Work Plan: Santa Maria and Cuyama Rivers Watershed Hydrology Model Development

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ACRONYMS

3DEP	3D Elevation Program
ALWU	Agricultural Land use & Water Use
ASCE-PM	American Society of Civil Engineers version of the Penman-Monteith equation
CAL FIRE	California Department of Forestry and Fire Protection
CDEC	California Data Exchange Center
CDL	Cropland Data Layer
CDT	California Department of Technology
CIMIS	California Irrigation Management Information System
CoCoRaHS	Community Collaborative Rain Hail and Snow Network
COOP	Cooperative Observer Program
DEM	Digital Elevation Model
DWR	California Department of Water Resources
ET	Evapotranspiration
ET_0	Reference evapotranspiration
eWRIMS	Electronic Water Rights Information Management System
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
GSA	Groundwater Sustainability Agency
HRU	Hydrologic Response Unit
HSG	Hydrologic Soil Group
HSPF	Hydrologic Simulation Program - Fortran
HUC	Hydrologic Unit Code
LCD	Local Climatological Data
LSM	Land Surface Model
LSPC	Loading Simulation Program in C++
MODFLOW	USGS Modular Hydrologic Model
MRLC	Multi-Resolution Land Consortium
NCEI	National Centers for Environmental Information
NHD	National Hydrography Dataset
NID	National Inventory of Dams
NLCD	National Land Cover Database
NLDAS	North American Land Data Assimilation System
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Model Efficiency Coefficient
PBIAS	Percent Bias
PEVT	Potential Evapotranspiration

POD	POINT OF DIVERSION
PRISM	PARAMETER-ELEVATION REGRESSIONS ON INDEPENDENT SLOPES MODEL
RAWS	REMOTE AUTOMATED WEATHER STATIONS
SFEI	SAN FRANCISCO ESTUARY INSTITUTE
SGMA	SUSTAINABLE GROUNDWATER MANAGEMENT ACT
SSURGO	SOIL SURVEY GEOGRAPHIC DATABASE
STATSGO2	STATE SOIL GEOGRAPHIC DATABASE
SWAT	SOIL AND WATER ASSESSMENT TOOL
SWRCB	STATE WATER RESOURCES CONTROL BOARD
USDA	UNITED STATES DEPARTMENT OF AGRICULTURE
USFS	UNITED STATES FOREST SERVICE
USGS	UNITED STATES GEOLOGICAL SURVEY
WBD	WATERSHED BOUNDARY DATASET

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1 INTRODUCTION

1.1 Project Objectives

In April 2021, Governor Gavin Newsom issued a state of emergency proclamation for specific watersheds across California in response to exceptionally dry conditions throughout the state. The April 2021 proclamation, as well as subsequent proclamations, directed the State Water Resources Control Board (Water Board) to address these emergency conditions to ensure adequate, minimal water supplies for critical purposes. To support Water Board's actions to address emergency conditions, hydrologic modeling and analysis tools are being developed to contribute to a comprehensive decision support system that assesses water supply and demand and the flow needs for watersheds throughout California.

This work plan presents the available data and methodology that will be used to develop a hydrologic model of the Santa Maria and Cuyama Rivers watershed. This model will use historical records of precipitation, temperature, and evapotranspiration (ET) for simulation of processes associated with surface runoff, infiltration, interflow, and groundwater flow. The final calibrated model will be used to evaluate scenarios including current hydrologic conditions, water allocation, changes in demand, and the impact of extreme events such as droughts or atmospheric rivers.

1.2 Watershed Background

The Santa Maria and Cuyama Rivers watershed is composed of two eight-digit hydrologic unit codes (HUC): Santa Maria River (HUC 8: 18060008) and Cuyama River (HUC 8: 18060007). Combined, a few of the boundaries they share include the Central Coastal watershed to the northwest, San Antonio watershed to the southwest, and Santa Ynez watershed to the south. Santa Maria and Cuyama Rivers is a coastal watershed that drains approximately 1828 square miles and is composed of fifty-nine HUC-12 subwatersheds: Corralitos Canyon (180600080503), Manzana Creek (180600080301), and Santa Barbara Canyon (180600070202) are a few shown in **Error! Reference source not found.**. Santa Maria is a free-flowing river with 19 principal tributaries: most notable are the Sisquoc River, Tebusquet Creek, Orcutt Creek, La Brea Creek, and Manzana Creek. From its confluence at the Sisquoc and Cuyama Rivers, the river flows west before reaching the City of Santa Maria and drains to the Pacific Ocean.

The Santa Maria and Cuyama Rivers watershed ranges in elevation from near sea level near the outlet to over 2,600 meters at the easternmost portion of the watershed near Los Padres National Forest. The watershed has a Mediterranean climate with distinct wet and dry seasons and a mean annual precipitation total of 14 in. (CSWRCB 2024). The watershed is dominated by shrub/scrub (55%) and grassland/herbaceous (22%) areas. Other land cover types include cultivated crops (5%), evergreen forest (6%), mixed forest (5%), and developed (4%).

The Santa Maria and Cuyama Rivers watershed is an important habitat for both non-anadromous rainbow trout and anadromous steelhead. A critical spawning and rearing tributary within the Santa Maria and Cuyama Rivers watershed system is the Sisquoc River (Booth et al. 2014). The Sisquoc converges with the flow-regulated Cuyama River, in the north of Santa Maria and Cuyama Rivers watershed. Twitchell Dam, located on the Cuyama River, is operated primarily for groundwater recharge and flood control (CSBPW 2025) which limits surface flows through Santa Maria River—flows that are essential for steelhead migration between the ocean and upstream habitat. Although the Santa Maria River is naturally intermittent, dam operations have further restricted the frequency,

timing, and duration of fish-passable flows. In a recent U.S. Supreme Court decision, Twitchell Dam operations were found to be subject to the requirements of the Endangered Species Act and must now ensure the protection of the endangered steelhead population (EDC 2023). In addition to hydrologic barriers, the Santa Maria River is impaired by multiple pollutants, including metals, pesticides, nutrients, toxicity, and pathogens. The primary sources of these impairments are agricultural and urban runoff as well as stormwater discharges (CSWRCB 2024).

The Santa Maria River exhibits substantial variability in its hydrology. Upstream of Highway 1, the river is dry for most of the year, flowing intermittently in a braided pattern during and shortly after rainfall events, and during releases from Twitchell Dam. Downstream from Highway 1, shallow surface water is almost always present and riparian vegetation is more prevalent. Flows observed during the dry season above Highway 1 are largely a result of agricultural or urban runoff, and releases from Twitchell Dam that are conducted for the purpose of recharging the Santa Maria groundwater basin. Alternatively, flows observed downstream from Highway 1 during the dry season are due primarily to agricultural and urban runoff, as well as emergence of subsurface flow (SAIC 2004).
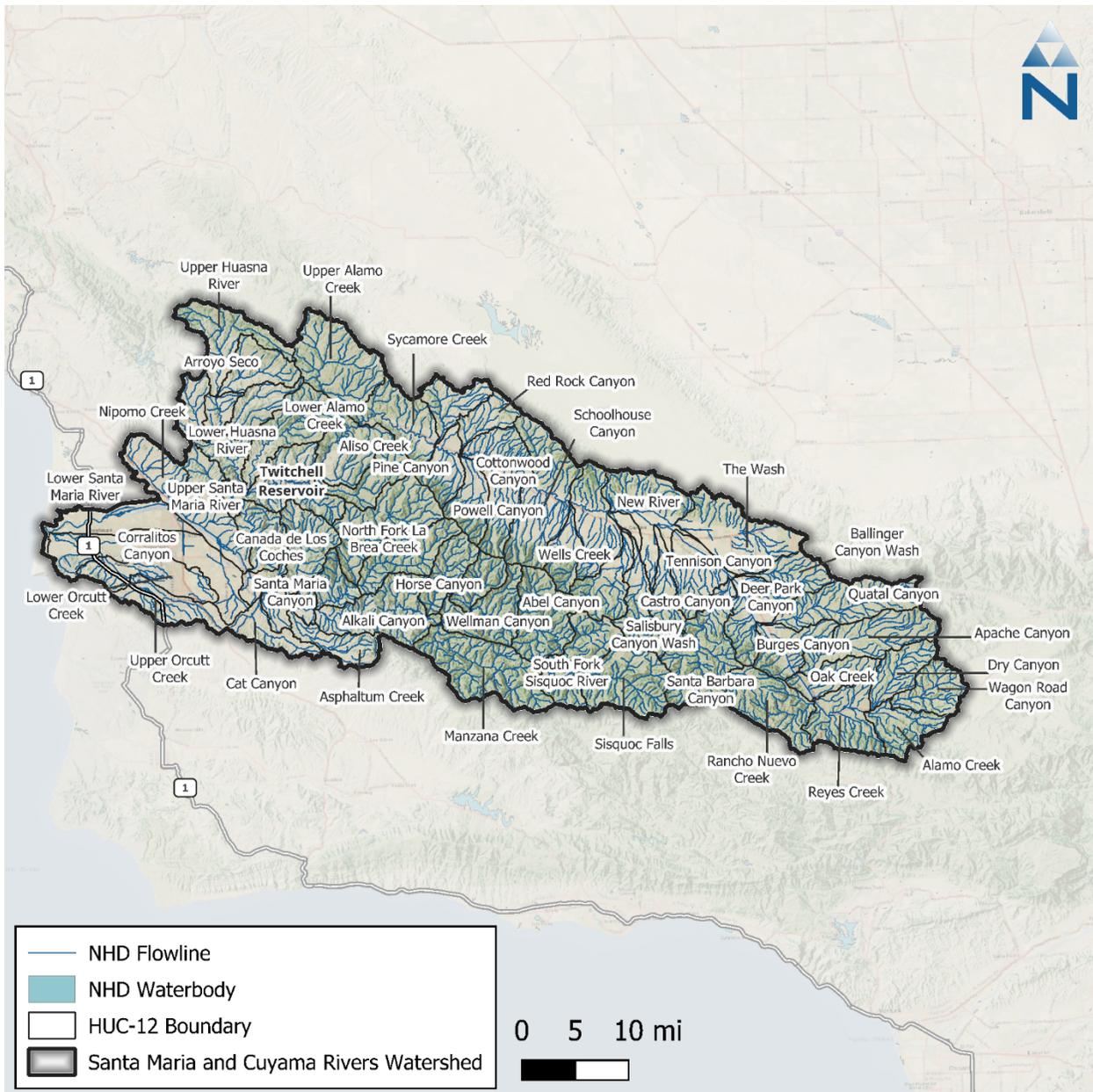
Figure 1-1. Santa Maria and Cuyama Rivers watershed.

1.3 Model Approach

The primary goal of this work plan is to outline an approach with sufficient robustness to support an analytical assessment of the Santa Maria and Cuyama Rivers watershed. This is presented first through a comprehensive inventory of available meteorological, hydrological, and geographic information system (GIS) data available for the Santa Maria and Cuyama Rivers watershed. The data compilation and assessment processes are outlined below and aim to highlight any existing data gaps that create limitations for the analysis. Based on the available data, any data gaps are identified that may be filled through additional outreach, data collection efforts, or noted as points of uncertainty in the model documentation.

This hydrologic analysis is based on a model development process that has been a tested platform for gaining valuable information and insight about hydrologic systems. The model development process proposed is an iterative and adaptive cycle that improves understanding of the system over time as better information becomes available. Figure 1-2 is a conceptual schematic of the proposed model development cycle, which is represented as circular as opposed to linear. The cycle is best summarized by the following six interrelated steps:

1. **Assess Available Data**: Data for source characterization, trends analysis, and defining modeling objectives.

2. **Delineate Model Domain**: Model segmentation and discretization needed to simulate streamflow at temporal and reach scales appropriate for assessing supply and demand.

3. **Set Required Model Inputs**: Spatial and temporal model inputs defining the appropriate hydrologic inputs and outputs.

4. **Represent Processes (Calibration)**: Adjustment of model rates and constants to mimic observed physical processes of the natural system.

5. **Confirm Predictions (Validation)**: Model testing with data not included in the calibration to assess predictive ability and robustness.

6. **Assess Applicability for Scenarios**: Sometimes the nature of modeled responses can indicate the influence of unrepresented physical processes in the modeled system. Sometimes that can be resolved with minor parameter adjustments, while other times the assessment exposes larger data gaps. A well-designed model can be adapted for future applications as new information about the system becomes available. Depending on the study objectives, data gaps sometimes provide a sound basis for future data collection efforts to refine the model. New information may require minor parameter adjustments affecting the configuration or calibration.
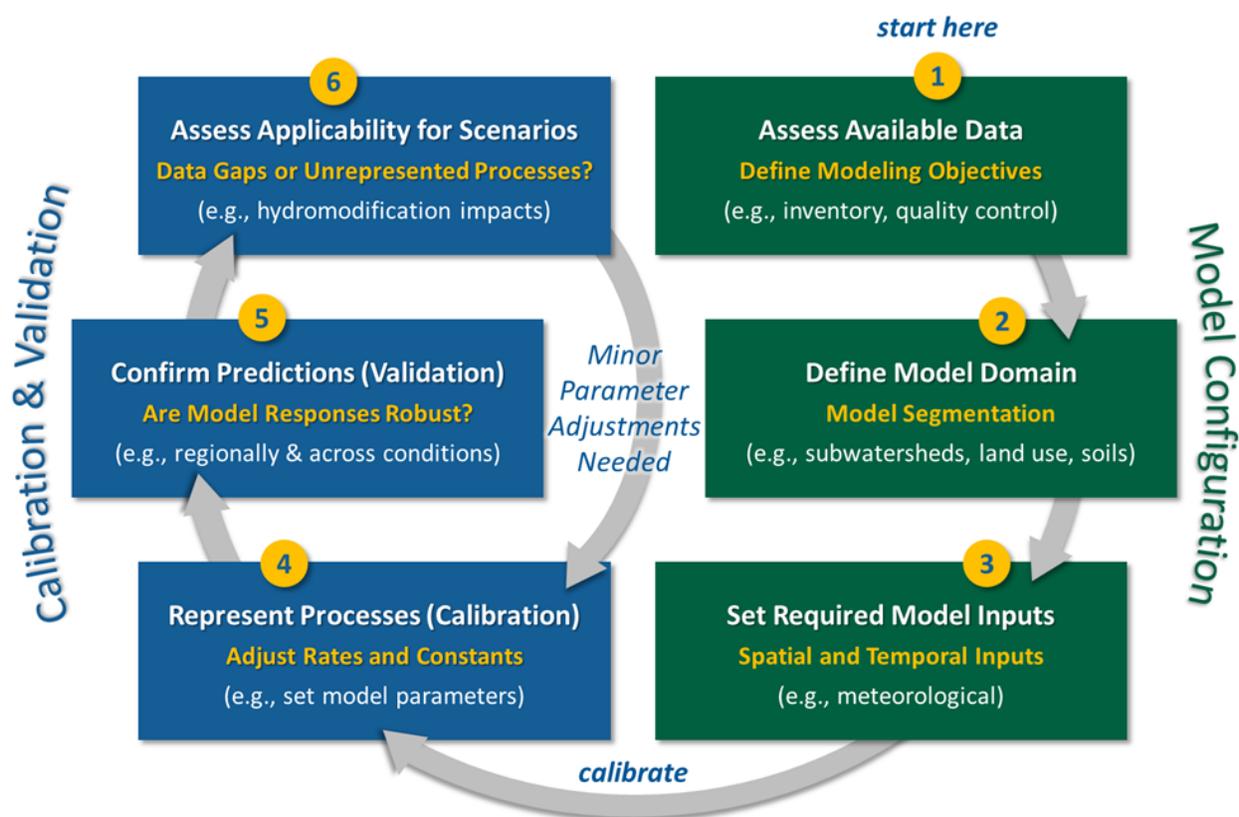
Figure 1-2. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Santa Maria and Cuyama Rivers watershed.

1.4 Data Availability

Table 1-1 through Table 1-4 present an inventory of the initial data collected that will form the basis of this modeling workplan. These datasets were compiled from readily available sources, primarily those publicly available and published online by state and federal agencies. The data in the tables are organized by data type as listed below and described further in the following sections.

▼ **Meteorology Datasets**: Time series that represent water balance inputs and outputs to the watershed primarily from precipitation and ET. These time series are often used as forcing inputs for hydrologic models.

▼ **Surface & Groundwater Datasets**: Datasets describing stream flow, groundwater, water use, and stream conditions for the Santa Maria and Cuyama Rivers. Time series observations of instream responses for the Santa Maria and Cuyama Rivers are often used as calibration and validation datasets for hydrologic models.

▼ **Geospatial Datasets**: Spatial datasets describing the landscape of the Santa Maria and Cuyama Rivers watershed. These datasets include physical properties (e.g., soil, land cover, elevation).

Table 1-1. Inventory of meteorology datasets

Source	Dataset	Date Range	Description	Model Use
National Centers for Environmental Information (NCEI)	Global Historic Climate Network (GHCN)	--	Daily precipitation and temperature data (varied data quantity/quality).	Rainfall input boundary time series.
NCEI	Local Climatological Data (LCD)	--	Hourly precipitation, temperature, wind speed, dewpoint, cloud cover.	Rainfall input boundary time series.
Remote Automated Weather Stations (RAWS)	Hourly Climate Data	--	Meteorological records are available for twelve stations.	Climate data boundary time series.
California Data Exchange Center (CDEC)	Precipitation, Temperature	--	Meteorological records are available for nine stations.	Rainfall input boundary time series.
PRISM Climate Group	AN81m Monthly	1900- Present	4-km grid resolution time series of precipitation (1900 – present).	Rainfall time series QA; address rainfall data gaps.
North American Land Data Assimilation System (NLDAS)	NLDAS-2 Forcing Data	1979 - Present	1/8th-degree grid resolution hourly time series of precipitation and other surface parameters (e.g., potential evapotranspiration (PEVT), and solar radiation).	Rainfall hourly distributions; address rainfall data gaps. Daily PEVT totals × hourly solar radiation distributions.
Earth Observing Laboratory (EOL)	Daily/Hourly Gridded Precipitation	--	Various gridded precipitation time series; both daily and hourly time steps.	Rainfall hourly distributions; address rainfall data gaps.
California Irrigation Management Information System (CIMIS)	Reference ET	1990 – Present	Relative ET spatial zones and monthly scaling factors. There is also a grid-based model data product.	Deriving PEVT input forcing time series; estimation of irrigation demand.
OpenET	OpenET CONUS Ensemble Monthly ET	2016 - 2024	Satellite-based estimates (30-m res) of observed monthly ET for the CONUS; data is bias corrected against observational weather station networks.	Parameterization & evaluation of ET; estimation of irrigation demand.

Table 1-2. Inventory of surface water datasets

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Streamflow	Local	United States Geological Survey (USGS)	Stream Station Discharge	1941 – Current	Observed Streamflow at seven active locations on the Santa Maria and Cuyama Rivers.	Hydrology calibration.	LINK
		CDEC	Reservoir Storage Data	2021- Current	Observed storage data at Twitchell Dam near Twichell Reservoir.	Hydrology calibration.	LINK
		National Inventory of Dams (NID)	Dams of the United States	Current	Locations for dams across the United States.	Hydrology calibration.	LINK
Streamflow	Local	CSWRCB	Santa Maria River Total Maximum Daily Load for Toxicity and Pesticides	2014	Report that documents USEPA approves the Santa Maria Pesticide and Toxicity TMDL	Hydrology calibration & validation.	LINK
Water Budget	State	DWR	Well Completion Reports	Current	Well completion logs and reports.	Water budget.	LINK
		SWRCB eWRIMS	Water Rights Points of Diversion (POD)	Current	Locations where water is being drawn from a surface water source such as a stream or river.		LINK
			Water Rights Overview Report	Current	This report will provide counts of various entities such as Applications, Registrations, Petitions etc. that will reflect the progress in processing such entities as of the current date.		LINK
			Annual Water Use Report	1906 – 2023	Annual reports that provide monthly diversion data for various entities such as Applications, Registrations, Petitions, etc.		LINK

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
		DWR	Agricultural Land and Water Use Estimates	1998 – 2015	Water use estimates by various planning units.		LINK
		CDT	Water Districts	2022	Boundaries of all public water agencies in California.		LINK
			California Drinking Water System Area Boundaries	2024	Public California drinking water systems and state small drinking water system boundaries and information.		LINK

Table 1-3. Inventory of geospatial datasets

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Watershed Boundaries	National	USGS	Watershed Boundaries Dataset (WBD)	2023	Hydrologic unit boundaries to the 12-digit (6th level).		LINK
Hydrology	National	USGS	National Hydrography Dataset (NHD) Plus High-Resolution National Release 1	2023	The NHDPlus HR combines the NHD, 3DEP DEMs, and WBD to create a stream network with linear referencing.	Model segmentation.	LINK
	National	USGS	NHD Best Resolution	2023	1:24,000; represents reaches and other network elements.		LINK
Soil	National	USDA NRCS	Grided Soil Survey Geographic Database (SSURGO)	2022	State-wide, 10-meter raster grid approximating the SSURGO vector dataset.	Represent infiltration process within land segments.	LINK
	National	USDA NRCS	Digital General Soil Map of the United States (STATSGO2)	2016	State-wide, 10-meter raster grid approximating the STATSGO2 vector dataset.	Represent infiltration process within land segments.	LINK

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Surficial Geology	National	USGS	The State Geologic Map Compilation (SGMC)	2017	1:1,000,000: Vector-based, state geologic map database.	As needed, hydrologic process with land segments.	LINK
Land Cover	National	MRLC	National Land Cover Dataset (NLCD) Land Cover	2021	Broad, 30 m grid-based land characterization. Differentiates developed land from coarse classifications of forest, cropland, wetlands, etc.	Land segment representation.	LINK
			NLCD Fractional Imperviousness	2021	Broad, 30-meter grid-based land characterization. Represent percent impervious area within raster cells.		LINK
Land Use	State	DWR	Statewide Crop Mapping	2020	Polygons attributed to DWR crop categories.	Identify crop distributions; estimate irrigation demand.	LINK
Vegetation	National	MRLC	Tree Canopy Cover	2021	Percent tree canopy estimates for each 30-meter pixel across all land covers and types.	Land segment representation.	LINK
	State	USFS	Existing Vegetation	2018	1:24,000 to 1:100,000: Existing vegetation mapping.	As necessary, additional vegetation types for model land segments.	LINK
Agriculture & Crop Cover	National	USDA	Cropland Data Layer	2022	30-meter grid-based crop-specific land cover data layer.	Identify crop distributions; estimate irrigation demand.	LINK
Timber Harvesting	National	USDA	Timber Harvests	1820 - Present	Area planned and accomplished acres treated as a part of the timber harvest program of work.	Representing changes in land cover due	LINK

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
	State	CAL FIRE	Nonindustrial Timber Management Plans TA83	1991 - Present	Timber management plans.	to timber harvest activities.	LINK
			Notices of Timber Operations TA83	1991 - Present	Notice of Timber Operations accepted by CAL FIRE.		LINK
			Working Forest Management Plans TA83	2019 - Present	Working forest management plans approved by CAL FIRE.		LINK
Fire Perimeters & Burn Areas	State	CAL FIRE	California Fire Perimeters	1950 - Present	Wildfire perimeters.	Representing changes in land cover due to forest fire activities.	LINK
Elevation	National	USGS	USGS ten-meter resolution digital elevation model (DEM)	2020	10-meter resolution DEM produced through the 3D Elevation Program (3DEP).	Land segment representation.	LINK

Table 1-4. Inventory of groundwater datasets

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Groundwater Basin Boundaries	State	DWR	DWR's Bulletin 118	2020	Groundwater basin boundaries represent alluvial basins delineated by DWR.	Groundwater domain.	LINK
Groundwater levels	State	DWR	Periodic Groundwater Level Measurements	2023	Groundwater levels.	Model calibration.	LINK
Geological information	State	DWR	Well Completion Reports (OSWCR)	2023	Geological information.	Groundwater stratigraphy and properties.	LINK

2 METEOROLOGY

Precipitation and ET are key components of the water balance and critical inputs for developing a hydrologic model. The following subsections describe the primary data sources for precipitation and ET.

2.1 Precipitation

The primary source of precipitation data for the Santa Maria and Cuyama Rivers watershed model will be the observed data from land-based stations within and in the vicinity of the watershed. However, any gaps in observed data from the land-based stations will be filled with grid-based data. This is referred to as the "hybrid" approach, which has been shown to improve model predictive capabilities by leveraging the strengths of both land-based and grid-based data. Use of a hybrid approach preserves locally sampled station data while increasing the spatial and temporal quantity and quality of data over the watershed. This approach has been applied for large watershed-scale modeling applications including the County-wide model for Los Angeles County (LACFCD 2020).

Land-based observed precipitation data are primarily acquired from the National Centers for Environmental Information (NCEI), which maintains data from the National Oceanic and Atmospheric Administration's (NOAA) climate networks including the Global Historic Climate Network (GHCN), the Cooperative Observer Program (COOP), and the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). These networks provide quality-controlled hourly or daily observed precipitation data. Eight GHCN stations were identified within or near the Santa Maria and Cuyama Rivers watershed, with each having a varied quantity and quality of data. In addition to the daily precipitation stations, NCEI also maintains the Local Climatological Data (LCD) network, which reports hourly observations. There is one LCD station within 15 km of the Santa Maria and Cuyama Rivers watershed. The California Data Exchange Center (CDEC) and the Remote Automated Weather Stations (RAWS) networks also report hourly precipitation. CDEC reports at nine locations and RAWS reports at twelve locations within and near the watershed.

In addition to precipitation data, snow data was also screened for the Santa Maria and Cuyama Rivers watershed model and yielded six GHCN stations within a 15km buffer (reference **Error! Reference source not found.**) that had some data (e.g., snowfall measurements) overlapping with the model time period. These stations can be further evaluated if needed; however, snow simulation is not expected to be required because of the relatively low elevations and negligible overall snow activity in this watershed.

Table 2-1 is an inventory of precipitation stations near the Santa Maria and Cuyama Rivers watershed with available data after 2000 with at least 75% data coverage during the modeling period. It also includes stations with 60% or more data coverage during the modeling period, provided that these stations have 90% or more station record coverage (station record coverage is defined as the percentage of available records that are not missing throughout the duration of the record) for the period overlapping with the modeling period. Additionally, all recently installed stations with at least 6 years of data (i.e., 30% or more model period availability) for the modeling period are included, as long as they have 90% or more station record coverage for their reported period overlapping with the modeling period. Lastly, any stations with no neighboring stations within a seven-kilometer buffer are included. However, these stations may not have sufficient data quality for use in model development. **Error! Reference source not found.** shows the location of the identified stations. There are five locations where CDEC and RAWS stations appear to be co-located (i.e., within 500 m radius) and one location

where GHCN and LCD stations appear to be co-located; these will be further assessed under Task 3.2 and the stations with the highest quality data will be chosen for use.

The primary source of the grid-based data for the Santa Maria and Cuyama Rivers watershed will be the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al. 2008, 1994; Gibson et al. 2002). PRISM is developed and maintained by the PRISM Climate Group at Oregon State University and provides gridded estimates of event-based climate parameters including precipitation, temperature, and dew point. The algorithm uses observed point data, a digital elevation model (DEM), and other spatial datasets to capture influences such as high mountains, rain shadows, temperature inversions, coastal effects, and other complex climatic regimes (Gibson et al. 2002). Because of its spatial and temporal resolution and consistency across the lower 48 contiguous United States (4-km spatial resolution for the AN81d daily/monthly time series dataset and 800-m for the AN81m long term averages), PRISM is a commonly used and widely accepted source for meteorological data for hydrologic models (Behnke et al. 2016). The subset of the PRISM grid that covers the current study area is shown in **Error! Reference source not found.**. To disaggregate the PRISM data to hourly, North American Land Data Assimilation System (NLDAS) data will be used. NLDAS is a quality-controlled land surface model (LSM) dataset of meteorological data designed specifically to support continuous simulation modeling activities (Cosgrove et al. 2003; Mitchell et al. 2004). NLDAS provides real-time hourly predictions of meteorological data required for LSPC at a 1/8th degree spatial resolution (about 8.625-mile intervals) for North America, with retrospective simulations beginning in January 1979. NLDAS has undergone rounds of refinement, extensive peer review, and performance validation through case study applications, all of which have demonstrated it to be a more robust predictor of variable meteorological conditions for continuous simulation modeling than using individual stations (Xia et al. 2012).

Table 2-1. Summary of precipitation stations with observations available after 2000

Agency	Station ID	Station Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Model Period Coverage (%)[1]	Station Record Coverage (%)[2]
GHCN	GHCND:USC00046154	NEW CUYAMA FIRE STN	1/1/1974	Present	34.9456	-119.683	658.4	89	89
	GHCND:USW00023273	SANTA MARIA PUBLIC AP	1/1/1948	Present	34.8942	-120.452	74.1	100	100
	GHCND:USC00049111	TWITCHELL DAM	3/1/1962	Present	34.9881	-120.321	177.4	92	92
	GHCND:USC00045107	LOS ALAMOS	1894-04-27	4/30/2008	34.7456	-120.28	172.2	19	85
	GHCND:US1CASL0022	ARROYO GRANDE 2.5 NW	4/22/2016	1/4/2017	35.155	-120.610	149.7	3	91
	GHCND:US1CASL0037	NIPOMO 1.2 NNE	12/11/2022	Present	35.0488	-120.474	112.2	4	95
	GHCND: US1CAKN0021	MARICOPA 0.4 WNW	10/1/2015	3/23/2018	35.0627	-119.407	276.1	2	14
	GHCND:USC00047672	SALINAS DAM	7/1/1948	Present	35.3372	-120.504	424.3	97	97
CDEC	ARG	ARROYO GRANDE	2/6/1989	Present	35.117	-120.417	182.9	97	97
	FIG	FIGUEROA	11/26/2001	Present	34.734	-120.007	975.4	87	87
	VAN	VANDENBERG	4/8/2002	Present	34.759	-120.486	320.0	86	86
	BMO	BRANCH MOUNTAIN	2/20/2001	Present	35.189	-120.083	1,149.1	90	90
	OZN	OZENA	11/26/2001	Present	34.682	-119.354	1,118.6	83	83
	BLM	BLACK MOUNTAIN	1/1/1987	Present	35.394	-120.353	1,104.9	96	99
	LPZ	LA PANZA	1/1/1984	Present	35.3806	-120.188	502.92	100	100
	AOM	ALAMO MOUNTAIN	10/10/2018	Present	34.6702	-118.98	2,042.2	21	84
	GMO	SAN GUILLERMO	10/16/2018	Present	34.6772	-119.17	1,566.1	24	98

Agency	Station ID	Station Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Model Period Coverage (%)[1]	Station Record Coverage (%)[2]
RAWS	VDBC1	VANDENBERG	3/30/2002	Present	34.759	-120.486	309.982	89	89
	FGMC1	FIGUEROA	11/22/2002	Present	34.734	-120.007	970.178	96	96
	TSQC1	TEPUSQUET	10/8/2015	Present	34.920	-120.181	975.360	38	96
	SXWC1	SEDGWICK	5/25/2017	Present	34.681	-120.047	427.330	31	99
	PUSC1	PURISIMA HILLS	2/22/2020	Present	34.712	-120.391	356.616	18	100
	CUVC1	CUYAMA VALLEY	5/17/2019	Present	34.965	-119.880	772.668	22	100
	CUUC1	CHUCHUPATE	2/17/1993	Present	34.8063	-119.014	1,609.3	99	99
	ROVC1	ROSE VALLEY	11/9/1993	Present	34.5433	-119.185	1,015.28	96	96
	LPZC1	LA PANZA	5/3/1990	Present	35.3807	-120.118	497.738	99	99
	CAZC1	CARRIZO	10/21/1991	Present	35.0965	-119.773	758.952	99	99
	OZNC1	OZENA	9/1/2001	Present	34.6817	-119.354	1,124.7	95	95
	BRHC1	BRANCH MOUNTAIN	5/16/1996	Present	35.1852	-120.085	1,149.1	94	95
LCD	WBAN:23273	SANTA MARIA PUBLIC AIRPORT, CA US	10/20/1954	Present	34.894	-120.452	74.2	100	100

1. Data coverage for LCD stations are LCD reported values which are reflective of data availability between the reported start date and end date in this table, not proportionally scaled to the modeling period (i.e., 10/2003 to 9/2023) when LCD's coverage period does not fully overlap with the modeling period. Data coverage for CDEC, GHCN, and RAWS are based on data availability for the modeling period (10/2003 to 9/2023). Data completeness will be further assessed under Task 3.2 and additional stations may be considered as needed.
2. Station record coverage is defined as the percentage of available records that are not missing from the Start Date to the End Date overlapping with the modeling period.
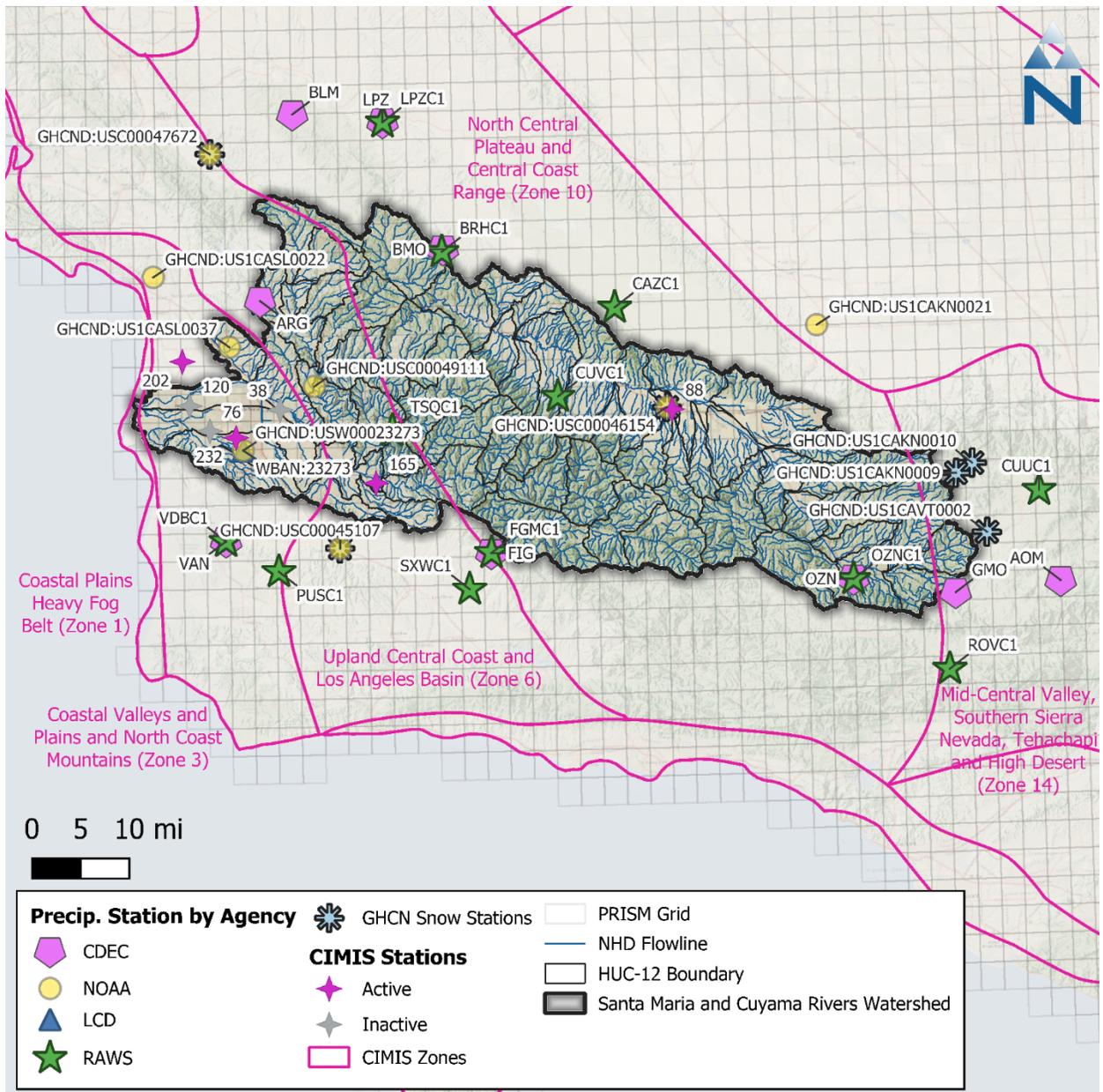
Figure 2-1. Identified rainfall stations and CIMIS ET Zones near the Santa Maria and Cuyama Rivers watershed.

The hybrid approach mentioned above entails three main steps. First, impaired intervals (i.e., missing, or accumulated) at observed stations will be patched with grid-based data. Second, the PRISM grid cells, and patched observed stations are mapped to the NLDAS grid cells to disaggregate the monthly PRISM and daily station data using normalized hourly data from NLDAS. Third, the disaggregated gridded meteorological data from PRISM are used to fill any remaining spatial gaps in the observed station network as needed. It should be noted that while PRISM gridded data also provides estimates of precipitation on a daily time step, using monthly PRISM totals for disaggregating with hourly observed data, as opposed to daily PRISM totals, eliminates the need to estimate distributions for instances where an hourly distribution does not coincide with a daily total.

Error! Reference source not found. presents a summary of the hybrid approach to blend observed precipitation with gridded meteorological products. Observed data and gridded products are to be

processed in parallel to: (1) create a temporally complete set of hourly distributions and (2) identify spatial gaps in coverage to be supplemented with disaggregated gridded data. Assuming a 10-km buffer around observed stations for this approach, the coverage shown in the lower right map in **Error! Reference source not found.** also shows what a hybrid dataset of observed time series, supplemented by gridded products would look like.
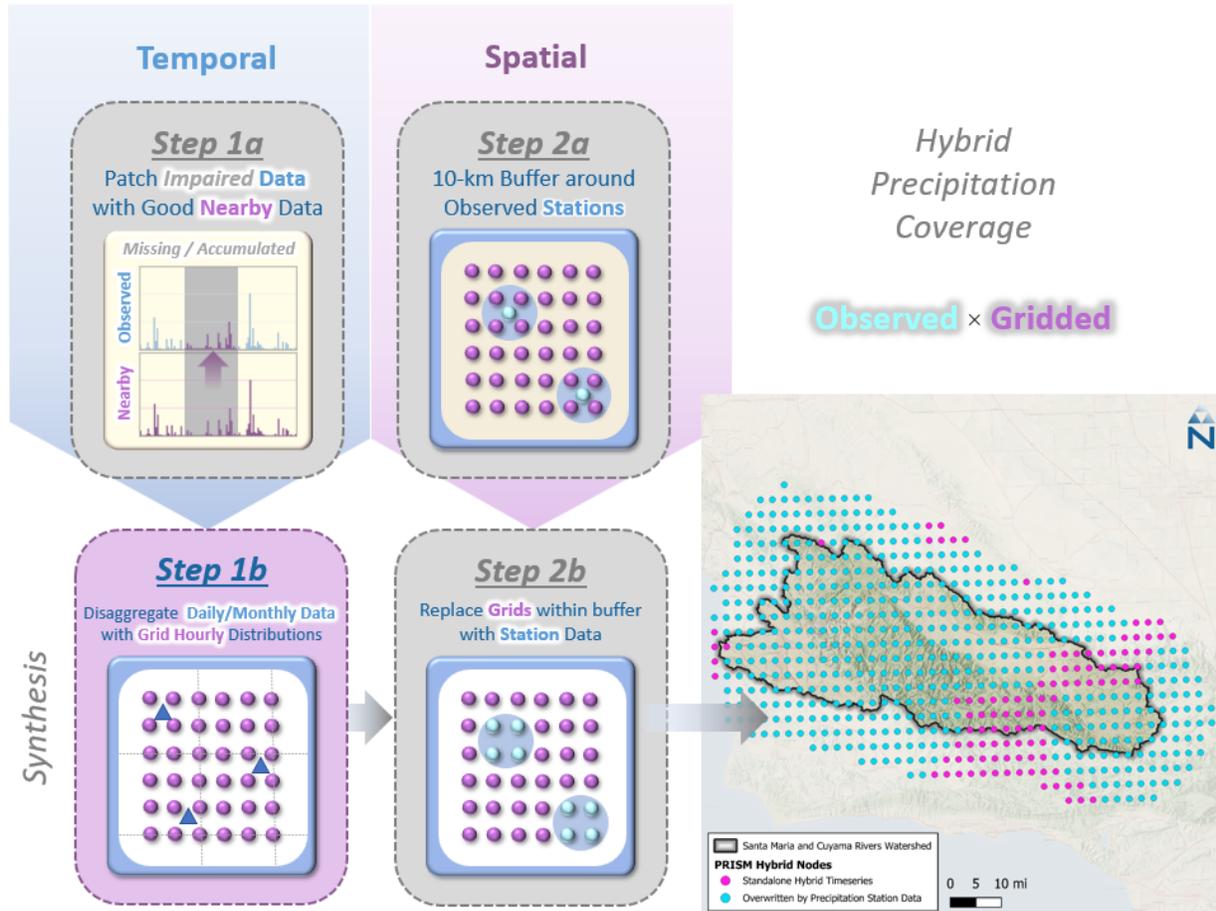

Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products.

2.2 Evapotranspiration (ET)

The primary ET dataset identified for consideration is CIMIS. CIMIS was developed in 1982 by the California Department of Water Resources (DWR) and the University of California, Davis. The network is composed of over 145 automated weather stations throughout California where primary weather data including temperature, relative humidity, wind speed, and solar radiation are monitored and quality controlled. Observations are measured over standardized reference surfaces (e.g., well-watered grass or alfalfa) and are used to estimate reference evapotranspiration (ET_o) using versions of the Penman and Penman-Monteith equations. CIMIS has divided California into 18 zones based on long-term monthly average ET_o values calculated using data from CIMIS weather stations. Note that the CIMIS zones dataset is distorted, with zone boundaries failing to encompass all coastal areas. To address this issue, the CIMIS zone layer displayed in Figure 2-1 was manually adjusted to achieve proper spatial alignment.

There are seven CIMIS stations near the Santa Maria and Cuyama Rivers watershed: Cuyama, Sisquoc, Nipomo, Santa Maria, Santa Maria II, Guadalupe, and Betteravia. Cuyama, Sisquoc, Nipomo, and Santa Maria II are active, but Guadalupe, Santa Maria, and Betteravia are no longer operating. The historical time series data for Guadalupe spans from December 1993 to November 2000, while the historical data for Santa Maria covers the period from May 1983 to April 1999. The historical data for Betteravia is available from May 1983 to July 1993. There are four active stations with more recent data. Cuyama has data from May 1989 to the present, Sisquoc from April 2000 to the present, Nipomo from June 2006 to the present, and Santa Maria II from April 2011 to the present. As shown in **Error! Reference source not found.**, the Santa Maria and Cuyama Rivers watershed intersects five CIMIS zones with 70% of the watershed area in Zone 10 (North Central Plateau & Central Coast Range), 16% of the watershed area in Zone 6 (Upland Central Coast and Los Angeles Basin), 11% of the watershed in Zone 3 (Coastal Valleys and Plains and North Coast Mountains), 2% of the watershed in Zone 14 (Mid-Central Valley, Southern Sierra Nevada, Tehachapi & High Desert) and a marginal portion (less than 1%) of the watershed existing within Zone 1 (Coastal Plains Heavy Fog Belt).

CIMIS also has a newly derived gridded product, CIMIS Spatial, that expresses daily ET_o estimates calculated at a statewide 2-km spatial resolution using the American Society of Civil Engineers version of the Penman-Monteith equation (ASCE-PM) (Allen et al. 2005). The ASCE-PM method calculates ET_o using solar radiation, air temperature, relative humidity, and wind speed at two meters height. This product provides a consistent spatial estimate of ET_o that is California-specific, implicitly captures macro-scale spatial variability and orographic influences, is available from 2003 through Present, and is routinely updated within a couple of days.

Representative potential evapotranspiration (PEVT) time series can be estimated for the Santa Maria and Cuyama Rivers watershed from daily data from CIMIS Spatial by disaggregating the hourly time series using hourly distributions from land observation stations (e.g., RAWS, NCEI) or hourly distributions from NLDAS. PEVT is reported at 3-hour intervals; however, the hourly distributions of solar radiation from NLDAS, which have sinusoidal patterns over daylight hours, provide a sound basis for disaggregating the daily CIMIS depths while maintaining the overall annual water budget reflected in CIMIS.

For LSPC, the user provides PEVT rates as model input. The LSPC model then uses these values along with other model parameters to estimate actual ET. Sometimes ET_o is provided instead, and HRU-specific coefficient multipliers are used to stratify those inputs based on physical HRU properties such as vegetation density. Additionally, for applications where the study area has significant irrigation practices, the user can provide irrigation water usage rates to represent additional water beyond precipitation that is added to the system—that water would also be available for ET.

The actual ET estimated by an LSPC model can be validated through comparison with data from OpenET. The OpenET project is an operational system for generating and distributing ET data at a field scale using an ensemble of six well-established satellite-based approaches for mapping ET(Melton et al. 2022). OpenET has undergone extensive intercomparison and accuracy assessment conducted using ground measurements of ET; results of these assessments demonstrate strong agreement between the satellite-driven ET models and observed flux tower ET data. Within California, OpenET has data beginning in 2016 and uses CIMIS meteorological datasets to compute ET_o. In addition to LSPC ET validation, OpenET data can be used to help inform irrigation estimation and parameterization.

3 SURFACE HYDROLOGY

3.1 Watershed Segmentation

The United States Geological Survey (USGS) delineates watersheds nationwide based on surface hydrological features and organizes the drainage units into a nested hierarchy using HUCs. These HUCs have a varying number of digits to denote scale ranging from 2-digit HUCs (largest) at the region scale to 12-digit HUCs (smallest) at the subwatershed scale. The Santa Maria and Cuyama Rivers watershed is defined by two HUC-8 watersheds that are collectively comprised of 59 HUC-12 subwatersheds.

For subwatersheds smaller than HUC-12, catchment and tributary boundaries, flowlines, outlet points, and related attribute information will rely on the National Hydrography Dataset (NHD), HUC, and catchment delineations. This analysis will primarily use readily available data to define the outer watershed boundary. Any available local data will be used to supplement and refine the understanding of tributary boundaries and reach geometry. The NHD Plus v2 (NHDPlus) further discretizes the watershed into 2,769 catchments ranging between 0.2 to nearly 14,600 acres. Table 3-1 presents summary statistics of NHDPlus catchment sizes by HUC-12 subwatershed. Figure 3-1 is a map of HUC-12 and NHDPlus catchments within the Santa Maria and Cuyama Rivers watershed (HUC-8).

The NHDPlus dataset provides a good foundation for model segmentation at a spatial scale that is suitable for representing the watershed for the purposes of modeling daily, seasonal, and annual streamflow. The NHDPlus catchment boundaries will be aggregated and/or adjusted only as necessary to align with any selected points of interest (e.g., flow monitoring sites) to allow for direct output of model results for comparison and analysis.

Table 3-1. Summary of NHDPlus catchment sizes within the Santa Maria and Cuyama Rivers HUC-8s

HUC-12 Name	Count	Catchment Size (acres)			
		Minimum	Mean	Median	Maximum
Abel Canyon	85	3.1	287.7	244.0	1,218.1
Alamo Creek	43	0.2	336.6	260.3	1,408.4
Alejandro Canyon	37	1.1	242.2	238.0	763.5
Aliso Creek	32	11.8	633.9	460.5	4,273.3
Alkali Canyon	102	1.1	284.3	212.5	1,567.9
Apache Canyon	57	9.8	443.4	303.3	1,457.6
Arroyo Seco	18	32.5	842.6	491.7	2,965.2
Asphaltum Creek	23	89.2	564.7	342.9	4,208.1
Ballinger Canyon Wash	38	0.7	301.4	237.1	1,216.7
Bitter Creek	32	20.7	673.6	312.2	5,871.2
Branch Canyon Wash	51	3.1	363.0	241.1	2,552.0
Burges Canyon	59	1.1	283.5	168.4	1,732.9
Canada de Los Coches	48	1.1	298.8	124.4	2,301.1
Carrie Creek	9	174.8	1,401.6	1,078.2	2,925.8

HUC-12 Name	Count	Catchment Size (acres)			
		Minimum	Mean	Median	Maximum
Carrizo Canyon	34	9.1	373.6	311.1	1,223.9
Castro Canyon	24	32.0	487.5	364.4	3,765.4
Cat Canyon	15	3.1	780.3	550.0	3,500.0
Corralitos Canyon	41	1.8	952.0	142.3	10,601.3
Cottonwood Canyon	68	2.9	405.9	340.0	1,757.4
Deer Park Canyon	46	4.9	410.7	316.4	2,098.1
Dry Canyon	43	10.2	321.8	287.6	1,149.1
Horse Canyon	51	5.3	274.9	181.3	1,398.4
Huasna Creek	9	238.0	1,036.2	1,108.9	1,993.7
Lower Alamo Creek	31	0.9	773.1	514.2	3,138.0
Lower Huasna Creek	28	15.6	555.8	460.7	2,171.9
Lower Orcutt Creek	8	286.4	2,395.8	575.9	14,586.0
Lower Santa Maria River	34	0.2	575.5	141.8	4,112.8
Manzana Creek	108	0.4	333.1	324.5	1,198.0
Mustang Canyon	28	0.4	505.6	368.4	3,735.6
New River	62	0.9	402.0	250.0	2,695.6
Nipomo Creek	18	5.1	809.1	705.0	1,685.6
North Fork La Brea Creek	87	1.6	352.7	297.3	1,898.1
Oak Creek	33	5.6	375.2	295.6	1,151.8
Pine Canyon	26	21.6	548.2	358.4	2,546.4
Powell Canyon	28	8.9	466.7	398.1	2,175.5
Quatal Canyon	87	2.7	310.1	214.2	1,403.3
Rancho Nuevo Creek	62	4.0	404.1	371.4	1,079.8
Red Rock Canyon	22	34.7	459.3	344.2	1,382.0
Reyes Creek	57	6.4	375.5	272.9	1,724.0
Salisbury Canyon Wash	50	2.7	307.6	250.4	1,204.0
Santa Barbara Canyon	117	4.4	284.2	222.8	1,608.8
Santa Maria Canyon	43	0.7	390.2	134.1	2,258.6
Schoolhouse Canyon	87	2.9	423.2	283.6	2,202.4
Sisquoc Falls	86	2.7	325.6	254.1	1,565.0
South Fork La Brea Creek	66	2.9	306.5	249.3	1,588.1
South Fork Sisquoc River	86	0.7	257.5	220.5	752.6
Sycamore Creek	25	96.7	818.0	532.0	3,787.8

HUC-12 Name	Count	Catchment Size (acres)			
		Minimum	Mean	Median	Maximum
Tennison Canyon	37	4.9	540.2	222.6	10,958.5
Tepusquet Creek	49	6.4	379.7	308.5	2,221.7
The Wash	38	28.9	839.2	408.9	9,794.0
Twitchell Reservoir	60	0.4	451.4	348.7	2,941.2
Upper Alamo Creek	53	18.5	611.9	553.8	1,820.1
Upper Huasna River	22	0.9	1,030.4	674.2	5,279.5
Upper Orcutt Creek	31	2.0	517.6	291.1	2,927.7
Upper Santa Maria River	78	1.1	329.5	194.4	1,523.4
Wagon Road Canyon	50	3.1	299.7	268.9	1,585.4
Water Canyon	23	59.6	450.5	388.3	1,208.1
Wellman Canyon	56	4.0	351.2	271.4	1,719.6
Wells Creek	28	2.0	369.6	306.5	1,381.1
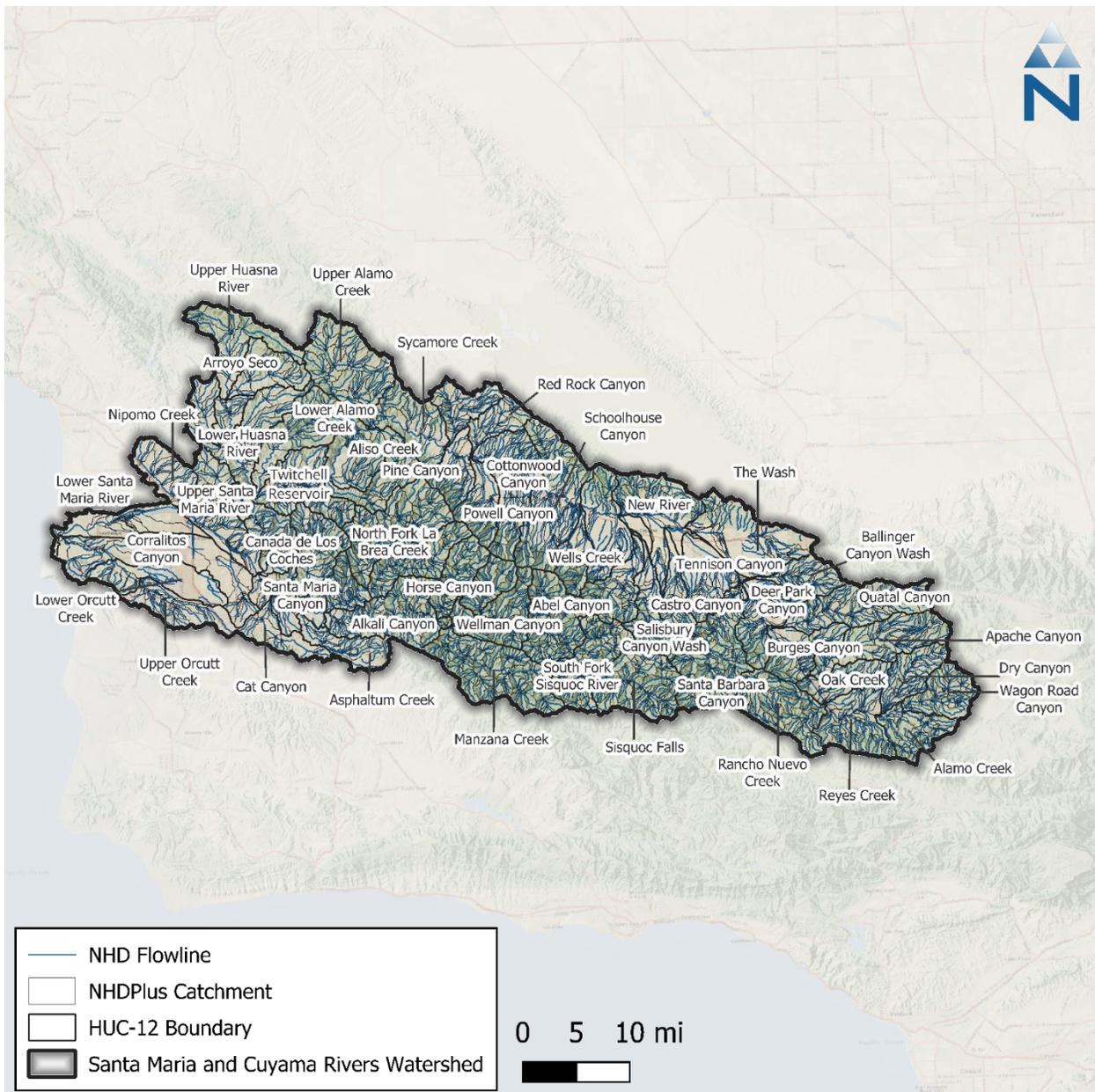
Figure 3-1. Initial catchment segmentation for the Santa Maria and Cuyama Rivers watershed.

3.2 Streams and Channels

As described above, the hydrographic characteristics of the streams and rivers within the Santa Maria and Cuyama Rivers watershed are primarily derived from NHDPlus. This dataset depicts primary flow paths based on a nation-wide 10-meter DEM and includes additional attributes such as hydrologic sequence and flow line slope. These characteristics will be important for creating representative reach segments within the hydrologic model. Reference Figure 3-1 for the location of the watershed's major tributaries ("NHD Flowline").

7. USGS notes "No records computed below 200 ft³/s, since October 1, 2020. No regulation upstream from station. Minor diversion for irrigation at the gage."
    (https://waterdata.usgs.gov/ca/nwis/wys_rpt/?site_no=11138500)
8. USGS notes "No regulation upstream from station."
    (https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=11136600)
9. USGS notes "Small diversion above station for irrigation."
    (https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=11136500)
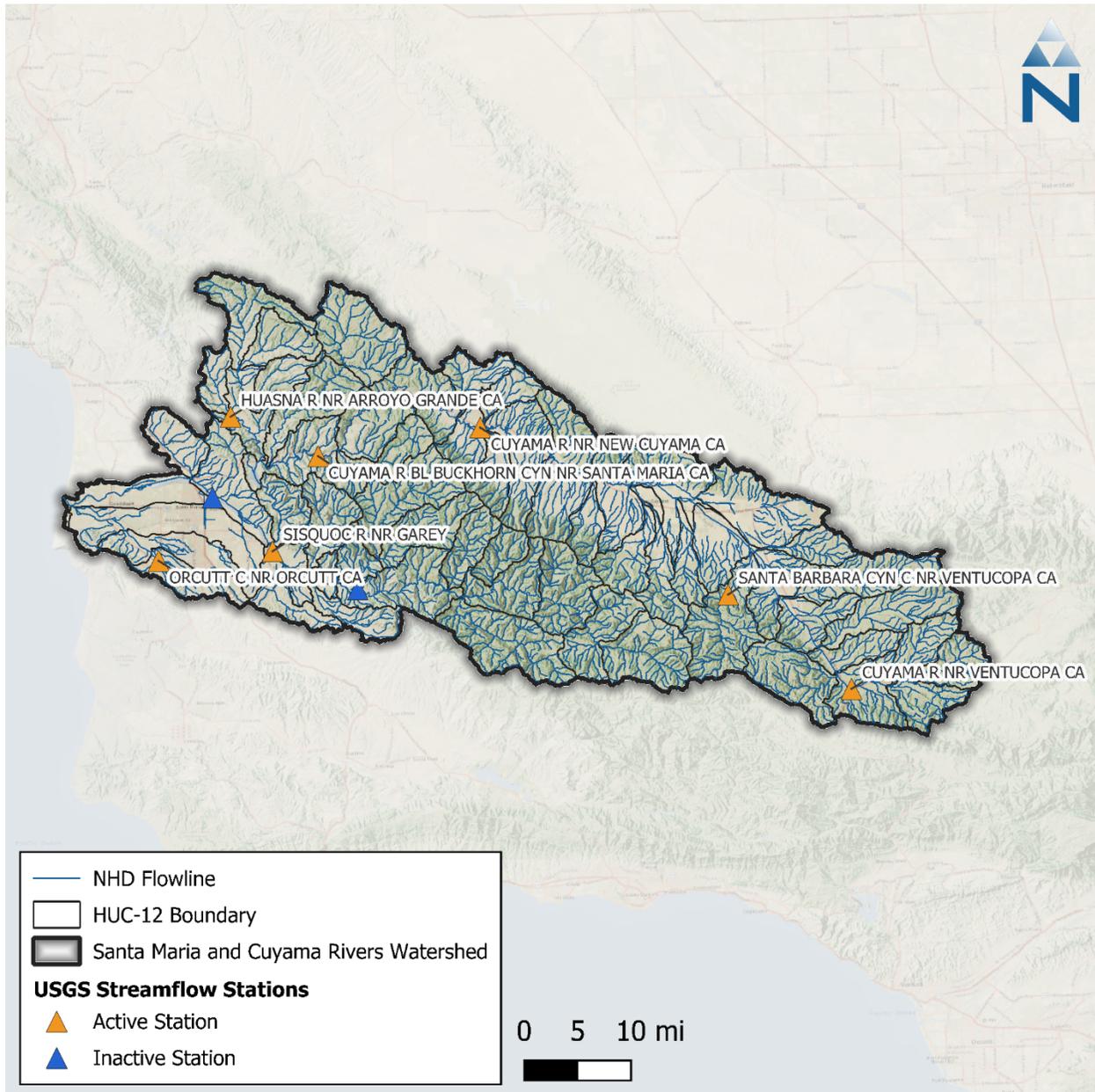
Figure 3-2. USGS streamflow stations in the Santa Maria and Cuyama Rivers watershed.

3.4 Dams, Reservoirs, and Impounds

The Santa Maria and Cuyama Rivers watershed contains several small waterbodies, ranging from around 2.5 acres to just under 111 acres. These unnamed waterbodies are identified in the NHD

database by reference numbers ("COMID"). A search of the NID database revealed the presence of Twitchell dam within the watershed and its reservoir which was not within the NHD database (NID 2025). Twitchell Reservoir is federally owned and used for flood risk reduction and groundwater recharge. CDEC provides daily reservoir storage from January 2023 until the present day. The available CDEC dataset reviewed during the development of this work plan did not provide any stage values for the reservoir. Having stage-storage relationships as well as any flow release data and other reservoir operation data for reservoirs such as Twitchell Reservoir (NID ID CA10197), will allow for more accurate model representation and improving model calibration.
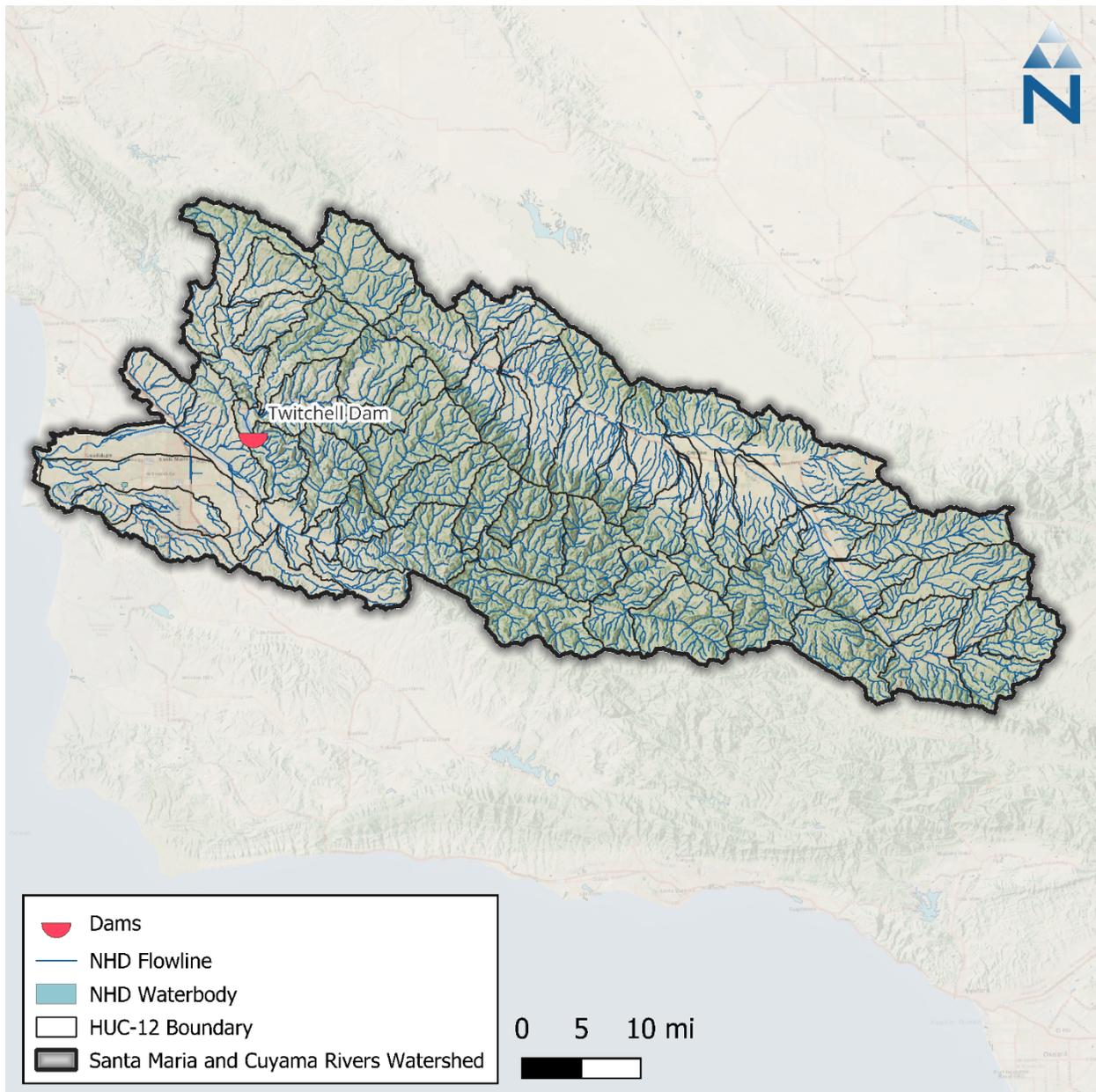
Figure 3-3. Dams within the Santa Maria and Cuyama Rivers watershed relevant for watershed modeling effort (NID 2025).

Table 3-3. Waterbodies and Dams within the Santa Maria and Cuyama Rivers watershed

Waterbody	Dam Name	NID ID	Drainage Area (sq-mile)	Area (ac)	Storage Capacity (ac-ft)	Average Stage (ft)	Average Flow Volume (ac-ft)	Average Storage (ac-ft)
Twitchell Reservoir[1]	Twitchell Dam	CA10197	1,121	9,448	151,050	Unknown[2]	Unknown[2]	44,994

1. The waterbody has no name provided in the NHD dataset, instead the waterbody's name was assigned based on NID.
2. Data not available from CDEC, NID or NHD but may exist elsewhere.

3.5 Surface Water Withdrawals

Datasets related to water rights, points of diversion (PODs), and surface withdrawals (i.e., wells and irrigation) were identified through searches of the Water Board's Electronic Water Rights Information Management System database (eWRIMS) and the DWR Agricultural Land and Water Use Estimates database (ALWU). These datasets can be used to represent diversions, withdrawals, and irrigation practices in the watershed model. The volumes quantified in those datasets can be compared to annual and seasonal water budget estimates in the Santa Maria and Cuyama Rivers watershed to assess the relative impacts based on observed precipitation, ET, and streamflow data. The impact of diversions or water usage may be localized along specific tributaries; however, the temporal resolution of the data determines the resolution of those impacts in the model. Additionally, the extent of modeled irrigation will depend on land-use classification, and its water usage rates will be corrected against spatial variations in the observed evaporative deficit where necessary.

Figure 3-4 provides an overview of the primary drinking water sources in the watershed. Water systems distributed throughout the watershed include a mixture of both surface water diversions from the Santa Maria and Cuyama Rivers and their primary tributaries, as well as groundwater withdrawals for the Santa Maria and Cuyama Rivers watershed groundwater basin. There are 21 drinking water systems in the watershed. For 15 out of the 21 drinking water systems, the water source is listed as groundwater, and 6 have surface water listed as the source. The number of active surface water PODs and withdrawal volumes will be evaluated from eWRIMS reports during model development.
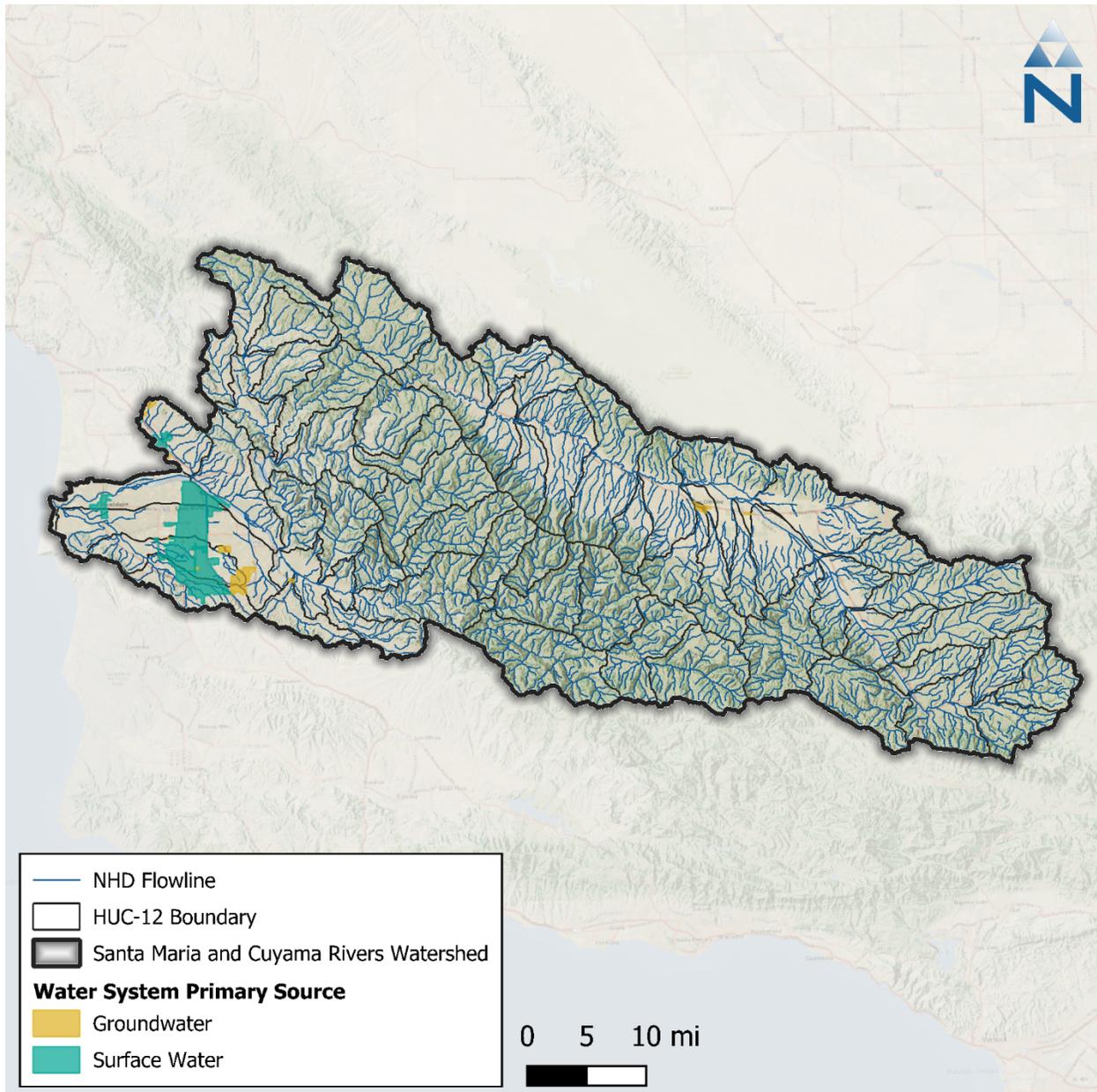
Figure 3-4. Primary Water System Sources in the Santa Maria and Cuyama Rivers watershed.

4 SUBSURFACE HYDROLOGY

The Santa Maria and Cuyama Rivers watershed overlaps with six groundwater basins as delineated by Bulletin 118 (DWR 2020b). The watershed overlaps with the Santa Maria River Valley – Santa Maria sub-basin (# 3-012-01), the San Antonio Creek Valley basin (# 3-014), the Carrizo Plain basin (# 3-019), and the Lockwood Valley basin (# 4-017). The watershed contains the Huasna Valley basin (# 3-045) and the Cuyama Valley basin (# 3-013). There are slivers containing negligible overlap at the border of the Santa Ynez River Valley basin (# 3-015). Approximately 32% of the watershed area falls within the groundwater basins delineated by Bulletin 118 and the remaining 68% consists of Miocene, Eocene and Cretaceous formations as outlined in the geology section.
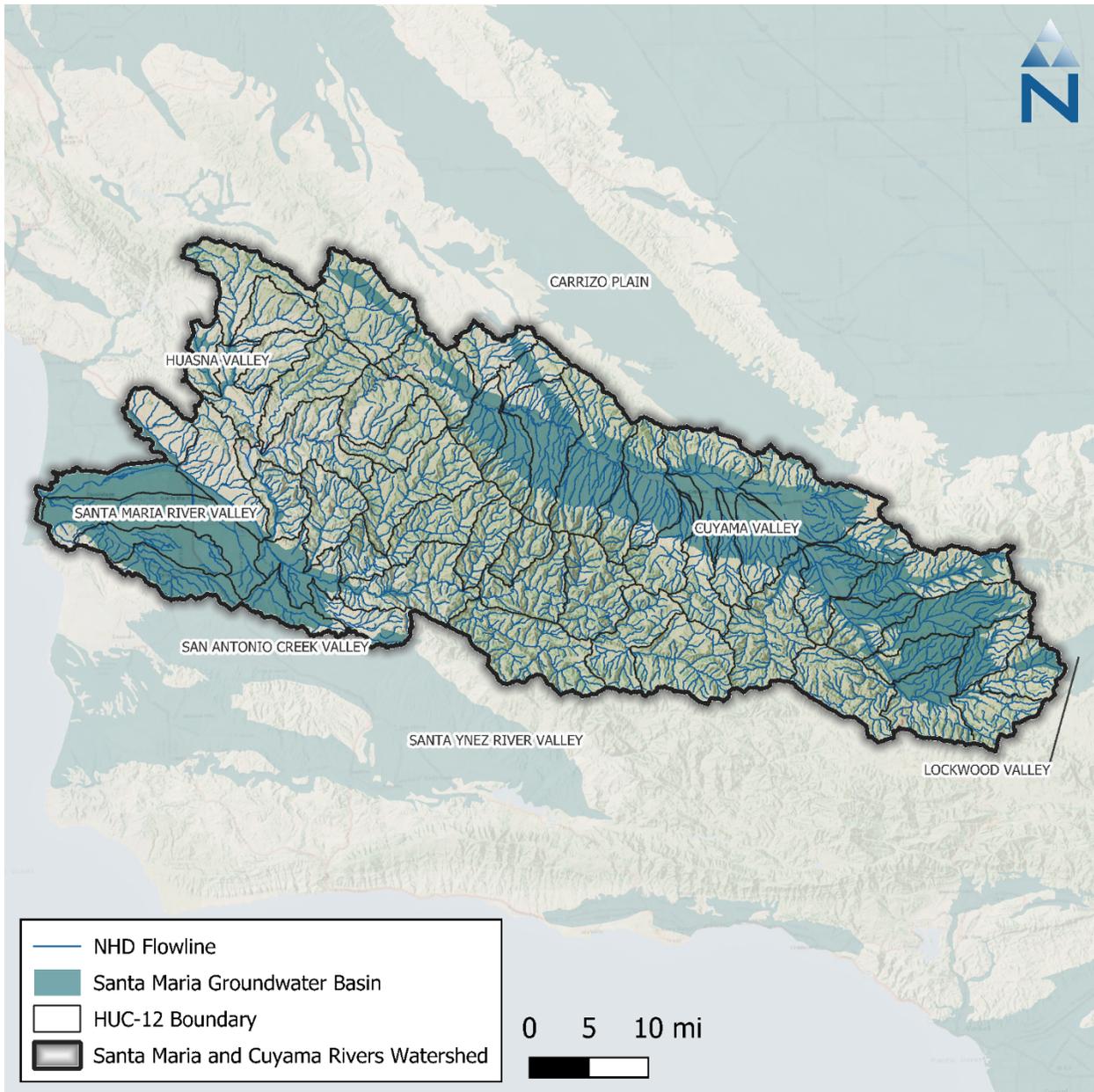
Figure 4-1. Groundwater basins delineated by DWR (2020a), also known as Bulletin 118.

As per the respective basin priority details, the overlapping basins are classified at various priority levels as designated by Sustainable Groundwater Management Act (SGMA) Basin Prioritization. The Santa Maria groundwater basin has documented saltwater intrusion issues and declining groundwater levels but is classified as Very Low priority due to low groundwater usage volumes. Approximately 74% of the Santa Maria groundwater basin overlaps the Santa Maria and Cuyama Rivers watershed. The Lockwood Valley basin, Carrizo Plain basin and Huasna Valley basin are also classified as Very Low priority. Approximately 15% of the Lockwood Valley basin overlaps the Santa Maria and Cuyama Rivers watershed, and 1% of the Carrizo Plain basin, while the Huasna basin is fully contained. The San Antonio Creek Valley basin is classified as Medium priority due to water quality declines and lowered groundwater levels. Only about 3% of the San Antonio Creek Valley basin overlaps the Santa Maria and Cuyama Rivers watershed. The Cuyama Valley basin is classified as

High priority due to critical conditions of overdraft and basin subsidence and is contained in the watershed.

The San Antonio Basin GSA operates within the San Antonio Creek Valley basin, the County of San Luis Obispo GSA -Santa Maria Basin Fringe Areas operates at the northern border of the Santa Maria basin, and the Cuyama Basin GSA operates within the Cuyama Valley basin.

4.1 Water Budget Components

The US Geological Survey maintains a number of public domain models for Northern California (USGS 2024). No public domain model contains the entirety of the Santa Maria and Cuyama Rivers watershed, but the Cuyama Valley model covers the Cuyama Valley basin. Model results estimate that the largest demand on the aquifer is agricultural pumping, where withdrawals total 65,300 acre-feet per year. The main source of recharge is streamflow infiltration at 27,500 acre-feet per year, with an additional 34,100 acre-feet per year of water depleted from aquifer storage (Hanson et al. 2015). The Bulletin 118 basin description for the Santa Maria sub-basin estimates an average inflow of 29,200 acre-feet per year and outflow of 33,100 acre-feet per year for the eastern highlands portion of the basin within San Luis Obispo County, and an annual recharge of 85,300 acre-feet per year with an outflow of 105,100 acre-feet per year for the western portion of the basin within Santa Barbara County. A groundwater budget was not provided for the Huasna valley in the Bulletin 118 basin description.

4.2 Geology

The foregoing references provide coverage primarily within the groundwater basins delineated as per Bulletin 118. The water bearing units within the Santa Maria sub-basin consist of Pliocene marine sand deposits, Pleistocene alluvial deposits, and Quaternary alluvial deposits and dunes. The water bearing units within the Cuyama valley are Pleistocene and Holocene alluvial deposits.

In the Santa Maria and Cuyama Rivers watershed outside the delineated basins, the bedrock is shown by the Santa Maria and Los Angeles regional geologic maps. The bedrock is composed principally of the Miocene Monterey formation, the Cretaceous Jalama formation, and Eocene sedimentary rocks.

Several faults cross the Santa Maria and Cuyama Rivers watershed, including the Casmalia fault, the Santa Maria River fault, and the East Huasna fault. The Bulletin 118 basin description indicates that the Santa Maria River fault is considered a partial barrier to groundwater flow through its vertical displacement of conductive units. Per the USGS modeling report, the Cuyama Valley is a fault-bounded graben bordered by the Cuyama Fault and the San Andreas fault. Airborne Electromagnetic (AEM) survey flight lines are available within the Cuyama valley area only.
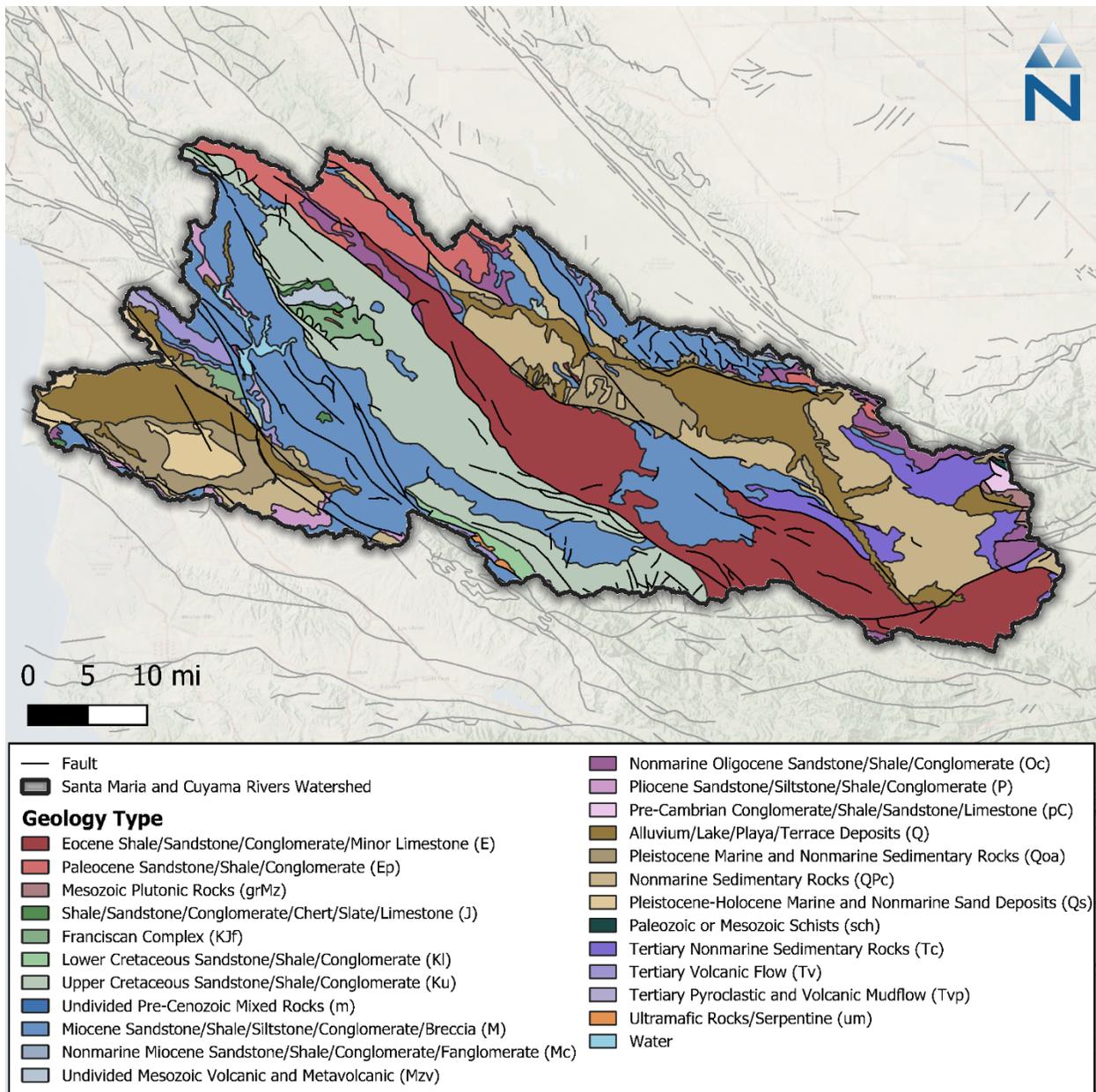
Figure 4-2. Geology types within the Santa Maria and Cuyama Rivers watershed.

5   LANDSCAPE CHARACTERIZATION

Landscape characterization describes the physical characteristics of the landscape including the types of soils and geology, topography, land cover, land use, and other physical properties that can be represented within the hydrological model. Hydrologic Response Units (HRUs) are the core landscape unit in a watershed model. Each HRU represents areas of similar physical characteristics attributable to certain hydrologic processes. Spatial or geological characteristics such as land cover, soils, geology, and slopes are typically used to define HRUs. The spatial combinations of these various characteristics ultimately determine the number of meaningful HRU categories considered for the model. The

following sections describe the component layers available to derive HRUs for the Santa Maria and Cuyama Rivers watershed.

5.1 Elevation & Slope

The USGS publishes DEMs expressing landscape elevation through a raster grid data product with 30-meter resolution. The Santa Maria and Cuyama Rivers watershed ranges in elevation from near sea level at the outlet of the watershed to over 2,600 meters in the east. As a geoprocessing input, the DEM can be used to derive both slope and aspect as data inputs to a model. Figure 5-1 shows the change in elevation across the Santa Maria and Cuyama Rivers watershed.

Figure 5-1. DEM of the Santa Maria and Cuyama Rivers watershed.

5.2 Soils

Soils data for the Santa Maria and Cuyama Rivers watershed were obtained from the Soil Survey Geographic Database (SSURGO) (USDA 2024a) and State Soil Geographic Database (STATSGO2) (USDA 2024b) both published by the Natural Resource Conservation Service (NRCS).

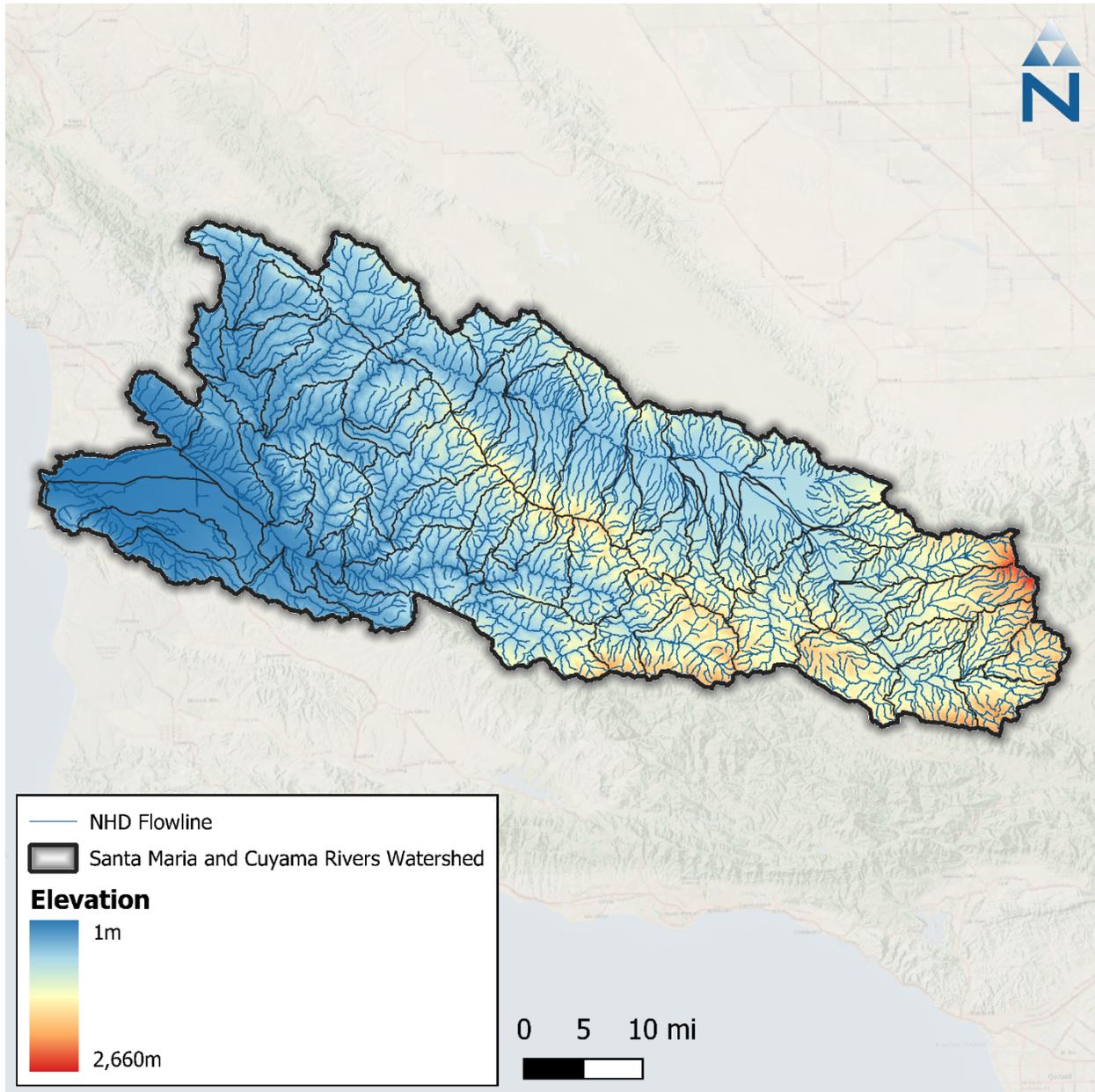There are four primary hydrologic soil groups (HSG) used to characterize soil runoff potential. Group A generally has the lowest runoff potential (e.g., sands) whereas Group D has the highest runoff potential (e.g., clays). Both SSURGO and STATSGO2 soils databases are composed of a GIS polygon layer of map units and a linked database with multiple layers of soil property. Soil characteristics for predominant hydrologic soil groups are described in Table 5-1.

Table 5-1. NRCS Hydrologic soil group descriptions

Hydrologic Soil Group	Description
A	Sand, Loamy Sand, or Sandy Loam
B	Silt, Silt Loam or Loam
C	Sandy Clay Loam
D	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay, or Clay

Source: Natural Resource Conservation Service (NRCS), Technical Release 55 (TR-55) (USDA 1986) .

Table 5-2 provides a summary of areas occupied by each SSURGO HSG, and Figure 5-2 shows the spatial distribution of these groups throughout the Santa Maria and Cuyama Rivers watershed. The dominant soil group in the watershed is Group D (44%) which consists of soils with the lowest infiltration rates, such as clay loams, silty clay loam, sandy and silty clay and clay. Group C makes up 32% of the watershed and contains sandy clay loam with typically low infiltration rates. Group B (10%) contains moderately well to well-drained silt loams and loams. Group A makes up 9% of the watershed and contains well-draining sand, loamy sand, and sandy loam. Less than 0.2% of the watershed areas have mixed soils. For modeling purposes, mixed soils will be grouped with the nearest primary group as follows: A/D → B, B/D → C, and C/D → D. Finally, approximately 5% of the watershed HSG area is classified as unknown in the SSURGO database and reside primarily within the mountainous areas. For these areas, the corresponding HSG from the STATSGO2 dataset will be used to supplement the data gaps; some of these unknown soil areas may also correspond to waterbodies.

Table 5-2. NRCS Hydrologic soil groups in the Santa Maria and Cuyama Rivers watershed

Hydrologic Soil Group	Area (acres)	Percent Area
A	105,792.32	9.04%
A/D	1,685.99	0.14%
B	114,908.78	9.82%
C	370,011.26	31.63%
D	514,813.48	44.00%
N/A	62,746.45	5.36%
Total	**1,169,958.27**	**100.00%**

Source: State Soil Geographic and Soil Survey Geographic Database (STATSGO2/SSURGO)
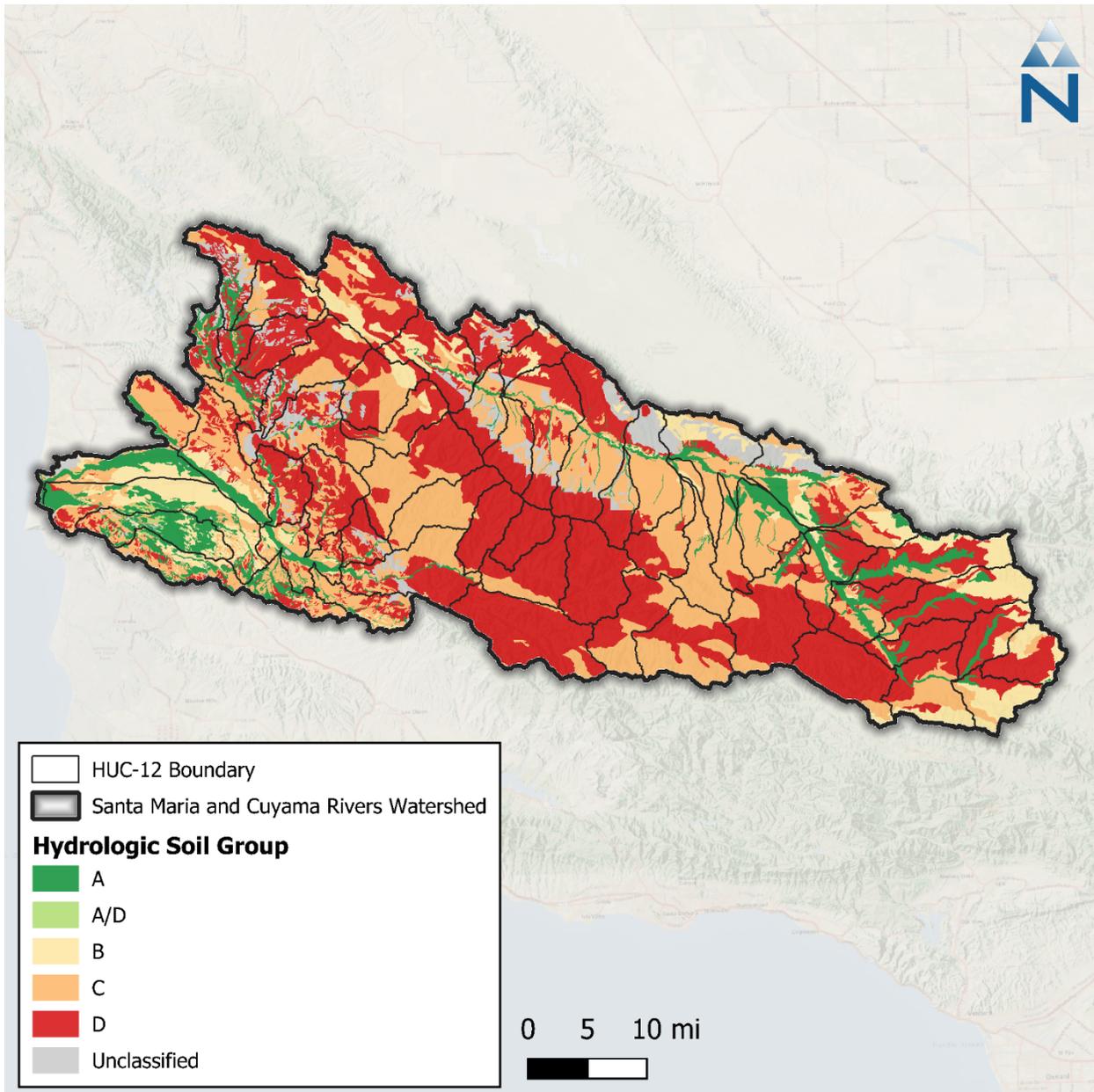
Figure 5-2. SSURGO hydrologic soil groups within the Santa Maria and Cuyama Rivers watershed.

5.3 Land Cover

Land cover data are a key layer for HRUs. The primary source of land cover data identified for this effort is the 2021 National Land Cover Database (NLCD) maintained by the Multi-Resolution Land Consortium (MRLC), a joint effort between multiple federal agencies. The primary objective of the MRLC NLCD is to provide a current data product in the public-domain with a consistent characterization of land cover across the United States. The first iteration of the NLCD dataset was in 1992. Since the 2001 NLCD version, a consistent 16-class land cover classification scheme has been adopted nationwide. The 2021 NLCD adopted this 16-class scheme at a 30-meter grid resolution.

Error! Reference source not found. summarizes the areal coverage of land use classes from a subset of the 2021 NLCD dataset that covers the Santa Maria and Cuyama Rivers watershed and Figure 5-3 shows the spatial distribution of these classifications. Scrub/shrub is the dominant land cover classification covering approximately 55% of the watershed area. When combined, the undeveloped categories of evergreen forest, deciduous forest, mixed forest, shrub/scrub, and grassland/herbaceous account for approximately 89% of the total watershed area. Developed land cover makes up approximately 4% of the total watershed area. A majority of the developed land cover is classified as either "Developed, Open Space" (2.37%).

Table 5-3. National Land Cover Database 2021 land cover summary in the Santa Maria and Cuyama Rivers watershed

NLCD Class	Classification Description	Area (acres)	Percent
11	Open Water	647.90	0.06%
21	Developed, Open Space[1]	27,711.78	2.37%
22	Developed, Low Intensity[1]	8,585.06	0.73%
23	Developed, Medium Intensity[1]	9,322.12	0.80%
24	Developed, High Intensity[1]	1,476.57	0.13%
31	Barren Land (Rock/Sand/Clay)	2,100.02	0.18%
41	Deciduous Forest	4.22	0.00%
42	Evergreen Forest	75,965.27	6.49%
43	Mixed Forest	60,637.70	5.18%
52	Shrub/Scrub	645,010.39	55.14%
71	Grassland/Herbaceous	256,963.64	21.97%
81	Pasture/Hay	9,098.00	0.78%
82	Cultivated Crops	58,201.50	4.98%
90	Woody Wetlands	3,600.60	0.31%
95	Emergent Herbaceous Wetlands	10,423.38	0.89%
TOTAL[2]		**1,169,748.15**	**100%**

Source: 2021 National Land Cover Database

1. Imperviousness: Open Space (<20%); Low Intensity (20-49%); Medium Intensity (50-79%); High Intensity (≥80%).
2. Note that because of the raster resolution, this total is approximately 210 acres less than the model domain.
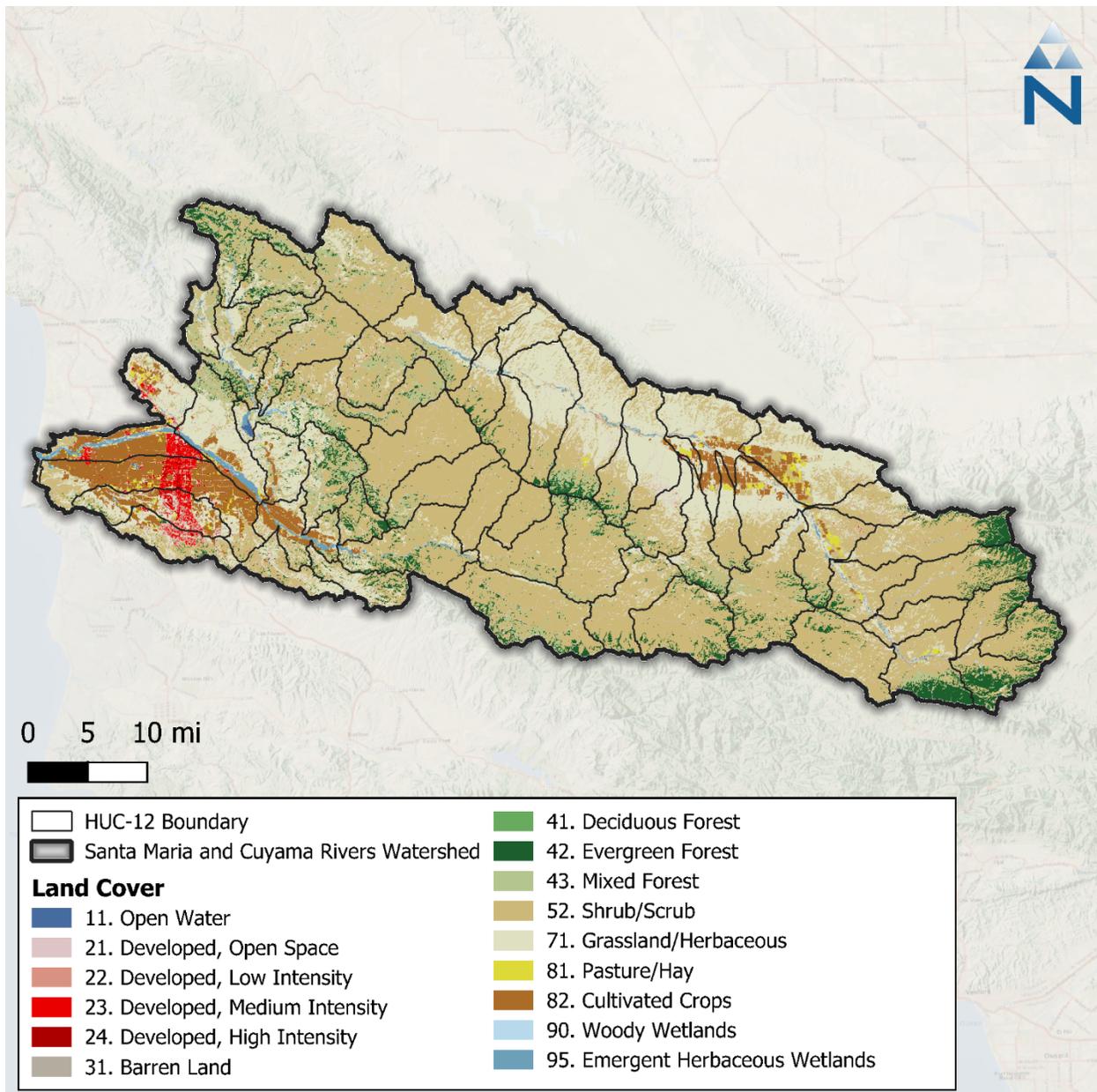
Figure 5-3. NLCD 2021 land cover within the Santa Maria and Cuyama Rivers watershed.

MRLC publishes a developed impervious cover dataset as a companion to the NLCD land cover; this dataset is also provided as a raster with a 30-meter grid resolution. Impervious cover is expressed in each raster pixel as a percentage of total area ranging from 0 to 100 percent. Because this dataset provides impervious cover estimates for areas classified as *developed,* non-zero values closely align with developed areas (NLCD classification codes 21 through 24). Review of the Santa Maria and Cuyama watershed using this dataset shows that nearly 4% of the area is developed. The developed area is classified further into open space and low, medium, and high intensity development. Of those subcategories, open space makes up most of the total developed area.

Because land cover can vary significantly over time due to anthropogenic changes (e.g., development, timber harvest) or naturally occurring events (e.g., forest fires, landslides), it may be necessary to also time-vary land cover through the model simulation or, at a minimum, align the dataset used to

represent land cover with the same time period as streamflow data used for model calibration. The NLCD 1992, 2001, 2006, 2011, and 2021 snapshots are all available for representing land cover changes within the model depending on the period, or multiple periods, or time selected for model calibration and validation. Land use change in the Santa Maria and Cuyama Rivers watershed will be assessed as part of the model development, and a decision will be made based on the results as to whether land use change is represented explicitly, or a single land use snapshot is used.

Furthermore, the California Department of Forestry and Fire Protection (CAL FIRE) maintains databases of timber harvest plans and fire perimeters (see Table 1-3) which may be used in conjunction with the basic NLCD land cover snapshots to vary the land cover representing dynamic processes like timber harvests or episodic fire-related activities.

5.4 Tree Canopy Cover

MRLC publishes a tree canopy dataset as a companion to the NLCD land cover dataset that estimates the percentage of tree canopy cover spatially. The underlying data model was developed by the United States Forest Service (USFS) and is available through their partnership with the MRLC. This dataset is also provided as a raster with a 30-meter grid resolution. Like the impervious cover dataset, each raster pixel expresses the percent of the total area covered by tree canopy with values ranging from 0 to 100 percent. The percent tree canopy cover layer was produced by the USFS using a Random Forests regression algorithm (Housman et al. 2023). Across the Santa Maria and Cuyama Rivers watershed, an average of 11% of the total watershed area is covered by tree canopy. Tree canopy cover data can be used to estimate model parameters like interception storage and lower-zone ET rates.

5.5 Agriculture & Crops

Land cover data for the Santa Maria and Cuyama Rivers Watershed (see Section 5.3) was analyzed to identify predominant cropland vegetation classes. This analysis revealed that approximately 1% of the Santa Maria and Cuyama Rivers watershed area is classified as Pasture/Hay (class 81) and just over 77% of the watershed was classified as either Shrub/Scrub (class 52) or Grassland/Herbaceous (class 71); of the area that is classified as shrub or grassland, a portion may include areas of cultivated crops that were not automatically recognized through processing of the remote sensing data or include cultivated crops on a rotating schedule. To reflect these situations, supplemental information published by the United States Department of Agriculture (USDA) can be used. The USDA Cropland Data Layer (CDL) (USDA 2024c) is an annually updated raster dataset that geo-references crop-specific land use. The 30-meter resolution raster dataset contains a linked lookup table of 85 standard crop types which can be used to classify agricultural land. The purpose of the CDL dataset is to provide a supplemental estimate of annual acreage used for major crop commodities. Figure 5-4 shows the spatial distribution of these classes through the study area, and

Table 5-4 summarizes their areal coverage. Nearly 4% of the watershed is classified as cropland. The dominant crop types include grapes (0.8%), fallow/idle cropland (0.4%), and other hay/non alfalfa (0.3%). Additionally, a large-scale crop and land use identification dataset for the year 2020 is made available by DWR (DWR 2019) and could be used to supplement data gaps if necessary. This dataset is intended to quantify crop acreage statewide and was constructed by analyzing remote sensing data gathered at the field scale.
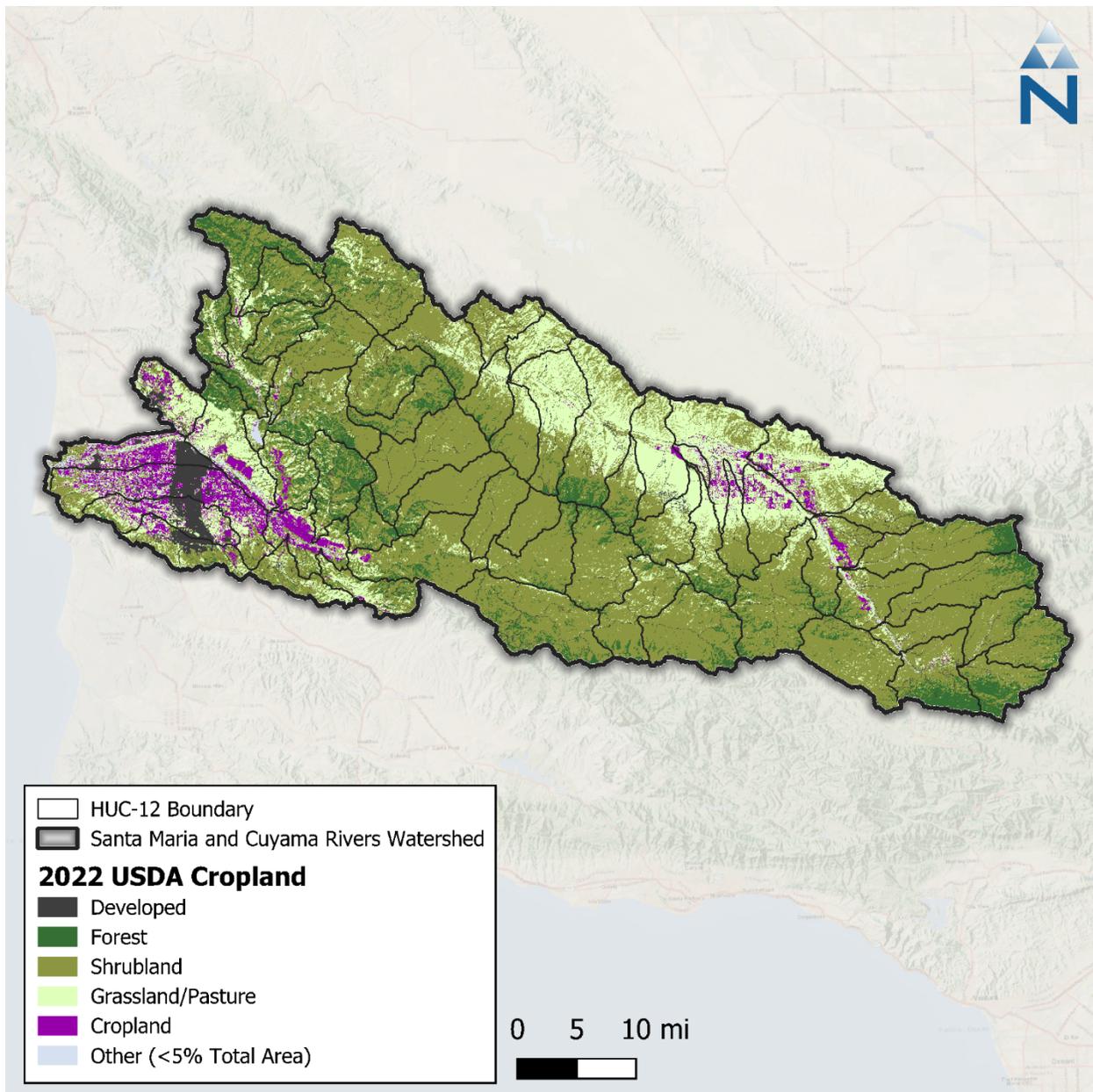
Figure 5-4. USDA 2022 Cropland Data within the Santa Maria and Cuyama Rivers watershed.

Table 5-4 USDA 2022 Cropland Data summary within the Santa Maria and Cuyama Rivers watershed

Crop Type	Area (ac)	Area (%)
Developed	46,377.53	3.96%
Forest	122,956.59	10.51%
Shrubland	705,019.46	60.27%
Grassland/Pasture	235,976.62	20.17%
Cropland	45,910.87	3.92%
Other (<5%)	13,574.84	1.16%
Total	**1,169,815.91**	**100.00%**

6 DATA GAPS AND LIMITATIONS

Based on review of the datasets presented in this report, one potential limitation is the temporal extent of available reservoir operations data (e.g., timing and magnitude of flow releases) and stage-storage relationships for the Twitchell Reservoir to support model calibration.

Another potential limitation is the availability, quality, and temporal resolution of data for surface water diversions within the watershed. The eWRIMS database identifies ## major surface water diversions that are likely to have data to integrate into the model; however, other surface water diversions, such as water use to support cannabis cultivation, may not be mapped or have available data. These diversions may need to be mapped, and assumptions could be needed to represent water demand in the model if these demands are needed for model calibration purposes.

Another potential limitation is access to robust data and/or model for groundwater analysis. Groundwater plays a significant role in portions of the watershed and upon further assessment an integration of the surface hydrology model with a groundwater model may be required. Based on initial assessments, a hydrogeologic model developed for the City of Pismo Beach and South San Luis Obispo County Sanitation District overlaps the western portion of the Santa Maria groundwater basin (GEOSCIENCE Support Services 2019). If available, access to these model files would help develop inputs more efficiently on the west side of the groundwater basin.

7 MODEL CONFIGURATION

Model configuration encompasses model selection and data integration. Model selection considered not only available data and the ability of available models to address key study objectives, but also, considered how existing or on-going modeling efforts could be leveraged to address the specific objectives of this study (Section 1). This section elaborates further on model selection and model configuration.

7.1 Model Selection

The objectives of this modeling study influence both hydrologic model selection and technical approach development. The available data presented in Section 2 through Section 0 for characterizing the watershed also influence model selection. The key study objectives to be addressed with the selected hydrologic model are summarized below:

▼ Representation of unimpaired flows and baseline flows (e.g., water use and other human activities that impact instream flows and how they affect the water balance)

▼ The model simulation period should be long enough to capture the variability of the full range of a water year such that it can represent varied conditions including dry and wet year flows, environmental flows, drought curtailment, etc.

To simulate streamflow, the model must be able to represent seasonal variability on the landscape and be responsive to both natural changes (e.g., meteorological conditions, vegetation cycles) and anthropogenic/hydromodification impacts (e.g., stream diversions, impoundments, groundwater pumping, timber harvest). An ideal platform should also be adaptable for simulating (1) spatial changes like those associated with representing pre-developed/unimpaired land cover states, (2) temporal changes like those associated with modeling climate change impacts, or (3) catastrophic impacts like those associated with extreme events such as 100-year storms and forest fires.

Public-domain models that can address those study objectives include the Hydrologic Simulation Program – Fortran (HSPF) (Barnwell and Johanson 1981), the LSPC (Shen et al. 2005; USEPA 2009), the Precipitation-Runoff Modeling System (PRMS) (Markstrom et al. 2015), and the Soil and Water Assessment Tool (SWAT) (Neitsch et al. 2011). LSPC has been used extensively throughout California to model the unique hydrologic characteristics of the State's watersheds and to inform regulatory decisions (i.e., development of TMDLs and associated amendments to Water Quality Control Plans), watershed management, or climate change analyses. Watersheds in California where LSPC modeling has been conducted include those in the San Francisco Bay region (SCVURPPP 2019; SMCWPPP 2020; Zi et al. 2021 and 2022), the Clear Lake watershed in the Central Valley Region (CVRWQCB 2006), the Lake Tahoe watershed in the Lahontan Region (LRWQCB and NDEP 2010; Riverson et al. 2013), all coastal watersheds of Los Angeles County n(LACFCD 2020; LARWQCB 2010, 2012, 2013a, 2013b, and 2015; LARWQCB and USEPA 2005, 2006, and 2011; Tariq et al. 2017), the San Jacinto River watershed in the Santa Ana Region (SAWPA 2003 and 2004), and most coastal watersheds of the San Diego Region (City of San Diego and Caltrans 2016; City of Vista 2008; Los Peñasquitos Responsible Agencies 2015; San Diego Bay Responsible Parties 2016; SDRWQCB 2008, 2010, and 2012). These efforts have included comprehensive peer review processes and public comment, requiring demonstration of model accuracy based on standard practices for quantifying and documenting model performance. All the modeling documentation and reports cited here have withstood peer review and have supported amendments to Water Quality Control Plans or the approval of watershed plans submitted to the Water Board or Regional Water Quality Control Boards to demonstrate regulatory compliance. Additionally, the Water Board recently utilized LSPC to perform hydrology analyses within the South Fork Eel River and Shasta River watersheds.

LSPC is a modernized version of the HSPF platform that is now organized around a Microsoft Access relational database; otherwise, the LSPC model is functionally identical to the HSPF model. The relational database provides efficient data management, model maintenance, and development of alternative scenarios. The LSPC model runs using hourly input boundary conditions and can be sufficiently configured using the meteorological datasets discussed in Section 2. LSPC also has a feature that can vary land use over time when needed to explicitly represent dynamic processes such as timber harvests and wildfires—that feature needs supporting spatial and temporal data to represent dynamic land use changes. Additionally, LSPC was the selected modeling platform for two other Water Board studies performed for the South Fork Eel River and Shasta River watersheds. Those two watershed models utilize data from many of the same sources compiled in this study plan for the Santa Maria and Cuyama Rivers watershed. Based on the extensive history of successful LSPC model applications and its strengths and flexibility for potential coupling with a groundwater model (e.g., MODFLOW), LSPC is recommended as the watershed model for this study.

7.2 Model Configuration

An LSPC model will be configured using the datasets presented in Section 2 through Section 0. A hydrologic analysis will be developed with the primary goal of simulating instream flow time series for a minimum of 20 years through water year 2023 (10/1/2003 – 9/30/2023) and capable of representing both current/managed flow conditions and natural (pre-development) conditions. The following briefly describes how major elements of the model will be constructed using the available datasets. Further details about each process and underlying assumptions will be documented in a modeling report:

- ▼ **Climate Forcing Inputs:** Climate forcing inputs to the model will include both precipitation and ET. Precipitation will be represented using the observed GHNC, RAWS, and CDEC station data identified in Section 2. A hybrid approach using the 4-km gridded PRISM monthly precipitation to promote the most accurate representation of the long-term water balance will be used in areas where station data are not available. Monthly PRISM precipitation totals will be disaggregated using the hourly NLDAS time series. ET will be represented using the CIMIS daily ET_0 2-km gridded dataset and disaggregated to hourly based on the distribution of clear sky solar radiation from NLDAS.

- ▼ **Model Segmentation**: Watershed delineations will be based on HUC-12 boundaries and use NHDPlus catchment boundaries to subdivide the HUC-12 boundaries to represent key points of interest in the network (e.g., confluence of tributaries, PODs, etc.). Up to one primary reach segment will be represented per catchment and will use a cross-section calculated using trapezoidal geometry as a function of cumulative upstream drainage area. If additional cross-sectional information is available, these geometries can be updated per catchment in the model.

- ▼ **Hydrologic Response Units**: HRUs represent unique combinations of landscape characteristics that will be derived by overlaying GIS datasets describing land cover, hydrologic soil group, and slope. The unique combinations of these three elements will form a set of HRUs that will be configured within the LSPC model. Due to the relatively small area of land cover with a specific crop type, we anticipate relying on the 2021 NLCD data to represent land cover; however, the USDA 2022 CDL may be considered if necessary during model configuration and calibration based on results. In the final model configuration, some HRUs may be reclassified and grouped when appropriate for model parameterization (e.g., multiple types of forest may be grouped into a single "forest" HRU category unless there is reason to represent different responses in the model for each type).

- ▼ **Water Use & Inflows**: To the extent that major sources of water use (e.g., groundwater pumping, surface diversions) or inter-basin transfers are known, these volumes will be included as withdrawals or inputs to the model. Assumptions may need to be made and documented for some of these sources/sinks and others may need to be excluded entirely if the impact(s) on the model prediction raises questions about the accuracy of the data. Priority will be given to representing these features when they influence points where the model is being compared to observed data for calibration purposes.

- ▼ **Groundwater**: Based on the current understanding of the groundwater basins presented in Section 4, a fully linked groundwater model may be necessary upon further assessment during calibration of the LSPC model. If initial LSPC calibration efforts suggest a groundwater model would benefit the analysis, the information obtained from well data available from well completion reports will be useful in estimating the depth of aquifers and water production zones. A MODFLOW model (Langevin et al. 2017) would be constructed approximating the bedrock units and the alluvial groundwater basins and will be integrated with a surface water model. Groundwater pumping would be estimated from water demand calculations based on land use information.

8 MODEL CALIBRATION

A combination of visual assessments and computed numerical evaluation metrics will be used to assess model performance during calibration. Model performance will be assessed using graphical comparisons of simulated vs. observed data (e.g., time-series plots, flow duration curves, etc.), quantitative metrics, and qualitative thresholds recommended by Moriasi et al. (2015) and Duda et al. (2012), which are considered highly conservative. Moriasi et al. (2015, 2007) assign narrative grades for hydrology and water quality modeling to the percent bias (PBIAS), the ratio of the root mean square error to the standard deviation of measured data (RSR), and the Nash-Sutcliffe model efficiency (NSE). These metrics are defined as follows:

- ▼ The percent bias (PBIAS) quantifies systematic overprediction or underprediction of observations. A bias towards underestimation is reflected in positive values of PBIAS while a bias towards overestimation is reflected in negative values. Low magnitude values of PBIAS indicate better fit, with a value of 0 being optimal.
- ▼ The ratio of the root mean square error to the standard deviation of measured data (RSR) provides a measure of error based on the root mean square error (RMSE), which indicates error results in the same units as the modeled and observed data but normalized based on the standard deviation of observed data. Values for RSR can be greater than or equal to 0, with a value of 0 indicating perfect fit. Moriasi et al. (2007) provides narrative grades for RSR.
- ▼ The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. Values for NSE can range between -∞ and 1, with NSE = 1 indicating a perfect fit.

Other metrics can also be computed and used to assess calibrated model performance, including the Kling-Gupta Efficiency (KGE). This metric can provide additional or complementary information on model performance to the three metrics listed above and is defined as follows:

- ▼ The Kling-Gupta Efficiency (KGE) metric is based on the Euclidean Distance between an idealized reference point and a sample's bias, standard deviation, and correlation within a three-dimensional space (Gupta et al. 2009). KGE attempts to address documented shortcomings of NSE, but the two metrics are not directly comparable. A KGE value of 1 indicates perfect fit, with agreement becoming worse for values less than 1. Knoben et al. (2019) have suggested a KGE value > - 0.41 as a benchmark that indicates a model has more predictive skill than using the mean observed flow. Qualitative thresholds for KGE have been used by Kouchi et al. (2017).

Both modeled time series and observed data will be binned into subsets of time to highlight seasonal performance and different flow conditions. Hydrograph separation will be performed to assess stormwater runoff vs. baseflow periods to isolate model performance on stormflows and low flows.

Table 8-1 is a summary of performance metrics that will be used to evaluate hydrology calibration; as shown in this table, "All Conditions" (i.e., annual interval) for R-squared and NSE is the primary condition typically evaluated during model calibration. For sub-annual intervals, the pattern established in the literature for PBIAS when going from "All Conditions" to sub-annual intervals is to shift the qualitative assessment by one category (e.g., use the "good" range for "very good," "fair" for "good," and so on). This pattern will also be followed for R-squared and NSE qualitative assessments of sub-annual intervals.

The LSPC calibration performance in the Santa Maria and Cuyama Rivers watershed will be assessed to see if linkage of the LSPC model with a groundwater model (e.g., MODFLOW) could improve performance and process interactions. This could be manifested through a significant mismatch between the simulated and observed baseflow during dry periods. Other indicators include the

mismatch between the simulated and observed hydrograph shape, demonstrating significant flow timing and magnitude differences.

Table 8-1. Summary of performance metrics used to evaluate hydrology calibration

Performance Metric	Hydrological Condition	Performance Threshold for Hydrology Simulation			
		Very Good	Good	Fair	Poor
Percent Bias (PBIAS)	All Conditions[1]	<5%	5% - 10%	10% - 15%	>15%
	Seasonal Flows[2]	<10%	10% - 15%	15% - 25%	>25%
	Highest 10% of Daily Flow Rates[3]				
	Days Categorized as Storm Flow[4]				
	Days Categorized as Baseflow[4]				
RMSE – Std Dev Ratio (RSR)	All Conditions[1]	≤0.50	0.50 - 0.60	0.60 - 0.70	>0.70
	Seasonal Flows[2]	≤0.40	0.40 - 0.50	0.50 - 0.60	>0.60
Nash-Sutcliffe Efficiency (NSE)	All Conditions[1]	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50
	Seasonal Flows[2]	>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40
Kling-Gupta Efficiency (KGE)	Monthly Aggregated[5]	≥0.90	0.90 - 0.75	0.75 - 0.50	<0.50

1. All Flows considers all daily time steps in the model time series.
2. Seasonal Flows consider daily flows during a predefined, seasonal period (e.g., Wet Season and Dry Season). The Wet Season includes the months of October through April. The Dry Season includes the months of May through September.
3. Highest 10% of Flows considers the top 10% of daily flows by magnitude as determined from the observed flow duration curve.
4. Baseflows and Storm flows were determined from analyzing the daily model time series by applying the USGS hydrograph separation approach (Sloto and Crouse 1996).
5. KGE evaluated using thresholds for monthly aggregated time series (Kouchi et al. 2017).

9 SUMMMARY & NEXT STEPS

This work plan presented the available data and proposed methods for developing a hydrologic model of the Santa Maria and Cuyama Rivers watershed. Once this work plan is finalized, the datasets described in this memo will be used to develop an LSPC model as described in Section 7. After finalizing the work plan, the first step of that process will be to present and finalize watershed boundaries and subcatchment delineations that capture key points of interest in the watershed (e.g., tributary confluences, station locations, and the like). Once built, this model will be calibrated using the metrics presented in Section 8 and documented in a model development report. Table 9-1 presents a summary of the deliverables planned for the Santa Maria and Cuyama Rivers watershed.

Table 9-1. Proposed schedule and summary of deliverables

Task	Subtask	Deliverable	Due Date
2	2.2	Draft Work Plan	7/11/2025
	2.3	Final Work Plan	Two (2) weeks after receiving comments
3	3.1	Subbasin delineation and stream GIS files	Two (2) weeks after completing Task 2.3
	3.2	LSPC database, model inputs, and GIS files[1]	Twelve (12) weeks after completing Task 3.1
4	4.1	Draft Calibration Slide Deck	Twelve (12) weeks after completing Task 3.2
		Final Calibration Slide Deck	Four (4) weeks after receiving comments on Draft Calibration Slide Deck
5	5.1	Partial Draft Model Development Report[1]	Twelve (12) weeks after completing Task 3.1
		Draft Model Development Report	Six (6) weeks after completing Task 3.2
	5.2	Final Model Development Report	Four (4) weeks after receiving comments on Task 5.1 Draft MDR
	5.3	Final LSPC Model Code & Software	Two (2) weeks after Task 5.2
	5.4	Final Model Files including LSPC executable, LSPC database, LSPC model inputs, final GIS files	Two (2) weeks after Task 5.2

1. Partial Draft Model Development Report under Task 5.1 will be delivered in conjunction with Task 3.2 to document the model configuration.

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