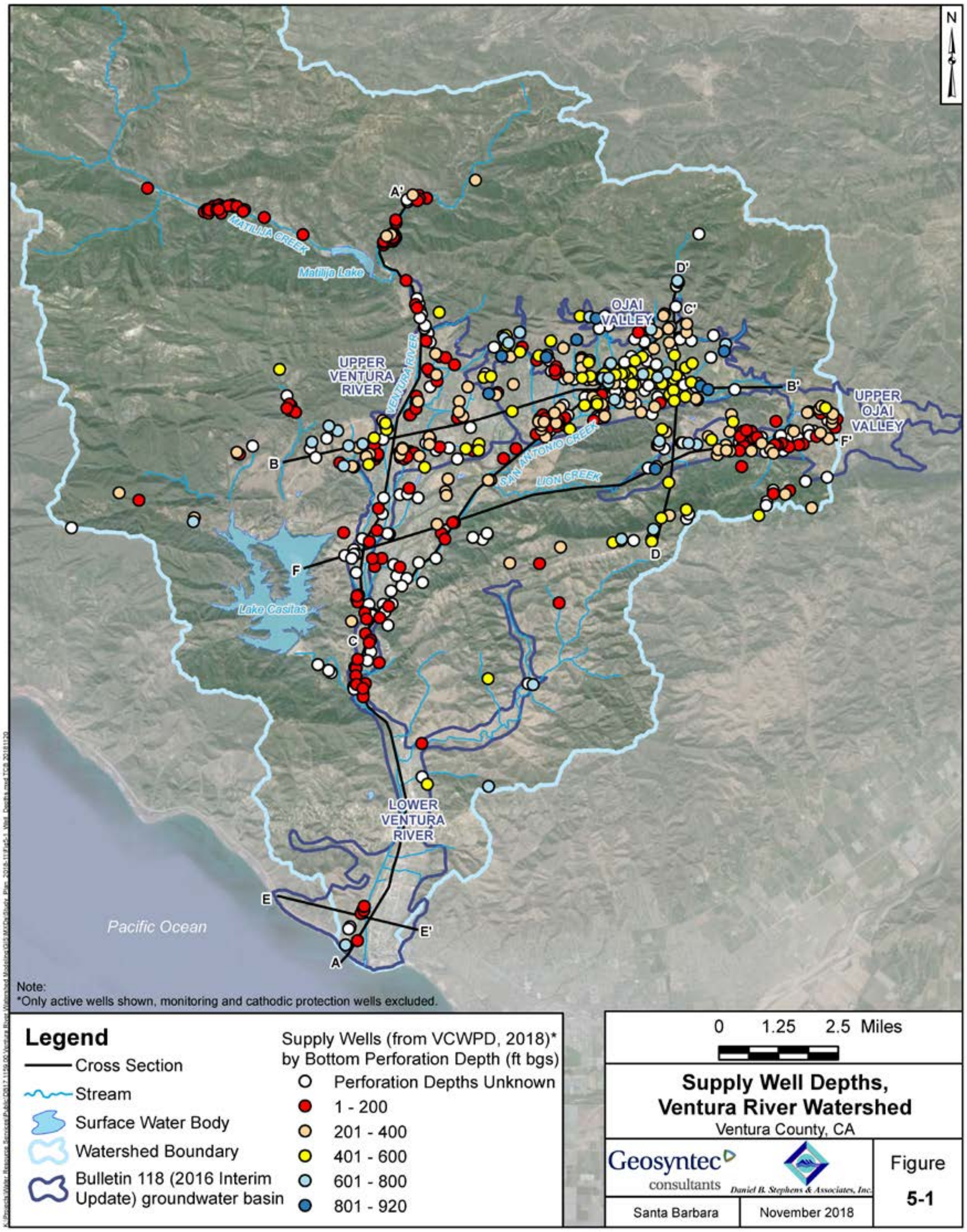

Figure 5-1 Supply Well Depths, Ventura River Watershed

Domestic groundwater extraction rates will be estimated based on assumed domestic water consumption, including domestic irrigation. Domestic irrigation rates will be consistent with those used in the PRMS-only model (see Section 4.3.5).

Groundwater was historically extracted from the alluvium in the Lower Ventura River Basin during oil extraction by Aera Energy LLC and its predecessors; however, extraction rates are not currently available (DBS&A, 2010). The Project Team will seek out records of historical Aera Energy LLC extraction and include pumping from these wells if possible.

The groundwater model and final integrated model will use monthly MODFLOW stress periods[13]; therefore, monthly extraction rates will need to be assigned for all wells. It is assumed that monthly extraction data will be available for municipal wells from water agencies and mutual water companies.

For agricultural and domestic wells, monthly extraction rates will be extrapolated from annual or semi-annual extraction records based on the fraction of reference evapotranspiration that occurs each month (see e.g., DBS&A, 2011). This approach assumes that extraction rates are related directly to reference evapotranspiration rates. This assumption is reasonable for agricultural wells, mixed use domestic/agricultural wells, and domestic wells that are used primarily for landscape irrigation. However, this assumption would not be appropriate for wells used strictly for non-irrigation supply. It will be assumed that even domestic wells in the Ojai Valley Basin are used partially for landscape irrigation. For example, for those wells in the OBGMA with a use description, 90 percent of them are either agricultural or domestic/landscape. Initial monthly reference evapotranspiration rates will be taken from CIMIS (1999); and eventually will be replaced with monthly reference evapotranspiration rates from the PRMS model.

5.3 Model domain and spatial discretization

Horizontally, the active groundwater model domain will extend throughout the entirety of the Ventura River Watershed. The groundwater model will represent groundwater flow in the alluvial groundwater basins (i.e., the Bulletin-118 basin delineations of the Ojai Valley, Upper Ojai Valley, Lower Ventura River and Upper Ventura River basins), additional areas of saturated alluvium (e.g., the area underlying San Antonio Creek south of the Ojai Valley Basin), and the

[13] Note, as discussed in Section 5.0 that the model will use daily time steps.

bedrock aquifers. Vertically, the full thickness of all alluvial basins will be represented, and the bedrock model layer thickness will be based on the depth of the majority of domestic and agricultural wells screened in the bedrock units.

The model domain will be uniformly divided into grid cells 330 feet on a side, consistent with the surface water model (see Section 4.1). For the OBGM, 10 model layers were included to represent alternative aquifer and aquiclude units within alluvial sediments, based on analysis and correlation of geophysical well logs (DBS&A, 2011). Representation of these units is important for the OBGM to simulate confining conditions that result in artesian conditions that exist for certain wells in the basin following heavy precipitation. It is anticipated that model layering and total model thickness will be adopted for the Ojai Valley Basin directly from the OBGM. Boring logs, and geophysical well logs if available, will be reviewed to determine appropriate model layering for remaining areas.

5.4 Geologic Analysis

A geologic analysis of the Ventura River Watershed was performed to support groundwater model development. The geologic analysis was performed by mapping the three-dimensional extent of surficial geologic units within the Ventura River Watershed, and results were plotted on a series of geologic cross-sections and maps. The geologic analysis will be used to assign three-dimensional model layer geometry, initial model hydraulic properties (e.g., hydraulic conductivity), and the presence of boundary conditions representative of faults that may provide a barrier to groundwater flow.

In Fall 2018, the Water Boards released a Draft Geologic Analysis of the Ventura River Watershed for public and TAC review (DBS&A, 2018). The Water Boards convened a TAC meeting to solicit review and feedback. The Project Team is using public and TAC comments to revise the analysis and will release an updated final version.

Geologic maps, boring logs, existing geologic studies and cross-sections, and the current Bulletin-118 (DWR, 2016a) basin boundaries were reviewed to assess the extent of alluvial aquifers. Geologic maps used in the analysis include the East Half Santa Barbara 30’ x 60’ Quadrangle prepared by the California Geologic Survey (Gutierrez et al., 2008), the Eastern Three-Quarters of the Cuyama 30’ x 60’ Quadrangle prepared by the U.S. Geologic Survey (Kelogg et. al, 2008), a tectonic and physiographic map of the White Ledge Peak and Matilija Quadrangles prepared by the U.S. Geologic Survey (Minor and Brandt, 2015) and older, preliminary geologic maps that do not include landslide deposits covering the bedrock units (i.e., Dibblee, 1981, 1987a, 1987b). Previous studies of the extent and thickness of alluvium include DBS&A (2011), Turner (1971), Kear (2016a, 2016b), Fugro (2002) and Hopkins (2007). Previous studies of bedrock geology in the watershed include DWR (1933), Rockwell et al. (1984) and California Division of Oil and Gas (1991). Boring logs are available from DWR (2018), VCWPD, Hopkins (2007), municipal water providers and from Cleanup and Waste Discharge Sites on the State Water Board GeoTracker[14] website (State Water Board, 2017). The State Water Board obtained available boring logs, geophysical logs ("E-logs"), and geophysical studies from VCWPD, local consultants, and municipal water providers.

Figure 5-2 displays the current Ventura River Watershed Bulletin 118 basin boundaries and major geologic structural features.

Boring logs available from VCWPD in the Upper Ventura, Lower Ventura and Upper Ojai Valley basins were used to determine the depth of alluvium for each well, and maps of the elevation and thickness of alluvium within the Ventura River Watershed were generated (DBS&A, 2018).

In addition, new geologic cross-sections were developed displaying alluvial thickness, the first several hundred feet of bedrock formations, major surface water features, major geologic features, faults, and basin/model boundaries (DBS&A, 2018). The Project Team generated six geologic cross-sections, with locations displayed in Figure 5-2. In general, cross-section locations were selected to inform development of the conceptual groundwater model, to be consistent with previous cross-sections developed in the Ventura River Watershed, and to follow the main surface water bodies.

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[14] GeoTracker is the State Water Boards' data management system for sites that impact, or have the potential to impact, water quality in California, with emphasis on groundwater. GeoTracker contains records for sites that require cleanup, such as Leaking Underground Storage Tank (LUST) sites, Department of Defense sites, and Cleanup Program sites. GeoTracker also contains records for various unregulated projects as well as permitted facilities including: Irrigated Lands, Oil and Gas production, operating Permitted USTs, and Land Disposal sites.

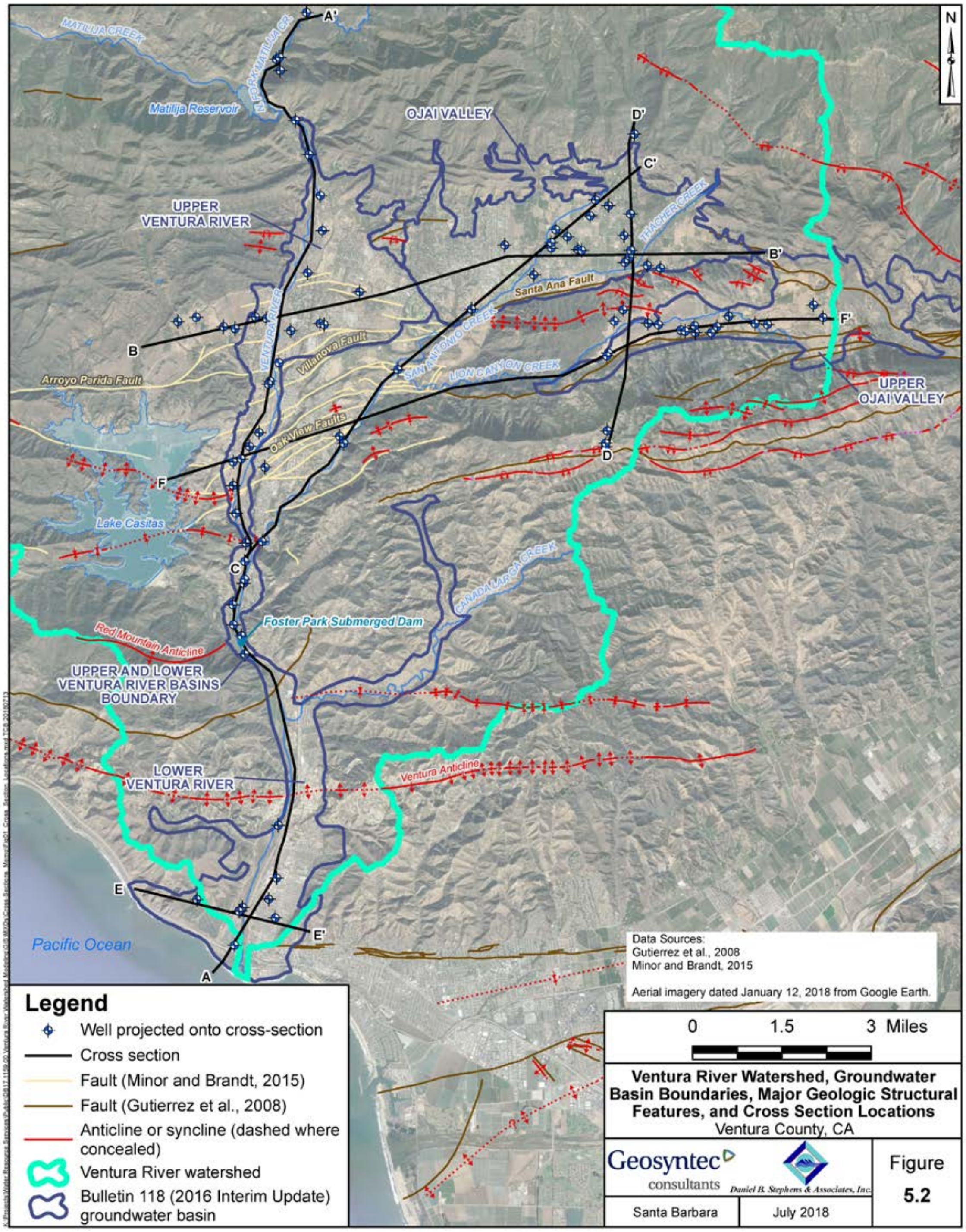

Figure 5-2 Ventura River Watershed, Groundwater Basin Boundaries, Major Geologic Structural Features, and Cross Section Locations

The numerical groundwater model will represent the entire Ventura River Watershed, including areas between the cross-sections. Geologic features that may control groundwater movement, such as major faults, that do not cut across these cross-sections will be represented in the groundwater model. Preliminary cross-section locations in Figure 5-2 were selected based on the following:

- Section A-A′ was selected to follow the main stem of the Ventura River and continue north to the area of supply wells located along North Fork Matilija Creek; within the Upper Ventura Basin this location is coincident with section A-A′ from Kear (2016b);
- Section B-B′ was selected to pass through the Upper Ventura Basin and into the Ojai Valley Basin; this section is coincident with section B-B′ from Kear (2016b) within the Upper Ventura Basin and section A-A′ from DBS&A (2011) within the Ojai Valley Basin;
- Section C-C′ was selected to follow San Antonio Creek and is coincident with section C-C′ from DBS&A (2011) within the Ojai Valley Basin;
- Section D-D′ was located to run south-to-north from the area south of the Upper Ojai Valley Basin (where several supply wells are located) to the Upper Ojai Valley Basin, and then through the Ojai Valley Basin. This section is coincident with section B-B′ from DBS&A (2011) within the Ojai Valley Basin;
- Section E-E′ was selected to pass through the widest area of alluvium in the Lower Ventura Basin and is also located based on availability of boring-log data; and
- Section F-F′ was selected to pass through the Upper Ventura Basin, the area of alluvium associated with San Antonio Creek, Lion Creek, and the Upper Ojai Valley Basin; this section is coincident with Section C-C′ from Kear (2016a) within the Upper Ventura Basin and the area around San Antonio Creek.

5.5 Model 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. Model boundary conditions and how they will be implemented are listed below:

- Recharge from precipitation and irrigation will come from the PRMS model in the final integrated GSFLOW model. For initial MODFLOW-only simulations, placeholder values will be used based on DPWM output for the Ojai Valley Basin and based on simple fractions of total precipitation and irrigation for the remaining basins using the MODFLOW recharge (RCH) package or unsaturated-zone flow (UZF) package.
- Recharge from spreading grounds, including the San Antonio Creek Spreading Grounds will be based on recorded diversions to the spreading grounds and will be implemented as infiltration and recharge specified flux using the MODFLOW RCH package or unsaturated-zone flow (UZF) package in the preliminary model. It is expected that recharge from spreading grounds will be implemented in PRMS in the final integrated model.
- Recharge from OWTS systems will be implemented as specified flux boundaries in the preliminary MODFLOW-only simulations and GSFLOW model using the MODFLOW well (WEL) package.
- Riparian evapotranspiration will come from the PRMS model in the final integrated GSFLOW model. For initial MODFLOW-only simulations, evapotranspiration will be represented with the MODFLOW evapotranspiration (EVT) package, based on mapped areas of riparian coverage.
- Flow between groundwater and stream channels will be represented by the MODFLOW streamflow routing (SFR) package in both GSFLOW and the preliminary MODFLOW runs. Placeholder values that govern flow in the streams at domain boundaries will be used for the MODFLOW-only simulations.
- Groundwater exchange along the bottom model boundary will be represented with the MODFLOW general-head boundary (GHB). The GHB package is used to calculate variable exchange at model boundaries using Darcy's law and based on a specified transmissivity of the boundary cell, a specified constant hydraulic head for the boundary, and the hydraulic head of the active model cell in contact with the boundary.
- Geologic fault-zones present in the watershed may in some cases act as a partial barrier to groundwater flow. The potential for fault zones to act as a barrier to groundwater flow will be evaluated based on available geologic cross-sections, geophysical studies and groundwater elevation

data. For wider fault zones that approximate the model grid cell width (330 feet), faults will be represented by assigning low hydraulic conductivity to the grid cells in the area; for thinner zones faults will be represented with the horizontal flow barrier (HFB) MODFLOW package.

- The Foster Park subsurface dam will be represented with the MODFLOW HFB package. The subsurface dam is absent along the eastern portion of the Ventura River bed (SBRA, 2002), and the HFB will not be implemented where the dam is absent.
- Groundwater extraction will be implemented using the MODFLOW multi-node well (MNW) package.
- Groundwater outflow and/or inflow from the Lower Ventura Basin to the Pacific Ocean will be represented with the MODFLOW GHB package, assigning a groundwater elevation of mean-sea level to the boundary.
- Groundwater flow at the location of the groundwater divide in the Upper Ojai Valley Basin (between the Ventura River and Santa Clara River watersheds) will be represented with the MODFLOW GHB package, assigning groundwater elevations based on observed groundwater levels at that location (e.g., using data from wells 04N22W12F01S/F04S, see Figure 5-3).

5.6 Preliminary Groundwater Model Simulations

The purpose of preliminary MODFLOW-only simulations is to ensure that the groundwater model runs without errors (e.g., due to clerical mistakes in the input files) and to ensure that the groundwater flow system is generally consistent with understanding of the hydrogeology. For example, groundwater flow directions should proceed generally to the south for the Upper and Lower Ventura River basins, towards the southwest for the Ojai Valley Basin, and towards the west for the Upper Ojai Valley Basin. Groundwater levels should be roughly consistent with the range of water level observations in the wells in the basins and should respond to dry and wet-weather cycles. The initial MODFLOW-only simulations will be run for a representative period of three consecutive years between WY1994 and WY2017, selected to provide a range of dry and wet conditions. As discussed in Section 6, the full GSFLOW model simulation period will be from WY1994 to WY2017 after key model inputs and boundary conditions are provided by PRMS.

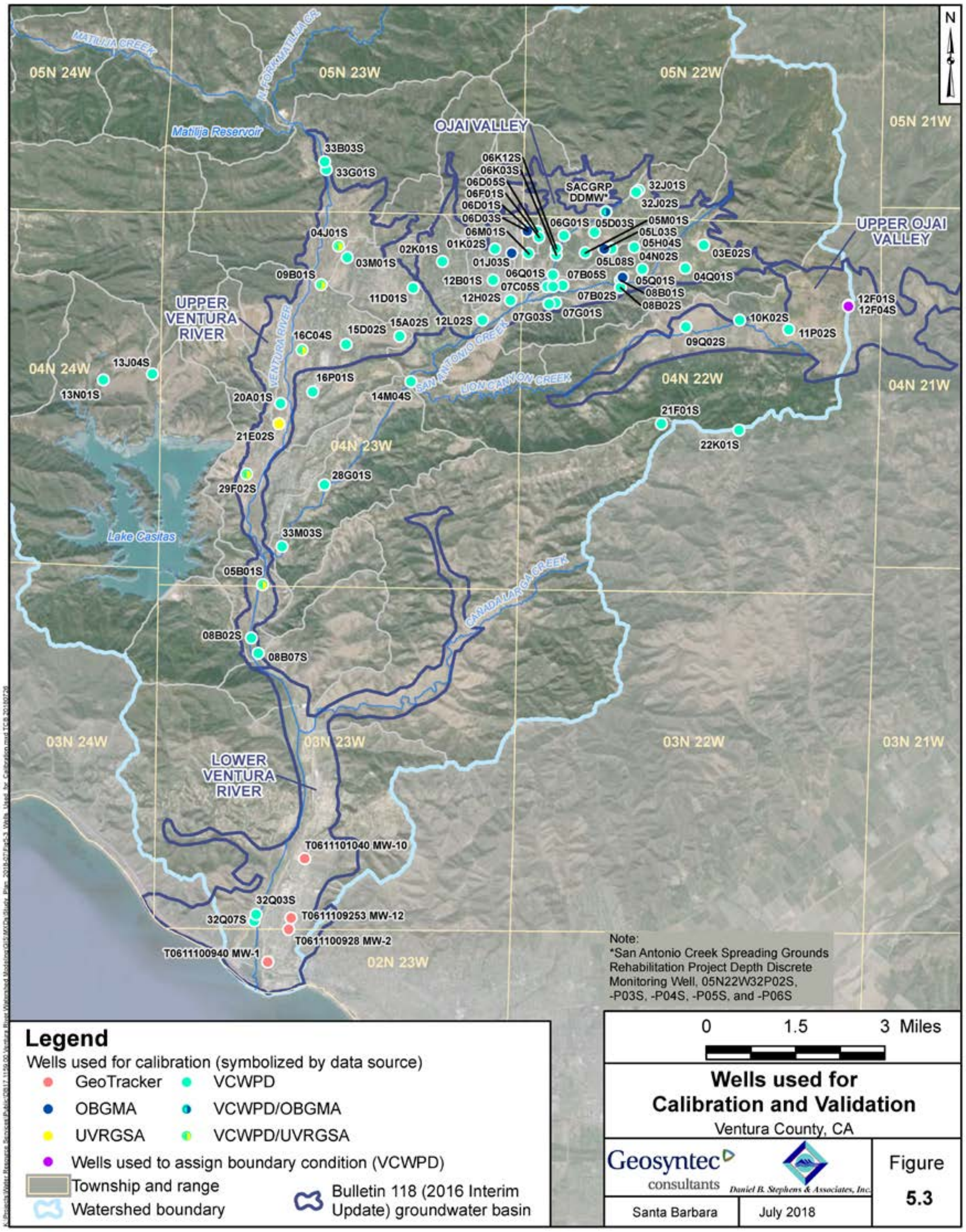

Figure 5-3 Wells used for Calibration and Validation

6. GSFLOW MODEL DEVELOPMENT, CALIBRATION, AND VALIDATION

The GSFLOW model will be developed by integrating the PRMS and MODFLOW models described in Sections 4 and 5, respectively. The GSFLOW platform is designed to integrate PRMS and MODFLOW models and includes scripts for facilitating this integration. The GSFLOW model grid will be developed with 330-foot grid cells (see Section 4.1).

Model calibration will generally consist of matching simulated groundwater levels to historic water level measurements from wells in the Ventura River Watershed and of matching simulated surface water flows to historic streamflow gage data. Additional spatial comparisons of simulated stream data will also be made to historic wet-dry stream mapping data. This section describes the calibration process, including the modeling period, calibration approach and parameters, and specific calibration goals. In addition to the calibration goals listed below, the model output will be evaluated to achieve a model mass-balance error that is within acceptable limits, defined as less than 0.5 percent based on USGS guidance (Reilly and Harbaugh, 2004).

6.1 Modeling Period

The GSFLOW modeling period will comprise a total of 24 years from WY1994 through WY2017. This period enables leveraging of the existing VSWHM (1987 – 2006), the existing OBGM (1970 – 2013), and groundwater budget study by DBS&A (2010) for the upper basins (1997 – 2007). New streamflow data (Section 4.3.7) will be used for a Post-Thomas Fire scenario (Section 6.5). It is anticipated that the model will be run with daily time steps and monthly groundwater modeling stress periods.

The modeling period will be divided into a 21-year calibration period (WY1994 through WY2014) and a three-year validation period (WY2015 through WY2017). This approach enables a sufficiently long period to calibrate the groundwater portion of the model. The model calibration period includes multiple wet years (e.g., WY1998 and WY2005) and a prolonged dry period (WY2012 – WY2014). A longer validation period was considered, but that would remove years from the calibration period. The Project Team determined this would decrease the efficacy of the calibration period. The validation period will end prior to the December 2017 outbreak of the Thomas Fire.

The 24-year modeling period was selected based upon weighing the benefits of potentially longer calibration and validation periods against availability and quality of historical data and the reasonableness of assumed fixed land use over a longer period. Prior to the mid-1990s, groundwater pumping datasets are limited, particularly outside of the Ojai Valley Groundwater Basin. Additionally, GSFLOW assumes a fixed land use for the selected 24-year modeling period, and model error will become larger if a longer calibration period is used.

6.2 Calibration Approach and Parameters

Calibration of the integrated GSFLOW model will consist of adjustment of specific parameters that govern the surface water and groundwater portions of the model domain. The model calibration approach and parameters that will be adjusted for the surface water and groundwater portions of the model are summarized in the following sections. While the calibrations of the surface water and groundwater models are discussed in separate sections, the final calibrations will be performed in the coupled GSFLOW model.

6.2.1 Surface Water

The surface water portion of the GSFLOW model will initially be run in PRMS-only mode based on the existing VSWHM parameterization, and then calibrated by comparing model-predicted flows to historic wet season streamflow gage data (Section 4.3.7). Calibrating the model for wet-weather flows in advance of integrating the models will aid the calibration of the groundwater portion of the model in GSFLOW by providing a well-defined spatial representation of groundwater recharge from rain events (Allander et al., 2014). The dry-weather surface water flows will be calibrated within the integrated GSFLOW model (i.e., in conjunction with the groundwater calibration described in Section 6.2.2), due to the inherent dependence of the low flows on the groundwater model. The calibration of dry-weather flows will be based upon comparison to historic streamflow gages, manual streamflow measurements, and wet-dry maps across different seasons and years (Section 4.3.8).

6.2.2 Groundwater

GSFLOW calibration will include matching of simulated groundwater levels to available historic groundwater-level data. Historic groundwater level monitoring data are available from the VCWPD (which conducts a quarterly groundwater monitoring program throughout the watershed), selected GeoTracker cleanup sites, and pressure-transducer data collected by OBGMA and UVRGA. Well locations for wells that have been preliminarily identified to be used for calibration are shown on Figure 5-3. Each well on Figure 5-3 will be evaluated to determine if the well is screened in alluvium and/or bedrock, and calibration will be conducted for the model layer of the corresponding lithologic unit. For areas with no available groundwater-level monitoring data, available driller's logs will be reviewed for the groundwater level recorded at the time of well installation. In addition, calibration will include matching simulated groundwater elevations to stream elevations in reaches identified as perennially wetted.

Groundwater-level calibration will be conducted consistent with standard protocols and best practices as defined by DWR (2016b) and American Society for Testing and Materials (ASTM) (2008). Calibration consists of adjusting model parameters to minimize the difference (i.e., residual) between the simulated groundwater level at a specific location and observed groundwater level data from a well at that location. Calibration will also include consideration of wet-dry mapping as discussed above.

Parameters adjusted during the calibration process (i.e., calibration parameters) will include hydraulic conductivity and storage coefficient of each model layer. Values of hydraulic conductivity and storage coefficient from available aquifer tests and specific capacity measurements will be used to constrain calibration goals. For example, for the OBGM the calibrated hydraulic conductivity and storage coefficient values were within the range of available aquifer test results (DBS&A, 2011). In general, values of these parameters in the model should be similar, but do not have to be identical to field observations; the field observations have errors themselves. There are also differences in the associated scale of aquifer-test results (i.e., the volume of aquifer stressed) versus what is implemented in a regional groundwater model (ASTM, 2008).

6.3 Calibration Goals

The model calibration goals for the surface water and groundwater portions of the model are presented in the following sections. While the surface water and groundwater calibration goals are discussed in separate sections, the final calibrations will be performed in the coupled GSFLOW model.

6.3.1 Surface Water

It is generally accepted that a 'weight of evidence' approach be adopted when calibrating continuous output hydrological simulations (Donigian, 2002);

whereby, both qualitative graphical comparisons and quantitative statistical comparisons are made. Graphical comparisons will generally include visual evaluation of timeseries plots comparing the observed and model simulated flow rates at key locations, while quantitative comparisons may include calculating a range of standard statistical measures.

In general, model accuracy cannot exceed the accuracy or uncertainty associated with the data used to develop and calibrate the model. Thus, it is recognized that it is often difficult to pre-define specific calibration goals (Donigian, 2002). Relative calibration goals are proposed based on guidance from USGS (Woolfenden and Nishikawa, 2014) specific to GSFLOW application. These goals are discussed in more detail below.

During the calibration, simulated and observed daily mean streamflow, moving three-day daily mean streamflow, monthly mean streamflow, and annual mean streamflow will be compared visually with hydrographs and flow-duration curves, and also through goodness of fit statistics. These goodness of fit statistics include the percent average estimation error (PAEE), the absolute average estimation error (AAEE), and the Nash-Sutcliffe model efficiency (NSME). 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 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).

Table 6-1 shows the ranges of the goodness of fit statistics that are associated with overall classifications ranging from fair to excellent. Comparisons will be made between simulated and observed daily mean[15] and monthly mean streamflow, and the weighted average statistics for these comparisons will be considered. The goal of the calibration will be to achieve “very good” classifications for the PAEE and AAEE and an NSME value of 0.7 or greater[16]

[15] The moving three-day average may be used, instead of the daily mean, if there are potential backwater conditions caused by high flows.

[16] Per Table 6-1, an NSME value of 0.7 is classified as a “fair” model performance. However, it is noted that other authors use different classifications. For example, Caldwell et al. (2015) considers NSME values (for

per guidance from the USGS (Woolfenden and Nishikawa, 2014). Although the goals will be considered for both comparison of daily means and monthly mean streamflow, statistics for the monthly averages are expected to be superior to the daily averages (Caldwell et al. 2015). The calibration statistics will be evaluated across different seasons to enable low-flow periods to be assessed independently of wet seasons.

Table 6-1 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

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

Although the model calibration goal will be to achieve “very good” classifications, it is noted that in practice this is often not achieved at every gage location. Specifically, in the USGS study by Woolfenden and Nishikawa (2014), the “very good” classification was only met or exceeded at six of the twelve gage locations for calibration of daily flow, and in nine of the twelve gage locations for calibration of monthly flow. For validation, the “very good” classification was only met at one of six locations for daily flow, and 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”

comparison of monthly average streamflow) greater than 0.50, 0.65, and 0.75 to be considered satisfactory, good, and very good performance, respectively. Therefore, under these classifications, an NSME value of 0.7 is considered “good” model performance.

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 nature of the specific watershed, including the accuracy of input data and flow gages.

In considering the Ventura River Watershed, it is useful to assess the previous surface water modeling efforts. The VSWHM calibration established target criteria of ±30% for volume of flow over different seasons (Tetra Tech, 2009; Table 5-3), but these targets were not always achieved. For example, the seasonal goals relevant to wet-weather (i.e., winter and spring volume error criterion) were achieved at seven of the eight gages used for calibration[17], while the seasonal goals relevant to dry-weather (i.e., summer and fall volume error criterion) were achieved at five of the eight gages.

The addition of the groundwater component in GSFLOW is expected to result in substantially improved ability to model dry-weather flows, compared to the VSWHM which had noted difficulty modeling low flows. These large discrepancies may in part reflect the difficulties in calibrating to low flow rates, including the uncertainties in the accuracies of various streamflow gages. For example, more than one-third of the automated measurements at streamflow VCWPD Gage 608 (operated by USGS as gage 11118500, Ventura River near Ventura) (see Figure 4-10 for location) have poor data quality with errors in excess of 15 % (Tetra Tech, 2012). Measurement errors would not be accounted for in model prediction error estimates, so these errors would be compounded to reflect true model accuracy. The likely accuracy of flow gages, including owner/operator quality control practices, morphological stability at gaging location, and how frequently or recently the rating curve was updated, will be considered in the assessment of the model calibration.

Historic wet-dry mapping data (described in Section 4.3.8) will be an important part of the calibration for dry-weather flows. These represent key data that will demonstrate the ability of the model to predict gaining and losing reaches during different seasons and different water year types. Output from the model will be extracted to re-create the spatial and temporal information in the maps to enable a qualitative visual (i.e., side-by-side) comparison for each set of wet-dry observations. The percent of river channel correctly predicted as wet, dry, or intermittent, will also be calculated for each comparison. In addition, specific

[17] It is noted that wet-weather calibration in GSFLOW may be more challenging due to the use of a daily time step that may not fully take into account differences in storm intensities.

locations of interest (e.g., critical habitat areas) will be assessed separately to calculate the temporal accuracy of the model (i.e., percent of time the model correctly predicts wet versus dry conditions). These metrics can be used to inform the ability of the model to make accurate predictions at key locations.

It is noted that the groundwater-portion of the model domain will play a key role in the determination of wet-dry regions. In particular, the locations of the wet and gaining reaches during dry weather will primarily depend upon the calculated groundwater head elevation. As such, the groundwater calibration (discussed next) will be conducted in conjunction with the surface water model dry-weather flow calibration. It is noted that it will be challenging to perfectly match these wet-dry maps since locations of surface water upwellings will be highly sensitive to the modeled groundwater elevations.

6.3.2 Groundwater

Groundwater model calibration results are typically presented in terms of several statistical 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.
- 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.
- 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.

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, 2002; 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 will include:

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

Initial model calibration will be conducted by the traditional manual (or ‘trial-and-error’) approach, which consists of changing model inputs, running the program with the new input, and then comparing results to calibration targets (ASTM, 2008). Automated calibration, using software such as Model-Independent Parameter Estimation and Uncertainty Analysis; Doherty, 2015), relies on a computer code to adjust model inputs to iteratively improve model simulations and reduce residuals and will be tested and utilized if found to efficiently reduce residual values compared to the manual approach.

6.4 Sensitivity Analysis

In general, sensitivity analysis of models can range from qualitative descriptions of the relative importance of the input parameters, to more detailed quantitative approaches where parameters are varied independently and the model output responses to the input variations are evaluated systematically.

The GSFLOW manual (Markstrom et al., 2008) provides an example sensitivity analysis limited to the evaluation of effect of hydraulic conductivity on groundwater recharge and discharge. More typically GSFLOW studies vary several parameters and assess their importance on a range of model outputs. For example, Tian et al. (2015) independently varied nine GSFLOW input parameters using increases and decreases of 20% to assess effects on key model outputs, including groundwater heads, streamflows, surface water to groundwater fluxes, and groundwater to surface water fluxes throughout the watershed. The nine model input parameters were selected based upon understanding of the watershed, and experience gained through the manual model calibration process.

Allander et al. (2014) varied 11 GSFLOW input parameters using a range of increases and decreases to enable a more detailed evaluation of sensitivity, including non-linear changes. Analyses were limited to a few key model outputs (i.e., the elevation of a lake and loss rate in a river) that were of importance in their study. Ely and Kahle (2012) calculated normalized scaled composite sensitivities for more than 40 model inputs, and provided discussion related to the ability to estimate parameter values during the calibration process. Notably, they identified the importance of calculating separate sensitivities during low-flow and high-flow periods.

During the current study, a methodology to conduct a sensitivity analysis of the GSFLOW model will be developed. The approaches used in the development of the VSWHM and OBGM will also be considered in the development of the approach. The methodology will compare the calibrated model output with output obtained by running the model with specific parameters or inputs systematically changed. The model inputs and parameters will be established during model development using experience gained during the calibration process (Tian et al., 2015). Comparisons will be made both visually via time-series plots and quantitatively via tabulation of relevant metrics (e.g., relative or absolute changes in groundwater heads and stream flow rates at key locations). It is anticipated that metrics will be computed separately for low-flow and high-flow periods (Ely and Kahle, 2012).

Prior to implementation of the sensitivity analysis, the methodology will be presented in a Draft GSFLOW Sensitivity Analysis Methodology Memo for TAC and public review.

6.5 GSFLOW Scenarios

The calibrated and validated GSFLOW model will be used to evaluate and document a maximum of eight (8) scenarios. Prior to modeling scenarios, a GSFLOW Scenarios Methodology Memo will be released for public and TAC review. The memo will describe the scenarios in detail. Scenarios not covered in the memo can be modeled by Water Boards staff or interested parties in the future. Anticipated scenarios include:

- One scenario shall simulate surface water flows and groundwater levels in the watershed under unimpaired conditions.
- One scenario shall evaluate the effects of climate change and population change on surface water flows and groundwater levels in the watershed.
- One scenario shall evaluate the effects of Matilija Dam removal on surface water flows and groundwater levels in the watershed.
- One scenario shall evaluate the impacts of the Thomas Fire on surface flows and groundwater levels from January 2018 through Spring 2020.
- Four (4) additional scenarios to be determined by the Water Boards after consideration of TAC and stakeholder input.

7. NITROGEN TRANSPORT MODEL DEVELOPMENT

This section describes how the groundwater nitrogen transport model will be developed. Datasets and sources for model inputs files and calibration are described below, as well as the calibration process and goals. The modeling calibration and validation periods will be the same as used for the GSFLOW model described in Section 6.1. Specifically, there will be a 21-year calibration period (WY1994 through WY2014) and a three-year validation period (WY2015 through WY2017).

7.1 Mass Balance Approach

The emphasis of the nitrogen modeling will be characterizing nitrogen loading from OWTS effluent, ranching activities, and agricultural fertilizer and irrigation to groundwater. The model will also simulate how nitrogen in groundwater may be transported to surface water. A mass balance approach (e.g., Viers et al., 2012), considering the sources of nitrogen listed above, together with estimates for natural soil levels, atmospheric deposition of nitrogen, nitrogen fixation by plants, uptake of nitrogen by plants, and loss of nitrogen to the atmosphere, will be used to estimate the loading and transformation of nitrogen from the soil zone[18] to groundwater in the subsurface[19]. This relatively simple mass balance approach has been shown to be comparable to more complex two- and three-dimensional modeling approaches in terms of yielding estimates for nitrogen loading to groundwater (Botros et al., 2012).

The mass balance will consider nitrate, nitrite, ammonia, and organic nitrogen, but will assume that the species are converted to nitrate form by the time it is transported to the groundwater (Harter, 2017; Viers et al., 2012). Therefore, the MT3D-USGS groundwater model will only model nitrate. This approach is generally supported by the limited available ammonia data (three data points from three different wells) that indicate non-detects in the groundwater (State Water Board Groundwater Ambient Monitoring and Assessment Program [GAMA]). The approach will be further confirmed as sampling results for nitrate, nitrite, ammonia, and total nitrogen at approximately 20 groundwater locations

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[18] The soil zone is defined with respect to the GSFLOW terminology in Figure 3-1. The soil zone is not modeled explicitly with MODFLOW + MT3D-USGS, but will rather be accounted for using a mass balance approach.

[19] The subsurface comprises the unsaturated and saturated zones, as defined with respect to the GSFLOW terminology in Figure 3-1. The subsurface is modeled by MODFLOW + MT3D-USGS.

become available from the ongoing VCEHD OWTS Study. If necessary, the model will also consider nitrogen lost from the system due to denitrification.

7.2 Implementing Flows from GSFLOW into MT3D-USGS

MT3D-USGS will be the modeling platform for groundwater nitrate transport simulations (Bedekar et al. 2016). MT3D-USGS is a solute transport model designed to be run in conjunction with MODFLOW. MT3D-USGS represents saturated and unsaturated-zone transport, advection, dispersion, solute exchange between groundwater and surface water, transport within streams and lakes, chemical reactions and degradation, and sorption of solutes to aquifer media. MT3D-USGS will be used to simulate nitrate loading from land sources and transport through the unsaturated zone and groundwater. In cases where groundwater flow discharges to surface water, MT3D-USGS will represent loading of nitrate from groundwater to surface water.

MT3D-USGS is not directly compatible with GSFLOW (Morway, 2017), but rather is designed to run with output from MODFLOW-only, including a designated output 'linker' file that provides flow information to MT3D-USGS from MODFLOW. Therefore, a separate MODFLOW model will be developed for the purpose of linking to 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 the surface water and groundwater will be determined from the calibration of the integrated GSFLOW model described in Section 6). Custom coding will be used to assign MODFLOW boundary conditions from the calibrated GSFLOW model. For example, PRMS-assigned recharge from precipitation and irrigation will be converted to the format of the MODFLOW RCH package. In this way, the MODFLOW model will be fully consistent with the flow terms in the calibrated GSFLOW model and will also allow for application of MT3D-USGS.

In addition to the flow boundary conditions that will be extracted from the calibrated GSFLOW model, the MT3D-USGS model will require nitrate concentrations to be specified at the top of the subsurface (for fluxes from the soil zone) and for surface water percolation. These concentrations will be estimated from mass balance calculations as described above, and surface water concentrations, using data described below.

7.3 Datasets and Sources

A range of datasets (see Table 7-1) will be used to determine inflow nitrate concentrations from the soil zone (not modeled in MT3D-USGS) to groundwater and from surface water in losing stream reaches. Additional datasets, such as measured dry weather surface water nitrate loads, will be used for model calibration to verify that the model is able to represent the watershed nitrate mass balance and predict transport of nitrate from groundwater to surface water in gaining reaches. The data will be described in more detail in an upcoming data compilation report (see Section 8 for more information).

7.3.1 Nitrate Concentrations from the Soil Zone to Groundwater

Because direct measurements of nitrogen concentrations in the soil zone pore-water are not available, mass balance calculations (described above) will be made based on available nitrogen data from within the watershed, and published data on nitrogen loading from contributing sources to the subsurface. The goal of these calculations will be to estimate the nitrate concentrations that reach groundwater in MT3D-USGS for different land use types, such as urban, open land, and agriculture (likely for one representative crop), while also including specific information and data, such as those related to nitrogen loadings from OWTS (see Section 4.3.4 and Figure 4-8).

Multiple sources of nitrogen to the soil zone must be considered to estimate nitrogen concentrations from the soil zone to the subsurface. These sources and data used to characterize them include fertilizers from residential and commercial landscaping, fertilizers from agricultural crops, animal manure from agricultural crops and horse facilities, OWTS effluent, sanitary sewer leaks, and background loading from natural soils and atmospheric deposition (Table 7-1). In addition, the mass balance calculations will require estimates of the uptake of nitrogen by crops and plants in the soil zone (Table 7-2). The outcome of the mass balance calculations will be an estimate of the nitrate load from the soil zone to groundwater as a function of land use. Land use in the MT3D-USGS model will be the same as used for the GSFLOW model (see Section 0). The nitrate loads will be converted to concentrations and applied with the flow rates determined from the integrated GSFLOW model Table 7-2, as described in Section 7.2.

It is recognized that the mass balance calculations may include some uncertainty (e.g., due to ranges in literature values for nitrogen applications, farming practices, sewer and OWTS exfiltration, plant uptake rates, timing of fertilizer application, and antecedent soil moisture), and as such, bracketed ranges of nitrogen loads and concentrations to the subsurface groundwater may be developed. Mid-range values will be chosen for initial model development, and if necessary, these will be adjusted and refined during the calibration process (see Section 7.4).

Table 7-1 Data Anticipated to be Used to Develop, Calibrate, and Validate the Nitrogen Transport Model For Mass Balance Calculations to Estimate Nitrogen Concentrations From the Soil Layer to the Subsurface Layer In MT3D-USGS

Need for Nitrogen Transport Model	Anticipated Data to be Used
Nitrogen loading from urban areas	Literature values for residential and commercial fertilizer application
Nitrogen loading from agriculture fertilization	Literature values for nitrogen application rates by crop type in California and nitrogen fixation from leguminous crops if applicable
Nitrogen loading from animal manure	Published manure application by crop type and loading from horse facilities
OWTS loading	OVSD nitrogen data, published nitrogen removal for OWTS
Nitrogen loading from sanitary sewer leaks	Published sewer exfiltration rates
Nitrogen loading from background sources (natural soils and atmospheric deposition)	Published nitrate concentrations for groundwater in natural areas not impacted by upgradient/upstream development
Nitrogen uptake rates by plants and crops	Published literature values

OVSD = Ojai Valley Sanitation District
OWTS = onsite wastewater treatment systems

Table 7-2 Data Anticipated to be Used to Develop, Calibrate, and Validate the Nitrogen Transport Model For Modeling Nitrate Transport Through the Subsurface In MT3D-USGS

Need for Nitrogen Transport Model	Anticipated Data to be Used
Flow rates to the land surface and groundwater	Output from integrated GSFLOW model
Nitrate concentrations from the soil zone to subsurface groundwater	Published literature and mass balance calculations from above
Surface water nitrogen concentration data (ammonia, nitrate, nitrite, and total nitrogen) in losing reaches	OVSD, VCWPD, CEDEN, CMWD, VCAILG, SBCK

CEDEN = California Environmental Data Exchange Network
CMWD = Casitas Municipal Water District
MT3D-USGS = Groundwater Solute Transport Simulator
SBCK = Santa Barbara Channel Keeper
VCAILG = Ventura County Agricultural Irrigated Lands Group
VCWPD = Ventura County Watershed Protection District

Table 7-3 Data Anticipated to be Used to Develop, Calibrate, and Validate the Nitrogen Transport Model to Calibrate/Validate Nitrate Transport In MT3D-USGS

Need for Nitrogen Transport Model	Anticipated Data to be Used
Surface water nitrogen concentration data in gaining reaches	OVSD, VCWPD, CEDEN, CMWD, VCAILG, SBCK
Groundwater nitrate concentration data	VCWPD, State Water Board GAMA
Surface water and groundwater nitrogen concentration data (ammonia, nitrate, nitrite, and total nitrogen), nitrate isotope ratios, and chemical sewage markers (PPCPs)	VCEHD (Study of Water Quality Impairments attributable to OWTS in the Ventura River Watershed)

GAMA = Groundwater Ambient Monitoring and Assessment Program
PPCP = Pharmaceuticals and Personal Care Products
VCEHD = Ventura County Environmental Health Department

7.3.2 Nitrate Concentrations from Surface Water to Groundwater

Nitrogen inputs to the groundwater from surface water in losing reaches (i.e., where there is a net loss of surface water to groundwater) will be incorporated as boundary conditions to the MT3D-USGS model using measured surface water nitrogen concentrations, coupled with flow rates from the integrated GSFLOW model (see Section 7.2). Surface water nitrogen concentration data are available from more than 50 locations in the watershed, as indicated in Figure 7-1, and include data from Ojai Valley Sanitary District, VCWPD, California Environmental Data Exchange Network (CEDEN), CMWD, VCAILG, and Santa Barbara Channel Keeper (see Table 7-2).

7.3.3 Data to be Used for Calibration

Surface water nitrate concentration data (Figure 7-1) in gaining reaches (i.e., where there is a net gain of surface water from groundwater) and groundwater nitrate concentration data (Figure 7-2) will be used to compare to the MT3D-USGS model output for calibration purposes as described in Section 7.4. The groundwater nitrate data are from the VCWPD and Water Boards GAMA, as summarized in Table 7-3.

Other key information that will be used to inform the calibration, specifically the nitrate in the surface water and groundwater attributable to OWTS, are the results of the ongoing VCEHD Study of Water Quality Impairments from OWTS in the Ventura River Watershed, using isotope ratios and chemical sewage markers. Geosyntec is managing this State grant-funded study in coordination with VCEHD. Results of this study were released in 2018 (Geosyntec, 2018).

7.4 Calibration Approach and Parameters

Nitrate-transport simulations will be calibrated by comparison of simulated values in the groundwater model to available data from groundwater monitoring wells and by comparison of simulated and observed values in the surface water in gaining reaches.

Initial nitrate-transport calibration will consist of adjusting the following transport parameters:

- Dispersivity;
- Effective porosity;
- Decay rates (e.g., denitrification rate); and
- Nitrate concentrations from the soil layer (see Section 7.3.1).

If necessary to obtain an adequate calibration, additional parameters may be considered for adjustment in consultation with the Water Boards, including the hydraulic conductivity and storage coefficient values assigned in the original GSFLOW flow model. If hydraulic conductivity and storage coefficient values are adjusted, this will necessitate revisiting the original flow model calibration to ensure that adjusted values are within acceptable limits and adjustment does not result in the flow-model calibration falling outside of designated calibration goals (Section 6.3.2).

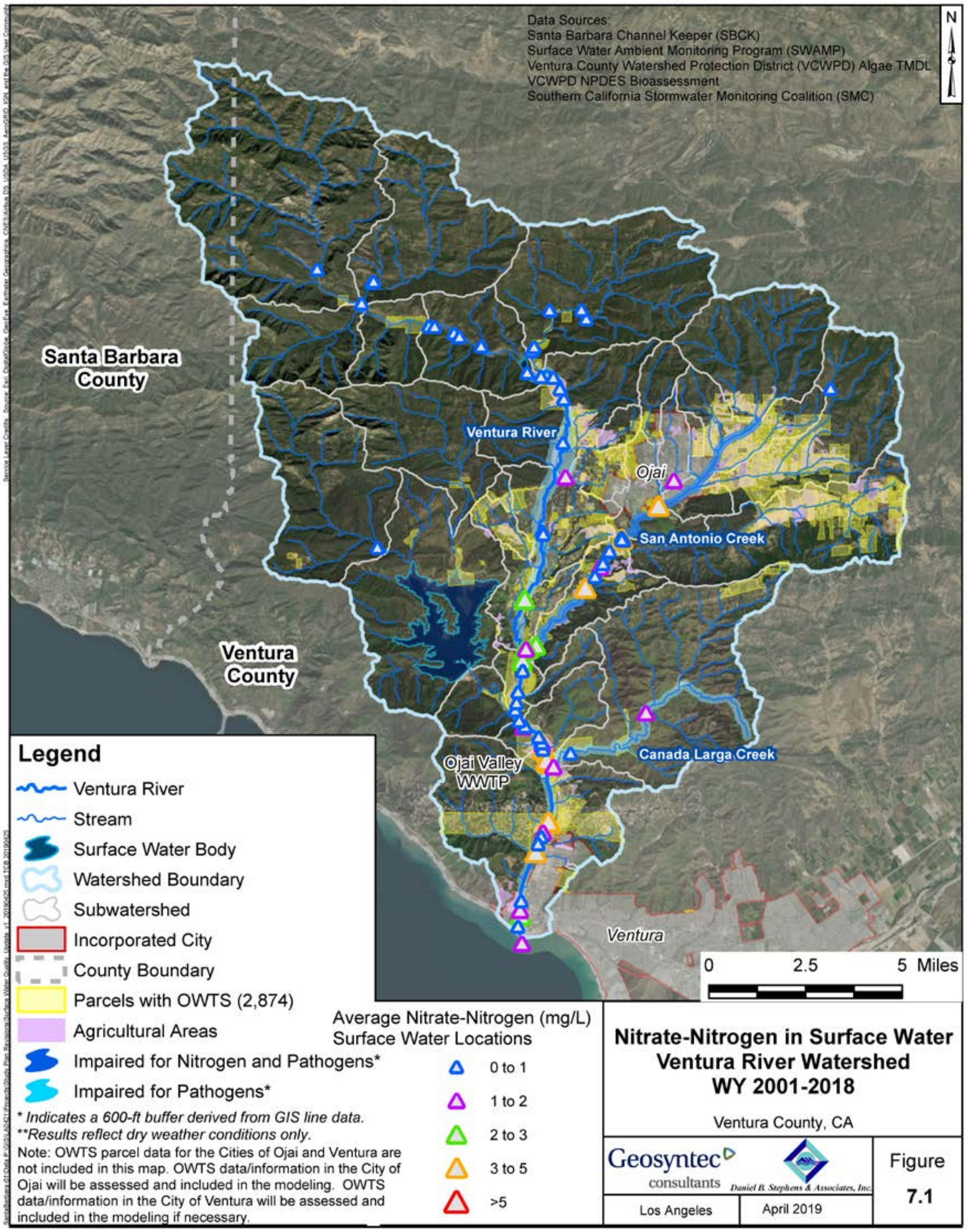

Figure 7-1 Nitrate-Nitrogen in Surface Water, Ventura River Watershed, Water Year 2001-2018

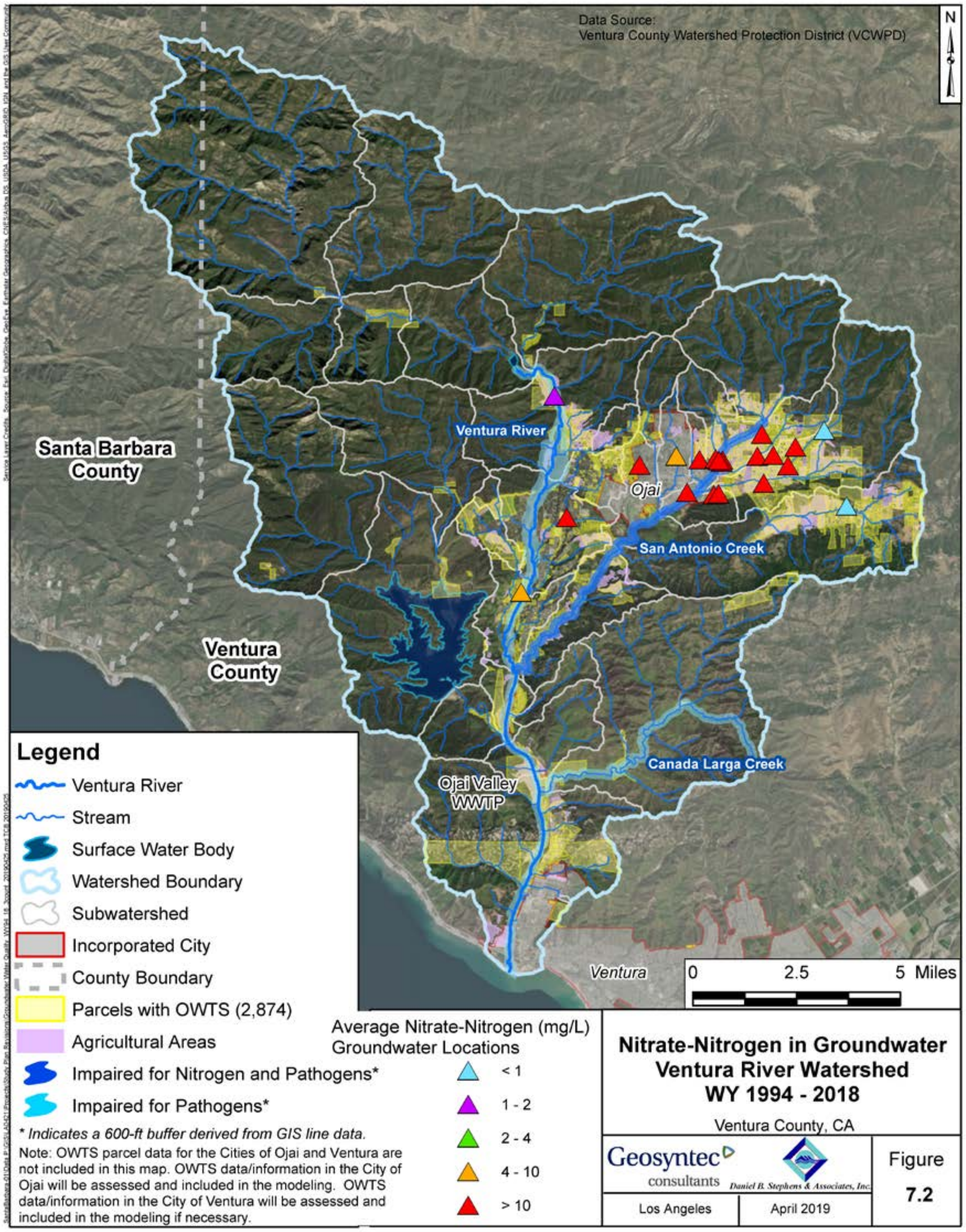

Figure 7-2 Nitrate-Nitrogen in Groundwater, Ventura River Watershed, Water Year 1994 - 2018

7.5 Calibration Goals

The objective of model calibration will be to minimize the difference between simulated and observed nitrate concentrations in groundwater. Nutrient calibration results will be presented in terms of the statistical measures ME, MAE, RMSE, and R, as described in Section 6.3.2. The calibration goal for nutrients will be a scaled RMSE (RMSE divided by the observed range in nutrient concentrations in the watershed) (Zheng et al., 2012; Hill and Tiedeman, 2007) of less than 20 percent. For example, if the total range in nitrate concentrations in the watershed is 5 mg N/L, the calibration goal will be a RMSE of less than 1 mg N/L.

7.6 Sensitivity Analysis

A sensitivity analysis of the calibrated and validated Nutrient Transport model will be performed. The analysis approach will be established during the model development and calibration and is anticipated to follow similar procedures to that used for the GSFLOW model (Section 6.4), but will consider variation of parameters and inputs specific to the nitrogen transport. These parameters and inputs will be varied systematically using the final calibrated model (existing conditions) as the "base run." The methodology will compare outputs from the sensitivity runs with the base run, both visually via time-series plots and quantitatively via tabulation of relevant metrics (e.g., relative or absolute changes in nitrogen concentrations/loads at key locations).

7.7 Nutrient Transport Model Scenarios

The Project Team will use the calibrated and validated MT3D-USGS model to evaluate and document four scenarios that will each simulate the mass loading and travel time of nutrients from groundwater to surface water. These scenarios will be defined later in the project and may include some scenarios evaluated using GSFLOW (Section 6.5) and/or implementation of TMDL-required nitrogen load reductions. Scenarios not covered in the current project can be modeled by Water Boards staff or stakeholders in the future.

8. OUTREACH ANTICIPATED APPROACH AND TIMEFRAME

The Water Boards are committed to a transparent model development process. The Water Boards held TAC meetings on November 28, 2017 and September 24, 2018, to solicit feedback on the Draft Study Plan for the Development of an Integrated Groundwater-Surface Water Model of the Ventura River Watershed and Draft Geologic Analysis of the Ventura River Watershed, respectively (Geosyntec and DBS&A, 2017; DBS&A, 2018). Both meetings were held at the Oak View Park and Resource Center in Oak View, CA. The Water Boards will continue to solicit the TAC and the public for critical review and feedback throughout model development.

Table 8-1 provides an anticipated approach and timeframe for TAC and public review opportunities.

Table 8-1 Anticipated Approach and Timeframe for TAC and Public Review of Model Development Deliverables

Deliverable	Anticipated Approach for TAC Review	Anticipated Approach for Public Review	Anticipated Timeframe
Data compilation report	30-day TAC comment period, no TAC meeting	30-day public comment period and presentation at Ventura River Watershed Council	2020
Memo describing methodology for GSFLOW sensitivity analysis	30-day TAC comment period, no TAC meeting	30-day public comment period	2020
Memo describing methodology for GSFLOW scenario evaluation	30-day TAC comment period and TAC meeting	30-day public comment period and presentation at Ventura River Watershed Council	2020
GSFLOW calibration and validation update (no report)	TBD	TBD	2020
Calibrated and validated GSFLOW and MT3D-USGS models and model development report	60-day TAC comment period and 2-day local training event	60-day public comment period and presentation at Ventura River Watershed Council	Spring 2021

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