
Work Plan: Sonoma Creek Watershed Hydrology Model Development

SUBMITTED TO:

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ACRONYMS

| | |
|-----------------|---|
| 3DEP | 3D ELEVATION PROGRAM |
| AET | ACTUAL EVAPOTRANSPIRATION |
| 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 |
| 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 |
| 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 |
| 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-SUTCLIFE MODEL EFFICIENCY COEFFICIENT |
| PBIAS | PERCENT BIAS |

Work Plan: Sonoma Creek Watershed Hydrology Model Development

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

Contents

| | |
|--|----|
| ACRONYMS | 3 |
| 1 Introduction..... | 5 |
| 1.1 Project Objectives | 5 |
| 1.2 Watershed Background | 5 |
| 1.3 Leveraging Previous Modeling Efforts | 6 |
| 1.4 Model Approach..... | 8 |
| 1.5 Data Availability..... | 9 |
| 2 Meteorology | 16 |
| 2.1 Precipitation | 16 |
| 2.2 Evapotranspiration (ET)..... | 21 |
| 3 Surface Hydrology | 24 |
| 3.1 Watershed Segmentation..... | 24 |
| 3.2 Streams and Channels..... | 25 |
| 3.3 Streamflow | 26 |
| 3.4 Dams, Reservoirs, and Impoundments..... | 27 |
| 3.5 Surface Water Withdrawals..... | 29 |
| 4 Subsurface Hydrology | 30 |
| 4.1 Water Budget Components..... | 32 |
| 4.2 Geology..... | 34 |
| 5 Landscape Characterization | 36 |
| 5.1 Elevation & Slope | 36 |
| 5.2 Soils & Geology..... | 37 |
| 5.3 Land Cover | 39 |
| 5.4 Tree Canopy Cover..... | 42 |
| 5.5 Agriculture & Crops..... | 42 |
| 6 Data Gaps and Limitations..... | 44 |
| 7 Model Configuration..... | 46 |
| 7.1 Model Selection | 46 |
| 7.2 Model Reconfiguration | 47 |
| 8 Model Calibration..... | 52 |
| 9 Summary & Next Steps | 54 |
| 10 References..... | 55 |

Figures

| | |
|---|----|
| Figure 1-1. Sonoma Creek watershed. | 6 |
| Figure 1-2. Map of the SFEI regional model domain, which includes the Sonoma Creek watershed (Zi et al. 2021). | 7 |
| Figure 1-3. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Sonoma Creek watershed. | 9 |
| Figure 2-1. Identified rainfall stations and CIMIS ET Zones near the Sonoma Creek watershed. | 20 |
| Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products. | 21 |
| Figure 2-3. Evaluation of monthly evapotranspiration in existing SFEI model. Note that AET is used as an abbreviation for actual ET. | 23 |
| Figure 3-1. Initial catchment segmentation for the Sonoma Creek watershed. | 25 |
| Figure 3-2. USGS streamflow stations in the Sonoma Creek watershed. | 27 |
| Figure 3-3. Dams within the Sonoma Creek watershed relevant for watershed modeling effort (NID 2025). | 28 |
| Figure 3-4. Water system sources in the Sonoma Creek watershed. | 30 |
| Figure 4-1. Outlines of Sonoma Watershed Study Area, Sonoma Valley Subbasin Boundary (Bulletin 118), and USGS Sonoma Valley Model Boundary. | 31 |
| Figure 4-2. Annual Groundwater Budget Components for Year 2000 as per the USGS Sonoma Valley Model (Farrar et al. 2006: Table 7). | 33 |
| Figure 4-3. Geology map of the Sonoma Creek watershed (CGS 2010) including the approximate USGS groundwater model area boundary. | 35 |
| Figure 5-1. Digital elevation model of the Sonoma Creek watershed. | 37 |
| Figure 5-2. SSURGO hydrologic soil groups within the Sonoma Creek watershed. | 39 |
| Figure 5-3. NLCD 2021 land cover within the Sonoma Creek watershed. | 41 |
| Figure 5-4. USDA 2022 Cropland Data within the Sonoma Creek watershed. | 43 |
| Figure 6-1. Estimating actual irrigation evapotranspiration (AET) from OpenET and modeled AET (data from the Napa River watershed). | 45 |
| Figure 6-2. Monthly precipitation variability (data from the Napa River watershed). | 45 |
| Figure 7-1. Comparison of monthly diurnal NLDAS potential evapotranspiration (A) and solar radiation (B) (data from NLDAS grids for the Napa River watershed). | 48 |

Tables

| | |
|---|----|
| Table 1-1. Inventory of meteorology datasets. | 10 |
| Table 1-2. Inventory of surface water datasets. | 12 |
| Table 1-3. Inventory of geospatial datasets. | 13 |
| Table 1-4. Inventory of groundwater datasets. | 15 |
| Table 2-1. Summary of precipitation stations with observations available after 2000. | 18 |
| Table 3-1. Summary of NHDPlus catchment sizes (acres) within the Sonoma Creek HUC-10. | 24 |
| Table 3-2. Summary of USGS daily streamflow data. | 26 |
| Table 3-3. Waterbodies and Dams within the Sonoma Creek watershed. | 29 |
| Table 5-1. NRCS Hydrologic soil group descriptions. | 38 |
| Table 5-2. NRCS Hydrologic soil groups in the Sonoma Creek watershed. | 38 |
| Table 5-3. National Land Cover Database 2021 land cover summary in the Sonoma Creek watershed. | 40 |
| Table 5-4. USDA 2022 Cropland Data summary within the Sonoma Creek watershed. | 43 |
| Table 7-1 Summary of SFEI model and proposed modifications. | 50 |
| Table 8-1. Summary of performance metrics used to evaluate hydrology calibration. | 53 |
| Table 9-1. Proposed schedule and summary of deliverables. | 54 |

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 Sonoma Creek watershed. This model will use historical records of precipitation, temperature, and evapotranspiration (ET) for simulation of processes associated with surface runoff, infiltration, interflow, and groundwater flow. The final calibrated model will be used to evaluate scenarios including current hydrologic conditions, water allocation, changes in demand, and the impact of extreme events such as droughts or atmospheric rivers.

1.2 Watershed Background

The Sonoma Creek, identified by a ten-digit hydrologic unit code (HUC), is one of the major tributaries to the San Pablo and San Francisco Bays. Sonoma Creek (HUC-10: 1805000203) is part of the San Pablo Bay drainage area, which shares a boundary with the Petaluma River watershed to the west, and Napa River watershed to the east. The non-estuarine watershed area drains approximately 170 square miles and is composed of 3 HUC-12 subwatersheds: Upper Sonoma Creek (180500020301), Lower Sonoma Creek (180500020303), and Fowler Creek (180500020302) as shown in Figure [Figure 1-1](#). Sonoma Creek originates northeast of Kenwood at the heart of Sugarloaf Ridge State Park, where it flows south-west to converge with the tributaries descending from the Mayacamas and Sonoma Mountains. The river then flows for approximately 33 miles before descending towards the Napa-Sonoma Marshes in San Pablo Bay.

Elevations in the watershed range from near sea level south of the city of Sonoma to over 830 meters at the northernmost portion of the watershed near Hood Mountain. The watershed has a Mediterranean climate with distinct wet and dry seasons with a mean annual precipitation total of 39.5 in. (USGS 2019). The watershed is dominated by grassland (27%) and shrubland (26%) areas based on the National Land Cover Database (NLCD). Other land cover types include evergreen forest (16%), mixed forest (9%), and developed (14%).

The Sonoma Creek watershed represents an important habitat for native aquatic species and spawning ground for anadromous fish, especially chinook salmon and steelhead trout. The initial decline in anadromous fish populations within the Sonoma Creek watershed was linked to an increase in sediment delivery and other human activities above that which support salmonid life (Sonoma Ecology Center 2025). The conservation of these species and their habitat, among other environmental concerns, led to the development of Total Maximum Daily Loads (TMDLs) for nutrients, pathogens, and sediment in 2011 and 2008. 2021 was a vital year for Sonoma Creek, as it marked the return of Chinook salmon in North Bay. The watershed's vision to continue to sustain their aquatic species also led to major restoration projects and plans that include the Upper Sonoma Creek Restoration Vision; these projects resulted in the de-listing of Creek's TMDL for nutrients in 2014 as part of the Integrated Report submitted to the 2018 U.S EPA listing cycle (SFBRWCB 2022).

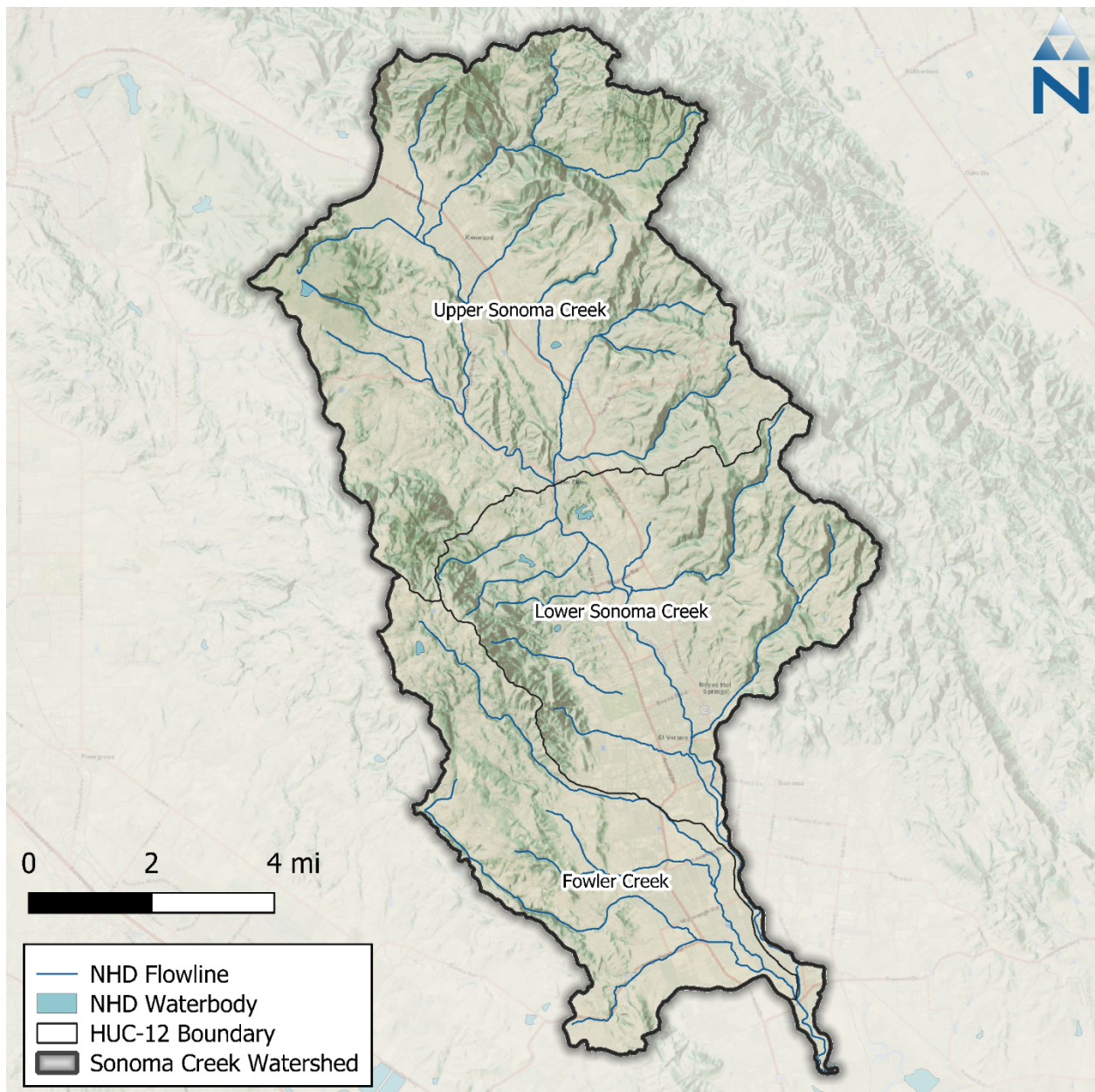


Figure 1-1. Sonoma Creek watershed.

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 Sonoma Creek watershed (Zi et al. 2021 and 2022). [Figure 1-2](#) shows the location of the Sonoma Creek watershed within the larger extent of the SFEI model domain. SFEI’s modeling work utilizes the Loading Simulation Program in C++ (LSPC) (Shen, Parker, and Riverson 2005) for long term continuous simulation with the objective of supporting management decisions regarding stormwater runoff and pollutant loads including mercury, PCBs, and sediment. 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 Sonoma Creek watershed-specific hydrologic study.

As part of the screening process of available data, the Sonoma Creek subset of the SFEI model was assessed to determine 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.

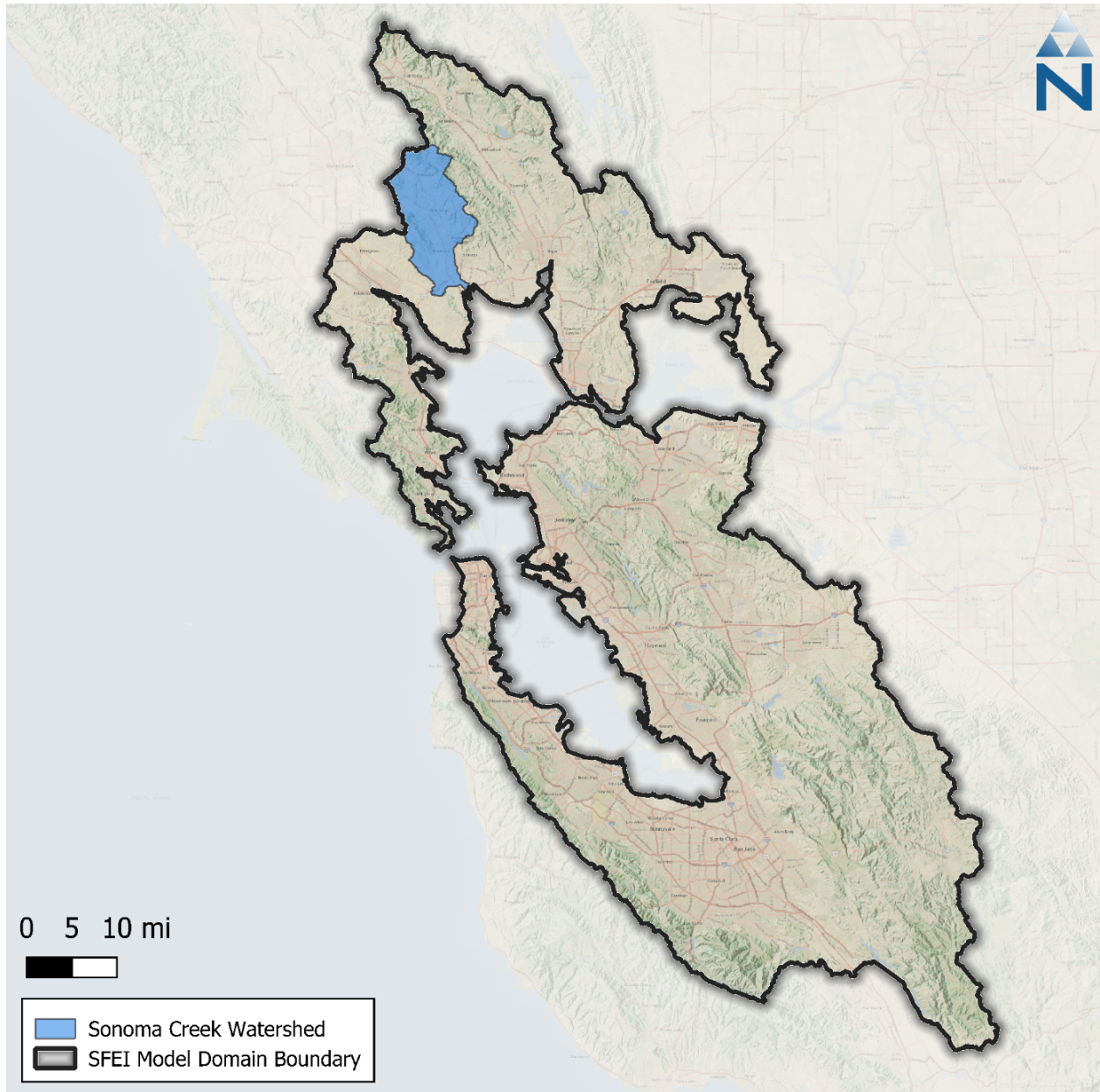


Figure 1-2. Map of the SFEI regional model domain, which includes the Sonoma Creek watershed (Zi et al. 2021).

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 Sonoma Creek watershed. This is presented first through a comprehensive inventory of available meteorological, hydrological, and geographic information system (GIS) data available for the Sonoma Creek watershed. The data compilation and assessment processes are outlined below and aim to highlight any existing data gaps that create limitations for the analysis. Based on the available data, any data gaps are identified that may be filled through additional outreach, data collection efforts, or noted as points of uncertainty in the model documentation.

This hydrologic analysis is based on a model development process that has been a tested platform for gaining valuable information and insight about hydrologic systems. The model development process proposed is an iterative and adaptive cycle that improves understanding of the system over time as better information becomes available. [Figure 1-3](#) 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.

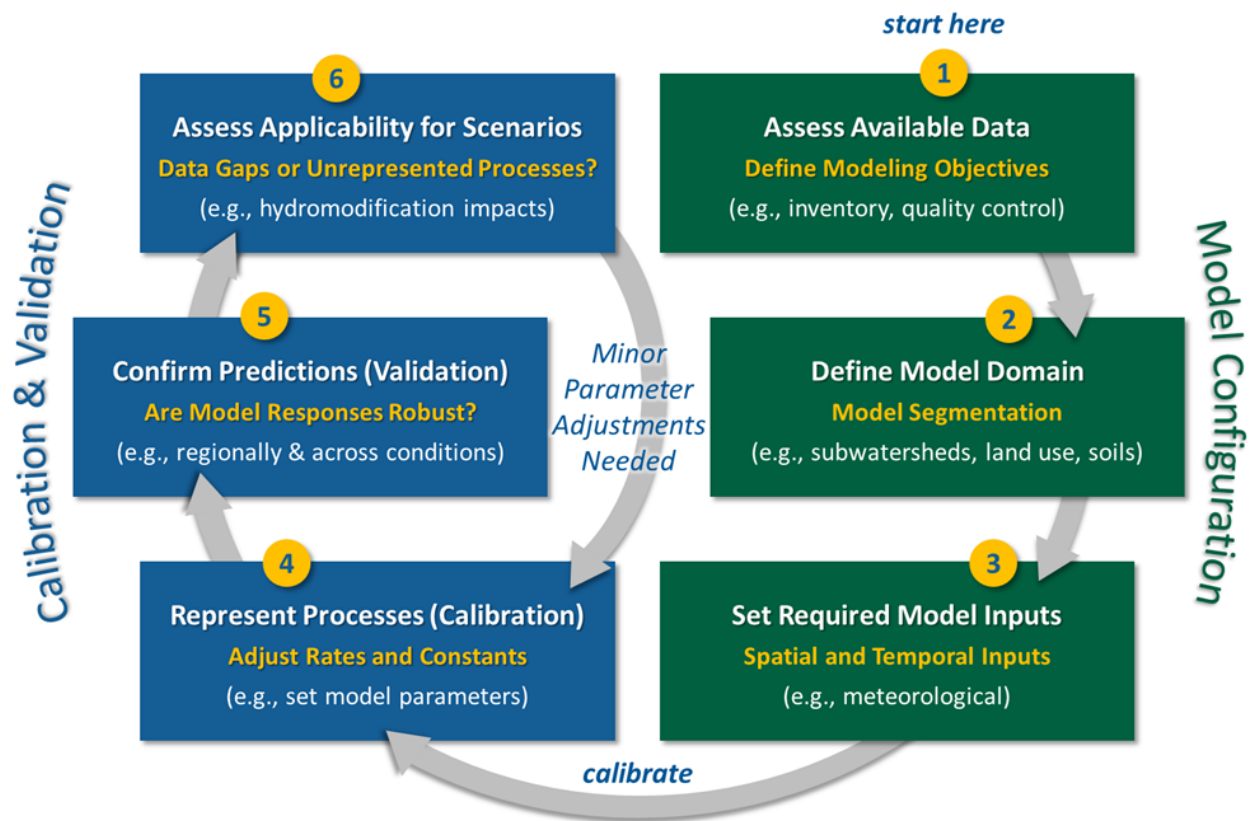


Figure 1-3. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Sonoma Creek watershed.

1.5 Data Availability

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

- ▼ **Meteorology Datasets:** Time series that represent water balance inputs and outputs to the watershed primarily from precipitation and ET. 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 Sonoma Creek. Time series observations of instream responses for the Sonoma Creek are often used as calibration and validation datasets for hydrologic models.
- ▼ **Geospatial Datasets:** Spatial datasets describing the landscape of the Sonoma Creek watershed. These datasets include physical properties (e.g., soil, land cover, elevation).

Table 1-1. Inventory of meteorology datasets

| Data Source | Dataset | Date Range | Description | Model Use |
|---|--|----------------|---|--|
| National Center 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 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 Santa Rosa. | Climate data boundary time series. |
| California Data Exchange Center (CDEC) | Precipitation, Temperature | -- | Meteorological records available for 2 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 ETn | 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 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 Date | Description | Model Use | Link |
|--------------|-------|--|---|----------------|--|-------------------------------------|----------------------|
| Streamflow | Local | United States Geological Survey (USGS) | Stream Station Discharge | 1929 – Current | Observed streamflow at two active locations on the Sonoma Creek. | Hydrology calibration. | LINK |
| | | National Inventory of Dams (NID) | Dams of the United States | Current | Locations for dams across the United States. | Hydrology Calibration. | LINK |
| Habitat | Local | CDFW | Sonoma Creek Watershed Sediment TMDL and Habitat Enhancement Plan | 2008 | 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 current date. | | LINK |
| | | | Annual Water Use Report | 1906 – 2023 | Annual reports that provide monthly diversion data for various entities such as Applications, Registrations, Petitions, etc. | | LINK |
| | | DWR | Agricultural Land and Water Use Estimates | 1998 – 2015 | Water use estimates by various planning units. | | LINK |
| | | CDT | Water Districts | 2022 | Boundaries of all public water agencies in California. | | LINK |
| | | | California Drinking Water System Area Boundaries | 2024 | Public California drinking water systems and state small drinking water system boundaries and information. | | LINK |

Table 1-3. Inventory of geospatial datasets

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

| Category | Scale | Source | Dataset | Date Range | Description | Model Use | Link |
|--------------------------|----------|----------|--|----------------|--|--|----------------------|
| Land Use | State | 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 |
| | 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 |
| | | | 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 |

| Category | Scale | Source | Dataset | Date Range | Description | Model Use | Link |
|------------------------------|----------|----------|---|----------------|---|---|----------------------|
| Fire Perimeters & Burn Areas | State | CAL FIRE | California Fire Perimeters | 1950 - Present | Wildfire perimeters. | Representing changes in land cover due to forest fire activities. | 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 | 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 |
| Groundwater Extraction | State | DWR | GSP Annual Report Data | 2023 | Groundwater extraction | Groundwater extraction | 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 Sonoma Creek watershed 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 leverages both land-based and grid-based data to build a complete spatial and temporal meteorological dataset. Use of a hybrid approach preserves locally sampled station data while increasing the spatial and temporal quantity and quality over the watershed. This approach has been applied for large watershed-scale modeling applications including the County-wide model for Los Angeles County (LACFCD 2020).

Land-based observed precipitation data are primarily acquired from the National Centers for Environmental Information (NCEI), which maintains data from the National Oceanic and Atmospheric Administration (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. Twelve GHCN stations were identified within or near the Sonoma Creek watershed, with each having a varied quantity and quality of data. In addition to the daily precipitation stations, NCEI also maintains the Local Climatological Data (LCD) network, which reports hourly observations. There are three LCD stations within 15 km of the Sonoma Creek watershed. The California Data Exchange Center (CDEC) and the Remote Automated Weather Stations (RAWS) networks also report hourly precipitation. CDEC reports at three locations and RAWS reports at one location within and near the watershed.

In addition to precipitation data, snow data was also screened for the Sonoma Creek watershed model, which yielded eight GHCN stations within a 15 km 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 Sonoma Creek watershed with available data after 2000 with at least 75% data coverage during the modeling period. It also includes stations with 60% or more data coverage during the modeling period, provided that these stations have 90% or more station record coverage. Station record coverage is defined as the percentage of available records that are not missing throughout the duration of the record for the period overlapping with the modeling period. Additionally, all recently installed stations with at least 6 years of data (i.e., 30% or more model period availability) for the modeling period are included if they have 90% or more station record coverage for their reported period overlapping with the modeling period. Lastly, any stations with no neighboring stations within a 7 km buffer are included. [Figure 2-1](#) shows the location of the stations proposed for model development. There is one location where CDEC and RAWS stations appear to be co-located (i.e., within a 500m radius) and one location where LCD and GHCN stations appear to be co-located; these will be further assessed under Task 3.2 and the stations with the highest quality data will be chosen for use.

The primary source of the grid-based data for Sonoma Creek Watershed will be the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al. 2008 and 1994; 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 (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 |
|-----------|-------------------|------------------------------|------------|-----------|---------|----------|--------------------|--|--|
| NOAA-LCD | WBAN:93227 | NAPA CO AIRPORT | 12/31/1999 | Present | 38.2075 | -122.280 | 4.7 | 100% | 100% |
| | WBAN:00135 | GNOSS FIELD AIRPORT | 7/30/2014 | Present | 38.150 | -122.550 | 1.2 | 46% | 100% |
| | WBAN:00320 | PETALUMA MUNICIPAL AIRPORT | 7/30/2014 | Present | 38.250 | -122.600 | 27.1 | 46% | 100% |
| NOAA-GHCN | GHCND:USC00041312 | CALISTOGA | 3/1/1906 | Present | 38.576 | -122.578 | 106.7 | 87% | 87% |
| | GHCND:USC00047643 | SAINT HELENA | 10/1/1907 | 4/30/2023 | 38.506 | -122.471 | 68.6 | 88% | 89% |
| | GHCND:USC00048351 | SONOMA | 1893-01-01 | Present | 38.299 | -122.462 | 29.6 | 92% | 92% |
| | GHCND:USC00040212 | ANGWIN PACIFIC UNION COLLEGE | 1/1/1940 | Present | 38.573 | -122.440 | 522.7 | 94% | 94% |
| | GHCND:USC00046826 | PETALUMA AP | 1893-02-01 | Present | 38.257 | -122.607 | 6.1 | 100% | 100% |
| | GHCND:USW00093227 | NAPA CO AP | 5/1/1998 | Present | 38.207 | -122.280 | 4.9 | 100% | 100% |
| | GHCND:US1CANP0003 | CALISTOGA 0.4 SSE | 2/1/2009 | Present | 38.576 | -122.578 | 106.1 | 69% | 95% |
| | GHCND:US1CASN0071 | ROHNERT PARK 0.9 SW | 2/1/2009 | Present | 38.339 | -122.711 | 29.3 | 70% | 96% |
| | GHCND:US1CASN0061 | SANTA ROSA 1.3 NW | 2/1/2009 | Present | 38.464 | -122.715 | 52.7 | 70% | 96% |
| | GHCND:US1CASN0080 | GLEN ELLEN 1.5 N | 4/1/2009 | Present | 38.377 | -122.534 | 102.7 | 72% | 100% |
| | GHCND:US1CASN0121 | SANTA ROSA 2.1 NNE | 11/1/2015 | Present | 38.477 | -122.690 | 196.0 | 38% | 96% |
| | GHCND:USC00049859 | YOUNTVILLE | 11/1/2002 | 6/30/2012 | 38.395 | -122.356 | 29.0 | 30% | 70% |
| CDEC | SH4 | ST. HELENA 4WSW | 1/2/1984 | Present | 38.493 | -122.539 | 527.0 | 98% | 98% |
| | ANG | ANGWIN | 1/1/1987 | Present | 38.571 | -122.433 | 553.2 | 98% | 98% |

| Agency | Station ID | Station Name | Start Date | End Date | Lat. | Long. | Elevation (meters) | Model Period Coverage (%) ¹ | Station Record Coverage (%) ² |
|--------|------------|------------------|------------|----------|--------|----------|--------------------|--|--|
| | STA | SANTA ROSA (CDF) | 4/1/1991 | Present | 38.479 | -122.712 | 170.7 | 70% | 94% |
| RAWS | RSAC1 | SANTA ROSA | 03/06/1991 | Present | 38.478 | -122.712 | 182.6 | 100% | 100% |

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

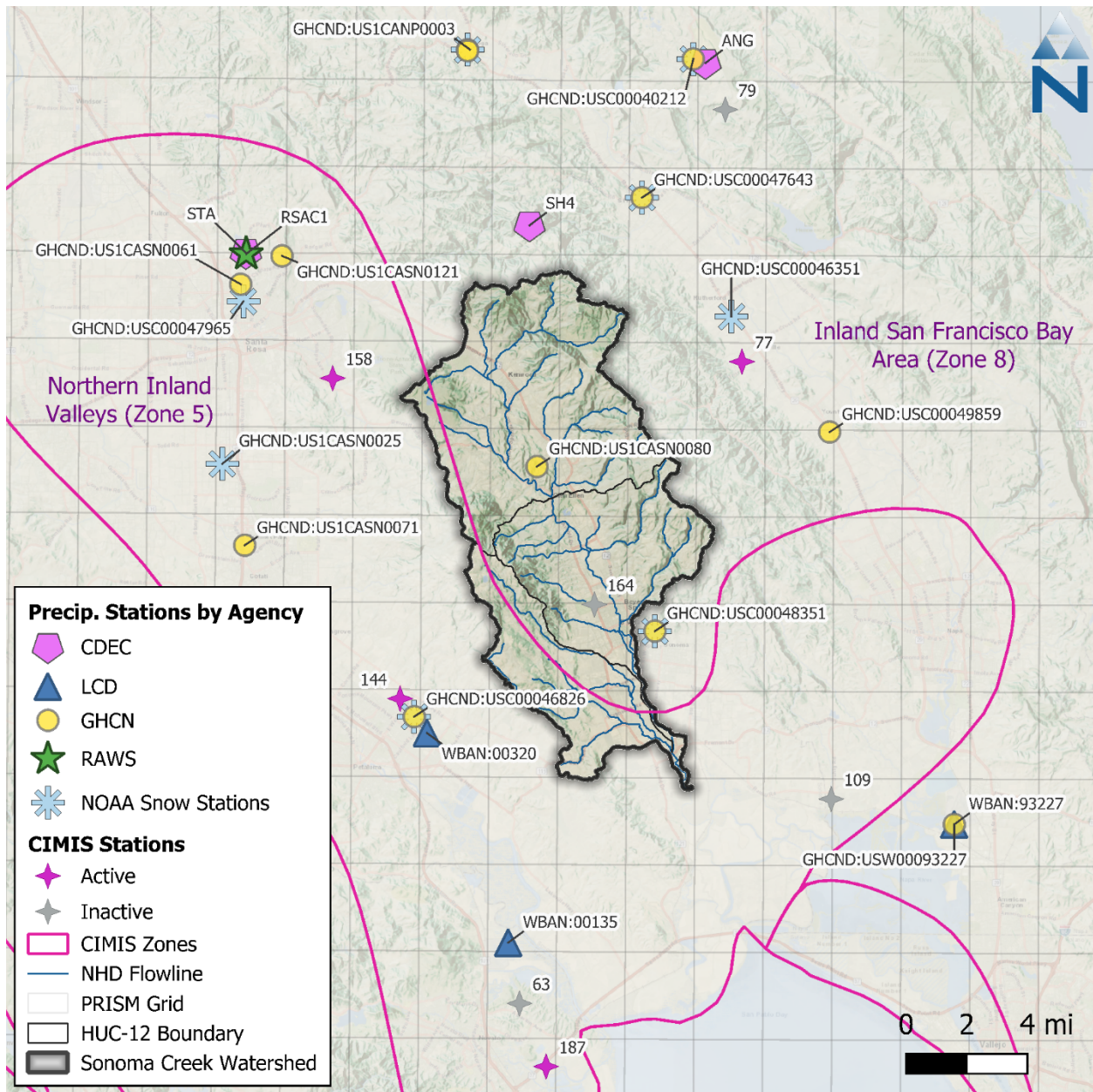


Figure 2-1. Identified rainfall stations and CIMIS ET Zones near the Sonoma Creek watershed.

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

[Figure 2-2](#) presents a summary of the hybrid approach to blend observed precipitation with gridded meteorological products. Observed data and gridded products are to be processed in parallel to: (1)

create a temporally complete set of hourly distributions and (2) identify spatial gaps in coverage to be supplemented with disaggregated gridded data. Assuming a 10 km buffer around observed stations for this approach, the coverage shown in the lower right map in [Figure 2-2](#) also shows what a hybrid dataset of observed time series, supplemented by gridded products would look like.

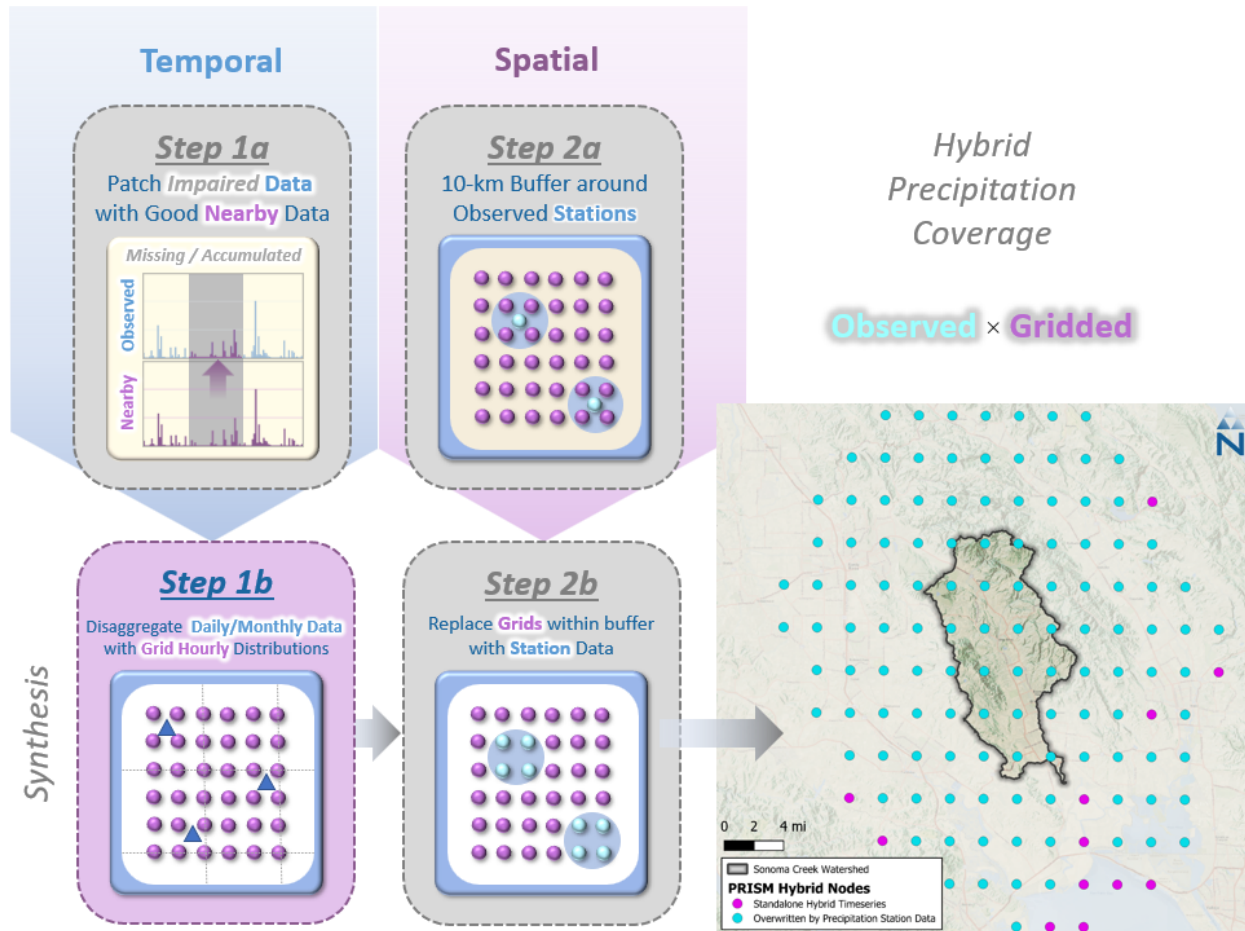


Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products.

2.2 Evapotranspiration (ET)

The primary ET dataset identified for consideration is the California Irrigation Management Information System (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.

CIMIS operates eight stations within ten miles of the Sonoma Creek watershed, including: Novato (ID 63), Oakville (ID 77), Angwin (ID 79), Carneros (ID 109), Petaluma (ID 144), Bennett Valley (ID 158), Valley of the Moon (ID 164), and Black Point (ID 187). The Angwin, Valley of the Moon, Carneros, and Novato stations are no longer operating, but their collective historical time series data covers the period from June 1986 through January 2022. Of the active stations within the 10-mile

watershed buffer, the Bennett Valley, Petaluma, and Black Point stations are slightly west of the watershed region while Oakville is in the east. Collectively, they contain data from March 1989 through the present. There are also three active stations (83, 103, 157) and two inactive stations (51 and 123) situated just outside the 10-mile watershed buffer. As shown in Figure 2-1, the Sonoma Creek watershed intersects two CIMIS zones with 82% of the watershed area in Zone 8 (Inland San Francisco Bay Area), and 18% of the watershed area in Zone 5 (Northern Inland Valleys). Most of the Sonoma Creek watershed falls within Zone 8, and the western edge 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.

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

For LSPC, the user provides PEVT rates as model input. The LSPC model then uses these values along with other model parameters to estimate actual ET. Sometimes ET_0 is provided instead, and HRU-specific coefficient multipliers are used to stratify those inputs based on physical HRU properties such as vegetation density. Additionally, for applications where the study area has significant irrigation practices, the user can provide irrigation water usage rates to represent additional water beyond precipitation that is added to the system—that water would also be available for ET.

The actual ET estimated by an LSPC model can be validated through comparison with data from OpenET. The OpenET project is an operational system for generating and distributing ET data at a field scale using an ensemble of six well-established satellite-based approaches for mapping ET (Melton et al. 2022). OpenET has undergone extensive intercomparison and accuracy assessment conducted using ground measurements of ET; results of these assessments demonstrate strong agreement between the satellite-driven ET models and observed flux tower ET data. Within California, OpenET has data beginning in 2016 and uses CIMIS meteorological datasets to compute ET_0 . In addition to LSPC ET validation, OpenET data can be used to help inform irrigation estimation and parameterization.

In the SFEI LSPC model containing the Sonoma Creek watershed, PEVT is represented using NLDAS and no irrigation is simulated. To assess the 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 for the adjacent Napa River watershed that is expected to have similar ET signatures (except for the CIMIS dataset, which shows the spatial-temporal average of Zone 8). Findings from the Napa River watershed shown in [Figure 2-3](#) are expected to be applicable for the Sonoma Creek watershed due to its proximity. However, a similar analysis will be performed for the Sonoma Creek watershed to confirm.

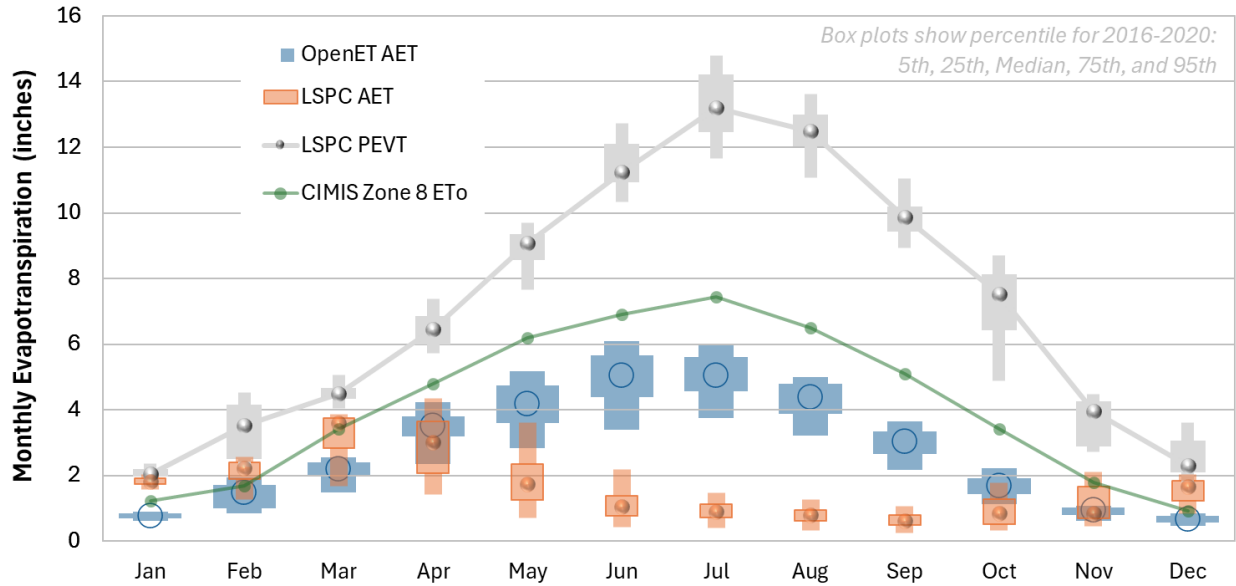


Figure 2-3. Evaluation of monthly evapotranspiration in existing SFEI model. Note that AET is used as an abbreviation for actual ET¹.

This analysis yielded three key findings for the SFEI model:

1. Modeled input for PEVT based on NLDAS is significantly greater than observed ET₀ 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 the Sonoma Creek watershed, 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 irrigation rates are critical steps to improve ET predictions and representation of the overall hydrologic budget. The existing PEVT data set 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 actual evapotranspiration (AET) with irrigation turned off.

¹ Data illustrated on the figure are from the review of the SFEI model for Napa River watershed area ([Supply and Demand Assessment \(SDA\) – Napa River | California State Water Resources Control Board](#)), which is proximal to the Sonoma Creek watershed and expected to follow the illustrated general trend.

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 Sonoma Creek watershed is defined by a HUC-10 watershed that comprises three HUC-12 subwatersheds.

For units 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 59 catchments ranging between 6.4 acres to over 4,200 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 Sonoma Creek watershed (HUC-10).

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

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

| HUC-12 Name | Count | Catchment Size (acres) | | | |
|--------------------|-------|------------------------|---------|---------|---------|
| | | Minimum | Mean | Median | Maximum |
| Upper Sonoma Creek | 25 | 77.4 | 1,151.4 | 1,140.8 | 4,044.3 |
| Lower Sonoma Creek | 20 | 6.4 | 897.7 | 604.7 | 4,241.1 |
| Fowler Creek | 14 | 31.9 | 875.3 | 662.9 | 3,095.2 |

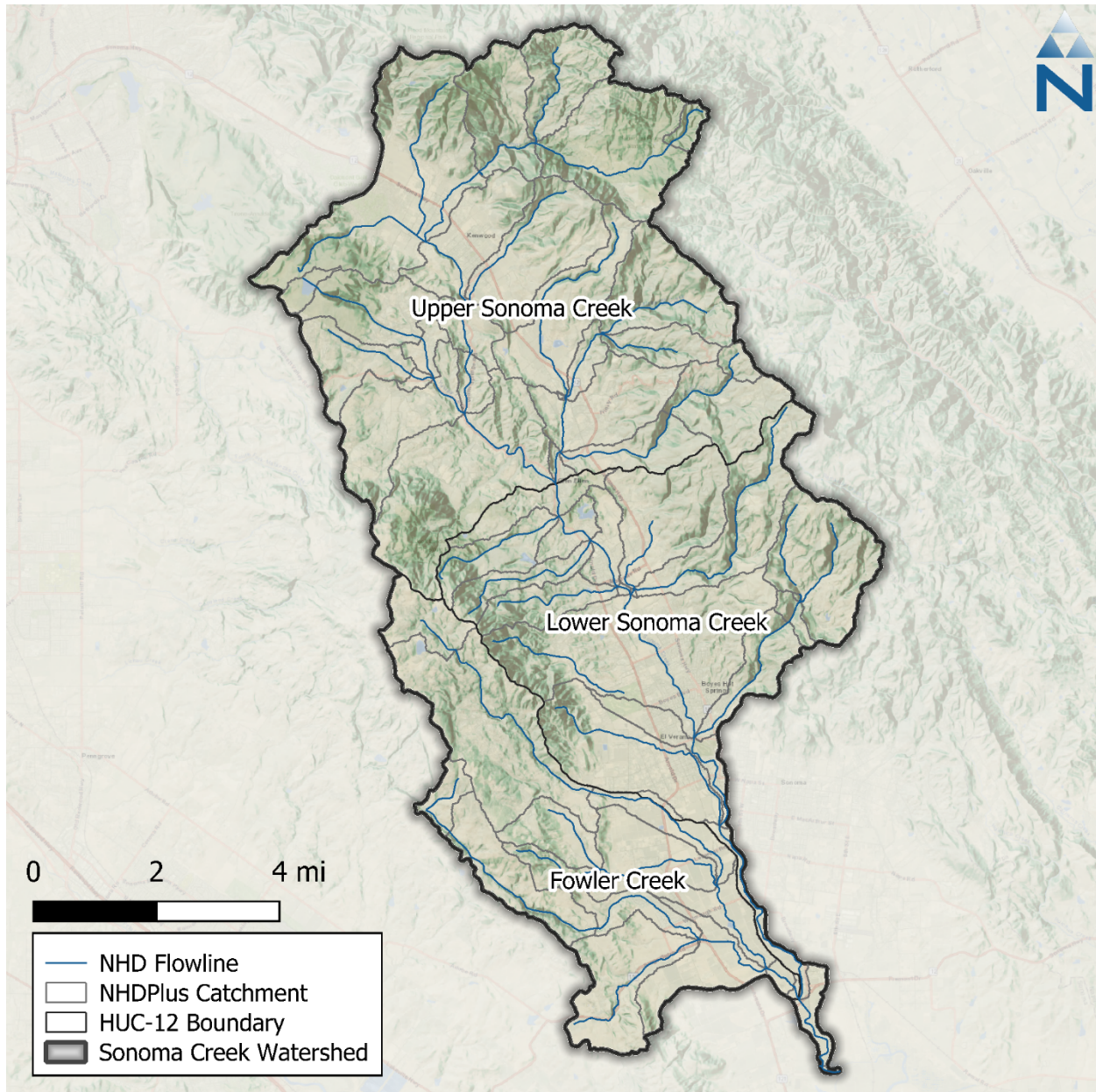


Figure 3-1. Initial catchment segmentation for the Sonoma Creek watershed.

3.2 Streams and Channels

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

3.3 Streamflow

The primary source of streamflow data is from the USGS, which includes two current long-term stations: the Sonoma Creek at Kenwood, CA (USGS 11458433) and the Sonoma Creek at Agua Caliente, CA (USGS 11458500). There are no historical flow stations located upstream on tributaries. [Table 3-2](#) presents a summary of the available USGS flow stations within the Sonoma Creek watershed and [Figure 3-2](#) shows their location.

Table 3-2. Summary of USGS daily streamflow data

| Station Description | Station ID | Drainage Area (mi ²) | Start Date | End Date | Station Active? |
|--|------------|----------------------------------|------------|----------|-----------------|
| SONOMA CREEK A KENWOOD CA ¹ | 11458433 | 14.3 | 10/01/2008 | Present | Yes |
| SONOMA C A AGUA CALIENTE CA ² | 11458500 | 58.4 | 02/09/1955 | Present | Yes |

1. USGS notes “No regulation above station. Diversions for irrigation of about 1,500 acres upstream from station.” (https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=11458433&agency_cd=USGS#adr).
2. USGS notes “No regulation; some diversion above station for irrigation of about 2,000 acres.” (https://waterdata.usgs.gov/nwis/wys_rpt/?site_no=11458500&agency_cd=USGS#adr).

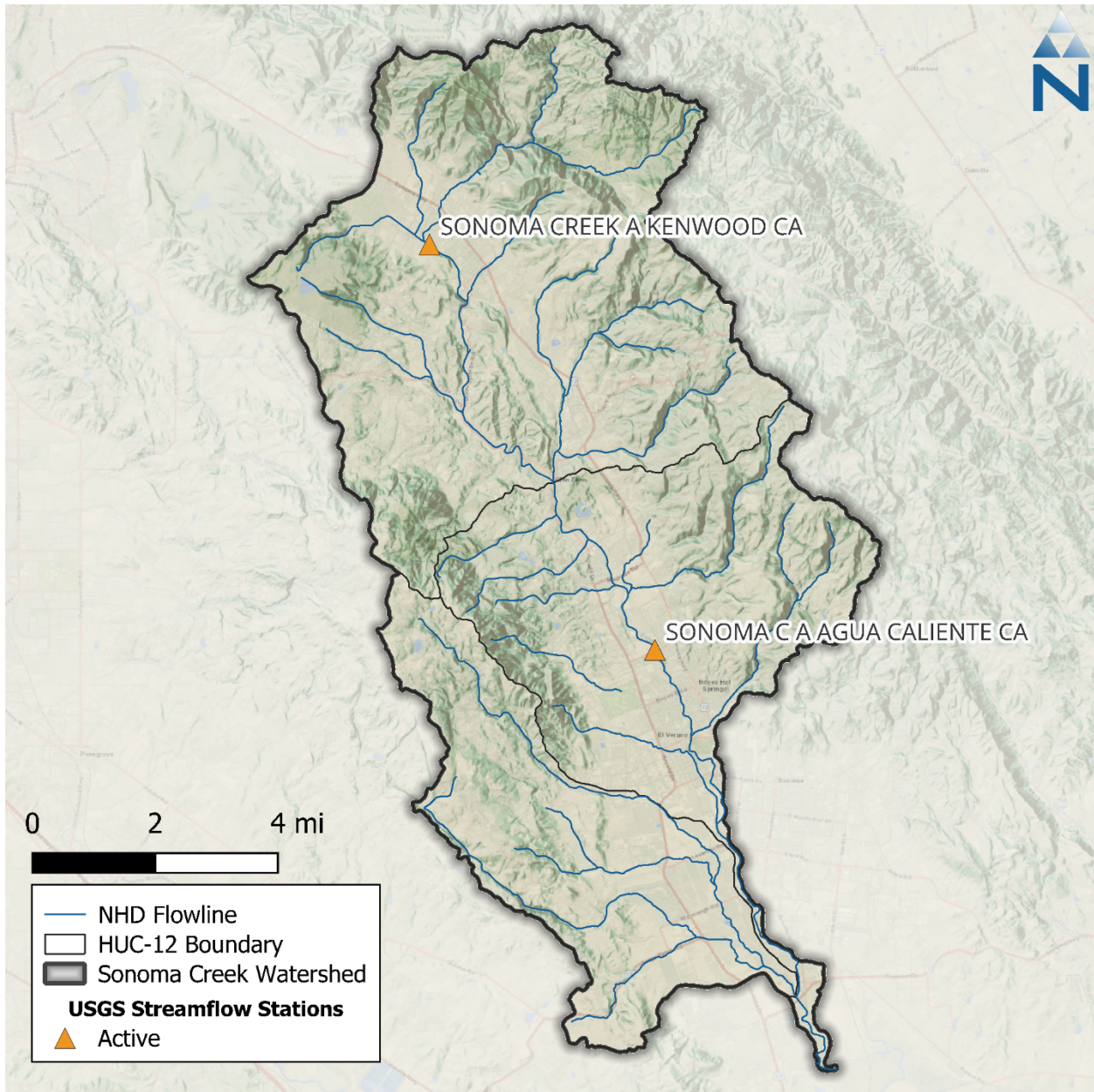


Figure 3-2. USGS streamflow stations in the Sonoma Creek watershed.

3.4 Dams, Reservoirs, and Impoundments

The Sonoma Creek watershed contains several small reservoirs that may require representation within the hydrology model, as listed in [Table 3-3](#) and shown in [Figure 3-3](#). Capturing the operation of these features will be important to accurately represent the movement of water throughout the watershed. Having stage-storage relationships for reservoirs, and any other outflow rates or operating conditions, will allow for more accurate model representation.

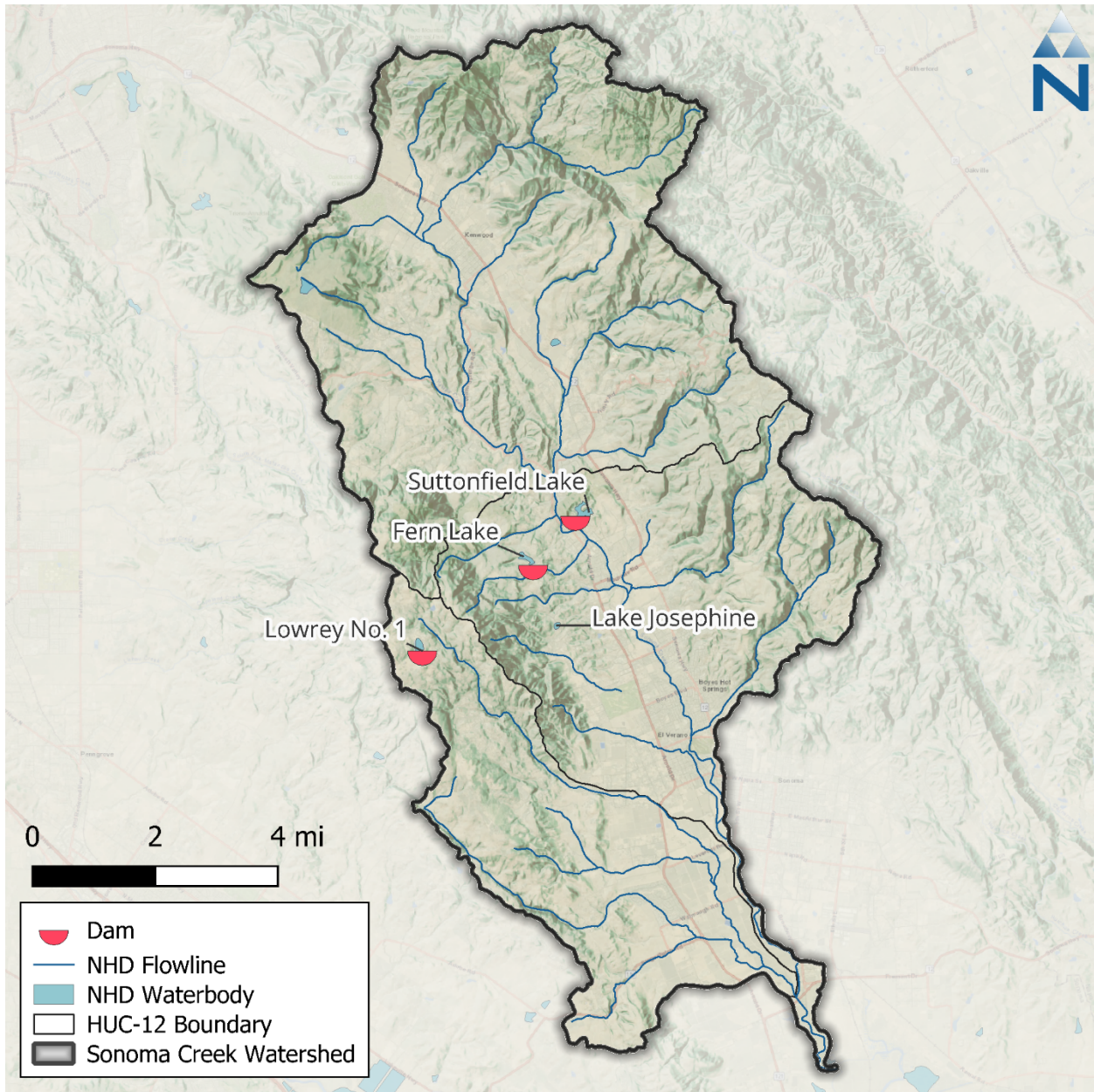


Figure 3-3. Dams within the Sonoma Creek watershed relevant for watershed modeling effort (NID 2025).

There are three dams within the Sonoma Creek watershed, listed in [Table 3-3](#). Suttonfield (NID CA00010) and Fern Lake (NID CA00007) are state owned while Lowrey No. 1 (NID CA00990) is privately owned. All three dams are used for the purpose of water supply and irrigation. It is currently unknown whether the size and capacity of Lowrey No. 1, which is notably smaller than Suttonfield and Fern Lake, is significant enough to have an impact on the hydrologic model. Key metrics such as the average flow volume and average storage of each dam are currently unknown, since there are no CDEC stations with this data. The NID database also does not report this information.

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

| NHD Waterbody | Dam Name | NID ID | Drainage Area (ac) | Area (ac) ¹ | Storage Capacity (ac-ft) | Average Flow Volume (ac-ft) | Average Storage (ac-ft) |
|------------------|--------------|---------|--------------------|------------------------|--------------------------|-----------------------------|-------------------------|
| Suttonfield Lake | Suttonfield | CA00010 | 76.8 | 24 | 600 | -.3 | -.3 |
| Fern Lake | Fern Lake | CA00007 | 160 | 14 | 241 | -.3 | -.3 |
| Lake Josephine | NA | NA | -.2 | 5.4 | -.2 | -.3 | -.3 |
| Unknown | Lowrey No. 1 | CA00990 | 89.6 | 16 | 82 | -.3 | -.3 |
| Unknown | NA | NA | -.2 | 24 | -.2 | -.3 | -.3 |
| Unknown | NA | NA | -.2 | 8.4 | -.2 | -.3 | -.3 |

1. The primary source of data for area is NID. If NID is not available because of the absence of dams associated with the waterbody, then NHD data is used.
2. Data not listed from NID or NHD.
3. Data may exist but does not appear readily accessible.

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

Figure 3-4 provides an overview of the primary drinking water sources in the watershed. Water systems distributed throughout the watershed include 37 areas of groundwater withdrawals for the Sonoma Creek watershed groundwater basin. The number of active surface water PODs and withdrawal volumes will be evaluated from eWRIMS reports during model development.

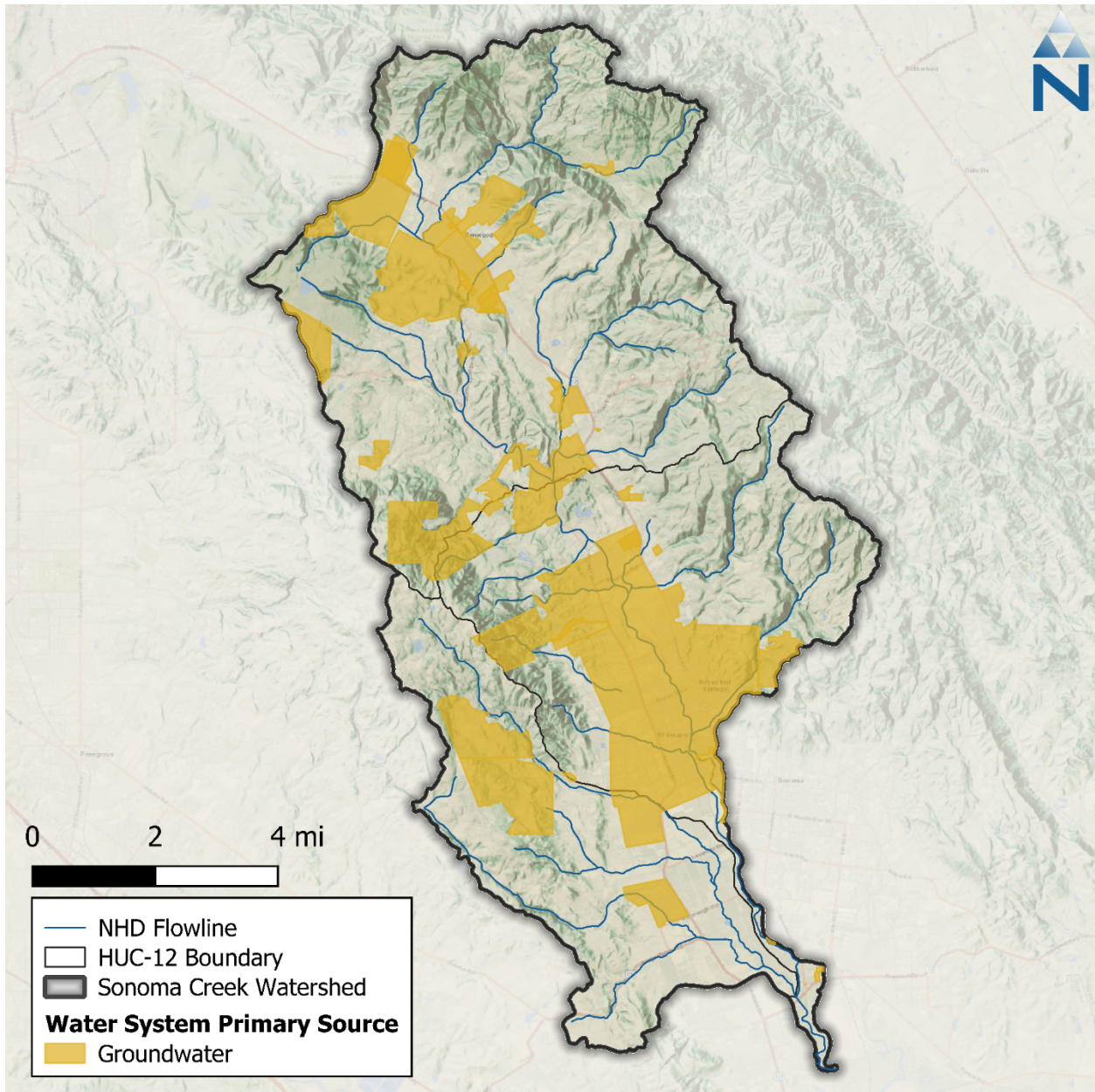


Figure 3-4. Water system sources in the Sonoma Creek watershed.

4 SUBSURFACE HYDROLOGY

The Sonoma Creek watershed contains two groundwater basins as delineated by Bulletin 118 (DWR 2020). The watershed overlaps with the Kenwood Valley basin (# 2-019), and the Sonoma Valley subbasin (# 2-002.02), with a silver containing negligible overlap at the border of the Petaluma Valley basin (# 2-001). The watershed does not fully contain any basins. Approximately 32% of the watershed area falls within the groundwater basins delineated by Bulletin 118 and the remaining 68% consists of andesitic and basaltic volcanic rock.

As per the Sustainable Groundwater Management Act's (SGMA) Basin Prioritization Dashboard details (DWR 2020), the Sonoma Creek Subbasin has a variety of prioritizations as designated by

SGMA. The Kenwood Valley basin is Very Low priority due to total groundwater use of less than 2,000 acre-feet/year. Approximately half of the Kenwood Valley basin falls within the Sonoma Creek watershed. The Sonoma Valley sub-basin is High priority due to declining water levels, saline intrusion, and a large number of water supply and total wells. Approximately the upper third of the Sonoma Valley subbasin falls within the Sonoma Creek watershed. The Sonoma Valley GSA operates within the Sonoma Valley sub-basin (Sonoma Valley GSA 2021). [Figure 4-1](#) is a map overlaying the Sonoma Creek Watershed, the Bulletin 118 Sonoma Valley subbasin, and the USGS Sonoma Valley model domain.

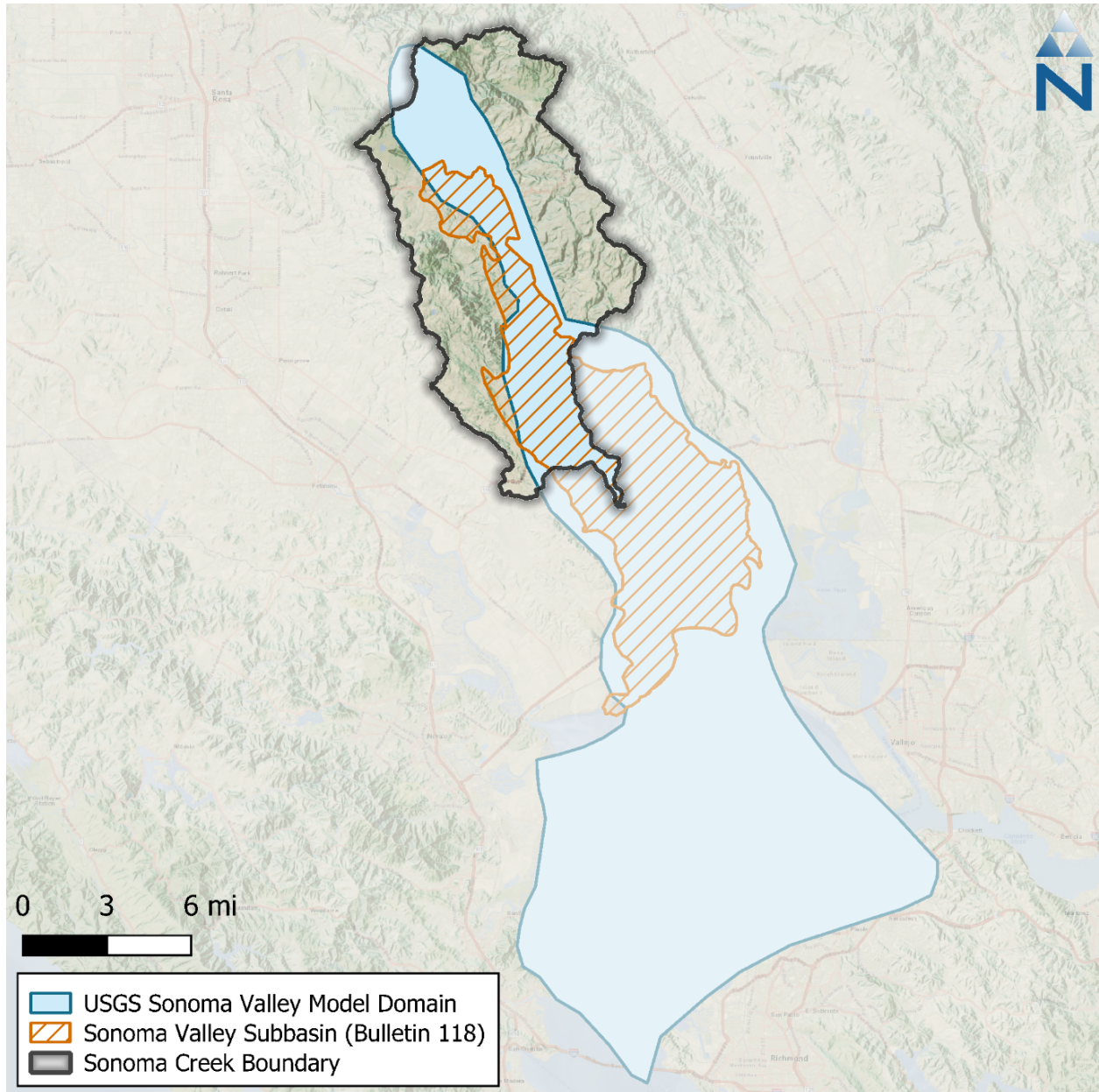


Figure 4-1. Outlines of Sonoma Watershed Study Area, Sonoma Valley Subbasin Boundary (Bulletin 118), and USGS Sonoma Valley Model Boundary.

4.1 Water Budget Components

The publicly available groundwater models in the region partially overlap the Sonoma Creek basin. The USGS Sonoma Valley model simulated a water budget for the year 2000, estimating inflows including 36,600 acre-feet/year from natural recharge, 1,570 acre-feet/year from seawater in San Pablo Bay, and 1,270 acre-feet/year infiltrating from Sonoma Creek. Estimated outflows included 769 acre-feet/year to the Bay Mud deposits, 755 acre-feet/year to San Pablo Bay, 30,400 acre-feet/year flowing to Sonoma Creek, and 8,340 acre-feet/year of groundwater pumping. Approximately 10% of the groundwater pumping is supplied through storage depletion (Farrar et al. 2006). Bulletin 118 reports did not contain groundwater budget information for the Kenwood Valley basin but referenced a 1958 study by the US Geological Survey that estimated a groundwater storage capacity of 40,000 acre-feet. Within the USGS public domain models for Northern California, the Sonoma Valley model partially overlaps the Sonoma Creek basin (USGS 2024). [Figure 4-2](#) shows the annual water budget components reported in the USGS groundwater analysis for Sonoma Valley (Farrar et al. 2006).

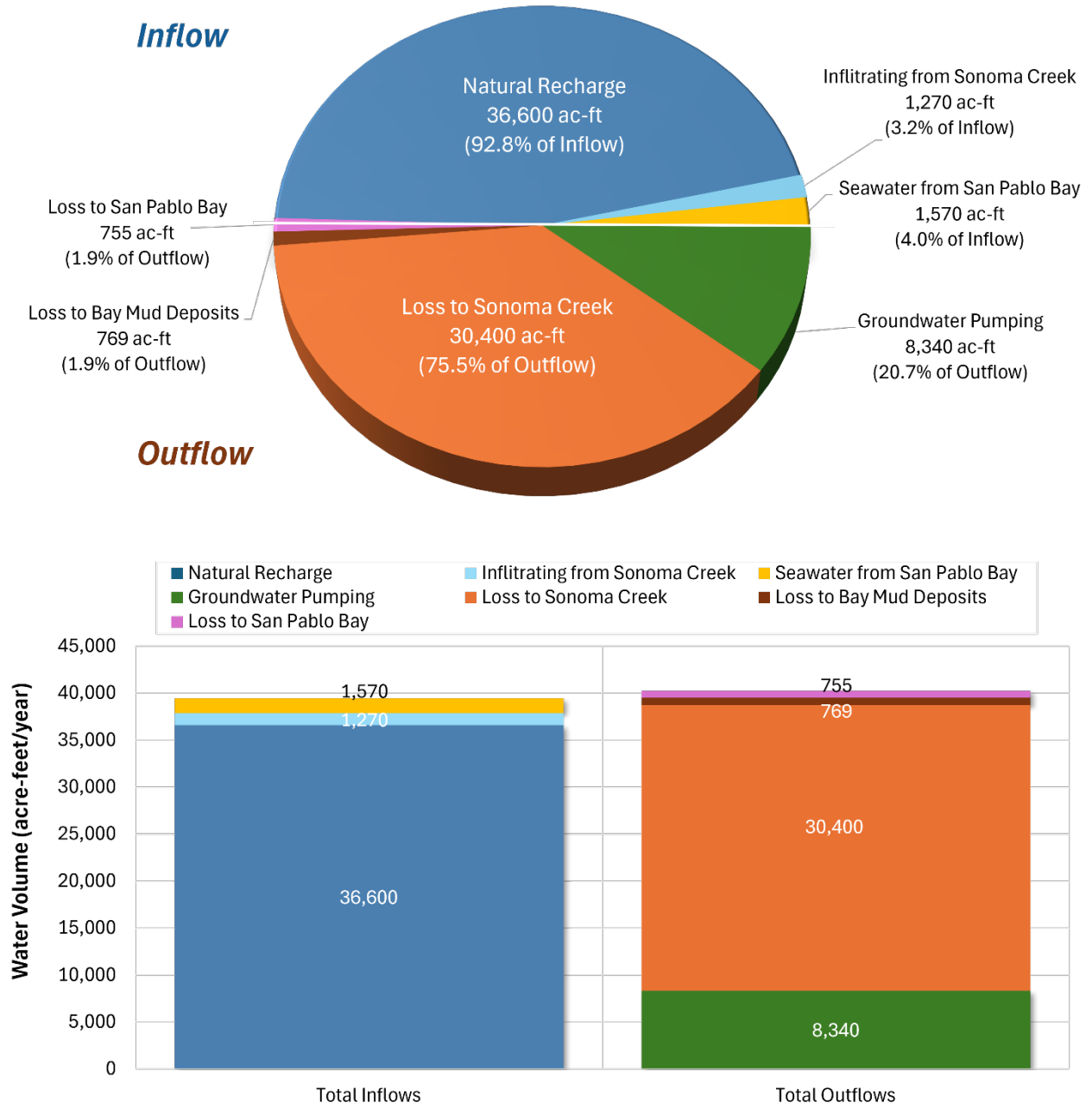


Figure 4-2. Annual Groundwater Budget Components for Year 2000 as per the USGS Sonoma Valley Model (Farrar et al. 2006: Table 7).

4.2 Geology

The foregoing references provide coverage primarily within the groundwater basins delineated as per Bulletin 118. The water bearing units within the Sonoma Valley sub-basin include Quaternary alluvial deposits, with occasional wells also completed in the St Helena rhyolite member of the Sonoma Volcanics. The water bearing units within the Kenwood Valley basin include Quaternary alluvial deposits and the Plio-Pleistocene Glen-Ellen formation. In the Sonoma Creek watershed outside the delineated basins, the bedrock is principally composed of the Sonoma Volcanics, a group of andesitic to basaltic rocks shown by the California Geological Survey in their 1982 regional Santa Rosa map (California Division of Mines and Geology 1982). 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. The Rodgers Creek fault zone parallels the eastern boundary of the basin.

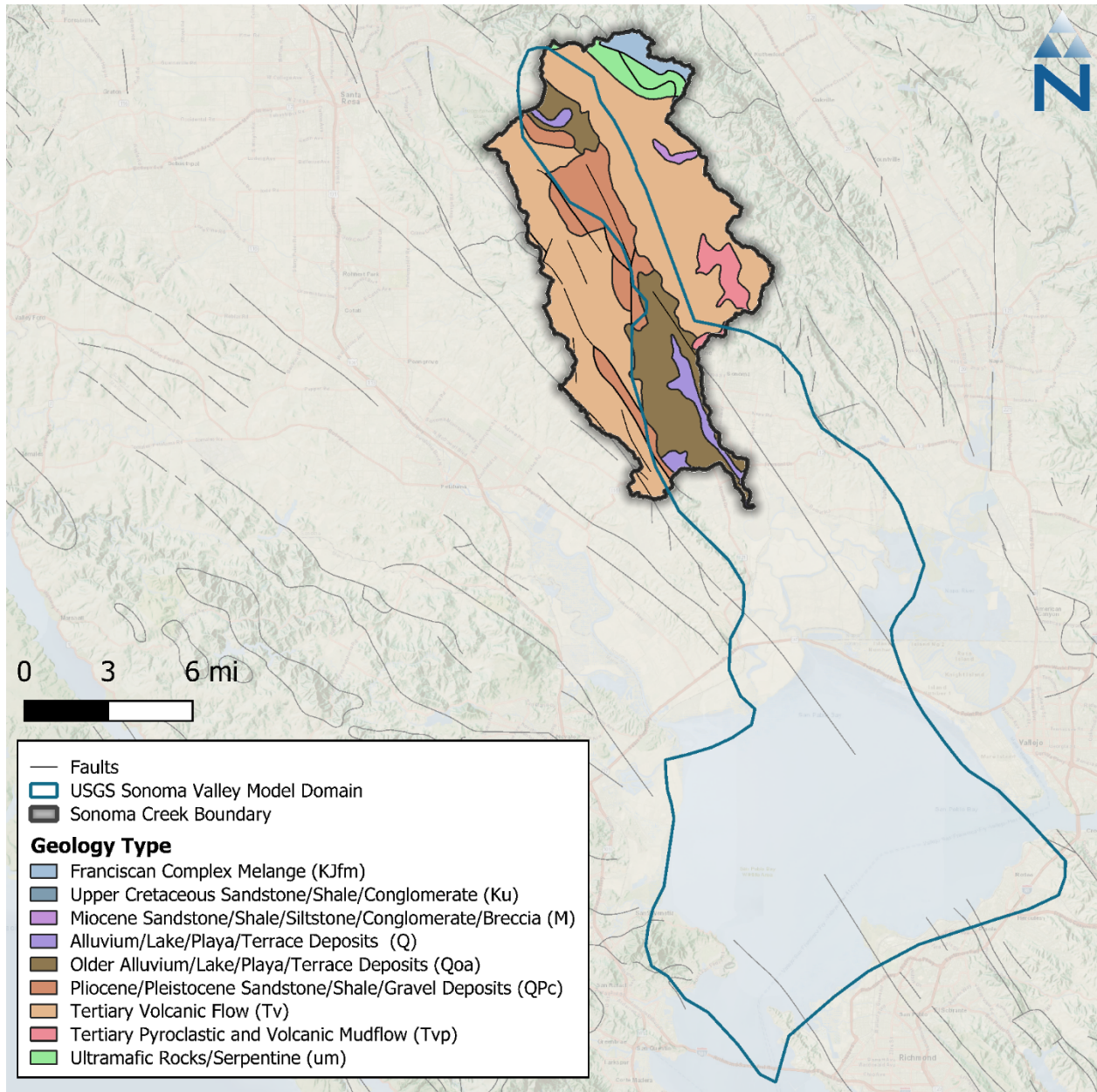


Figure 4-3. Geology map of the Sonoma Creek watershed (CGS 2010) including the approximate USGS groundwater model area boundary.

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 Sonoma Creek watershed.

5.1 Elevation & Slope

The USGS publishes DEMs expressing landscape elevation through a raster grid data product with 30-meter resolution. The Sonoma Creek watershed ranges in elevation from near sea level (1.7 meters) near the outlet of the watershed to over 830 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 Sonoma Creek watershed.

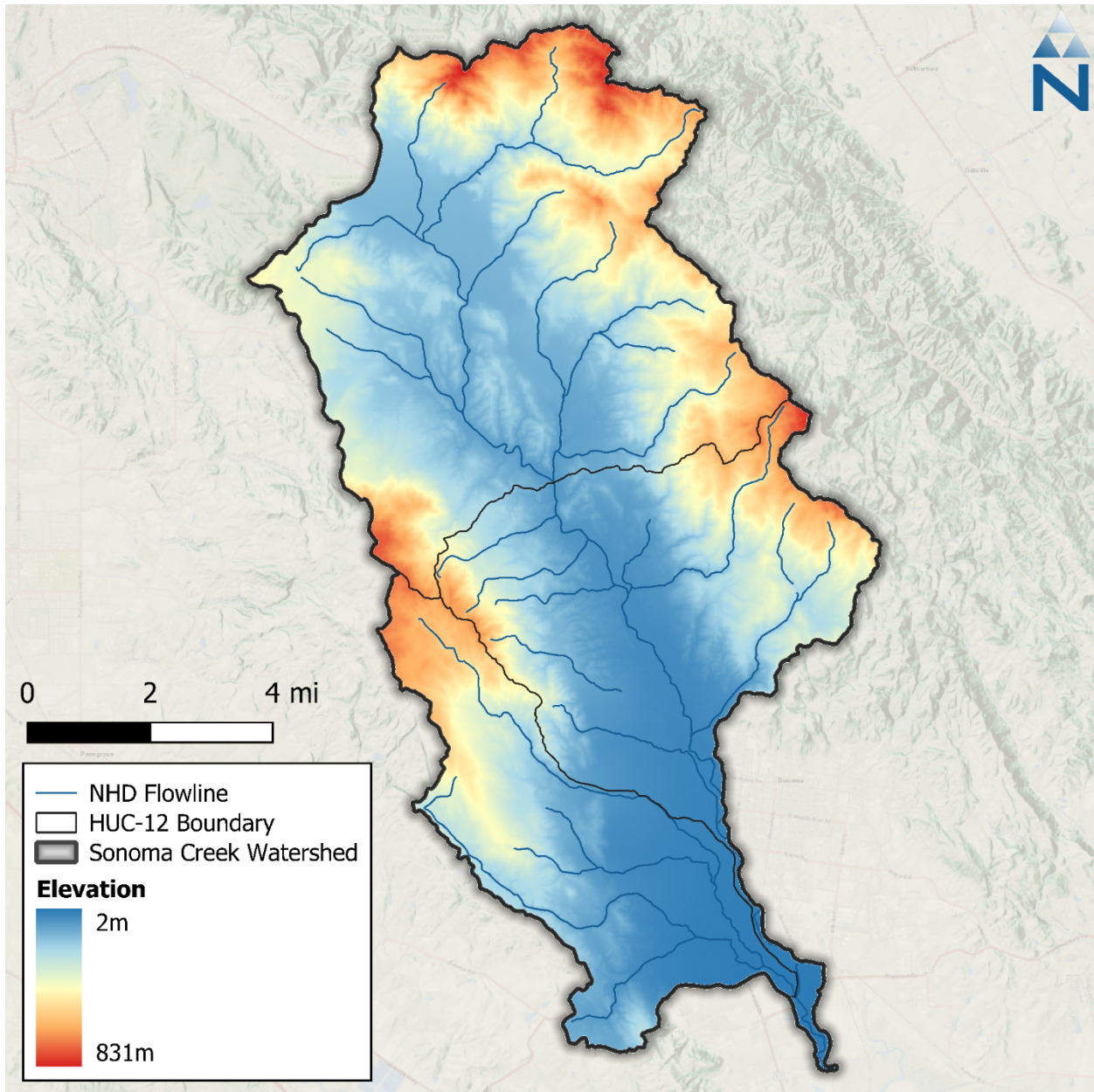


Figure 5-1. Digital elevation model of the Sonoma Creek watershed.

5.2 Soils

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

There are four primary hydrologic soil groups (HSG) used to characterize soil runoff potential. Group A generally has the lowest runoff potential whereas Group D has the highest runoff potential. 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 Sonoma Creek watershed. The dominant soil group in the watershed is Group C (46%) and contains sandy clay loam that typically have low infiltration rates. Group D (39%) 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 2% of the watershed, contains moderately well to well-drained silt loams and loams, and Group A, contains well-draining sand, loamy sand, and sandy loam, makes up less than 1%. Only 3% 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 10% of the watershed HSG area is classified as unknown in the SSURGO database and reside primarily within 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 Sonoma Creek watershed

| Hydrologic Soil Group | Area (acres) | Percent Area |
|-----------------------|------------------|---------------|
| A | 38.48 | 0.07% |
| B | 1,1221.02 | 2.07% |
| C | 26,968.34 | 45.63% |
| C/D | 1,954.44 | 3.31% |
| D | 22,985.46 | 38.90% |
| N/A | 5,928.59 | 10.03% |
| Total | 59,091.33 | 100.0% |

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

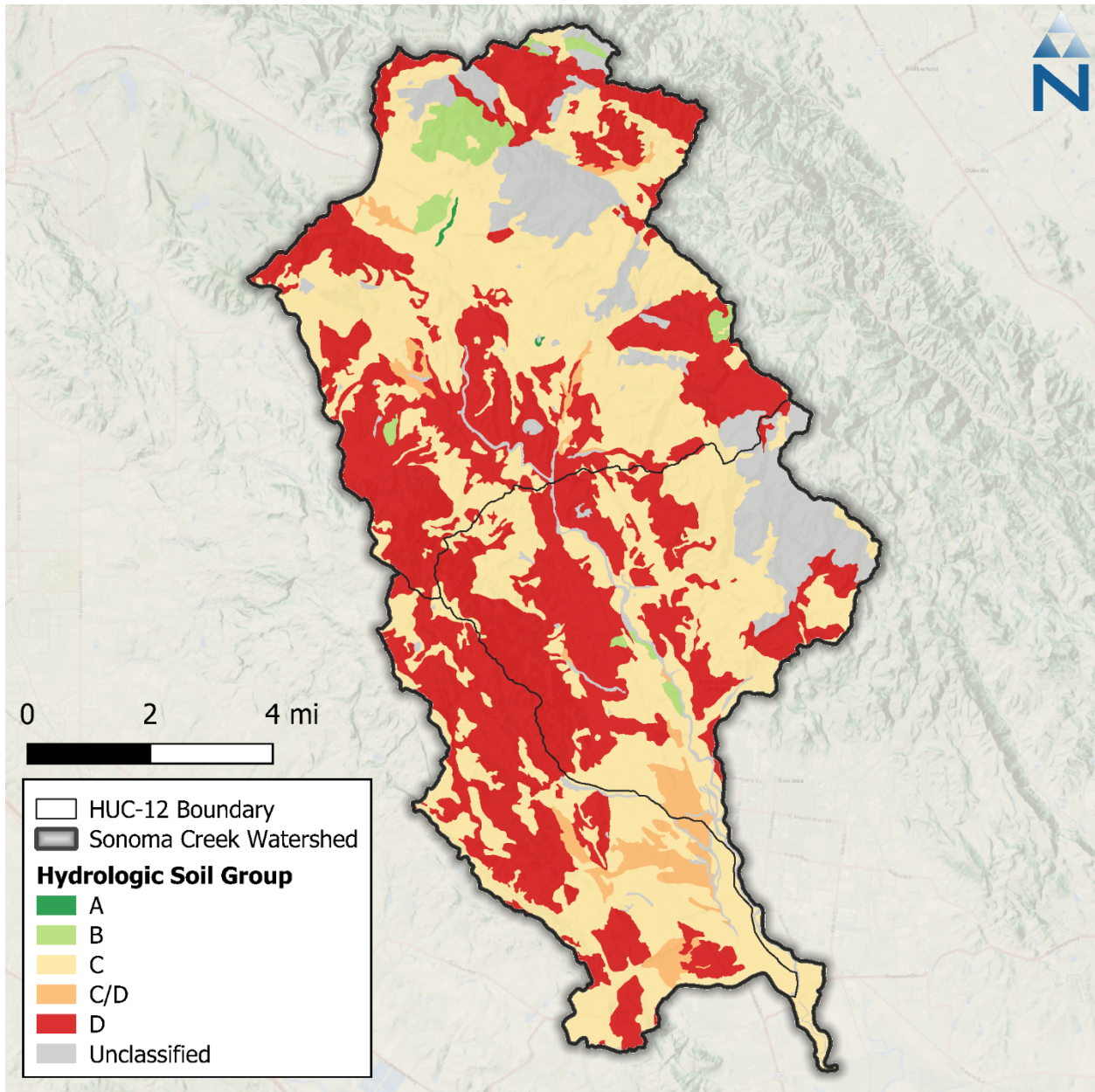


Figure 5-2. SSURGO hydrologic soil groups within the Sonoma Creek watershed.

5.3 Land Cover

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

[Table 5-3.](#) summarizes areal coverage of land use classes from a subset of the 2021 NLCD dataset that covers the Sonoma Creek watershed and

Figure 5-3 shows the spatial distribution of these classifications. Grassland/Herbaceous is the dominant land cover class covering approximately 27% of the watershed. When combined, deciduous forest, evergreen forest, mixed forest, shrub/scrub, and grassland/herbaceous account for 78% of the total watershed area. Developed land cover makes up approximately 14% of the total watershed area, with half classified as “Developed, Open Space”. Approximately 6% 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 Sonoma Creek watershed

| NLCD Class | Classification Description | Area (acres) | Percent |
|--------------------------|--|------------------|-------------|
| 11 | Open Water | 111.11 | 0.19% |
| 21 | Developed, Open Space ¹ | 4,156.84 | 7.03% |
| 22 | Developed, Low Intensity ¹ | 2,649.13 | 4.48% |
| 23 | Developed, Medium Intensity ¹ | 1,409.51 | 2.39% |
| 24 | Developed, High Intensity ¹ | 140.06 | 0.24% |
| 31 | Barren Land (Rock/Sand/Clay) | 8.24 | 0.01% |
| 41 | Deciduous Forest | 1,186.40 | 2.01% |
| 42 | Evergreen Forest | 9,196.13 | 15.56% |
| 43 | Mixed Forest | 5,077.59 | 8.59% |
| 52 | Shrub/Scrub | 15,176.44 | 25.68% |
| 71 | Grassland/Herbaceous | 15,794.35 | 26.73% |
| 81 | Pasture/Hay | 89.74 | 0.15% |
| 82 | Cultivated Crops | 3,696.80 | 6.26% |
| 90 | Woody Wetlands | 293.48 | 0.50% |
| 95 | Emergent Herbaceous Wetlands | 103.32 | 0.17% |
| TOTAL² | | 59,089.15 | 100% |

Source: 2021 National Land Cover Database

1. Imperviousness: Open Space (<20%); Low Intensity (20-49%); Medium Intensity (50-79%); High Intensity (≥80%).
2. Note that because of the raster resolution, this total is approximately 2 acres less than the model domain.

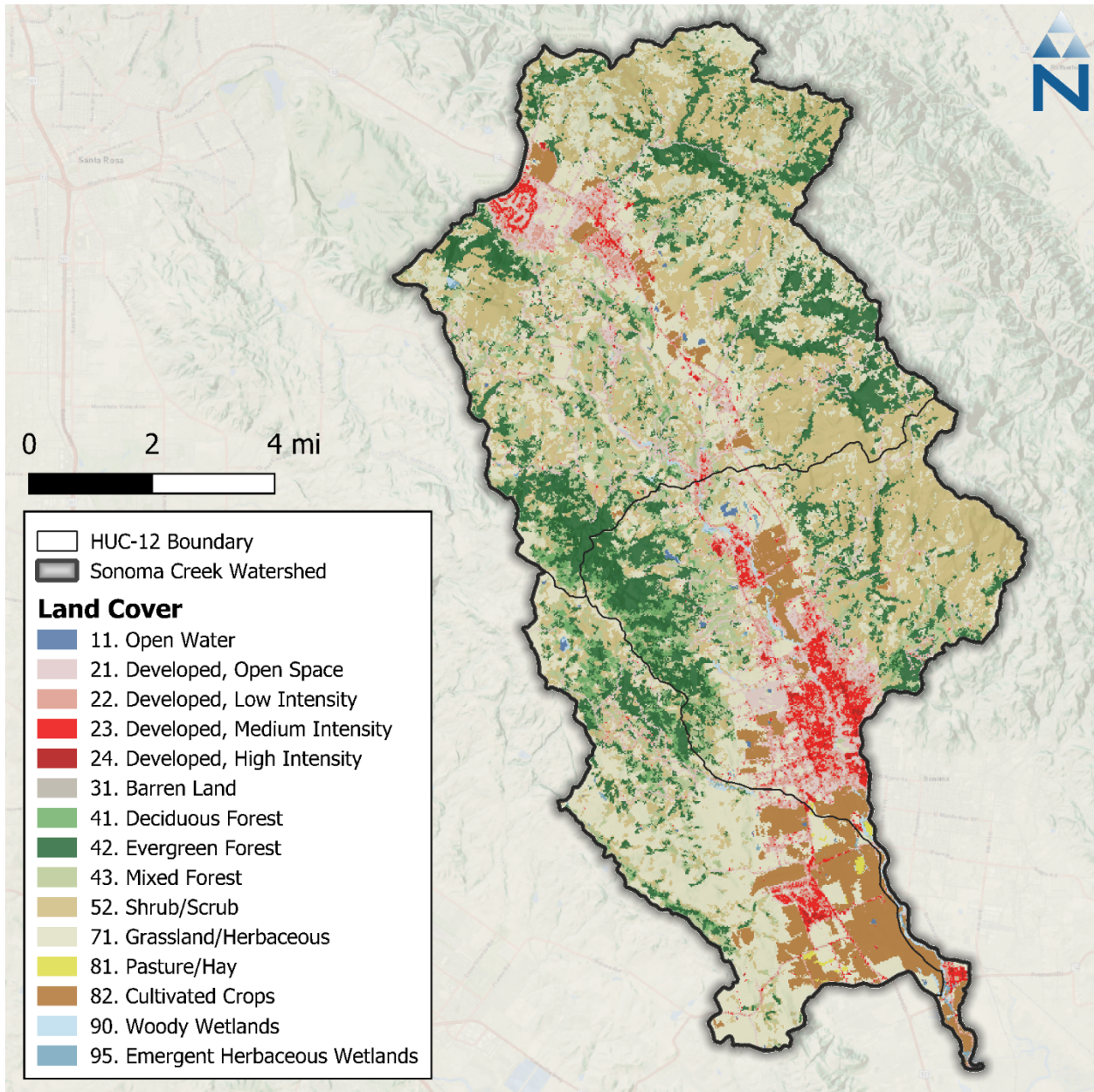


Figure 5-3. NLCD 2021 land cover within the Sonoma Creek watershed.

MRLC publishes a developed impervious cover dataset as a companion to the NLCD land cover; this dataset is also provided as a raster with a 30-meter grid resolution. Impervious cover is expressed in each raster pixel as a percentage of total area ranging from 0 to 100 percent. Because this dataset provides impervious cover estimates for areas classified as *developed*, non-zero values closely align with developed areas (NLCD classification codes 21 through 24). Review of the Sonoma Creek watershed using this dataset shows that just over 14% 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 Sonoma Creek watershed will be assessed as part of the model development, and a decision will be made based on the results as to whether land use change is represented explicitly, or a single land use snapshot is used.

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

5.4 Tree Canopy Cover

MRLC publishes a tree canopy dataset as a companion to the NLCD land cover dataset that estimates the percentage of tree canopy cover spatially. The underlying data model was developed by the United States Forest Service (USFS) and is available through their partnership with the MRLC. This dataset is also provided as a raster with a 30-meter grid resolution. Like the impervious cover dataset, each raster pixel expresses the percent of the total area covered by tree canopy with values ranging from 0 to 100 percent. The percent tree canopy cover layer was produced by the USFS using a Random Forests regression algorithm (Housman et al. 2023). Across the Sonoma Creek 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

NLCD 2021 land cover data for the Sonoma Creek watershed (see Section [5.3](#)) was analyzed to identify predominant cropland vegetation classes. This analysis revealed that about 6% of the Sonoma Creek watershed area is classified as Pasture/Hay (class 81) or Cultivated Crops (class 82), and 52% 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 dataset comes as a 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. [Figure 5-4](#) shows the spatial distribution of these classes within 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 (2022) 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.

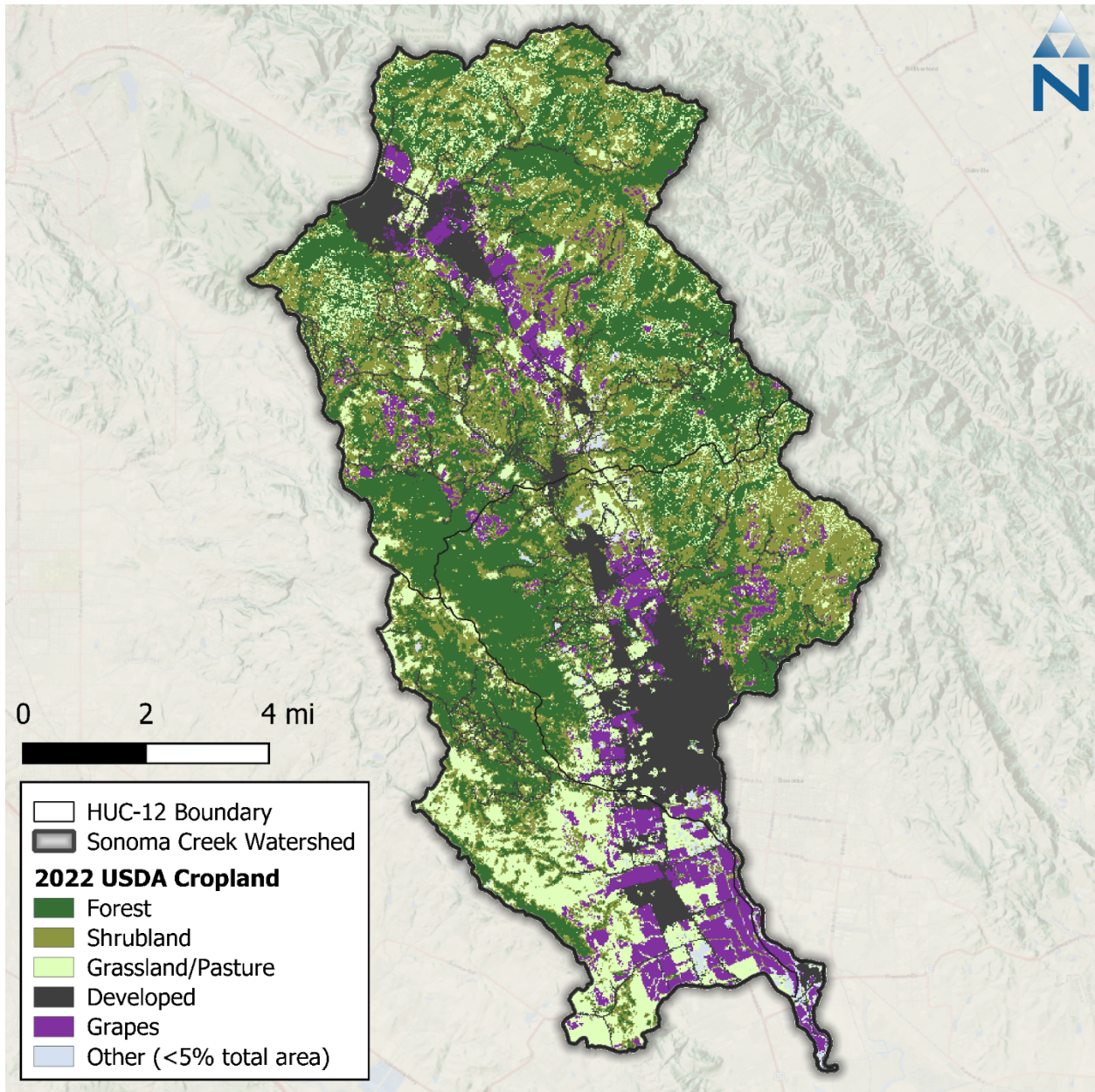


Figure 5-4. USDA 2022 Cropland Data within the Sonoma Creek watershed.

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

| Crop Type | Area (ac) | Area (%) |
|------------------------|------------------|----------------|
| Developed | 8,169.38 | 13.82% |
| Forest | 18,846.87 | 31.89% |
| Shrubland | 15,266.65 | 25.83% |
| Grassland/Pasture | 10,543.59 | 17.84% |
| Grapes | 5,095.63 | 8.62% |
| Other (<5% Total Area) | 1,171.53 | 1.98% |
| Totals | 59,093.67 | 100.00% |

6 DATA GAPS AND LIMITATIONS

Because the Sonoma Creek watershed has irrigated agricultural areas, 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 California 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 Sonoma Creek 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 the 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) and model estimates of AET could be used to estimate water volume differences attributable to irrigation activity.

[Figure 6-1](#) shows an example of the monthly variation of OpenET and LSPC AET (based on the SFEI LSPC model) for the Napa River watershed which is adjacent to the Sonoma Creek watershed. 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; this excess 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 AET depending on assumptions about the source of irrigation water, irrigation method, efficiency, and excess runoff from irrigated lands.

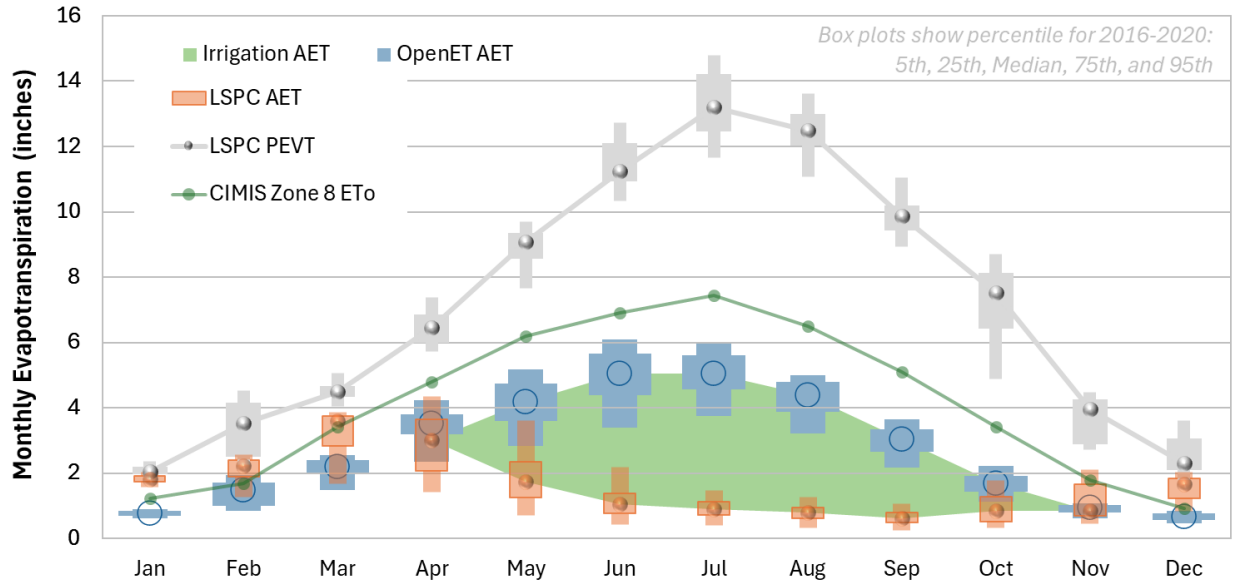


Figure 6-1. Estimating actual irrigation evapotranspiration (AET) from OpenET and modeled AET (data from the Napa River watershed).

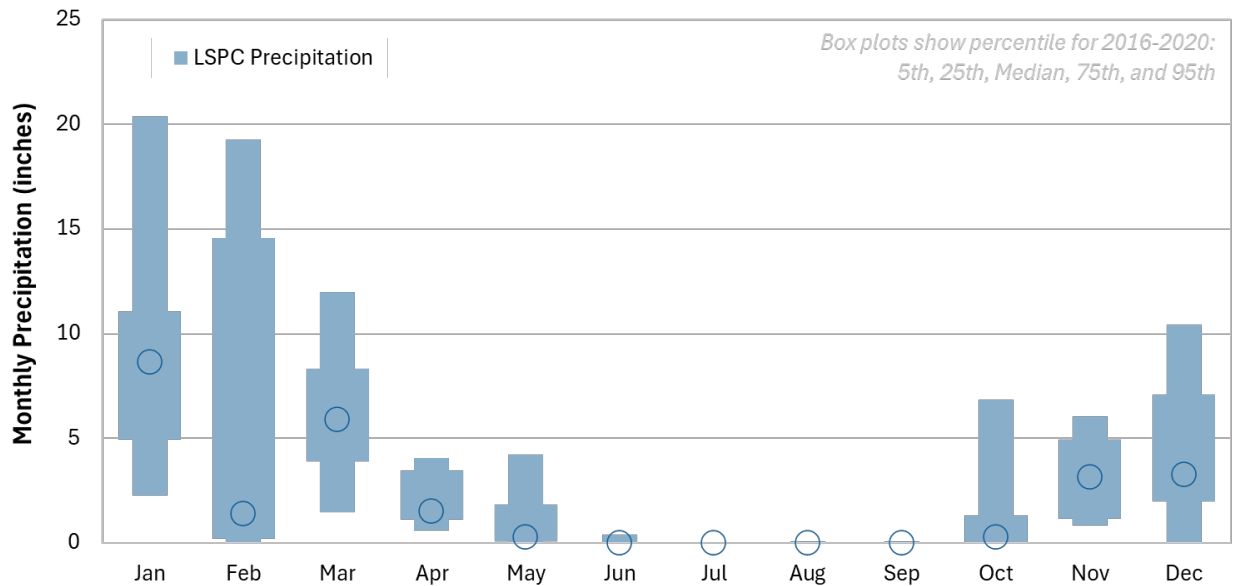


Figure 6-2. Monthly precipitation variability (data from the Napa River watershed).

Modeled hydrology in the Sonoma Creek watershed will depend on the spatial distribution and the relative intensity of surface vs. groundwater-derived irrigation 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.

Additionally, at the time of writing, it is unknown what stage-storage relationships or operational records or rules may be available for the three 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 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 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, Parker, and Riverson 2005), 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, 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, 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 Sonoma Creek watershed. Based on the extensive history of successful LSPC model applications and its strengths and flexibility for potential coupling with a groundwater model (e.g., MODFLOW), LSPC is recommended as the watershed model for this study.

As described in Section 1.3, SFEI has developed an LSPC model for watersheds draining to San Francisco Bay with a spatial domain that includes the Sonoma Creek 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 5. 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 Forcing Inputs:** Climate forcing 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 disaggregated using daily and hourly NCEI, 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-km²). 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 disaggregated to hourly based using NLDAS. It is important to note that the 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 disaggregating 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 disaggregate CIMIS daily to hourly.

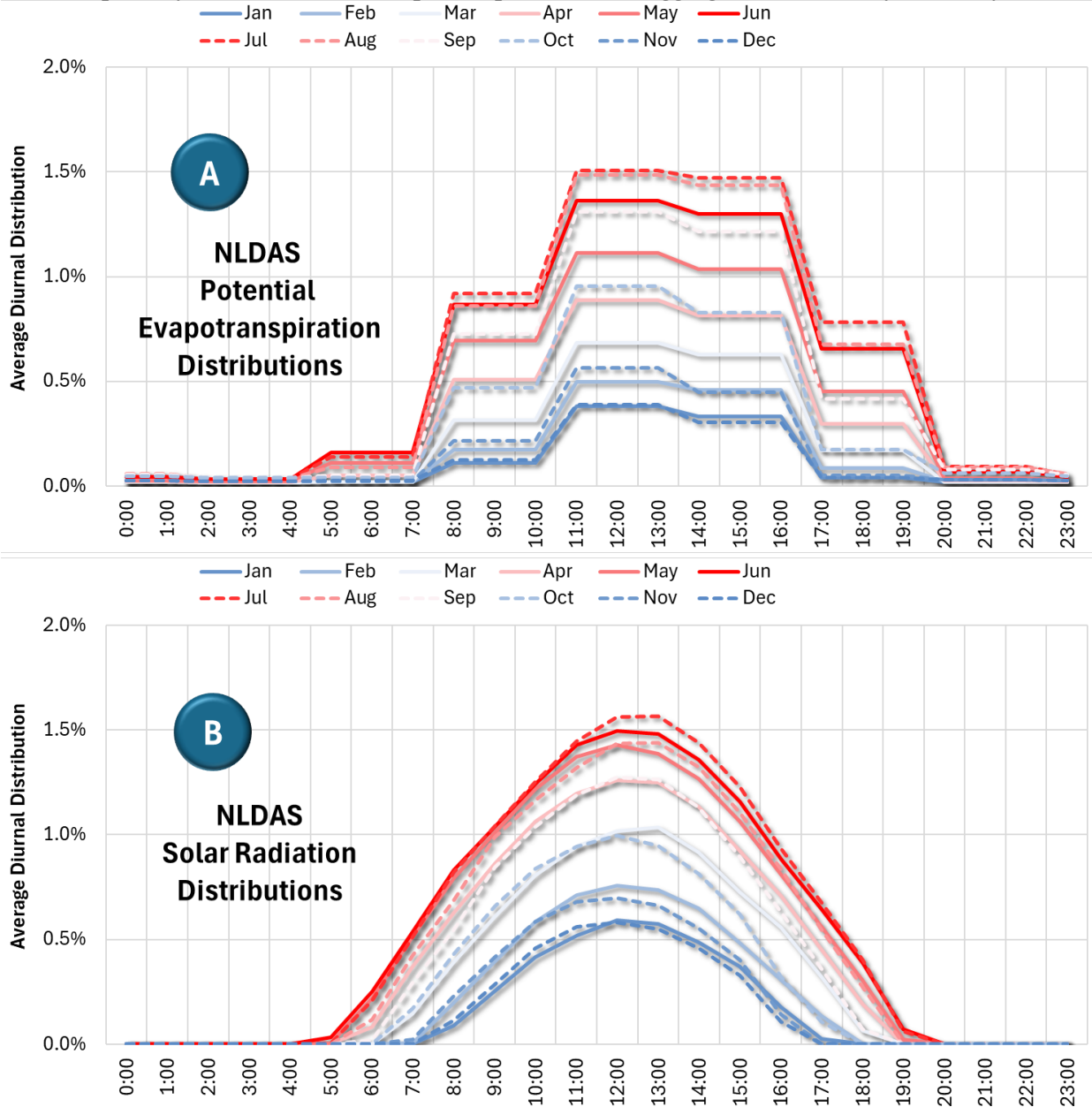


Figure 7-1. Comparison of monthly diurnal NLDAS potential evapotranspiration (A) and solar radiation (B) (data from NLDAS grids for the Napa River watershed).

- ▼ **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). Up to 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 reach 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 the dominant crop type in the Sonoma Creek 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 areas in some parts of Sonoma Creek 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 Use & Inflows:** 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 Sonoma Creek 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 the 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 | Disaggregate monthly PRISM using Observed ³ data, then assign single grid cell to each subcatchment based on areal coverage. | Disaggregating 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. 2015). |
| Model Segmentation | Watershed Boundaries | 3 | 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 | 0 | 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 stations 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: 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 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 [Acr](#) 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. Hydrograph separation was also performed to assess stormwater runoff vs. baseflow periods to isolate model performance on stormflows and low flows.

[Table 8-1](#) summarizes 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 Sonoma Creek watershed will be assessed to see if linkage of the LSPC model with a groundwater model (e.g., MODFLOW) could improve performance and process interactions. This could be manifested through a significant mismatch between the simulated and observed baseflow during dry periods. Other indicators include the mismatch between the

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

| 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 Sonoma Creek watershed. Once this work plan is finalized, the data sets described in this memo will be used to develop an LSPC model as described in Section 7. After finalizing the work plan, the first step of that process will be to present and finalize watershed boundaries and subcatchment delineations that capture key points of interest in the watershed (e.g., tributary confluences, 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 Sonoma Creek watershed.

Table 9-1. Proposed schedule and summary of deliverables

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

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

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