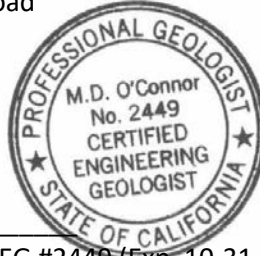


June 12, 2024

MEMORANDUM

To: Maxville Winery
4105 Chiles-Pope Valley Road
St. Helena, CA 94574

From: 
Matthew O'Connor, PhD CEG #2449 (Exp. 10-31-2025)
President, O'Connor Environmental Inc.



Katherine Woodworth B.S.
Assistant Hydrologist

Subject: BASEFLOW WATER AVAILABILITY FOR DIVERSION AT MAXVILLE WINERY, (APNS 025-020-025, 025-020-028)

This memorandum analyzes the availability of surface water baseflow to four Points of Diversion (PODs) owned by Maxville Winery as requested by County of Napa. It is supported by a hydrology analysis completed by HDVine LLC in April 2023. This analysis utilizes hydrologic modeling by O'Connor Environmental, Inc. (OEI), which implemented the US Geological Survey model code "Soil-Water Balance" for all of Napa County, as well as rational runoff calculation and an investigation of simulated unimpaired flows in Maxwell Creek in order to assess "baseflow" availability to satisfy Water Rights that provide water for vineyard irrigation. The term "baseflow" is replaced by "runoff" in this report.

Water System Overview

Water for the proposed project (vineyard development and cultivation including irrigation) is sourced from Water Rights allowing surface water diversion at four Points of Diversion (PODs) on Maxwell Creek, a tributary of Pope Creek which drains into Lake Berryessa in eastern Napa County (Attachment A). All four water rights are on-stream diversions to storage.

- Water Right A013711 allows 183 Acre-Feet (AF) of diversion to storage for the purpose of irrigation of 212 acres of vineyard during the storage season between November 1 and April 1.
- Water Right A016960 permits 12 AF of diversion to storage during the period of November 1 to June 1 for irrigation of 126 acres of vineyard.
- Water Right L032173 permits diversion of 3 AF to storage between November 1 and April 1 for the purpose of livestock watering.
- Water Right L032174 permits diversion of 7 AF to storage between November 1 and April 1 for the purpose of livestock watering.



O'Connor Environmental, Inc. www.oe-i.com (707) 431-2810
Hydrology & Hydraulics ▪ Hydrogeology ▪ Geomorphology
P.O. Box 794, Healdsburg, CA 95448

In total, these Water Rights allow diversion of 205 AF per year on Maxwell Creek for vineyard irrigation and livestock watering on the project parcel (APNs 025-020-025 and -028).

Soil-Water Balance Model

Runoff available to each POD was estimated using a Modified Thornthwaite-Mather Soil-Water-Balance¹. This model (referred to here as SWB) developed by the U.S. Geological Survey utilizes a soil-water accounting method to calculate recharge on a grid-cell scale based on inputs including climate data and landscape characteristics. Recharge is calculated as the difference between sources (precipitation, snowmelt, and inflow) and sinks (interception, outflow, evapotranspiration) and change in soil moisture. Runoff is also calculated in this model at the model grid-cell scale based on defined antecedent runoff conditions determined by soil wetness and seasonality of vegetation and calculated based on the following equation:

$$R = \frac{(P - I_a)^2}{(P + [S_{\max} - I_a])} \quad P > I_a$$

where
 R is runoff,
 P is daily precipitation,
 $S_{\max}$ is maximum soil-moisture holding capacity, and
 I_a is initial abstraction, the amount of precipitation that must fall before any runoff is generated.

Runoff is estimated based on spatially distributed input data including hydrologic soil type, land use, flow direction, available water capacity, soil-water retention, and climatic data. The model does not route runoff to stream channels, nor does it account for groundwater recharge or discharge to stream channels as the model was designed to estimate groundwater recharge. Nevertheless, this model structure does estimate the process of runoff generation on a daily model timestep that accounts for the relevant hydrologic processes. In particular, the model accounts for antecedent conditions of soil moisture and is thus well-suited to estimating runoff generation from the seasonal winter rainstorms that are responsible for the bulk of runoff from upland watersheds that may be collected to storage.

Annual Runoff Estimates

Approach. Given the following information the volume of runoff available for diversion to storage per the available Water Rights can be estimated with reasonable confidence:

- the 10-year average rainfall for the watershed drainage areas corresponding to each of the four PODs from the County's PRISM GIS data set for mean annual precipitation (39.9 inches),
- a relationship between annual rainfall and annual runoff, and
- the contributing drainage area for each POD.

The SWB model provides an estimate of annual runoff as a function of annual precipitation as described below.

¹ Westenbroek, S.M., Kelson, V.A., Dripps, W.R., Hunt, R.J., and Bradbury, K.R., 2010, SWB—A Modified Thornthwaite-Mather Soil-Water-Balance Code For Estimating Groundwater Recharge: U.S. Geological Survey Techniques and methods 6—A31, 60p.

Rainfall-Runoff Relationship. Two SWB models were developed for Napa County by OEI (Attachment B), one for an average Water Year (2010) and one for a dry year (2014). The average Water Year (2010) was selected as the best-fit representation of average precipitation for the period 1981-2010 across all of available rain gage data for Napa County based on (the 30-year period of record available at the time of model development). Water Year 2014, a drought year, was selected to represent dry year conditions. In 2022, the County of Napa adopted new guidance for groundwater availability analyses instructing practitioners to utilize 10-year average precipitation data for the period between 2012 and 2021 provided by the PRISM Climate Group at Oregon State University². Runoff has been estimated for purposes of this analysis based on the 10-year average precipitation data (as required by County of Napa) assuming a linear relationship between precipitation and runoff and utilizing 2010 and 2014 precipitation and runoff values as shown in Figure 1 for one of the four PODs. Because the SWB model operates on a daily time step with inputs of precipitation and potential evapotranspiration, it isn't possible to directly evaluate an average annual precipitation independent of annual climate time series data.

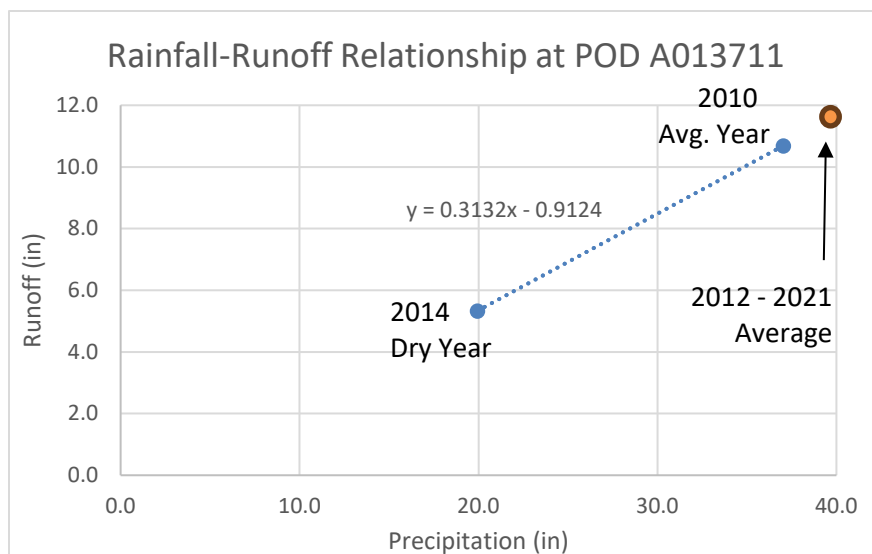


Figure 1: Relationship between rainfall and runoff values in “dry year” and “average year” Soil-Water Balance Model inputs and regression equation estimating 2012-2021 10-year average runoff.

Equations representing the relationships between rainfall and runoff for all four points of diversion are provided in Table 1.

Contributing Drainage Area for PODs. The US Geological Survey’s Streamstats web application was queried to determine contributing drainage area for each POD as shown in Table 1.

Computed Runoff. Annual runoff to each POD is calculated as the product of drainage area (acres), annual precipitation (feet), and runoff as a percentage of annual precipitation calculated per Table 1. Computed runoff is given in Tables 2 and 3.

² www.prism.oregonstate.edu

Table 1: Summary of Data Associated with PODs. Mean annual Precipitation (MAP) is assumed to be the same for each POD due to the small drainage areas and is estimated at 37 inches in the 2010 (normal year) model, 19.9 inches in the 2014 (dry year) model, and 39.9 inches in the 2012-2021 10-year average from Napa Co./PRISM.

Point of Diversion (POD)	Drainage Area at POD (acres)	Formula for Annual Runoff as a Function of MAP (inches)
A013711	433	$0.313 \text{ MAP} - 0.912$
A016960	68.7	$0.295 \text{ MAP} - 1.704$
L032174	38.0	$0.287 \text{ MAP} - 1.460$
L032173	31.6	$0.356 \text{ MAP} - 4.736$

Runoff Available for Storage

Computed runoff to each POD is compared to allowed annual diversion to storage per Water Right conditions (Table 2) and to cumulative diversions upstream (Table 3). Cumulative demand is evaluated as the PODs are nested in a single drainage system and overall availability of runoff to each POD must consider upstream storage requirements.

In the average water year (2010) and the 10-year (2012-2021) average water year scenario, it is estimated that there is sufficient runoff in the system for all four water rights to be fulfilled; there is approximately twice as much runoff relative to the amount required for the full amount of diversion allowed per Water Rights conditions. In the dry year scenario (WY 2014), the cumulative allocation of all four water rights exceeds estimated available runoff by approximately 12.4 AF (Table 3). This is about 6% of the cumulative diversion of 205 AF. Note that the “dry year” scenario reflects extreme drought conditions, and that even in such an adverse year for water supply, there is runoff available to fill about 95% of storage.

Table 2: Diversion volume at each POD compared to available runoff in acre feet in average water year, dry water year, and 10-year average water year.

POD	Total Diversion (ac-ft/yr)	Average Water Year (2010)			Dry Water Year (2014)			2012-2021 Avg. Year		
		Runoff (ac-ft/yr)	Runoff Surplus (ac-ft/yr)	Diversion as % of Runoff	Runoff (ac-ft/yr)	Runoff Surplus (ac-ft/yr)	Diversion as % of Runoff	Runoff (ac-ft/yr)	Runoff Surplus (ac-ft/yr)	Diversion as % of Runoff
POD-A013711	183.0	386.2	203.2	47%	192.6	9.6	95%	415.7	232.7	44%
POD-A016960	12.0	52.0	40.0	23%	23.6	11.6	51%	56.4	44.4	21%
POD-L032174	7.0	29.1	22.1	24%	13.5	6.5	52%	31.5	24.5	22%
POD-L032173	3.0	22.2	19.2	14%	6.2	3.2	49%	24.7	21.7	12%

Table 3: Cumulative diversion volume to each POD on project parcels compared to estimated available runoff from Soil-Water Balance Model.

POD	Cummulative Diversion (ac-ft/yr)	Average Water Year (2010)			Dry Water Year (2014)			2012-2021 Avg. Year		
		Runoff (ac-ft/yr)	Runoff Surplus (ac-ft/yr)	Diversion as % of Runoff	Runoff (ac-ft/yr)	Runoff Surplus (ac-ft/yr)	Diversion as % of Runoff	Runoff (ac-ft/yr)	Runoff Surplus (ac-ft/yr)	Diversion as % of Runoff
POD-A013711	205.0	386.2	181.2	53%	192.6	-12.4	106%	415.7	210.7	49%
POD-A016960	22.0	52.0	30.0	42%	23.6	1.6	93%	56.4	34.4	39%
POD-L032174	10.0	29.1	19.1	34%	13.5	3.5	74%	31.5	21.5	32%
POD-L032173	3.0	22.2	19.2	14%	6.2	3.2	49%	24.7	21.7	12%

Rational Runoff Calculations

A Rational Runoff analysis was performed to compare with the runoff values extracted from the Soil-Water-Balance Model. This analysis was conducted based on the 433-acre drainage to POD-A013711 which contains the drainages to the other PODs on the property. For this analysis we used a runoff coefficient of 0.4 appropriate for a drainage with woodland cover and shallow soils over bedrock³. This analysis was conducted using precipitation data from 2010, the “average” water year for the SWB. Daily precipitation data for WY 2010 was obtained from the PRISM climate group at Oregon State University which provides spatially interpolated daily precipitation data (Figure 2). We estimated runoff generated by storm events with precipitation greater than 0.5 inches per day showed that 32.11 inches (2.67 feet) of precipitation fell during these events, yielding a total runoff of approximately 463 AF to the POD (runoff = $0.4 \times 2.67 \text{ ft} \times 433 \text{ ac}$). This is approximately 112% of the runoff estimated by SWB and provides confirmation of the SWB-derived estimate.

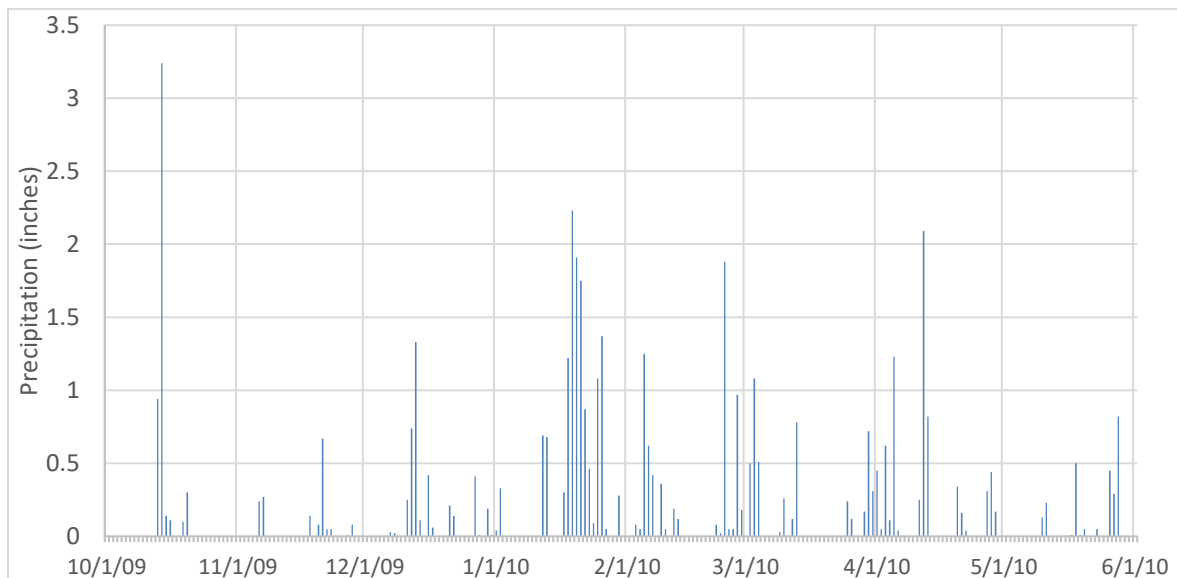


Figure 2: Water Year 2010 Precipitation Data for project site. Data from Prism Climate Group at Oregon State University.

³ Dunne, T. and Leopold, L. (1978) Water in Environmental Planning. WH Freeman & Co.

The Nature Conservancy Natural Flows Database

The Nature Conservancy maintains the Natural Flows Database, a web-based tool which predicts unimpaired flow in rivers and streams statewide based on statistical models trained on data from a network of 250 reference gages distributed throughout the state of California. This tool provides predicted monthly flows and predicted “Functional Flows” based on the California Environmental Flow Framework⁴. Monthly maximum, mean, median, and minimum natural flows are modeled for the period between 1950 and 2015. Predicted Functional Flows are classified for “wet” “moderate” and “dry” years and 10th, 25th, 50th, 75th and 90th percentile values are provided. While this remains a useful tool for estimating unimpaired flows, due to the small size of the drainages as well as the relative lack of reference gages in the vicinity of the project parcel, we do not have high confidence in the ability of this tool to accurately represent a total volume of flow available in Maxwell Creek. The Natural Flows database does not include peak flows in its simulated hydrograph, but in a drainage as small and high relief as that of Maxwell Creek, winter storms are a substantial source of runoff. Although the Natural Flows Database is a useful tool for evaluating many aspects of streamflow, it is not a viable means to estimate water availability for diversion of storm runoff to storage.

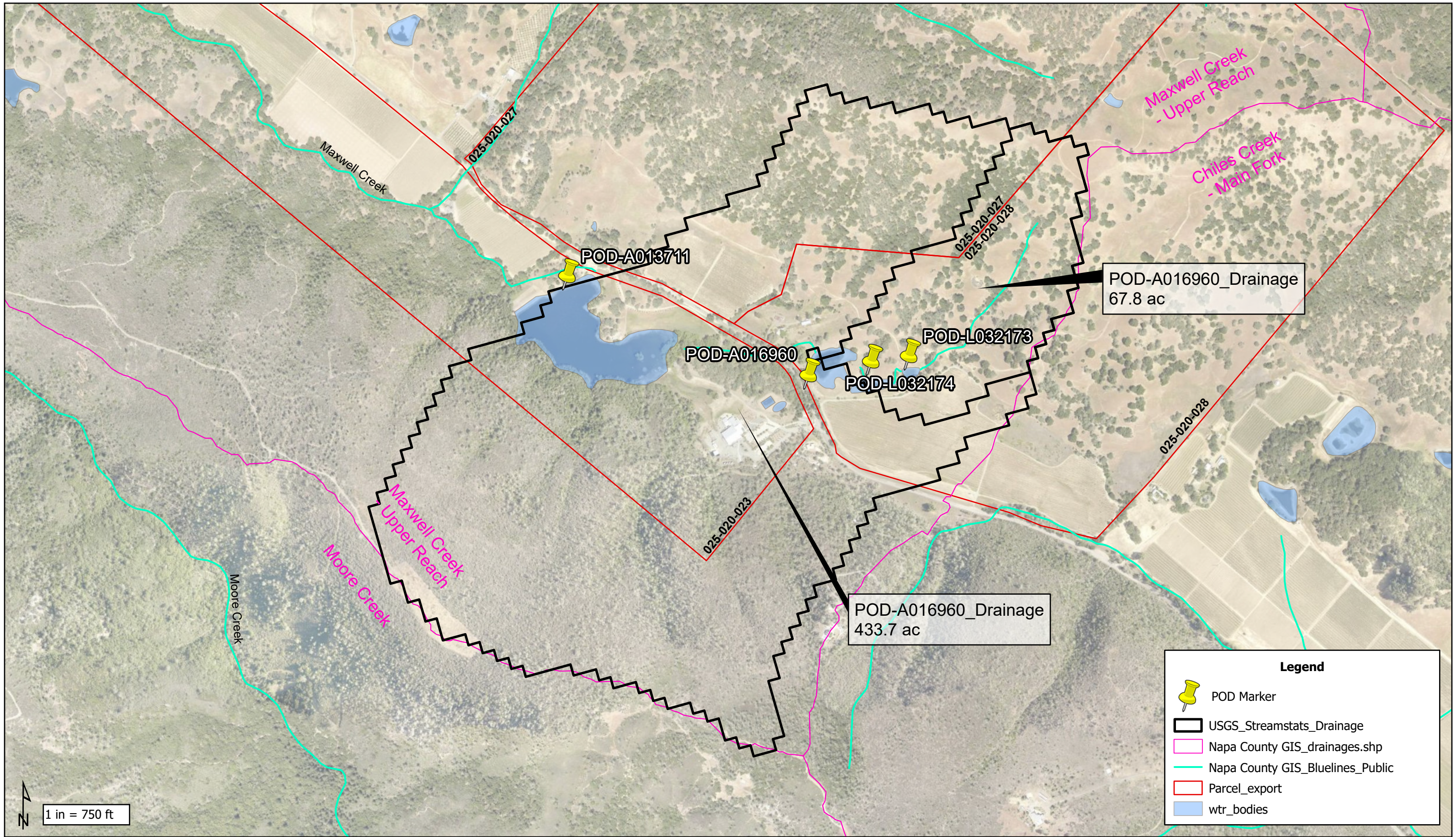
Summary

Streamflow availability (“baseflow” as described by County of Napa and “runoff” as described in this analysis) in Maxville Creek is sufficient to meet the surface water allotment of all four of the PODs for on-channel diversions to storage. This is true for dry year conditions (WY 2014; 95% of allotment for diversion to storage) as well as in average year conditions for the period 2012-2021. This demonstrates that the project area vineyards can be irrigated without the need for utilization of groundwater.

⁴ Yarnell, S. M., Stein, E. D., Webb, J. A., Grantham, T., Lusardi, R. A., Zimmerman, J., Peek, R. A., Lane, B.A., Howard, J., Sandoval-Solis, S. (2020). A functional flows approach to selecting ecologically relevant flow metrics for environmental flow applications. *River Research and Applications*, 36(2), 318-324.

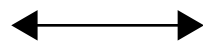
ATTACHMENT A

Drainage Map



HDVine LLC

Santa Rosa, CA
www.HDVine.com
707-533-3511



*If bar does not measure 1 in
then map is not to scale.*

Drawn By: Coda Rainsford, CPESC #9225

Date: 6/25/24

Revision: -

Map Page: 1 of 1

File: ...PRO_Maxville_ECP.aprx

Maxville Drainage Map

APNs 025-020-023, 027, 028

4105 Chiles Pope Valley Road, St Helena, CA 94574

ATTACHMENT B
Napa County Groundwater Recharge Analysis

Napa County Groundwater Recharge Analysis

Introduction

Developing accurate estimates of the spatial and temporal distribution of groundwater recharge is a key component of sustainable groundwater management. Efforts to quantify recharge are inherently difficult owing to the wide variability of factors controlling hydrologic processes, the wide range of available tools/methods for estimating recharge, and the difficulty in assessing the accuracy of estimates because direct measurement of recharge rates is, for the most part, infeasible (Healy 2010, Seiler and Gat 2007).

Numerical modeling is a common approach for developing recharge estimates. Soil-water-balance modeling is one category of numerical models particularly well-suited for estimating recharge across large areas with modest data requirements. This study describes an application of the U.S. Geological Survey's (USGS) Soil Water Balance Model (SWB) (Westenbroek et al. 2010) to develop spatial and temporal distributions of groundwater recharge across Napa County. This model operates on a daily timestep and calculates surface runoff based on the Natural Resources Conservation Service (NRCS) curve number method and potential evapotranspiration based on the Hargreaves-Samani methods (Hargreaves and Samani 1985). Actual evapotranspiration (AET) and recharge are calculated using a modified Thornthwaite-Mather soil-water-balance approach (Westenbroek et al. 2010).

It is important to note that the SWB model focuses on surface and soil-zone processes and does not simulate the groundwater system or track groundwater storage over time. The model also does not simulate surface water/groundwater interaction or baseflow; thus, the runoff estimates represent only the surface runoff component of streamflow resulting from rainstorms and the recharge estimates represent only the infiltration recharge component (also referred to as diffuse recharge) of total recharge (stream-channel recharge is not simulated).

This modeling work and summary report has been prepared by O'Connor Environmental, Inc., for its private use in relation to Water Availability Analyses (WAA) prepared on behalf of private clients for projects using groundwater in "hillside" areas of Napa County as required by Napa Planning, Building & Environmental Services. The modeling to-date is complete in its current form but remains subject to revision; it is considered a working draft with information suitable for use to support WAA projects. Parties interested in obtaining more information regarding the modeling or who may wish to offer comments should contact O'Connor Environmental, Inc.



Model Development

The model was developed using a 30-meter (98.4 ft) resolution rectangular grid. Water budget calculations were made on a daily time step. Key spatial inputs included a flow direction map developed from the USGS 1 arc-second resolution Digital Elevation Model (DEM), a land cover map derived from the U.S. Forest Service (USFS) CALVEG dataset that was supplemented by a database of agricultural areas maintained by the County of Napa (Figure 1), a distribution of Hydrologic Soil Groups (A through D classification from lowest to highest runoff potential; Figure 2), and a distribution of Available Water Capacity (AWC) developed from the NRCS Soil Survey Geographic Database (SSURGO) (Figure 3).

A series of model parameters were assigned for each land cover type/soil group combination including an infiltration rate, a curve number, dormant and growing season interception storage values, and a rooting depth (Table 1).

Infiltration rates for hydrologic soil groups A through D were applied based on Cronshey et al. (1986) (Table 2) along with default soil-moisture-retention relationships based on Thornthwaite and Mather (1957) (Figure 4). Curve numbers were assigned based on standard NRCS methods. Interception storage values and rooting depths were assigned based on literature values and from previous modeling experience including a SWB model covering Sonoma County and calibrated using runoff volumes from several stream gages (OEI 2017).

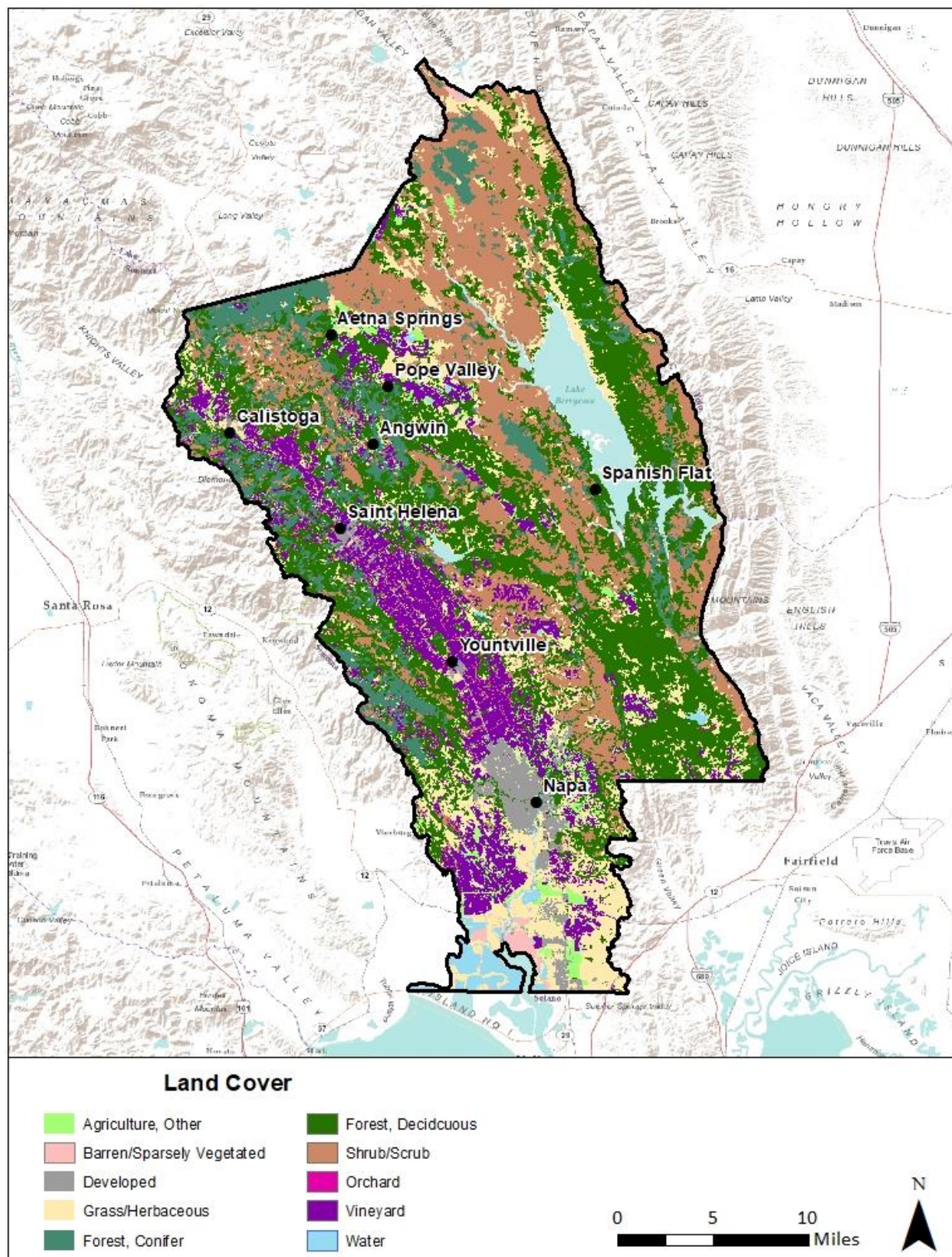


Figure 1: Land cover distribution used in the Napa County SWB model.

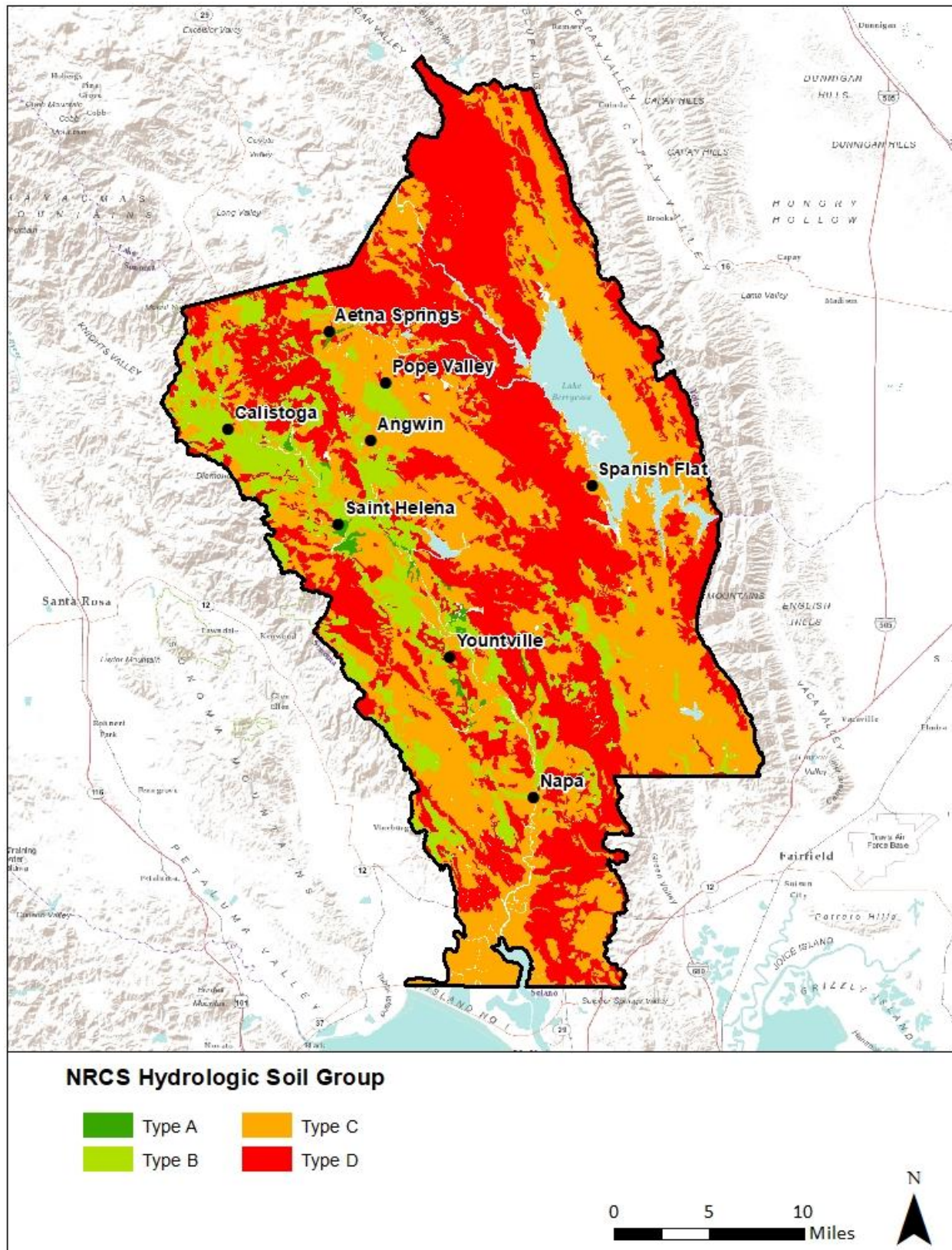


Figure 2: Hydrologic soil group distribution used in the Napa County SWB model.

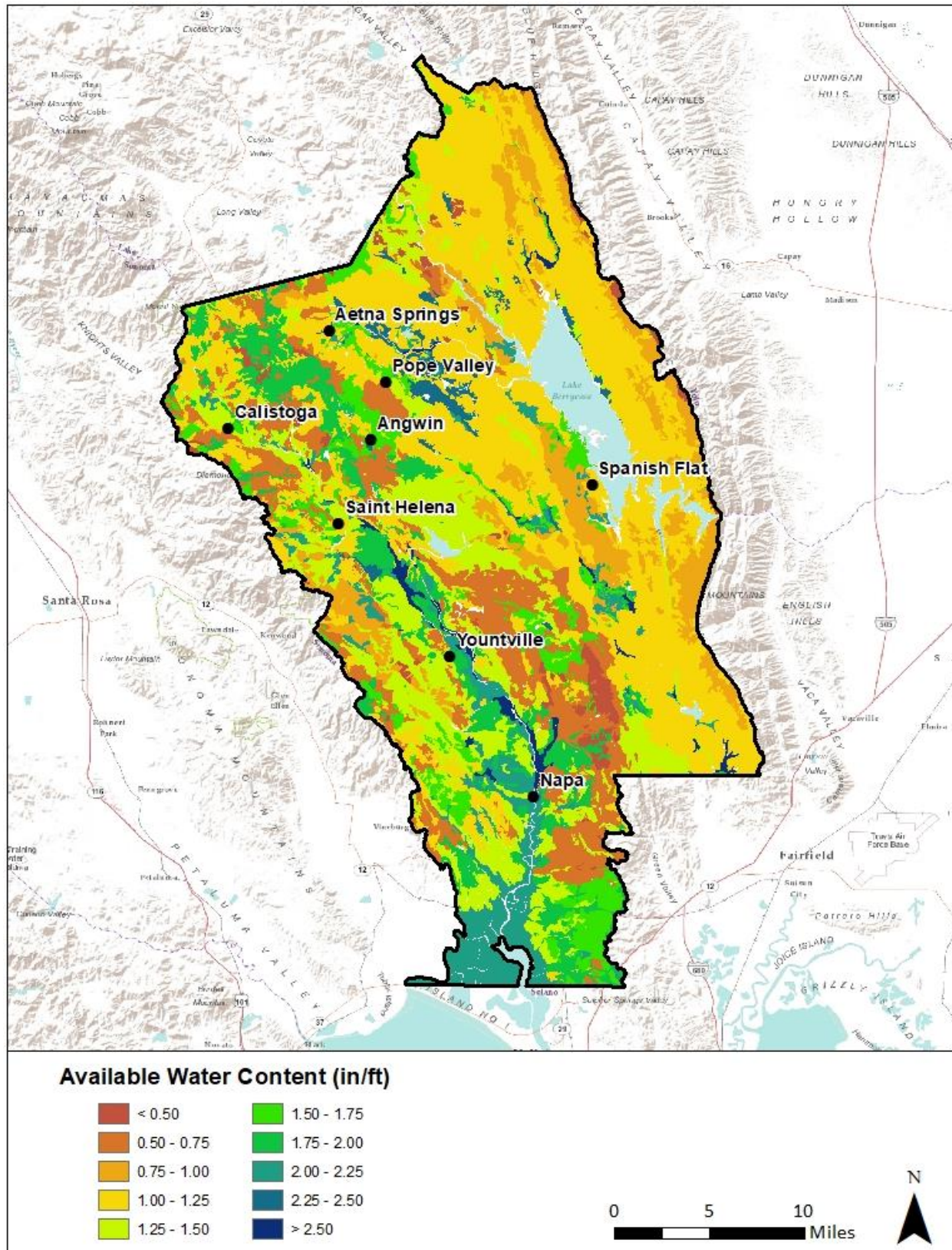


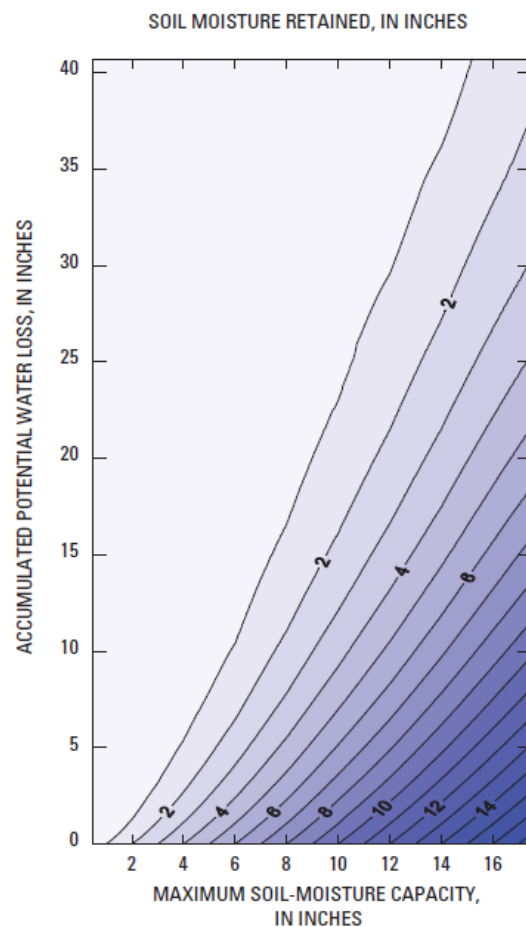
Figure 3: Available water capacity distribution used in the Napa County SWB model.

Table 1: Soil and land cover properties used in the Napa County SWB model.

Land Cover	Interception Storage Values (")		Curve Number by NRCS Soil Type (")				Rooting Depth by NRCS Soil Type (ft)			
	Growing Season	Dormant Season	Type A	Type B	Type C	Type D	Type A	Type B	Type C	Type D
Agriculture, Other	0.080	0.040	38	61	75	81	2.0	1.9	1.8	1.7
Barren	0.000	0.000	77	86	91	94	0.0	0.0	0.0	0.0
Developed	0.005	0.002	61	75	83	87	2.3	2.1	2.0	1.8
Grassland/Herbaceous	0.005	0.004	30	58	71	78	1.3	1.1	1.0	1.0
Forest, Coniferous	0.050	0.050	30	55	70	77	5.9	5.1	4.9	4.7
Forest, Deciduous	0.050	0.020	30	55	70	77	5.9	5.1	4.9	4.7
Shrub/Scrub	0.080	0.015	30	48	65	73	3.2	2.8	2.7	2.6
Orchard	0.050	0.015	38	61	75	81	3.2	2.8	2.7	2.6
Vineyard	0.080	0.015	38	61	75	81	2.2	2.1	2.0	1.9
Water	0.000	0.000	100	100	100	100	0.0	0.0	0.0	0.0

Table 2: Infiltration rates for NRCS hydrologic soil groups (Cronshey et al. 1986).

Soil Group	Infiltration Rate (in/hr)
A	> 0.3
B	0.15 - 0.3
C	0.05 - 0.15
D	<0.05

**Figure 4: Soil-moisture-retention table (Thorntwaite and Mather 1957).**

The SWB model utilizes daily precipitation and mean daily temperature data derived from climate stations. To account for the spatial variability of these parameters, daily precipitation and mean daily temperature were input as gridded (spatially-distributed) time-series. The gridded precipitation time-series was created using data from 15 weather stations in Napa County, and the gridded mean temperature time-series was created using data from 8 stations (Table 3). These stations were selected based on completeness of the records and to provide station data representative of the range of climates experienced in the county. Data was obtained from the California Data Exchange Center (CDEC), the National Climatic Data Center (NCDC), and from Napa One Rain.

To create the gridded time-series, the model domain was divided into discrete areas represented by individual weather stations (Figures 5 and 6). This delineation was based on climate variations described by existing gridded mean annual (1981-2010) precipitation and temperature data (PRISM 2010) and local knowledge of climatic variations across the county.

For the precipitation time-series, each area representing a weather station was subdivided into four to twenty-three zones based on 1-inch average annual precipitation contours. Within each zone the raw station data was multiplied by a unique scaling factor. This scaling factor was calculated as the ratio of average annual precipitation within a zone to average annual precipitation at the representative rain gage. In certain locations, typically near the boundary of areas represented by gages located on the valley bottom and at higher elevations, this scaling was unable to smoothly resolve differences in annual and event precipitation totals. To more accurately estimate precipitation near these boundaries, precipitation records from the two gages in question were averaged using weights calculated proportionally to the difference between PRISM mean annual precipitation at a rain gage and within a selected zone. The resulting gridded time-series is comprised of 220 individual time-series based on the scaled station data from 15 stations.

The assignment of temperature stations was based on the understanding that the spatial variability of temperatures across Napa County is relatively homogenous, with elevation being the primary variable. Temperature records were classified either as Mountain, Valley Bottom, or East County and applied within areas the PRISM datasets described as being similar. To smooth the transition from Mountain zones to Valley Bottom and East County zones, Hillside zones were created where the temperature records of the two nearest gages were averaged.

Missing and suspect data was encountered in the raw precipitation and temperature data from the weather stations used by the model. Values that were significantly outside the typical range, and where similar observations were not found at nearby stations, were removed from the datasets. These and missing values were filled using scaled data from other nearby stations. Precipitation data used for gap filling was scaled using the ratio of the 1981 to 2010 mean annual precipitation (PRISM 2010) between the two stations. Temperature data was scaled using the ratio of the 1981 to 2010 mean monthly minimum and maximum temperatures (PRISM 2010) between the two stations.

The current analysis focuses on Water Year 2010 (October 1, 2009 – September 30, 2010) and Water Year 2014 (October 1, 2013 – September 30, 2014). These years were selected because they represent periods with data available from most weather stations in the county and where most stations reported annual precipitation totals close to the long-term average (WY 2010) and significantly below the long term average (WY 2014). Based on a comparison between station data and PRISM average precipitation depths during Water Year 2010, rainfall averaged 101% of long-term average conditions and ranged from 78% at Lake Hennessey to 111% at the Napa County Airport. In Water Year 2014, rainfall averaged 55% of long-term average conditions and ranged from 41% at Lake Hennessey to 73% at the Napa State Hospital (Table 3).

Table 3: Weather stations used in the Napa County SWB model. See Figures 7- 9 for associated timeseries.

Station	Data Used	1981 - 2010 Mean Annual Precip (in)	WY 2010		WY 2014	
			Precip (in)	% Avg	Precip (in)	% Avg
Angwin ¹	Precip & Temp	42.54	44.64	105%	25.04	59%
Atlas Peak ¹	Precip & Temp	41.76	39.04	93%	20.08	48%
Berryessa ¹	Precip & Temp	28.97	28.16	97%	13.97	48%
Calistoga ²	Precip	39.41	41.75	106%	18.18	46%
Knoxville Creek ¹	Temp Only	-	-	-	-	-
Lake Hennessey ³	Precip Only	34.09	26.52	78%	13.92	41%
Mt. George ³	Precip Only	31.15	29.64	95%	18.24	59%
Mt. Veeder ³	Precip Only	44.81	46.44	104%	28.6	64%
Napa County Airport ²	Precip & Temp	21.14	23.56	111%	9.87	47%
Napa River at Yountville Cross Rd ³	Precip Only	31.86	32.72	103%	14.93	47%
Napa State Hospital ²	Precip & Temp	26.81	28.85	108%	19.66	73%
Petrified Forest ³	Precip Only	42.39	46.6	110%	22.84	54%
Redwood Creek At Mt. Veeder Road ³	Precip Only	34.71	37.36	108%	23.48	68%
Saint Helena ²	Precip & Temp	37.43	39.11	104%	19.11	51%
Saint Helena 4WSW ¹	Precip & Temp	45.44	47.88	105%	28.88	64%
Sugarloaf Peak ³	Precip Only	32.20	26.16	81%	17.12	53%

1 – Data accessed from California Data Exchange Center (CDEC)

2 – Data accessed from National Climate Data Center (NCDC)

3 – Data access from Napa One Rain

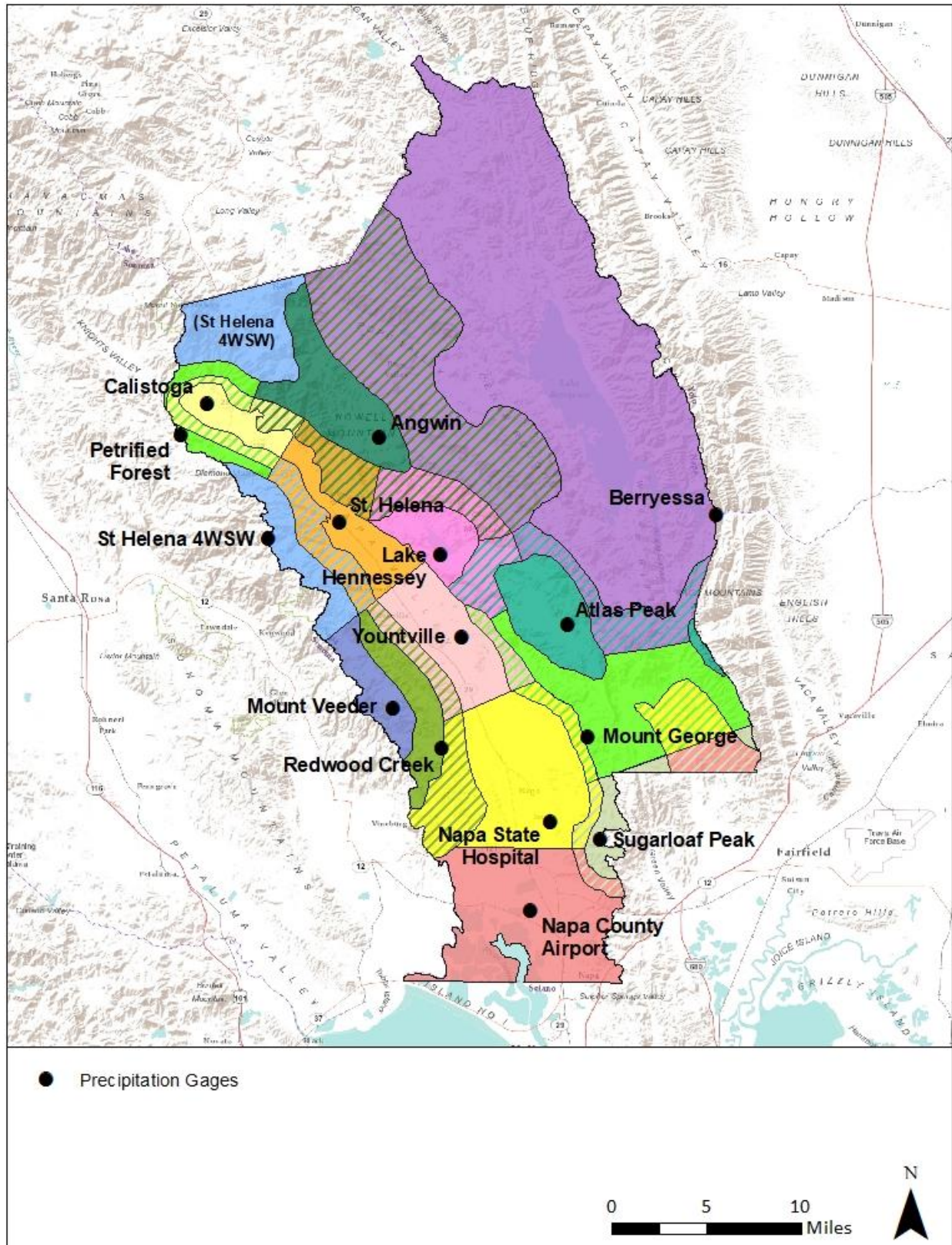


Figure 5: Precipitation zones used in the Napa County SWB model. Hatching indicates areas where two precipitation records were averaged across a zone.

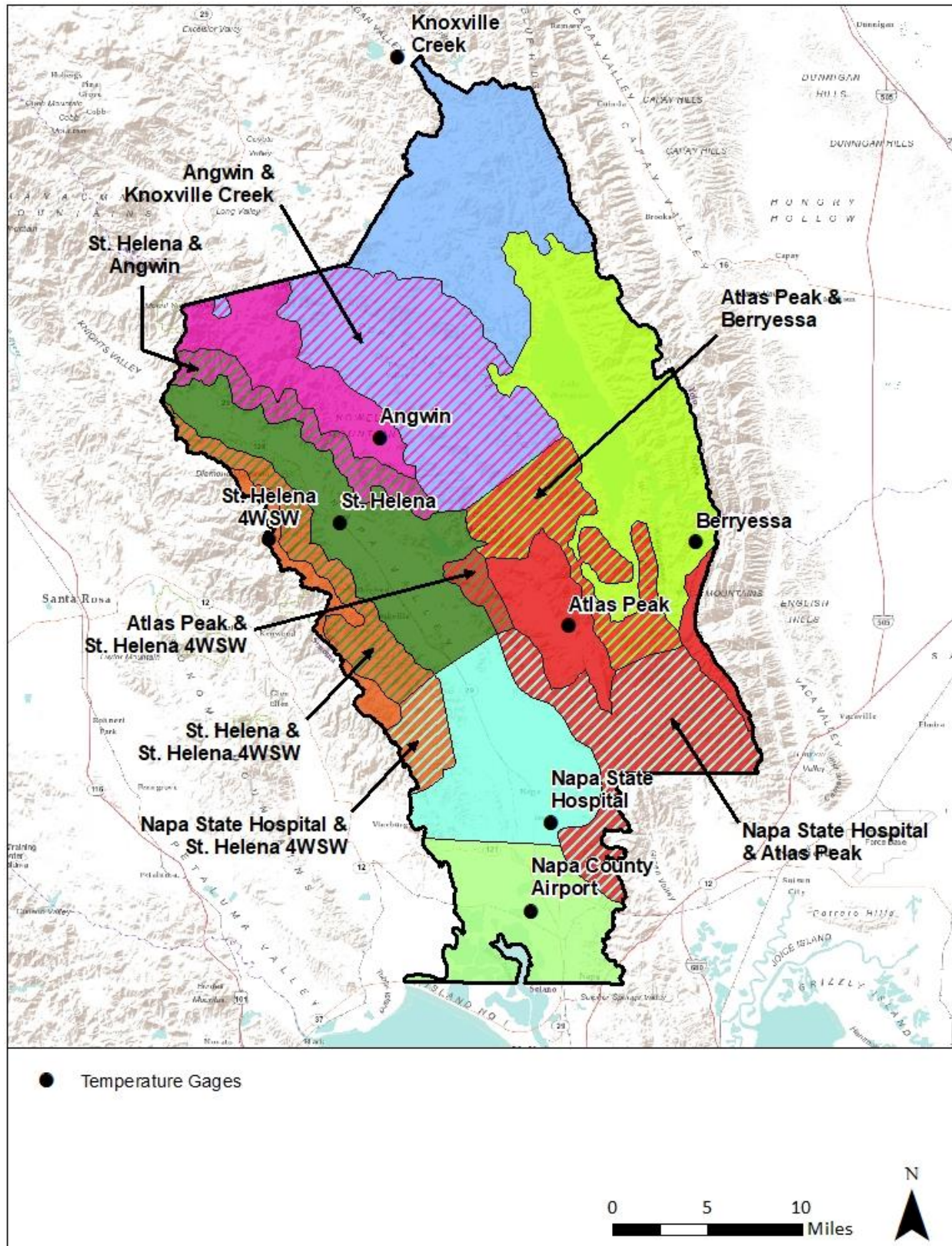


Figure 6: Temperature zones used in the Napa County SWB model. Hatching indicates areas where two temperature records were averaged across a zone.

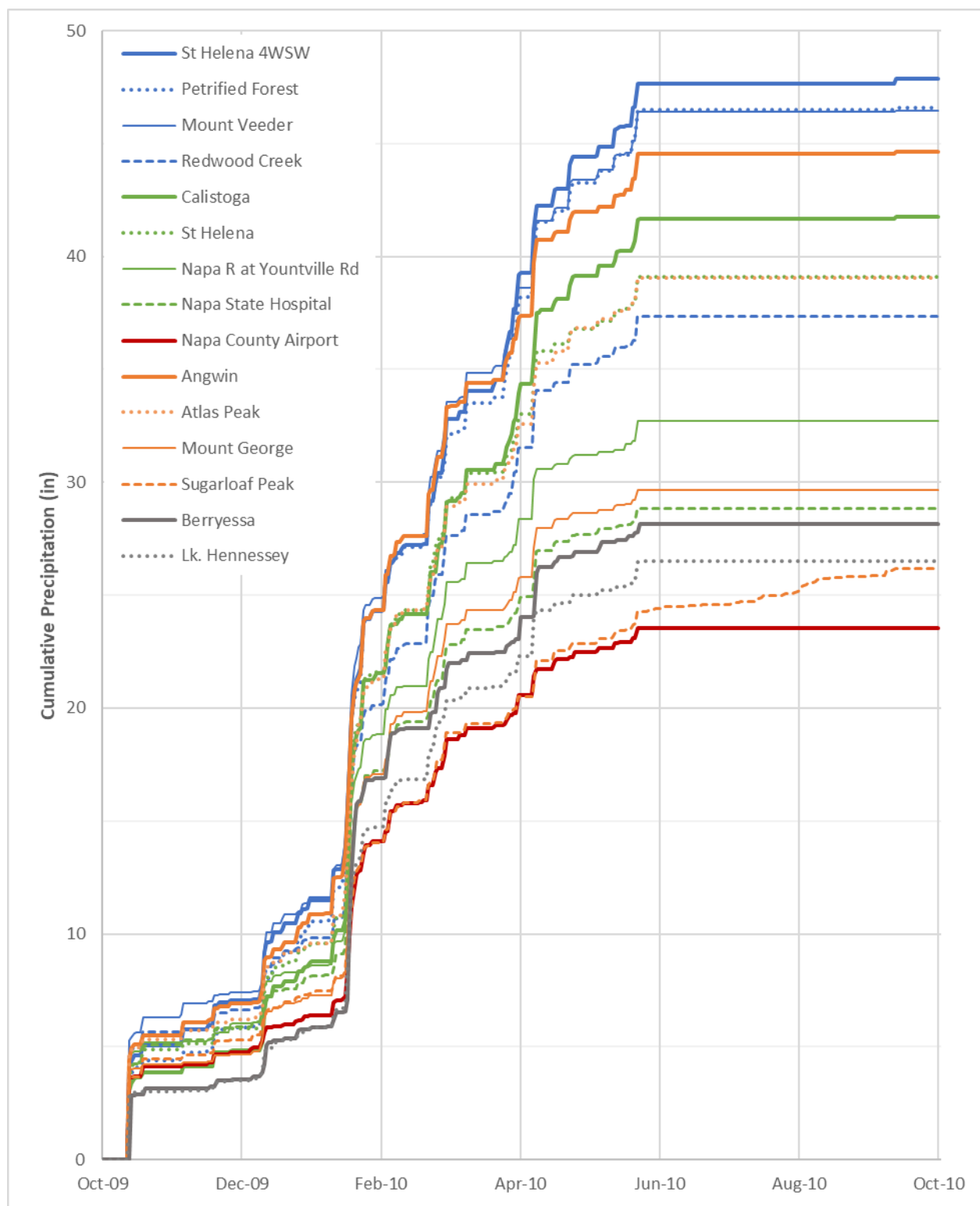


Figure 7a: Daily precipitation data used in the Napa County SWB model for WY 2010.

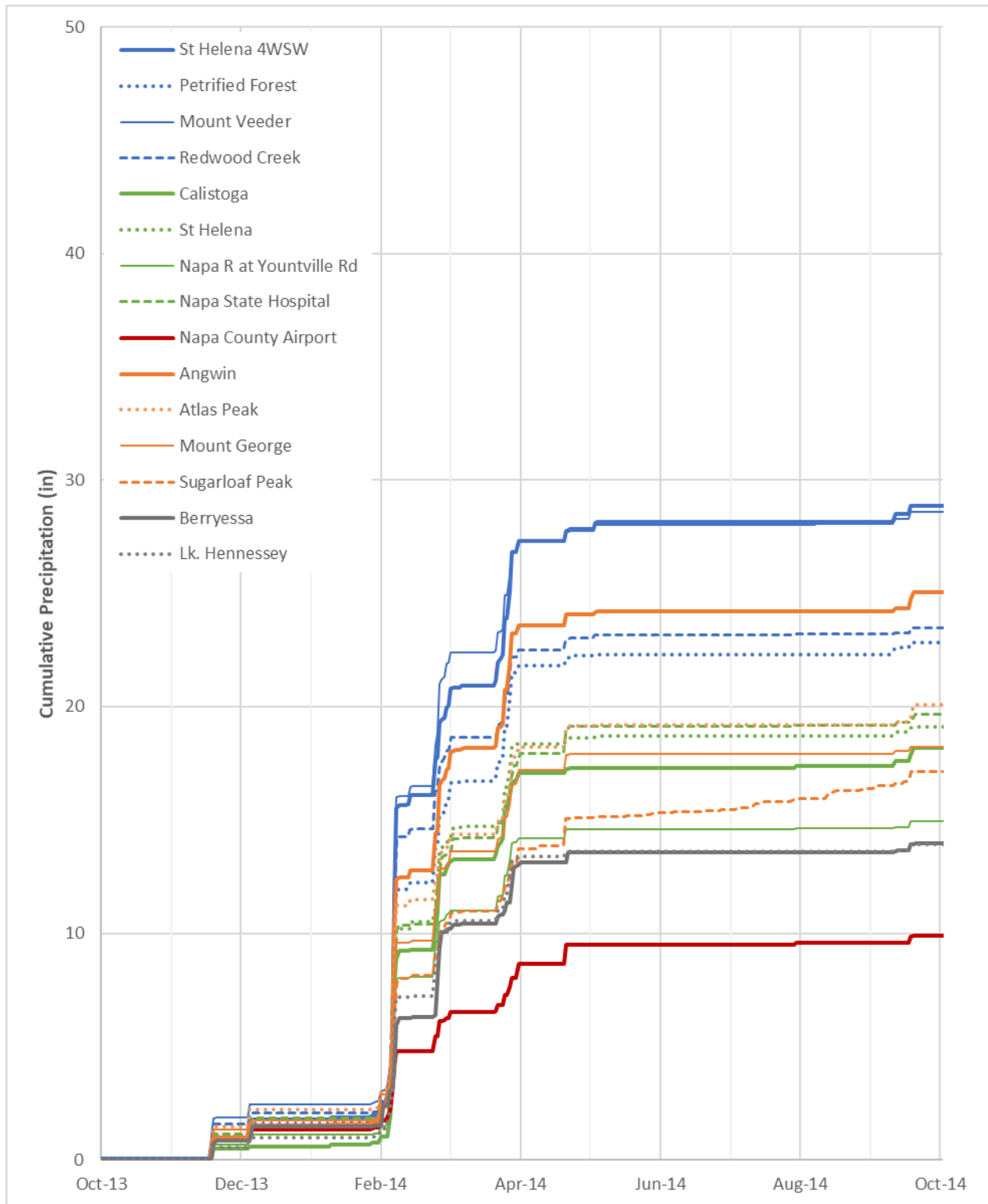


Figure 7b: Daily precipitation data used in the Napa County SWB model for WY 2014.

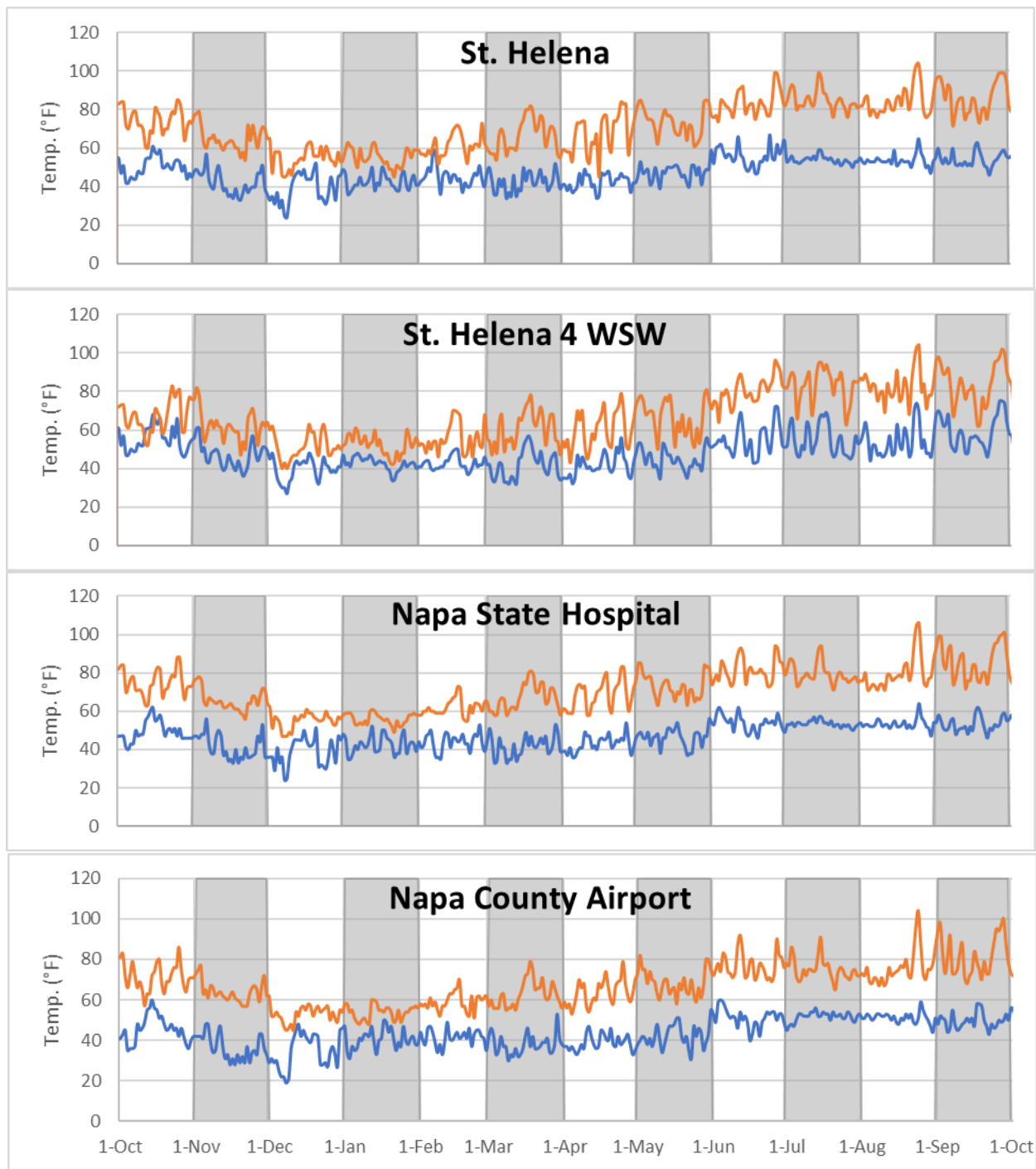


Figure 8: Daily minimum and maximum temperature data used in the Sonoma County SWB model for WY 2010.

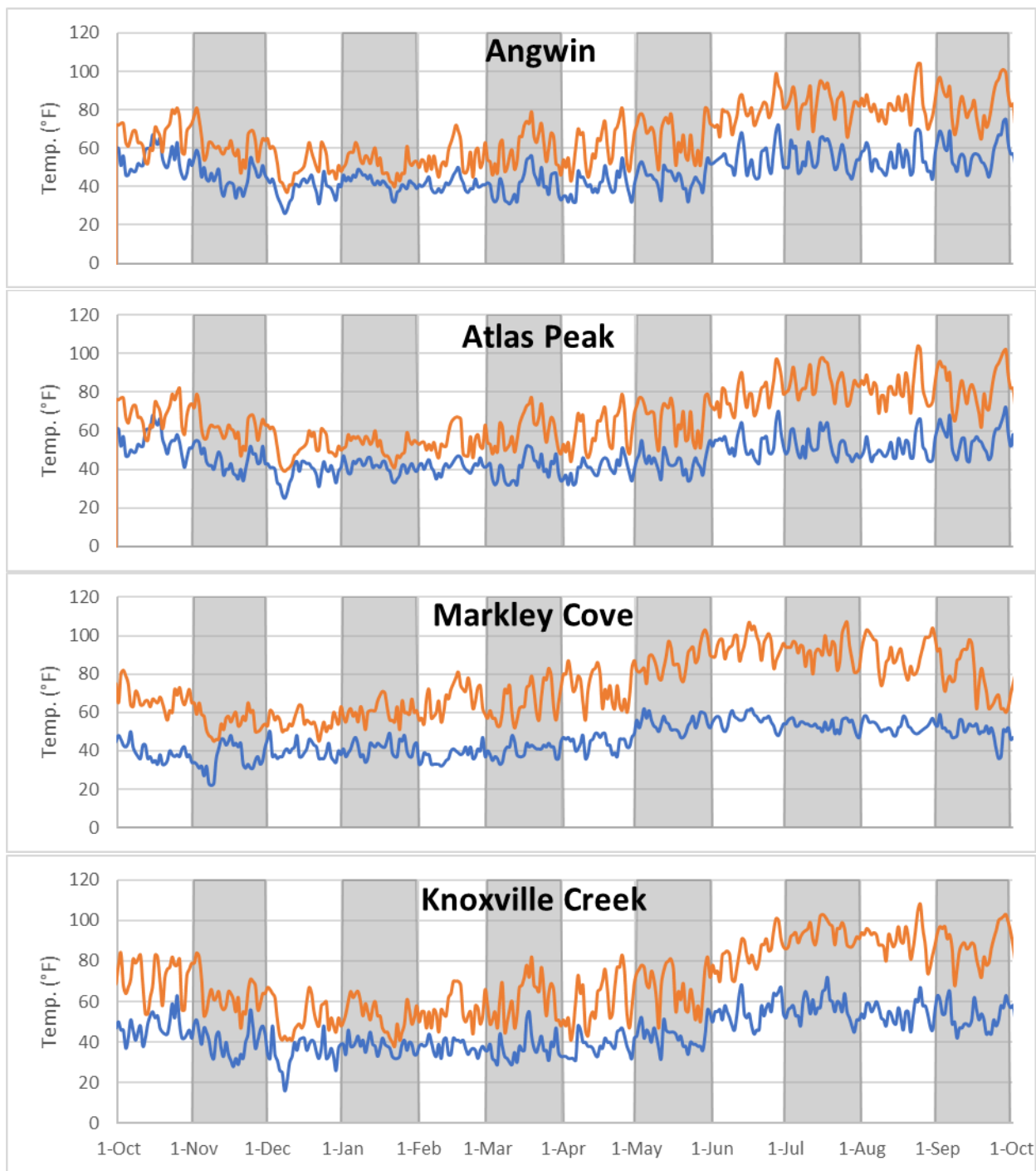


Figure 8 – cont.

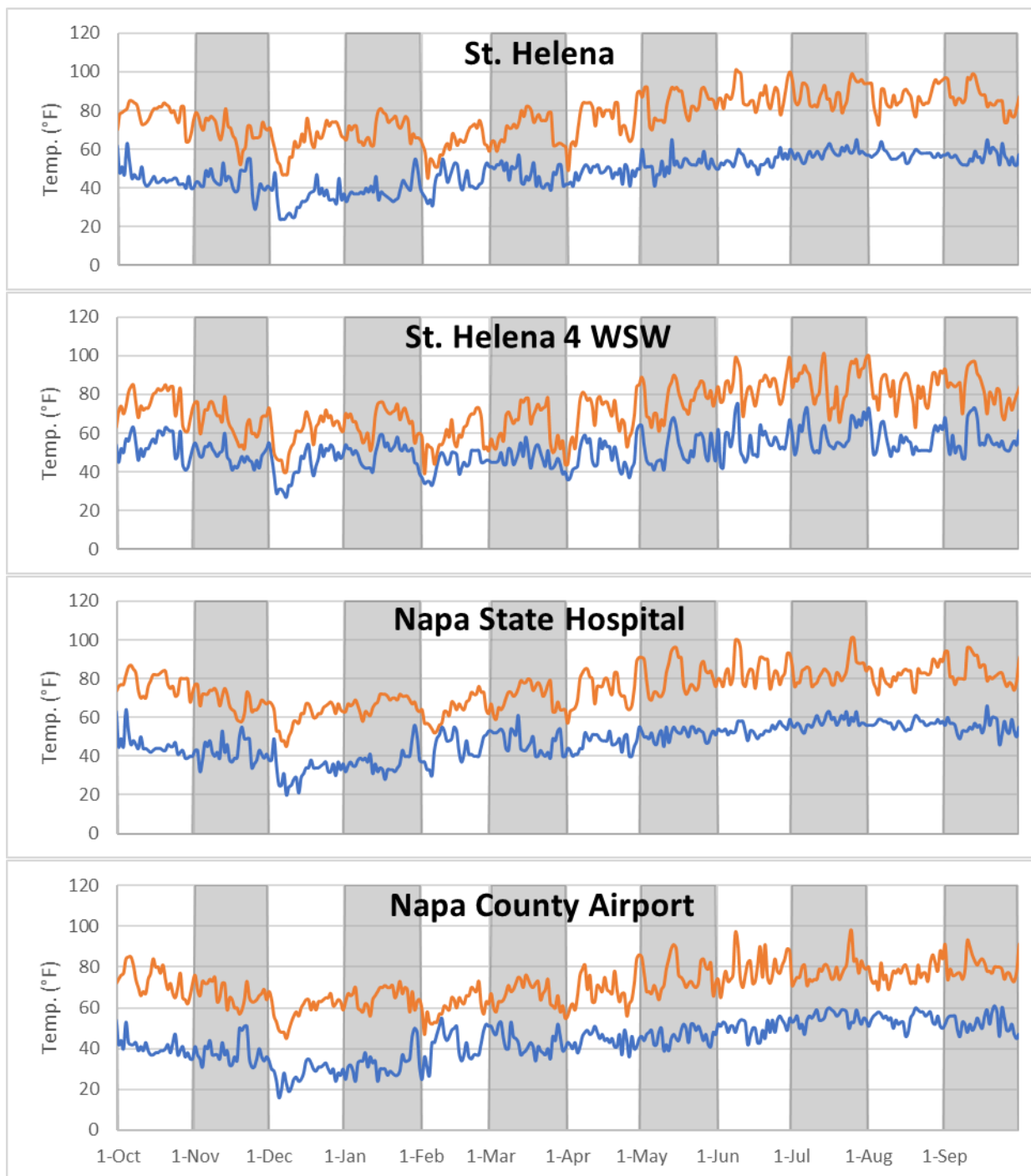


Figure 9: Daily minimum and maximum temperature data used in the Sonoma County SWB model for WY 2010.

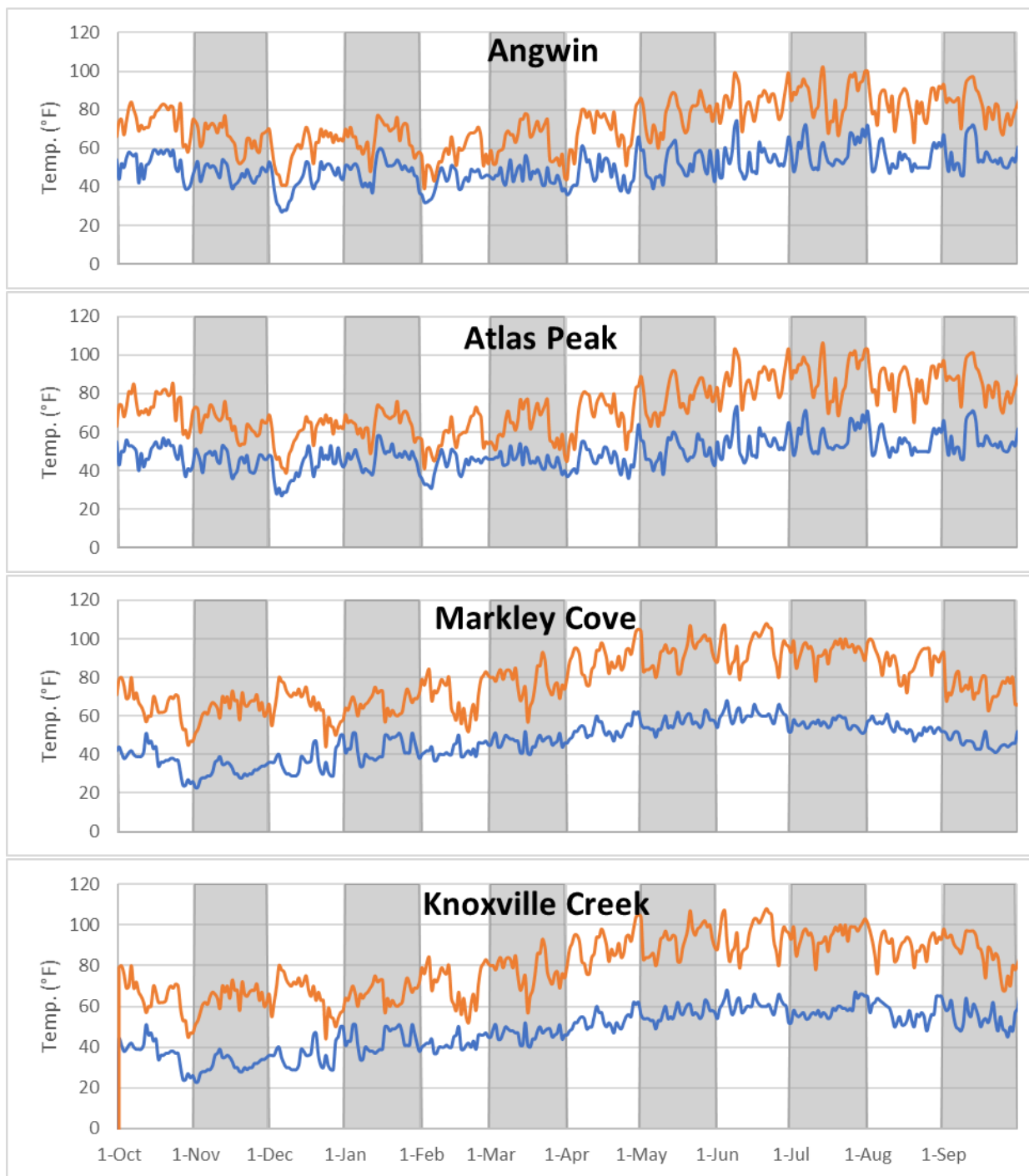


Figure 9 – cont.

Model Calibration

Available data are insufficient to calibrate the Water Year 2010 and 2014 SWB simulations; however, the land cover and soil properties used in the model were obtained from a previously prepared and calibrated SWB model of Sonoma County (OEI 2017). The Sonoma County model was calibrated against total monthly runoff volumes derived using baseflow separation of streamflow data for five watersheds within Sonoma County. Gages were selected because they represented relatively small watersheds (1.2 – 14.3 mi²) without significant urbanization, diversions, groundwater abstraction, reservoir impoundments, or large alluvial bodies where significant exchanges between surface water and groundwater may be expected. These attributes are desirable because the hydrographs can more readily be separated into surface runoff and baseflow components and the surface runoff pattern is more directly comparable to the SWB simulated surface runoff which does not account for water use, reservoir operations, or surface water/groundwater exchange.

SWB utilizes a simplified routing scheme whereby surface runoff is routed to downslope cells or out of the model domain on the same day in which it originates as rainfall, thus it is not capable of accurately estimating streamflow over short time periods. The use of the total monthly surface runoff volumes provided a means of calibrating the Sonoma County SWB model to measured surface runoff data within the limitations of the model's approach to simulating surface runoff.

The SWB model of Sonoma County reproduced seasonal variations in surface runoff in all five calibration watersheds. Monthly Mean Errors (ME) ranged from -0.2 to 0.4 inches with a mean value of 0.1 inches. Annual surface runoff totals ranged from an under-prediction of approximately 10% at Franchini Creek to an over-prediction of approximately 19% at Buckeye Creek, with a mean over-prediction of approximately 6% across the five watersheds. These results indicate that the SWB model was able to reproduce monthly surface runoff volumes with a reasonable degree of accuracy and that the model tends to over-predict surface runoff somewhat, suggesting that the model may generate a low-range estimate of recharge.

Although the climate in Napa County is slightly drier than in Sonoma County, the vegetation, soils, and geology are similar and parameters calibrated using data from Sonoma County should be applicable to Napa County. Calibration of the Napa County SWB model was not performed due to a lack of publicly-available contemporary discharge records in suitable watersheds. Contemporary discharge records exist for USGS gaging stations located along the Napa River near St. Helena and Napa, but the watersheds above these gages are large and contain significant groundwater abstraction, reservoir impoundments, and alluvial bodies. USGS gages on smaller watersheds in Napa County have been inactive since 1983 or earlier. Discharge records exist through Napa One Rain for several streams gaged by the Napa County Resource Conservation District (RCD) but the RCD has cautioned against use of these discharge records for calibration purposes due to incomplete rating curve development.

Estimates of groundwater recharge are also available from an earlier model prepared by Luhdorff and Scalmanini Engineers and MBK Engineers (LSCE 2013). This report provided estimates of average annual recharge as a percentage of average annual precipitation for nine watersheds in Napa County. Averaged across the same nine watersheds, the SWB model predicts significantly higher rates of recharge than the model prepared by LSCE, which predicts slightly lower AET but significantly more runoff (Table 4). Differences in methodology between these two models complicate direct comparisons. The LSCE model calculated infiltration into the soil as the difference between monthly precipitation and discharge volumes within each watershed. Discharge volumes were calculated from USGS stream gages and included both direct runoff and baseflow from groundwater. Inclusion of baseflow with direct runoff in these calculations may inappropriately reduce the estimated volume of water infiltrated into the soil and available for recharge.

Table 4: Comparison of results from SWB model and Luhdorff and Scalmanini model.

USGS Gage	HUC	Mean Precip, 2010 (in)	Mean AET, 2010 (% Precip)		Mean Runoff, 2010 (% Precip)		Mean Recharge, 2010 (% Precip)	
			SWB	LSCE	SWB	LSCE	SWB	LSCE
Conn Ck nr Oakville	11456500	34.8	59%	53%	21%	25%	21%	21%
Dry Ck nr Napa	11457000	41.5	56%	50%	18%	43%	25%	6%
Milliken Ck nr Napa	11458100	32.3	52%	41%	20%	51%	28%	8%
Napa Ck at Napa	11458300	36.6	61%	43%	16%	46%	23%	11%
Napa R nr Napa	11458000	39.5	56%	48%	20%	35%	24%	17%
Napa R nr St Helena	11456000	47.9	46%	45%	23%	42%	30%	14%
Redwood Ck nr Napa	11458200	39.6	53%	49%	26%	40%	22%	10%
Tuluca Ck nr Napa	11458300	27.0	64%	49%	16%	47%	20%	5%

Model Results

The principal elements of the annual water budget simulated with the Napa County SWB model for Water Years 2010 and 2014 are presented in map form in Figures 10 - 19 and in tabular form for 27 major watershed areas in Napa County (Tables 5 - 8). The watersheds are based on USGS HUC-12 watersheds and are named for the stream which comprises the largest proportion of the area; in many cases the areas consist of multiple tributary streams (Figure 20).

In Water Year 2010 (representing “average” hydrologic conditions) precipitation varied from 21.8 inches in the Ledge Creek watershed to 53.3 inches in the Saint Helena Creek watershed (Figure 10, Table 5). Actual evapotranspiration (AET) ranged from 13.4 inches in the Jackson Creek watershed to 25.2 inches in the Saint Helena Creek watershed (Figure 11). Surface runoff ranged from 3.4 inches in the Ledge Creek watershed to 13.5 inches in the Saint Helena Creek watershed (Figure 12). Recharge ranged from 3.3 inches in the Ledge Creek watershed to 14.4 inches in the Saint Helena watershed. (Figure 13). Small decreases in soil moisture storage (up to 1.8 inches) occurred in most watersheds, with changes in most

watersheds being less than an inch (Figure 14). Note that the San Pablo Bay estuaries have been excluded from these comparisons.

Expressed as a percentage of the annual precipitation, AET ranged from 77% in the Ledgewood Creek watershed to 45% in the Jackson Creek watershed (Table 6). Surface runoff ranged from 15% of precipitation in the Ledgewood Creek watershed to 42% in the Jackson Creek watershed. Recharge ranged from 10% of the precipitation in the Jackson Creek watershed to 27% in the Saint Helena watershed.

In Water Year 2014 (representing “dry” hydrologic conditions during the second year of an extreme three-year drought) precipitation varied from 10.1 inches in the American Canyon Creek watershed to 32.2 inches in the Saint Helena Creek watershed (Figure 15, Table 7). Actual evapotranspiration (AET) ranged from 10.3 inches in the Jackson Creek watershed to 17.8 inches in the Saint Helena Creek watershed (Figure 16). Surface runoff ranged from 0.7 inches in the American Canyon Creek watershed to 13.2 inches in the Saint Helena Creek watershed (Figure 17). Recharge ranged from 0.6 inches in the Wragg Canyon watershed to 4.1 inches in the Saint Helena watershed. (Figure 18). Large decreases in soil moisture storage of between 2.3 and 4.3 inches were also simulated (Figure 19).

Expressed as a percentage of the annual precipitation, AET ranged from 55% in the Saint Helena Creek watershed to 121% in the Jackson Creek watershed (Table 8). These very large AET rates caused significant decreases in soil moisture. Decreases in soil moisture ranged from 9% of precipitation in the Saint Helena watershed to 36% in the American Canyon Creek watershed. Surface runoff ranged from 7% of precipitation in the American Canyon Creek watershed to 41% in the Saint Helena Watershed. Recharge ranged from 18% in the Milliken Creek Watershed to 5% in the Jackson Creek and Wragg Canyon watersheds.

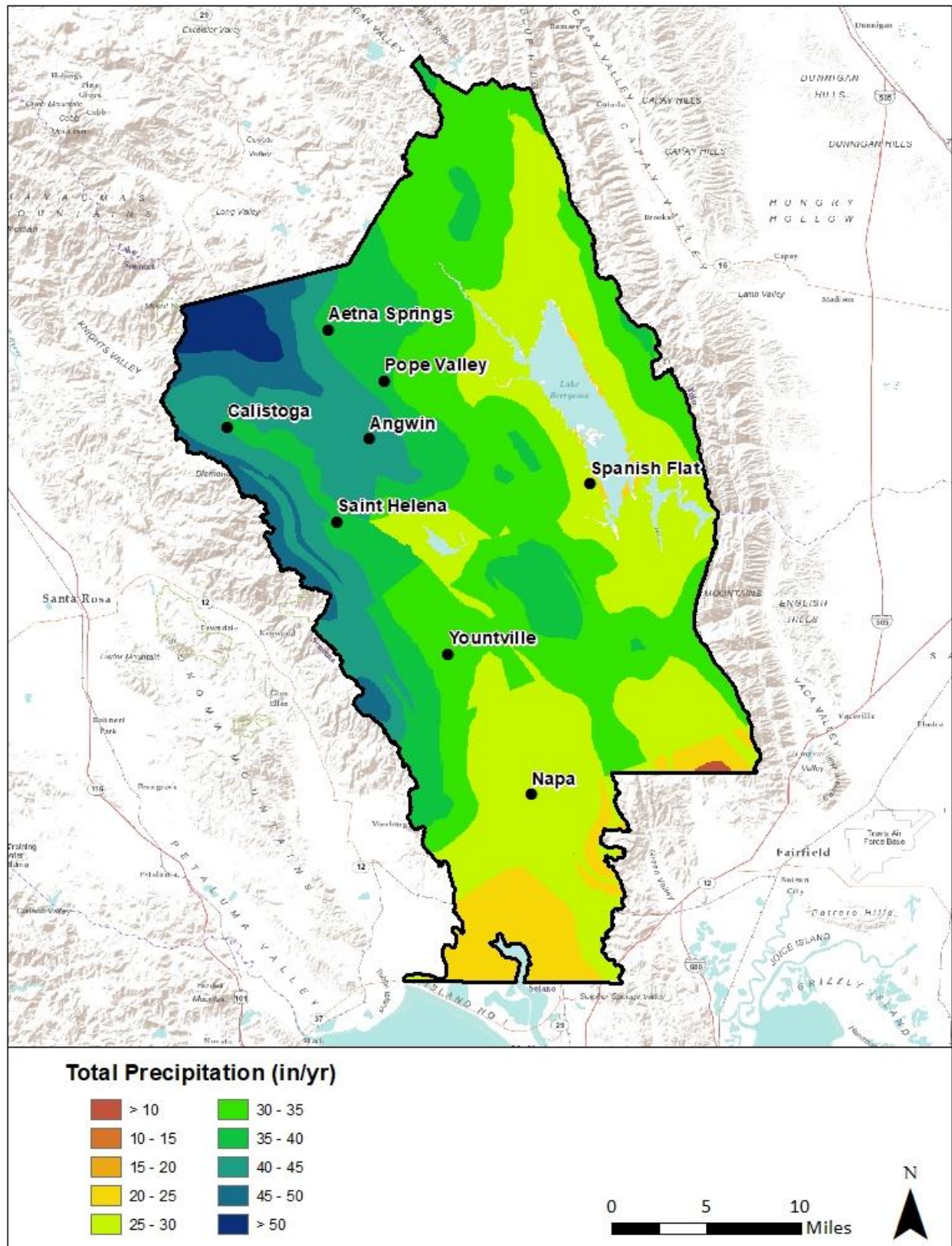


Figure 10: Water Year 2010 precipitation simulated with the Napa County SWB model.

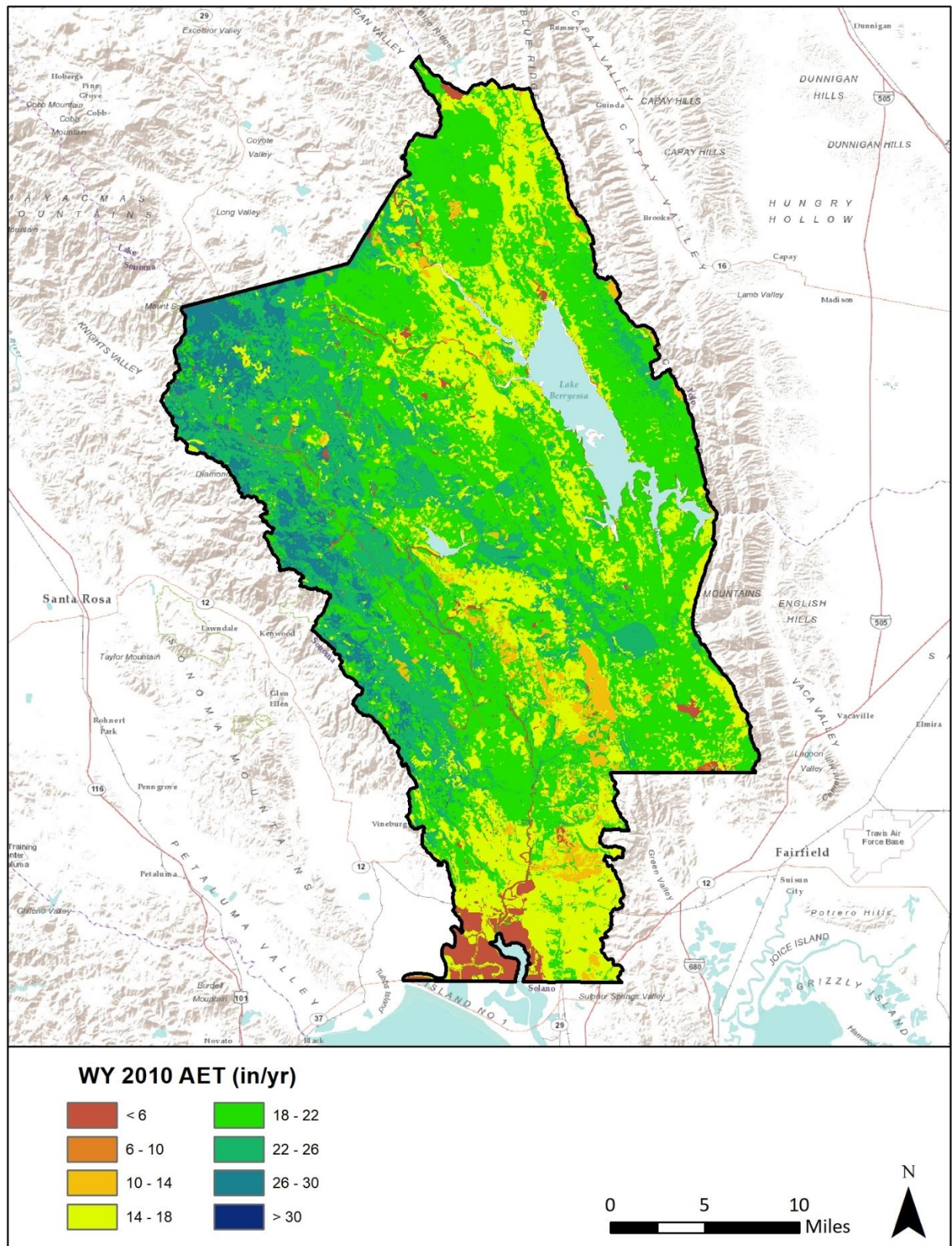


Figure 11: Water Year 2010 AET simulated with the Napa County SWB model.

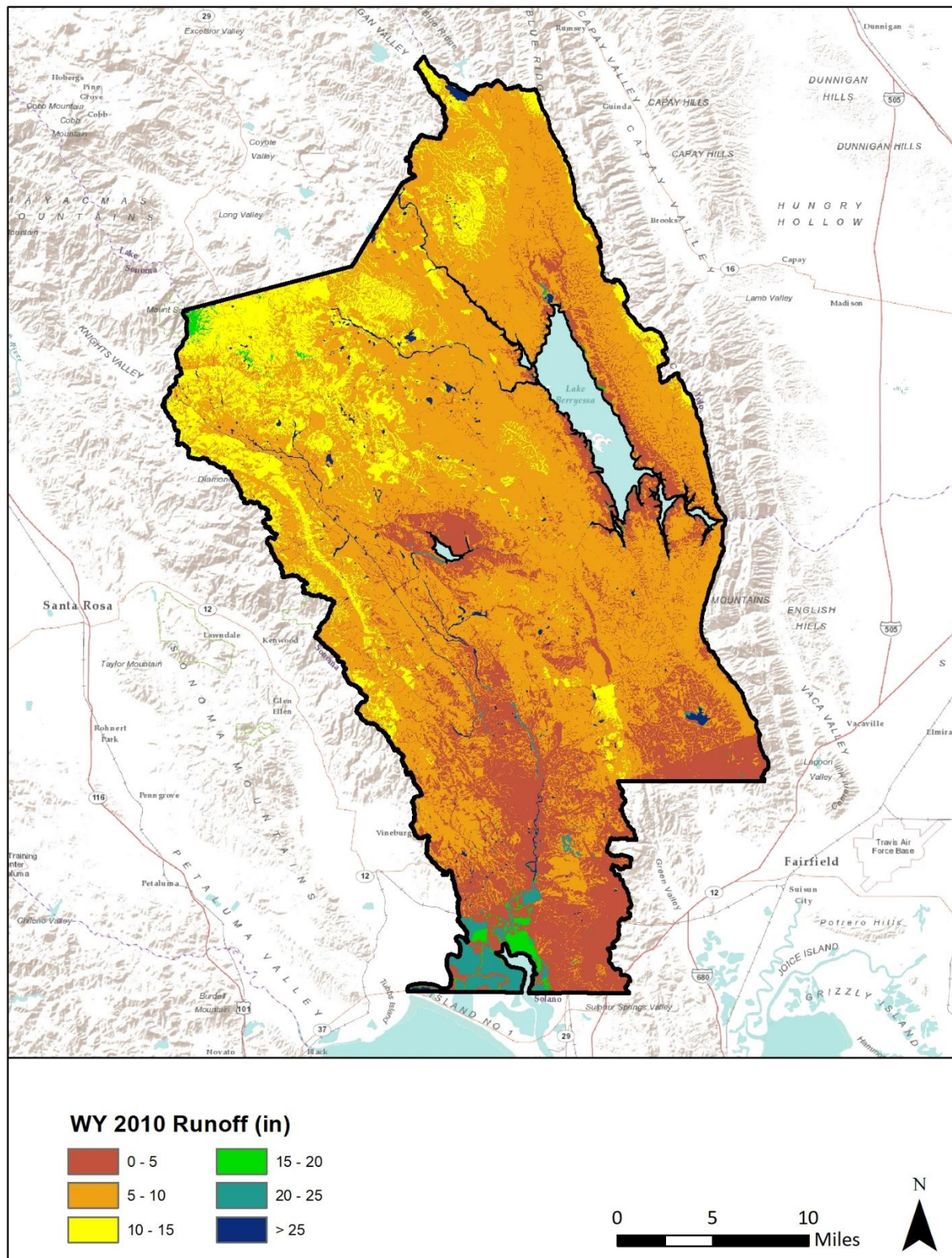


Figure 12: Water Year 2010 runoff simulated with the Napa County SWB model.

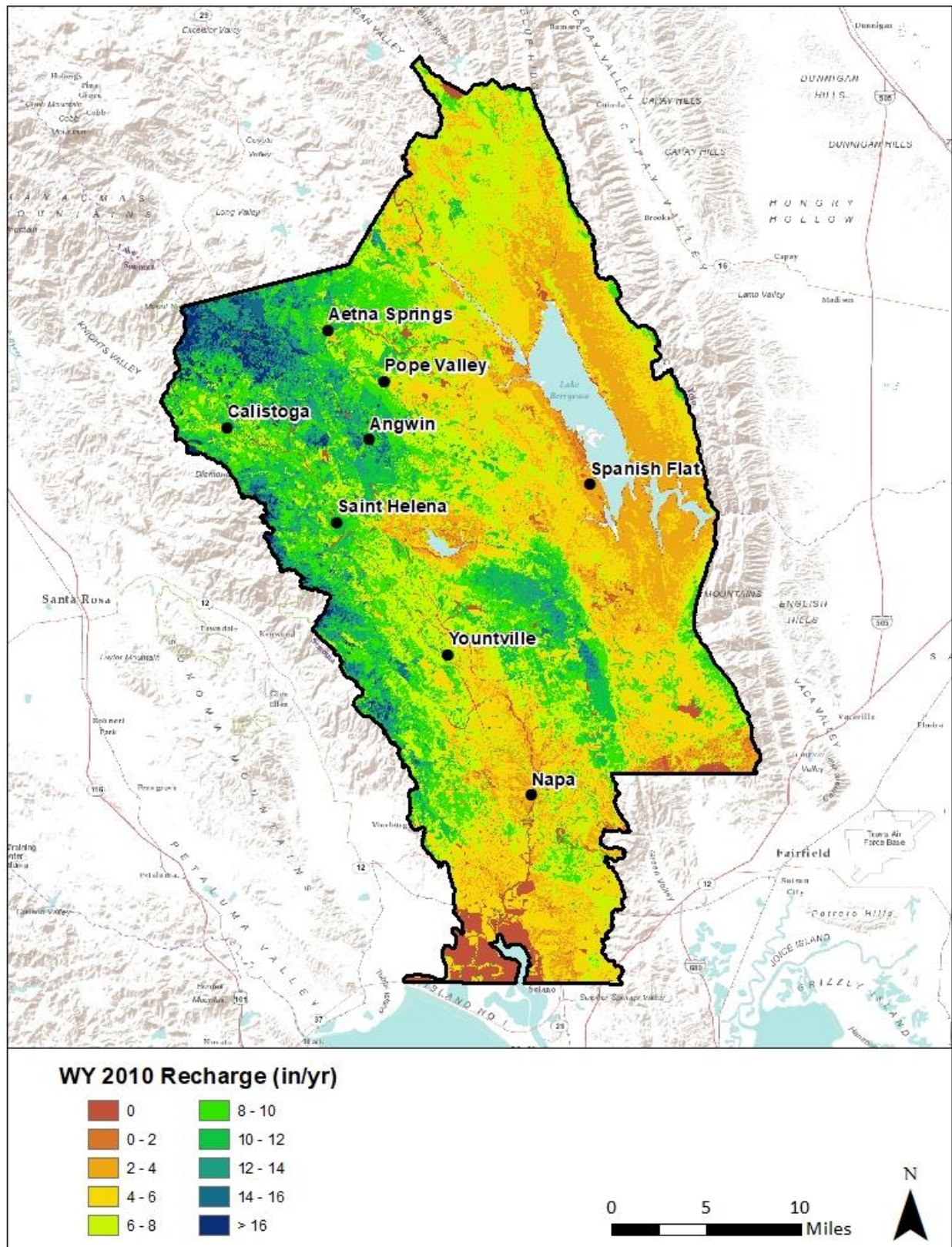


Figure 13: Water Year 2010 recharge simulated with the Napa County SWB model.

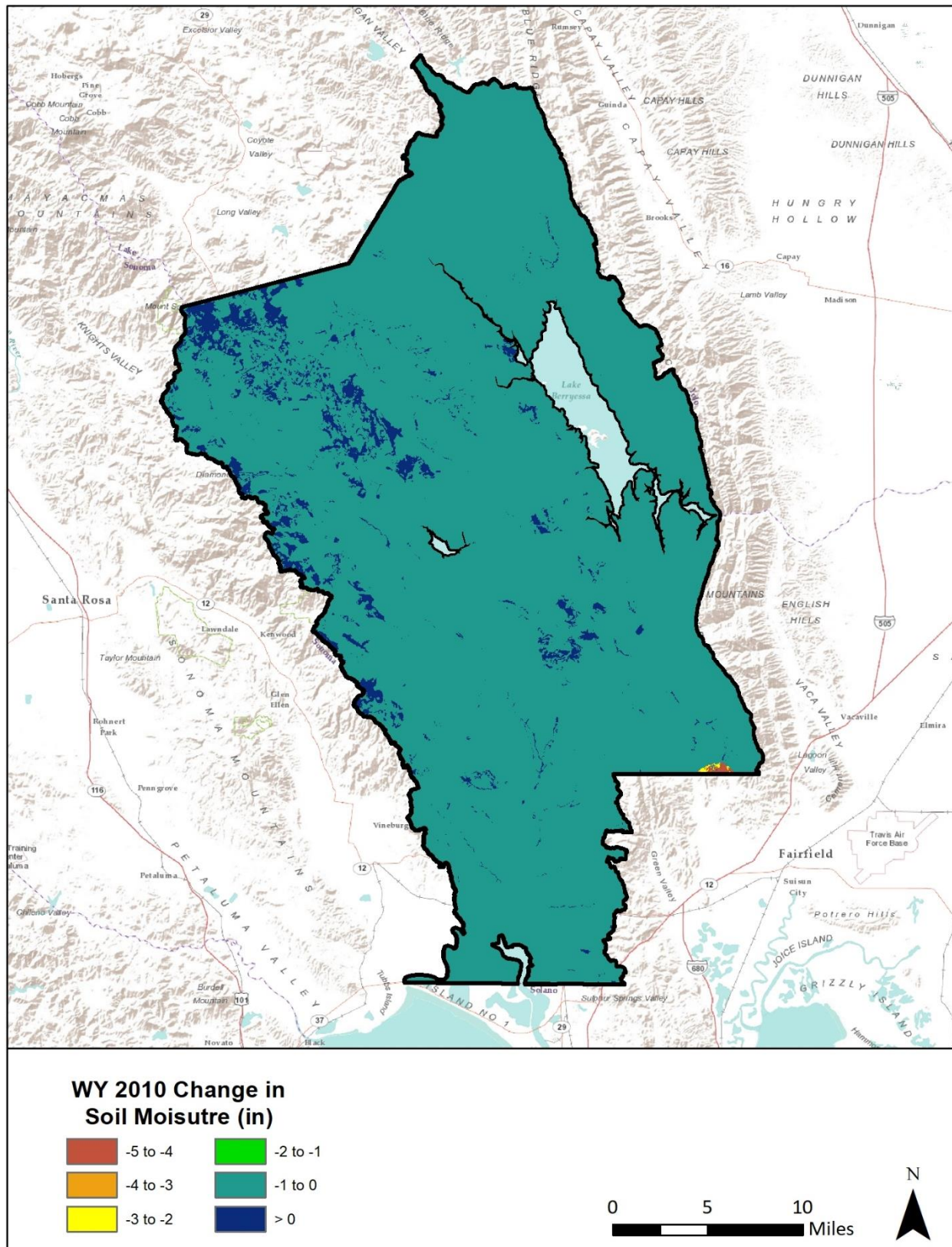


Figure 14: Water Year 2010 change in soil moisture content simulated with the Napa County SWB model.

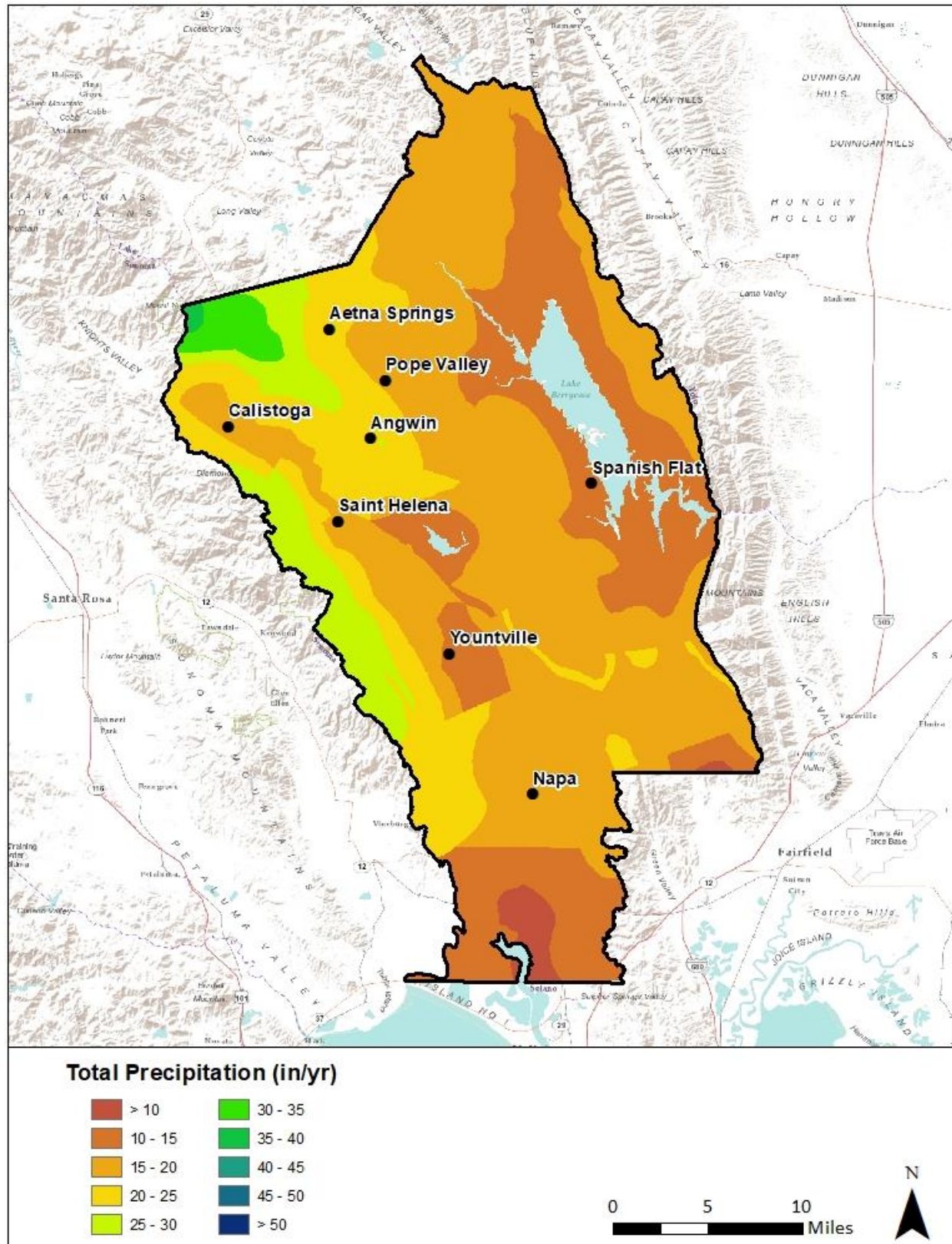


Figure 15: Water Year 2014 precipitation simulated with the Napa County SWB model.

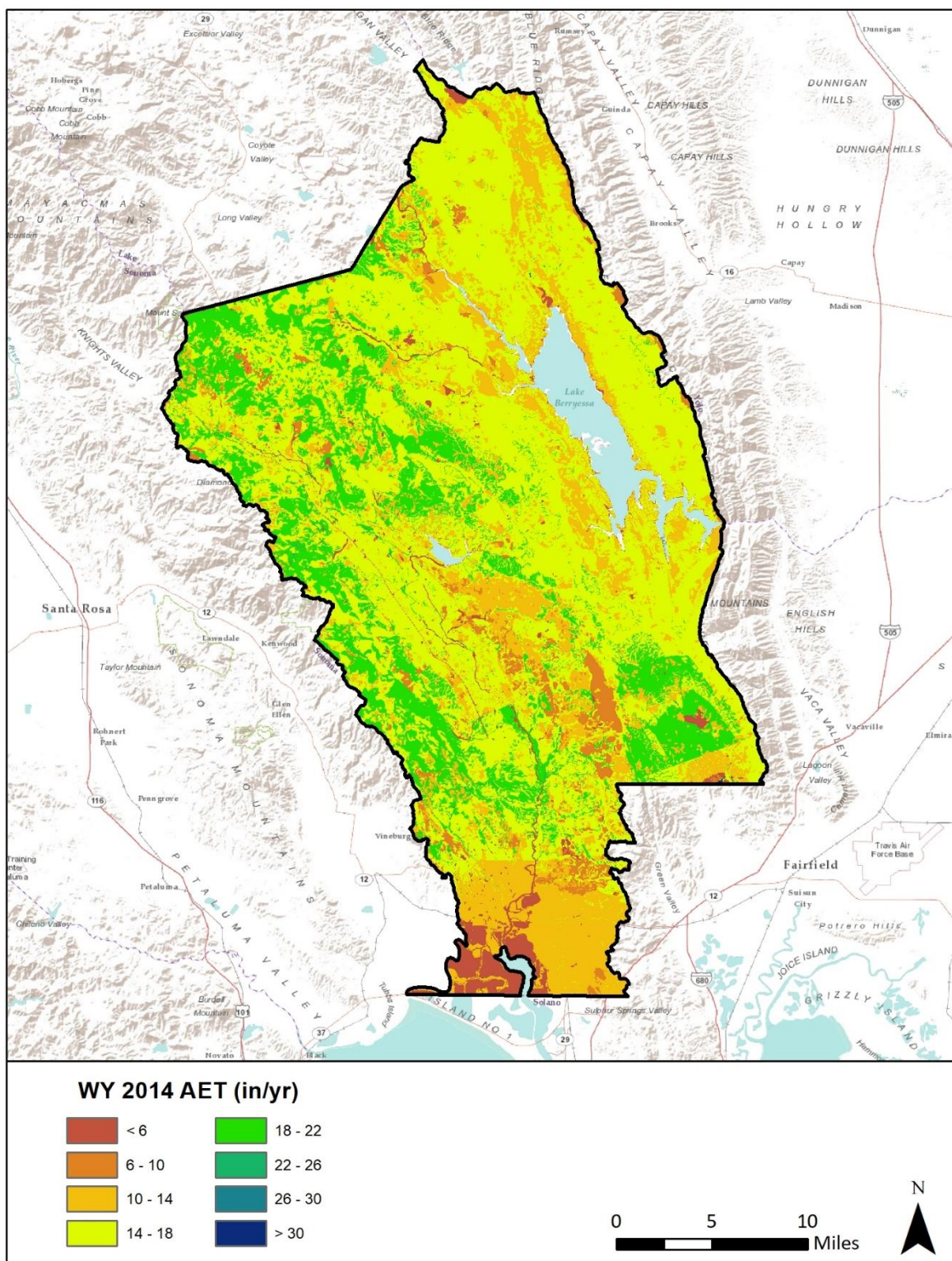


Figure 16: Water Year 2014 AET simulated with the Napa County SWB model.

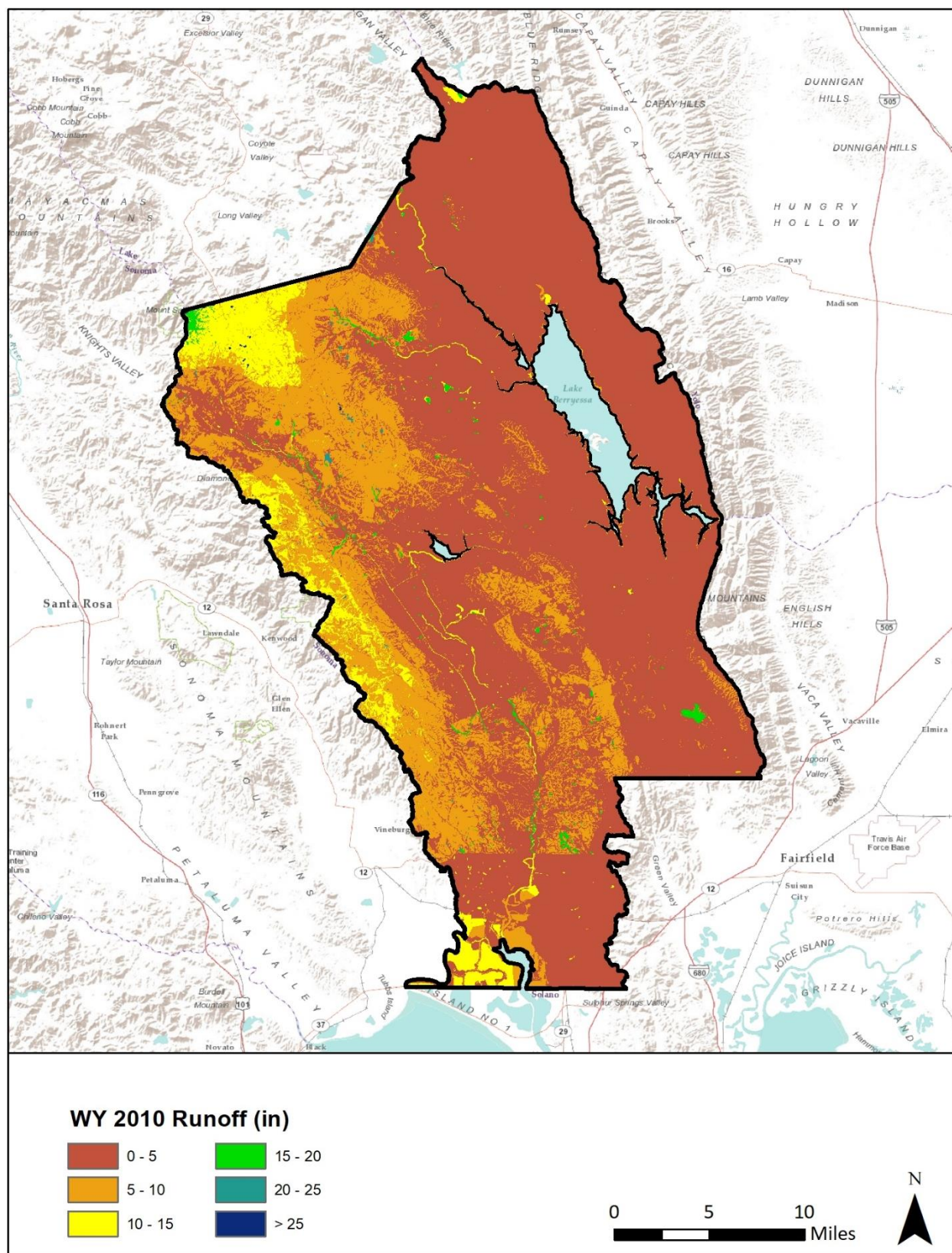


Figure 17: Water Year 2014 recharge simulated with the Napa County SWB model.

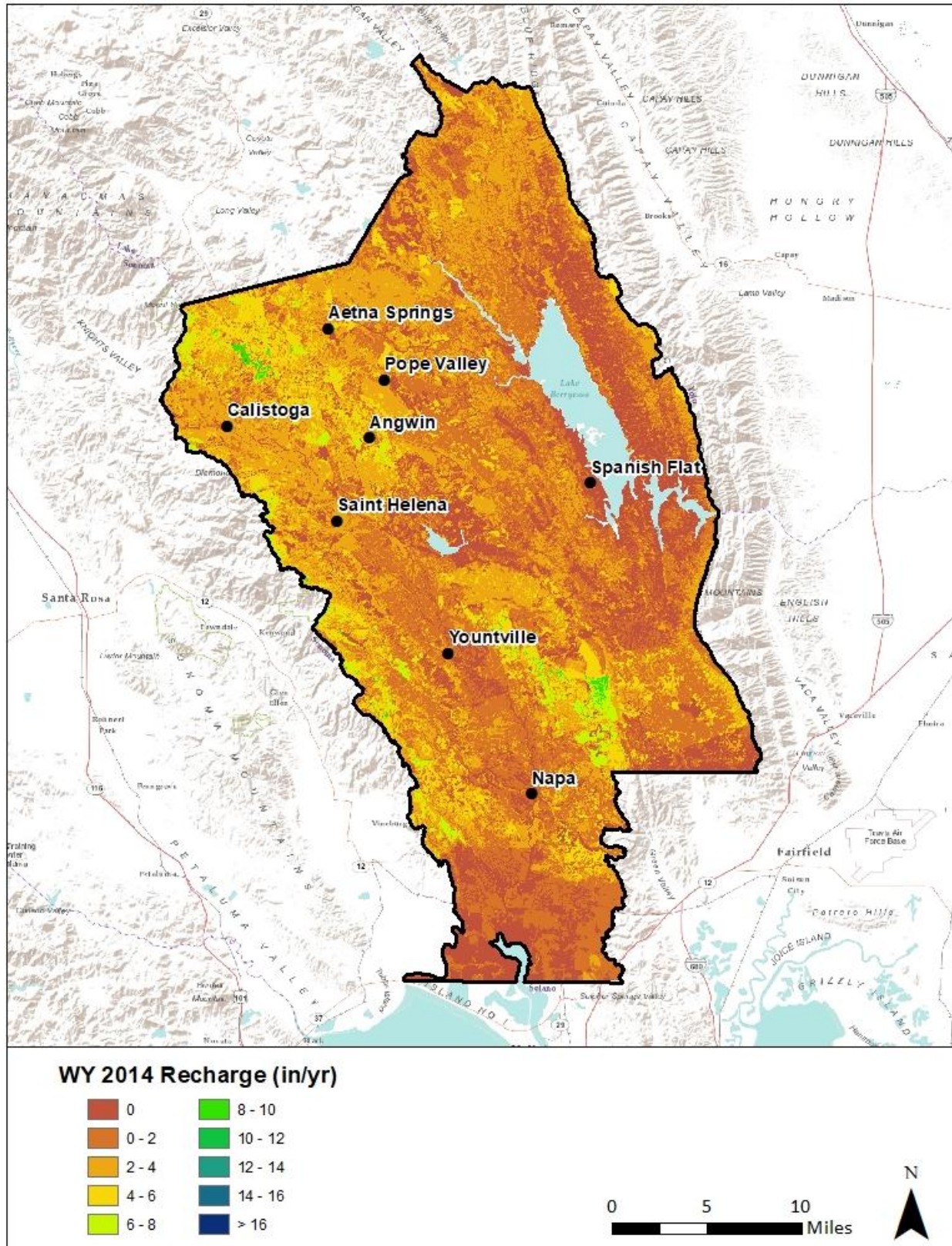


Figure 18: Water Year 2014 recharge simulated with the Napa County SWB model.

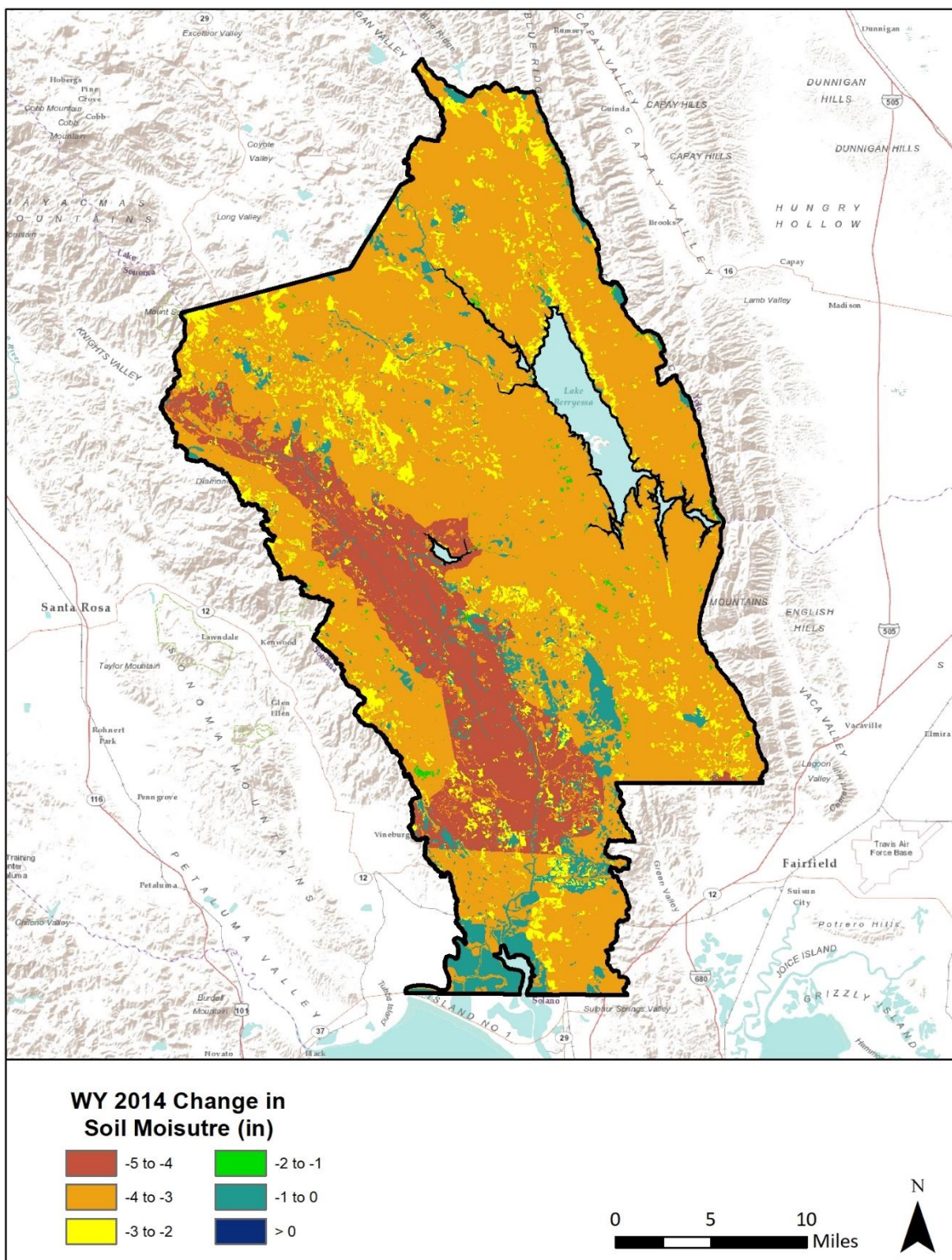


Figure 19: Water Year 2014 change in soil moisture content simulated with the Napa County SWB model.

Table 5: Simulated precipitation and recharge values averaged across HUC-12 watersheds in Napa County for Water Year 2010 expressed as depths. See Figure 20 for watershed locations.

Name	Drainage Area (mi ²)	Precipitation (in)	AET (in)	Surface Runoff (in)	Recharge (in)	Soil Moisture Change (in)
American Canyon Creek	10.8	24.1	16.3	3.7	4.7	-0.6
Bucksnort Creek	1.9	47.9	24.5	12.1	11.1	0.1
Butts Creek-Putah Creek	49.9	33.0	17.4	9.7	6.2	-0.7
Capell Creek	43.0	31.1	19.1	7.4	5.0	-0.6
Carneros Creek	29.7	28.0	18.6	5.2	5.5	-0.6
Chiles Creek	32.0	34.6	21.1	7.1	6.8	-0.5
Dry Creek	28.8	37.0	22.2	7.2	8.4	-0.5
Hunting Creek	12.0	33.7	19.0	9.7	5.7	-0.8
Jackson Creek-Putah Creek	54.5	29.9	13.4	12.6	3.0	-0.5
Lake Curry-Suisun Creek	16.4	30.7	18.9	6.5	5.9	-0.6
Lake Hennessey-Conn Creek	20.0	35.1	19.6	8.5	7.3	-0.4
Ledgewood Creek	6.4	21.8	16.9	3.4	3.3	-1.8
Lower Eticuera Creek	44.0	30.0	17.7	8.1	4.7	-0.7
Lower Napa River	45.0	31.7	19.9	5.6	6.7	-0.6
Lower Pope Creek	31.8	33.9	18.0	9.7	6.5	-0.6
Maxwell Creek	35.1	34.7	19.6	8.7	6.9	-0.6
Middle Napa River	60.3	39.9	22.8	8.5	9.2	-0.5
Milliken Creek	29.7	30.9	16.9	6.6	7.9	-0.6
Rector Creek-Conn Creek	22.3	32.8	18.0	7.1	8.2	-0.7
Saint Helena Creek	7.7	53.3	25.2	13.5	14.4	0.1
San Pablo Bay Estuaries	19.5	23.9	8.1	13.8	2.3	-0.3
Tuluca Creek	34.2	26.1	16.7	4.6	5.4	-0.7
Upper Eticuera Creek	25.6	31.2	17.2	8.6	6.1	-0.8
Upper Napa River	44.6	44.7	23.6	10.6	10.8	-0.4
Upper Pope Creek	21.7	44.5	22.7	10.5	11.5	-0.3
Wooden Valley & Suisun Creeks	23.3	29.0	19.0	5.1	5.5	-0.6
Wragg Canyon-Putah Creek	34.2	28.3	16.3	8.6	3.3	-0.6

Table 6: Simulated precipitation and recharge values averaged across HUC-12 watersheds in Napa County for Water Year 2010 expressed as a percentage of precipitation. See Figure 20 for watershed locations.

Name	Drainage Area (mi ²)	Precipitation (in)	AET (%)	Surface Runoff (%)	Recharge (%)	Soil Moisture Change (%)
American Canyon Creek	10.8	24.1	67%	15%	19%	-3%
Bucksnort Creek	1.9	47.9	51%	25%	23%	0%
Butts Creek-Putah Creek	49.9	33.0	53%	29%	19%	-2%
Capell Creek	43.0	31.2	61%	24%	16%	-2%
Carneros Creek	29.7	29.7	66%	19%	20%	-2%
Chiles Creek	32.0	34.6	61%	21%	20%	-1%
Dry Creek	28.8	37.8	60%	20%	23%	-1%
Hunting Creek	12.0	33.7	56%	29%	17%	-2%
Jackson Creek-Putah Creek	54.5	29.7	45%	42%	10%	-2%
Lake Curry-Suisun Creek	16.4	30.7	61%	21%	19%	-2%
Lake Hennessey-Conn Creek	20.0	36.0	56%	24%	21%	-1%
Ledgewood Creek	6.4	21.8	77%	15%	15%	-8%
Lower Elicuera Creek	44.0	30.0	59%	27%	16%	-2%
Lower Napa River	45.0	31.7	63%	18%	21%	-2%
Lower Pope Creek	31.8	33.9	53%	29%	19%	-2%
Maxwell Creek	35.1	34.7	56%	25%	20%	-2%
Middle Napa River	60.3	40.4	57%	21%	23%	-1%
Milliken Creek	29.7	30.9	55%	21%	26%	-2%
Rector Creek-Conn Creek	22.3	32.8	55%	22%	25%	-2%
Saint Helena Creek	7.7	53.3	47%	25%	27%	0%
San Pablo Bay Estuaries	19.5	23.9	34%	58%	10%	-1%
Tuluca Creek	34.2	26.1	64%	18%	21%	-3%
Upper Elicuera Creek	25.6	31.2	55%	28%	19%	-3%
Upper Napa River	44.6	44.7	53%	24%	24%	-1%
Upper Pope Creek	21.7	44.5	51%	23%	26%	-1%
Wooden Valley & Suisun Creeks	23.3	29.0	65%	18%	19%	-2%
Wragg Canyon-Putah Creek	34.2	28.3	58%	31%	12%	-2%

Table 7: Simulated precipitation and recharge values averaged across HUC-12 watersheds in Napa County for Water Year 2014 expressed as depths. See Figure 20 for watershed locations.

Name	Drainage Area (mi ²)	Precipitation (in)	AET (in)	Surface Runoff (in)	Recharge (in)	Soil Moisture Change (in)
American Canyon Creek	10.8	10.1	12.3	0.7	0.7	-3.6
Bucksnot Creek	1.9	28.8	17.6	11.5	2.6	-3.0
Butts Creek-Putah Creek	49.9	16.9	14.2	3.9	1.9	-3.2
Capell Creek	43.0	15.8	14.8	3.1	1.1	-3.1
Carneros Creek	29.7	15.0	14.7	4.6	2.0	-3.7
Chiles Creek	32.0	18.3	16.5	3.7	1.5	-3.3
Dry Creek	28.8	21.5	16.5	6.8	2.5	-3.7
Hunting Creek	12.0	16.7	15.4	3.1	1.6	-3.4
Jackson Creek-Putah Creek	54.5	14.9	10.3	6.1	0.7	-2.3
Lake Curry-Suisun Creek	16.4	18.4	16.1	3.7	1.9	-3.4
Lake Hennessey-Conn Creek	20.0	19.1	14.8	5.7	2.2	-3.2
Ledgewood Creek	6.4	12.2	13.9	1.7	0.8	-4.3
Lower Elicuera Creek	44.0	14.9	14.0	2.6	1.3	-3.1
Lower Napa River	45.0	19.4	15.9	5.0	2.2	-3.6
Lower Pope Creek	31.8	17.8	14.5	4.5	2.0	-3.2
Maxwell Creek	35.1	18.3	15.9	3.8	2.0	-3.3
Middle Napa River	60.3	21.3	16.5	6.6	2.5	-3.7
Milliken Creek	29.7	18.7	13.7	4.5	3.4	-2.9
Rector Creek-Conn Creek	22.3	16.5	13.6	4.0	2.3	-3.4
Saint Helena Creek	7.7	32.2	17.8	13.2	4.1	-3.0
San Pablo Bay Estuaries	19.5	10.4	6.0	5.6	0.5	-1.6
Tuluca Creek	34.2	14.6	13.5	2.6	1.7	-3.3
Upper Elicuera Creek	25.6	15.5	14.1	2.5	2.1	-3.2
Upper Napa River	44.6	22.9	16.2	6.9	3.3	-3.5
Upper Pope Creek	21.7	25.6	16.8	8.5	3.5	-3.2
Wooden Valley & Suisun Creeks	23.3	17.9	16.4	3.1	2.0	-3.5
Wragg Canyon-Putah Creek	34.2	14.1	12.6	3.6	0.6	-2.8

Table 8: Simulated precipitation and recharge values averaged across HUC-12 watersheds in Napa County for Water Year 2014 expressed as a percentage of precipitation. See Figure 20 for watershed locations.

Name	Drainage Area (mi ²)	Precipitation (in)	AET (%)	Surface Runoff (%)	Recharge (%)	Soil Moisture Change (%)
American Canyon Creek	10.8	10.1	121%	7%	7%	-36%
Bucksnot Creek	1.9	28.8	61%	40%	9%	-10%
Butts Creek-Putah Creek	49.9	16.8	84%	23%	11%	-19%
Capell Creek	43.0	15.8	94%	20%	7%	-20%
Carneros Creek	29.7	17.6	98%	30%	13%	-25%
Chiles Creek	32.0	18.4	90%	20%	8%	-18%
Dry Creek	28.8	22.1	77%	32%	12%	-17%
Hunting Creek	12.0	16.7	92%	18%	10%	-20%
Jackson Creek-Putah Creek	54.5	14.7	69%	41%	5%	-16%
Lake Curry-Suisun Creek	16.4	18.4	88%	20%	10%	-19%
Lake Hennessey-Conn Creek	20.0	19.6	78%	30%	12%	-17%
Ledgewood Creek	6.4	12.2	114%	14%	7%	-35%
Lower Elicuera Creek	44.0	14.9	94%	18%	9%	-21%
Lower Napa River	45.0	19.4	82%	26%	11%	-19%
Lower Pope Creek	31.8	17.8	81%	25%	11%	-18%
Maxwell Creek	35.1	18.3	87%	21%	11%	-18%
Middle Napa River	60.3	21.8	77%	31%	12%	-18%
Milliken Creek	29.7	18.7	74%	24%	18%	-16%
Rector Creek-Conn Creek	22.3	16.5	83%	24%	14%	-21%
Saint Helena Creek	7.7	32.2	55%	41%	13%	-9%
San Pablo Bay Estuaries	19.5	10.4	58%	53%	4%	-16%
Tuluca Creek	34.2	14.6	93%	18%	12%	-23%
Upper Elicuera Creek	25.6	15.5	91%	16%	14%	-21%
Upper Napa River	44.6	22.9	71%	30%	14%	-15%
Upper Pope Creek	21.7	25.6	66%	33%	14%	-12%
Wooden Valley & Suisun Creeks	23.3	17.9	91%	17%	11%	-20%
Wragg Canyon-Putah Creek	34.2	14.1	90%	26%	5%	-20%

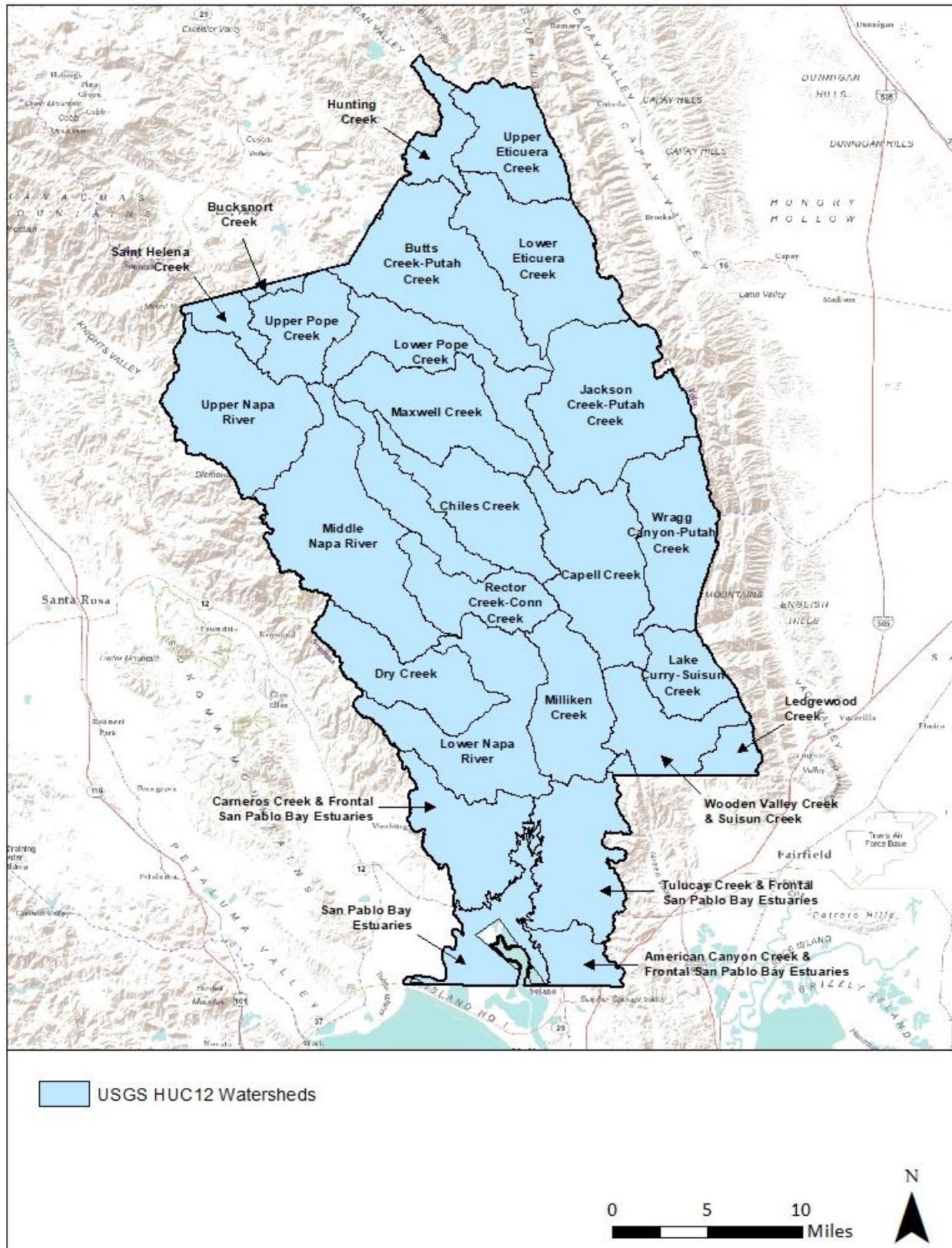


Figure 20: Major watersheds areas used to summarize water budget information in Tables 5 - 8.

Discussion and Conclusion

Numerous previous modeling studies have estimated water budget components in several larger watershed areas in Sonoma and Napa Counties including the Santa Rosa Plain, the Green Valley and Dutch Bill Creek watersheds, and the Sonoma Valley (Farrar et. al., 2006; Kobor and O'Connor, 2016; Woolfenden and Hevesi, 2014). Comparisons to these water budgets are useful for evaluating the SWB results, but one would not expect precise agreement owing to significant variations in climate, land cover, soil types, underlying hydrogeologic conditions, and different spatial scales of modeling studies. These regional analyses estimate that average annual recharge varies from 7% to 19% of the annual precipitation. The equivalent county-wide value from this study is slightly higher at 20%.

Water budgets for the Napa River and selected sub-basins were also estimated in a previous study by Luhdorff and Scalmanini Engineers and MBK Engineers (LSCE 2013). The LSCE study estimated that, as a percentage of annual precipitation, AET comprised slightly less, runoff significantly more, and recharge substantially less of the typical annual water budget. LSCE (2013) calculated infiltration of precipitation based on the difference between total monthly streamflow at selected gaging stations and total monthly precipitation for the gages' drainage area. Streamflow volumes include both direct runoff (overland flow and interflow) and baseflow from groundwater. Inclusion of baseflow with direct runoff in these calculations may inappropriately reduce the estimated volume of water infiltrated into the soil and available for recharge; the LSCE approach therefore tends to underestimate groundwater recharge. Additionally, many of the gauging stations used for the analysis are located in reaches that may be significantly influenced by upstream reservoir releases, surface water diversions, groundwater abstraction, and/or surface water groundwater exchanges, further complicating the interpretation of the LSCE (2013) runoff rates and the interrelated calculations of AET and recharge rates. In contrast, the SWB model presented here is based on calibrated parameter values developed for a similar model in Sonoma County which was calibrated to gauges specifically selected to minimize the effects of reservoir releases, water use, or significant surface water/groundwater interaction, and after separating and removing the baseflow component of streamflow.

The recharge estimates presented here arguably represent the best available county-wide estimates produced at a fine spatial resolution using a consistent and objective data-driven approach. This analysis focused on two Water Years, 2010 and 2014, which represent average and drought conditions respectively. Input parameters were determined based on literature values and values calibrated through prior modeling experience in Sonoma County.

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