Groundwater Report

1267 Jensen Lane, Windsor (APN 162-020-007)

Prepared per Sonoma County Policy & Procedure 8-1-14

Prepared for:

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On behalf of:

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September 5th, 2019

Contents

Introduction

The applicant, Famiglia Liberta, LLC, is seeking permits to subdivide a 38.0-acre parcel at 1276 Jensen Lane (Sonoma County APN 162-020-007). If approved, the subject parcel, which currently contains approximately 24.9 acres of vineyard, will be subdivided into three parcels. Each resulting parcel is intended to have a primary residence; the majority of the existing vineyard will be retained.

The parcel is currently supplied with water from two existing wells; these wells will remain the water source for project. A well on the project parcel is currently used to irrigate trees along the entry road and will become a shared well supplying water for domestic use on each of the three proposed parcels. Vineyards are presently, and will continue to be, irrigated with water from a higher-yield well on an adjacent parcel to the west which is under the same ownership (APN 162-020-066).

Both wells and the majority of the project parcel lie within an area identified by the County of Sonoma as having Class 1 groundwater availability. However, a small portion (less than one-acre) of the northeastern corner of the project parcel is located within a Class 3 groundwater zone defined as an area with “marginal” groundwater availability (Figure 1). Additionally, the entire project parcel is located within the Santa Rosa Plain Groundwater Basin, designated a medium priority basin under California’s Sustainable Groundwater Management Act. Consequently, Permit Sonoma Procedure & Policy 8-1-14 and Sonoma County General Policy WR-2e require that a Goundwater Report be prepared for this project.

Robert Pennington (Permit Sonoma) has communicated that a simplified Groundwater Report that does not include a detailed review of nearby wells will be sufficient for this project; the local aquifer and hydrogeology has been characterized by studies supporting management of the Santa Rosa Plain Groundwater Basin. This report has been prepared to meet all other Permit Sonoma requirements pursuant to General Plan Policy WR-2e and Procedure and Policy 8-1-14. It includes the following elements: estimates of existing and proposed water use within the project impact area, estimates of annual groundwater recharge, and the potential for well interference between the project well and neighboring wells. Note that this report only evaluates potential impacts of the proposed project to groundwater. All other plans and documents related to permitting the project are being prepared by other professionals.

Limitations

Groundwater systems of Sonoma County and the Coast Range are typically complex, and available data rarely allows for more than general assessment of groundwater conditions and delineation of aquifers. Hydrogeologic interpretations are based on the drillers' reports made available to us through the California Department of Water Resources, available geologic maps and hydrogeologic studies and professional judgment. This analysis is based on limited available data and relies significantly on interpretation of data from disparate sources of disparate quality. Existing and proposed future water use on and near the project site is estimated based on the applicant's experience and expectations, and on regionally-appropriate water duties for the observed and expected uses. The recharge estimates presented below are based on established soil water balance modeling techniques for calculating infiltration recharge and they do not account for the role of surface water/groundwater interaction or bedrock geology in controlling recharge and groundwater availability.

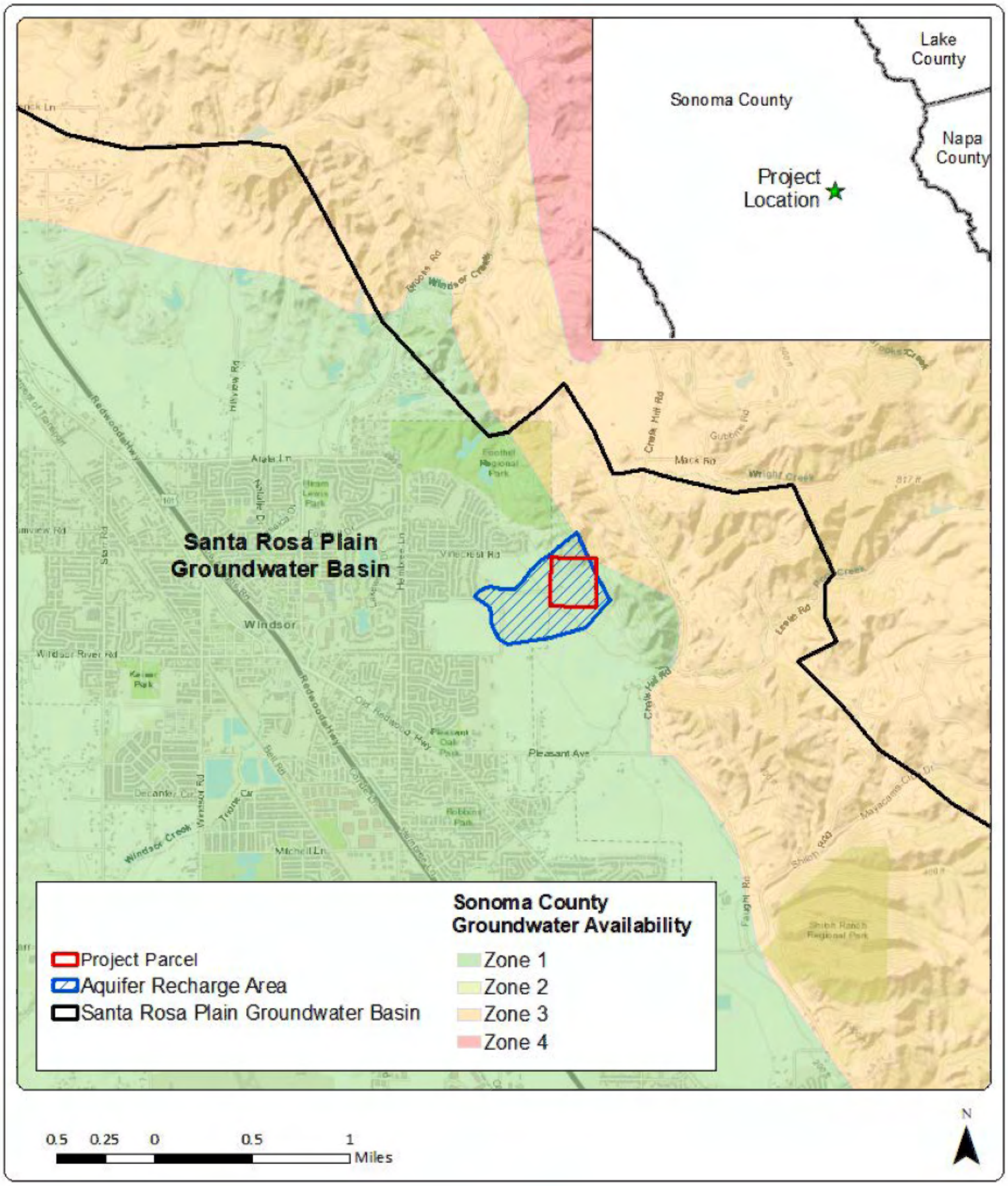


Figure 1: Project location map.

Hydrogeologic Conditions

The project parcel is located in the foothills of the Mayacamas Mountains east of Windsor (Figure 1). It is within the northwest to southeast-trending Healdsburg Fault Zone which divides two large structural blocks (Figure 2). To the west is a large block of the Pliocene and late-Miocene-aged Petaluma Formation (map unit Tp) which is overlain by Pleistocene-aged and younger alluvial fan and fluvial deposits (map units Qal and Qpoaf). To the east is a large block of the Pliocene and Miocene-aged Sonoma Volcanics (map unit Tsv) overlain by the Pleistocene and Pliocene-aged Glen Ellen Formation (map unit QTge) (Blake et al., 2002).

Wells in this area, including the two project wells, are likely completed in the alluvium and potentially penetrate the upper portions of the Petaluma Formation. The alluvium consists of a heterogeneous mixture of poorly to well sorted sand, silt, clay, gravel, cobbles, and boulders in thin to massive interfingered beds. Reported well yields from the alluvium are highly variable and range from one to several hundred gallons per minute (gpm) (Nishikawa et al., 2013). Specific yields are estimated to be between 8 and 17 % (Herbst et al., 1982). The Petaluma Formation consists of brown and green pebble and cobble conglomerate, gritstone, lithic and quartz-lithic arenite, and mudstone (Blake et al., 2002). Wells within this formation typically have yields from 10 to 50 gpm but yields of greater than 100 gpm have been documented where sand and gravel beds were encountered (Nishikawa et al., 2013). Specific yields for the Petaluma Formation are estimated to be between 3 and 7% (Herbst et al., 1982).

The depth of the alluvium overlying the Petaluma Formation within the Santa Rosa Plain is typically a few hundred feet thick but older deposits may up to 400 feet thick (Nishikawa, 2013). The depth of the Glen Ellen Formation is highly variable but is typically a few hundred feet or less (Sweetkind et al., 2010). The Healdsburg Fault Zone is believed to dip steeply (~70 degrees) to the northeast (Nishikawa, 2013). Based on this information, a geologic cross-section was cut from the southwest to northeast through the two project wells (Figure 3, see Figure 2 for location). The contacts between the alluvium and underlying Petaluma Formation and between the Glen Ellen Formation and the underlying Sonoma Volcanics could not be interpreted from available data and are therefore not shown. Besides serving as the contact between these two blocks, the Healdsburg Fault Zone may also function as a barrier to groundwater flow. Nishikawa et al., (2013) found that based on both water surface elevations and major ion composition the Rodgers Creek Fault Zone, which is the southern continuation of the Healdsburg Fault Zone, may function as a groundwater barrier. However, this report also notes that it has not been shown conclusively whether faults within the Santa Rosa Plain function as barriers to groundwater flow (Nishikawa et al., 2013, therefore it is uncertain whether this trace functions as a groundwater barrier. Attempts to investigate this further using data from Well Completion Reports were unsuccessful due to insufficient data. There is a substantial difference in groundwater elevation reported for the two project wells (Figure 3), suggesting that the fault is a barrier to groundwater flow in this location.

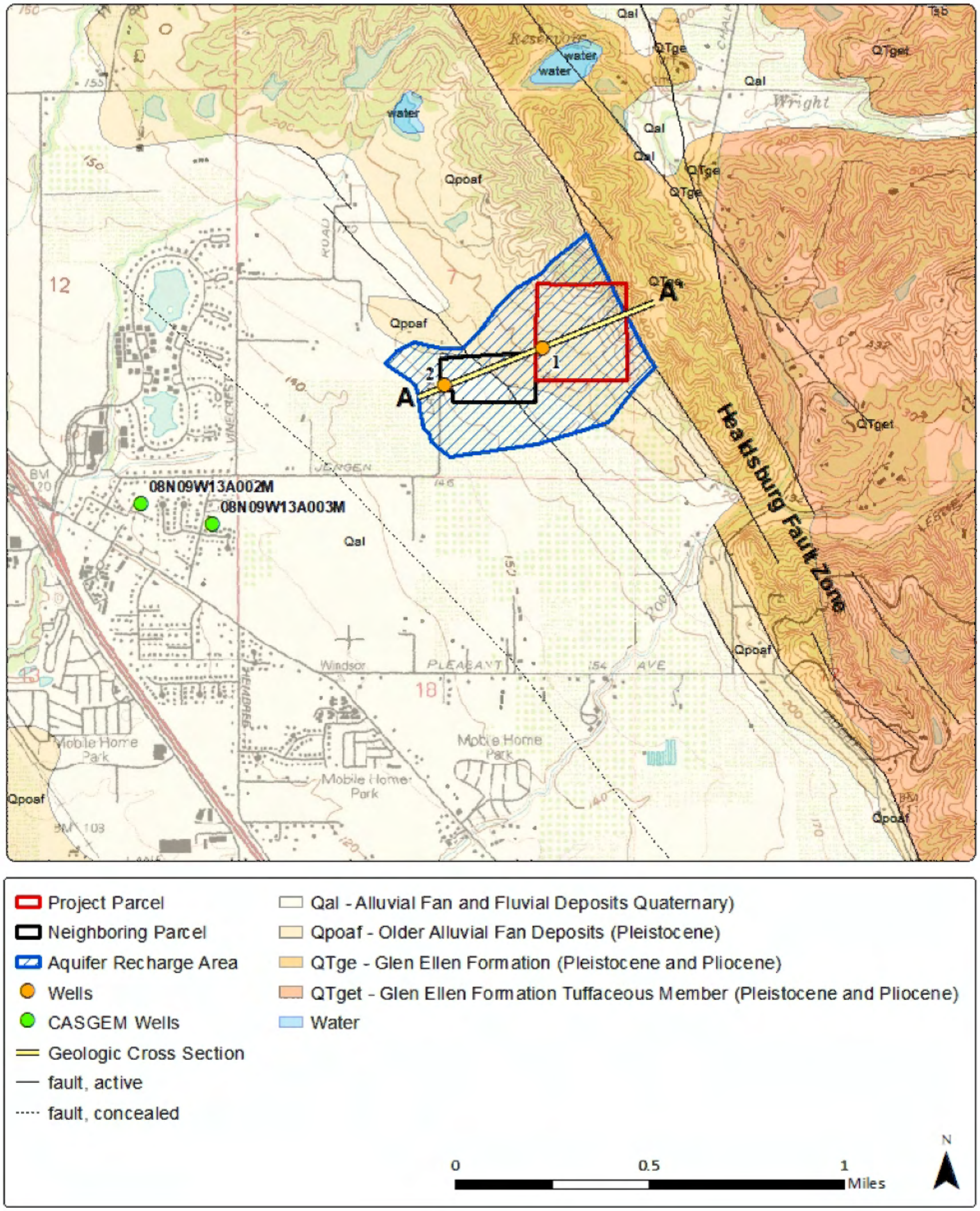
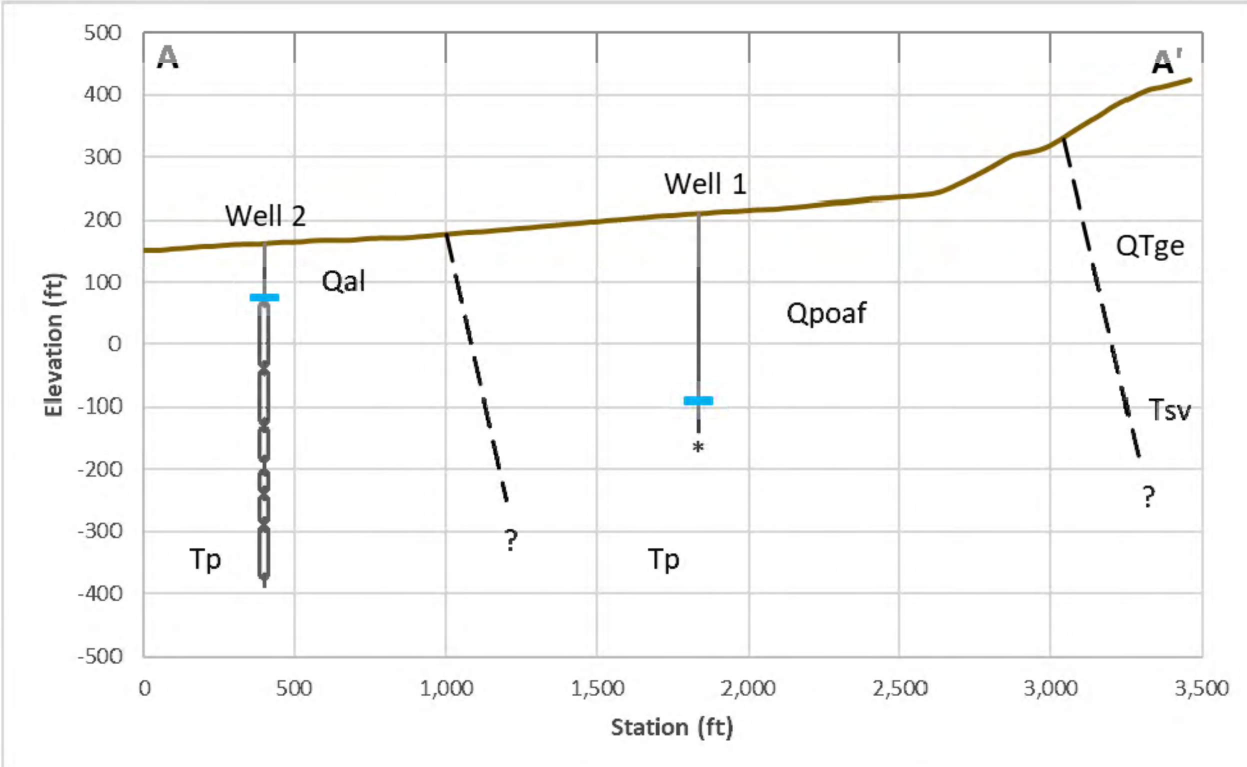
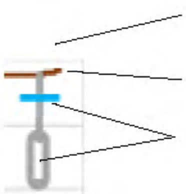


Figure 2: Surficial geology and locations of wells in the vicinity of the project parcel. Surficial geology based on data from the Geologic Map of Western Sonoma, Northernmost Marin, and Southernmost Mendocino Counties (Blake et al.,2002).



Wells **Faults** **Fault, Active**



Ground surface

Groundwater Elevation

Screened Section of Well

*** Depth, screened interval, and static water level unknown for Well 1.**

Figure 3: Hydrogeologic cross section A - A' through the vicinity of the project parcel (see Figure 2 for location).

Project Wells

The project parcel is supplied with groundwater from two wells. The first of these (Well 1), is located on the project parcel and is currently used to irrigate trees along the entrance road. The applicant plans on supplying all three planned residences with water from this well. While a Well Completion Report is unavailable for this well, a pump test record is available for a test conducted on March 24, 2017 (see Attachment A). At the time this test was conducted, the well had a static water level of 300 feet and an estimated capacity of 65 gpm. Well depth and screened interval are unknown.

The second well (Well 2), is located on the adjacent parcel to the west (APN 162-020-066) which is also owned by the project applicant. It is currently used to irrigate approximately 36.2 acres of vineyard on the project parcel and this adjacent parcel. A Well Completion Report is available and indicates that this well was completed to a depth of 600 feet and that it is screened at several intervals between 101 and 531 feet. Given its depth, it likely penetrates the overlying alluvial fan deposits and is screened at least partially within the Petaluma Formation. However, given similarities in how alluvium and the Petaluma Formation are reported on driller's logs, it is not possible to say at what depth this contact occurs. At the time a pump test was conducted on July 6th, 2017, the well had a static water level of 87 feet and an estimated yield of 300 gpm (see Appendix A for Well Completion Report).

CASGEM Monitoring Wells

Long-term groundwater elevation data is available from a California State Groundwater Elevation Monitoring (CASGEM) well located between 0.7 and 1.0 miles southwest of the two project wells (State Well ID 08N09W13A003M). Bi-annual groundwater elevation measurements were taken at this well between 1989 and 2001 and show relatively consistent Spring groundwater elevations and a gradual but relatively consistent increase in Fall elevations (Figure 4). However, the data are difficult to interpret since details such as well depth and screened interval are not available for this well and the available record does not provide recent measurements of groundwater elevation. Another CASGEM well is located within this vicinity (State Well ID 08N09W13A002M), but no groundwater elevations are published for this well.

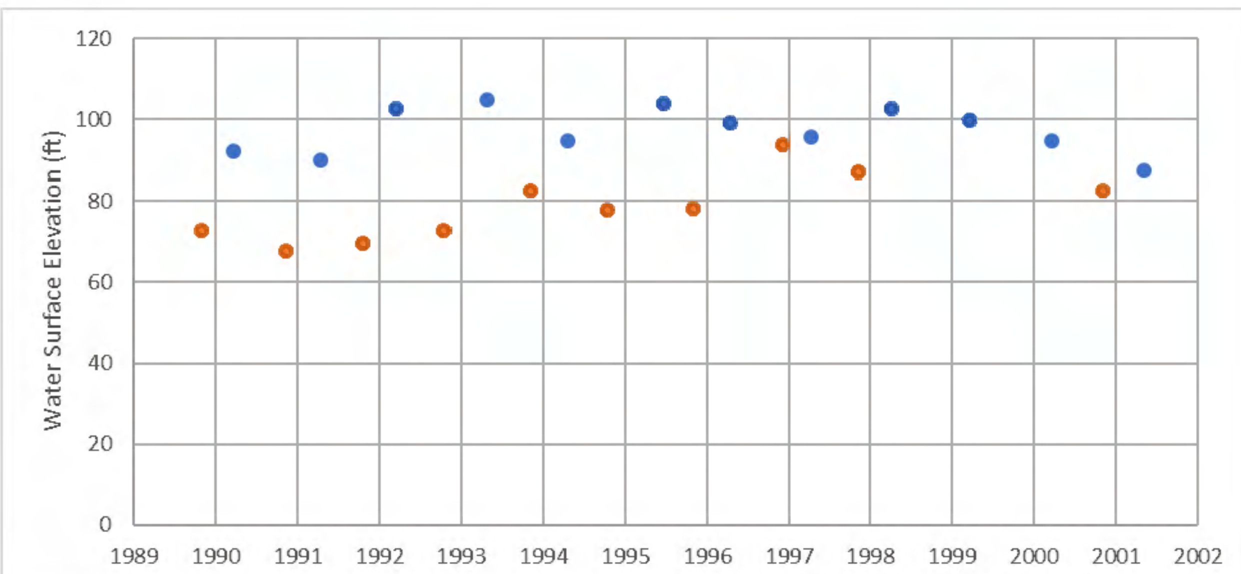


Figure 4: **Bi-annual groundwater elevations for State Well ID 08N09WW13A003M accessed through CASGEM; blue dots indicate Spring measurements, orange dots indicate Fall measurements.**

Project Aquifer

The project aquifer as defined in Figure 2 also represents the project recharge area has been conceptualized to include nearby portions of the alluvium and the underlying Petaluma Formation. Given the proximity of both project wells, a single recharge area has been used for both. We believe that the estimated groundwater recharge is not significantly affected by the groundwater flow barrier created by the local trace of the Healdsburg Fault Zone located between these wells.

The eastern boundary of the project recharge area is defined as the contact between the Petaluma Formation and the Glen Ellen Formation in in the center of the Healdsburg Fault Zone. The northern, southern, and western boundaries are located within Santa Rosa Plain and are defined by general topographic patterns which groundwater elevations are believed to mimic.

In total, the recharge area is approximately 134 acres. Of this, approximately 80 acres is underlain by Pleistocene-aged alluvial fan deposits (map unit Qpoaf) and approximately 54 acres is underlain by younger alluvial fan and fluvial deposits (map unit Qal). At depth, both of these units are underlain by the Petaluma Formation (map unit Tp). Given the clay-rich nature of these units the aquifer is likely confined or semi-confined.

Groundwater Storage Volume

An estimate of the total available groundwater storage within the aquifer recharge area can be obtained as the product of the recharge area (impact area) in units of acres, the saturated aquifer thickness in units of feet, and the aquifer specific yield. Although this method does not accurately predict total water availability in a confined aquifer, it is useful for purposes of general aquifer characterization and for comparison with other aquifers.

The saturated aquifer thickness was estimated as the difference between the static water level and the bottom of Well 2. At the time a pump test was conducted on July 6th, 2017, the static water level was 87 feet. The well is completed to a depth of 551 feet, yielding an estimated saturated thickness of 464 feet. This provides a minimum estimate of the saturated thickness; the Petaluma Formation likely extends to greater depth beneath the project recharge area.

Published specified yields for the Petaluma Formation range between 3 and 7% and between 8 and 17% for alluvial fan deposits (Herbst et al., 1982). Because the depth of the contact between the Petaluma Formation and the alluvial fan deposits is uncertain, we have conservatively applied the lower specific yields from the Petaluma Formation for the entire aquifer thickness. This results in an estimated available groundwater storage of 1,865 acre-ft (134 acres x 0.03 x 464 feet).

Water Demand

Within the project recharge area, water demand was estimated for three conditions: existing, proposed, and full build-out. The full-build out condition reflects full development of neighboring parcels consistent with their current zoning. Water uses on the project parcel were determined using site details provided by the project applicants and verified using available satellite imagery. Water uses on other parcels within the project recharge area were determined using satellite imagery. Annual rates for the various uses were estimated primarily based on Napa County's Water Availability Analysis Guidance Document, dated May 2015 (Napa County, 2015). Note that because water is exchanged between the project parcel and a neighboring parcel under the same ownership, there are multiple ways of expressing water demand on the project parcel. Unless otherwise noted, water demand on the project parcel is expressed as the amount of water used on the project parcel, not the amount of water supplied by the well on the project parcel.

Existing Condition

In the existing condition the project parcel contains 24.9 acres of vineyard (Figure 5). There are no other existing water uses on the parcel. Historic aerial and satellite imagery shows residences, but these were removed in 2017.

The other parcels within the project recharge area are primarily planted with vineyard. Based on the most recent satellite imagery available through Google Earth, the portions of neighboring parcels included within the project recharge area contain 61.4 acres of vineyard (Figure 5). Note that because the precise locations of wells irrigating these vineyards are not known, only the portions of vineyard blocks contained within the project recharge area were included in the water use calculations. This provides a general representation of the intensity of groundwater use in the area. The project applicant also indicates that water is used to irrigate several palm trees along the entrance road to the neighboring parcel (APN 162-020-066). Water use for these trees is considered negligible compared to the amount of water used for vineyard irrigation.

Neighboring parcels also include several residences. Of these, four primary residences and one secondary residence are outside the service area for the Town of Windsor's Water District and are assumed to use groundwater. One contains a pool and one contains an approximately 3,000 ft^2 irrigated lawn. Of this, the water use for 1,000 ft^2 was included in the water use estimate for the residence and water use for the additional 2,000 ft^2 was accounted for separately (per Napa County, 2015). Other suburban residences fall within the western edge of the project recharge area but are included within the service area for the Town of Windsor's Water District. These residences were not included in the water use calculations.

Based on these uses, existing water demand within the project recharge area is estimated to be 46.62 acre-ft/yr (Table 1). Of this, 12.45 acre-ft/yr comes from the project parcel (Table 2) and 34.17 acre-ft/yr comes from neighboring parcels included within the project recharge area (Table 3). Almost all (~93% or 43.15 acre-ft/yr) of the water demand is for vineyard irrigation with the remaining 7% representing residential use.

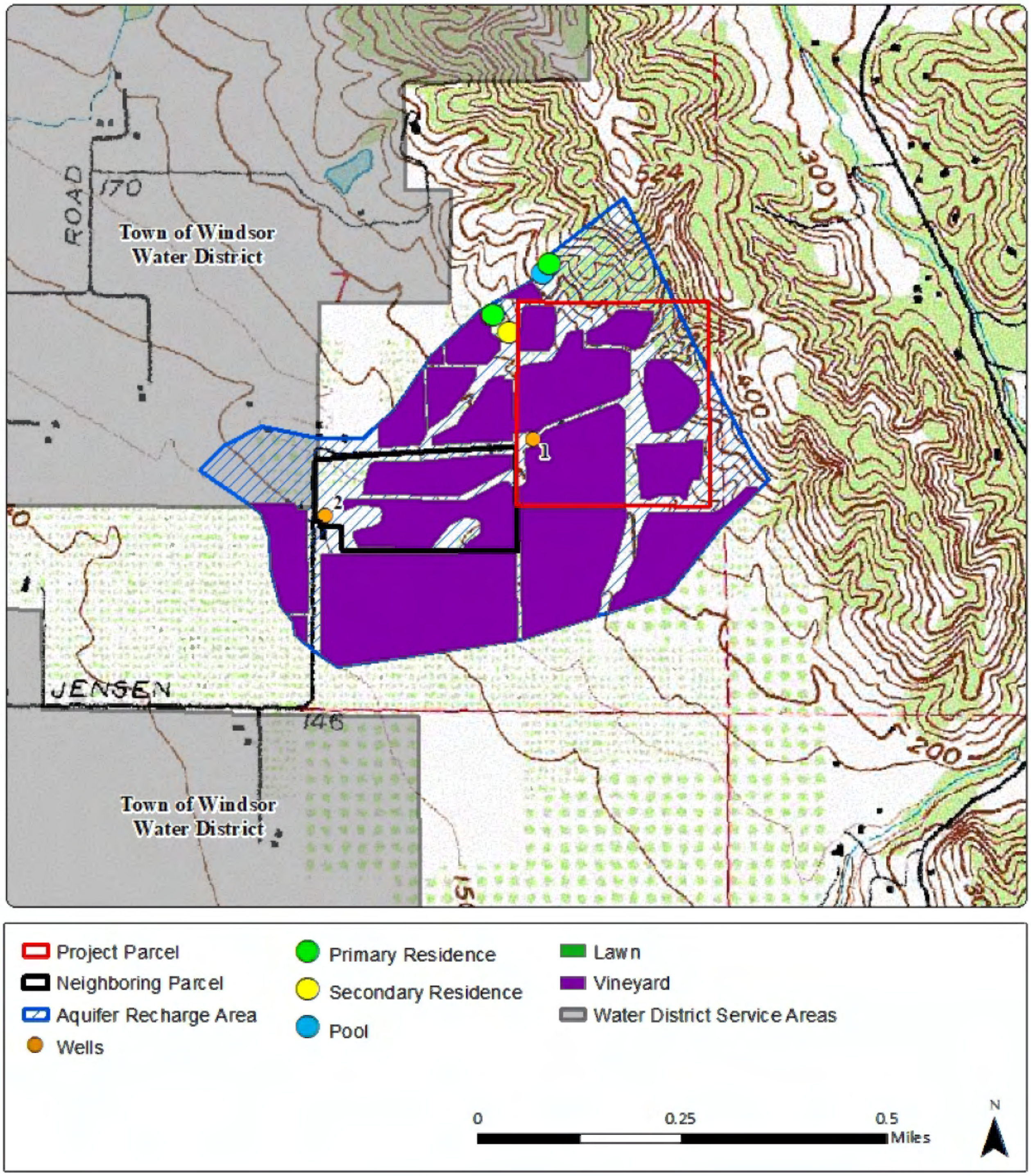


Figure 5: Existing uses included in the water demand calculations

Table 1: Estimated groundwater use within the project recharge area in the existing, proposed, and full build-out conditions.

	Existing Condition (acre-ft/yr)	Proposed Condition (acre-ft/yr)	Full Build-Out Condition (acre-ft/yr)
Project Parcel	**12.45**	**14.70**	**15.40**
Residential Use	0.00	2.25	2.95
Irrigation Use	12.45	12.45	12.45
Neighboring Parcels	**34.17**	**34.17**	**36.37**
Residential Use	3.47	3.47	4.92
Irrigation Use	30.70	30.70	31.45
Total	**46.62**	**48.87**	**51.77**

Table 2: Existing water use on the project parcel.

	# of Units	Use per Unit	Annual Water Use (AF/yr)
Agricultural Use			**12.45**
Vineyard	24.89 Acres	0.50 AF/acre/yr	12.45
Total			**12.45**

Table 3: Existing water use on portions of neighboring parcels included within the project recharge area.

	# of Units	Use per Unit	Annual Water Use (AF/yr)
Residential Use			**3.47**
Residences, Primary	4 Residences	0.75 AF/Residence	3.00
Residences, Secondary	1 Residence	0.35 AF/Residence	0.35
Pools	1 Pool	0.10 AF/Pool	0.10
Lawn, Additional	2000 sq. ft.	0.10 AF/10,000 sq. ft.	0.02
Agricultural Use			**30.70**
Vineyard	61.4 Acres	0.50 AF/acre/yr	30.70
Total			**34.17**

Proposed Condition

In the proposed condition, the project parcel will be subdivided into three smaller parcels with provisions for a primary residence to be constructed on each. The existing vineyard will be retained, but its acreage may be slightly reduced to make space for the planned residences. However, because exact numbers for this reduction are not available at the time of this report, vineyard acreage was not reduced in the water use calculations. Future vineyard acreage and water use may be less than presented in this report.

Based on these uses, total water demand in the project recharge area is estimated to increase by 2.25 acre-ft/yr to 48.87 acre-ft/yr (Table 1). All of this increase comes from the three planned residences. In the proposed condition, the 38.0-acre project parcel, which accounts for 28% of the 134-acre project recharge area, will use 14.70 acre-ft/yr (Table 4). This is equivalent to 30% of the total use within the project recharge area.

Table 4: Proposed water use on the project parcel.

	# of Units	Use per Unit	Annual Water Use (AF/yr)
Residential Use			**2.25**
Residences, Primary	3 Residences	0.75 AF/Residence	2.25
Agricultural Use			**12.45**
Vineyard	24.89 Acres	0.50 AF/acre/yr	12.45
Total			**14.70**

Full Built-Out Condition

The full build-out condition reflects the full development of parcels consistent with their current zoning. Uses in the full build-out condition were estimated using the following assumptions:

- All parcels will have primary dwellings and half will have secondary dwellings (unless fully built out with agricultural or other existing uses)
- For parcels with existing vineyards, orchards, or other established agricultural uses, 50% of open land was assumed to be developed. Open land was considered to be areas classified as non-riparian shrubs or as herbaceous by the Vegetation and Habitat Map Key accompanying the Sonoma County Fine Scale Vegetation Map (SCAPOSD, 2015). Limitations on maximum slope, riparian setbacks, and feasibility were not considered (except as noted below).
- Parcels without vineyard, orchard, or other established agricultural uses were not considered to have agriculture in the future.
- Subdivisions and other discretionary projects were not considered.

Based on these assumptions, two secondary residences were added to the project parcel in the full build-out condition. Additional open land is not available on the project parcel for vineyard expansion. Similarly, most of the neighboring parcels included within the project recharge are completely planted with vineyard and do not have space for additional residences or vineyard. Of these only one parcel, APN 162-020-066, appears to have space available for a new primary residence or additional vineyard. In the full build-out condition, it was assumed to have an additional 1.5 acres of vineyard and one new primary residence. This brings the total number of primary residences on neighboring parcels to five. Three were considered to have secondary residences, two more than in the existing condition.

Based on these developments, water use in the full-build out condition is estimated to be as high as 51.77 acre-ft/yr (Table 1). Water use on the project parcel may increase up to 15.40 acre-ft/yr (Table 5) and water use on neighboring parcels may increase up to 36.37 acre-ft/yr (Table 6).

Table 5: Water use on the project parcel in the full build-out condition.

	# of Units	Use per Unit	Annual Water Use (AF/yr)
Residential Use			**2.95**
Residences, Primary	3 Residences	0.75 AF/Residence	2.25
Residences, Secondary	2 Residences	0.35 AF/Residence	0.70
Agricultural Use			**12.45**
Vineyard	24.89 Acres	0.50 AF/acre/yr	12.45
Total			**15.40**

Table 6: Water use on neighboring parcels within the project recharge area in the full build-out condition.

	# of Units	Use per Unit	Annual Water Use (AF/yr)
Residential Use			**4.92**
Residences, Primary	5 Residences	0.75 AF/Residence	3.75
Residences, Secondary	3 Residences	0.35 AF/Residence	1.05
Pools	1 Pool	0.10 AF/Pool	0.10
Lawn, Additional	2000 sq. ft.	0.10 AF/10,000 sq. ft.	0.02
Agricultural Use			**31.45**
Vineyard	62.9 Acres	0.50 AF/acre/yr	31.45
Total			**36.37**

Groundwater Recharge Analysis

Groundwater recharge within the project recharge area was estimated using the Soil Water Balance (SWB) model developed for Sonoma County and portions of Marin County (Appendix B). The SWB model was developed by the U.S. Geological Survey (Westenbroek at al., 2010) and produces a spatially distributed estimate of annual recharge. This model operates on a daily timestep and calculates runoff based on the Natural Resources Conservation Service (NRCS) curve number approach and Actual Evapotranspiration (AET) and recharge based on a modified Thornthwaite-Mather soil-water-balance approach (Westenbroek et al., 2010). Details of this model are included in Appendix B.

Groundwater recharge was simulated for Water Year 2010 which was selected as precipitation was close to the 30-year average for much of Sonoma County. During the simulated water year, precipitation averaged 43.9 inches across the project recharge area and actual evapotranspiration (AET) averaged 26.2 inches. Groundwater recharge varied across the project recharge area from 4.4 to 13.7 inches with a spatially averaged recharge of 9.3 inches (Table 7). Groundwater recharge estimates can also be expressed as a total volume by multiplying the calculated recharge by the project aquifer recharge area of 134 acres. This calculation yields an estimated mean annual recharge of 103.9 acre-ft/yr.

Table 7: Summary of water balance results from the SWB model for Water Year 2010.

	2010 Normal Year	
	inches	% of precip
Precipitation	43.9	-
AET	26.2	60%
Runoff	8.4	19%
Recharge	9.3	21%

Water budget estimates are available for several larger watershed areas nearby including the Santa Rosa Plain, the Green Valley Creek watershed, and the Sonoma Valley. Comparisons to these water budgets are useful for determining the overall reasonableness of the results although one would not expect precise agreement owing to significant variations in climate, land cover, soil types, and underlying hydrogeologic conditions. These regional analyses estimated that mean annual recharge was equivalent to between 7% and 28% of mean annual precipitation (Farrar et. al., 2006; Flint and Flint, 2014, Kobor and O'Connor, 2016; Woolfenden and Hevesi, 2014). The simulated water year 2010 groundwater recharge for the project recharge area represents approximately 21% (Table 7) of the precipitation, within the range of these regional estimates.

Comparison of Water Demand and Groundwater Recharge

The total proposed groundwater use for the project recharge area is estimated to be 48.9 acre-ft/yr, 14.7 acre-ft/yr of which is from the project parcel. Proposed groundwater use in the project recharge area is equivalent to 47% of the estimated mean annual groundwater recharge of 103.9 acre-ft/yr (Table 8). In the full build-out condition, total groundwater use in the project recharge area may increase to 51.8 acre-ft/yr, equivalent to 50% of the estimated mean annual groundwater recharge. Given the magnitude of these surpluses, groundwater use is unlikely to result in significant reductions in groundwater levels or depletion of groundwater resources over time in either the proposed or full build-out conditions.

Table 14: Comparison of estimated water use and mean annual recharge within the project recharge area

Condition	Total Demand (ac-ft/yr)	Recharge (ac-ft/yr)	Recharge Surplus (ac-ft/yr)	Demand as % of Recharge
Proposed	48.9	103.9	55.0	47%
Full Build-Out	51.8	103.9	52.1	50%

Potential Impacts to Streams and Neighboring Wells

Both wells supplying water to the project parcel are located significant distances from nearby streams and wetlands. The nearest water body to Well 1 is located approximately 450 feet northwest and is a drainage ditch which likely provides minimal aquatic habitat. The nearest mapped wetland is approximately 700 feet to the southeast and the nearest USGS blue-line stream (Pool Creek) is approximately 0.6 miles to the southeast. Well 2 is located adjacent to the same drainage ditch but is more than 800 feet northwest of the nearest wetland and approximately 0.8 miles northwest of the nearest USGS blue line stream. Given the significant horizontal separation between the two project wells and the nearest surface water bodies and the relatively minor proposed increases in use, increased use from these wells is unlikely to have a significant negative impact on aquatic habitat.

The specific locations of nearby wells has not been determined by this report. However, based on available satellite imagery, the nearest plausible location for a well on a neighboring parcel is approximately 500 feet northwest of Well 1. Given this substantial horizontal separation and the relatively minor proposed increases in use, increased pumping from Well 1 is unlikely to negatively impact this or more distant well sites. There may be a well on the small residential parcel immediately south of Well 2. However, because water use from Well 2 is not anticipated to increase as part of this project, it is unlikely that the project will have negative impacts on wells near Well 2.

Summary

The proposed project seeks to subdivide an existing parcel resulting in an estimated increase in water use of approximately 2.25 ac-ft/yr. This use would be provided by an existing well which is completed in the Petaluma Formation and overlying alluvial deposits. Application of the Soil Water Balance (SWB) model to the project recharge area revealed that average water year recharge was approximately 9.3 inches/yr or 103.9 acre-ft/yr. The total proposed water use for the project aquifer recharge area is estimated to be 48.9 acre-ft/yr. This represents 47% of the estimated mean annual recharge, indicating that the project is unlikely to result in declines in groundwater elevations or depletion of groundwater resources over time. The project well is not located near any significant surface water features or neighboring wells and is thus not expected to negatively impact aquatic habitat or neighboring users.

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APPENDIX A

WELL COMPLETION REPORT

Well 1

BARTLEY PUMP
SANTA ROSA, CA

REF. NO. ____________

WELL TEST RECORD

Date ____________ W. O. NO. ____________
Owner ____________
Location of Well ____________
Well Age ____________ Well Diameter ____________
Reported Depth ____________ Measured Depth ____________
Other information ____________

Date	Time	W/L Feet	Cap GPM	Inclination ↕ ←→	Remarks
3/24/17	11:45	300	65		29 Amps
	12:00	300	65		29 Amps
	12:15	300	65		29 Amps
	12:30	300	65		29 Amps
	12:45	300	65		30 Amps
	1:00	300	65		30 Amps
	1:30	300	65		30 Amps
	2:00	300	65		29 Amps
	2:30	300	65		29 Amps
	3:00	300	65		29 Amps

Test Pump Type ____________
Test Pump Setting ____________
Method of Measurement ____________

We certify that the above information is correct to the best of our knowledge and belief.

____
FOR BARTLEY PUMP, INC.

Well 2

ORIGINAL
File with DWR

Page 1 of 1

STATE OF CALIFORNIA

WELL COMPLETION REPORT

Refer to Instruction Pamphlet

No. **e0346600**

Owner's Well No. 1-2017

Date Work Began 6/22/2017, Ended 7/6/2017

Local Permit Agency Sonoma County PRMD

Permit No. WEL17-0115 Permit Date 6/22/2017

DWR USE ONLY — DO NOT FILL IN

STATE WELL NO./ STATION NO.

LATITUDE LONGITUDE

APN/TRS/OTHER

GEOLOGIC LOG

ORIENTATION (✓) ✓ VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)

DRILLING METHOD ROTARY FLUID BENTONITE

DEPTH FROM SURFACE Ft.	to Ft.	DESCRIPTION *Describe material, grain, size, color, etc.*
0	5	BROWN CLAY
5	15	SAND & GRAVEL
15	39	LARGE GRAVEL
39	55	BROWN CLAY
55	90	50% SAND&GRAVEL/50%BROWN CLAY LAYERS
90	118	TAN CLAY WITH GRAVELS
118	150	50% SAND&GRAVEL / 50% TAN CLAY LAYERS
150	198	50% SAND&GRAVEL/50%BROWN CLAY LAYERS
198	265	TAN, BLUE, BLACK CLAY WITH GRAVELS
265	280	SAND & GRAVELS
280	340	GREEN CLAY WITH GRAVEL STRINGERS
340	370	GREEN CLAY
370	420	SAND & GRAVEL W GREEN CLAY STRINGERS
420	440	SAND & GRAVEL
440	465	GREEN CLAY
465	530	SAND & GRAVEL W GREEN CLAY STRINGERS
530	545	50% GREEN CLAY / 50% SAND & GRAVEL
545	597	GREEN CLAY
597	598	COURSE SAND
598	600	GREEN CLAY
		CONTINUED CASING LAYOUT
281	301	BLANK PVC 8"
301	341	SCREEN PVC 8" .032 SLOT
341	371	BLANK PVC 8"
371	391	SCREEN PVC 8" .032 SLOT
391	411	BLANK PVC 8"
411	441	SCREEN PVC 8" .032 SLOT
441	461	BLANK PVC 8"
461	531	SCREEN PVC 8" .032 SLOT
531	551	BLANK PVC 8"

TOTAL DEPTH OF BORING 600 (Feet)

TOTAL DEPTH OF COMPLETED WELL 551 (Feet)

WELL OWNER

Name John Borg

Mailing Address 1296 Jensen Lane

Windsor CA 95492

CITY STATE ZIP

WELL LOCATION

Address 1296 Jensen Lane

City Windsor CA

County Sonoma

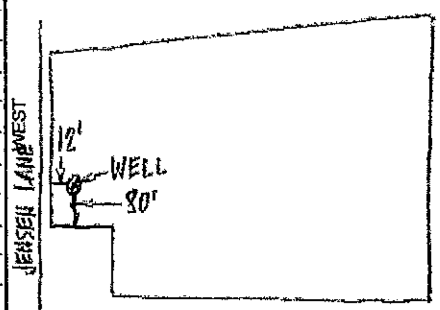
APN Book 162 Page 020 Parcel 066

Township ___ Range ___ Section ___

Latitude DEG. MIN. SEC. Longitude DEG. MIN. SEC.

LOCATION SKETCH

NORTH



WEST EAST

SOUTH

Illustrate or Describe Distance of Well from Roads, Buildings, Fences, Rivers, etc. and attach a map. Use additional paper if necessary. **PLEASE BE ACCURATE & COMPLETE.**

ACTIVITY (✓)

✓ NEW WELL

MODIFICATION/REPAIR
— Deepen
— Other (Specify)

— DESTROY (Describe Procedures and Materials Under "GEOLOGIC LOG")

PLANNED USES (✓)

WATER SUPPLY
✓ Domestic ___ Public
✓ Irrigation ___ Industrial

MONITORING ___
TEST WELL ___
CATHODIC PROTECTION ___
HEAT EXCHANGE ___
DIRECT PUSH ___
INJECTION ___
VAPOR EXTRACTION ___
SPARGING ___
REMEDIATION ___
OTHER (SPECIFY) ___

WATER LEVEL & YIELD OF COMPLETED WELL

1

DEPTH TO FIRST WATER N/A (Ft.) BELOW SURFACE

DEPTH OF STATIC WATER LEVEL 87 (Ft.) & DATE MEASURED 7/6/2017

ESTIMATED YIELD * 300 (GPM) & TEST TYPE AIR LIFT

TEST LENGTH 3 (Hrs.) TOTAL DRAWDOWN N/A (Ft.)

May not be representative of a well's long-term yield.

CASING (S)

DEPTH FROM SURFACE Ft.	to Ft.	BORE-HOLE DIA. (Inches)	BLANK	SCREEN	CON-DUCTOR	FILL PIPE	MATERIAL / GRADE	INTERNAL DIAMETER (Inches)	GAUGE OR WALL THICKNESS	SLOT SIZE IF ANY (Inches)
0	560	15								
560	600	12								
0	101		✓				PVC F480	8	SDR-21	
101	191			✓			PVC F480	8	SDR-21	.032
191	211		✓				PVC F480	8	SDR-21	
211	281			✓			PVC F480	8	SDR-21	.032

ANNULAR MATERIAL

DEPTH FROM SURFACE Ft.	to Ft.	CE-MENT (✓)	BEN-TONITE (✓)	FILL (✓)	FILTER PACK (TYPE/SIZE)
0	52	✓			10 SK SAND
52	560			✓	#6 SAND
560	600			✓	CUTTINGS

ATTACHMENTS (✓)

— Geologic Log
— Well Construction Diagram
— Geophysical Log(s)
— Soil/Water Chemical Analysis
— Other ___

ATTACH ADDITIONAL INFORMATION, IF IT EXISTS.

CERTIFICATION STATEMENT

I, the undersigned, certify that this report is complete and accurate to the best of my knowledge and belief.

NAME HUCKFELDT WELL DRILLING, INC.
(PERSON, FIRM, OR CORPORATION) (TYPED OR PRINTED)

2110 Penny Lane Napa CA 94559
ADDRESS CITY STATE ZIP

Signed [signature] 07/10/17 439-746
WELL DRILLER/AUTHORIZED REPRESENTATIVE DATE SIGNED C-57 LICENSE NUMBER

DWR 188 REV. 11-97

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

APPENDIX B

SONOMA COUNTY GROUNDWATER RECHARGE ANALYSIS

Sonoma 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 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.

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 Sonoma County. Hydrologically connected portions of Marin County, including the San Antonio Creek and Walker Creek watersheds, were also included in the model domain. This model operates on a daily timestep and calculates surface runoff based on the Natural Resources Conservation Service (NRCS) curve number method, actual evapotranspiration (AET), and recharge based on 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).

Model Development

The model was developed using a 1 arc-second (90.8-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 dataset derived from the Sonoma County Veg Map Lifeform dataset supplemented by the U.S. Forest Service (USFS) CALVEG dataset for portions of Marin County (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 a curve number, dormant and growing season interception storage values, and a rooting depth (Table 1). Curve numbers were assigned based on standard NRCS methods. Interception storage values and rooting depths were assigned based on literature values and

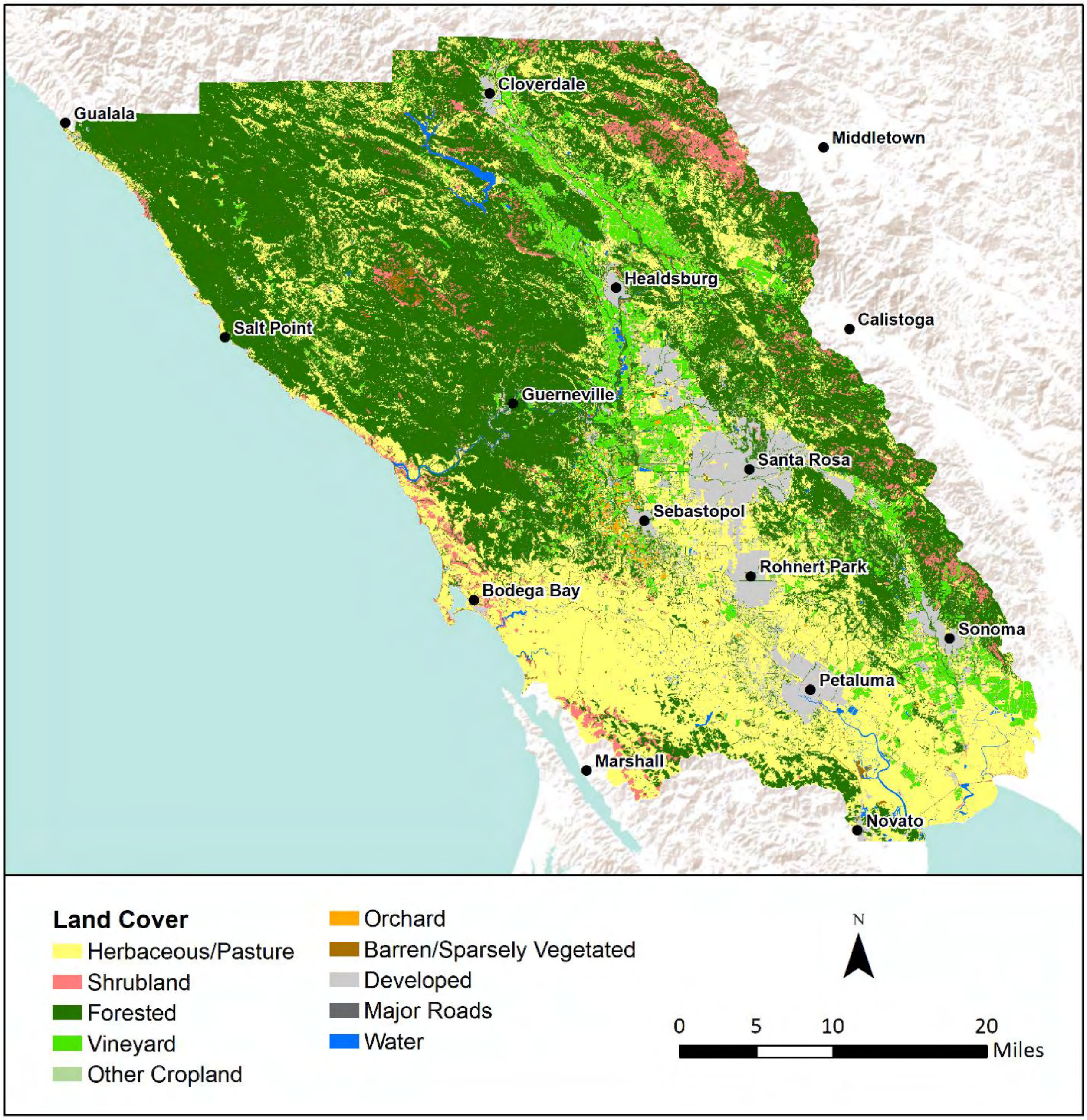


Figure 1: Land cover map used in the Sonoma County SWB model.

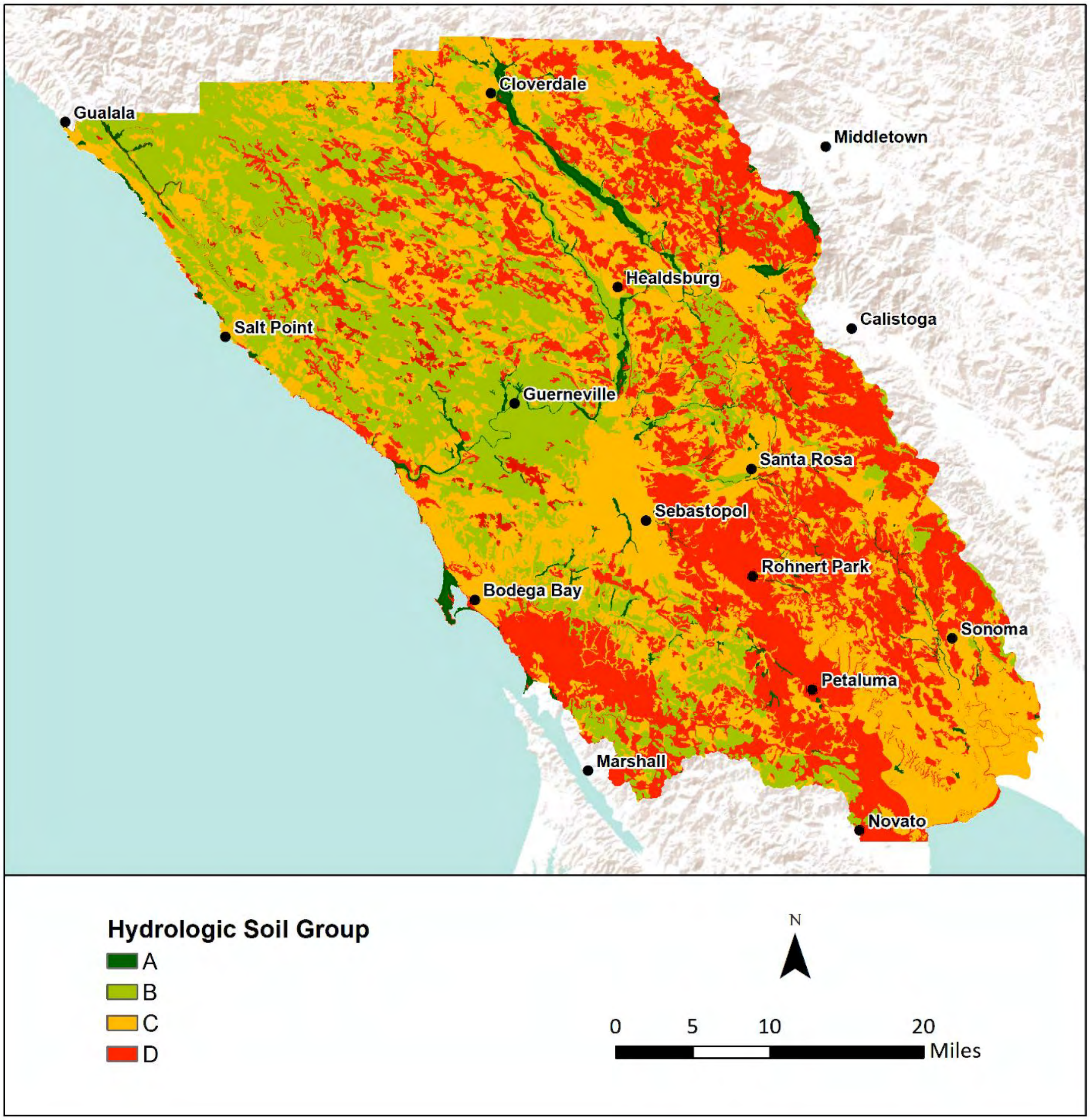


Figure 2: Hydrologic soil group map used in the Sonoma County SWB model.

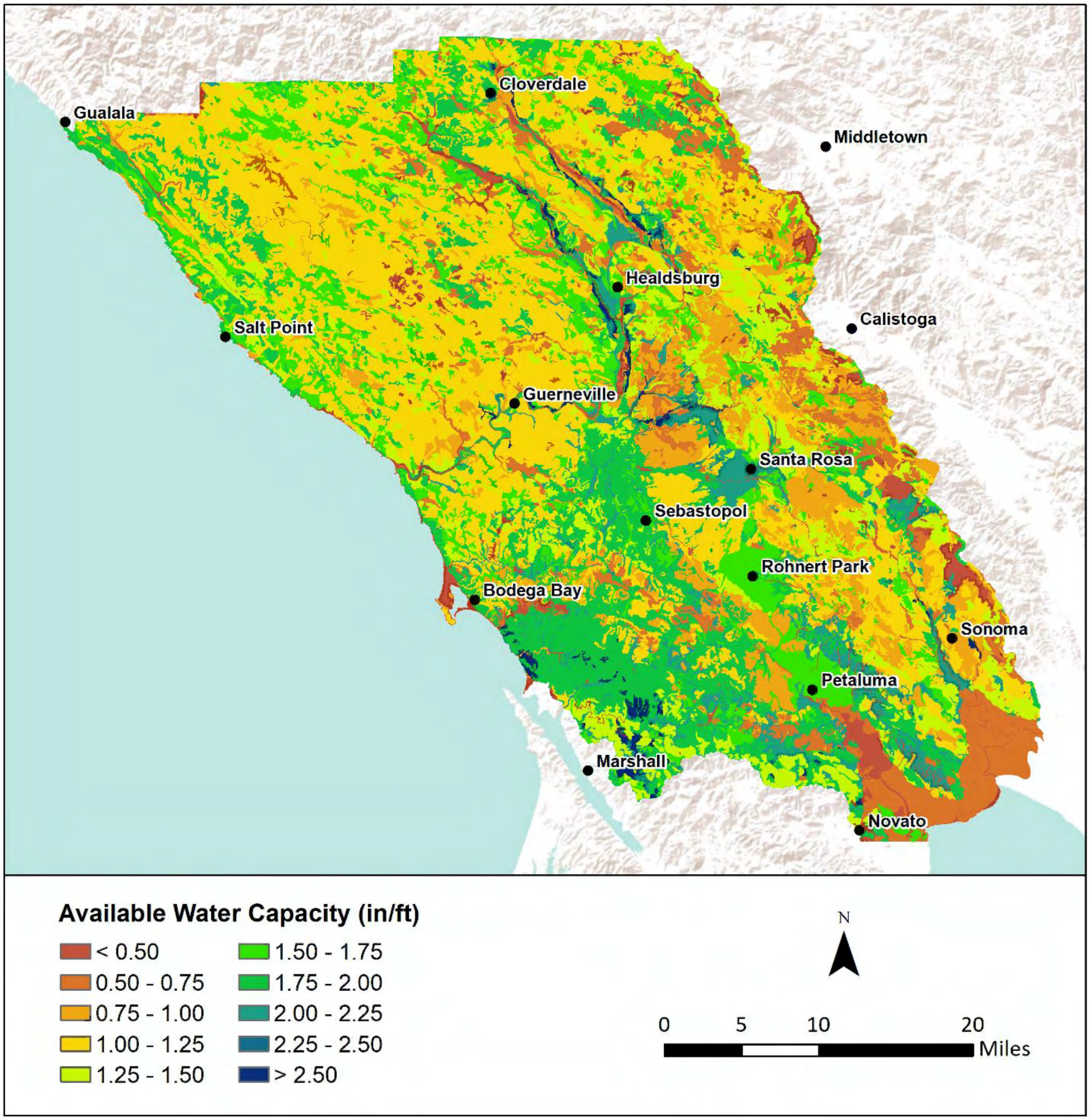


Figure 3: Available water capacity map used in the Sonoma County SWB model.

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

	Curve Number				Interception Storage Values		Rooting Depth (ft)			
Land Cover	**A Soils**	**B Soils**	**C Soils**	**D Soils**	**Growing Season**	**Dormant Season**	**A Soils**	**B Soils**	**C Soils**	**D Soils**
Herbaceous	30	58	71	78	0.005	0.004	1.3	1.1	1.0	1.0
Shrubland	30	48	65	73	0.080	0.015	3.2	2.8	2.7	2.6
Forested	30	55	70	77	0.050	0.020	5.9	5.1	4.9	4.7
Vineyard	38	61	75	81	0.080	0.015	2.2	2.1	2.0	1.9
Other Cropland	38	61	75	81	0.080	0.040	2.0	1.9	1.8	1.7
Orchard	38	61	75	81	0.050	0.015	3.2	2.8	2.7	2.6
Barren	77	86	91	94	0.000	0.000	0.7	0.6	0.5	0.4
Developed	61	75	83	87	0.005	0.002	2.3	2.1	2.0	1.8
Major Roads	77	85	90	92	0.005	0.002	0.7	0.6	0.5	0.4
Water	100	100	100	100	0.000	0.000	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

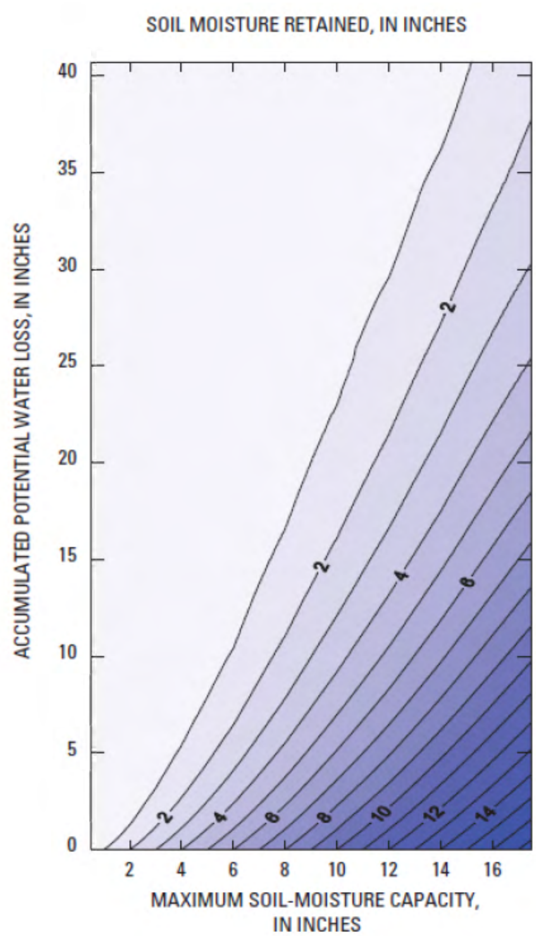


Figure 4: Soil-moisture-retention table (Thornthwaite and Mather, 1957).

previous modeling experience. 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).

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 time-series. The gridded precipitation time-series was created using data from 22 weather stations in Sonoma County, and the gridded mean temperature time-series was created using data from 10 stations (Table 3, Figures 5 & 6). These stations were selected based on completeness of the records and to provide station data across the range of climates experienced in the county. Temperature and precipitation data were obtained from the California Data Exchange Center (CDEC), the Western Regional Climate Center (WRCC), the National Climatic Data Center (NCDC), and data collected by O'Connor Environmental, Inc. from work on prior projects.

To create the gridded time-series, the model domain was divided into discrete areas represented by individual weather stations (Figures 7 and 8). This delineation was based on the USGS HUC-10 watersheds, local knowledge of climate variations across the county, and climate variations described by existing gridded mean annual (1981-2010) precipitation and temperature data (PRISM, 2010).

For the precipitation time-series, each area representing a weather station was subdivided into three to fifteen zones based on PRISM-derived 2-inch interval mean annual precipitation zones. The ratio of mean annual precipitation within a given zone and at a given gauge location was used to define scaling factors for each zone. The raw station data (daily precipitation) was then multiplied by the scaling factor to develop the final timeseries for each zone. The resulting gridded time-series is comprised of 215 individual time-series based on the scaled station data from the twenty-two stations.

The assignment of temperature stations was based on the understanding that the 10 available stations represent distinct climate zones in Sonoma County. Coastal climate conditions are best represented by the Fort Ross and Bodega Bay weather stations. The Occidental station is most representative of climate conditions in the coastal mountains of western Sonoma County, and the St. Helena station is most representative of conditions in the mountains of eastern Sonoma County. The remaining 6 stations all represent climate conditions in the inland valley bottom areas of the county. The temperature areas were not divided into additional zones for scaling because variations in temperatures within each representative area are expected to be relatively minor compared with the variations in precipitation; also the model sensitivity to temperature is expected to be small compared to the sensitivity to precipitation.

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 outlying observations were not observed at nearby stations were removed from the datasets. These and missing values were filled using scaled data from other nearby stations. Precipitation data 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 a Water Year 2010 (October 1, 2009 – September 30, 2010). This year was selected because it represents a recent year with data available from most weather stations in the county, and the total annual rainfall was near long-term average conditions at most of the weather stations. Water year 2010 rainfall ranged from 83% of long-term average conditions at the Sonoma and Petaluma 10.1 W station to 137% at the Fort Ross station based on a comparison between the station data and the 1981-2010 average precipitation from PRISM (2010) (Table 3).

Table 3: Weather stations used in the Sonoma County SWB model.

Climate Zone	Station	Data Source	Data Used	1981 - 2010 Mean Annual Precip (in)	WY 2010 Precip (in)	WY 2010 Precip (% Avg.)
Coastal	Bodega Bay 6 WSW	NOAA accessed via NCDC	Precip. & Temp.	34.06	37.11	109%
	Fort Ross	NOAA accessed via WRCC	Precip. & Temp.	35.10	48.01	137%
Western Mountains	Francini Creek	OEI Project Data	Precip. Only	46.99	59.71	127%
	Geyserville 10.6 WNW	NOAA accessed via NCDC	Precip. Only	52.34	52.97	101%
	Monte Rio	NOAA accessed via NCDC	Precip. Only	48.44	51.01	105%
	Occidental	NOAA accessed via WRCC	Precip. & Temp.	55.37	57.02	103%
	Petaluma 10.1 W	NOAA accessed via NCDC	Precip. Only	37.90	31.57	83%
	SF Fuller Creek	OEI Project Data	Precip. Only	56.49	60.89	108%
	Venado	CA DWR accessed via CDEC	Precip. Only	60.14	66.01	110%
Valleys	Cloverdale	NOAA accessed via WRCC	Precip. & Temp.	42.63	52.65	123%
	Glen Ellen 1.5 N	NOAA accessed via NCDC	Precip. Only	36.14	46.74	129%
	Graton	NOAA from WRCC	Precip. & Temp.	41.07	45.00	110%
	Healdsburg	NOAA accessed via WRCC	Precip. Only	40.95	47.65	116%
	Petaluma River Airport	NOAA accessed via WRCC	Precip. & Temp.	26.60	26.92	101%
	Rohnert Park 0.9 SW	NOAA accessed via NCDC	Precip. Only	33.36	34.73	104%
	Santa Rosa	CAL Fire accessed via CDEC	Precip. & Temp.	31.90	39.55	124%
	Sonoma	NOAA accessed via WRCC	Precip. & Temp.	31.77	26.35	83%
	Calistoga	NOAA accessed via WRCC	Temp. Only	na	na	na
	Warm Springs Dam	USACE accessed via CDEC	Precip. Only	43.44	53.29	123%
Eastern Mountains	Calistoga 4.6 WSW	NOAA accessed via NCDC	Precip. Only	39.64	44.85	113%
	Glen Ellen 1.9 WNW	NOAA accessed via NCDC	Precip. Only	49.16	46.32	94%
	Hawkeye	NOAA accessed via WRCC	Precip. Only	45.57	51.06	112%
	St. Helena 4 WSW	CA DWR accessed via CDEC	Precip. & Temp.	49.12	47.88	97%

Notes: NOAA – National Oceanic and Atmospheric Administration; CA DWR – California Department of Water Resources NCDC- National Climate Data Center; USACE – United States Army Corps of Engineers; WRCC – Western Regional Climate Center; CDEC – California Data Exchange Center

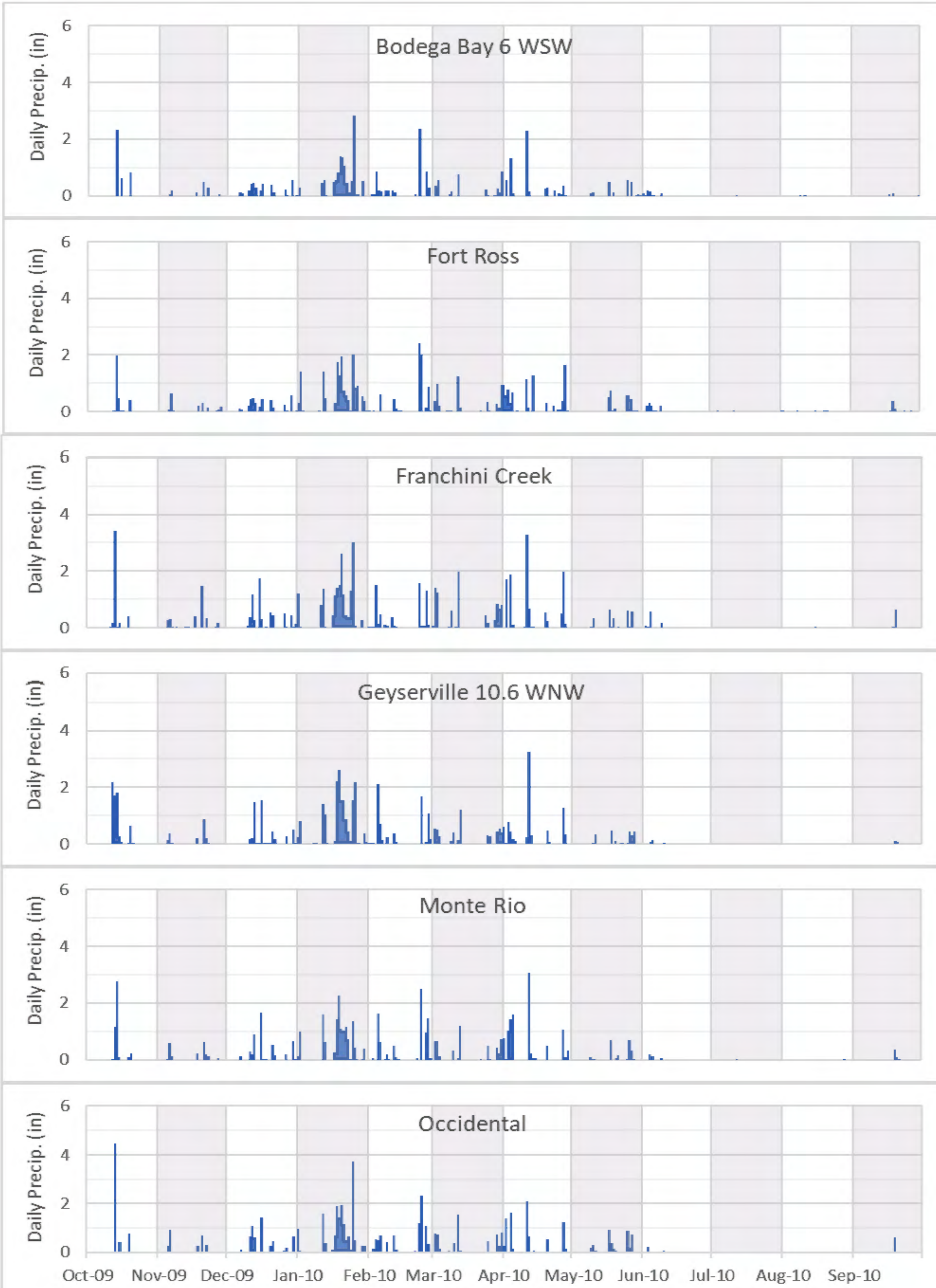


Figure 5: Daily precipitation data used in the Sonoma County SWB model.

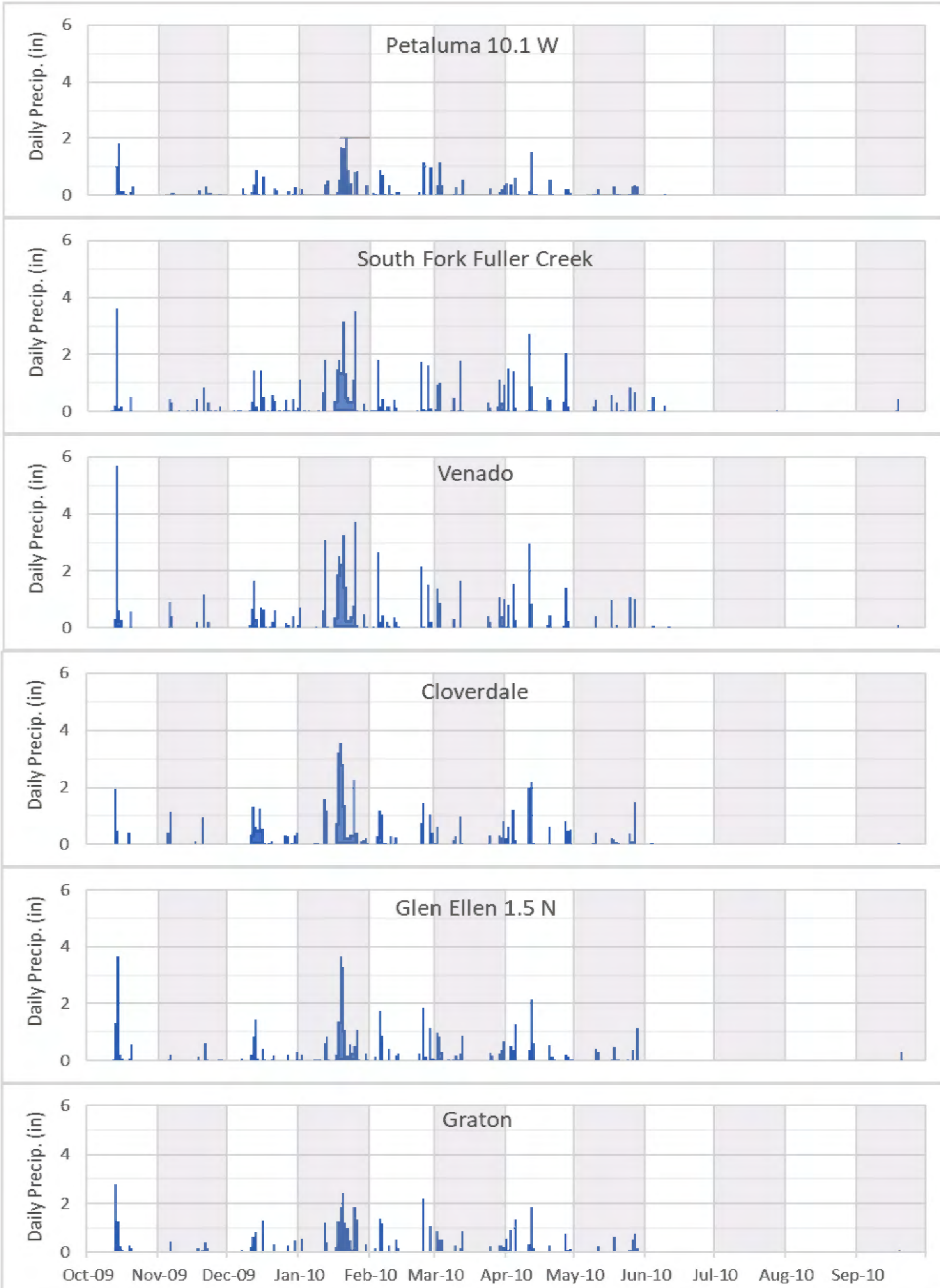


Figure 5 (continued)

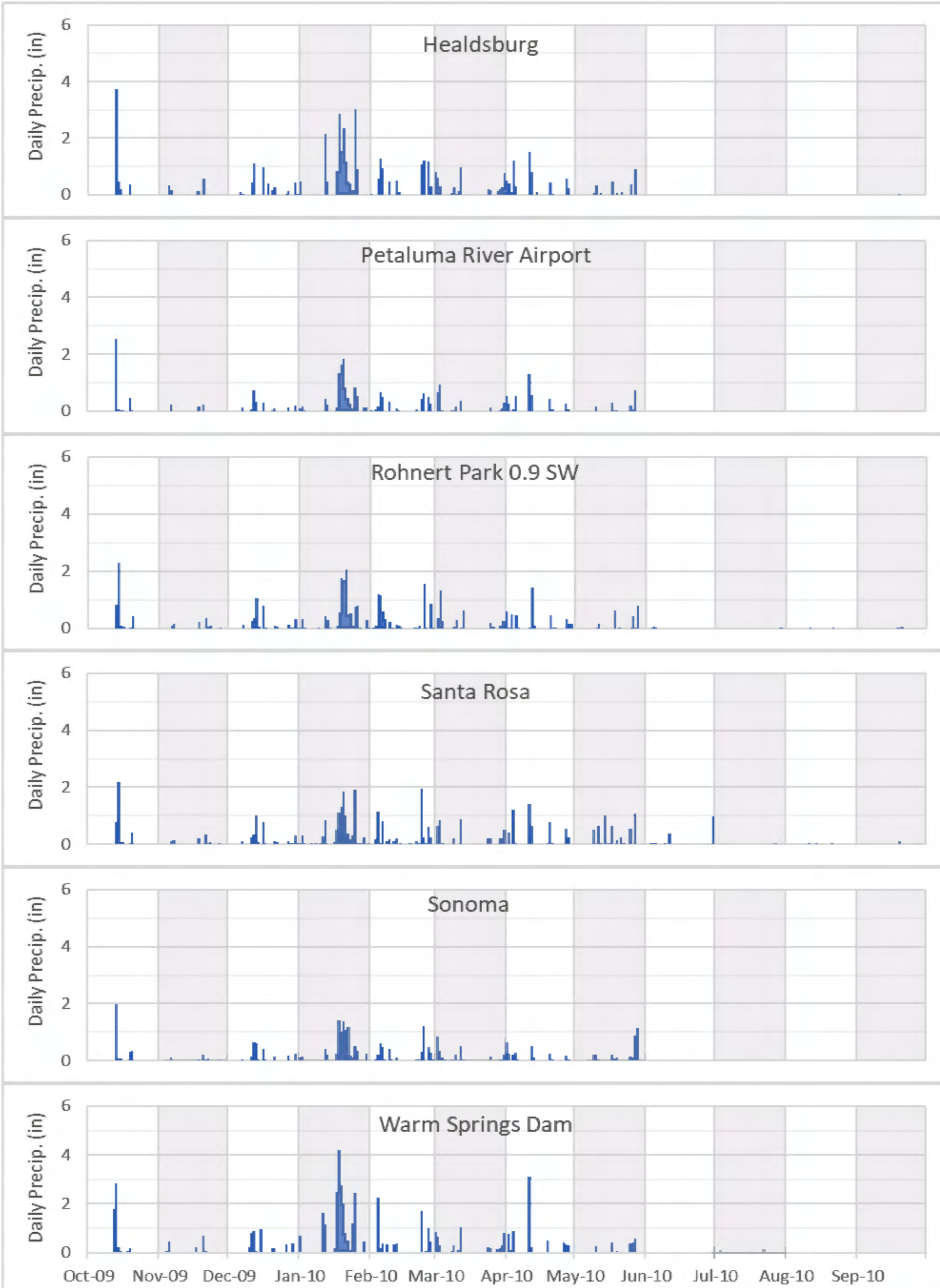
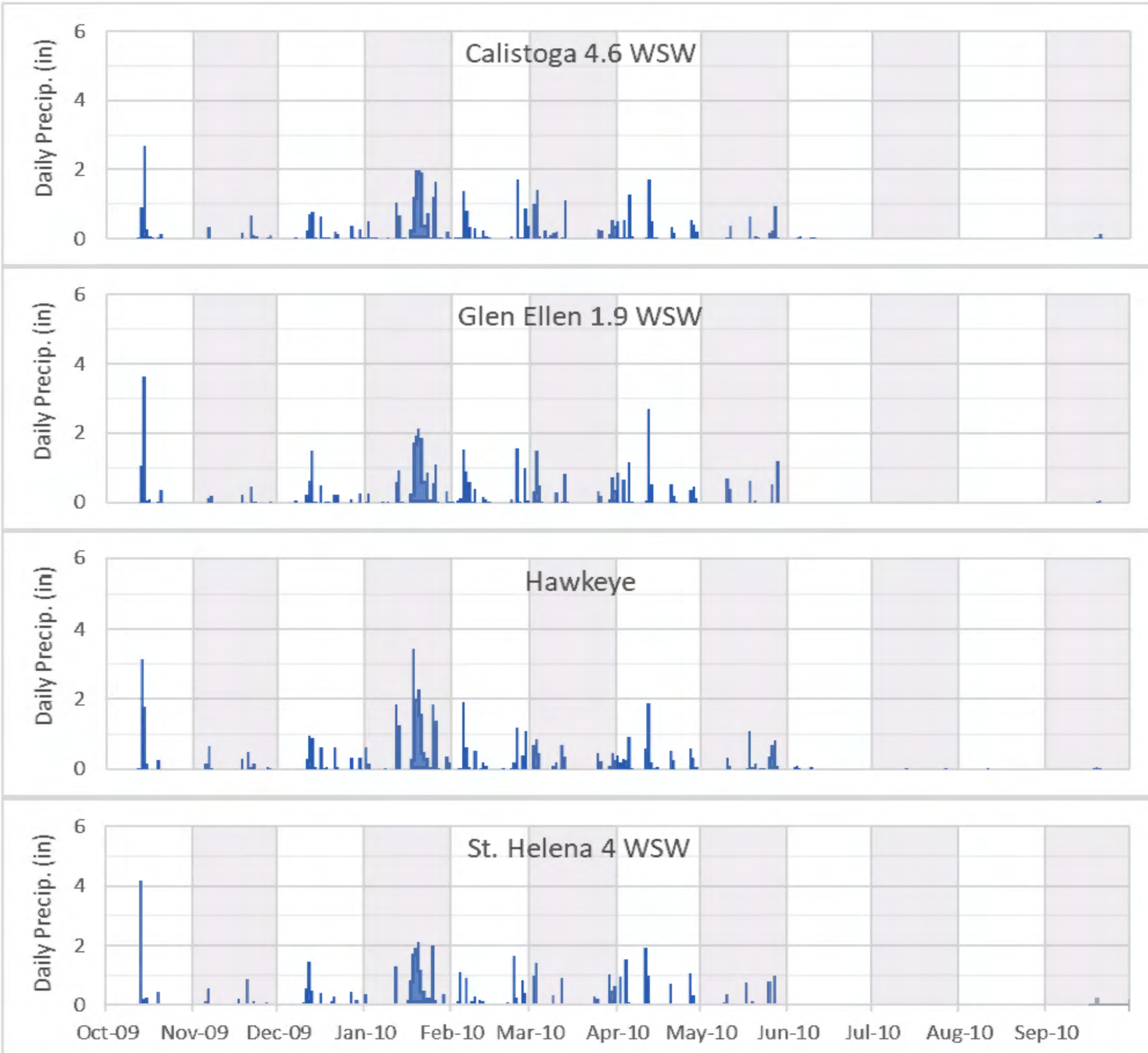


Figure 5 (continued)



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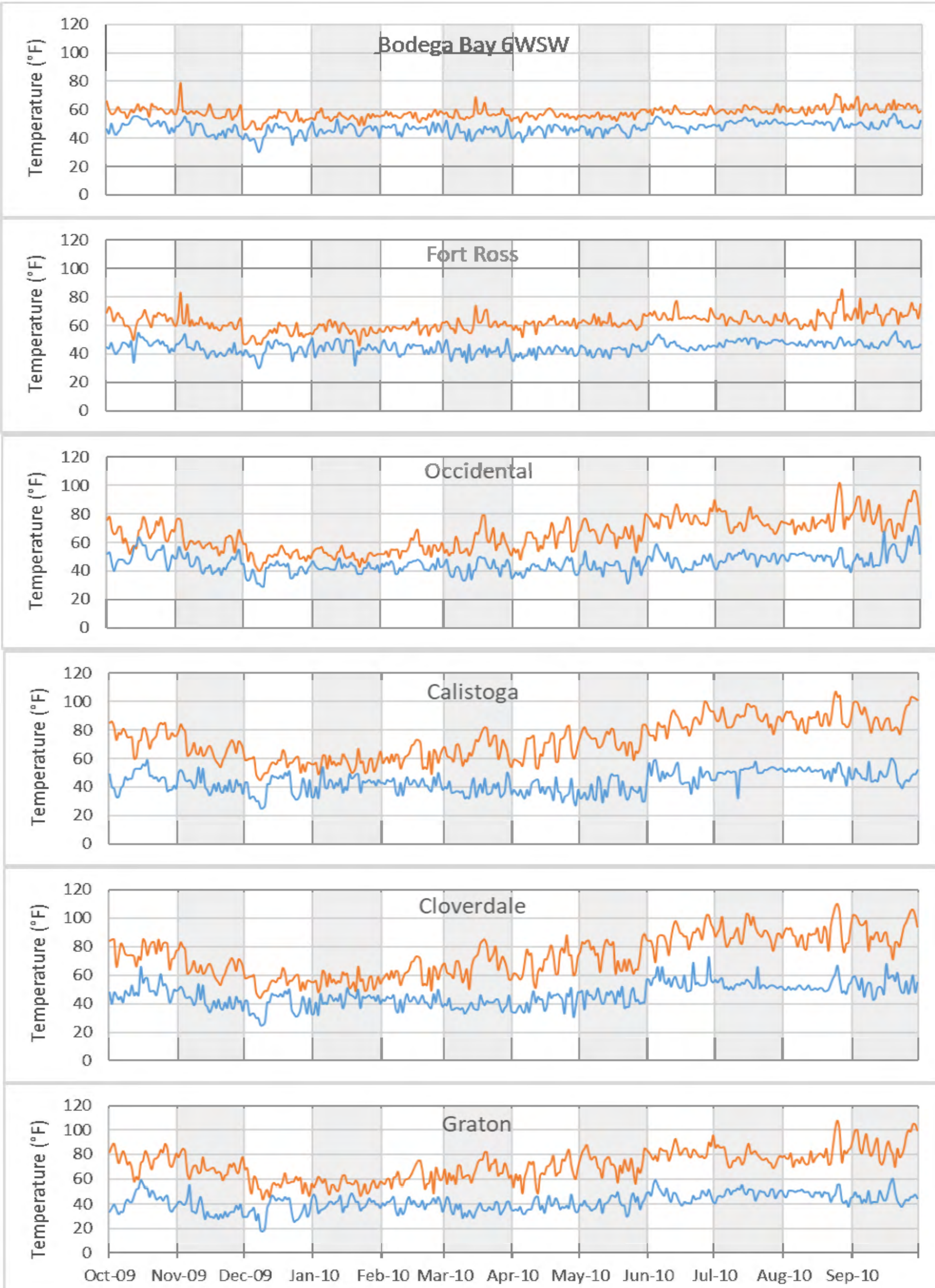
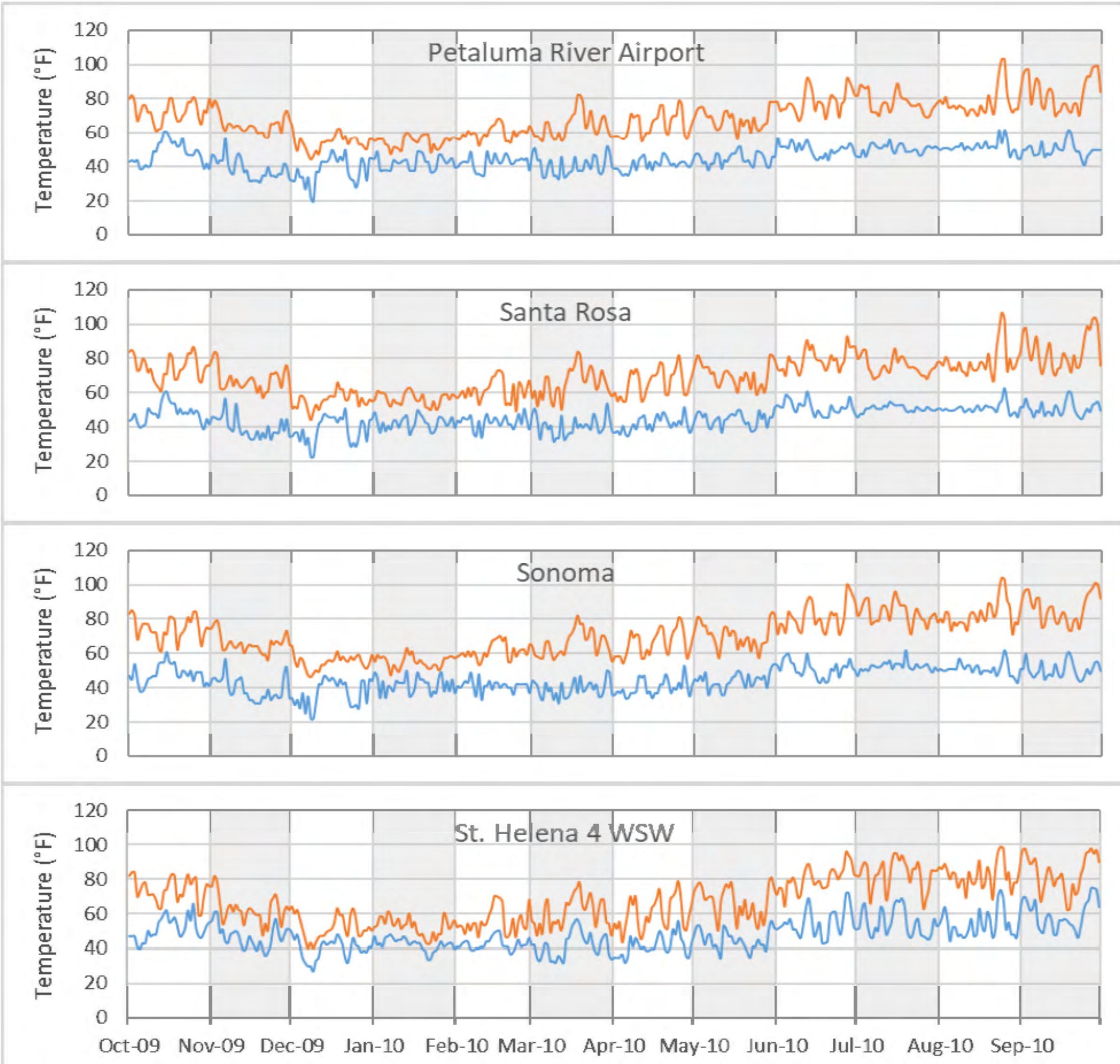


Figure 6: Daily minimum and maximum temperature data used in the Sonoma County SWB model.



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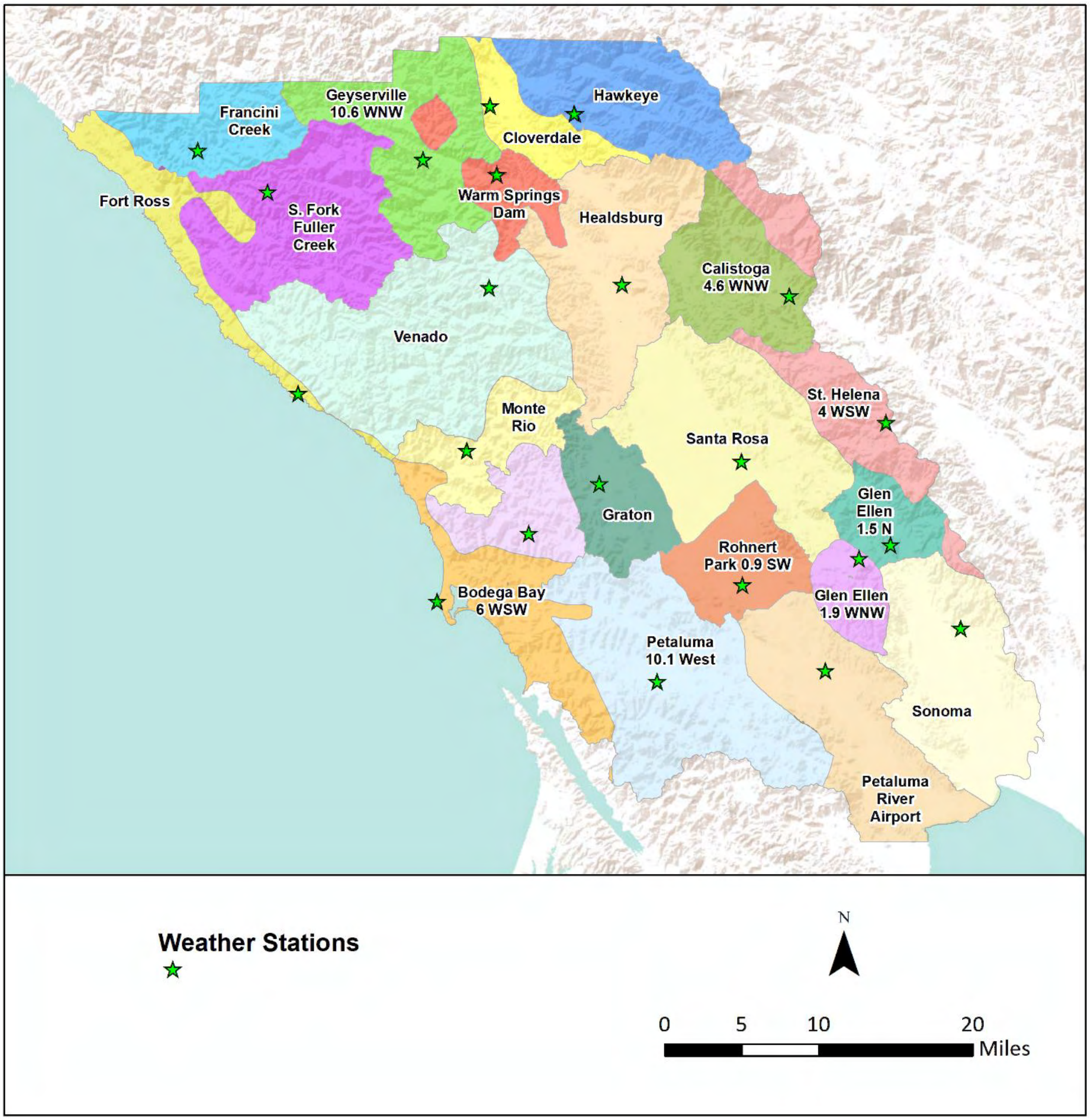


Figure 7: Precipitation zones used in the Sonoma County SWB model.

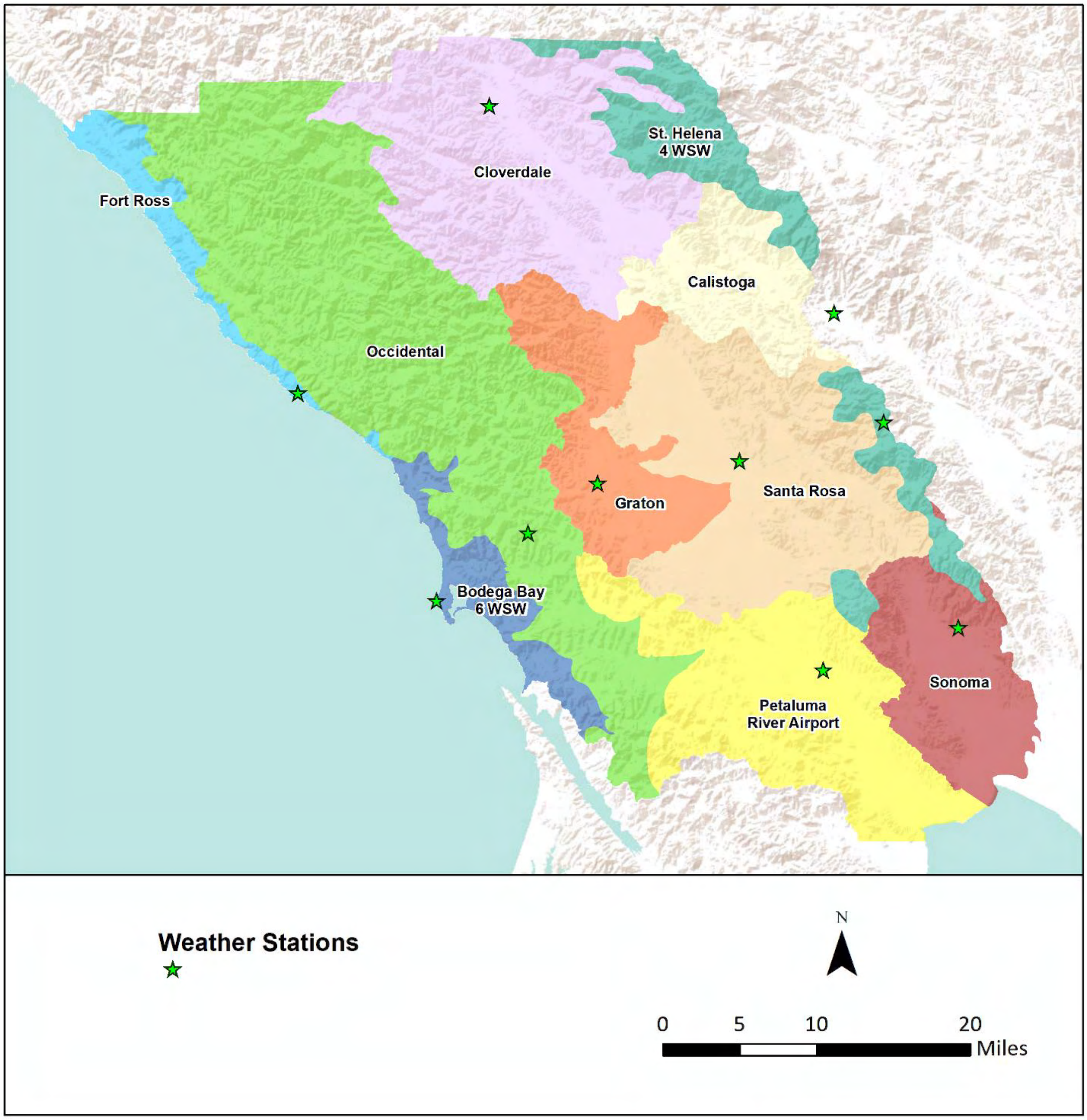


Figure 8: Temperature zones used in the Sonoma County SWB model.

Model Calibration

To provide a means of calibrating the Sonoma County SWB model, streamflow data was compiled from five gauges with available data for water year 2010 (Figure 9, Table 4). These gauges were selected because they represent relatively small watersheds 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. An overview of hydrograph separation methods may be found in Healy (2010, pp. 85-90).

We utilized the web-based Hydrograph Analysis Tool (Lim et al., 2005) to perform baseflow separations on the gauge records using the recursive digital filter method (Eckahardt, 2005) and default filter parameters for perennial streams with hard rock aquifers. Total monthly surface runoff volumes were compiled for each gauge and compared to the mean monthly surface runoff volumes predicted by SWB within each corresponding watershed area. 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 frames. The use of the total monthly surface runoff volumes provides a means of calibrating the model to measured surface runoff data within the limitations of the model's routing scheme.

The model successfully reproduced the seasonal variations in surface runoff at all five gauge locations (Figure 10). Monthly Mean Errors (ME) ranged from -0.2 to 0.4 inches with a mean value of 0.1 inches (Table 5). Monthly Root Mean Square Errors (RMSE) ranged from 0.5 to 1.5 inches with a mean value of 1.0 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 stations (Table 5). 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.

Table 4: Overview of the streamflow gauges used for calibrating the Sonoma County SWB model.

	Operated By	Drainage Area (mi^2)	Period of Record
Sonoma Creek at Kenwood, CA (#11458433)	USGS	14.3	Oct 2008 - present
Buckeye Creek	OEI	3.1	Dec 2005 - Sept. 2012
Franchini Creek	OEI	1.8	Dec 2005 - Sept. 2012
South Fork Fuller Creek	OEI	1.2	Mar 2006 - Sept. 2012
Soda Springs Creek	OEI	1.5	Dec 2005 - Sept. 2012

Notes: USGS - U.S. Geological Survey, OEI - O'Connor Environmental, Inc.

Table 5: Calibration statistics for the Sonoma County SWB model calibration.

	Annual Simulated Surface Runoff (in)	Annual Observed Surface Runoff (in)	Annual PE	Monthly ME (in)	Monthly RMSE (in)
Sonoma Creek	12.7	11.7	8.1%	0.1	0.6
Buckeye Creek	31.6	26.5	19.2%	0.4	1.2
Franchini Creek	22.1	24.5	-9.6%	-0.2	1.0
South Fork Fuller Creek	24.1	21.9	10.2%	0.2	1.5
Soda Springs Creek	24.2	24.1	0.6%	0.0	0.5
MEAN	**23.0**	**21.7**	**5.7%**	**0.1**	**1.0**

Notes: PE - Percent Error, ME - Mean Error, RMSE – Root Mean Square Error

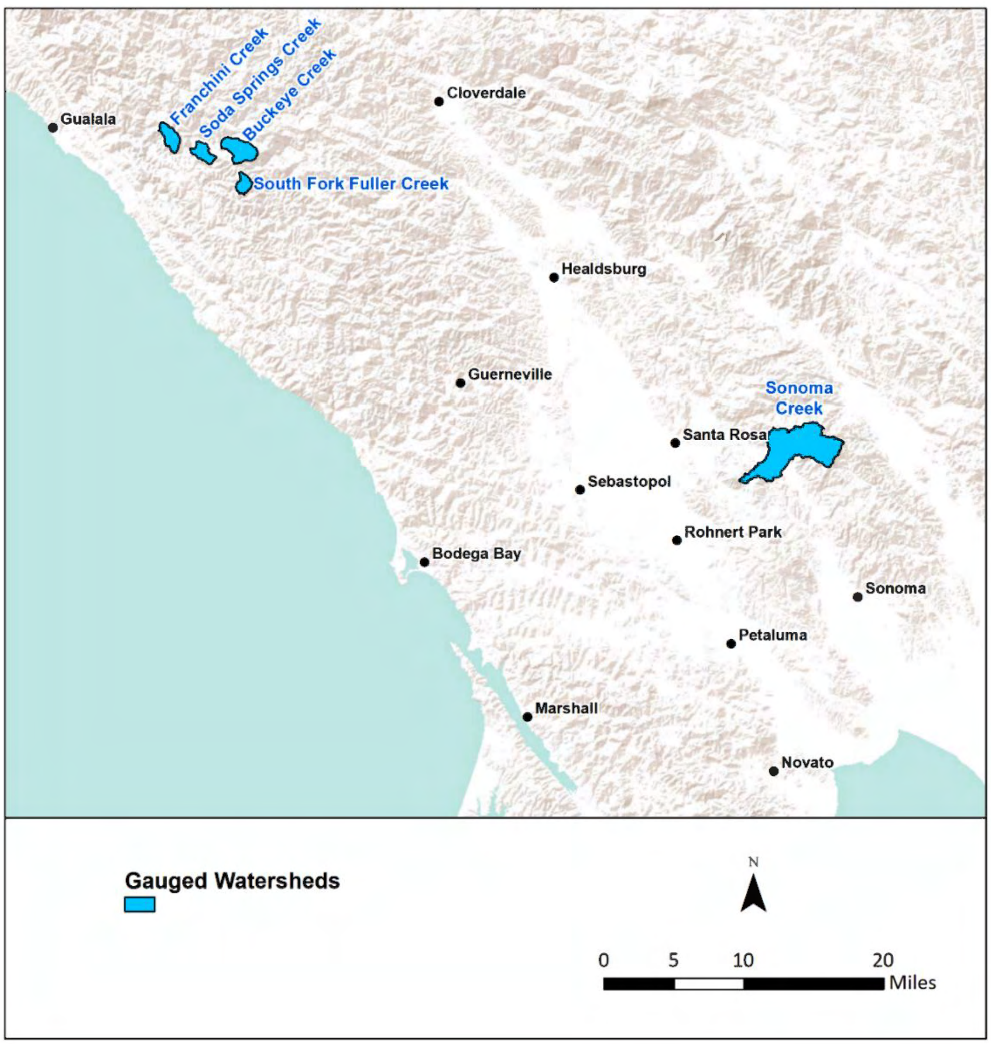
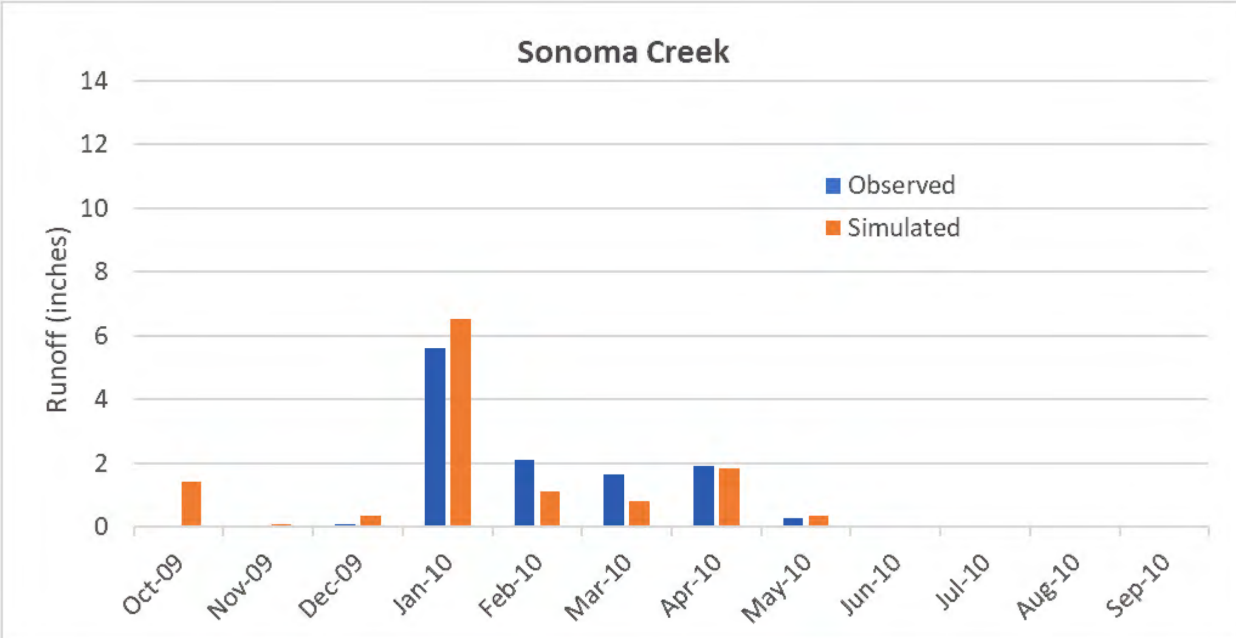


Figure 9: Gauged watersheds used to calibrate the Sonoma County SWB model.



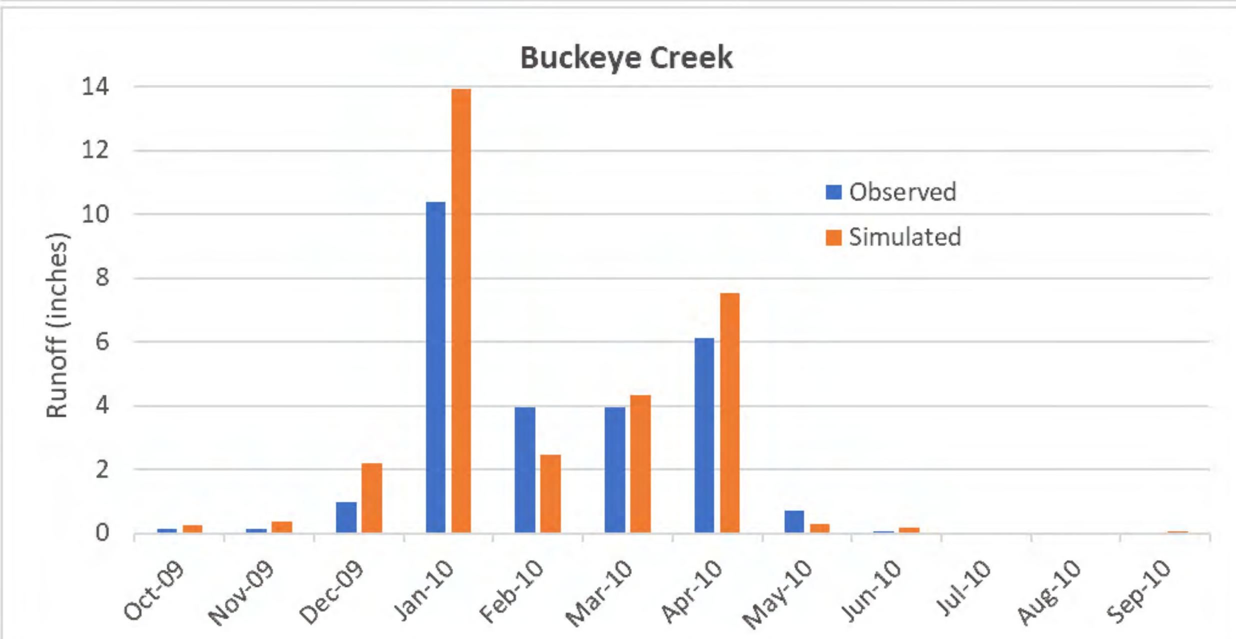


Figure 10: Comparison between monthly surface runoff computed from hydrograph separation at streamflow gauges and monthly surface runoff simulated with the Sonoma County SWB model.

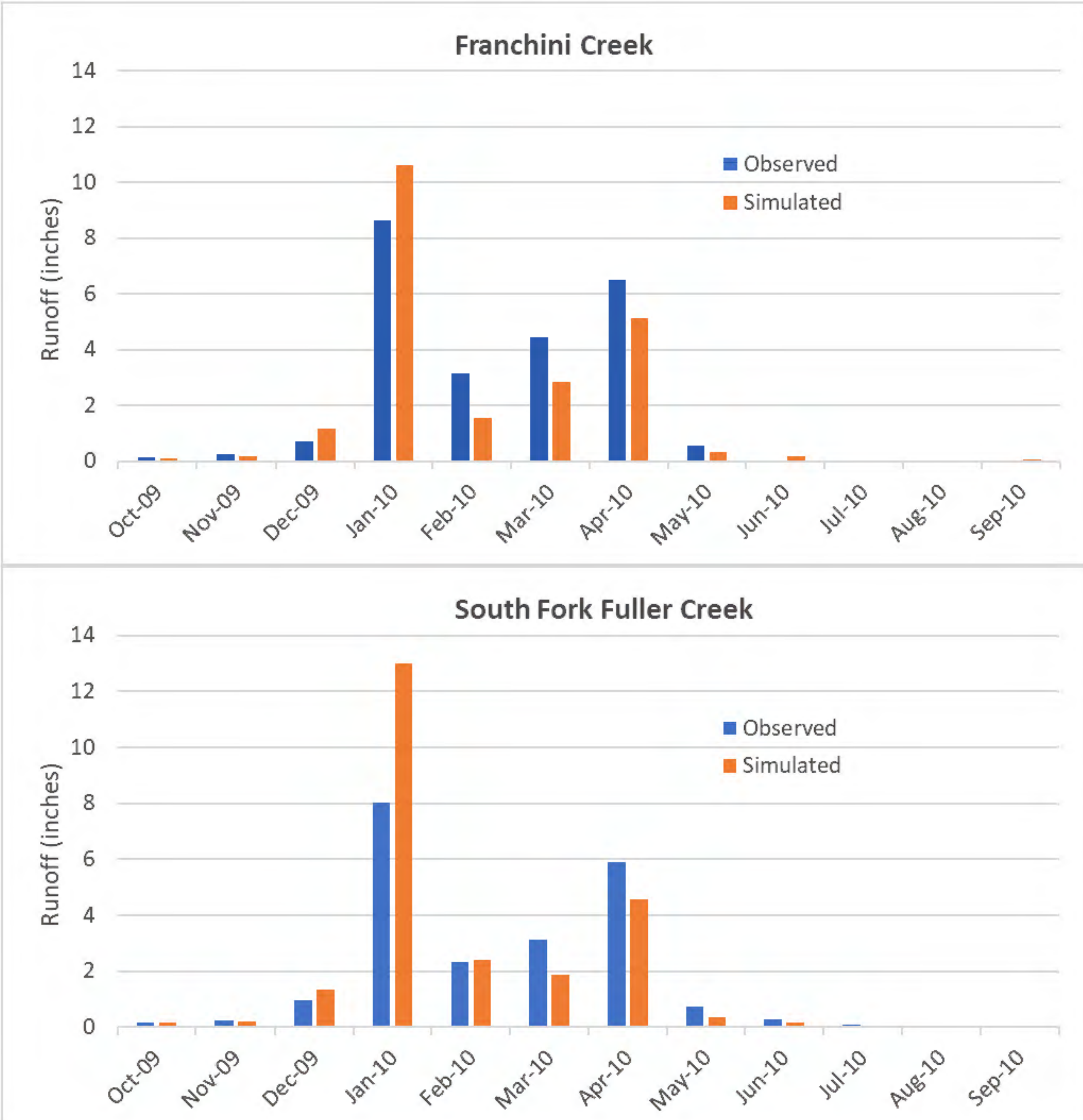


Figure 10 (continued)

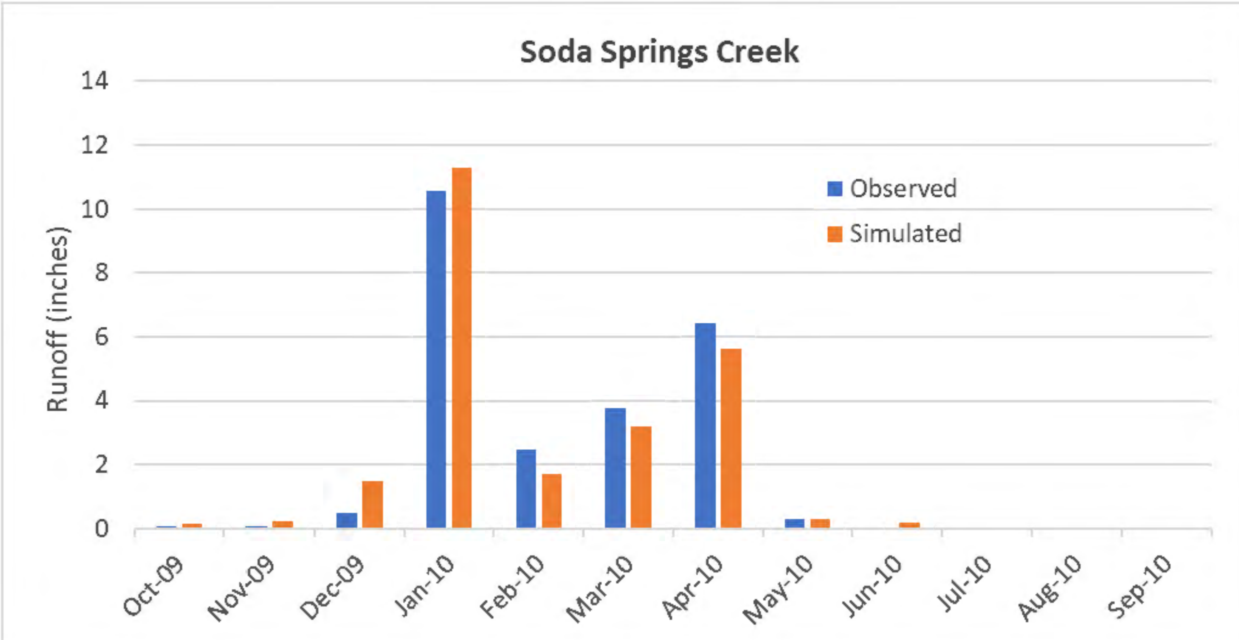


Figure 10 (continued)

Model Results

The principal elements of the annual water budget simulated with the Sonoma County SWB model for water year 2010 are shown in map form in Figures 12 through 16 and in tabular form (sorted by total annual precipitation) for 23 major watershed areas in the county in Table 6. The watersheds areas are a modified version of the USGS HUC-10 watersheds and are named for the stream which comprises the largest proportion of the area; although in many cases the areas consist of multiple tributary streams (Figure 11).

Water year 2010 precipitation varied from 26.1 inches in the Lower Sonoma Creek watershed to 70.7 inches in the Austin Creek watershed (Table 6, Figure 12). Actual evapotranspiration (AET) ranged from 17.9 inches in the San Antonio Creek watershed to 29.5 inches in the Pena Creek watershed (Table 6, Figure 13). Surface runoff ranged from 4.0 inches in the Lower Sonoma Creek watershed to 28.1 inches in the Austin Creek watershed (Table 6, Figure 14). Recharge ranged from 5.0 inches in the Lower Sonoma Creek watershed to 16.4 inches in the Austin Creek watershed (Table 6, Figure 15). Small decreases in soil moisture storage (up to 0.8 inches) occurred in 16 of the 23 watersheds and small increases (up to 0.8 inches) occurred in the remaining watersheds (Table 6, Figure 16).

When expressed as a percentage of the annual precipitation, AET ranged from 37% in the Austin Creek watershed to 69% in the Lower Sonoma Creek watershed (Table 7). Surface runoff ranged from 15% of precipitation in the Lower Sonoma Creek watershed to 40% in the Austin Creek watershed. The variations in recharge as a percentage of precipitation is relatively narrow ranging from 19% in the Lower Sonoma Creek watershed to 27% in the Salmon Creek watershed (Table 7).

Table 6: Water budgets simulated with the Sonoma County SWB model for water year 2010 (see Figure 11 for locations).

Watershed	Drainage Area (sq. mi.)	Precipitation (in)	AET (in)	Surface Runoff (in)	Recharge (in)	Soil Moisture Change (in)
Lower Sonoma Creek	120	26.1	18.0	4.0	5.0	-0.8
San Antonio Creek	79	29.6	17.9	6.0	6.4	-0.7
Petaluma River	76	31.4	19.3	5.9	6.9	-0.7
Chileno Creek	145	33.3	19.1	7.0	7.9	-0.6
Upper Laguna De Santa Rosa	62	36.2	21.6	8.0	7.5	-0.8
Mark West Creek	161	43.3	26.6	8.7	8.5	-0.5
Lower Laguna De Santa Rosa	31	43.6	25.8	9.6	9.0	-0.8
Upper Sonoma Creek	45	46.4	24.1	13.4	9.4	-0.4
Sausal Creek	46	47.8	24.3	13.4	10.8	-0.8
Maacama Creek	97	47.9	25.4	12.6	10.6	-0.7
Salmon Creek	53	48.7	22.3	13.2	13.1	0.2
Atascadero Creek	38	50.2	28.1	12.7	10.0	-0.6
Big Sulphur Creek	130	52.6	26.2	16.5	10.5	-0.5
Lower Dry Creek	42	53.5	26.4	17.2	10.7	-0.7
Willow Creek	24	53.9	22.8	18.2	12.7	0.2
Mill Creek	53	55.4	27.7	17.1	11.3	-0.6
Upper Dry Creek	89	57.4	27.0	20.0	10.9	-0.5
Dutch Bill Creek	55	57.7	25.2	18.6	13.7	0.1
Wheatfield Fork Gualala River	145	61.4	26.0	20.9	14.0	0.5
Pena Creek	23	63.0	29.5	21.6	12.5	-0.5
Buckeye Creek	60	65.7	26.4	24.0	14.4	0.8
South Fork Gualala River	65	68.2	25.7	26.2	16.1	0.1
Austin Creek	70	70.7	26.1	28.1	16.4	0.0

Table 7: Water budgets simulated with the Sonoma County SWB model for water year 2010 expressed as a percentage of annual precipitation (see Figure 11 for locations).

Watershed	Drainage Area (sq. mi.)	Precipitation (in)	AET (%)	Surface Runoff (%)	Recharge (%)
Lower Sonoma Creek	120	26.1	69%	15%	19%
San Antonio Creek	79	29.6	60%	20%	22%
Petaluma River	76	31.4	62%	19%	22%
Chileno Creek	145	33.3	57%	21%	24%
Upper Laguna De Santa Rosa	62	36.2	59%	22%	21%
Mark West Creek	161	43.3	61%	20%	20%
Lower Laguna De Santa Rosa	31	43.6	59%	22%	21%
Upper Sonoma Creek	45	46.4	52%	29%	20%
Sausal Creek	46	47.8	51%	28%	23%
Maacama Creek	97	47.9	53%	26%	22%
Salmon Creek	53	48.7	46%	27%	27%
Atascadero Creek	38	50.2	56%	25%	20%
Big Sulphur Creek	130	52.6	50%	31%	20%
Lower Dry Creek	42	53.5	49%	32%	20%
Willow Creek	24	53.9	42%	34%	24%
Mill Creek	53	55.4	50%	31%	20%
Upper Dry Creek	89	57.4	47%	35%	19%
Dutch Bill Creek	55	57.7	44%	32%	24%
Wheatfield Fork Gualala River	145	61.4	42%	34%	23%
Pena Creek	23	63.0	47%	34%	20%
Buckeye Creek	60	65.7	40%	37%	22%
South Fork Gualala River	65	68.2	38%	38%	24%
Austin Creek	70	70.7	37%	40%	23%

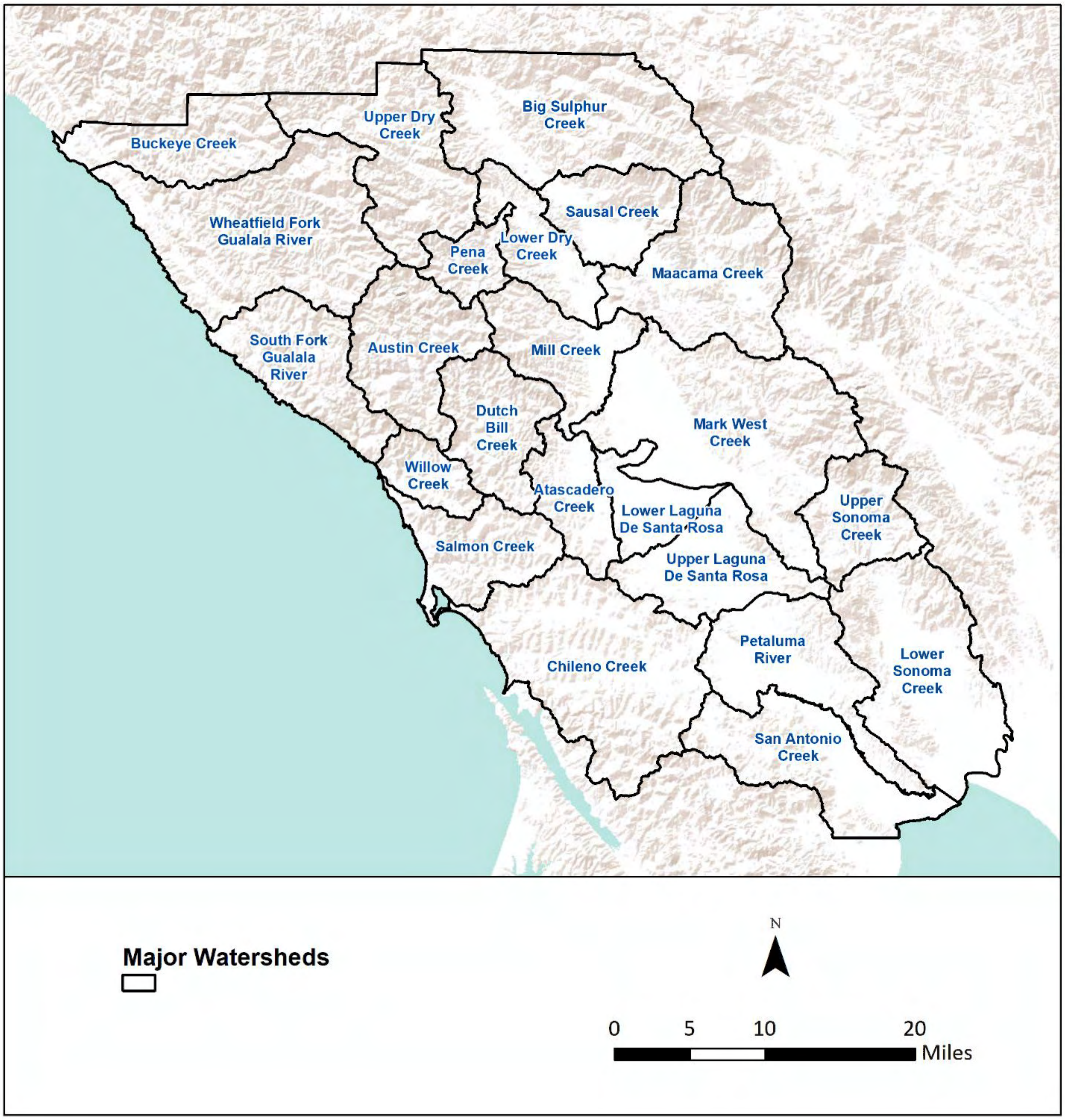


Figure 11: Major watersheds areas used to summarize water budget information in Tables 6 & 7).

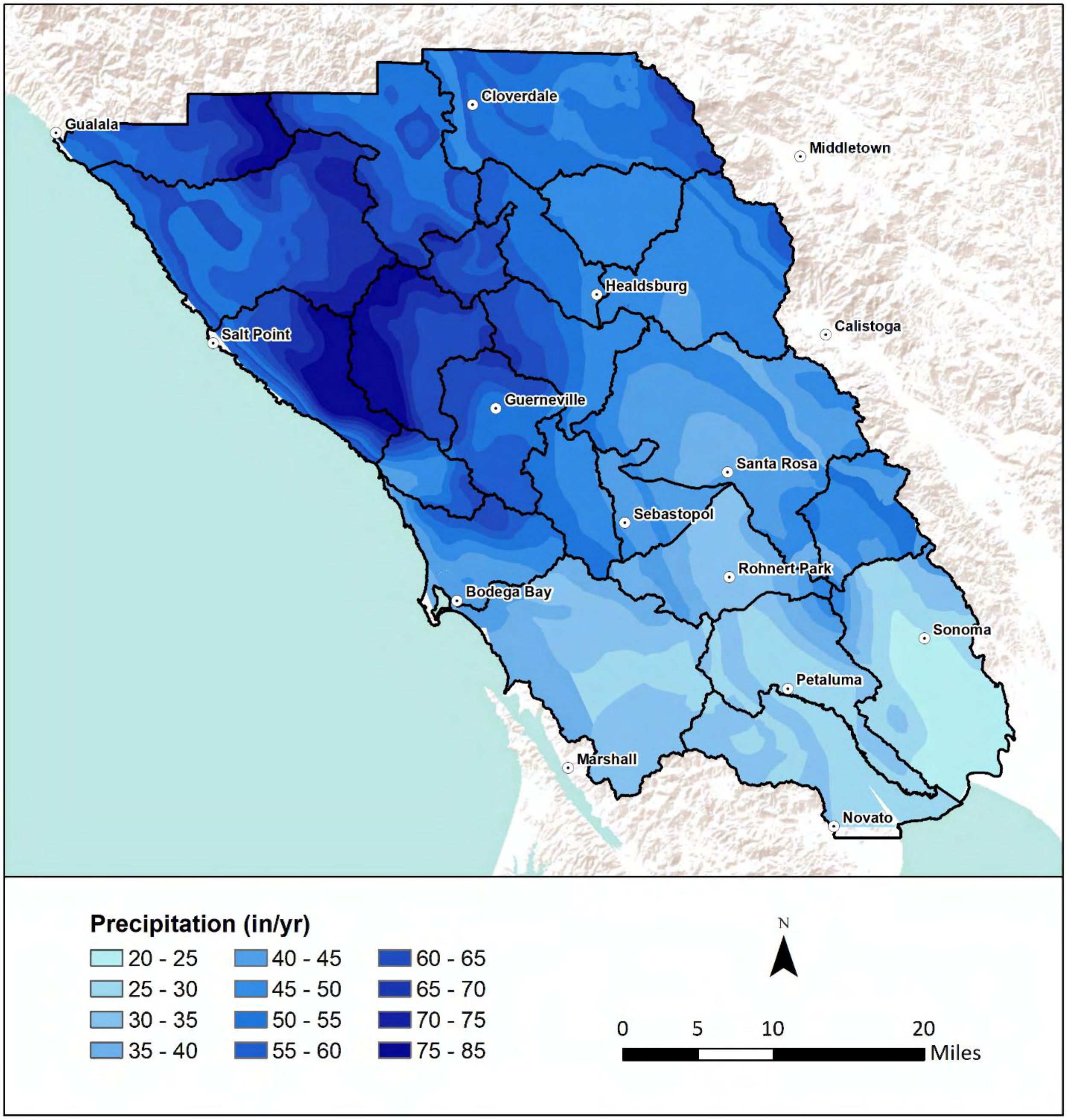


Figure 12: Water year 2010 Precipitation simulated with the Sonoma County SWB model.

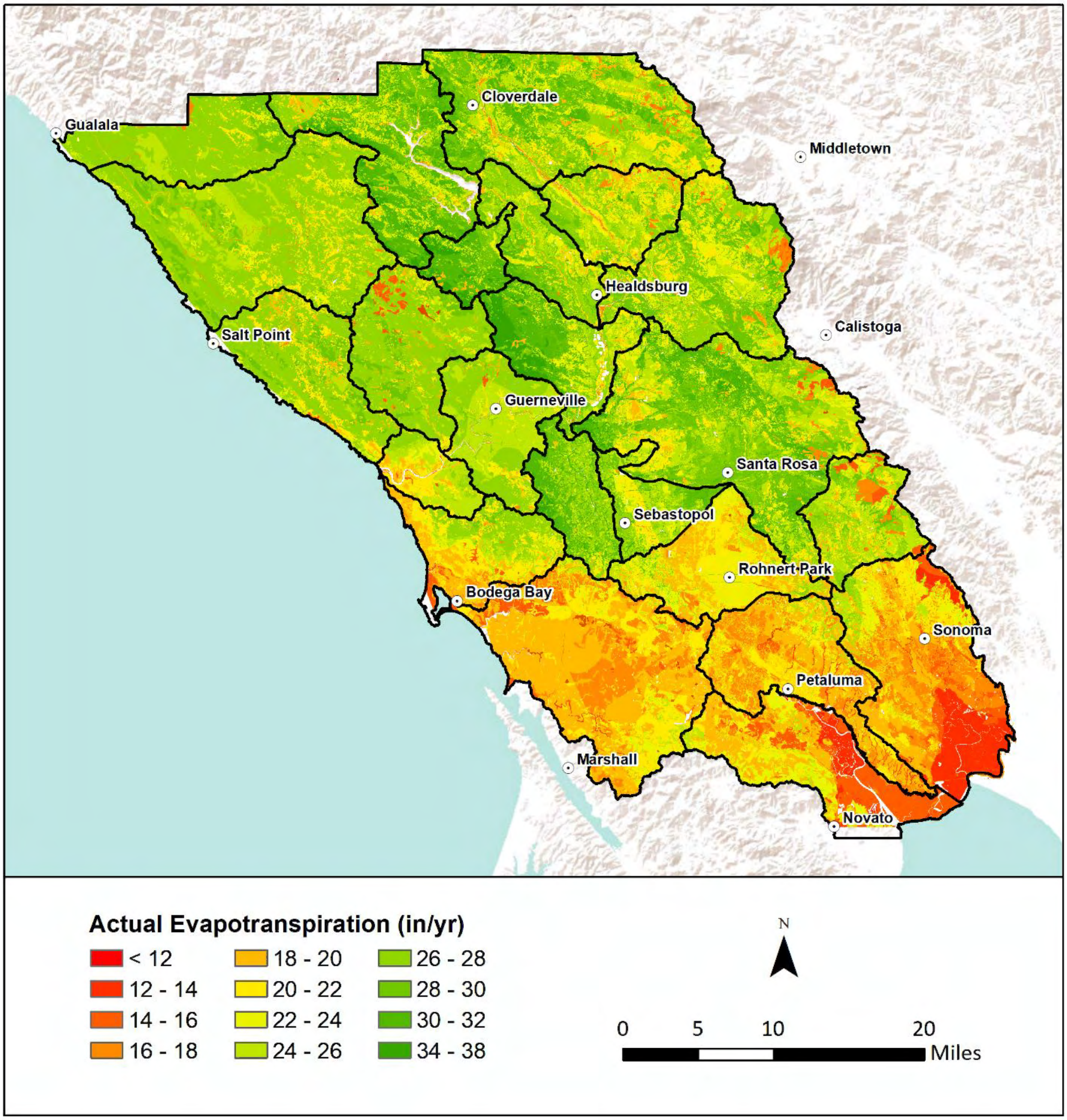


Figure 13: Water year 2010 Actual Evapotranspiration (AET) simulated with the Sonoma County SWB model.

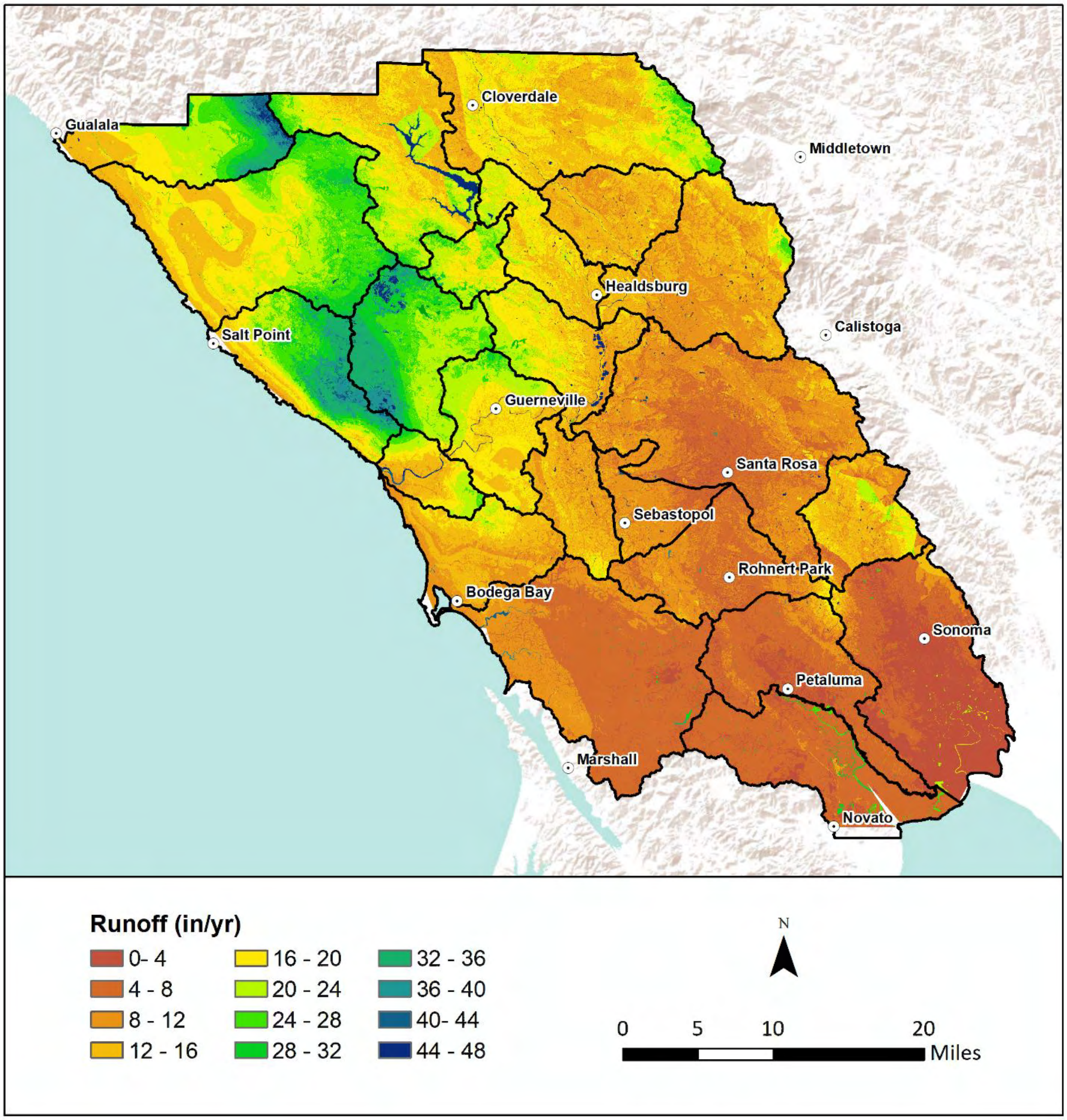


Figure 14: Water year 2010 Surface unoff simulated with the Sonoma County SWB model.

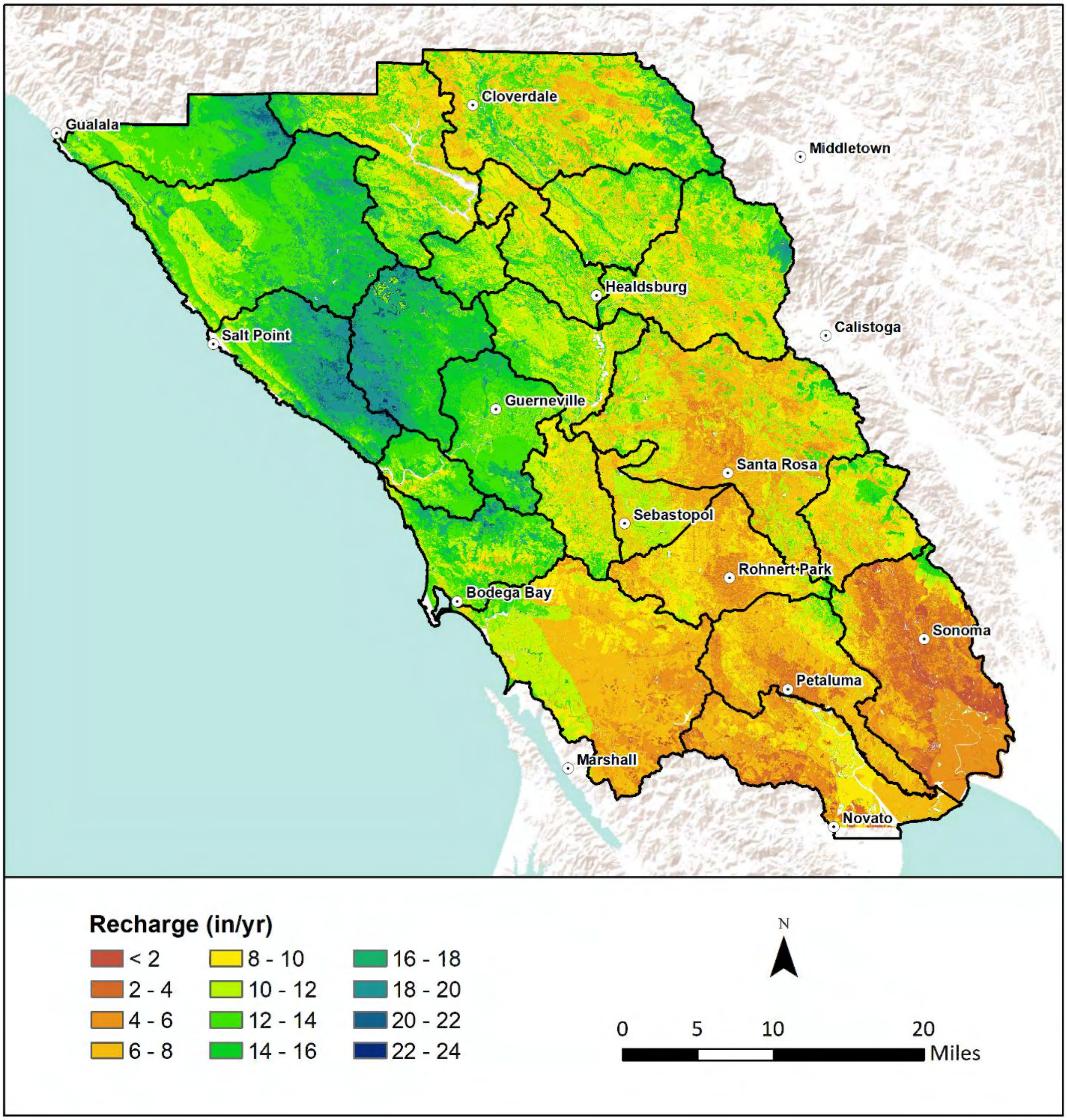


Figure 15: Water year 2010 Recharge simulated with the Sonoma County SWB model.

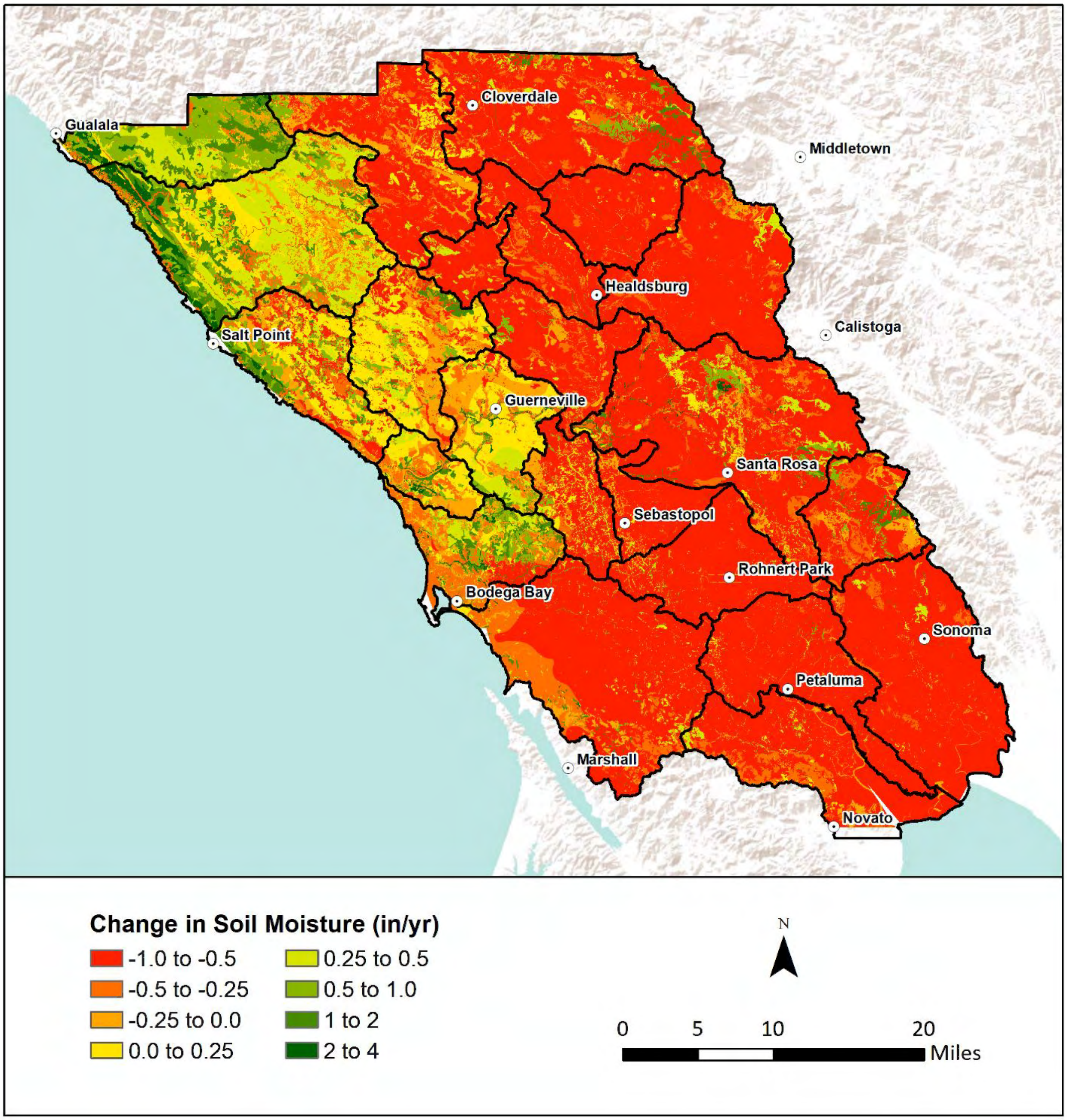


Figure 16: Water year 2010 Soil Moisture Change simulated with the Sonoma County SWB model.

Discussion and Conclusion

Previous modeling studies have estimated water budget components in several larger watershed areas in the county 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. 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 estimated that AET was equivalent to between 44% and 49% of mean annual precipitation which is consistent with this analysis where the county-wide AET was equivalent to 48% of the annual precipitation. The regional analyses estimated that surface runoff ranged from 37 to 55% of the annual precipitation which is somewhat higher than this analysis where the equivalent county-wide value was 29%. In the regional analyses, recharge varied from 7% to 19% of the annual precipitation. The equivalent county-wide value from this study is somewhat higher at 22%.

At the local scale, the simulation results indicate sensitivity of the water budget components to variations in topographic position, land cover, and soil texture, however at the watershed scale much of the variation in the principal water budget components (AET, surface runoff, and recharge) are correlated with variations in precipitation across the county (Figure 17). AET increases as a function of precipitation in watersheds with annual precipitation up to about 45 in/yr. Above 45 in/yr AET remains relatively constant (average of about 27 in/yr). This suggests that in portions of the county experiencing low precipitation, AET is limited by available soil moisture in contrast to areas of the county with higher precipitation where AET is limited by the potential ET. Although surface runoff varies more or less linearly as function of precipitation (Figure 17), the slope of the relationship with precipitation increases above precipitation of about 45 in/yr. This suggests that surface runoff increases with precipitation more sharply where precipitation is great enough to fully satisfy potential ET. Recharge also varies linearly as a function of precipitation (Figure 17).

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. The current analysis focused on a single water year, 2010, and was calibrated to streamflow gauge-derived monthly surface runoff rates at five locations. Future work to expand the analysis to additional water years and calibrate to additional gauge locations would help to further evaluate, refine, and quantify the uncertainty associated with the model's recharge estimates.

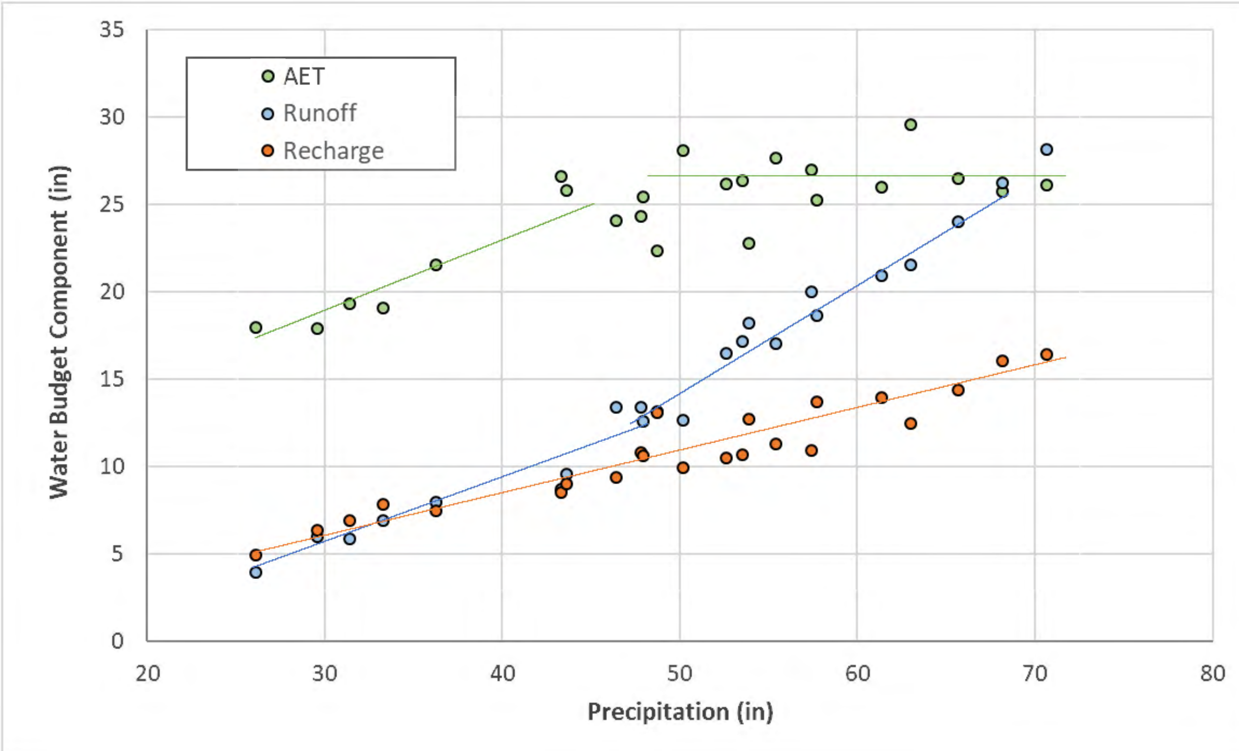


Figure 17: Principal water budget components simulated with the SWB model for major watersheds in Sonoma County as a function of annual precipitation. Trend lines fit by eye.

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