
Work Plan: San Lorenzo River Watershed Hydrology Model Development

SUBMITTED TO:

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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
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
GSP	GROUNDWATER SUSTAINABILITY PLAN
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
UCCE	UNIVERSITY OF CALIFORNIA COOPERATIVE EXTENSION
USDA	UNITED STATES DEPARTMENT OF AGRICULTURE
USFS	UNITED STATES FOREST SERVICE
USGS	UNITED STATES GEOLOGICAL SURVEY
WBD	WATERSHED BOUNDARY DATASET

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1 INTRODUCTION

1.1 Project Objectives

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

This work plan presents the available data and methodology that will be used to develop a hydrologic model of the San Lorenzo River 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 San Lorenzo River watershed, identified by a ten-digit hydrologic unit code (HUC), shares a boundary with the Pescadero Creek watershed to the north, Guadalupe River watershed to the northeast, Waddell Creek watershed to the west, and the Monterey Bay watershed to the south. San Lorenzo River (HUC-10: 1806001502) is a coastal watershed that drains approximately 137 square miles and is composed of three subwatersheds: Bear Creek (HUC-12: 180600150201), Carbonera Creek (HUC-12: 180600150203), and Zayante Creek (HUC-12: 180600150202) as shown in [Figure 1-1](#). San Lorenzo River is a free-flowing river with nine principal tributaries: most notable are Kings, Boulder, Bear, Bean, Fall, Newell, Zayante, and Branciforte Creeks. From its confluence, the river flows approximately 29 miles before reaching the City of Santa Cruz and draining to the Pacific Ocean.

The San Lorenzo River watershed ranges in elevation from near sea level in Scotts Valley and Santa Cruz to over 900 meters at the northernmost portion of the watershed near Castle Rock State Park. The watershed has a Mediterranean climate with distinct wet and dry seasons and a mean annual precipitation total of 47 in. (Central Coast Regional Water Quality Control Board 2002a). The watershed is dominated by evergreen forest (55%) and developed (19%) and open space (14%) areas. Other land cover types include mixed forest (12%), grassland/herbaceous (11%), and barren land (0.24%).

The San Lorenzo River plays a vital role in providing a drinking water supply for the City of Santa Cruz — approximately 54% of the drinking water for the City of Santa Cruz comes directly from the San Lorenzo River (Coastal Watershed Council 2024). The San Lorenzo River watershed also represents an important habitat for native aquatic species and spawning ground for anadromous fish (e.g., steelhead trout, coho salmon) and tidewater goby. Declining anadromous fish populations within the San Lorenzo River watershed have been linked to extensive logging, agricultural development, and road building practices that increased sediment delivery above that which supports salmonid life and high silt-covered bottoms in the river (CCRWQCB 2002). These and other factors

led to the development of Total Maximum Daily Loads (TMDLs) for pesticides, nitrate, pathogens, and sediment in 2014, 2000, 2009, and 2003, respectively (CCCWB 2025). It also led to partnership programs with the San Lorenzo Valley Water District (SLVWD), a water district responsible for management of all entrusted resources, including land and to control sedimentation, water quality, and protection from invasive species (SLVWD 2025).

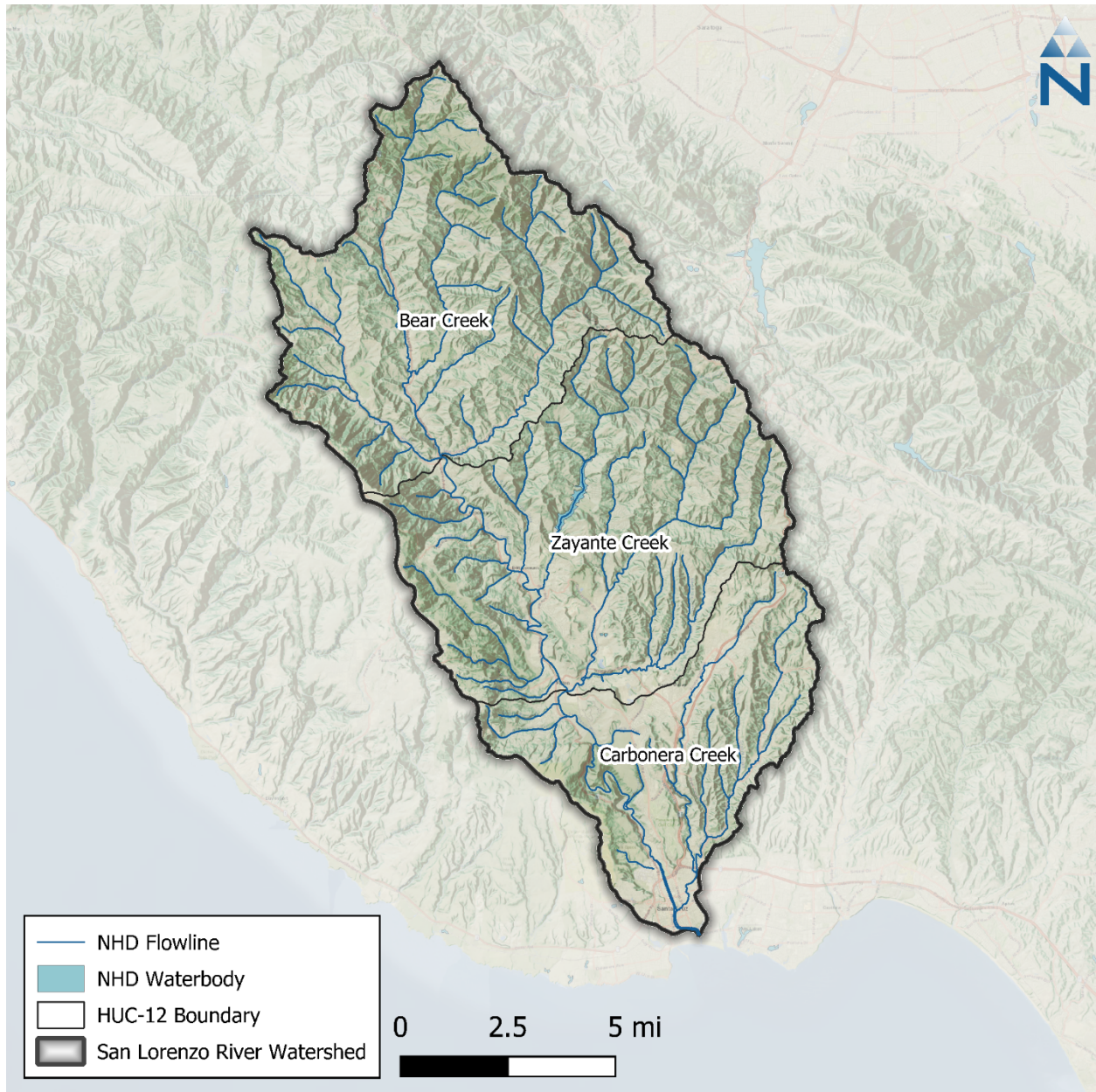


Figure 1-1. San Lorenzo River watershed.

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 San Lorenzo River watershed. This is presented first through a comprehensive inventory of available meteorological, hydrological, and geographic information

system (GIS) data available for the San Lorenzo River 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.

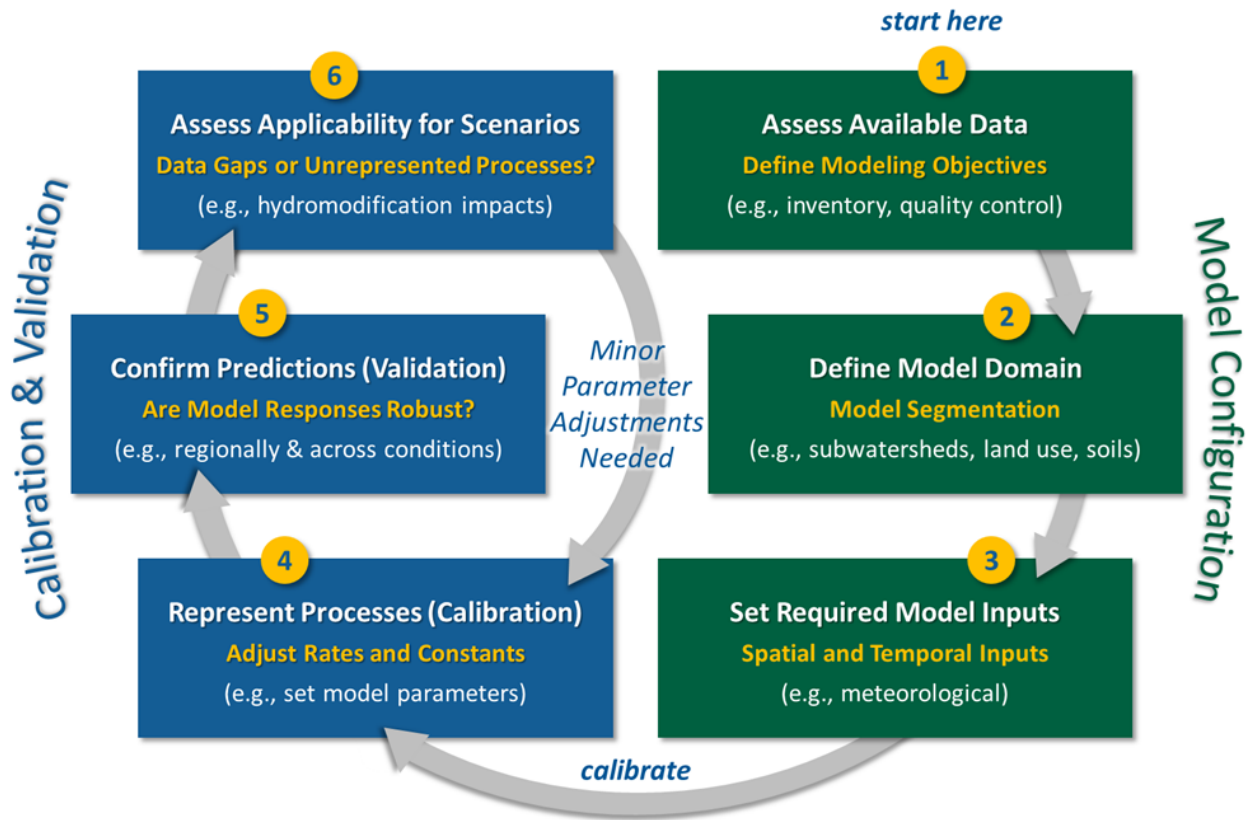


Figure 1-2. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the San Lorenzo River watershed.

1.4 Data Availability

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

- ▼ **Meteorology Datasets:** Time series that represent water balance inputs and outputs to the watershed primarily from precipitation and ET. These time series are often used as forcing inputs for hydrologic models.
- ▼ **Surface & Groundwater Datasets:** Datasets describing stream flow, groundwater, water use, and stream conditions for the San Lorenzo River. Time series observations of instream responses for the San Lorenzo River are often used as calibration and validation datasets for hydrologic models.
- ▼ **Geospatial Datasets:** Spatial datasets describing the landscape of the San Lorenzo River 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 four 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 on the San Lorenzo River.	Hydrology calibration.	LINK
		CDEC	Reservoir Stage, Storage, and Flow Data	2020-Current	Observed stage, storage, and flow data at Newell Creek Dam near Loch Lomond.	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	San Lorenzo River Total Maximum Daily load for Sediment	2002	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 (POD)	Current	Locations where water is being drawn from a surface water source such as a stream or river.		LINK
			Water Rights Overview Report	Current	This report will provide counts of various entities such as Applications, Registrations, Petitions etc. that will reflect the progress in processing such entities as of the current date.		LINK
			Annual Water Use Report	1906 – 2023	Annual reports that provide monthly diversion data for various entities such as Applications, Registrations, Petitions, etc.		LINK
		DWR	Agricultural Land and Water Use Estimates	1998 – 2015	Water use estimates by various planning units.		LINK

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
		CDT	Water Districts	2022	Boundaries of all public water agencies in California.		LINK
			California Drinking Water System Area Boundaries	2024	Public California drinking water systems and state small drinking water system boundaries and information.		LINK

Table 1-3. Inventory of geospatial datasets

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Watershed Boundaries	National	USGS	Watershed Boundaries Dataset (WBD)	2023	Hydrologic unit boundaries to the 12-digit (6th level).	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
			NHD Best Resolution	2023	1:24,000; represents reaches and other network elements.		LINK
Soil	National	USDA NRCS	Gridded 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

Category	Scale	Source	Dataset	Date Range	Description	Model Use	Link
Land Cover	National	MRLC	National Land Cover Dataset (NLCD) Land Cover	2021	Broad, 30 m grid-based land characterization. Differentiates developed land from coarse classifications of forest, cropland, wetlands, etc.	Land segment representation.	LINK
			NLCD Fractional Imperviousness	2021	Broad, 30-meter grid-based land characterization. Represent percent impervious area within raster cells.		LINK
Land Use	State	DWR	Statewide Crop Mapping	2020	Polygons attributed to DWR crop categories.	Identify crop distributions; estimate irrigation demand.	LINK
Vegetation	National	MRLC	Tree Canopy Cover	2021	Percent tree canopy estimates for each 30-meter pixel across all land covers and types.	Land segment representation.	LINK
	State	USFS	Existing Vegetation	2018	1:24,000 to 1:100,000: Existing vegetation mapping.	As necessary, additional vegetation types for model land segments.	LINK
Agriculture & Crop Cover	National	USDA	Cropland Data Layer	2022	30-meter grid-based crop-specific land cover data layer.	Identify crop distributions; estimate irrigation demand.	LINK
Timber Harvesting	National	USDA	Timber Harvests	1820 - Present	Area planned and accomplished acres treated as a part of the timber harvest program of work.	Representing changes in land cover due to timber harvest activities.	LINK
	State	CAL FIRE	Nonindustrial Timber Management Plans TA83	1991 - Present	Timber management plans.		LINK

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

Table 1-4. Inventory of groundwater datasets

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

2 METEOROLOGY

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

2.1 Precipitation

The primary source of precipitation data for the San Lorenzo River 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. Fourteen GHCN stations were identified within or near the San Lorenzo River 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 San Lorenzo River watershed. The California Data Exchange Center (CDEC) and the Remote Automated Weather Stations (RAWS) networks also report hourly precipitation. CDEC reports at four locations and RAWS reports at four locations within and near the watershed.

In addition to precipitation data, snow data was also screened for the San Lorenzo River watershed model and yielded six GHCN stations within a 15km buffer (reference [Figure 2-1](#)) that had 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 in this watershed.

[Table 2-1](#) is an inventory of the precipitation stations near the San Lorenzo River 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. [Figure 2-1](#) shows the location of the stations proposed for model development. 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 the San Lorenzo River 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 (%) ¹	Station Record Coverage (%) ²
GHCN	GHCND:USC0004 8273	SKYLINE RIDGE PRESERVE	7/1/1995	Present	37.3133	-122.185	691.9	97%	97%
	GHCND:USC0004 0673	BEN LOMOND #4	12/1/1972	Present	37.0869	-122.082	132.6	94%	94%
	GHCND:USC0004 7916	SANTA CRUZ	1/1/1893	4/30/2022	36.9878	-121.999	21.3	82%	89%
	GHCND:US1CAS C0011	CAMBRIAN PARK 2.2 SE	11/1/2008	Present	37.2341	-121.897	76.8	62%	98%
	GHCND:US1CAS Z0024	FELTON 4.5 NNE	2/1/2010	Present	37.1051	-122.047	255.4	64%	94%
	GHCND:US1CAS C0040	LOS GATOS 5.4 SSW	10/1/2010	Present	37.156	-121.988	506.6	65%	100%
	GHCND:US1CAS Z0006	BOULDER CREEK 3.6 NE	10/1/2008	12/31/2024	37.1811	-122.091	525.5	69%	93%
	GHCND:US1CAS Z0021	BOULDER CREEK 3.0 NW	1/1/2010	Present	37.1693	-122.164	266.7	66%	97%
	GHCND:US1CAS C0032	SAN JOSE 6.2 W	6/1/2009	Present	37.3185	-121.961	42.4	71%	100%
	GHCND:US1CAS Z0028	SOQUEL 0.8 NE	4/1/2012	Present	37.0022	-121.936	126.2	52%	92%
	GHCND:US1CAS Z0041	SCOTTS VALLEY 1.4 W	11/1/2015	Present	37.0554	-122.032	113.4	36%	91%
	GHCND:US1CAS C0042	SUNNYVALE 3.6 S (W6NW)	9/1/2011	Present	37.3344	-122.018	51.8	57%	95%
	GHCND:US1CAS C0053	LOS GATOS 9.6 SSE	7/1/2014	Present	37.1039	-121.89	670.3	42%	91%
	GHCND:US1CAS C0015	SARATOGA 0.5 N	11/1/2008	Present	37.2748	-122.023	113.7	74%	99%
CDEC	LAH	LA HONDA	3/23/1987	Present	37.3053	-122.254	129.5	99%	99%
	LSG	LOS GATOS	7/1/1994	Present	37.2068	-121.943	196.9	85%	85%
	SCH	SCHULTIES RD	10/1/2016	Present	37.133	-121.969	426.7	32%	92%

Agency	Station ID	Station Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Model Period Coverage (%) ¹	Station Record Coverage (%) ²
	BLO	BEN LOMOND (CDF)	11/26/2001	Present	37.132	-122.17	801.6	40%	100%
RAWS	BNDC1	BEN LOMOND	6/16/1998	Present	37.1309	-122.173	791.9	100%	100%
	LAHC1	LA HONDA	5/2/1990	Present	37.3052	-122.255	245.1	99%	99%
	LSGC1	LOS GATOS	5/29/1997	Present	37.2041	-121.951	561.4	93%	93%
	LOAC1	LOS ALTOS	2/18/1998	Present	37.3547	-122.142	164.3	92%	92%

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.

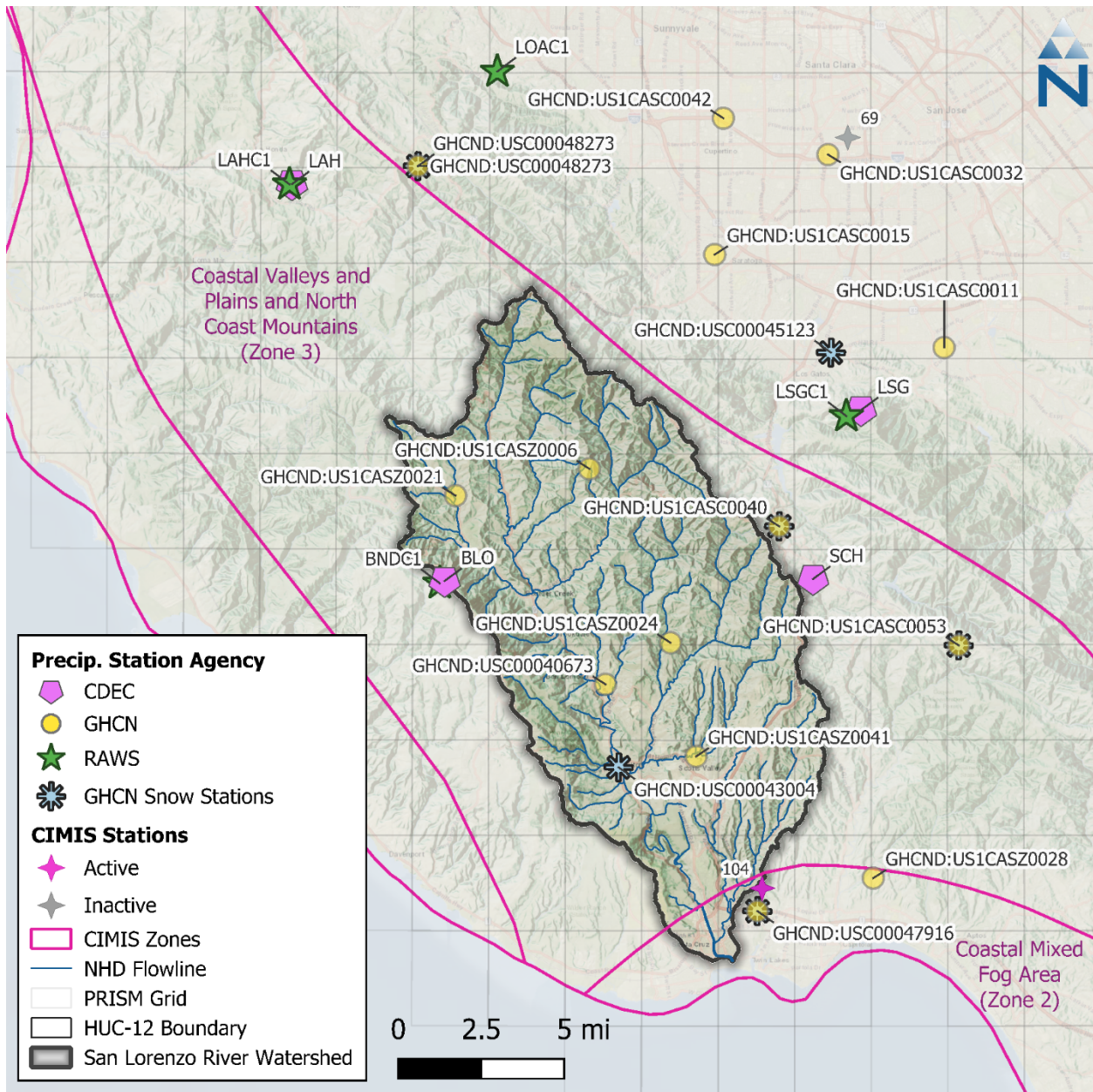


Figure 2-1. Identified rainfall stations and CIMIS ET Zones near the San Lorenzo River watershed.

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.

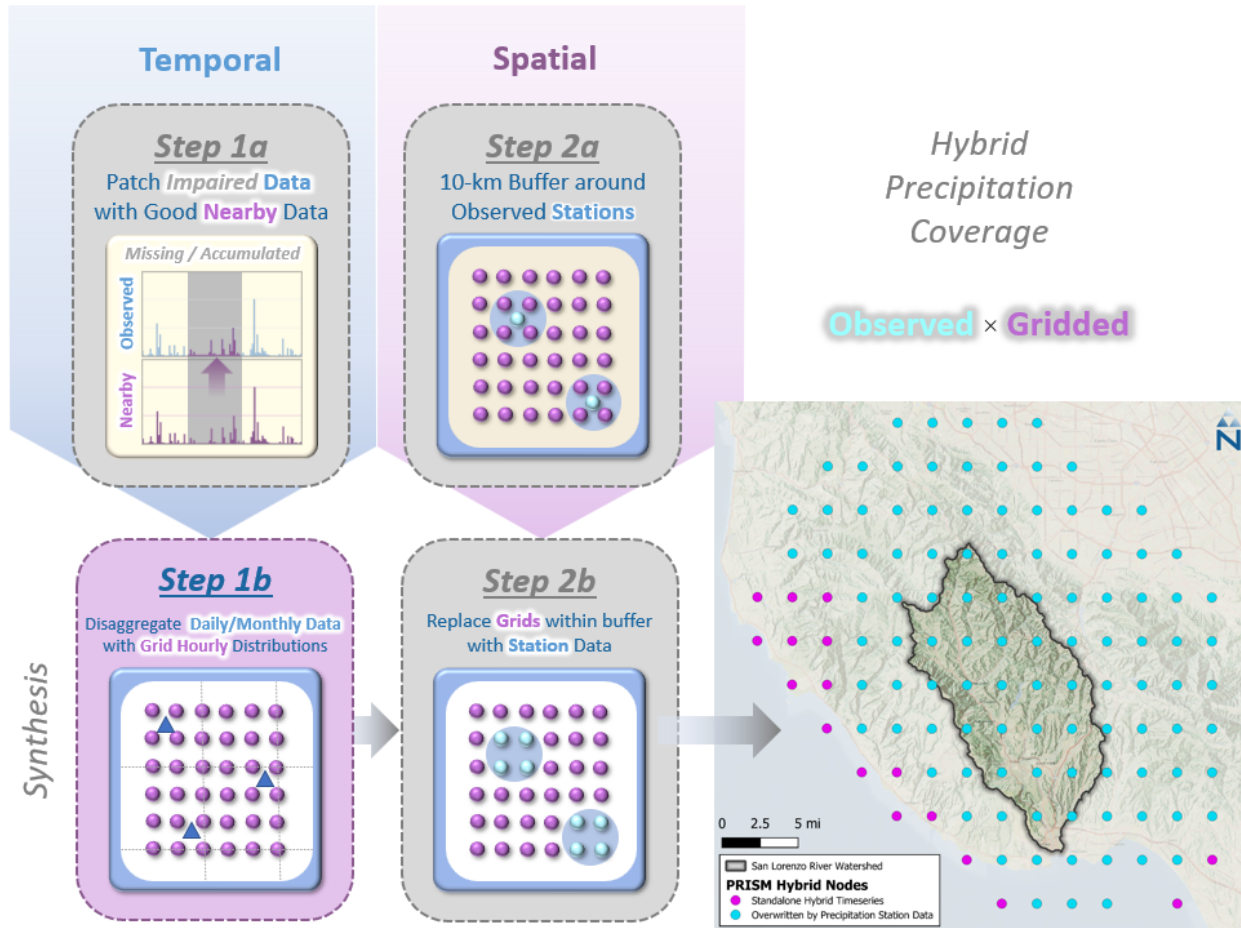


Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products.

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.

There are two CIMIS stations near the San Lorenzo River watershed: De Laveaga and San Jose. De Laveaga is active, but San Jose is no longer operating. The historical time series data for San Jose covers the periods from June 1987 through November 2011. The De Laveaga station in the nearby Guadalupe River watershed is still active and contains data from September 1990 to the present. As

shown in [Figure 2-1](#), the San Lorenzo River watershed intersects two CIMIS zones with 98% of the watershed area in Zone 3 (Coastal Valleys and Plains and North Coast Mountains), and 2% of the watershed area in Zone 2 (Coastal Mixed Fog Area). Most of the San Lorenzo River watershed falls within Zone 3, and the southern, coastal outlet of the watershed falls into Zone 2. These zones experience average annual reference ET levels from 39.0 inches per year in Zone 2 to 46.3 inches per year in Zone 3.

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 San Lorenzo River 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 San Lorenzo River watershed is defined by a HUC-10 watershed that is comprised of three 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 154 catchments ranging between 2.4 to nearly 3,000 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 San Lorenzo River 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 San Lorenzo River HUC-10

HUC-12 Name	Count	Catchment Size (acres)			
		Minimum	Mean	Median	Maximum
Bear Creek	53	2.4	618.6	509.2	2,570.9
Carbonera Creek	40	2.9	489.7	305.4	2,908.2
Zayante Creek	61	15.6	568.6	452.8	1,784.5

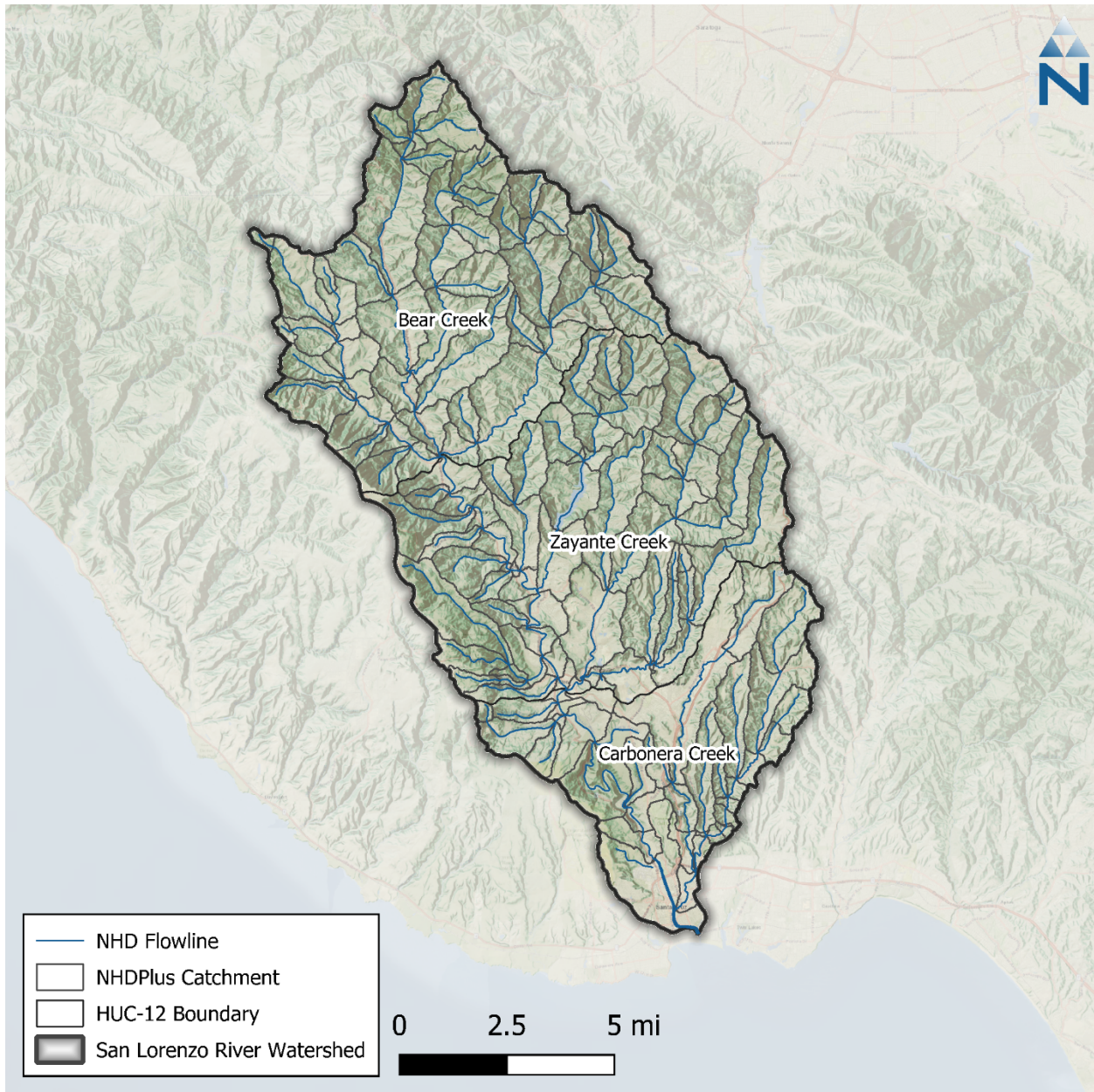


Figure 3-1. Initial catchment segmentation for the San Lorenzo River watershed.

3.2 Streams and Channels

As described above, the hydrographic characteristics of the streams and rivers within the San Lorenzo River 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 two current long-term stations: the San Lorenzo River at Big Trees, CA (USGS 11160500) and San Lorenzo River at Santa Cruz, CA (USGS 11161000). There are also three historical flow stations 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 five USGS flow stations within the San Lorenzo River 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?
SAN LORENZO R A BIG TREES CA	11160500	106.0	10/01/1936	Present	Yes
SAN LORENZO R A SANTA CRUZ CA	11161000	115.0	10/01/1952	Present	Yes
BEAN C NR SCOTTS VALLEY CA	11160430	8.8	01/06/1989	09/29/2007	No
CARBONERA C A SANTA CRUZ CA	11161400	7.4	09/01/2015	08/31/2021	No
CARBONERA C A SCOTTS VALLEY CA	11161300	3.6	01/31/1985	10/04/2007	No

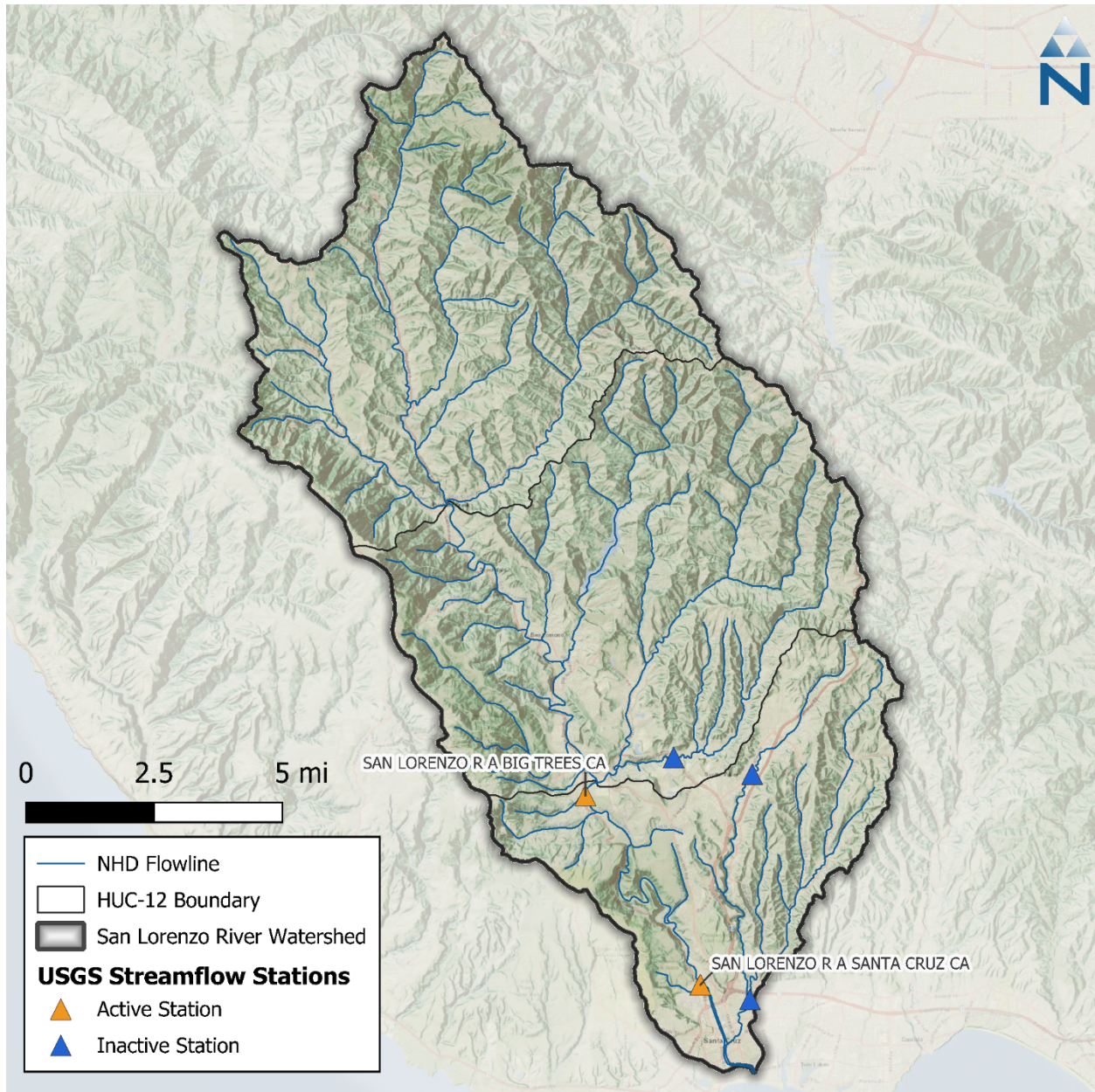


Figure 3-2. USGS streamflow stations in the San Lorenzo River watershed.

3.4 Dams, Reservoirs, and Impoundments

The San Lorenzo River watershed contains one large reservoir, Loch Lomond, that may require representation within the hydrology model, as listed in [Table 3-3](#) and shown in [Figure 3-3](#). Capturing the operation of this feature will be important to accurately represent the movement of water throughout the watershed. For example, outflow from the reservoir controls the flow of Newell Creek, which is a tributary of the San Lorenzo River, below the dam. CDEC provides daily reservoir storage and stage data from October 2021 until the present day, in addition to monthly flow data from January 2020 until the present day. Having stage-storage relationships for reservoirs such as Loch Lomond, and any other outflow rates or operating conditions at Newell Creek Dam (NID ID CA00990), will allow for more accurate model representation.

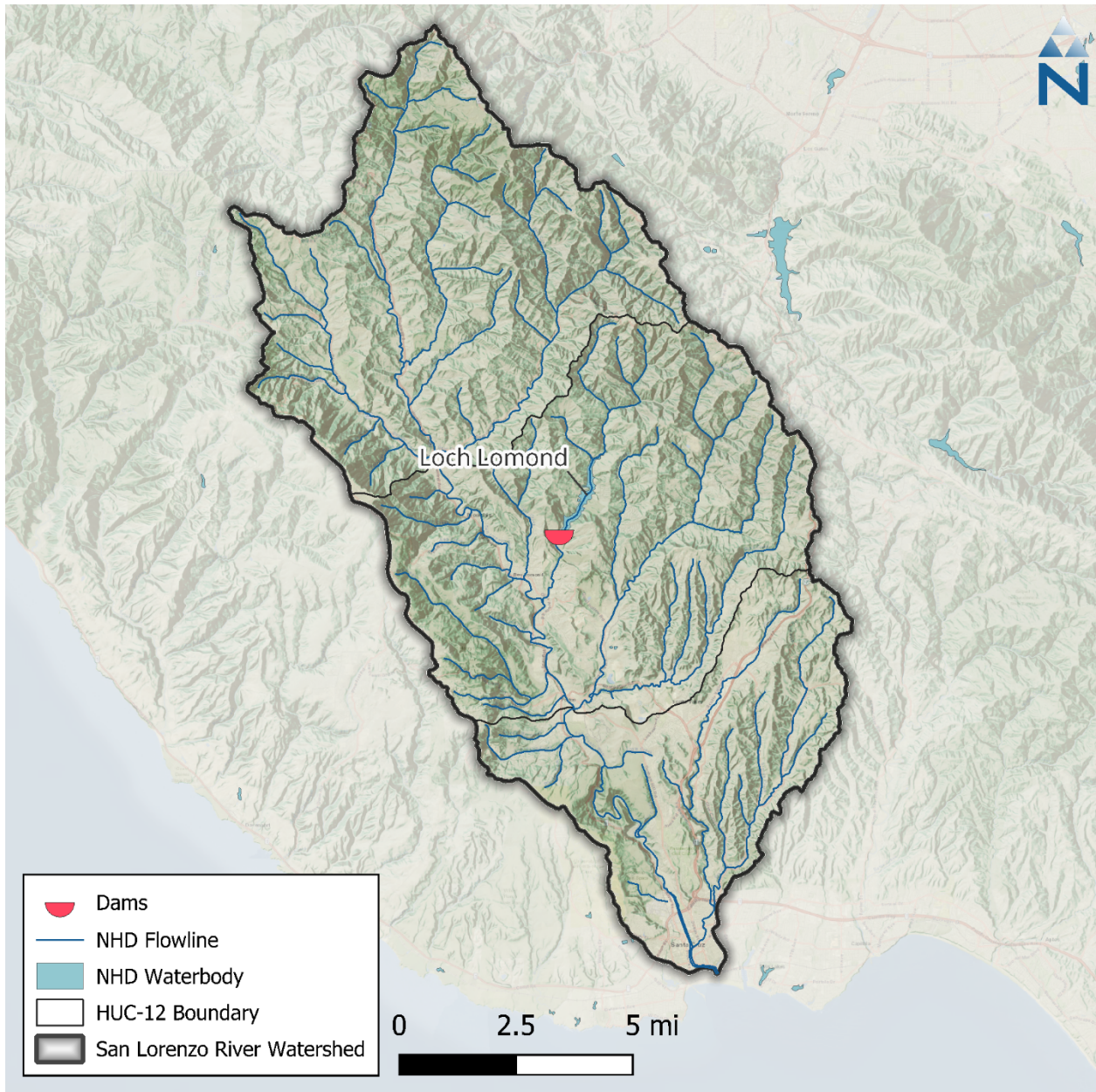


Figure 3-3. Dams within the San Lorenzo River watershed relevant for watershed modeling effort (NID 2025).

Table 3-3. Large waterbodies and dams within the San Lorenzo River watershed

Waterbody	NID ID	Drainage Area (ac)	Area (ac)	Storage Capacity (ac-ft)	Average Stage (ft)	Average Flow Volume (ac-ft)	Average Storage (ac-ft)
Loch Lomond	CA00990	5,120	172	8,991	568	0.13	7,938

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 San Lorenzo River watershed to assess the relative impacts based on observed precipitation, ET, and streamflow data. The impact of diversions or water usage may be localized along specific tributaries; however, the temporal resolution of the data determines the resolution of those impacts in the model. Additionally, the extent of modeled irrigation will depend on land-use classification, and its water usage rates will be corrected against spatial variations in the observed evaporative deficit where necessary.

[Figure 3-4](#) provides an overview of the primary drinking water sources in the watershed. Water systems distributed throughout the watershed include a mixture of both surface water diversions from the San Lorenzo River and its primary tributaries, as well as groundwater withdrawals for the San Lorenzo River watershed groundwater basin. There are 34 drinking water systems in the watershed. For 21 out of the 34 drinking water systems, the water source is listed as groundwater, and 13 have surface water listed as the source. The number of active surface water PODs and withdrawal volumes will be evaluated from eWRIMS reports during model development.

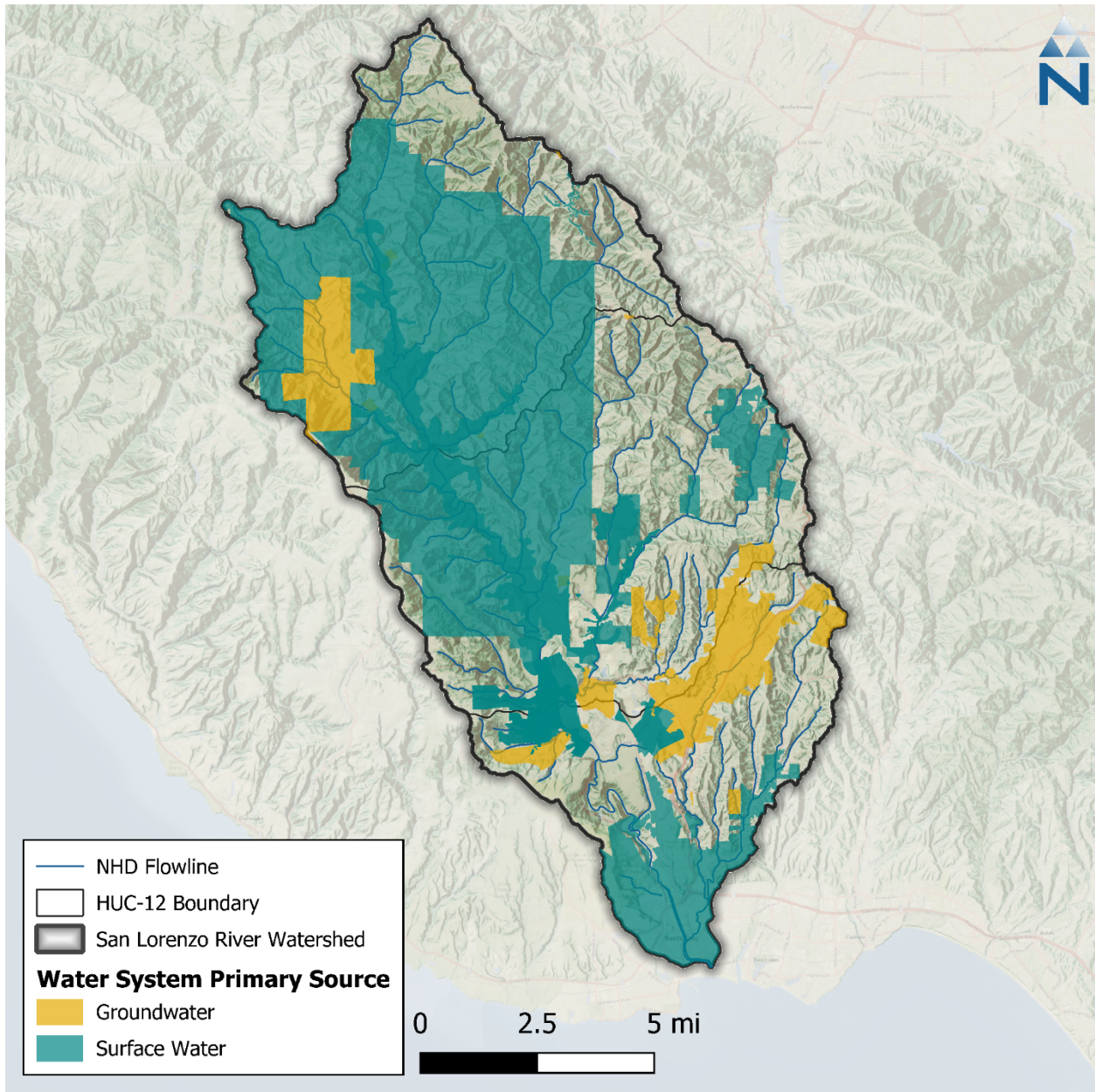


Figure 3-4. Primary Water System Sources in the San Lorenzo River watershed.

4 SUBSURFACE HYDROLOGY

The San Lorenzo River watershed contains several groundwater basins as delineated by Bulletin 118 (DWR 2020). The watershed principally overlaps with the Santa Margarita basin (number 3-027) and partly overlaps with three additional basins: the West Santa Cruz Terrace (number 3-026), the Santa Cruz Mid-County basin (number 3-001) and the Corralitos-Purisima Highlands basin (number 3-002.02). The watershed does not fully contain any basins. Approximately 36% of the watershed area falls within the groundwater basins delineated by Bulletin 118 and the remaining 64% consists of metamorphic and granitic bedrock.

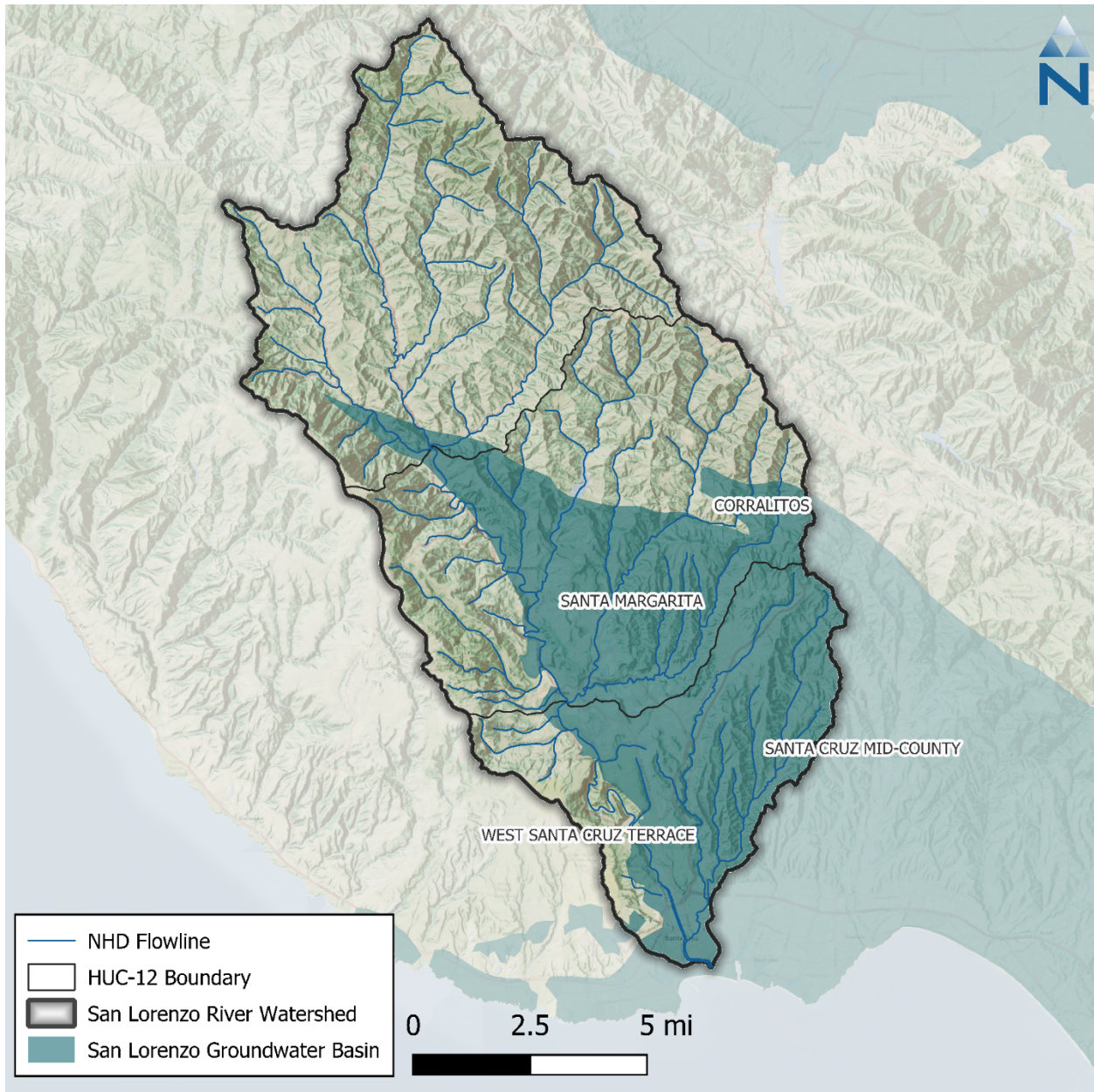


Figure 4-1. Groundwater basins delineated by DWR (2020), also known as Bulletin 118.

As per the respective basin priority details ([Sustainable Groundwater Management Act \(SGMA\) Basin Prioritization Dashboard](#)), the overlapping basins have a variety of prioritizations as designated by the Sustainable Groundwater Management Act’s (SGMA) basin prioritization. The Santa Margarita basin is Medium priority due to declining water levels and a large number of water supply and total wells, with the majority of the basin boundary encompassed by the San Lorenzo River watershed. Although the West Santa Cruz Terrace has documented groundwater declines and saltwater intrusion, it is prioritized as Very Low priority due to a total groundwater use less than 2,000 ac-ft/year. Approximately half of the West Santa Cruz Terrace basin area lies within the San Lorenzo River watershed. The Santa Cruz Mid-County basin is High priority due to a critical overdraft classification, with high groundwater use and declining groundwater levels. The Corralitos-Purisima Highlands basin is Very Low priority. Only small portions of the Santa Cruz Mid-County and the Corralitos-Purisima Highlands basins are within the watershed boundary.

Four Groundwater Sustainability Agencies (GSAs) overlap the San Lorenzo River watershed. The Santa Margarita GSA operates within the Santa Margarita basin, the County of Santa Cruz – West Santa Cruz Terrace GSA operates within the West Santa Cruz Terrace basin, the Santa Cruz Mid-County GSA operates within the Santa Cruz Mid-County basin, and the County of Santa Cruz – Purisima Highlands GSA operates within the Corralitos- Purisima Highlands basin.

4.1 Water Budget Components

No publicly available groundwater models focusing on the San Lorenzo River basin were located. Bulletin 118 reports for the Santa Margarita Valley basin relied on a 1956 study to estimate that groundwater extraction in 1953 was about 7,070 ac-ft, with replenishment through percolation of streamflow the same year estimated as 6,300 ac-ft. None of the USGS public domain models for Northern California (USGS 2024) overlap the San Lorenzo River basin.

4.2 Geology

The foregoing references provide coverage primarily within the groundwater basins delineated as per Bulletin 118. The water bearing unit within the Santa Margarita Valley consists mainly of Quaternary deposits, with water also extracted from fractured bedrock. The Santa Margarita valley is bordered by the Quaternary-era Zayante fault to the northeast and the pre-Quaternary Ben Lomond fault to the west (USGS 2000 and 2017; CA DOC 2025). Outside the delineated basins, formations include Oligocene-age Vaqueros Sandstone and San Lorenzo formation, shown by the California Geological Survey in their 1991 regional San Francisco/San Jose map (CA Mines 1991). As shown by the fault map on the California Geological Survey website, multiple faults cross the area outside the delineated basins (CA DOC 2025). The Bulletin 118 delineations do not account for any potential sources of ‘non-basin’ water within weathered bedrock formations, fractures, or other void spaces outside or underneath the designated basins.

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 San Lorenzo River watershed.

5.1 Elevation & Slope

The USGS publishes DEMs expressing landscape elevation through a raster grid data product with 30-meter resolution. The San Lorenzo River watershed ranges in elevation from near sea level at the outlet of the watershed to over 980 meters in the north. 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 San Lorenzo River watershed.

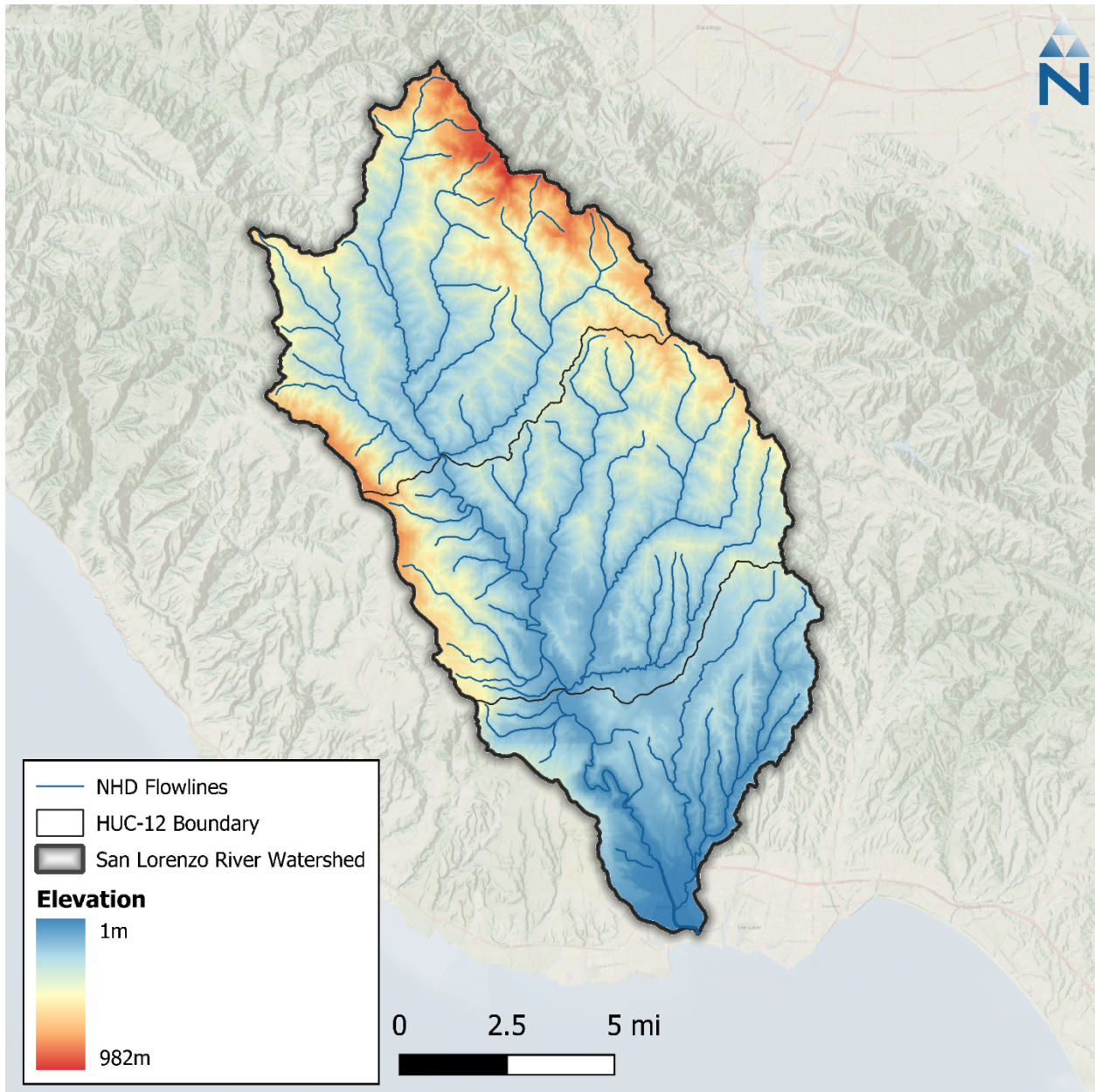


Figure 5-1. DEM of the San Lorenzo River watershed.

5.2 Soils & Geology

Soils data for the San Lorenzo River 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 San Lorenzo River watershed. The dominant soil group in the watershed is Group B (33%) and contains moderately well to well-drained silt loams and loams. Group A makes up 26% of the watershed and contains well-draining sand, loamy sand, and sandy loam. Group C makes up 22% of the watershed and contains sandy clay loam with typically low infiltration rates. 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 nearly 17% of the watershed. There are no mixed soils within the San Lorenzo watershed. Finally, approximately 1% 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 San Lorenzo River watershed

Hydrologic Soil Group	Area (acres)	Percent Area
A	23,060.39	26.45%
B	29,182.64	33.48%
C	19,596.15	22.48%
D	14,471.85	16.60%
N/A	858.92	0.99%
Total	87,169.95	100.00%

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

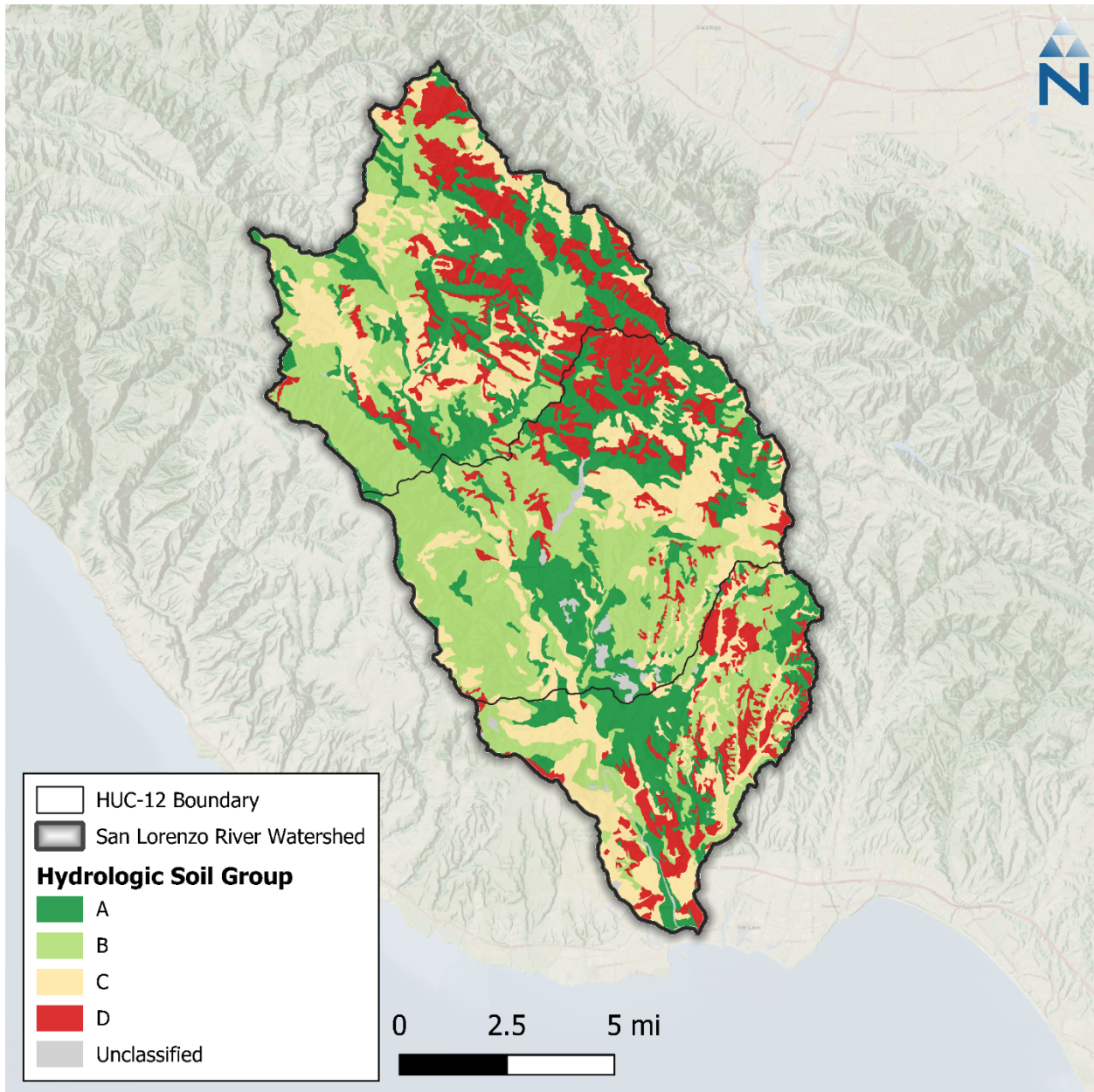


Figure 5-2. SSURGO hydrologic soil groups within the San Lorenzo River watershed.

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 San Lorenzo River watershed and [Figure 5-3](#) shows the spatial distribution of these classifications. Evergreen forest is the dominant land cover classification covering approximately 55% of the watershed area. When combined, evergreen forest, the undeveloped categories of deciduous forest, mixed forest, shrub/scrub, and grassland/herbaceous account for approximately 80% of the total watershed area. Developed land cover makes up approximately 19% 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 San Lorenzo River watershed

NLCD Class	Classification Description	Area (acres)	Percent
11	Open Water	167.03	0.19%
21	Developed, Open Space ¹	12,167.45	13.95%
22	Developed, Low Intensity ¹	2,334.25	2.68%
23	Developed, Medium Intensity ¹	1,757.20	2.01%
24	Developed, High Intensity ¹	518.92	0.59%
31	Barren Land (Rock/Sand/Clay)	206.23	0.24%
41	Deciduous Forest	8.24	0.01%
42	Evergreen Forest	48,385.17	55.46%
43	Mixed Forest	10,872.82	12.46%
52	Shrub/Scrub	850.32	0.97%
71	Grassland/Herbaceous	9,816.05	11.25%
81	Pasture/Hay	0.22	0.00%
82	Cultivated Crops	7.13	0.01%
90	Woody Wetlands	127.84	0.15%
95	Emergent Herbaceous Wetlands	31.85	0.04%
TOTAL²		87,250.72	100%

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 80 acres more than the model domain.

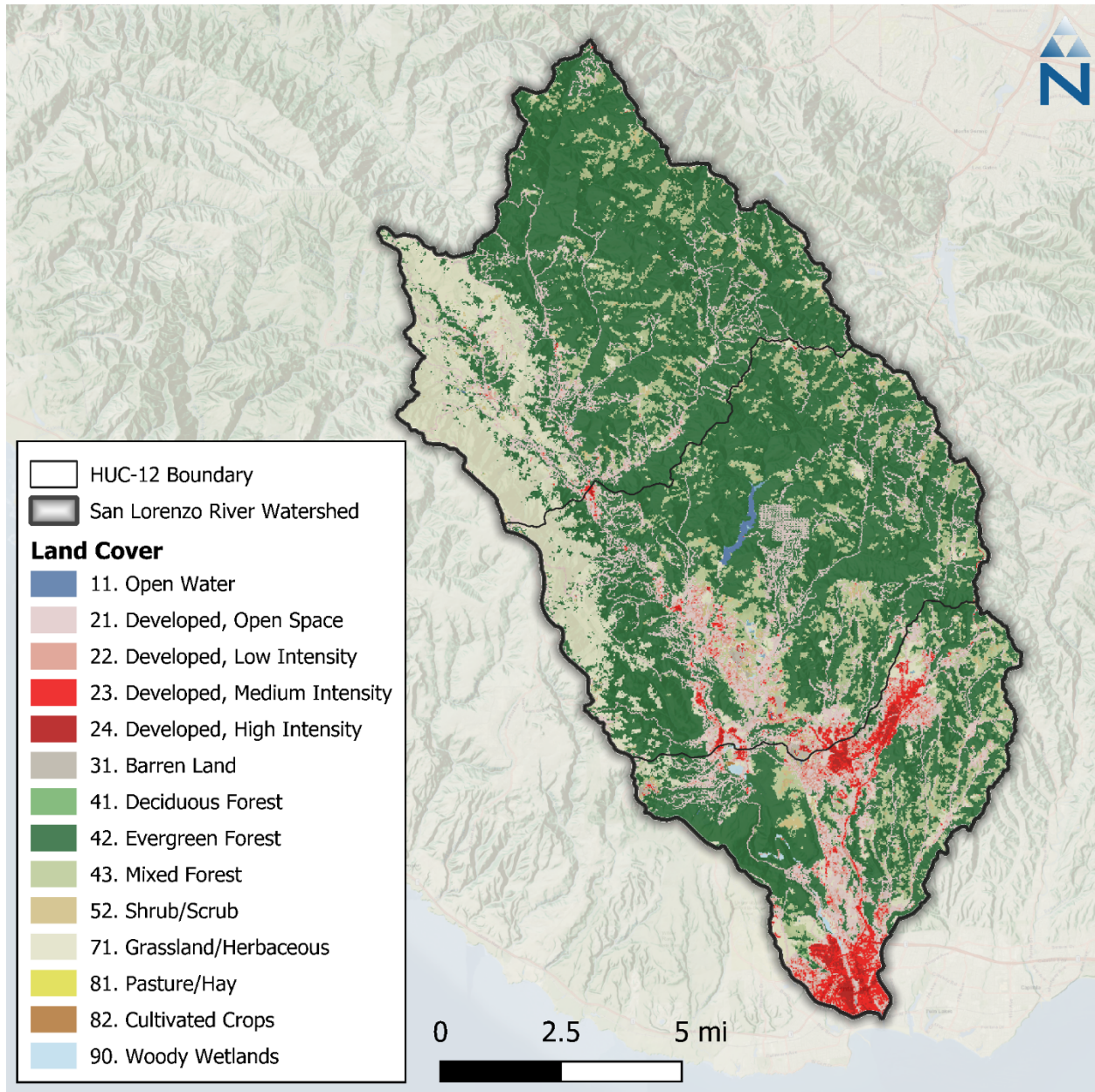


Figure 5-3. NLCD 2021 land cover within the San Lorenzo River watershed.

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 San Lorenzo watershed using this dataset shows that just over 19% 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 and low intensity development make 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 San Lorenzo River 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 San Lorenzo River watershed, an average of 62% 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 San Lorenzo River Watershed (see Section [5.3](#)) was analyzed to identify predominant cropland vegetation classes. This analysis revealed that less than 0.01% of the San Lorenzo River watershed area is classified as Pasture/Hay (class 81) and just over 12% 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.

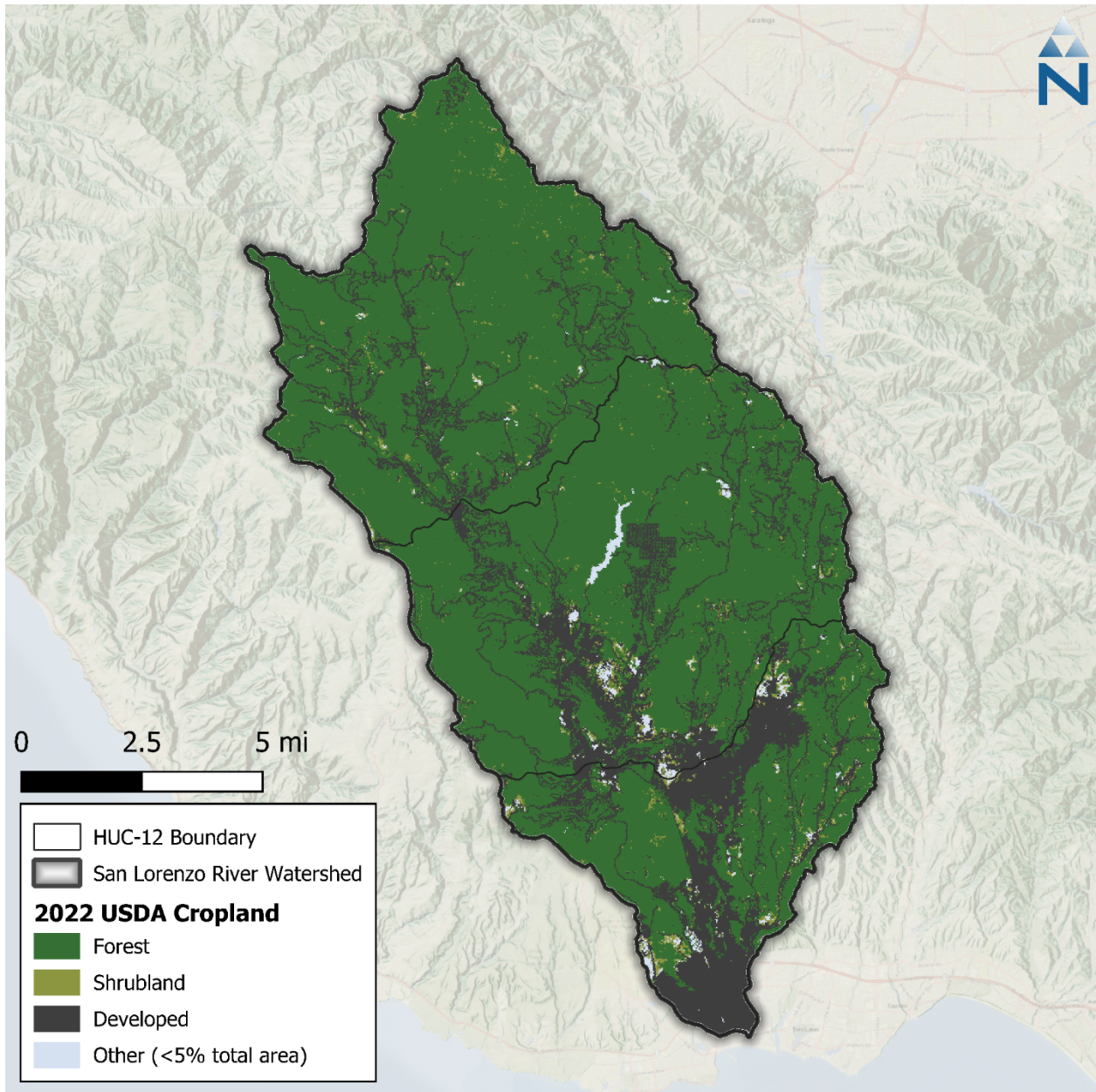


Figure 5-4. USDA 2022 Cropland Data within the San Lorenzo River watershed.

Table 5-4 USDA 2022 Cropland Data summary within the San Lorenzo River watershed

Crop Type	Area (ac)	Area (%)
Forest	67,743.12	77.64%
Shrubland	1,763.44	2.02%
Developed	16,782.94	19.24%
Other (<5% Total Area)	959.45	1.10%
Totals	87,248.94	100.00%

6 DATA GAPS AND LIMITATIONS

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

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

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 n(LACFCD 2020; LARWQCB 2010, 2012, 2013a, 2013b, and 2015; LARWQCB and USEPA 2005, 2006, and 2011; Tariq et al. 2017), the San Jacinto River watershed in the Santa Ana Region (SAWPA 2003 and 2004), and most coastal watersheds of the San Diego Region (City of San Diego and Caltrans 2016; City of Vista 2008; Los Peñasquitos Responsible Agencies 2015; San Diego Bay Responsible Parties 2016; SDRWQCB 2008, 2010, and 2012). These efforts have included comprehensive peer review processes and public comment, requiring demonstration of model accuracy based on standard practices for quantifying and documenting model performance. All the modeling documentation and reports cited here have withstood peer review and have supported amendments to Water Quality Control Plans or the approval of watershed plans submitted to the Water Board or Regional Water Quality Control Boards to demonstrate regulatory compliance. Additionally, the Water Board recently utilized LSPC to perform hydrology analyses within the South Fork Eel River and Shasta River watersheds (SWRCB 2021 and 2022).

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 San Lorenzo River 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 San Lorenzo River 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 San Lorenzo River 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 San Lorenzo River watershed.

Table 9-1. Proposed schedule and summary of deliverables

Task	Subtask	Deliverable	Due Date
2	2.2	Draft Work Plan	5/2/2025
	2.3	Final Work Plan	Two (2) weeks after receiving comments
3	3.1	Subbasin delineation and stream GIS files	Two (2) weeks after completing Task 2.3
	3.2	LSPC database, model inputs, and GIS files ¹	Twelve (12) weeks after completing Task 3.1
4	4.1	Draft Calibration Slide Deck	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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