Groundwater Report
APN 030-050-009
Prepared per Sonoma County Policy & Procedure 8-1-14

Prepared for:

Lisa Lai
2000 Los Alamos Road
Santa Rosa, CA 95409

Prepared by:

OEI

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CERTIFIED ENGINEERING GEOLOGIST
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Hydrologist

July 26, 2018

Contents

Introduction

The applicant is seeking permits to cultivate 6,649 square feet (0.15 acres) of cannabis at 2000 Los Alamos Road (Sonoma County APN 030-050-009), which is located in the upper Santa Rosa Creek watershed approximately 4 miles north of Kenwood near the northern edge of Hood Mountain Regional Park (Figure 1). The project parcel is located in a Class 4 groundwater area defined by Sonoma County to be an area with "low and highly variable water yield". This hydrogeologic report was prepared as required by Sonoma County Permit and Resource Management Division (PRMD) pursuant to General Plan Policy WR-2e, Procedure and Policy 8-1-14, and section 10d of Exhibit A-2 of County Ordinance No. 6189 regarding water availability in Zone 3 and 4 areas where groundwater is believed to be of limited supply. 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.

This hydrogeologic report includes the following elements: estimates of existing and proposed water use within the project recharge area, compilation of well completion reports (drillers' logs) from the area and characterization of local hydrogeologic conditions, estimates of annual groundwater recharge and existing and proposed groundwater use, and the potential for well interference between the project well and neighboring wells.

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.

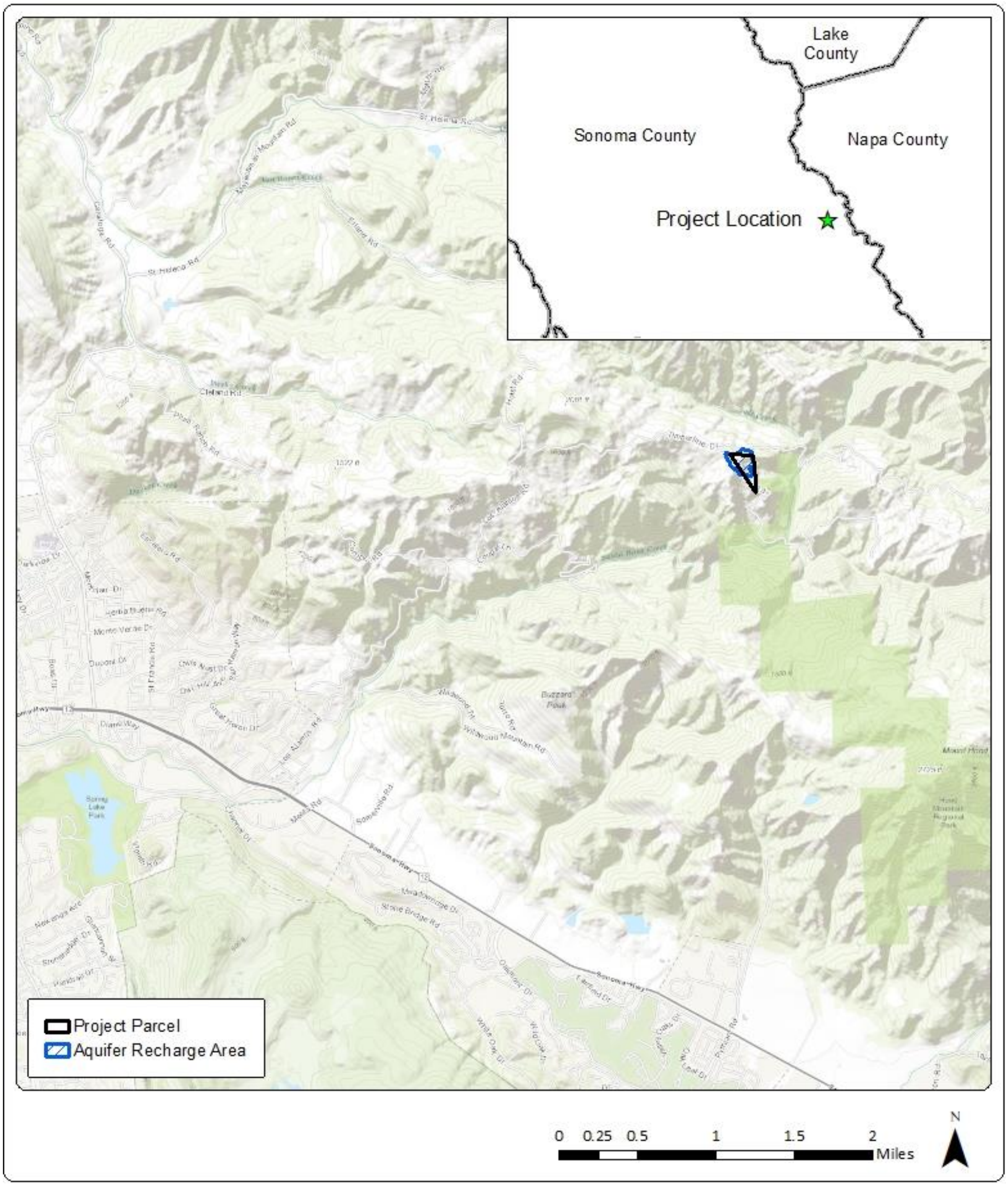


Figure 1: Project location map.

Hydrogeologic Conditions

Overview

The project parcel is located in the mountains northeast of Santa Rosa and is underlain by Cretaceous-aged mélange rocks of the Franciscan Complex (map unit fsr)(Figure 2). This map unit consists primarily of a sheared argillite and greywacke matrix enclosing blocks and lenses of chert, metachert, greenstone, serpentinite, and other Franciscan rocks (Graymer et al., 2007). The block underlying the project parcel is approximately 4.5 square miles and is oriented northwest to southeast, parallel to nearby faults. Surrounding rocks belong to other units of the Franciscan Complex, primarily late-Jurassic to early-Cretaceous-aged greywacke and mélange (map unit KJfs).

The Franciscan Complex is generally considered poor aquifer material; however, successful wells of generally limited capacity are common in this highly variable geologic unit. Primary porosity in the Franciscan Complex is low and groundwater occurs primarily in fractures. Well yields are variable depending on the degree of fracturing; however, yields are generally low and on the order of a few gallons per minute; dry test holes are also common within these rocks (LCSE, 2013).

The project parcel is located near several northwest to southeast trending faults. The nearest of these is located approximately 0.25 miles northeast of the project parcel. The nearest major fault, the northwest to southeast trending St. John Mountain Fault, is located approximately 1.0 mile southwest of the project parcel.

Well Data

Well Completion Reports for wells on and around the project parcel were obtained from the California Department of Water Resources (Table 1). Well test reports were also provided by the client for two wells associated with the project parcel. A subset of these logs and reports was compiled (Appendix A) and georeferenced based on parcel and location sketch information (Figure 2).

There are two wells associated with the project parcel. The first, Well 1, is located near the existing residence at the northwestern corner of the parcel. This well was completed to a depth of 174 feet in the Franciscan mélange (map unit fsr). At the time a pump test was performed in 1995, the well had a static water level of 107 feet and an estimated yield of 0.8 gpm (Table 1). A Geologic Log is not available for this well and the screened interval is unknown. The second, Well 2, is located west of the existing residence, south of the access road. This well was completed in 1985 to a depth of 124 feet. A surficial layer of clay, followed by alternating layers of grey sandstone and shale were encountered while drilling this well. These rock descriptions are consistent with the Franciscan mélange (map unit fsr). At the time of completion, the static water level was 20 feet. Ten years later when a pump test was performed in 1995, the static water level was observed at 20 feet; this indicates a relatively stable groundwater resources in the vicinity of the project parcel. This well test estimated the stable yield at 1.6 gpm (Table 1).

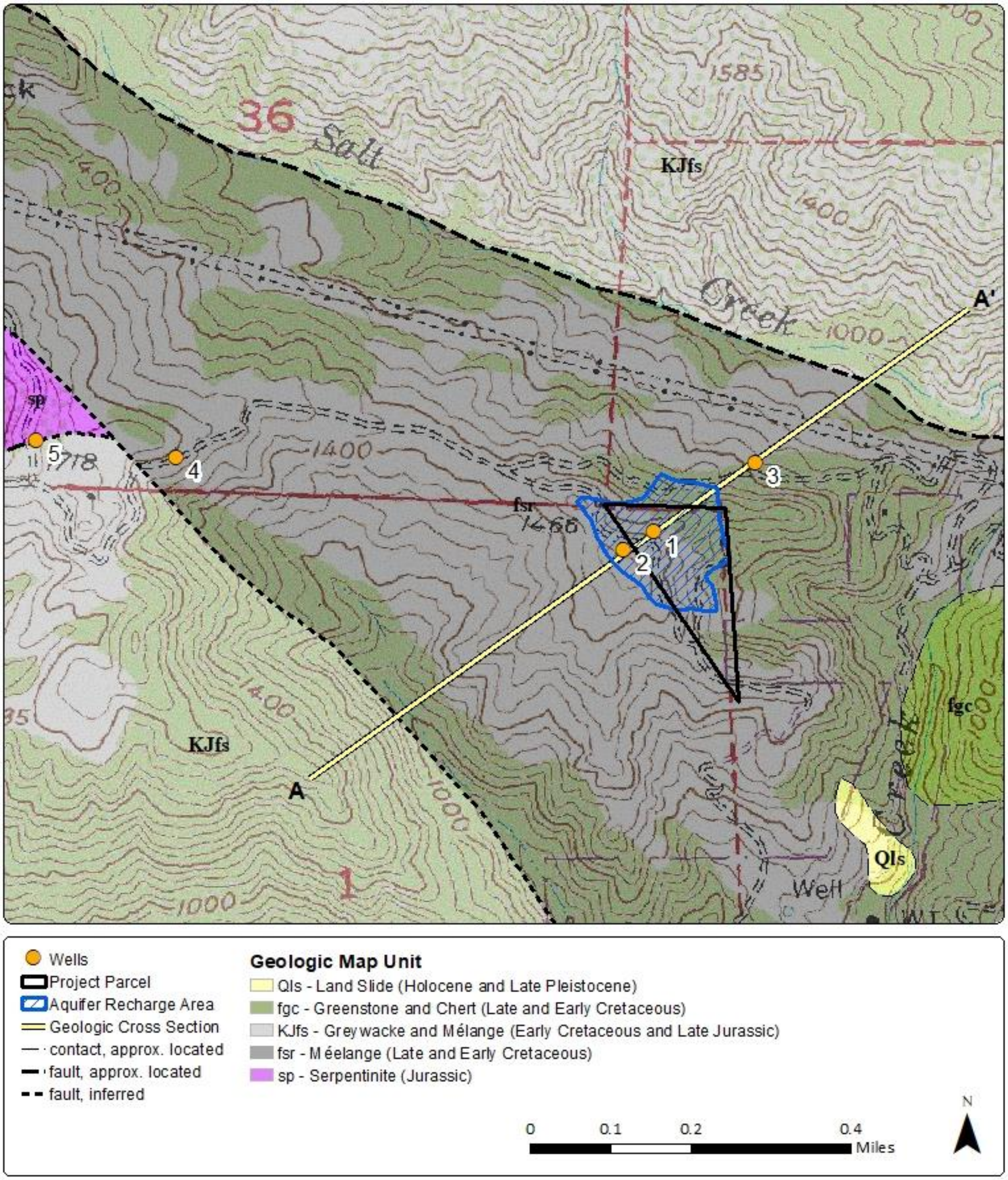


Figure 2: Surficial geology and locations of wells in the vicinity of the project parcel. Surficial geology based on data from the Geologic Map of Parts of Eastern Sonoma and Western Napa Counties (Graymer et al., 2007)

Well Completion Reports for four additional wells were located within the vicinity of the project recharge area. All of these wells are completed in the Franciscan mélange (map unit fsr) or other similar rock types. Estimated yields ranged from 12 gpm (Well 5) to 0.75 gpm (Well 6). Static water levels were relatively consistent (15 – 21 feet).

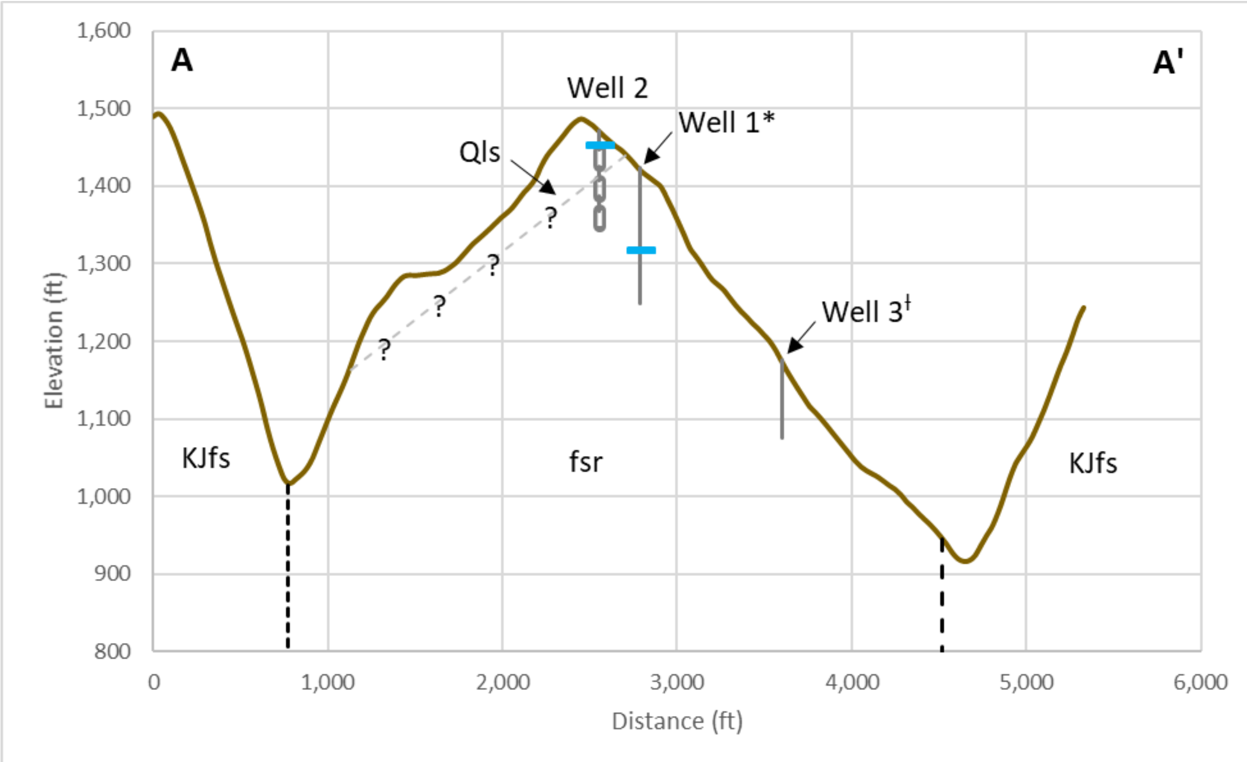
Based on available satellite imagery, several additional wells appear to be located on the neighboring parcel to the east (APN 030-050-008). Well Completion Reports were unavailable for these wells and specific details of the wells are unknown. However, based on available topographic data, the ground surface elevation of all of these wells appear to be below the bottom of the screened intervals of both wells associated with the project parcel. In other words, the wells on the neighboring parcel are likely not screened within the same thickness of the Franciscan mélange as the project wells.

Table 1: Well completion details for wells near the project parcel

Comments	1	2	3	4	5	6
Year Completed	Unk.	1985	<2006	<2012	1989	1979
Depth (ft)	174	124	Unk.	360	246	140
Estimated Yield (gpm)	0.85	1.6	Unk.	Unk.	12	0.75
Static Water Level (ft)	107	20	Unk.	Unk.	15	21
Top of Screen (ft)	Unk.	26	Unk.	Unk.	36	30
Bottom of Screen (ft)	Unk.	124	Unk.	Unk.	183	140
Geologic Map Unit	fsr	fsr	fsr	fsr	sp/KJfs	fsr/sp

Geologic Cross-Section

A geologic cross-section oriented southwest to northeast through the project recharge area is shown in Figure 3 (see Figure 2 for location). Elevations along the cross-section ranged from approximately 1,500 feet on the ridgeline near the project parcel to approximately 900 feet in the adjacent valley bottoms. All surrounding rocks belong to various units of the Franciscan Complex. Based on water surface elevation data from wells test reports, the groundwater surface is estimated to mimic surface topography.

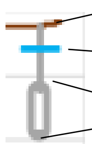


*** Screened interval unknown for Well 1**
ⱡ Location only. Depth, screened interval, and water surface elevation unknown for Well 3

Faults: Fault, Inferred
Fault, Approximately Located
? ? Contact, Inferred

Groundwater Surface:
Estimated Groundwater Surface

Well



Ground surface
Groundwater Elevation
Screened Section of Well

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

Project Aquifer

Within the vicinity of the project parcel, all areas are underlain by the Franciscan mélange (map unit fsr). The nearest mapped geologic contacts and faults are located approximately 0.25 miles northeast of the project parcel. Due to the compact nature and relatively low hydraulic conductivity of the Franciscan Complex, the project aquifer is not believed to extend as far as these contacts. Therefore, the project recharge area is defined based on local groundwater flow patterns which are believed to mimic surface topography.

The groundwater elevation near the ground surface in Well 2 contrasts sharply with the groundwater elevation in Well 1 (Figure 3). The near-surface water table associated with Well 2 may be associated with geologic materials in the Franciscan Complex that often manifest as deep-seated rockslides and/or earthflows. Aerial imagery of the project recharge area reveals that the ridgetop to the west of the project parcel is vegetated by grassland, and, on the opposite side of the ridge from the project parcel, gullies and hummocky terrain characteristic of earthflow terrain is evident. On the east side of the ridge where the project parcel is located, oak savannah vegetation is dominant; the upper portion of the slope is grassland contiguous with the west side of the ridge. The different characteristics of water level and well yield in Well 2 compared to Well 1 would be consistent with a perched aquifer in the “landslide” deposits (Figure 3) defined by the grassland vegetation. Well 2 is located at the eastern edge of the grassland near the top of the ridge and Well 1 is located farther to the east and downhill in the oak savannah.

The southwestern boundary of the project recharge area is defined by the prominent ridgeline near the project parcel which has been conceptualized as a groundwater divide. The northeastern boundary of the project recharge area is defined as the surface contour level with the bottom of the screened interval of the deeper well on the project parcel (Well 1, approximately 1,250 ft using the North American Vertical Datum of 1988 (NAVD 88)). The northwestern and southeastern boundaries are defined by minor ridges connecting the main ridgeline and the surface contour.

The total project recharge area is approximately 12.6 acres, all of which is underlain by the Franciscan mélange (map unit fsr). Because the project aquifer is located in fractured bedrock and clay-rich earth materials of the Franciscan Complex, it is likely that the project aquifer is 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 project recharge area, the saturated aquifer thickness, and the aquifer specific yield. Because of the large change in elevation across the project recharge area, water surface elevation and saturated thickness are expected to have a high degree of spatially variability. Therefore, the estimated groundwater storage was calculated using a spatial average of saturated thickness across the project recharge area.

Using well test data for the two wells associated with the project parcel, the water surface appears to mimic surface topography at an average depth of 64 ft. Based on the 10m USGS DEM, the average surface elevation of the project recharge area is 1,380 ft NAVD 88 and the average water surface elevation is estimated to be 1,316 ft NAVD 88. The bottom of the deeper of the two wells associated with the project parcel is approximately 1,250 ft NAVD 88. Calculating the average saturated thickness as the difference between the average water surface elevation and the bottom of the lower screened interval of the project well yields an estimated average saturated thickness of 66 feet. This provides a minimum estimate of the saturated thickness; the Franciscan Complex extends to significantly greater depths beneath the project recharge area.

Based on the well completion report for the project well, the saturated zone is located entirely within the Franciscan Complex. While specific yield values are unavailable for the Franciscan Complex, the porosity of fractured bedrock such as the fsr unit of the Franciscan Complex is expected to lie between <1 and 10% (Freeze and Cherry, 1979; Weight and Sonderegger, 2000). To be conservative, we have used low-end estimates of specific yield of 1% for the TKfss. This results in an estimate of the available groundwater storage of 8.3 acre-ft. (66-ft x 0.01 x 12.6 acres).

Water Demand

Within the project recharge area, water demand was estimated for both the existing and proposed conditions. Water uses were determined using site details provided by the applicant and verified using satellite imagery. Annual use rates for the various water uses were estimated primarily based on Napa County's Water Availability Analysis Guidance Document, dated May 2015 (Napa County, 2015). Water use rates for cannabis cultivation on the project parcel were determined based on correspondence with the applicant.

The project recharge area covers portions of four parcels: the project parcel and three adjacent parcels. Based on satellite imagery and information provided by the project applicant, none of the neighboring parcels have developed water uses within the project recharge area. While there appear to be wells and water use on the neighboring parcel to the east (APN 030-050-008), this parcel is located outside of the project recharge area and wells on this parcel are screened below the bottom of the lowest well on the project parcel (Well 1). Therefore, in both the existing and proposed conditions, the only water use within the project recharge area was assumed to be associated with the project parcel.

Existing Condition

The water supply system for the project parcel is comprised of Wells 1 and 2. Each well has a new pump. Well yields are 0.6 gpm and 1.6 gpm, respectively, with a combined yield of 2.4 gpm; these wells slow-pump to fill a 5,000-gallon storage tank. Half of the tank storage is allocated for fire protection; the other half is available for irrigation use.

In the existing condition, 1,563 ft^2 of cannabis is cultivated indoors on the project parcel. The indoor cultivation area currently houses 376 plants. The operation irrigates at a rate of 200/gal/week for each 500 ft^2 section, year-round. Although the use rate per plant is very low (approximately 0.24 gallons/plant/day), the size of the plants grown is also very small (less than 1 ft^2/plant). Higher water use rates of several gallons per plant per day estimated for large outdoor plants (Bauer 2015) are not applicable to small plants grown indoors.

There is an agricultural barn on the project parcel; there is no residence on the parcel. The two owner-operators are the only full-time employees and were assumed to work five days per week, year round. During trimmings, independent contractors work on-site; however, the duration that these contractors are on-site, typically about three days, four times per year, requires minimal water use.

Based on these uses, existing water demand within the project recharge area is estimated at 0.12 acre-ft/yr (Table 2). The majority of this is for cannabis irrigation (Table 3) and the balance is used by employees (Table 4).

Table 2: Estimated existing and proposed water demand for the project recharge area.

	Irrigation Use (acre-ft/yr)	Employee Use (acre-ft/yr)	Total Use (acre-ft/yr)
Existing Use	0.10	0.02	**0.12**
Proposed Use	0.67	0.02	**0.69**

Table 3: Estimated existing irrigation water use within the project recharge area.

Use Category	Indoor Cultivation Area (ft^2)	# of plants	Weekly Use Rate (gal/week)	Estimated Use per Plant (gal/day)	Annual Water Use (ac-ft/yr)
Cannabis Irrigation	1,563	376	625	0.24	0.10
TOTAL					**0.10**

Table 4: Estimated existing and proposed employee use within the project recharge area.

Work Category	# of Employees	# Work Days per Year	Use per Employee (gal/day)	Annual Water Use (ac-ft/yr)
Full-time	2	260	15	0.02
TOTAL				**0.02**

Proposed Condition

In the proposed condition, the indoor cultivation area will be expanded to 3,799 ft^2 and will house approximately 1,816 plants. Indoor irrigation rates will be comparable to the existing condition with each 500 ft^2 section of the indoor cultivation area using 200 gallons per week. Although the per-plant irrigation rate is less than in the existing condition, the planting density is correspondingly higher.

A 2,850ft^2 mixed-light cultivation area housing 2,144 plants is also proposed. Plants will be watered bi-weekly in groups of 16. Each group of 16 plants will receive 10 gallons/watering, equivalent to 0.18 gallons/plant/day. Although the per-plant irrigation rate is low, the planting density is high. Normalized for area, plants in the mixed-light cultivation area will be irrigated at a rate of 0.13 gal/ft^2/day. This is conservative compared to rates reported by other mixed-light cultivators in Sonoma county for whom OEI has previously prepared groundwater report. These cultivators typically report using 0.07 – 0.12 gal/ft^2/day. The expanded operation will continue to be run by the two owner-operators with independent contractors being brought in only for short periods of time for trimming. Therefore, employee use will be minimal in the proposed condition.

Table 5: Estimated proposed irrigation water use within the project recharge area.

Cultivation Method	Cultivation Area (ft^2)	# of plants	Weekly Use Rate (gal/week)	Estimated Use per Plant (gal/day)	Annual Water Use (ac-ft/yr)
Indoor Cultivation	3,799	1,816	1,520	0.12	0.24
Mixed Light Cultivation	2,850	2,144	2,680	0.18	0.43
TOTAL					**0.67**

The total proposed water demand within the project recharge area is estimated to increase by 0.57 acre-ft/yr to 0.69 acre-ft/yr (Table 2). All of this proposed increase comes from increases in irrigation use (Table 5). All water use comes from the project parcel which comprises approximately 64% of the project recharge area.

Groundwater Recharge Analysis

Groundwater recharge within the project recharge area was estimated using a Soil Water Balance (SWB) model developed for Sonoma County and portions of Marin County. 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 C.

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. In Water Year 2010, recharge varied across the project recharge area from 6.2 to 11.7 inches with a spatially averaged recharge of 9.5 inches. Groundwater recharge estimates can also be expressed as a total volume by multiplying the calculated recharge by the project aquifer recharge area of 12.6 acres. This calculation yields an estimated mean annual recharge of 10.0 acre-ft/yr.

Comparison of Water Demand and Groundwater Recharge

The total proposed groundwater use for the project recharge area is estimated to be 0.69 acre-ft/yr, all of which is from the project parcel. Groundwater use in the project recharge area is equivalent to 6.9% of the estimated mean annual groundwater recharge of 10.0 acre-ft/yr, indicating that there is a substantial surplus of groundwater resources (Table 6). Given the magnitude of the surpluses, the small amount of groundwater use proposed by the project is unlikely to result in significant reductions in groundwater levels or depletion of groundwater resources over time.

Table 6: Comparison of estimated water use and mean annual recharge within the project recharge area.

Total Proposed Demand (ac-ft/yr)	Recharge (ac-ft/yr)	Recharge Surplus (ac-ft/yr)	Demand as % of Recharge
0.69	10.0	9.3	7.0%

Potential Impacts to Streams and Neighboring Wells

Based on available well completion reports, the nearest well (Well 3) is located 1,600 feet northeast of the nearest of the two wells associated with the project parcel (Well 1). Potential wells on the neighboring parcel to the east may be closer. The nearest potential well location on this parcel is approximately 500 feet southeast of Well 1. However, both Well 3 and the potential wells on the neighboring parcel are located outside of the project recharge area. As such, it is unlikely that increased pumping in Well 1 will result in negative impacts at either of these two wells. Similarly, there are no streams within the project recharge area.

Summary

Application of the Soil Water Balance (SWB) model to the project recharge area revealed that average water year recharge was approximately 9.5 inches/yr or 10.0 acre-ft/yr. The total proposed Water Use for the project aquifer recharge area is estimated to be 0.69 acre-ft/yr. This represents 6.9% of the estimated mean annual recharge indicating that the project is unlikely to result in declines in groundwater elevations or depletion of the groundwater resources over time.

References

Bauer, S. et. Al., 2015. Impacts of Surface Water Diversions for Marijuana Cultivation on Aquatic Habitat in Four Northwestern California Watersheds. California Department of Fish and Wildlife and the National Marine Fisheries Service.

Graymer, R.W., Brabb, E.E., Jones, D.L., Barnes, J., Nicholson, R.S., and Stamski, R.E., 2007. Geologic Map and Database of Eastern Sonoma and Western Napa Counties, California. Pamphlet to accompany Scientific Investigations Map 2956. U.S. Department of the Interior U.S. Geological Survey

Herbst, C. M., 1982. Evaluation of Ground Water Resources: Sonoma County. California Department of Water Resources Bulletin 118-4.

Luhdorff and Scalmanini Consulting Engineers (LSCE) and MBK Engineers, 2013. Updated hydrogeologic conceptualization and characterization of conditions. Prepared for Napa County.

Weight, W. and Sonderegger, J. 2000. Manual of Applied Field Hydrogeology. McGraw-Hill. 608p.

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, 60 pgs.

APPENDIX A

WELL COMPLETION REPORTS

ORIGINAL

File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
WATER WELL DRILLERS REPORT

030 650 009

Do not fill in

No. 177198 A B

State Well No.

Other Well No. 07N07W01

N of Intent No.

L Permit No. or Date 300-85

(1)

Address

City

(2) LOCATION OF WELL (See instructions):

County Sonoma Owner's Well Number 030-050-09

Well address if different from above 2000 Los Alamos Rd.

Township Santa Rosa Range 07W Section

Distance from cities, roads, railroads, fences, etc.

WELL LOCATION SKETCH

(3) TYPE OF WORK:

New Well ☒ Deepening ☐

Reconstruction ☐

Reconditioning ☐

Horizontal Well ☐

Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:

Domestic ☒

Irrigation ☐

Industrial ☐

Test Well ☐

Stock ☐

Municipal ☐

Other ☐

(5) EQUIPMENT:

Rotary ☐ Reverse ☐

Cable ☐ Air ☒

Other ☐ Bucket ☐

(6) GRAVEL PACK:

Yes ☐ No ☐ Size Weeks

Diameter of bore 10 5/8 - 6 3/4

Packed from 21 to 124 ft.

(7) CASING INSTALLED:

Steel ☐ Plastic ☒ Concrete ☐

(8) PERFORATIONS:

Type of perforation or size of screen Saw Cut

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	124	4 1/2	CL200	26	46	.090
				65	85	.090
				104	124	.090

(9) WELL SEAL:

Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 21 ft.

Were strata sealed against pollution? Yes ☐ No ☐ Interval ft.

Method of sealing Neat cement on pack

(10) WATER LEVELS:

Depth of first water, if known ft.

Standing level after well completion 20' ft.

(11) WELL TESTS:

Was well test made? Yes ☒ No ☐ If yes, by whom? Weeks

Type of test Pump ☐ Bailer ☐ Air lift ☒

Depth to water at start of test 20 ft. At end of test 80 ft

Discharge 2 gal/min after 1 hours Water temperature cool

Chemical analysis made? Yes ☐ No ☒ If yes, by whom?

Was electric log made? Yes ☐ No ☒ If yes, attach copy to this report

(12) WELL LOG:

Total depth ~~187~~ 124 ft. Depth of completed well ~~0~~ 124 ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
		Log Of Test Hole #1 A
0	10	Sandy gray rock
10	22	Shale with sandy gray rock
22	64	Clayee gray shale with streaks of serpantine
64	89	Sandy gray rock
89	110	Gray shale with clay
110	129	Sandy gray rock
129	143	Sandy gray rock
143	152	Sandy gray rock with streaks of shale
152	187	Gray shale with serpentine
		Dry Hole - Backfilled & aBAndoned
		Log Of Test Hole #2 B
0	10	Brown clay
10	21	Sandstone & brown clay
21	41	Gray sandstone
41	43	Gray shale
43	47	Sandy gray rock with streaks of shale
47	91	Gray shale with streaks of sandy gray rock
91	102	Hard sandy gray rock
102	124	Gray shale & sandy gray rock
		Cased and completed

Work started 8/19 19 85 Completed 8/21 19 85

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED Gerald G. Thompson, By: Ward Thompson
(Well Driller)

NAME WEEKS DRILLING AND PUMP COMPANY
(Person, firm, or corporation) (Typed or printed)

Address P. O. Box 176

City Sebastopol, CA Zip 95472

License No. C57-177681 Date of this report Aug. 26, 1985

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

Well 2, Well Completion Report not available for Well 1

*The free Adobe Reader may be used to view and complete this form. However, software must be purchased to complete, save, and reuse a saved form.

File Original with DWR

State of California

Well Completion Report

Refer to Instruction Pamphlet

No. e059776

Page 1 of 1

Owner's Well Number GEO. BORINGS

Date Work Began 04/14/2006 Date Work Ended 4/17/2006

Local Permit Agency SONOMA COUINTY

Permit Number WEL06-0126 Permit Date

DWR Use Only – Do Not Fill In

07N06W06

State Well Number/Site Number

N Latitude

W Longitude

APN/TRS/Other

Geologic Log

Orientation ⦿ Vertical ○ Horizontal ○ Angle Specify

Drilling Method Solid-Stem Auger Drilling Fluid

Depth from Surface Feet	to Feet	Description (Describe material, grain size, color, etc)
		CLEAR HEART DRILLING INSTALLED (2)
		SLOPE INCLINOMETERS TO 60' & 69.5'
		WITH 6" SOLID FLIGHT AUGERS.

Total Depth of Boring 60'-69.5' Feet

Total Depth of Completed Well Feet

Well Owner

Na

Ma

Cit

Well Location

Address 3000 LOS ALAMOS RD.

City SANTA ROSA County Sonoma

Latitude Deg. Min. Sec. N Longitude Deg. Min. Sec. W

Datum Decimal Lat. Decimal Long.

APN Book Page Parcel 030-050-021

Township Range Section

Location Sketch

(Sketch must be drawn by hand after form is printed.)

North

West East

see attached map

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 and complete.

Activity

○ New Well

○ Modification/Repair

○ Deepen

○ Other

○ Destroy

Describe procedures and materials under "GEOLOGIC LOG"

Planned Uses

○ Water Supply

☐ Domestic ☐ Public

☐ Irrigation ☐ Industrial

○ Cathodic Protection

○ Dewatering

○ Heat Exchange

○ Injection

○ Monitoring

○ Remediation

○ Sparging

○ Test Well

○ Vapor Extraction

⦿ Other LANDSLIDE IN.

Water Level and Yield of Completed Well

Depth to first water 15 (Feet below surface)

Depth to Static Water Level (Feet) Date Measured

Estimated Yield * (GPM) Test Type

Test Length (Hours) Total Drawdown (Feet)

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

Casings

Depth from Surface Feet	to Feet	Borehole Diameter (Inches)	Type	Material	Wall Thickness (Inches)	Outside Diameter (Inches)	Screen Type	Slot Size if Any (Inches)

Annular Material

Depth from Surface Feet	to Feet	Fill	Description

Attachments

☐ Geologic Log

☐ Well Construction Diagram

☐ Geophysical Log(s)

☐ Soil/Water Chemical Analyses

☑ Other SITE MAP

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 CLEAR HEART DRILLING, INC.

Person, Firm or Corporation

555 W. COLLEGE AV. SUITE B SANTA ROSA CA 95401

Address City State Zip

Signed Jerri White 08/17/2007 780357

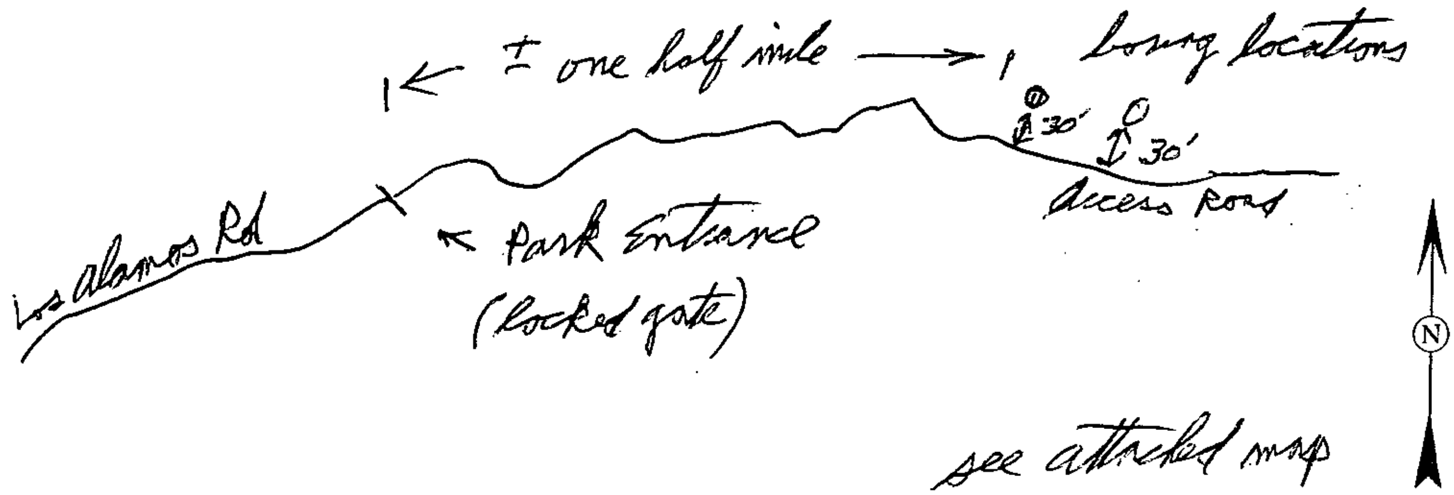
C-57 Licensed Water Well Contractor Date Signed C-57 License Number

DWR 188 REV. 1/2006

IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

Well 3

e059776



sennis WSS-014.cdr Rev. 10/07/03 Distribution: White - PRMD, Canary - Well Driller

ORIGINAL
File with DWR
Page 1 of 1

STATE OF CALIFORNIA
WELL COMPLETION REPORT
Refer to Instruction Pamphlet
No e0147180

DWR USE ONLY DO NOT FILL IN
08N07W36
STATE WELL NO / STATION NO
38 29 23 122 35 26
LATITUDE LONGITUDE
APN/TRS/OTHER

Owner's Well No DRY HOLE #1
Date Work Began 2/27/2012 Ended 2/28/2012
Local Permit Agency Sonoma County PRMD
Permit No WEL12 0003 Permit Date 1/11/2012

GEOLOGIC LOG

ORIENTATION (✓) ✓ VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)
DRILLING METHOD N/A FLUID N/A

DEPTH FROM SURFACE Ft	to Ft	DESCRIPTION *Describe material grain size color etc*
		DRY HOLE
		=
0	2	Loam
2	20	Brown sandstone rock
20	30	Gray shale like rock
30	50	Dark gray with white banding
50	70	Blue sandstone rock
70	80	Shale rock
80	90	Dark gray shale rock
90	100	Green blue serpentine sandstone
100	120	Sandstone with serpentine shale
120	200	Blue white sandstone rock
200	300	In and out bedded sandstone then shale
		with occasional small fractures with sand
300	360	Blue speckled sandstone harder with
		fractured zones

TOTAL DEPTH OF BORING N/A (Feet)
TOTAL DEPTH OF COMPLETED WELL N/A (Feet)

WELL OWNER

WELL LOCATION

Address 2355 Los Alamos Road
City Santa Rosa CA
County Sonoma
APN Book 030 Page 090 Parcel 005
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

DEPTH TO FIRST WATER N/A (Ft) BELOW SURFACE 1
DEPTH OF STATIC WATER LEVEL N/A (Ft) & DATE MEASURED ___
ESTIMATED YIELD N/A (GPM) & TEST TYPE N/A
TEST LENGTH N/A (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	CONDUCTOR	FILL PIPE	MATERIAL / GRADE	INTERNAL DIAMETER (Inches)	GAUGE OR WALL THICKNESS	SLOT SIZE IF ANY (Inches)
0	20	11								
20	360	8								

ANNULAR MATERIAL

DEPTH FROM SURFACE Ft	to Ft	CEMENT (✓)	BENTONITE (✓)	FILL (✓)	FILTER PACK (TYPE/SIZE)

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 Weeks Drilling & Pump
(PERSON FIRM OR CORPORATION) (TYPED OR PRINTED)
P.O. Box 176 Sebastopol CA 95473
ADDRESS CITY STATE ZIP
Signed Melissa G Lopez 03/02/12 177681
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

Well 4

ORIGINAL

File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WATER WELL DRILLERS REPORT

Do not fill in

No. 17214

State Well No. ____

Other Well No. 08N07W36

Notice of Intent No. ____

Local Permit No. or Date 389-89

(1) OWNER: ____

Address ____

City ____

(2) LOCATION OF WELL (See instructions) 030-090-04

County Son. Owner's Well Number ____

Well address if different from above 2300 Los Alamos Rd.

Township S. R. Range ____ Section ____

Distance from cities, roads, railroads, fences, etc. ____

WELL LOCATION SKETCH

(3) TYPE OF WORK:

New Well ☒ Deepening ☐

Reconstruction ☐

Reconditioning ☐

Horizontal Well ☐

Destruction ☐ (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:

Domestic ☒

Irrigation ☐

Industrial ☐

Test Well ☐

Stock ☐

Municipal ☐

Other ☐

(5) EQUIPMENT:

Rotary ☐ Reverse ☐

Cable ☐ Air ☒

Other ☐ Bucket ☐

(6) GRAVEL PACK:

Yes ☒ No ☐ Size Fine Pea

Diameter of bore 7 7/8, 9 7/8

Packed from 21 to 246 ft.

(7) CASING INSTALLED:

Steel ☐ Plastic ☒ Concrete ☐

(8) PERFORATIONS:

Type of perforation or size of screen micro perforations

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	183	5½	CL200	36	56	.032
				123	183	11

(9) WELL SEAL:

Was surface sanitary seal provided? Yes ☒ No ☐ If yes, to depth 21 ft.

Were strata sealed against pollution? Yes ☐ No ☐ Interval ____ ft.

Method of sealing Neat cement on pack

(10) WATER LEVELS:

Depth of first water, if known ____ ft.

Standing level after well completion 15' ft.

(11) WELL TESTS:

Was well test made? Yes ☒ No ☐ If yes, by whom? Weeks

Type of test Pump ☐ Bailer ☐ Air lift ☐

Depth to water at start of test 21 ft. At end of test 180 ft.

Discharge 12 gal/min after 2 hours Water temperature cool

Chemical analysis made? Yes ☐ No ☒ If yes, by whom? ____

Electric log made? Yes ☐ No ☒ If yes, attach copy to this report

(12) WELL LOG: Total depth 246 ft. Depth of completed well 183 ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	1	Topsoil
1	11	Shale & Serpentine clay
11	15	Sandy gray rock
15	18	Shale & clay
18	20	Gray sandy rock with streaks of quartz
20	30	Shale & shalee clay
30	46	Gray & green sandy rock with streaks of quartz (large fractured)
46	55	Shale & shalee clay
55	60	Black rock with streaks of quartz
60	206	Gray rock with streaks of quartz & seams of clay
206	246	Shale & shalee clay

Work started 9-12 1989 Completed 9-13 1989

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED Ward Thompson (Well Driller)

NAME WEEKS DRILLING AND PUMP COMPANY, INC.
(Person, firm, or corporation) (Typed or printed)

Address P.O. Box 176

City Sebastopol, CA Zip 95473

License No. C57-177681 Date of this report 9-22-89

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM 43816-950 7-76 50M QUAD OSP

Well 5

ORIGINAL

File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
WATER WELL DRILLERS REPORT

Do not fill in

No. 066148

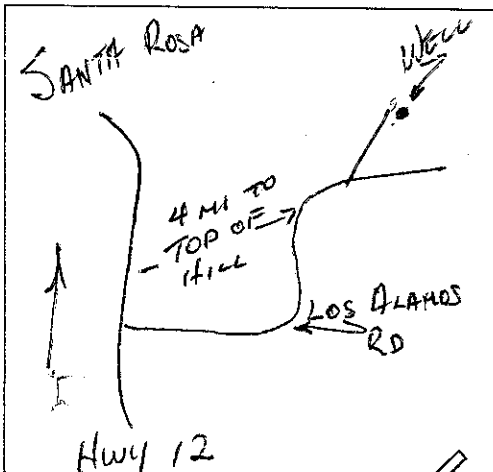
State Well No. ______
Other Well No. 08N07W36

of Intent No. ______
Local Permit No. or Date ______

(1)
Add
City

(2) LOCATION OF WELL (See instructions):

County Sonoma Owner's Well Number ______
Well address if different from above Same
Township 8N Range 7W Section 36
Distance from cities, roads, railroads, fences, etc. 4 miles northeast of Hwy 12 on Los Alamos Rd, 40' left of this road



WELL LOCATION SKETCH

(3) TYPE OF WORK:

New Well [X] Deepening [ ]
Reconstruction [ ]
Reconditioning [ ]
Horizontal Well [ ]
Destruction [ ] (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:

Domestic [X]
Irrigation [ ]
Industrial [ ]
Test Well [ ]
Stock [ ]
Municipal [ ]
Other [ ]

(5) EQUIPMENT:

Rotary [X] Reverse [ ]
Cable [ ] Air [X]
Other [ ] Bucket [ ]

(6) GRAVEL PACK:

Yes [X] No [ ] Size 3/8 pea
Diameter of bore 9"
Packed from 23 to 140 ft.

(7) CASING INSTALLED:

Steel [ ] Plastic [X] Concrete [ ]

(8) PERFORATIONS:

Type of perforation or size of screen Saw

From ft.	To ft.	Dia. in.	Gage or Wall	From ft.	To ft.	Slot size
0	140	6	160	30	140	1/16x3"

(9) WELL SEAL:

Was surface sanitary seal provided? Yes [X] No [ ] If yes, to depth 23 ft.
Were strata sealed against pollution? Yes [ ] No [X] Interval ______ ft.
Method of sealing Grout

(10) WATER LEVELS:

Depth of first water, if known 42 ft.
Standing level after well completion 21 ft.

(11) WELL TESTS:

Was well test made? Yes [X] No [ ] If yes, by whom? A&K Drilling
Type of test Pump [X] Bailer [ ] Air lift [ ]
Depth to water at start of test 21 ft. At end of test 130 ft
Discharge 3/4 gal/min after 4 hours Water temperature Cold
Chemical analysis made? Yes [ ] No [X] If yes, by whom? ______
Was electric log made? Yes [ ] No [X] If yes, attach copy to this report

(12) WELL LOG:

Total depth 140 ft. Depth of completed well 140 ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	26	Light brown soil with rock
26	42	Soft white clay, stones
42	43	Small gravel layer
43	89	Soft white clay, stones
89	140	Medium hard rock, clay, stones

Work started 29 Jul 1979 Completed 10 Aug 1979

WELL DRILLER'S STATEMENT:

This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.

SIGNED David L. Anderson/90
(Well Driller)

NAME A & K Drilling
(Person, firm, or corporation) (Typed or printed)

Address 1708 Putnam Way
City Petaluma CA Zip 94952
License No. 307800 Date of this report 26 Sep 79

  IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

Well 6

WEEKS DRILLING & PUMP CO., INC.

PHONES: (707) 823-3184 or (707) 542-3272 • P.O. BOX 176 • 6100 SEBASTOPOL ROAD • SEBASTOPOL, CALIFORNIA 95473
FAX: (707) 823-4258
LICENSE NO. C57-177681

REPORT OF WELL TEST

Date 8-16-95

Owners Name Summit Savings Bank

c/o

Mailing Address 6305 Commerce Blvd., Rohnert Park, CA 94928

Location Of Well 2000 Los Alamos Rd., Santa Rosa, CA

WELL INFORMATION

Drilled Well X Hand-dug Spring

Well Depth 174' Casing Size & Type 5" Steel

Static Water Level 107'

Draw Down From Top Of Well 130' after 3 hours pumping.

Yield Of Water Source .84 GPM

PUMP INFORMATION

Method Of Test 3/4 HP ☐ Jet ☒ Submersible

Pump Setting 130' Pump Production 5.4 GPM

Pump Static Pressure 50# + Pressure Tank Size 82 gal

Pressure Tank Type galv

Storage Tank Type concrete Storage Tank Capacity 1250

COMMENTS

5000 gal redwood tank on hill. Condition unknown. Well Warrick inoperative. JS05 Goulds booster. Well for redwood tank inoperative at this time.

Serviceman Tim K.

Water quality test results are attached if requested at time of order.

Total hours of testing

M. Wilson
Pump Department Manager

Well 1

FORM 25

WEEKS DRILLING & PUMP CO., INC.

PHONES: (707) 823-3184 or (707) 542-3272 • P.O. BOX 176 • 6100 SEBASTOPOL ROAD • SEBASTOPOL, CALIFORNIA 95473
FAX: (707) 823-4258
LICENSE NO. C57-177681

REPORT OF WELL TEST

Date 8-30-95

Owners Name Summit Savings Bank

c/o

Mailing Address 6305 Commerce Blvd., Rohnert Park, CA 94928

Location Of Well 2000 Los Alamos Rd., Santa Rosa, CA

WELL INFORMATION

Drilled Well X Hand-dug Spring

Well Depth 124' Casing Size & Type 4" PVC

Static Water Level 20' ?

Draw Down From Top Of Well 120' after 3 hours pumping.

Yield Of Water Source 1.536 GPM

PUMP INFORMATION

Method Of Test ½ HP ☐ Jet ☒ Submersible

Pump Setting 120' Pump Production 15 GPM

Pump Static Pressure 50# + Pressure Tank Size None

Pressure Tank Type N/A

Storage Tank Type Redwood Storage Tank Capacity 4000 ?

COMMENTS

Serviceman Tim K.

Water quality test results are attached if requested at time of order.

Total hours of testing

K. Wilson
Pump Department Manager

Well 2

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

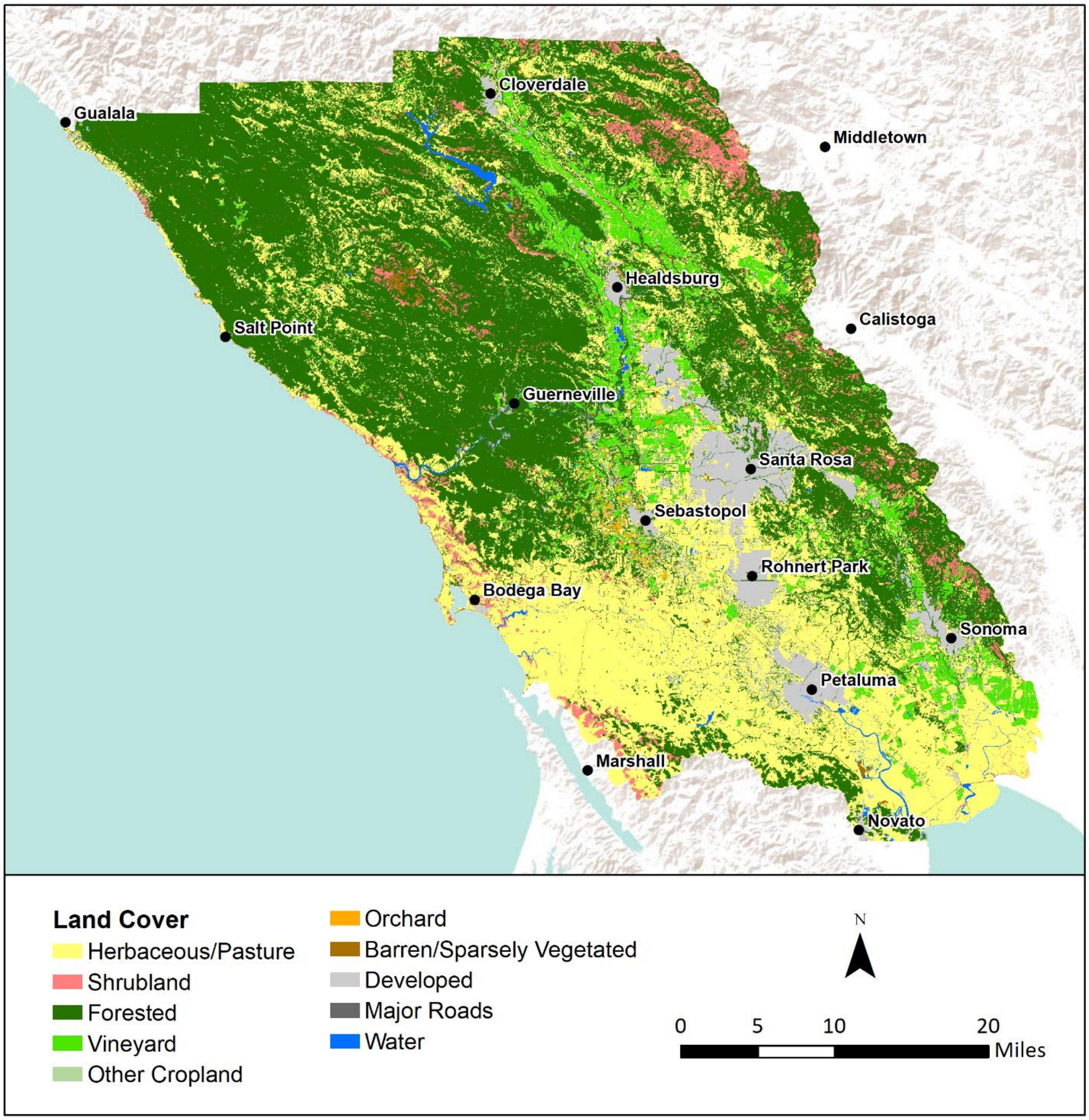


Figure 1: Land cover map used in the Sonoma County SWB model.

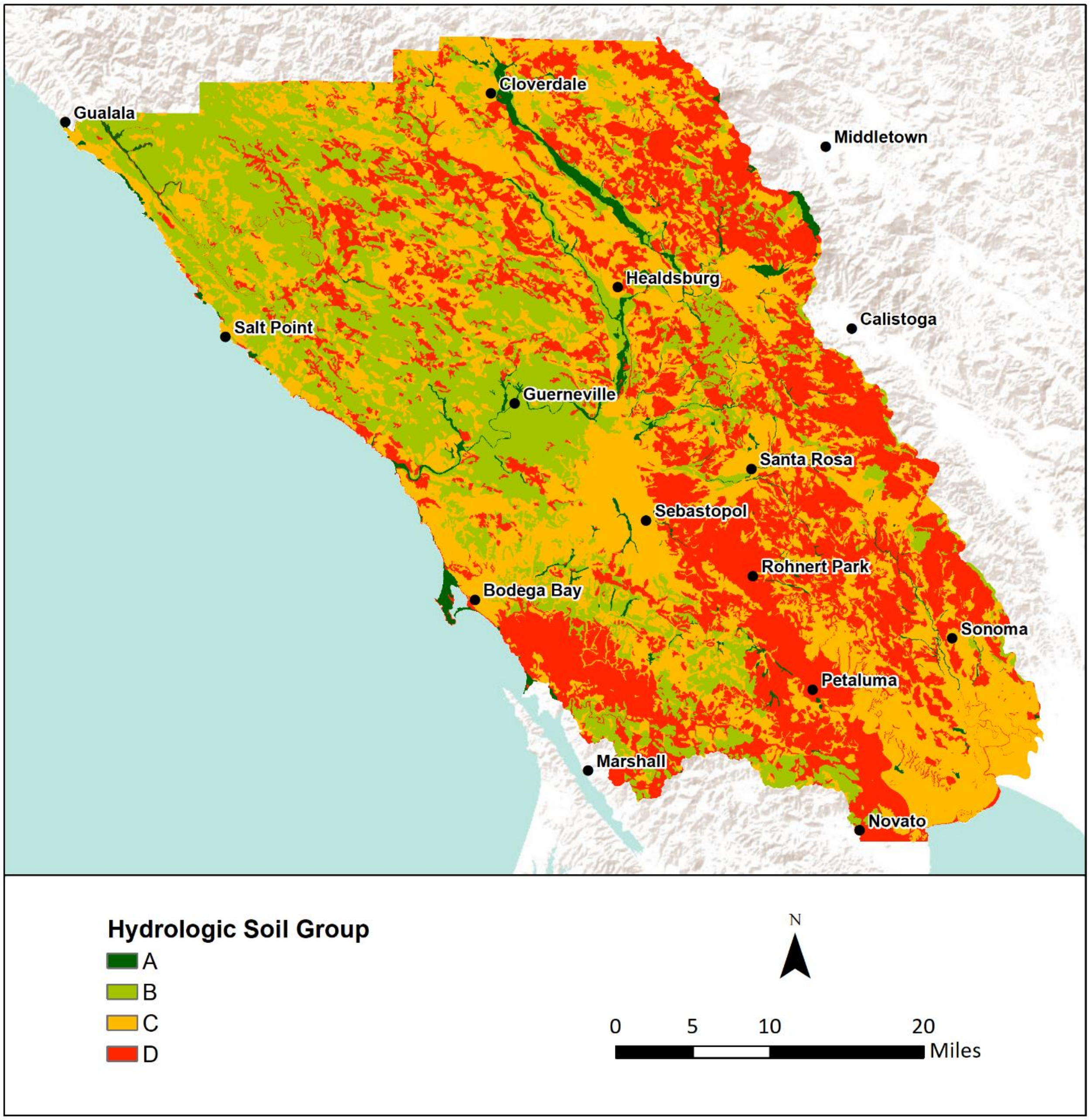


Figure 2: Hydrologic soil group map used in the Sonoma County SWB model.

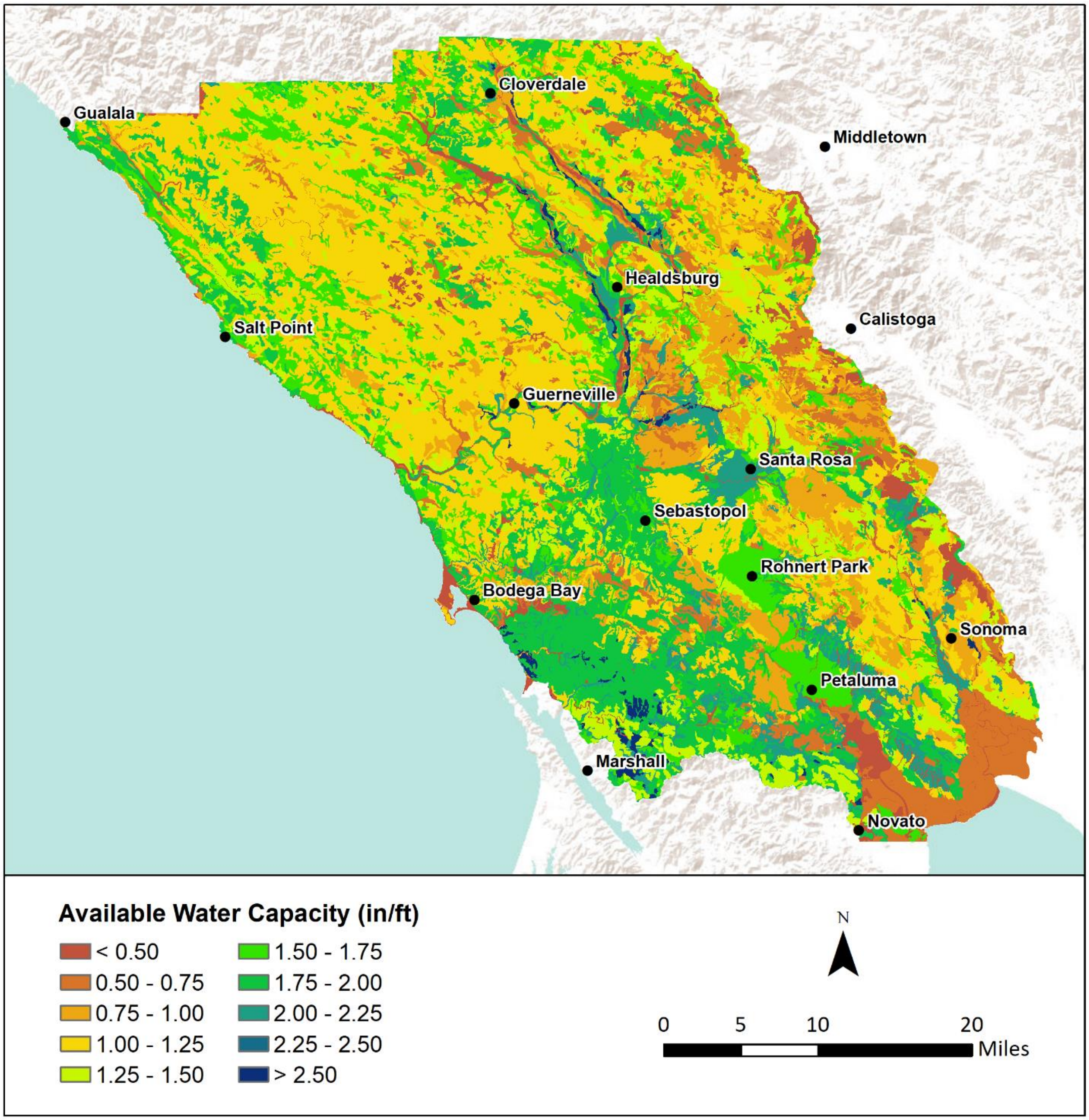


Figure 3: Available water capacity map used in the Sonoma County SWB model.

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

Land Cover	Curve Number				Interception Storage Values		Rooting Depth (ft)			
	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

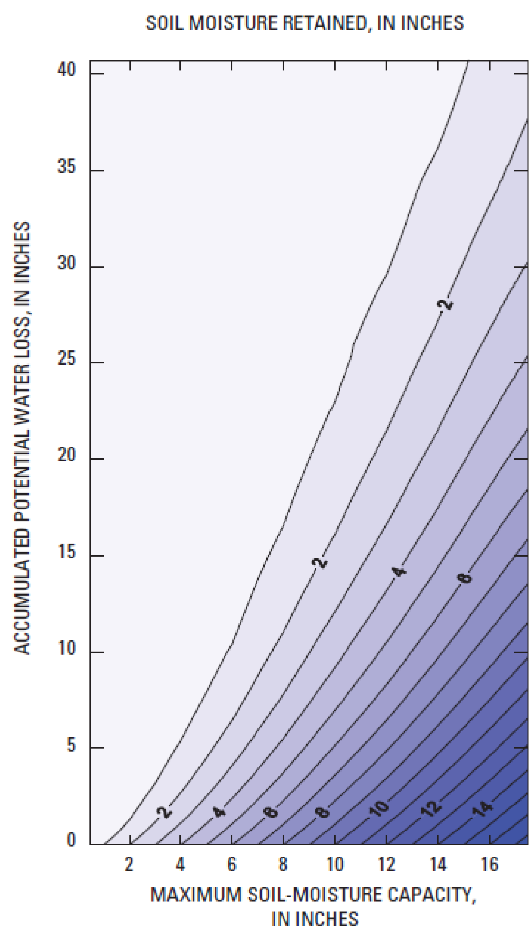


Figure 4: Soil-moisture-retention table (Thornthwaite and Mather, 1957).

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

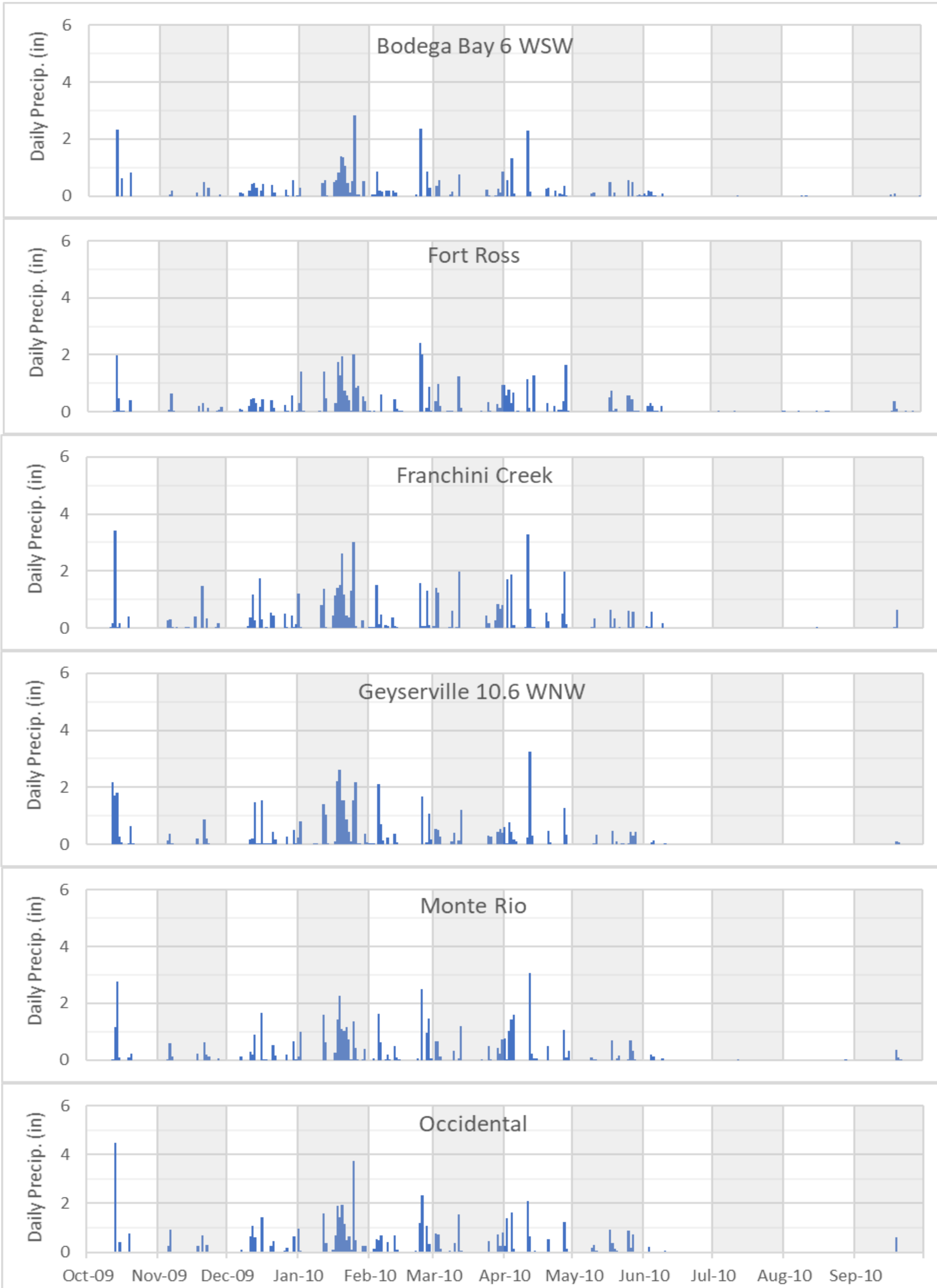


Figure 5: Daily precipitation data used in the Sonoma County SWB model.

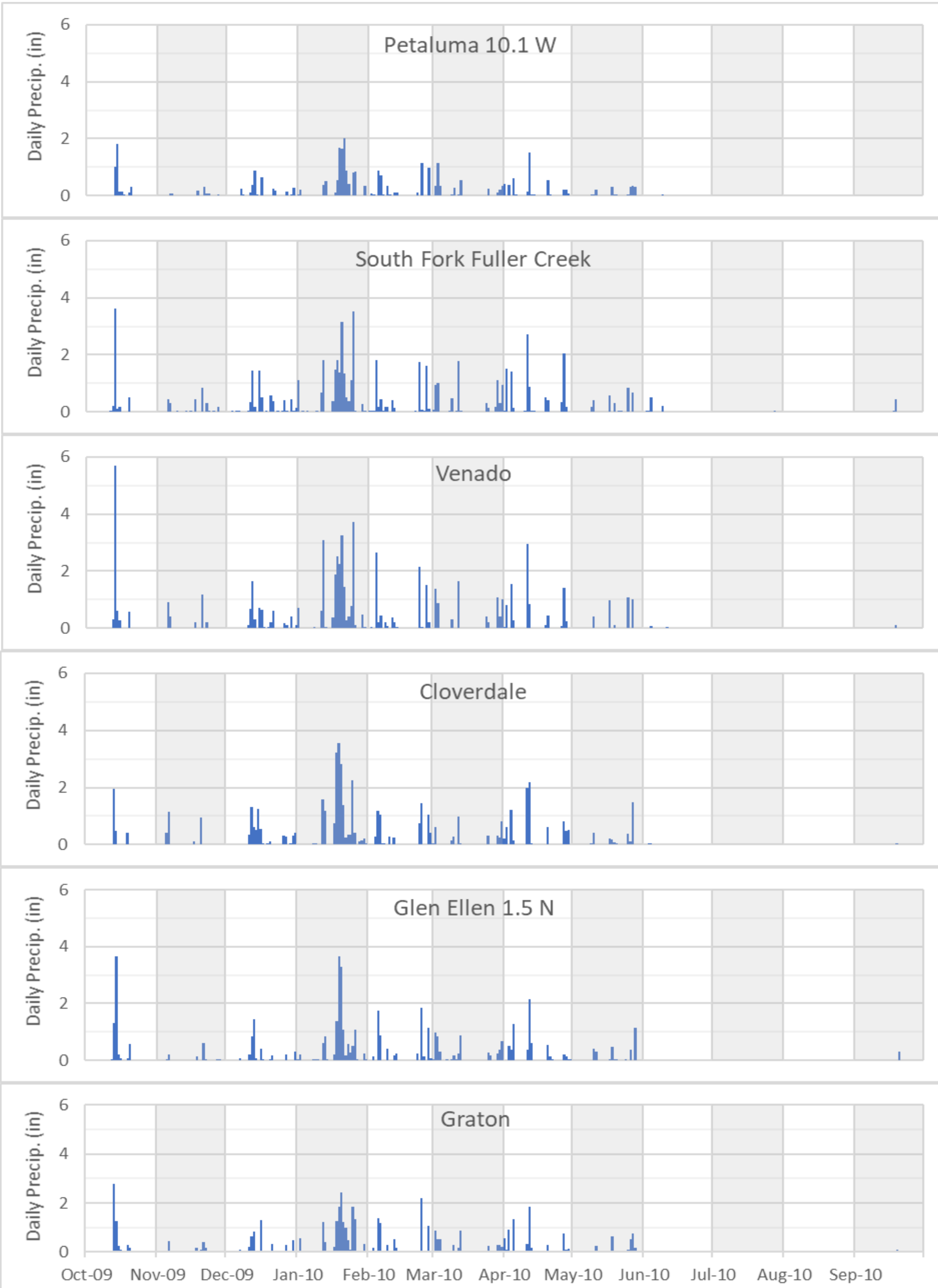


Figure 5 (continued)

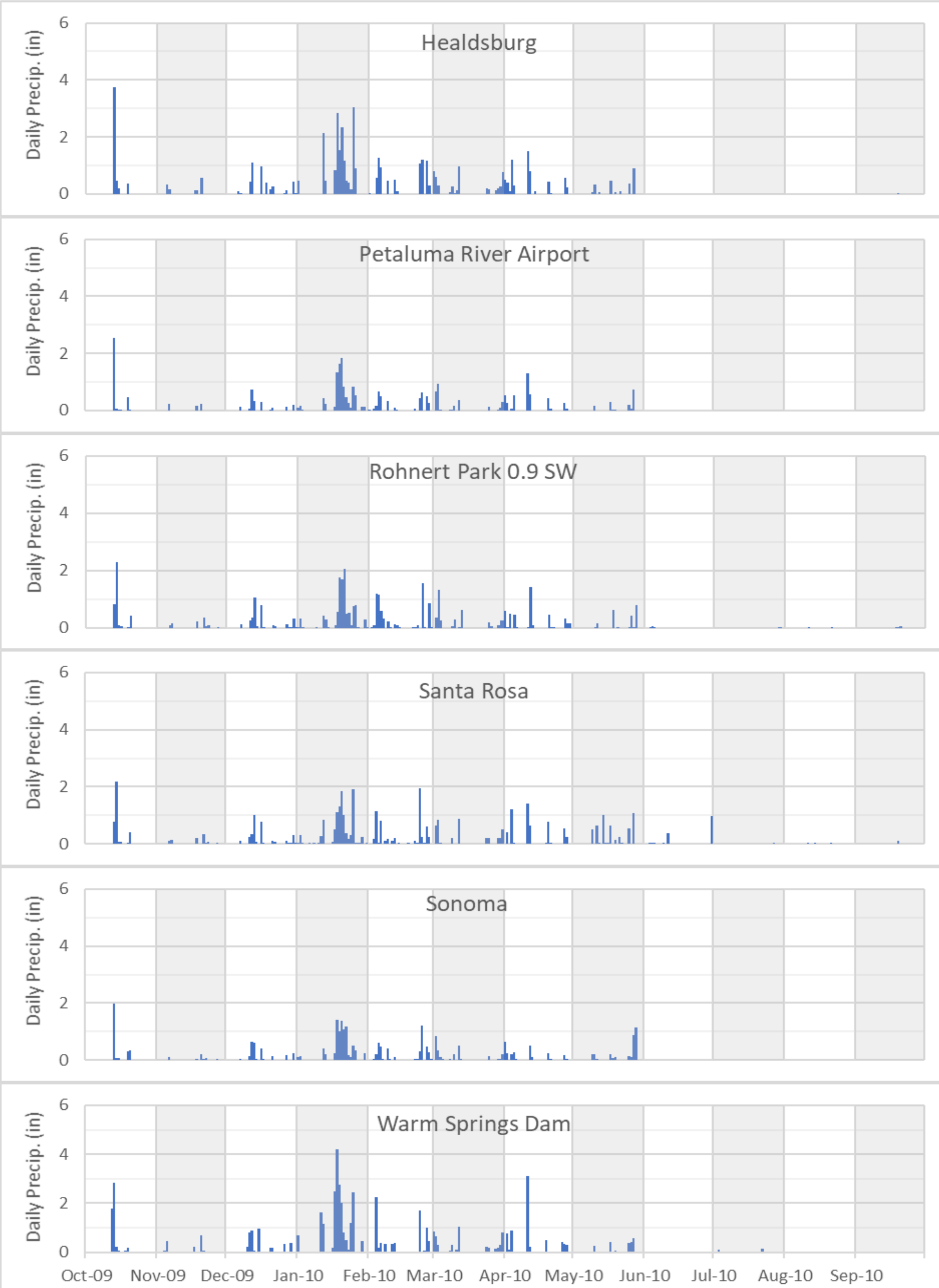


Figure 5 (continued)

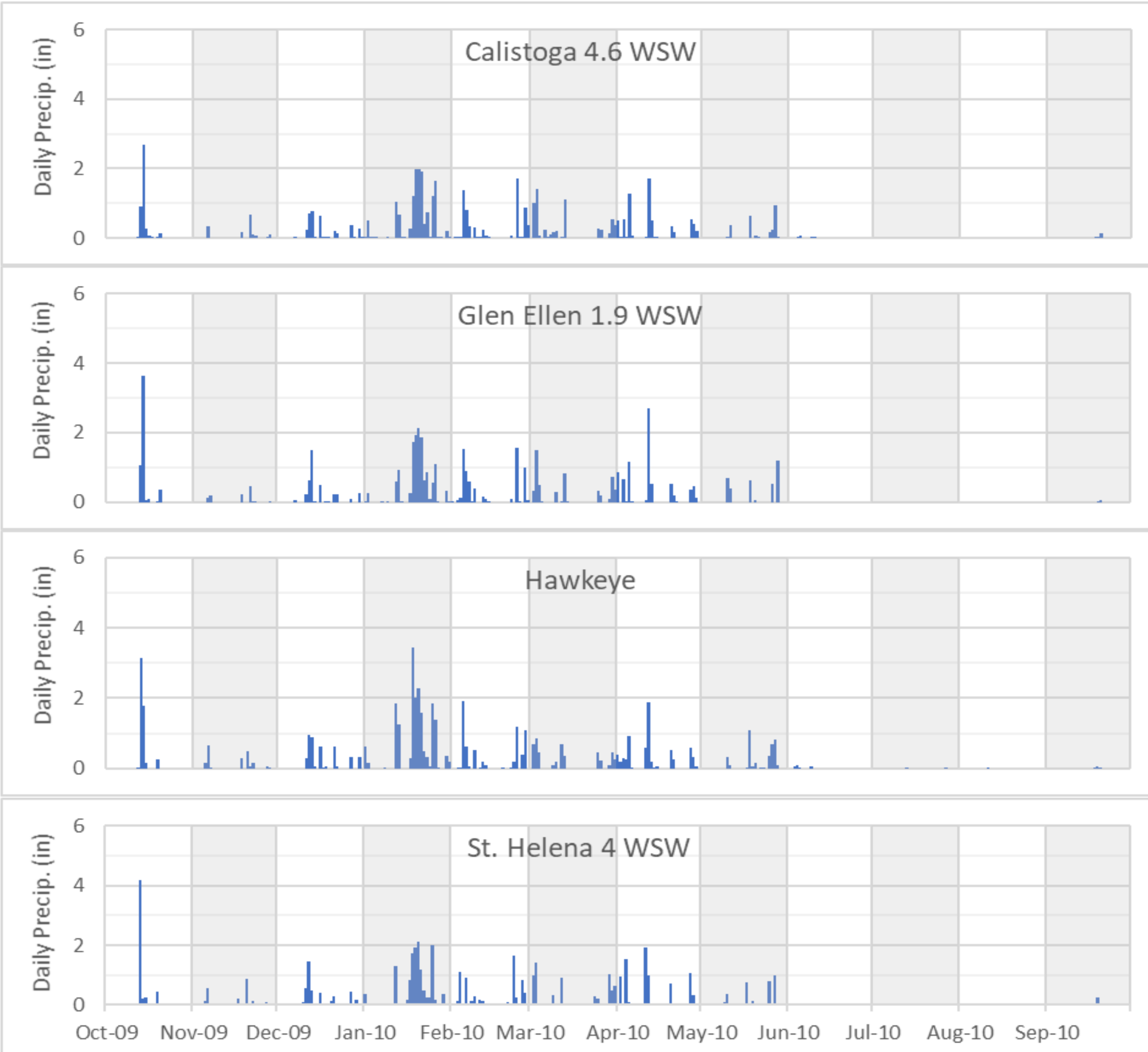


Figure 5 (continued)

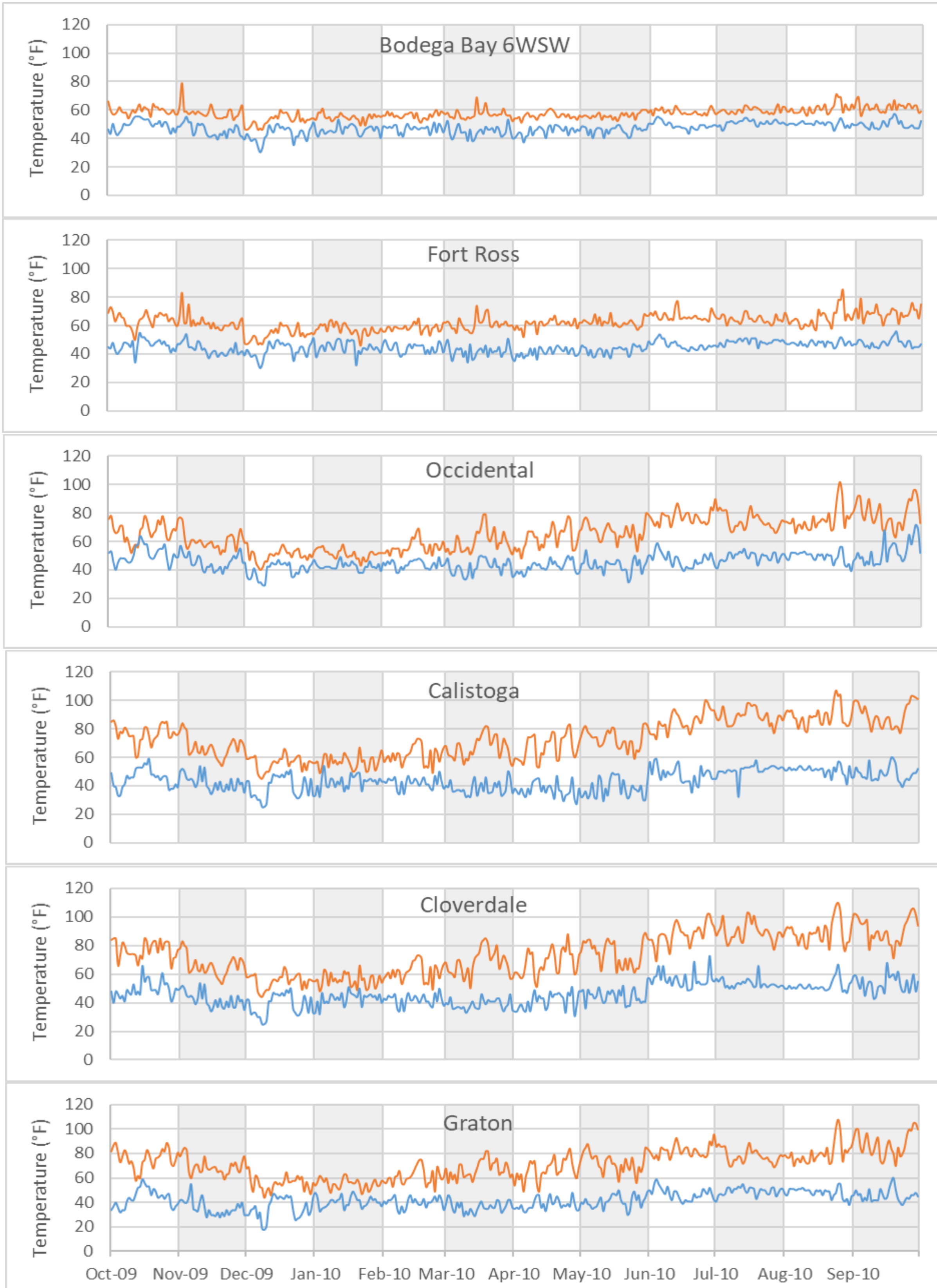
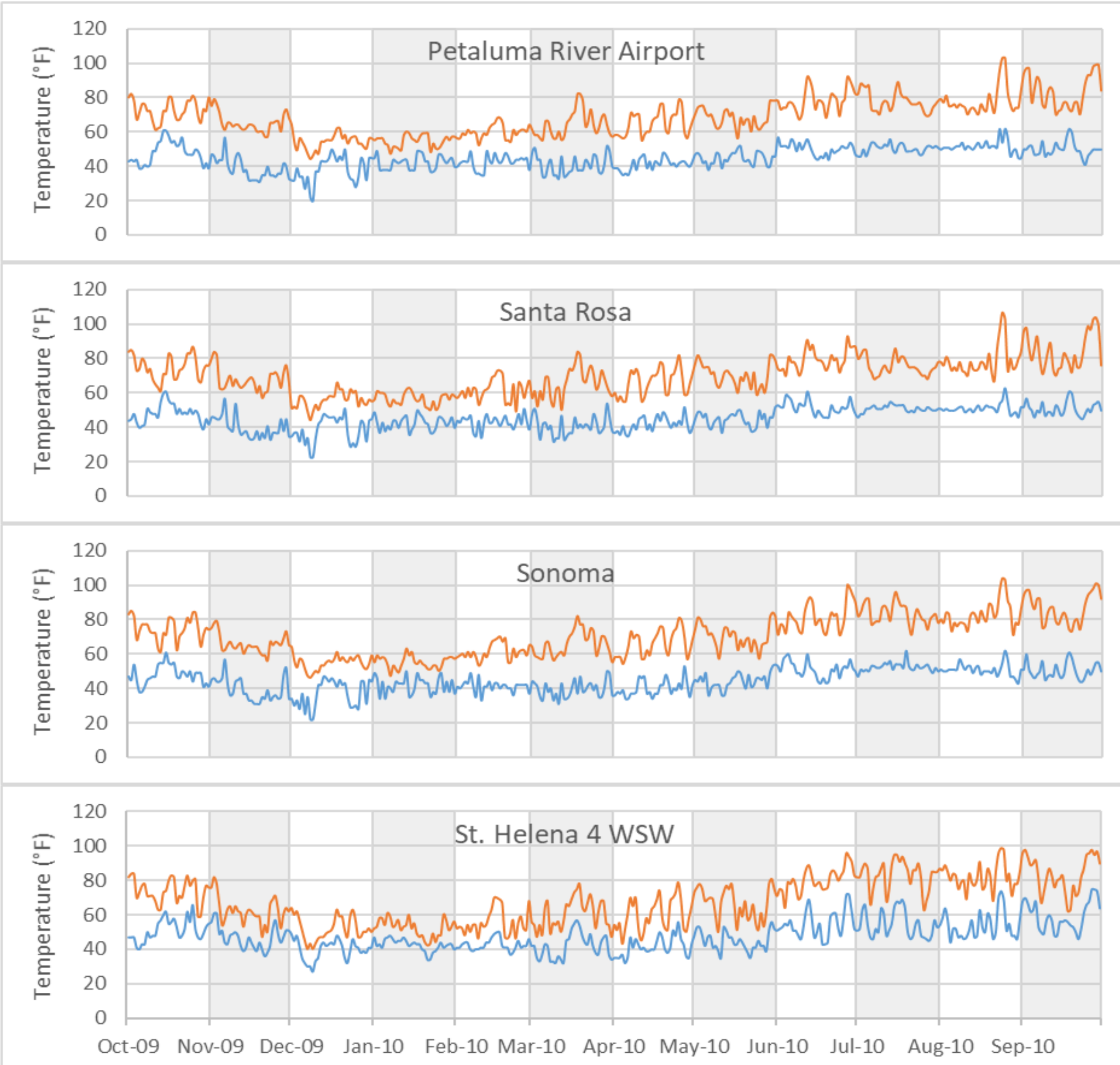


Figure 6: Daily minimum and maximum temperature data used in the Sonoma County SWB model.



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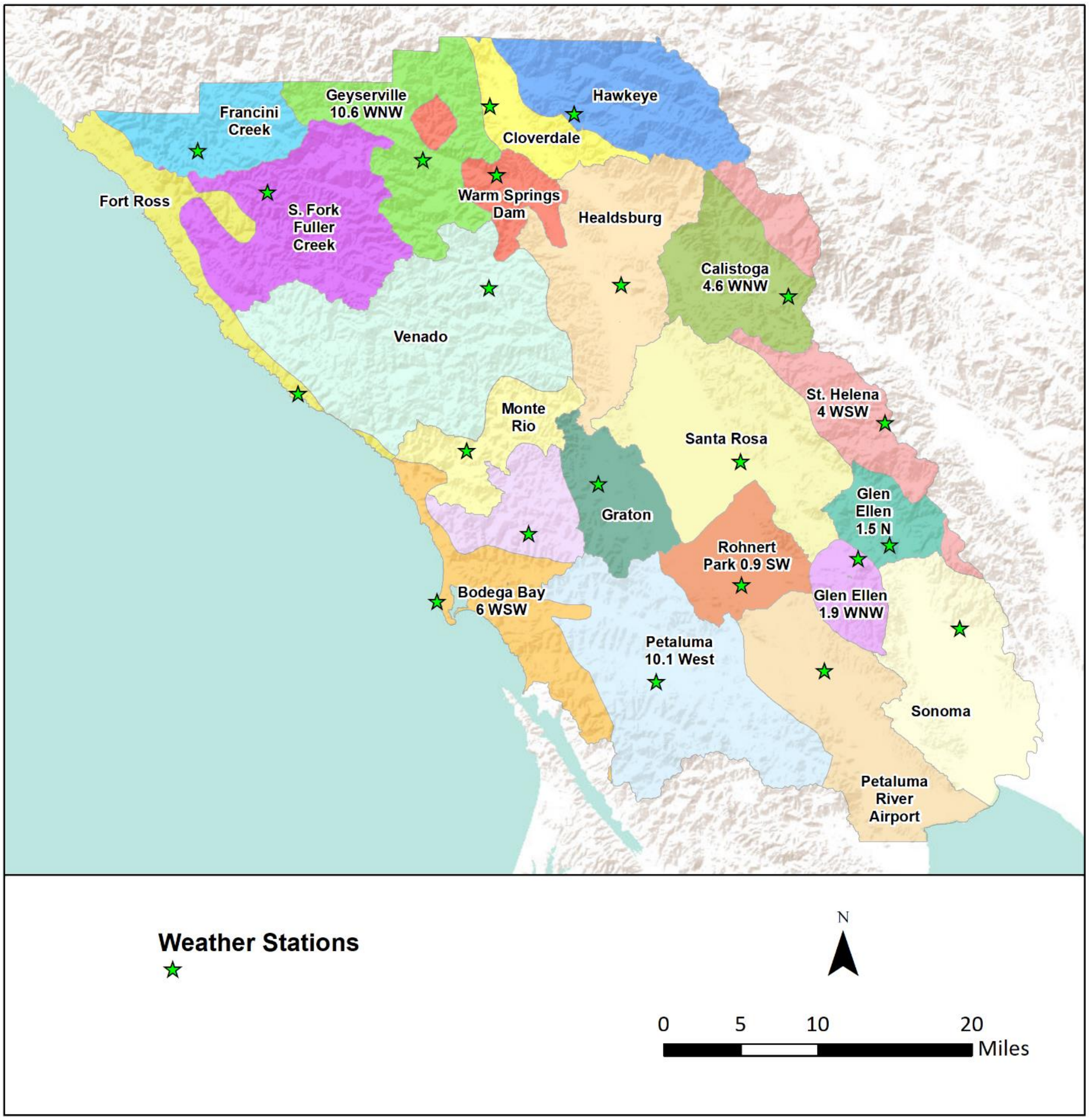


Figure 7: Precipitation zones used in the Sonoma County SWB model.

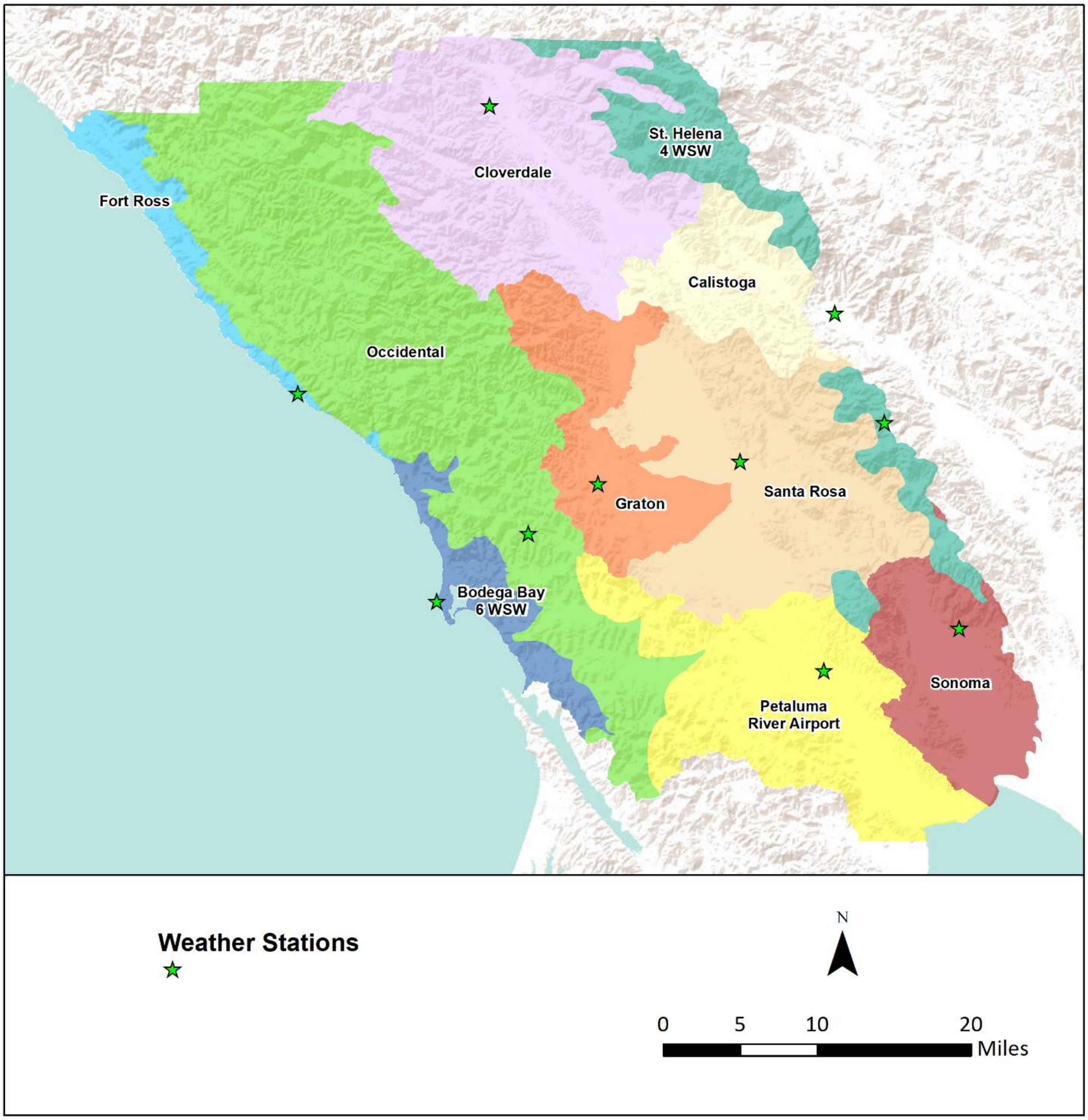


Figure 8: Temperature zones used in the Sonoma County SWB model.

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

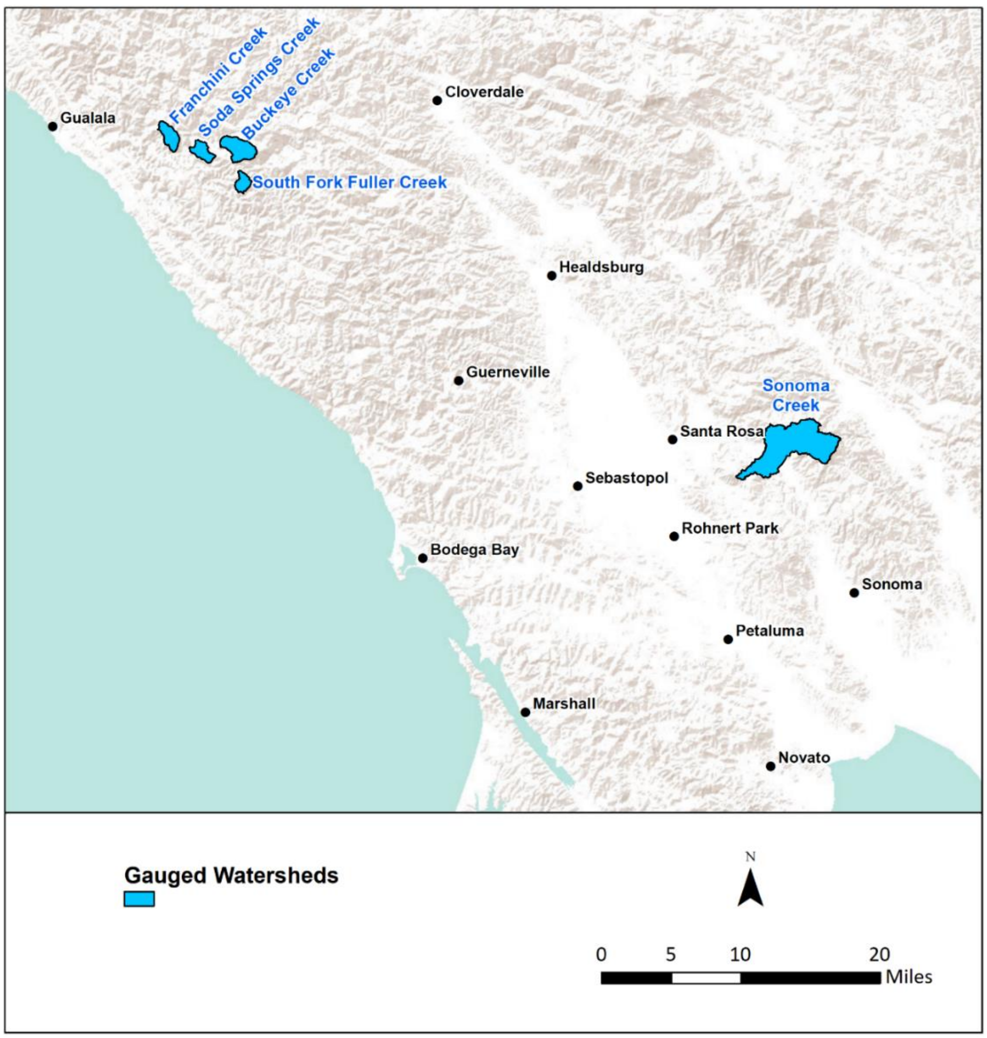
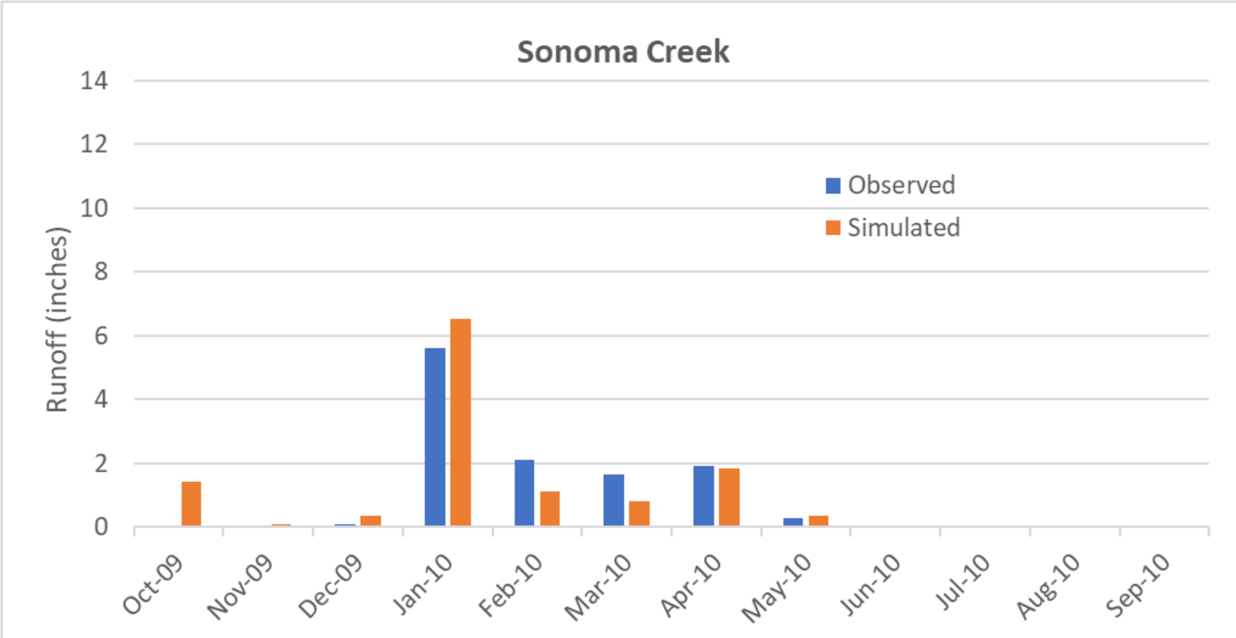


Figure 9: Gauged watersheds used to calibrate the Sonoma County SWB model.



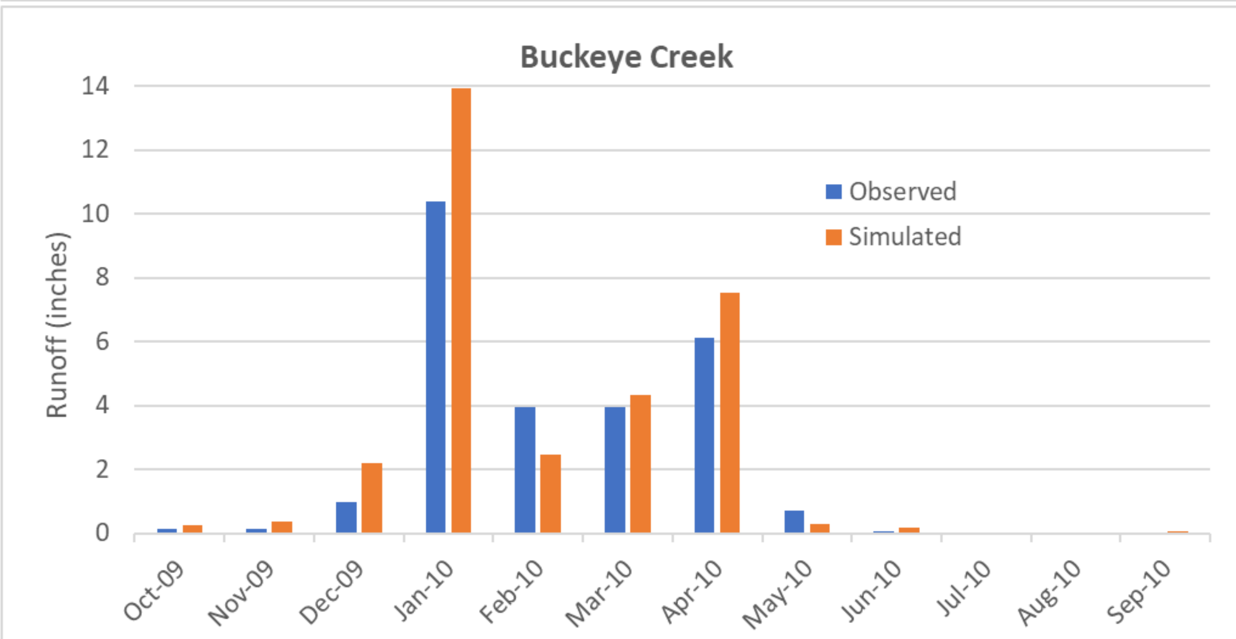
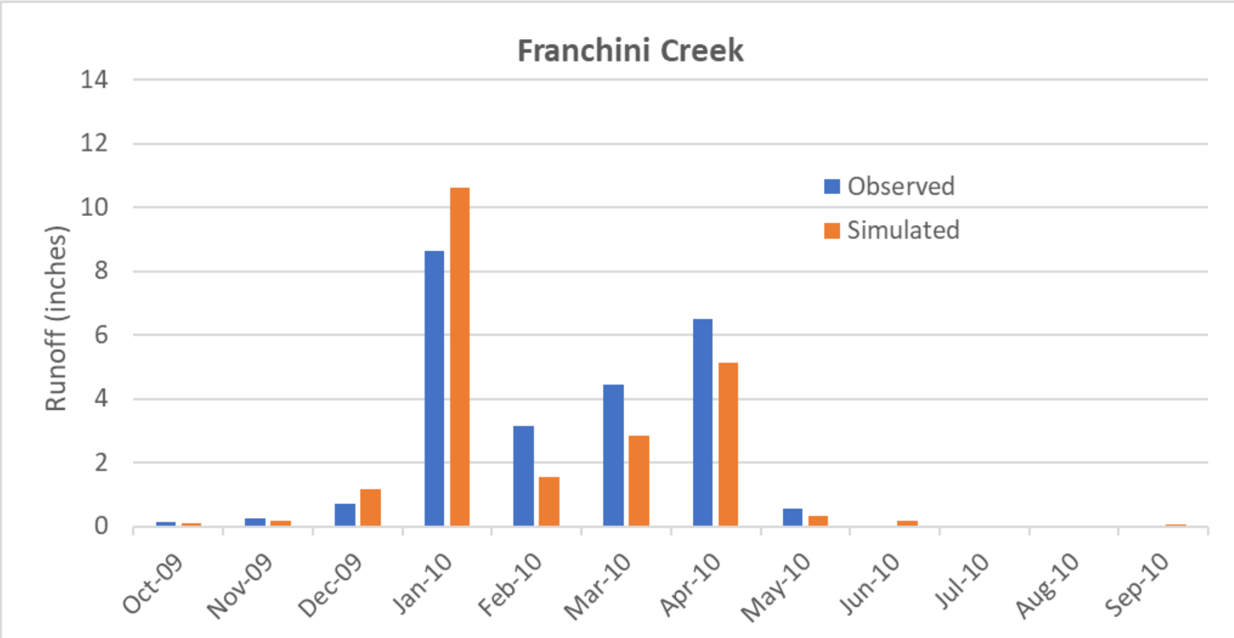
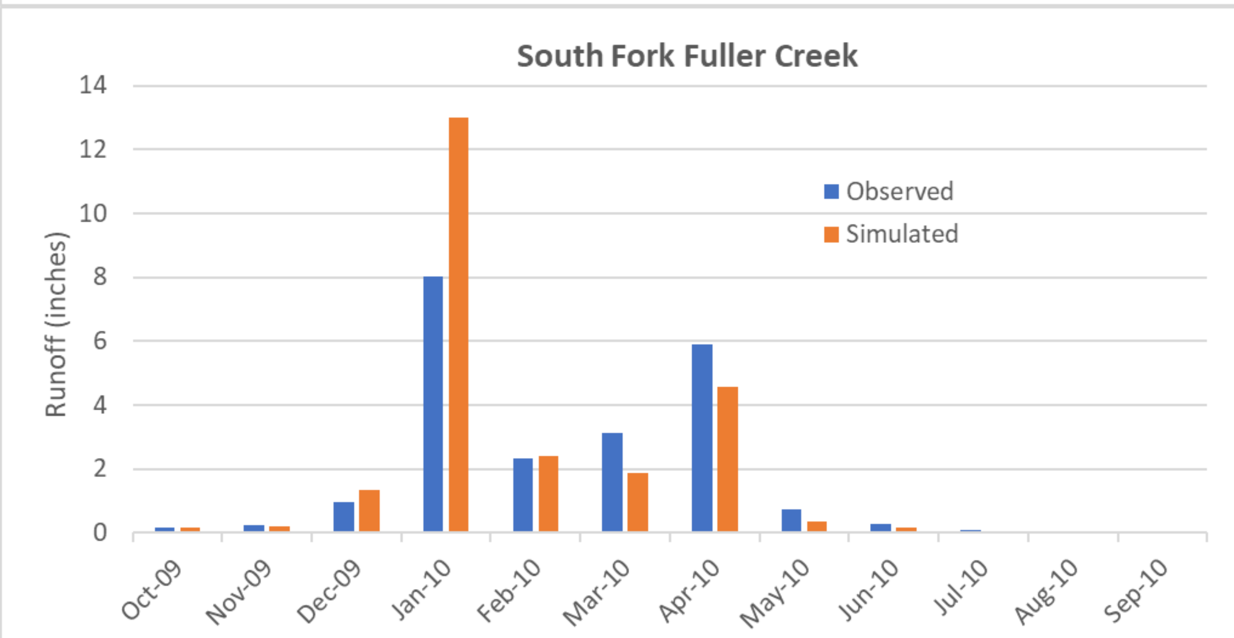


Figure 10: Comparison between monthly surface runoff computed from hydrograph separation at streamflow gauges and monthly surface runoff simulated with the Sonoma County SWB model.





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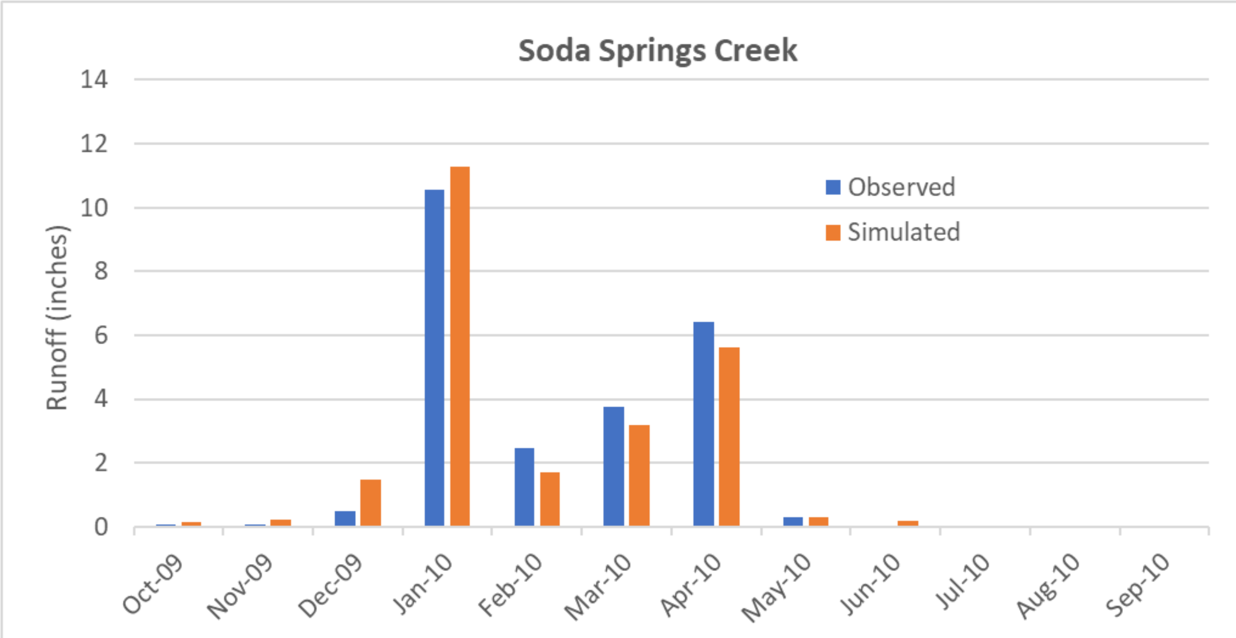

Figure 10 (continued)

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%

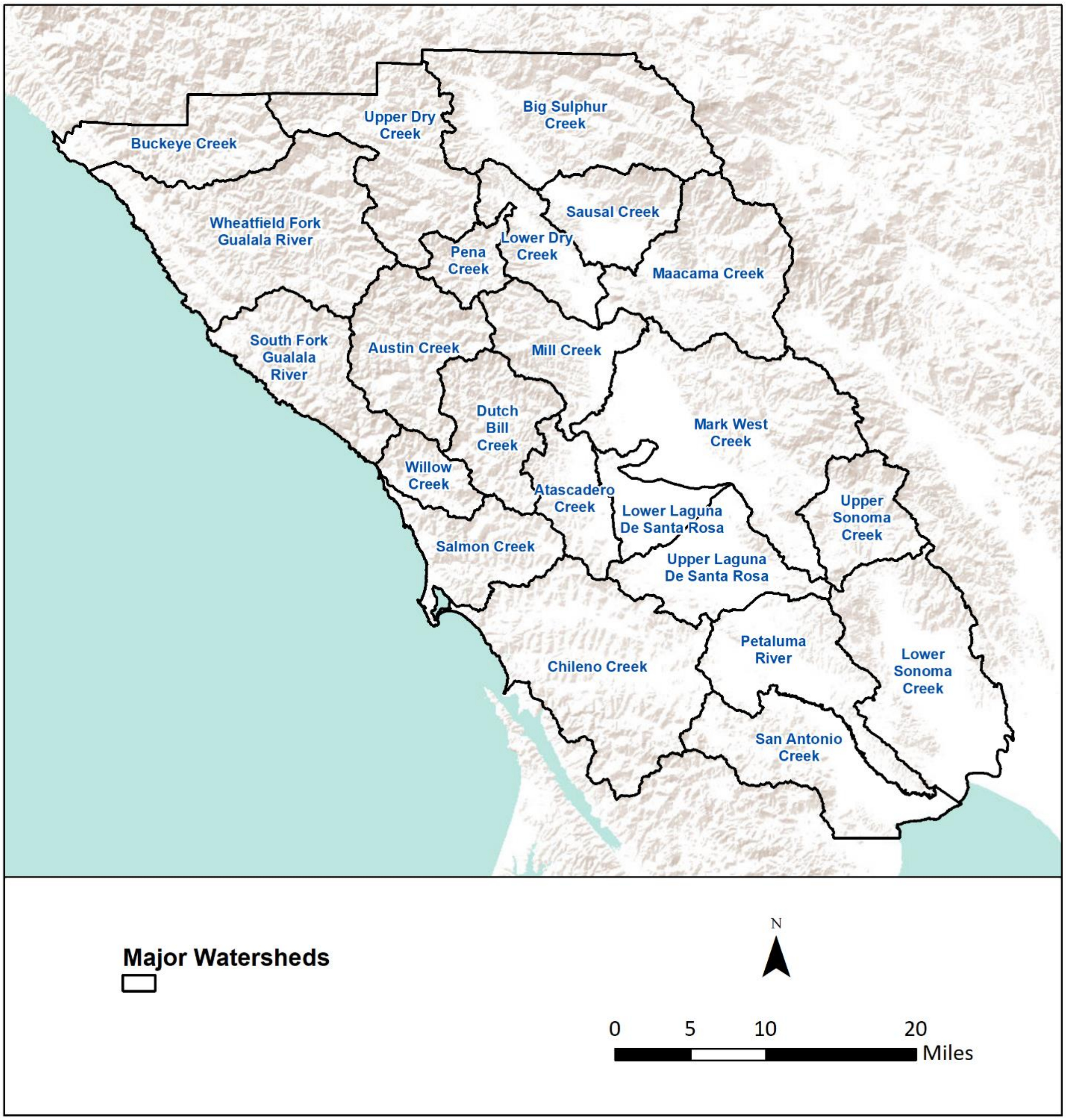

Figure 11: Major watersheds areas used to summarize water budget information in Tables 6 & 7).

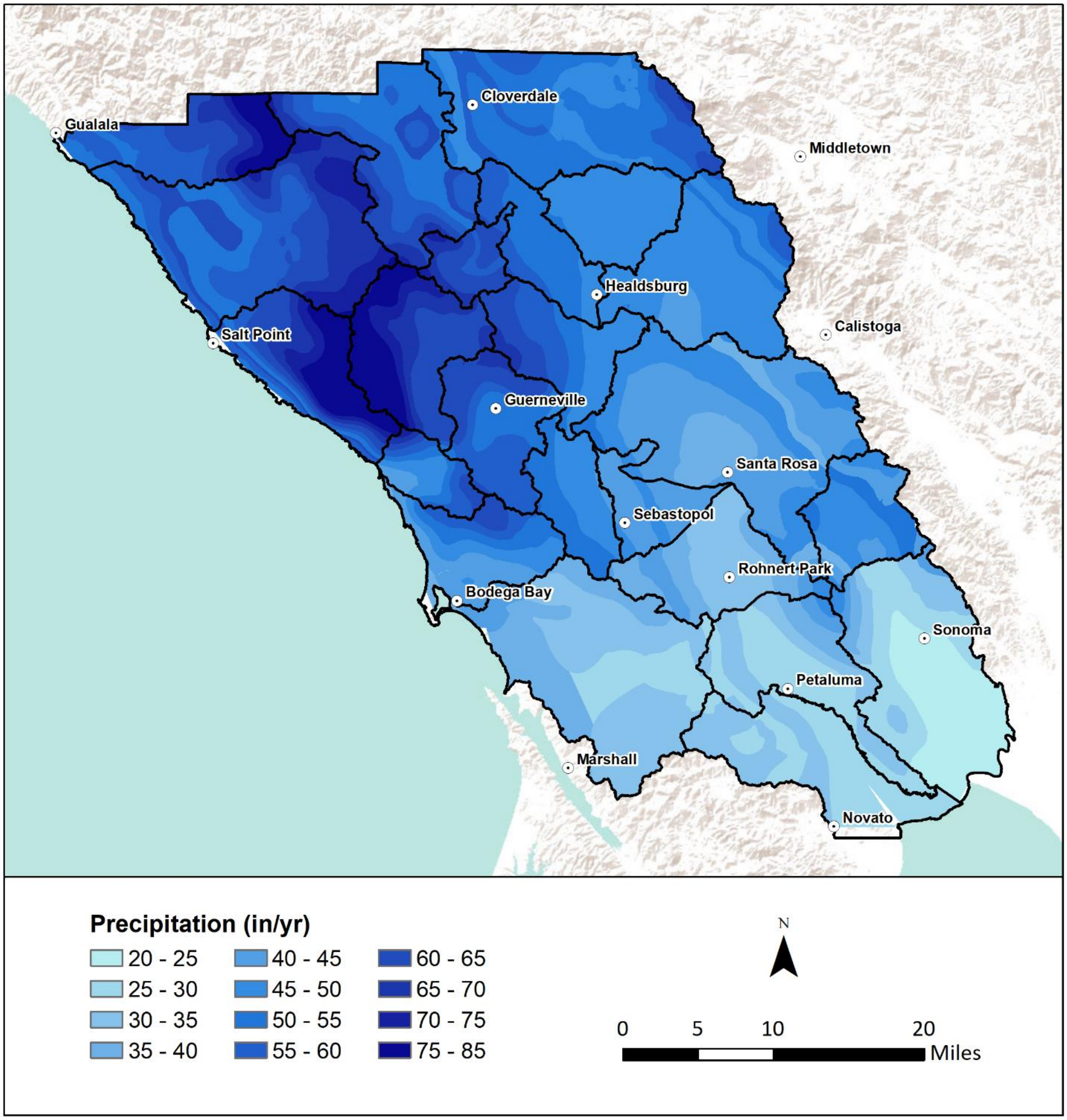

Figure 12: Water year 2010 Precipitation simulated with the Sonoma County SWB model.

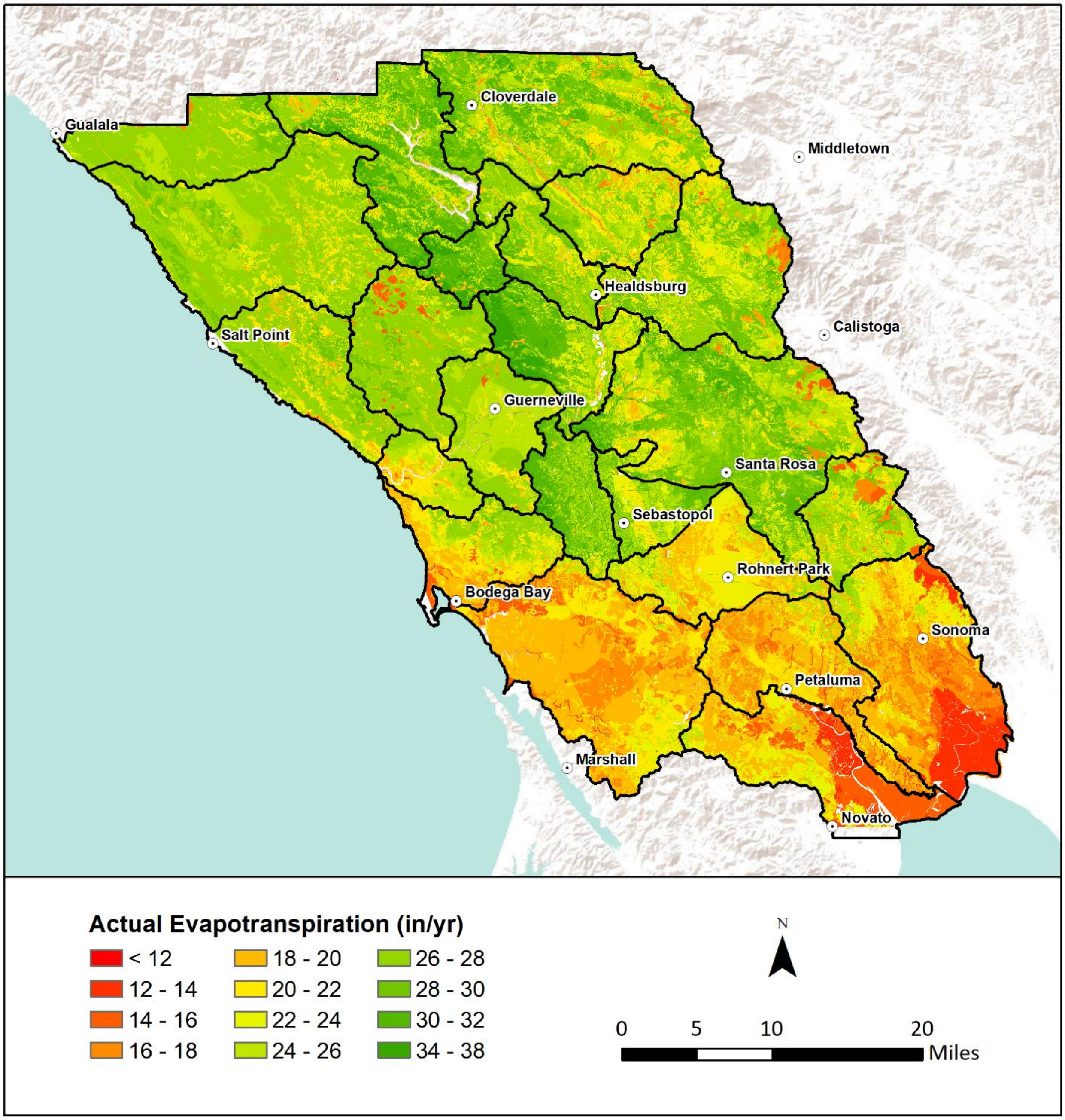

Figure 13: Water year 2010 Actual Evapotranspiration (AET) simulated with the Sonoma County SWB model.

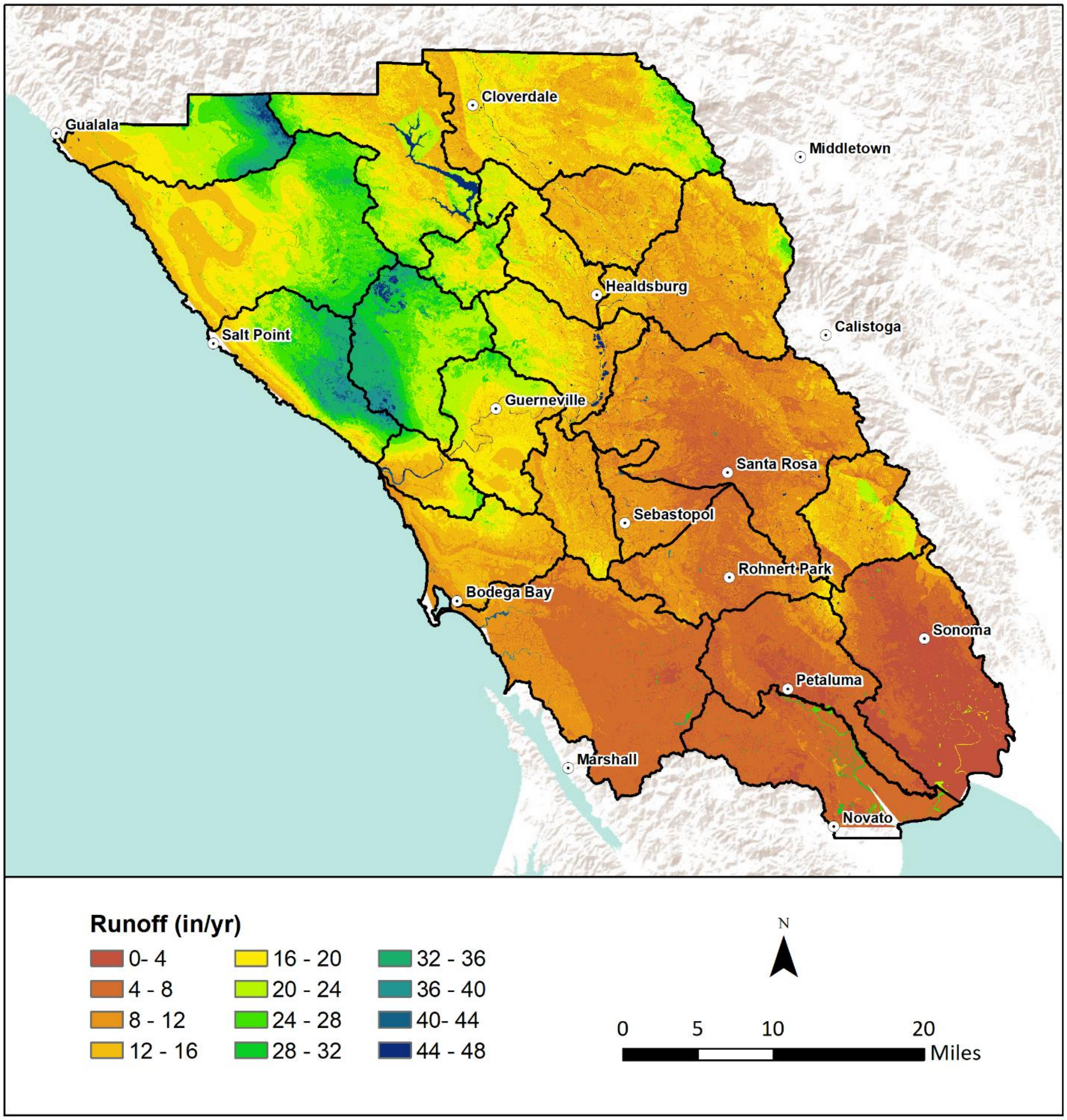

Figure 14: Water year 2010 Surface unoff simulated with the Sonoma County SWB model.

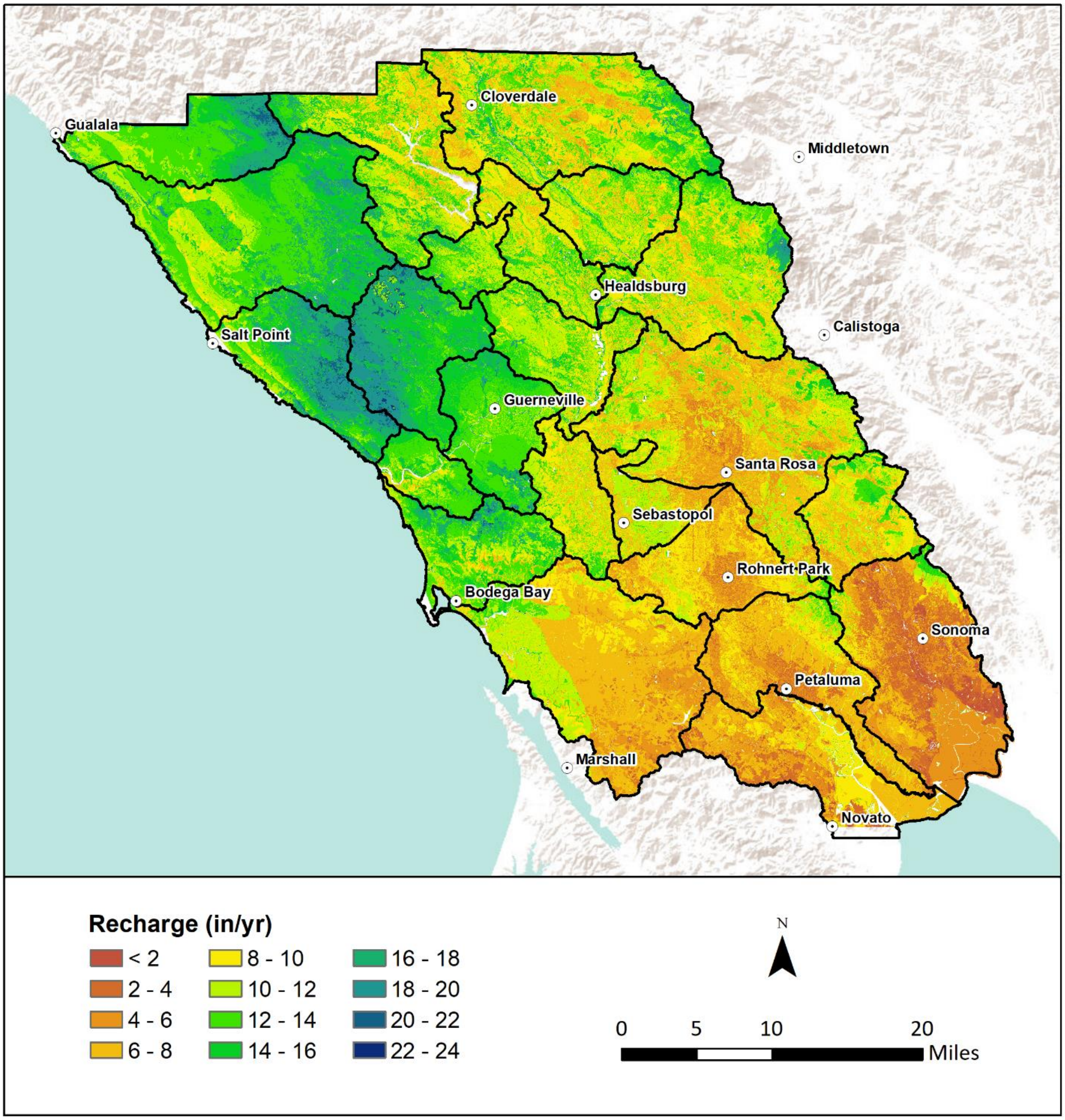

Figure 15: Water year 2010 Recharge simulated with the Sonoma County SWB model.

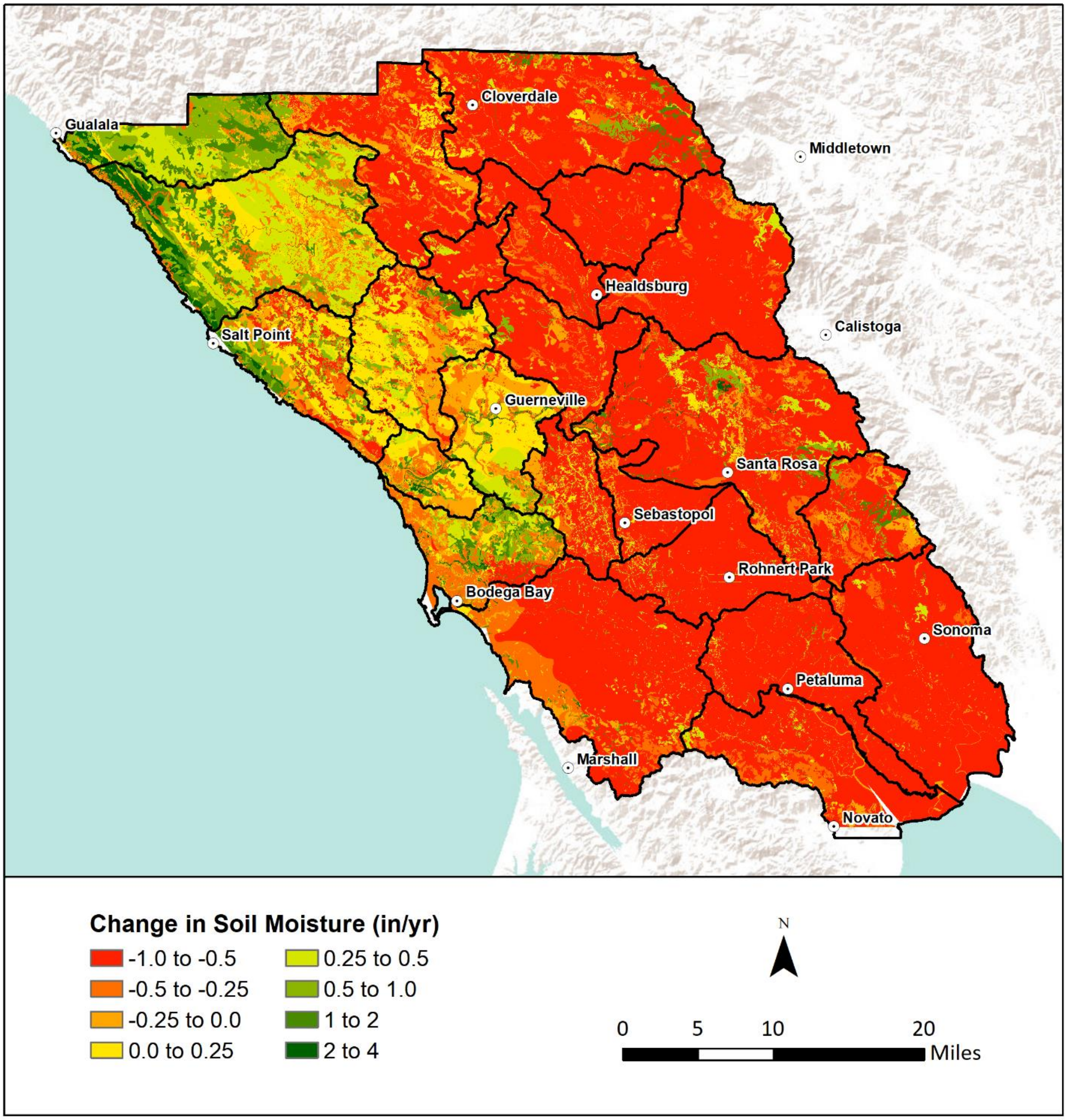

Figure 16: Water year 2010 Soil Moisture Change simulated with the Sonoma County SWB model.

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.

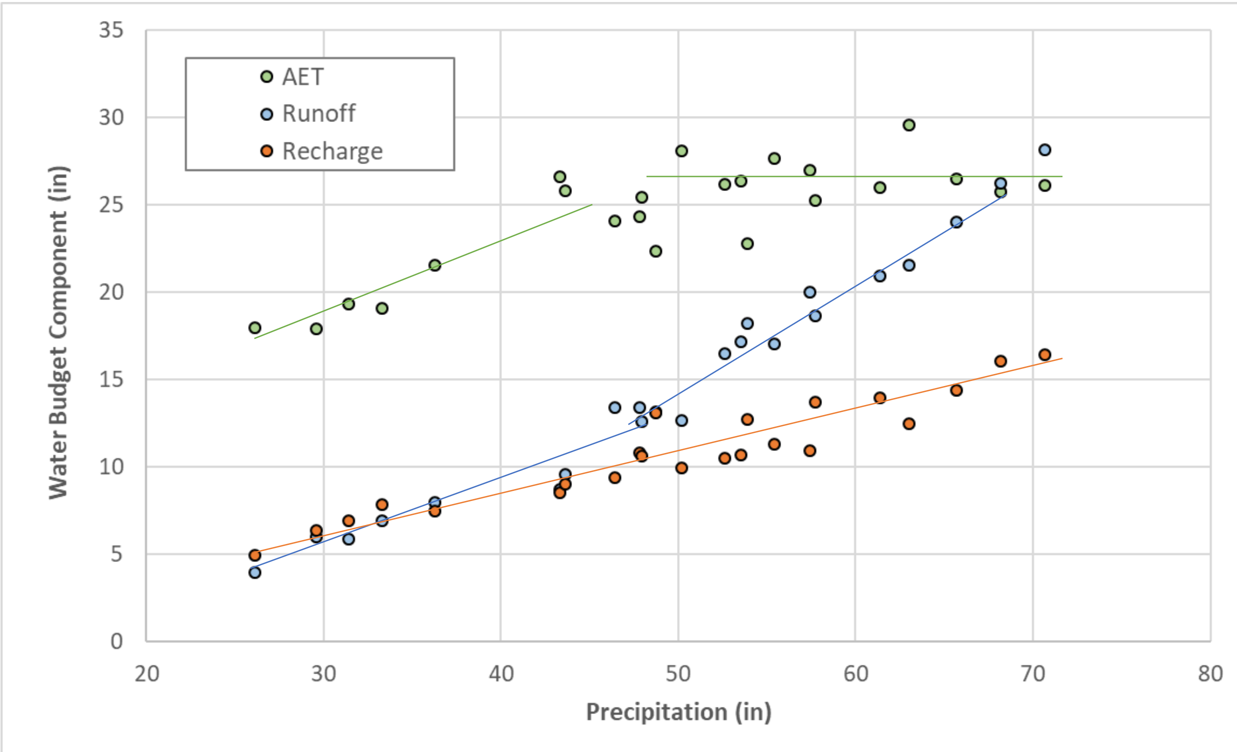

Figure 17: Principal water budget components simulated with the SWB model for major watersheds in Sonoma County as a function of annual precipitation. Trend lines fit by eye.

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