NORTH COAST RESOURCE PARTNERSHIP

CLIMATE & NATURAL RESOURCE ANALYSES AND PLANNING FOR THE NORTH COAST RESOURCE PARTNERSHIP

A Technical Memorandum Summarizing Data Products

FINAL TECHNICAL REPORT

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January 2018

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1. INTRODUCTION

A. PROJECT OVERVIEW

Communities of California's North Coast already experience climate-related impacts to their valuable natural resource base, impacts including droughts, floods, and wildfire, that are projected to potentially increase in both frequency and magnitude. This project provides regional data products that describe historical and potential future patterns linking climate, watersheds, and forests. The primary result of this project is a consistent knowledge base on local climate variability that members of the North Coast Resource Partnership can use across their region to create customized, yet comparable, data products to inform multiple long-term planning efforts.

Pepperwood partnered with the U.S. Geologic Survey (USGS) and West Coast Watershed to provide analysis and planning support for the following priority areas identified as part of the Regional Growth Council planning project for the North Coast Resource Partnership (NCRP) region.

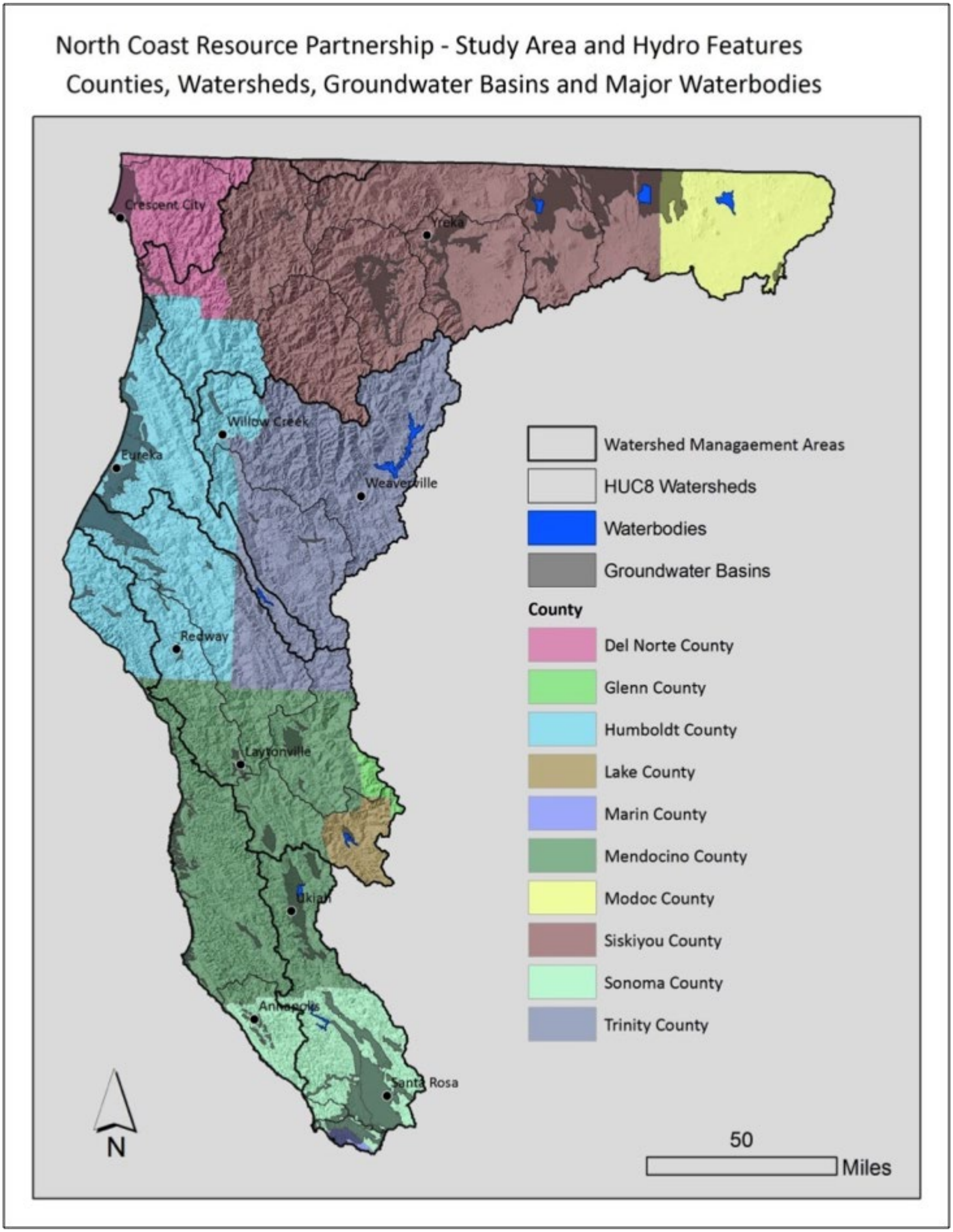
- Priority 2: Climate change adaptation
- Priority 4: Forest ecology and watershed hydrology
- Priority 5: Groundwater analyses and planning

This project relies on methods developed by Pepperwood's Terrestrial Biodiversity Climate Change Collaborative (tbc3.org) that build on the foundational USGS California Basin Characterization Model (Flint et al. 2013). The majority of products are localized summaries of historical and projected future scenarios for climate, watershed processes, groundwater resources, forest vegetation vulnerabilities, and fire frequencies for the North Coast generated using the California Basin Characterization Model (2014 CA BCM) These include 2014 CA BCM -derived models of native vegetation vulnerability (Thorne et al. 2016) and fire risks (Krawchuk and Moritz 2012).

Projections summarized here focus primarily on capturing the effects of "business as usual" emissions on long-term (30-y) trends in climate and hydrology and include low, moderate, and high precipitation scenarios. Data products provided also include a "mitigated" low emissions scenario for comparison. Given the resources available, we focused on summarizing results for the region as a whole, and in some cases complement these regional results with comparative summaries for sub-regions including Watershed Management Areas (WMAs), major drainage basins (HUC-8 units defined by the CA Department of Water Resources), and groundwater basins (defined by the CA Department of Water Resources), as described within. These results generate spatially and temporally variable estimates of natural resource vulnerabilities to inform priorities for climate change adaptation including forest, watershed, and groundwater planning.

Thus, primary outputs of this project are comprehensive data sets that can be queried at finer spatial or temporal scales as needed. This technical memorandum complements data products by providing a brief summary of each analysis, appendices for reference, and a detailed inventory of project deliverables, including maps and time series provided in ArcMap, Excel, and PowerPoint formats.

Figure 1: PROJECT AREA



This technical memorandum is supported by the following attachments and supporting files (see Appendix A for details).

1. Attached appendices providing supplementary documentation
2. Companion PowerPoint compilation of 37 map plates generated. There were 63 total maps created.
3. Excel spreadsheets containing all generated numeric data tables (GIS zonal statistics and numeric time series), referenced here by filename
4. ESRI map package including ASCII data files from 2014 California Basin Characterization Model including annual, seasonal, and 30 year statistics

B. KEY FINDINGS FOR THE REGION

Highlights of key findings by analysis area, described in more detail in the memorandum body, are summarized below. Projected ranges represent values for "business as usual" emissions across three scenarios including low, moderate, and high precipitation.

Historical and Projected Climate and Hydrology

- Summer season temperatures are projected to increase on the order of 3 – 5 °F by mid-century (2040-2069) and 6–9 °F degrees by end-century (2070-2099).
- Winter season temperatures are expected to increase on the order of 5–7 °F by mid-century and 8–11 °F by end-century.
- Warmer temperatures are projected to increase rates of modeled actual evapo-transpiration on the order of 4–11% by mid-century and 11–13 % by end-century.
- Increased rainfall variability combined with increased evapo-transpiration rates are projected to increase climatic water deficits in soils, a measure of drought stress, by approximately 10–19% by mid-century and 16–32% by end-century.
- End-century projected water deficits represent an effective loss of 3–6" of rainfall equivalent from soils by the end of the dry season relative to today's conditions.
- The majority of the area of the North Coast is projected to experience water deficit conditions (drought stress on soils) exceeding a standard measure of historical variability (1 standard deviation) by end-century.
- The observed geographic extent of snow cover on April 1st has decreased by 10% over the recent period (1981-2010) relative to the historical average (1951-1980).
- The geographic extent of April 1st snow cover is projected to shrink from approximately 60% to 30% of the project area by mid-century, and to just 11% of the project area by end-century.
- The average "snow water equivalent" on April 1st, a proxy for snow depth over these areas, is projected to decline from approximately 10" of water (1951–1980) to just 1" by end-century.

Watershed Runoff and Stream Flow

- A water supply indicator comprised of recharge plus runoff can be used to provide an overview of potential impacts of climate change. A comparison of this indicator for the 1920-2009 period to the projected conditions for 2010-2099 suggests that a high rainfall scenario (with on the order of 20% greater rainfall than the baseline) would result in only 4% more water supply, while the low rainfall scenario could result in 13% less available water.
- Watershed resilience can be estimated in part by comparing the relative dominance of runoff or recharge on hydrology, with runoff-dominated watersheds hypothesized to be more vulnerable in terms of water supply to more variability in projected future conditions.
- Cumulative stream flow volumes for three study basins (Russian River, Eel River, and Redwood Creek) show the potential impact of low versus high rainfall scenarios ranging from -25 % to +40% of reference values for annual cumulative discharge under 90 year projections.
- More variable precipitation is projected to create more inter-annual variability in stream flow, with potentially more frequent droughts and flood years with increases of greater than 50% more high and low values for annual discharge.
- The moderate rainfall scenario, although similar in long term rainfall averages to historical conditions, also features more low and high stream flow years: thus all projections evaluated suggest great inter-annual variability in available stream flow.

Groundwater Resources

- Average recharge is projected to decrease under moderate and low rainfall scenarios due to rainfall variability combined with increased evaporative demand. In-situ regional recharge is projected to decrease by approximately 20% by end-century under low rainfall scenarios.

- Where available, groundwater recharge is estimated to be a less variable supply of water from year-to-year than watershed runoff under projected futures.
- Under low rainfall scenarios, rainfall is projected to become a more significant fraction of total potential water supply.
- Comparisons of spatial variability in historical recharge rates can be used to assess the relative vulnerability of groundwater basins in the North Coast, and to inform recharge protection strategies.

Forest Ecology

- Approximately 65% of the region's natural vegetation is currently estimated to be prone to climatic stress: by end-century, this is projected to grow to approximately 85% of the project area.
- There is uncertainty about how native vegetation may respond to unprecedented combinations of temperature and rainfall in California.
- The projected extents of stress on vegetation are similar for both high and low rainfall scenarios, since high rainfall scenarios generate novel climates for California vegetation in this region, which absent data, are considered stress-inducing.
- There are likely to be vegetation species climate "winners" and "losers," with future conditions likely favoring drought-adapted species, which may promote expansion of chaparral and shrublands at the expense of woody species.
- Long-term monitoring of native forest vegetation is needed to better inform models with an improved understanding of mechanisms and trajectories of potential change.

Fire Risks

- With projected climate change the fire risk, as measured by the 30 year average in the probability of burning in a given year averaged across the NCRP increases from 10% historically to 15% by the end of century under both examined scenarios.
- Critical data gaps in fire modeling include the short historical record available to calibrate models and the challenges of incorporating ignition risks attributable to urban development expanding into wild land regions.

C. IMPLICATIONS FOR LONG TERM PLANNING

Adaptive management planning in the context of climate change and other stressors should consider the following principles.

- The two greatest uncertainties in localized climate-hydrology projections are 1) how fast projected changes will occur due to uncertainties in future rates of greenhouse gas emissions and 2) whether rainfall trends will increase or decrease overall in Northern California.
- Physical, process-based watershed models (featuring well-mapped topography, geology, and soils) can estimate the response of watersheds as a function of seasonal temperature and seasonal rainfall projections.
- Given the hydrologic effects of projected increased temperatures across all climate models, water conservation and long-term plans for water security are increasingly important under projected futures.
- Protecting high value recharge zones will be critical to enhancing water security by maximizing subsurface storage in aquifers, a relatively resilient form of natural water storage, where available.
- Effective watershed protection strategies can utilize maps of historical watershed behavior (rather than utilizing models of projected future conditions) for planning purposes, since the location of key watershed structural elements, such as recharge zones, are relatively fixed facets of the landscape.
- Communities need to innovate ways to capture winter precipitation, storm water runoff, and peak flows for use during dry seasons and to recycle wastewater streams.
- Land stewards should aim to increase soil moisture holding capacity of soils where feasible through vegetation management, soil amendments, and approaches to sequestering carbon.
- Long-term vegetation monitoring sites, coordinated with local weather and water data stations, are needed to measure stress and/or mortality, in locations identified with high vegetation vulnerabilities.
- Managers should expand collaborative approaches to landscape-level vegetation management and treatments capable of reducing accumulated fuel loads and associated fire risks.
- Communities should develop plans for post-fire management that address strategies for native vegetation resilience and mitigation of potential impacts on watershed runoff and water quality.
- Climate adaptive strategies should be integrated into all aspects of hazard mitigation planning, including responses to drought, flood, earthquake and fire.

D. RESOURCES FOR NEXT STEPS

- California features a growing community of natural resource planners and managers focused on climate adaptation. This project team and many others share our work with local resource managers as data sets and case studies featured on the California Climate Commons (http://climate.calcommons.org/) established by the multi-jurisdictional California Landscape Conservation Cooperative. For example, the Climate Ready North Bay project, supported by the California Coastal Conservancy, shows how local water and open space agencies in Marin, Sonoma, and Napa counties utilized CA Basin Characterization Model outputs to inform specific natural resource management strategy questions (see Micheli et. al. 2016 and http://climate.calcommons.org/crnb/home).
- There are many gatherings and data clearinghouses emerging to support local communities and their leaders seeking to advance local climate adaptation efforts. For national resources, we also recommend exploring the new national Partnership for Resilience and Enhanced Preparedness website (www.prepdata.org/).

2. NATURAL RESOURCE ANALYSES AND DATA PRODUCTS

A. HISTORICAL AND PROJECTED CLIMATE AND HYDROLOGY

Summary

Climate and hydrology data products generated by this project are based on historical measurements combined with climate projections derived from a global set of atmospheric circulation models peer-reviewed by the Intergovernmental Panel on Climate Change (IPCC) (Meehl et al. 2007; Taylor et al. 2011). A carefully selected set of these global models were “downscaled” to increase their spatial resolution via a California-wide downscaling effort called the USGS California Basin Characterization Model (2014 CA BCM) (Flint and Flint 2014). Climate vulnerability analyses conducted for this study are thus grounded in an empirical, watershed-based approach to assessing landscape vulnerability with a focus on climate-driven impacts to the hydrologic cycle. The coupled USGS climate-watershed 2014 CA BCM model was then used in the following sections to estimate key climate threats to resources including rivers, groundwater basins, and forest ecosystems.

This approach enables a process-based translation of how climate interacts with physical geography to estimate local watershed response in terms of microclimate, runoff, recharge, soil moisture, the amount of snow, and evapo-transpiration. The 2014 CA BCM produces high-resolution maps of climate trends (by aggregating 18-acre grid cells) as well as tabular time series data (by aggregating monthly time steps) for a place of interest.

In addition to historical and projected change in temperature, precipitation, runoff and recharge, this section includes a summary of changes in snow extent, snow water content and patterns of projected climatic water deficits in soils. Climatic water deficit projections, including where deficits are projected to exceed a historical range of variability, integrate the combined effects of topography, rainfall, temperature, energy loading, and soil/geology properties on soil water availability in the landscape. This is a useful indicator of landscape stress due to potential drought caused by projected climate change and is also strongly correlated with vegetation cover and fire risks.

Data set description

Historical and projected climate and hydrology data sets were created by querying the USGS California Basin Characterization Model (2014 CA BCM) at multiple temporal and spatial scales. Results are generally analyzed in ESRI ArcMap and R programming formats to generate maps, data spreadsheets, and graph products. Spatial scales range from the North Coast region as a whole, to Watershed Management Area (WMA) boundaries, and Department of Water Resources HUC-8 watershed boundaries (defining major river systems) nested within WMAs. Products include spatial data sets, extracted map products for key variables of interest, and numeric time series of key variables for a range of seasonal, annual, or 30-year time steps.

The primary source data set used for extracting these analyses was the peer-reviewed 2014 California Basin Characterization Model (2014 CA BCM), a watershed model at the spatial resolution of a 270 meter grid (Flint et al. 2013, Flint and Flint 2014). This model applies a set of regional water-balance equations to simulate hydrologic responses to climate variability. Empirical (historical) climate input data is derived from PRISM (Daly et al. 2008) and data measured at weather stations throughout the region from 1920–2010. The 2014 CA BCM models the interactions of climate (rainfall and temperature) with mapped landscape attributes including topography, soils, and underlying geology. For a detailed description of the 2014 CA BCM source data inputs, methods, and resulting datasets please see: California Basin Characterization Model: A Dataset of Historical and Future Hydrologic Response to Climate Change: U.S. Geological Survey Data Release.

NCRP managers selected four global future scenarios (shown below) for direct analysis that provided a set of projections for the next 90 years (2010–2099). Data products derived include 30-year average values to delineate potential long-term trends in adherence with USGS recommendations. This allows comparison of two historical periods: 1951–1980 (often considered a "pre-climate change" reference period), and 1981–2010 ("recent" conditions) that have been calibrated using empirical weather and stream flow data. These can be compared with three projected 30-year periods (2010–2039, 2040–2069, and 2070–2099). The majority of data products highlighted in this section represent "business as usual" emissions scenarios, with a "mitigated" emissions scenario provided in the data deliverables set for comparison.

Table 1: GLOBAL CIRCULATION MODELS DOWNSCALED FOR ANALYSES, NCRP REGION

Model Name	Emmisions Scenario	Climatic Trend
CNRM	rcp 8.5 (business as usual)	warm, high rainfall
CCSM 4	rcp 8.5 (business as usual)	warm, moderate rainfall
MIROC esm	rcp 8.5 (business as usual)	hot, low rainfall
GFDL	sres B1 (mitigated)	warm, moderate rainfall

The 2014 CA BCM's downscaled climate and hydrology outputs include air temperature (reported as summer or winter seasonal averages), precipitation (snow and rainfall), runoff, recharge, potential and actual evapo-transpiration, and soil moisture storage. From these direct outputs, with additional analysis, derivative products can be generated that include climatic water deficit (the difference between potential and actual evapo-transpiration—an indicator of drought stress and environmental water demand), water supply (runoff plus recharge), and stream flow based on correlations with stream gage data, as are summarized in subsequent sections. For a more detailed summary of 2014 CA BCM global circulation model inputs used for this study and a glossary of terms, please see Appendices B and C.

Methodology

Climate and hydrology projection data products for the NCRP region were generated by combining historical data with a subset of global circulation models used to generate a set of three futures (in concert with managers) that capture a range of low to high rainfall conditions for "business as usual" emissions scenarios. The global climate models included in 2014 CA BCM model outputs in this report include: 1) CNRM, rcp 8.5 (business as usual), warm, high rainfall climatic trend; 2) CCSM 4, rcp 8.5 (business as usual), warm, moderate rainfall climatic trend; 3) MIROC esm, rcp 8.5 (business as usual), hot, low rainfall climatic trend; and, 4) GFDL, sres B1 (mitigated), high warming, low rainfall climatic trend) (Table 1).

We completed spatial queries of 2014 CA BCM raster layers using both ESRI software and the R programming language. These spatial queries included extracting zonal statistics, tabulating area, masking rasters dependent upon value ranges of other rasters and complete pixel-by-pixel raster calculations, each described below.

Average raster value for polygon extents (zonal statistics): Average pixel values of raster layers within project area watersheds and jurisdictions were obtained in the programming language R. We utilized the rgdal, raster and maptools libraries and the extract and raster tools on ASCII format raster files. See Appendix D for code resources.

Variability calculations (standard deviation and standard error of climate projections): We calculated the standard error for 30-year averages of climate projections for polygons from the extracted zonal statistic for average 30-year standard deviation 2014 CA BCM layers for each time period, and divided that value by the square root of total observed or modeled values (n=30).

Average snow water equivalent above 3,000 ft elevation and percent area of queried region with snow cover: The extent of the project area above 3,000 feet elevation was defined using the 30meter Digital Elevation Model (DEM) by reclassifying all elevations <= 3,000 feet to 'no data' and elevations >3,000 feet to '1' utilizing the ESRI reclassify tool. The resulting layer was used to mask analyses in the ESRI environments, and zonal statistics for the average values of the snow water content estimates for April 1st ("APRPK") layers were calculated in ESRI using the zonal statistics table tool. To calculate the percent area of queried polygon with and without snow, APRPK layers were reclassified to have all values > 0 = '1' and the resultant layer was used with the ESRI Tabulate Area tool to calculate the number of cells of each class within each polygon. The Tabulate Area tool in ESRI allowed for the parsing of a raster layer by polygons and raster values providing a calculation for the area in each polygon filled by a raster value.

Climatic Water Deficit (CWD) beyond historical range analysis: We utilized the spatial (sp) and raster libraries in R to complete pixel by pixel mathematical calculations and to mask regions where projected change in CWD does not exceed historical variability, as represented by one standard deviation of annual values over the 30-year historical period (1951–1980).

Data product summary and key findings

The products described in this section focus on climate trends in temperature, rainfall, April 1st snow water equivalent, extent of snow cover, and climatic water deficit. Tables also display 2014 CA BCM values for evapo-transpiration, recharge, and runoff. Subsequent sections translate 2014 CA BCM model outputs to potential impacts on water supply, groundwater, and forest resources.

Baseline (1951–1980) and recent (1981–2010) climate-hydrology conditions for the NCRP region

Parameters include temperature, rainfall, actual evapo-transpiration, and climatic water deficits with a summary of spatial and temporal trends in climate using 30-year time steps. Products include regional maps for baseline and recent conditions for all BCM variables and data tables summarizing regional baseline and trends in a numeric format.

Table 2: HISTORICAL CA 2014 BASIN CHARACTERIZATION MODEL OUTPUTS (1950-2010), NCRP REGION

NCRP Project Area: Basin Charqacterization Model Outputs, 1950–2010				
	Historical		Recent Values	
	1950-1981	± SE	1981-2010	± SE
CWD (in/y)	20.7	0.5	20.9	0.6
DJF (°F)	31.5	2.2	32.3	2.2
JJA (°F)	80.4	2.0	80.5	1.8
PPT (in/y)	55.7	2.5	54.1	2.8
RCH (in/y)	20.5	1.0	19.3	1.0
RUN (in/y)	18.1	1.8	17.0	1.8
AET (in/y)	16.0	0.4	16.5	0.5
SWE (in)	10.0	–	7.9	–

Table 2 acronyms apply to all generated 2014 CA BCM table products: JJA=average monthly temperature for June, July and August; DJF=average monthly temperature for December, January, and February; PPT=average annual precipitation; RCH=average annual recharge; RUN=average annual runoff; AET=actual evapo-transpiration; CWD=climate water deficit (calculated as actual evapo-transpiration minus potential evapo-transpiration); SWE=snow water equivalent (as of April 1st on portion of project area exceeding 3000' elevation); and SE=standard error.

Table 2 summarizes "historical" (1950–1981, considered a "reference" baseline) for comparison with "recent" observed (1981–2010) and future "projected" values.

Comparable tables for historical and recent conditions have been generated at all of the following scales: Watershed Management Area boundaries (WMAs), counties, and HUC-8 watersheds. These are available in the Excel sheet labeled "NCRP BCM tables for polygons.xls."

Mapped 2014 CA BCM variables for historical and current conditions can be viewed in Appendix H and on Map Slides 6–30, and are often displayed as a temporal map sequence to show changes in landscape patterns over time.

Magnitude of projected climate change for NCRP region

We projected changes in climate parameters including temperature, precipitation, recharge, runoff, evapo-transpiration, April 1st snow water content and extent, and climatic water deficits. We compare outputs for three selected climate scenarios (high, moderate, and low rainfall) for future time periods defined as early-century (2010-2039), mid-century (2040–2069) and end-century (2070–2099). Products include map and tabular spatial and temporal trends comparing historical and projected 30-year time steps. The snow analyses were only completed for the moderate rainfall scenario, as this analysis was not included in the original project scope. Companion data products also include mapped data (based exclusively on the moderate rainfall scenario) showing the spatial variability underlying these regional results, which are often displayed temporal sequences. Data files also include summaries for a "mitigated scenario" (not shown below due to space limitations).

Table 3: PROJECTED CA 2014 BASIN CHARACTERIZATION MODEL OUTPUTS (2010–2099), THREE FUTURES, NCRP REGION

NCRP Project Area: Basin Characterization Outputs, 2010 - 2099																		
	Scenario 1 (CCSM rcp 8.5)						Scenario 2 (CNRM rcp 8.5)						Scenario 3 (MIROC esm rcp 8.5)					
	Warm, Moderate Rainfall						Warm, High Rainfall						Hot, Low Rainfall					
	2010-2039	± SE	2040-2069	± SE	2070-2099	± SE	2010-2039	± SE	2040-2069	± SE	2070-2099	± SE	2010-2039	± SE	2040-2069	± SE	2070-2099	± SE
CWD (in/y)	21.8	0.5	23.1	0.5	24.0	0.5	21.1	0.5	22.8	0.6	24.9	0.5	22.6	0.5	24.6	0.5	27.2	0.5
DJF (°F)	33.6	2.3	34.5	3.2	37.3	3.0	34.4	2.2	36.0	2.7	39.6	2.4	33.9	2.8	36.8	2.4	40.0	2.4
JJA (°F)	82.9	2.2	85.5	2.0	88.8	2.1	83.0	2.0	85.3	2.3	88.8	2.4	82.7	2.6	87.3	2.3	91.4	2.1
PPT (in/y)	56.3	2.6	55.2	2.4	55.0	3.1	64.6	2.3	65.5	3.3	68.4	3.1	52.2	1.5	47.1	2.2	46.8	2.1
RCH (in/y)	19.9	0.9	19.3	1.0	18.3	0.9	21.2	0.8	21.0	0.9	21.1	0.8	19.1	0.7	16.6	1.0	16.9	0.8
RUN (in/y)	18.6	1.8	18.3	1.6	18.4	2.2	24.7	1.9	26.3	2.6	29.4	2.5	16.0	1.1	13.3	1.4	13.5	1.2
AET (in/y)	17.0	0.5	16.9	0.5	17.8	0.5	18.0	0.5	17.7	0.5	17.7	0.4	16.2	0.4	16.6	0.4	16.2	0.4

- *Magnitude of projected climate change for NCRP region-key findings*: Table 3 above shows the projected 2014 CA BCM values for three scenarios, including a moderate rainfall, a high rainfall, and a low rainfall future, in 30-year time steps for the period spanning 2010–2099.

Table 4 below shows recent and projected future values to the historical baseline and expresses the difference as a "delta" temperature increase in degrees Fahrenheit and percent change in 2014 CA BCM variables from those reported in Table 2 as inches of water per year.

Table 4: CHANGE IN 2014 CA BASIN CHARACTERIZATION MODEL OUTPUTS (1981–2099), THREE FUTURES, NCRP REGION

NCRP Project Area: Recent observed and projected change from historical baseline (1951–1980) under three futures, 30-y time steps										
		Scenario 1 (CCSM rcp 8.5)			Scenario 2 (CNRM rcp 8.5)			Scenario 3 (MIROC esm rcp 8.5)		
		Warm, Moderate Rainfall			Warm, High Rainfall			Hot, Low Rainfall		
*Variable	1981-2010	2010-2039	2040-2069	2070-2069	2010-2039	2040-2069	2070-2069	2010-2039	2040-2069	2070-2069
Pct Change CWD	1	5	12	16	2	10	21	9	19	32
Delta DJF (°F)	0.8	2.1	3.0	5.9	2.9	4.6	8.1	2.5	5.3	8.5
Delta JJA (°F)	0.2	2.6	5.1	8.4	2.6	5.0	8.5	2.4	6.9	11.0
Pct Change PPT	-3	1	-1	-1	16	18	23	-6	-15	-16
Pct Change RCH	-6	-3	-6	-11	3	2	3	-7	-19	-18
Pct Change RUN	-6	3	1	2	36	45	63	-11	-26	-25
Pct Change AET	4	6	6	12	13	11	11	2	4	1
Pct Change SWE	-23	-	-64	-90	-	-	-	-	-	-

*Changes in temperature expressed as deltas (°F) and change in hydrologic variables (original units in/y) expressed as percentages (Pct).

Table 4 shows that climate change impacts range from increases in winter average monthly temperatures (Delta DJF) ranging from 3.0–5.3 °F by mid-century (2040–2069) and ranging from 5.9–8.5 °F by end-century (2070–2099). Summer average monthly temperatures are projected to increase (Delta JJA) by 5.0–6.9 ° by mid-century (2040–2069) and by 8.4–11.0 °F by end-century (2070–2099). The warm, moderate rainfall model displays 30-year precipitation averages comparable to the baseline and recent conditions, while the high rainfall scenario projects up to 23% more rainfall by end of century. By contrast, the hot, low rainfall scenario projects decreases in 30-year rainfall of up to 16%. These rainfall projections drive the direction and magnitude of projected change in recharge and runoff.

Table 4 also shows that actual evapo-transpiration, which can be considered a surrogate for plant productivity, is the least variable of 2014 CA BCM outputs, but sensitive to rainfall, with a relative increase under the high rainfall scenario.

Comparable tables for projected conditions have been generated at the following scales: Watershed Management Area boundaries (WMAs), counties, and HUC-8 watersheds. These are available in the Excel sheet labeled "NCRP BCM tables for polygons.xls."

Mapped 2014 CA BCM variables for projected climate-hydrology conditions can be viewed in Appendix H and on companion PowerPoint slides 6–30.

Impact of climate change on projected snow extent across region

- We analyzed historical and potential future snow conditions for the portion of the study area exceeding 3000' in elevation, which comprises 46% of the North Coast Region. Products generated include maps and zonal statistics using just the moderate rainfall scenario. Climate change appears to be already causing reductions in springtime snow extent and water content, with potentially drastic reductions projected by end-century.

- The average spatial extent of snow on April 1st has recently declined from approximately 60% to 50% of the project area (1951–1980 versus 1980–2010) (see Appendix H, Map 9). The Klamath WMA is projected to be particularly vulnerable to snow losses, with a reduction in April 1st snow extent shrinking from 91% of the WMA area to just 16% of the WMA area by the end of the 21st century (see WMA summary table in Appendix G). The annual snow water equivalent, an estimate of equivalent rainfall stored in snow, is expected to be reduced to less than 10% of historical levels across the region, reduced from 10" historically to 1" by the end of the 21st century (Table 5). The implications of these results merit closer observation, as they go beyond the scope of this current analysis.

Table 5: HISTORICAL AND PROJECTED AREA SNOW EXTENT AND SNOW WATER EQUIVALENT (1951-2099), MODERATE RAINFALL FUTURE, NCRP REGION

	Historical	Recent	Warm, moderate rainfall	
	1951–1980	1981–2010	2040–2069	2070–2099
	(in/y)	(in/y)	(in/y)	(in/y)
Spring Snow Extent: Percent of area with April 1st snow water equivalent above zero inches (%)	60	51	29	11
Average April 1st snow water equipvalent at elevations above 3,000 feet (in)	10.3	7.9	3.6	1.0

Impact of climate change on climatic soil water deficits across region

Climatic water deficit (CWD) calculations integrate the combined effects of variable rainfall, temperature, topographic effects, and soil structure on soil water availability. This term can be thought of as a measure of drought stress, or an estimate of how much more water the landscape would have used had it been available (calculated as the difference between potential and actual evapo-transpiration). It captures the effect of limited soil storage to meet increasing evapo-transpiration demand due to rising temperatures. CWD turns out to be an excellent indicator of native vegetation cover, agricultural irrigation demand and fire risks (Micheli et al. 2016). In general, there is a trend of increasing climatic water deficits across all scenarios, despite the variability of projected precipitation.

For mid-century projections (2040–2069), climatic water deficit results for business as usual emissions scenarios can be summarized as follows. The warm, moderate rainfall scenario projects deficits of 23.1 in/y, 12% greater than the historical period. The warm, high rainfall scenario projects deficits of 22.8 in/y, 10% greater than the historical average. The hot, low rainfall scenario projects deficits of 24.6 in/y, 19% greater than the historical average. See Tables 3 and 4.

For end-century projections (2070–2099), the range of potential change in water deficits is projected as follows (Table 4). The warm, moderate rainfall scenario projects deficits of 24.0 in/y, 16% greater than the historical period. The warm, high rainfall scenario projects deficits of 24.9 in/y, 21% greater than the historical average. The hot, low rainfall scenario projects 27.2 in/y, 32% greater than the historical average. This suggests an increased demand for water in vegetated landscapes, whether native or cultivated, ranging from 3-6 inches of water per unit area by the century's end. See Tables 3 and 4.

Table 6 below summarizes climatic water deficit (CWD) results by HUC-8 river watershed boundaries (companion data files and Appendix G also include results by Watershed Management Areas). Results are displayed in a ranked order of the potential change in CWD under the low rainfall ("worst case") scenario, showing that the Chetco watershed would experience on the order of a 54% increase in CWD, while the Russian River would experience impacts on the order of a 23% increase. These values can be used to compare different river basins' relative response and vulnerability to drought conditions.

Table 6: PROJECTED CLIMATIC WATER DEFICITS (OBSERVED VERSUS 2070–2099), BY MAJOR RIVER (HUC-8) BASINS, NCRP REGION

Watershed average climatic water deficit (inches per year)						
	Historical	Recent	End of Century (2070-2099)			
Watershed (HUC 8)	(1951–1980)	(1981–2010)	Warm, moderate rainfall	Warm, high rainfall	Hot, low rainfall	% change from historical with hot, low rainfall
Chetco	10.6	10.3	11.9	14.7	16.3	54%
Illinois	13.7	14.5	16.8	18.6	20.0	46%
Smith	13.9	13.9	15.2	17.8	19.2	38%
Mattole	14.3	14.2	16.2	17.5	19.9	39%
Mad-Redwood	14.9	14.8	17.0	18.6	20.7	39%
Lower Klamath	16.4	16.5	18.5	20.5	22.0	35%
Applegate	17.0	17.9	21.3	22.5	24.0	41%
Salmon	17.9	18.3	21.7	22.9	24.5	37%
Trinity	18.9	19.1	22.2	23.3	25.1	33%
Lower Eel	19.6	19.3	22.1	23.0	25.4	29%
South Fork Eel	19.9	19.5	22.3	22.9	25.5	28%
Butte	20.8	22.2	26.6	27.6	30.0	44%
Scott	20.8	21.3	25.1	26.0	27.6	33%
South Fork Trinity	21.6	21.5	25.0	25.8	28.0	30%
Shasta	22.2	22.7	26.3	27.2	29.3	32%
Upper Klamath	22.4	23.1	26.8	27.6	29.4	31%
Lost	23.1	24.1	28.8	29.4	32.5	41%
Middle Fork Eel	23.4	23.2	26.9	27.3	29.8	28%
Big-Navarro-Garcia	23.7	23.6	26.9	27.1	30.1	27%
Upper Eel	25.0	24.8	28.0	28.2	30.9	23%
Gualala-Salmon	26.4	26.7	29.7	29.8	33.1	26%
Russian	27.5	27.9	30.8	30.7	33.8	23%
Tomales-Drake Bays	28.0	28.5	31.6	31.6	35.0	25%

We propose that the climate impacts of increases (deltas) in CWD may be best weighted by localized estimates of CWD historical variability, since ecosystems accustomed to high CWD variability may be relatively resilient to a specific CWD increase compared to regions with historically low CWD variability. To demonstrate this concept, we used one standard deviation of the 30-year time series to define a threshold for "historical variability." We then mapped projected increases only where projected change (as a delta) exceeds one standard deviation of historical variability. Appendix H, Map 10 shows that in the southern portion of the project area, relatively small increases in water deficits in traditionally cooler and moister coastal areas can exceed this threshold in comparison to similar magnitudes of change inland, where watersheds and ecosystems have adapted to high variability. This analysis is summarized by WMA for the project area in Table 7, showing that for the hot, low rainfall scenario, this threshold would be exceeded across the project area.

Table 7: PROJECTED AREA EXCEEDING CLIMATIC WATER DEFICIT HISTORICAL VARIABILITY, BY WATERSHED MANAGEMENT AREA, NCRP REGION

Percent Area at risk of drought stress*				
	Projected values			
	Warm, moderate rainfall		Hot, low rainfall	
	2040-2069	2070-2099	2040-2069	2070-2099
Project Area	41	75	95	100
Eel WMA	12	69	98	100
Klamath WMA	72	85	96	100
Humboldt WMA	17	47	94	100
Russian Bodega WMA	0	85	98	100
Trinity WMA	53	82	97	100
North Coast Rivers WMA 2	28	78	100	100
North Coast Rivers WMA 1	13	15	61	100

*Drought stress defined as projected change exceeding one standard deviation of historical CWD

Data gaps, limitations and suggestions for improving analyses

The provided data set lacks future scenario diversity for snow predictions. April 1st snow water equivalent is provided for a warm, moderate rainfall scenario only. Under the analyzed scenario, projections are dire and consideration of hotter or drier scenarios would be of value to assess scenarios with additional reductions in snow, including worst case scenarios. Additional analyses would be required to actually route snowmelt and better estimate impacts on water resources.

Navigating the necessarily *probabilistic* nature of climate data projections is perhaps one of the greatest challenges in applying these kinds of data products to real-world management issues. While managers wish we could simply provide the *most likely* outcome, for inland climate conditions, due to the uncertainty in how climate change will impact rainfall in our region, we need to facilitate consideration of multiple scenarios. In general all of the scenarios need to be considered as equally likely. In the literature this has been labeled a "scenario neutral" approach (Brown et al. 2012). This is why, moving forward, real-time climate-hydrology-ecosystem monitoring, akin to the Sentinel Site at Pepperwood's Preserve, will be critical to understanding how climate impacts will unfold in the North Bay landscape (Micheli and DiPietro 2013, Ackerly et al. 2013).

It is important to emphasize when describing 2014 CA BCM data products at a finer temporal resolution than the 30-year averages (such as decades, years, months or days), that in contrast to a weather forecast, the 2014 CA BCM does not generate *predictions* of precisely when climatic events will occur, but rather generates a physics-based time series projecting conditions for each scenario. By comparing results from a range of models, statistics can be used to describe a potential range of outcomes, but presently it cannot be determined which outcome is more likely to occur. Best practice is to consider 2014 CA BCM outputs as reflective of specific temperature and rainfall combinations, rather than a time bound projection, with the understanding that the rate of temperature change is a source of uncertainty, as are future precipitation patterns.

Although the 2014 CA BCM represents the most detailed downscaling of global climate models available for the project area (270 meter or 18 acre scale of analysis for the 2014 BCM), there are limitations on understanding the effects of topography on microclimates. Data are also limited by the quality of baseline geology and soil maps. For example, the soil maps for Mendocino County provide much more accurate details than the less developed maps of Humboldt County (L. Flint personal communication). A future opportunity to provide more detailed analysis could be achieved using a finer resolution, 30 meter pixel size 2014 CA BCM. Improved mapping of soils and geology could also provide the opportunity for better modeling of hydrological function across the North Coast region.

As the raw 2014 CA BCM data has been provided to the NCRP team for future analyses, this vulnerability assessment team recommends that the model not be used to facilitate pixel-by-pixel comparisons, but rather be applied to minimum units ideally at the scale of sub-watershed planning units, or areas no smaller than parcels on the order of hundreds of acres.

B. WATERSHED RUNOFF AND STREAM FLOW

Summary

The sum of 2014 CA BCM runoff and recharge metrics provide an indicator of potential total water supply (surface water and groundwater combined). The relative ratio of recharge to runoff for a particular watershed reflects how permeable soils and underlying geology are to water infiltration and storage. Runoff is critical to fill reservoirs, while recharge maintains soil and aquifers in sub-surface storage. This combined water supply indicator allows us to analyze the projected spatial and projected temporal variability across the region, and to reflect on modeled tradeoffs that occur between runoff and recharge under climate variability. In general, recharge is a less variable source of water supply than runoff, and becomes increasingly important under drought scenarios. The significance of recharge for managed groundwater basins is explored in more detail in the following Groundwater Resources section.

Hydrology outputs from the 2014 CA BCM can be used to model stream flow at sites with good stream flow gage records. Ideally, relatively "unimpaired" gages (where upstream withdrawals do not significantly reduce flow) are selected for modeling future stream flow variability. Stream flow estimates require an additional step of accumulating flow and calibrating it to historical gage records to effectively the combine runoff and shallow recharge rate in a way that matches measured hydrographs. This approach allows us to calculate stream flow from BCM outputs when there is no precipitation and to produce annual flow estimates that can be used to consider the range of potential climate impacts on water supply, flooding risks, and aquatic and riparian resources. We summarize the effects of high versus low rainfall scenarios on cumulative stream flow and variability of extreme flow events (high and low flow years).

Data set description

Data sets generated include historical and projected summaries of watershed runoff, recharge, and the combined water supply indicator for a variety of scales across the project area including Watershed Management Areas and major river (HUC-8) basins. The source data set used to extract all historical and projected recharge and runoff analyses was the Basin Characterization Model (2014 CA BCM) (Flint et al., 2013; Flint and Flint 2014), as described in the Climate Change section. The provision of the raw 2014 CA BCM data results allows NCRP partners to also access monthly hydrology results to generate seasonal or monthly data summaries using the methods demonstrated here.

Historical and projected stream flow, displayed as an annual discharge time series at a subset of sample stream flow gages in the study area. Local calibration to historical stream flow was done for the Russian River at Guerneville (USGS gage 11467000), the Eel River at Scotia (USGS gage 1147700) and Redwood Creek at Orick (USGS gage 11482500). All historical stream flow data extracted for calibration was derived from the USGS National Water Information System. Due to the need for calibration, additional stream flow analyses would require engagement of project authors.

Methodology

Recharge and runoff time series: values for the annual time series of recharge and runoff in WMAs were extracted as zonal statistics from 2014 CA BCM layers for average output values over water years. Average pixel values of raster layers within project area watersheds and jurisdictions were obtained in the programming language R. We utilized the rgdal, raster and maptools libraries and the extract and raster tools on ASCII format raster files. See

Appendix D for code resources. Linear trend lines of observed and projected values of recharge and runoff were added in Excel via the add trend line function for each data series.

Stream flow time series: Local calibration of historical stream flow was done for the Russian River at Guerneville (Station ID 11467000; 1958–2009), the Eel River at Scotia (Station ID 1147700; 1920–2009), and Redwood Creek at Orick (Station ID 11482500; 1920–2009). Using recharge and runoff time series for each of the watersheds upstream of the stream gages, processing was done in Excel to calculate stream flow using exponential decay functions for surface water, shallow groundwater, and deep groundwater to match measured hydrographs. Coefficients developed for the historical calibration were then used with projected recharge and runoff time series to calculate projected stream flow for each watershed. Calculations of the 90th percentile and 10th percentile exceedance probabilities were calculated for the historical record for each watershed. These exceedance probabilities were used as thresholds to compare observed versus projected frequencies of extreme highs and lows in cumulative discharge.

Data product summary and key findings

Based on secondary analyses conducted using the 2014 CA BCM, we assess relative watershed sensitivity to climate change based on water supply indicators and potential stream flow variability. Parameters under consideration focus on relative variability in terms of water supply and stream flow for selected basins.

Watershed supply resilience indicators

A water supply indicator (combined runoff plus recharge) and projected changes in water supply are estimated for the entire region for extended observed (1920-2009) and extended modeled (2010-2099) time periods as well as for 30-year observed (historical and recent) and three future projected time periods at multiple scales.

Table 8 below shows historical and projected annual total water supply by Watershed Management Areas for observed conditions (1910–2009) and for three projected scenarios (2010–2099). Results are shown in units of inches of water per unit area, units equivalent to what is typically used for rainfall totals. These values can be converted to volumes (such as acre-feet) by multiplying by the referenced polygon area. Total water supply over the observed period ranges from a minimum for the Russian River WMA (27.2 inches per year) to a maximum for the North Coast Rivers WMA (75.1 inches per year). Mapped 2014 CA BCM variables for projected climate-hydrology conditions, which show the spatial variability of rainfall, recharge and runoff per unit area, can be viewed in Appendix G and on Map Slides 6–30.

Table 8: ANNUAL WATER SUPPLY RESILIENCE INDICATORS (1920-2009 VERSUS 2010-2099), WATERSHED MANAGEMENT AREAS, 3 SCENARIOS, NCRP REGION

Water Supply Indicator (annual recharge plus runoff) (1920-2009 v 2010-2099) 3 projected scenarios, per Watershed Management Area (WMA)												
all values represent average inches/year per unit area (rainfall equivalent)												
	Observed 1920-2009 (in/y)			Projected 2010-2099 Warm, High Rainfall			Projected 2010-2099 Warm, Moderate Rainfall			Projected 2010-2099 Hot, Low Rainfall		
WMA	Runoff	Recharge	Total	Runoff	Recharge	Total	Runoff	Recharge	Total	Runoff	Recharge	Total
Russian Bodega WMA	15.7	11.5	27.2	18.9	11.0	29.9	17.4	11.7	29.2	12.2	10.0	22.2
Klamath WMA	15.3	12.5	27.7	16.4	11.6	28.0	15.9	12.1	28.0	13.0	11.2	24.2
North Coast Rivers WMA 2	13.2	22.6	35.9	17.1	20.8	37.9	15.0	22.8	37.8	10.3	20.3	30.6
Trinity WMA	18.3	22.6	40.9	21.0	20.6	41.7	19.6	22.0	41.7	15.2	20.4	35.6
Eel WMA	16.3	25.2	41.6	20.6	22.6	43.2	18.5	24.8	43.3	13.3	22.6	35.9
Humboldt WMA	17.8	31.7	49.5	21.9	28.6	50.6	20.3	30.6	50.9	16.0	28.2	44.2
North Coast Rivers WMA 1	40.5	34.6	75.1	44.1	31.6	75.7	42.7	32.6	75.2	37.4	30.8	68.2

Table 9 below compares the ratio of recharge to runoff for the same areas and shows the percent change in water supply indicators for the observed (1920-2009) versus projected (2010-2099) record. Examination of the trends in recharge to runoff ratios show that the most recharge-dominated management area is the Humboldt WMA (with a ratio of 1.78) – indicating a relatively high watershed resilience, as compared to the Russian River (with a ratio of 0.73). You can also detect a trend of higher recharge relative to runoff under lower rainfall scenarios, reflected in the highest recharge to runoff ratios under the hot, low rainfall climatic trend. Overall, uncertainties in projected rainfall could generate a range of impacts on water supply across the region, with increases on the order of 4% in water supply under the high rainfall scenario, and decreases on the order of 13% in available water supply under the low rainfall scenario.

Table 9: PERCENT CHANGE IN TOTAL WATER SUPPLY AND RECHARGE TO RUNOFF RATIOS (1920-2009 VERSUS 2010-2099), WATERSHED MANAGEMENT AREAS, NCRP REGION

Water Supply, Recharge/Runoff Ratio, 1920-2009 vs 2010-2099, 3 projected scenarios, per Watershed Management Area (WMA)										
	Observed 1920-2009		Projected 2010-2099 Warm, High Rainfall		Projected 2010-2099 Warm, Moderate Rainfall		Projected 2010-2099 Hot, Low Rainfall		Warm, High Rainfall	Hot, Low Rainfall
	Total RCH+RUN	RCH/RUN ratio	Total RCH+RUN	RCH/RUN ratio	Total RCH+RUN	RCH/RUN ratio	Total RCH+RUN	RCH/RUN ratio	Total RCH+RUN	Total RCH+RUN
WMA	in/y	unitless	in/y	unitless	in/y	unitless	in/y	unitless	% change	% change
Russian Bodega WMA	27.2	0.73	29.9	0.58	29.2	0.67	22.2	0.82	10%	-18%
Klamath WMA	27.7	0.81	28.0	0.71	28.0	0.76	24.2	0.86	1%	-13%
North Coast Rivers WMA 2	35.9	1.71	37.9	1.22	37.8	1.52	30.6	1.98	6%	-15%
Trinity WMA	40.9	1.23	41.7	0.98	41.7	1.12	35.6	1.34	2%	-13%
Eel WMA	41.6	1.54	43.2	1.10	43.3	1.35	35.9	1.70	4%	-14%
Humboldt WMA	49.5	1.78	50.6	1.31	50.9	1.50	44.2	1.76	2%	-11%
North Coast Rivers WMA 1	75.1	0.86	75.7	0.72	75.2	0.76	68.2	0.82	1%	-9%
Region Average	42.6	1.2	43.8	0.9	43.7	1.1	37.3	1.3	4%	-13%

Table 10 below displays the same water supply indicator (runoff plus recharge) for each major river basin in the project area, comparing baseline (1951–1980) and recent (1981–2010) conditions to end-of-century conditions for three scenarios, including the percent change from baseline projected for the lowest ("worst case") rainfall scenario. This plot shows that under the low rainfall scenario, the Lost River watershed stands to lose the greatest fraction of historical supply (52%) while the Chetco River watershed (only a portion of which lies within the NCRP region) is potentially the most resilient with respect to water supply, with a 13% reduction, by comparison.

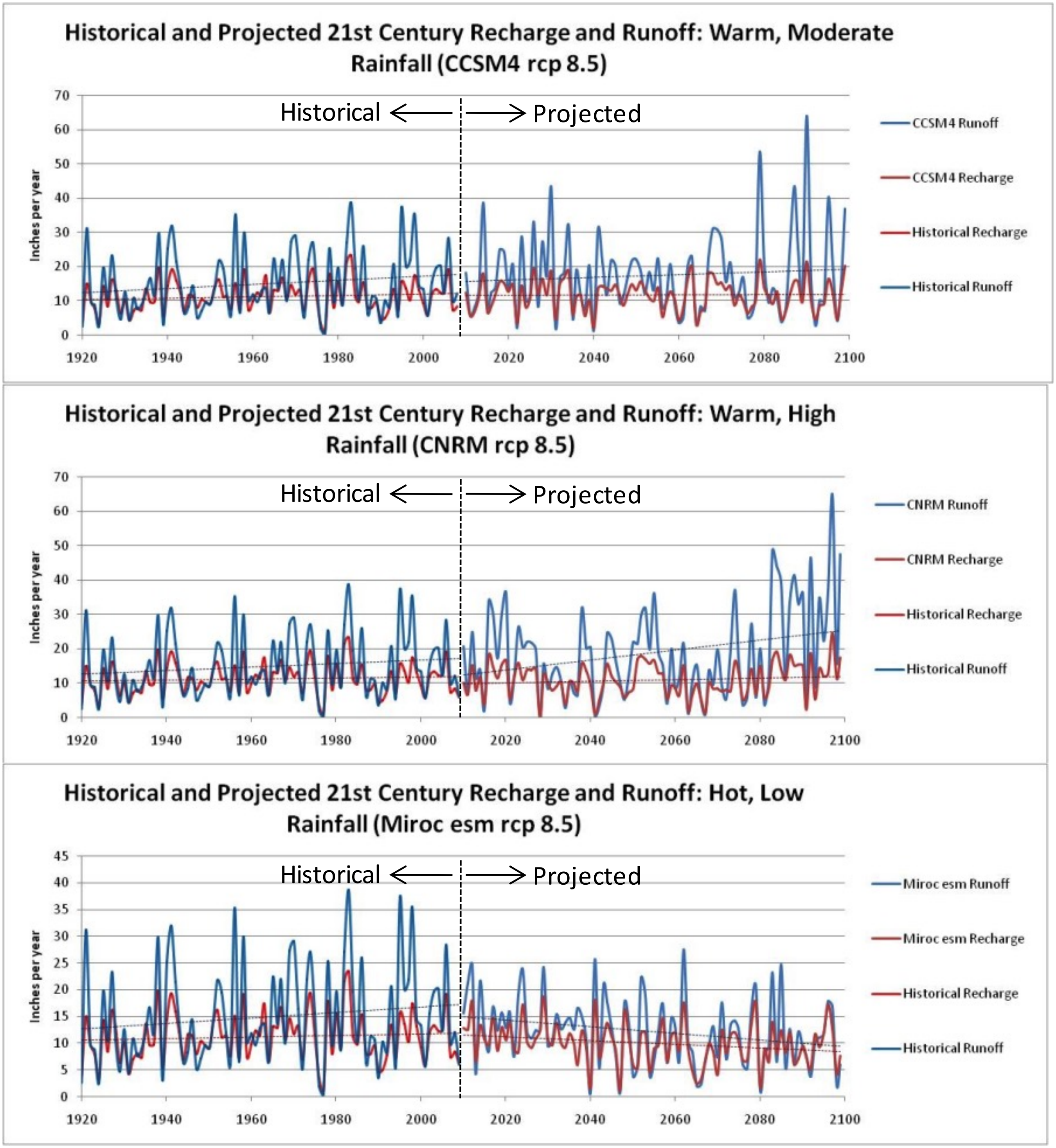
Combining these water supply indicators with climatic water deficit indicators presented in the earlier section helps to refine explorations of watershed resilience. For example, while the NCRP portion of the Chetco watershed is relatively vulnerable to increased soil water deficits (i.e. increased water demand due to drought stress on soils), from a water supply perspective, in terms of water available for storage, it may be relatively resilient. Thus, this particular basin may experience high demand, but also have the water supply retention capacity to help it adapt to relatively more arid conditions. This is typical of watersheds characterized by deep alluvial deposits that allow for both large amounts of storage but also significant water losses during drought periods.

Table 10: WATER SUPPLY INDICATORS (1951-2010 VERSUS 2070-2099), MAJOR RIVER (HUC-8) BASINS, NCRP REGION

Watershed average water supply, or runoff plus recharge (inches per year)						
	Historical	Recent	End of Century (2070-2099)			
Watershed (HUC 8)	(1951–1980)	(1981–2010)	Warm, moderate rainfall	Warm, high rainfall	Hot, low rainfall	% change from historical under Hot, low rainfall
Lost	5.3	4.9	4.1	5.9	2.5	-52%
Butte	8.9	8.6	7.3	10.7	5.3	-40%
Shasta	14.1	13.7	12.0	17.6	9.6	-32%
Tomales-Drake Bays	20.4	20.7	24.0	34.8	14.1	-31%
Upper Klamath	18.1	15.9	14.7	21.1	12.8	-29%
Russian	28.5	28.4	31.3	44.5	20.9	-27%
Scott	21.6	19.7	18.4	26.3	15.9	-27%
Gualala-Salmon	34.7	34.5	38.6	54.1	26.1	-25%
Upper Eel	39.3	37.5	40.1	56.0	29.8	-24%
Middle Fork Eel	40.0	38.0	39.6	55.1	30.4	-24%
South Fork Trinity	44.7	41.9	40.7	56.6	34.0	-24%
Big-Navarro-Garcia	30.9	30.4	33.4	47.4	23.7	-23%
Applegate	35.3	31.2	29.8	40.4	27.5	-22%
Mattole	54.5	48.3	51.9	70.9	42.6	-22%
Lower Eel	43.2	41.3	41.9	58.5	34.2	-21%
South Fork Eel	53.5	50.8	53.3	73.4	42.4	-21%
Trinity	42.5	40.6	39.3	54.3	34.0	-20%
Salmon	47.9	44.5	43.1	58.9	38.5	-20%
Lower Klamath	73.8	68.5	67.0	88.4	61.1	-17%
Mad-Redwood	51.5	48.1	49.4	67.4	43.0	-17%
Smith	85.5	79.1	79.1	102.1	73.1	-15%
Chetco	66.7	62.1	62.7	82.0	58.2	-13%

- To examine the inter-annual variability underlying these long-term averages, annual values of runoff and recharge were plotted as time series for historical conditions and all three future scenarios. This facilitates an exploration of potential inter-annual variability under climate change compared to historical conditions, with the caveat previously discussed that projected values are not *predictions* of flow timing, but rather a physically-based simulation that aligns with projected long-term trends.
- Figure 2 shows a sample plot of annual runoff and recharge values for the observed record (1920-2009) and for projected futures (2010-2099). Companion materials feature similar plots for each of the seven Watershed Management Areas. By separating values for runoff and recharge, the plot displays the lower variability of year-to-year recharge values in comparison to runoff distribution.

Figure 2: ANNUAL RUNOFF AND RECHARGE (1920-2099), RUSSIAN BODEGA WMA



Stream flow assessments

A detailed time series of unimpaired stream flows, including base flows, has been completed for the historical record and three future scenarios to evaluate projected changes in flows for the Eel River, Russian River, and Redwood Creek.

Stream flow assessments were restricted to watersheds where sufficient historical stream gage data was available, per the methodology section above.

Redwood Creek is small, with the most extreme stream flow pulses above the historical 90th percentile exceedance in all futures, in comparison to the other basins.

Figure 3: HISTORICAL AND PROJECTED ANNUAL STREAM FLOW, RUSSIAN RIVER AT GUERNEVILLE GAGE, THREE SCENARIOS

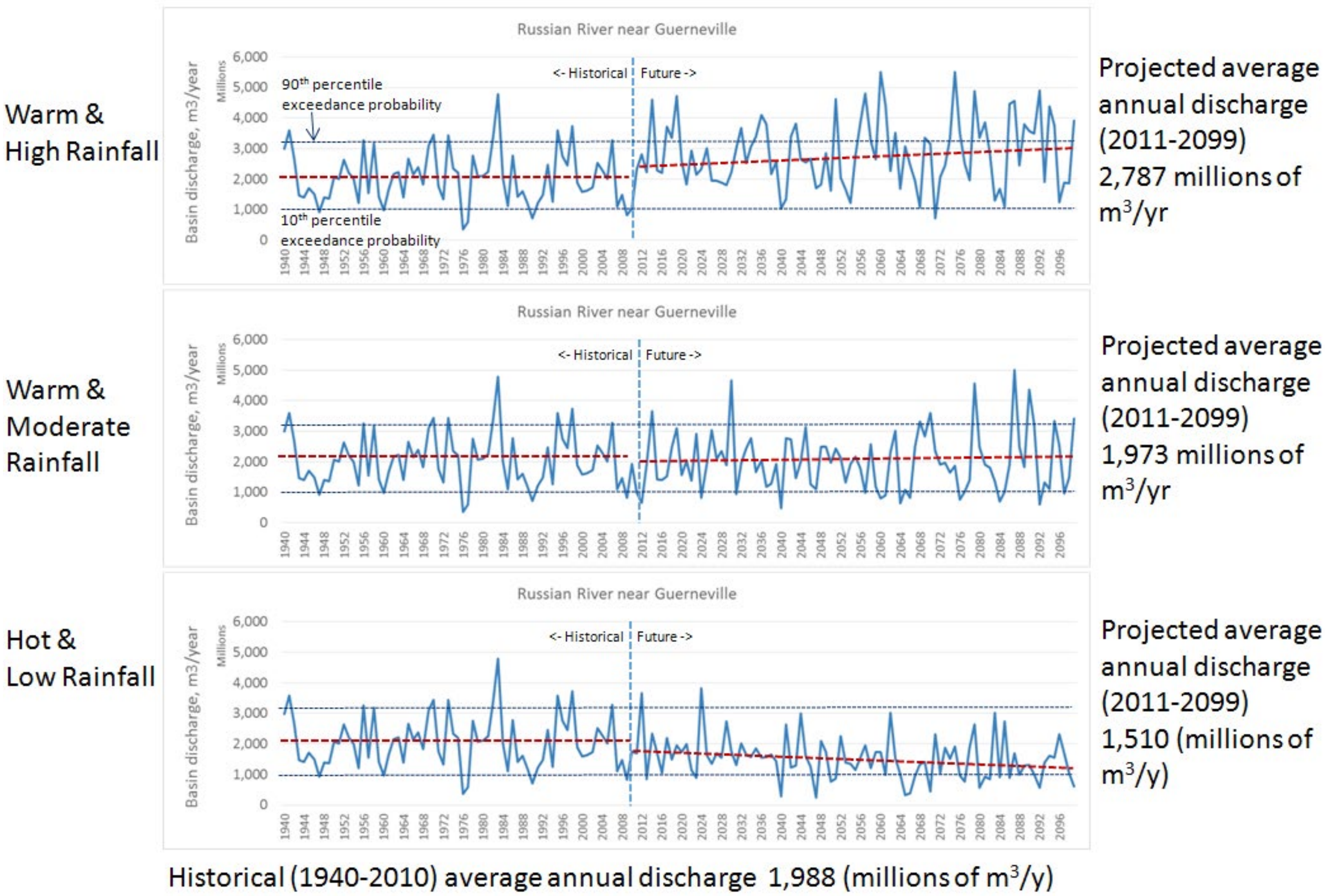
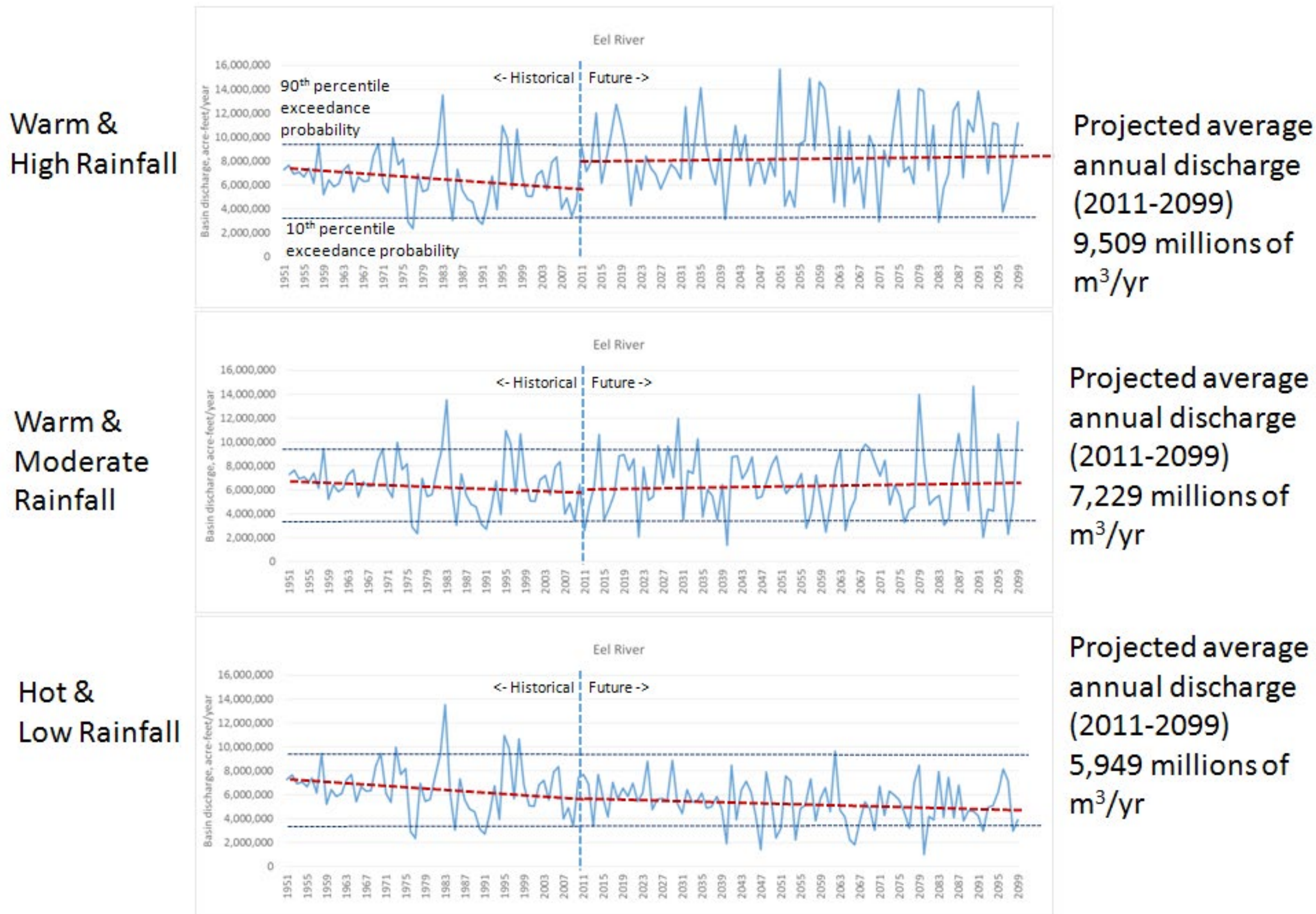
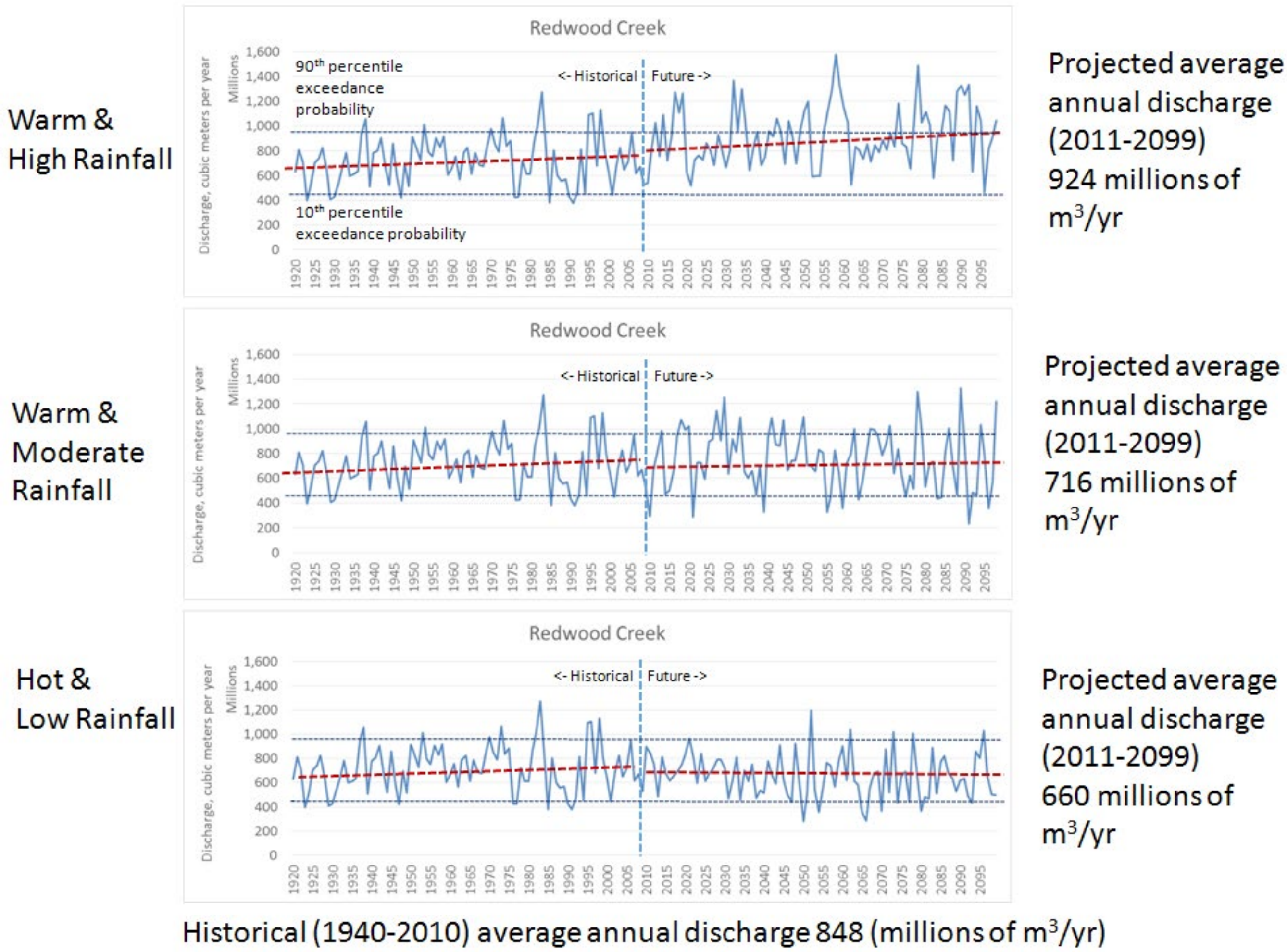


Figure 4: HISTORICAL AND PROJECTED ANNUAL STREAM FLOW, EEL RIVER AT SCOTIA GAGE, THREE SCENARIOS



Historical (1940-2010) average annual discharge 7,918 (millions of m^3/yr)

Figure 5: HISTORICAL AND PROJECTED ANNUAL STREAM FLOW, REDWOOD CREEK AT ORICK GAGE, THREE SCENARIOS



In terms of cumulative annual discharge, Figure 4 shows that the Eel River has by far the most stream flow of the three analyzed streams, which makes sense as it drains the largest watershed. While the recharge and runoff graphs indicate that this watershed is recharge-dominated with permeable bedrock, the stream flow graphs indicate that much of the recharge returns to streams as base flow. The impacts of climate change on cumulative annual discharge on the Eel, in comparing the 1940-2009 reference period to projections the 2010-2099 period as a whole, show impacts ranging from an average 20% increase in discharge under the high rainfall scenario to a 25% reduction under the low rainfall scenario.

While stream flow for all the watersheds shift as expected relative to lower or higher rainfall scenarios, Redwood Creek (Figure 5) changes the least under both wet and dry scenarios, while the Russian River (Figure 3) changes the least for the moderate scenario. Alternatively Redwood Creek declines the most under the moderate rainfall scenario, while the Eel declines the most under the low rainfall scenario and the Russian increases the most under the high rainfall scenario.

Table 11 below summarizes the range of projected change in annual discharge extremes, defined by flows either falling below the 10th percentile (extreme dry years) or exceeding the 90th percentile (extreme wet years), with thresholds shown in Figures 3-5.

Table 11: HISTORICAL AND PROJECTED ANNUAL CUMULATIVE DISCHARGE, EEL RIVER, REDWOOD CREEK AND RUSSIAN RIVER

Frequency of annual cumulative discharge exceedance of the 90th and 10th percentiles per decade								
Basin	Historical record (time period varies)		Hot, low rainfall (2010–2099)		Warm, moderate rainfall (2010–2099)		Warm, high rainfall (2010–2099)	
	< 10th	> 90th	< 10th	> 90th	< 10th	> 90th	< 10th	> 90th
Eel River	5	5	12	1	9	12	3	28
Redwood Creek	7	10	7	5	10	19	0	29
Russian River	9	8	19	2	14	9	2	29

Although these results are based on a small sample size with variable time periods for comparison, the results show 80 percent more drought type years during the projected low rainfall time series, and on the order of 50% more low flow years even for the moderate rainfall scenario. In terms of high discharge years, the range is approximately 70% more high flow years under the moderate rainfall scenario, and well greater than 100% more high flow years under the high rainfall scenario. This points to the fact that increased rainfall variability suggests we need to prepare for both more frequent droughts and floods, and that although the moderate rainfall scenario is similar to historical conditions in terms of long-term rainfall averages, that projected future features greater inter annual variability in rainfall and related water supply parameters than the historical reference period, which is arguably already quite variable.

Data gaps, limitations and suggestions for analysis improvement

Hydrological data in the 2014 CA BCM driving recharge and runoff values are limited by the quality of baseline geology and soil maps and the location and quality of record for weather stations used in the calibration. Better mapping of soils and geology could provide opportunity for better modeling of hydrological function across the North Coast region, particularly in regions such as Humboldt County where historical soil and geology mapping was less extensive.

With regards to stream flow analyses, data gaps include missing records from stream flow data and inaccurate precipitation records. Primarily, however, unimpaired stream flow data is not readily available for many locations, particularly in headwaters of streams where the runoff and recharge processes are initiated. This speaks to the value of improved monitoring of stream flow moving forward to inform effective adaptive management strategies.

- Further, the 2014 CA BCM is developed to determine the water balance for unimpaired natural conditions. Calibration of stream flow is limited by the upstream impairments such as reservoirs and releases, agricultural return flows, stream diversions, and well extractions. Improvements in the overall calibration would be improved by additional stream gaging, estimates of actual evapo-transpiration, and precipitation gages. These indicators of water inputs would be well complemented by more comprehensive data on water withdrawals (including locations and magnitude) across the project area.

C. GROUNDWATER RESOURCES

Summary

The 2014 CA Basin Characterization Model calculates in-place (in-situ) recharge for every grid cell, depending on the available water, geology, and soil properties. Recharge is calculated as the amount of water that penetrates below the rooting zone of vegetation and thus is not utilized in evapo-transpiration. Within this definition, in-situ recharge has the potential to become base flow downstream or recharge to groundwater aquifers. This calculation is not equivalent to the total amount of water that recharges the regional or local groundwater aquifer, because that requires a detailed aquifer model that includes water accumulation and routing considerations. However, in-situ recharge can be considered a good indicator of local recharge variability due to climate change and a good first assessment of underlying aquifer vulnerability. In locations with relatively short groundwater flow pathways that do not laterally transmit water, 2014 CA BCM recharge estimates are likely to be quite good surrogates for aquifer recharge.

Data set description

We summarized recharge indicators for the entire NCRP region, key management areas, and specific groundwater basins delineated for management by the California Department of Water Resources under California's new Sustainable Groundwater Management Act. Data generated for groundwater resource assessments for the NRCP is extracted from the source data set of the 2014 CA Basin Characterization Model (Flint and Flint 2007 and 2014), as described above in the Climate and Hydrology section. The GIS layer for groundwater basins was delimited by the California Department of Water Resources (DWR) and is shown as a map of specific basins in Appendix E.

Methodology

Regional recharge assessments: We generated a regional recharge map displaying the variable recharge potential across the NCRP region based on precipitation combined with underlying soils and geology. We used zonal statistics (summarized earlier) to calculate average values for recharge in historical and projected 30-year time steps at multiple scales, including the project area, WMAs, counties, and HUC-8 watersheds. Mapped recharge values for historical and current conditions can be viewed on Map Slides 17–21. Extracted numerical results are available in the companion data file labeled "NCRP BCM tables for polygons.xls."

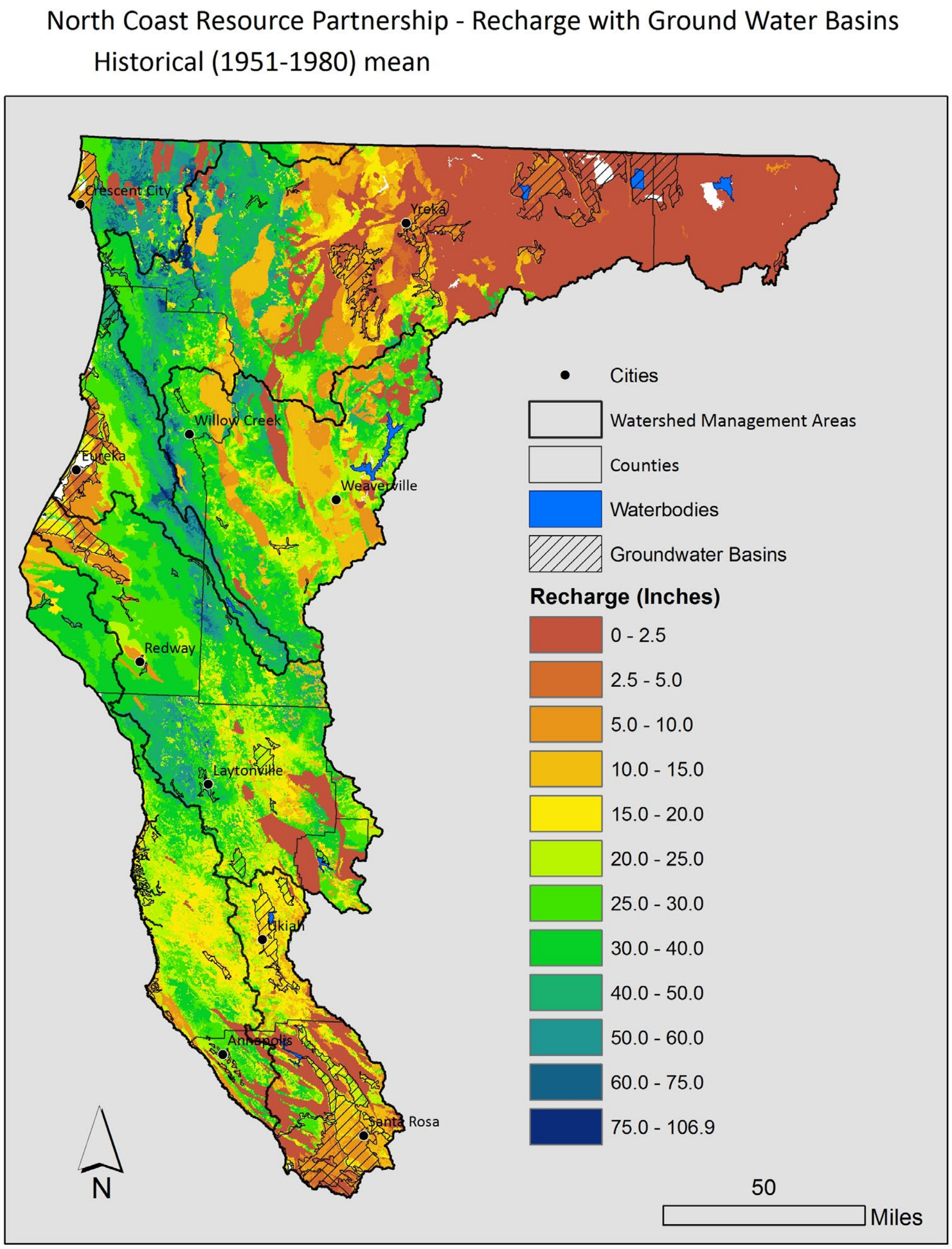
Estimates for recharge within delineated DWR groundwater basins: values were extracted as zonal statistics for the DWR groundwater basin layer and their containing Watershed Management Areas from 2014 CA BCM layers for average output values over 30-year periods (see sections on zonal statistics in R in Climate Change and Watershed Hydrology sections). Groundwater basins and WMA recharge attributes were calculated in ESRI software with the calculate geometry function. A weighted average for historical delineated groundwater basin recharge was calculated for each WMA using the average recharge rate per groundwater basin polygon multiplied by that polygon's area, and summing these results for WMA's featuring multiple groundwater basins. Groundwater basins analyzed are shown in slides 4, 18 and 53.

Data product summary and key findings

In-situ recharge summaries by regions of interest

Recharge potential maps can play a critical role in increasing our understanding of how the landscape captures and stores water subsurface. Protecting and enhancing subsurface storage will be critical to increasing our resilience to an increasingly variable climate. Water held deep in soils is what enables our native vegetation to withstand the extremes of our Mediterranean climate. Groundwater aquifers provide critical back up supplies of water when low rainfall conditions deplete surface supplies in lakes, reservoirs and streams.

Figure 6: HISTORICAL RECHARGE MAP SHOWING DELINEATED GROUNDWATER BASINS



- Groundwater data provided here, starting with the historical recharge maps alone, provide a basis for NCRP partners to move forward with evolving groundwater management programs to identify and protect high value recharge zones. There are opportunities to intersect the recharge potential maps with potential changes in land or water use, and to identify recharge relative to existing or planned impervious areas or existing or planned well installations. Many communities are now exploring how to link storm water capture to recharge enhancement projects, and recycled wastewater has been used for recharge purposes in Southern California for decades now.

Estimated in-situ recharge within Department of Water Resources-delineated groundwater basins

- *Groundwater basin recharge*: In-place recharge within delineated groundwater basins was calculated for historical and projected scenarios. For each WMA, the total number and area of groundwater basins was calculated relative to the recharge potential map. A map of groundwater basins overlying historical recharge values is included in the companion materials.

Table 12: DEPARTMENT OF WATER RESOURCES GROUNDWATER BASIN ATTRIBUTES PER WATERSHED MANAGEMENT AREA

Groundwater Basin Summary by WMA					Historical (1951-1980) hydrology (inches/year)		
WMA	No. GWB's in WMA	WMA Square Miles	Total GWB Square Miles	Percent area WMA equal to GWB	Weighted average of recharge in GWB's	Average Recharge in WMA	Average Runoff in WMA
Eel WMA	16	3682	355	9.6	18.0	26.6	17.1
Humboldt WMA	6	1148	308	26.8	44.4	32.9	18.6
Klamath WMA	11	7039	1097	15.6	4.2	13.1	16.7
North Coast Rivers WMA 1	1	872	114	13.1	10.9	35.3	43.6
North Coast Rivers WMA 2	12	2098	155	7.4	14.9	23.7	13.6
Russian Bodega WMA	14	1628	743	45.6	9.7	12.0	15.9
Trinity WMA	4	2970	25	0.9	25.2	23.8	19.4
Total Project Area	64	19438	2797	14.4	NA	20.5	18.1

Table 12 shows that the Russian River WMA contains the largest extent of delineated groundwater basins in the region (46% of WMA), with the Trinity WMA containing the least (1%). Area-weighted annual groundwater basin recharge is highest in the Humboldt WMA (44 in/y) as opposed to the lowest rates calculated for the Klamath WMA (4.2 in/y). Table 12 also shows that delineated groundwater basins are not always co-located with zones of highest recharge potential, which speaks to the value of communities taking a landscape-level approach to recharge protection, since there may be critical recharge pathways well outside of the footprint of aquifers designated by the state.

- We assessed recharge rates for DWR-identified groundwater basins under three future climate scenarios to compare and contrast with historical conditions using 30-year averages (see Appendix E for a summary and map of individual groundwater basins analyzed). These results suggest that under the hot, low rainfall scenario, in-situ recharge associated with delineated groundwater basins could be reduced on the order of 27% across the NCRP region (Table 13).

Table 13: HISTORICAL AND PROJECTED RECHARGE FOR GROUNDWATER BASINS UNDER HOT, LOW RAINFALL SCENARIO, NCRP REGION

	Historical (1951–1981)	End of century (2070–2099) hot, low rainfall	
Ground Water Basin	Average recharge (in/yr)	Average recharge (in/yr)	Percent change in recharge
KLAMATH RIVER VALLEY - TULE LAKE	0.2	0.0	-79
KLAMATH RIVER VALLEY - LOWER KLAMATH	0.6	0.2	-74
FAIRCHILD SWAMP VALLEY	0.8	0.3	-69
RED ROCK VALLEY	2.7	1.1	-60
BUTTE VALLEY	3.2	1.4	-57
BRAY TOWN AREA	4.1	1.9	-53
SCOTT RIVER VALLEY	7.8	4.4	-44
SHASTA VALLEY	6.9	4.0	-41
SANTA ROSA VALLEY - SANTA ROSA PLAIN	11.4	7.4	-35
GARCIA RIVER VALLEY	10.1	6.8	-33
SANTA ROSA VALLEY - HEALDSBURG AREA	16.3	11.1	-32
KENWOOD VALLEY	15.7	10.7	-31
SANTA ROSA VALLEY - RINCON VALLEY	14.8	10.4	-30
KNIGHTS VALLEY	15.1	10.7	-29
LOWER RUSSIAN RIVER VALLEY	18.3	13.0	-29
SANEL VALLEY	15.5	11.0	-29
ANDERSON VALLEY	16.6	11.8	-29
ALEXANDER VALLEY - ALEXANDER AREA	18.4	13.2	-28
UKIAH VALLEY	16.6	12.0	-28

Ground Water Basin	Historical (1951–1981)	End of century (2070–2099) hot, low rainfall	
	Average recharge (in/yr)	Average recharge (in/yr)	Percent change in recharge
LITTLE LAKE VALLEY	25.4	18.6	-27
ALEXANDER VALLEY - CLOVERDALE AREA	17.9	13.1	-27
HAYFORK VALLEY	19.6	14.4	-27
BIG RIVER VALLEY	20.3	15.0	-26
GRAVELLY VALLEY	25.6	19.0	-26
NAVARRO RIVER VALLEY	19.8	14.7	-26
COVELO ROUND VALLEY	21.4	15.9	-25
WILSON POINT AREA	18.6	13.9	-25
POTTER VALLEY	18.8	14.1	-25
BODEGA BAY AREA	15.3	11.6	-24
McDOWELL VALLEY	17.3	13.1	-24
SEIAD VALLEY	16.4	12.5	-23
FORT ROSS TERRACE DEPOSITS	10.8	8.3	-23
HETTENSHAW VALLEY	41.1	31.6	-23
LITTLE VALLEY	20.3	15.7	-22
WILLIAMS VALLEY	20.9	16.2	-22
DINSMORES TOWN AREA	41.2	32.1	-22
EDEN VALLEY	24.3	19.0	-22
TEN MILE RIVER VALLEY	20.6	16.2	-21
FORT BRAGG TERRACE AREA	18.2	14.4	-21
WILSON GROVE FORMATION HIGHLANDS	5.6	4.4	-21
LAYTONVILLE VALLEY	39.7	31.5	-21
ANNAPOLIS OHLSON RANCH FM HIGHLANDS	12.9	10.4	-20
LOWER LAYTONVILLE VALLEY	37.0	29.9	-19
LARABEE VALLEY	43.8	35.4	-19
SHERWOOD VALLEY	36.4	29.4	-19
MATTOLE RIVER VALLEY	34.6	28.0	-19
HYAMPOM VALLEY	25.5	20.8	-18
HAPPY CAMP TOWN AREA	33.8	27.8	-18
EEL RIVER VALLEY	12.8	10.6	-17
WEOTT TOWN AREA	20.0	16.6	-17
EUREKA PLAIN	7.2	6.0	-17
GARBERVILLE TOWN AREA	14.4	12.0	-17
BRANSCOMB TOWN AREA	40.2	33.6	-17
REDWOOD CREEK AREA	32.7	27.4	-16
HOOPA VALLEY	30.8	25.9	-16
MAD RIVER VALLEY - MAD RIVER LOWLAND	11.6	9.8	-15
HONEYDEW TOWN AREA	39.7	33.6	-15
PEPPERWOOD TOWN AREA	6.7	5.7	-15
COTTONEVA CREEK VALLEY	31.0	26.4	-15
MAD RIVER VALLEY - DOWS PRARIE SCHOOL AREA	9.9	8.5	-14
LOWER KLAMATH RIVER VALLEY	42.2	36.5	-14
SMITH RIVER PLAIN	10.9	9.4	-13
BIG LAGOON AREA	16.8	14.6	-13
PRAIRIE CREEK AREA	46.2	40.3	-13
AVERAGE OF GROUND WATER BASINS	19.9	15.6	-27

Data gaps, limitations, and suggestions for analysis improvement

The 2014 CA BCM uses estimates of shallow bedrock permeability that are developed iteratively in the calibration process to assess recharge rates in the context of empirical data on stream flow and evapotranspiration. A notable data gap is the lack of measured estimates of bedrock permeability along with recharge estimates at the watershed scale. These data are rare to find, but incredibly valuable where recharge management is a critical dimension of a local water security strategy.

Groundwater resources are poorly understood in most locations. This analysis illustrates the relative extent of recharge potential relative to watersheds and delineated groundwater basins given potential recharge across the region. This analysis should not be used to try to quantify retrievable groundwater resources from aquifers. Recharge of groundwater basins/aquifers results from a combination of recharge that occurs directly above the basin and that delivered via the surrounding watersheds via multiple surface and subsurface pathways. While 2014 CA BCM products taken together (in particular looking at runoff sources combined with potential recharge in terms of adjacency) does provide a good starting point for evaluating the role of potential recharge, a much more comprehensive approach is required to truly quantify groundwater inputs and outputs, including surface-groundwater interactions and the effects of water management infrastructure. More accurate assessments of groundwater availability require in-depth, subsurface hydro-geologic investigations along with groundwater modeling capable of estimating groundwater inputs as well as simulating stresses on the system due to water use combined with climatic variability.

D. FOREST ECOLOGY

Summary

Using a model developed by Dr. Jim Thorne of UC Davis in concert with Pepperwood's Terrestrial Biodiversity Climate Change Collaborative and the California Department of Fish and Wildlife (CADFW), we evaluate current and future projected climate stress of current forest vegetation cover in the project area. We also summarize exposure and vulnerability metrics that estimate projected changes in suitability for vegetation that may lead to declines or expansions in forest composition as a result of climate change.

Data set description

Data generated for the NCRP is extracted from the California Department of Fish and Wildlife's statewide modeling effort (Thorne et al. 2016) that builds on CA

2014 BCM-derived indicators of climate exposure for native vegetation (including seasonal temperature, rainfall, snow water equivalent and snow extent, evapotranspiration, runoff, recharge and climatic water deficits). The data set includes maps showing the distribution of current and projected climate stress on vegetation, and tables summarizing the area extent of different stress categories for a range of scales, including the project area and Watershed Management Areas ("NCRP Veg Exposure Tabulated Area Tables (WMA).xls)".

The vegetation vulnerability model summaries for the North Coast utilize the statewide vegetation map produced by the CalFire Fire and Resource Assessment Program (FRAP). The unit of analysis for the vegetation model is a "macrogroup" community-level classification. Spatially-explicit vegetation exposure rankings are based on the 2014 CA BCM model used in earlier sections of this memorandum. We extracted results from only "business as usual" emissions scenarios, to be consistent with the models used throughout this memorandum. We focus on summarizing the area extent and mapping regions projected to be stressed relative to climate thresholds set by the CDFW team. These "exposure rankings" are deemed the most robust output of the vegetation model relative to NCRP forest ecology assessment objectives defined for this team (Thorne 2017, personal communication).

The full vegetation vulnerability assessment combines multiple 2014 CA BCM exposure outputs with biological data and expert opinion on plant sensitivity and adaptive capacity. We have provided summary tables on sensitivity and adaptive capacity for every macrogroup classification of the North Coast in Appendix F, to facilitate NCRP review of details on potential plant vulnerabilities at the species level, where available.

Methodology

Summaries of vegetation exposures due to climate change were derived using similar zonal statistics methods as described in earlier sections and reiterated below.

Percent area of polygons with different vegetation macrogroups: The percent area of project polygons containing vegetation macrogroups was calculated by using the Tabulate Area tool in ESRI ArcMap, which allows for the parsing of a raster layer (vegetation cover) by polygons and raster values providing a calculation for the area in each polygon filled by a raster value.

Average raster value for polygon extents (zonal statistic): Average pixel values of exposure raster layers within project area watersheds and jurisdictions were obtained in the programming language R. We utilized the rgdal, raster and maptools libraries and the extract () and raster tools on raster files. See Appendix D for code resources.

The current extent of vegetation is used by Thorne et. al. 2016 to generate site-specific assessments of where key vegetation macrogroups will be stressed based on 2014 CA BCM-based projected climate exposures. Exposure values were then ranked based on specific macrogroup sensitivities, generating a combined metric that evaluates "vulnerability" on a 1–100% scale. We generated a temporal sequence of maps for the study area displaying relative rankings of vegetation exposure combining vegetation macrogroup sensitivities with climate variables derived from the 2014 CA BCM. For each Watershed Management Area, we used zonal statistics methods described earlier and in Appendix D to summarize the proportion of study area prone to climatic stress.

Sensitivity and adaptive capacity: Appendix F summarizes key macrogroup attributes in terms of climate sensitivity and adaptive capacity, which represent a "best professional judgment" assessment from California vegetation experts. Scores for the sensitivity and adaptive capacity of dominant species for each macrogroup were generated from biological and life history data in the California Manual of Vegetation, the USDA plants database and the Jepson Interchange (Thorne et al. 2016). Sensitivity scores were based on sensitivity to temperature, precipitation and fire as well as dispersal modes, lifespan and germination agents. Traits of adaptive capacity that were scored were seed longevity, adaptive capacity to fire and recruitment attributes. Scores were ranked from 1–5 with 1 being the least adaptive and/or most sensitive. For neutral or unknown conditions, a score of 3 was allocated. A composite score for each macrogroup was created by averaging the scores of all component species. Scores for NCRP macrogroups are extracted from Thorne et al 2016 and are provided in Appendix F.

We rank potentially stressed areas using the vulnerability classifications described in Thorne et. al. 2016. Pixels for a given vegetation type which lie at the center of their distribution across current "climate space" are considered more suitable, where as those further away from the central core are considered less suitable. For cells lying within 80% of the current climate space distribution for the relevant macrogroup, the cells are considered to be climatically suitable areas. Climatically stressed or marginal classes include cells with greater than 95% exposure and non-analog cells. Non-analog cells are those that lie outside the space defined by the 99% contour of any vegetation type. Non-analog cells have conditions that lie outside of the conditions for which there is a good sample in the historical time frame, or conditions which are outside the range of historical conditions for the whole state.

For non-analog cells, the status is uncertain and no explicit percent exposed ranking is made but the cells are considered either marginal or climatically stressed.

Data product summary and key findings

Products include maps of vegetation macrogroup classes for the project area and tables that summarize cover by both project area and WMA. Companion data products summarize vegetation exposures and vulnerability rankings, ranging from suitable, to unsuitable, to stressed and "no analog" (meaning that the climate shifts to conditions presently not associated with locations occupied by the relevant macrogroup).

Vegetation Cover: Our characterization of project area vegetation cover utilizes the vegetation classification called "macrogroups," a mid-level step in the National Vegetation Classification System which represents the 4th level of generalization from the most detailed descriptions (Association) and the 5th level from the most general. Project area vegetation cover is summarized below in Table 14.

Table 14: VEGETATION COVER BY MANUAL OF CALIFORNIA VEGETATION MACROGROUP, NCRP*

Macro Group	Common Name	Percent of Land Cover
23	North Coastal Mixed Evergreen and Montane Conifer Forests	38
9	California Foothill and Valley Forests and Woodlands	27
24	Pacific NW Conifer Forests	8
45	California Grassland and Flowerfields	8
43	Chaparral	3
52	Montane Chaparral	3
26	Great Basin Pinyon-Juniper Woodland	3
97	Great Basin Dwarf Sagebrush Scrub	2
25	Pacific Northwest Subalpine Forest	2
96	Big Sagebrush Scrub	2
98	Great Basin Upland Scrub	1
114	NW Coast Cliff and Outcrop	1
34	North Coastal and montane Riparian Forest and Woodland	1
50	North Coast Deciduous Scrub and Terrace Prairie	1
20	Subalpine Aspen Forests & Pine Woodlands	1
58	Coastal Dune and Bluff Scrub	1
47	Mountain Riparian Scrub and wet meadow	0.3
48	Western Upland Grasslands	0.3
110	California Foothill and Coastal Rock Outcrop Vegetation	0.2

*We scored each of the dominant species comprising each macrogroup, according to life history characteristics defined in attribute tables of the Manual of California Vegetation (Sawyer et al. 2009). www.cnps.org/cnps/vegetation/manual.php

Vegetation exposure: Vegetation exposure in the CDFW model to a changing climate is more properly an assessment of vegetation vulnerability (integrating climate exposure, vegetation sensitivity, and adaptive capacity) given the spatial distribution of a given macrogroup. High levels of vegetation exposure for a given vegetation macrogroup indicate climatic conditions that occur rarely for that macrogroup, and represent or exceed the extreme of climate conditions where the macrogroup occurs.

Table 15 provides a breakdown of climate-based vegetation vulnerability rankings for the project area. Parallel tables for projected conditions have been generated for the scale of both Watershed Management Area boundaries (WMAs) and counties. These are available in the Excel sheet "NCRP Veg Macrogroup Tables (County_WMA).xls" Climate-based vegetation vulnerability rankings for vegetation macrogroups (Thorne et al. 2016) are provided in Appendix F.

Table 15: PERCENT OF PROJECT AREA IN UNSUITABLE AND CLIMATE STRESSED VEGETATION CATEGORIES (1981-2010 VERSUS 2070–2099), THREE SCENARIOS, NCRP REGION

*Percent of Project Area		End of Century (2070-2099)		
	Recent	Scenario 1 (CCSM rcp 8.5)	Scenario 2 (CNRM rcp 8.5)	Scenario 3 (MIROC esm rcp 8.5)
Vegetation Exposure Class	(1981-2010)	Warm, Moderate Rainfall	Warm, High Rainfall	Hot, Low Rainfall
Unsuitable (80% to 95%)	9	11	10	9
Climate stressed (95% to 99%)	8	11	15	13
Highly Climate Stressed (99%-100%)	2	8	23	10
Climate Stressed (Non-Analog)	0	0	3	0
Total	**19**	**30**	**51**	**32**

Percent area excludes urban and agricultural lands

*Cells which fall completely outside the range of recent historical conditions observed for the vegetation type are also considered "highly climate stressed." Cells that are marginal or highly exposed to climate stress are considered to be potentially subject to vegetation type conversion. Regions with less than 80% future exposure levels may be considered refugia.

Comparable tables for projected conditions have been generated at the following scales: Watershed Management Area boundaries (WMAs) and counties (see Appendix A). These are available in the Excel sheet named NCRP Veg Exposure Tabulated Area Tables (WMA).xls.

Data gaps, limitations, and suggestions for analysis improvement

Macrogroup 106 (Temperate Pacific Intertidal Shore) was excluded from analysis due to limited distributions, making an accurate fit of climate space unobtainable (Thorne et al. 2016). Some data points, which lie far outside the distribution of climate space for vegetation types may represent microclimate variation not captured in the climate data, misclassified vegetation types in source data, or historical anomalies.

The next generation of vegetation models will expand beyond simply looking at risks to existing vegetation due to climate stress, and begin to explore which plants may actually replace those vulnerable to climate change. We are currently working with the Ackerly Lab at UC Berkeley to apply a statewide model that takes this approach (piloted in Micheli et al 2016). The project team will be exploring opportunities to look at potential shifts in species composition, and in particular, adaptation strategies to identify and foster potentially resilient native seeds stock, in partnership with the Terrestrial Biodiversity Climate Change Collaborative and its affiliates.

E. FIRE RISKS

Summary

Climate change has the potential to increase risks of fire, including more frequent, larger, and intense fires, through its potential impacts on climatic conditions and fuel attributes, including fuel moisture and fuel loading. This analysis utilizes a model generated via the Terrestrial Biodiversity Climate Change Collaborative (Krawchuk and Mortiz 2012) that correlates 2014 CA BCM climate and hydrology models with historical fire frequencies to project the impact of climate change on fire probabilities over time and return intervals.

Data set description

Data generated for the NCRP is comprised of extracted map and tabular results from the statewide model of potential climate impacts on fire return intervals, and in turn, the risk of fire estimated over a 30-year period. Historical fire risk and projected changes in fire risk over the 21st century were modeled by Krawchuk and Moritz (2012) as the probability of burning at least once within a given 30-year interval (probability of burn) and conversely, as the estimated fire return interval (FRI). The probability of burn and FRI data sets were generated from the combination of 2014 CA BCM outputs including: maximum temperature, minimum temperature, total precipitation, potential evapo-transpiration, climatic water deficit, and actual evapo-transpiration combined with historical fire data and historical and projected human development patterns (Krawchuck and Moritz 2012).

Methodology

Fire risk modeling: Potential changes in fire activity over time were modeled from the record of recent historical burning across the state, combined with 2014 CA BCM outputs that describe seasonal aridity and vegetation growing conditions, at a spatial resolution of 1080 meters and a temporal resolution of 30 years for the 1971–2000, 2040–2069 and 2070–2099 periods. The final set of variables includes maximum monthly temperature, precipitation seasonality, potential evapo-transpiration seasonality, actual evapo-transpiration seasonality, and climatic water deficit as well as distance to development, with the latter designed to capture risk of ignition due to human activities.

Historical fire data polygons came from Cal FIRE and FRAP datasets. The minimum size of fires included in the datasets ranges from 10–300 acres. Ten models of recent historical fire were built from random samples of the historical period (1971–2000) for fire, climate and infrastructure and averaged into a final map of fire risk. Historical fire probability was validated by back-casting the probability of fire from the baseline (1971–2000) to the earlier period (1941–1971) with model parameters including climate and development data.

A metric of distance to human development is included in the model in order to estimate the additional influence of human access on fire risks (Krawchuk and Moritz 2012). Current levels of human development and projected growth, for non-rural areas were obtained through the UPlan urban projection model. Agricultural lands and water bodies were excluded from analyses and were designated from FRAP data.

Average pixel values for fire risk raster layers defined by project area watersheds and jurisdictions were obtained in the programming language R. We utilized the rgdal, raster and maptools libraries and the extract and raster tools on raster files (see Appendix D for code resources).

Data product summary and key findings

We created a regional assessment (maps and summary tables) from the statewide data set to assess current conditions and potential change in risk of wildfire on the basis of projected environmental conditions for climate and hydrologic stress on the landscape. The potential for increases in fuel load as a result of plant productivity based on modeled rates of actual evapo-transpiration are included, but no assumptions are made about management. Regional maps at 1080 meter scale resolution of historical (Map 15) and mid-century conditions are provided with a summary table of change over time for the project area, Watershed Management Areas, and major river (HUC-8) basins (see Appendix A).

Table 16 shows an approximately 40% increase in probability of fire across the region by end-century, with an increase in the spatially-averaged probability of burn over the entire project area increasing from 10 to 15% by end-century.

Table 16: PROBABILITY OF FIRE OVER A THIRTY 30-YEAR PERIOD, (1971-2000 VERSUS 2040-2099), NCRP REGION

	Historical	low warming, low rainfall		low warming, moderate rainfall	
Project Area	1971 - 2000	2040-2069	2070-2099	2040-2069	2070-2099

Probability of Fire (Percent Chance over 30 years)	10	13	15	13	15

Comparable tables for projected conditions have been generated at the following scales: Watershed Management Area boundaries (WMAs) counties are available in the Excel sheet NCRP Fire Tables (WMA and County).xls. Table 17 below summarized fire risks (percent chance) by major river (HUC-8) basins, with related data to be found in NCRP Fire Tables (HUC-8 Rankings).xls

Table 17: FIRE PROBABILITIES BY MAJOR RIVER (HUC-8) BASINS (1971-2000 VERSUS 2040-2099), NCRP REGION

Fire — Burn probability over 30 years in HUC 8 watersheds	Historical	low warming, low rainfall		low warming, moderate rainfall	
	1971-2000	2040-2069	2070-2099	2040-2069	2070-2099
Russian	19	24	25	23	26
Tomales-Drake Bays	15	19	21	18	21
Upper Eel	15	19	22	19	21
Gualala-Salmon	15	20	23	19	21
Marin County	15	18	20	18	20
Middle Fork Eel	13	17	20	17	20
Big-Navarro-Garcia	13	17	19	16	18
South Fork Eel	12	15	18	15	17
Trinity	11	15	18	15	17
Lower Eel	11	15	17	14	16
South Fork Trinity	11	14	17	14	16
Mattole	10	13	17	12	14
Lower Klamath	10	13	16	12	14
Salmon	10	13	16	13	14
Illinois	9	12	15	11	13
Smith	8	11	14	10	12
Scott	8	10	11	10	12
Mad-Redwood	8	11	13	10	12
Chetco	7	9	11	8	10
Upper Klamath	6	8	8	8	8
Applegate	6	8	11	8	10
Shasta	5	6	6	7	7
Butte	4	5	5	5	6
Lost	4	4	2	4	4

The Russian River basin displays the maximum historical (19%) and highest projected probability of burn (23–26%) averaged over its watershed. The Shasta, Butte and Lost River basins show extremely low historical rates of burning and essentially no projected increases resulting from climate change.

Data gaps, limitations, and suggestions for analysis improvement

Data gaps include a very short data set on historical fire frequencies (which in some part of the study area resulted in unrealistic return intervals), a lack of rural development data across the state, and a lack of models of how development correlates to ignition risks. In addition, there is a lack of historical data and future projections for lightning, as well as a limited understanding of how fire ignitions due to lightning may change in the future.

The model utilized here is very basic in terms of its primary focus on assessing 2014 CA BCM projections to estimate the natural landscape's vulnerability to fire. Lightning was not included as an ignition source in historical fire models due to the lack of future projections for lightning. A limitation to the fire risk data sets utilized (Krawchuck and Moritz 2012), now being addressed in emerging modeling efforts, is that they do not account for changes in human population density and location in rural regions of the NCRP (Thorne 2016, personal communication). Part of this is a data gap, as rural development data are not currently available for the State of California. Projections in this realm are even less available.

As the vast majority of fire in our region results from human-caused ignition, ignitions can be expected to increase as population densities in the North Coast region increase, but this effect is challenging to model. The relationship between human population density and fire risk appear to be hump shaped, with the highest risk at intermediate densities (Syphard et al. 2007). Another important consideration is the limit in the quality with which the historical fire data were tracked (see Krawchuck and Moritz 2012): however, it will be difficult to backfill this lack of historical data.

Empirical data that would help improve fire models include high resolution of weather events classified as "fire weather" and better modeling of fuels accumulation as a result of climate trends impacts on standing fuels moisture and flammability. There also remains significant work to be done on effective approaches to vegetation management and ignition hazard reduction strategies on the part of land managers, energy providers, local planners, and home owners.

3. REFERENCES

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4. APPENDICES

APPENDIX A: GENERATED DATA AND MAP PRODUCTS

The tables below summarize products generated by the Pepperwood team in the course of this project provided on data files accompanying this report. Tabular data can be found at www.pepperwoodpreserve.org/ncrp.

LIST OF DATA PRODUCTS AND FILE NAMES

Folder	FileName
Basin Characterization Model	BCM - Downscaled inputs and output variables - APX_B 18-01-22.xlsx
Basin Characterization Model	BCM - GCM used in the CA BCM - APX_B 18-03-01.xlsx
Basin Characterization Model	BCM - Glossary of terms - APX_C 18-01-22.xlsx
Basin Characterization Model	Global Circulation Models 18-01-03.xlsx
Basin Characterization Model	Water Supply Indicators HUC8.xlsx
Basin Characterization Model/ BCM Basic Output Tables	NCRP BCM Tables - HUC8 Rankings 16-08-31.xlsx
Basin Characterization Model/ BCM Basic Output Tables	NCRP BCM Tables All Polygons 18-02-26.xlsx
Basin Characterization Model/ BCM Basic Output Tables	raw data
Basin Characterization Model/ CWD Exceedance	CWD ExceedHistoric SD Table 16-12-19.xlsx
Basin Characterization Model/ CWD Exceedance	raw data
Basin Characterization Model/ Ground Water Basins	NCRP_GroundwaterBasin_ Rch_PercentChange.xlsx
Basin Characterization Model/ Ground Water Basins	NCRP_GroundwaterBasin_Rch_ WMA_Table 16-08-26.xlsx
Basin Characterization Model/ Ground Water Basins	NCRP_GroundwaterBasin_ RchData 16-10-14.xlsx
Basin Characterization Model/ Ground Water Basins	DWR_Groundwater_Basin_IDs 18-03-05.xlsx
Basin Characterization Model/Snow	NCRP_SWE_SummaryTables (WMA Proj Area rank) 16-12-09.xlsx
Basin Characterization Model/Snow	NCRP_SWE_Tables (WMA Proj Area) 16-11-23.xlsx
Basin Characterization Model/Snow	raw data
Basin Characterization Model/ Stream Flow Analysis	raw data
Basin Characterization Model/ Stream Flow Analysis	NCRP_Historical_and_projected_ annual_cumulative_discharge.xlsx
Basin Characterization Model/ Stream Flow Analysis	PW-USGS NCRP stream flow data visualizations deck 18-02-20.pptx
Basin Characterization Model/ Water Supply Timeseries	NCRP_BCM_WaterSupply_Summary (WMAs) 16-06-11.xlsx
Basin Characterization Model/ Water Supply Timeseries	NCRP_BCM_WY_timeseries_ ChartImages_RchRun 16-06-11.pptx
Basin Characterization Model/ Water Supply Timeseries	raw data
Fire Risk	NCRP Fire Prob Tables (HUC8 Rankings) 16-11-23.xlsx
Fire Risk	NCRP Fire Prob Tables (WMA County Proj Area) 16-11-23.xlsx
Fire Risk	raw data
Fire Risk	read me.txt
Summary Tables	NCRP Project Area BCM Hist Summary 18-03-05.xlsx
Summary Tables	NCRP Project Area BCM Projection Summary 18-03-05.xlsx
Summary Tables	NCRP Project Area CWD table 18-01-03.xlsx
Summary Tables	NCRP summary tables (WMA Proj Area) 18-03-05.xlsx
Summary Tables	NCRP_Acreage (WMA Proj Area) 16-12-19.xlsx
Vegetation Exposure	NCRP Veg Exposure Tabulated Area Tables (WMA) 16-12-19.xlsx
Vegetation Exposure	NCRP Veg Macrogroup Tables (County_WMA) 18-03-13.xlsx
Vegetation Exposure	raw data
Vegetation Sensitivity Adaptive Capacity tables (Thorne)	NCRP Veg Macro Groups Tables 18-03-13.doc
Vegetation Exposure	NCRP Veg Macrogroup Tables (County_WMA) 16-06-08.xls
Vegetation Exposure	raw data
Vegetation Sensitivity Adaptive Capacity tables (Thorne)	NCRP Veg Macro Groups Tables 16-12-29.doc
Vegetation Sensitivity Adaptive Capacity tables (Thorne)	images
zip archive of results for sharing	NCRP Map and Data Results 18-01-17.zip

LIST OF MAP PRODUCTS

Folder	FileName
Intro Maps	NCRP_IntroHydroMap 16-08-25.jpg
Intro Maps	NCRP_IntroHydroMap_ GWBasins 16-08-25.jpg
Intro Maps	NCRP_IntroHydroMap_GWBasins_ WMA_labels 16-08-25.jpg
Intro Maps	NCRP_IntroMap 16-08-25.jpg
Intro Maps	NCRP_IntroMap_GWBasins 16-08-25.jpg
Intro Maps	North Coast DWR Ground Water Basins with Numbers.pdf
Basin Characterization Model (BCM) Maps	NCRP_CWD_5180 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_CWD_5180_STD_16-09-01.jpg
Basin Characterization Model (BCM) Maps	NCRP_CWD_8110 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_CWD_CCSM_4069 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_CWD_CCSM_7099 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_CWD_DeltaMasked_ CCSM_4069 16-07-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_CWD_DeltaMasked_ CCSM_7099 16-07-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_CWD_DeltaMasked_ Miroc_4069 16-07-19.jpg

Basin Characterization Model (BCM) Maps	NCRP_CWD_DeltaMasked_Miroc_7099 16-07-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_DJF_5180 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_DJF_8110 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_DJF_CCSM_4069 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_DJF_CCSM_7099 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_JJA_5180 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_JJA_8110 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_JJA_CCSM_4069 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_JJA_CCSM_7099 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_PPT_5180 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_PPT_8110 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_PPT_CCSM_4069 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_PPT_CCSM_7099 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_RCH_5180 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_RCH_8110 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_RCH_CCSM_4069 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_RCH_CCSM_7099 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_RCH_wGWB_5180 16-12-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_RCH_wHUC8s_8110 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_RUN_5180 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_RUN_8110 16-06-09.jpg
Basin Characterization Model (BCM) Maps	NCRP_RUN_CCSM_4069 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_RUN_CCSM_7099 16-06-10.jpg
Basin Characterization Model (BCM) Maps	NCRP_SWE_5180 16-07-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_SWE_8110 16-07-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_SWE_CCSM_4069 16-07-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_SWE_CCSM_7099 16-07-19.jpg
Basin Characterization Model (BCM) Maps	NCRP_SWE_Changing_Footprint_Snow 16-09-02.jpg
Basin Characterization Model (BCM) Maps	NCRP_SWE_Elevation_SnowProne 16-08-16.jpg
Vegetation Exposure Maps	NCRP_VegClimateExposure_7099_CCSM 16-06-09.jpg
Vegetation Exposure Maps	NCRP_VegClimateExposure_7099_CNRM 16-06-09.jpg
Vegetation Exposure Maps	NCRP_VegClimateExposure_7099_Miroc 16-06-09.jpg
Vegetation Exposure Maps	NCRP_VegClimateExposure_8110 16-06-09.jpg
Vegetation Exposure Maps	NCRP_VegMacroGroups 16-06-08.jpg
Fire Risk Maps	NCRP_Fire_MasksMap 16-09-01.jpg
Fire Risk Maps	NCRP_Fire_Prob_7100 16-06-10.jpg
Fire Risk Maps	NCRP_Fire_Prob_GFDL_4069 16-06-10.jpg
Fire Risk Maps	NCRP_Fire_Prob_GFDL_7099 16-06-10.jpg
Fire Risk Maps	NCRP_Fire_Prob_PCM_4069 16-06-10.jpg
Fire Risk Maps	NCRP_Fire_Prob_PCM_7099 16-06-10.jpg
Fire Risk Maps	NCRP_Fire_ReturnInterval_7100 16-08-16.jpg
Fire Risk Maps	NCRP_Fire_ReturnInterval_GFDL_4069 16-08-16.jpg
Fire Risk Maps	NCRP_Fire_ReturnInterval_GFDL_7099 16-08-16.jpg
Fire Risk Maps	NCRP_Fire_ReturnInterval_PCM_4069 16-08-16.jpg
Fire Risk Maps	NCRP_Fire_ReturnInterval_PCM_7099 16-08-16.jpg

APPENDIX B: GLOBAL CIRCULATION MODELS ANALYZED VIA THE 2014 CALIFORNIA BASIN CHARACTERIZATION MODEL

Model Abbreviation	Originating Group(s)	Country	IPCC Assessment Report	Emissions scenario or representative concentration pathway	Emissions Scenario	Downscaling method	Climate Trend	Memo section where model utilzied (per Table of Contents)
CCSM_4	National Center for Atmospheric Research	USA	5	RCP 8.5	business as usual	BCSD	warm, moderate rainfall	Climate and Hydrology, Runoff and Stream Flow, Ground Water Resources
CNRM-CM5	Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	France	5	RCP 8.5	business as usual	BCSD	warm, high rainfall	Climate and Hydrology, Runoff and Stream Flow, Ground Water Resources, Native Vegetation Climate Vulnurabilities
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	Japan	5	RCP 8.5	business as usual	BCSD	hot, low rainfall	Climate and Hydrology, Runoff and Stream Flow, Ground Water Resources, Native Vegetation Climate Vulnurabilities
GFDL	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	4	A2	business as usual	CA	warm, low rainfall	Fire Risks
PCM	National Center for Atmospheric Research	USA	4	A2	business as usual	CA	warm, high rainfall	Fire Risks
GFDL	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	4	B1	mitigated	CA	high warming, low rainfall	Supplemental data products for Climate and Hydrology, Runoff and Stream Flow, Ground Water Resources.

BCSD = Bias correction and spatial downscaling (Wood and others, 2004)

CA = Constructed analogues (Hidalgo and others, 2008)

APPENDIX C: 2014 CALIFORNIA BASIN CHARACTERIZATION MODEL VARIABLE DEFINITIONS

Variable	Code	Creation Method	Units	Equation/model	Description
Maximum air temperature	tmx	downscaled	degree C	Model input	The maximum monthly temperature averaged annually
Minimum air temperature	tmn	downscaled	degree C	Model input	The minimum monthly temperature averaged annually
Precipitation	ppt	downscaled	mm	Model input	Total monthly precipitation (rain or snow) summed annually
Potential evapotranspiration	pet	Modeled/ pre-processing input for BCM	mm	Modeled* on an hourly basis from solar radiation that is modeled using topographic shading, corrected for cloudiness, and partitioned on the basis of vegetation cover to represent bare-soil evaporation and evapotranspiration due to vegetation	Total amount of water that can evaporate from the ground surface or be transpired by plants summed annually
Runoff	run	BCM	mm	Amount of water that exceeds total soil storage + rejected recharge	Amount of water that becomes stream flow, summed annually
Recharge	rch	BCM	mm	Amount of water exceeding field capacity that enters bedrock, occurs at a rate determined by the hydraulic conductivity of the underlying materials, excess water (rejected recharge) is added to runoff	Amount of water that penetrates below the root zone, summed annually
Climatic water deficit	cwd	BCM	mm	pet-aet	Annual evaporative demand that exceeds available water, summed annually
Actual evapotranspiration	aet	BCM	mm	pet calculated* when soil water content is above wilting point	Amount of water that evaporates from the surface and is transpired by plants if the total amount of water is not limited, summed annually
Sublimation	subl	BCM	mm	Calculated*, applied to swe	Amount of snow lost to sublimation (snow to water vapor) summed annually
Soil water storage	stor	BCM	mm	ppt + melt - aet - rch - run	Average amount of water stored in the soil annually
Snowfall	snow	BCM	mm	precipitation if air temperature below 1.5 degrees C (calibrated)	Amount of snow that fell summed annually
Snowpack water equivalent	swe	BCM	mm	Prior month swe + snow - subl -melt	Amount of snow as a water equivalent that is accumulated per month summed annually (if divided by 12 would be average monthly snowpack)
Snowmelt	melt	BCM	mm	Calculated*, applied to swe	Amount of snow that melted summed annually (snow to liquid water)
Excess water	exc	BCM	mm	ppt - pet	Amount of water that remains in the system, assuming evapotranspiration consumes the maximum possible amount of water, summed annually for positive months only

Source: Flint, L.E., A.L. Flint, and J.H. Thorne. 2013. California Basin Characterization Model: A Dataset of Historical and Future Hydrologic Response to Climate Change: U.S. Geological Survey Data Set, http://calcommons.org; http://cida.usgs.gov/climate/gdp.

APPENDIX D: SPATIAL STATISTICS METHODS

ZONAL STATISTICS R CODE

```
#Generalized R code for polygon extraction of raster values (Zonal Stats)
#Authors Celeste Dodge and Prahlada Papper
############################
library(raster)
library(maptools)
rm(list= ls())
polygons <- readShapePoly("F:/Local GIS Data/directory containing
shapefile of analyzed polygons/",",delete_null_obj=TRUE)
tablezs <- as.data.frame(Polygons@data$FieldName)
asc_files <- c( "asciFile 1.asc", "asciiFile2.asc" ,...)
for(i in 1:length(asc_files)) {
 temp_asc <- raster(paste("F:/Local GIS Data/directory containing analyzed rasters/",asc_files[i],sep=""))
 temp_asc[temp_asc==-9999] <- NA
 tempStats <- extract(temp_asc, polygons, fun=mean, na.rm=TRUE)
 tablezs[paste(WY_asc_files[i],sep="")] <- tempStats
}
write.csv(tablezs, "F:/Prefered Directory/OutputFileName.csv")
################################
```

Climatic Water Deficit and Historical Variability Exceedance R Code:

```
#Creates delta CWD raster layers, and binary raster layers with pixels classified as either within
(0) or outside (1) of historical CWD variability. Creates a mask layer blocking out regions where
the future CWD is within historical variation and reclassifies mask into binary values.
#Authors Celeste Dodge and Sam Veloz

(The logic behind delta and mask layers is as follows:
        "Delta" = CWDprojected - CWDhistoric
        "Masked Area"(data value = 0) where "Delta"< 30-year standard deviation = 0
        else, "Mask" = 1)
################################
library(raster)
rm(list=ls())
historical<-raster("C:/File Location/HistoricalAVGLayer.asc")
historicalSD<-raster("C:/File Location/HistoricalSDLayer.asc")
future<-raster("C:/File Location/FutureAVGLayer.asc")
future[future<0]<-NA
historical[historical<0]<-NA
delta <-future-historical
writeRaster(delta,"C:/File Destination/DeltaLayer.asc")
delta[delta>historicalSD]<-0
delta[delta!=0]<-1
writeRaster(delta,"C:/File Destination/MaskLayer.asc")
################################
```

APPENDIX E: NORTH COAST GROUNDWATER BASINS

Extracted from the State of California's Department of Water Resources (DWR):California Department of Water Resources. 2013. *California Water Plan Update 2013*. Sacramento, CA.

Alluvial Groundwater Basins and Subbasins within the North Coast Hydrologic Region

Source: Department of Water Resources, CWP 2013

Map Legend: Basin Names and Department of Water Resources ID

Groundwater Basin	Basin ID
ALEXANDER VALLEY - ALEXANDER AREA	1-54.01
ALEXANDER VALLEY - CLOVERDALE AREA	1-54.02
ANDERSON VALLEY	1-19
ANNAPOLIS OHLSON RANCH FM HIGHLANDS	1-49
BIG LAGOON AREA	1-27
BIG RIVER VALLEY	1-45
BODEGA BAY AREA	1-57
BRANSCOMB TOWN AREA	1-39
BRAY TOWN AREA	1-17
BUTTE VALLEY	1-03
COTTONEVA CREEK VALLEY	1-37
COVELO ROUND VALLEY	1-11
DINSMORES TOWN AREA	1-34
EDEN VALLEY	1-44
EEL RIVER VALLEY	1-10
EUREKA PLAIN	1-09
FAIRCHILD SWAMP VALLEY	1-22
FORT BRAGG TERRACE AREA	1-21
FORT ROSS TERRACE DEPOSITS	1-61
GARBERVILLE TOWN AREA	1-32
GARCIA RIVER VALLEY	1-20
GRAVELLY VALLEY	1-48
HAPPY CAMP TOWN AREA	1-15
HAYFORK VALLEY	1-06
HETTENSHAW VALLEY	1-36
HONEYDEW TOWN AREA	1-29
HOOPA VALLEY	1-07
HYAMPOM VALLEY	1-35
KENWOOD VALLEY	2-19
KLAMATH RIVER VALLEY - LOWER KLAMATH	1-02.02
KLAMATH RIVER VALLEY - TULE LAKE	1-02.01
KNIGHTS VALLEY	1-50
LARABEE VALLEY	1-33
LAYTONVILLE VALLEY	1-12
LITTLE LAKE VALLEY	1-13
LITTLE VALLEY	1-41
LOWER KLAMATH RIVER VALLEY	1-14
LOWER LAYTONVILLE VALLEY	1-38
LOWER RUSSIAN RIVER VALLEY	1-60
MAD RIVER VALLEY - DOW'S PRARIE SCHOOL AREA	1-08.01
MAD RIVER VALLEY - MAD RIVER LOWLAND	1-08.02
MATTOLE RIVER VALLEY	1-28
McDOWELL VALLEY	1-56
NAVARRO RIVER VALLEY	1-46
PEPPERWOOD TOWN AREA	1-30
POTTER VALLEY	1-51
PRAIRIE CREEK AREA	1-25
RED ROCK VALLEY	1-18
REDWOOD CREEK AREA	1-26
SANEL VALLEY	1-53
SANTA ROSA VALLEY - HEALDSBURG AREA	1-55.02
SANTA ROSA VALLEY - RINCON VALLEY	1-55.03
SANTA ROSA VALLEY - SANTA ROSA PLAIN	1-55.01
SCOTT RIVER VALLEY	1-05
SEIAD VALLEY	1-16
SHASTA VALLEY	1-04
SHERWOOD VALLEY	1-42
SMITH RIVER PLAIN	1-01
TEN MILE RIVER VALLEY	1-40
UKIAH VALLEY	1-52
WEOTT TOWN AREA	1-31
WILLIAMS VALLEY	1-43
WILSON GROVE FORMATION HIGHLANDS	1-59
WILSON POINT AREA	1-62

APPENDIX F: CLIMATE SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR VEGETATION MACROGROUPS OF THE NORTH COAST

The tables below are excerpted from report titled: A climate change vulnerability assessment of California's terrestrial vegetation. California Department of Fish and Wildlife (CDFW), Sacramento, CA (Thorne et. al 2016).
The tables define sensitivity and adaptive capacity parameters and scores developed by a committee of experts for those parameters relative to 2014 CA BCM-derived climate drivers for the North Coast vegetation macrogroups. Vegetation cover for the North Coast is described in Table 14 as the percent area of each WMA occupied by vegetation macro groups listed below. No species were scored for sensitivity or adaptive capacity for macro group 114.

TABLE F.1: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE DOMINANT SPECIES COMPRISING MACROGROUP 9

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Hardwoods										
Quercus agrifolia	3	3	5	3	2	4	5	3	1	**3.2**
Quercus englemannii	3	3	4	3	2	3	5	1	1	**2.8**
Quercus douglasii	4	4	3	3	2	4	3	1	1	**2.8**
*Pinus sabiniana**	4	3	2	4	5	3	1	4	4	**3.3**
Quercus chrysolepis	3	3	4	3	2	5	5	3	1	**3.2**
Quercus lobata	3	3	5	3	2	5	5	1	1	**3.1**
Quercus wislizeni	4	3	4	3	2	3	5	4	1	**3.2**
Mean	**3.43**	**3.14**	**3.86**	**3.14**	**2.43**	**3.86**	**4.14**	**2.43**	**1.43**	
					Mean	**3.31**		**Mean**	**2.67**	
Conifers										
Pinus radiata	3	3	1	4	3	3	5	4	5	**3.4**
Juniperus californica	3	3	1	2	2	3	5	2	2	**2.6**
Pinus attenuata	4	3	1	4	5	2	5	4	5	**3.7**
Pinus ponderosa	3	3	5	2	4	5	4	4	1	**3.4**
Calocedrus decurrens	3	3	5	2	3	5	1	5	1	**3.1**
Abies concolor	2	2	2	2	4	5	1	5	1	**2.7**
Mean	**3.00**	**2.83**	**2.50**	**2.67**	**3.50**	**3.83**	**3.50**	**4.00**	**2.50**	
					Mean	**3.06**		**Mean**	**3.33**	
Grand Mean	**3.12**									

*TWO SPECIES, PINUS SABINIANA AND PINUS ATTENUATE, ARE KNOWN TO SPROUT AFTER A FIRE, SO SENSITIVITY IN GERMINATION IS NOT AS LOW AS GENERAL SCORING FOR THE AGENTS LISTED.

TABLE F.2: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 23.

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Repro-ductive Lifespan**	**Fire**	**Recruit-ment Mode /Fecundity**	**Seed Long-evity**	
Lithocarpus densiflorus	3	3	4	3	2	5	5	1	1	**3.0**
Arbutus menziesii	2	2	2	2	2	5	2	1	3	**2.3**
Quercus kelloggii	3	2	3	3	2	5	5	3	2	**3.1**
Acer macro-phyllum	2	2	4	3	3	2	5	1	1	**2.6**
Quercus garryana	3	2	4	3	2	5	5	1	1	**2.9**
Pseudotsuga menziesii	3	3	5	3	4	5	1	3	1	**3.1**
Pseudotsuga macrocarpa	3	3	4	2	3	5	5	1	1	**3.0**
Abies concolor	2	2	2	2	4	5	1	5	1	**2.7**
Pinus jeffreyi	2	3	4	2	3	5	1	3	2	**2.8**
Calocedrus decurrens	3	3	5	2	3	5	1	5	1	**3.1**
Pinus lambertiana	3	3	5	2	4	5	1	2	1	**2.9**
Pinus ponderosa	3	3	5	2	4	5	4	4	1	**3.4**
Mean	**2.64**	**2.55**	**3.82**	**2.45**	**2.91**	**4.73**	**2.91**	**2.36**	**1.36**	
Grand Mean	**2.86**				**Mean**	**3.18**		**Mean**	**2.21**	

TABLE F.3: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 20

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Populus tremuloides	1	2	4	3	3	3	4	1	1	**2.4**
Pinus flexilis	1	3	2	2	1	5	1	3	3	**2.3**
Pinus albicaulis	1	3	1	2	1	5	1	4	3	**2.3**
Pinus contorta	2	3	2	3	3	4	5	3	1	**2.9**
Mean	**1.25**	**2.75**	**2.25**	**2.50**	**2.00**	**4.25**	**2.75**	**2.75**	**2.00**	
Grand Mean	**2.50**				**Mean**	**2.50**		**Mean**	**2.50**	

*THE SPECIES *PINUS CONTORTA* COMBINES TWO SUBSPECIES WITH DIFFERENT LIFESPANS, AND SEROTINOUS CONES.

TABLE F.4: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 24

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Sequoia sempervirens	2	2	4	3	3	5	5	1	1	**2.9**
Mean	**2.00**	**2.00**	**4.00**	**3.00**	**3.00**	**5.00**	**5.00**	**1.00**	**1.00**	
Grand Mean	**2.89**				**Mean**	**3.17**		**Mean**	**2.33**	

TABLE F.5: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 25

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Abies amabilis	2	2	1	3	3	5	1	3	2	**2.4**
Abies lasiocarpa	2	2	1	2	3	5	1	4	1	**2.3**
Abies magnifica	2	2	5	2	3	5	1	3	1	**2.7**
Callitropsis nootkatensis	2	2	2	2	3	3	2	3	1	**2.2**
Tsuga mertensiana	3	2	1	2	3	3	1	4	1	**2.2**
Mean	**2.20**	**2.00**	**2.00**	**2.20**	**3.00**	**4.20**	**1.20**	**3.40**	**1.20**	
Grand Mean	**2.38**				**Mean**	**2.60**		**Mean**	**1.93**	

TABLE F.6: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 26

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Pinus monophylla	2	3	1	3	3	5	1	1	1	**2.2**
Juniperus occidentalis	3	3	1	2	3	3	2	1	3	**2.3**
Juniperus osteosperma	3	3	1	3	3	3	2	1	3	**2.4**
Mean	**2.67**	**3.00**	**1.00**	**2.67**	**3.00**	**3.67**	**1.67**	**1.00**	**2.33**	
Grand Mean	**2.33**				**Mean**	**2.50**		**Mean**	**1.67**	

TABLE F.7: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 34

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Populus trichocarpa	4	3	4	3	3	3	5	5	1	**3.4**
Alnus rhombifolia	3	2	4	3	3	2	5	4	1	**3.0**
Alnus rubra	2	2	2	3	3	2	1	4	1	**2.2**
Fraxinus latifolia	2	3	4	1	3	3	5	4	5	**3.3**
Mean	**2.75**	**2.50**	**3.50**	**2.50**	**3.00**	**2.50**	**3.67**	**4.25**	**2.00**	
Grand Mean	**3.00**				**Mean**	**2.79**		**Mean**	**3.42**	

*THREE SPECIES ARE INCLUDED FOR THE WILDLIFE HABITAT RELATIONSHIP TYPE MONTANE RIPARIAN (MRI). RIPARIAN SHRUBS AND WILLOWS ARE NOT INCLUDED IN THIS TYPE.

TABLE F.8: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 43

	Sensitivity						Adaptive Capacity			Specie s Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Arctostaphylos viscida	4	3	1	4	2	2	1	4	5	**2.9**
Ceanothus cuneatus	4	3	1	4	3	2	2	3	5	**3.0**
Adenostoma fasciculatum	4	3	4	4	2	3	5	4	3	**3.6**
Heteromeles arbutifolia	4	3	4	2	2	3	3	3	1	**2.8**
Quercus durata	4	3	4	3	2	2	5	3	1	**3.0**
Mean	**4.00**	**3.00**	**2.80**	**3.40**	**2.20**	**2.40**	**3.20**	**3.00**	**3.00**	
Grand Mean	**3.04**				**Mean**	**2.97**		**Mean**	**3.20**	

**QUERCUS DURATA* WAS USED TO REPRESENT ALL SHRUB OAKS, ALSO TRUE FOR REPRESENTATIVE SPECIES OF *ARCTOSTAPHYLOS* AND *CEANOTHUS*.

TABLE F.9: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 45

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Avena & Bromus genera	4	2	4	3	5	2	1	5	3	**3.2**
Nassella pulchra	4	3	4	3	3	2	5	5	1	**3.3**
Eschscholzia californica	4	3	2	3	3	2	1	5	1	**2.7**
Lasthenia californica	4	3	1	3	3	2	1	3	5	**2.8**
Amsinckia menziesii	4	3	1	3	2	2	1	3	3	**2.4**
Plagiobothrys nothofulvus	4	3	1	3	2	2	1	3	3	**2.4**
Mean	**4.00**	**2.83**	**2.17**	**3.00**	**3.00**	**2.00**	**1.67**	**4.00**	**2.67**	
Grand Mean	**2.81**				**Mean**	**2.83**		**Mean**	**2.78**	

*THE ANNUALS AND GRASS SPECIES LISTED BY CDFW FOR THIS MACROGROUP HAVE DIFFERENT CHARACTERISTICS, BUT MOST OF THE GRASSES WERE NOT QUANTIFIED IN THE MCV LIFE HISTORY TABLES, AND ARE NOT REPRESENTED HERE.

TABLE F.10: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 47

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Populus trichocarpa	4	3	4	3	3	3	5	1	1	**3.0**
Alnus rhombifolia	3	2	4	3	3	2	5	4	1	**3.0**
Acer macrophylum	3	2	4	3	3	2	5	1	1	**2.7**
Fraxinus latifolia	2	3	4	1	3	3	5	4	5	**3.3**
Populus fremontii	4	3	3	3	5	3	3	5	1	**3.3**
Salix sp	3	2	4	3	5	3	5	3	1	**3.2**
Mean	**3.17**	**2.50**	**3.83**	**2.67**	**3.67**	**2.67**	**4.67**	**3.00**	**1.67**	
Grand Mean	**3.09**				**Mean**	**3.08**		**Mean**	**3.11**	
Species - WTM	2	1	3	3	2	2	4	2	2	**2.3**
Carex sp	3	2	3	3	2	4	3	2	2	**2.7**
Juncus sp	3	2	4	3	3	4	4	3	3	**3.2**
Danthonia sp	3	2	3	3	4	3	3	3	2	**2.9**
Mean	**3.00**	**2.20**	**3.60**	**2.80**	**3.30**	**2.90**	**4.20**	**2.80**	**1.90**	
Grand Mean	**2.97**				**Mean**	**2.97**		**Mean**	**2.97**	

*THE SCORE USED FOR THIS MACROGROUP IS SELECTED FROM THE SECOND LINE, THE GENERA-LEVEL SCORING AS MOST TREES WERE INCLUDED IN MG034.

TABLE F.11: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 48.

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
PGS - habitat level	3	3	4	3	3	3	4	3	3	**3.2**
Species										
Festuca idahoensis	3	2	1	3	2	1	1	3	3	**2.1**
Elymus glaucus	3	2	4	3	2	1	5	3	1	**2.7**
Poa secunda	3	2	1	3	4	1	1	3	3	**2.3**
Mean	**3.00**	**2.25**	**2.50**	**3.00**	**2.75**	**1.50**	**2.75**	**3.00**	**2.50**	
Grand Mean	**2.58**				**Mean**	**2.50**		**Mean**	**2.75**	

TABLE F.12: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 50

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Rubus ursinus	2	2	4	2	2	2	5	5	3	**3.0**
Rubus parviflorus	2	2	4	2	2	2	5	5	3	**3.0**
Toxicodendron diversilobum	2	2	4	3	2	3	5	5	1	**3.0**
Danthonia californica	3	2	4	3	4	1	5	3	1	**2.9**
Mean	**2.25**	**2.00**	**4.00**	**2.50**	**2.50**	**2.00**	**5.00**	**4.50**	**2.00**	
Grand Mean	**2.97**				**Mean**	**2.83**		**Mean**	**3.00**	

TABLE F.13: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 52

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Arctostaphylos [illegible]	3	3	4	4	2	2	5	4	5	**3.6**

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Lupinus chamissonis	3	3	2	3	3	3	1	2	5	**2.8**
Ambrosia chamissonis	3	2	1	2	3	2	2	1	1	**1.9**
Plantago maritima	3	2	1	3	3	2	1	3	5	**2.6**
Mean	**3.00**	**2.33**	**1.33**	**2.67**	**3.00**	**2.33**	**1.33**	**2.00**	**3.67**	
Grand Mean	**2.41**				**Mean**	**2.44**		**Mean**	**2.33**	

**Lupinus chamissonis* life history indicates underground structures, but does not specify sprouting after fire. *Ambrosia chamissonis* was not rated in the MCV life history tables, and *Plantago maritima* was used instead.

TABLE F.15: SENSITIVITY AND ADAPTIVE CAPACITY RANKINGS FOR THE MAJOR SPECIES COMPRISING MACROGROUP 96

	Sensitivity						Adaptive Capacity			Species Score
Species	**Climate Temp**	**Climate Precip**	**Fire Sensitivity**	**Germination Agents**	**Mode Dispersal**	**Reproductive Lifespan**	**Fire**	**Recruitment Mode /Fecundity**	**Seed Longevity**	
Artemisia tridentata	3	3	2	3	3	3	2	5	2	**2.9**
Grayia spinosa	2	2	2	2	5	2	1	3	3	**2.4**
Kraschinnikovia lanata	2	3	2	2	3	2	1	1	3	**2.1**
Ephedra sp.	2	3	4	3	3	3	5	2	2	**3.0**
Coleogyne ramosissima	4	4	1	2	2	2	1	1	3	**2.2**
Cercocarpus	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Coreopsis gigantea	3	3	2	3	3	2	2	4	3	**2.8**
Mean	**3.00**	**3.00**	**2.00**	**3.00**	**3.00**	**2.00**	**2.00**	**4.00**	**3.00**	
Grand Mean	**2.78**				**Mean**	**2.67**		**Mean**	**3.00**	

APPENDIX G: DATA SUMMARY TABLES BY WATERSHED MANAGEMENT AREA (WMA)

TABLE G.1: EEL RIVER WMA HISTORICAL BASELINE CONDITIONS

Eel River WMA — Historical Baseline				
All parameters				
variable	1951-1980	±SE	1981-2010	±SE
Basin Characterizaton Model				
CWD (in/y)	21.5	0.4	21.2	0.6
DJF (°F)	34.4	2.0	35.1	2.1
JJA (°F)	81.9	1.9	81.6	1.7
PPT (in/y)	63.0	2.9	61.5	3.4
RCH (in/y)	26.6	1.4	24.8	1.4
RUN (in/y)	17.1	2.0	16.8	2.1
AET (in/y)	18.1	0.5	18.8	0.6
Avg SWE above 3,000 ft (in/y)	5.7	-	4.0	-
% WMA Snow Area	39	-	24	-
Vegetation Vulnerabilities				
Avg Vegetation Climate Exposure (%)	-	-	70.2	-
% WMA Area Veg Exposure > 80%	-	-	17	-
% WMA Area Veg Exposure > 95%	-	-	7	-
% WMA Area Non-Analog Condition	-	-	0	-
Probability of Fire in a 30-y window				
Fire Probability (%) (1970-2000 baseline)	12			

TABLE G.2: EEL RIVER WMA PROJECTED CONDITIONS

Eel River WMA — Projected Conditions						
All parameters						
variable	2010-2039	±SE	2040-2069	±SE	2070-2069	±SE
Basin Characterization Model						
(warm, moderate rainfall) CWD (in/y)	22.5	0.5	23.5	0.5	24.3	0.6
DJF (°F)	36.4	2.3	37.3	3.2	40.1	3.1
JJA (°F)	83.9	1.9	86.1	1.7	89.0	1.8
PPT (in/y)	63.4	3.2	62.2	3.0	63.1	4.0
RCH (in/y)	25.5	1.3	25.0	1.4	23.9	1.3
RUN (in/y)	18.3	2.1	17.8	1.8	19.3	2.9
AET (in/y)	18.7	0.6	18.8	0.5	19.6	0.6
Avg SWE above 3,000 ft (in/y)	-	-	1.5		0.2	-
% WMA Snow Area	-	-	15		4	-
Vegetation Vulnerabilities						
Avg Vegetation Climate Exposure (%)	80.2	-	75.8	-	80.0	-
% Area Veg Exposure > 80%	-	-	-	-	26	-
% Area Veg Exposure > 95%	-	-	-	-	12	-
% WMA Area Non-Analog Condition	-	-	-	-	0	-
Probability of Fire in a 30-y window						
Fire Probability (warm, high rainfall) (%)	-	-	16	-	18	
Fire Probability (warm, low rainfall) (%)	-	-	16	-	19	

TABLE G.3: HUMBOLDT WMA HISTORICAL BASELINE CONDITIONS

Humboldt WMA — Historical Baseline				
All parameters				
variable	1951-1980	±SE	1981-2010	±SE
Basin Characterizaton Model				
CWD (in/y)	14.9	0.4	14.8	0.5
DJF (°F)	35.5	1.9	36.2	2.0
JJA (°F)	73.7	1.5	74.4	1.4
PPT (in/y)	71.9	2.9	70.0	3.3
RCH (in/y)	32.9	1.4	30.7	1.4
RUN (in/y)	18.6	2.0	17.4	2.0
AET (in/y)	20.2	0.4	20.9	0.6
Avg SWE above 3,000 ft (in/y)	8.4	-	5.1	-
% WMA Snow Area	34	-	29	-
Vegetation Vulnerabilities				
Avg Vegetation Climate Exposure (%)	-	-	76	-
% WMA Area Veg Exposure > 80%	-	-	27	-
% WMA Area Veg Exposure > 95%	-	-	16	-
% WMA Area Non-Analog Condition	-	-	0	-
Probability of Fire in a 30-y window				
Fire Probability (%) (1970-2000 baseline)	8			

TABLE G.4: HUMBOLDT WMA PROJECTED CONDITIONS

Humboldt WMA — Projected Conditions						
All parameters						
variable	2010-2039	±SE	2040-2069	±SE	2070-2069	±SE
Basin Characterization Model						
(warm, moderate rainfall) CWD (in/y)	15.5	0.5	16.5	0.5	17.0	0.6
DJF (°F)	37.4	2.4	38.3	3.2	41.1	3.0
JJA (°F)	76.4	1.7	78.7	1.5	81.8	1.5
PPT (in/y)	73.3	3.2	72.3	3.0	71.1	3.8
RCH (in/y)	31.9	1.4	30.7	1.4	29.0	1.4
RUN (in/y)	20.1	2.1	20.6	1.9	20.3	2.6
AET (in/y)	21.2	0.6	21.2	0.5	22.2	0.6
Avg SWE above 3,000 ft (in/y)	-	-	2.0		0.1	-
% WMA Snow Area	-	-	22	-	3	-
Vegetation Vulnerabilities						
Avg Vegetation Climate Exposure (%)	77.2	-	69.8	-	68.1	-
% Area Veg Exposure > 80%	-	-	-	-	21	-
% Area Veg Exposure > 95%	-	-	-	-	11	-
% WMA Area Non-Analog Condition	-	-	-	-	0	-
Probability of Fire in a 30-y window						
Fire Probability (warm, high rainfall) (%)	-	-	10	-	12	-
Fire Probability (warm, low rainfall) (%)	-	-	11	-	13	-

TABLE G.5: KLAMATH WMA HISTORICAL BASELINE CONDITIONS

Klamath WMA — Historical Baseline				
All parameters				
variable	1951-1980	±SE	1981-2010	±SE
Basin Characterizaton Model				
CWD (in/y)	20.4	0.5	21.0	0.6
DJF (°F)	26.4	2.4	27.4	2.3
JJA (°F)	80.4	2.4	80.8	2.1
PPT (in/y)	44.0	2.0	42.3	2.1
RCH (in/y)	13.1	0.6	12.3	0.6
RUN (in/y)	16.7	1.4	15.0	1.4
AET (in/y)	12.9	0.4	13.4	0.5
Avg SWE above 3,000 ft (in/y)	9.4	-	7.3	-
% WMA Snow Area	91	-	82	-
Vegetation Vulnerabilities				
Avg Vegetation Climate Exposure (%)	-	-	63.1	-
% WMA Area Veg Exposure > 80%	-	-	20	-
% WMA Area Veg Exposure > 95%	-	-	12	-
% WMA Area Non-Analog Condition	-	-	1	-
Probability of Fire in a 30-y window				
Fire Probability (%) (1970-2000 baseline)	7			

TABLE G.6: KLAMATH WMA PROJECTED CONDITIONS

Klamath WMA — Projected Conditions						
All parameters						
variable	2010-2039	±SE	2040-2069	±SE	2070-2069	±SE
Basin Characterization Model						
(warm, moderate rainfall) CWD (in/y)	21.7	0.5	23.4	0.4	24.6	0.5
DJF (°F)	28.7	2.4	29.6	3.2	32.5	3.0
JJA (°F)	83.4	2.7	86.5	2.5	90.3	2.5
PPT (in/y)	44.7	1.8	43.7	1.7	42.3	2.0
RCH (in/y)	12.7	0.5	12.1	0.5	11.4	0.5
RUN (in/y)	16.5	1.3	16.3	1.2	14.9	1.4
AET (in/y)	14.3	0.5	14.3	0.4	15.4	0.5
Avg SWE above 3,000 ft (in/y)	-	-	3.4	-	1.0	-
% WMA Snow Area	-	-	39	-	16	-
Vegetation Vulnerabilities						
Avg Vegetation Climate Exposure (%)	74.9	-	76.1	-	75.0	-
% Area Veg Exposure > 80%	-	-	-	-	35	-
% Area Veg Exposure > 95%	-	-	-	-	23	-
% WMA Area Non-Analog Condition	-	-	-	-	0	-
Probability of Fire in a 30-y window						
Fire Probability (warm, high rainfall) (%)	-	-	9	-	10	-
Fire Probability (warm, low rainfall) (%)	-	-	9	-	10	-

TABLE G.7 : NORTH COAST RIVERS WMA 1 HISTORICAL BASELINE CONDITIONS

North Coast Rivers WMA 1 — Historical Baseline				
All parameters				
variable	1951-1980	±SE	1981-2010	±SE
Basin Characterizaton Model				
CWD (in/y)	14.1	0.5	14.3	0.6
DJF (°F)	33.5	1.9	34.5	1.9
JJA (°F)	76.2	1.9	76.6	1.8
PPT (in/y)	99.8	4.0	95.0	4.2
RCH (in/y)	35.3	1.1	34.0	1.1
RUN (in/y)	43.6	3.4	38.9	3.3
AET (in/y)	19.8	0.5	20.7	0.6
Avg SWE above 3,000 ft (in/y)	23.1	-	15.5	-
% WMA Snow Area	72	-	67	-
Vegetation Vulnerabilities				
Avg Vegetation Climate Exposure (%)	-	-	89.8	-
% WMA Area Veg Exposure > 80%	-	-	55	-
% WMA Area Veg Exposure > 95%	-	-	33	-
% WMA Area Non-Analog Condition	-	-	3	-
Probability of Fire in a 30-y window				
Fire Probability (%) (1970-2000 baseline)	8			

TABLE G.8: NORTH COAST RIVERS WMA 1 PROJECTED CONDITIONS

North Coast Rivers WMA 1 — Projected Conditions						
All parameters						
variable	2010-2039	±SE	2040-2069	±SE	2070-2069	±SE
Basin Characterization Model						
(warm, moderate rainfall) CWD (in/y)	14.4	0.5	15.5	0.4	15.9	0.5
DJF (°F)	35.5	2.4	36.3	3.1	39.2	3.0
JJA (°F)	78.8	1.8	81.2	1.6	84.5	1.6
PPT (in/y)	100.0	4.0	97.9	3.6	95.6	4.3
RCH (in/y)	34.3	1.0	32.5	0.9	30.9	1.0
RUN (in/y)	43.2	3.3	43.2	2.9	41.6	3.5
AET (in/y)	21.5	0.6	21.6	0.5	22.8	0.5
Avg SWE above 3,000 ft (in/y)	-	-	7.1	-	0.9	-
% WMA Snow Area	-	-	47	-	15	-
Vegetation Vulnerabilities						
Avg Vegetation Climate Exposure (%)	96.4	-	94.0	-	91.0	-
% Area Veg Exposure > 80%	-	-	-	-	54	-
% Area Veg Exposure > 95%	-	-	-	-	35	-
% WMA Area Non-Analog Condition	-	-	-	-	2	-
Probability of Fire in a 30-y window						
Fire Probability (warm, high rainfall) (%)	-	-	10	-	12	-
Fire Probability (warm, low rainfall) (%)	-	-	11	-	13	-

TABLE G.9: NORTH COAST RIVERS WMA 2 HISTORICAL BASELINE CONDITIONS

North Coast Rivers WMA 2 — Historical Baseline				
All parameters				
variable	1951-1980	±SE	1981-2010	±SE
Basin Characterizaton Model				
CWD (in/y)	21.9	0.5	21.9	0.6
DJF (°F)	38.6	1.9	38.7	2.1
JJA (°F)	77.4	1.4	77.6	1.5
PPT (in/y)	57.6	2.6	56.0	3.1
RCH (in/y)	23.7	1.4	22.4	1.4
RUN (in/y)	13.6	1.7	13.0	1.7
AET (in/y)	19.9	0.5	20.2	0.6
Avg SWE above 3,000 ft (in/y)	1.0	-	0.2	-
% WMA Snow Area	0	-	0	-
Vegetation Vulnerabilities				
Avg Vegetation Climate Exposure (%)	-	-	63.7	-
% WMA Area Veg Exposure > 80%	-	-	13	-
% WMA Area Veg Exposure > 95%	-	-	6	-
% WMA Area Non-Analog Condition	-	-	0	-
Probability of Fire in a 30-y window				
Fire Probability (%) (1970-2000 baseline)	13			

TABLE G.10: NORTH COAST RIVERS WMA 2 PROJECTED CONDITIONS

North Coast Rivers WMA 2 — Projected Conditions						
All parameters						
variable	2010-2039	±SE	2040-2069	±SE	2070-2069	±SE
Basin Characterization Model						
(warm, moderate rainfall) CWD (in/y)	23.3	0.5	24.2	0.5	24.9	0.6
DJF (°F)	40.3	2.3	41.3	3.2	44.1	3.1
JJA (°F)	79.8	1.7	81.7	1.6	84.3	1.7
PPT (in/y)	58.1	3.1	56.7	2.9	59.1	4.0
RCH (in/y)	23.0	1.4	23.0	1.4	22.4	1.4
RUN (in/y)	14.9	1.9	13.8	1.6	16.4	2.8
AET (in/y)	19.9	0.5	19.7	0.5	20.4	0.6
Avg SWE above 3,000 ft (in/y)	-	-	0.0	-	0.0	-
% WMA Snow Area	-	-	0	-	0	-
Vegetation Vulnerabilities						
Avg Vegetation Climate Exposure (%)	62.5	-	63.7	-	84.0	-
% Area Veg Exposure > 80%	-	-	-	-	31	-
% Area Veg Exposure > 95%	-	-	-	-	18	-
% WMA Area Non-Analog Condition	-	-	-	-	0	-
Probability of Fire in a 30-y window						
Fire Probability (warm, high rainfall) (%)	-	-	16	-	18	-
Fire Probability (warm, low rainfall) (%)	-	-	16	-	19	-

TABLE G.11: RUSSIAN BODEGA WMA HISTORICAL BASELINE CONDITIONS

Russian Bodega WMA — Historical Baseline				
All parameters				
variable	1951-1980	±SE	1981-2010	±SE
Basin Characterizaton Model				
CWD (in/y)	27.5	0.5	27.9	0.6
DJF (°F)	38.0	2.1	38.7	2.1
JJA (°F)	84.2	1.7	83.8	1.6
PPT (in/y)	46.2	2.5	46.4	2.9
RCH (in/y)	12.0	0.9	11.5	0.9
RUN (in/y)	15.9	1.7	16.4	1.8
AET (in/y)	17.9	0.5	18.1	0.6
Avg SWE above 3,000 ft (in/y)	0.0	-	0.0	-
% WMA Snow Area	0	-	0	-
Vegetation Vulnerabilities				
Avg Vegetation Climate Exposure (%)	-	-	68.6	-
% WMA Area Veg Exposure > 80%	-	-	7	-
% WMA Area Veg Exposure > 95%	-	-	2	-
% WMA Area Non-Analog Condition	-	-	0	-
Probability of Fire in a 30-y window				
Fire Probability (%) (1970-2000 baseline)	19			

TABLE G.12: RUSSIAN BODEGA WMA PROJECTED CONDITIONS

Russian Bodega WMA — Projected Conditions						
All parameters						
variable	2010-2039	±SE	2040-2069	±SE	2070-2069	±SE
Basin Characterization Model						
CWD (in/y)	28.7	0.5	29.8	0.5	30.8	0.6
DJF (°F)	40.0	2.3	41.1	3.2	43.8	3.1
JJA (°F)	85.9	1.6	87.7	1.6	90.2	1.7
PPT (in/y)	47.4	2.8	45.5	2.5	49.0	3.7
RCH (in/y)	11.8	0.9	11.7	0.9	11.7	0.9
RUN (in/y)	17.3	2.0	15.9	1.6	19.2	2.8
AET (in/y)	18.1	0.5	17.8	0.5	18.1	0.5
Avg SWE above 3,000 ft (in/y)	-	-	0.0	-	0.0	-
% WMA Snow Area	-	-	0	-	0	-
Vegetation Vulnerabilities						
Avg Vegetation Climate Exposure (%)	70.3	-	70.6	-	91.3	-
% Area Veg Exposure > 80%	-	-	-	-	60	-
% Area Veg Exposure > 95%	-	-	-	-	46	-
% WMA Area Non-Analog Condition	-	-	-	-	0	-
Probability of Fire in a 30-y window						
Fire Probability (warm, high rainfall) (%)	-	-	23	-	26	-
Fire Probability (warm, low rainfall) (%)			23	-	24	-

TABLE G.13: TRINITY WMA HISTORICAL BASELINE CONDITIONS

Trinity WMA - Historical Baseline				
All parameters				
variable	1951-1980	±SE	1981-2010	±SE
Basin Characterization Model				
CWD (in/y)	19.7	0.4	19.9	0.6
DJF (°F)	29.2	2.1	30.2	2.1
JJA (°F)	82.1	2.3	82.6	1.9
PPT (in/y)	58.8	2.8	57.7	3.1
RCH (in/y)	23.8	1.1	22.4	1.1
RUN (in/y)	19.4	1.8	18.6	2.0
AET (in/y)	14.0	0.4	14.7	0.5
Avg SWE above 3,000 ft (in/y)	14.0	-	11.6	-
% WMA Snow Area	94	-	80	-
Vegetation Vulnerabilities				
Avg Vegetation Climate Exposure (%)	-	-	60.6	-
% WMA Area Veg Exposure > 80%	-	-	14	-
% WMA Area Veg Exposure > 95%	-	-	7	-
% WMA Area Non-Analog Condition	-	-	0	-
Probability of Fire in 30-y window				
Fire Probability (%) (1970-2000 baseline)	11			

TABLE G.14: TRINITY WMA PROJECTED CONDITIONS

Trinity WMA - Projected Conditions						
All parameters						
variable	2010-2039	±SE	2040-2069	±SE	2070-2069	±SE
Basin Characterization Model						
CWD (in/y)	20.7	0.5	22.2	0.4	23.1	0.5
DJF (°F)	31.4	2.3	32.3	3.1	35.0	3.0
JJA (°F)	84.9	2.4	87.7	2.3	91.2	2.2
PPT (in/y)	59.7	2.6	58.7	2.6	57.0	3.1
RCH (in/y)	23.2	1.0	22.1	1.0	20.8	1.0
RUN (in/y)	19.8	1.8	20.1	1.7	19.0	2.2
AET (in/y)	15.3	0.6	15.2	0.5	16.4	0.5
Avg SWE above 3,000 ft (in/y)	-	-	5.3	-	1.6	-
% WMA Snow Area	-	-	56	-	22	-
Vegetation Vulnerabilities						
Avg Vegetation Climate Exposure (%)	72.7	-	64.1	-	59.2	-
% Area Veg Exposure > 80%	-	-	-	-	5	-
% Area Veg Exposure > 95%	-	-	-	-	2	-
% WMA Area Non-Analog Condition	-	-	-	-	0	-
Probability of Fire in 30-y window						
Fire Probability (warm, high rainfall) (%)	-	-	14	-	16	-
Fire Probability (warm, low rainfall) (%)			15	-	18	-

APPENDIX H: SAMPLE MAP PRODUCTS

The maps listed below and shown in the following plate set are a subset of the 37 maps displayed in the companion PowerPoint presentation to this report. Underlying spatial data have been provided via an ESRI Map Package.

MAP 1 — HISTORICAL WINTER TEMPERATURE

MAP 2 — MID-CENTURY WINTER TEMPERATURE

MAP 3 — END OF CENTURY WINTER TEMPERATURE

MAP 4 — HISTORICAL SUMMER TEMPERATURE

MAP 5 — MID-CENTURY SUMMER TEMPERATURE

MAP 6 — END OF CENTURY SUMMER TEMPERATURE

MAP 7 — HISTORICAL PRECIPITATION

MAP 8 — HISTORICAL CLIMATIC WATER DEFICIT

MAP 9 — HISTORICAL AND PROJECTED APRIL 1st SNOW EXTENT

MAP 10 — HISTORICAL VARIABLILITY OF CLIMATIC WATER DEFICIT

MAP 11 — END OF CENTURY INCREASES IN CLIMATIC WATER DEFICIT EXCEEDING HISTORICAL VARIABILITY, WARM MODERATE RAINFALL SCENARIO

MAP 12 — END OF CENTURY INCREASES IN CLIMATIC WATER DEFICIT EXCEEDING HISTORICAL VARIABILITY, HOT LOW RAINFALL SCENARIO

MAP 13 — HISTORICAL RECHARGE

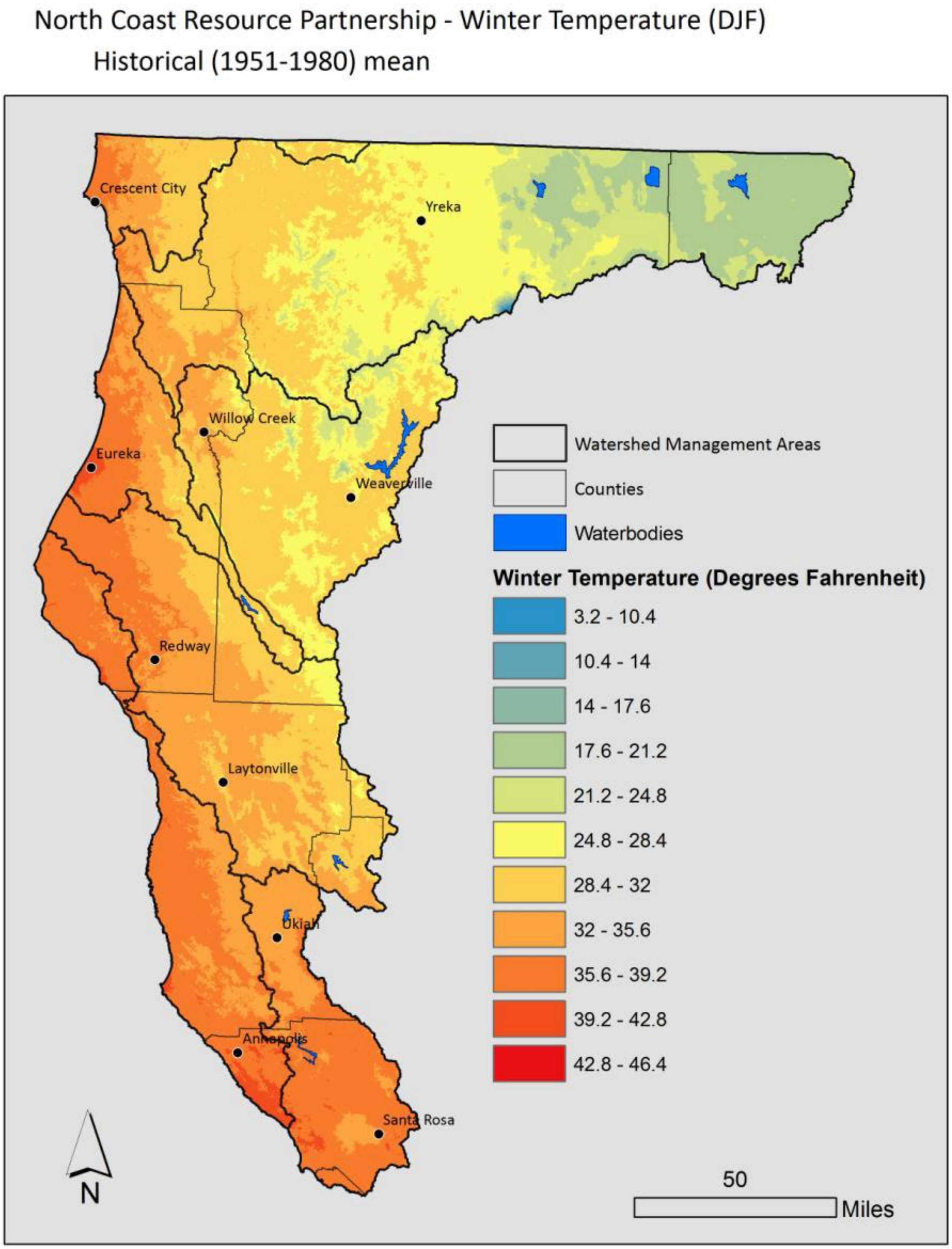
MAP 14 — HISTORICAL RUNOFF

MAP 15 — HISTORICAL FIRE PROBABILITY

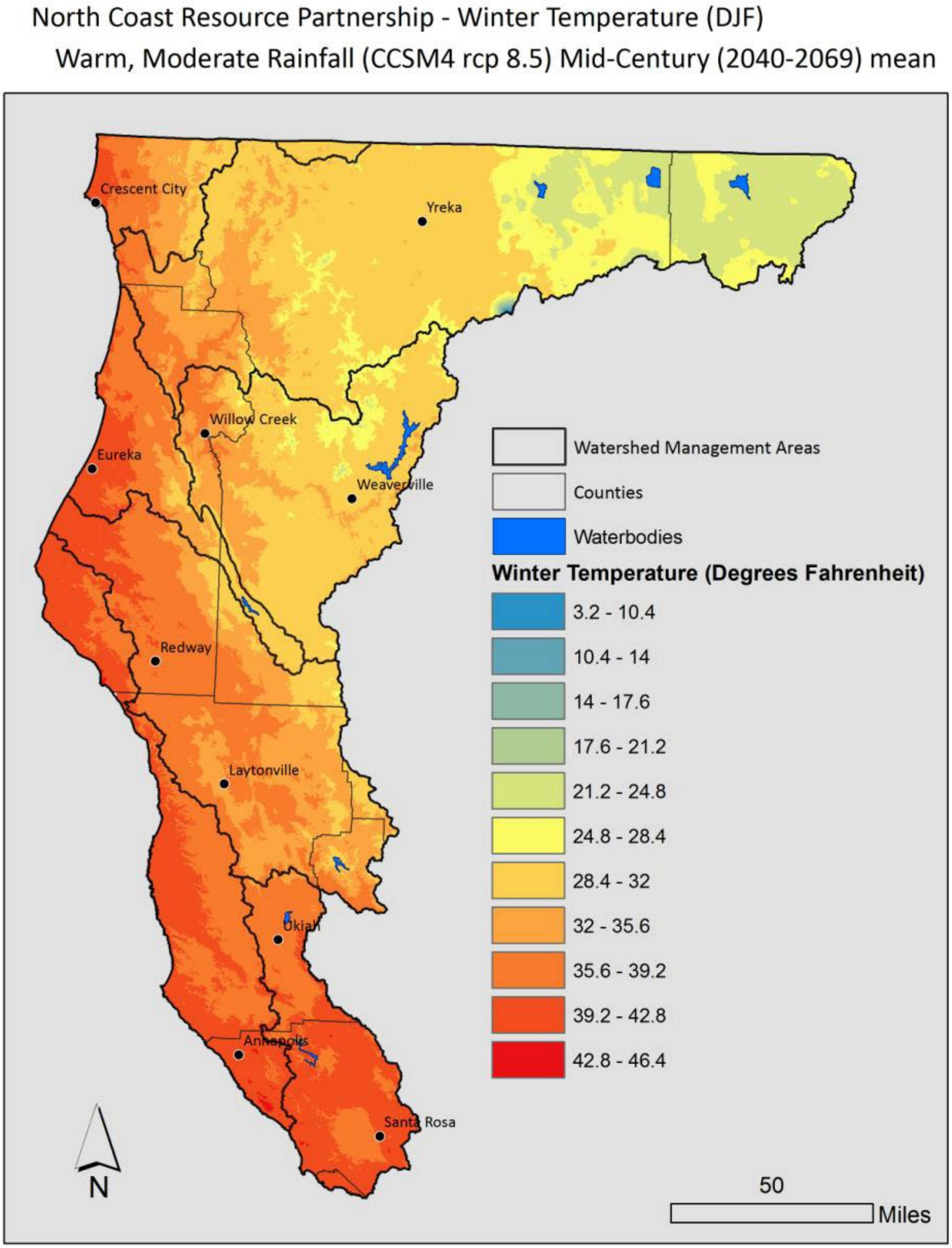
MAP 16 — RECENT VEGETATION CLIMATE EXPOSURE

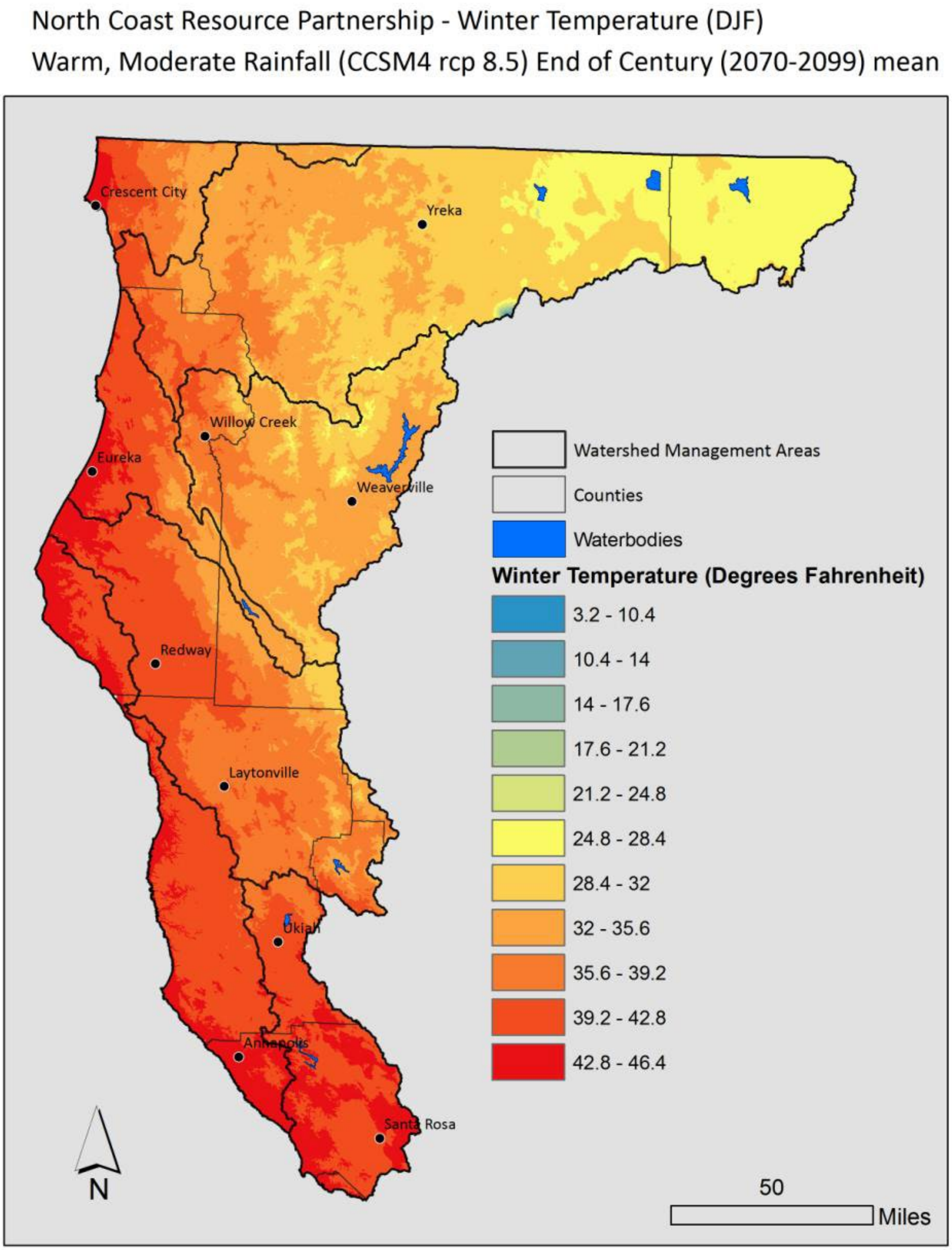
MAP 17 — STUDY AREA AND HYDRO FEATURES

MAP 1 — HISTORICAL WINTER TEMPERATURE



MAP 2 — MID-CENTURY WINTER TEMPERATURE

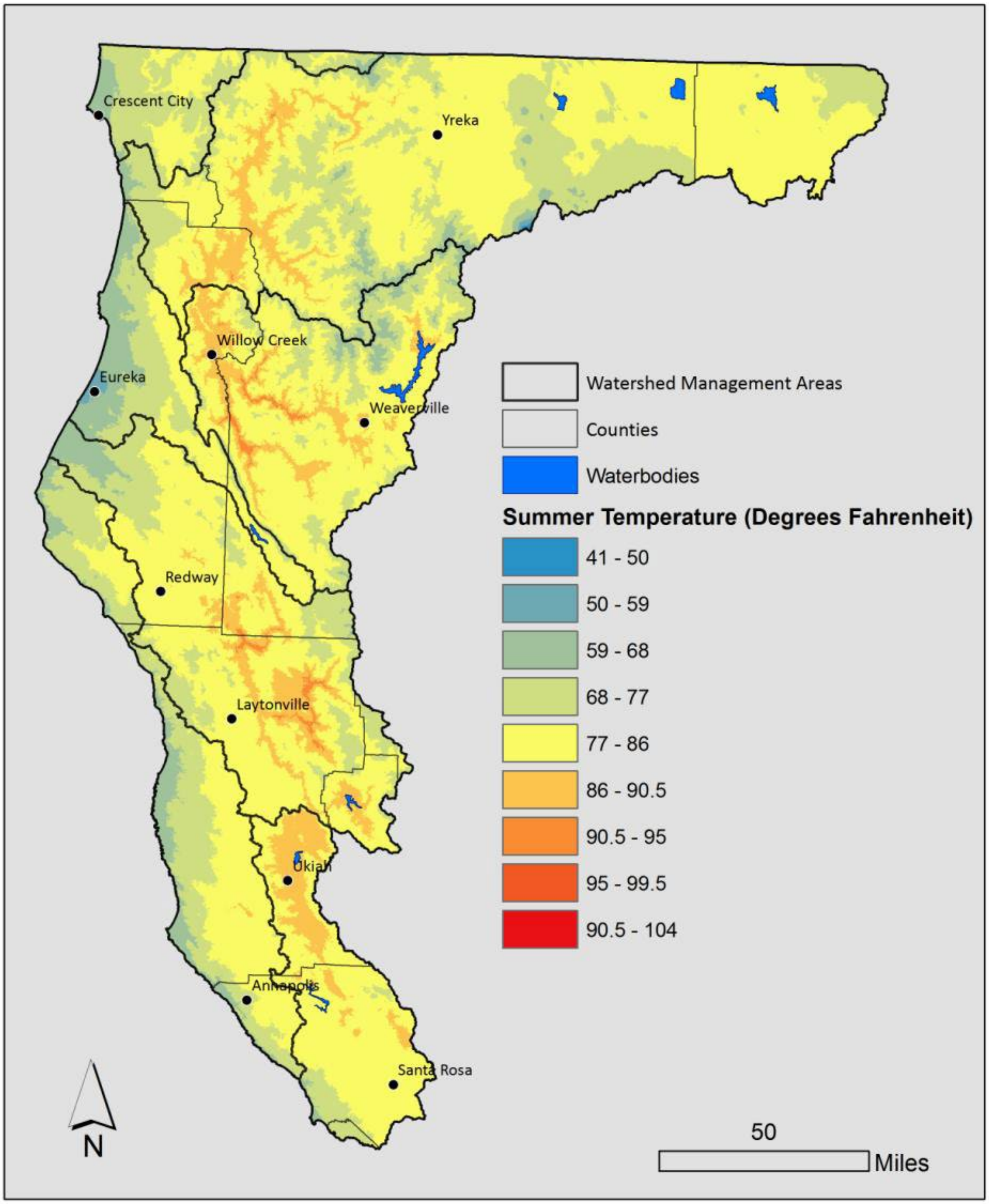




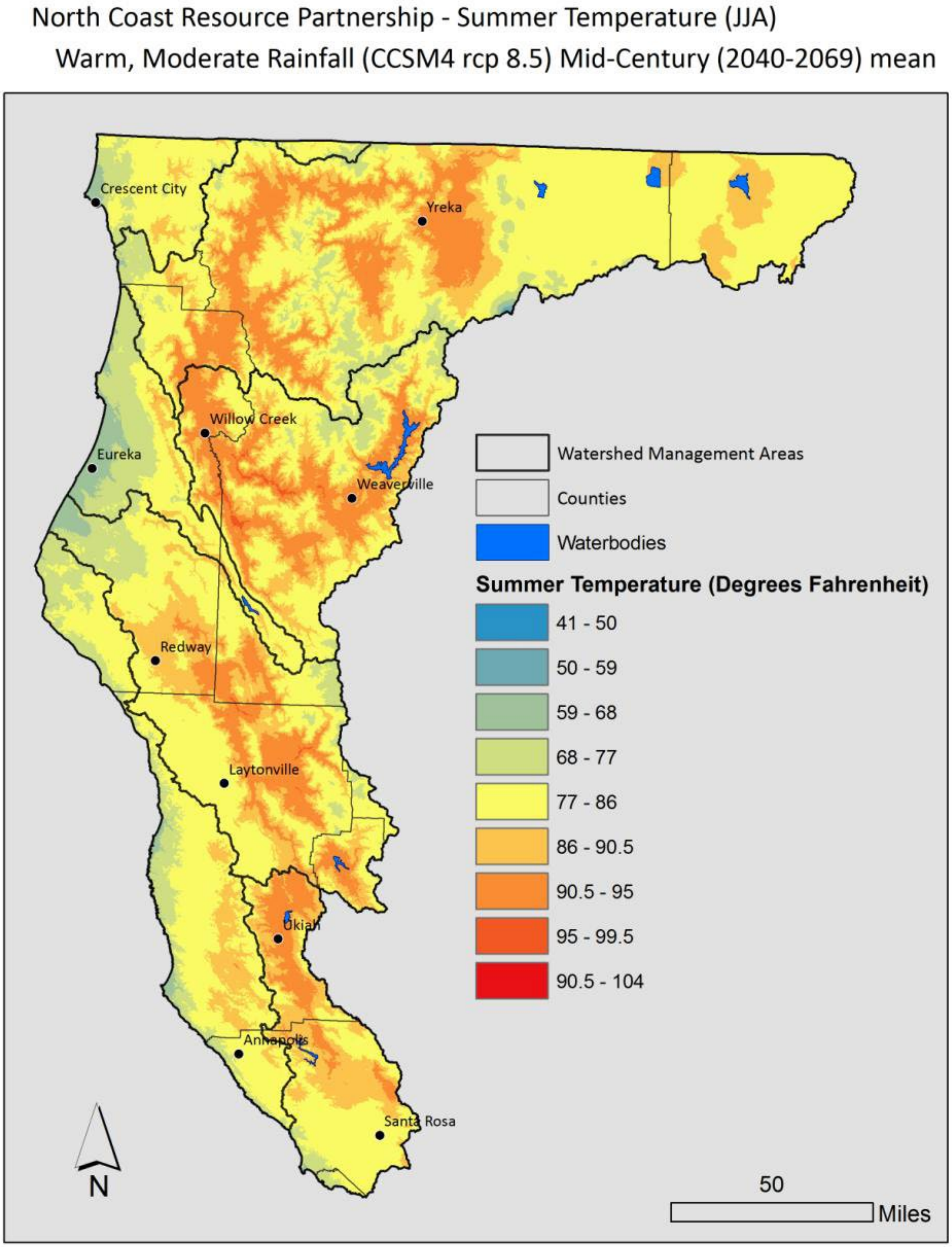
MAP 3 — END OF CENTURY WINTER TEMPERATURE

MAP 4 — HISTORICAL SUMMER TEMPERATURE

North Coast Resource Partnership - Summer Temperature (JJA)
Historical (1951-1980) mean

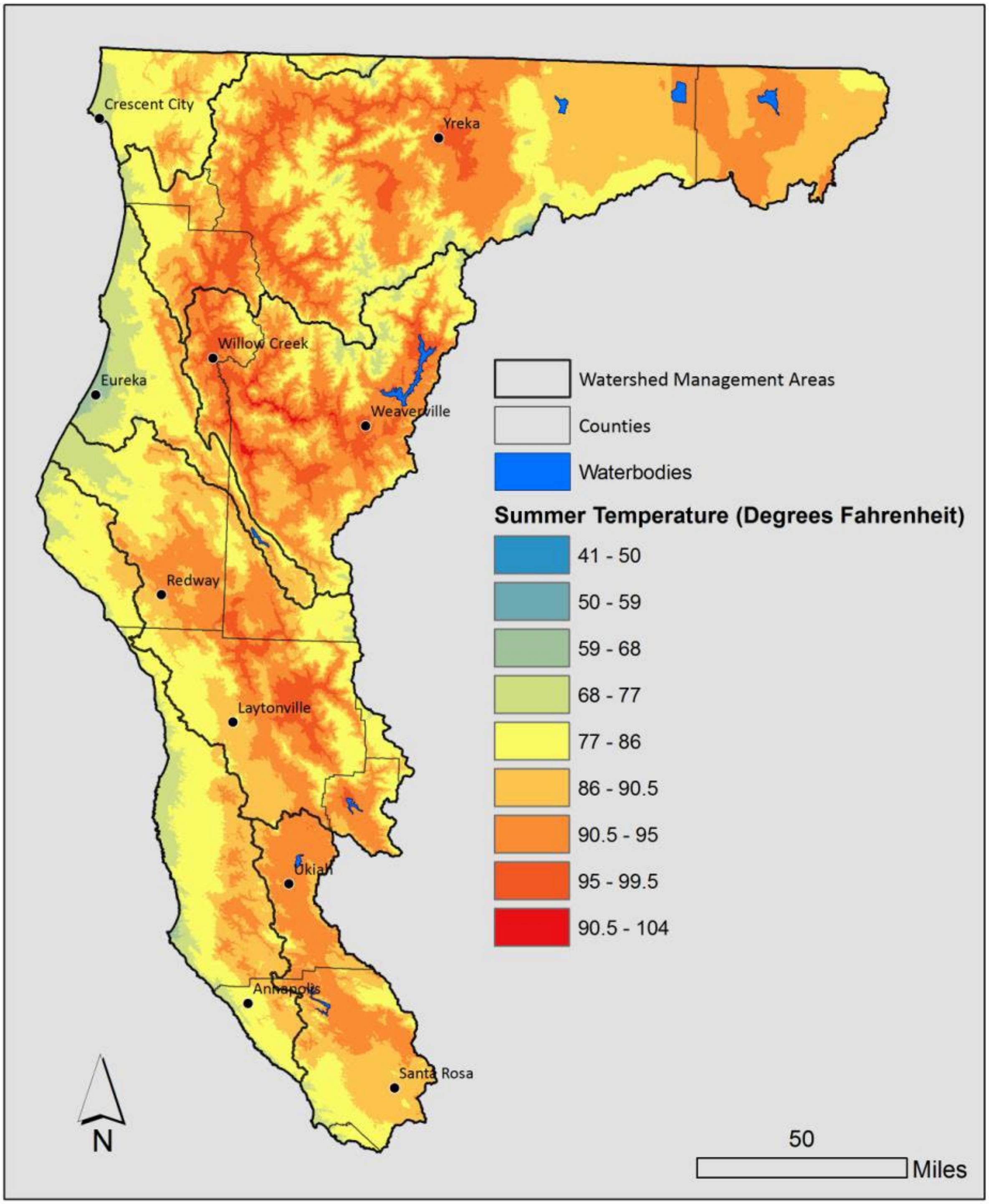


MAP 5 — MID-CENTURY SUMMER TEMPERATURE

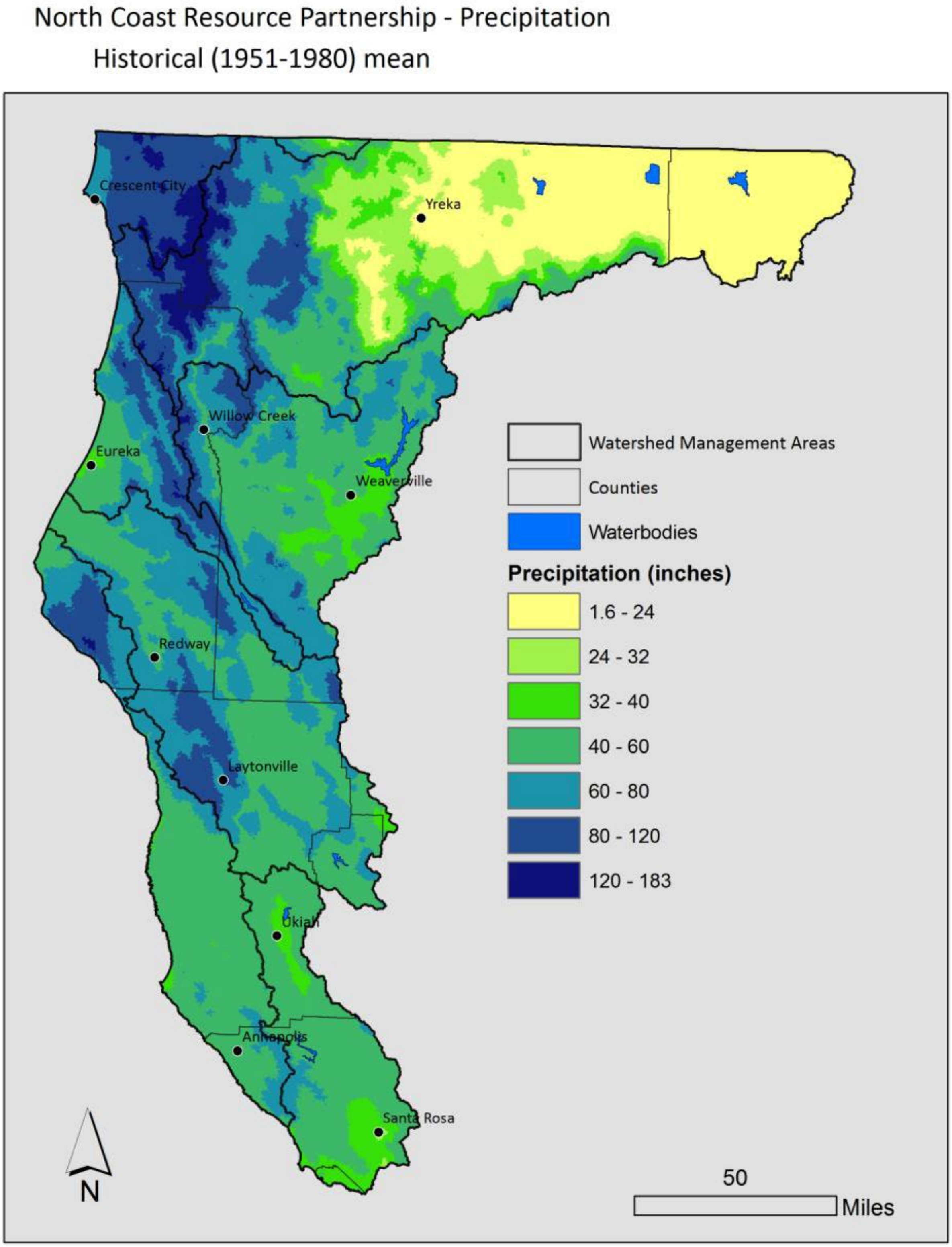


MAP 6 — END OF CENTURY SUMMER TEMPERATURE

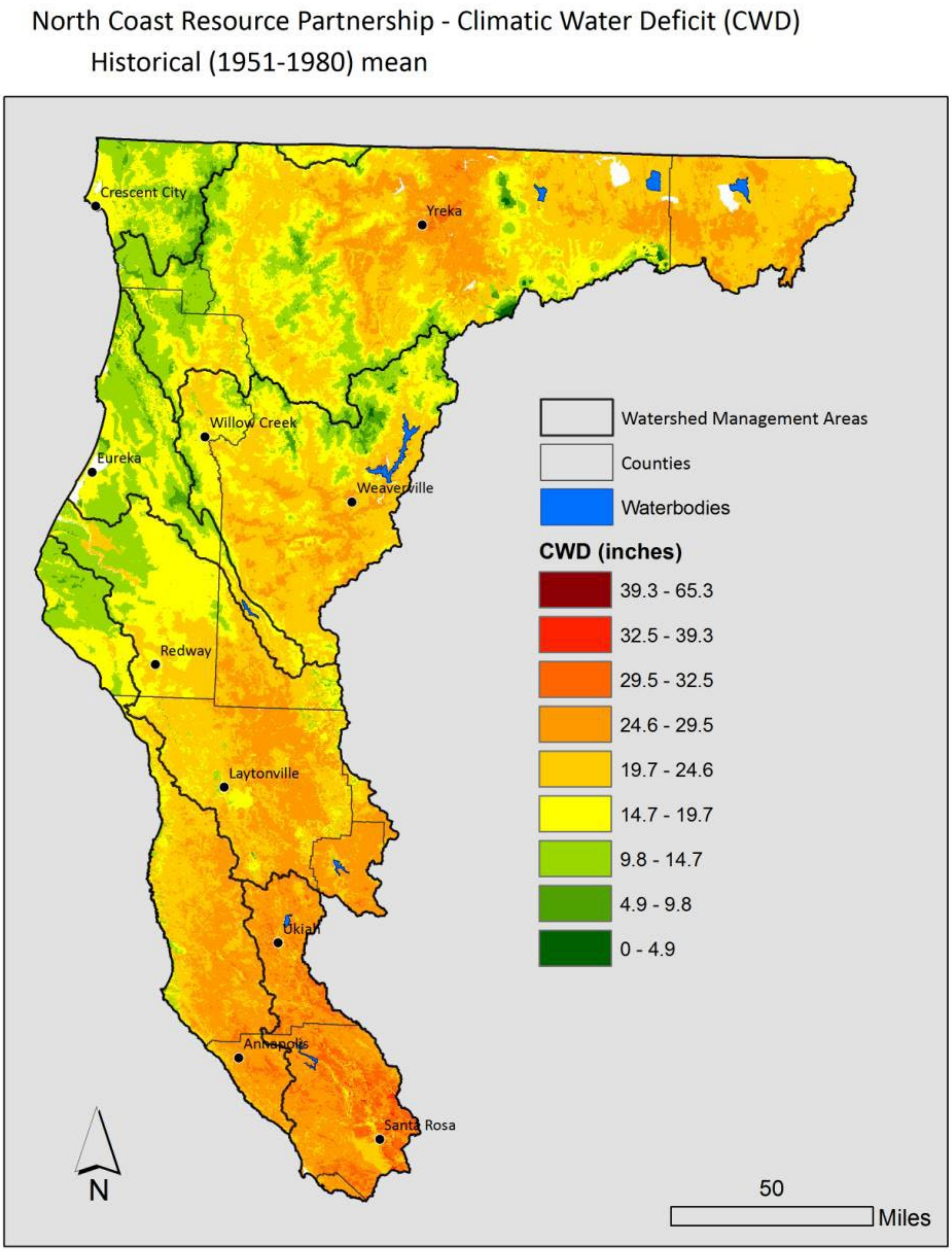
North Coast Resource Partnership - Summer Temperature (JJA)
Warm, Moderate Rainfall (CCSM4 rcp 8.5) End of Century (2070-2099) mean



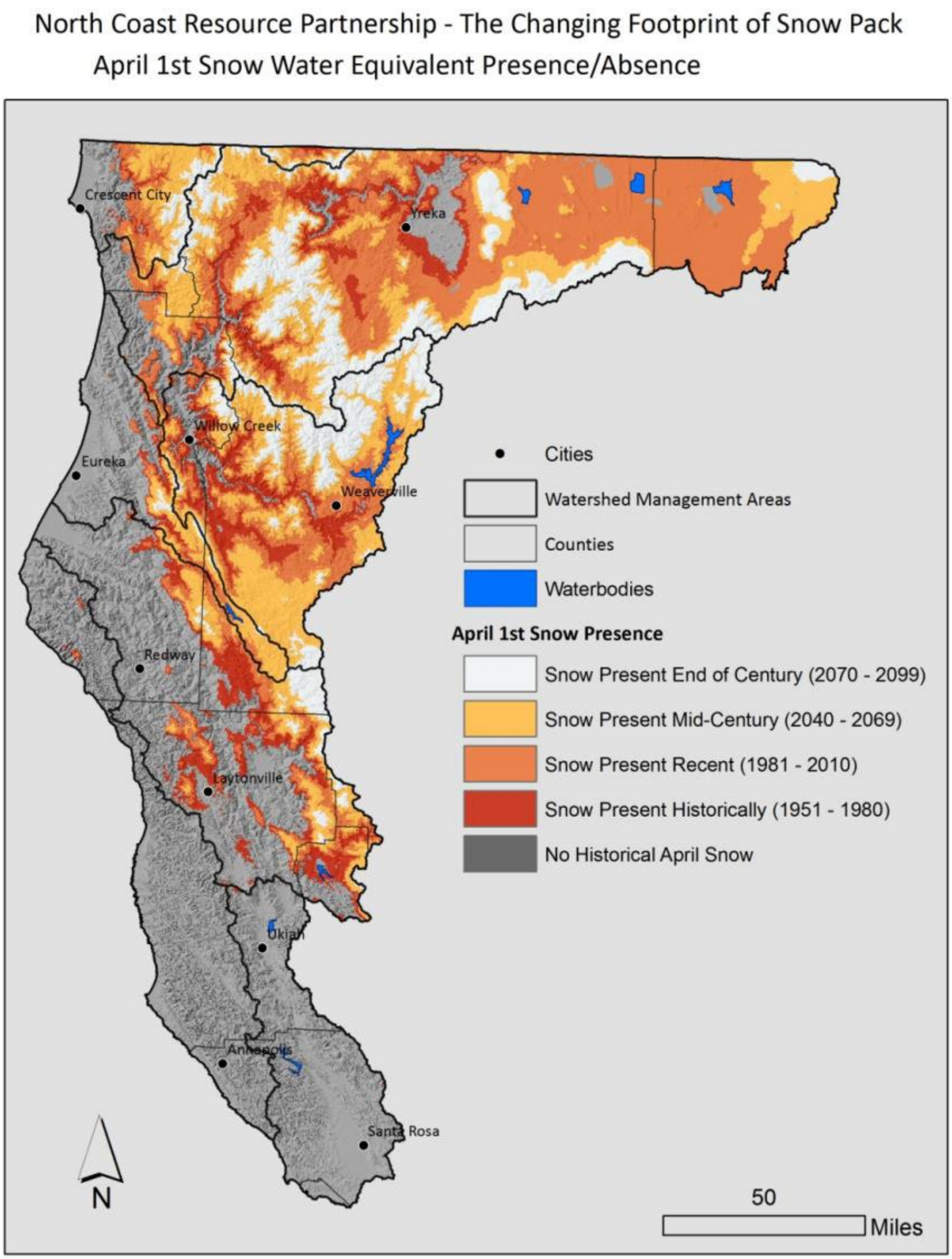
MAP 7 — HISTORICAL PRECIPITATION

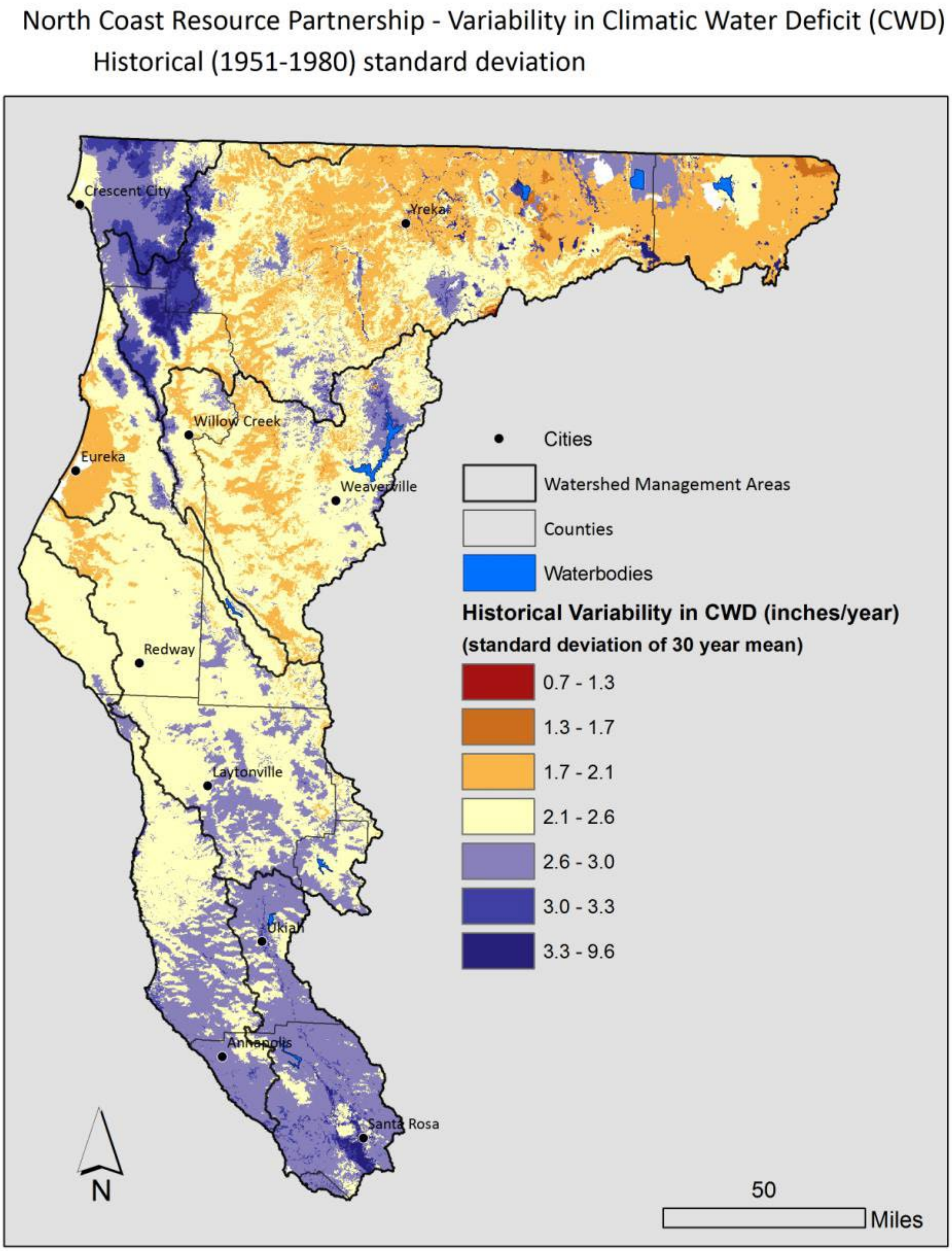


MAP 8 — HISTORICAL CLIMATIC WATER DEFICIT



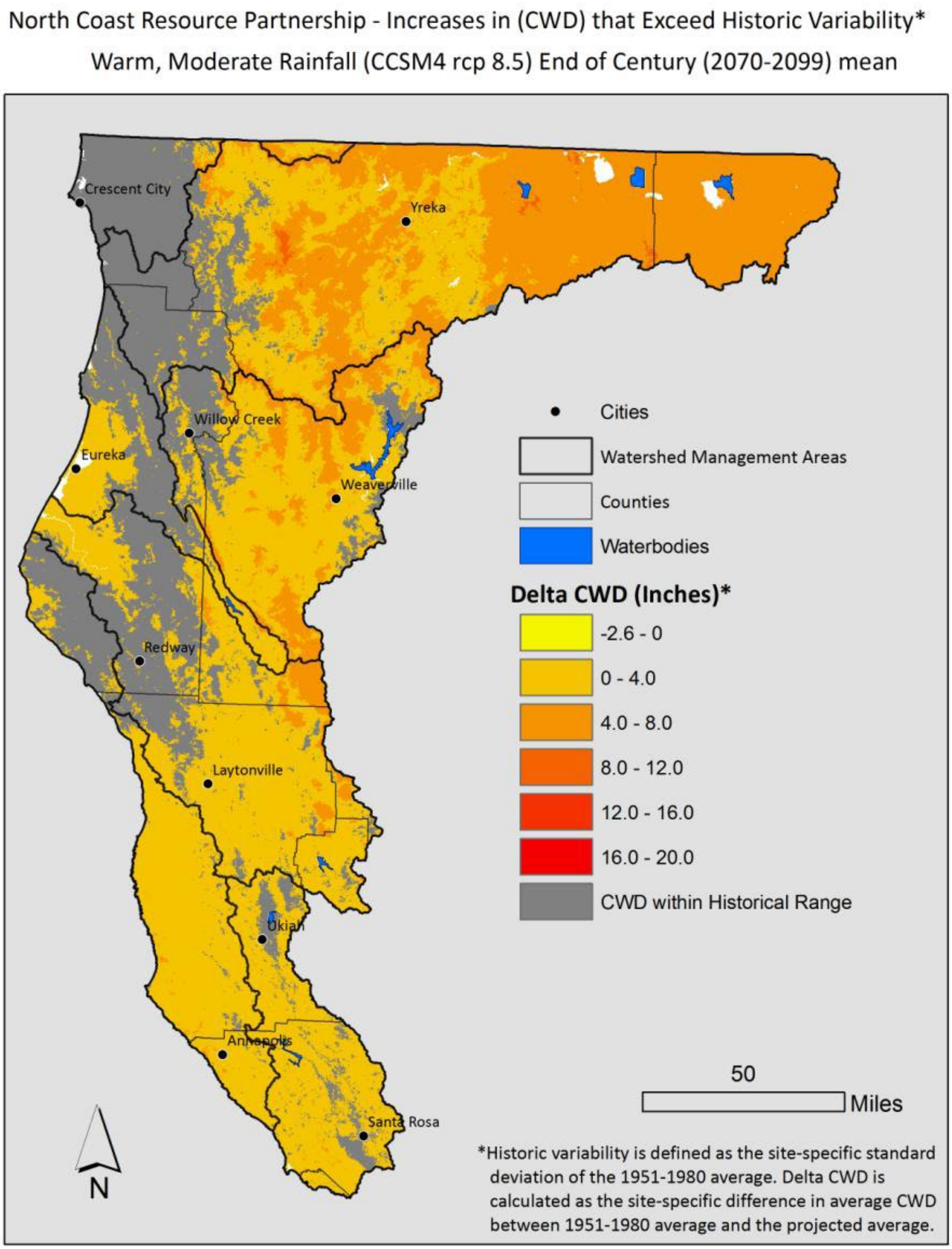
MAP 9 — HISTORICAL AND PROJECTED APRIL 1st SNOW EXTENT



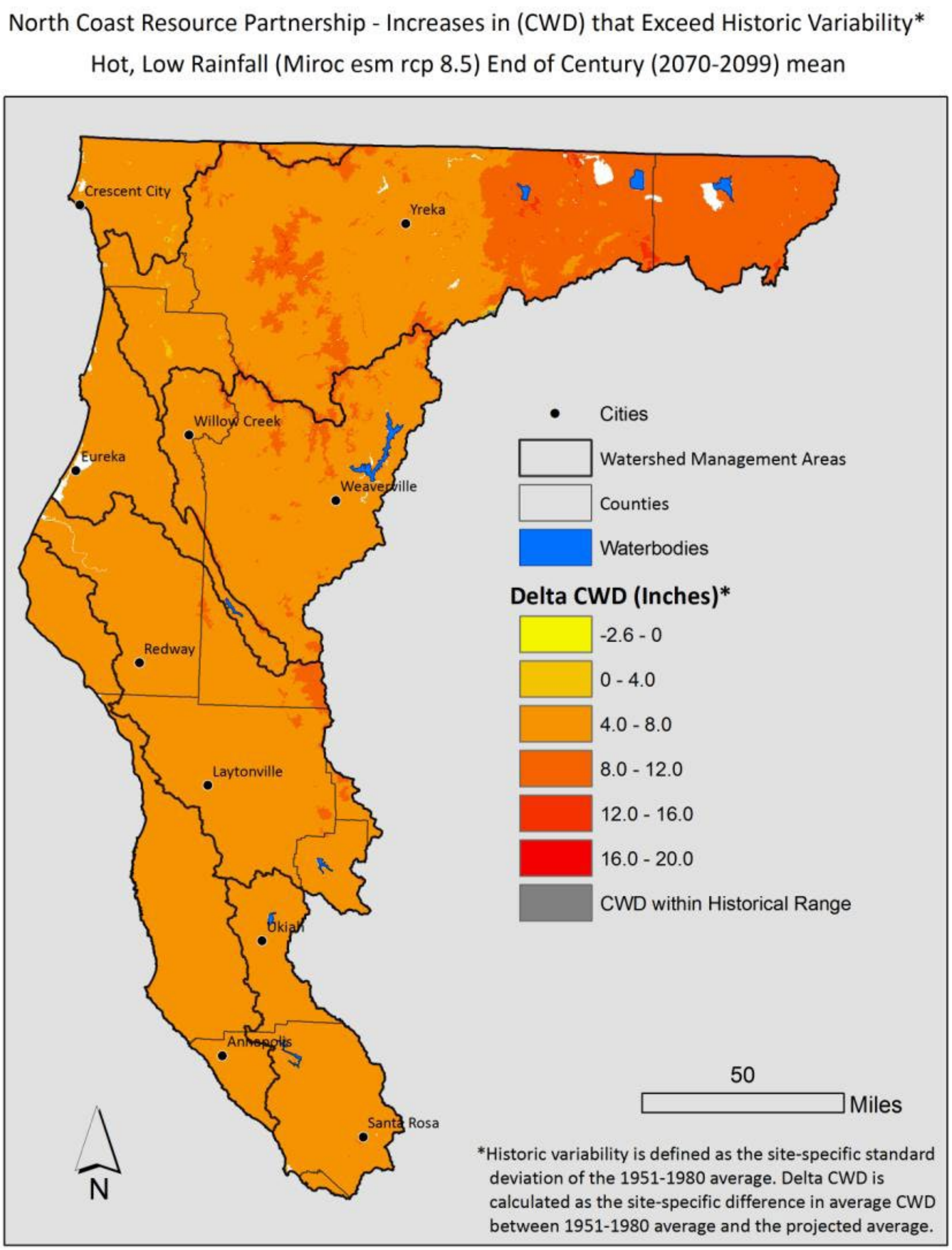


MAP 10 — HISTORICAL VARIABLILITY OF CLIMATIC WATER DEFICIT

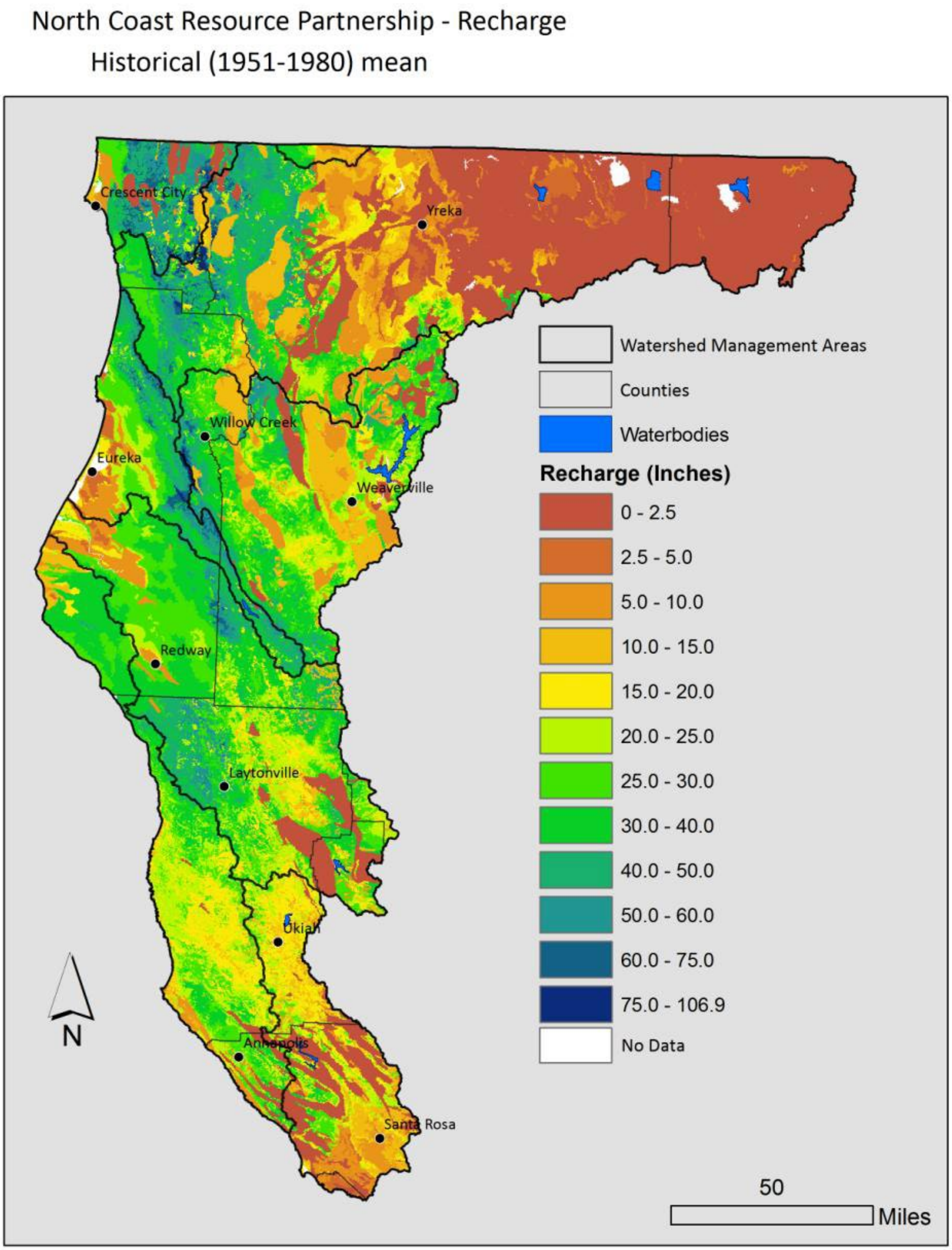
MAP 11 — END OF CENTURY INCREASES IN CLIMATIC WATER DEFICIT EXCEEDING HISTORICAL VARIABILITY, WARM MODERATE RAINFALL SCENARIO



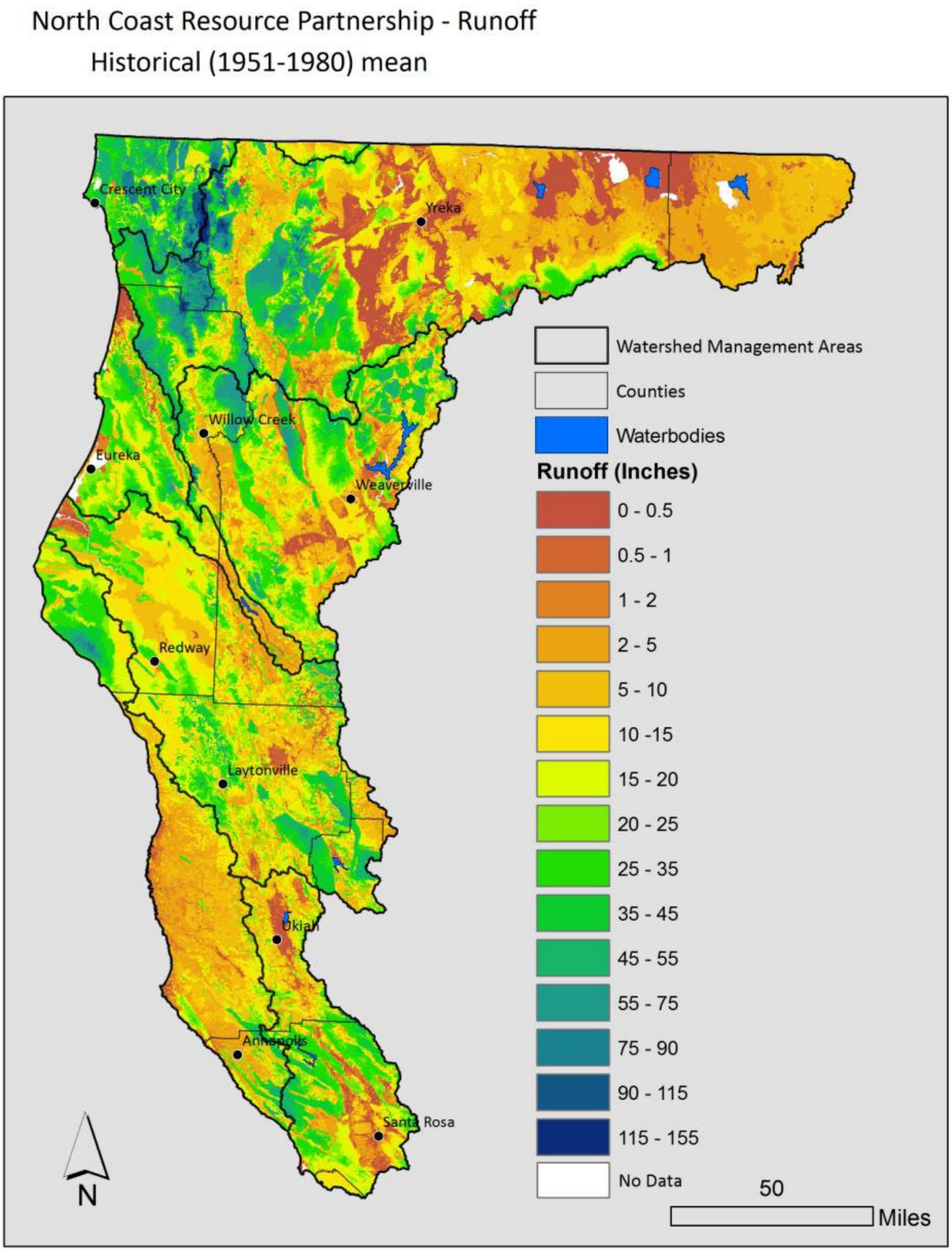
MAP 12 — END OF CENTURY INCREASES IN CLIMATIC WATER DEFICIT EXCEEDING HISTORICAL VARIABILITY, HOT DRY SCENARIO



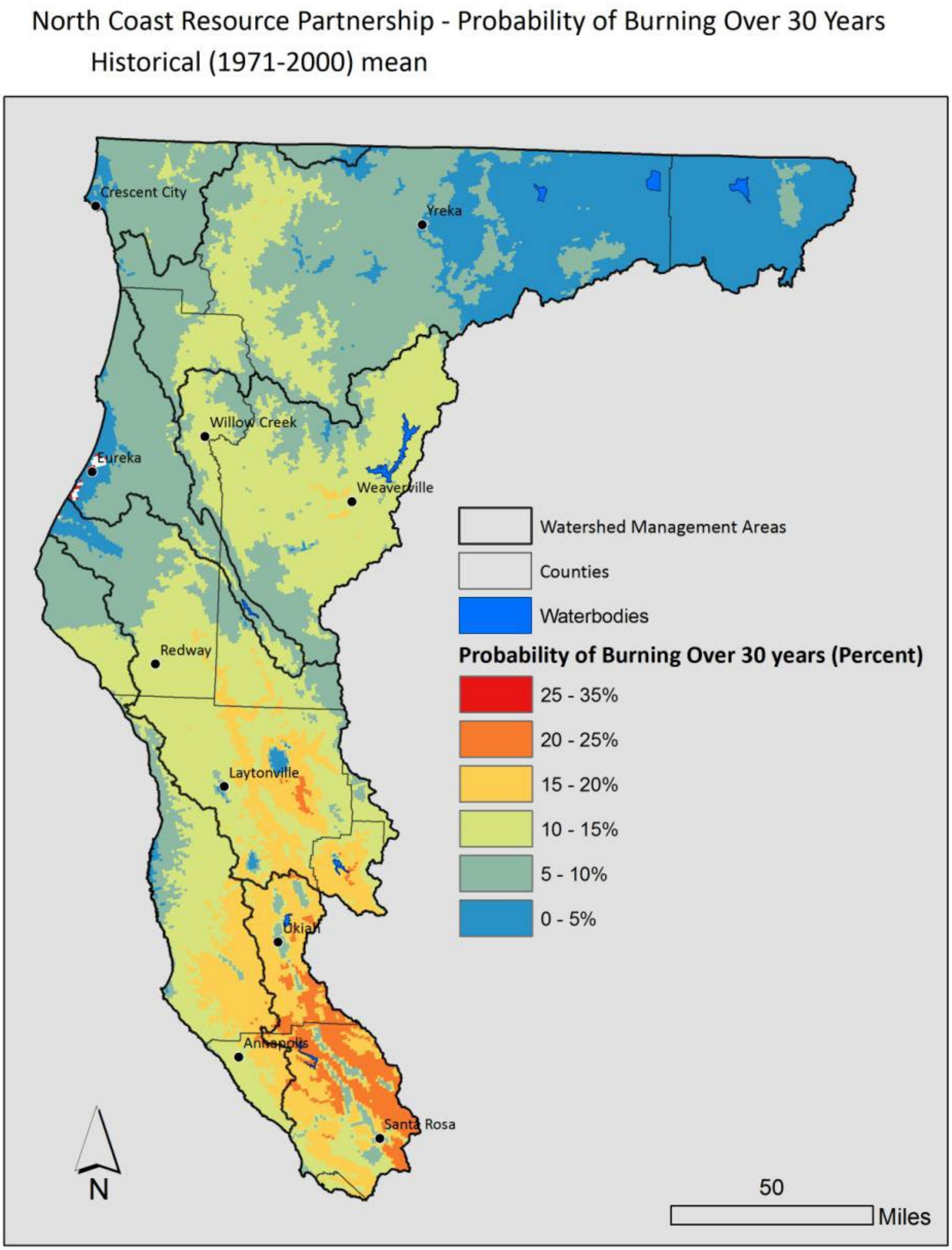
MAP 13 — HISTORICAL RECHARGE



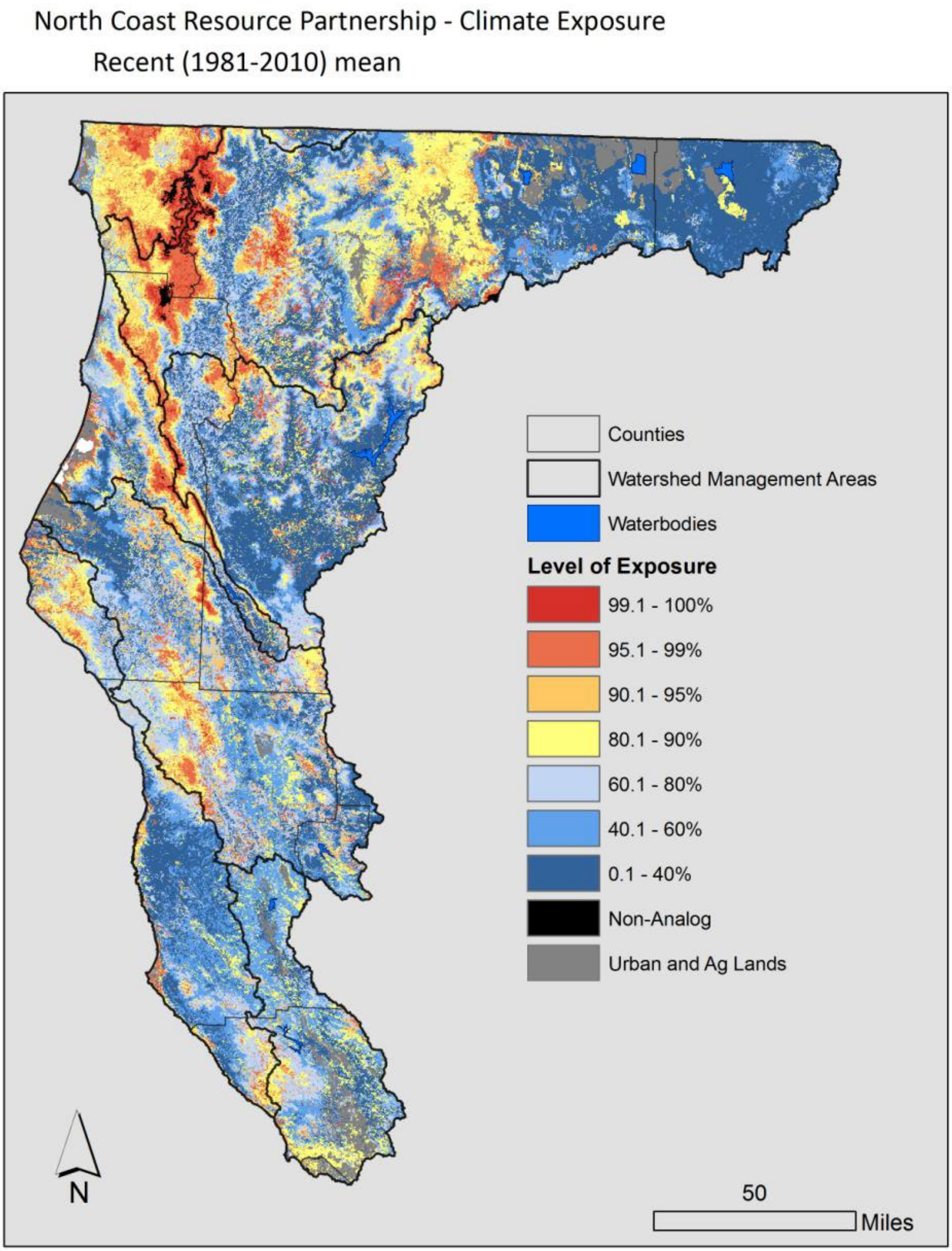
MAP 14 — HISTORICAL RUNOFF



MAP 15 — HISTORICAL FIRE PROBABILITY



MAP 16 — RECENT VEGETATION CLIMATE EXPOSURE



MAP 17 — STUDY AREA