Work Plan: Trinity River Watershed Hydrology Model Development

SUBMITTED TO:

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FINAL
MAY 8, 2025

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ACRONYMS

3DEP	3D Elevation Program
AET	Actual evapotranspiration
AEM	Airborne Electromagnetic (Flight Surveys)
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
EOL	Earth Observing Laboratory
ET	Evapotranspiration
ET$_0$	Reference evapotranspiration
eWRIMS	Electronic Water Rights Information Management System
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
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
NCDC	National Climatic Data Center
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NLDAS	North American Land Data Assimilation System
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Model Efficiency Coefficient
PBIAS	Percent Bias
PEVT	Potential Evapotranspiration
POD	Point of Diversion
PRISM	Parameter-elevation Regressions on Independent Slopes Model

RAWS	Remote Automated Weather Stations
SGMA	Sustainable Groundwater Management Act
SNODAS	Snow Data Assimilation System
SnoTEL	SNOwpackTELemetryNetwork
SSURGO	Soil Survey Geographic Database
STATSGO	State Soil Geographic Database
SWAT	Soil and Water Assessment Tool
SWE	Snow-Water Equivalant
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

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1. INTRODUCTION

1.1 Project Objectives

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

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

1.2 Watershed Background

The Trinty River watershed, the largest tributary to the Klamath River, has two main branches, Trinity River and South Fork Trinity River. The watershed shares a boundary with several others including Lower Klamath to the northwest, the Mad-Redwood watershed to the west, and the Cottonwood Creek watershed to the southeast. The Trintiy River Basin can be divided into seventeen hydrologic unit codes (HUC)-10 sub-basins, the three largest of which are Connor Creek, Salt Creek and Pelletreau Creek. The estimated watershed area drains approximately 2,970 square miles and is made up of 83 smaller HUC-12 subwatersheds (Figure 11). The Trinity River extends south from Trinity Lake and curves westward toward the South Fork Trinity River. The South Fork Trinity River originates in the North Yolla Bolly mountains about 50 miles southwest of Redding and continues northwest for approximately 90 miles before reaching its confluence with the Trinity River near Salyer. Although Trinity River has been dammed to create Trinity Lake, South Fork Trinity River and its main tributary, Hayfork Creek, are both undammed.

The Trinity River watershed ranges in elevation from 59 meters in Hoopa to over 2,600 meters at the north of the watershed near Sawtooth Mountain. The watershed has a Mediterranean climate with distinct wet and dry seasons and a mean annual precipitation of 58.3 inches (USGS 2024a). However, the annual precipitation can reach over 80 inches on the west side of the South Fork Trinity basin along the northern end of the South Fork Mountain (EPA 1998). The watershed is dominated by evergreen forest and shrubland which cover approximately 58% and 22% of the total area, respectively. Other land cover types include grassland (11%), developed, open space (4%), and mixed forest (2%).

The Trinity River watershed represents an important habitat for native species and is a spawning ground for anadromous fish, especially the spring Chinook. The Trinity River and its tributaries hosted an abundance of native anadromous fish, including the steelhead trout, Chinook, and coho salmon. However, native fish populations in the river began to decline in the 1960s due to harmful sediment loading caused by flooding, landslides, logging, and road building (Western Rivers Conservancy

2024). Moreover, the construction of Trinity and Lewiston dams in the early 1960's had and continues to have a major impact on the flow, function, and use of the Trinity River (EPA 2021). Further studies conducted, including the Supplemental Watershed Assessment, linked the dominant process of increased sedimentation to mass wasting (landslides), most of which occurred between 1960-1975 and was associated with non-management-related sources in the Upper and Lower South Fork sub-basins (Smith et al. 2016). Moreover, the combination of heavy rainfall, unstable geology, and rain on snow events causes intense flooding in some years (EPA 1998).

The South Fork branch of Trinity River is California’s longest Wild and Scenic River, a title awarded under the Wild and Scenic Rivers Act of 1968 for its outstanding natural, cultural, and recreational values in a free-flowing condition for the enjoyment of present and future generations (National Wild and Scenic River System 2024). The Trinity River is subject to an increase in restoration efforts, particularly for reducing sediment loading. The decline of native fish populations, and increased levels of mass waste led to the development of a Sediment Total Maximum Daily Load (TMDL) for South Fork Trinity in December 1992 (EPA 1998) and for Trinity River in December 2001 (EPA 2001). It also led to partnership programs with the U.S Bureau of Reclamation creating the Trinity River Restoration Program, a grant program that supports local and regional restoration projects to reduce fine sediment delivery and improve habitat connectivity across Trinity Basin.

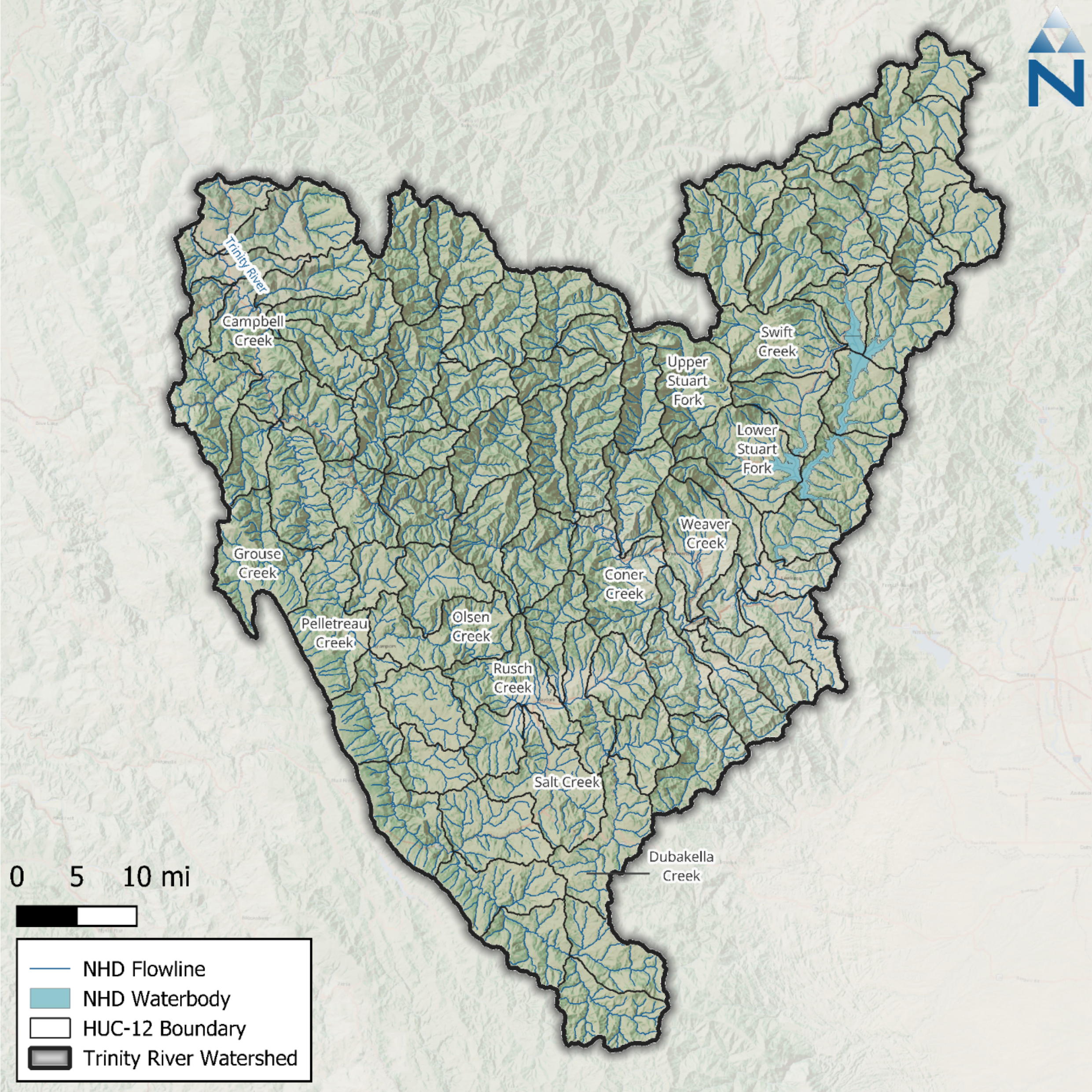


Figure 1-1. Trinity River watershed.

1.3 Model Approach

The primary goal of this work plan is to outline an approach with sufficient robustness to support an analytical assessment of the Trinity River watershed. This is presented first through a comprehensive inventory of available hydrologic, meteorological, and geographic information system (GIS) data available for the Trinity River watershed. The data compilation and assessment processes are outlined below and aim to highlight any existing data gaps that create limitations for the analysis. Based on the available data, any data gaps are identified that may be filled through additional outreach, data collection efforts, or noted as points of uncertainty in the model documentation.

This hydrologic analysis is based on a model development process that has been a tested platform for gaining valuable information and insight about hydrologic systems. The model development process proposed is an iterative and adaptive cycle that improves understanding of the system over time as better information becomes available. Figure 1-2 is a conceptual schematic of the proposed model development cycle, which is represented as circular as opposed to linear. The cycle is best summarized by the following six interrelated steps:

1. **Assess Available Data**: Data for source characterization, trends analysis, and defining modeling objectives.
2. **Delineate Model Domain**: Model segmentation and discretization needed to simulate streamflow at temporal and reach scales appropriate for assessing supply and demand.
3. **Set Required Model Inputs**: Spatial and temporal model inputs defining the appropriate hydrologic inputs and outputs.
4. **Represent Processes (Calibration)**: Adjustment of model rates and constants to mimic observed physical processes of the natural system.
5. **Confirm Predictions (Validation)**: Model testing with data not included in the calibration to assess predictive ability and robustness.
6. **Assess Applicability for Scenarios**: Sometimes the nature of modeled responses can indicate the influence of unrepresented physical processes in the modeled system. Sometimes that can be resolved with minor parameter adjustments, while other times the assessment exposes larger data gaps. A well-designed model can be adapted for future applications as new information about the system becomes available. Depending on the study objectives, data gaps sometimes provide a sound basis for future data collection efforts to refine the model. New information may require minor parameter adjustments affecting the configuration or calibration.

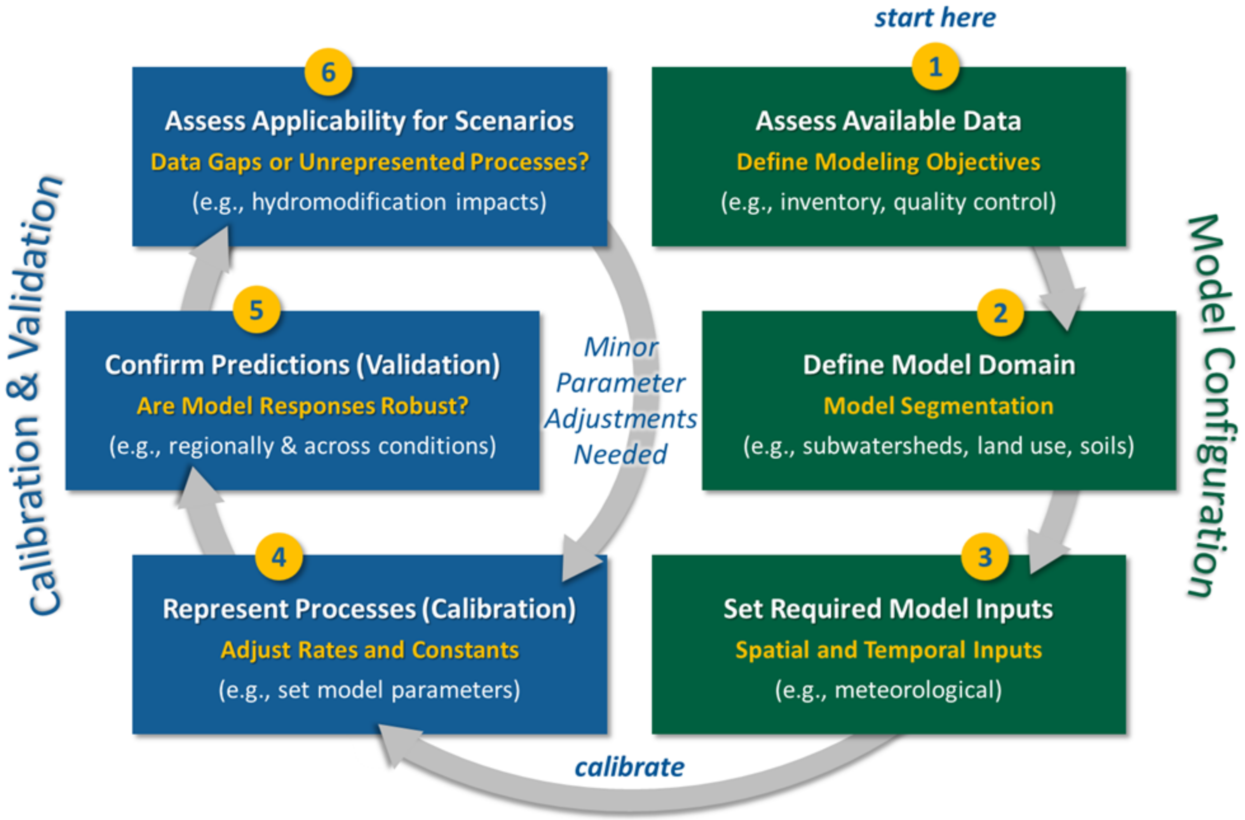


Figure 1-2. Conceptual schematic of model development cycle proposed for assessing instream flow needs in the Trinity River watershed.

1.4 Data Availability

Table 1-1 through Table 1-4 present an inventory of the initial data collected that will form the basis of this modeling work plan. These datasets were compiled from readily available sources, primarily those publicly available and published online by state and federal agencies. The data in the tables is organized by data type including:

- **Meteorology Datasets**: Time series that represent water balance inputs and outputs to the watershed primarily from precipitation and evapotranspiration. These time series are often used as forcing functions for hydrologic models.
- **Surface & Groundwater Datasets**: Datasets describing Snow-Water Equivalent (SWE), stream flow, groundwater, water use, and stream conditions for the Trinity River. Time series observations of instream responses for the Trinity River are often used as calibration and validation datasets for hydrologic models.
- **Geospatial Datasets**: Spatial datasets describing the landscape of the Trinity River watershed. These datasets include physical properties (e.g., soils, land cover, elevation).

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

Table 1-1. Inventory of meteorology datasets

Data Source	Data Set	Data Date	Description	Model Use
National Climatic Data Center (NCDC)	Global Historic Climate Network (GHCN)	--	Daily precipitation and temperature data (varied data quantity/quality).	Rainfall input boundary time series.
National Climatic Data Center (NCDC)	Local Climate Data (LCD)	--	Hourly precipitation, temperature, wind speed, dewpoint, cloud cover.	Rainfall input boundary time series.
Remote Automated Weather Stations (RAWS)	Hourly Climate Data	--	Meteorological records available for nineteen stations.	Climate data boundary time series.
California Data Exchange Center (CDEC)	Precipitation, Temperature, Snow	--	Meteorological records available for thirty-one stations.	Rainfall input boundary time series.
PRISM Climate Group	AN81m Monthly	1900- Present	4-km grid resolution time series of precipitation (1900 – present).	Rainfall time series QA; address rainfall data gaps.
North American Land Data Assimilation System (NLDAS)	NLDAS-2 Forcing Data	1979 - Present	1/8th-degree grid resolution hourly time series of precipitation and other surface parameters (e.g., potential evapotranspiration, and solar radiation).	Rainfall hourly distributions; address rainfall data gaps. Daily potential evapotranspiration totals × hourly solar radiation distributions.
Earth Observing Laboratory (EOL)	Daily/Hourly Gridded Precipitation	--	Various gridded precipitation time series; both daily and hourly time steps.	Rainfall hourly distributions; address rainfall data gaps.
California Irrigation Management Information System (CIMIS)	Reference Evapotranspiration	1990 – Present	Relative evapotranspiration spatial zones and monthly scaling factors. There is also a grid-based model data product.	Deriving PEVT input forcing time series; estimation of irrigation demand.
National Water and Climate Center (NWCC) Snow Survey and Water Supply Forecasting (SSWSF) Program	Snow Course/Aerial Marker	--	Manual snow measurements taken either on foot or by air to determine depth and water content of snowpack.	Assessing the performance of model snow simulation module
California Department of Water Resources (CDWR)	California Cooperative Snow Surveys	1929 - Present	Snow measurements taken from >265 snow courses and >130 snow sensors	Assessing the performance of model snow simulation module

Data Source	Data Set	Data Date	Description	Model Use
			throughout the Sierra Nevada and Shasta-Trinity mountains.	
OpenET	OpenET CONUS Ensemble Monthly Evapotranspiration	2016 - 2024	Satellite-based estimates (30-m res) of observed monthly evapotranspiration for the CONUS; data is bias corrected against observational weather station networks.	Parameterization & evaluation of ET; estimation of irrigation demand.
National Snow and Ice Data Center (NSIDC)	Snow Data Assimilation System (SNODAS)	2003-2023	High-resolution dataset that integrates ground observations, satellite imagery, and meteorological data for spatial estimates of snow cover, depth, and water equivalent	Estimates of snow-water equivalent and snow melt for snow module calibration and comparison for model snow simulation

Table 1-2. Inventory of surface water datasets

Category	Scale	Data Source	Data Set	Data Date	Description	Model Use	Link
Streamflow	Local	USGS	Stream Gauge Discharge	1965 – Current	Observed Streamflow at eleven active locations on the Trinity River.	Hydrology calibration.	LINK
Habitat	Local	CDFW	Trinity River Total Maximum Daily Load for Sediment	2001	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
			Interconnected Surface Water	2008	One (1) river stage CDEC station and two (2) rain CDEC stations within the watershed identified as interconnected.		LINK
		SWRCB eWRIMS	Water Rights Points of Diversion	Current	Locations where water is being drawn from a surface water source such as a stream or river.		LINK
			Water Rights Overview Report	Current	This report will provide counts of various entities such as Applications, Registrations, Petitions etc. that will reflect the progress in processing such entities as of current date.		LINK
			Annual Water Use Report	1906 – 2023	Annual reports that provide monthly diversion data for various entities such as Applications, Registrations, Petitions, etc.		LINK
		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 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	Data Source	Data Set	Data Date	Description	Model Use	Link
Watershed Boundaries	National	USGS	Watershed Boundaries (WBD)	2023	Hydrologic unit boundaries to the 12-digit (6th level).	Model segmentation	LINK
Hydrology	National	USGS	National Hydrography Dataset (NHD) Plus High-Resolution National Release 1	2023	The NHDPlus HR combines the NHD, 3DEP DEMs, and WBD to create a stream network with linear referencing.		LINK
			National Hydrography Dataset (NHD) Best Resolution	2023	1:24,000; represents reaches and other network elements.		LINK
Soil	National	USDA NRCS	Grided Soil Survey Geographic Database (gSSURGO)	2022	State-wide, 10-meter raster grid approximating the SSURGO vector dataset.	Represent infiltration process within land segments.	LINK
Surficial Geology	National	USGS	The State Geologic Map Compilation (SGMC)	2017	1:1,000,000: Vector-based, state geologic map database.	As needed, hydrologic process with land segments.	LINK
Land Cover	National	MRLC	National Land Cover Dataset (NLCD) Land Cover	2021	Broad, 30-meter grid-based land characterization. Differentiates developed land from coarse classifications of forest, cropland, wetlands, etc.	Land segment representation.	LINK
			National Land Cover Dataset (NLCD) Imperviousness All Years	2021	Broad, 30-meter grid-based land characterization. Represent percent impervious area within raster cells.		LINK
Land Use	State	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

Table 1-3. Inventory of geospatial datasets (continued)

Category	Scale	Data Source	Data Set	Data Date	Description	Model Use	Link
	State	USFS	Existing Vegetation	2018	1:24,000 to 1:100,000: Existing vegetation mapping.	As necessary, additional vegetation types for model land segments.	LINK
Agriculture & Crop Cover	National	USDA	Cropland Data Layer	2022	30-meter grid-based crop-specific land cover data layer.	Identify crop distributions; estimate irrigation demand.	LINK
Timber Harvesting	National	USDA	Timber Harvests	1820 - Present	Area planned and accomplished acres treated as a part of the timber harvest program of work.	Representing changes in land cover due to timber harvest activities.	LINK
	State	CAL FIRE	CAL FIRE Nonindustrial Timber Management Plans TA83	1991 - Present	Timber management plans.		LINK
			CAL FIRE Notices of Timber Operations TA83	1991 - Present	Notice of Timber Operations accepted by CAL FIRE.		LINK
			CAL FIRE Working Forest Management Plans TA83	2019 - Present	Working forest management plans approved by CAL FIRE.		LINK
Fire Perimeters & Burn Areas	State	CAL FIRE	California Fire Perimeters	1950 - Present	Wildfire perimeters.	Representing changes in land cover due to forest fire activities.	LINK
Elevation	National	USGS	USGS ten-meter resolution digital elevation model (DEM)	2020	10-meter resolution digital elevation model (DEM) produced through the 3D Elevation Program (3DEP).	Land segment representation.	LINK

Table 1-4. Inventory of groundwater datasets

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

2 METEOROLOGY

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

2.1 Precipitation

The primary source of precipitation data for the Trinity River watershed will be the observed data from land-based stations within and in the vicinity of the watershed (Table 2-1). However, any gaps in observed data from the land-based stations will be filled with grid-based data. This is referred to as the "hybrid" approach, which has shown promising results by leveraging the strengths of both land-based and grid-based data. Use of a hybrid approach preserves locally sampled gauge data while increasing the spatial and temporal quantity and quality over the watershed. This approach has been applied for large watershed-scale modeling applications including the County-wide model for Los Angeles County (LACFCD 2020).

Land-based observed precipitation data are mainly acquired from the National Climatic Data Center (NCDC), which maintains climate networks including the Global Historic Climate Network (GHCN), the Cooperative Observer Program (COOP), and the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). These networks provide quality-controlled hourly or daily observed precipitation and temperature data. There are 5 GHCN gauges identified within or near the Trinity River watershed. These gauges all have data with varied quantity and quality. In addition to the daily precipitation gauges, NCDC also maintains the Local Climatological Data (LCD) network. There are 2 LCD stations within 15 km of the Trinity River watershed. The California Data Exchange Center (CDEC) and Remote Automated Weather Stations (RAWS) networks also report hourly precipitation. CDEC reports at 31 locations and RAWS reports at 19 locations within and near the watershed. Table 2-1 is an inventory of the precipitation stations near the Trinity River watershed with available data after 2000 and around 75% completeness or better; Figure 2-1 shows the location of the stations proposed for model development in Table 2-1.

The primary source of the grid-based data for Trinity River Watershed will be the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al. 2008, 1994; Gibson et al. 2002). PRISM is developed and maintained by the PRISM Climate Group at Oregon State University and provides gridded estimates of event-based climate parameters including precipitation, temperature, and dew point. The algorithm uses observed point data, a digital elevation model, and other spatial datasets to capture influences such as high mountains, rain shadows, temperature inversions, coastal regions, and other complex climatic regimes (Gibson et al. 2002). Because of its spatial and temporal resolution and consistency across the lower 48 contiguous United States (4-km spatial resolution for the AN81d daily/monthly time series dataset and 800-m for the AN81m long term averages), PRISM is a commonly used and widely accepted source for meteorological data for hydrologic models (Behnke et al. 2016). The subset of the PRISM grid that covers the current study area is shown in Figure 2-1. To downscale the PRISM data to hourly, North American Land Data Assimilation System (NLDAS) is used. NLDAS is a quality-controlled land surface model (LSM) dataset of meteorological data designed specifically to support continuous simulation modeling activities (Cosgrove et al. 2003; Mitchell et al. 2004). NLDAS provides real-time hourly predictions of meteorological data required for LSPC at a 1/8th degree spatial resolution (about 8.625-mile intervals) for North America, with retrospective simulations beginning in January 1979. NLDAS has undergone rounds of refinement, extensive peer review, and performance validation through case study applications, all of which have demonstrated it to be a more robust predictor of variable meteorological conditions for continuous simulation modeling than using individual gauges (Xia et al. 2012).

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

Agency	Station ID	Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Data Coverage (%)[1]
CDEC	PET	PETERSON FLAT	10/1/1985	present	41.302	-122.528	2179	78%
	MDF	MAD RIVER (USFS)	9/8/2000	present	40.463	-123.524	846	79%
	CFR	COFFEE RIDGE	1/31/1989	present	41.083	-122.717	927	79%
	SCP	SCORPION	9/1/2000	present	41.112	-122.697	1341	82%
	SCT	SCOTT MOUNTAIN	12/17/1985	present	41.272	-122.719	1798	82%
	BFL	BIG FLAT	10/1/1985	present	41.078	-122.942	1554	86%
	HYF	HAYFORK	5/1/1991	present	40.500	-123.333	1219	87%
	MTA	MT SHASTA	4/8/2002	present	41.315	-122.317	1082	87%
	CHA	CALLAHAN (USFS)	7/10/1990	present	41.300	-122.824	956	88%
	GIB	GIBSON	12/2/2005	present	41.022	-122.399	498	89%
	GRD	GIRARD	1/31/1989	present	41.133	-122.283	1463	906%
	BDY	BRANDY CREEK	1/31/1989	present	40.617	-122.567	396	90%
	TYR	TAYLOR RIDGE	1/31/1989	present	40.917	-122.817	1219	89%
	HDL	HOADLEY	1/31/1989	present	40.683	-122.750	1396	93%
	RTH	RUTH LAKE	11/5/1996	present	40.319	-123.374	823	94%
	TGS	TRINITY GUARD STATION	1/31/1989	present	40.825	-122.660	1250	95%
	OGO	OGO RANGER STATION	1/1/1984	present	40.423	-122.738	396	96%
CDEC	MUD	MUD SPRINGS	1/1/1984	present	40.712	-123.289	1036	96%

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

Agency	Station ID	Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Data Coverage (%)[1]
CDEC	BNK	BONANZA KING	1/31/1989	present	41.083	-122.631	1966	96%
	BGB	BIG BAR	1/1/1989	present	40.733	-123.200	387	97%
	OLS	KLAMATH RIVER AT ORLEANS	1/1/1984	present	41.303	-123.535	131	97%
	FVC	FIVE CENT	4/3/2006	present	40.760	-122.931	777	98%
	CTN	COTTONWOOD CREEK NEAR BEEGUM	1/31/1989	present	40.317	-122.881	1036	98%
	HPA	TRINITY RIVER AT HOOPA	1/1/1987	present	41.050	-123.674	101	98%
	TNC	TRINITY CAMP	4/23/2001	present	40.679	-122.833	640	99%
	SLT	SLATE CREEK	4/13/1988	present	41.044	-122.480	1737	99%
	CLR	CLEAR CREEK	1/31/1989	present	40.639	-122.667	1006	99%
	MTS	MOUNT SHASTA	10/4/2000	present	41.315	-122.317	1081	100%
	LFH	LEWISTON FISH HATCHERY	10/1/2016	present	40.727	-122.793	570	100%
	CLE	TRINITY LAKE	11/1/1962	present	40.801	-122.762	722	100%
	WHI	WHISKEYTOWN DAM (USBR)	10/1/1997	present	40.598	-122.537	369	100%
LCD	WBAN:24215	MOUNT SHASTA, CA US	3/31/1948	3/31/2025	41.315	-122.317	1,083	95%
	WBAN:04222	REDDING 12 WNW, CA US	3/25/2003	present	40.651	-122.607	432	100%
NOAA - GHCN	GHCND:USC00049621	WHISKEYTOWN RSVR	4/1/1960	4/30/2025	40.612	-122.528	395	90%
NOAA - GHCN	GHCND:USC00042574	DUNSMUIR TRTMT PL	7/1/1978	4/30/2025	41.183	-122.282	661	97%

	GHCND:USW00004222	REDDING 12 WNW	3/1/2003	4/30/2025	40.651	-122.607	432	95%

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

Agency	Station ID	Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Data Coverage (%)[1]
NOAA-CHCN	GHCND:USC00049026	TRINITY RVR HATCHERY	8/1/1974	2/28/2025	40.726	-122.795	567	99%
	GHCND:USW00024215	MT SHASTA	4/1/1998	3/31/2025	41.315	-122.317	1,083	100%
RAWS	BILLC1	BIG HILL	3/31/1997	Present	41.097	-123.636	1088	85%
	WEFC1	FIVE CENT	6/12/2004	Present	40.754	-122.932	793	87%
	PMCC1	PATTYMOCUS	10/29/1990	Present	40.286	-122.875	1150	89%
	UDWC1	UNDERWOOD	8/22/2002	Present	40.721	-123.496	800	91%
	MDDC1	MAD RIVER	10/6/1999	Present	40.463	-123.524	876	91%
	SMSC1	SIMS	11/13/1989	Present	41.071	-122.370	773	92%
	RLKC1	RUTH	6/24/2003	Present	40.251	-123.320	833	93%
	BABC1	BACKBONE	10/5/2000	Present	40.889	-123.143	1405	94%
	FMOC1	FRIEND MTN.	9/10/1990	Present	40.506	-123.343	1347	94%
	CFCC1	SCORPION	10/15/1990	Present	41.109	-122.697	1026	94%
	PLIC1	ARBUCKLE BASIN	1/1/1995	Present	40.438	-122.831	747	95%
	SLFC1	SUGARLOAF (SHF)	11/1/1999	Present	40.916	-122.435	993	96%
	YOBC1	YOLLA BOLLA	9/24/1990	Present	40.337	-123.066	1366	96%
	BGBC1	BIG BAR	11/13/1989	Present	40.742	-123.249	525	97%
RAWS	SHUC1	SCHOOLHOUSE	1/4/2001	Present	41.138	-123.907	809	97%

	HYFC1	HAYFORK	4/8/1997	Present	40.549	-123.165	709	97%
	TCAC1	TRINITY CAMP	4/16/1996	Present	40.786	-122.804	1008	97%

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

Agency	Station ID	Name	Start Date	End Date	Lat.	Long.	Elevation (meters)	Data Coverage (%)[1]
RAWS	HOAC1	HOOPA	4/19/1997	Present	41.048	-123.671	114	98%
	MSAC1	MT. SHASTA	7/8/1999	Present	41.315	-122.317	1089	99%

1. Data coverage for LCD gauges are LCD portal-reported values, which is reflective of data availability between the reported start date and end date in this table, not the modeling period (i.e. 10/2003 to 9/2023). However, data coverages for CDEC, NOAA-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 requested.

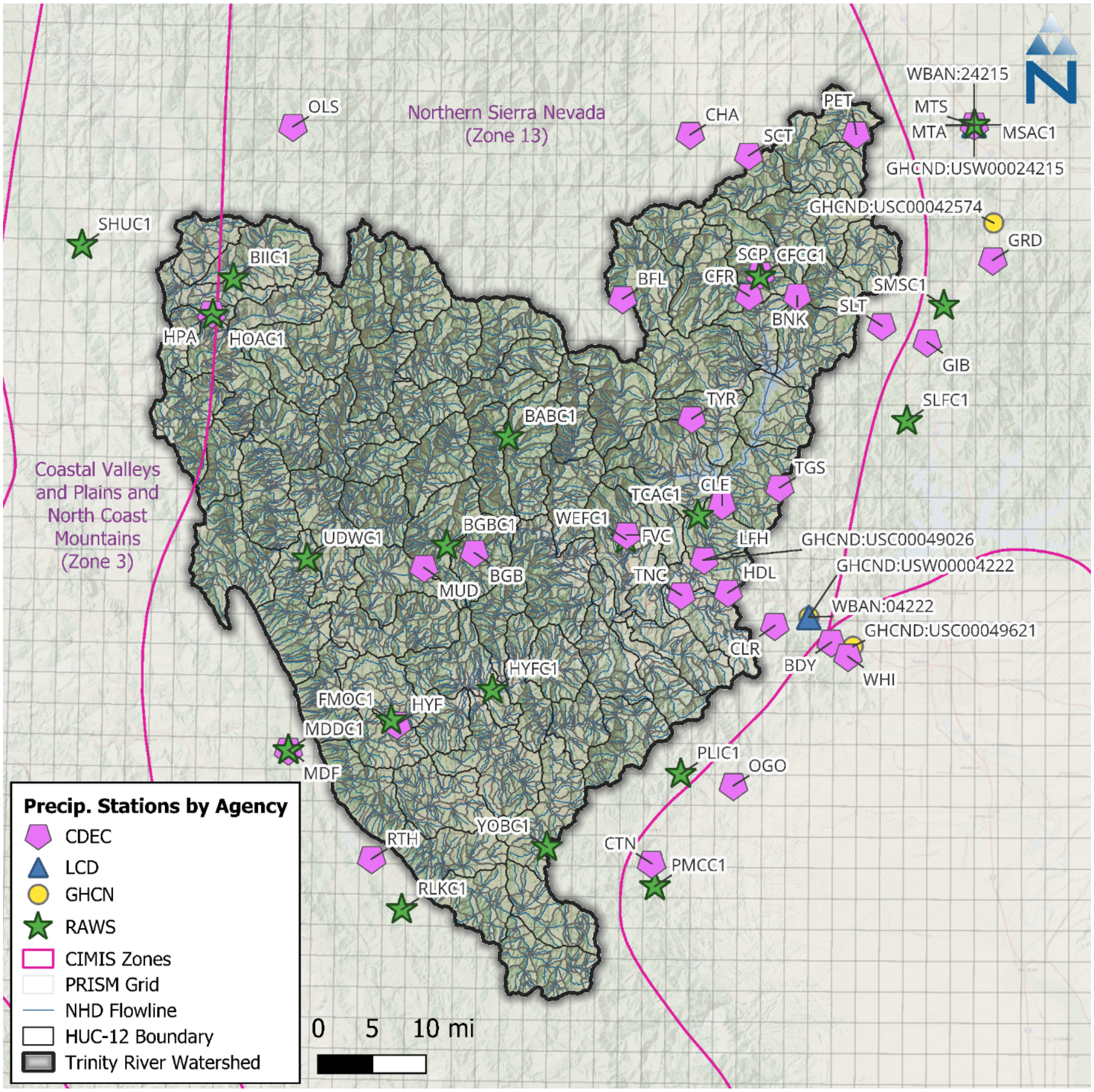


Figure 2-1. Identified precipitation gauges and CIMIS ET Zones near the Trinity River watershed.

The hybrid approach entails three main steps. First, impaired intervals (i.e., missing, or accumulated) at observed stations will be patched with quality-controlled data from nearby stations. Second, the PRISM grid cells and patched observed stations are mapped to the NLDAS grid cells to downscale the monthly PRISM and daily station data using normalized hourly data from NLDAS. Third, the downscaled gridded meteorological data from PRISM are used to fill any remaining spatial and temporal 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 downscaling with hourly observed data, as opposed to daily PRISM totals, eliminates the need to estimate distributions for instances where an hourly distribution does not coincide with a daily total.

Figure 2-2 presents a summary of the hybrid approach to blend observed precipitation with gridded meteorological products. Observed data and gridded products are to be processed in parallel to: (1) create a temporally complete set of hourly distributions and (2) identify spatial gaps in coverage to be supplemented with downscaled gridded data. Assuming a 10-km buffer around observed gauges for this approach, the coverage shown in the lower right map in Figure 2-2 also shows what a hybrid dataset of observed time series, supplemented by gridded products would look like.

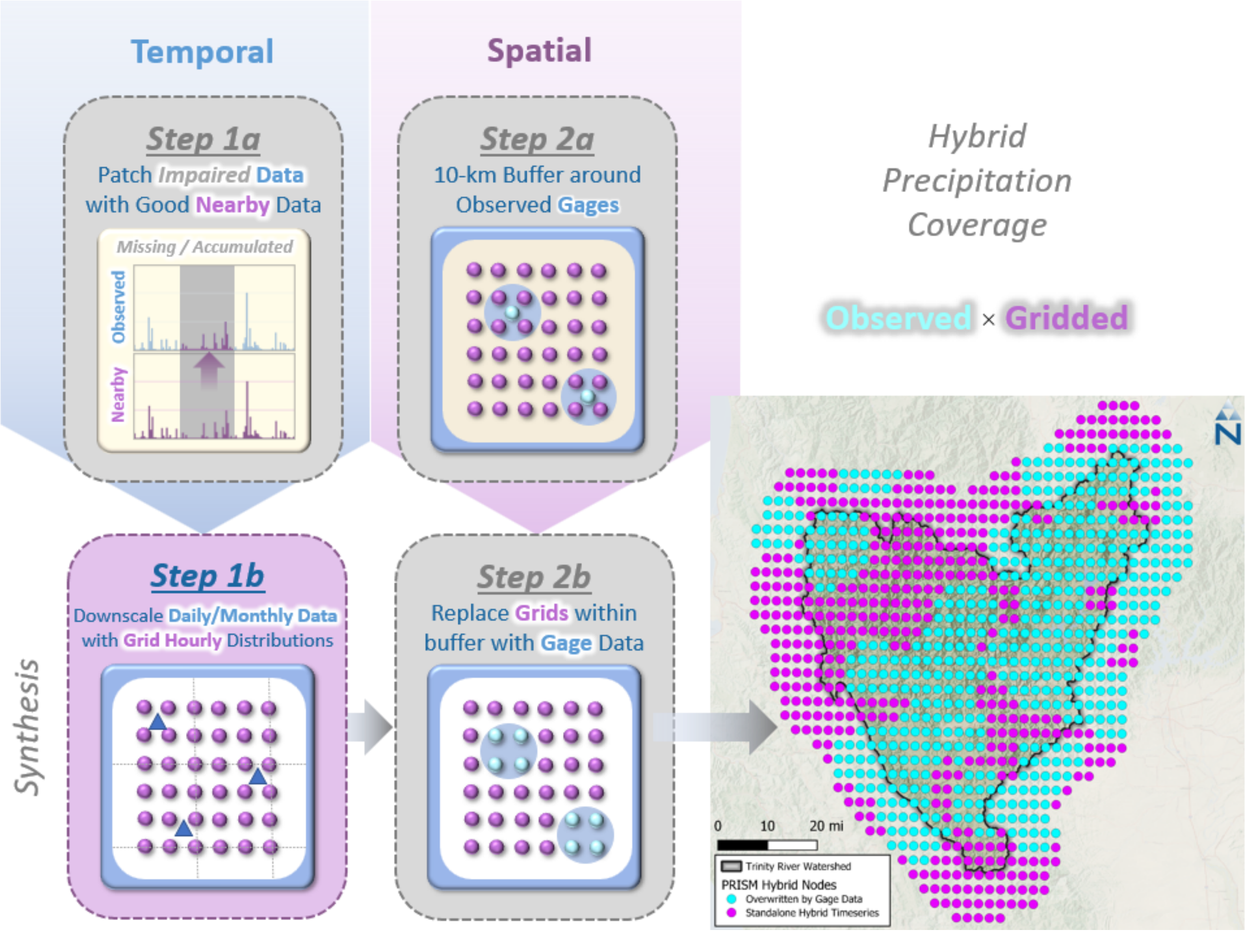


Figure 2-2. Hybrid approach to blend observed precipitation with gridded meteorological products.

2.2 Evapotranspiration

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

There are no CIMIS stations, active or inactive, within ten miles of the Trinity River watershed. As shown in Figure 2-1, the Trinity River watershed intersects two CIMIS zones with just over 96% of the watershed area in Zone 13 (Northern Sierra Nevada), and less than 4% of the watershed area in Zone 3 (Coastal Valleys and Plains and North Coast Mountains). Almost all the Trinity River watershed falls within Zone 13, but there is a small portion of the watershed near the north-western end that falls within Zone 3. These zones experience average annual ET_o levels from 46.3 inches per year in Zone 3 to 54.3 inches per year in Zone 13 (DWR 2024a).

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

Representative potential evapotranspiration (PEVT) time series can be estimated for the Trinity River watershed from daily data from CIMIS Spatial and downscaling the hourly time series using hourly distributions from land observation stations (e.g., RAWS, NCDC) or hourly distributions from 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 downscaling the daily CIMIS depths while maintaining the overall annual water budget reflected in CIMIS.

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

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

2.3 Other Meteorological Data

In addition to precipitation and ET, LSPC also uses time series of air temperature, wind speed, solar radiation, and dew point temperature to simulate snow processes using an energy balance approach. Snow is an important component of the water budget for the Trinity River watershed. The NLDAS gridded data provides continuous records of hourly data for those parameters, which will be used as input into the model. The NLDAS datasets are the result of collaboration between several groups, including NOAA and NASA. The NLDAS data were developed using a forcing dataset from a daily gauge-based precipitation analysis (temporally disaggregated to hourly using Stage II radar data), and bias-corrected shortwave radiation. NLDAS is available at 1/8th degree (approximately 8.4 miles) spatial resolution on an hourly basis.

3 SURFACE HYDROLOGY

3.1 Watershed Segmentation

The United States Geological Survey (USGS) delineates watersheds nationwide based on surface hydrological features and organizes the drainage units into a nested hierarchy using hydrologic unit codes (HUC). These HUCs have a varying number of digits to denote scale ranging from 2-digit HUCs (largest) at the region scale to 12-digit HUCs (smallest) at the subwatershed scale. The Trinity River watershed is defined by a HUC-08 watershed that comprises 83 HUC-12 subwatersheds.

For units smaller than HUC-12 subwatersheds, catchment and tributary boundaries, flowlines, outlet points and related attribute information will rely on the National Hydrography Dataset (NHD) hydrologic unit code (HUC) and catchment delineations. This analysis will primarily use readily available data to define the outer watershed boundary. Any available local data will be used to supplement and refine the understanding of tributary boundaries and reach geometry. The NHD Plus v2 (NHDPlus) further discretizes the watershed into 2,903 catchments ranging in size between 0.2 acres to approximately 9.3 square miles. Table 3-1 presents summary statistics of NHDPlus catchment sizes by HUC-12 subwatershed. Figure 3-1 is a map of HUC-12 and NHDPlus catchments within the Trinity River watershed (HUC-08).

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

Upon further assessment, grid-based segmentation may be adopted for watershed areas with higher elevations to enhance simulating the snow processes. This approach will entail developing a variable size quadtree grid where the size of the grid is dictated by elevation gradient. Areas with highly variable elevation will get smaller grid cells to more accurately capture the elevation change.

Table 3-1. Summary of NHDPlus catchment sizes (acres) within the Trinity River HUC-8

HUC-12 Name	Count	Catchment Minimum (acres)	Catchment Mean (acres)	Catchment Median (acres)	Catchment Maximum (acres)
Conner Creek	85	3.3	453.0	351.6	1,411.3
Little French Creek	38	2.2	732.2	507.7	3,767.6
Grass Valley Creek	27	35.4	873.0	593.6	3,489.2
Sharber Creek	40	41.6	490.0	408.0	1,963.1
Reading Creek	14	31.6	1,421.6	981.0	5,982.4
Willow Creek	55	3.3	504.7	416.5	2,062.0
Dutton Creek	18	35.6	923.1	353.7	5,103.1
Indian Creek	20	4.7	1,078.6	1,016.0	2,918.5
Campbell Creek	62	0.2	501.6	268.4	2,905.6
Lower East Fork	41	0.9	723.2	594.5	3,057.5
Don Juan Creek	49	8.0	435.8	283.3	2,005.8
Upper Browns Creek	42	14.0	608.5	513.1	2,408.4

Table 3-1. Summary of NHDPlus catchment sizes (acres) within the Trinity River HUC-8 (continued)

HUC-12 Name	Count	Catchment Minimum (acres)	Catchment Mean (acres)	Catchment Median (acres)	Catchment Maximum (acres)
Mumbo Creek	14	308.9	979.8	829.2	2,986.7
Soctish Creek	17	0.2	918.8	803.3	4,082.9
Middle East Fork	18	11.1	708.2	571.7	2,601.9
Lower Canyon Creek	41	12.5	552.5	432.8	1,972.6
Upper East Fork	30	14.5	618.1	545.5	1,754.1
Big Bar Creek	41	7.1	514.9	420.5	1,895.2
Lower Browns Creek	26	28.7	828.0	677.5	3,748.3
McDonald Creek	43	7.8	461.7	391.2	2,705.4
Deadwood Creek	30	3.1	470.3	307.4	2,957.6
Supply Creek	14	0.2	735.3	360.5	3,211.8
Deerhorn Creek	23	0.4	743.0	620.5	2,081.6
East Fork North Fork	34	71.2	869.2	551.9	5,648.1
Quinby Creek	53	8.2	402.9	315.8	1,406.0
East Fork New River	45	0.4	585.7	461.2	2,806.2
Upper North Fork	32	1.6	731.5	446.6	3,454.7
Virgin Creek	27	21.6	891.4	712.3	2,516.2
Mooney Gulch	27	0.7	620.0	252.2	2,447.2
Bell Creek	54	5.3	402.8	320.7	1,203.1
North Fork Coffee Creek	19	6.0	820.6	617.4	2,002.7
Swift Creek	51	4.0	706.1	461.5	3,503.8
Upper Coffee Creek	35	0.9	824.4	579.6	5,316.2
Lower Stuart Fork	58	0.7	608.6	489.9	3,562.3
Middle North Fork	19	17.8	718.8	341.2	3444.2
Buckeye Creek	30	1.6	519.9	297.1	3,300.8
Upper Canyon Creek	55	2.9	333.9	259.8	1,361.9
Slide Creek	29	72.7	898.2	717.2	3,329.0
Lower Coffee Creek	34	2.0	892.0	693.5	3,618.1
Weaver Creek	41	2.2	775.8	292.0	5,286.3
Upper Stuart Fork	39	0.9	818.2	665.6	5,008.8
Big French Creek	43	6.9	574.6	399.0	2,786.1
Picayune Creek	32	17.1	791.8	679.4	2,227.2
Horse Linto Creek	33	26.9	767.4	560.2	2,560.0
Eagle Creek	21	28.7	1,174.9	752.6	5,981.1
Devils Canyon	35	11.3	504.7	389.4	1,602.1
Lower North Fork	34	7.6	610.9	428.1	2,578.0
Bear Creek	29	75.4	765.6	690.1	2,556.6

Table 3-1. Summary of NHDPlus catchment sizes (acres) within the Trinity River HUC-8 (continued)

HUC-12 Name	Count	Catchment Minimum (acres)	Catchment Mean (acres)	Catchment Median (acres)	Catchment Maximum (acres)
Tish Tang a Tang Creek	23	60.9	832.2	467.9	4,123.4
Rush Creek	11	60.7	1,309.5	586.7	4,674.5
High Camp Creek	11	149.4	1,369.0	1,004.9	2,803.4
Mill Creek	26	94.7	1,186.5	1,146.5	3,645.6
Cedar Creek	25	18.2	670.5	352.7	2,763.9
Tangle Blue Creek	19	47.6	740.7	604.9	1,829.4
Big Creek	20	2.0	613.9	462.7	2,968.3
East Fork Stuart Fork	21	34.5	1,006.1	967.6	3,434.0
Bragdon Gulch	17	225.3	1,456.6	1028.2	5,615.9
Papoose Creek	37	20.0	741.0	508.3	3,750.7
Rattlesnake Creek	16	22.0	629.7	434.2	2,081.8
Salt Creek	65	1.1	567.2	423.4	3,006.3
Grouse Creek	61	4.2	593.8	428.5	2,637.7
Mingo Creek	63	3.8	457.5	419.2	1,744.9
Smoky Creek	45	26.0	600.9	500.8	1,774.0
East Fork	33	13.6	744.6	391.3	2,693.2
Butter Creek	28	1.3	836.1	608.0	2,884.0
Sulphur Glade Creek	50	0.4	459.6	391.4	1,326.6
Plummer Creek	23	60.7	702.2	511.5	2,005.8
Dubakella Creek	39	45.8	833.0	694.5	2,640.7
Big Creek	35	0.7	499.1	369.6	1,667.7
Pelletreau Creek	63	0.4	582.7	490.0	2,533.6
Corral Creek	29	0.2	798.9	745.0	1,917.0
Barker Creek	43	1.3	483.1	358.7	1,555.4
Eltapom Creek	15	59.8	837.5	514.4	2,648.9
Little Bear Wallow Creek	42	28.7	631.1	590.2	1,496.2
Happy Camp Creek	27	104.1	808.1	685.4	2,316.7
Rattlesnake Creek	49	12.5	610.8	588.7	1,470.9
Olsen Creek	54	9.6	642.3	635.7	1,357.9
Old Campbell Creek	23	2.2	646.3	629.2	1,347.0
Rusch Creek	45	3.8	716.7	447.2	3,134.9
Shell Mountain Creek	51	4.0	533.5	373.1	2,192.6
Carr Creek	28	33.6	647.5	620.0	1,487.6
Tule Creek	26	1.6	573.8	412.5	2,582.9
East Fork Hayfork Creek	43	3.1	390.6	175.7	1,750.2

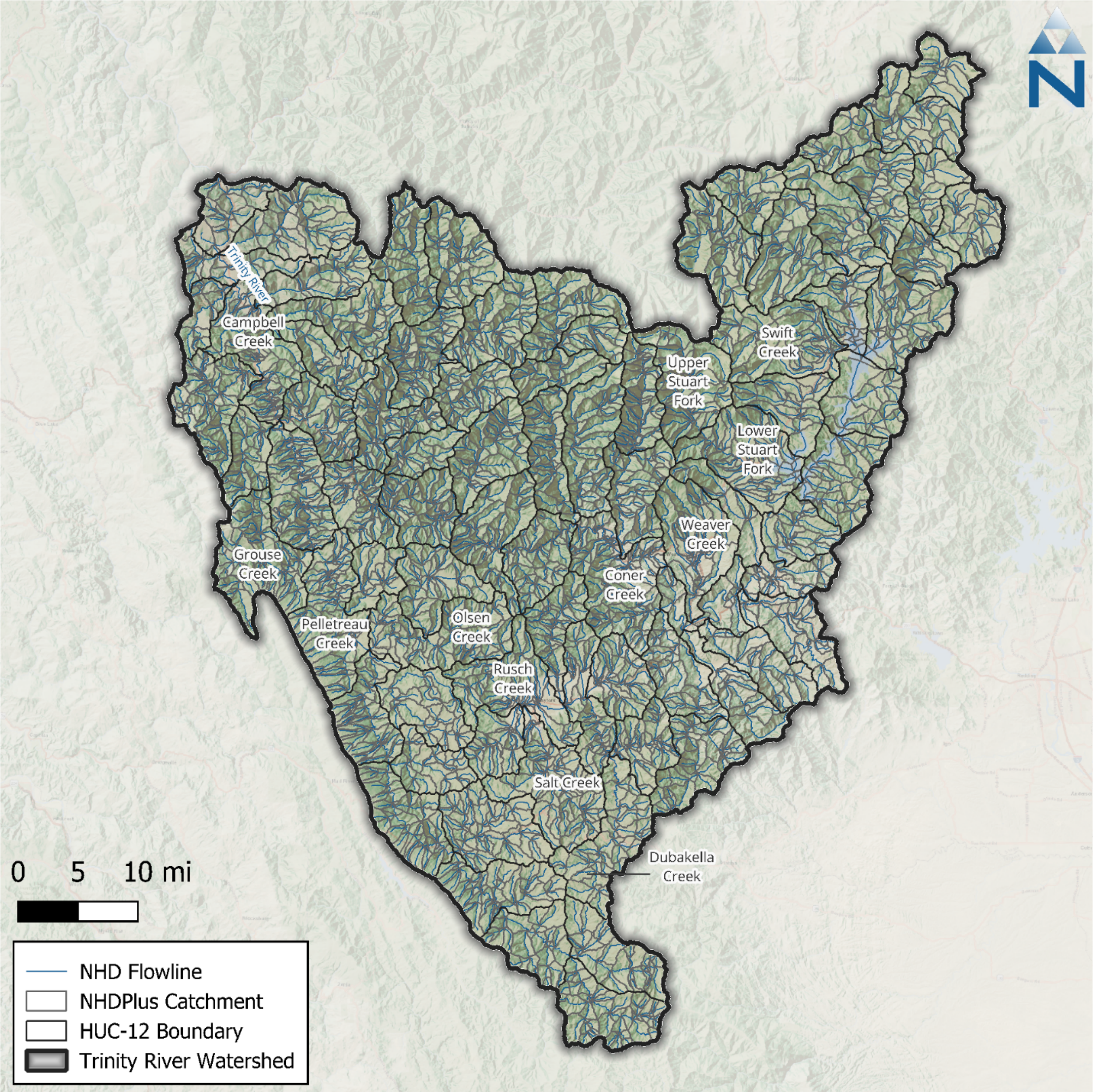


Figure 3-1. Initial catchment segmentation for the Trinity River watershed.

3.2 Streams and Channels

The hydrographic characteristics of the streams and rivers within the Trinity River watershed (as shown in Figure 3-1) are primarily derived from NHDPlus. This dataset depicts primary flow paths based on a nation-wide 10-meter Digital Elevation Model (DEM) and includes additional attributes such as hydrologic sequence and flow line slope. These characteristics will be important for creating representative reach segments within the hydrologic model. Figure 3-1 maps the location of the Trinity River and its major tributaries.

3.3 Streamflow

The primary source of streamflow data is from the USGS, which includes 11 current long-term gauges. Table 32 presents a summary of the available USGS streamflow gauges. Figure 32 shows the location of both the active and inactive gauges within the Trinity River watershed.

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

Gauge Description	Station ID	Drainage Area (mi^2)	Start Date	End Date	Gauge Active?
TRINITY R AB COFFEE C NR TRINITY CENTER CA	11523200	149	10/01/1988	Present	Yes
TRINITY R A LEWISTON CA	11525500	719	10/01/1988	Present	Yes
RUSH C NR LEWISTON CA	11525530	22.3	10/01/2004	Present	Yes
TRINITY R BL LIMEKILN GULCH NR DOUGLAS CITY CA	11525655	810	10/01/1988	Present	Yes
INDIAN C NR DOUGLAS CITY CA	11525670	33.5	10/01/2004	Present	Yes
TRINITY R A DOUGLAS CITY CA	11525854	931	10/01/2004	Present	Yes
TRINITY R A JUNCTION CITY CA	11526250	1057	10/01/2004	Present	Yes
TRINITY R AB NF TRINITY R NR HELENA CA	11526400	1137	03/29/2005	Present	Yes
TRINITY R NR BURNT RANCH CA	11527000	1439	10/01/1988	Present	Yes
SF TRINITY R BL HYAMPOM CA	11528700	764	10/01/1988	Present	Yes
TRINITY R A HOOPA CA	11530000	2853	10/01/1988	Present	Yes
TRINITY R BL RUSH C NR LEWISTON CA	11525535	759	05/05/2004	07/22/2004	No
TRINITY R AB GRASS VALLEY C NR LEWISTON CA	11525540	762	04/01/2006	07/31/2006	No
GRASS VALLEY C A FAWN LODGE NR LEWISTON CA	11525600	30.8	11/25/1975	09/24/2002	No
GRASS VALLEY C NR LEWISTON CA	11525630	36.2	10/01/2004	10/01/2019	No
WEAVER C NR WEAVERVILLE CA	11525750	44.8	10/01/2004	09/29/2005	No
BROWNS C NR DOUGLAS CITY CA	11525900	72.7	01/01/1957	09/29/2005	No
NF TRINITY R A HELENA CA	11526500	151	10/01/2004	10/01/2019	No

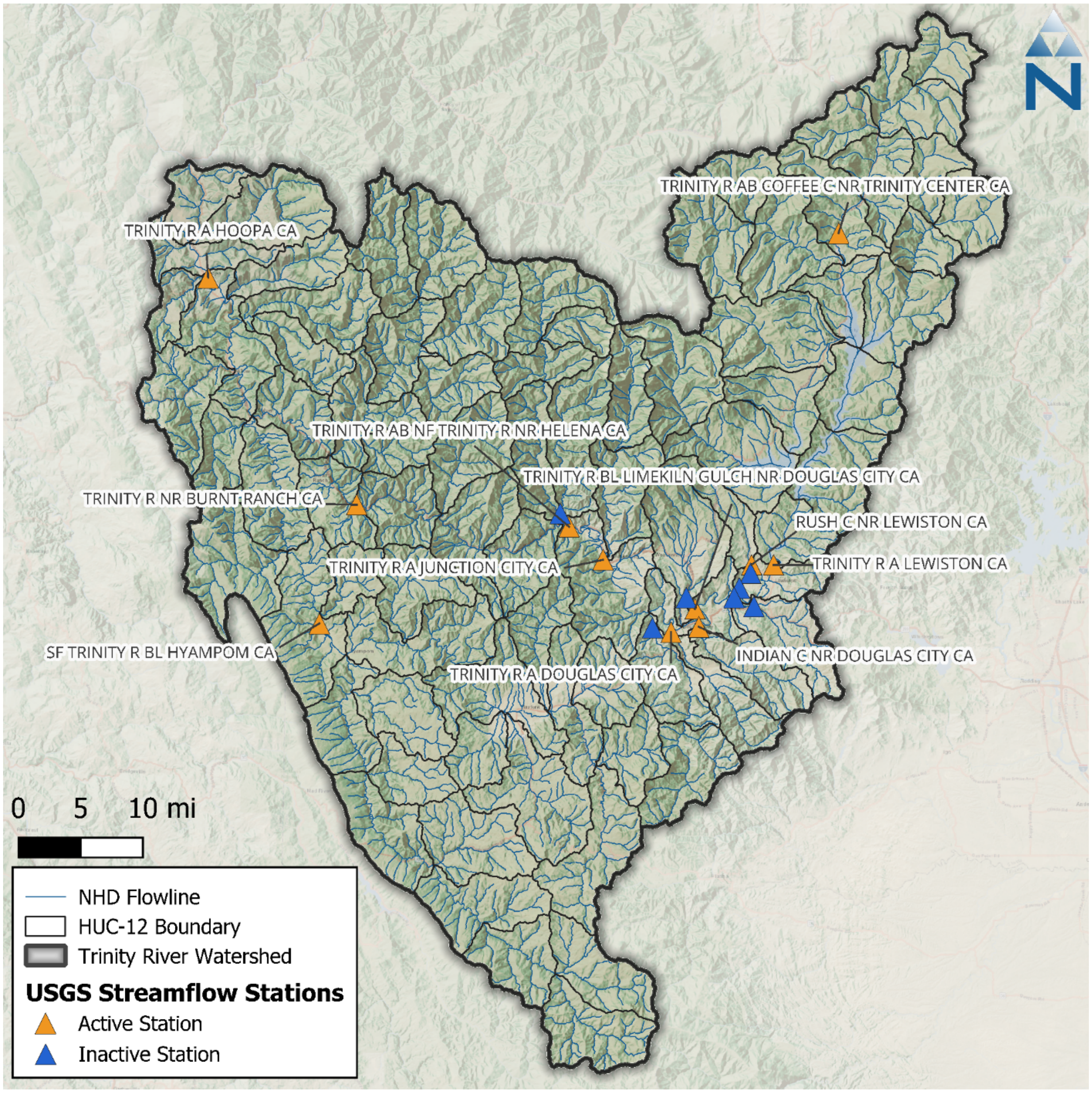


Figure 3-2. USGS streamflow stations in the Trinity River watershed.

3.4 Dams and Reservoirs

The Trinity River watershed contains two main reservoirs, the Trinity Lake, and Lewiston Lake both located in the eastern portion of the watershed (Figure 3-3). Trinity Lake is a sprawling reservoir formed by the Trinity Dam on the Trinity River. Completed in 1963 as part of the Central Valley Project, the dam was constructed to provide water for irrigation and generate hydroelectric power. The lake spans approximately 19 miles in length with 145 miles of shoreline, and holds up to 2.45 million acre-feet of water, making it one of the largest reservoirs in California (USFS 2025).

Below Trinity Lake is the much smaller Lewiston Lake which serves as a regulating reservoir for diverting water through the Clear Creek Tunnel into the Sacramento River. The diverted water is conveyed through the 10.7-mile Clear Creek Tunnel under the Trinity Mountains to the Whiskeytown Lake reservoir, and from there it flows 2.4 miles through the Spring Creek Tunnel to join the

Sacramento River at Keswick Dam (USBR 2025). Along the way, the diverted water also generates hydropower. Water flow data for the Judge Francis Carr hydroelectric station located at the end of Trinity Tunnel indicates an annual average of 1,154 cubic feet per second diverted flow between water years 1963 and 2024 (USGS 2025).

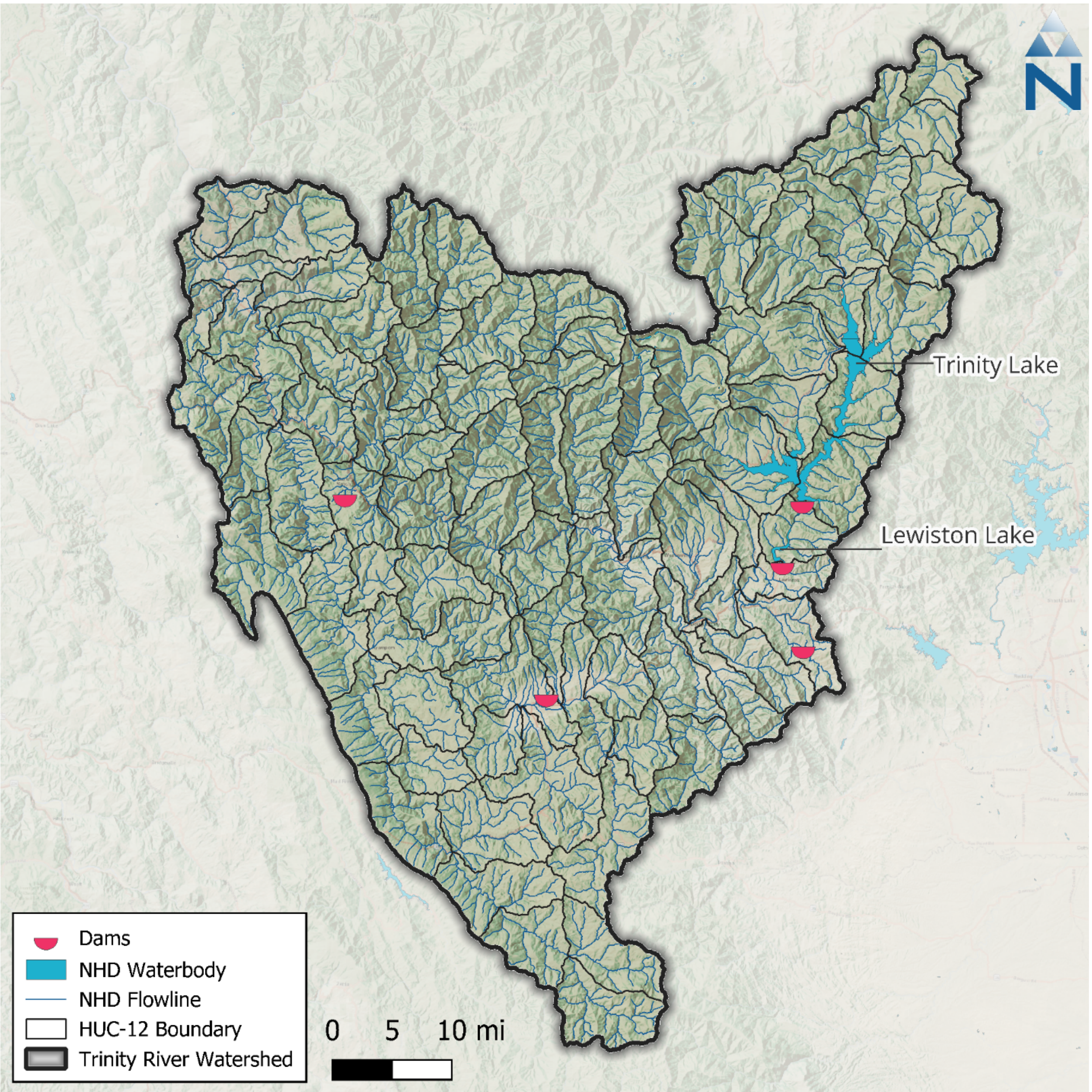


Figure 3-3. Reservoirs and dams location in the Trinity River watershed.

3.5 Snow Impact

Snow is an important part of the Trinity River water budget, especially in the higher-elevation regions of the watershed. The snowpack acts as a reservoir, storing water as snow during the colder months, and releasing that water as spring snowmelt. Within the Trinity River watershed, there are 11 snow monitoring stations – 4 "Snow Course/Aerial Markers", 2 "Cooperator Snow Sensors", and 5 stations with both snow course/aerial markers and cooperator snow sensors. As shown in Figure 3-4, the snow stations are concentrated across a relatively small area northeast of the watershed. Furthermore, some of the stations provide only monthly data, and there are temporal gaps in the data available for the stations.

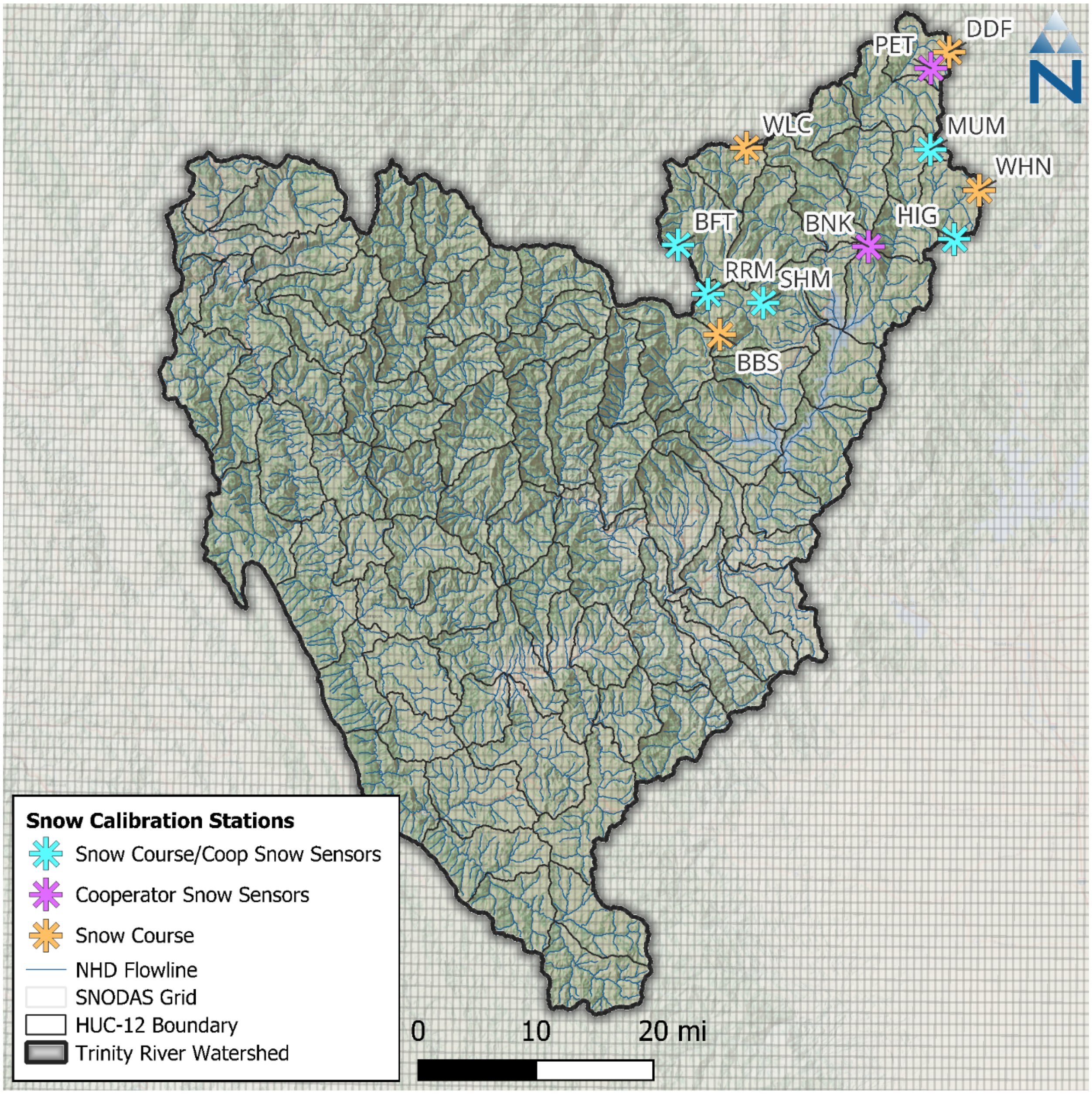


Figure 3-4. Identified snow calibration stations within Trinity River Watershed.

Due to the issues mentioned, an application of the grid-based SNOw Data Assimilation System (SNODAS) dataset in conjunction with land-based snow gauges was considered for this watershed.

Table 3-3. Summary of snow calibration stations within Trinity River Watershed

Station Name	Station ID	Network	Latitude	Longitude	Elevation (m)
Bear Basin	BBS	Snow Course/Aerial Marker	40.967	-122.867	1,981.2
Big Flat	BFT	Snow Course/Aerial Marker and Cooperator Snow Sensors	41.080	-122.942	1,554.5
Red Rock Mountain	RRM	Snow Course/Aerial Marker and Cooperator Snow Sensors	41.023	-122.885	2,042.2
Shimmy Lake	SHM	Snow Course/Aerial Marker and Cooperator Snow Sensors	41.008	-122.800	1,950.7
Wolford Cabin	WLC	Snow Course/Aerial Marker	41.200	-122.830	1,959.9
Deadfall Lakes	DDF	Snow Course/Aerial Marker	41.320	-122.500	2,212.8
Mumbo Basin	MUM	Snow Course/Aerial Marker and Cooperator Snow Sensors	41.200	-122.530	1,728.2
Highland Lakes	HIG	Snow Course/Aerial Marker and Cooperator Snow Sensors	41.090	-122.490	1,804.4
Whalan	WHN	Snow Course/Aerial Marker	41.150	-122.450	1,737.4
Bonanza King	BNK	Cooperator Snow Sensors	41.080	-122.630	1,993.4
Peterson Flat	PET	Cooperator Snow Sensors	41.300	-122.530	2,090.9

The SNODAS dataset is created and managed by NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) (National Operational Hydrologic Remote Sensing Center 2004). SNODAS data is generated as gridded rasters with 1-kilometer spatial resolution across the continental United States (grid shown on Figure 3-4). SNODAS provides a robust temporal resolution, generating daily data, spanning from September 30, 2003, to the current day.

Each cell of the daily SNODAS gridded data provides estimates of metrics related to snow and precipitation. The basis for these estimates includes assimilated snow data from satellites as well as in-situ airborne and ground-based observations. SNODAS provides estimates of snow-water equivalent (SWE), snow depth, snow melt runoff, sublimation from snowpack, sublimation of blowing snow, solid precipitation, liquid precipitation, and snowpack average temperatures. The SNODAS data has gone through limited quality checks across the US (Barrett 2003). A local statistical analysis of the SNODAS data will be performed to further assess the quality of the data for California and the study watershed specifically.

To assess the performance validity of the SNODAS data for the study region, first, the data from the 11 identified nearby snow course/coop sensors will be compared with the corresponding SNODAS data. Furthermore, additional SnoTEL stations with high quality and frequency of observed daily snow data will be identified across California and a detailed statistical analysis will be performed to assess the quality of SNODAS data when compared to the observed snow gauge data. The additional stations will be selected such that in addition to having robust daily snow data, they are scattered across locations with diverse orographic conditions so they can represent various snow conditions. Once the quality of the SNODAS data is verified, it will be used to supply data for snow simulation in the LSPC model.

3.6 Surface Water Withdrawals

Datasets related to water rights, points of diversion, and surface withdrawals (i.e., wells and irrigation) were identified through searches of the Water Board's Electronic Water Rights Information Management System database (eWRIMS) 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 Trinity River watershed to assess the relative impacts based on observed precipitation, evapotranspiration, and streamflow data. The impact of diversions or water usage may be localized along specific tributaries; however, the temporal resolution of the data determines the resolution of those impacts in the model. Additionally, the extent of modeled irrigation will depend on land-use classification, and its water usage rates will be corrected against spatial variations in the observed evaporative deficit where necessary.

Figure 3-5 provides an overview of points of diversion in the watershed. Water systems distributed throughout the watershed include surface water diversions from Trinity River and its primary tributaries. There are forty-one drinking water systems in the watershed. For 16 out of the 41 drinking water systems, the water source is listed as surface water and the remaining 25 have groundwater sources.

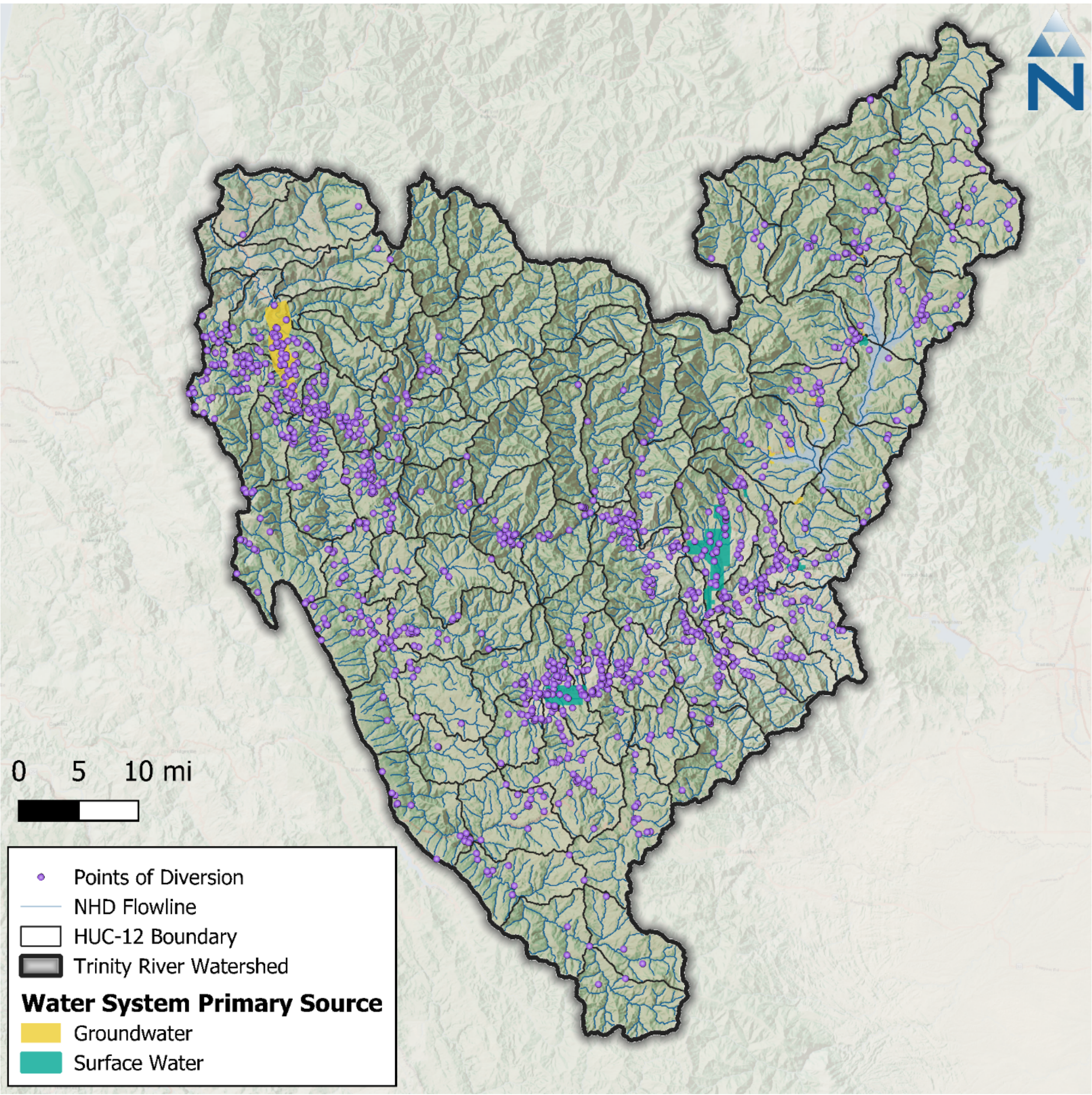


Figure 3-5. P Primary water system sources in the Trinity River watershed.

4 SUBSURFACE HYDROLOGY

The Trinity River watershed contains several groundwater basins as delineated by Bulletin 118 (DWR, 2020). The watershed contains the Hoopa Valley (number 1-007), Hyampom Valley (number 1-035), Hayfork Valley (number 1-006) and Wilson Point Area (number 1-062). There are no partial overlaps. Approximately 1% of the watershed area falls within the groundwater basins delineated by Bulletin 118 and the remaining 99% consists of metamorphic and granitic bedrock.

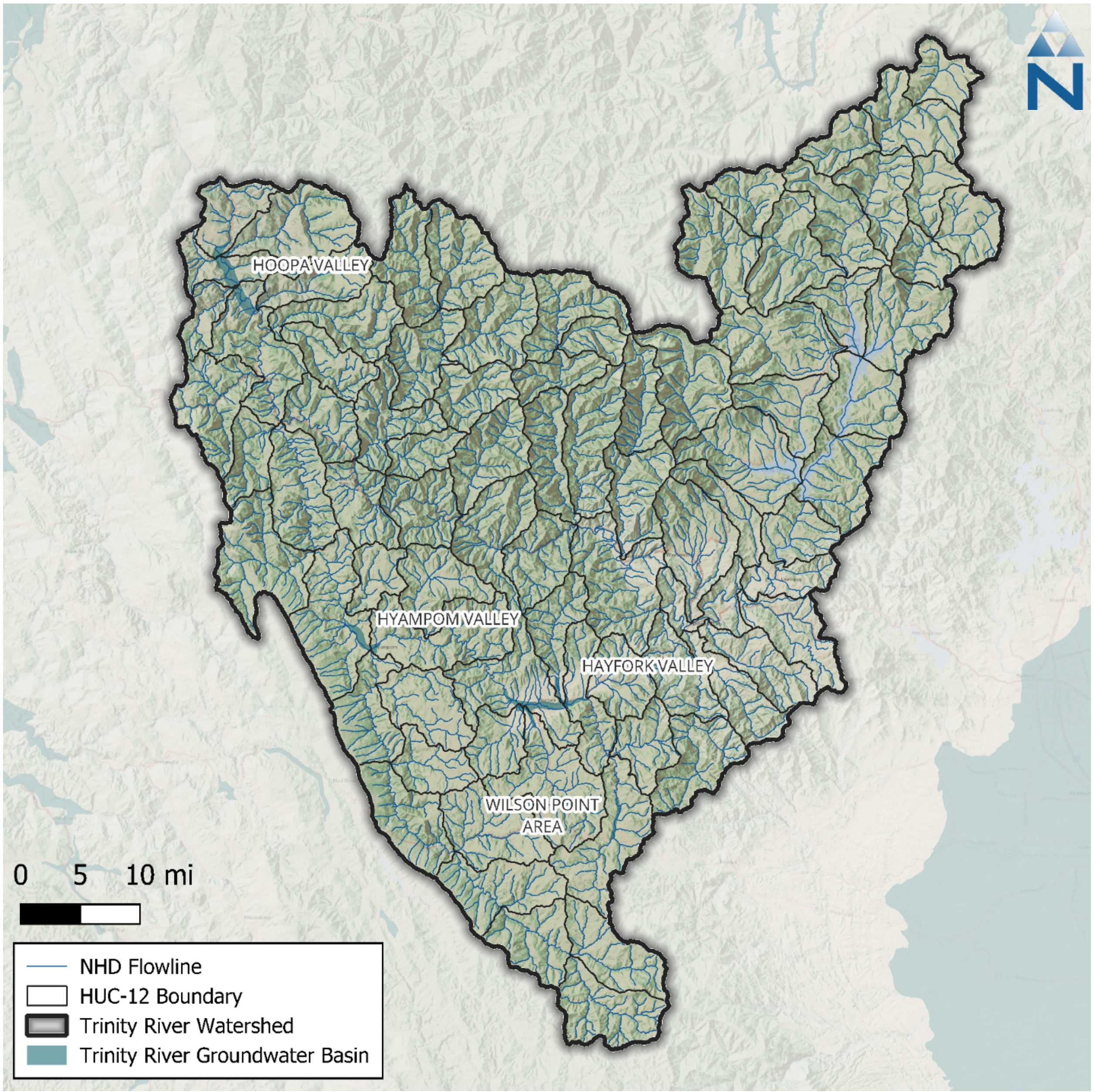


Figure 4-1. Groundwater basins delineated by DWR (2020), also known as Bulletin 118.

As per the respective basin priority details (Sustainable Groundwater Management Act (SGMA) Basin Prioritization Dashboard), all four contained basins are Very Low priority basins as designated by SGMA's basin prioritization. Although the Hayfork Valley basin relies on groundwater for 61% of its supply, it is prioritized as Very Low priority due to groundwater use of less than 9,500 acre-feet per year. The Hyampom Valley, Hayfork Valley and Wilson Point Area basins have no documented impacts to groundwater supplies, such as declining groundwater levels, saline intrusion or subsidence. The Hoopa Valley basin, located within the Hoopa Valley Reservation, uses groundwater for 77% of its supply and has noted seasonal overdraft or declines. However, it is prioritized as "Very Low" priority due to groundwater use of less than 9,500 acre-feet per year. No Groundwater Sustainability Agency (GSA) overlaps the Trinity River watershed.

4.1 Water Budget Components

No publicly available groundwater models were located focusing on the Trinity River. Bulletin 118 reports for all four basins relied on a 1996 study to estimate groundwater extraction. For the Hyampom Valley groundwater basin, estimated groundwater extraction for agricultural use is 84 acre-feet/year, municipal and industrial use is 44 acre-feet/year, and deep percolation of applied water is 42 acre-feet/year. For the Hayfork Valley, estimated groundwater extraction for agricultural use is 960 acre-feet/year and deep percolation of applied water is 4 acre-feet/year. For the Wilson Point Area, estimated groundwater extraction for agricultural use is 30 acre-feet/year, municipal and industrial use is 4 acre-feet/year, and deep percolation of applied water is 6 acre-feet/year. For the Hoopa Valley, estimated groundwater extraction for agricultural use is 56 acre-feet/year, municipal and industrial use is 260 acre-feet/year, and deep percolation of applied water is estimated to be 220 acre-feet. None of the US Geological Survey public domain models for Northern California (viewed at https://ca.water.usgs.gov/sustainable-groundwater-management/california-groundwater-modeling.html) overlap the Trinity River basin.

4.2 Geology

The foregoing references provide coverage primarily within the groundwater basins delineated as per Bulletin 118. The Hyampom basin consists of Quaternary alluvial and terrace deposits along the South Fork Trinity River. The Hayfork Valley, Hoopa Valley, and Wilson Point Area all consist of Quaternary alluvial deposits. Outside the delineated basins, formations include pre-Cretaceous metamorphic rocks, Mesozoic granitic rocks, and Oligocene nonmarine rocks, shown by the California Geological Survey in their 1962 regional Redding map (California Division of Mines and Geology, 1962) and their 1987 Weed map (California Division of Mines and Geology, 1987). The Bulletin 118 delineations do not account for any potential sources of ‘non-basin’ water within weathered bedrock formations, fractures, or other void spaces outside or underneath the designated basins.

5 LANDSCAPE CHARACTERIZATION

Landscape characterization describes the physical characteristics of the landscape including the types of soils and geology, topography, land cover, land use, and other physical properties that can be represented within the hydrological model. Hydrologic Response Units (HRUs) are the core landscape unit in a watershed model. Each HRU represents areas of similar physical characteristics attributable to certain hydrologic processes. Spatial or geological characteristics such as land cover, soils, geology, and slopes are typically used to define HRUs. The spatial combinations of these various characteristics ultimately determine the number of meaningful HRU categories considered for the model. The following sections describe the component layers available to derive HRUs for the Trinity River watershed.

5.1 Elevation & Slope

The USGS publishes DEMs expressing landscape elevation through a raster grid data product with 30-meter resolution. The Trinity River watershed ranges in elevation from near sea level around 59 m along the riverbed in the northwestern part of the watershed to over 2,600 meters in the northeast. 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 Trinity River watershed.

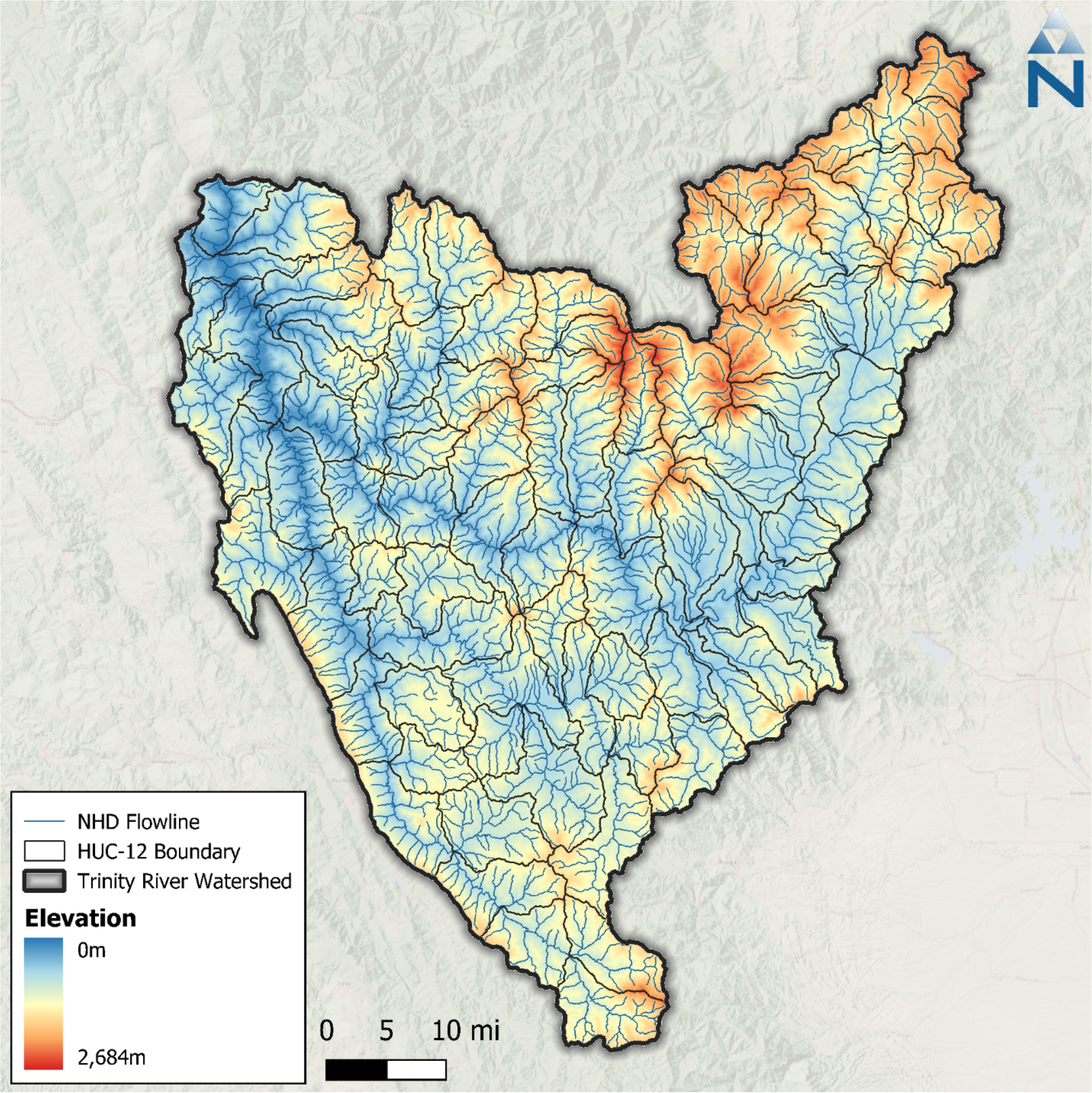


Figure 5-1. Digital elevation model of the Trinity River watershed.

5.2 Soils

Soils data for the Trinity River watershed were obtained from the Soil Survey Geographic Database (SSURGO) (USDA 2024d) and State Soil Geographic Database (STATSGO) (USDA 2024b) both published by the Natural Resource Conservation Service (NRCS). There are four primary hydrologic soil groups (HSG) used to characterize soil runoff potential. Group A generally has the lowest runoff potential whereas Group D has the highest runoff potential. Both SSURGO and STATSGO soils databases are composed of a GIS polygon layer of map units and a linked database with multiple layers of soil property. Soil characteristics for predominant hydrologic soil groups are described in Table 5-1.

Table 5-1. NRCS Hydrologic soil group descriptions

Hydrologic Soil Group	Description
A	Sand, Loamy Sand, or Sandy Loam
B	Silt, Silt Loam or Loam
C	Sandy Clay Loam
D	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay, or Clay

Source: Natural Resource Conservation Service (NRCS), Technical Release 55 (TR-55) (USDA 1986) .

Table 5-2 provides a summary of areas occupied by each SSURGO HSG, and Figure 5-2 shows the spatial distribution of these groups throughout the Trinity River watershed. The dominant soil group in the watershed is Group C (31%), containing sandy clay loam with typically low infiltration rates. Group B, makes up 29% of the watershed, containing moderately well to well-drained silt loams and loams. Group D makes up 27% of the watershed, and includes soils with the lowest infiltration rates, such as clay loam, silty clay loam, sandy and silty clay, and clay. Group A, which consists of well-draining sand, loamy sand, and sandy loam, constitutes nearly 11% of the watershed. Only 0.28% of the watershed areas have mixed soils. For modeling purposes, mixed soils will be grouped with the nearest primary group as follows: C/D → D. Finally, approximately 2% of the watershed HSG area is classified as unknown in the soils database and reside primarily within mountainous areas. For these areas, the corresponding HSG from the STATSGO dataset will be used to supplement the data gaps; some of these unknown soil areas may correspond to waterbodies.

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

Hydrologic Soil Group	Area (acres)	Area (%)
A	207,622.39	10.92%
B	543,659.04	28.60%
C	588,095.88	30.94%
C/D	5,349.12	0.28%
D	518,664.25	27.29%
N/A	37,291.87	1.96%
Total	**1,900,682.55**	**100.00%**

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

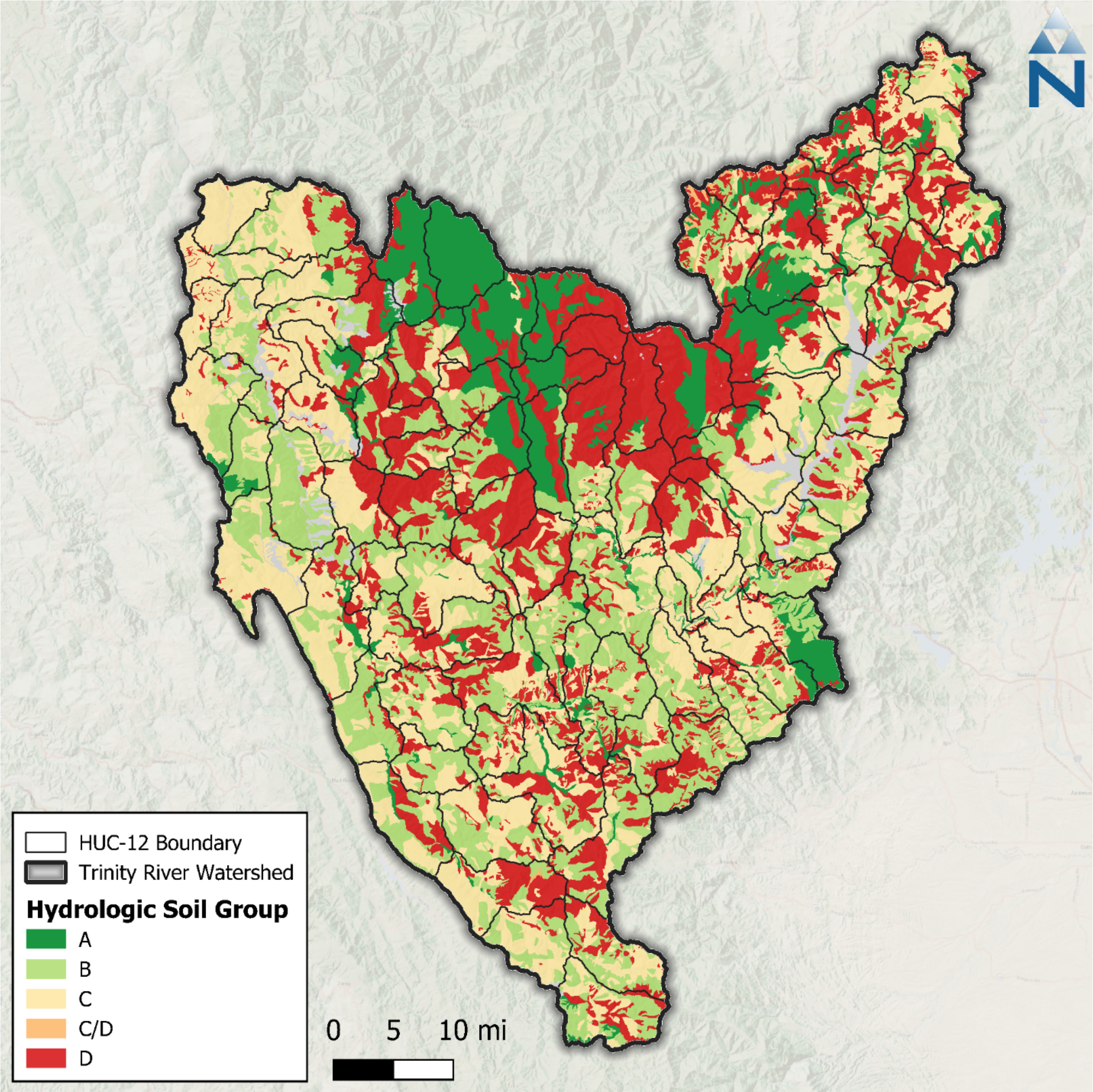


Figure 5-2. SSURGO hydrologic soil groups within the Trinity River watershed.

5.3 Land Cover

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

Table 5-3 summarizes area coverage of land use classes from a subset of the 2021 NLCD dataset that covers the Trinity River watershed and Figure 5-3 shows the spatial distribution of these classifications. Evergreen forest is the dominant land cover classification, covering approximately 58% of the watershed area. When combined, evergreen forest, the undeveloped categories of deciduous forest, mixed forest, shrub/scrub, and grassland/herbaceous account for close to 93% of the total watershed area. Developed land cover makes up less than 5% of the total watershed area and is classified mostly as "Developed, Open Space," which suggests that much of the developed area is dispersed.

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

NLCD Class	Classification Description	Area (acres)	Area (%)
11	Open Water	13,258.77	0.70%
12	Perennial Ice/Snow	1,631.82	0.09%
21	Developed, Open Space[1]	80,885.47	4.25%
22	Developed, Low Intensity[1]	6,985.51	0.37%
23	Developed, Medium Intensity[1]	2,535.60	0.13%
24	Developed, High Intensity[1]	991.19	0.05%
31	Barren Land (Rock/Sand/Clay)	11,067.73	0.58%
41	Deciduous Forest	9,941.07	0.52%
42	Evergreen Forest	1,109,061.98	58.31%
43	Mixed Forest	38,943.49	2.05%
52	Shrub/Scrub	410,851.88	21.60%
71	Grassland/Herbaceous	208,324.11	10.95%
81	Pasture/Hay	533.63	0.03%
90	Woody Wetlands	2,793.40	0.15%
95	Emergent Herbaceous Wetlands	4,300.21	0.23%
TOTAL*		**1,902,105.88**	**100.00%**

Source: 2021 National Land Cover Database

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

* Note that because of the raster resolution, this total is approximately 253 acres more than the model domain.

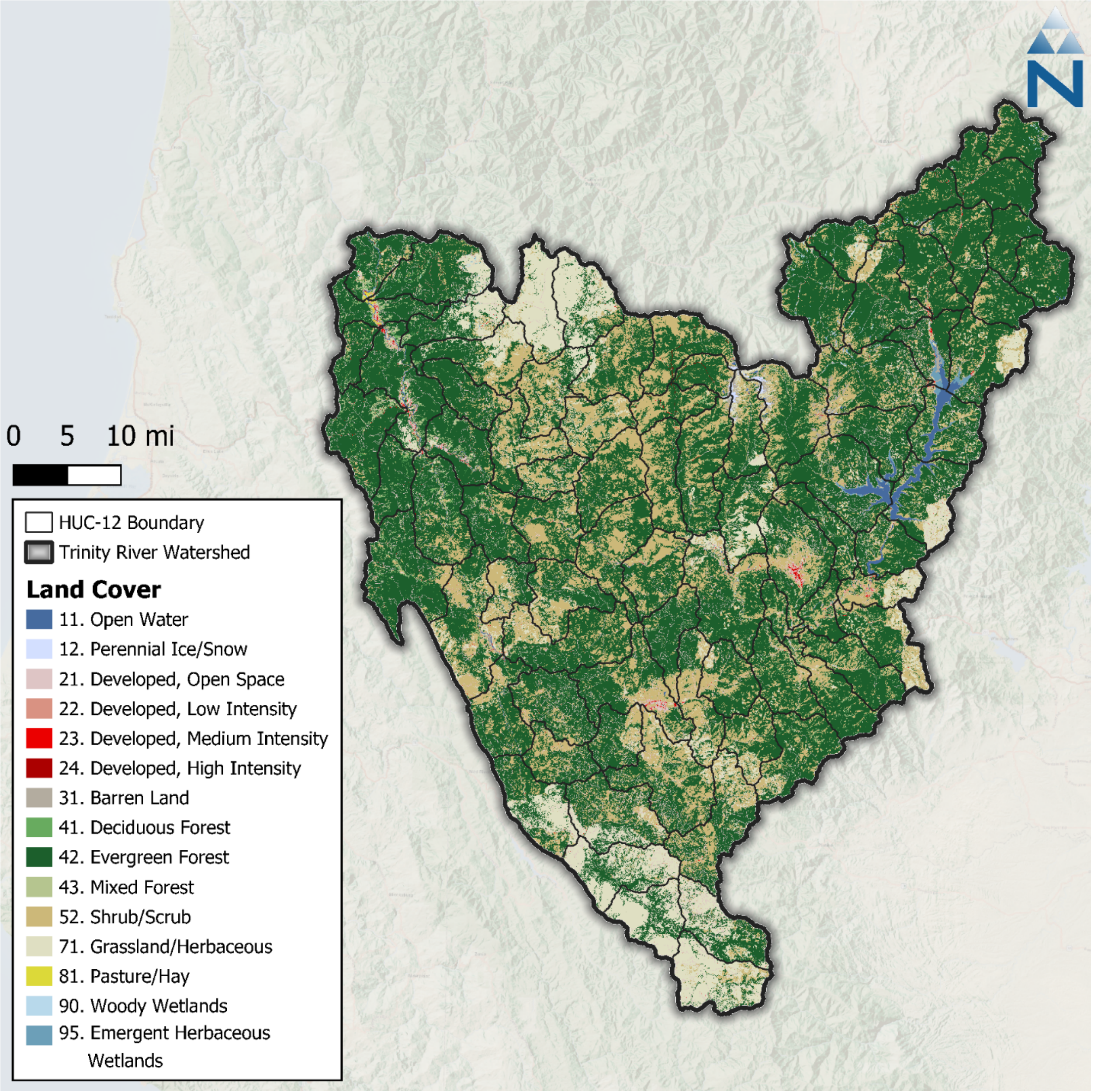


Figure 5-3. NLCD 2021 land cover within the Trinity River watershed.

MRLC publishes a developed impervious cover dataset as a companion to the NLCD land cover; this dataset is also provided as a raster with a 30-meter grid resolution. Impervious cover is expressed in each raster pixel as a percentage of total area ranging from 0 to 100 percent. Because this dataset provides impervious cover estimates for areas classified as *developed,* non-zero values closely align with developed areas (NLCD classification codes 21 through 24). Review of the Trinity River watershed using this dataset shows that around 5% 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. Therefore, the total watershed area is largely undeveloped, and the areas that are developed are mostly developed to a small degree.

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 Trinity River watershed will be assessed as part of the model development, and a decision will be made based on the results as to whether land use change is represented explicitly, or a single land use snapshot is used.

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

5.4 Tree Canopy Cover

MRLC publishes a tree canopy dataset as a companion to the NLCD land cover dataset that estimates the percentage of tree canopy cover spatially. The underlying data model was developed by the United States Forest Service (USFS) and is available through their partnership with the MRLC. This dataset is also provided as a raster with a 30-meter grid resolution. Like the impervious cover dataset, each raster pixel expresses the percent of the total area covered by tree canopy with values ranging from 0 to 100 percent. The percent tree canopy cover layer was produced by the USFS using a Random Forests regression algorithm (Housman et al. 2023). Across the Trinity River watershed, an average of 51% of the total watershed area is covered by tree canopy. Tree canopy cover data can be used to estimate model parameters like interception storage and lower-zone evapotranspiration rates.

5.5 Agriculture & Crops

Land cover data for the Trinity River watershed (see Section 5.3) was analyzed to identify predominant cropland vegetation classes. This analysis revealed that less than 0.03% of the Trinity River watershed area is classified as Pasture/Hay (class 81) and 33% 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 2024a) is an annual updated raster dataset that geo-references crop-specific land use. The dataset comes as 30-meter resolution raster with a linked lookup table of 85 standard crop types which can be used to classify agricultural land. The purpose of the CDL dataset is to provide a supplemental estimate of annual acreage used for major crop commodities. Figure 5-4 shows the spatial distribution of these classes through the study area, and Table 5-4 summarizes their areal coverage. Additionally, a large-scale crop and land use identification dataset for the year 2020 is made available by DWR (DWR 2019) and could be used to supplement data gaps if necessary. This dataset is intended to quantify crop acreage statewide and was constructed by analyzing remote sensing data gathered at the field scale.

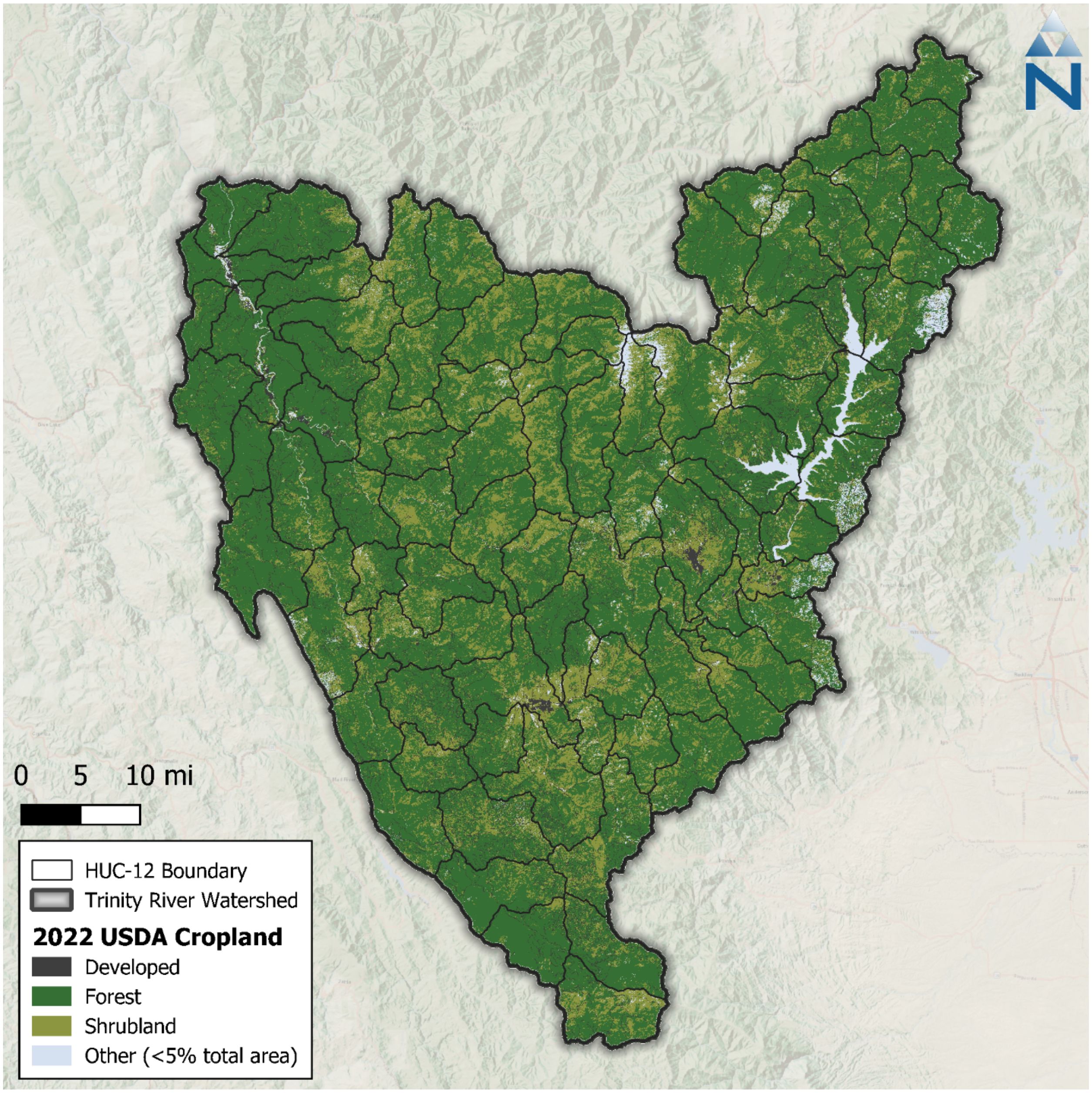


Figure 5-4. USDA 2022 Cropland Data within the Trinity River watershed.

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

Crop Type	Area (acres)	Area (%)
Developed	95,558.1	5.02%
Forest	1,312,841.6	69.02%
Shrubland	430,158.4	22.61%
Other (<5% Total Area)	63,576.5	3.34%
Totals	**1,902,134.6**	**100.00%**

6 DATA GAPS AND LIMITATIONS

One of the limitations for Trinity River watershed is limited availability of snow monitoring stations. The snow stations with available data (snow course and cooperator snow sensors) are concentrated on a relatively small portion of the watershed to the northeast. Some of the stations contain only monthly data and there are data gaps in the data available from the stations. Due to these shortcomings, using SNODAS data in conjunction with available snow gauges is considered for this watershed. While SNODAS provides seamless coverage of daily snow data for entire watershed at 1-km resolution, it has its own limitations that should be considered and addressed as discussed below.

There are a few days with missing data from SNODAS for the watershed. Only 20 days have missing data from the entire SNODAS SWE dataset across the simulation period (2003-2023). These few instances of data gaps can be patched by interpolating the data for days prior to and after the gap. NOHRSC did not begin to routinely perform snow assimilation until the start of Water Year 2005. Therefore, the use of SNODAS data prior to Water Year 2005 is not recommended. SNODAS has gone through limited quality checks and therefore a local assessment of the data is necessary (Barrett 2003). Limited assessment of the SNODAS model has shown that it tends to underestimate snow removal at high elevations, leading to erroneously high snow-water equivalent estimates at high elevations. NSIDC recommends caution for using SNODAS for quantitative water budget analysis as its data is a model output (NSIDC 2024). Due to these limitations, a detailed quality check of the SNODAS data for the study region will be done before adopting its data for this study.

Another limitation is the availability of only one USGS gauge with daily streamflow data for the South Fork branch of the Trinity River: the South Fork Trinity River Below Hyampom (USGS 11528700), which has one long-term daily data from 10/1/1965 through the present. This limits the assessment of hydrology for the South Fork branch. Other sources of streamflow data may be available from local agencies or stakeholders; however, none were readily available through online searches while developing this work plan. Using a top-down weight-of-evidence-based approach described in this work plan tends to limit the propagation of error and uncertainty in the system since the core components are derived using the best and highest-resolution data available.

Another potential limitation is the availability, quality, and temporal resolution of data for surface water diversions within the watershed. The eWRIMS database identifies major surface water diversions that are likely to have data to integrate into the model; however, other surface water diversions, such as water use to support cannabis cultivation, may not be mapped or have available data. These diversions may need to be mapped, and assumptions could be needed to represent water demand in the model if these demands are needed for model calibration purposes.

Regarding groundwater, no groundwater model is available for the Trinity River basin. No Airborne Electromagnetic (AEM) survey flights were flown across the basin. The California state database of well logs does not include any available measurements within the Trinity River basin. The California state database of groundwater levels includes three locations in and near Hoopa Valley.

7 MODEL CONFIGURATION

Model configuration encompasses model selection and data integration. Model selection considered not only available data and the ability of available models to address key study objectives, but also, considered how existing or on-going modeling efforts could be leveraged to address the specific objectives of this study (Section 1). This section elaborates further on model selection and model configuration.

7.1 Model Selection

The objectives of this modeling study influence both hydrologic model selection and technical approach development. The available data presented in Section 2 through Section 5 for characterizing the watershed also influences model selection. The key study objectives to be addressed with the selected hydrologic model are summarized below:

- Representation of unimpaired flows and baseline flows (e.g., water use and other human activities that impact instream flows and how they affect the water balance)
- The model simulation period should be long enough to capture the variability of the full range of water years such that it can represent varied conditions including dry and wet year flows, environmental flows, drought curtailment, etc.

To simulate streamflow, the model must be able to represent seasonal variability in the landscape and be responsive to both natural changes (e.g., meteorological conditions, vegetation cycles) and anthropogenic/hydromodification impacts (e.g., stream diversions, impoundments, groundwater pumping, timber harvest). An ideal platform should also be adaptable for simulating (1) spatial changes like those associated with representing pre-developed/unimpaired land cover states, (2) temporal changes like those associated with modeling climate change impacts, or (3) catastrophic impacts like those associated with extreme events such as 100-year storms and forest fires.

Public-domain models that can address those study objectives include the Hydrologic Simulation Program – Fortran (HSPF) (Barnwell and Johanson 1981), the LSPC (Shen et al. 2005; USEPA 2009), the Precipitation-Runoff Modeling System (PRMS) (Markstrom et al. 2015), and the Soil and Water Assessment Tool (SWAT) (Neitsch et al. 2011). LSPC has been used extensively throughout California to model the unique hydrologic characteristics of the State's watersheds and to inform regulatory decisions (i.e., development of TMDLs and associated amendments to Water Quality Control Plans), watershed management, or climate change analyses. Watersheds in California where LSPC modeling has been conducted include those in the San Francisco Bay region (SCVURPPP 2019; SMCWPPP 2020; Zi et al. 2021 and 2022), the Clear Lake watershed in the Central Valley Region (CVRWQCB 2006), the Lake Tahoe watershed in the Lahontan Region (LRWQCB and NDEP 2010; Riverson et al. 2013), all coastal watersheds of Los Angeles County (LACFCD 2020; LARWQCB 2010, 2012, 2013b, 2013a, and 2015; LARWQCB and USEPA 2005a, 2005b, 2006, and 2011; Tariq et al. 2017), the San Jacinto River watershed in the Santa Ana Region (SAWPA 2003 and 2004), and most coastal watersheds of the San Diego Region (City of San Diego and Caltrans 2016; City of Vista 2008; Los Peñasquitos Responsible Agencies 2015; San Diego Bay Responsible Parties 2016; SDRWQCB 2008, 2010, and 2012). These efforts have included comprehensive peer review processes and public comment, requiring demonstration of model accuracy based on standard practices for quantifying and documenting model performance. All the modeling documentation and reports cited here have withstood peer review and have supported amendments to Water Quality Control Plans or the approval of watershed plans submitted to the Water Board or Regional Water Quality Control Boards to demonstrate regulatory compliance.

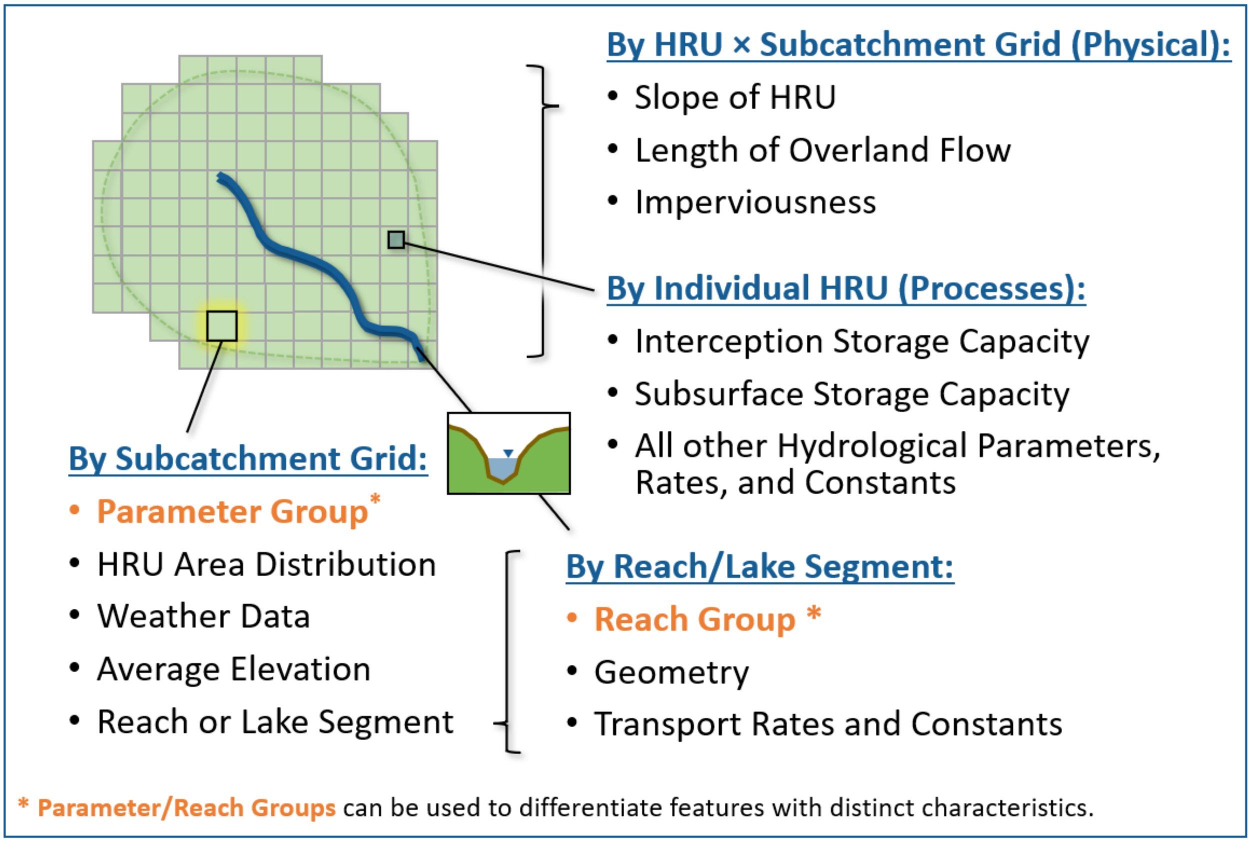
LSPC is a modernized version of the HSPF platform that is now organized around a Microsoft Access relational database; otherwise, the LSPC model is functionally identical to the HSPF model. The relational database provides efficient data management, model maintenance, and development of alternative scenarios. The LSPC model runs using hourly input boundary conditions and can be sufficiently configured using the meteorological datasets discussed in Section 2. LSPC also has a feature that can vary land use over time when needed to explicitly represent dynamic processes such as timber harvests and wildfires—that feature needs supporting spatial and temporal data to represent dynamic land use changes. Additionally, LSPC was the selected modeling platform for other Water

Board studies, including the South Fork Eel River, Shasta River, Navarro River, and several others that were under development at the time of writing this work plan. Based on the extensive history of successful LSPC model applications and its strengths and flexibility for potential coupling with a groundwater model (e.g., MODFLOW), LSPC is recommended as the watershed model for this study.

7.2 Model Configuration

An LSPC model will be configured using the datasets presented in Section 2 through Section 5. A hydrologic analysis 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. While the LSPC model is not a grid-based model by default, the flexibility of the model for subcatchment segmentation and HRU development provides the opportunity for a grid-based setup for a more detailed representation of hydrological processes and forcing inputs (i.e., weather data).

Upon further assessment and in coordination with the State Board, a decision will be made on whether a grid-based scheme should be used for the watershed segmentation. For this approach, a quadtree grid mesh will be developed to segment the watershed into "subcatchments grids." The grid cell size will be dictated by the elevation gradient assigning finer resolution to areas with higher elevation change over shorter distances. This approach will ensure capturing the heterogeneity while maintaining balanced model efficiency. Each grid will have a distribution of HRUs, which are derived at a finer grid resolution than the subcatchment grids. Figure 7-1 shows how those LSPC model configurations are organized. Because LSPC assigns attributes such as weather data and average elevation by subcatchment, using a gridded layer can improve the performance of processes such as snow simulation in areas with large elevation changes over short distances. For surface routing, LSPC allows multiple subcatchment grids to be routed to a modeled stream routing segment by turning off routing in grids without stream segments and pointing them directly to one with a modeled stream segment.



* Parameter/Reach Groups can be used to differentiate features with distinct characteristics.

Figure 7-1. Organization of LSPC model configuration components.

The following describes how major elements of the model will be constructed using the available data sets. Further details about each process and underlying assumptions will be documented in a modeling report:

- **Climate Boundaries:** Climate boundary inputs to the model will include both precipitation and ET. To create a dataset with the highest coverage, and spatial and temporal resolution, a hybrid land-based/grid-based approach will be used as explained in section 2. To prepare the precipitation input data, the land-based data from NOAA (LCD, GHCN, and CoCoRaHS), RAWS, and CDEC gauges identified in Section 2 will be used as a base. The 4-km gridded PRISM monthly precipitation data will also be collected and downscaled to hourly using land-based hourly data and/or NLDAS. The gaps in land-based data will be filled with the downscaled hourly PRISM data. Section 3.4 provides a detailed explanation of the approach for representing snow processes in the model.
- **Model Segmentation**: If catchment-based segmentation is adopted for this watershed, watershed delineations will be based on HUC-12 boundaries and use NHDPlus catchment boundaries to subdivide the HUC-12 boundaries to represent key points of interest in the network (e.g., confluence of tributaries, points of diversion, etc.). One primary reach segment will be represented per catchment and will use a cross-section calculated using trapezoidal geometry as a function of cumulative upstream drainage area. If additional cross-sectional information is available, these geometries can be updated per catchment in the model. If upon further assessment grid-based segmentation is adopted, the subcatchment delineation will entail generating a quadtree grid mesh. This mesh will be overlayed with the NHDPlus catchment boundaries described in Section 3.1 to determine the routing scheme for the grids. Depending on the resolution of the grid mesh and availability of a high-resolution LiDAR dataset, a detailed flow accumulation raster will also be generated to assist with determining

grid routing if needed. Each grid will represent an LSPC subcatchment, with multiple grids associated with NHDPlus stream segments. _Ref164410808 illustrates the relationship between the regular grid segmentation, catchment boundaries, stream segments, and HRUs. This approach will create a consistent spatial representation of hydrologic processes to ensure a seamless linkage between LSPC and a possible groundwater model. One primary reach segment will be represented per subcatchment and will use a cross-section calculated using trapezoidal geometry as a function of the cumulative upstream drainage area. If additional cross-sectional information is available, these geometries can be updated based on better available data.

- **Hydrologic Response Units**: HRUs represent unique combinations of landscape characteristics derived by overlaying GIS datasets describing land cover, hydrologic soil group, and slope. The unique combinations of these three elements will form a set of HRUs that will be configured within the LSPC model. When crop type is known, this will be used to override the land cover data. In the final model configuration, some HRUs may be reclassified and grouped when appropriate for model parameterization (e.g., multiple forest types may be grouped into a single "forest" HRU category unless there is reason to represent different responses in the model for each type).
- **Water Use and Inflows**: To the extent that major sources of water use (e.g., groundwater pumping, surface diversions) or inter-basin transfers are known, these volumes will be included as withdrawals or inputs to the model. Assumptions may need to be made and documented for some of these sources/sinks, and others may need to be excluded entirely if the impact(s) on the model prediction raises questions about the accuracy of the data. Priority will be given to representing these features when they influence points where the model is being compared to observed data for calibration purposes.

8 MODEL CALIBRATION

A combination of visual assessments and computed numerical evaluation metrics will be used to assess model performance during calibration. Model performance will be assessed using graphical comparisons of 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. (2015, 2007) assign narrative grades for hydrology and water quality modeling to the percent bias (PBIAS), the ratio of the root mean square error to the standard deviation of measured data (RSR), and the Nash-Sutcliffe model efficiency (NSE). These metrics are defined as follows:

- The percent bias (PBIAS) quantifies systematic overprediction or underprediction of observations. A bias towards underestimation is reflected in positive values of PBIAS while a bias towards overestimation is reflected in negative values. Low magnitude values of PBIAS indicate better fit, with a value of 0 being optimal.
- The ratio of the root mean square error to the standard deviation of measured data (RSR) provides a measure of error based on the root mean square error (RMSE), which indicates error results in the same units as the modeled and observed data but normalized based on the standard deviation of observed data. Values for RSR can be greater than or equal to 0, with a value of 0 indicating perfect fit. Moriasi et al. (2007) provides narrative grades for RSR.
- The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. Values for NSE can range between $-\infty$ and 1, with NSE = 1 indicating a perfect fit.

Other metrics can also be computed and used to assess calibrated model performance, including the Kling-Gupta Efficiency (KGE). This metric can provide additional or complementary information on model performance to the three metrics listed above and is defined as follows:

- The Kling-Gupta Efficiency (KGE) metric is based on the Euclidean Distance between an idealized reference point and a sample's bias, standard deviation, and correlation within a three-dimensional space (Gupta et al. 2009). KGE attempts to address documented shortcomings of NSE, but the two metrics are not directly comparable. A KGE value of 1 indicates a perfect fit, with agreement becoming worse for values less than 1. Knoben et al. (2019) have suggested a KGE value > - 0.41 as a benchmark that indicates a model has more predictive skill than using the mean observed flow. Qualitative thresholds for KGE have been used by Kouchi et al. (2017).

Both modeled time series and observed data will be binned into subsets of time to highlight seasonal performance and different flow conditions. Hydrograph separation 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 Trinity River watershed will be assessed to see if linkage of the LSPC model with a groundwater model (e.g., MODFLOW) could improve performance and process interactions. This could be manifested through a significant mismatch between the simulated and observed baseflow during dry periods. Other indicators include the mismatch between the simulated and observed hydrograph shape, demonstrating significant flow timing and magnitude differences. The presence of any 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)	All Conditions [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, six-month 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 consider the top 10% of daily flows by magnitude as determined from the 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 developed 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 Trinity River watershed. Once this work plan is finalized, the data sets described in this memo will be used to develop an LSPC model as described in Section 7. After finalizing the work plan, the first step of that process will be to present and finalize watershed boundaries and subcatchment delineations that capture key points of interest in the watershed (e.g., tributary confluences, gauge locations, and the like). Once built, this model will be calibrated using the metrics presented in Section 8 and documented in a model development report. Table 9-1 presents a summary of the deliverables planned for the Trinity River watershed.

Table 9-1. Proposed schedule and summary of deliverables

Task	Subtask	Deliverable	Due Date
2	2.1	Data Compilation Inventory in Excel Format	--
	2.2	Draft Work Plan	--
	2.3	Final Work Plan	Two (2) weeks after receiving comments
3	3.1	Subbasin delineation and stream GIS files	Two (2) weeks after completing Task 2.3
	3.2	LSPC database, model inputs, and GIS files[1]	Fourteen (14) weeks after completing Task 3.1
4	4.1	Draft Calibration Slide Deck	Twenty (20) weeks after completing Task 3.2
		Final Calibration Slide Deck	Eight (8) weeks after receiving comments on Draft Calibration Slide Deck
5	5.1	Partial Draft Model Development Report	Twelve (12) weeks after completing Task 3.1
		Draft Model Development Report	Ten (10) weeks after completing Task 3.2
	5.2	Final Model Development Report	Ten (10) 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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