

---

# Work Plan: Big Creek Watershed Hydrology Model Development

---

SUBMITTED TO:

State Water Resources Control Board  
1001 I Street, 14th Floor  
Sacramento, CA 95814

PREPARED BY:



Paradigm Environmental  
9320 Chesapeake Drive, Suite 100  
San Diego, CA 92123

FINAL  
AUGUST 29, 2025

THIS PAGE INTENTIONALLY LEFT BLANK

## 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
CDFW	CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE
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 <sub>0</sub>	REFERENCE EVAPOTRANSPIRATION
EWRIMS	ELECTRONIC WATER RIGHTS INFORMATION MANAGEMENT SYSTEM
GHCN	GLOBAL HISTORICAL CLIMATOLOGY NETWORK
GIS	GEOGRAPHIC INFORMATION SYSTEM
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

## Contents

ACRONYMS .....	i
1 Introduction.....	1
1.1 Project Objectives .....	1
1.2 Watershed Background .....	1
1.3 Model Approach.....	3
1.4 Data Availability.....	5
2 Meteorology .....	11
2.1 Precipitation .....	11
2.2 Evapotranspiration (ET).....	15
3 Surface Hydrology .....	16
3.1 Watershed Segmentation.....	16
3.2 Streams and Channels.....	18
3.3 Streamflow .....	19
3.4 Dams, Reservoirs, and Impoundments.....	20
3.5 Surface Water Withdrawals.....	20
4 Subsurface Hydrology .....	22
4.1 Water Budget Components.....	23
4.2 Geology.....	23
5 Landscape Characterization .....	24
5.1 Elevation & Slope .....	25
5.2 Soils .....	26
5.3 Land Cover .....	28
5.4 Tree Canopy Cover .....	31
5.5 Agriculture & Crops.....	31
6 Data Gaps and Limitations.....	33
7 Model Configuration.....	33
7.1 Model Selection .....	33
7.2 Model Configuration.....	34
8 Model Calibration.....	35
9 Summary & Next Steps .....	38
10 References.....	39

Figures

Figure 1-1. Big Creek watershed.....3  
Figure 1-2. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Big Creek watershed. ....5  
Figure 2-1. Identified rainfall stations and CIMIS ET Zones near the Big Creek watershed. .... 14  
Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products. .... 15  
Figure 3-1. Initial catchment segmentation for the Big Creek watershed. .... 18  
Figure 3-2. USGS streamflow stations in the Big Creek watershed. .... 20  
Figure 3-3. Primary Water System Sources in the Big Creek watershed. .... 22  
Figure 4-1. Groundwater basins delineated by DWR (2020), also known as Bulletin 118. .... 23  
Figure 4-2. Geology map of the Big Creek watershed. .... 24  
Figure 5-1. DEM of the Big Creek watershed. .... 26  
Figure 5-2. SSURGO hydrologic soil groups within the Big Creek watershed. .... 28  
Figure 5-3. NLCD 2021 land cover within the Big Creek watershed. .... 30  
Figure 5-4. USDA 2022 Cropland Data within the Big Creek watershed. .... 32

Tables

Table 1-1. Inventory of meteorology datasets .....6  
Table 1-2. Inventory of surface water datasets .....7  
Table 1-3. Inventory of geospatial datasets .....8  
Table 1-4. Inventory of groundwater datasets ..... 10  
Table 2-1. Summary of precipitation stations with observations available after 2000 ..... 13  
Table 3-1. Summary of NHDPlus catchment sizes within the Big Creek HUC-10 ..... 17  
Table 3-2. Summary of USGS daily streamflow data after 2000 ..... 19  
Table 5-1. NRCS Hydrologic soil group descriptions ..... 27  
Table 5-2. NRCS Hydrologic soil groups in the Big Creek watershed ..... 27  
Table 5-3. National Land Cover Database 2021 land cover summary in the Big Creek watershed .. 29  
Table 5-4 USDA 2022 Cropland Data summary within the Big Creek watershed ..... 32  
Table 8-1. Summary of performance metrics used to evaluate hydrology calibration ..... 37  
Table 9-1. Proposed schedule and summary of deliverables ..... 38

# 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 Big Creek 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 Big Creek watershed, delineated by a ten-digit Hydrologic Unit Code (HUC), shares its northern boundary with the Carmel River and Carmel Bay watersheds, its eastern boundary with the Arroyo Seco, San Antonio River, and Nacimiento River watersheds, and its southern boundary with the Santa Rosa Creek watershed. Big Creek (HUC-10:1806000603) is a coastal watershed that drains approximately 235 square miles and is composed of seven subwatersheds: Big Creek (HUC-12: 180600060303), Big Sur River (HUC-12: 180600060301), Limekiln Creek (HUC-12: 180600060305), Partington Creek (HUC-12: 180600060302), Salmon Creek (HUC-12: 180600060307), San Carpoforo Creek (HUC-12: 180600060306) and Willow Creek (HUC-12: 180600060304), as shown in [Figure](#). Big Creek is a free-flowing river within the Big Creek watershed (HUC-10 and HUC-12). Other notable streams within the broader watershed include the Big Sur River, San Carpoforo Creek, and Willow Creek, all of which, similar to Big Creek, originate on the western side of the Santa Lucia Mountain Range and generally flow from east to west before discharging into the Pacific Ocean. In the central part of the watershed, Big Creek flows approximately 6 miles before reaching the City of Santa Cruz and discharging into the Pacific Ocean. In the northern portion of the watershed, the Big Sur River meanders westward for about 16 miles before entering the Pacific Ocean. In the central-southern region, Willow Creek flows roughly 6 miles before discharging into the Pacific. In the southern portion of the watershed, San Carpoforo Creek flows approximately 8 miles before reaching the Pacific Ocean.

The Big Creek watershed ranges in elevation from near sea level along the coastline to over 1,500 meters near Junipero Serra Peak in Pfeiffer Big Sur State Park. The watershed spans approximately 50 miles of rugged coastal terrain and experiences a Mediterranean climate with distinct wet and dry seasons. Mean annual precipitation varies across the region, averaging 42.5 inches in the northern Big Sur basin, 47.9 inches in the central Big Creek (HUC-12) basin, and 35.4 inches in the southern San Carpoforo Creek basin (USGS 2019). The watershed is dominated by shrub/scrub (35%), grassland/herbaceous (26%) and evergreen forest (25%) areas. Other land cover types include mixed forest (11%) and developed open space (2%).

The Big Creek watershed, located along California's central coast, is an ecologically sensitive region facing multiple environmental stressors. It is particularly vulnerable to wildfires due to its highly flammable forested land cover, with post-wildfire flooding and sedimentation further stressing stream habitats (Warrick et. al. 2022). Erosion is also a major concern, driven by seismic activity and ocean wave energy (USGS 2005). The watershed contains critical habitat for threatened anadromous fish species. Big Creek plays a vital role in supporting southern steelhead trout and serves as a key site for research and education on the species' ecology and conservation. Researchers at the University of California, Santa Cruz are studying the steelhead population to better understand its evolving food web, especially in relation to non-native insects, and its responses to disturbances such as flooding, debris flows, drought, and wildfire (UCSC 2024). The Big Sur River, another key habitat for steelhead trout in California, has experienced population decline in recent years, largely due to insufficient streamflow (CDFW 2016). Big Sur's naturally low baseflows in late summer and fall are expected to worsen under future climate change scenarios.

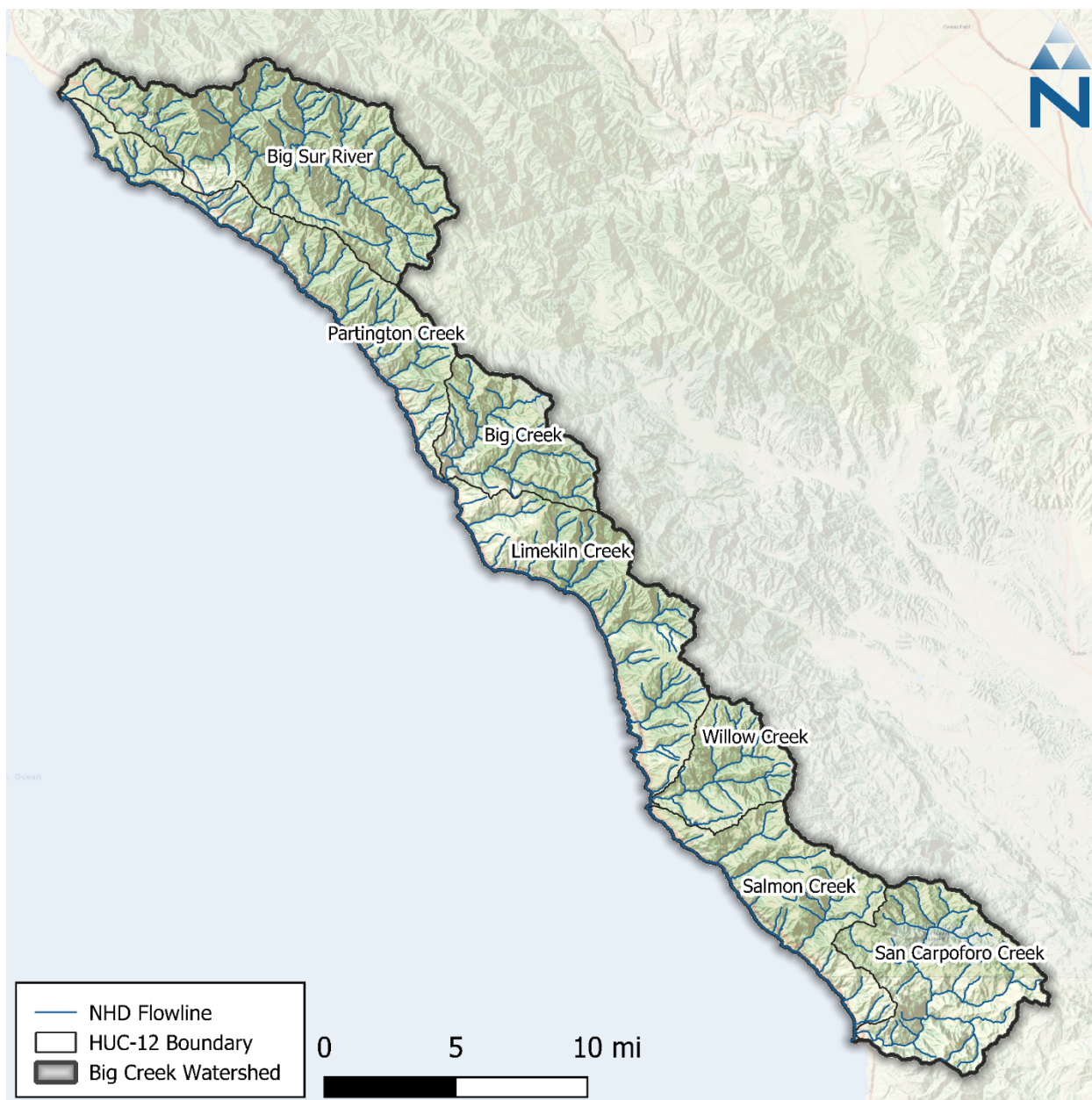


Figure 1-1. Big Creek watershed.

### 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 Big Creek watershed. This is presented first through a comprehensive inventory of available meteorological, hydrological, and geographic information system (GIS) data available for the Big Creek 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.

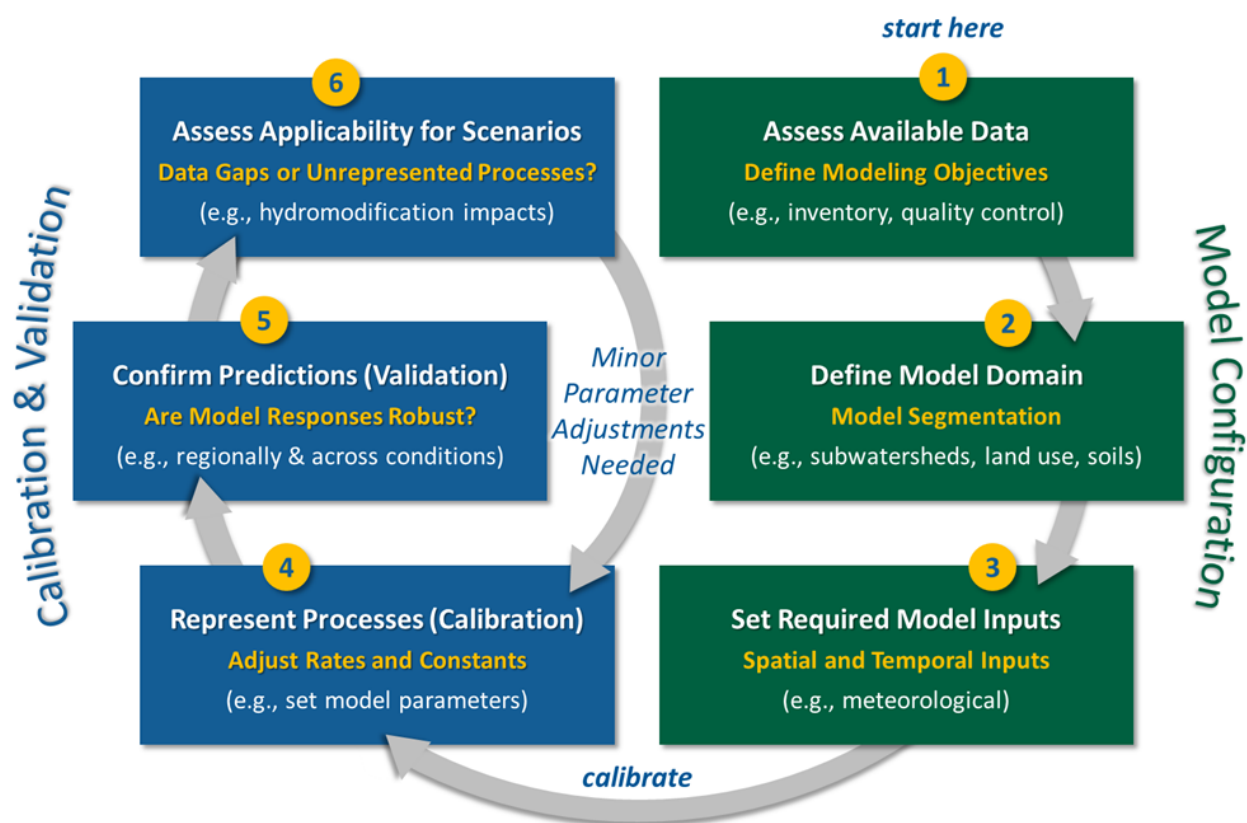


Figure 1-2. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Big Creek watershed.

## 1.4 Data Availability

Table 1-1 through Table 14 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 Big Creek. Time series observations of instream responses for the Big Creek are often used as calibration and validation datasets for hydrologic models.
- ▼ **Geospatial Datasets:** Spatial datasets describing the landscape of the Big Creek 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 three stations.	Climate data boundary time series.
California Data Exchange Center (CDEC)	Precipitation, Temperature	--	Meteorological records are available for two 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	1991 – Current	Observed Streamflow at two active locations within the Big Creek watershed.	Hydrology calibration.	<a href="#">LINK</a>
Water Budget	State	DWR	Well Completion Reports	Current	Well completion logs and reports.	Water budget.	<a href="#">LINK</a>
Water Budget	State	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.	Water budget.	<a href="#">LINK</a>
		SWRCB eWRIMS DWR	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.		<a href="#">LINK</a>
			Annual Water Use Report	1906 – 2023	Annual reports that provide monthly diversion data for various entities such as Applications, Registrations, Petitions, etc.		<a href="#">LINK</a>
			Agricultural Land and Water Use Estimates	1998 – 2015	Water use estimates by various planning units.		<a href="#">LINK</a>
		CDT	Water Districts	2022	Boundaries of all public water agencies in California.		<a href="#">LINK</a>
		CDT	California Drinking Water System Area Boundaries	2024	Public California drinking water systems and state small drinking water system boundaries and information.		<a href="#">LINK</a>

**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).	Model segmentation.	<a href="#">LINK</a>
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.		<a href="#">LINK</a>
			NHD Best Resolution	2023	1:24,000; represents reaches and other network elements.		<a href="#">LINK</a>
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.	<a href="#">LINK</a>
			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.	<a href="#">LINK</a>
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.	<a href="#">LINK</a>
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.	<a href="#">LINK</a>
			NLCD Fractional Imperviousness	2021	Broad, 30-meter grid-based land characterization. Represent percent impervious area within raster cells.		<a href="#">LINK</a>

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Land Use	State	DWR	Statewide Crop Mapping	2020	Polygons attributed to DWR crop categories.	Identify crop distributions; estimate irrigation demand.	<a href="#">LINK</a>
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.	<a href="#">LINK</a>
	State	USFS	Existing Vegetation	2018	1:24,000 to 1:100,000: Existing vegetation mapping.	As necessary, additional vegetation types for model land segments.	<a href="#">LINK</a>
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.	<a href="#">LINK</a>
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 to timber harvest activities.	<a href="#">LINK</a>
	State	CAL FIRE	Nonindustrial Timber Management Plans TA83	1991 - Present	Timber management plans.		<a href="#">LINK</a>
			Notices of Timber Operations TA83	1991 - Present	Notice of Timber Operations accepted by CAL FIRE.		<a href="#">LINK</a>
			Working Forest Management Plans TA83	2019 - Present	Working forest management plans approved by CAL FIRE.		<a href="#">LINK</a>

Category	Scale	Source	Dataset	Date Range	Description	Model Use	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.	<a href="#">LINK</a>
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.	<a href="#">LINK</a>

**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.	<a href="#">LINK</a>
Groundwater levels	State	DWR	Periodic Groundwater Level Measurements	2023	Groundwater levels.	Model calibration.	<a href="#">LINK</a>
Geological information	State	DWR	Well Completion Reports (OSWCR)	2023	Geological information.	Groundwater stratigraphy and properties.	<a href="#">LINK</a>

## 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 Big Creek 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. Three GHCN stations were identified within or near the Big Creek 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. However, there are no LCD stations within 15 km of the Big Creek watershed. The California Data Exchange Center (CDEC) and the Remote Automated Weather Stations (RAWS) networks also report hourly precipitation. CDEC reports at two locations and RAWS reports at three locations within and near the watershed.

In addition to precipitation data, snow data was also screened for the Big Creek watershed model and yielded three GHCN stations within a 15km buffer (reference [Figure 2-1](#)) 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.

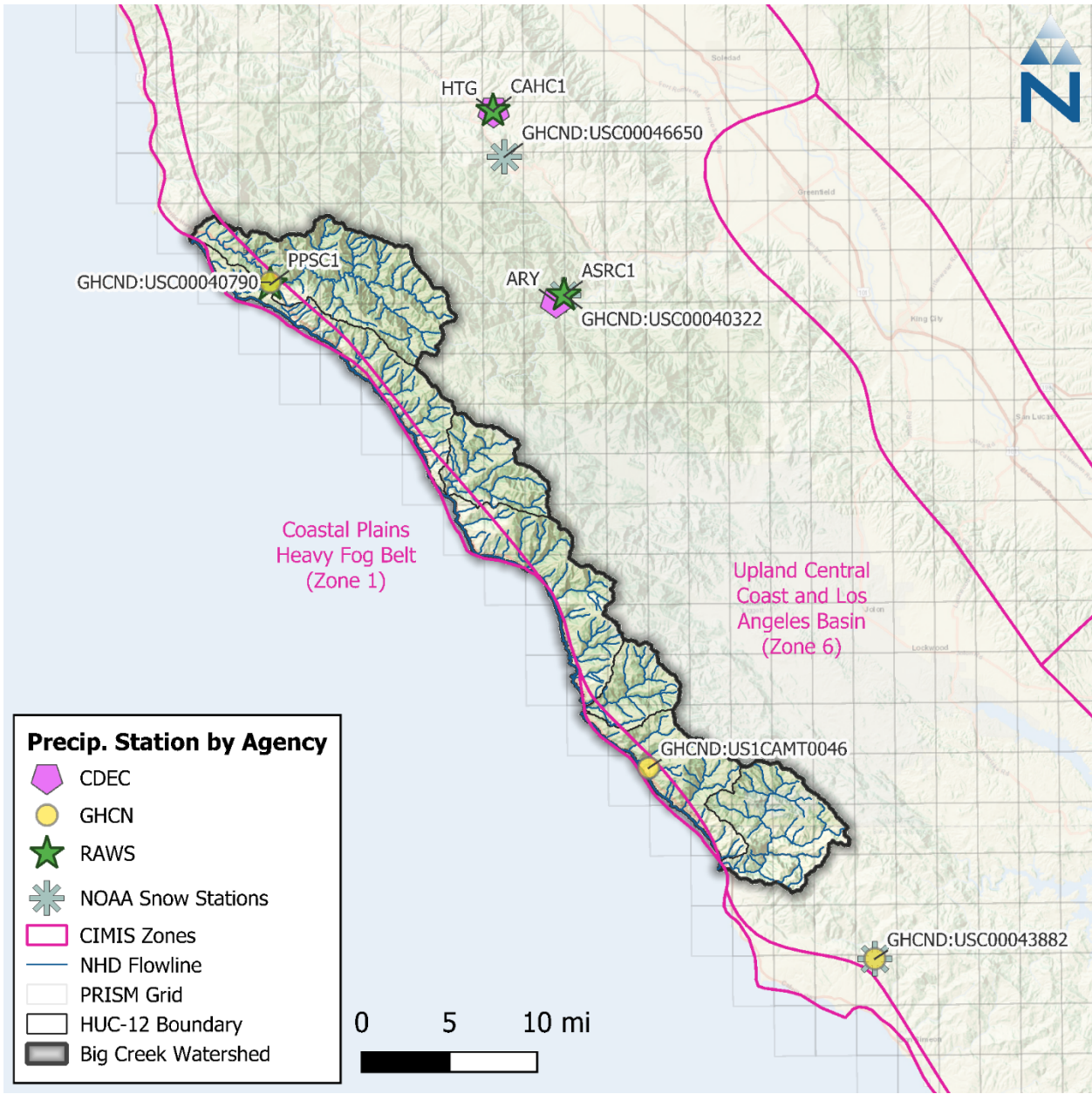
[Table 2-1](#) is an inventory of the precipitation stations near the Big Creek watershed with available data after 2000 with at least 75% data coverage during the modeling period. It also includes stations with 60% or more data coverage during the modeling period, provided that these stations have 90% 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. [Figure 2-1](#) shows the location of the identified stations. There is one location where CDEC and RAWS stations appear to be co-located (i.e., within a 500 m radius) and one location where GHCN and RAWS 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 Big Creek 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 [Figure 2-1](#). 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 (%) <sup>1</sup>	Station Record Coverage (%) <sup>2</sup>
GHCN	GHCND:USC00040790	BIG SUR STN	1/1/1915	Present	36.247	-121.780	61.0	88.7	88.7
	GHCND:US1CAM T0046	CAMBRIA 27.2 NW	1/8/2018	3/28/2025	35.844	-121.397	252.4	6.9	24.2
	GHCND:USC00043882	HEARST CASTLE	12/1/1999	Present	35.684	-121.168	465.1	98.5	98.5
CDEC	ARY	ARROYO SECO	6/3/1999	present	36.230	-121.488	298.7	85.9	95.5
	HTG	HASTINGS	12/24/1997	present	36.388	-121.551	556.0	89.3	99.3
RAWS	ASRC1	ARROYO SECO	5/8/1996	Present	36.235	-121.480	267.9	97.1	97.1
	PPSC1	BIG SUR	7/27/2001	Present	36.245	-121.780	107.9	96.5	96.5
	CAHC1	HASTINGS	4/30/1997	Present	36.389	-121.552	574.5	97.4	97.4

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 Big Creek 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.

[Figure 2-2](#) 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 [Figure 2-2](#) also shows what a hybrid dataset of observed time series, supplemented by gridded products would look like.

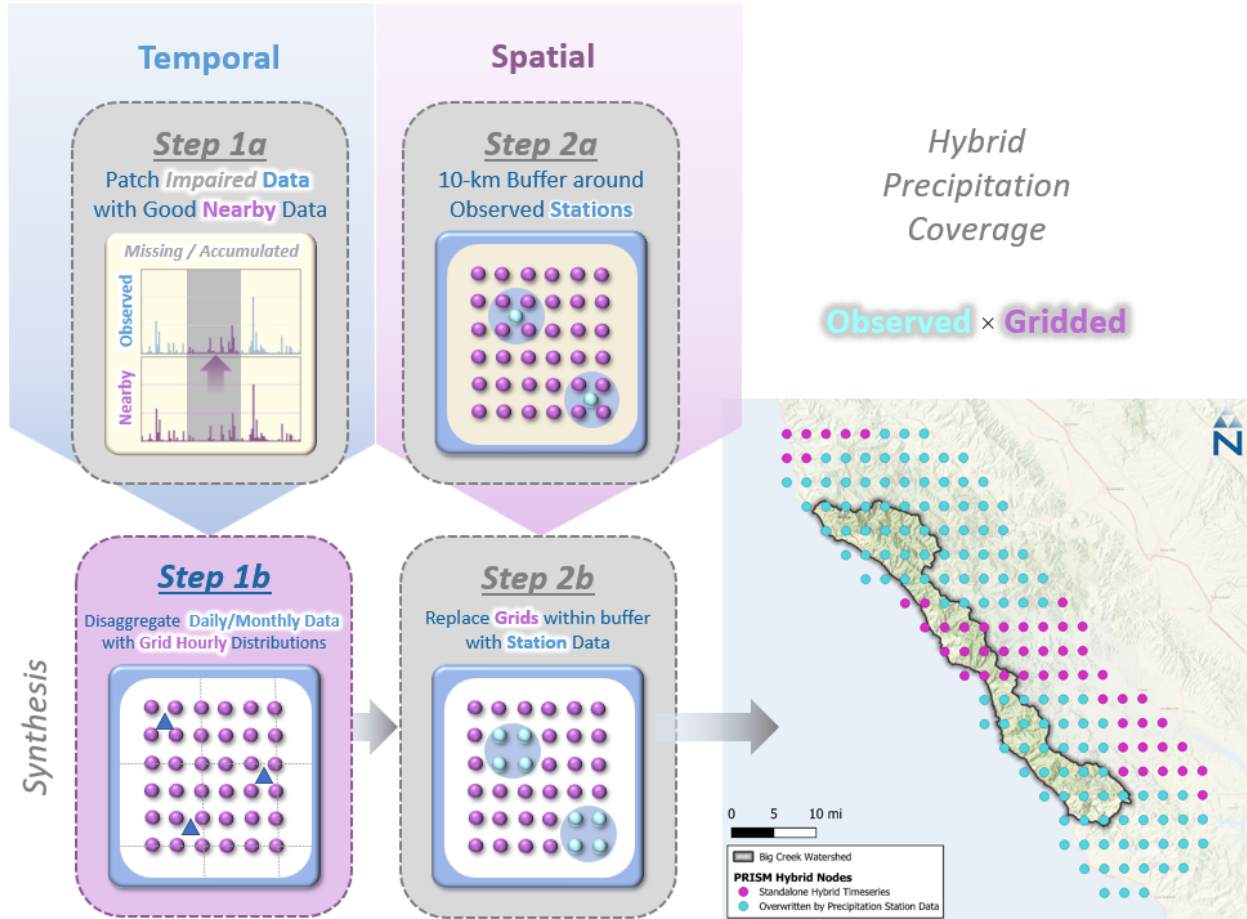


Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products.

## 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 ( $ET_0$ ) using versions of the Penman and Penman-Monteith equations. CIMIS has divided California into 18 zones based on long-term monthly average  $ET_0$  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 closer spatial alignment.

There are no CIMIS stations near the Big Creek watershed. As shown in [Figure 2-1](#), the Big Creek watershed intersects two CIMIS zones with approximately 82% of the watershed area in Zone 6 (Upland Central Coast and Los Angeles Basin), and around 18% of the watershed area in Zone 1 (Coastal Plains Heavy Fog Belt). Most of the Big Creek watershed falls within Zone 6, and the western coast of the watershed falls into Zone 1. These zones experience average annual reference ET levels from 33.0 inches per year in Zone 1 to 49.7 inches per year in Zone 6.

CIMIS also has a newly derived gridded product, CIMIS Spatial, that expresses daily  $ET_0$  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  $ET_0$  using solar radiation, air temperature, relative humidity, and wind speed at two meters height. This product provides a consistent spatial estimate of  $ET_0$  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 Big Creek 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  $ET_0$  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  $ET_0$ . 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 Big Creek watershed is defined by a HUC-10 watershed that is comprised of 7 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 388 catchments ranging between 0.66 to nearly 2,262 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 Big Creek watershed (HUC-10).

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 Big Creek HUC-10**

HUC-12 Name	Count	Catchment Size (acres)			
		Minimum	Mean	Median	Maximum
Big Sur River	96	7.784	389.1	350.8	1,239.1
Partington Creek	67	1.331	321.9	286.4	909.2
Big Creek	32	36.472	444.7	303.9	2,095.4
Willow Creek	24	7.561	433.7	355.0	1,515.7
Limekiln Creek	81	0.667	316.2	227.9	2,113.2
San Carpoforo Creek	47	20.682	485.1	338.9	2,261.7
Salmon Creek	41	2.002	447.8	345.0	1,543.7

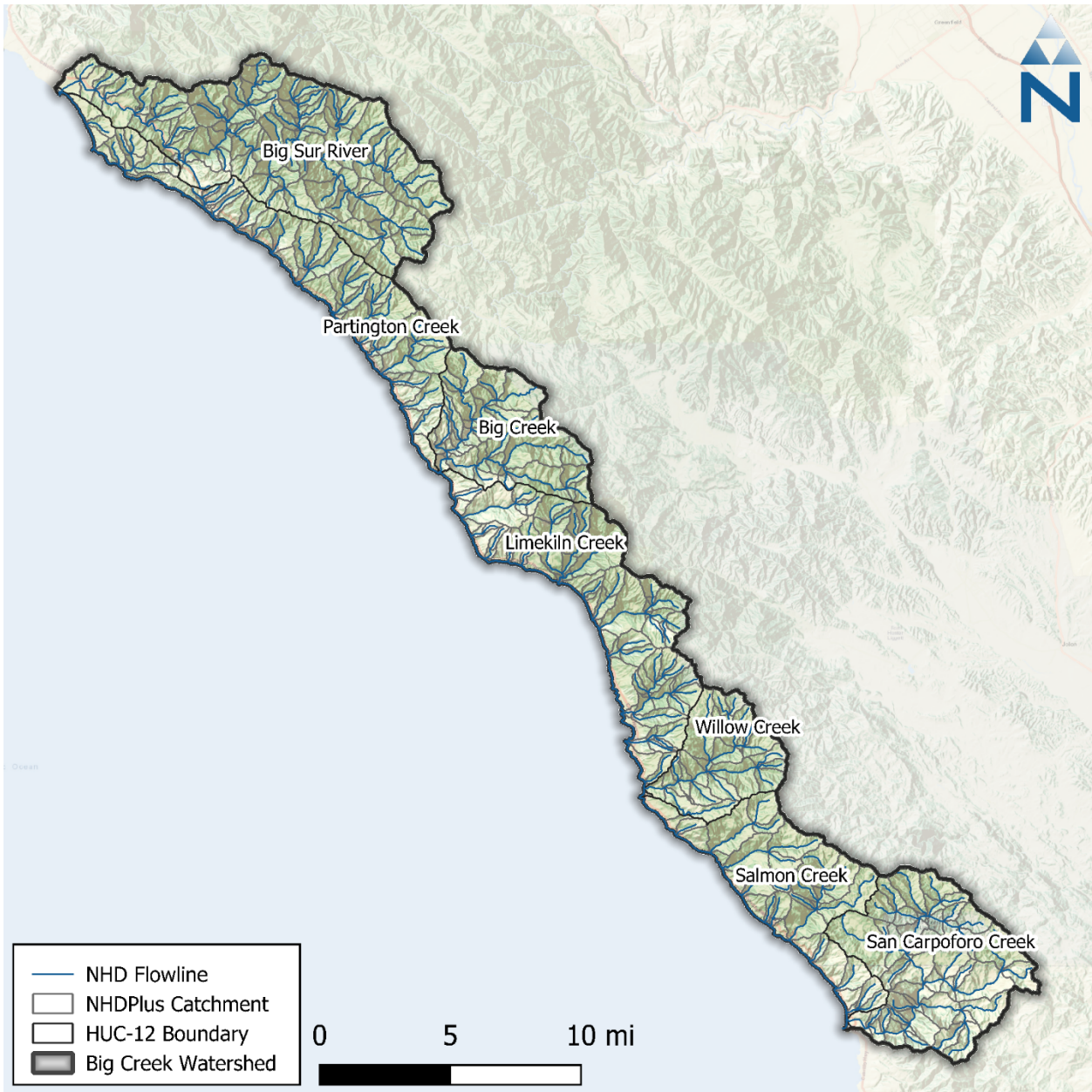


Figure 3-1. Initial catchment segmentation for the Big Creek watershed.

### 3.2 Streams and Channels

As described above, the hydrographic characteristics of the streams and rivers within the Big Creek 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”).

### 3.3 Streamflow

The primary source of streamflow data is from the USGS, which includes one current long-term station: the Big Sur River near Big Sur, CA (USGS 11143000). There is also one historical flow station within the watershed with data after 2000. [Table 3-2](#) presents a summary of the available USGS streamflow data. [Figure 3-2](#) shows the locations of the two USGS flow stations within the Big Creek watershed.

**Table 3-2. Summary of USGS daily streamflow data after 2000**

Station Description	Station ID	Drainage Area (mi <sup>2</sup> )	Start Date	End Date	Station Active?
BIG SUR R A ANDREW MOLERA STATE PARK NR BIG SUR CA <sup>1</sup>	11143010	57.9	10/22/2010	03/30/2014	No
BIG SUR R NR BIG SUR CA <sup>2</sup>	11143000	46.5	04/01/1950	Present	Yes

1. USGS notes “No records computed above 400 ft<sup>3</sup>/s. No regulation or known diversion upstream from station.” ([USGS Water-Year Summary for Site 11143010](#))
2. USGS notes “No regulation or diversion upstream from station.” ([USGS Water-Year Summary for Site 11143000](#))

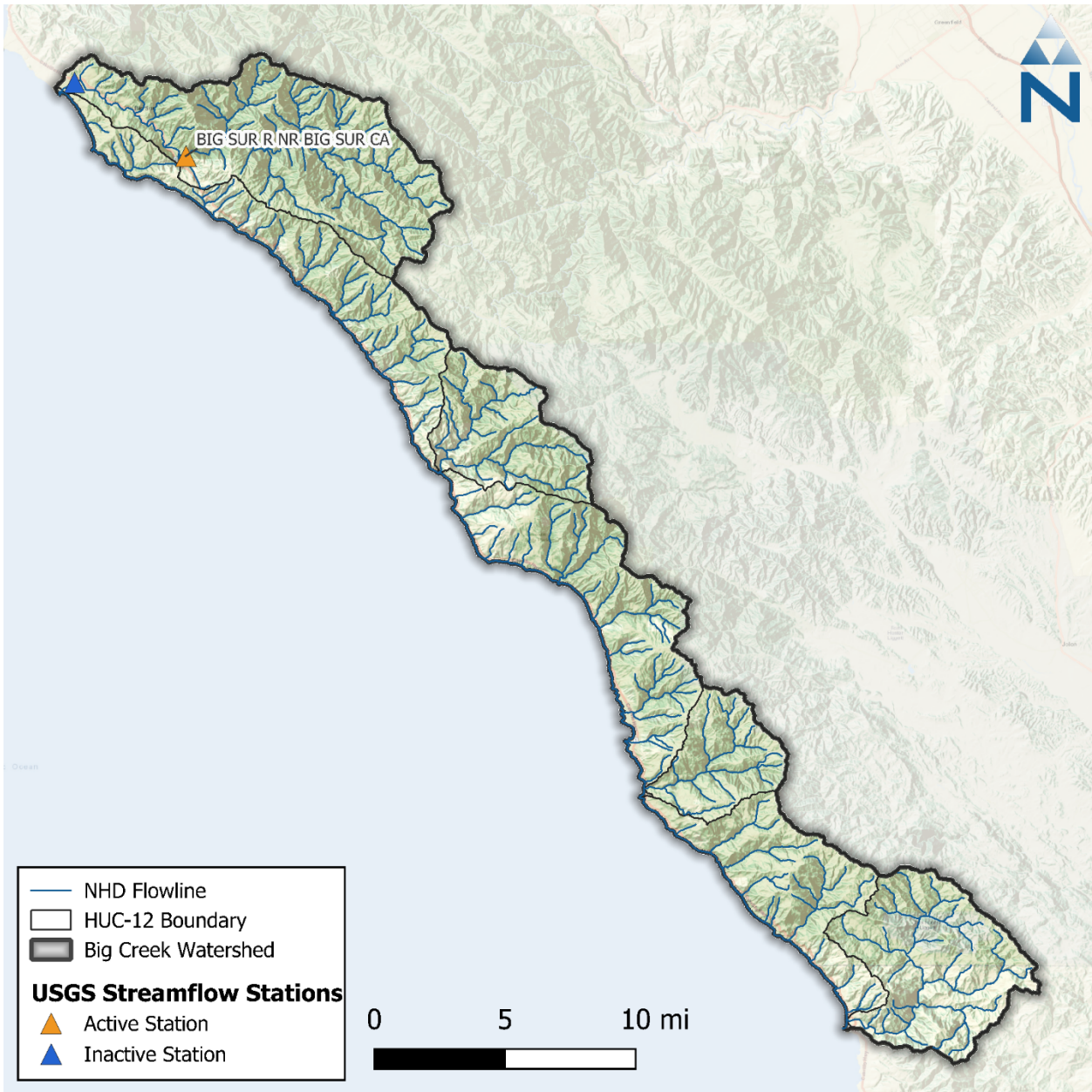


Figure 3-2. USGS streamflow stations in the Big Creek watershed.

### 3.4 Dams, Reservoirs, and Impoundments

There are no NID dams or NHD waterbodies located within the Big Creek watershed (NID 2025). Additional data such as reservoir flow, stage, or storage data from CDEC is also unavailable.

### 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 Big Creek 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 3-3](#) 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 Big Creek and its primary tributaries, as well as groundwater withdrawals for the Big Creek watershed groundwater basin. There are 24 drinking water systems in the watershed. For 19 out of the 24 drinking water systems, the water source is listed as groundwater, and 5 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.

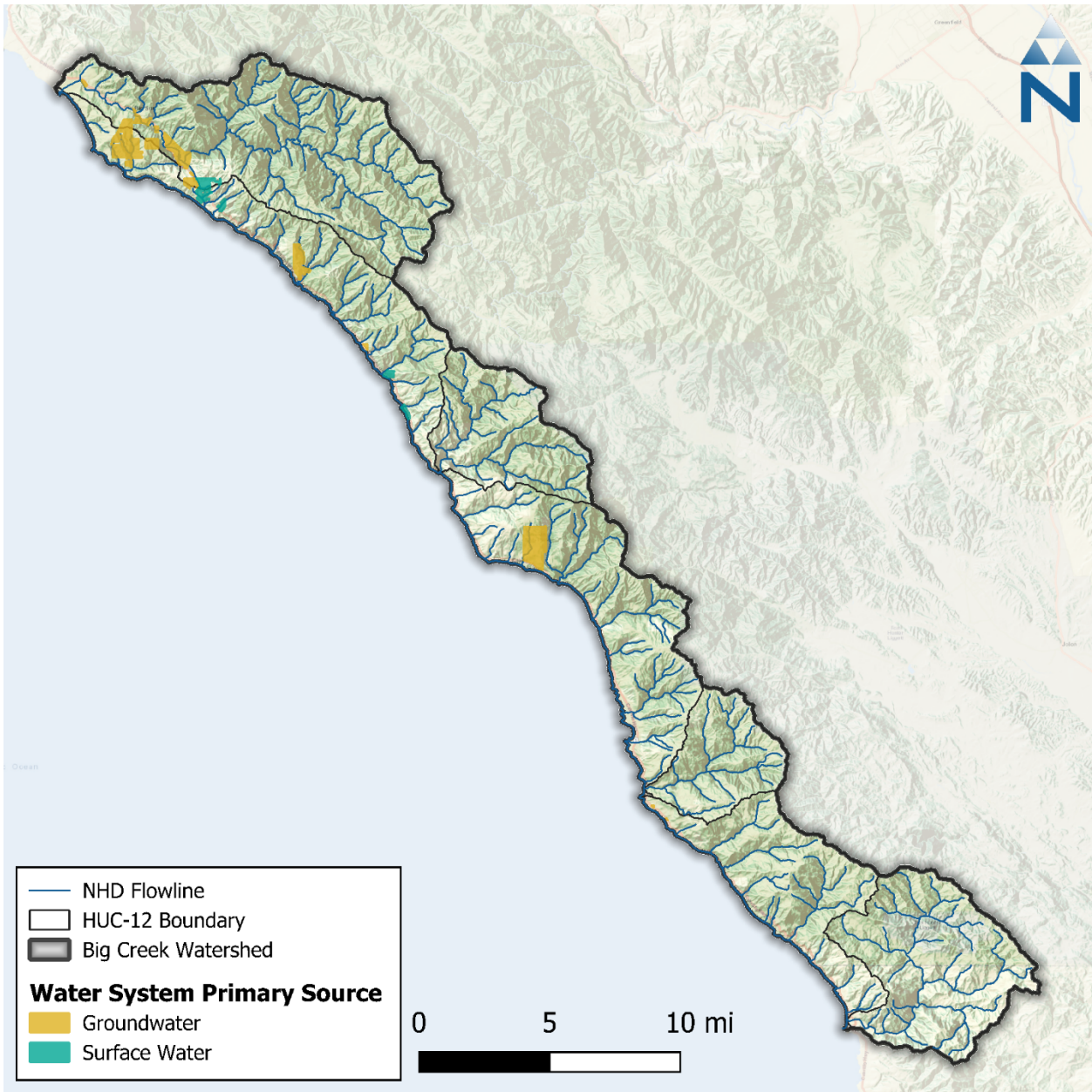


Figure 3-3. Primary Water System Sources in the Big Creek watershed.

## 4 SUBSURFACE HYDROLOGY

The Big Creek watershed overlaps with one groundwater basin as delineated by Bulletin 118 (DWR, 2020). The watershed contains the San Carpoforo Valley basin (number 3-033). Less than 1% of the watershed area falls within the groundwater basins delineated by Bulletin 118, and the watershed otherwise consists of Cretaceous and pre-Cretaceous metamorphic rocks. As per the respective basin priority details ([Sustainable Groundwater Management Act \(SGMA\) Basin Prioritization Dashboard](#)), the San Carpoforo Valley basin is classified as Very Low priority by the Sustainable Groundwater Management Act's (SGMA's) basin prioritization.

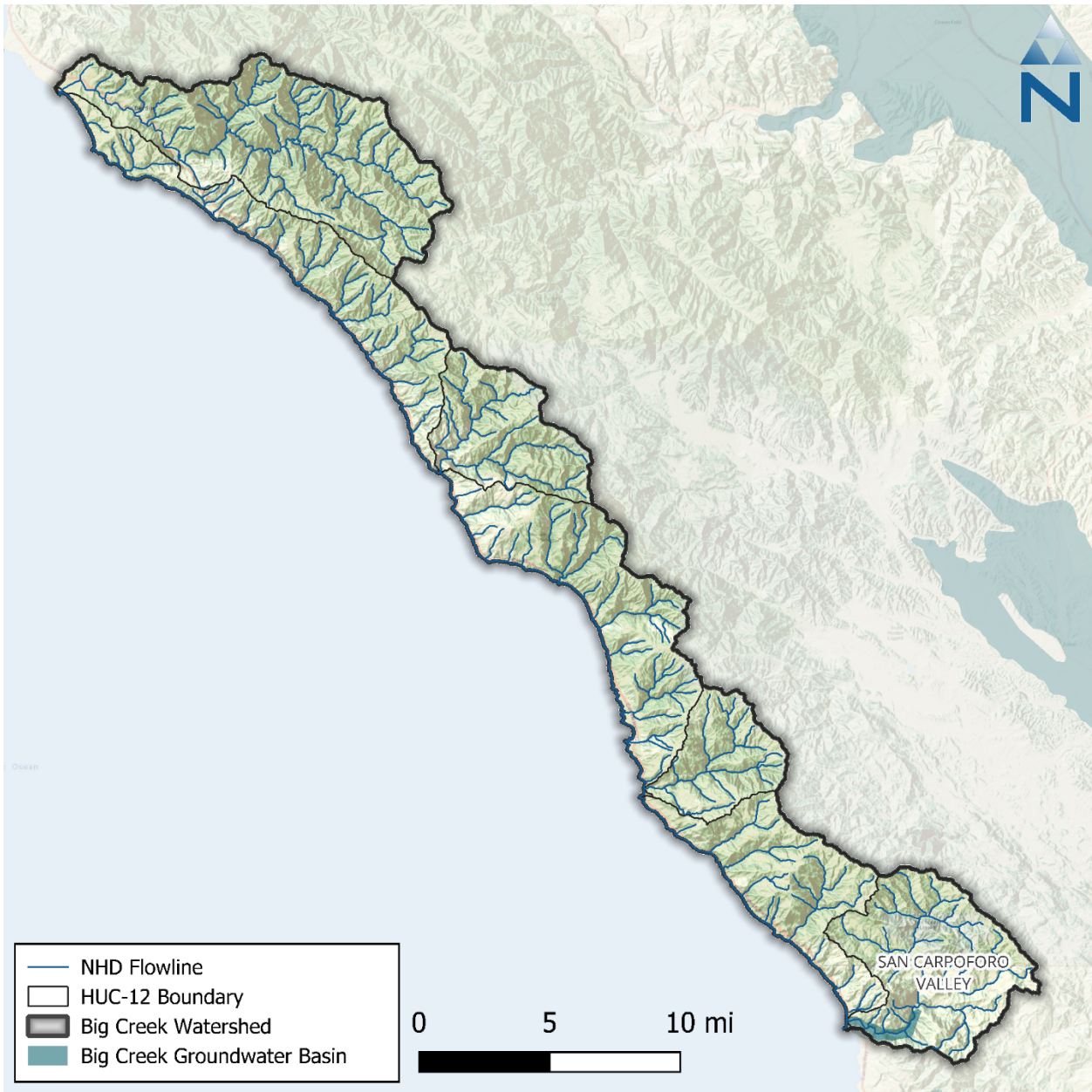


Figure 4-1. Groundwater basins delineated by DWR (2020), also known as Bulletin 118.

## 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 overlaps the Big Creek watershed. The Bulletin 118 basin descriptions for the San Carpoforo Valley does not include a water budget.

## 4.2 Geology

The foregoing references provide coverage primarily within the groundwater basins delineated as per Bulletin 118. The water bearing units within the San Carpoforo Valley consists of alluvial deposits of Quaternary to late Pleistocene age. In the Big Creek watershed outside the delineated basins, the

bedrock is shown by the Santa Cruz and San Luis Obispo regional geologic maps (Figure 4-2). The bedrock is composed of the Cretaceous-age Franciscan mélange to the south and pre-Cretaceous metamorphic rocks to the north. The San Gregorio fault zone runs along the western boundary of the basin.

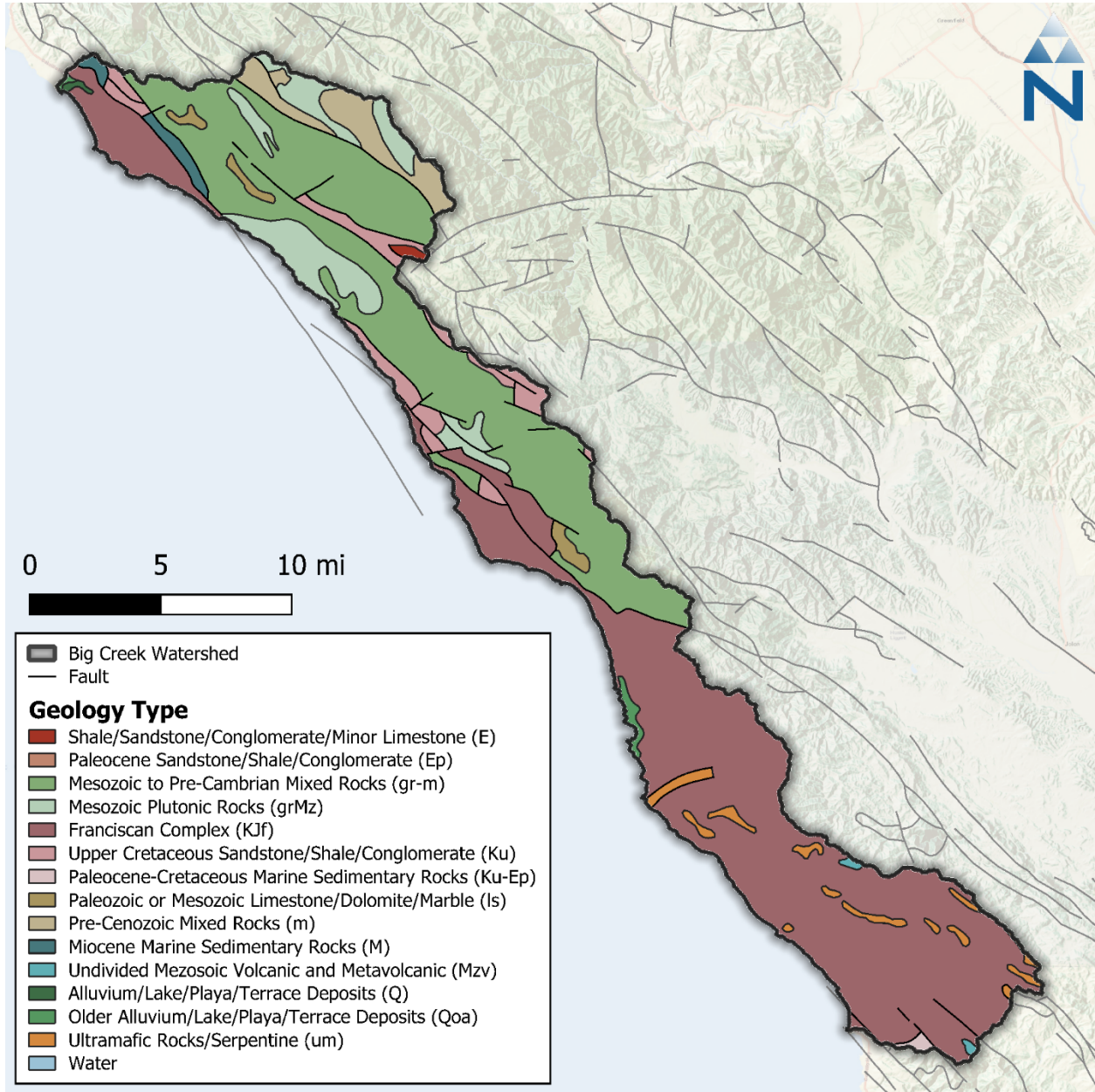


Figure 4-2. Geology map of the Big Creek watershed.

## 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 Big Creek watershed.

## 5.1 Elevation & Slope

---

The USGS publishes DEMs expressing landscape elevation through a raster grid data product with 30-meter resolution. The Big Creek watershed ranges in elevation from near sea level at the coast of the watershed to over 1,500 meters along the eastern border. 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 Big Creek watershed.

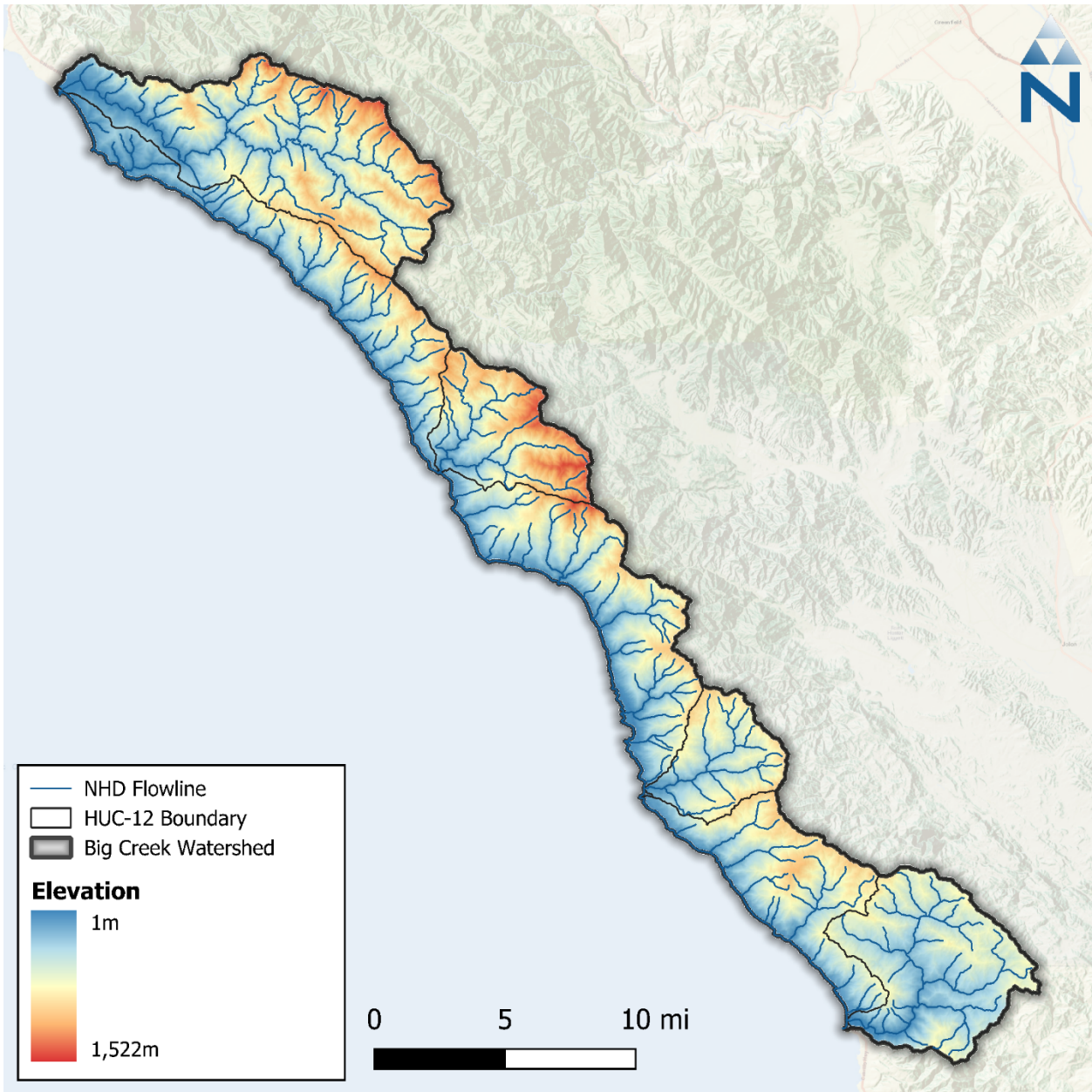


Figure 5-1. DEM of the Big Creek watershed.

## 5.2 Soils

Soils data for the Big Creek 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 Big Creek watershed. The dominant soil group in the watershed is Group D (55%) consists of soils with the lowest infiltration rates, such as clay loam, silty clay loam, sandy and silty clay, and clay. Group B makes up 26% of the watershed and contains moderately well to well-drained silt loams and loams. Group C makes up 13% of the watershed and contains sandy clay loam with typically low infiltration rates. Group A which contains well-draining sand, loamy sand, and sandy loam, constitutes nearly 1% of the watershed. There are no mixed soils within the Big Creek watershed. Finally, approximately 5% of the watershed HSG area is classified as unknown in the soils 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 Big Creek watershed**

Hydrologic Soil Group	Area (acres)	Percent Area
A	1,144.43	0.76%
B	39,721.22	26.49%
C	20,015.33	13.35%
D	81,803.87	54.55%
N/A	7,289.64	4.86%
<b>Total</b>	<b>149,974.48</b>	<b>100.00%</b>

Source: State Soil Geographic and Soil Survey Geographic Database (STATSGO2/SSURGO)

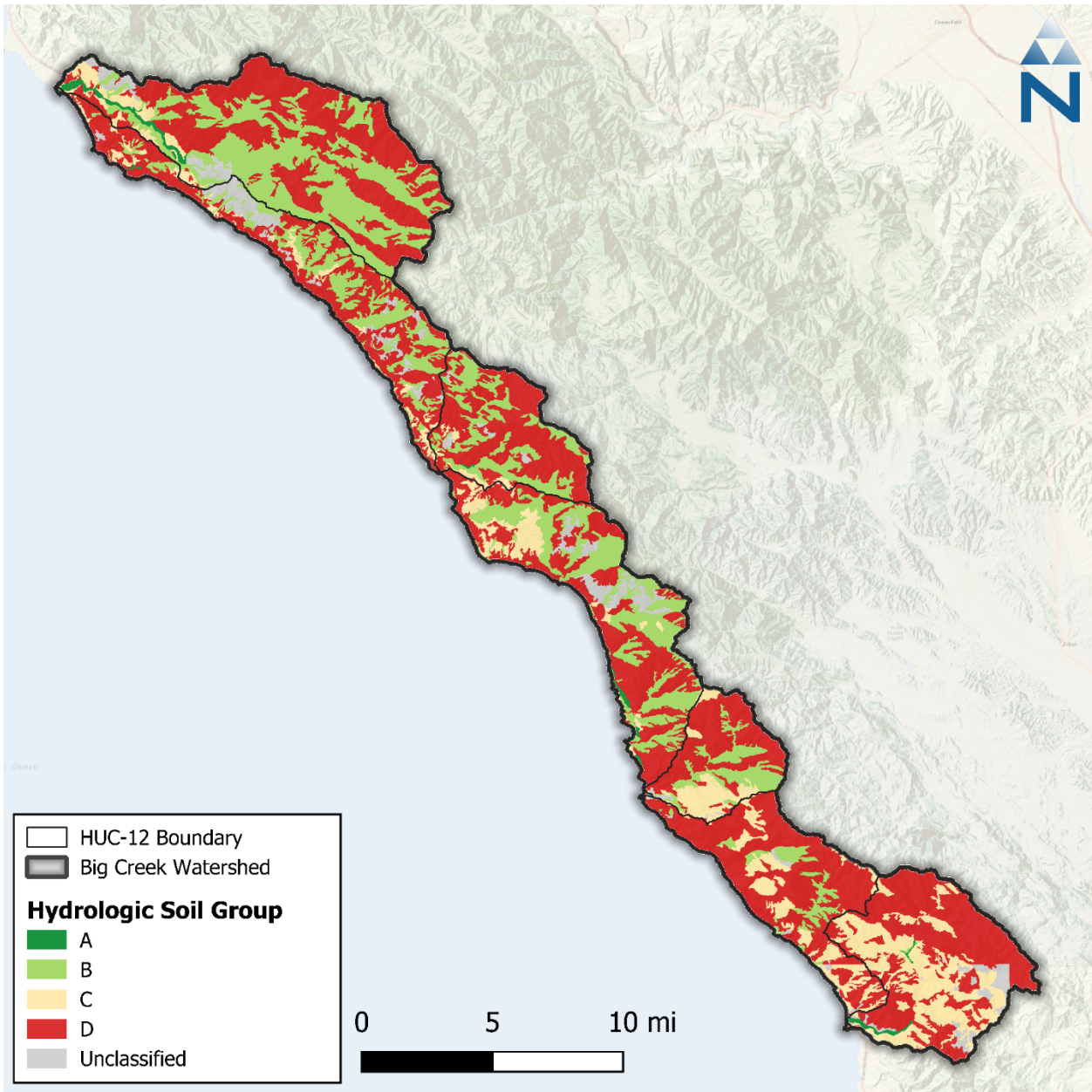


Figure 5-2. SSURGO hydrologic soil groups within the Big Creek watershed.

### 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.

Table 5-3 summarizes areal coverage of land use classes from a subset of the 2021 NLCD dataset that covers the Big Creek watershed and Figure 5-3 shows the spatial distribution of these classifications. Shrub/scrub is the dominant land cover classification covering approximately 35% of the watershed area. When combined, evergreen forest, the undeveloped categories of deciduous forest, mixed forest, shrub/scrub, and grassland/herbaceous account for approximately 96% of the total watershed area. Developed land cover makes up approximately 2.8% of the total watershed area and is classified mostly as “Developed, Open Space.”

**Table 5-3. National Land Cover Database 2021 land cover summary in the Big Creek watershed**

NLCD Class	Classification Description	Area (acres)	Percent
11	Open Water	395.80	0.26%
21	Developed, Open Space <sup>1</sup>	3,480.62	2.31%
22	Developed, Low Intensity <sup>1</sup>	378.86	0.25%
23	Developed, Medium Intensity <sup>1</sup>	200.69	0.13%
24	Developed, High Intensity <sup>1</sup>	83.17	0.06%
31	Barren Land (Rock/Sand/Clay)	13.60	0.01%
41	Deciduous Forest	0.00	0.00%
42	Evergreen Forest	38,399.64	25.45%
43	Mixed Forest	16,020.57	10.62%
52	Shrub/Scrub	52,303.16	34.67%
71	Grassland/Herbaceous	38,582.26	25.57%
81	Pasture/Hay	23.41	0.02%
82	Cultivated Crops	14.94	0.01%
90	Woody Wetlands	443.52	0.29%
95	Emergent Herbaceous Wetlands	536.51	0.36%
<b>TOTAL<sup>2</sup></b>		<b>150,876.75</b>	<b>100%</b>

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 390 acres more than the model domain.

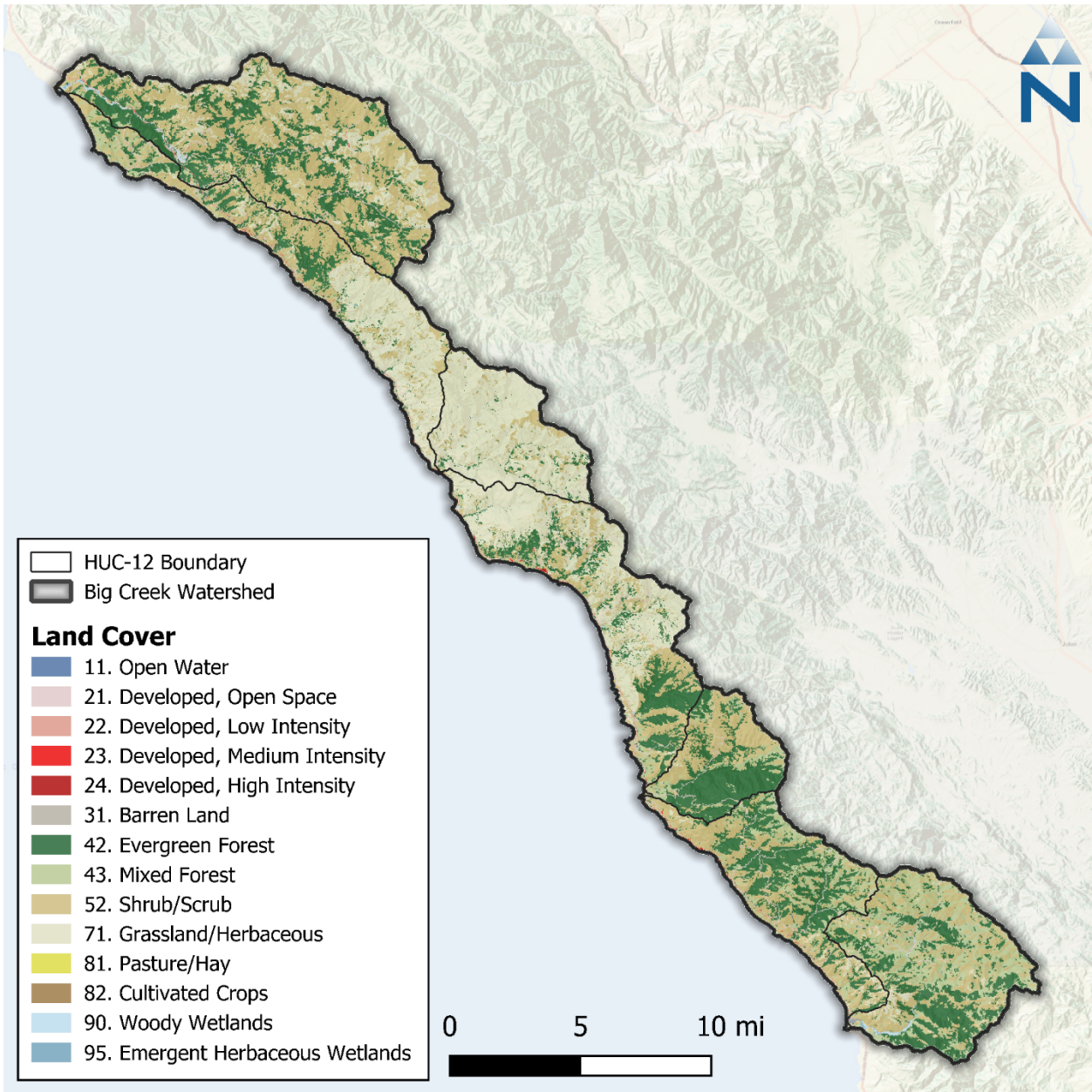


Figure 5-3. NLCD 2021 land cover within the Big Creek watershed.

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 Big Creek watershed using this dataset shows that 2.8% 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 Big Creek 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 Big Creek watershed, an average of 37% 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 Big Creek Watershed (see Section [5.3](#)) was analyzed to identify predominant cropland vegetation classes. This analysis revealed that less than 0.02% of the Big Creek watershed area is classified as Pasture/Hay (class 81) and just over 60% 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. 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.

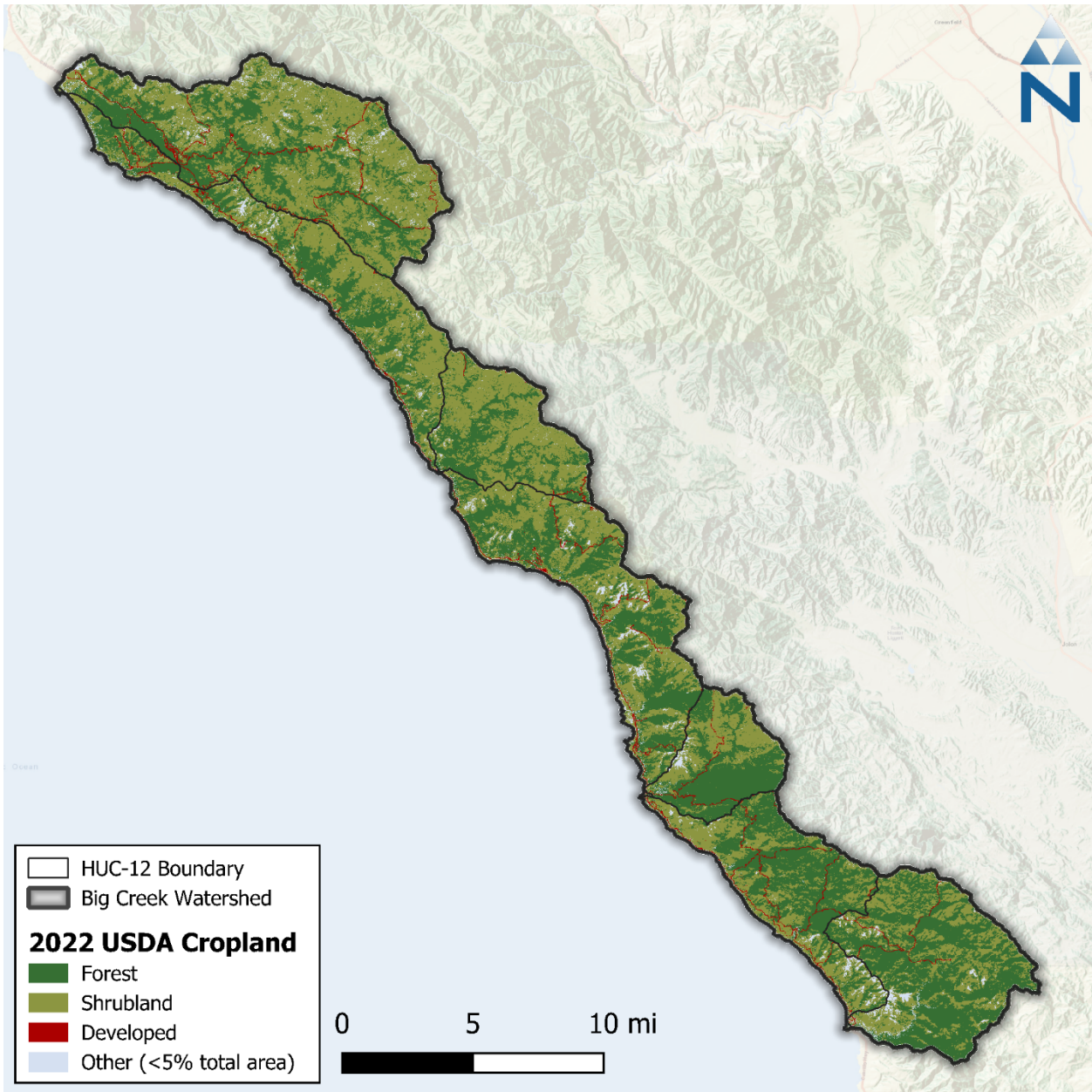


Figure 5-4. USDA 2022 Cropland Data within the Big Creek watershed.

Table 5-4 USDA 2022 Cropland Data summary within the Big Creek watershed

Crop Type	Area (ac)	Area (%)
Forest	65,359.59	43.50%
Shrubland	75,631.02	50.34%
Developed	4,084.95	2.72%
Other (<5% Total Area)	5,168.37	3.44%
<b>Totals</b>	<b>150,243.93</b>	<b>100.00%</b>

## 6 DATA GAPS AND LIMITATIONS

---

Based on a review of the hydrology datasets presented in Section 3.3, one potential limitation is the spatial extent of available daily streamflow data to support model calibration. USGS operates only one active gauge with daily streamflow records within the HUC-10 in the Big Sur River watershed. The calibration would need to be extrapolated outside of these tributaries to other waterbodies of interest unless other local gauge data is available.

Another potential limitation is the availability, quality, and temporal resolution of data for surface water diversions within the watershed. The eWRIMS database will be queried to identify 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.

If groundwater modeling is deemed necessary after further assessments during model calibration, alternative sources of groundwater data from local agencies would need to be acquired. No AEM flight lines are available in the watershed and the California state database of well logs does not include any available measurements within the Big Creek watershed. The California state database of groundwater levels also includes no measurement locations within the Big Creek watershed.

## 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 5 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 (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 Big Creek 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 5. 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 and associated data gaps describing the groundwater system, a fully linked groundwater model is not planned for this effort. However, if initial 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  $-\infty$  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 Big Creek 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 <sup>1</sup>	<5%	5% - 10%	10% - 15%	>15%
	Seasonal Flows <sup>2</sup>	<10%	10% - 15%	15% - 25%	>25%
	Highest 10% of Daily Flow Rates <sup>3</sup>				
	Days Categorized as Storm Flow <sup>4</sup>				
	Days Categorized as Baseflow <sup>4</sup>				
RMSE – Std Dev Ratio (RSR)	All Conditions <sup>1</sup>	≤0.50	0.50 - 0.60	0.60 - 0.70	>0.70
	Seasonal Flows <sup>2</sup>	≤0.40	0.40 - 0.50	0.50 - 0.60	>0.60
Nash-Sutcliffe Efficiency (NSE)	All Conditions <sup>1</sup>	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50
	Seasonal Flows <sup>2</sup>	>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40
Kling-Gupta Efficiency (KGE)	Monthly Aggregated <sup>5</sup>	≥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 SUMMARY & NEXT STEPS

This work plan presented the available data and proposed methods for developing a hydrologic model of the Big Creek 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 Big Creek watershed.

**Table 9-1. Proposed schedule and summary of deliverables**

Task	Subtask	Deliverable	Due Date
2	2.2	Draft Work Plan	7/28/2025
	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 <sup>1</sup>	Twelve (12) weeks after completing Task 3.1
4	4.1	Draft Calibration Slide Deck	Six (6) 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 <sup>1</sup>	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.

## 10 REFERENCES

- Allen, R. G., Walter, I. A., Elliott, R., Howell, T., Itenfisu, D., & Jensen, M. 2005. The ASCE Standardized Reference Evapotranspiration Equation.
- Barnwell, T. O., & Johanson, R. 1981. HSPF: A comprehensive package for simulation of watershed hydrology and water quality.
- Behnke, R., Vavrus, S., Allstadt, A., Albright, T., Thogmartin, W. E., & Radeloff, V. C. 2016. Evaluation of downscaled, gridded climate data for the conterminous United States. *Ecological Applications*, 26(5), 1338–1351. <https://doi.org/10.1002/15-1061>.
- CDFW (California Department of Fish and Wildlife). 2016. Instream Flow Regime Recommendations BIG SUR RIVER, Monterey County. Accessed July 2025 from <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=145698&inline>
- City of San Diego and Caltrans. 2016. Mission Bay Watershed Management Area Water Quality Improvement Plan. Submitted to the San Diego Regional Water Quality Control Board by the City of San Diego and Caltrans. San Diego, CA.
- City of Vista. 2008. Agua Hedionda Watershed Management Plan – Final. Prepared by Tetra Tech for the City of Vista, CA.
- Cosgrove, B. A., Lohmann, D., Mitchell, K. E., Houser, P. R., Wood, E. F., Schaake, J. C., Robock, A., Marshall, C., Sheffield, J., Duan, Q., Luo, L., Higgins, R. W., Pinker, R. T., Tarpley, J. D., & Meng, J. 2003. Real-time and retrospective forcing in the North American Land Data Assimilation System (NLDAS) project. *Journal of Geophysical Research: Atmospheres*, 108(22), 8842. <https://doi.org/10.1029/2002jd003118>.
- CVRWQCB (Central Valley Regional Water Quality Control Board). 2006. Amendment to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins for The Control of Nutrients in Clear Lake. California Water Quality Control Board, Central Valley Region. Rancho Cordova, CA.
- Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., Curtis, J., & Pasteris, P. P. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology*, 28(15), 2031–2064. <https://doi.org/10.1002/joc.1688>.
- Daly, C., Neilson, R. P., & Phillips, D. L. 1994. A Statistical-Topographic Model for Mapping Climatological Precipitation over Mountainous Terrain. *Journal of Applied Meteorology*, 33(2), 140–158. [https://doi.org/10.1175/1520-0450\(1994\)033<0140:ASTMFM>2.0.CO;2](https://doi.org/10.1175/1520-0450(1994)033<0140:ASTMFM>2.0.CO;2).
- Duda, P. B., Hummel, P. R., Donigian Jr., A. S., & Imhoff, J. C. 2012. BASINS/HSPF: Model Use, Calibration, and Validation. *Transactions of the ASABE*, 55(4), 1523–1547. <https://doi.org/10.13031/2013.42261>.
- DWR (California Department of Water Resources). 2019. Statewide Crop Mapping. California Natural Resources Agency Open Data. Accessed April 2025 from <https://data.cnra.ca.gov/dataset/statewide-crop-mapping>.

- DWR (California Department of Water Resources). 2020. California's Groundwater Basin Boundary Descriptions. California Natural Resources Agency. Accessed April 2025 from <https://data.cnra.ca.gov/dataset/ca-gw-basin-boundary-descriptions>.
- Gibson, W. P., Daly, C., Kittel, T., Nychka, D., Johns, C., Rosenbloom, N., McNab, A., & Taylor, G. 2002. Development of a 103-year high-resolution climate dataset for the conterminous United States.
- Gupta, H. V., Kling, H., Yilmaz, K. K., & Martinez, G. F. 2009. Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. *Journal of Hydrology*, 377(1–2), 80–91. <https://doi.org/10.1016/j.jhydrol.2009.08.003>.
- Housman, I., K. Schleeweis, J. Heyer, B. Ruefenacht, S. Bender, K. Megown, W. Goetz, & S. Bogle, 2023. National Land Cover Database Tree Canopy Cover Methods. Salt Lake City, Utah. Accessed April 2025 from [https://data.fs.usda.gov/geodata/rastergateway/treecanopycover/docs/TCC\\_v2021-4\\_Methods.pdf](https://data.fs.usda.gov/geodata/rastergateway/treecanopycover/docs/TCC_v2021-4_Methods.pdf).
- Knoben, W. J. M., Freer, J. E., & Woods, R. A. 2019. Technical note: Inherent benchmark or not? Comparing Nash–Sutcliffe and Kling–Gupta efficiency scores. *Hydrology and Earth System Sciences*, 23(10), 4323–4331. <https://doi.org/10.5194/hess-23-4323-2019>.
- Kouchi, D.H., Esmaili, A.K., Faridhosseini, S.H., Khalili D. Sanaeinejad, and Abbaspour. K.C. 2017. Sensitivity of Calibrated Parameters and Water Resource Estimates on Different Objective Functions and Optimization Algorithms *Water*. <https://doi.org/10.3390/w9060384>.
- LACFCD (Los Angeles County Flood Control District). 2020. WMMS Phase I Report: Baseline Hydrology and Water Quality Model. Prepared for the Los Angeles County Flood Control District by Paradigm Environmental. Alhambra, CA.
- Langevin, C. D., Hughes, J. D., Banta, E. R., Niswonger, R. G., Panday, S., & Provost, A. M. 2017. Documentation for the MODFLOW 6 Groundwater Flow Model. U.S. Geological Survey Techniques and Methods, Book 6, Chap. A55, 197 p. <https://doi.org/10.3133/tm6A55>.
- LARWQCB (Los Angeles Regional Water Quality Control Board). 2010. Los Angeles River Watershed Bacteria Total Maximum Daily Load. California Regional Water Quality Control Board, Los Angeles Region. Los Angeles, CA.
- LARWQCB (Los Angeles Regional Water Quality Control Board). 2012. Reconsideration of Certain Technical Matters of the Malibu Creek and Lagoon Bacteria TMDL. California Regional Water Quality Control Board, Los Angeles Region. Los Angeles, CA.
- LARWQCB (Los Angeles Regional Water Quality Control Board). 2013a. Reconsideration of Certain Technical Matters of the Santa Monica Bay Beaches Bacteria TMDLs; Marina del Rey Harbor Mothers' Beach and Back Basins TMDL; and the Los Angeles Harbor Inner Cabrillo Beach and Main Ship Channel Bacteria TMDL. California Regional Water Quality Control Board, Los Angeles Region. Los Angeles, CA.
- LARWQCB (Los Angeles Regional Water Quality Control Board). 2013b. Reconsideration of Certain Technical Matters of the TMDL for Bacteria Indicator Densities in Ballona Creek, Ballona Estuary, and Sepulveda Channel. California Regional Water Quality Control Board, Los Angeles Region. Los Angeles, CA.

- LARWQCB (Los Angeles Regional Water Quality Control Board). 2015. Total Maximum Daily Loads for Indicator Bacteria in San Gabriel River, Estuary and Tributaries. California Regional Water Quality Control Board, Los Angeles Region. Los Angeles, CA.
- LARWQCB (Los Angeles Regional Water Quality Control Board) and USEPA (U.S. Environmental Protection Agency). 2005. Total Maximum Daily Load for Metals in Ballona Creek. California Regional Water Quality Control Board, Los Angeles Region, and U.S. Environmental Protection Agency Region 9. Los Angeles, CA.
- LARWQCB (Los Angeles Regional Water Quality Control Board) and USEPA (U.S. Environmental Protection Agency). 2006. Total Maximum Daily Loads for Metals and Selenium, San Gabriel River and Tributaries. California Regional Water Quality Control Board, Los Angeles Region, and U.S. Environmental Protection Agency, Region 9. Los Angeles, CA.
- LARWQCB (Los Angeles Regional Water Quality Control Board) and USEPA (U.S. Environmental Protection Agency). 2011. Dominguez Channel and Greater Los Angeles and Long Beach Harbor Waters Toxics Total Maximum Daily Loads. California Regional Water Quality Control Board, Los Angeles Region, and U.S. Environmental Protection Agency Region 9. Los Angeles, CA.
- Los Peñasquitos Responsible Agencies. 2015. Los Peñasquitos Watershed Management Area Water Quality Improvement Plan and Comprehensive Load Reduction Plan. Submitted to the San Diego Regional Water Quality Control Board by the City of San Diego, County of San Diego, City of Del Mar, Caltrans, and City of Poway. San Diego, CA.
- LRWQCB (Lahontan Regional Water Quality Control Board) and NDEP (Nevada Division of Environmental Protection). 2010. Lake Tahoe Total Maximum Daily Load Technical Report. California Regional Water Quality Control Board, Lahontan Region. South Lake Tahoe, CA.
- Markstrom, S. L., Regan, R. S., Hay, L. E., Viger, R. J., Webb, R. M., Payn, R. A., & LaFontaine, J. H. 2015. PRMS-IV, the precipitation-runoff modeling system, version 4.
- Melton, F. S., Huntington, J., Grimm, R., Herring, J., Hall, M., Rollison, D., Erickson, T., Allen, R., Anderson, M., Fisher, J. B., Kilic, A., Senay, G. B., Volk, J., Hain, C., Johnson, L., Ruhoff, A., Blankenau, P., Bromley, M., Carrara, W., ... Anderson, R. G. 2022. OpenET: Filling a Critical Data Gap in Water Management for the Western United States. *JAWRA Journal of the American Water Resources Association*, 58(6), 971–994. <https://doi.org/10.1111/1752-1688.12956>.
- Mitchell, K. E., Lohmann, D., Houser, P. R., Wood, E. F., Schaake, J. C., Robock, A., Cosgrove, B. A., Sheffield, J., Duan, Q., Luo, L., Higgins, R. W., Pinker, R. T., Tarpley, J. D., Lettenmaier, D. P., Marshall, C. H., Entin, J. K., Pan, M., Shi, W., Koren, V., ... Bailey, A. A. 2004. The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system. *Journal of Geophysical Research: Atmospheres*, 109(7). <https://doi.org/10.1029/2003jd003823>.
- Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *Transactions of the ASABE*, 50(3), 885–900. <https://doi.org/10.13031/2013.23153>.
- Moriasi, D. N., Gitau, M. W., Pai, N., & Daggupati, P. 2015. Hydrologic and water quality models: Performance measures and evaluation criteria. *Transactions of the ASABE*, 58(6), 1763–1785. <https://doi.org/10.13031/trans.58.10715>.

- Nash, J. E., & Sutcliffe, J. V. 1970. River flow forecasting through conceptual models part I - A discussion of principles. *Journal of Hydrology*, 10(3), 282–290. [https://doi.org/10.1016/0022-1694\(70\)90255-6](https://doi.org/10.1016/0022-1694(70)90255-6).
- Neitsch, S. L., Arnold, J. G., Kiniry, J. R., & Williams, J. R. 2011. *Soil and Water Assessment Tool Theoretical Documentation*.
- NID (National Inventory of Dams). 2025. USACE (United States Army Corps of Engineers): Dams of the Nation. Accessed April 2025 from <https://nid.sec.usace.army.mil/>.
- Riverson, J., Coats, R., Costa-Cabral, M., Dettinger, M., Reuter, J., Sahoo, G., & Schladow, G. 2013. Modeling the transport of nutrients and sediment loads into Lake Tahoe under projected climatic changes. *Climatic Change*, 116(1), 35–50. <https://doi.org/10.1007/s10584-012-0629-8>.
- San Diego Bay Responsible Parties. 2016. *San Diego Bay Watershed Management Area Water Quality Improvement Plan*. Submitted to the San Diego Regional Water Quality Control Board by the San Diego Bay Responsible Parties. San Diego, CA.
- SAWPA (Santa Ana Watershed Project Authority). 2003. *Lake Elsinore and Canyon Lake Nutrient Source Assessment*. Prepared by Tetra Tech for the Santa Ana Watershed Project Authority. Riverside, CA.
- SAWPA (Santa Ana Watershed Project Authority). 2004. *San Jacinto Nutrient Management Plan*. Prepared by Tetra Tech for the Santa Ana Watershed Project Authority. Riverside, CA.
- SCVURPPP (Santa Clara Valley Urban Runoff Pollution Prevention Program). 2019. *Santa Clara Valley Reasonable Assurance Analysis Addressing PCBs and Mercury: Phase II Green Stormwater Infrastructure Modeling Report*. Prepared by Paradigm Environmental for the Santa Clara Valley Urban Runoff Pollution Prevention Program. Sunnyvale, CA.
- SDRWQCB (San Diego Regional Water Quality Control Board). 2008. *Total Maximum Daily Loads (TMDLs) for Copper, Lead, and Zinc in Chollas Creek*. California Regional Water Quality Control Board, San Diego Region. San Diego, CA.
- SDRWQCB (San Diego Regional Water Quality Control Board). 2010. *Revised Total Maximum Daily Loads for Indicator Bacteria Project I – Twenty Beaches and Creeks in the San Diego Region (Including Tecolote Creek)*. California Regional Water Quality Control Board, San Diego Region. San Diego, CA.
- SDRWQCB (San Diego Regional Water Quality Control Board). 2012. *Los Peñasquitos Lagoon Sediment/Siltation TMDL*. California Regional Water Quality Control Board, San Diego Region. San Diego, CA.
- Shen, J., Parker, A., & Riverson, J. 2005. A new approach for a Windows-based watershed modeling system based on a database-supporting architecture. *Environmental Modelling & Software*, 20(9), 1127–1138. <https://doi.org/10.1016/j.envsoft.2004.07.004>.
- Sloto, R. A., & Crouse, M. Y. 1996. *HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis*: U.S. Geological Survey Water-Resources Investigations Report 1996–4040. <https://doi.org/10.3133/wri964040>.
- SMCWPPP (San Mateo Countywide Water Pollution Prevention Program). 2020. *San Mateo County-wide Reasonable Assurance Analysis Addressing PCBs and Mercury: Phase II Green*

Infrastructure Modeling. Prepared by Paradigm Environmental and Larry Walker Associates for the San Mateo Countywide Water Pollution Prevention Program. Redwood City, CA.

Tariq, A., Lempert, R. J., Riverson, J., Schwartz, M., & Berg, N. 2017. A climate stress test of Los Angeles' water quality plans. *Climatic Change*, 144(4), 625–639. <https://doi.org/10.1007/s10584-017-2062-5>.

UCSC (University of California Santa Cruz). 2024. Big Creek Steelhead Ecology. Accessed July 2025 from <https://fisheries.ucsc.edu/research-teams/big-creek/>.

USDA (United States Department of Agriculture). 1986. Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55).

USDA (United States Department of Agriculture). 2024a. Digital General Soil Map of the United States (SSURGO). Accessed April 2025 from <https://nrcs.app.box.com/v/soils>.

USDA (United States Department of Agriculture). 2024b. Digital General Soil Map of the United States (STATSGO2). Accessed April 2025 from <https://www.nrcs.usda.gov/resources/data-and-reports/description-of-statsgo2-database>.

USDA (United States Department of Agriculture). 2024c. Cropland Data Layer. Accessed January 31, 2024. Accessed April 2025 from <https://croplandcros.scinet.usda.gov/>.

USEPA (U.S. Environmental Protection Agency). 2009. Loading Simulation Program C++. Science Inventory. Record ID: 75860.

USGS (United States Geological Survey). 2024. Sustainable Groundwater, California Groundwater Model Archive. Sustainable Groundwater, California Groundwater Model Archive. Accessed April 2025 from <https://ca.water.usgs.gov/sustainable-groundwater-management/california-groundwater-modeling.html>.

USGS (United States Geological Survey). 2019. *The StreamStats Program*. <https://www.usgs.gov/streamstats>

USGS (United States Geological Survey). 2005. Rates of Landsliding and Cliff Retreat Along the Big Sur Coast, California—Measuring a Crucial Baseline. Accessed July 2025 from [Rates of Landsliding and Cliff Retreat Along the Big Sur Coast, California—Measuring a Crucial Baseline | USGS Fact Sheet 2004-3099](#).

Warrick, J.A. et al. 2022 Fire (plus) flood (equals) beach: coastal response to an exceptional river sediment discharge event. *Sci Rep* 12, 3848. <https://doi.org/10.1038/s41598-022-07209-0>.

Xia, Y., Mitchell, K., Ek, M., Cosgrove, B., Sheffield, J., Luo, L., Alonge, C., Wei, H., Meng, J., Livneh, B., Duan, Q., & Lohmann, D. 2012. Continental-scale water and energy flux analysis and validation for North American Land Data Assimilation System project phase 2 (NLDAS-2): 2. Validation of model-simulated streamflow. *Journal of Geophysical Research Atmospheres*, 117(3). <https://doi.org/10.1029/2011JD016051>.

Zi, T., Braud, A., McKee, L., & Foley, M. 2022. San Francisco Bay Watershed Dynamic Model (WDM) Progress Report, Phase 2. Report prepared for the Sources Pathways and Loadings Workgroup of the Regional Monitoring Program for Water Quality. SFEI Contribution #1091. Accessed April 2025 from <https://www.sfei.org/documents/san-francisco-bay-watershed-dynamic-model-wdm-progress-report-phase-2>.

Zi, T., McKee, L., Yee, D., & Foley, M. 2021. San Francisco Bay Regional Watershed Modeling Progress Report, Phase 1. Report prepared for the Sources Pathways and Loadings Workgroup of the Regional Monitoring Program for Water Quality. SFEI Contribution #1038. Accessed April 2025 from <https://www.sfei.org/documents/san-francisco-bay-regional-watershed-modeling-progress-report-phase-1>.