Work Plan: Napa River Watershed Hydrology Model Development

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ACRONYMS

3DEP	3D Elevation Program
AET	Actual evapotranspiration
AGLW	Agricultural Land use & Water Use
ASCE-PM	American Society of Civil Engineers version of the Penman-Monteith equation
CA DWR	California Department of Water Resources
CAL FIRE	California Department of Forestry and Fire Protection
CASGEM	California Statewide Groundwater Elevation Monitoring Program
CA-WRCB	California Water Resource Control Board
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
DEM	Digital Elevation Model
DWR	California Department of Water Resources
EOL	Earth Observing Laboratory
ESU	Evolutionary Significant Unit
ET	Evapotranspiration
ET_0	Reference evapotranspiration
eWRIMS	Electronic Water Rights Information Management System
FEMA	Federal Emergency Management Agency
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
GSP	Groundwater Sustainability Plan
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
NAPA GSA	Napa Valley Groundwater Sustainability Agency
NCDC	National Climatic Data Center
NHD	National Hydrography Dataset
NLCD	National Land Cover Database

NLDAS	North American Land Data Assimilation System
NMFS	National Marine Fisheries Service
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
STATSGO	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 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 Napa 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 Napa River is one of the major tributaries to the San Pablo and San Francisco Bays. The Napa River watershed is part of the San Pablo Bay drainage area, which shares a boundary with the Russian watershed to the west, Upper Putah watershed to the north-east, and Suisun Bay watershed to the east. The non-estuarine watershed area drains approximately 283 square miles and is made up of two main catchments: the Napa River (HUC-10: 1805000202) and its major tributary, Conn Creek (HUC-10: 1805000201) (Figure 1-1). The Napa River originates as Kimball Creek just south of Mount St. Helena and then flows south-east through the Napa Valley. The river is joined by Conn Creek near Yountville before flowing approximately 11 miles to the City of Napa and the limits of tidal influence at the beginning of the Napa-Sonoma Marshes.

The Napa River watershed ranges in elevation from near sea level in the City of Napa to over 1,200 meters at the northern most portion of the watershed near Mount St. Helena. The watershed has a Mediterranean climate with distinct wet and dry seasons with a mean annual precipitation total of 36.4 in. (USGS 2019). The valley floor of the watershed is dominated by agriculture and development, which cover approximately 15% and 11% of the total area, respectively. Beyond the valley floor, the watershed is predominantly grassland (33%), shrubland (20%), or forest (20%).

The Napa River watershed represents an important habitat for native aquatic species and spawning ground for anadromous fish, especially chinook salmon and steelhead trout. However, there have been substantial declines in salmonid populations over time; coho were once present but extirpated in the late 1960s (Napa County Watershed Information and Conservation Council 2023). The decline in anadromous fish populations within the Napa River watershed was linked to an increase in sediment delivery and other factors including stream temperatures above that which supports salmonid life and low dry season flows (Stillwater Sciences and Dietrich 2002). These factors led to the development of a Total Maximum Daily Load (TMDL) for sediment in 2009 (Stillwater Sciences 2013) and implementation of the Napa River and Sonoma Creek Vineyard General Permit Program (San

Francisco Bay Regional Water Quality Control Board 2022) to control erosion and manage stormwater runoff.

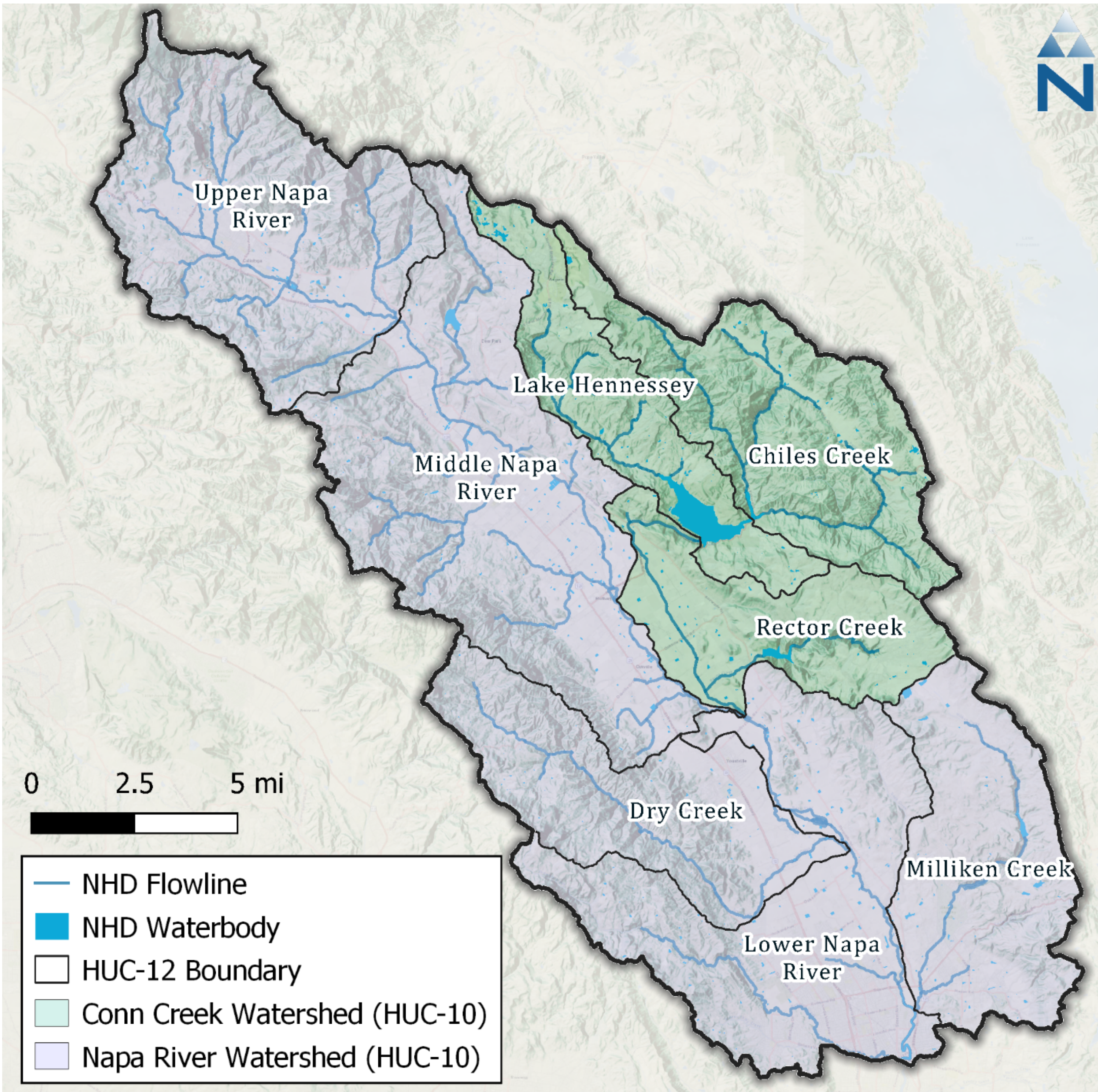

Figure 1-1. The Napa River watershed.

1.3 Leveraging Previous Modeling Efforts

The San Francisco Estuary Institute (SFEI) has performed hydrologic model development in the San Francisco Bay drainage area, which includes the Napa River watershed (Zi et al. 2021 and 2022). Figure 1-2 shows the location of the Napa River watershed within the larger extent of the SFEI model domain. SFEI's modeling work utilizes the Loading Simulation Program in C++ (LSPC) for long term continuous simulation with the objective of supporting management decisions regarding stormwater runoff and pollutant loads including mercury, PCBs, and sediment (Shen et al. 2005). This model was constructed at the regional scale to address San Francisco Bay-wide pollutant loading issues; therefore, the focus of model configuration and calibration differs slightly from the needs of this Napa River watershed-specific hydrologic study.

As part of the screening process of available data, the Napa River subset of the SFEI model was assessed to see how it could be used to support modeling for this study. Overall, the existing model offers a strong foundation, however, certain elements of that model will need some modifications to address the hydrology simulation accuracy and water budgeting needs of this project. Section 7.2 provides additional discussion on proposed modifications to the SFEI model for this project.

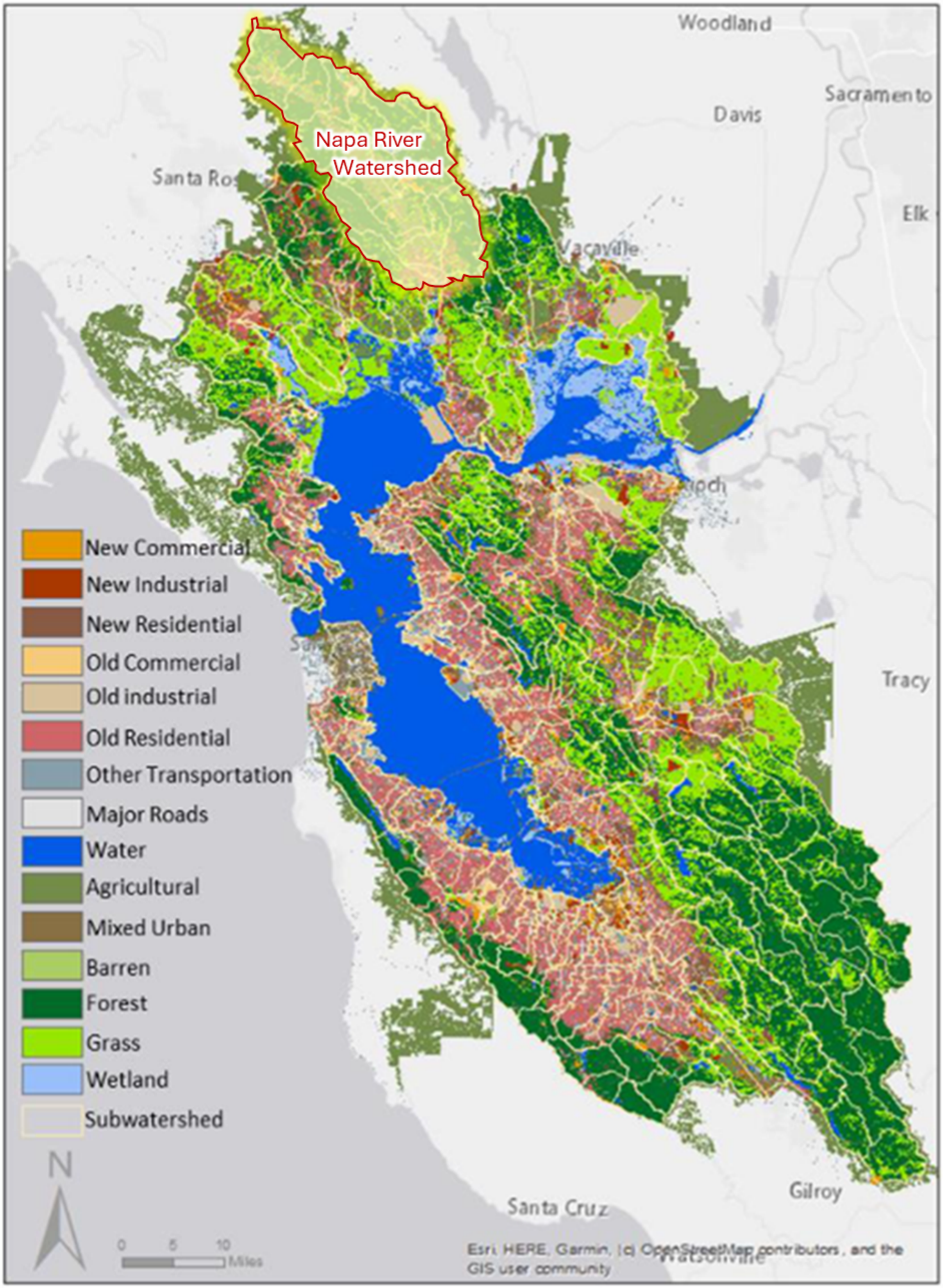

Figure 1-2. Map of the SFEI regional model domain, which includes the Napa River watershed (Zi et al. 2021).

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 Napa River watershed. This is presented first through a comprehensive inventory of available hydrologic, meteorological, and geographic information system (GIS) data available for the Napa 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 1-3 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.

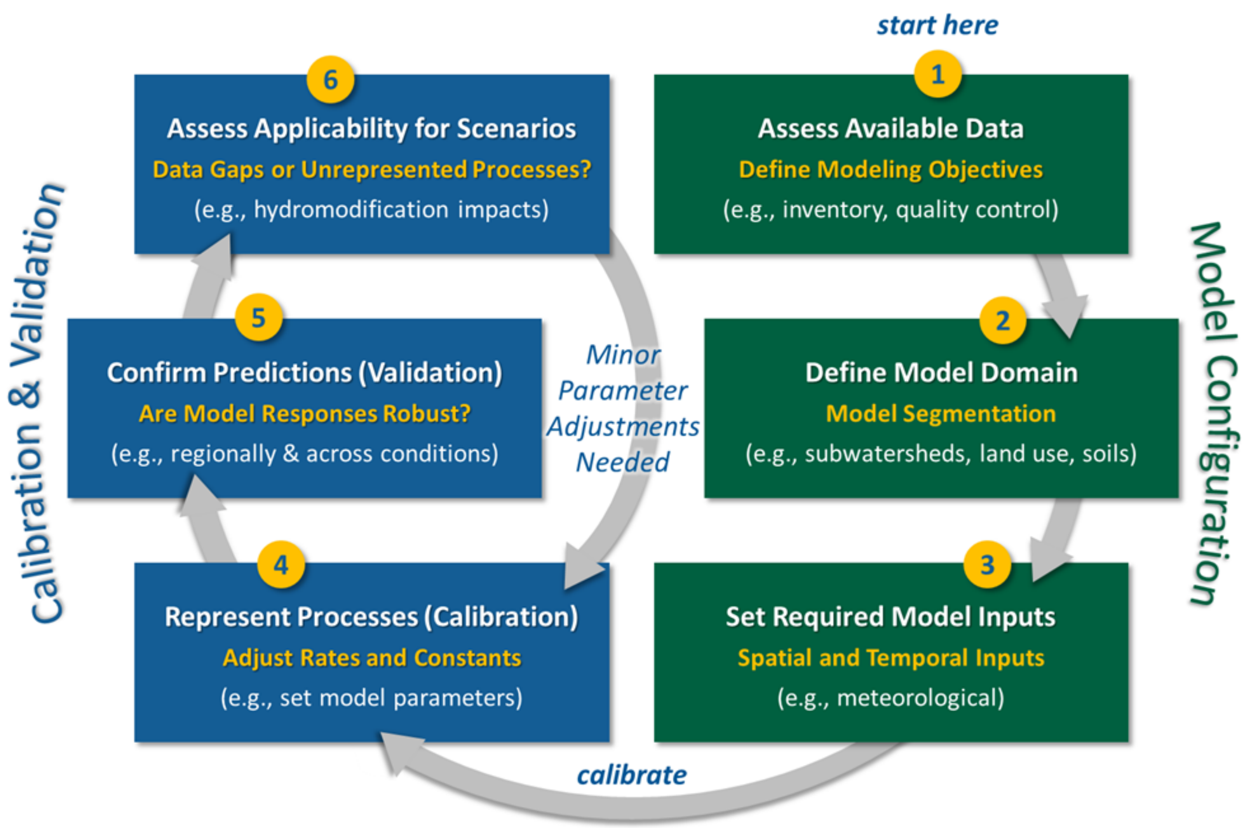

Figure 1-3. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Napa River watershed.

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 is organized by data type including:

- **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 Napa River. Time series observations of instream responses for the Napa River are often used as calibration and validation datasets for hydrologic models.
- **Geospatial Datasets**: Spatial datasets describing the landscape of the Napa River watershed. These datasets include physical properties (e.g., soils, land cover, elevation).

Each of these types of datasets is described in the sections below.

Table 1-1. Inventory of meteorology datasets

Data Source	Data Set	Data Date	Description	Model Use
National Climatic Data Center (NCDC)	Global Historic Climate Network (GHCN)	--	Daily precipitation and temperature data (varied data quantity/quality).	Rainfall input boundary time series.
National Climatic Data Center (NCDC)	Local Climate 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 for Atlas Peak.	Climate data boundary time series.
California Data Exchange Center (CDEC)	Precipitation, Temperature	--	Meteorological records available for 3 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 evapotranspiration 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 Evapotranspiration	2016 - 2024	Satellite-based estimates (30-m res) of observed monthly evapotranspiration 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	Data Source	Data Set	Data Date	Description	Model Use	Link
Streamflow	Local	USGS	Stream Gage Discharge	1929 – Current	Observed Streamflow at two active locations on the Napa River.	Hydrology calibration.	LINK
Habitat	Local	CDFW	Napa River Sediment TMDL Monitoring Program: Summary Report of Pilot Implementation.	2013	Report that documents salmonid habitat and stream conditions under the sediment TMDL.	Hydrology calibration & validation.	LINK
Water Budget	State	CA DWR	Well Completion Reports	Current	Well completion logs and reports.	Water budget.	LINK
			Interconnected Surface Water	2008	Two (2) river flow CDEC stations and six (6) rain CDEC stations identified as interconnected.		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
		CA 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 Locations	2023	Public California drinking water systems and state small drinking water system boundaries and information.		LINK

Table 1-3. Inventory of geospatial datasets

Category	Scale	Data Source	Data Set	Data Date	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 (gSSURGO)	2022	State-wide, 10-meter raster grid approximating the SSURGO 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
			National Land Cover Dataset (NLCD) Imperviousness All Years	2021	Broad, 30-meter grid-based land characterization. Represent percent impervious area within raster cells.		LINK
Land Use	State	CA DWR	Statewide Crop Mapping	2020	Polygons attributed with 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

Category	Scale	Data Source	Data Set	Data Date	Description	Model Use	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
Timber Harvesting	State	CAL FIRE	CAL FIRE Nonindustrial Timber Management Plans TA83	1991 - Present	Timber management plans.	Representing changes in land cover due to timber harvest activities.	LINK
Timber Harvesting	State	CAL FIRE	CAL FIRE Notices of Timber Operations TA83	1991 - Present	Notice of Timber Operations accepted by CAL FIRE.	Representing changes in land cover due to timber harvest activities.	LINK
Timber Harvesting	State	CAL FIRE	CAL FIRE Working Forest Management Plans TA83	2019 - Present	Working forest management plans approved by CAL FIRE.	Representing changes in land cover due to timber harvest activities.	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
Fire Perimeters & Burn Areas	State	CAL FIRE	Prescribed Burns	1950 - Present	Prescribed burns 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 digital elevation model (DEM) produced through the 3D Elevation Program (3DEP).	Land segment representation.	LINK

Table 1-4. Inventory of groundwater datasets

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

2 METEOROLOGY

Precipitation and evapotranspiration (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 evapotranspiration.

2.1 Precipitation

The primary source of precipitation data for the Napa River 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 has shown promising results by leveraging the strengths of both land-based and grid-based data. Use of a hybrid approach preserves locally sampled gauge 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 mainly acquired from the National Climatic Data Center (NCDC) maintains 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 eight GHCN Co-Op, CoCoRaHS, or other NOAA gauges identified near the Napa River watershed. These gauges all have data with varied quantity and quality. In addition to the daily precipitation gauges, NCDC also maintains the Local Climatological Data (LCD) network. There is one LCD station with hourly observations located at the Napa County Airport approximately 1.5 miles south of the HUC-10 boundary. The California Data Exchange Center (CDEC) and Remote Automated Weather Stations (RAWS) networks also report hourly precipitation within the watershed. CDEC reports at two locations and RAWS reports at eight locations. Table 2-1 is an inventory of the precipitation stations near the Napa River watershed with available data after 2000 and around 90% completeness or better; Figure 2-1 shows the location of the stations proposed for model development in Table 2-1.

The primary source of the grid-based data for Napa River Watershed will be the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al. 2008; Daly, Neilson, and Phillips 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.

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

Agency	Station ID[1]	Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Data Coverage (%)[2]
NOAA-LCD	WBAN:93227	NAPA CO AIRPORT, CA US	12/31/1999	Present	38.2075	-122.28	4.7	100%
NOAA-GHCN	GHCND:USW 00093227	NAPA CO AIRPORT, CA US	5/21/1998	Present	38.2075	-122.28	4.7	100%
	GHCND:USC 00046074	NAPA STATE HOSPITAL, CA US	12/31/1892	Present	38.2777	-122.265	10.7	94%
CDEC	ANG	ANGWIN	1/1/1987	Present	38.5712	-122.433	1815	--
	SH4	ST. HELENA 4WSW	1/2/1984	Present	38.4931	-122.54	1729	--
RAWS	ATLC1	ATLAS PEAK	12/1/2011	Present	38.4749	-122.265	1934	--
	QSHC1	SRFD HARVILLE ROAD	9/1/2022	Present	38.4903	-122.661	420	--
	QSWC1	SRFD WHITE OAK DRIVE	9/1/2022	2/1/2024	38.4217	-122.599	1110	--

1. Stations presented have at least 90% data coverage.

2. NCDC and NOAA data coverage as reported; CDEC and RAWS estimated based on data flagging and count of time steps. Data completeness will be further assessed under Task 3.2 and additional stations may be considered as required.

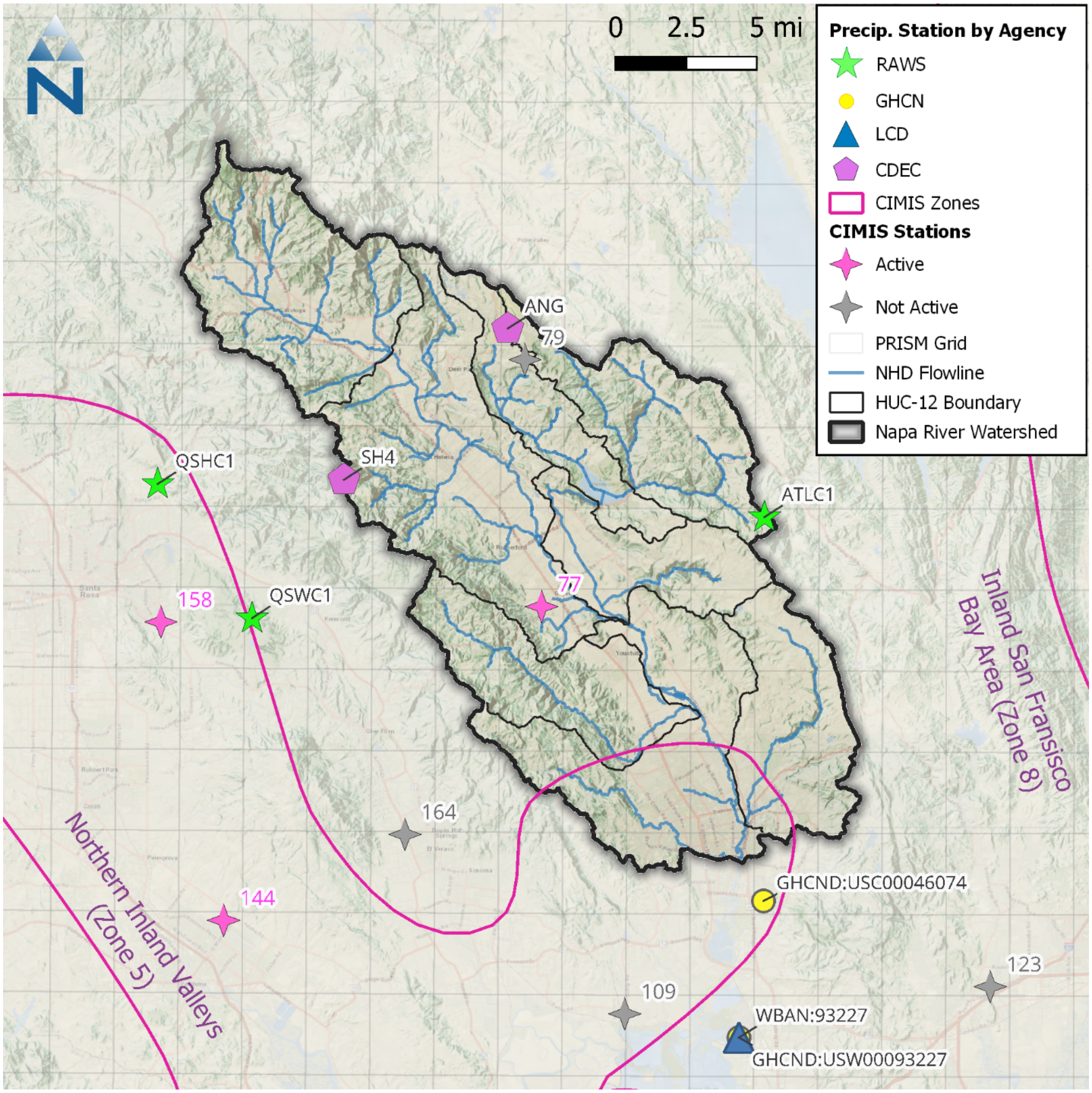

Figure 2-1 Identified rainfall gauges and CIMIS ET Zones near the Napa River watershed. Note that the Napa County Airport LCD station is located just south of the map extent.

The hybrid approach entails three main steps. First, impaired intervals (i.e., missing, or accumulated) at observed stations will be patched with quality data from nearby gauges. Second, observed gages are mapped to the nearest PRISM grid cell and temporally complete hourly observed data distributions will be used to downscale the monthly PRISM gridded data. The resulting set of gridded precipitation time series reflect monthly PRISM totals that have hourly distributions from the nearest observed gage. If the number of sub-daily time series from observed data are limited, hourly data from North American Land Data Assimilation System (NLDAS) will be used to supplement observed distributions for downscaling the PRISM data. Third, the downscaled gridded meteorological data from the PRISM are used to fill spatial gaps in the observed station network as needed. It should be noted that while PRISM gridded data also provides estimates of precipitation on daily time step, using monthly PRISM totals for downscaling 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 downscaled gridded data. Assuming a 10-km buffer around observed gauges 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.

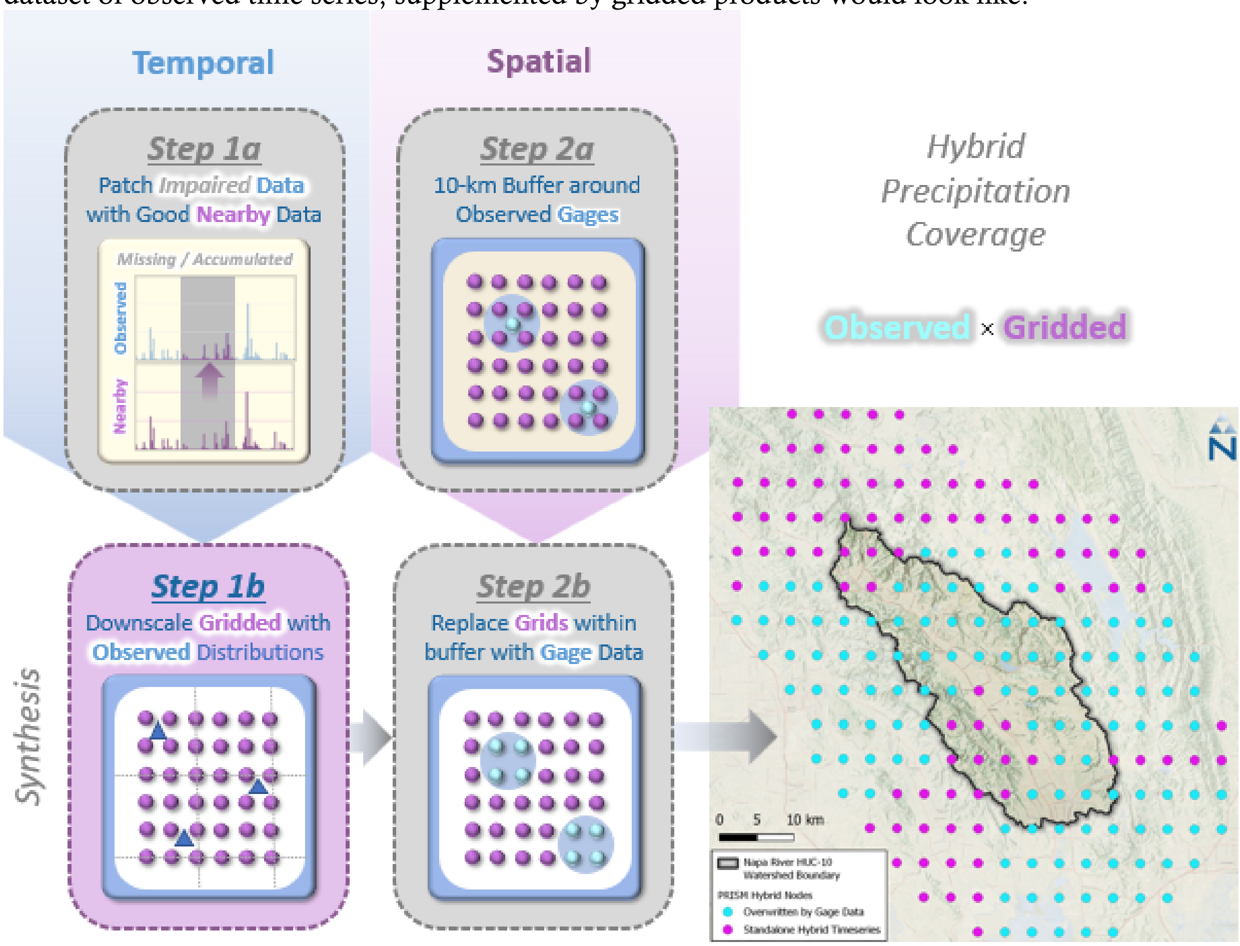

Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products.

2.2 Evapotranspiration

The primary evapotranspiration dataset identified for consideration is the California Irrigation Management Information System (CIMIS) (CA DWR 1982). 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.

CIMIS operates six stations within ten miles of the Napa River watershed, including: Oakville (ID 77), Bennett Valley (ID 158), Angwin (ID 79), Valley of the Moon (ID 164), Carneros (ID 109), and Suisun Valley (ID 123). The Angwin, Valley of the Moon, Carneros, and Suisun Valley stations past the southern end of the watershed are no longer operating, but their collective historical time series data covers the period from May 1989 through January 2022. Of the active stations within the 10-mile watershed buffer, the Oakville gage is within the central watershed region and contains data from March 1989 through the present, and the Bennett Valley gage is slightly west of the watershed region and contains data from October 2000 through the present. There are also five active gauges (103, 83, 187, 139) and two inactive gauges (51 and 63) situated just outside the 10-mile watershed buffer.

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) (ASCE 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. As shown in Figure 2-1, the Napa River watershed intersects two CIMIS zones with 91% of the watershed area in Zone 8 (Inland San Francisco Bay Area), and 9% of the watershed area in Zone 5 (Northern Inland Valleys). Most of the Napa River watershed falls within Zone 8, and the southern end of the watershed falls into Zone 5. These zones experience average annual reference evapotranspiration levels from 43.9 inches per year in Zone 5 to 49.4 inches per year in Zone 8.

Representative potential evapotranspiration (PEVT) time series can be estimated for the Napa River watershed from daily data from CIMIS Spatial and downscaling the hourly time series using hourly distributions from land observation stations (e.g., RAWS, NCDC) or hourly distributions from the North American Land Data Assimilation System (NLDAS). 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 gauges (Xia et al. 2012). Potential evapotranspiration 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 downscaling 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 agricultural practice, 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 evapotranspiration.

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.

In the SFEI LSPC model for Napa Valley, PEVT is represented using NLDAS and no irrigation is represented in the model. To assess performance of this model, simulated ET was compared to the model input PEVT timeseries, CIMIS Zone 8 observed ET_0, and gridded ET estimates from OpenET for the years 2016-2020. Figure 2-3 summarizes the distribution of spatial and temporal variation of monthly ET for these datasets (except for the CIMIS dataset, which shows the spatial-temporal average of Zone 8).

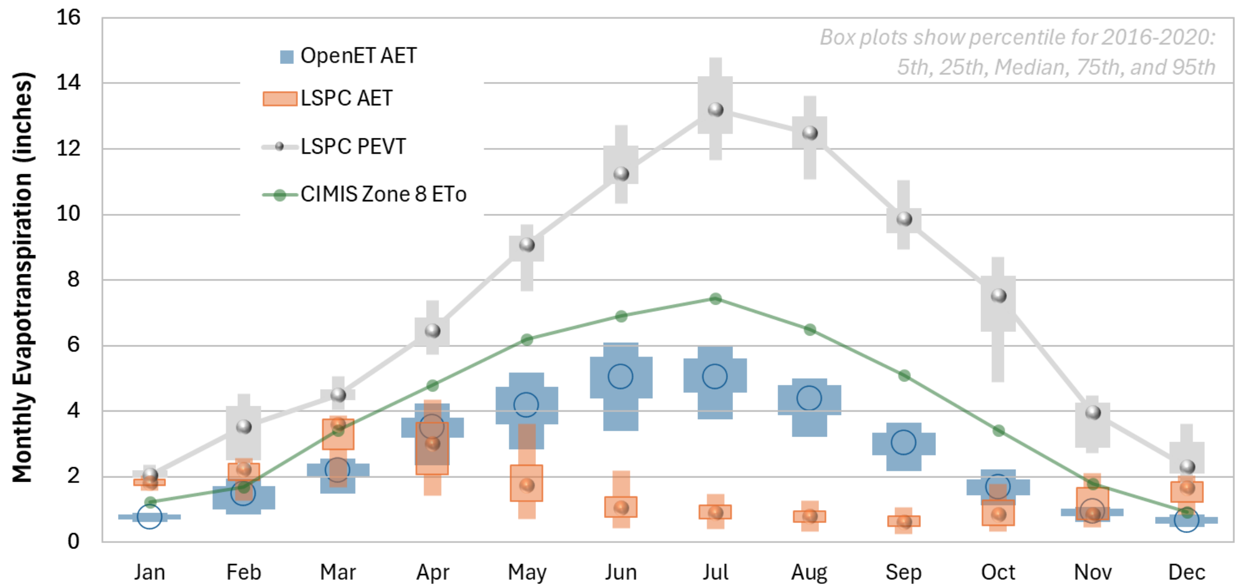

Figure 2-3 Evaluation of monthly evapotranspiration in existing SFEI model. Note that AET is used as an abbreviation for actual ET.

This analysis yielded three key findings for the SFEI model:

1. Modeled input for PEVT based on NLDAS is significantly greater than observed ET_0 from CIMIS.
2. During non-growing season months, modeled ET has a positive bias relative to ET from OpenET. This indicates overestimation of the system energy balance.
3. During growing season months, modeled ET is significantly lower than observed ET from OpenET. Given the extent of agricultural practice in Napa Valley, without including irrigation in the model, along with any necessary adjustments to subsurface storage, there is not enough water available to make up for this deficit, which could then result in misleading inferences about the overall hydrologic budget.

Enhancing PEVT accuracy and integrating Napa Valley irrigation rates are critical steps to improve ET predictions and representation of the overall hydrologic budget. The existing PEVT dataset used in the model (from NLDAS) results in overestimated rates of simulated ET compared to in situ observations (Xia et al. 2015). To remove this positive bias and smooth diurnal cycles of ET, the hourly sinusoidal distribution of NLDAS short-wave radiation would be used to disaggregate daily ET0 from CIMIS Zone 8. The disaggregated ET0 CIMIS data could then be used as PEVT input data to the model. Additionally, irrigation water usage should be represented with observed rates where data are available. The observed irrigation rates should be evaluated against estimated monthly irrigation derived by calculating differences in observed ET (OpenET) and model-simulated AET with irrigation turned off.

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 hydrologic unit codes (HUC). These HUCs have a varying number of digits to denote scale ranging from 2-digit HUCs (larges) at the region scale to 12-digit HUCs (smallest) at the subwatershed scale. The Napa River watershed is defined by a HUC-10 watershed that comprises 8 HUC-12 subwatersheds.

For units smaller than HUC-12 subwatersheds, catchment and tributary boundaries, flow lines, outlet points and related attribute information will rely on the National Hydrography Dataset (NHD) hydrologic unit code (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 293 catchments ranging in size between 0.2 acres to approximately 9 square miles. 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 Napa River watershed (HUC-10).

Table 3-1. Summary of NHDPlus catchment sizes (acres) within the Napa River HUC-10

HUC-12 Name	Count	Catchment Size (acres)			
		Minimum	Mean	Median	Maximum
Chiles Creek	37	82.7	817.8	723.0	2,161.9
Middle Napa River	71	0.2	950.8	605.6	5,841.2
Milliken Creek	28	2.9	970.7	960.0	3,102.2
Rector Creek	38	7.8	991.6	637.5	5,841.2
Upper Napa River	38	4.7	918.5	752.4	3,163.1
Lower Napa River	44	11.8	1,222.6	900.5	5,751.3
Lake Hennessey	44	4.7	843.7	599.2	5,841.2
Dry Creek	30	122.8	1,208.2	688.3	5,751.3

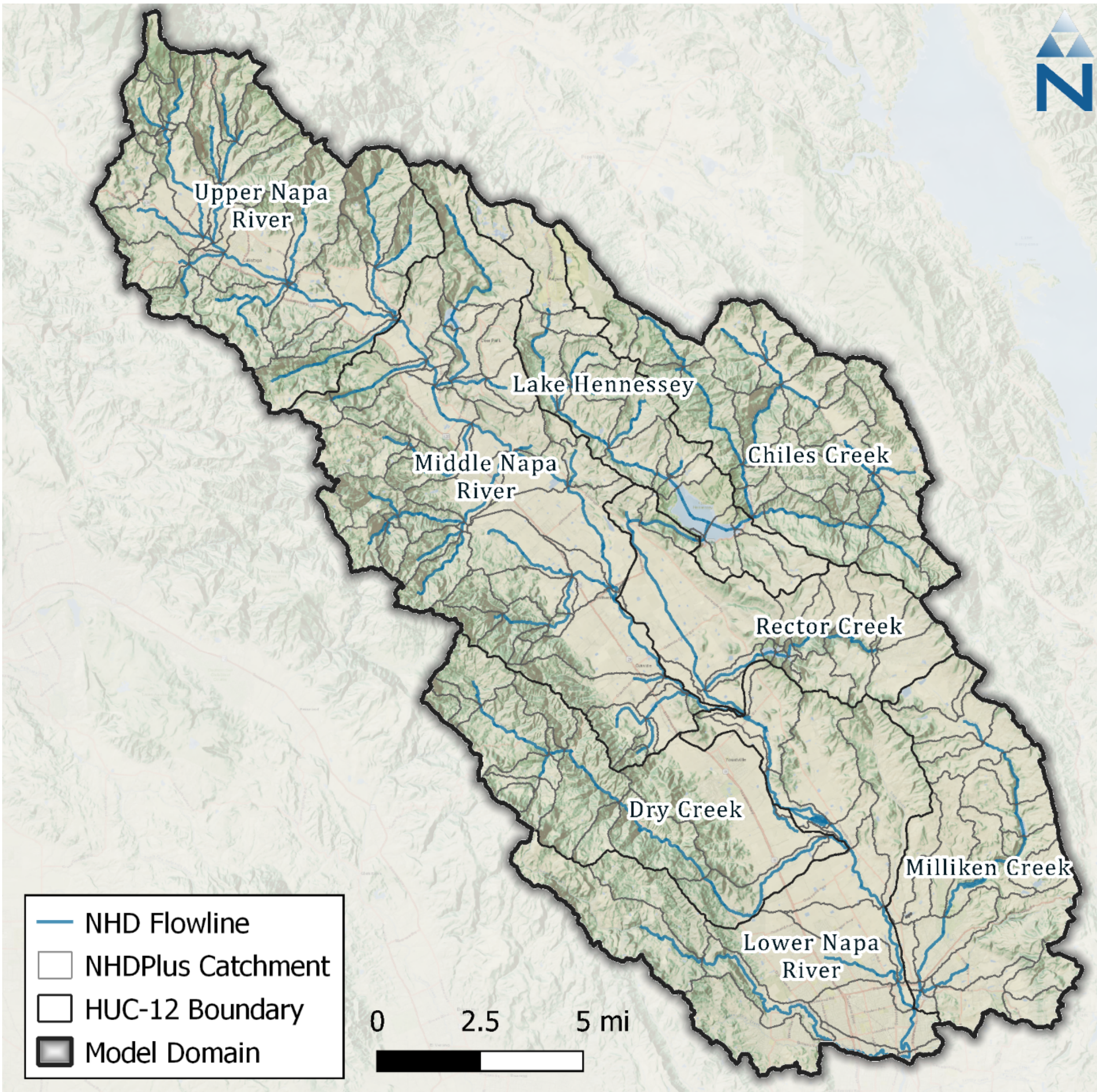

Figure 3-1. Initial catchment segmentation for the Napa River watershed.

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 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.

3.2 Streams and Channels

The hydrographic characteristics of the streams and rivers within the Napa River watershed (as shown in Figure 3-1) are primarily derived from NHDPlus. This dataset depicts primary flow paths based on a nation-wide 10m 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. Figure 3-1 maps the location of the Napa River and its major tributaries.

3.3 Streamflow

The primary source of streamflow data is from the USGS, which includes two current long-term gauges: the Napa River near Napa gage (USGS 11458000), located approximately 6 river miles upstream of the Napa River HUC-10 outlet, and the Napa River near St. Helena gage (USGS 11456000), which is further upstream and located approximately 15 miles downstream of the river's headwaters near Robert Louis Stevenson State Park. There are also eight historical streamflow gauges located upstream on tributaries, but none have passed 1983 and won't be useful for calibrating the model. Table 3-2. presents a summary of the available USGS streamflow data. The Napa County Flood Control and Water Conservation District (RCD) also operates streamflow gauges within the Napa River watershed (Napa RCD 2024). While the USGS gauges are located on the mainstem Napa River, the RCD gauges are located on tributaries and will be especially useful for model calibration. Table 3-3 presents a summary of the available RCD streamflow data. Figure 3-2 shows the locations of the two USGS gauges and five RCD gauges within the Napa River watershed.

Table 3-2. Summary of USGS daily streamflow data

Gage Description	Station ID	Drainage Area (mi^2)	Start Date	End Date	Gage Active?
NAPA R AT CALISTOGA CA	11455900	21.9	10/1/1975	9/29/1983	No
SULPHUR C NR ST HELENA CA	11455950	4.5	2/1/1966	9/29/1967	No
CONN C NR OAKVILLE CA	11456500	55.4	10/1/1929	9/30/1975	No
DRY C NR NAPA CA	11457000	17.4	4/1/1951	9/29/1966	No
DRY C NR YOUNTVILLE CA	11457500	18.7	10/1/1940	9/30/1941	No
MILLIKEN C NR NAPA	11458100	17.3	10/1/1970	9/29/1983	No
NAPA C A NAPA	11458300	14.9	10/1/1970	9/29/1983	No
NAPA R NR NAPA CA	11458000	218	10/1/1929	Present	Yes
NAPA R NR ST HELENA CA	11456000	78.8	10/1/1929	Present	Yes
REDWOOD C NR NAPA CA	11458200	9.79	8/1/1958	10/1/1973	No

Table 3-3. Summary of RCD river and streamflow data

Gage Description	Station ID	Drainage Area (mi^2)	Start Year	End Year	Gage Active?
Napa River at Dunaweal Ln	40142	30.51	2009	Present	Yes
York Creek at Hwy 29	40129	3.89	2015	Present	Yes
Dry Creek at Hwy 29	40115	23.53	1997	Present	Yes
Salvador Channel at Big Ranch Rd	40128	5.57	2008	Present	Yes
Milliken Creek at Atlas Peak Rd	40113	17.2	1997	Present	Yes

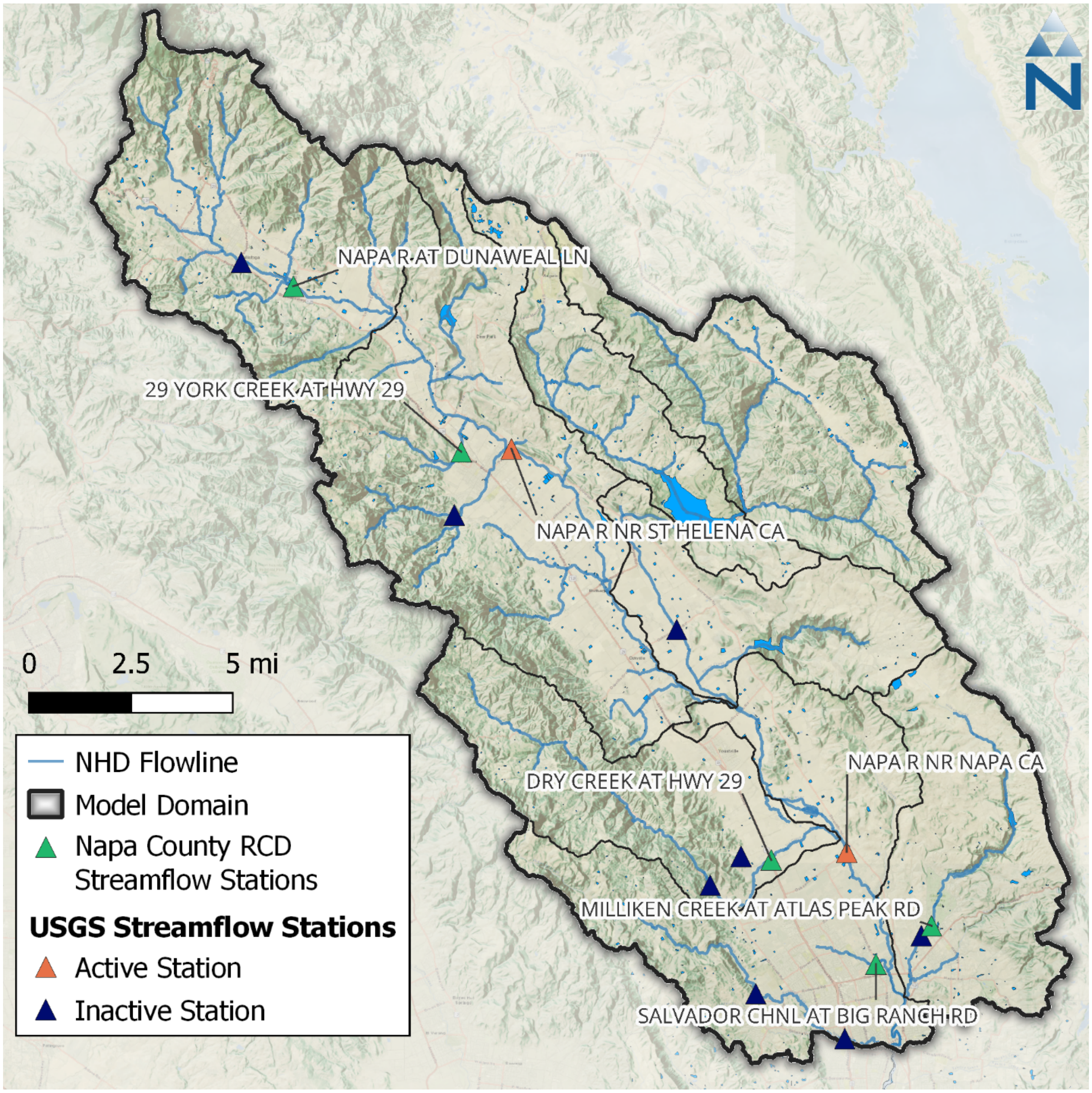

Figure 3-2. USGS and RCD streamflow stations in the Napa River watershed.

3.4 Dams, Reservoirs, and Impoundments

The Napa River watershed contains several large reservoirs and many small agricultural ponds that will require varying levels of representation within the hydrology model. The largest waterbodies are listed in Table 3-4; the dams, location of vineyards with registered ponds, and other waterbodies are shown in Figure 3-3. Capturing the operation of these features will be important to accurately represent the movement of water throughout the watershed. For example, Lake Hennessey impounds Conn Creek and its tributaries: Chiles Creek and Sage Creek. Outflow from the lake controls the flow of Conn Creek, which is a major tributary of the Napa River, below the dam. Having stage-storage relationships for reservoirs, and any other outflow rates or operating conditions, will allow for more accurate model representation.

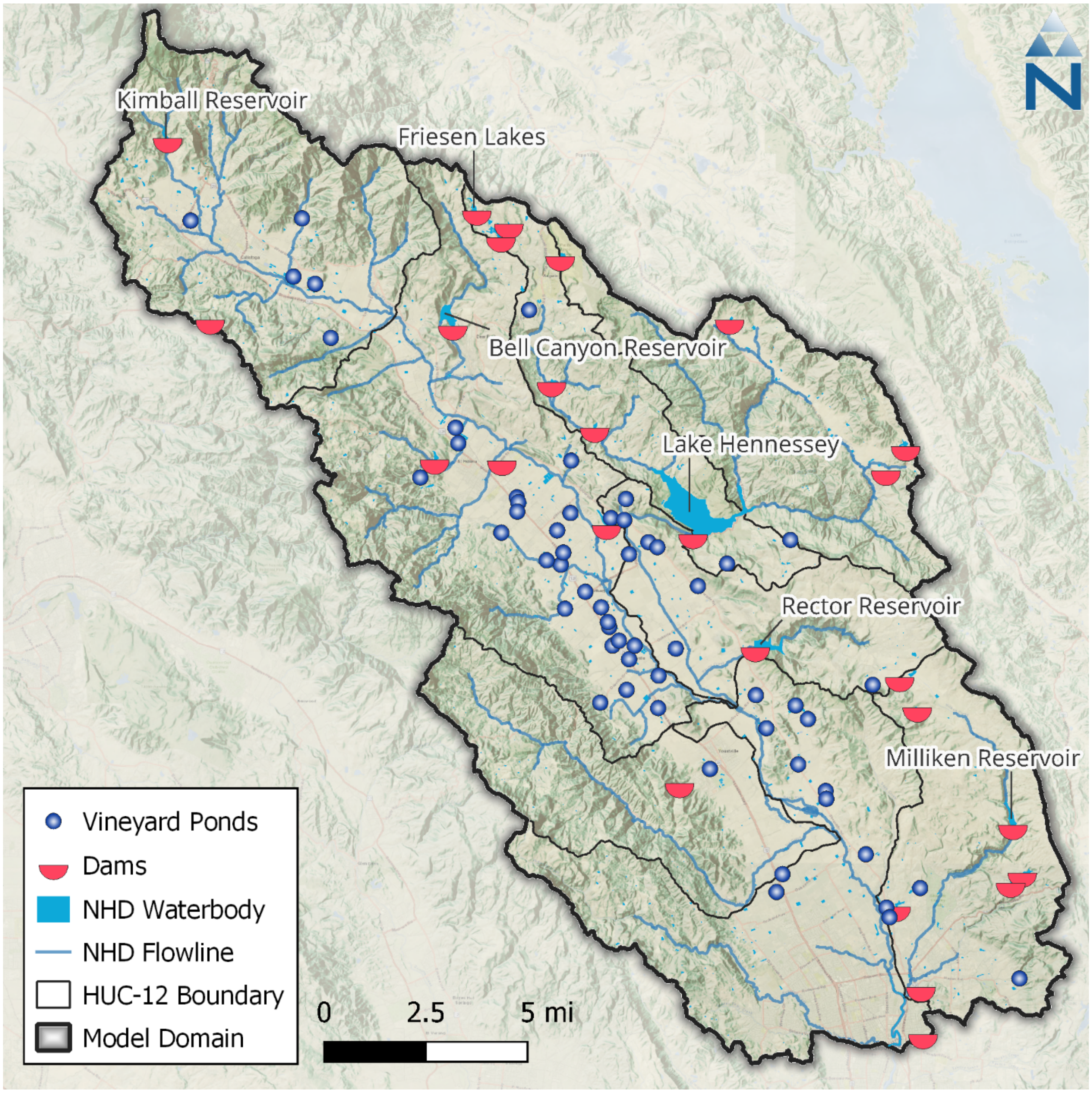

Figure 3-3. Dams and vineyards with registered ponds in the Napa River watershed. Note that vineyard pond locations are not exact.

Table 3-4. Large waterbodies with the Napa River watershed

Waterbody	Area (ac)
Lake Hennessey	787.4
Rector Reservoir	83.2
Bell Canyon Reservoir	77.2
Friesen Lakes	63.4
Milliken Reservoir	38.3
Kimball Reservoir	16.3

3.5 Surface Water Withdrawals

Datasets related to water rights, points of diversion, 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) (SWRCB n.d.), the Napa County Groundwater Sustainability Agency's (Napa GSA) Groundwater Sustainability Plan (GSP) (Napa GSA 2022), and the CA DWR Agricultural Land and Water Use Estimates database (ALWU) (CA DWR n.d.). Those data 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 Napa River watershed to assess the relative impacts based on observed precipitation, evapotranspiration, 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 water users in the watershed. Water systems are evenly distributed throughout the entire watershed and include a mixture of both surface water diversions from the Napa River and its primary tributaries, as well as ground water withdrawals for the Napa-Sonoma Valley groundwater basin. Surface water is the primary water source for municipal consumption throughout the Napa River watershed; based on the Napa GSP, 30-50% of municipal water usage come from local reservoirs, 2% is extracted from the local groundwater aquifer, and the remaining 30-60% is imported. Conversely, local groundwater extraction accounts for 98% (on average) of the water used for agricultural practices (irrigation), with the remaining 2% coming from surface water diversions from the local watershed.

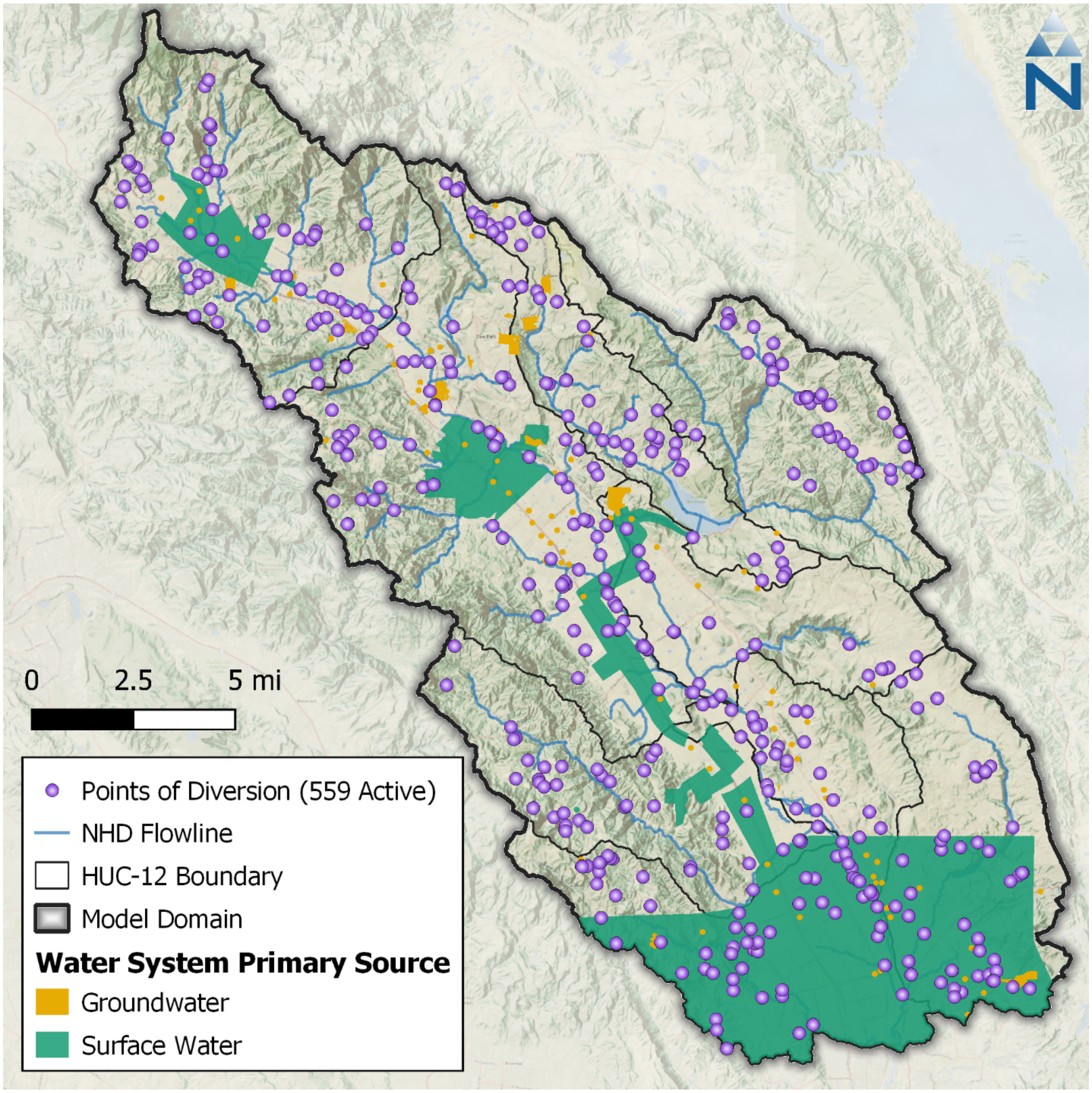

Figure 3-4. Water users in the Napa River watershed.

4 SUBSURFACE HYDROLOGY

The alluvial groundwater basin within the Napa-Sonoma Valley (Basin number 2-002) is comprised of three subbasins: Napa Valley, Sonoma Valley, and Napa-Sonoma Lowlands. The Napa Valley groundwater subbasin (number 2-002.01) overlaps with the Napa River Watershed and interacts with the surface water features of the watershed. The Napa Valley Subbasin as delineated by CA DWR (2020a) are shown in Figure 4-1; approximate areal coverage for this subbasin is about 72 square miles. In compliance with the Sustainable Groundwater Management Act (SGMA), the Napa Valley subbasin has been designated as a high-priority groundwater source by California's Groundwater (Bulletin 118) (CA DWR 2020b) and therefore will be considered for this study.

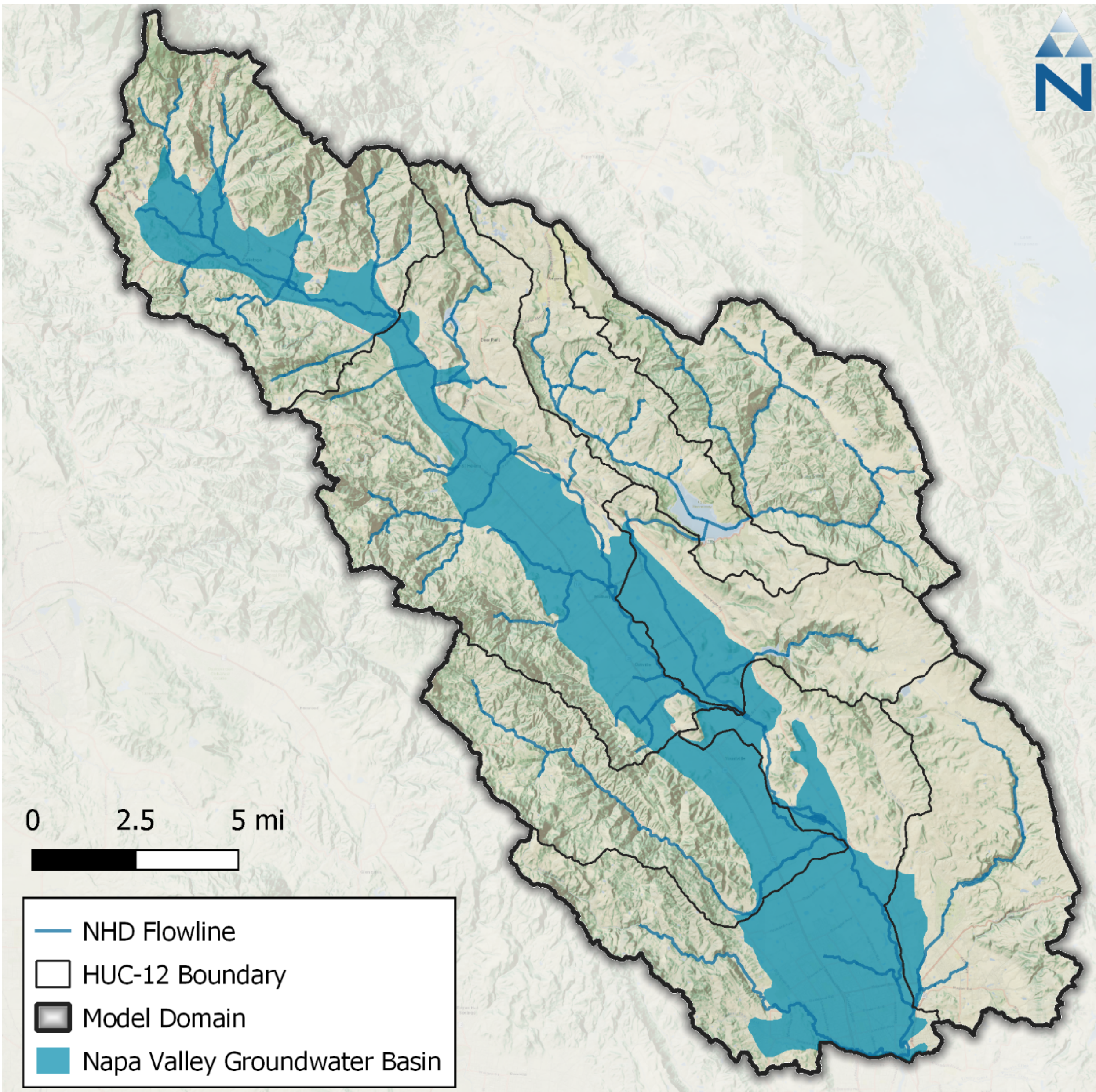

Figure 4-1. Groundwater basins delineated by DWR (2020), also known as Bulletin 118.

The Napa Groundwater Sustainability Plan (Napa GSA 2022) and its accompanied groundwater sustainability summary report for water year 2022 (LSCE 2023) provide estimates of current and past water usage within the Napa Valley groundwater subbasin. The overall state of the groundwater system is monitored through a network of 60 wells spread across the subbasin; these monitoring wells provide data for assessing changes in groundwater levels both spatially and temporally. In addition to the monitoring wells located within the alluvial groundwater basin, monitoring wells are also located within the non-basin portions of the Napa River watershed. All available water level data will be utilized for assessing groundwater conditions within the Napa River watershed. Land subsidence and saltwater intrusion processes reported do not contribute significantly to the hydrology of Napa River watershed, and therefore, will be ignored for water resources assessment for the watershed.

4.1 Water Budget Components

Water budget estimates for the Napa Valley Subbasin were provided as part of the Napa Groundwater Sustainability Plan in their annual report for water year 2022 (LSCE 2023). The total water use in the subbasin is estimated to be 40,302 acre-feet/year (AFY), with contributions from groundwater extraction estimated at 25,230 AFY, surface water supply at 13,852 AFY, and recycled water at 1,220 AFY. The report also estimates a total increase in storage of 11,910 AFY for the water year 2022, based on calculations from an integrated model. Note that these estimates are provided for the alluvial subbasin and do not include areas outside of the designated subbasin boundary within the Napa River Watershed.

Pumping well data, such as location and well depth, are provided in Well Completion Reports (WCRs) hosted by CA DWR (2024). Pumping locations and rates within the alluvial basin were inferred from demand-based calculations based on land use and municipal service area maps provided in the Napa GSP annual report; based on these calculations, the estimated number of service wells use for domestic purpose, irrigation/agriculture, public supply, and industry is about 1,452, 957, 110, and 108 respectively.

Both short and long-term water budget estimates are available and will be compared against the findings in this study. Furthermore, a water budget analysis based on meteorological data, runoff, and streamflow will be conducted to help ascertain whether there are any significant groundwater contributions to streamflow. These water budget estimates will guide the modeling process and help determine whether explicitly representing the groundwater system is warranted.

4.2 Geology

Based on Bulletin 118, the Napa Valley Subbasin is an alluvial subbasin comprised of Recent Alluvium, Pleistocene Alluvium, Huichica Formation, and Sonoma Volcanics. The highly permeable Recent Alluvium comprises a 30 - 120 feet thick unconfined aquifer with gravel, sand, silt, and clay. The Pleistocene Alluvium is a principal source of water in the valley with well yields less than 50 GPM due to its fine-grained sediments. It has a maximum thickness of 500 feet and pinches out at the edge of the valley. The Huichica Formation underlies the Pleistocene Alluvium and is primarily fine grained with low permeability with an estimated thickness of 900 feet. The Sonoma Volcanics is a thick, highly variable series of continental volcanic rocks with very low permeability.

The groundwater basins delineated as per Bulletin 118 are primarily comprised of alluvial basins and 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. The non-basin areas of the Napa River watershed are a source of water for domestic use and irrigation. Monitoring wells within the non-basin areas provides information regarding the changes in non-basin storage within the Napa River 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 hydrologic 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 Napa River watershed.

5.1 Elevation & Slope

The USGS publishes DEMs expressing landscape elevation through a raster grid data product with 30-meter resolution. The Napa River watershed ranges in elevation from sea level (0 meters) along the estuary border in the southern part of the watershed to over 1,200 meters at St. Helena in the northern most portion of the watershed. 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 Napa River watershed.

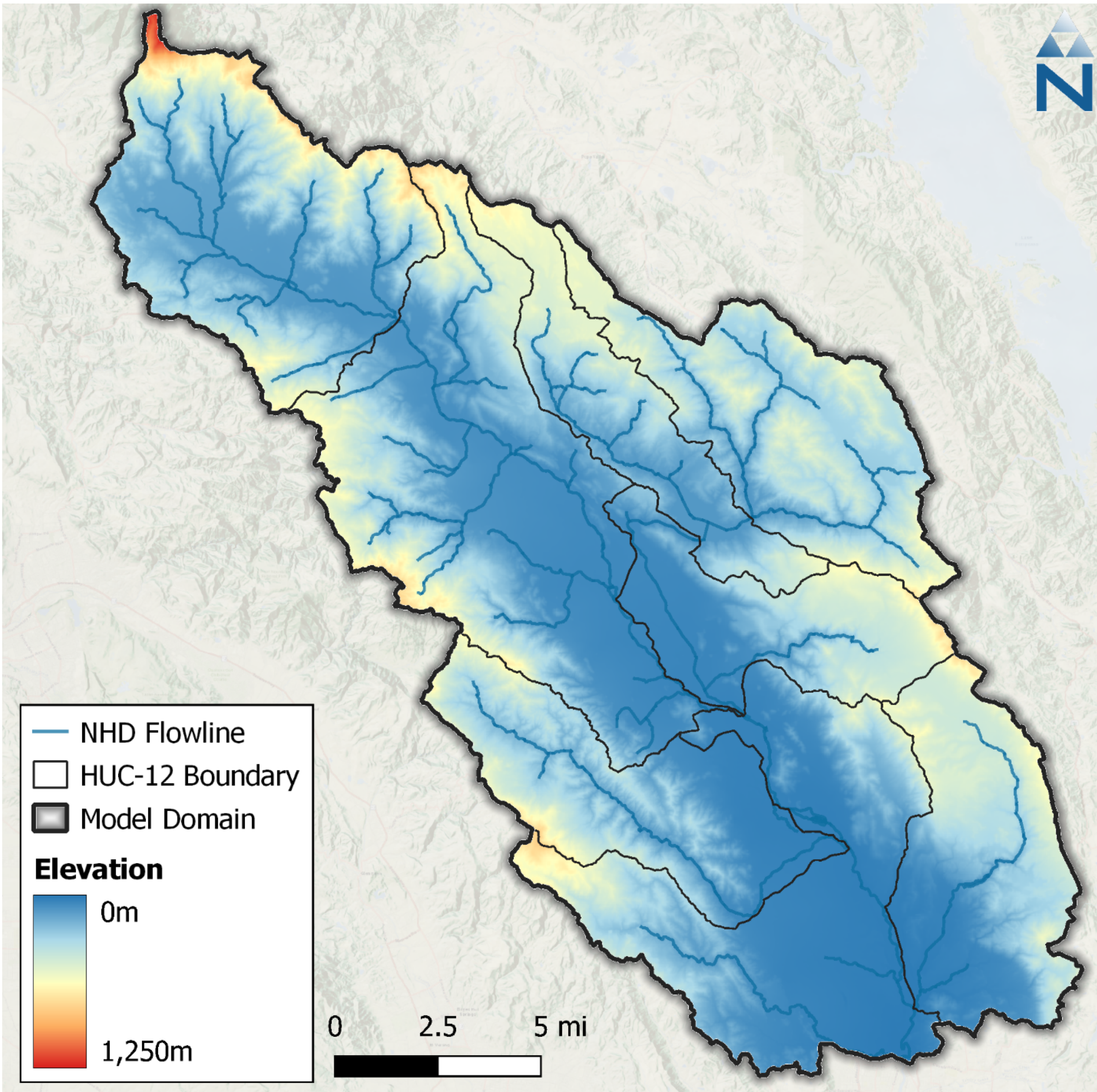

Figure 5-1. Digital elevation model of the Napa River watershed.

5.2 Soils & Geology

Soils data for the Napa River watershed were obtained from the Soil Survey Geographic Database (SSURGO) (USDA 2024a) and State Soil Geographic Database (STATSGO) (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 Napa River watershed. The dominant soil group in the watershed is Group C (49%), containing sandy clay loam that typically have low infiltration rates. Group D (23%) is the next most common soil group in the watershed, with the lowest infiltration rates, containing clay loam, silty clay loam, sandy and silty clay, and clay. Group B makes up 13% of the watershed, containing moderately well to well-drained silt loams and loams, and Group A, containing well-draining sand, loamy sand, and sandy loam, makes up nearly 1.5%. Only 0.03% 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 14% of the watershed HSG area is classified as unknown in the soils database and reside primarily within mountainous areas. For these areas, the corresponding HSG from the STATSGO dataset will be used to supplement the data gaps; some of these unknown soil areas may correspond to waterbodies.

Table 5-2. NRCS Hydrologic soil groups in the Napa River watershed

Hydrologic Soil Group	Area (acres)	Percent Area
A	2,472.51	1.40%
B	23,948.34	13.20%
C	89,212.44	49.30%
C/D	55.92	0.03%
D	40,889.55	22.60%
N/A	24,501.82	13.50%
Total	**181,080.58**	**100.0%**

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

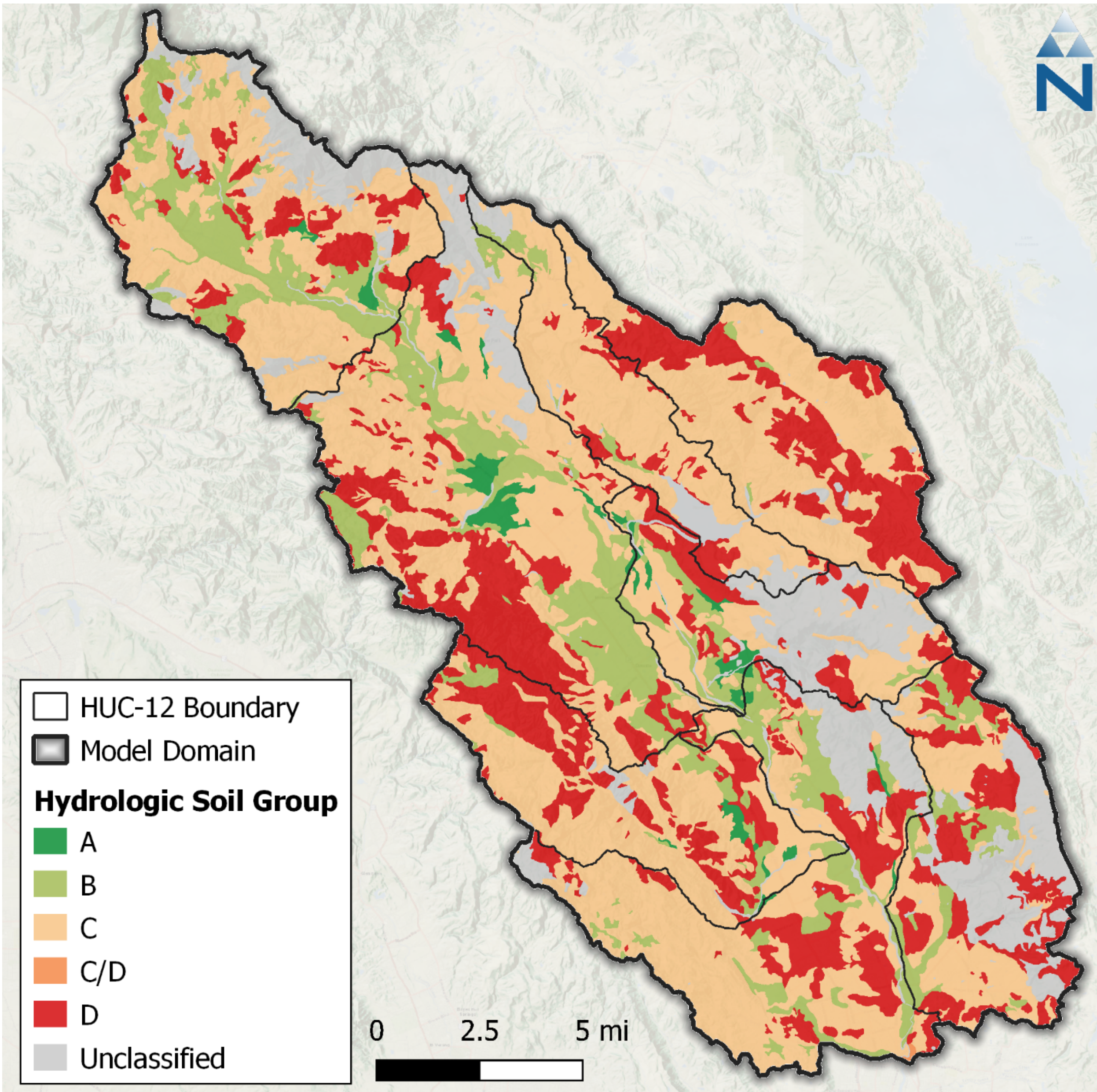

Figure 5-2. SSURGO hydrologic soil groups within the Napa River watershed.

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 Napa River Watershed and Figure 5-3 shows the spatial distribution of these classifications.

Grassland/Herbaceous is the dominant land cover class covering approximately 33% of the watershed. When combined, deciduous forest, evergreen forest, mixed forest, shrub/scrub, and grassland/herbaceous account for 73% of the total watershed area. Developed land cover makes up approximately 11% of the total watershed area and is roughly evenly split between Open Space, Low Intensity Development, and High Intensity Development. Approximately 15% of the total watershed area is cultivated crop land, which potentially underestimates the true cultivated area because many individual cultivated areas in the watershed may be smaller than the NCLD's 2.7-acre minimum mapping unit.

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

NLCD Class	Classification Description	Area (acres)	Percent
11	Open Water	1,254.92	0.69%
21	Developed, Open Space[1]	7,120.93	3.93%
22	Developed, Low Intensity[1]	5,793.77	3.20%
23	Developed, Medium Intensity[1]	5,224.36	2.89%
24	Developed, High Intensity[1]	1,007.47	0.56%
31	Barren Land (Rock/Sand/Clay)	40.13	0.02%
41	Deciduous Forest	2,134.21	1.18%
42	Evergreen Forest	25,534.44	14.10%
43	Mixed Forest	9,324.47	5.15%
52	Shrub/Scrub	35,404.89	19.55%
71	Grassland/Herbaceous	60,289.01	33.30%
81	Pasture/Hay	172.78	0.10%
82	Cultivated Crops	26,975.52	14.90%
90	Woody Wetlands	577.86	0.32%
95	Emergent Herbaceous Wetlands	214.91	0.12%
	TOTAL*	**181,069.67**	**100%**

Source: 2021 National Land Cover Database

1: Imperviousness: Open Space (<20%); Low Intensity (20-49%); Medium Intensity (50-79%); High Intensity (≥80%).

* Note that because of the raster resolution, this total is approximately 11 acres less than the model domain.

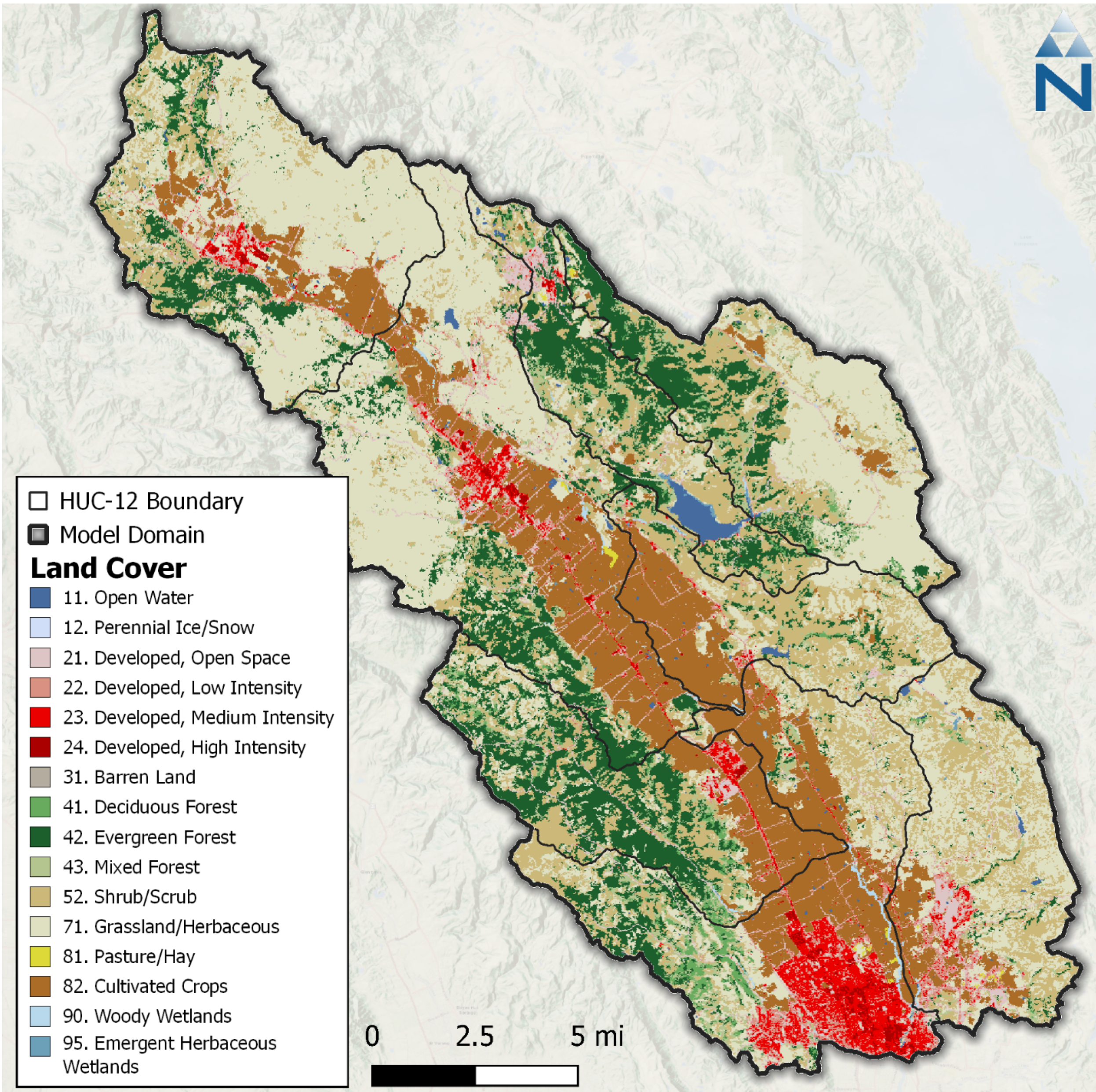

Figure 5-3. NLCD 2021 land cover within the Napa River watershed.

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 Napa River watershed using this dataset shows that approximately 8% of the area has imperviousness ≥ 10%; 92% of the watershed is less than 10 percent impervious.

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 Napa 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 Napa River watershed, an average of 22% 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 evapotranspiration rates.

5.5 Agriculture & Crops

Land cover data for the Napa River Watershed (see Section 5.3) was analyzed to identify predominant cropland vegetation classes. Figure 5-4 USDA 2022 Cropland Data within the Napa River watershed. shows the spatial distribution of these classes through the study area, and Table 5-4 summarizes their areal coverage. This analysis revealed that about 15% of the Napa River watershed area is classified as Pasture/Hay (class 81) or Cultivated Crops (class 82), and 53% 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 annual updated raster dataset that geo-references crop-specific land use. The dataset comes as 30-meter resolution raster with 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. Additionally, a large-scale crop and land use identification dataset for the year 2020 could be used to supplement data gaps if necessary (CA DWR 2022). This dataset is intended to quantify crop acreage statewide and was constructed by analyzing remote sensing data gathered at the field scale.

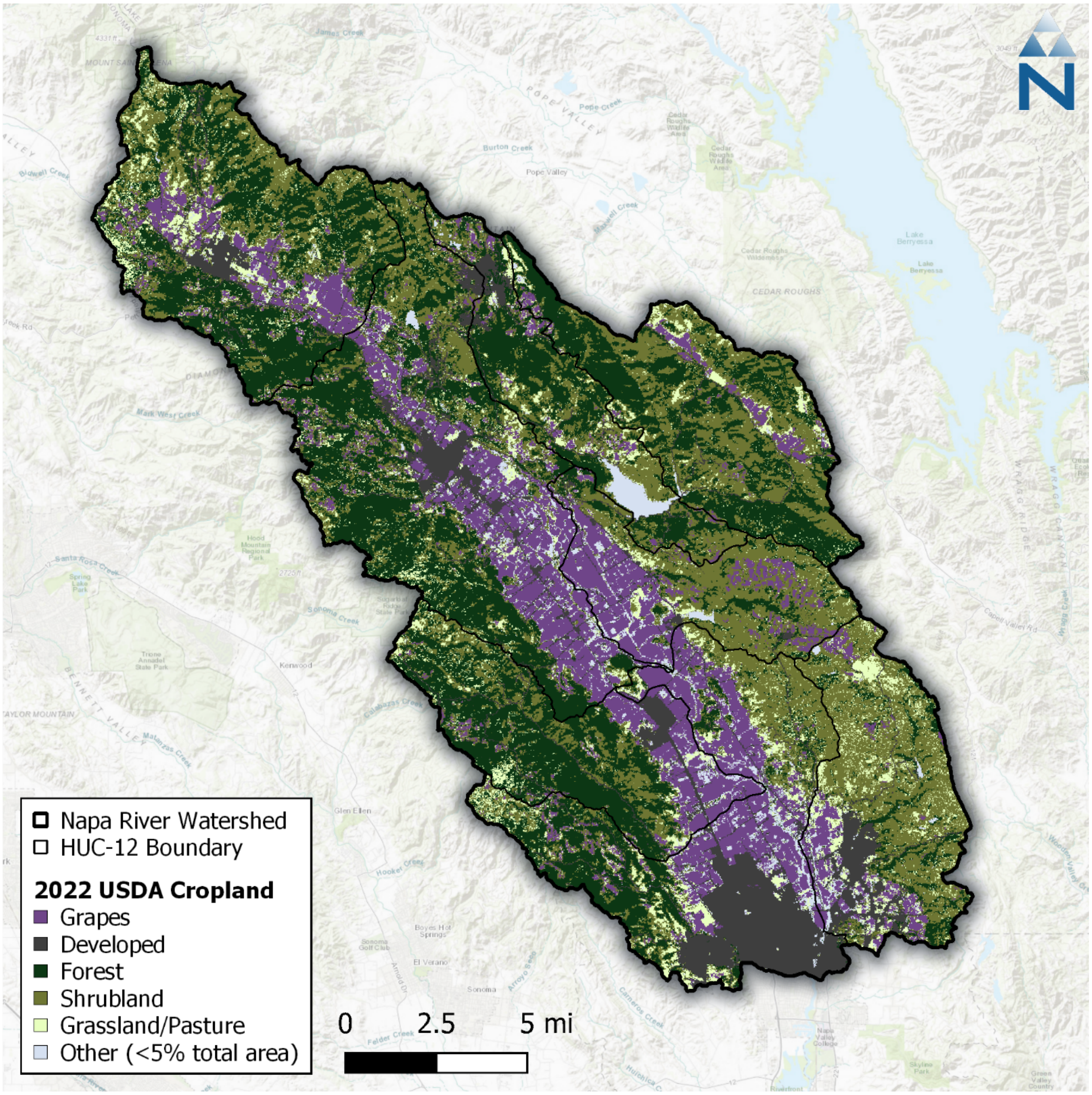

Figure 5-4 USDA 2022 Cropland Data within the Napa River watershed.

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

Crop Type	Area (ac)	Area(%)
Developed	18,707.3	10.21%
Forest	59,922.2	32.71%
Shrubland	54,854	29.94%
Grassland/Pasture	14,678.9	8.01%
Grapes	28,581	15.60%
Other (>5% Total Area)	6,447.2	3.52%
Totals	**183,190.6**	**100.00%**

6 DATA GAPS AND LIMITATIONS

Since the Napa River watershed is a heavily irrigated system, a potential limitation is data availability, quality, and temporal resolution for surface water diversions and irrigation within the watershed. The eWRIMS database was used to initially 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. Those diversions may need to be mapped, and assumptions could be needed to represent water demand in the model if these demands are deemed to be significant enough to impact model calibration. The CA DWR Agricultural Land & Water Use Estimates database was the only identified source for irrigation usage. This dataset lacks the spatial and temporal coverage necessary for this modeling study, providing only area average annual estimates for the Napa River watershed, which could make modeling spatial and temporal variability of irrigation difficult. The database does not provide descriptive information about the irrigation application methods (i.e., traditional vs drip), irrigation efficiency (more water lost by canopy capture or not), or sources of water for irrigation, which will require assumptions that can have significant implications for the water balance.

Some of irrigation data gaps can be estimated from related data sources. For example, as previously mentioned in Section 2.2, the difference between OpenET (reasonable large-scale gridded estimate for observed AET) and model estimates of AET could be used to estimate water volume differences attributable to irrigation activity. In Figure 6-1, the green shaded area between OpenET and LSPC AET represents excess evapotranspiration volume—that volume would not have naturally occurred had it not been added to the system. The green shaded area in Figure 6-1 overlaps with the summer months where there is little to no rainfall, as shown in Figure 6-2. Irrigation volumes will most likely need to be slightly larger than that estimated difference because only a portion of irrigation volume would ultimately be expressed as actual evapotranspiration, depending on assumptions about the source of irrigation water, irrigation method, efficiency, and excess runoff from irrigated lands.

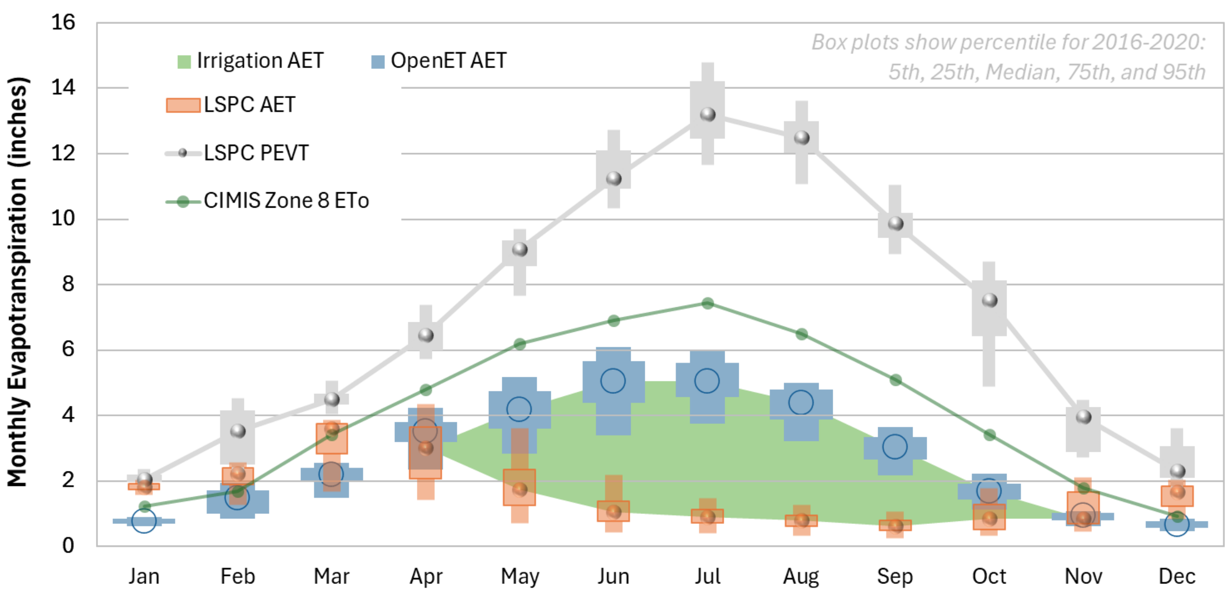

Figure 6-1 Estimating actual irrigation evapotranspiration (AET) from OpenET and modeled AET.

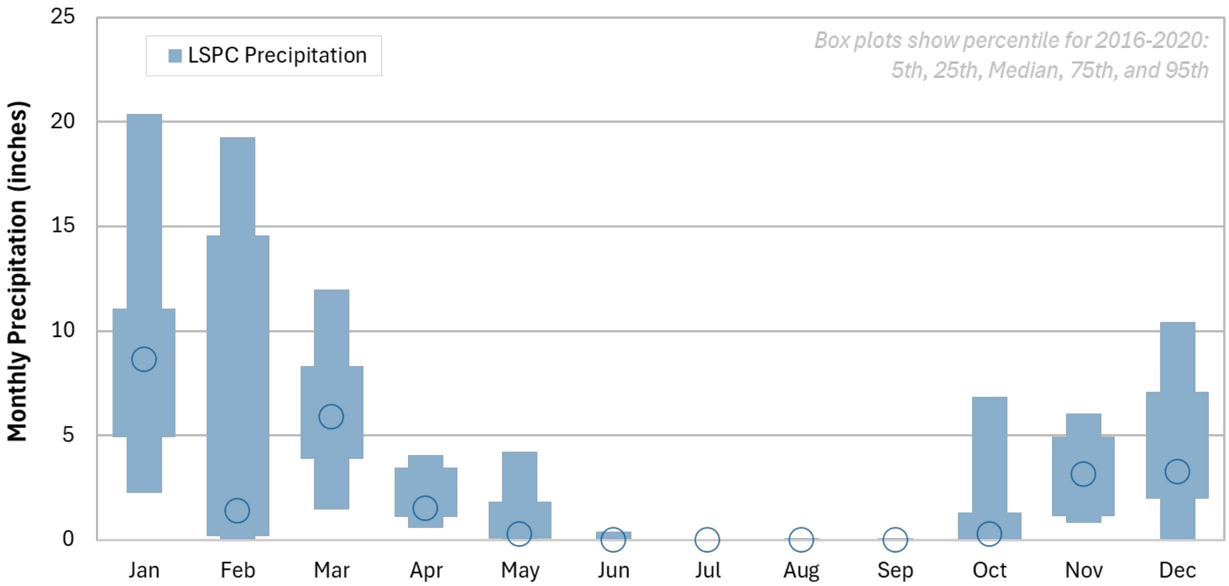

Figure 6-2 Monthly precipitation variability in the Napa River Watershed.

In Section 3.4, it was noted that some irrigation water is stored in small ponds. It was also noted in Section 3.5 that most of the water used for irrigation in the Napa River watershed comes from groundwater sources. Modeled hydrology in the Napa River watershed will depend on the spatial distribution and the relative intensity of surface vs. groundwater-derived sources. This will be further evaluated during model configuration and calibration to determine if a linkage to a groundwater model is needed to better represent watershed hydrology.

The Napa Valley Integrated Hydrologic Model (NVIHM) referenced in the Napa County GSA Report WY-2022 (LSCE 2023) may provide insights into hydrologic and hydrogeologic information, boundary conditions, calibration datasets, and several other features helpful in developing the integrated model for this study. However, NVIHM is not publicly available and is therefore identified here as a data gap.

Finally, at the time of writing it is unknown what stage-storage relationships or operational records or rules may be available for the six reservoirs identified in Section 3.4; obtaining additional information or deriving estimates may be necessary to achieve an acceptable calibration.

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 SFEI watershed modeling efforts could be leveraged to address the specific objectives of this study (Section 1.3). This section elaborates further on model selection and model reconfiguration.

7.1 Model Selection

This modeling study's objectives influence hydrologic model selection and technical approach development. The available data presented in Section 2 through Section 6 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 variability between water years to represent conditions such as dry and wet year flows, environmental flows, drought curtailment, and other hydrological impacts.

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 wildfires.

Public-domain models that can address those study objectives include the Hydrologic Simulation Program – Fortran (HSPF) (Barnwell and Johanson 1981), LSPC (Shen et al. 2005; USEPA 2009), the Precipitation-Runoff Modeling System (PRMS) (Markstrom et al. 2015), and 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 2005a, 2005b, 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 is 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 Napa 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.

As described in Section 1.3, SFEI has developed an LSPC model for watersheds draining to San Francisco Bay with a spatial domain that includes the Napa River watershed (Zi et al. 2021 and 2022). The SFEI modeling objective was to support management decisions regarding stormwater runoff and pollutant loads including mercury, PCBs, and sediment. Because this model was 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 Reconfiguration

The SFEI LSPC model will be reconfigured using the data sets presented in Section 2 through Section 60. A hydrologic analysis shall 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 describes how major elements of the model will be structured using the available data sets. Further details about each process and underlying assumptions will be documented in a modeling report:

- **Climate Boundaries:** Climate boundary inputs to the model will include both precipitation and evapotranspiration. As was done for the SFEI model, precipitation will be represented using the 4-km gridded PRISM monthly precipitation, which provides an accurate representation of the long-term water balance. Monthly PRISM precipitation totals will be downscaled using daily and hourly NCDC, RAWS, and CDEC observed timeseries. The SFEI model used area-weighted average monthly PRISM totals per subcatchment; however, for this effort, precipitation data will simply be assigned based on the grid cell with the largest areal coverage. Eliminating the step of area-weighting is not expected to have a significant impact given that the 4-km spatial resolution is already finely resolved compared to the average NHDPlus subcatchment size (~2-km^2). Another benefit of this reconfiguration is that it streamlines processing effort when (1) extending the timeseries in the future or (2) making updates to model subcatchment boundaries. It also establishes a consistent methodology across other modeled watersheds.

  Evapotranspiration will be represented using the CIMIS daily reference evapotranspiration 2-km gridded data set and downscaled to hourly based using NLDAS. It is important to note that in the Napa River watershed, NLDAS potential evapotranspiration is reported at a 3-hour interval as shown in Figure 7-1, panel A. However, the hourly *distribution* of solar radiation from NLDAS, which has a sinusoidal pattern over daylight hours, offers a suitable alternative for downscaling daily CIMIS depths (Figure 7-1, panel B). Daylight hours in NLDAS solar radiation also exhibit natural seasonal variation with latitude. The hourly distribution is derived by dividing the hourly solar radiation values for each day by the corresponding total solar radiation for the day. Those distributions are then multiplied by the total CIMIS evapotranspiration to downscale CIMIS daily to hourly.

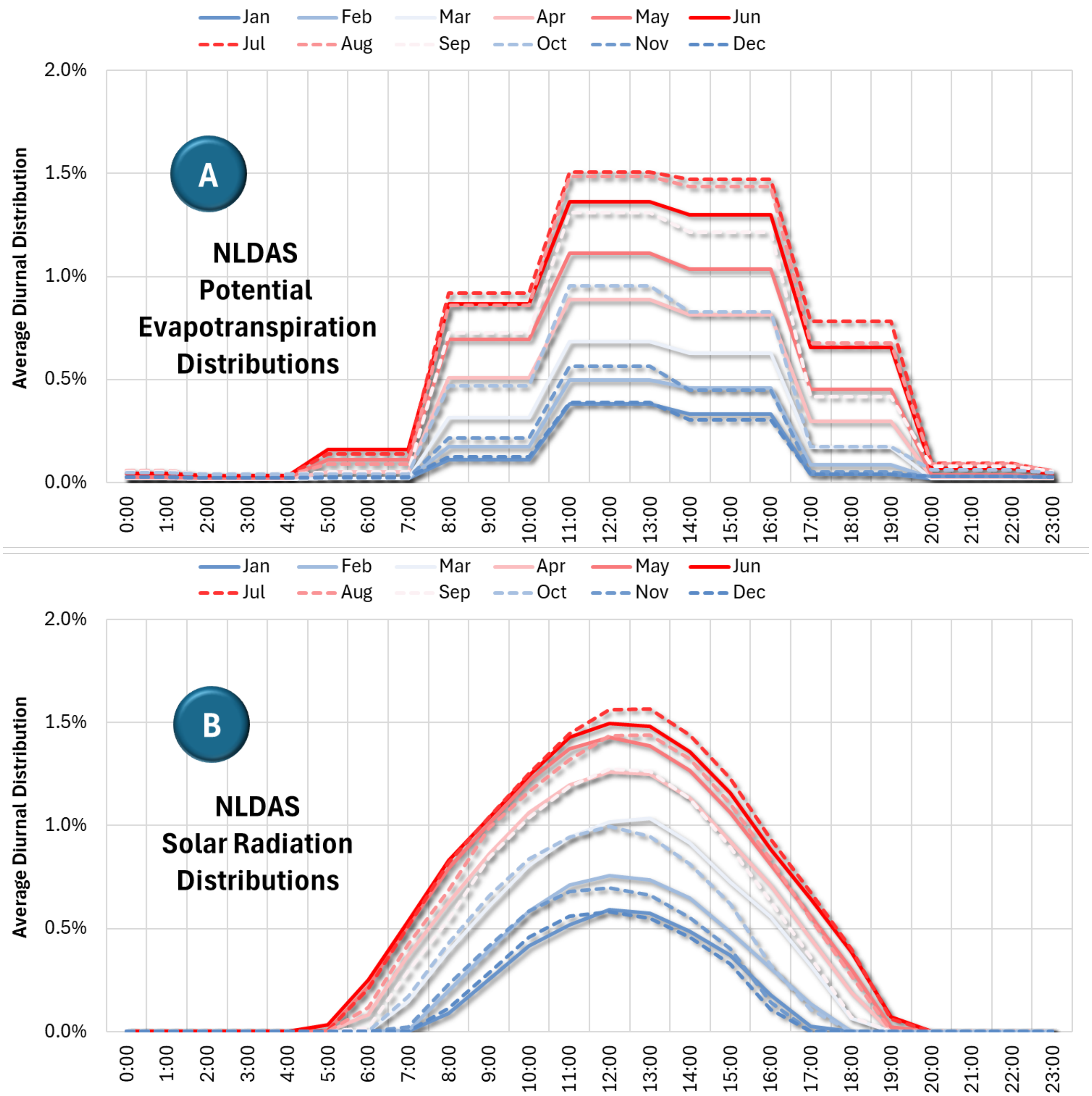

Figure 7-1. Comparison of monthly diurnal NLDAS potential evapotranspiration and solar radiation for a Napa River NLDAS watershed grid.

- **Model Segmentation**: The SFEI subcatchment delineations were at a coarser resolution as part of a larger model of San Francisco Bay watersheds. (As previously noted, area weighting PRISM grids by subcatchment is reasonable at the larger subcatchment scale, but is not as beneficial when the average subcatchment size is *smaller* than a PRISM grid). For this effort, subcatchment 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, gage locations, points of diversion, and other points of interest). One primary reach segment will be represented per subcatchment and will use a cross-section calculated using trapezoidal geometry as a function of cumulative upstream drainage area (Bent and Waite 2013; McCandless 2003; McCandless and Everett 2002). If additional cross-sectional information is available, these geometries can be updated per subcatchment 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. When crop type is known, this will be used to override the land cover data. As described in Section 5.5, "Grapes" are by far the dominant crop type in the Napa River watershed. 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 a reason to represent different responses in the model for each type). Because of the density of developed area in the lower Napa River watershed, the acreage of mapped impervious area (MIA) may be adjusted for calibration to effective impervious area (EIA), or to the portion of MIA which is directly connected to the conveyance network, using the Sutherland Equations. This refinement is necessary to avoid an initial overestimation of impervious surfaces contributing to runoff before initiating process-based model calibration (Sutherland 2000).

- **Water Budget**: To the extent that major sources of water use (e.g., irrigation, groundwater pumping, surface diversions) or inter-basin transfers are known, these volumes will be included as withdrawals or inputs to the model. Because grapes are the dominant crop type in the Napa River watershed, assumptions about irrigation will be configured accordingly. In cases where specific data are not available, reasonable assumptions may need to be made and documented for some sources/sinks, while others may need to be excluded entirely if the impact(s) on the model prediction cannot be quantified in a representative way. Priority will be given to features that directly influence predictions at points where the model is being compared to observed data for calibration purposes.

Table 7-1 summarizes key components of the SFEI LSPC model, proposed changes that would make it more suitable for this application, as well as reasoning for these changes. Given that accurate flow simulation and associated water budgeting are the overarching objectives of this workplan, the primary purpose of these proposed changes is to improve the model's ability to predict key water balance components (streamflow, evapotranspiration, interflow, and groundwater flow) to increase confidence in the output of potential water management scenarios that are simulated.

Table 7-1 Summary of SFEI model and proposed modifications

Data Group	Data Category	Reference Section[1]	Description	Data Set(s)[2]	Proposed Changes	Reasoning
Climate Boundaries	Precipitation (hourly)	2.1	Daily 4 km gridded precipitation (PRISM) is spatially bias corrected and temporally disaggregated using observed gage networks and hourly 12 km gridded NLDAS-2 data; area weighted aggregation by subcatchment is conducted before temporal disaggregation.	PRISM (daily), NLDAS-2 (hourly) Observed[3]	Downscale monthly PRISM using Observed[3] data, then assign single grid cell to each subcatchment based on areal coverage.	Downscaling raw PRISM grid cells (rather than area averages for subcatchments) improves efficiency when modifying meteorological forcing; consistent with our other modeling efforts.
	PET (hourly)	2.2	12 km resolution gridded dataset of hourly potential evapotranspiration.	NLDAS-2 (3-hourly)	Disaggregate daily ET_0 for CIMIS Zone 8 using hourly NLDAS-2 short-wave radiation.	NLDAS-2 overestimates evapotranspiration (Xia et al. 2014).
Model Segmentation	Watershed Boundaries	3.1	Subcatchments manually delineated from HUC-8 drainage boundaries.	WBD HUC-8	Use NHDPlus watershed boundaries and stream network.	Increased spatial resolution will improve routing accuracy; consistent with our other modeling efforts.
	Stream Network	3.2	Composite of stream segmentation datasets at varying spatial resolutions; intended to fill spatial gaps in stream network.	BAARI, NHD, WBD		
HRUs	Land use & Landcover	5.3	Composite of proprietary (ABAG) and open-source (NLCD) grid-based land characterization; Differentiates developed land from coarse classifications of forest, cropland, and wetlands; Identifies the age of development of existing infrastructure (ABAG).	ABAG, NLCD	Only use NLCD.	ABAG is a proprietary and requires special permissions whereas NLCD is open source; ABAG includes age of development data for infrastructure, which is useful for identifying contaminant point sources, but outside of the scope of this study.
	Soil	5.2	Composite of state-wide 10 m gridded and 1:1,000,000 vector-based datasets that identify primary hydrologic soil groups	SSURGO, STATSGO	-	-
	Elevation & Slope	5.1	10-m resolution gridded digital elevation map.	NED	-	-
	Impervious Areas	5.3	Broad, 30-meter grid-based land characterization; Represent percent impervious area within raster cells.	NLCD	-	-

Data Group	Data Category	Reference Section[1]	Description	Data Set(s)[2]	Proposed Changes	Reasoning
	Vegetation & Disturbances	5.4	Existing tree canopy cover	Missing	Include available open-source datasets as they fit within the project scope. Some potential sources include: MRLC, USFS, USDA, USGS, and CAL FIRE.	Improved accuracy of HRU construction and model parameterization; represents changes in land cover from disturbances.
		5.5	Existing vegetation and cropland classification			
		-	Timber harvesting records and GIS mapping			
Water Budget	Streamflow	3.3	Observed average daily streamflow.	USGS Streamflow (daily)	Use the additional RCD flow gages data	The additional observed flow data can be leveraged to improve the model calibration/testing
	Reservoir Operations	3.4	Geolocation and withdrawal time series of major reservoirs.	USGS, CDWR, SFPUC, EBMUD, SCVWD	-	-
	Diversions	3.5	Distributary and flood diversion channel routing	Missing	Include available open-source datasets as they fit within the project scope. Some potential sources include: CA DWR, SWRCB eWRIMS, and CDT.	Better inform parameterization to enhance accuracy of water budget; consistent with other modeling efforts.
	Withdrawals	3.5	Irrigation water usage			
			Wells and other groundwater withdrawal rates			
	Hydrogeology	4	Geospatial identification and description of geologic features used for groundwater routing.	UNK	Utilize blend of CA DWR datasets to identify key groundwater properties required for MODFLOW.	Data source is unknown; additional parameters are required for MODFLOW implementation (if necessary); consistent with other modeling efforts.

1. Points to the section in this workplan that the dataset is category is discussed.
2. For the full name of these acronyms refer to the *Acronyms* section of this report; for more information about how this source will be used and links to the dataset, refer to *Table 1-1, Table 1-2, Table 1-3.*
3. Observed precipitation gage data reportedly used by SFEI includes: HPD, ISD, CIMIS, SCVWD, and GHCND. For more information on their usage, refer to Zi et al. 2021.

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 or modeled vs. observed data (e.g., time-series plots, flow duration curves, cumulative distribution plots, and others) quantitative metrics and qualitative thresholds recommended by Moriasi et al. (2015) and Duda et al. (2012), which are considered highly conservative. Moriasi et al. (2007 and 2015) 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, Freer, and Woods (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.

Both modeled time series and observed data will be binned into subsets of time to highlight seasonal performance and different flow conditions. Those bins include annual average streamflow, highest 10% of flows (to isolate model performance during high flows), lowest 50% of flows (to isolate model performance during low flows). Hydrograph separation will also be performed to assess stormwater runoff vs. baseflow periods. 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/RME 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," "satisfactory" 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 Napa 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. The presence of substantial agricultural operations in the watershed, which alters the overall hydrologic budgets through groundwater pumping, stream flow diversions, and return flows, could also necessitate the linkage of the LSPC model with a groundwater model.

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

<table>
<tr><th rowspan="2">Performance Metric</th><th rowspan="2">Hydrological Condition</th><th colspan="4">Performance Threshold for Hydrology Simulation</th></tr>
<tr><th>Very Good</th><th>Good</th><th>Fair</th><th>Poor</th></tr>
<tr><td rowspan="10">Percent Bias (PBIAS)</td><td>All Conditions [1]</td><td><5%</td><td>5% - 10%</td><td>10% - 15%</td><td>>15%</td></tr>
<tr><td>Seasonal Flows [2]</td><td rowspan="9"><10%</td><td rowspan="9">10% - 15%</td><td rowspan="9">15% - 25%</td><td rowspan="9">>25%</td></tr>
<tr><td>Highest 10% of Daily Flow Rates [3]</td></tr>
<tr><td>Lowest 50% of Daily Flow Rates [4]</td></tr>
<tr><td>Days Categorized as Storm Flow [5]</td></tr>
<tr><td>Days Categorized as Baseflow [5]</td></tr>
<tr><td>Highest 10% of Daily Flow Rates [3]</td></tr>
<tr><td>Lowest 50% of Daily Flow Rates [4]</td></tr>
<tr><td>Days Categorized as Storm Flow [5]</td></tr>
<tr><td>Days Categorized as Baseflow [5]</td></tr>
<tr><td rowspan="2">RMSE – Std Dev Ratio (RSR)</td><td>All Conditions [1]</td><td>≤0.50</td><td>0.50 - 0.60</td><td>0.60 - 0.70</td><td>>0.70</td></tr>
<tr><td>Seasonal Flows [2]</td><td>≤0.40</td><td>0.40 - 0.50</td><td>0.50 - 0.60</td><td>>0.60</td></tr>
<tr><td rowspan="2">Nash-Sutcliffe Efficiency (E)[6]</td><td>All Conditions [1]</td><td>>0.80</td><td>0.70 - 0.80</td><td>0.50 - 0.70</td><td>≤0.50</td></tr>
<tr><td>Seasonal Flows [2]</td><td>>0.70</td><td>0.50 - 0.70</td><td>0.40 - 0.50</td><td>≤0.40</td></tr>
</table>

1. All Flows considers all daily time steps in the model time series.
2. Seasonal Flows considers daily flows during a predefined, six-month seasonal period (e.g., Wet Season and Dry Season). The Wet Season includes the months of November through April. The Dry Season includes the months of May through October.
3. Highest 10% of Flows considers the top 10% of daily flows by magnitude as determined from the flow duration curve.
4. Lowest 50% of Flows considers the bottom 50% of daily flows by magnitude as determined from the flow duration curve.
5. Baseflows and Storm flows were determined from analyzing the daily model time series by applying the USGS hydrograph separation approach (Sloto and Crouse 1996).
6. The Kling-Gupta Efficiency (KGE) is an alternative method that attempts to address documented shortcomings of NSE. Although the two metrics are not directly comparable, it has an “acceptable” predictive threshold of > - 0.41.

9 SUMMARY & NEXT STEPS

This work plan presented the available data and proposed methods for developing a hydrologic model of the Napa River 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, gage 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 Napa River watershed.

Table 9-1. Proposed schedule and summary of deliverables

Task	Subtask	Deliverable	Due Date
2	2.1	Data Compilation Inventory in Excel Format	--
	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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