climate action 2020

A Regional Program for Sonoma County Communities

Climate Ready Sonoma County: Climate Hazards and Vulnerabilities

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Prepared by:

North Bay Climate Adaptation Initiative

North Bay CLIMATE ADAPTATION INITIATIVE

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North Bay Climate Adaptation Initiative

Caitlin Cornwall, Sonoma Ecology Center
Sara Moore, climate adaptation consultant
Deanne DiPietro, California Landscape Conservation Cooperative, California Climate Commons
Dr. Sam Veloz, Point Blue Conservation Science
Dr. Lisa Micheli, Pepperwood's Dwight Center for Conservation Science
Alex Young, Sonoma Ecology Center

Technical advisor

Stu Weiss, Creekside Center for Earth Observation

ICF International

Susan Asam
Brian Schuster
Rich Walter

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Foreword

Sonoma County is a national leader in setting ambitious goals for combating climate change by reducing greenhouse gas emissions. However, even with widespread efforts to curb these emissions, some level of climate change is inevitable. Indeed changes in climate, such as warmer temperatures, are already evident and have serious implications for the future of Sonoma County.

The hazards that climate change contributes to are not new; we have experienced severe storms, floods, droughts, heat waves, and fires in the past and already have planning processes in place to manage risk related to these hazards. But the severity and frequency of these crises are increasing. Understanding how these hazards are changing and making more informed decisions about them, as a community, will help Sonoma County remain vibrant and resilient long into the future.

The purpose of this climate vulnerability assessment is to provide an initial screening of the county's community resources that are vulnerable to climate change hazards. It is not intended to be a comprehensive vulnerability analysis or to provide site-specific prescriptions for action. Instead, the intent is to provide a starting point for a countywide discussion on climate impacts and our vulnerabilities to climate change. We hope it serves as a guide for elected officials, planners, engineers, land managers, and others in assessing risk from climate hazards and identifying strategies to reduce risk. It was developed as part of a broader planning framework called Climate Action 2020 to identify and implement specific, high-priority strategies to respond to the climate crisis here in Sonoma County.

We know that climate change is already happening, and causing hotter, drier weather with longer summers, more variable rain, and rising sea level and storm surge. These impacts create many cascading hazards to our people, our infrastructure, our wildlife, and our natural and working lands. Everything we depend on for our health and well-being will be affected. Understanding and evaluating the ways in which each climate-change hazard may impact our specific community resources is an essential first step in preparing for change.

Moving forward, the RCPA will be working with the North Bay Climate Adaptation Initiative and a variety of public and private partners to conduct more detailed analysis regarding climate change hazards, downscaled to specific watersheds and landscapes. This will allow people responsible for protecting public health and safety, economic security, and natural and working lands to make more informed decisions about preparing for the future.

As specific strategies related to climate readiness are identified, the RCPA will work to integrate them into the Climate Action 2020 planning and implementation framework and will support our member jurisdictions, partner agencies, and the private sector to identify best practices, secure funding for implementation, and monitor and evaluate progress.

Current scientific consensus reveals the magnitude and urgency of climate change threats. Continued and heightened commitment to reduce human contributions to climate change is imperative as part of a holistic strategy to ensure the long-term health of the people and places we hold dear.

Onward, towards a climate ready Sonoma County,

Sarah Glade Gurney

Chair, Sonoma County Regional Climate Protection Authority

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Executive Summary

Climate Readiness – Why do we need to prepare?

As scientists refine global climate models to create projections of future conditions at the local level, it becomes clear that Sonoma County's future climate will include more very hot days, less predictable rain, more extreme weather events, and higher ocean levels. Using historic data to predict future conditions is no longer adequate for long-term policy planning and decision-making, as local leaders work to protect the long-term vision for a vibrant Sonoma County.

The risks, uncertainties, and volatility associated with climate change pose potentially high costs to communities in terms of public health, safety, economic vitality, security, and quality of life. While some uncertainty remains in the timing of changes – especially due to uncertainty regarding future global greenhouse gas (GHG) emissions scenarios – there is enough confidence in projected trends to begin the work of preparing for climate hazards now. Preparing now will yield more cost-effective and flexible strategies than delaying action until responding to unprecedented conditions.

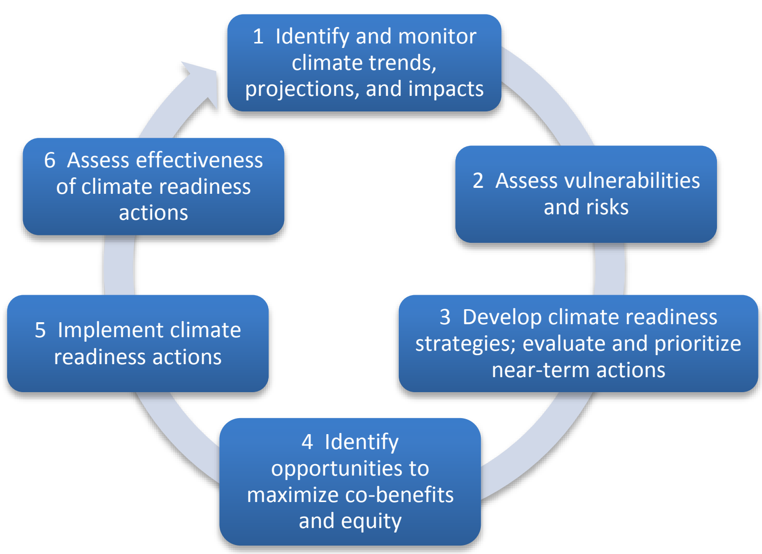
Reducing greenhouse gas emissions is essential, but not enough

Our vulnerability to climate hazards is determined in large part by whether humanity reduces GHG emissions. The worst-case future scenarios are created by runaway emissions. Stopping climate change by dramatically reducing emissions is the most effective way to reduce climate change hazards. Sonoma County has long been a leader in mitigating GHG emissions and working to reduce the pace of climate change. However, despite local efforts, climate change is already happening and accelerating. Climate adaptation refers to policies, programs, and actions that reduce our vulnerability to climate change hazards and bolster community readiness to face the unavoidable climate impacts already underway.

How can we prepare?

Cities, counties, and other institutions throughout the United States and California have begun to prepare for climate change by assessing local risks and developing plans to respond to those risks. A model process for climate adaptation planning is illustrated below:

Climate Readiness Planning Process (Adapted from Multnomah County, 2014)



Taking the first steps toward climate readiness

The purpose of this climate vulnerability assessment is to provide an initial screening of the county's community resources that are vulnerable to climate change hazards. This report categorizes community resources as people and social systems, built systems, and natural and working lands. The intent is to provide a starting point for a countywide discussion on climate impacts and our climate vulnerabilities.

Much as we begin climate planning to reduce greenhouse gas emissions with an inventory of sources that enables us to prioritize actions towards those sources with the most opportunity, we must take stock of local vulnerabilities in order to understand which systems will be most affected by various climate change hazards.

Starting with climate change projections

During 2014, multiple landmark documents were published at international, national, and state levels that reveal a virtual consensus among climate change scientists that the global climate is warming as a result of greenhouse gas emissions, that local weather patterns are already disrupted, that ocean levels are rising, that there is a long lag between emissions reductions and climate response, and that the changes are accelerating.

In order to understand how these trends will change into the future scientists use climate change models that have been validated against past conditions. Model results are not intended to be a time-specific prediction of local conditions in a certain year or season, but instead are intended as scenarios to help planners bracket the range of future conditions we can expect on the best available information.

Climate change models vary in their projections of the amount and timing of change, as well as in their levels of certainty about these changes. There are several primary sources of uncertainty in climate projections including high natural variability of the climate system, unknowns regarding certain climate mechanics, and uncertainty regarding how quickly and vigorously humanity will reduce GHG emissions. These uncertainties can be addressed by comparing projections across models using different emissions assumptions ranging from highly mitigated to business-as-usual, and models that represent different assumptions about uncertain variables such as precipitation.

Also, despite uncertainties inherent in modeled futures regarding the magnitude and timing of specific events, certain climate change trends are understood with a high degree of confidence. Efforts to improve forecasting and monitor actual conditions are essential to continually improve upon the ability of local decision makers to plan for future changes.

Understanding Sonoma County trends

Sonoma County is fortunate to be the beneficiary of a number of cutting-edge efforts to understand climate trends, in part because local entities are key participants in these efforts. Local governments and County-wide regional agencies are partnering with research collaboratives, academic institutions, and federal agencies to improve and extend climate projections and make them more relevant to local decision-making.

A local consortium – the North Bay Climate Adaptation Initiative (NBCAI) – has worked with the U.S. Geological Survey and others to derive a set of projections for local temperature, precipitation, and hydrology across Sonoma County by downscaling global circulation models to a resolution that is meaningful for understanding watershed-level impacts of climate change. The datasets used to derive the conclusions in this vulnerability assessment were generated using four different climate futures that reflect the range of possible scenarios for Sonoma County. The major factors that vary among these four futures are future greenhouse emissions levels (and therefore temperature change) and precipitation amounts. These four representative futures have been summarized as:

Future assumptions:	**Less Precipitation**	**More Precipitation**
High Emissions (greater temperature increase)	**"Hot/Dry"**	**"Hot/Wet"**
Mitigated Emissions (less temperature increase)	**"Warm/Dry"**	**"Warm/Wet"**

Projections of local climate and hydrology in these four representative futures reveal some uncertainty about the timing and magnitude of changes. However, the projections illuminate clear trends regarding climate change hazards in Sonoma County.

Weather is famously variable. Here in Sonoma County we are used to a certain range of variability. Comparing historic climate with the four representative climate futures, we find that the range of variability in the "warm/wet" future overlaps to some degree with the historical variability we are used to, but the three other equally-likely futures bring conditions we have never seen before. The "warm/wet" future will occur only if humanity takes unprecedented action to reduce emissions. Hence the urgent need to prepare for climate-induced hazards now.

What are climate change hazards?

The term climate change hazards is used to refer to both long term changes to climate and to extreme events, which are increasing in severity and frequency. Specific indicators of climate change identified by the State of California include rising average temperatures and increased frequency of extreme heat events, wildfire frequency and extent, spring snowmelt and runoff, and annual precipitation.

Climate change hazards in Sonoma County

The first step to respond to climate change locally is to assess our exposure to climate hazards. Across all four of the representative climate futures Sonoma County can expect to experience:

Hotter, drier weather with longer summers
More extreme heat events
Longer and more frequent droughts
Greater frequency and intensity of wildfires
Fewer winter nights that freeze
More variable rain
Bigger, more variable floods
Sea level rise
Higher sea level and storm surge

Hotter, drier weather with longer summers

More extreme heat events

Sonoma County is expected to experience more very hot days than in the past, and overall higher temperatures over a longer period of dry weather even under forecasts that predict overall wetter conditions. Spring will come earlier and fall will come later, and these extended periods of hotter, drier weather will impact many community resources.

Heat will increase soil moisture deficit and reduce groundwater recharge, meaning that less water will be available even in futures with more precipitation. Heat will also increase the demand for water, exacerbating pressures on limited water resources in periods of drought.

Average monthly maximum temperatures have already risen by 2.7° F in Sonoma County since 1900, and temperatures are expected to continue to rise. The increase to average temperatures could be as high as 15° F by the end of the century in futures with business as usual emission growth. The number of extreme heat days will also increase. For example, Santa Rosa currently experiences between zero and ten days over 93° F in a typical year. Under business as usual emissions growth Santa Rosa may start seeing 40-80 days over 93° F in any given year.

Longer and more frequent droughts

Changes to drought frequency and intensity are driven both by hotter weather with longer summers, but also by more variable rain. Whether the North Bay region experiences more or less rainfall over the year, our land and watersheds will be hotter and drier overall due to rising temperatures and increased evapotranspiration (the process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants). Essentially, even with more rain overall, warmer weather causes soils and plants to dry out.

Greater frequency and intensity of wildfires

Wildfire is a serious threat to human safety, property, and the infrastructure systems on which our communities rely. The consequences of wildfire are not limited to the burning itself: during the winters after a wildfire, catastrophic landslides and flooding can occur when rain falls on the newly unprotected slopes that burned. Water quality can also be diminished by increased sedimentation and contamination.

Wildfire risk has already been increasing due to fuel build-up over decades of wildfire suppression and new development of buildings and infrastructure near flammable natural vegetation, in border areas between urban and natural lands called the “wildland-urban interface.” Risk of fire is likely to continue to rise due to increased dryness of vegetation, compounded by productivity of plants in the spring. Other potential factors in wildfire risk are tree mortality and a potential increase in the extent of flammable invasive species.

Fewer winter nights that freeze

Freezing temperatures are an important aspect of healthy plant communities and pest control. Warm-climate pathogens and disease vectors, as well as invasive species may thrive under increasing winter minimum temperatures. Overall, projected increases in winter low temperatures are greater than projected increases in summer high temperatures.

More variable rain

Models disagree about whether Sonoma County will be faced with consistently more or less precipitation as a result of climate change. The climate models analyzed in this study represent a range of precipitation scenarios, with the wettest scenario projecting almost a 25% increase in precipitation compared to historical (20th century) conditions while the driest scenario projects an approximately 20% decrease.

All of the scenarios indicate that we will continue to have some years with precipitation similar to historic averages interspersed with more extreme conditions. The warm/wet scenario projects some years with an almost 75% increase in mean annual precipitation while the dry scenarios project years with decreases between 25 – 50% of historical averages.

More erratic rainfall, with unusual amounts of rain occurring at unusual times, is a recipe for increased drought, with longer periods of time when soils are drier, and less runoff into reservoirs, such as those on the Russian River that are critical to urban water supply.

Bigger and more frequent floods

Another important factor to understand to assess flood risks is atmospheric rivers. Atmospheric rivers are narrow, long ribbons of moisture that transport huge amounts of water vapor from the tropics toward the poles, creating heavy rainfall in association with winter storms. A well-known example of a type of strong atmospheric river that can hit California is the "Pineapple Express," due to its apparent ability to bring moisture from the tropics near Hawaii to California. Sonoma County's wintertime precipitation comes mainly in storms from the Pacific Ocean brought on atmospheric rivers, and these events have been found to cause 87% of the floods in the Russian River from 1948 to 2011. The amount and intensity of precipitation depends greatly on whether these atmospheric rivers make landfall in California, or hit farther north of our region, a phenomenon that is difficult to predict and model. The Sonoma County Water Agency is working with several partners to evaluate whether future climate conditions are conducive for increased atmospheric rivers.

Higher sea level and storm surge

More frequent inundation, increased erosion, and saltwater intrusion

There is a scientific consensus that global sea level will rise in response to climate change. The two major contributors to sea level rise are the expansion of water and the melting of land ice both due to increasing global temperatures. From 1900 -2008, sea level has been rising by 0.08 inches per year in San Francisco Bay, based on tidal gage observations, and is projected to rise 16.5 – 65.8 inches by 2100.

Rising sea levels, combined with increased storm surge, will lead to more frequent inundation of low-lying areas, flooding homes, infrastructure, and natural areas on the shores of San Pablo Bay and the ocean coast, with the greatest impact anticipated during winter storms.

Sonoma's coastal communities will face a number of public safety hazards associated with rising sea levels. These include flooding, with bigger waves, storm surges, and wave run-up. Erosion—already threatening coastal infrastructure—will be exacerbated. Saltwater may intrude into wells along the coast and in the southern part of the county, even significantly inland from San Pablo Bay.

Protecting quality of life in Sonoma County
The high quality of life in Sonoma County depends upon maintaining three primary categories of community resources:

- **People and social systems**. This community resource category includes Sonoma County's individuals, households, neighborhoods, cities, economic activities, social services, the food system, education, business, emergency services, public safety, and law enforcement.
- **Built systems**. This community resource category includes residential, commercial, and industrial buildings and facilities, and the infrastructure associated with providing water, sanitation, drainage, communications, transportation, and energy.
- **Natural and working lands**. This community resource category includes Sonoma County's public and private natural areas and open space, wildlife, the network of streams and wetlands, sensitive and protected species and habitats, farms, ranches, and timberlands.

Understanding climate change vulnerabilities in Sonoma County
In order to understand the implications of climate change for Sonoma County, it is essential to understand how climate hazards will affect various community resources and how well equipped those resources (or the people who protect them) are to adapt to those hazards.

Climate vulnerability consists of the combined effect of exposure, sensitivity, and adaptive capacity. Exposure is how much change a species or system is likely to experience. Sensitivity is a measure of whether and how much a species or system is likely to be affected by its exposure. Adaptive capacity is the ability to avoid, accommodate or cope with climate change impacts.

The main goal of adaptation is to reduce vulnerability
Investing in actions to reduce vulnerability before harm is done may be more cost-effective than responding after the impact. For example, it would be safer and cheaper to prevent home construction in future potential flood zones than resettling people displaced by a flood. It would also be safer and cheaper to educate people about how to keep cool in extreme heat than relying exclusively on emergency health care during a heat wave to address heat-related illness.

Sensitivity to climate impacts will vary depending on the exposure (magnitude of climate stress and location) and baseline condition of the community resource. For example, a small increase in average temperature is likely to disproportionately harm people, plants and animals not acclimatized to extreme heat, such as those on the coast. In all locations, heat will do more harm to those with compromised or fragile health.

People and Social Systems
All people in Sonoma County are at risk from climate change, but some people and communities are much more vulnerable than others. In order to understand opportunities to build community resilience, it is important to understand how existing disparities in human development intersect geographically with climate vulnerabilities in Sonoma County.

The social systems that support basic needs—including food, water, shelter, transportation, and healthcare—are also vulnerable to climate-related crises such as massive wildfires or floods. Vulnerable populations are at greater risk to climate change hazards because of poor health, living in or at risk of poverty, being very young or elderly, or lacking resources such as access to health care or emergency services. People can be at greater risk because they lack the physical, mental or financial ability to adapt to changing conditions, and therefore experience a greater burden. This disparity, sometimes called the "climate gap," affects various groups in Sonoma County and can have serious health and economic consequences.

Additional efforts are needed to understand the social and cultural networks that can strengthen communities, with the goal of allowing all Sonoma County residents to live to their full potential.

Summary of climate change vulnerabilities for people and social systems

Hotter, drier weather with longer summers	
More extreme heat events	Increased heat-related illness, particularly among those inland, in poor health, working outdoors, in urban heat islands, and/or without air conditioning. Premature death. Added stress on emergency services and health care systems.
Longer and more frequent droughts	Higher prices for water and food. Water shortages from reduced surface water supplies and wells drying up. Food shortages and rising food costs. Potential pressure on housing and social services due to climate migrants from elsewhere. Increase in respiratory problems. Loss of recreation or tourism revenue from water-dependent activities.
Fewer winter nights that freeze	Potential increase in disease vectors such as mosquitoes and rodents.
Greater frequency and intensity of wildfires	Risk of lost connections to energy, water, and food supplies, especially for isolated populations. Displacement and loss of homes. Injuries and death from burns and smoke inhalation. Lung damage and exacerbation of eye and respiratory illness due to air quality. Loss of recreation and tourism revenue in wake of major fire.
More variable rain	
Bigger, more variable floods	Physical danger and economic impact for people living in low-lying areas along rivers and bay lands, especially those without reliable transportation. Death from drowning and injuries from flood. Public health risks from damage to sanitation, utility, and irrigation systems. Limitations on access to critical services. Economic impact to businesses in or affected by flooded areas.
Sea level rise	
Higher sea level and storm surge	Physical danger and economic impact for people living near bay lands or the coast. Disruption in the movement of people and goods.

Built Systems

Functioning buildings and infrastructure including transportation, utility, and sanitation systems are essential for our livelihood and economy. Climate hazards pose physical risks to built systems, but the full costs of hazards can extend beyond the economic cost of physical damage to the structures to include economic, social, and health costs to the people that rely on built systems to work properly. Sonoma County's health, quality of life, safety, security and economy depend on well-functioning transportation, water supply, and utility infrastructure.

Many of the built systems and structures within Sonoma County are already at risk for failure due to age and deferred maintenance. Some public infrastructure is currently capable of withstanding extreme weather events, yet with climate change the frequency and intensity of the events is set to increase, thus further increasing the stress on existing systems.

Summary of climate change vulnerabilities for built systems in Sonoma County

Hotter, drier weather with longer summers	
More extreme heat events	Damage, buckling, warping, and disruption to paved roads, rail lines, bridges, electricity transmission lines, solar and battery facilities. Thermal expansion of bridges. Spikes in energy and water demand, potential stress to supplies. Reduced outputs from thermal power plants, transformers and other parts of electric systems. Brown and blackouts.
Longer and more frequent droughts	Increased demand, and reduced supply, of water. Disruption of hydropower operations such as Warm Springs Dam. Algae and bacterial growth in water supplies. Accelerated over-pumping of groundwater aquifers, leading to failure of wells, saltwater intrusion, degraded water quality, and possibly subsidence. Increased evaporation from reservoirs. Impacts to power generation supplies that relay on water as a cooling source.
Fewer winter nights that freeze	None identified.
Greater frequency and intensity of wildfires	Disruption of electricity transmission lines. Impacts to roadways. Subsequent landslides can close roads and bury infrastructure, including water supply wells.
More variable rain	
Bigger, more variable floods	Less predictable reservoir operation. Road closures, landslides, loss of expensive infrastructure such as bridges and culverts. Increased potholes and roadway damage from intensity of rainfall Failure of storm water and water treatment systems. More difficult to plan for development or infrastructure projects or to retrofit existing infrastructure
Sea level rise	
Higher sea level and storm surge	Roads and highways crossing formerly tidal or estuarine areas (Highways 1 and 37) are more subject to closure and damage. Increased storm damage to boats and related infrastructure. Flooding of low-lying infrastructure such as Sonoma Valley County Sanitation District. Saltwater intrusion and reduced water quality. Disruption of transit routes and travel delays.

Natural and Working Lands

Natural and working lands include Sonoma County's public and private open space, farms, ranches, and timberlands, the network of streams and wetlands, and sensitive and protected species and habitats. These resources are central to the Sonoma County economy and cultural identity.

In addition to producing crops and livestock, agricultural lands can maintain wildlife habitats, provide scenic beauty, enhance biodiversity, provide water filtration, increase nutrient cycling and storage, recharge groundwater, enrich soils, and support pollinators. Conditions in natural areas control wildfire risk, water supply, scenic beauty critical to our tourism sector, pollination, and play a large role in maintaining clean air and water. Collectively, natural ecosystems, plants, and animals provide services that cannot be duplicated and are essential for human vitality.

Landscapes, water supplies, and the agricultural systems that depend on them are more vulnerable when they are already in a compromised state or lacking protection. Plants and animals that are already declining from other stresses like pollution, reduced stream flow, habitat loss, and invasive species may also be more vulnerable to harm from climate change.

Summary of climate change vulnerabilities to natural and working lands in Sonoma County

Hotter, drier weather with longer summers	
More extreme heat events	Loss of wine grape quality. Land use pressure for vineyards in areas closer to the coast. Changes in yield, types and cultivars of crops. Increased animal vulnerability to pests, stress, and mortality. Lower production in animals. Reduced chill hours.
Longer and more frequent droughts	Increased need for water on farms and ranches, and for water-dependent ecosystems. Increased urban water use, at possible expense of agriculture water availability. Shortage of feedstock or rise in cost and access. Increased evapotranspiration rates from open water sources. Decline or death of water-dependent plants and animals. Potential change in suitable grape varieties. Increased tree stress and death in timberlands and other forests. Increased off-stream storage of water for agriculture.
Fewer winter nights that freeze	Unpredictable, potentially sudden, shifts in populations of disease, pest, or invasive species. Earlier bud break may lead to increased use of water for frost protection.
Greater frequency and intensity of wildfires	Loss of habitat. Death of wildlife. Loss of recreational lands and commercial forests. Subsequent erosion and landslides may cause more losses, plus sedimentation of streams and wetlands.
More variable rain	
Bigger, more variable floods	Increased erosion in, and sediment pollution of, streams and wetlands.
Sea level rise	
Higher sea level and storm surge	Loss of prime recreational and natural areas, including marshes, beaches, mudflats, and dunes. Risk of levee breaches and inundation of agricultural land in formerly tidal areas in southern Sonoma County.

Other Vulnerability Considerations

This report primarily discusses the primary or direct hazards of climate change on Sonoma County, with some discussion of secondary or indirect effects. Changes in other parts of the country and around the world could also affect Sonoma County. Examples of these impacts include affects to local supply changes from extreme events in other parts of the world or the possibility that Sonoma County may become a destination for people fleeing climate-related crises elsewhere.

More work, such as scenario planning and cross-disciplinary discussion, is needed to foresee and prepare for potentially serious higher-order or cascading climate impacts.

What can we do to reduce vulnerability in Sonoma County?

Sonoma County's vulnerabilities to climate change are numerous, large, and cross-cutting. Fortunately, many entities in Sonoma County have begun implementing strategies and planning processes that increase our resilience and readiness for climate change. Existing efforts to prepare for climate changes should be integrated, expanded, and evaluated to explore how well they are serving to increase our readiness for increased exposure to climate hazards. On an ongoing basis, specific climate readiness strategies should be more explicitly integrated into existing plans and projects that are already used to promote public health, safety, and prosperity in Sonoma County.

The RCPA will coordinate with local elected officials, planning staff, and community leaders to identify adaptation objectives to be included in the long range community-wide climate planning effort known locally as Climate Action 2020. Having specific objectives to reduce local climate vulnerability will allow for common understanding around future priorities in responding to climate change. Adaptation objectives within the Climate Action 2020 framework will also allow us to identify and promote win-win strategies that both reduce GHG emissions and increase climate resilience.

1. Climate Readiness

Why do we need to prepare?

As scientists refine global climate models to create projections of future conditions at the local level, it becomes clear that Sonoma County's future climate will include more very hot days, less predictable rain, more extreme weather events, and higher ocean levels. Scientists predict that weather patterns of the future will differ significantly from those experienced over the past century. Using historic data to predict future conditions is no longer adequate for long-term policy planning and decision-making.

Weather patterns in Sonoma County already show the evidence of climate change. For example, long-term average air temperatures for the North Bay have risen by 2.7°F over the last century.

Senior military leaders urge governments to act now to reduce climate hazards, describing climate change as a "catalyst for conflict." "The projected impacts of climate change can be detrimental to the physical components of infrastructure and information systems." Climate impacts "will threaten major sectors of the US economy" and "major sections of our society and stress social support systems such as first responders" –CNA Military Advisory Board, 2014

The heart of local land use planning in each Sonoma County community is their General Plan, which is the guiding document on how communities will grow, outlining the key policies from which decisions flow. Within all jurisdictions' General Plans **Sonoma County jurisdictions have a vision to preserve, protect, and enhance the character of the community and critical environmental resources, foster economic development, and maintain a high quality of life**.

Climate Change will cause new challenges that threaten the community guiding principles outlined in our General Plans and other guiding policies. Climate change affects the health of our people, especially poor and isolated populations; the reliability of our water supply; patterns of commercial and residential energy use; where food and commodity crops will thrive; and many other aspects of community well-being. The risks, uncertainties, and volatility associated with climate change pose potentially high costs to communities in terms of public health, safety, economic vitality, security, and quality of life.

Therefore, we must act to avoid or reduce harm from the most significant hazards of climate change. The first critical step of climate readiness is to understand the risks associated with local climate hazards. The second step is to understand what populations and resources are vulnerable to those hazards. The RCPA has developed this assessment of local climate driven risks and vulnerabilities to assist the communities of Sonoma County in taking these first critical steps.

The leading American assessment of climate impacts emphasizes the need to act. "Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited." "It is prudent to invest in creating the strongest climate-health preparedness programs possible." –National Climate Assessment, 2014

Now is the time to act. We have enough confidence in projected climate trends to begin the work of preparing for climate hazards now. Preparing now will yield more cost-effective and flexible strategies than if we wait until we are reacting to unprecedented conditions.

Reducing Greenhouse Gas Emissions is Not Enough

Sonoma County has long been a leader in addressing greenhouse gas (GHG) emissions and working to reduce the pace of climate change. Sonoma County communities have adopted bold reduction targets and have been implementing strategies to reduce emissions for over a decade. However, despite local and global efforts to reduce emissions, climate change is already happening, and accelerating. The impacts to Sonoma County are expected to increase over time.

Most work on climate change to date has focused on reducing GHG emissions, a strategy known as **climate mitigation**. It is essential to continue this work to limit future impacts from climate change and give us the best chances of avoiding catastrophic changes. The speed and magnitude of climate changes can be affected by the rate of greenhouse gas emissions; if we successfully reduce emissions worldwide to levels necessary to halt or limit global warming, we may avoid the worst impacts of climate change. However, even under scenarios with low future emissions concentrations, climate change impacts in Sonoma County are expected to increase over time.

Climate adaptation refers to policies, programs, and actions that reduce our vulnerability to climate change hazards and bolster community readiness to face the unavoidable climate impacts already underway. In this document, the terms “climate adaptation,” “climate preparation,” and “climate readiness” are used synonymously.

> “Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term, and contribute to climate-resilient pathways for sustainable development.”
> – IPCC, 5th Assessment Report, Headline Statements

Over the long term, climate mitigation can help make climate change less severe, but the changes cannot be avoided entirely. Therefore we must continue to pursue both goals – to mitigate GHGs towards targets consistent with the scientific imperative, and to implement strategies that minimize the toll climate change will take on our well-being. Figure 1 illustrates how mitigation and adaptation are related as strategies in responding to the challenges of climate change.

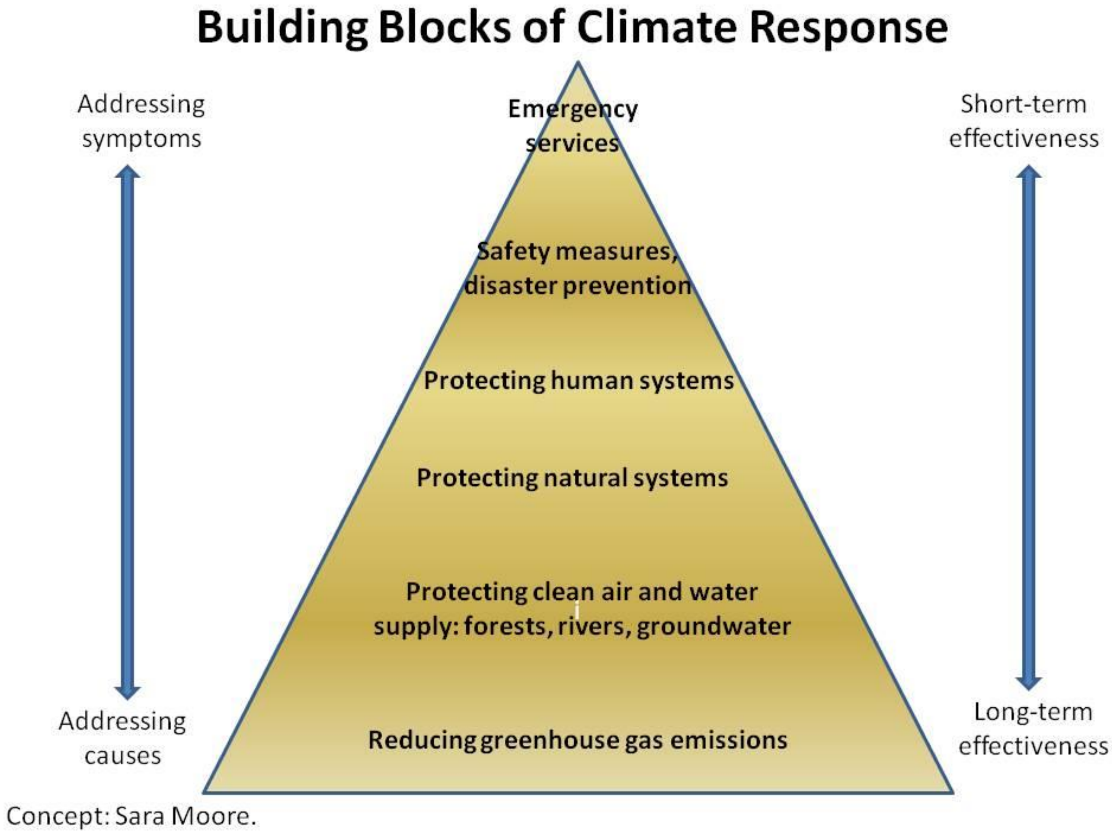


Figure 1. The Building Blocks of Climate Adaptation Planning.

Many climate strategies accomplish both mitigation and adaptation objectives, sometimes called "win-win" strategies. The Bay Area Climate & Energy Resilience Project (Sasso, 2013) identified ten of these strategies, shown in Table 1.

Table 1: Win-win strategies identified by the Bay Area Climate & Energy Resilience Project

San Francisco Bay Area Win-Win Strategies	Climate Impacts Addressed
Cooling communities (reducing urban heat island effects)	Extreme heat, energy demand, water shortage
Bay Area Priority Development Areas and Priority Conservation Areas	Sea level rise, Storms, Heat, Energy, Water
Integrated building design for new buildings and development	Energy, water supply
Local renewable power + intelligent grid	Energy supply/price
Community choice aggregation	Energy supply/price
Energy efficiency for existing buildings	Energy supply/price
Wetland systems as adaptive infrastructure	Sea level rise, extreme storms
Low impact development / stormwater management	Sea level rise, storms, energy, water
Urban water conservation and efficiency	Energy supply/price
Local food supply chains	Energy, food prices

Climate Action 2020 is a regional planning effort led by the Regional Climate Protection Authority that will outline near-term priorities for strategies to reduce greenhouse gas emissions, and will highlight those win-win strategies that have an adaptation benefit. Neither adaptation nor mitigation alone can eliminate all climate change hazards; these approaches complement each other and together can significantly reduce the risks.

How can we prepare?

Cities, counties, and other institutions throughout the U.S. and California have begun to identify risks and develop climate adaptation plans and strategies to respond to those risks. This can be done in many ways. Good climate readiness planning increases the adaptive capacity of the most vulnerable individuals, communities, built assets, and natural systems. Figure 2 illustrates the full sequence of climate readiness planning steps.

"Effective adaptation will require ongoing, flexible, transparent, inclusive, and iterative decision-making processes, collaboration across scales of government and sectors, and the continual exchange of best practices and lessons learned. All stakeholders have a critical role to play in ensuring the preparedness of our society to extreme events and long-term changes in climate." –National Climate Assessment, 2014

Climate Readiness Planning Process

Adapted from Portland and Multnomah County, 2014

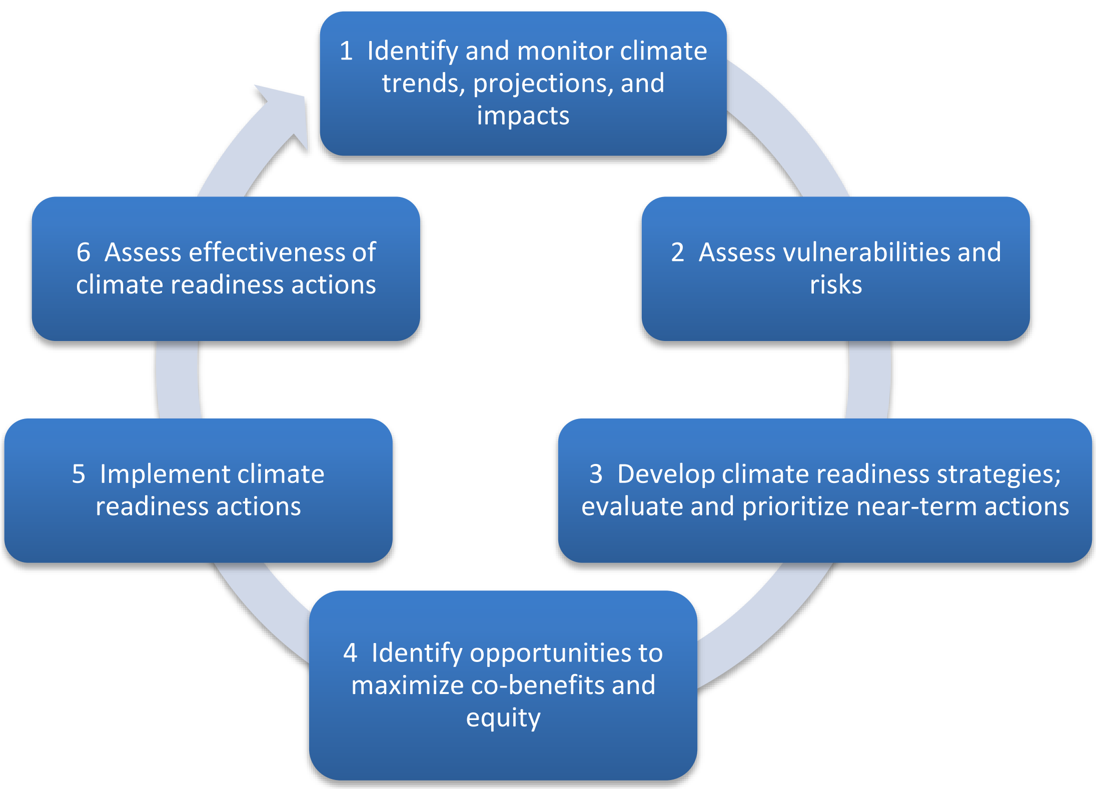


Figure 2. Climate Readiness Planning Steps

Purpose

The purpose of this climate vulnerability assessment is to provide an initial screening of the county's **community resources** that are vulnerable to climate change hazards. It is not intended to be a comprehensive vulnerability analysis or to provide site-specific prescriptions for action. Instead, the intent is to provide a starting point for a countywide discussion on climate impacts and our climate vulnerabilities, tackling the first two steps outlined in Figure 2 for Sonoma County.

Here we use "**community resources**" to mean individuals and communities, infrastructure, and natural resources ecosystems that government institutions are concerned with protecting, for the public good, that are potentially vulnerable to harm from climate change.

Much as we begin climate planning to reduce greenhouse gas emissions with an inventory of sources that enables us to prioritize actions towards those sources with the most opportunity, we must take stock of local vulnerabilities in order to understand which systems will be most affected by various climate change hazards.

This **vulnerability assessment** uses the best available science to identify local impacts and to describe the community's exposure and sensitivity to these impacts. It is intended to incite discussion about where and how a community needs to improve its capacity to adapt to these impacts. This risk and vulnerability assessment document is intended to:

- Serve as a reference for local government staff, elected officials, and the community at large to help prepare the county for climate change.
- Support efforts to build the adaptive capacity of the community, based on the best available science and information on climate change projections and hazards.
- Support development of specific strategies to be adopted to achieve climate readiness objectives.
- Spur consideration of climate change hazards in planning and municipal operations, by showing that past trends are no longer sufficient as a basis for planning and prioritizing.
- Empower people to reduce the local hazards of climate change, especially among vulnerable populations

This document was developed as part of Climate Action 2020, a collaborative effort coordinated by the RCPA through which all communities in Sonoma County will develop and implement a plan to help them remain vibrant and resilient in a changing climate. Through Climate Action 2020, the RCPA is engaging elected officials, local government staff, community experts from diverse geographies and sectors, and the general public to identify and pursue actions to reduce greenhouse gas emissions and respond to climate change hazards. Integration of vulnerability analysis into the Climate Action 2020 framework is essential in recognizing that mitigation is the foundation of efforts to minimize the risks of future climate change and our ability to adapt to those risks.

2. Climate Change Projections

Uncertainty

Just as there is uncertainty in all long-term planning and risk management, there is uncertainty about climate change hazards. These uncertainties do not change the virtual consensus among climate scientists that the global climate is warming as a result of greenhouse gas emissions, that local weather patterns are already disrupted, that ocean levels are rising, that there is a long lag between emissions reductions and climate response, and that the changes are accelerating.

Climate change models vary in their projections of the amount and timing of change, as well as levels of certainty about these changes. There are two primary sources of uncertainty in climate projections. The first is the extremely high natural variability of the climate system. For example, rainfall totals from year to year are completely independent: you cannot predict next year's rainfall based on this year's rainfall. For this reason, projections should be considered a "scenario" based on climatic physics that captures underlying long-term trends and estimates variability around that trend, not a time-specific prediction of weather for a specific year or season.

Is Climate Change in Doubt?
"The evidence is overwhelming: levels of greenhouse gases in the atmosphere are rising. Temperatures are going up. Springs are arriving earlier. Ice sheets are melting. Sea level is rising. The patterns of rainfall and drought are changing. Heat waves are getting worse as is extreme precipitation. The oceans are acidifying.
The science linking human activities to climate change is analogous to the science linking smoking to lung and cardiovascular diseases. Physicians, cardiovascular scientists, public health experts and others all agree smoking causes cancer. And this consensus among the health community has convinced most Americans that the health risks from smoking are real. A similar consensus now exists among climate scientists, a consensus that maintains climate change is happening, and human activity is the cause."
---American Association for the Advancement of Science, 2014.

The second source of uncertainty in modeling arises from actual unknowns regarding climate mechanics and social behavior. For example, while it is quite clear that higher greenhouse gas levels cause higher temperatures, for our region it is less clear whether rainfall will increase or decrease as a result of the changing climate. Even less understood are the physical mechanisms that drive fog, wind, and ocean upwelling, and therefore scientists do not know exactly how these systems will respond in a changing climate. See Appendix B, Resources, for more reading on these topics. Different models make different assumptions about these factors, which causes differences in their projections. There is also uncertainty about how quickly and vigorously humanity will reduce greenhouse gas emissions. This uncertainty can be addressed by comparing the projections generated by models using different emissions assumptions.

"Essentially, all models are wrong, but some are useful."
–George E. P. Box, British statistician, 1919-2013

Another poorly understood phenomenon that may be changing is the "atmospheric rivers" that can bring heavy winter rains from the western Pacific to California, sometimes called the "pineapple express." A large percentage of Sonoma County's annual rainfall comes from atmospheric rivers, which occur over a small fraction of days during a typical year. Historically, Sonoma County has been prone to both flooding and droughts that can be correlated to the occurrence – or lack thereof – of atmospheric rivers. Consequently, a better understanding of these events will aid water managers in designing and operating water systems and managing water resources in a more resilient manner. As the modeling of these climatic systems improves, we should gain insights into how much climate change will affect the occurrence of these high intensity rainfall events and their impact on regional water resources.

The wide range of projected future conditions is meaningful information in itself, indicating a need for planning approaches that work across the full range of possible outcomes. Even as we consider these widely ranging future scenarios, there are recurring themes that scientists agree are important to understand about what the future holds for our region.

> The speed and severity with which climate hazards increase in Sonoma County depend on many factors, particularly how vigorously and quickly people reduce greenhouse gas emissions globally.

Trying to predict future climate puts planners in a situation where there is high uncertainty about critical factors that cannot be controlled, such as the impacts of greater flooding or more frequent heat waves. Uncertainty about the future is not new to planners. Scenario planning is a process that can help planners to prepare for what lies ahead in the future. It provides a framework for developing a shared vision for the future by analyzing various forces (e.g., health, transportation, livability, economic, environmental, land use), that affect communities. The technique was originally used by private industry to anticipate future business conditions and to better manage risk. For example; Bankers might use scenarios to determine the impact of different investment performance scenarios on asset levels, or large retailers will use scenario planning to contemplate the impact of demographic change on the need for new retail store locations.

Novel futures are hard to imagine, but just as land use planners routinely use scenario planning to evaluate options for accommodating population growth, scenario planning is also an appropriate tool for planning and prioritizing action for climate preparedness. "Scenario planning is … a systematic way of bracketing uncertainty. A strength of scenario planning is that it can incorporate multiple types of drivers and information. Using scenarios, managers can project the outcome of a set of relatively certain drivers—like sea level rise and increasing human demand on resources— interacting with relatively uncertain drivers— like rainfall declining or increasing (in addition to how much it will decline or increase), and the changing timing of rainfall or drought. Scenarios can take into account average projections and also extremes or critical improbabilities that would be highly disruptive to the decision-making environment." (Moore et al., 2013).

Modeled futures are artificial constructs of extremely complex interacting systems. We will not know how Sonoma County's climate actually changes, or the effects that a changed climate actually produces unless we monitor in real time the changing climate and its effects. Examples of monitoring and reporting that contribute to informed climate response include: for health and social well-being, the Healthy Sonoma community dashboard (2014); for economic well-being, the reporting of the Sonoma County Economic Development Board (2014); and for ecosystem resilience, North Bay Vital Signs (Micheli and DiPietro, 2013).

Global, national, and state trends

The Intergovernmental Panel on Climate Change (IPCC) completed its fifth assessment of climate change impacts in fall 2014, asserting that scientists are more certain than ever that climate change is already having measurable impacts. Drawing on a larger body of evidence than ever before, it highlights a wide range of risks in vital areas such as food supply, human health and economic development. The report urges policy-makers to cooperate to effectively fight climate change, to make links between their actions and knowledge about the risks of inaction.

A few key findings of IPCC 5th Asessment:

- The design of climate policy is influenced by how individuals and organizations perceive risks and uncertainties and take them into account.
- Despite a growing number of climate mitigation policies, annual GHG emissions have continued to increase from 1970 to 2010 with larger absolute decadal increases toward the end of the period.
- The global economic crisis of 2007/2008 only temporarily decreased global emissions.
- About half of cumulative anthropogenic CO2 emissions (those caused by human activity) between 1750 and 2010 have occurred in the past 40 years.

Alongside the IPCC assessment process, the U.S. Global Change Research Program, a collaboration of 13 federal science agencies, released the third National Climate Assessment (NCA) in 2014. The NCA summarizes the impacts of climate change on the U.S., now and in the future. The report includes a highly interactive website and 12 findings on the impacts of climate change on every sector and region of the United States. The NCA found that current strategies to prepare for the impacts of climate change are insufficient to avoid consequences from climate impacts. A few key messages from the report include:

- Barriers to implementation of climate adaptation include limited funding, policy and legal impediments and difficulty in anticipating climate related changes at local scales
- Climate adaptation, often fulfill other societal goals, and can therefore be incorporated into existing decision-making processes
- Mitigation efforts that only stabilize global emissions, will not reduce atmospheric concentrations of carbon dioxide, but will only limit their rate of increase.
- Decisions about how to address climate change can be complex and responses will require a combination of adaptation and mitigation actions.
- Decision-makers may need help integrating scientific information into adaptation and mitigation decisions.
- Rural communities are highly dependent upon natural resources that are affected by climate change, and therefore will need assistance in adaptation.

The 2014 update of the California Climate Adaptation Strategy, called Safeguarding California (California Natural Resources Agency, 2014), highlights three main strategies: reducing emissions; investing in climate readiness for California's people, environment, and economy; and conducting research to understand risks and track progress toward climate resilience. The California Climate Adaptation Planning Guide (Resources Agency, 2012) helps institutions tackle the challenges of climate change.

There are many efforts underway to understand and respond to the climate impacts we can expect in California. California's first major policy initiative was the groundbreaking Global Warming Solutions Act of 2006, the state's legislation on reducing greenhouse gas emissions (also known as AB 32).

In 2013, the California Environmental Protection Agency's Office of Environmental Health Hazard Assessment released *Indicators of Climate Change in California* (OEHHA, 2013). The OEHHA report is a good example of climate guidance intended to help the state track, assess, and report on the climate change issues its policies seek to address. By tracking indicators of change, such as those in the text box on the previous page, the report identifies several important trends.

- The state's temperatures (high, low, average) are rising. Extreme heat events have increased in duration and frequency. The rate of warming has accelerated since the mid-1970s. Nighttime minimum temperatures have increased almost two times as fast as maximum daytime temperatures. Nighttime heat waves have been increasing in all regions.
- Wildfire-burned acreage has been increasing over the past 60 years. The three largest fire years on record occurred in the last 10 years.
- Spring snowmelt runoff has decreased. This indicates warmer winters and more precipitation falling as rain rather than snow, and has negative implications for the state's water supply.
- Among other changes detected in the ocean and marine species, CO_2 levels have increased in coastal waters, making them more acidic (lowering the pH), potentially damaging shell-forming species and the food chain that depends on them.
- Some species are already moving to higher elevations, such as conifer forests in the Sierra and certain small mammals in Yosemite National Park.

Researchers have documented the impacts of climate change in California, including evidence pointing to climate change being a primary factor in people dying of heat-related illness (Luber and McGeehin, 2008), reduced crop yields (Lobell and Field, 2007), emergency services being overstressed during fire season (Westerling and Bryant, 2008), and prime agricultural land in the San Joaquin and San Fernando Valleys being left fallow because of lack of water (Church, 2014). Other climate change-driven impacts that are being monitored by researchers are ocean food-chain disruptions and species endangerment or extinction.

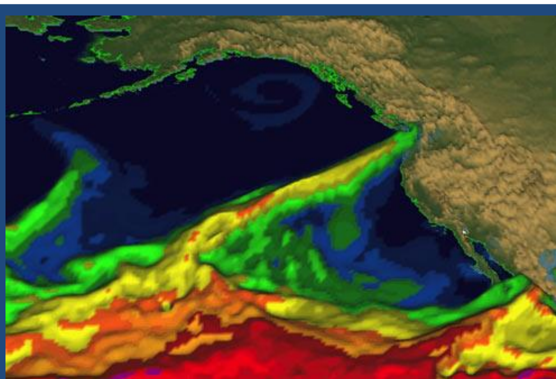
Other issues need further study to understand their connection to climate change in California. These include the occurrence of harmful algal blooms, the decrease in fog in the Central Valley, the increased survival and spread of disease-causing pathogens, and the increased susceptibility of trees to disease, such as Sudden Oak Death.

Indicators of Climate Change in California *(OEHHA, 2013)*

Climate change drivers: *greenhouse gas emissions; atmospheric greenhouse gas concentrations; atmospheric black carbon concentrations; acidification of coastal waters.*

Changes in climate: *annual air temperature; extreme heat events; winter chill; freezing level elevation; annual precipitation.*

Impacts of climate change: *annual Sierra Nevada snowmelt runoff; snow-water content; glacier change; sea level rise; lake water temperature; Delta water temperature; coastal ocean temperature; oxygen concentrations, California current; mosquito-borne diseases; heat-related mortality and morbidity; exposure to urban heat islands; tree mortality; large wildfires; forest vegetation patterns; subalpine forest density; vegetation distribution shifts; alpine and subalpine plant changes; wine grape bloom; migratory bird arrivals; small mammal range shifts; spring flight of Central Valley butterflies; effects of ocean acidification on marine organisms; copepod populations; Sacramento fall run Chinook salmon abundance; Cassin's auklet breeding success; Shearwater and auklet populations off Southern California; sea lion pup mortality and coastal strandings.*



Most of Sonoma County's precipitation originates as water vapor transported from the Pacific Ocean, often in concentrated winter storm events. "Atmospheric rivers," first identified in 2000 using new satellite imagery, are a particularly concentrated region of water vapor transported by strong winds. Atmospheric rivers can carry water vapor equivalent to 10 times the amount of water flowing at the mouth of the Mississippi River and can cause extreme amounts of precipitation and subsequent storm and flood risk. The Water Agency is partnering with Scripps Institute of Oceanography and the Center for Western Weather and Water Extremes to install an observation system intended to improve quantitative forecasts of precipitation and flooding. It will also allow the Water Agency to better define the role of atmospheric rivers in securing water supply in Lake Mendocino without increasing flood risk. (Water Agency, 2014)

Sonoma County trends

Sonoma County is fortunate to be the beneficiary of a number of cutting-edge efforts to understand climate trends, in part because local entities are key participants in these efforts. Local government agencies such as Sonoma County Water Agency and RCPA are partnering with research collaboratives such the Terrestrial Biodiversity Climate Change Consortium, the Scripps Institute of Oceanography Center for Weather and Water Extremes, U.S. Geological Survey, and the National Oceanic and Atmospheric Administration (National Weather Service, Office of Atmospheric Research, Coastal Services, and National Marine Fisheries Service). Local governments are also working in an unprecedented fashion with non-governmental technical groups such as the North Bay Climate Adaptation Initiative to improve and extend climate projections and make them more relevant to local decision-making. Ultimately, local government partnerships with non-governmental organizations seek to find new ways to integrate climate considerations into local plans, priorities, and decisions.

Downscaling Models

Projections of future local temperature, precipitation, and hydrology across Sonoma County described here are derived largely from a dataset called the California Basin Characterization Model (BCM), developed by the US Geological Survey (Flint et al., 2013) which provides historical and projected future climate and hydrologic data.

The BCM data is downscaled at a sufficiently granular resolution to be relevant for the study of watershed response to climate change. This report uses the 2013 version of the dataset. Four of the available 18 future scenarios in the BCM were selected to represent the range of possible future scenarios projected for Sonoma County in terms of temperatures and precipitation (Weiss et al., 2013). For more about how global climate models (called global circulation models) are scaled down to a level meaningful for regional, county, or watershed planning and management, please see "Downscaling," an article on the California Climate Commons (2014). We have given short-hand names to these climate futures that reflect the end-of-century conditions that they project that are summarized in Table 2.

Model of how the world's climate system works ("general circulation model" or GCM)
+
Concentration of greenhouse gases in circulation ("emissions scenario")
=
Climate future ("climate scenario")

Table 2: Short-hand names for the four representative future climate scenarios that informed this report

Future assumptions:	**Less Precipitation**	**More Precipitation**
High Emissions (greater temperature increase)	**"Hot/Dry"**	**"Hot/Wet"**
Mitigated Emissions (less temperature increase)	**"Warm/Dry"**	**"Warm/Wet"**

The two major factors that distinguish among the four futures are GHG emission levels and precipitation amounts. If humans succeed globally in significantly reducing GHG emissions in the near term, the future will be warmer. If we proceed in a business-as-usual fashion (as we have so far) and continue to produce ever-increasing GHG emissions, then the future will be far hotter. There is greater uncertainty around precipitation in the global circulation models. Global climate is complex, and scientific understanding of it is imperfect. Therefore, the difference between the "hot" and "warm" scenarios is based on the effects of higher GHG emissions versus lower (more mitigated) GHG emissions. The difference between the "wet" and "dry" futures reflects the fact that different global climate models use different rainfall projections. Figure 3 below shows how strongly climate futures diverge from our historical regional climate in the San Francisco Bay Area.

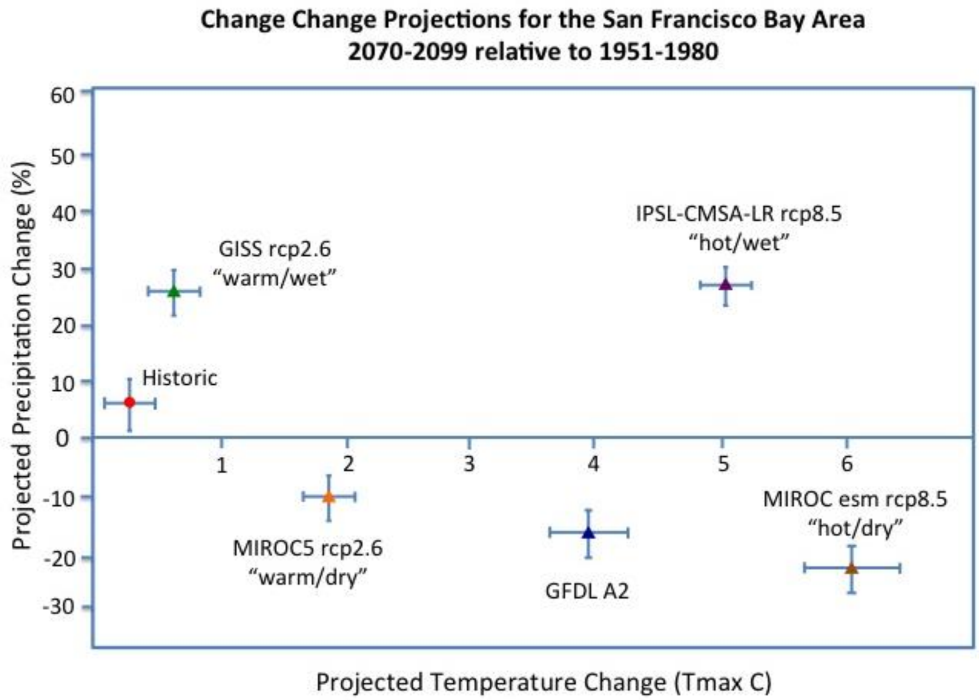


Figure 3: Comparison of equally likely climate futures to historical climate (in red), showing non-overlap of future conditions with historical conditions.

The red dot in Figure 3 represents average historical climate (in terms of precipitation amount and temperature). The lines extending from the red dot indicate the range of variability (1 standard deviation) around that historical average. We see that the range of variability in the "warm/wet" future overlaps to some degree with the historical variability we are used to, but the three other equally-likely futures bring conditions we have never seen before. Hence the urgent need to plan for climate-induced hazards now.

"Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread, and irreversible impacts globally (high confidence)." -IPCC, 5^{th} Assessment (2014).

Also, it is important to note how strongly Sonoma County's future is affected by factors within human control. Our vulnerability to climate hazards is determined in large part by whether humanity reduces GHG emissions. The worst-case future scenarios are created by runaway emissions. Stopping climate change is the most effective way to reduce climate change hazards.

As evidence that the BCM dataset is capturing accurate understanding about how climate influences hydrology in the North Bay despite the complexities of climate behavior, the model can derive historic stream flow records from historic weather records with impressive accuracy.

Figure 4 shows the BCM-generated historic stream flow predictions of Maacama Creek, at tributary of the Russian River in red, overlaid on the actual historic stream flow in blue.

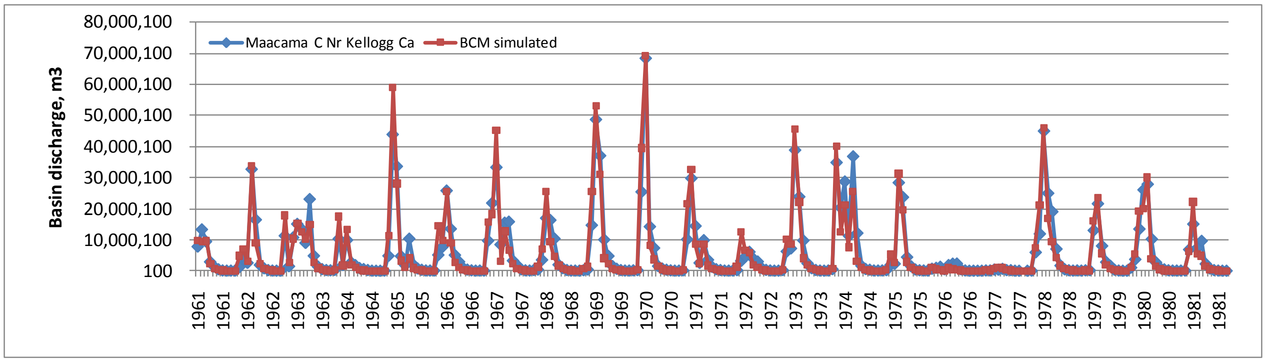


Figure 4: Actual historic stream flow in Maacama Creek, from 1961 to 1981, in blue, overlaid with stream flow as projected by the BCM using historic weather data. Source: NBCAI

Other major data sources that informed the findings of this document are the California Adaptation Strategy (2009, updated in 2014), Krawchuk and Moritz (2012) regarding future fire frequency, and Our Coast Our Future (2013) regarding sea level rise.

Despite differences in the magnitude and timing of various impacts projected across the four representative future climate scenarios, there are clear trends in the climate change hazards that are affecting Sonoma County. The next section describes the major hazards facing Sonoma County as a result of climate change based on the analysis of future climate scenarios and related variables affecting Sonoma County.

3. Climate Hazards in Sonoma County

To understand Sonoma County's vulnerabilities to climate change, we start by identifying and understanding our exposure to climate hazards. The key known climate change hazards affecting Sonoma County are summarized below:

Hotter, drier weather with longer summers
More extreme heat events
Longer and more frequent droughts
Greater frequency and intensity of wildfires
Fewer winter nights that freeze
More variable rain
Bigger, more variable floods
Sea level rise
Higher sea level and storm surge

This chapter will discuss the science and local relevance for each climate change hazard shown above. At the beginning of each climate hazard discussion, there is a table that cross references the known hazard's impact on our community resources that are categorized as:

- People and Social Systems
- Built Systems
- Natural and Working Lands

Chapter 4 will go into greater detail on the climate change hazard impacts and to the community resources across these three categories. There will be some repetition between Chapter 3 and Chapter 4, which is intentional, as much of this information is interrelated and interdependent, and is difficult to categorize and contain within discrete silos.

Hotter, drier weather with longer summers // More extreme heat events

Sonoma County is expected to experience more very hot days than in the past, and overall higher temperatures over a longer period of dry weather even under forecasts that predict overall wetter conditions. Spring will come earlier and fall will come later, and these extended periods of hotter, drier weather will impact many community resources. Heat will also increase soil moisture deficit and reduce groundwater recharge.

Summary of vulnerabilities to extreme heat hazards in Sonoma County

People and Social Systems	• Increased heat-related illness and death, especially for babies, children, elderly, isolated, the poor, poorly housed, and outdoor workers. • Reduced air quality, increased respiratory illness. • Increase in household expenses for cooling. • Increase in urban heat island effect on paved surfaces.
Built Systems	• Spikes in demand for water (for irrigation) and energy (for cooling) during heat waves. • Reduced surface and groundwater supplies and storage. • Physical damage to infrastructure, equipment, and buildings. • Strain on electric grid causing brown and blackouts.
Natural and Working Lands	• Dying plants in natural areas. • Increased fire risk. • Reduced groundwater recharge. • Potential impairment of water quality due to reduced baseflows. • Heat-related death in wildlife. • Changes to suitability of grape varieties. • Loss of wine grape quality. • Land use pressure for vineyards in previously natural areas closer to the coast. • Increased groundwater pumping for agricultural irrigation.

Historic and projected trends

Sonoma County has already experienced warming temperatures over the last century. Average monthly maximum temperatures have increased approximately 2.7° F for the county as a whole since 1900. During this time period average maximum temperatures (daytime high temperatures during June, July, and August) have increased approximately 1.0 °F while average minimum temperatures (night-time low temperatures during November, December, and January) have increased approximately 1.7 °F.

The weather has changed differently in different parts of the County, with a trend towards warming of valley bottoms and cooling in some mountainous areas. Figure 4 below depicts changes in monthly maximum and minimum temperatures averaged over the last 30 years (1981-2010) compared to a pre-climate change period of the same duration (1951-1980). While some areas (in blue) have cooled slightly over this time period, the overall warming trend (in warm colors) is clear.

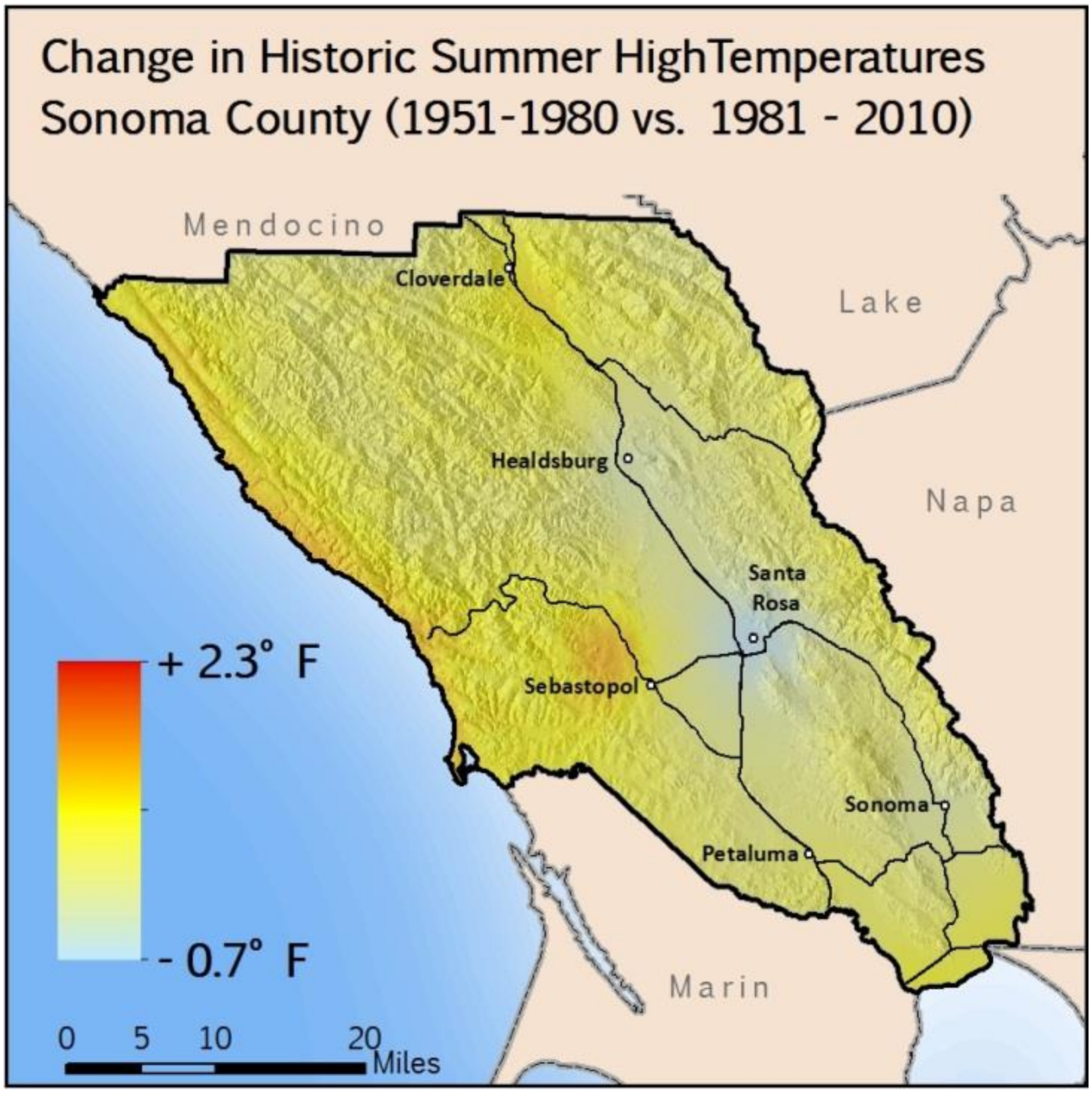


Figure 5. Changes in monthly maximum and minimum temperatures averaged over the last 30 years (1981-2010) compared to a pre-climate change period of the same duration (1951-1980). While some areas (in blue) have cooled slightly over this period, the overall warming trend (in warm colors) is clear.

Temperatures are expected to continue to rise as projected by most climate change models, whether they use high or mitigated carbon emissions trends. Figure 5 depicts average summer high and winter low temperatures projected by the four models chosen for comparison in this report. In the two models with uncurbed emissions, temperatures are projected to increase steadily with average temperatures projected to increase approximately 5-15°F by the end of the century. By contrast, the heavily-mitigated emissions models show an increase of only a few degrees.

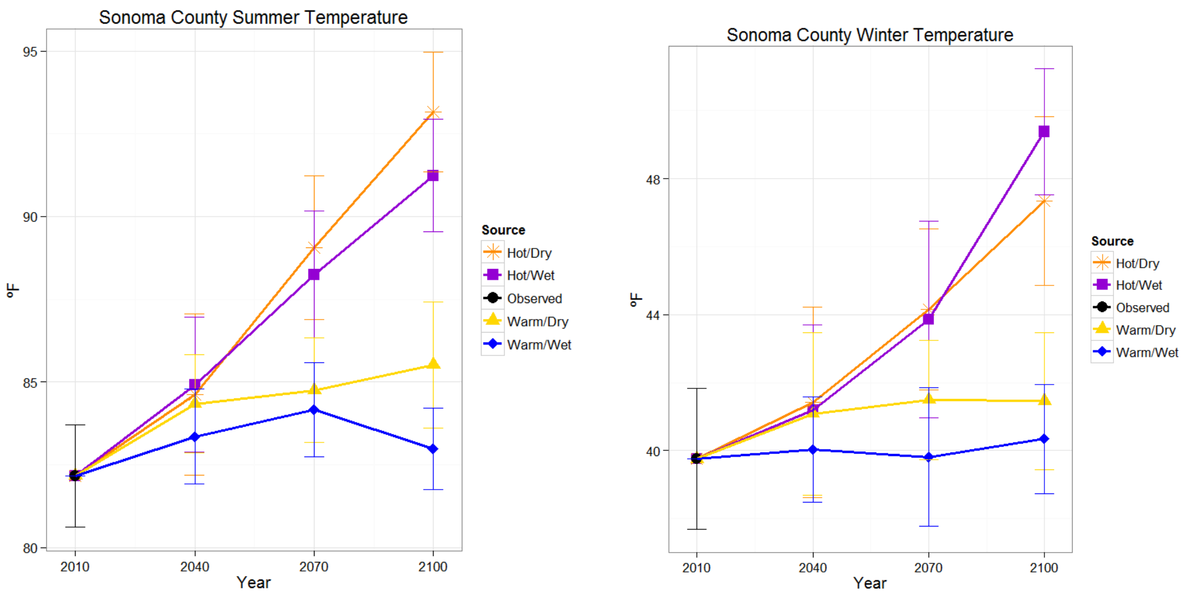


Figure 6. Observed (1981-2010) and projected future summer and winter temperature for Sonoma County. Data source: California Basin Characterization Model, Flint et al., 2013.

Even one of the highly mitigated emission models shows a similar temperature increase in the near future compared to the higher emissions models. This is commonly seen in climate models, because there is a lag in the response time between carbon being added to the atmosphere and the resulting increase in temperature. We will be experiencing climate change over the next half-century caused by emissions already produced to date.

Sonoma County is projected to see extremely hot days much more frequently, particularly in the valley along Highway 101 near Santa Rosa and southward, and in Sonoma Valley.

Projected future changes in air temperatures vary across the county. In Figure 6, the map shows the geographic distribution of changing temperatures using the “hot/dry” future scenaro, which is a conservative scenario to use when planning for heat-related hazards. Inland valleys and mountain ridges are most affected, and some regions experience no change.

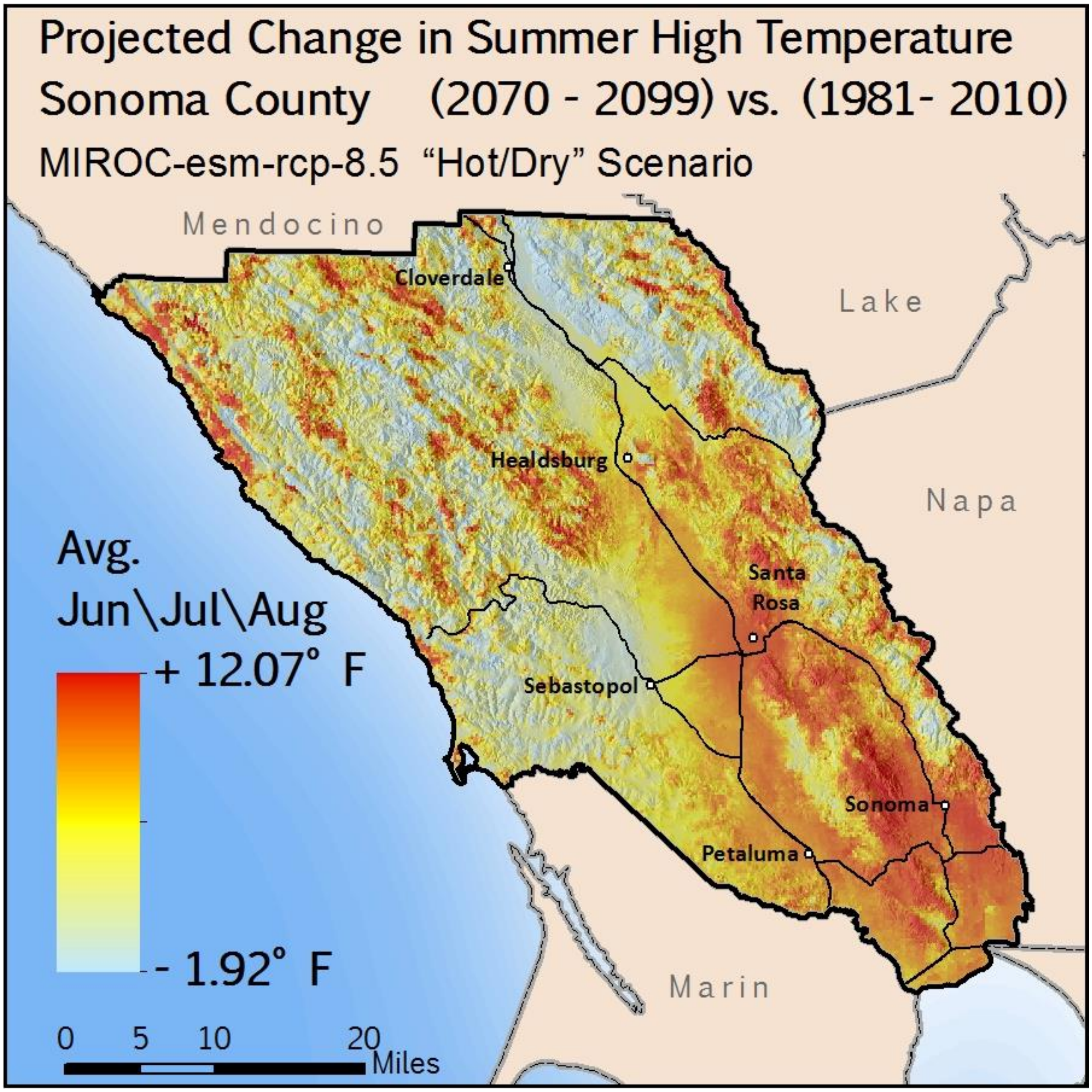


Figure 7: Projected change in summer high temperature: June/July/Aug average maximum temperature 1981-2000 vs. June/July/Aug average maximum temperature 2070-2099

The microclimates of Sonoma County include warm spots (e.g., fog-free parts of the coastal mountains, such as Occidental) called "banana belts," the cool coast with temperatures stabilized by the ocean, and places which experience relatively steep drops in temperature (e.g., because of lack of sun exposure in deep north-south valleys). There are also relatively rainy places (e.g., Cazadero). The diversity of the landscape calls for localized climate readiness approaches. Meanwhile, this diverse landscape could provide critical refuges (*refugia)* for species whose habitat is dangerously altered by climate change (Moritz and Agudo, 2013).

An extreme heat day is currently defined for the Santa Rosa region as having a high temperature above 93°F. The number of extreme heat days is projected to steadily increase under the "warm/dry" climate future, increasing to a range of 40-80 per year, far more frequent than our usual 0-10 extreme heat days per year. The graph in Figure 8 depicts the number of extreme heat days per year in the Santa Rosa area for the historical time period 1950 to the present and for the projected time period to the end of the century. Over the coming decades, people and animals will likely acclimate to the heat and the definition of an extreme heat day for our region will be adjusted upward (Knowlton et al., 2007). For comparison, currently the extreme heat day threshold for a much warmer region of the state, Fresno, is 104°F (Cal-Adapt, 2014).

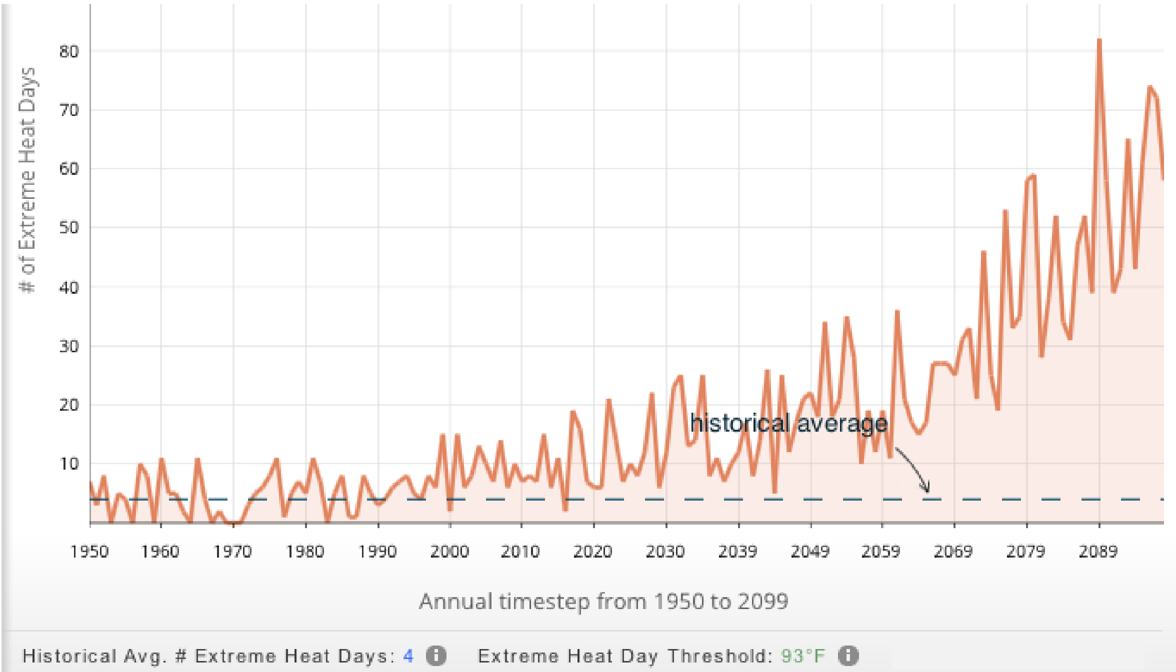


Figure 8: Graph of extreme heat days (>93°F) per year for Santa Rosa (Cal-Adapt.org). The Cal-Adapt definition of an extreme heat day is "a day in April through October where the maximum temperature (Tmax) exceeds the 98th historical percentile of maximum temperatures based on daily temperature data between 1961-1990." (Cal-Adapt, 2014).

Hotter summer days could add a new type of agricultural irrigation demand, if winegrape growers adopt a practice used in other wine-growing regions of using overhead irrigation to cool grapevines (Hannah et al., 2013).

Hotter, drier weather with longer summers // Longer and more frequent droughts

Several consecutive dry years, capped by California's driest year on record in 2014, has resulted in severe drought conditions for Sonoma County. Many critical water storage lakes and reservoirs—key sources for drinking and irrigation water—are at historically low levels. In the future, we can expect longer and more frequent droughts, even in climate futures that project overall wetter conditions.

Summary of vulnerabilities to drought hazards in Sonoma County

People and Social Systems	• Reduced water availability and quality. • Higher prices for water and food, disproportionately affecting low-income people. • Increase in asthma and allergies due to longer pollen and allergen season. • Potential for influx of "climate refugees" from harder-hit areas. • Impacts to tourism, recreation and business activities; potential increased visitation and travel, by residents and out-of-area visitors, due to reduction in rainy days.
Built Systems	• Difficulty meeting water demand: failing wells, drying reservoirs, lower water quality. • Less water available for hydropower or geothermal energy production such as at the Geysers. • Saltwater intrusion into southern Sonoma County groundwater aquifers as pumping increases. • Increased risk of subsidence in groundwater basins. • Shrinking of soil moisture can erode roads faster.
Natural and Working Lands	• Increased need for irrigation and water storage on farms and ranches. • Increased need for imported hay and feed. • Harm to water-dependent streams, fisheries, wetlands, springs, and the wildlife depending on them. • Death of forests and other natural vegetation, permanent shifts in vegetation type.

Historic and projected trends

The future will be effectively drier, even if total rainfall during the year increases, because warmer weather causes soils and plants to dry out.

Whether the North Bay region experiences more or less rainfall over the year, our land and watersheds will be hotter and drier overall due to rising temperatures and increased evapotranspiration (the process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration from plants (Micheli et al., 2012). Climatic water deficit (CWD) is a numeric measure of drought stress which quantifies plant's need for water that exceeds moisture available in the soil. CWD is projected to increase over this century, producing 10-20% drier conditions in the summer months, leaving less water available for recharge and runoff (Ibid). Three of the four climate scenarios examined in this report indicate rising CWD for the 21st century while the warm/wet scenario indicates nearly equivalent CWD to the historic period (Figure 8).

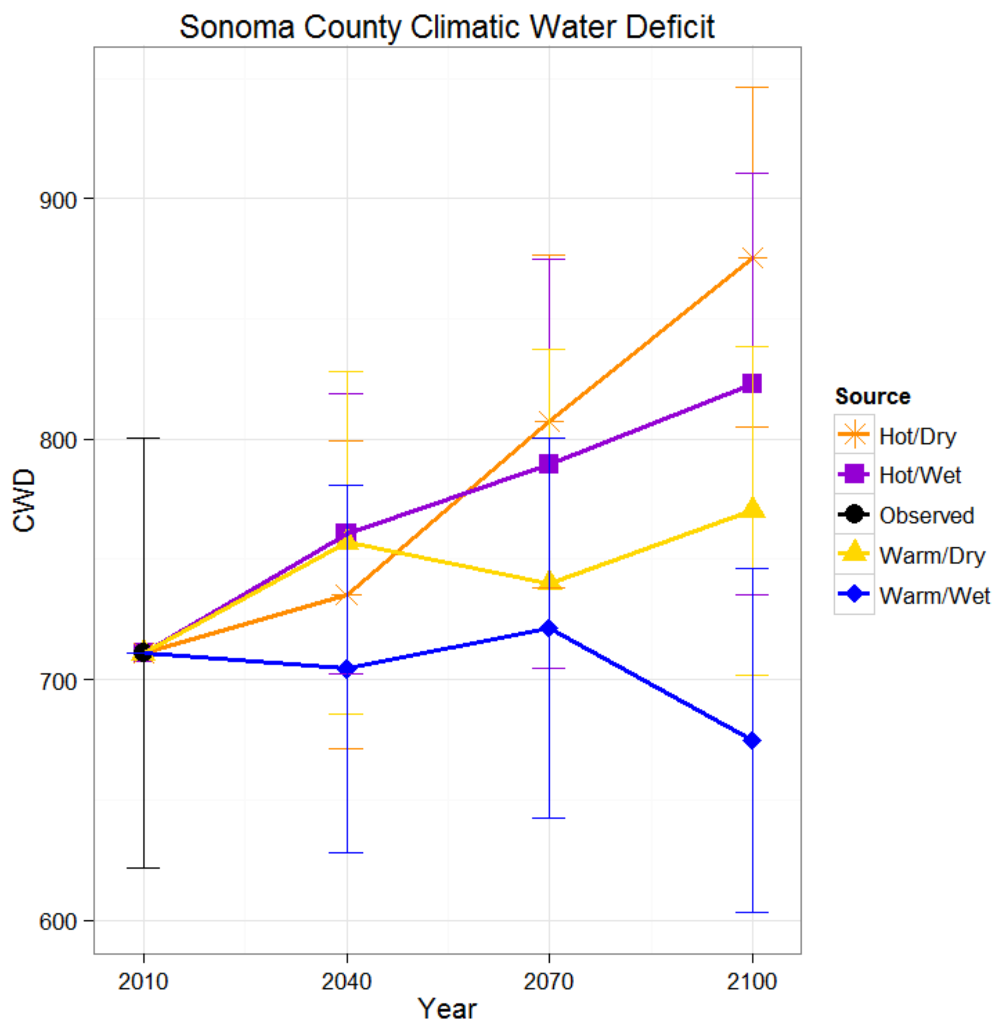


Figure 9. A graph of climatic water deficit projections from four models. The points on the graph are averages of thirty-year time periods plotted at the end of the time periods. Note the error-bars, which indicate the spread of the standard deviation, and how there is a wider possible range (more uncertainty) in the farthest future time period.

Fog from the Pacific Ocean and the San Francisco Bay is important for both moderating temperatures and providing moisture in Sonoma County, but currently the projections for future fog patterns are inconsistent, so this factor is not discussed in detail here.

Increased aridity is likely to be a driving force for changes on the landscape and for adaptive management of resources. Water resource management will face additional challenges such as increased demands with scarcer supply, more frequent fires, changes in suitable crops, change of natural vegetation and habitat, and stresses on aquatic habitat and species. The map in Figure 9 shows a geographic distribution of CWD across Sonoma County as a project change from present-day conditions. Areas with more water to lose will experience the most dramatic change from their current states; these include the coastal region and the valley floors, especially the Laguna de Santa Rosa and riparian regions.

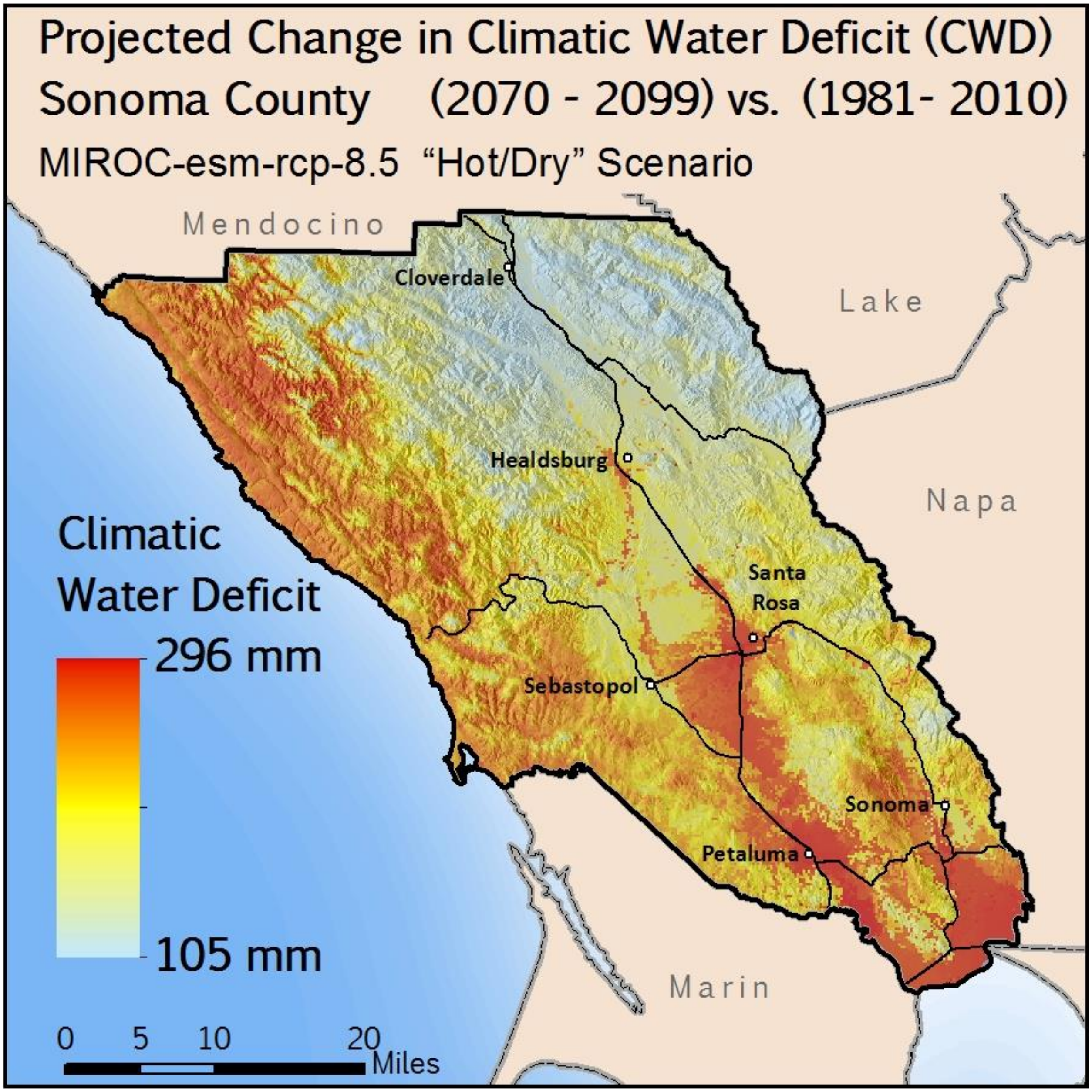


Figure 10. Projected change in Climatic Water Deficit between the averages of the thirty-year time periods 1981-2010 and 2070-2099 using the "Hot/dry" scenario, showing the geographic distribution of CWD changes. Valley bottoms and coastal regions change more because they have more moisture to lose.

Hotter, drier weather with longer summers // Greater frequency and intensity of wildfires

Wildfire is a serious threat to human safety, property, and the infrastructure systems our communities rely on, such as roads, power lines, and communications networks. The consequences of wildfire are not limited to the burning itself: during the winters after a wildfire, catastrophic landslides and flooding can occur when rain falls on the newly unprotected slopes that burned. Water quality can also be diminished by increased sedimentation and contamination. Local, state, and federal resources for preventing, fighting, and recovering from increased wildfires are stretched thin.

Summary of vulnerabilities to wildfire hazards in Sonoma County

People and Social Systems	• Health impacts from smoke. • Danger of death and loss of property, especially for isolated households and communities, and to individuals without transportation. • Greater costs for emergency services. • Displacement due to evacuation. • Loss of recreation and tourism revenue. • Impacts to surface water supply from storm water runoff in fire areas.
Built Systems	• Loss of private and public infrastructure, cost of repair and replacement, both from fire and from subsequent landslides and erosion. • Disruption to power, water, and transportation grids. • Rising insurance costs.
Natural and Working Lands	• Loss of vegetation and timber. • Subsequent landslides that remove vegetation and clog streams. • Permanent shifts in vegetation. • Expansion of invasive plant species. • Loss of grazing and rangeland, subsequent landslides, loss of farm infrastructure. • Reduction in crop value due to smoke contamination.

Historic and projected trends

Wildfire risk has already been increasing due to fuel build-up over decades of wildfire suppression and new development of buildings and infrastructure near flammable natural vegetation, especially in border areas between urban and natural lands called the "wildland-urban interface." The wildland-urban interface is an area of special concern, with a higher likelihood of fires starting and the potential for loss of lives and property.

> Most of Sonoma County is projected to have significantly more frequent wildfires.

Risk of fire is likely to rise due to increased dryness of vegetation (van Mantgem et al, 2013), compounded by productivity of plants in the spring. Other potential factors in wildfire risk are tree mortality and a potential increase in the extent of flammable invasive species. In Figures 10 and 11 below, the maps show the probability of burning one or more times in 30 years for the 1971-2000 time period compared to projected probabilities for the last 30 years of this century in Sonoma County. Percent probabilities increase in the mountainous areas of the county from 15-20% to 25-33%, a fire regime akin to that experienced today in the Santa Monica Mountains of southern California. In another study for northern California, future climate scenarios including warmer and windier conditions resulted in projected wildfire that burned more intensely and spread faster in most locations (Fried et al., 2004), although local coastal influence may dampen this effect.

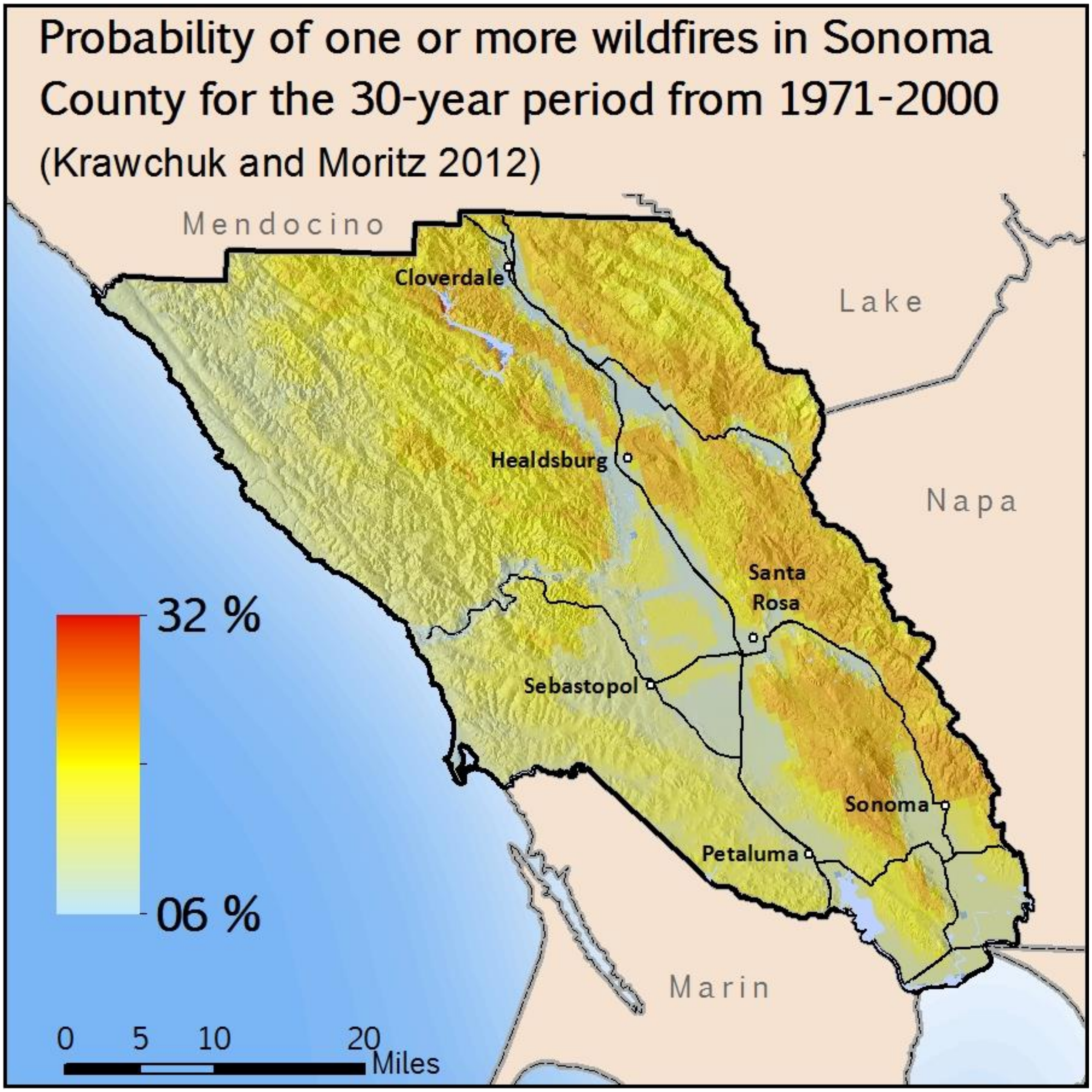


Figure 11. Historic probability of burning one or more times in 30 years for the 1971-2000 time period. Data source: Krawchuk and Moritz, 2012.

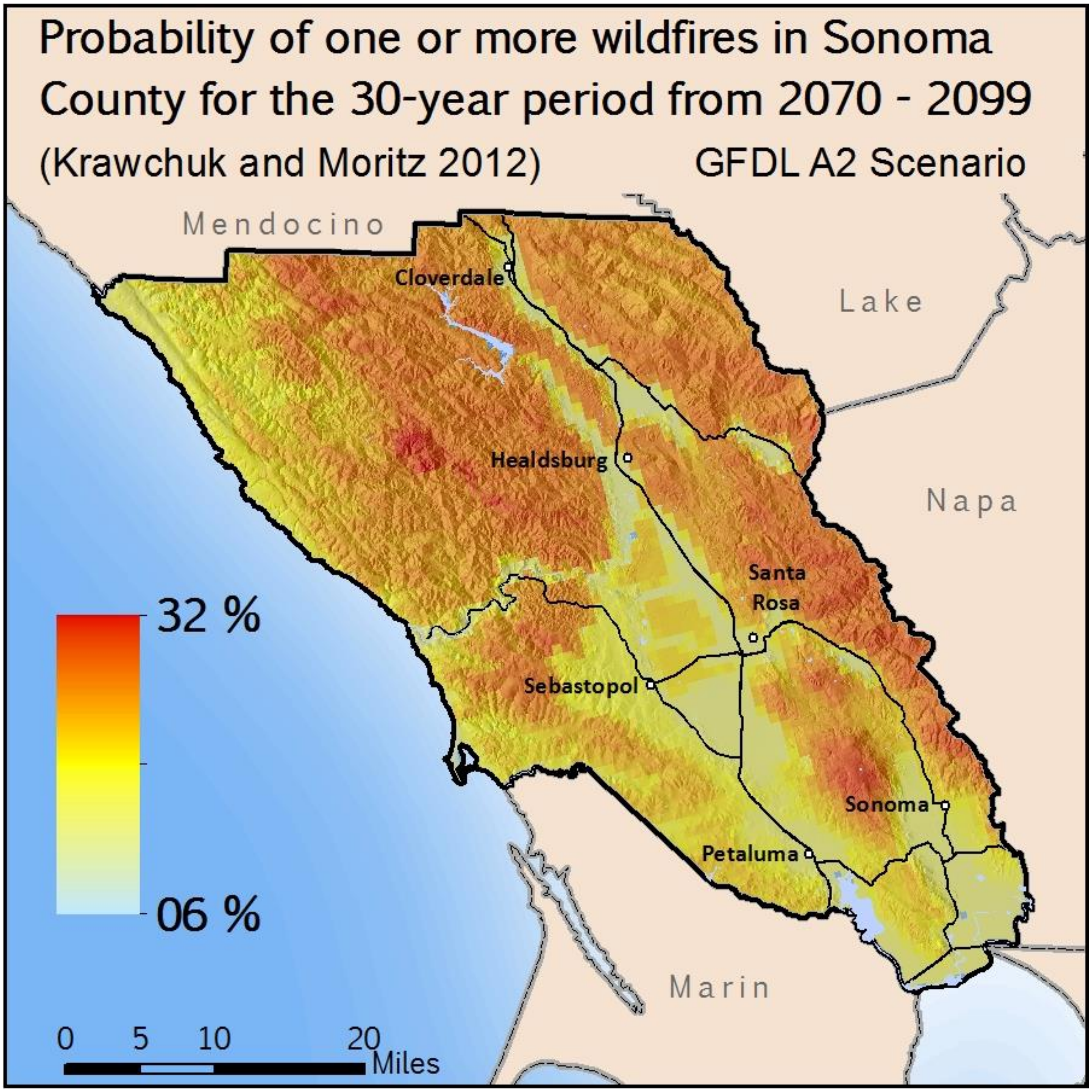


Figure 12. Projected probability of wildfire for the last 30 years of this century in Sonoma County. Data source: California Department of Forestry and Fire Protection (2014) and Krawchuk and Moritz, 2012.

Hotter, drier weather with longer summers // Fewer winter nights that freeze

Cold nights, specifically those with freezing temperatures are an essential aspect of ecologic health in Sonoma County as certain species are kept in check by freezing temperatures. Cold weather also promotes the health of certain crops, especially flowers, fruits, and nuts.

Summary of vulnerabilities to warmer winter hazards in Sonoma County

People and Social Systems	• Increases in warm-climate pathogens and disease vectors such as mosquitoes, ticks, rodents. • Potential increase in pesticide use to combat pests and disease vectors, with impacts to human health.
Built Systems	• None identified.
Natural and Working Lands	• Proliferation of insects and other organisms, including plant pests and pathogens, whose populations have previously been kept in check by freezing temperatures. • Reduced chill hours, with negative effects on yield and bloom time in specialty crops such as flowers, fruit, and nuts. • Reduced demand for frost protection.

Historic and projected trends

Figure 12 below shows that the coldest winter temperatures have substantially warmed over the last half-century, particularly in inland Santa Rosa and Sonoma Valley.

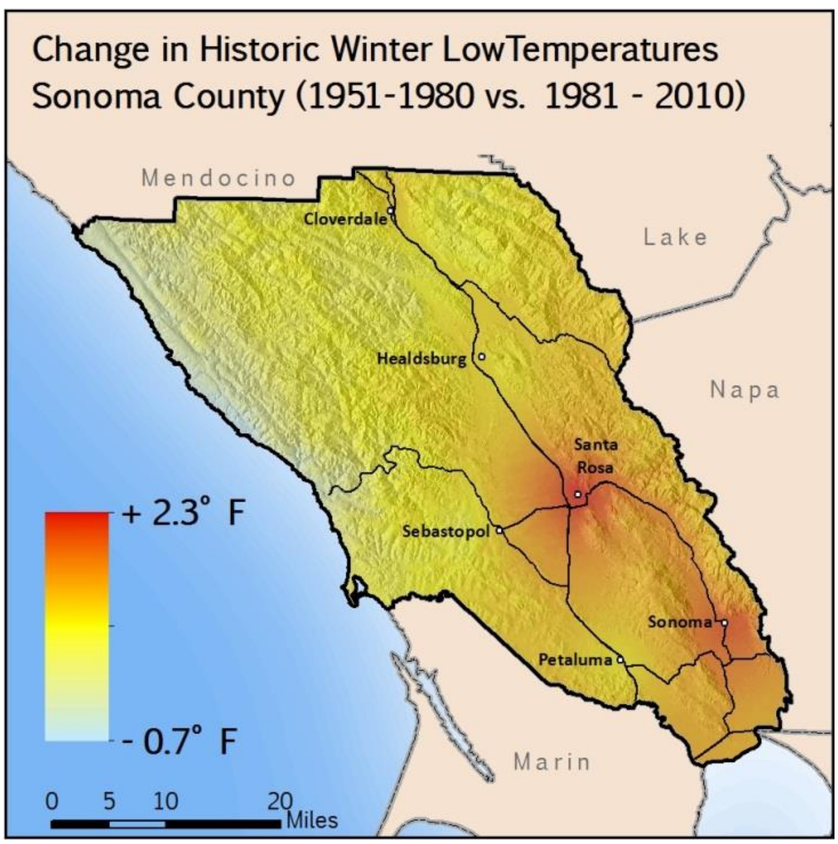


Figure 12. A Change in Historic Low Temperatures in Sonoma County over the last half century.

Overall, projected increases in winter low temperatures are greater than projected increases in summer high temperatures (see Figure 13 below). Valley bottoms are projected to warm less dramatically than the coastline, ridges, and mountain peaks.

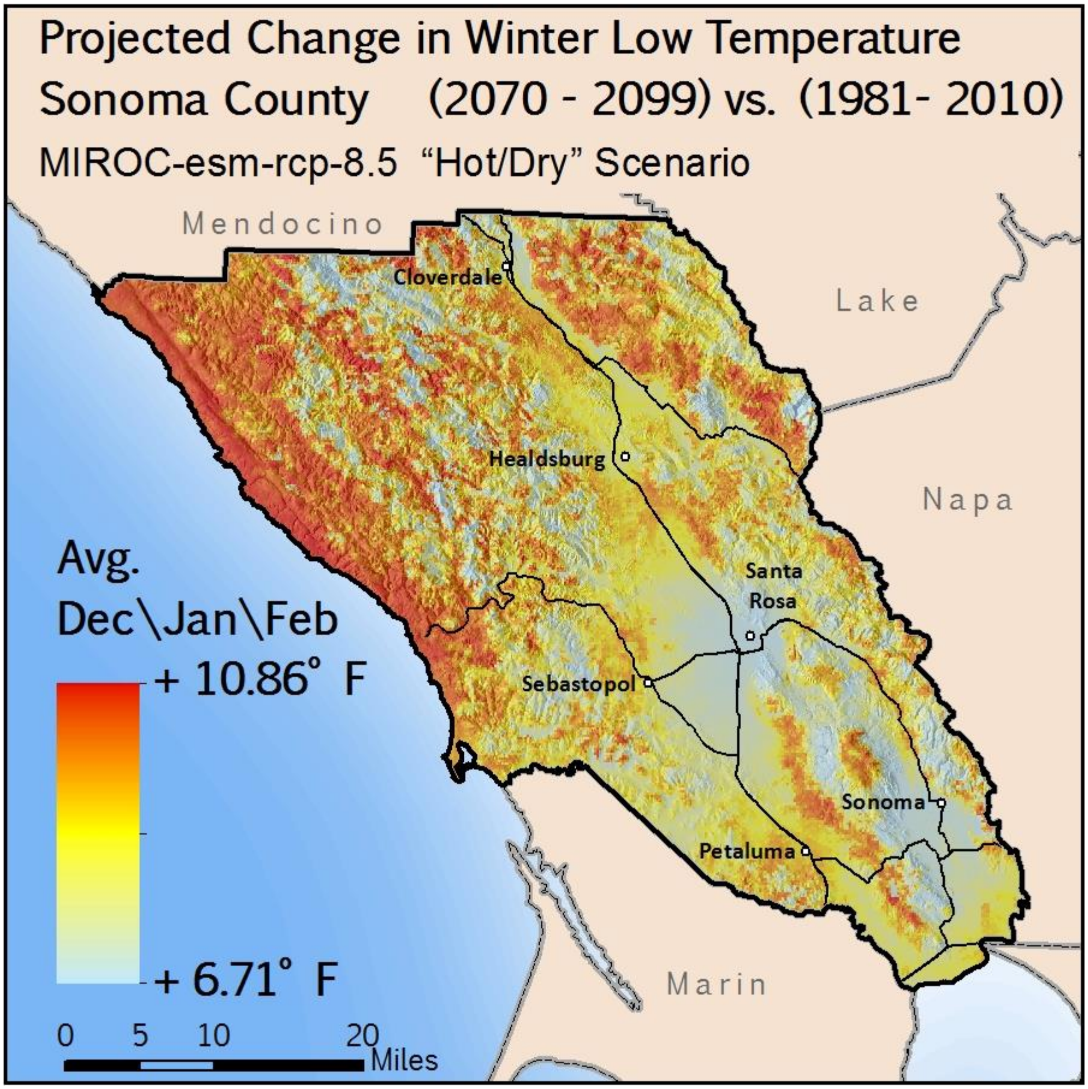


Figure 13. Projected change in average winter low temperatures: Dec-Jan-Feb minimums 1971-2000 vs. Dec-Jan-Feb minimums 2070-2099.

More variable rain // Bigger and more frequent floods

While there is a proven, direct link between growth in greenhouse gas emissions and increasing temperature, there is disagreement about whether the future will be wetter or drier overall. Some models predict less annual rainfall in our region than historic levels, while others predict more. However, in the climate future scenarios selected for this analysis, all futures include more variation in the timing and amount of precipitation occurring in individual rain events. This will exacerbate drought as discussed previously in connection to rising temperatures and extreme heat. However it will also create significant challenges for planning around water supply and flood control.

Summary of vulnerabilities to rain and flood hazards in Sonoma County

People and Social Systems	• Loss of land, housing, infrastructure, and life, particularly in low-lying communities along streams and estuaries. • Water quality problems in surface and drinking water as a result of contamination by floodwaters. • Economic losses due to recovery from a flood event. • Challenges in planning for reservoir operations. • Higher costs of water and food due to reduced water supply and drought.
Built Systems	• Disruption to energy, communications, water, and transportation systems during severe storms or floods. • Loss of critical public and private infrastructure, which can limit access to work, business, schools, and recreation. • Difficulty capturing sufficient water (in reservoirs or groundwater) during compressed rainy season to supply extended dry season.
Natural and Working Lands	• Increased erosion and sedimentation, and loss of habitat complexity, in streams. • Loss of prime recreational land along streams and shorelines, including beaches and campgrounds near the Russian River and in Sonoma Coast State Park.

Historic and projected trends

Historically, Sonoma County averaged 6.2 inches of rain in the December, the rainiest month of the year. Annual average rainfall has been approximately 44 inches, rainier than the California and the national averages, which have been 23 and 39 inches respectively.) Rainfall varies considerably across the County, with higher rainfall totals in the north and on the coast, and lower totals near San Francisco Bay and further inland.

Sonoma County's wintertime precipitation comes mainly in storms from the Pacific Ocean brought on atmospheric rivers. Between 1948 and 2011, 87% of floods on the Russian River were due to atmospheric rivers (Dettinger et al., 2011). The amount and intensity of precipitation depends greatly on whether these atmospheric rivers make landfall in California, or hit farther north of our region, a phenomenon that is difficult to predict and model. The Center for Western Climate Extremes is working in collaboration with the Sonoma County Water Agency to assess whether future climate conditions are conducive for increased atmospheric rivers.

Models disagree about whether Sonoma County will be faced with consistently more or less precipitation as a result of climate change. Depending on which climate model is selected, more or less rainfall may be projected. The climate models analyzed in this study represent a range of precipitation scenarios, with the wettest scenario projecting almost a 25% increase in precipitation compared to historical (20th century) conditions while the driest scenario projects an approximately 20% decrease. All of the scenarios indicate that we will continue to have some years with precipitation similar to historic averages as the error bars for all scenarios in Figure 14 overlap with the 0% change axis. However, the warm/wet scenario projects some years with an almost 75% increase in mean annual precipitation while the dry scenarios project years with decreases between 25 – 50% of historical averages.

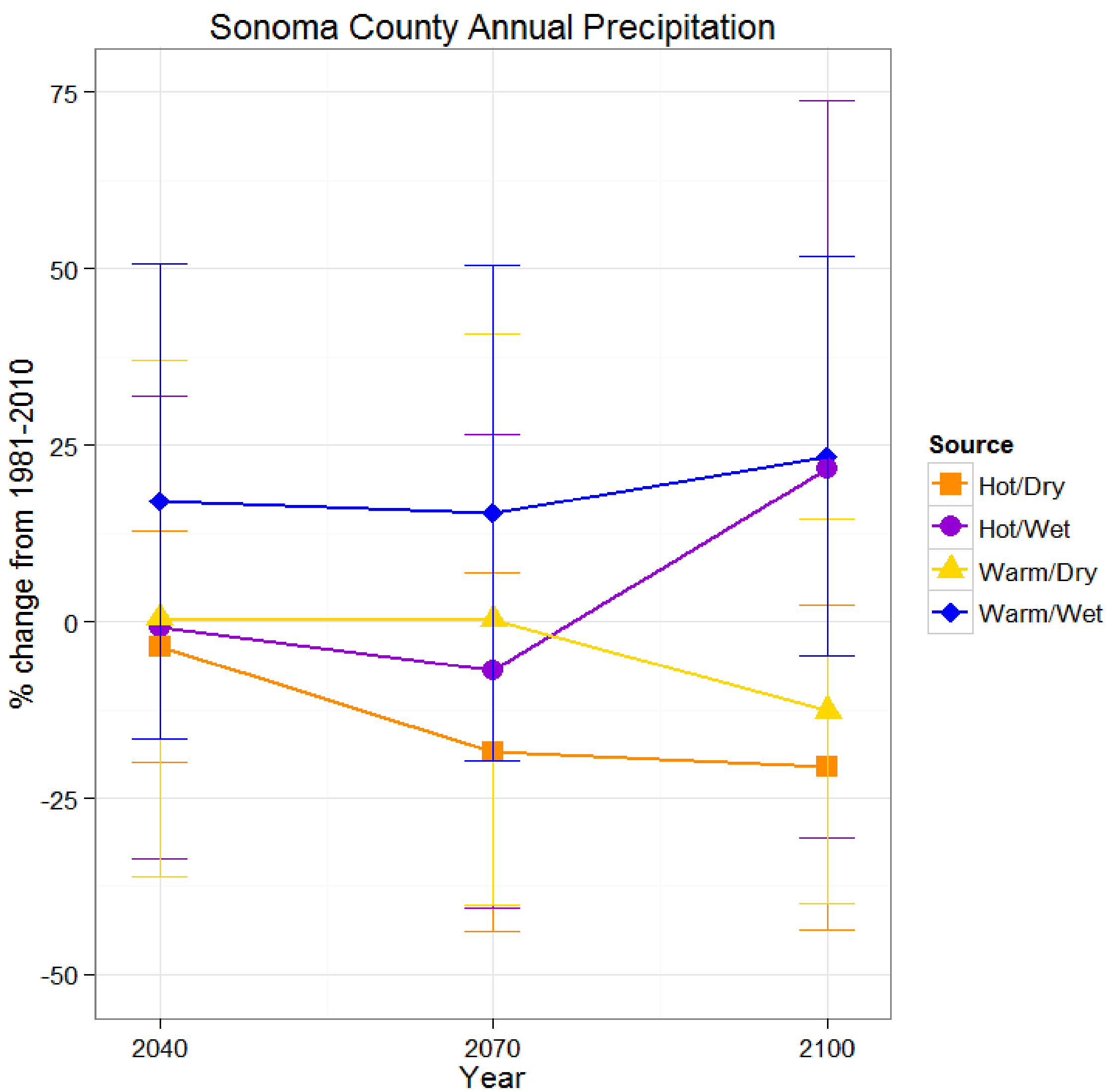


Figure 14. Graph of annual precipitation projected under four representative climate futures.

Under climatic change projections for California, the average intensity of atmospheric river and therefore storm events does not increase, but there may be more years with more frequent storm events and occasional events that are much stronger than historical ones. Moreover, the length of the season over which storm events may occur is predicted to increase. These changes to the patterns of storm events may result in more frequent and more severe floods in California (Dettinger et al., 2011).

The Basin Characterization Model also projects increased seasonal variability of precipitation, runoff, and stream flows for Sonoma County, with increased likelihood of previously rare or unprecedented precipitation and drought events (Flint et al., 2013). Figure 15 below shows a result from the Basin Characterization Model using the hot/dry scenario, indicating that variability can be expected across the geographic area. Areas in red are projected to experience a larger change from average precipitation in recent years.

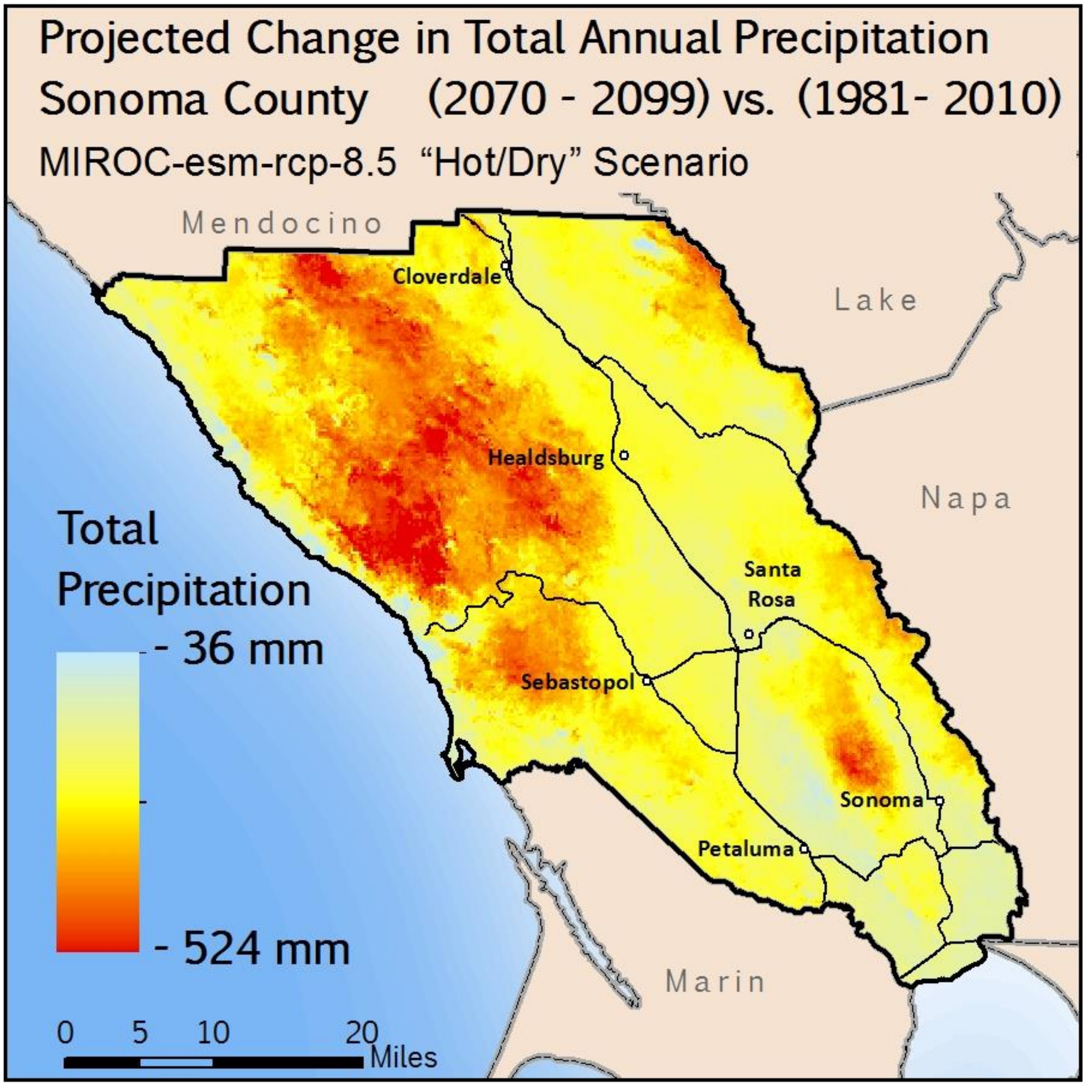


Figure 15. Map showing projected change in total annual precipitation between the 1981-2010 and 2070-2099 time periods.

More erratic rainfall, with unusual amounts of rain occurring at unusual times, is a recipe for increased drought, with longer periods of time when soils are drier. Reservoirs, such as those on the Russian River that are critical to urban water supply, depend on runoff from saturated soils over a large watershed area. If rain is more sporadic, soils are more rarely saturated to the point that they produce runoff.

Currently available models cannot predict flood risks with precision, because flood risk is a function of not only total runoff but the intensity of runoff, sometimes at the time-scale of hours. Storm intensity is typically measured as inches per hour, but the models reported on here can only produce monthly projections. To better assess potential flood impacts, these models are currently being further calibrated to estimate daily or hourly conditions. However, for now, it's feasible to draw some conclusions based on the fact that peak runoff months correlate to peak flood events. This concept was tested in the Napa River basin and found that maximum monthly runoff estimates were correlated with peak flood events approximately 60% of the time (Micheli et al., 2012). The monthly projections reported here show that rain will be more concentrated in the mid-winter months, rather than distributed evenly over the wet season. This indicates that it is likely that there will be increased flood frequency, particularly under the wetter climate scenarios.

Higher sea level and storm surge

Sea levels are rising as a result of melting ice and the expansion of water driven by warmer temperatures. Coastlines and low lying areas have already seen sea level rise in the 20th century and the rate of change is projected to accelerate. Inundation, increased erosion, and saltwater intrusion will become increasing problems for coastal areas. Increasingly severe and frequent storms will also exacerbate the effects of rising seas.

Summary of vulnerabilities to sea level rise hazards in Sonoma County

People and Social Systems	• Physical danger to people living in formerly tidal portions of southern Sonoma County, along the Petaluma and Russian Rivers, and low-lying areas along the coast such as Bodega Bay. • Difficulty providing emergency and recovery services to low-lying communities. • Impacts to drinking water from salt water intrusion. • Losses to fishing, recreational, and other commercial activity dependent on bay or ocean.
Built Systems	• Flooding and infrastructure damage farther upstream from stream mouths and bays: Sonoma Creek, Tolay Creek, Petaluma River, Russian River, Bodega Bay. • Increased likelihood of breaching levees such as those protecting Highway 37. • Disruption to communications, transportation, water, and energy systems.
Natural and Working Lands	• Loss of biodiverse transitional habitats such as marshes and mudflats, due to rising waters, that currently buffer against storm surge. • Loss of prime recreational and natural areas, including erosion of beaches, dunes, and cliffs. • Risk of levee breaches and inundation of agricultural lands in formerly tidal areas in southern Sonoma County. • Risk of crop loss. • Salt water intrusion into freshwater ecosystems.

Historic and projected trends

Areas to the south of Petaluma and Sonoma that were historically tidal, and low-lying areas along the Sonoma coast, are increasingly at risk of flooding.

There is a scientific consensus that global sea level will rise in response to climate change. The two major contributors to sea level rise are the expansion of water and the melting of land ice both due to increasing global temperatures. However, there is considerable uncertainty about the level or rate of change in sea level that will occur during the 21st century on the California Coast and San Francisco Bay. Some of this uncertainty comes from a lack of scientific understanding of the physical processes that lead to melting land ice at a global level, uncertainty about rates of change in the elevation of coastal land due to tectonic forces, and uncertainty about the occurrence of soil subsidence (when excessive groundwater pumping causes the ground level to sink downward). Additionally, rates of sea level rise will depend on future levels of GHG emissions, which are not known.

Low lying coastal communities will be extremely vulnerable to increasing rates of sea level rise. Globally, a recent study estimates that the current losses to flooding in coastal communities (approximately $6 billion annually) could increase to $1 trillion per year without the implementation of appropriate adaptation measures (Hallegatte et al., 2013). Human infrastructure will be vulnerable to periodic flooding and increased erosion with increasing sea level (National Research Council, 2012).

From 1900 -2008, sea level has been rising by 0.08 inches per year in San Francisco Bay, based on tidal gage observations (National Research Council, 2012). Sea levels are projected to rise 16.5 – 65.8 inches by 2100. Rising sea levels, combined with increased storm surge, will lead to more frequent inundation of low-lying areas, flooding homes, infrastructure, and natural areas on the shores of San Pablo Bay and the ocean coast, with the greatest impact anticipated during winter storms.

Floods will be worse in areas where streams and rivers meet the bay or the ocean. Areas of Sonoma County that were tidal before the extensive diking and leveeing of the 1800s—the southern ends of the Petaluma and Sonoma Valleys—are the most susceptible to flooding under low to moderate future projections of sea level rise, particularly in areas there the land has subsided due to soil compaction or groundwater withdrawal. Major roads define the former high tide extent: Highway 101, Lakeville Highway (US 116), and Carneros Highway (US 121). Large areas in the south part of the County are currently kept from the tide by older, privately maintained levees that do not meet current construction standards, and privately maintained pumps. The pattern of change in the bay shoreline is not predictable, because it depends on where and when particular levees break.

Several recent efforts have developed models of flood extents for Sonoma County coastal areas (Knowles, 2010). However, these models all are somewhat simplistic and do not include important physical processes such as vertical land movement caused by tectonics or subsidence (NRC, 2012), storm surges, or changes in the elevations of coastal baylands as marshes and mudflats build or subside (Strahlberg et al. 2011). The Our Coast Our Future project (2013) has recently made models including these factors available for viewing. Figures 16 and 17 show flood risks using the Our Coast Our Future viewer, using a consistent degree of sea level rise and storm frequency.

The Our Coast Our Future online viewer at http://data.prbo.org/apps/ocof/ allows a user to set their own degree of sea level rise, storm frequency, wave height, and other factors, and see the resulting flood impacts.

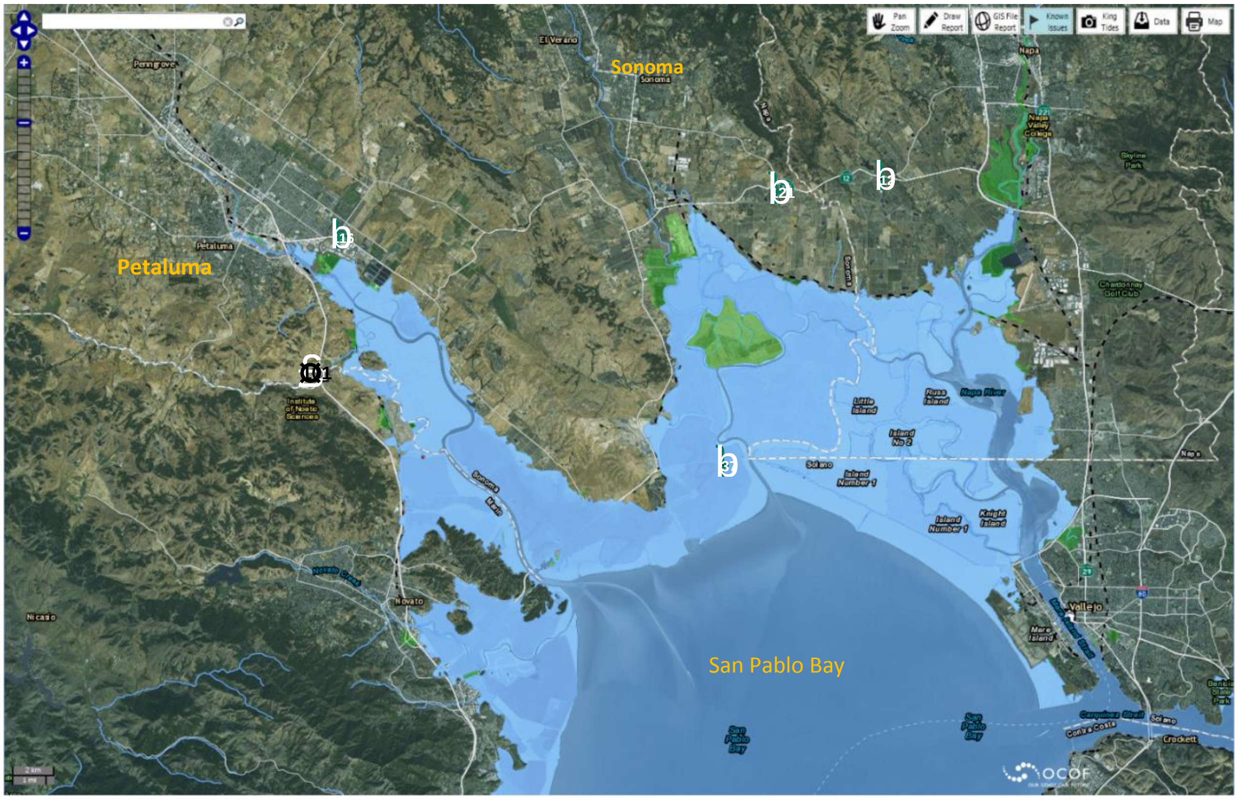


Figure 16. Areas at risk of flooding (light blue) with 39 inches (100 cm) of sea-level rise and a 20 year storm, near the cities of Petaluma and Sonoma. Darker blue is the current extent of the bay. Bright green areas are low enough to flood, but are protected by features such as levees or berms. Source: Our Coast Our Future (2014).

Sonoma's coastal communities will face a number of public safety hazards associated with rising sea levels. These include flooding, with bigger waves, storm surges, and wave run-up. Erosion—already threatening coastal infrastructure—will be exacerbated. Saltwater may intrude into wells along the coast. It also may intrude on the bay side of the county, even significantly inland from San Pablo Bay.

Flood risks associated with sea level rise can be estimated by projecting the coincidence of peak flood events, high tides, and storm surge. One study estimates that by the end of the century, what was considered a 100-year storm event in 2000 may become an annual event, in terms of water surface elevations (Bromirski et al, 2012). With rising sea levels and an increase in storms come significant risks to homes and public facilities, as well as loss of coastal habitat.

The County's Permit Resource and Management Department is in the process of updating the Local Coastal Plan, a document that guides future development in Coastal Sonoma County in accordance with community values. The update will include a discussion of how sea level rise and heightened storm surge will impact coastal communities, and start a dialogue about how to prepare.

Figure 17. Areas at risk of flooding (light blue) near Bodega Bay with 39 inches (100 cm) of sea-level rise and a 20 year storm. Darker blue is the current extent of the ocean. Bright green areas are low enough to flood, but are cut off from inundation by features such as levees or road berms. The light green dots show extent of waves during a 20 year storm; note that waves are projected to pass over Doran Beach and into Bodega Harbor. Source: Our Coast Our Future (2014).

4. Climate Vulnerabilities in Sonoma County

This section explores the key vulnerabilities of each community resource to climate hazards. The high quality of life in Sonoma County relies on maintaining three primary categories of community resources:

- **People and social systems**. This community resource category includes Sonoma County's individuals, households, neighborhoods, cities, economic activities, social services, the food system, education, business, emergency services, public safety, and law enforcement.
- **Built systems**. This community resource category includes residential, commercial, and industrial buildings and facilities, and the infrastructure associated with providing water, sanitation, drainage, communications, transportation, and energy.
- **Natural and working lands**. This community resource category includes Sonoma County's public and private natural areas and open space, wildlife, the network of streams and wetlands, sensitive and protected species and habitats, farms, ranches, and timberlands.

At the beginning of each community resource section, there is a table that cross references the known hazards that are introduced in the previous Chapter 3 on Climate Hazards. There will be some repetition between Chapter 3 and Chapter 4, which is intentional, as much of this information is interrelated and interdependent which makes them hard to categorize and contain within discrete silos.

Multiple aspects of climate vulnerability

Climate **vulnerability** consists of the combined effect of sensitivity, exposure, and adaptive capacity. The main goal of adaptation is to reduce vulnerability. **Exposure** is how much change a species or system is likely to experience. **Sensitivity** is a measure of whether and how much a species or system is likely to be affected by its exposure. **Adaptive capacity** is the ability to avoid, accommodate or cope with climate change impacts.

Investing in actions to reduce vulnerability before harm is done may be more cost-effective than responding after the impact. For example, it would be safer and cheaper to prevent home construction in future potential flood zones than resettling people displaced by a flood. It would also be safer and cheaper to educate people about how to keep cool in extreme heat than relying exclusively on emergency health care during a heat wave to address heat-related illness.

Sensitivity to climate impacts will vary depending on the exposure (magnitude of climate stress and location) and baseline condition of the community resource. For example, a small increase in average temperature is likely to disproportionately harm people, plants and animals not acclimatized to extreme heat, such as those on the coast. In all locations, heat will do more harm to those with compromised or fragile health.

PEOPLE AND SOCIAL SYSTEMS

Summary of climate vulnerabilities for people and social systems

Hotter, drier weather with longer summers	
More extreme heat events	• Increased heat-related illness, particularly among those inland, in poor health, working outdoors, in urban heat islands, and/or without air conditioning. • Premature death. • Added stress on emergency services and health care systems
Longer and more frequent droughts	• Higher prices for water and food. • Water shortages from reduced surface water supplies and wells drying up. • Food shortages and rising food costs. • Potential pressure on housing and social services due to climate migrants from elsewhere. • Increase in respiratory problems. • Loss of recreation or tourism revenue from water-dependent activities. • Increase in tourism revenue due to less rainy days overall.
Fewer winter nights that freeze	• Potential increase in disease vectors such as mosquitoes and rodents.
Greater frequency and intensity of wildfires	• Risk of lost connections to energy, water, and food supplies, especially for isolated populations. • Displacement and loss of homes. • Increase in insurance costs. • Injuries and death from burns and smoke inhalation. • Lung damage and exacerbation of eye and respiratory illness due to air quality. • Loss of recreation and tourism revenue in wake of major fire.
More variable rain	
Bigger, more variable floods	• Physical danger and economic impact for people living in low-lying areas along rivers and bay lands, especially those without reliable transportation. • Death from drowning and injuries from flood. • Public health risks from damage to sanitation, utility, and irrigation systems. • Limitations on access to critical services. • Economic impact to businesses in or affected by flooded areas.
Sea level rise	
Higher sea level and storm surge	• Physical danger and economic impact for people living near bay lands or the coast. • Disruption in the movement of people and goods.

People and social systems includes Sonoma County's individuals, households, neighborhoods, cities, economic activity, social services, the food system, education, business, recreation, emergency services, public safety, and law enforcement. These communities and community systems will exhibit a wide range of abilities to prepare for, respond to, and recover from climate hazards.

Existing Stressors

Sonoma County is a unique and beautiful county, with a thriving economy, rich cultural diversity, and a wealth of natural resources allowing us to boast a high quality of life for our nearly 500,000 residents. However, while we have many assets in our county, cities, and neighborhoods, we know that not all residents benefit from equal opportunities to realize their full potential. Disparities in health, education, and income levels have real individual and community impacts on long-term health and well-being. Existing disparities will also make certain populations and communities more vulnerable to climate change.

The Sonoma County Department of Health Services commissioned A Portrait of Sonoma County in 2014. Portrait looked at the status of human development throughout Sonoma County. Human development was measured across three dimensions: a long healthy life, access to knowledge, and a decent standard of living. The Portrait project reveals that there are many areas of unmet need in our county that may be exacerbated by climate change. It also explores the many social factors that determine individual and community health, and the uneven distribution of those factors throughout the County. In order to understand opportunities to build community resilience, it is important to understand how existing disparities in human development intersect geographically with climate vulnerabilities in Sonoma County.

Key Vulnerabilities

All people in Sonoma County are at risk from climate change, but some are much more vulnerable than others. Climate change will exacerbate longstanding social inequities. The social systems that help support basic needs for people—including food, water, shelter, transportation, and healthcare—are also vulnerable to breakdown from climate-related crises such as massive wildfires or floods. This disparity, sometimes called the "climate gap," affects various groups in Sonoma County and can have serious health and economic consequences. Sonoma County can be a leader in bridging these inequalities by focusing resources and attention to those most vulnerable to climate hazards. Additional efforts are needed to understand the social and cultural networks that can strengthen communities, with the goal of allowing all Sonoma County residents to live to their full potential.

> "Social vulnerability is a function of diverse demographic and socio-economic factors that influence a communities' sensitivity to climate change. Understanding vulnerability factors and the populations that exhibit these vulnerabilities is critical for crafting effective climate change adaptation policies and disaster response strategies. This is also important to achieving climate justice, which is the concept that no group of people should disproportionately bear the burden of climate impacts or the costs of mitigation and adaption." –The Pacific Institute, 2012

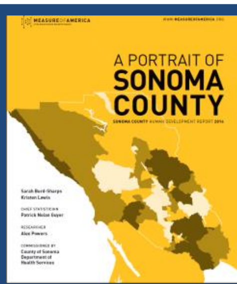
Vulnerable populations are at greater risk to climate change hazards because of poor health, living in or at risk of poverty, being very young or elderly, or lacking resources such as access to health care or emergency services. People can be at greater risk because they lack the physical, mental or financial ability to adapt to changing conditions, and therefore experience a greater burden. Vulnerable populations include the following categories (individuals may belong to more than one category):

- Children (particularly infants) and seniors
- People in poor health

- Isolated and rural populations
- People who do not receive emergency warnings or offers, because of language barriers
- People living in poverty or at high risk of falling into poverty
- Outdoor laborers
- Racial/ethnic minorities
- People without health insurance or with insufficient health insurance, or with barriers to accessing health services, such as the undocumented
- People without transportation
- People without adequate heating or cooling systems at home, or people without housing
- People who live with mental or physical disabilities
- Institutionalized populations

Children (particularly infants), seniors, and people in poor health are less able to acclimate to heat, so they are more at risk for sickness and death during heat waves. In flood conditions they may face physical barriers to evacuation and recovery from displacement (loss of health services, homes). These populations are more prone to acute and chronic illness from poor air quality.

Isolated individuals and populations are more difficult to reach with warnings of climate hazards and public health/emergency services. They may be self-isolating and resistant to being moved into centralized support facilities (may require home visits by public health workers), such as the chronically homeless. Isolated communities may depend on sources of food, water, and energy that are subject to interruption during climate-related emergency. Isolated households may not have TV, computer/internet, or newspaper subscriptions to get warnings of climate hazards and available public resources. Language abilities and citizenship status can also increase social isolation.



The Portrait of Sonoma County illustrates several examples of vulnerable populations by census tract that may be disproportionately impacted by climate change: 3 census tracts in the Russian River area, 1 census tract in Cloverdale, 1 census tract in Sonoma Valley and the 13 urban census tracts in Santa Rosa. Future exploration is needed to determine whether data found from this report can be used to identify high need areas that are more susceptible to storm events, fire, heat index and access to impacted services respectively.

People living under the poverty level or at high risk of falling into poverty may not be able to afford air conditioning or transit to cooling centers. They are more likely to be located in concrete-intensive (urban) areas that warm and retain heat faster than non-urban areas ("urban heat island"). Lower-income people may have barriers to evacuation during emergencies: they may not be willing to leave their property if it is at high risk of theft (having a higher relative cost of loss), and they may not have access to transportation. They are more likely to be homeless or lack health insurance. Outdoor or undocumented workers have greater physical exposure to high temperatures and poor air quality and/or barriers (or a perception of barriers) to using emergency or health services. Employers' compliance with public health requirements may not be enforced, and workers may have less recourse when violations result in sickness or death.

Racial or ethnic minorities may face social stigma for following public directives or calling the police or 911 in an emergency. They may not trust public authorities as a source of information. Public outreach materials may not sufficiently address cross-cultural barriers. Isolation, poverty, poor baseline health, and other constraining environmental and socio-economic factors sometimes correlated with racial/ethnic minority status may exacerbate these issues.

Additional efforts are needed to understand the social and cultural networks that can strengthen communities, with the goal of allowing all Sonoma County residents to live to their full potential.

Hotter, drier weather with longer summers

Extreme heat has always been a cause of illness and death. Health risks related to heat waves are related to many factors including existing illness, age, and acclimation to heat, housing condition, and isolation. In general, heat waves cause more fatalities among people living alone and lacking resources including air conditioning or transportation choices to get to a community cooling center. Agricultural and other outdoor workers are particularly vulnerable due to their high exposure. Heat also exacerbates air quality issues. Air pollution and allergen prevalence is likely to increase, aggravating asthma, lung disease, and allergic reactions.

Public health and safety will be threatened by longer and more severe droughts that reduce water quantity and quality. Households dependent on wells (not on piped water distribution systems) are particularly vulnerable in a drought. Water quality, availability, and cost may change, threatening water security in the county. Decreased water availability may lead to increased food prices and more frequent food shortages.

Sonoma County, as a coastal county experiencing less heat and drought than inland California, could see an influx of people leaving low lying coastal zones due to sea level rise and similarly leaving inland communities because of extreme heat and the related lack of economic opportunity in the agricultural sector.

Wildfire frequency and severity is projected to increase in Northern California as a result of climate change. Wildfire threatens public safety, infrastructure, economic activities (agricultural and otherwise), and also degrades air quality. Sensitive populations (such as the very young or elderly, or those with poor baseline health) may need to be evacuated not only from the path of a wildfire but, because of air quality concerns, from the path of its smoke. Wildfire may become a year-round hazard, a phenomenon for which emergency services are not sufficiently equipped or funded.

Warmer winters may allow pests to flourish and new pathogens to be introduced. These may include mosquitoes, ticks, rodents, and other carriers of infectious diseases. Pesticide use may increase as a result, potentially causing increased human exposure and illness.

More variable rain

Rain may be falling in a compressed rainy season with more extreme rainstorms, posing a challenge for low-lying areas, particularly coastal areas which may face both greater ocean storm surges and inland floods. People and businesses may be displaced temporarily or permanently displaced when structures are damaged in flood events.

Access to emergency services and other public safety systems may be compromised when flooding causes damages to roads and other infrastructure. Water supply and wastewater infrastructure may be compromised causing sanitation challenges. Landslides due to intense rain may increase in hilly areas, exacerbating widespread areas that are already slide-prone due to their underlying geology. Wildfires will also increase the likelihood and magnitude of landslides and erosion during intense rain.

Sea level rise

Coastal communities near the mouths of streams—Bodega Bay, for example—are increasingly at risk for flooding and landslides, as are neighborhoods along the current or historic bay shore. In Sonoma Valley and Petaluma Valley, substantial areas are protected from regular flooding only by old and inconsistently maintained private levees. Populations living in coastal areas may experience economic impacts associated with loss of land and property as levees fail or are inundated due to storm surge.

BUILT SYSTEMS

Summary of climate vulnerabilities for built systems

Hotter, drier weather with longer summers	
More extreme heat events	• Damage, buckling, warping, and disruption to paved roads, rail lines, bridges, electricity transmission lines, solar and battery facilities. • Thermal expansion of bridges. • Spikes in energy and water demand, potential stress to supplies. • Reduced outputs from thermal power plants, transformers and other parts of electric systems. • Brown and blackouts.
Longer and more frequent droughts	• Increased demand, and reduced supply, of water. Disruption of hydropower operations such as Warm Springs Dam. • Algae and bacterial growth in water supplies. • Accelerated over-pumping of groundwater aquifers, leading to failure of wells, saltwater intrusion, degraded water quality, and possibly subsidence. Increased evaporation from reservoirs. • Impacts to power generation supplies that relay on water as a cooling source.
Fewer winter nights that freeze	• None identified.
Greater frequency and intensity of wildfires	• Disruption of electricity transmission lines. • Impacts to roadways. • Subsequent landslides can close roads and bury infrastructure, including water supply wells.
More variable rain	
Bigger, more variable floods	• Less predictable reservoir operation. • Road closures, landslides, loss of infrastructure such as bridges and culverts. • Increased potholes and roadway damage from intensity of rainfall. • Failure of storm water and water treatment systems. • More difficult to plan for development or infrastructure projects or to retrofit existing infrastructure
Sea level rise	
Higher sea level and storm surge	• Roads and highways near the coast or crossing formerly tidal or estuarine areas (Highways 1, 12, 37, and 121) are more subject to closure and damage. • Increased storm damage to boats and related infrastructure. • Flooding of low-lying infrastructure such as Sonoma Valley County Sanitation District. • Saltwater intrusion and reduced water quality. • Disruption of transit routes and travel delays.

Built systems include assets in Sonoma County that are necessary for public services. This includes infrastructure such as streets, bridges, tunnels, drainage systems, parks and park facilities, water, sewer lines, pump stations and treatment plants, railroads, dams, energy and fuel systems, and lighting. This community resource category also includes buildings and other constructed urban and industrial spaces. This section does not include vegetation that is planted in the built environment (urban trees, plants, wildlife etc.); these resources are included in the Natural and Working Lands category.

Existing Stressors

Sonoma County is home to nearly 500,000 residents who live, work, and play in nine incorporated cities and large unincorporated rural areas. Sonoma County is expected to grow by over 100,000 people and over 40,000 jobs by the year 2050. We also see more than 7.5 million visitors to the area every year that enjoy our rural charm, scenic beauty and open spaces. Functioning buildings and infrastructure including transportation, utility, and sanitation systems are essential for our livelihood and economy. Significant new construction and retrofits will be needed to accommodate future growth for residents and visitors. Planning for future population and job expansion now helps to ensure that climate change impacts will be taken into account in the development of future buildings and maintenance of existing ones.

The full costs of impacts can extend beyond the economic cost of physical damage to the built structures, to include economic, social, and health costs to the people that rely on the systems to work properly. Sonoma County's health, quality of life, safety, security and economy depend on a well-functioning roadway, water supply and utility infrastructure system. Currently overall funding levels and replacement of aging infrastructure is less than is needed to keep up with maintenance. Climate impacts can increase the costs of keeping these critical elements functioning at necessary levels.

Aging Infrastructure. Some public infrastructure is currently capable of withstanding extreme weather events, yet with climate change the frequency and intensity of the events is set to increase, thus further increasing the stress on existing systems. Consecutive days of rain, high heat, winds, and storm surges are known to have impacts on infrastructure systems that are in declining condition. Many built systems and structures within Sonoma County are at risk for failure due to age and deferred maintenance. Additionally, climate change may significantly the operation of California's electric power system, on both the demand and supply sides. As temperatures rise, electricity demand will also increase to meet air conditioning and other cooling requirements for inland and northern parts of the County. Even for future climate scenarios that are wetter, increased summer temperatures will increase peak water demands thus placing a stress on water supply infrastructure to meet these higher peak demands.

Local Streets, Roads and Highways. Sonoma County has over 2,300 center line miles of city streets and county roads. In addition, we have 250 miles of state roads, including Highways 1, 12, 37, 116, and 121. Due to the age and vastness of the roadway system, rising construction costs, declining gas tax revenues and budget constraints, Sonoma County's local road network is falling into disrepair at an alarming rate. With heavier vehicles, increasing traffic and the need to accommodate alternative modes of transportation, the demands on streets and roads are growing.

According to a recent report, "California Statewide Local Streets & Roads Needs Assessment 2014", Sonoma County local streets and roads have an average pavement condition index (PCI) of 52, which is considered to be high risk. Additionally, in California the major source of funding for our state highways system is excise taxes on gasoline and diesel fuel. This funding has been declining over the years due to reduced fuel consumption among other factors. According to Caltrans 2013 Ten Year State Highway Operation and Protection Program Plan, the State focused their limited resources on the highest priority needs, which means there will be "higher incidence of drainage culvert failures … and higher incidence of emergency repair projects". Additionally, as long as the highway systems rely on gas/diesel excise tax funding, "the condition of the State Highway System will continue to deteriorate". Extreme weather events such as floods, fire, and increased temperature currently disrupt transportation network reliability, and due to climate impacts, it is projected that such disruptions will increase.

Energy. We depend on safe reliable sources of energy for our daily life and economic well being. The supply of fuels and electricity we consume in Sonoma County is vulnerable to climate change impacts associated with extreme events, sea level rise and heat waves. Many of the sources, and transmission and delivery systems of energy and electricity are currently out of our local control, yet we will be affected greatly from the climate hazards that threaten our energy and electricity systems. In the future, with the emergence of Sonoma Clean Power, the potential for locally sourced, locally controlled power is greater. Ignoring potential impacts to our energy and electricity could lead to a shortfall in the supply and reliability. Currently, as temperatures rise, more electricity is demanded for air-conditioning, especially in the northern and inland parts of the County.

Cascading impacts across sectors. Infrastructure systems are interdependent of one another, and our greatest risks occur when multiple systems fail at the same time. Nationally, real world lessons on the cascading impacts caused by extreme weather events can be learned from Superstorm Sandy and Hurricane Katrina.

Locally, an example of cascading impacts could be an extreme disruption to the electric grid that impacts the wastewater systems, and stoplight functions on local roadways, and heating for residents. Other impacts from such a crosscutting event could include disruption to our transportation and transit systems that allow us to safely travel to work, school, health services, and recreational sites.

Key Vulnerabilities

Hotter, drier weather with longer summers

It is expected that we will see hotter, drier overall weather with shorter winter and longer summers. Extreme heat can cause paved roads to soften and expand creating ruts and potholes, particularly in areas of intense traffic. Heat can also stress bridge joints. Rail lines become unsafe in extreme heat, as heat causes rails to expand and buckle (U.S. Environmental Protection Agency, 2013).

The structure of the energy transmission and distribution system makes it vulnerable to failure due to heat waves and wildfire. Temperature increases can negatively impact the operating and generation efficiency of numerous technologies including solar electricity generation. Altered wind patterns and speeds will impact the availability of wind generation potential. Heat waves lead to increased demand for cooling energy, causing higher summer peak loads, and a risk of increased brown-outs and black outs (Resources Agency, 2009). The climate in our County in the summer has historically seen warm days and cool nights. Due to climate change, longer summers will decrease the need for energy demand for heating in the winter, because overall the winter will be shorter.

Systems dependent on hydropower generation, such as the hydropower facility at Warm Springs Dam on Lake Sonoma, may be vulnerable to drought. A decrease in the amount of water available in these local bodies of water can constrain the current forms of energy production we rely on. Increased demand for water and energy during droughts and hot weather put strain on these systems.

As wildfires increase, roads and infrastructure can be damaged or closed causing disruptions to daily life. As a result of wildfires, hillsides and slopes can become more unstable and prone to landslides after a fire. This can damage roadways, transmissions lines and other infrastructure. Rural parts of the County are especially at risk, as they might not have access to other routes or amenities until the infrastructure can be repaired.

More variable rain

Intense storms may cause flooding of roadways and washout of transportation infrastructure. We are already seeing this during extreme rainstorms that last for many consecutive days, and this will be increased as the likelihood of these events increases into the future. Additionally, as rain increases in frequency for consecutive days, damage to our energy grid may occur. Damage to our key infrastructure from flooding will have impacts on people that live in rural parts of our community, as they might be isolated and without power for many days.

Sea level rise

Damage to coastal roads, highways, bridge supports, energy and fueling infrastructure within the areas at risk for sea level rise is a serious threat. There is a potential for disruption of transit routes, travel delays and goods movement that are critical to our economy.

When sea level rise is coupled with storm surge, it can temporarily close major roadways and bridges throughout the County. California Department of Transportation has already identified Highway 37 as one of the main aerial roadways in the State that is at risk of failure due to sea level rise.

Special Focus on Water Management Systems

Water is essential for essential for human consumption, energy production, industry, and recreation. The pressure on water resources in Sonoma County is projected to increase. Demand is projected to increase, while supply is likely to decrease. Population growth will lead to additional demand.

Vulnerabilities of Water Management Systems to Climate Hazards

Hotter, drier weather with longer summers

Rising temperatures will cause an increase in the demand for water, particularly for irrigation. Even in a wetter future, water demand will likely increase in wet years compared to historic conditions because of late summer drought stress on soils and reduced surface flows. Lakes, reservoirs, and holding ponds will evaporate faster from higher summer temperatures. Groundwater resources will become more important if surface water supply becomes less reliable, while climate change puts additional stresses on aquifers from reduced recharge and saline intrusion. Increased use of surface water and groundwater may contribute to saltwater intrusion, degrading groundwater quality.

The effects of drier conditions are exacerbated by regulatory requirements to protect listed fish species, especially regarding water diversion from the Russian River and other water bodies. The need to balance flood control and storage, summer irrigation, and the needs of aquatic species such as salmon and steelhead will likely become more challenging to meet.

More variable rain

The uncertain timing of rain may be a more critical factor than the amount of rainfall. If the county has a shorter, more intense rainy season, it may not be possible to capture sufficient rain for summer use. In more intense storms, more of the water runs off quickly and less infiltrates for groundwater recharge. Thus, even if the same amount of rain falls, less will be available for use.
Major storms can be highly disruptive for water systems. Water treatment facility managers will need to take into account potentially higher variability in quantities of storm water and resultant impacts on wastewater treatment facilities.

Sea level rise

Sea level rise may result in saltwater intrusion in wells near the coast and San Pablo Bay.

Secondary impacts

Other water quality risks that should be taken into account are the secondary impacts of catastrophic weather events and our responses to them, particularly droughts, floods, and wildfires. For example, well water quality can deteriorate when wells are over-pumped during drought. Erosion in an area after a wildfire can lead to sediment burying or clogging the water supply, as well as diminished water quality. There may also be secondary impacts on water treatment and supply infrastructure, when water systems may be over-taxed by the amount of sediment in the water.

NATURAL AND WORKING LANDS

Summary of climate vulnerabilities for natural and working lands

Hotter, drier weather with longer summers	
More extreme heat events	• Loss of wine grape quality. • Increased interest in vineyard development closer to the coast. • Changes in yield, types and cultivars of crops. • Increased vulnerability in wildlife and livestock to pests, stress, and mortality. • Lower production in livestock. • Reduced chill hours.
Longer and more frequent droughts	• Increased need for water on farms and ranches, and for water-dependent ecosystems. Increased off-stream storage of water for agriculture. • Shifts in natural vegetation away from forests toward grassland and shrubland. • Increased urban water use, at possible expense of agriculture water availability. • Potential loss, or dramatic shrinkage in the range, of iconic species such as coast redwood. • Shortage of feedstock or rise in cost and access • Increased evaporation from reservoirs. • Losses of wetlands, riparian forest, and other water-dependent ecosystems, and associated wildlife such as California tiger salamander. • Potential change in suitable grape varieties. • Increased tree stress and death in forests. • Mortality in protected aquatic species such as salmonids.
Fewer winter nights that freeze	• Unpredictable, potentially sudden, shifts in populations of disease, pest, or invasive species. • Earlier bud break may lead to increased use of water for frost protection.
Greater frequency and intensity of wildfires	• Loss of habitat. • Death of wildlife. • Loss of recreational lands and commercial forests. • Erosion and landslides after fires, destroying habitat and polluting streams and wetlands.
More variable rain	
Bigger, more variable floods	• Increased erosion in, and sediment pollution of, streams and wetlands, causing harm and death to aquatic and water-dependent species..
Sea level rise	
Higher sea level and storm surge	• Loss of prime recreational and natural areas, including marshes, beaches, mudflats, and dunes. Risk of levee breaches and inundation of agricultural land in formerly tidal areas in southern Sonoma County.

Natural and working lands include Sonoma County's public and private open space lands, wildlife, the network of streams and wetlands, sensitive and protected species and habitats, farms, ranches, and timberlands.

Existing Stressors

The agricultural lands of Sonoma County provide many public benefits. In addition to producing crops and livestock, agriculture lands can maintain wildlife habitats, provide scenic beauty, enhance biodiversity, provide water filtration, increase nutrient cycling and storage, recharge groundwater, enrich soils, and support pollinators. In 2013, wine grapes and livestock, particularly chickens and cows, were the largest agriculture commodities for the County. A study conducted by the County of Sonoma in 2012, estimated the economic value of working lands and natural areas in Sonoma County to be $2.2-6.8 billion per year.

Residents of Sonoma County benefit from and enjoy many aspects of Sonoma County's natural landscape and ecological systems. The natural heritage of Sonoma County includes trees, forests, vegetation, meadows, open spaces, rivers, floodplains, wetlands, fish, wildlife, birds, insects, soil and other assets. Collectively, the natural ecosystem, plants, and animals provide services that cannot be duplicated and are essential for human vitality. Conditions in natural areas control wildfire risk, water supply, scenic beauty critical to our tourism sector, pollination, and play a large role in maintaining clean air and water.

Sonoma County has high diversity both in its landscapes and species, potentially increasing the resilience of our biodiversity overall (Ackerly et al, 2010). The region also has many threatened and endangered species found nowhere else, some of which are restricted to very small areas or uncommon situations (Cornwall and Gaffney, 2010). Individual species' abilities to adapt depends on whether suitable habitat remains, whether patches of habitat are connected in ways that the particular species can navigate, the suite of competitors and predators present in potentially new combinations, and the species' tolerance of different temperatures.

Plants and animals that are already declining from other stresses like pollution, loss of streamflow, and invasive species may be more vulnerable to harm from climate change. Sonoma County has 187 special-status animals, plants, and ecological communities. This is a greater number of species of concern than listed for Marin (157 species), Napa (115), Lake (120), or Mendocino, largest of the surrounding counties, (180) (CDFW, 2014). 11 animals are federally listed as threatened or endangered and an additional four animals are state-listed as threatened or endangered. Listed animals include the California tiger salamander, California red-legged frog, tidewater goby, Central California Coast populations of steelhead and coho salmon, Chinook salmon, two species of clapper rails, the salt-marsh harvest mouse, California freshwater shrimp, and two species of silverspot butterfly. In addition, there are 26 species of plants in the County that are listed as endangered or threatened by the state or federal government. While many of these are vernal pool species, there are endangered and threatened animals and plants across the entire county.

Key factors for local climate are distance from the ocean, elevation, and the height of mountains or depth of valleys to the east and west. Because the two mountain ranges run parallel to the coast, the east-west climatic variation is generally greater than the north-south variation. The north-south gradient is influenced by the ocean and the bay, whose cool air and fog travel inland up river valleys, especially the Petaluma River and Sonoma Creek.

Fragile landscapes and water supplies and the agricultural systems that depend on them are vulnerable when they are already in a compromised state or lacking protection (for example, when an important wildlife habitat is fragmented by development, or when government agencies lack the capacity to adequately fulfill their mission to protect natural resources) and they are exposed to further stress from climate change.

Key Vulnerabilities

Hotter, drier weather with longer summers

Climate change is likely to cause changes in the physiology of plants and animals; the timing of key transitions such as flowering, migration, breeding, and birth; the location of species; how species of plants and animals interact with each other; and the frequency of disturbances such as flood, drought, and fire that can transform landscapes. Changes in the timing of plant blooming and insect lifecycles could lead to mismatches between currently linked species, such as a plant with its pollinator or a migratory animal with its food source. Whether species will adapt to these changes in timing is highly uncertain.

Increasing temperatures, overall dryness, and more frequent drought and wildfires will change Sonoma County's natural vegetation and habitats toward plant communities that can tolerate drought. Shrubby habitats such as coastal scrub and chaparral are likely to increase in area (Figure 18, Stralberg et al., 2009). It is projected that many areas now suitable for forests composed of mixed hardwood species and Douglas fir may disappear.

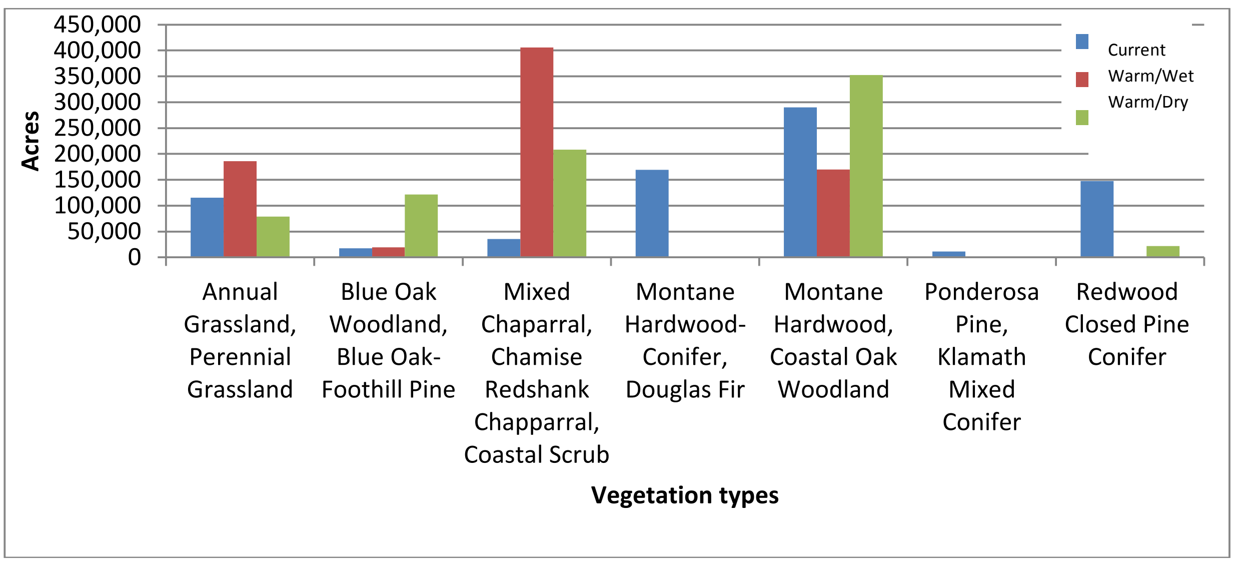


Figure 18. Comparison of the area within Sonoma County dominated by seven major vegetation types, between current conditions and two future climate models in the year 2070—CCSM (warm/wet, in red) and GFDL (warm/dry, in green).

The rainy season during which soil moisture is recharged may be compressed into a shorter time period. The spring and fall transition seasons may be shorter and warmer; spring may come earlier and fall later. The overall reduction in end-of-season soil moisture means that natural vegetation and rain-irrigated crops may be less productive, and may experience greatest growth rates during different parts of the seasons than in the past. Second-hand impacts from the reduction in plant health may occur, such as increased competition from invasive plants that adapt to the new climate faster, and related changes in soil chemistry or in fire patterns.

Because some species are more adaptable than others, we expect to see the emergence of new plant and animal communities (Stralberg et al., 2009) and new interactions between species, as has happened during historic climate change events (Williams et al., 2004). In general, the geographic range of species that rely on cool temperatures and wet soil conditions through the summer is expected to shrink. The range of coast redwoods and species that live in redwood forests, for example, will likely contract to smaller pockets that have a stable level of aridity (or *climatic water deficit*). Redwoods that currently occupy warmer sites will likely be under the most immediate stress (Flint and DiPietro, 2011). Adaptation of widespread species such as valley oak will likely vary widely across the county (Sork et al, 2010). One study found that the extent of two oak species important in Sonoma County, blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*), is projected to shrink considerably (to 59% and 54% of modern potential range sizes, respectively) and shift northward (Kueppers et al., 2005). Vernal pools and their dependent species are at risk of disappearing in areas that will be exposed to dramatic changes in their water regimes (Bauder, 2005). Steelhead spawning habitat, which relies on deep, cool pools that persist through the summer, is at risk due to rising stream temperatures, reduced groundwater, and increased pumping of stream water and near-stream groundwater (Sonoma Ecology Center, 2006; Hardiman, 2014).

Maps showing the projected future range of 79 invasive plants, based on current (2010) and future (2050) climate, as well as a list of invasive plants for the county, are available from the California Invasive Plant Council (2014). These maps can help land managers prioritize their invasive plant removal efforts.

Drought and wildfire exacerbated by changing temperature and rain patterns may pose serious economic threats to Sonoma County's agricultural and forestry. Warming temperatures pose risks to the forestry sector from invasive weeds and pests, decreased forest productivity, tree mortality, changes in the natural community structure, and changes in the timing of productivity, pollinators, chill days, harvest, and water demand. Impacts of warming temperatures on agriculture in Sonoma County include changes in crop yields, types, and cultivars, less productivity from animals, and increased mortality for animals (Resources Agency, 2009). Some crop yields may increase with climate change, while others may decrease.

Forest and rangeland may be at particular risk under future climate conditions, as wildfire acts as a catalyst for vegetation changes, possibly opening up land to invasive species. Also, tourism operations sited at the interface of wilderness and populated areas may face losses such as increased property damage from wildfire (Westerling and Bryant, 2008).

Ranching and dairy operations are affected in complex ways by climate change. There is a lack of modeling for the parameters that matter most to livestock production. It appears likely that although increased winter temperatures on their own may increase grass production, other climate changes such as more variable rainfall, a shorter season of high-quality forage, and extreme heat events are likely to reduce the quality and reliability of production, both production of forage and of meat and milk. (Chaplin-Kramer, 2012).

Aquatic species such as fish are affected by dry weather that reduces streamflows and in turn increases concentrations of pollutants (State Water Resources Control Board, 2014). Aquatic species, already under stress from current stream conditions and water diversion, will be further damaged by increased groundwater pumping and stream diversions to meet increased agricultural water demands (Hannah et al., 2013).

With increasing heat and more frequent and severe droughts, tourism and recreation related to the natural world—hiking, camping, boating, bird watching, photography, biking, fishing, horseback riding--will be affected. In particular, droughts may threaten the recreation industry dependent on the Russian River, because of unreliable stream flow.

Focus on Wine Grapes

There are almost 60,000 acres of vineyards in Sonoma County, accounting for 6% of the land area, and nearly $14 billion dollars annually (Agricultural Commissioner, 2013). The four major grape varieties grown are chardonnay, pinot noir, cabernet sauvignon, and zinfandel, which account for a combined 81% of total wine revenue. It is important to understand the hazards and threats climate change brings to our County's largest economic industry.

With warming temperatures, grapevines may flower earlier, set fruit earlier, and ripen earlier. Fruit may ripen at a warmer time of year. The temperature in the final 30 days before harvest is critical for wine quality, with some varieties losing quality above 68 °F (on average), so wine grape growers may need to substitute those varieties with more heat-tolerant types of grapes.

Average water demand, including general irrigation demand, is expected to increase in order to maintain vineyards. Water for frost protection will possibly be in greater demand due to an earlier growing season: frost would be more of a threat because of the increased likelihood of an early bud break followed by cold weather. The use of overhead sprinklers for protection against heat damage may also increase. Water storage will become more important for all these uses.

Climate change will make lands closer to the coast and higher in elevation more suitable to grow wine grapes. In the 1970s and 1980s it was not warm enough to ripen grapes along the Sonoma Coast, but the growing region has now expanded toward the coast: there are now coastal areas where it is possible to ripen Pinot Noir grapes. This new possible use for coastal land will mean that native vegetation and historical crops might be replaced by wine grapes (Weiss, personal communication, 2013; Hannah et al., 2013). Grasslands, which are the easiest to convert to new uses, will be the most likely to be converted to vineyards.

Production of wine grapes is expected to benefit overall from a warmer climate, in the short term, because of a longer growing season. However, in the long term, temperatures could increase to a point that is unfavorable to certain grape varies that are commonly grown in Sonoma County today, and to the more inland growing locations. Large areas in Oregon, Washington, Idaho, and British Columbia appear suitable for winegrapes by 2050, which will increase competition for Sonoma County wines (Hannah et al., 2013).

More Variable Rain

Depending on the direction of change in rainfall (in terms of frequency, timing, and intensity), wetter, warmer spring weather could introduce new pests and other vectors for disease that threaten the agricultural sector. It could also facilitate the growth in the range of existing pests, weeds, and diseases, causing loss of crop quality and increased crop and animal vulnerability to pests and disease (Resources Agency, 2009).

Fish, and other wildlife that rely on streams for habitat or food, are vulnerable to increased seasonal erosion from the projected shorter, more intense rainy seasons, exacerbating existing sediment problems in the Russian and Petaluma Rivers and Sonoma Creek (State Water Resources Control Board, 2014).

Rising Sea Levels

Coastal agricultural enterprises face the threat of saltwater intrusion into their groundwater resources, and low-lying working lands might also be degraded by saltwater (Resources Agency, 2009). Aquacultural enterprises like oyster and other shellfish businesses face the threat of ocean acidification, which may slow shellfish growth and degrade the shell quality (Kelly and Caldwell, 2012). Acidification is likely to stress an ocean ecosystem already stressed by overfishing, habitat destruction, and warming temperatures (Resources Agency, 2009).

Sea level rise poses threats to popular recreation sites on the Sonoma Coast. Increased wave run-up and storm surge could make beaches more hazardous, and contribute to the speed of erosion on beaches, cliffs, dunes, and important coastal infrastructure. Erosion and sea level rise could make some beaches inaccessible. It may become much more costly to maintain beach recreation areas.

Other vulnerability considerations

Changes in other parts of the country and around the world could also affect Sonoma County, such as the failure of some crops because of drought and the need to import more products from abroad. Supply chains are affected in the case of extreme weather events in other places, leading to economic slowdowns far from the site of the original impact.

Increased pressure on water supplies could come from many non-climatic trends, including economic incentives to cultivate water-intensive crops, such as marijuana. Should California follow Colorado's lead on legalizing and regulating the commercial cultivation of marijuana, federal water projects could not supply water to these farms, so they might be concentrated in coastal watersheds such as the Russian River.

This report primarily discusses the primary or direct hazards of climate change on Sonoma County, with some discussion of secondary or indirect effects. More work, such as scenario planning and cross-disciplinary discussion, is needed to foresee and prepare for potentially serious higher-order climate impacts. These impacts, also called cascading or follow-on impacts, are difficult to project. They require experienced experts to mentally construct novel, yet plausible, sets of future conditions for Sonoma County and then speculate about dynamics that could develop in those futures. Examples of possible cascading climate impacts are the potential impact of marijuana production on water supply discussed in the previous paragraph; the release of new wine-grape pest insects by reduced freezing nights; the interaction of water scarcity, rising irrigation demand, and new state groundwater legislation on winegrape production; or the possibility of simultaneous or record-breaking disasters that over-tax emergency resources or result in permanent changes in population distribution or loss of habitable areas.

Some regions of California and the United States will experience more severe impacts than Sonoma County. As a region facing less extreme climate hazards than areas further south and further from the ocean, Sonoma County may become a destination for people fleeing climate-related crises elsewhere, such as agricultural job losses or extreme heat. "**Climate refugees**" are people that are displaced by climatically induced by climate hazards. A rapid influx of population growth due to climate refugees could burden and strain our infrastructure, social services and emergency systems in ways that exacerbate local problems. We may also see a trend of people moving from more isolated rural areas into urbanized areas, possibly outside Sonoma County, where services are more secure. We have an opportunity to plan for the possibility of additional growth to our communities in a positive manner.

5. Responding to Climate Change Vulnerabilities in Sonoma County

What are we already doing?

The vulnerabilities outlined in the previous section are large and cross cutting. Fortunately many entities in Sonoma County have already begun implementing a number of strategies and planning processes that increase our resilience and readiness for climate change. In fact, the volume of existing efforts with a climate readiness benefit is too large to capture here, but a sample of critical activities underway are summarized in Table 3. This document is the first attempt to provide an overview of all climate hazards and vulnerabilities in Sonoma County that can inform both existing and future efforts to prepare for climate change.

What more can we do?

Existing efforts to prepare for climate changes should be integrated, expanded, and evaluated to explore how well they are serving to increase our readiness for climate trends and future projections. On an ongoing basis, specific climate readiness strategies should be more explicitly integrated into existing plans and projects that are already used to promote public health, safety, and prosperity in Sonoma County, such as the following:

- Hazard mitigation plans
- General Plans, particularly as they relate to locations vulnerable to flood, landslide, and wave hazards, or locations important for water supply, groundwater recharge, wave and flood attenuation
- Parks, trails and open space plans
- Water supply, storm water, and flood management plans and ordinances
- Environmental impact reports
- Capital improvement plans
- Transportation plans
- Public health monitoring
- Emergency preparedness plan
- Street tree and water- efficiency ordinances
- Zoning, building and fire codes
- Groundwater management plans
- Local Coastal Plans
- Administrative policies, procedures, and initiatives

The RCPA will be working with local leaders responsible for the planning activities list above – elected officials, local government staff, and members of the community – to respond to the findings of this vulnerability assessment. A critical near term opportunity is for the RCPA to support staff and decision makers in accessing and understanding the data products behind this assessment in order to incorporate climate futures into planning efforts to enhance resilience.

Table 3: Sample of existing efforts in Sonoma County that increase community resilience to climate change

Public Health and Social Vulnerability	
Hazard Mitigation Planning	Every five years the County updates a Hazard Mitigation Plan that seeks to reduce death, injuries, property loss, and community disruption caused by natural hazards by analyzing those hazards to which the County is most vulnerable, identifying tools to reduce the adverse effects of those hazards, and developing an implementation plan. Climate change is exacerbating hazards that we already prepare for through the HMP process.
Health Action Council	The County created a council charged with creating a healthier Sonoma County, such that all residents can achieve their full potential. Pursuit of Health Action goals across educational attainment, primary care, and economic security will increase the adaptation capacity of the Sonoma County communities that are most vulnerable to climate change.
Energy	
Energy Independence	Developing and implementing a countywide renewable and retrofit program that provides incentives, financing, tools, technical assistance, and contractor certifications to support the retrofit of residential and commercial properties. Lowering energy use and increasing on-site generation has many benefits including lowering GHG emissions, lowering energy demand and energy costs, and increasing energy independence with the potential to minimize the health and economic impacts of future outages.
Sonoma Clean Power	Sonoma County and several jurisdictions have created a community choice program that will allow for more local control in advancing lower emission, lower cost, and more distributed power supplies.
Water	
Integrated Water Resource Planning	The Water Agency's Water Supply Strategies Action Plan is a framework for regional integrated water management that is developed to increase water supply system reliability, resiliency, and efficiency, in the face of limited resources, regulatory constraints, and climate change. The plan adopted in 2011 included nine key strategies, one of which is to develop an adaptation plan.
Groundwater Management	Three groundwater management programs, led by The Water Agency, have engaged the public, collected substantial new data on groundwater conditions, developed groundwater models and management plans, and set management objectives that will improve the ability of groundwater-dependent communities, agricultural and commercial operations, rural residents, and ecosystems to function during drought periods.
End-use Water Efficiency	Municipal water and sanitation utilities throughout the county have established programs such as Direct Retrofit Installation Programs, Cash for Grass, Laundry to Landscape, Pay As You Save, Mulch Madness, and others to support property owners in reducing water use while investing in upgrades to their properties.
Food	
Sonoma County Healthy and Sustainable Food Action Plan	The County Department of Health Services has partnered with the Food System Alliance to develop a guide to local action on food production, land and natural resource stewardship, job development, public health, and equity in our food system. It specifically encourages practices to support the agricultural sector's ability to adapt to climate change, but overall emphasizes the health, sustainability, and equity of the food system that will enhance our overall community resilience to climate change.
Transportation	
Comprehensive Transportation Planning and Investment	Many projects to modernize our transportation system and increase the viability of multiple mobility options are underway. The SMART passenger rail will begin operations in 2016 and provide an attractive transit alternative. Countywide Bicycle and Pedestrian Master Plan implementation and Safe Routes to Schools projects are supporting expanded use of lower cost, reliable, and active transportation.
Highway 37 Sea Level Rise planning	Due to its proximity to San Pablo and San Francisco Bays the Hwy 37 corridor is at severe risk from sea level rise and storm surge. Local, regional and state partners are working to address infrastructure vulnerability while incorporating habitat enhancements that promote resilience to flooding and storm surge.
Natural and Working Lands	
Climate Action through Conservation	The Sonoma County Agricultural Preservation and Open Space District was created in 1990 to protect working farms and ranches, scenic hillsides, and natural areas that make our county special. The District has preserved over 100,000 acres to date, and is working on innovative approaches to incorporate the GHG mitigation and sequestration impacts of various land use choices, as well as to evaluate the ecosystem services provide by various landscapes that are becoming increasingly important under future climate projections.

The pervasive nature of vulnerabilities in Sonoma County means that actors across both the public and private sector have a role to play in enhancing local resilience. The RCPA will continue to advance a regional, countywide approach to adaptation planning via the Climate Action 2020 project. The RCPA will also support member jurisdictions and partners in conducting adaptation planning processes of their own. The North Bay Climate Adaptation initiative offered the enhanced adaptation planning process outlined in

Figure 19 for individual actors to consider as they begin to address climate change in their planning.

Climate Readiness Planning Process

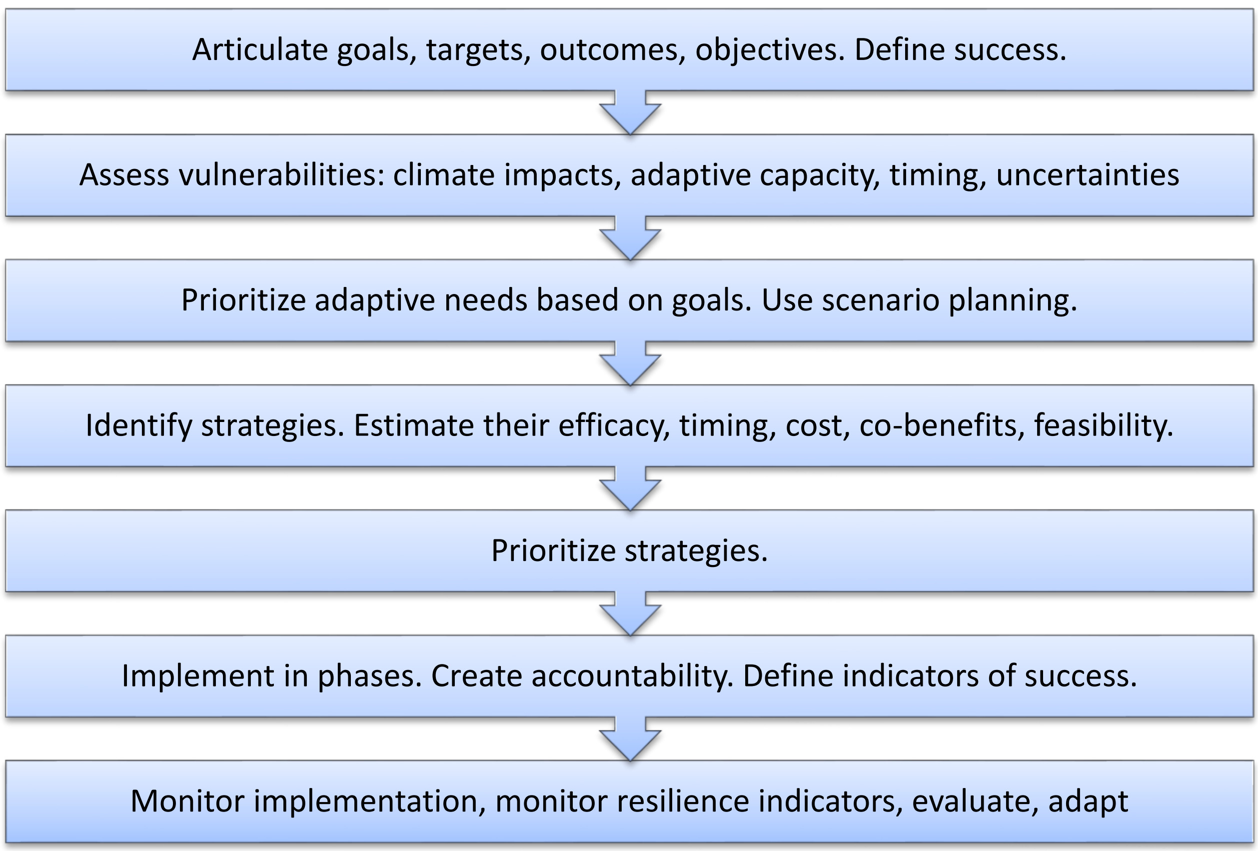


Figure 19 Enhanced Climate Readiness Planning Steps Proposed by NBCAI

Lastly, in order to succeed it is clear that we must act together in an integrated way. "Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales, and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives (IPCC, 5th Assessment Report, Summary for Policy Makers)." The RCPA will continue to provide for coordination across entities in Sonoma County working to build more resilient communities and to support the deployment of multi-benefit strategies.

Appendix

A. Glossary

Anthropogenic: Caused or influenced by humans. Anthropogenic carbon dioxide is the portion of carbon dioxide in the atmosphere that is produced directly by human activities, such as the burning of fossil fuels, rather than by such processes as respiration and decay.

Climate: The averages and patterns of variation and interaction in temperature, humidity, atmospheric pressure, wind, precipitation, and other meteorological variables over the long term (e.g., 30 years or longer).

Climate adaptation: Preparing for the effects of climate change. Generally redundant with climate readiness or climate preparedness.

Climate mitigation: Reducing the causes of climate change, usually by reducing emissions of carbon dioxide or other greenhouse gases, or sequestering carbon.

Climate model: A simulation of climate using quantitative methods. A global circulation model (GCM) is a physics-based estimation of potential interactions between atmosphere, oceans, land surface, and ice at a coarse scale. Downscaling: a method by which statistical or dynamic models are used to bring the projections of GCMs down to a finer scale in order to get a sense of the future climate for a local region.

Climate refugee: A person displaced by sudden or gradual changes in their environment as a result of climate change. A climate refugee may move voluntarily or involuntarily, within or across geographic boundaries.

Climatic water deficit (CWD): The amount of water by which potential evapotranspiration exceeds actual evapotranspiration (e.g., the amount of additional water that would have evaporated/transpired if it had been present in the soil), an estimate of drought stress on soils and plants. Local studies suggest that no matter which future plays out with regard to wind, fog, and precipitation, rising temperatures will cause an increase in climatic water deficit (e.g., even in a rainier future, the soil will be drier).

Community resources: Here used to mean individuals and communities, infrastructure, economic activities, and natural resources and ecosystems that government institutions are concerned with protecting, for the public good, that are potentially vulnerable to harm from climate change.

Ecosystem services: “The conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life” (U.S. Climate Change Program, 2008). In other words, it is the concept of evaluating natural processes in terms of how they support human life. The provision of clean water by a watershed is an example of an ecosystem service.

Heat wave: Definitions vary by locality and application. An example: there is a heat wave when temperature at a particular weather station exceeds the 99th percentile of its local summertime climatology computed over the base period 1950–1999. Definitions often require excessive heat to last at least 2-3 days. Heat that does not meet the criteria for a heat wave can still be very dangerous to health.

Microclimates: A climate found in a small area, particularly where it differs from the climate of the surrounding area.

Ozone: A poisonous gas made of oxygen (O_3) formed in the upper atmosphere (stratosphere), called the ozone layer, which protects and cools the earth, and also produced in the lower atmosphere (troposphere) by the reaction of certain pollutants with sunlight's ultraviolet rays, called smog. Climate change and the ozone hole are two human activity-driven problems with a complex relationship. Climate change appears to be causing the ozone layer to thin, while on the ground warming temperatures exacerbate the problem of smog. Ozone is a relatively weak greenhouse gas (25% the strength of CO_2), and so could be said to contribute to climate change, but it is not a major contributor. Some greenhouse gases worsen both climate change and the ozone hole.

Pollution: The act by which harmful substances are introduced into the air, soil, or water. The work being done to combat pollution will make people and landscapes less vulnerable to harm from climate change. Sometimes carbon pollution is used to refer to the release of greenhouse gases into the atmosphere. While greenhouse gases do not necessarily harm air, soil, or water directly, the secondary effects of climate change caused by their emission may be very harmful.

Prediction: A projection assigned the highest likelihood of occurrence, also called a forecast. (IPCC)

Projection: (1) Any description of the future and the pathway leading to it; (2) Results derived from a global climate model showing estimates of future climate. (IPCC)

Sea level rise (SLR): An increase in the level of the surface of the sea with respect to the land (the mean level between high and low tide). Some SLR is global (called eustatic), caused by melting land ice, changes to sea floor ridges, warming/ expanding water, etc.; other SLR is local (isostatic), and may be caused by local tectonic uplift. The sea level is rising faster in some places because of a combination of these factors.

Vulnerability assessment: A systematic evaluation of predicted or observed areas of particular exposure to negative impacts from a climate event or process. An impact assessment may be done as part of a vulnerability assessment, but does not necessarily identify areas of particular exposure (as in, relative to other areas of exposure). An impact assessment alone may list but not prioritize impacts along a continuum of vulnerability.

Vulnerable population: A group or category of people who are most at risk from harm, in this case harm from climate impacts, due to a range of factors, such as lacking air conditioning in their homes, having pre-existing asthma or other health conditions, living in neighborhoods with less open space and trees, lacking personal transportation to evacuate during emergencies or travel to air-conditioned buildings, or having language barriers to warnings and assistance messages.

Weather: The present condition of climatic variables and their interactions over the short term.

B. Information resources for climate readiness

Bay Area/North Bay

- The Bay Area Ecosystems Climate Change Consortium: http://www.baeccc.org/
- The Bay Area Flood Protection Agencies Association: http://bafpaa.org/
- The Bay Area Joint Policy Committee's Bay Area Climate & Energy Resilience Project: http://www.abag.ca.gov/jointpolicy/projects.html
- Climate Protection Campaign: http://climateprotection.org/
- Environmental Justice Coalition for Water, Bay Area Chapter: http://www.ejcw.org/
- North Bay Watershed Association: http://www.nbwatershed.org/

Online

- National Climate Assessment: http://www.globalchange.gov/what-we-do/assessment
- Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5): http://www.ipcc.ch/report/ar5/
- Cal-Adapt (online mapping of coarse-scale projections for heat, sea level rise, and fire in California): http://cal-adapt.org/
- California Climate Commons (repository of climate change projections and other data): http://climate.calcommons.org/
- Climate Access (climate change communication resource): http://www.climateaccess.org/
- Climate Adaptation Knowledge Exchange (CAKEX): http://www.cakex.org/
- U.S. Forest Service Climate Change Resource Center: http://www.fs.fed.us/ccrc/
- U.S. National Park Service Climate Change Response Program: http://www.nps.gov/subjects/climatechange
- Southwest Climate Science Center (USGS)/ Southwest Climate Change Network http://www.southwestclimatechange.org/

To learn more about fog, wind, ice, snow, and atmospheric rivers: Johnstone, J. and T. Dawson. (2010). Context and ecological implications of summer fog decline in the coast redwood region. Proceedings of the National Academy of Sciences (PNAS), 107(10): 4533-4538. http://www.pnas.org/content/early/2010/02/09/0915062107.full.pdf

To learn more about how climate change affects coastal upwelling, see Largier et al., 2010, Climate Change Impacts: Gulf of the Farallones and Cordell Bank National Marine Sanctuaries. http://farallones.noaa.gov/manage/climate/pdf/climate_report.pdf.

To learn more about climate change on timberlands see Hannah, L., Costello, C., Guo, C., Ries, L., Kolstad, C., Panitz, D., and Snider, N. (2011). The Impact of Climate Change on California Timberlands. Climatic Change 109:429–443. doi: 10.1007/s10584-011-0307-2.

For more information on climate change and melting ice, see the following resources: National Snow and Ice Data Center - http://nsidc.org; Arctic Sea Ice News - http://nsidc.org/arcticseaicenews/; Greenland Ice Sheet Updates - http://nsidc.org/greenland-today/; Burning Questions about Ice & Climate - http://nsidc.org/icelights/; About the Cryosphere - http://nsidc.org/cryosphere/; Earth Exploration Toolbox, Arctic Sea Ice - http://serc.carleton.edu/eet/seaice/index.html; NASA Cryospheric Sciences Program - http://ice.nasa.gov/

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