Work Plan: Pescadero 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

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ACRONYMS

3DEP	3D Elevation Program
ALWU	Agricultural Land use & Water Use
ASCE-PM	American Society of Civil Engineers version of the Penman-Monteith equation
CAL FIRE	California Department of Forestry and Fire Protection
CDEC	California Data Exchange Center
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
EOL	Earth Observing Laboratory
ET	Evapotranspiration
ET$_0$	Reference evapotranspiration
eWRIMS	Electronic Water Rights Information Management System
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
GSA	Groundwater Sustainability Agency
HRU	Hydrologic Response Unit
HSG	Hydrologic Soil Group
HSPF	Hydrologic Simulation Program - Fortran
HUC	Hydrologic Unit Code
LCD	Local Climate 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
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-Sutclife 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
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
WBD	Watershed Boundary Dataset

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1. INTRODUCTION

1.1 Project Objectives

In April 2021, Governor Gavin Newsom issued a state of emergency proclamation for specific watersheds across California in response to exceptionally dry conditions throughout the state. The April 2021 proclamation, as well as subsequent proclamations, directed the State Water Resources Control Board (Water Board) to address these emergency conditions to ensure adequate, minimal water supplies for critical purposes. To support Water Board 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 Pescadero 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 Pescadero Creek watershed, identified by the ten-digit USGS hydrologic unit code (HUC) 1805000601, shares a boundary with the neighboring Waddell Creek (HUC-10 1805000603) to the southwest, San Gregorio Creek (1805000602) to the northwest, Saratoga Creek (1805000304) to the northeast, and San Lorenzo River (1806001502) to the southeast. Pescadero Creek is a coastal watershed that drains approximately 81 square miles and is made up of three HUC-12 catchments: Upper Pescadero Creek (HUC-12 180500060101), Lower Pescadero Creek (180500060103), and Butano Creek (180500060102) as shown in Figure 1-1. The headwaters of Pescadero Creek start at the western edge of Castle Rock State Park and flow 26 miles west. Along it's flow path, Pescadero Creek is joined by several tributaries before draining to the Pacific Ocean via Pescadero Marsh approximately 37 miles south of San Francisco Bay at Golden Gate Bridge and 14 miles south of Half Moon Bay. The three largest tributaries include Butano Creek (14.8 mi), Peters Creek (7.3 mi), and Oils Creek (5.1 mi).

The Pescadero Creek watershed ranges in elevation from 2,749 feet above sea level in its mountainous headwaters on the western edge of Castle Rock State Park to sea level at its marshy mouth at the Pacific Ocean. The watershed has a Mediterranean climate with distinct wet and dry seasons; winters are mild and wet, with an average temperature of 50.2 ˚F, whereas summers are mild and dry with an average temperature of 65.0 ˚F (PRISM Group 2014). Mean annual precipitation totals 35 inches, with most events occurring between November and April (Stark, et al. 2024). The landscape of Pescadero Creek watershed is predominately evergreen forest (51%), grassland/herbaceous (23%), and mixed forest (14%). The remainder of the watershed is composed of shrubland (7%), developed open space (2%), and other (2%).

The Pescadero Creek watershed provides critical habitat for native aquatic species and serves as an important spawning ground for anadromous fish, particularly steelhead trout and coho salmon. At the outlet of the watershed, Pescadero Marsh—a 320-acre coastal wetland formed by the confluence of Pescadero and Butano Creeks—is one of the most ecologically significant wetlands along the central

California coast. However, over the past 150 years, human activities such as logging, road construction, and urban development have severely degraded the watershed's ecological function. These disturbances have increased sediment inputs while reducing the watershed's natural sediment storage capacity, leading to widespread habitat degradation. The resulting sedimentation has diminished the quality and availability of spawning habitat and compromised overall water quality, disrupting the life cycles of native aquatic and riparian species (SFBRWQCC 2019).

In 2006, Pescadero Creek was listed under Section 303(d) of the Clean Water Act as an impaired waterbody due to excessive sediment levels that impair multiple beneficial uses, including cold freshwater habitat, fish migration and spawning, endangered species protection, water recreation, and wildlife habitat. Although this listing did not result in a Water Quality Improvement Plan, it did prompt the development of a Total Maximum Daily Load (TMDL) for sediment, which was formally adopted in 2019. The TMDL sets sediment reduction targets, identifies major sediment sources, and outlines implementation actions for key stakeholders across the watershed, including local landowners, county agencies, and conservation partners. The implementation of the 2019 Pescadero Creek Sediment TMDL is comprehensively detailed in Chapter 7.4.2 of the San Francisco Bay Regional Water Board Staff Report, which outlines sediment allocations, stakeholder actions, and monitoring strategies as part of the Basin Plan Amendment (SFBRWQCC 2019). Since the TMDL implementation, the San Francisco Estuary Institute has conducted low flow monitoring to improve the understanding of flow and sediment dynamics during low-discharge periods near the mouth of Pescadero Creek (Peterson, et al. 2024).

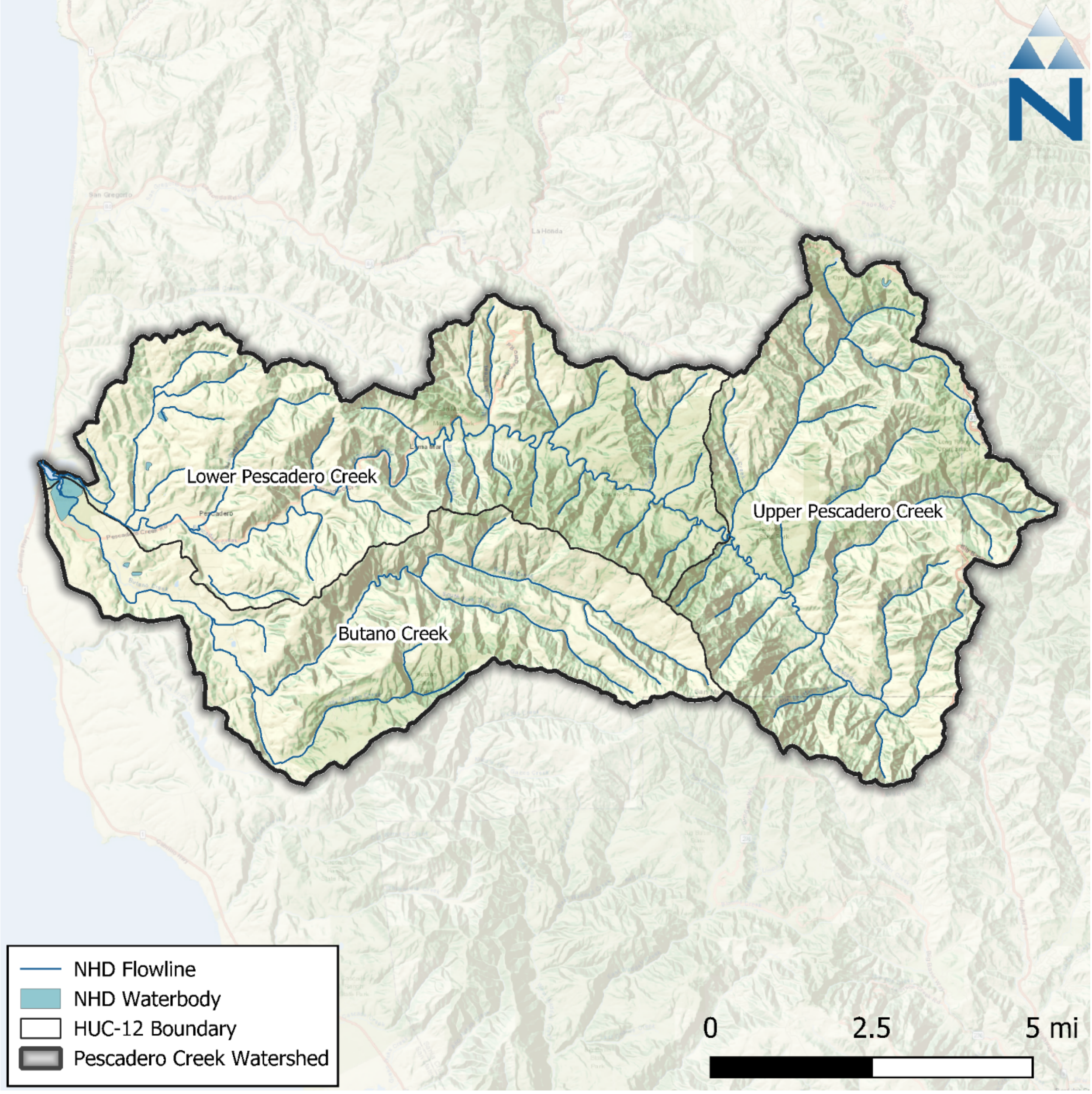

Figure 1-1. Pescadero Creek watershed.

1.3 Leveraging Previous and Concurrent Modeling Efforts

In 2020, as part of the San Mateo Countywide Water Pollution Prevention Program, the City/County Association of Governments of San Mateo County (C/CAG) developed a regional hydrologic model for watersheds in and around San Mateo County (C/CAG 2020), which includes large overlap with the Pescadero Creek watershed as illustrated in Figure 1-2. C/CAG's modeling effort utilized the Loading Simulation Program in C++ (LSPC) (described further in Section 7) for long-term continuous simulation with the objective of supporting management decisions regarding stormwater runoff and pollutant loads including mercury, Polychlorinated Biphenyls (PCBs), and sediment to characterize municipal stormwater discharges to the San Francisco Bay and Pacific Ocean. This model was constructed at the regional scale to address San Mateo County-wide pollutant loading issues (e.g., Hg, PCBs, and sediment) and leveraged many of the model characterization components referenced in this document (Section 2 through 5). In 2025, this LSPC model is expected to be updated under a current work order with C/CAG.

As part of the screening process of available data for the Pescadero Creek watershed Work Plan and subsequent modeling effort, the existing 2020 and soon-to-be-developed 2025 LSPC models will be reviewed and considered. Overall, the 2020 C/CAG model offers a strong foundation and reference for the current analysis and the 2025 C/CAG model is expected to augment this further. Section 7.2 provides additional discussion on proposed references to the model for this analysis.

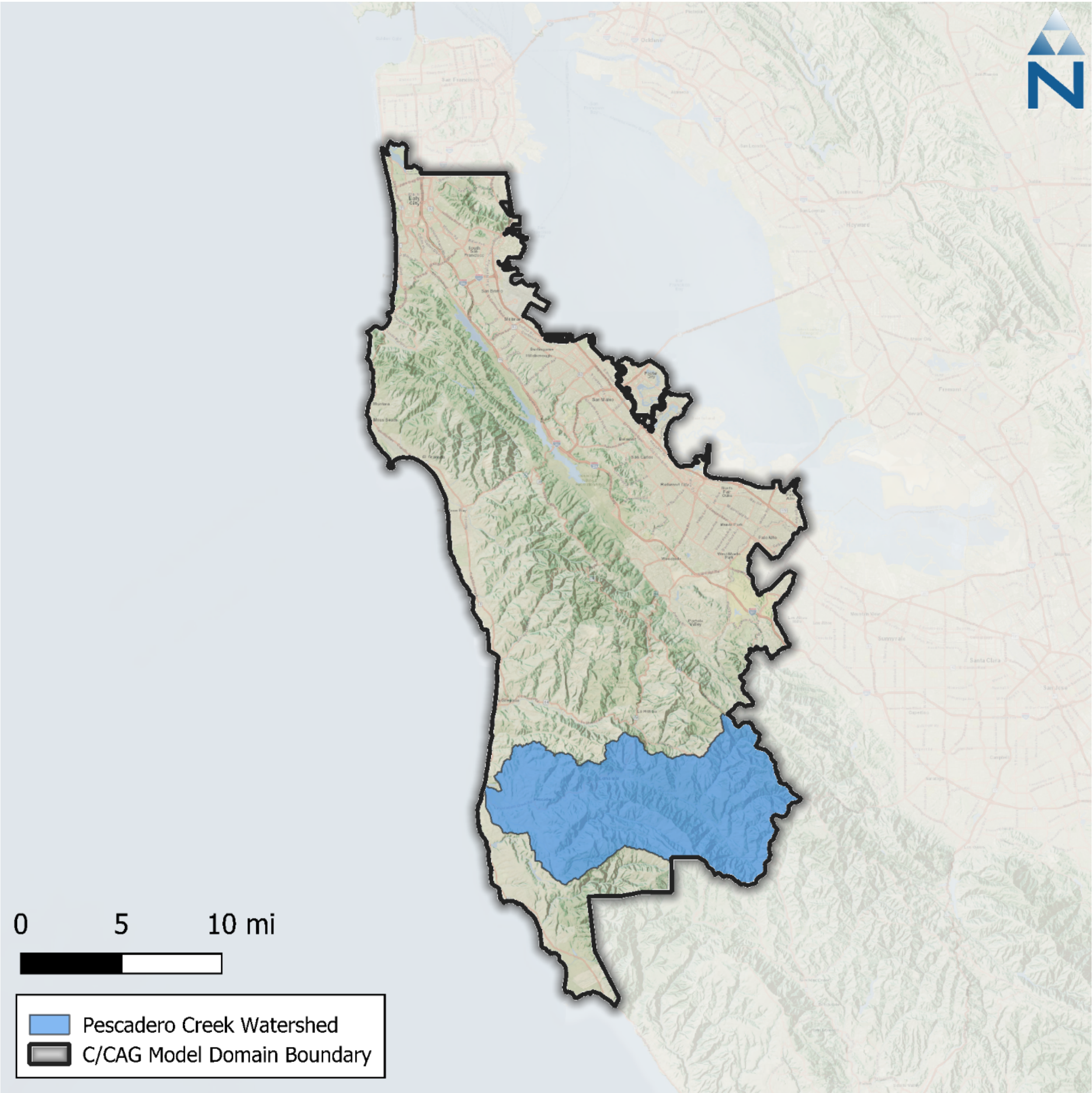

Figure 1-2. Map of the C/CAG regional model domain, which includes nearly all of the Pescadero Creek watershed.

1.4 Model Approach

The primary goal of this work plan is to outline an approach with sufficient robustness to support an analytical assessment of the Pescadero Creek watershed. This is presented first through a comprehensive inventory of available meteorological, hydrological, and geographic information system (GIS) data available for the 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 1-3 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.

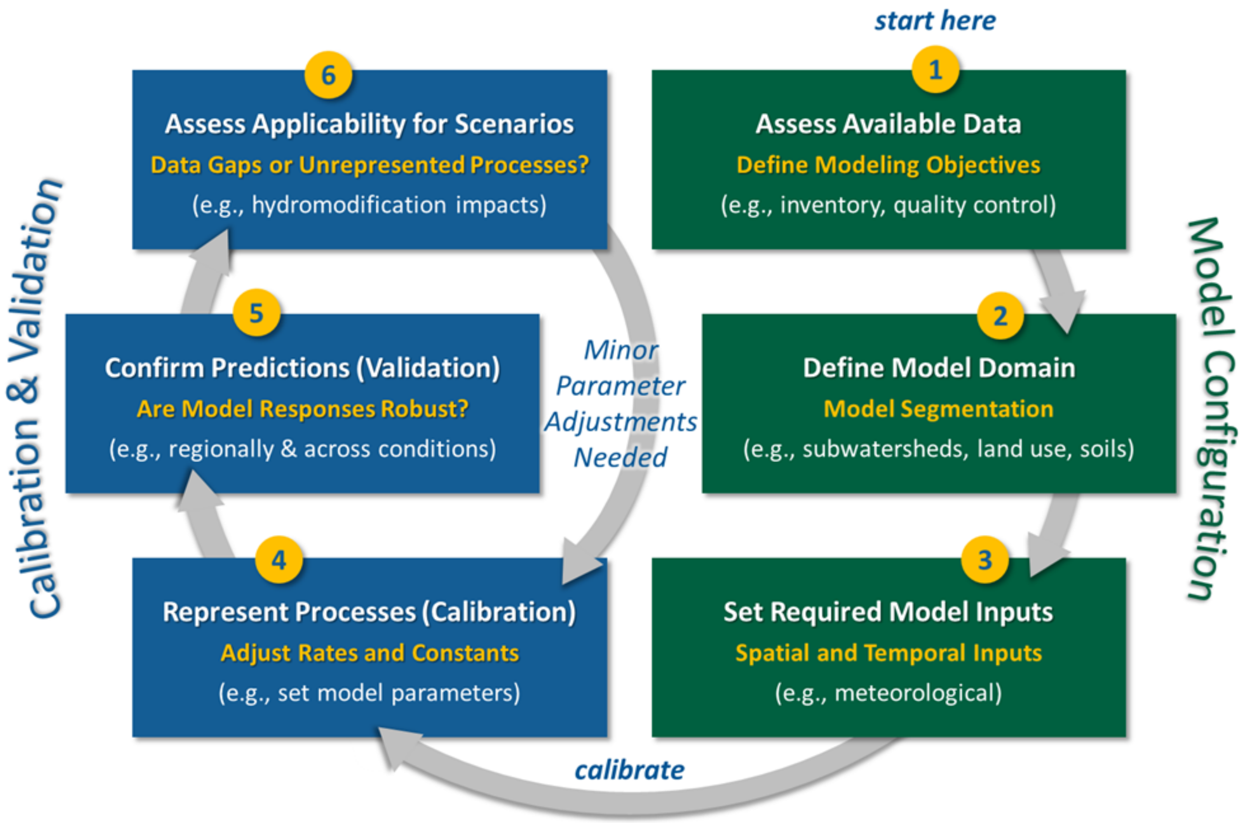

Figure 1-3. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Pescadero Creek watershed.

1.5 Data Availability

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

- **Meteorology Datasets**: Time series that represent water balance inputs and outputs to the watershed primarily from precipitation and evapotranspiration. These time series are often used as forcing functions for hydrologic models.
- **Surface & Groundwater Datasets**: Datasets describing stream flow, groundwater, water use, and stream conditions for the Pescadero Creek. Time series observations of instream responses for the Pescadero Creek are often used as calibration and validation datasets for hydrologic models.
- **Geospatial Datasets**: Spatial datasets describing the landscape of the Pescadero 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, and solar radiation).	Rainfall hourly distributions; address rainfall data gaps. Daily potential evapotranspiration 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 Evapotranspiration	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 on the Pescadero Creek.	Hydrology calibration.	LINK
		National Inventory of Dams (NID)	Dams of the United States	Current	Locations for dams across the United States.	Hydrology calibration.	LINK
Habitat	Local	CDFW	TMDL to Address the Sediment Impairment on the Pescadero Creek	2019	Report that documents salmonid habitat and stream conditions under the sediment TMDL.	Hydrology calibration & validation.	LINK
Water Budget	State	DWR	Well Completion Reports	Current	Well completion logs and reports.	Water budget.	LINK
		SWRCB eWRIMS	Water Rights Points of Diversion	Current	Locations where water is being drawn from a surface water source such as a stream or river.		LINK
			Water Rights Overview Report	Current	This report will provide counts of various entities such as Applications, Registrations, Petitions etc. that will reflect the progress in processing such entities as of current date.		LINK
			Annual Water Use Report	1906 – 2023	Annual reports that provide monthly diversion data for various entities such as Applications, Registrations, Petitions, etc.		LINK
		DWR	Agricultural Land and Water Use Estimates	1998 – 2015	Water use estimates by various planning units.		LINK
		CDT	Water Districts	2022	Boundaries of all public water agencies in California.		LINK
			California Drinking Water System Area Boundaries	2024	Public California drinking water systems and state small drinking water system boundaries and information.		LINK

Table 1-3. Inventory of geospatial datasets

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Watershed Boundaries	National	USGS	Watershed Boundaries (WBD)	2023	Hydrologic unit boundaries to the 12-digit (6th level).	Model segmentation	LINK
Hydrology	National	USGS	National Hydrography Dataset (NHD) Plus High-Resolution National Release 1	2023	The NHDPlus HR combines the NHD, 3DEP DEMs, and WBD to create a stream network with linear referencing.		LINK
			National Hydrography Dataset (NHD) Best Resolution	2023	1:24,000; represents reaches and other network elements.		LINK
Soil	National	USDA NRCS	Grided Soil Survey Geographic Database (SSURGO)	2022	State-wide, 10-meter raster grid approximating the SSURGO vector dataset.	Represent infiltration process within land segments.	LINK
			Digital General Soil Map of the United States (STATSGO2)	2016	State-wide, 10-meter raster grid approximating the STATSGO2 vector dataset.	Represent infiltration process within land segments	LINK
Surficial Geology	National	USGS	The State Geologic Map Compilation (SGMC)	2017	1:1,000,000: Vector-based, state geologic map database.	As needed, hydrologic process with land segments.	LINK
Land Cover	National	MRLC	National Land Cover Dataset (NLCD) Land Cover	2021	Broad, 30 m grid-based land characterization. Differentiates developed land from coarse classifications of forest, cropland, wetlands, etc.	Land segment representation.	LINK
			NLCD Fractional Imperviousness	2021	Broad, 30-meter grid-based land characterization. Represent percent impervious area within raster cells.		LINK
Land Use	State	DWR	Statewide Crop Mapping	2020	Polygons attributed with DWR crop categories.	Identify crop distributions; estimate irrigation demand.	LINK

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Vegetation	National	MRLC	Tree Canopy Cover	2021	Percent tree canopy estimates for each 30-meter pixel across all land covers and types.	Land segment representation.	LINK
	State	USFS	Existing Vegetation	2018	1:24,000 to 1:100,000: Existing vegetation mapping.	As necessary, additional vegetation types for model land segments.	LINK
Agriculture & Crop Cover	National	USDA	Cropland Data Layer	2022	30-meter grid-based crop-specific land cover data layer.	Identify crop distributions; estimate irrigation demand.	LINK
Timber Harvesting	National	USDA	Timber Harvests	1820 - Present	Area planned and accomplished acres treated as a part of the timber harvest program of work.	Representing changes in land cover due to timber harvest activities.	LINK
	State	CAL FIRE	CAL FIRE Nonindustrial Timber Management Plans TA83	1991 - Present	Timber management plans.		LINK
			CAL FIRE Notices of Timber Operations TA83	1991 - Present	Notice of Timber Operations accepted by CAL FIRE.		LINK
			CAL FIRE Working Forest Management Plans TA83	2019 - Present	Working forest management plans approved by CAL FIRE.		LINK
Fire Perimeters & Burn Areas	State	CAL FIRE	California Fire Perimeters	1950 - Present	Wildfire perimeters.	Representing changes in land cover due to forest fire activities.	LINK

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Elevation	National	USGS	USGS ten-meter resolution digital elevation model (DEM)	2020	10-meter resolution digital elevation model (DEM) produced through the 3D Elevation Program (3DEP).	Land segment representation.	LINK

Table 1-4. Inventory of groundwater datasets

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

2 METEOROLOGY

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

2.1 Precipitation

The primary source of precipitation data for the Pescadero Creek watershed will be the observed data from land-based stations within and in the vicinity of the watershed (Table 2-1). 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 leverages both land-based and grid-based data to build a complete spatial and temporal meteorological dataset. Use of a hybrid approach preserves locally sampled station data while increasing the spatial and temporal quantity and quality 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 and temperature data. There are 11 GHCN stations identified within or near the Pescadero Creek watershed. These stations all have data with varied quantity and quality. In addition to the daily precipitation stations, the California Data Exchange Center (CDEC) and the Remote Automated Weather Stations (RAWS) networks also report hourly precipitation. There are two reported CDEC stations and three reported RAWS stations within and near the watershed.

In addition to rainfall data, snow data was also screened for the Pescadero Creek watershed model and yielded 13 GHCN stations within a 15 km buffer (reference Figure 2-1) that had data (e.g., snowfall measurements). Only 4 of these stations have data 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 in this watershed.

Table 2-1 is an inventory of the precipitation stations near the Pescadero 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 for the period overlapping with the modeling period (station record coverage is defined as the percentage of available records that are not missing throughout the duration of the record). 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 7 km buffer are included. However, these stations may not have sufficient data quality for use in model development. Figure 2-1 shows the locations of the identified stations. There are two locations where CDEC and RAWS stations appear to be co-located (i.e., within a 500m radius); 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 Pescadero 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, and other spatial datasets to capture influences such as high mountains, rain shadows, temperature inversions, coastal regions, 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) is 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[1, 3]	Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Model Period Coverage (%)[1]	Station Record Coverage (%)[2]
GHCN	GHCND:US1CASC0015	SARATOGA 0.5 N	11/1/2008	Present	37.275	-122.023	113.7	74%	99%
	GHCND:US1CASC0042	SUNNYVALE 3.6 S (W6NW)	9/25/2011	Present	37.334	-122.018	51.8	57%	95%
	GHCND:US1CASM0002*	HALF MOON BAY 4.1 SE	10/27/2008	3/3/2010	37.420	-122.395	103.3	2%	26%
	GHCND:US1CASM0022	WOODSIDE 3.4 S	2/11/2009	Present	37.375	-122.264	485.2	72%	99%
	GHCND:US1CASZ0006	BOULDER CREEK 3.6 NE	10/31/2008	12/11/2024	37.181	-122.091	525.5	69%	93%
	GHCND:US1CASZ0021	BOULDER CREEK 3.0 NW	1/17/2010	Present	37.169	-122.164	266.7	66%	97%
	GHCND:US1CASZ0024	FELTON 4.5 NNE	2/15/2010	Present	37.105	-122.047	255.4	64%	94%
	GHCND:USC00040673	BEN LOMOND #4	12/2/1972	Present	37.087	-122.082	132.6	94%	94%
	GHCND:USC00046646	PALO ALTO	9/1/1953	12/30/2017	37.444	-122.14	7.6	65%	91%
	GHCND:USC00047807*	SAN GREGORIO 2 SE	6/1/1954	11/30/2007	37.311	-122.362	83.8	21%	100%
	GHCND:USC00048273	SKYLINE RIDGE PRESERVE	7/1/1995	Present	37.313	-122.185	691.9	97%	97%
CDEC	BLO	BEN LOMOND (CDF)	11/26/2001	present	37.132	-122.170	801.624	40%	100%
	LAH	LA HONDA	3/23/1987	present	37.305	-122.254	129.540	99%	99%
RAWS	BNDC1	BEN LOMOND	6/17/1998	Present	37.131	-122.173	791.870	98%	98%
	LAHC1	LA HONDA	5/3/1990	Present	37.305	-122.255	245.059	96%	96%
	LOAC1	LOS ALTOS	2/19/1998	Present	37.355	-122.142	164.287	90%	90%

1. Data coverage for LCD stations are LCD portal-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.
3. Stations marked with an asterisk were included because there are no neighboring stations within a 7 km buffer; data quality at these stations may be insufficient for use in model development and will be further assessed under Task 3.2.

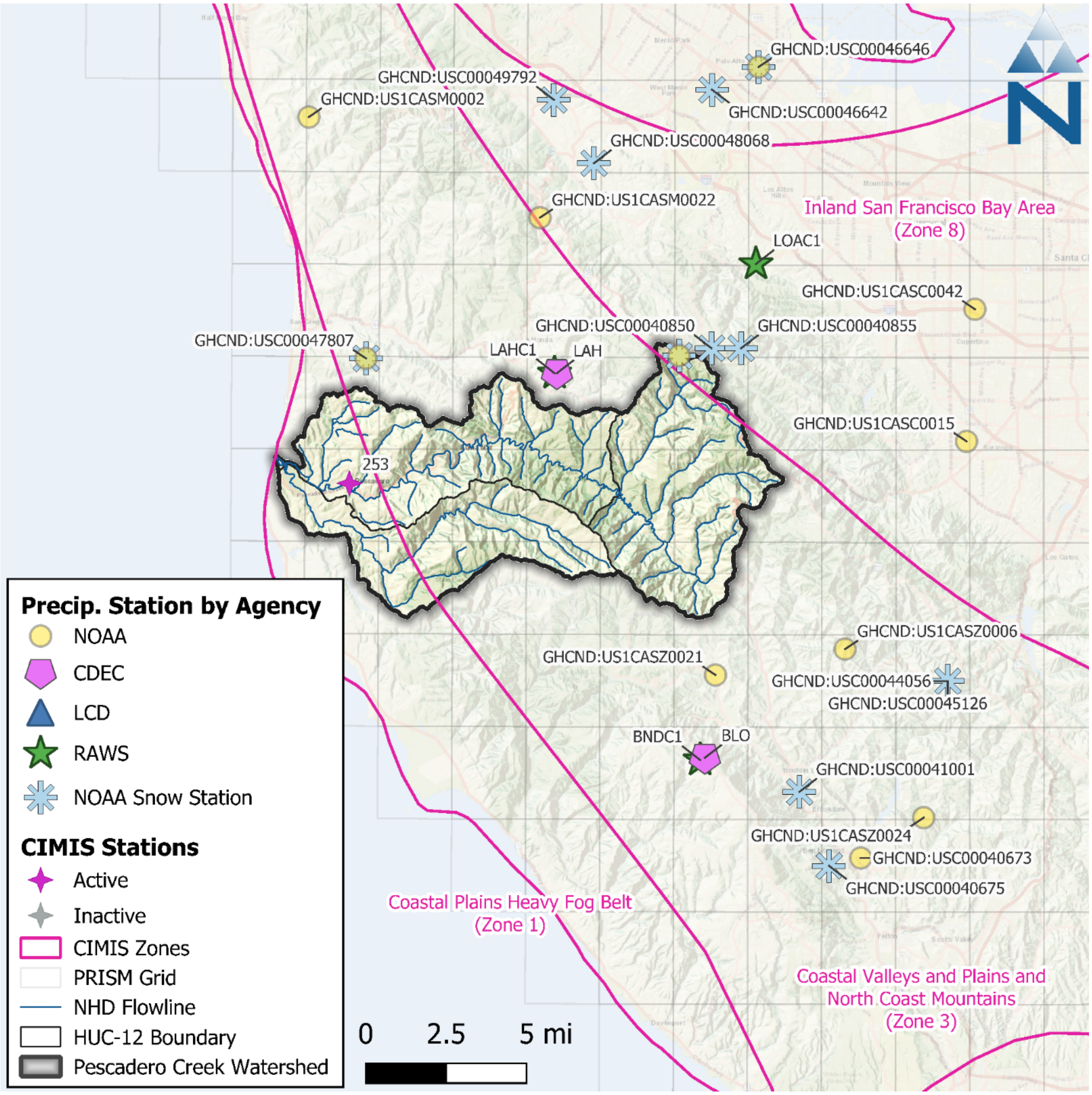

Figure 2-1. Identified rainfall stations and CIMIS ET Zones near the Pescadero Creek watershed.

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 will be 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 will be 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.

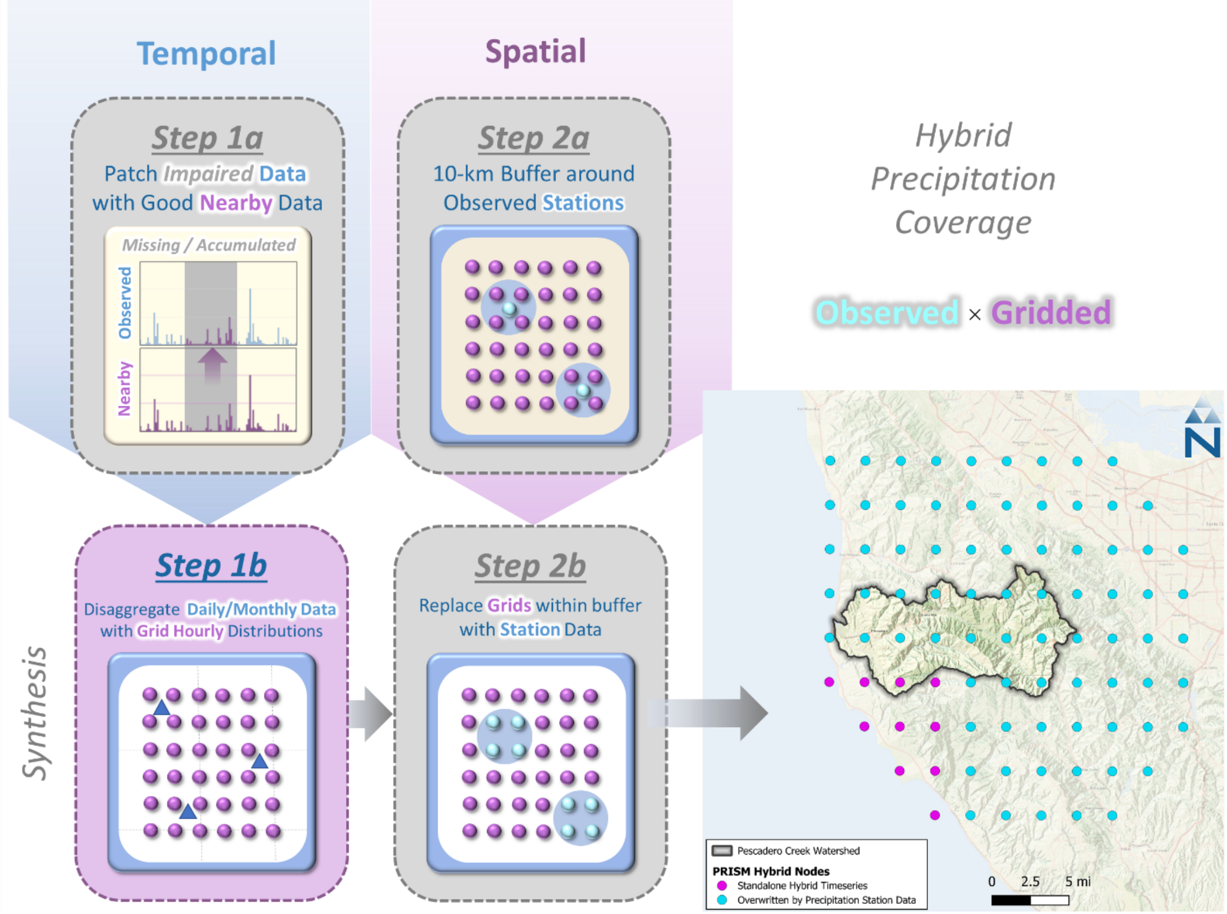

Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products.

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_o) using versions of the Penman and Penman-Monteith equations. CIMIS has divided California into 18 zones based on long-term monthly average ET_o values calculated using data from CIMIS weather stations.

The Pescadero Creek watershed has only one nearby CIMIS station (Pescadero). The Pescadero station is still active and contains data from August 2017 through the present. As shown in Figure 2-1, the Pescadero Creek watershed intersects three CIMIS zones with 80% of the watershed area in Zone 3 (Coastal Valleys and Plains and North Coast Mountains), 18% of the watershed in Zone 1 (Coastal Plains Heavy Fog Belt), and 2% of the watershed in Zone 8 (Inland San Francisco Bay Area). Most of the Pescadero Creek watershed falls within Zone 3, which covers all the central and eastern portions of the watershed. The western coastal edge of the watershed falls into Zone 1, and a small portion of the northeastern inland area of the watershed falls into Zone 8. These zones experience average annual reference evapotranspiration levels from 33.0 inches per year in Zone 1 to 49.4 inches per year in Zone 8.

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

Representative potential evapotranspiration (PEVT) time series can be estimated for the Pescadero 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_o is provided instead, and HRU-specific coefficient multipliers are used to stratify those inputs based on physical HRU properties such as vegetation density. Additionally, for applications where the study area has significant irrigation practices, the user can provide irrigation water usage rates to represent additional water beyond precipitation that is added to the system—that water would also be available for ET.

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

3 SURFACE HYDROLOGY

3.1 Watershed Segmentation

The United States Geological Survey (USGS) delineates watersheds nationwide based on surface hydrological features and organizes the drainage units into a nested hierarchy using HUCs. These HUCs use cascading digits to denote scale ranging from 2-digit HUCs (largest) at the region scale to 12-digit HUCs (smallest) at the subwatershed scale. The Pescadero Creek watershed is defined by a HUC-10 watershed that is comprised of three HUC-12 subwatersheds.

For units smaller than HUC-12 subwatersheds, 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. NHD Plus v2 (NHDPlus) further discretizes the watershed into 158 catchments ranging in size between 8.2 acres to over 4,000 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 Pescadero Creek watershed.

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 Pescadero Creek HUC-10

HUC-12 Name	Count	Catchment Size (acres)			
		Minimum	Mean	Median	Maximum
Upper Pescadero Creek	63	8.2	547.9	355.4	2,574.4
Butano Creek	29	38.5	722.0	377.6	2,308.7
Lower Pescadero Creek	66	8.9	430.0	287.0	4,117.6

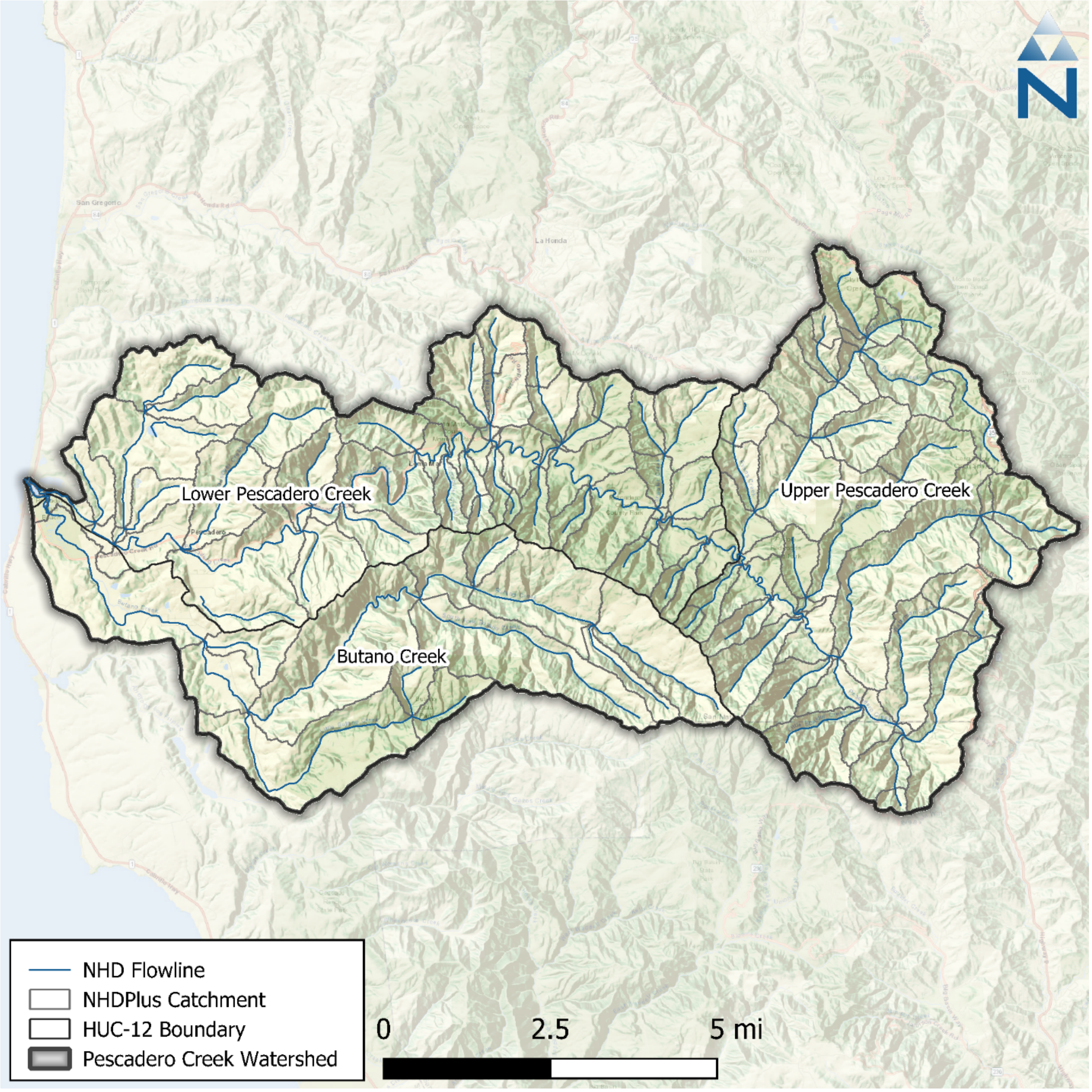

Figure 3-1. Initial catchment segmentation for the Pescadero Creek watershed.

3.2 Streams and Channels

As described above, the hydrographic characteristics of the streams and rivers within the Pescadero Creek watershed are primarily derived from NHDPlus. This dataset depicts primary flow paths based on a nation-wide 10-meter Digital Elevation Model (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.

3.3 Streamflow

The only source of streamflow data is from the USGS, which includes two current long-term stations: Pescadero Creek Near Pescadero CA (USGS 11162500) and Butano Creek Near Pescadero CA (USGS 11162540) Table 32 presents a summary of the available USGS streamflow data. Figure 32 shows the locations of the two USGS flow stations within the Pescadero Creek watershed.

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

Station Description	Station ID	Drainage Area (mi^2)	Start Date	End Date	Station Active?
PESCADERO C NR PESCADERO CA[1]	11162500	45.9	04/14/1951	Present	Yes
BUTANO C NR PESCADERO CA[2]	11162540	18.3	07/01/1962	Present	Yes

1. USGS notes “Small diversions upstream from station by pumping.” (https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=11162500&agency_cd=USGS).
2. USGS notes “No regulation; small diversions above station for irrigation.” (https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=11162540&agency_cd=USGS).

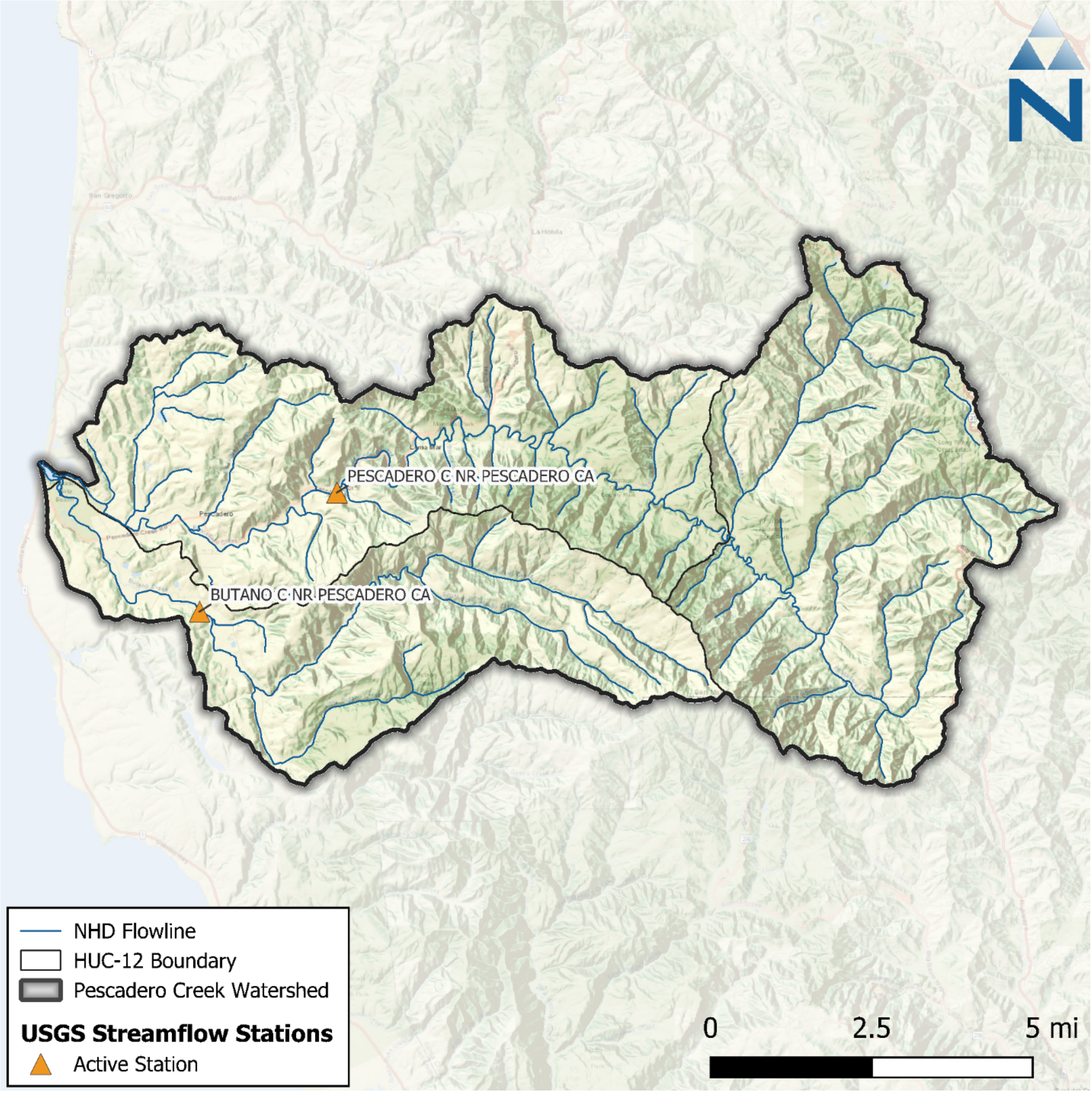

Figure 3-2. USGS streamflow stations in the Pescadero Creek watershed.

3.4 Dams, Reservoirs, and Impoundments

The Pescadero Creek watershed contains one notable dam that may require representation within the hydrology model, as shown in Figure 3-3. The Rickey dam, which impounds water near the northeast headwater of Pescadero Creek to create Horseshoe Lake, has data provided by the National Inventory of Dams (NID) and is listed in Table 3-3. Rickey dam is a publicly owned utility that is primarily used as a water supply for the local area and doubles as source of irrigation. Key metrics such as the average flow volume and average storage of this dam are currently unknown, as no readily accessible data was found and the NID database does not report this information. Capturing the operation of this feature may be important to accurately represent the movement of water throughout the watershed; however, given the small storage capacity is of this dam and its location in the watershed, it is not expected to have a significant impact. Having stage-storage relationships for reservoirs, and any other outflow rates or operating conditions, will be needed for any waterbodies represented in the model.

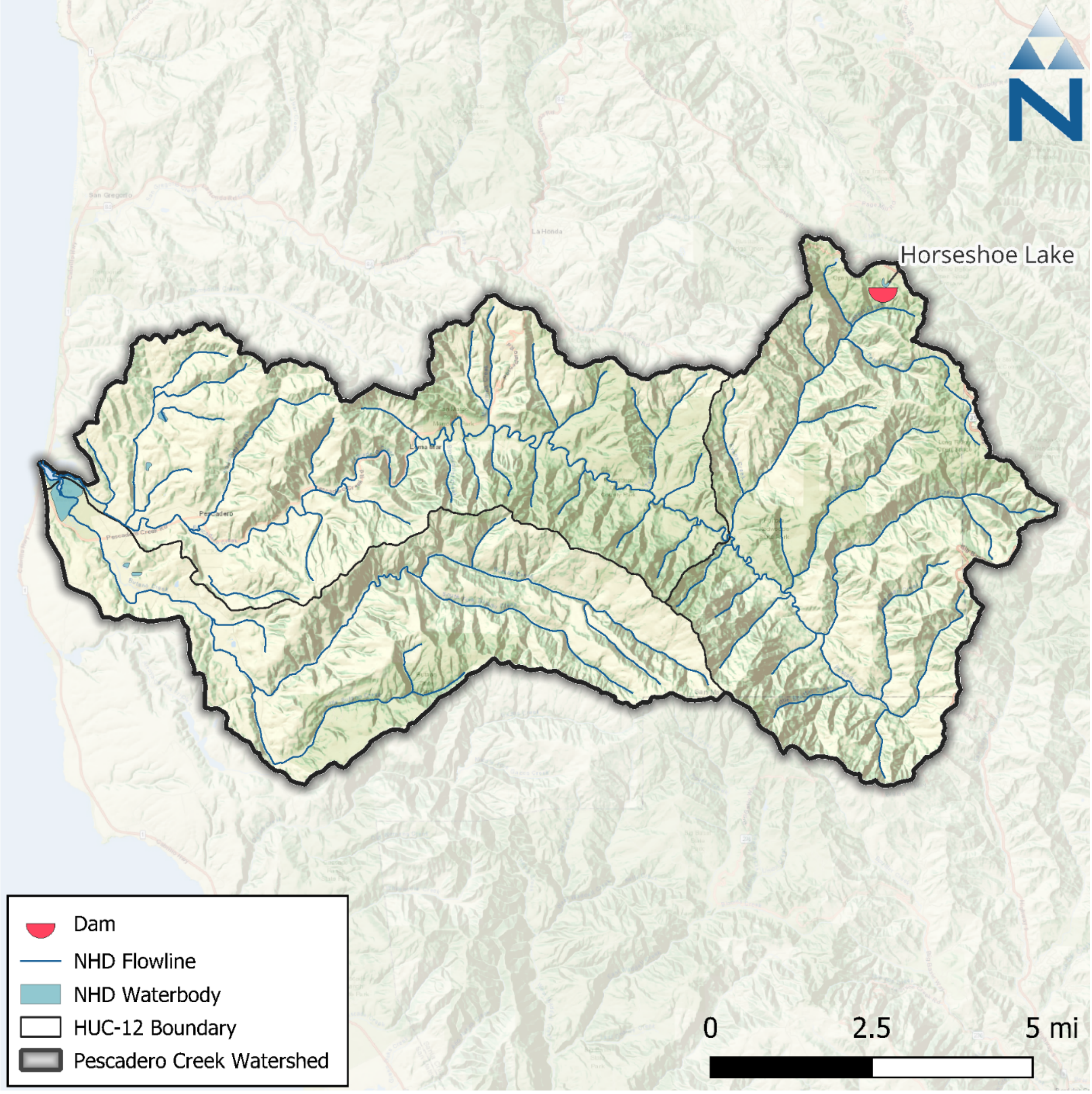

Figure 3-3. Dams within the Pescadero Creek watershed relevant for watershed modeling effort (NID 2025).

Table 3-3. Waterbodies and Dams within the Pescadero Creek watershed

NHD Waterbody	Dam Name	NID ID	Drainage Area (ac)	Area (ac) [1]	Storage Capacity (ac-ft)	Average Flow Volume (ac-ft)	Average Storage (ac-ft)
Horseshoe Lake[1]	Rickey	CA01009	147	4	47	Unknown[2]	Unknown[2]

1. The waterbody has no name provided in the NHD dataset, instead the waterbody's name was assigned based on a Google Earth Search.
2. Data is not listed from NID or NHD but may exist elsewhere.

3.5 Surface Water Withdrawals

Datasets related to water rights, points of diversion (PODs), and surface withdrawals (i.e., wells and irrigation) were identified through searches of the Water Board's Electronic Water Rights Information Management System database (eWRIMS) and the DWR Agricultural Land and Water Use Estimates database (ALWU). These datasets can be used to represent diversions, withdrawals, and irrigation practices in the watershed model. The volumes quantified in these datasets can be compared to annual and seasonal water budget estimates in the Pescadero 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 3-4 provides an overview of the primary drinking water sources in the watershed. Water systems distributed throughout the watershed include a mixture of both surface water diversions from Pescadero Creek and its primary tributaries, as well as groundwater withdrawals for the Pescadero Creek watershed groundwater basin. There are 21 drinking water systems in the watershed. For 9 out of the 21 drinking water systems, the water source is listed as groundwater, and 11 of the remaining 12 have surface water listed as the source; the last system is unclassified. The number of active surface water PODs and withdrawal volumes will be evaluated from eWRIMS reports during model development.

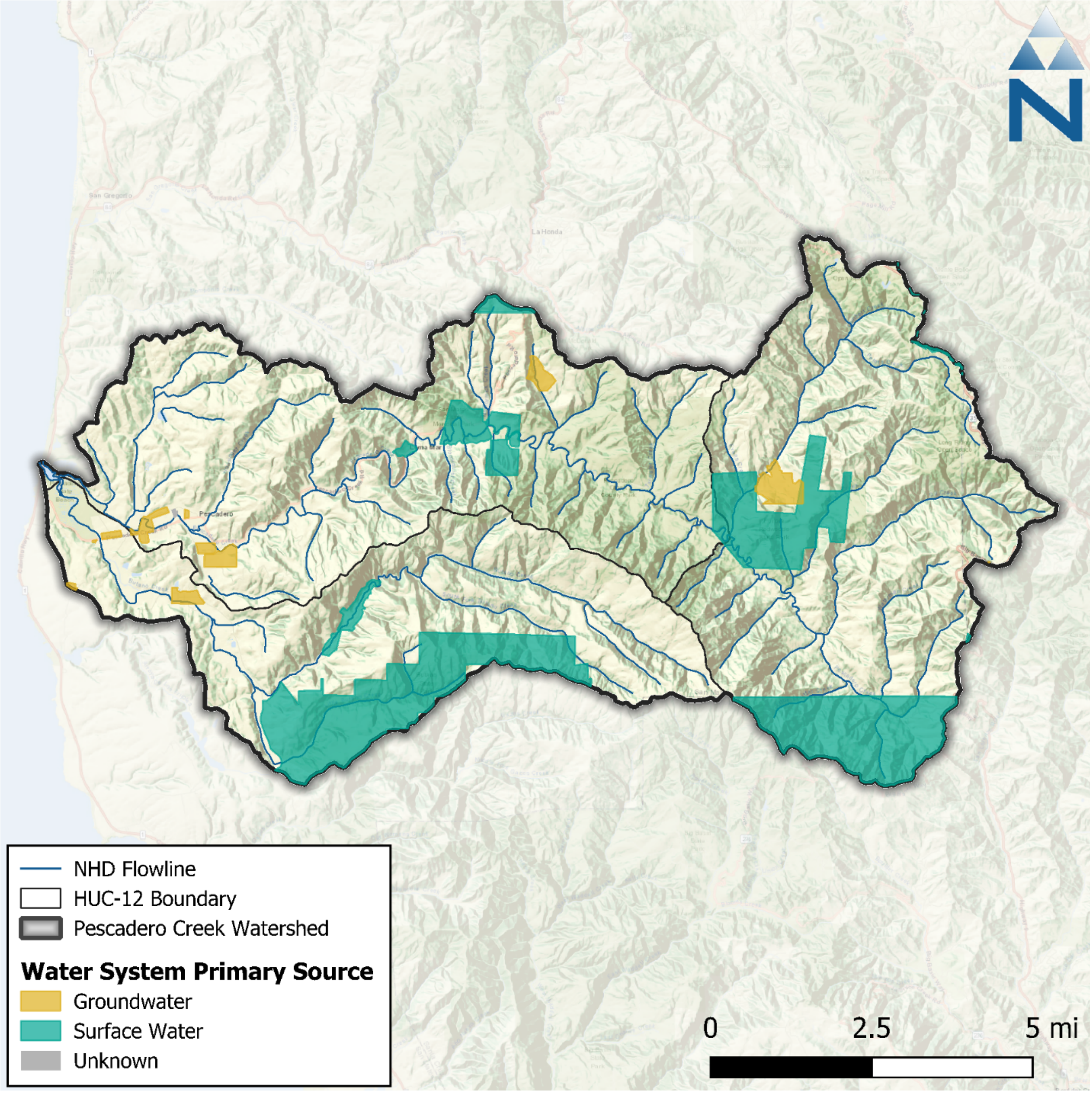

Figure 3-4. Primary Water System Sources in the Pescadero Creek watershed.

4 SUBSURFACE HYDROLOGY

The Pescadero Creek watershed overlaps with one groundwater basin as delineated by Bulletin 118 (DWR, 2020). The watershed mostly contains the Pescadero Valley basin (# 2-026). Approximately 5% of the watershed area falls within the groundwater basins delineated by Bulletin 118 and the remaining 95% consists of complex lithologies as outlined in the geology section.

The Pescadero Valley basin is classed as Very Low priority (Sustainable Groundwater Management Act (SGMA) Basin Prioritization Dashboard), as designated by the Sustainable Groundwater Management Act 's (SGMA) basin prioritization. Approximately 95% of the Pescadero Valley basin overlaps the Pescadero Creek watershed. No Groundwater Sustainability Agencies (GSAs) operate within the Pescadero Creek watershed.

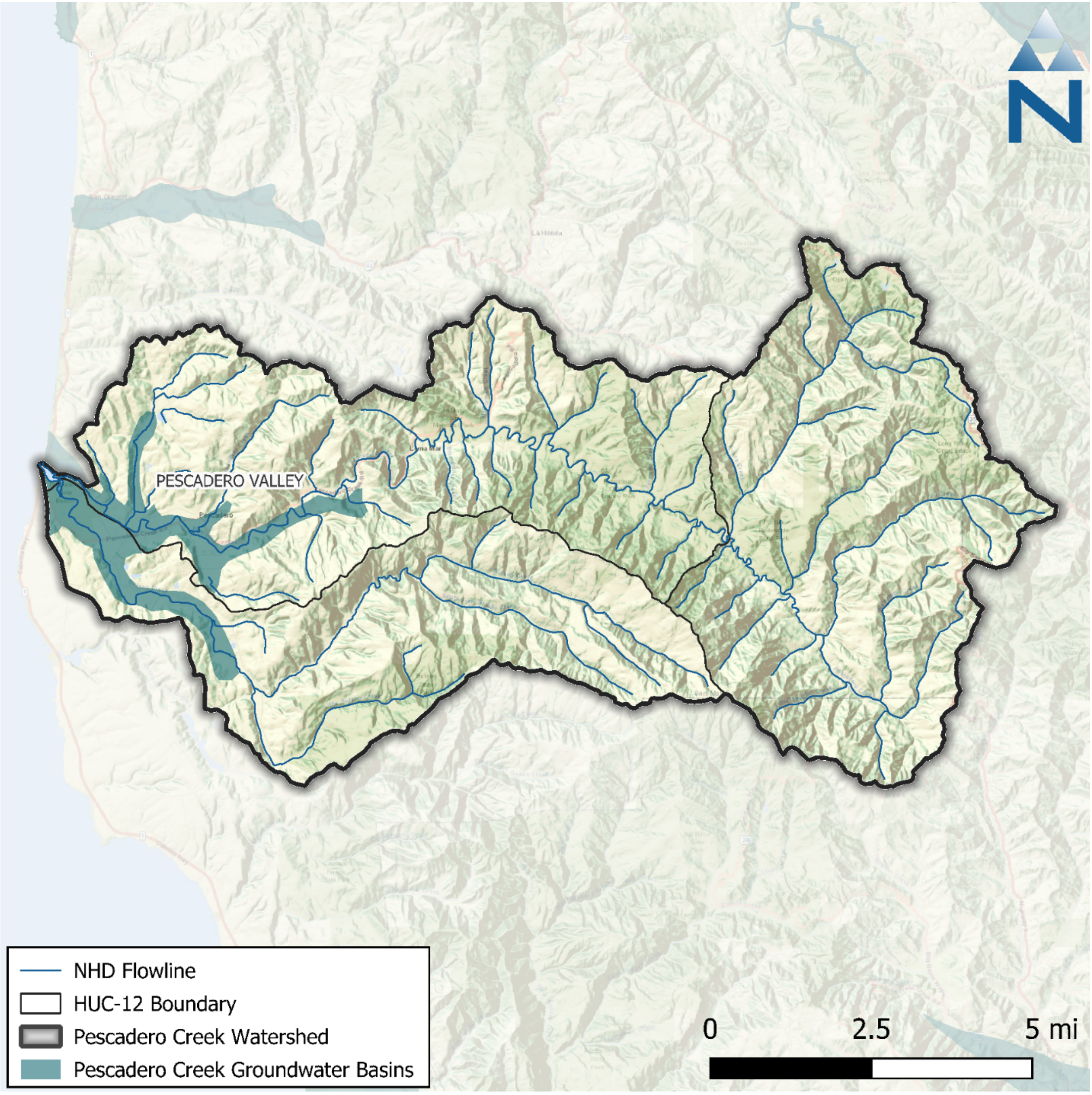

Figure 4-1. Groundwater basins delineated by DWR (2020), also known as Bulletin 118.

4.1 Water Budget Components

The US Geological Survey maintains a number of public domain models for Northern California (USGS 2024), but no public domain model contains the Pescadero Creek watershed. The Bulletin 118 basin description for the Pescadero Valley basin did not estimate a water budget but noted stable water levels with seasonal fluctuations.

4.2 Geology

Bulletin 118 also provides geological coverage for the Pescadero Valley groundwater basins. Key points are listed below.

- The water bearing units within the Pescadero Valley basin consist of Holocene alluvium and Pleistocene terrace deposits.
- In the Pescadero Creek watershed, outside the delineated basins, the bedrock is shown by the San Francisco/San Jose regional geologic map. The bedrock is composed principally of the Santa Cruz mudstone, Quaternary terraces, and Butano sandstone.
- The Butano Fault and Coastways Fault cross the Pescadero 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 Pescadero Creek watershed.

5.1 Elevation & Slope

The USGS publishes DEMs expressing landscape elevation through a raster grid data product with 30-meter resolution. The Pescadero Creek watershed ranges in elevation from sea level along the coast in the western part of the watershed to over 838 meters in the east near the edge of Castle Rock State Park and the Santa Cruz Mountains. 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 Pescadero Creek watershed.

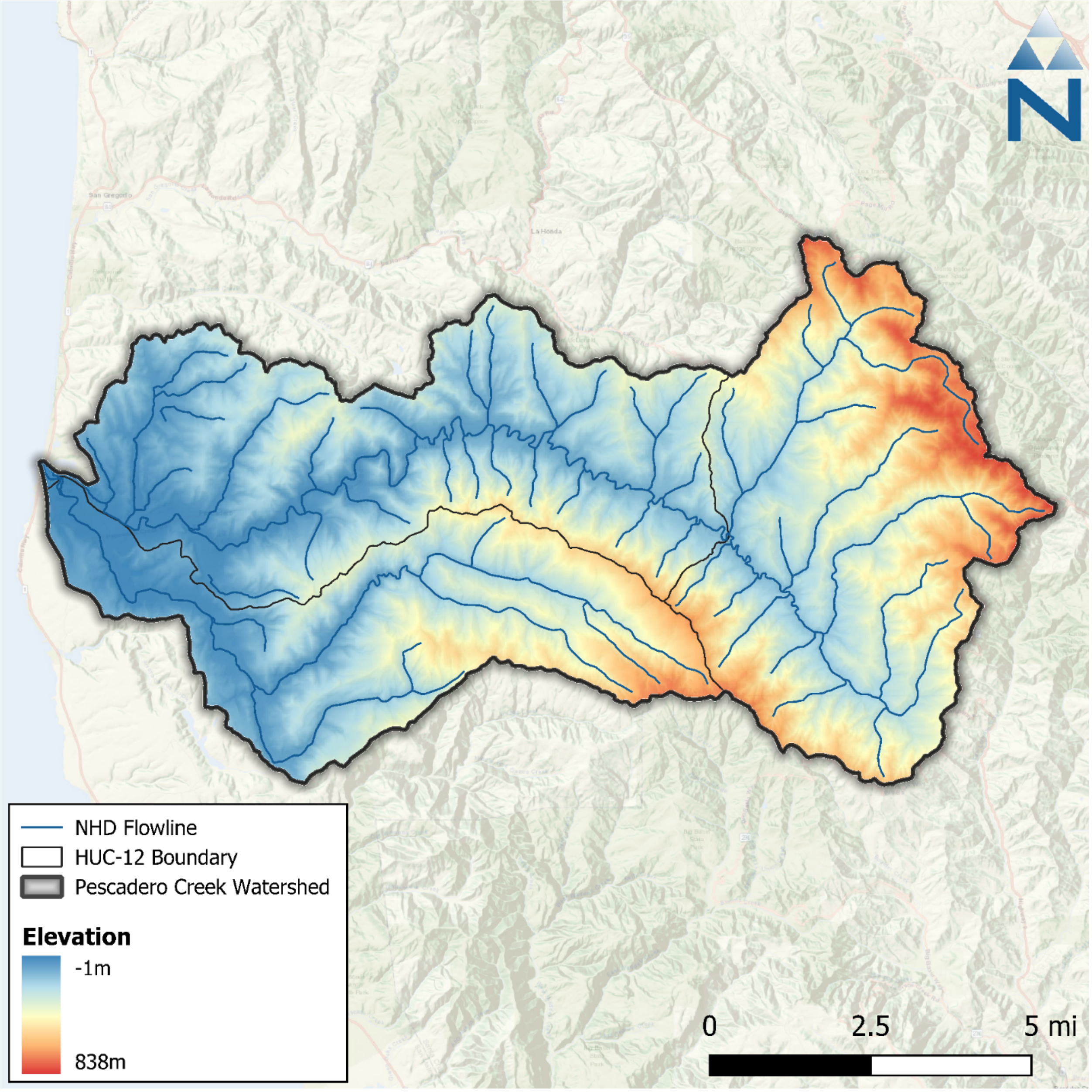

Figure 5-1. Digital elevation model of the Pescadero Creek watershed.

5.2 Soils

Soils data for the Pescadero Creek watershed were obtained from the Soil Survey Geographic Database (SSURGO) (USDA 2024a) and the 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 whereas Group D has the highest runoff potential. Both SSURGO and STATSGO 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 Pescadero Creek watershed. The dominant soil group in the watershed is Group C (41%), containing sandy clay loam with typically low infiltration rates. Group A, making up 27% of the watershed, contains well-draining sand, loamy sand, and sandy loam. Group B makes up 20% of the watershed and includes soils with moderately well to well-drained silt loams and loams. Group D, which consists of soils with the lowest infiltration rates, such as clay loam, silty clay loam, sandy and silty clay, and clay, constitutes 4% of the watershed. Less than 2% of the watershed areas have mixed soils. For modeling purposes, mixed soils will be grouped with the nearest primary group as follows: A/D → B, B/D → C, and C/D → D. Finally, approximately 6% of the watershed HSG area is classified as unknown in the SSURGO database. 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 Pescadero Creek watershed

Hydrologic Soil Group	Area (acres)	Percent Area
A	13,773.61	26.60%
A/D	383.56	0.74%
B	10,451.19	20.18%
C	20,990.26	40.54%
C/D	887.63	1.71%
D	2,283.47	4.41%
N/A	3,010.35	5.81%
Total	**51,780.05**	**100.00%**

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

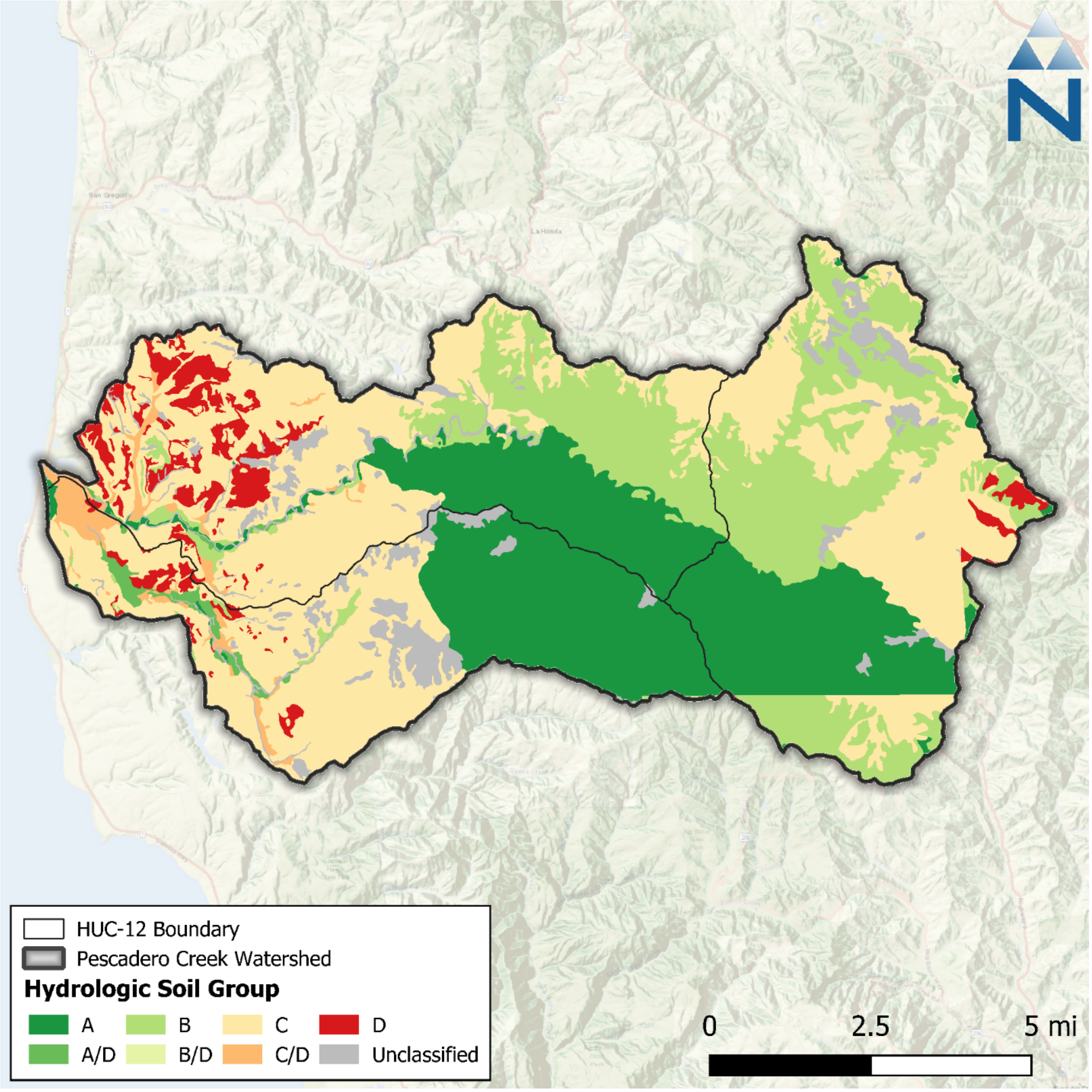

Figure 5-2. SSURGO hydrologic soil groups within the Pescadero Creek watershed.

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 Pescadero Creek Watershed and Figure 5-3 shows the spatial distribution of these classifications. Forests are the dominant land cover classification covering approximately two thirds (66%) of the watershed area, most of which is Evergreen (51%), followed by Mixed (14%), then Deciduous (<1%). The remaining third of the landscape is mostly composed of grassland (23%) and shrubland (7%), while the remaining 3% is predominately developed land; of the developed land, almost all is classified as "Developed Open Space" (86%).

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

NLCD Class	Classification Description	Area (acres)	Percent
11	Open Water	39.40	0.08%
21	Developed Open Space	1,083.14	2.09%
22	Developed Low Intensity	121.54	0.23%
23	Developed Med Intensity	44.96	0.09%
24	Developed High Intensity	12.91	0.02%
31	Barren Land	20.70	0.04%
41	Deciduous Forest	101.50	0.20%
42	Evergreen Forest	26,576.21	51.32%
43	Mixed Forest	7,276.83	14.05%
52	Shrub/Scrub	3,771.86	7.28%
71	Grassland/Herbaceous	11,907.46	23.00%
81	Pasture/Hay	94.83	0.18%
82	Cultivated Crops	197.66	0.38%
90	Woody Wetlands	431.83	0.83%
95	Emergent Herbaceous Wetlands	100.39	0.19%
TOTAL[2]		**51,781.24**	**100.00%**

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 1.2 acres more than the model domain.

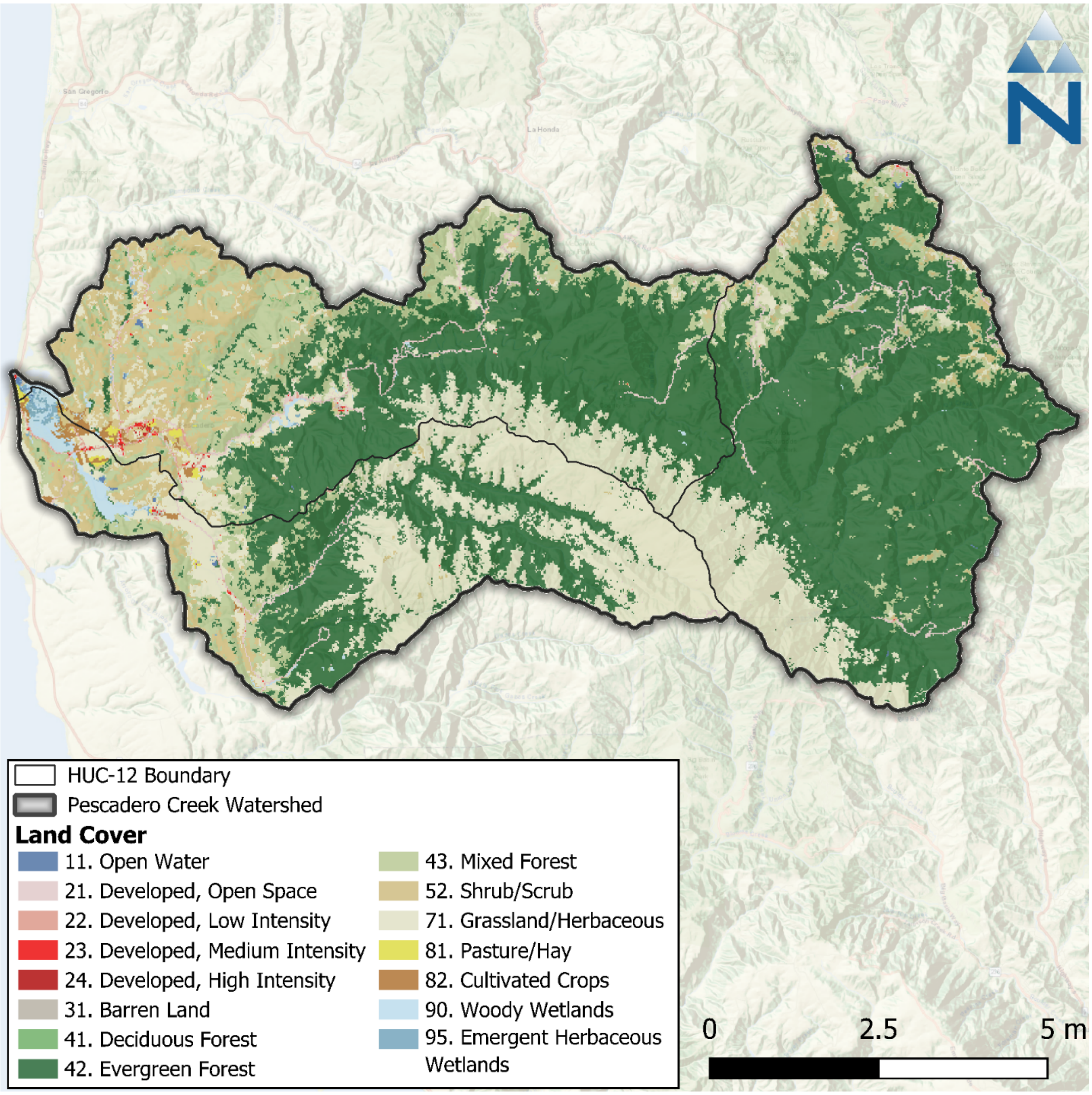

Figure 5-3. NLCD 2021 land cover within the Pescadero Creek watershed.

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 Pescadero Creek watershed using this dataset shows that just over 2% 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 development 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 Pescadero 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 as needed 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 Pescadero Creek watershed, an average of 59% 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 Pescadero Creek Watershed (see Section 5.3) was analyzed to identify predominant cropland vegetation classes. This analysis revealed that less than 0.18% of the Pescadero Creek watershed area is classified as Pasture/Hay (class 81) and 30.3% 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 from the United States Department of Agriculture (USDA) Cropland Data Layer (CDL) can be used. The USDA CDL (USDA 2024c) is an annual updated raster dataset that geo-references crop-specific land use. The 30-meter resolution raster 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 was 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.

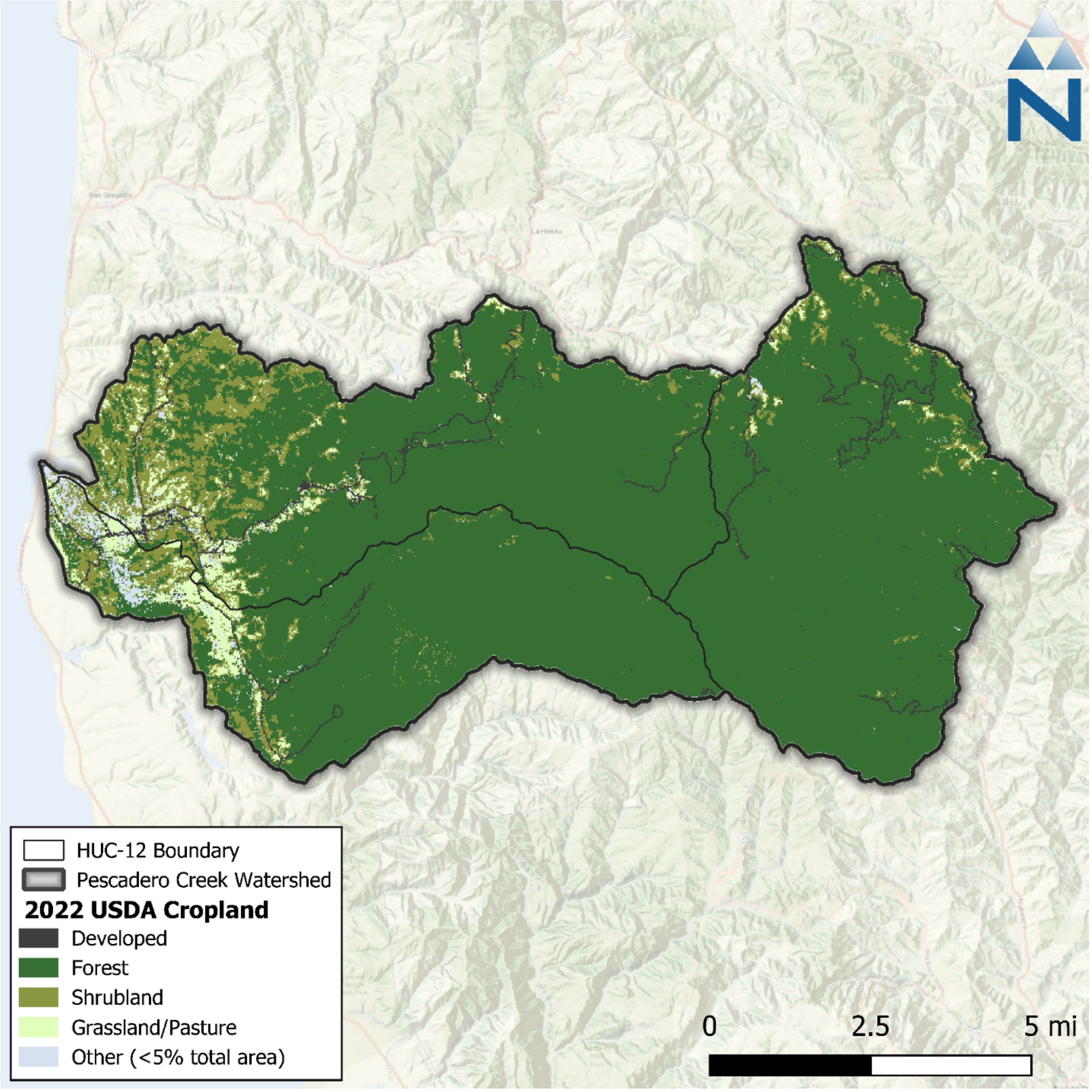

Figure 5-4. USDA 2022 Cropland Data within the Pescadero Creek watershed

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

Crop Type	Area (ac)	Area (%)
Developed	1,263.00	2.44%
Forest	43,138.12	83.32%
Shrubland	5,102.98	9.86%
Grassland/Pasture	1,555.49	3.00%
Other (<5%)	714.31	1.38%
TOTAL	**51,773.90**	**100.00%**

6 DATA GAPS AND LIMITATIONS

Based on review of the datasets presented in this report, a 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 agriculture, may not be mapped or have available data. These diversions may need to be mapped, and assumptions could be needed to represent water demand in the model if these demands are needed for model calibration purposes.

Another potential limitation is the availability, quality, and temporal extent data related to dams, reservoirs, and waterbodies listed in Section 3.4. For example, average flow volume and average storage of each reservoir are currently unknown, as no readily accessible data was found and the NID database does not report this information. Capturing the operation of these features may be important to accurately represent the movement of water throughout the watershed; however, these features are expected to have a negligible impact for this watershed. Additionally, stage-storage relationships for waterbodies and any other operating conditions will be needed for those represented in the model.

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, such as the 2020 and 2025 C/CAG model efforts described in Section 1.3, could be leveraged to support the specific objectives of this study. 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 and the presence of an existing calibrated and concurrently developed watershed model (Section 1.3) also influence model selection and approach. 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 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 in 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 Pescadero 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.

As described in Section 1.3, C/CAG developed a calibrated LSPC model for watersheds overlapping with the Pescadero Creek Watershed in 2020 and is concurrently developing an updated model for the same region. The modeling objective for these efforts is to support management decisions regarding stormwater runoff and pollutant loads including mercury, PCBs, and sediment to the San Francisco Bay and Pacific Ocean. Because these models were/are constructed at the regional scale, the focus of model configuration and calibration differs slightly from the needs of this study; however, elements such as initial process parameter values provide a good foundation for building upon for this study.

7.2 Model Configuration

An LSPC model will be configured using the data sets presented in Section 2 through Section 5 as well as the models developed as part of the C/CAG efforts described in Section 1.3. 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 data sets. 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 evapotranspiration. Consistent with the 2020 and 2025 C/CAG LSPC models, precipitation will be represented utilizing observed ground-based stations (GHNC, RAWS, and CDEC gauge data listed in Section 2) with gridded PRISM and NLDAS data in the hybrid approach also described in Section 2. Similarly, monthly PRISM precipitation totals will be disaggregated using the hourly NLDAS time series. Lastly, ET will be represented using the CIMIS daily reference evapotranspiration 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, points of diversion, etc.). As needed, the C/CAG LSPC models will be referenced to support model segmentation. 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 by catchment in the model.
- **Hydrologic Response Units**: HRUs represent unique combinations of landscape characteristics that will be derived by overlaying GIS data sets 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). As needed, the C/CAG LSPC models, which also utilize similar land cover datasets, will be referenced to support HRU development.
- **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. As appropriate, the C/CAG LSPC models will be referenced to support characterization of water use and inflows.
- **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 -∞ 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 Pescadero 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[1]	<5%	5% - 10%	10% - 15%	>15%
	Seasonal Flows[2]	<10%	10% - 15%	15% - 25%	>25%
	Highest 10% of Daily Flow Rates[3]				
	Days Categorized as Storm Flow[4]				
	Days Categorized as Baseflow[4]				
RMSE – Std Dev Ratio (RSR)	All Conditions[1]	≤0.50	0.50 - 0.60	0.60 - 0.70	>0.70
	Seasonal Flows[2]	≤0.40	0.40 - 0.50	0.50 - 0.60	>0.60
Nash-Sutcliffe Efficiency (NSE)	All Conditions[1]	>0.80	0.70 - 0.80	0.50 - 0.70	≤0.50
	Seasonal Flows[2]	>0.70	0.50 - 0.70	0.40 - 0.50	≤0.40
Kling-Gupta Efficiency (KGE)	Monthly Aggregated[5]	≥0.90	0.90 - 0.75	0.75 - 0.50	<0.50

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

9 SUMMARY & NEXT STEPS

This work plan presented the available data and proposed methods for developing a hydrologic model of the Pescadero Creek watershed. Once this work plan is finalized, the data sets 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, gauge 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 Pescadero Creek Watershed.

Table 9-1. Proposed schedule and summary of deliverables

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

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

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