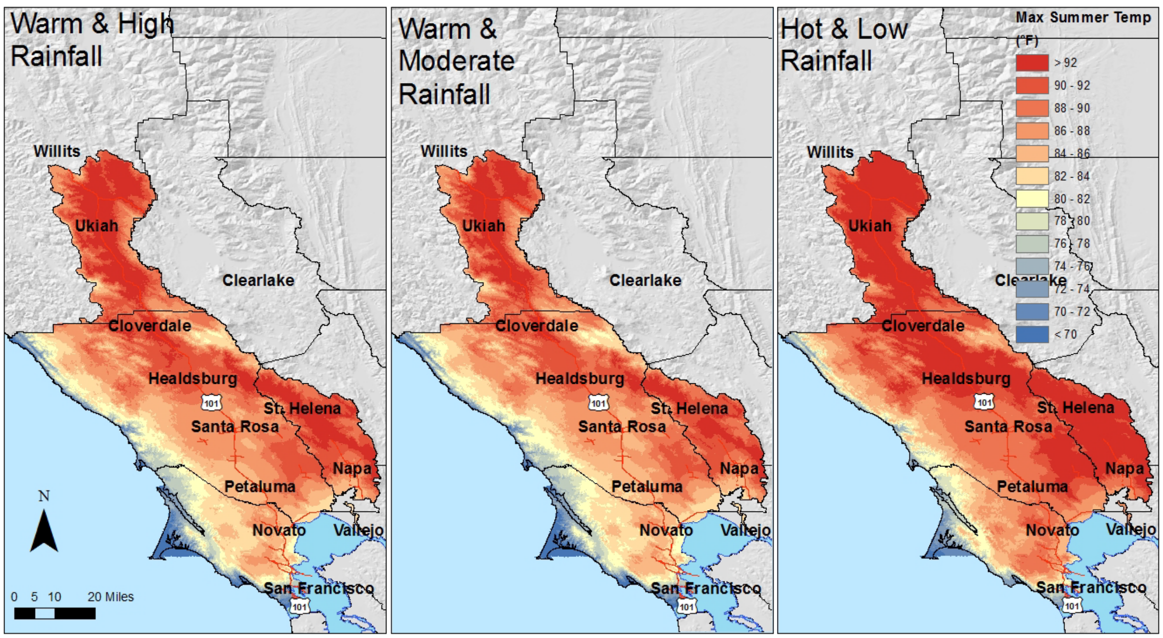
Climate Ready North Bay
Vulnerability Assessment Data Products

Sonoma County Agricultural Preservation and Open Space District and Regional Parks User Group

January 2016



End of century

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A Dwight Center for Conservation Science

Technical Memorandum

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Introduction

What is Climate Ready North Bay?

To create a framework for adapting to climate change, decision-makers working in Northern California's watersheds need to define climate vulnerabilities in the context of site-specific opportunities and constraints relative to water supply, land use suitability, wildfire risks, ecosystem services, biodiversity, and quality of life (e.g. Mastreanda 2010, Ackerly et al. 2012). Working in partnership with the Sonoma County Regional Climate Protection Authority (RCPA) and the North Bay Climate Adaptation Initiative (NBCAI), Pepperwood's Terrestrial Biodiversity Climate Change Collaborative (see Chornesky et al. 2013, TBC3.org) has developed customized climate vulnerability assessments with select natural resource agencies of California's Sonoma, Marin, Napa and Mendocino counties via *Climate Ready North Bay*, a public-private partnership funded by the California Coastal Conservancy's Climate Ready program.

The goal of *Climate Ready North Bay* is to engage natural resource agencies, including water agencies, parks, open space districts, and other municipal users to collaboratively design climate vulnerability information products specific to their jurisdictions, mandates, and management priorities. With agency input guiding the development of the vulnerability assessments, spatially-explicit data products are now available to help local governments and agency staff implement informed and effective climate adaptation strategies. These products include customized maps, graphs, and summary technical reports tailored to site-specific resource management challenges, located within the watersheds illustrated in Figure 1.

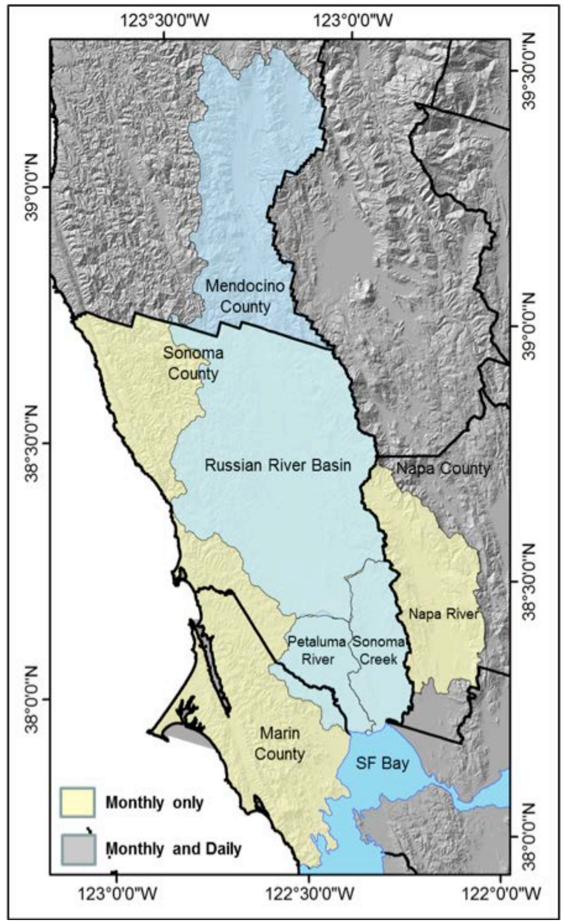


Figure 1: Map of study region shown in blue and yellow, including regions where daily data is available for analyses (blue) and those where monthly data is available (yellow). *Climate Ready North Bay 2015*.

Project Partners

Climate Ready North Bay is made up of a coalition of conservation leaders, land managers, decision-makers, and scientists all working together to better understand and address climate vulnerabilities to North Bay watersheds. Participating entities include: California Coastal Conservancy (funder); North Bay Climate Adaptation Initiative (partner); Sonoma County's Regional Climate Protection Authority (lead applicant): Sonoma County's Water Agency, Regional Parks, and Agricultural Preservation and Open Space District (users); multiple Napa County departments (users); Marin Municipal Water District (user); and Mendocino Flood Protection and Water Conservation District (user). The core vulnerability assessment technical team consisted of Drs. Lisa Micheli (project manager) and Nicole Heller (Dwight Center for Conservation Science at Pepperwood), Dr. Lorraine Flint (USGS), and Dr. Sam Veloz (Point Blue Conservation Science). The project management team consisted of Lauren Casey (Regional Climate Protection Authority), Caitlin Cornwall (NBCAI /Sonoma Ecology Center), Lisa Micheli, and Jay Jasperse and Chris Delaney (Sonoma County Water Agency).

Technical Memorandum Overview
This technical memorandum summarizes the outcomes of engaging Sonoma County Agricultural Preservation and Open Space District and Sonoma County Regional Parks in the *Climate Ready North Bay* collaboration to develop customized climate vulnerability assessment data products as a starting point for understanding potential climate stressors facing Sonoma County's open spaces in the decades to come. A companion technical memorandum summarizes results for the North Bay region as a whole (see *Climate Ready North Bay: Regional Vulnerability Assessment Summary Technical Memorandum*). This memo summarizes Sonoma County's open space and parks districts' jurisdictions and climate-related concerns, articulates key management questions, and provides highlights of sample data products co-created by managers and climate adaptation scientists in response to these questions. The Districts' and Parks' management concerns with summarized data findings are grouped into three resource areas: 1) Water Resources (including rainfall, water supply, and drought); 2) Native Vegetation Response; and 3) Fire Risks. Appendices include a glossary, details on climate models, summary tables, and a list of data products generated and provided to the District and Parks. A companion PowerPoint deck is also provided that showcases sample data products and take home messages for the Sonoma County District and Parks use. (see *CRNB SCAPOSD and Regional Parks deck.ppt).* Appendix A summarizes data products co-created with managers and provided for adaption planning applications.

Stakeholder Engagement

Stakeholder engagement was a key component of the *Climate Ready North Bay* project. User groups included North Bay natural resource management agencies from the counties of Marin, Sonoma and Napa, and a group of staff from the cities and County of Sonoma charged with land use and infrastructure planning facilitated by Sonoma County's Regional Climate Protection Authority's Climate Action 2020 process. The vulnerability assessment team worked closely with these stakeholders through a series of in-person meetings, complemented by a survey prior to the first meeting, and additional correspondence and webinars between meetings.

A central goal throughout the process was to maintain an applied science focus by defining key management questions for each jurisdiction at the onset of the project, and then refining those questions throughout the project duration. Stakeholder meetings were held to jointly engage key managers and key vulnerability assessment analysts in an open dialogue that was facilitated by a project manager with training and experience in both arenas. The overall stakeholder engagement process included the steps listed below, with many allowances for feedback throughout.

- As part of the project kick-off and prior to the first meeting, administer a *Questionnaire for Managers* to start a dialogue about how current weather variability impacts agency operations and what their concerns about future change are (see Appendix C of the *Regional Vulnerability Assessment Summary Technical Memorandum*).

- At the first half-day meeting of all users, present the available range of climate futures (see *Selection of Future Climate Scenarios* below for more information on the 18 potential futures) and select one set of climate futures based on shared regional management concerns and jointly-defined criteria across user groups.

- At follow-up agency-specific scoping meetings (two hours minimum), showcase potential products in depth, answer questions in detail, and review results of the managers' questionnaire to start collectively matching questions to data.

- As a follow up to the scoping meetings, draft an agency-specific scope of work for vulnerability data products that defines specific vulnerability metrics from the TBC3 knowledgebase of interest. Examples include: maximum and minimum temperatures, changes in water supply, degree of groundwater recharge, peak runoff and/or river discharge magnitude and frequency, drought frequency and intensity, drought stress (water deficit), changes in vegetation, and wildfire risk.

- Refine the scope based on refined management questions through iterative exchanges with users. Refinements may include time scale of data queries, revised jurisdictional boundaries, or comparisons of sites or time periods.

- Upon completion of the draft scope, the vulnerability assessment team generates products using computer models via a parallel process of in-person meetings, online coordination, and webinars.

- Present preliminary data products to user groups at a half-day meeting to review, discuss and refine through facilitated dialogue. Repeat if necessary.

- Finalize products for distribution, including production of technical memoranda and PowerPoint presentation materials.

- Scope opportunities for applications in the context of agency planning processes.

Climate Ready North Bay's extensive and iterative stakeholder engagement process can ideally inform technical groups in other regions working with local government and natural resource management agencies, providing a model of how to generate relevant information on climate change vulnerabilities in the context of land and water management. The North Bay approach was specifically commended in Deas (2015) as providing "…an opportunity for joint learning" as well as increasing functional access to what would have otherwise been a complicated data set by facilitating conversations between scientists and managers. A primary benefit of this project to managers was having direct access to the scientists who created the models, and therefore know the limitations of the data. In turn, the scientists learned about new dimensions of projected change that would not have been discovered without this collaborative exploration.

Slides 1-9 illustrate the project overview in the companion *CRNB SCAPOSD and Regional Parks deck.ppt.*

Sonoma County Agricultural Preservation and Open Space District and Regional Parks Responsibilities and Jurisdictions

Sonoma County is fortunate to have two County agencies working in concert to acquire and steward properties that protect and enhance the region's ecological health and provide recreational access for citizens.

The Sonoma County Agricultural Preservation and Open Space District (the District) is a voter-supported entity that utilizes dedicated sales tax revenues to strategically acquire conservation and working lands. Sonoma County voters approved Measures A and C to create the District and enable a quarter-cent sales tax to fund District operations until 2011. In 2006, with 76% of the vote, Sonoma County residents approved Measure F to extend the quarter-cent sales tax through 2031. As one of the first organizations in the country established to protect both agricultural and open space lands, the District has protected over 106,000 acres to benefit people and wildlife.

Sonoma County Regional Parks (Parks) operates more than 50 parks throughout the county for both resource value and public access. Many of these parks were originally acquired by the District and then transferred to Parks, as budgets allowed. Regional Parks' mission is to create healthy communities and to contribute to the economic vitality of Sonoma County by acquiring, developing, managing and maintaining parks and trails county-wide. Regional Parks preserves irreplaceable natural and cultural resources, and offers opportunities for recreation and education to enhance the quality of life and well-being of residents and visitors to Sonoma County.

Together the agencies identified a total of 28 parcels (10 parks and 28 open space parcels), that they wish to have assessed in the course of this analysis. Their goal was to think about this combined portfolio of park and open space lands as one resource. Data products focus on advancing our understanding the range and diversity of conditions across the portfolio in the context of Sonoma County as a whole to inform long-term planning. Thus, products are designed to compare and contrast parcels within the selected set as an input for management planning across the county, rather than providing management-level data and recommendations per parcel. At the next step of management planning, the agencies will have the ability to zoom in on large parcels with the raster Basin characterization model data set provided.

Sonoma County Agricultural Preservation and Open Space District and Regional Parks Climate-related Concerns and Management Priorities

The District and Parks are both interested in using project results to frame long-term *climate smart* land acquisition strategies and stewardship management plans. The District is involved with two related initiatives, one to incorporate climate considerations into a regional acquisition plan, and another to quantify the economic value of environmental services generated by protected lands, with a particular focus on watershed functions including water supply and flood attenuation. Parks is on the verge of beginning a comprehensive natural resource management planning effort for their properties, and selected a set of priority parks for this analysis based on a set of internal criteria. Their planning objective is to integrate climate considerations into all natural resource management projects with a planning horizon of five years and beyond in order to meet the goal of providing "resiliency" for existing systems.

Parks is concerned with how current climate variability already impacts operations, particularly the impacts of extreme events on their ability to conduct work and maintain facilities. Extreme storms and floods result in costly damage directly from water and indirectly due to landslide risks, particularly on riverside properties. Flood response requires diverting resources from other programs until damage is repaired. Extreme cold causes infrastructure damage and potential costly repairs. Extreme heat imposes regulatory limits on getting work done. Examples include: red flag days that limit maintenance activities using powered equipment; extreme heat days that trigger OSHA safety requirements for outside workers; and spare the air days that trigger prohibition of campground fires.

The current drought has also affected Parks' operations in a number of ways. The drought has increased the need for irrigation in habitat restoration projects, increased emphasis on water conservation and leak repair, and impacted mowing schedules due to increased fire risks. Parks indicated that they rely on the Sonoma County Water Agency to define a drought for them. The potential upside of the drought has been more visitors resulting in increased revenues due to the sunny weather.

Sonoma County's park and open space management concerns are grouped into three resource areas: 1) Water Resources (including rainfall, water supply, and drought); 2) Native Vegetation Response; and 3) Fire Risks.

Management Concerns for Future Analysis

In the process of identifying management concerns and questions, a number of key questions amenable to analysis in the scope of this project were identified and are presented by resource areas below. The following management question was also identified, but the team determined it was beyond the scope of this study, and therefore is not addressed here, but can be addressed using the core data set provided to the District in the process of site specific management planning.

What parcel-specific management recommendations can be drawn from *Climate Ready North Bay* data products?

The goal of this project was to assess the set of parks and open space parcels as a whole to look at the range of potential climate impacts across the portfolio. When the agencies begin to develop parcel-specific management plans, the *Climate Ready North Bay* Basin Characterization Model database, provided as an output of this project, will be available for site-specific planning since it is being transferred to the county for future use. However, the translation of climate vulnerabilities to specific management plans and actions will require another process at the local scale, akin to what Pepperwood is presently doing as a part of its Adaptive Management Plan for its own 3200-acre preserve. The project team would be happy to share that process and plan with the District and Regional Parks when the time is right relative to their planning process.

Vulnerability Assessment Methods

Selection of Future Climate Scenarios

The first *Climate Ready North Bay* regional stakeholder kick-off meeting was convened to select a consistent set of climate-hydrology "futures" based on regional management concerns. User groups were first introduced to a series of 18 Basin Characterization Model (BCM) downscaled future climate scenarios developed by the Terrestrial Biodiversity Climate Change Collaborative (TBC3) for the San Francisco Bay Area (Weiss et al. *in prep*). The climate futures included seasonal and annual climate and hydrology variables downscaled to 270-m grid cell resolution, derived from 18 of the approximately 100 Global Circulation Model (GCM) projections run under alternative future greenhouse gas emissions scenarios for both the 4th and 5th Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC; Meehl et al. 2007; Taylor et al. 2011). These 18 scenarios were selected via a statistical cluster analysis approach to find the minimum number of futures capable of capturing the full range of 100 peer-reviewed by the Intergovernmental Panel on Climate Change, IPCC (Weiss et al. *in prep*). See Appendix B for summarized of the 18 TBC3 selected GCMs.

Users representing all North Bay User Groups were provided a detailed introduction to the data using data visualizations (including a "climate space plot" showing each model's deviation from a common historic temperature and rainfall baseline) and explanatory tools. The users were then asked to help define a set of criteria (listed below) for selection of a final subset of climate futures.

- Is it a representative range of projected change that covers the full range of IPCC global scenarios and TBC3 Bay Area scenarios? The managers expressed a desire to focus on capturing the full range of temperature and rainfall scenarios for "business as usual" scenarios, and in particular wanted to capture the highest (Scenario 5) and lowest (Scenario 4) rainfall scenarios, in addition to the scenario that landed closest to the center (ensemble mean) of the full set of climate projections in terms of both rainfall and temperature change (Scenario 3). These three scenarios were intended to help bound the range of extreme conditions and capture "worst case scenarios." Capturing "mitigated" (significantly reduced emissions) scenarios was a lower priority than having a range of "business as usual" cases.

- Is the total number of scenarios reasonable to analyze? Since comparing and contrasting model outputs is labor intensive, a range of three to six scenarios was decided upon as reasonable for detailed comparative analyses. In combination with the other criteria, managers came to a consensus to analyze six scenarios total, with more emphasis placed on three that defined rainfall extremes plus a "central tendency" for the original set of 18 futures.

- Are scenarios realistic, do they have an equal likelihood of occurring? This discussion focused primarily on the reality of emissions scenarios, with the "super-mitigated" scenarios being judged less likely based on empirical emissions data. Managers agreed that they wanted multiple "business as usual" scenarios to compare, but also wanted to include at least one "mitigated" scenario to demonstrate the benefits of climate mitigation.

- Is it consistent with the State modeling efforts? The California Climate Change Technical Advisory Group was on a parallel track to select a set of IPCC models for statewide precipitation patterns for California's 4th Climate Assessment. To the extent feasible given that these projects were advancing in tandem, an effort to maximize the overlap between future state data products and *Climate Ready North Bay* products was made.

Through this facilitated dialogue, the user groups selected, by consensus, a subset of six future scenarios from which customized reports for the vulnerability assessments in Sonoma, Napa, Mendocino, and Marin counties would be developed (See below for a summarized list and *Appendix B: Selected Future Climate Scenarios)*.

Scenario 1: Low warming, low rainfall (mitigated emissions scenario) (GFDL-B1)
Scenario 2: Low warming, moderate rainfall (PCM A2)
Scenario 3: Warm, moderate rainfall (CCSM-4)
Scenario 4: Warm, low rainfall (GFDL-A2)
Scenario 5: Warm, high rainfall (CRNM-CM5)
Scenario 6: Hot, low rainfall (MIROC-ESM)

Slides 10-14 in *CRNB SCAPOSD and Regional Parks deck.ppt* provide project overview.

Basin Characterization Model (BCM)
The climate vulnerability analyses were grounded in a watershed-based approach to assessing "landscape vulnerability," with a focus on climate-driven impacts to the hydrologic cycle. The vulnerability data products are based on the six future climate projections derived from a global set of projections peer-reviewed by the IPCC (Meehl et al. 2007; Taylor et al. 2011) described above. These global models were "downscaled" to increase their spatial resolution via a California statewide downscaling effort (Flint and Flint 2012). The USGS partners on this project analyzed the downscaled historic and projected temperature and precipitation data using the U.S. Geological Survey California Basin Characterization Model (BCM) (Flint et al. 2013; Flint and

Flint 2014). The BCM models the interactions of climate (rainfall and temperature) with empirically-measured landscape attributes including topography, soils, and underlying geology. It is a deterministic grid-based model that calculates the physical water balance for each 18-acre cell (270m resolution) in a given watershed in set time steps for the entire area.

This approach enables a process-based translation of how climate interacts with physical geography to estimate local watershed response in terms of microclimate, runoff, recharge, soil moisture, and evapotranspiration. The BCM is capable of producing fine scale maps of climate trends as well as tabular time series data for a place of interest. For a detailed description of the BCM inputs, methods, and resulting datasets please see: *California Basin Characterization Model: A Dataset of Historical and Future Hydrologic Response to Climate Change: U.S. Geological Survey Data Release*. For a summary of BCM inputs, outputs and a glossary of terms, see Appendix C.

The Climate Ready North Bay project developed a customized BCM database for the North Bay region (Figure 1) extracted from the monthly California BCM and daily Russian River BCM (http://ca.water.usgs.gov/projects/reg_hydro/projects/russian_river.html). The California BCM uses a minimum time step of monthly results at the scale of a 270m grid, allowing the generation of scenarios at annual, seasonal, or monthly time steps. For *Climate Ready North Bay*, data was also extracted from a daily model for the Russian River to provide higher temporal resolution for evaluating potential extreme conditions within that geographic domain.

The monthly historic climate input data is downscaled from PRISM (Daly et al. 2008), and the daily data set includes historic data measured at weather stations from 1920–2010. The daily BCM model is extrapolated throughout the Russian River Basin using a method that is modified from that described in Flint and Flint (2012) in order to incorporate daily station data (Flint et al. *in prep*). Managers selected six future climate scenarios (described below) that provided a set of projections for the next 90 years (2010-2099). Data products derived include 30-year averages to delineate potential long-term trends in adherence with USGS recommendations. This allows comparison of three historic periods (1921-1950, 1951-1980—often referenced as a pre-climate change baseline, and 1981-2010—a period of assumed observed change) with three projected periods (2010-2039, 2040-2069, and 2070-2099). See Appendix D for a regional BCM output summary in 30-year time steps.

It is important to emphasize when describing BCM data products at a finer temporal resolution than the 30-y averages (such as decades, years, months or days), that unlike a weather forecast, the model does not generate *predictions* of precisely when climatic events will occur, but rather generates a physically-based time series of conditions for each scenario that is considered physically possible given the state of the science. By comparing results from a range of models, statistics can be used to describe a potential range of outcomes, but presently it cannot be determined which outcome is more likely to occur.

Navigating the necessarily *probabilistic* nature of climate data projections is perhaps one of the greatest challenges in applying these kinds of data products to real-world management issues.

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

In terms of spatial scale, the 18-acre resolution of BCM model pixels allows for aggregation of model results at spatial scales ranging from the North Bay region as a whole (the scale of this technical memorandum), to county boundaries and sub-regions (including watersheds, landscape units, service areas, and large parcels like parks). The vulnerability assessment team recommends that the model not be used to facilitate pixel-by-pixel comparisons, but rather be applied to minimum units ideally at the scale of sub-watershed planning units, or no smaller than parcels on the order of hundreds of acres.

The BCM's direct outputs include potential changes in air temperature, precipitation (snow and rainfall, but for the North Bay only rainfall is significant for precipitation), runoff, recharge, potential and actual evapotranspiration, and soil moisture storage. From these direct outputs, with additional analysis, derivative products can be generated that include climatic water deficit (the difference between potential and actual evapotranspiration—an indicator of drought stress and environmental demand), water supply, and stream flow.

Climatic water deficit projections, including where deficits are projected to exceed the historic range of variability, estimate the combined effects of rainfall, temperature, energy loading and topography, and soil properties on water availability in the landscape. This is a useful indicator of landscape stress due to potential drought. The combination of runoff and recharge values together provide an indicator of variability in water supply (surface water and groundwater combined). Stream flow estimates require an additional step of accumulating flow and calibrating it to historic gage records. Projected stream flow time-series can be used to consider impacts on water supply, flooding risks, and aquatic and riparian resources.

As a result of the TBC3 initiative, climatic water deficit has been determined to be an excellent indicator of forest health, species composition, and fire risk. The secondary models described below for estimating trends in native vegetation composition and fire risks use this BCM output as a critical input in combination with soils, land cover, and other landscape metrics.

Slides 15-19 in *CRNB SCAPOSD and Regional Parks deck.ppt* illustrate the BCM methodology, while slides 20-33 illustrate regional data samples.

Climate Ready North Bay Vegetation Model

Risk of potential future vegetation transitions were modeled using projected proportional area of landscape cover for 22 vegetation types for the historic (1951–1980) and recent (1981–2010) periods and each of the six future climate scenarios. Projected vegetation response includes the frequency and spatial extent of suitable climate space for each vegetation type throughout the region, the potential impact of climate change on vegetation for a "landscape unit" (as defined by the Bay Area Open Space Council's Conservation Lands Network) of interest, and an evaluation of which factors contribute to spatial variation in the sensitivity of the projected vegetation changes in response to climate (Ackerly et al. 2015). See Appendix A for a summary of dynamic vegetation model results for the project area.

Fire Risk Model
Statistical models of recent historic burning across the State, at a spatial resolution of 1080-m landscapes and a temporal resolution of 30 years (1971–2000) were combined with the BCM outputs (temperature, precipitation, potential evapo-transpiration, actual evapo-transpiration, and climatic water deficit) to determine how fire activity might change over time. North Bay Climate Ready futures used for this analysis include Scenarios 1, 2, and 4. Fire risk was modeled as the probability of burning occurring at least once within a given 30-year interval (2040-2069 and 2070-2099) or conversely, an estimated burn return interval. A metric of distance to human development is included in the model in order to estimate the additional influence of human access on fire risks (Krawchuk and Moritz 2012).

Key Vulnerability Assessment Findings

- → *Sonoma County is becoming more arid due to rising temperatures*
- → *Rainfall is likely to be more variable in the future*
- → *Runoff may be increasingly flashy, with rates of groundwater recharge potentially less variable over time*
- → *Protecting recharge areas will be critical to water supply sustainability*
- → *Water demand for agriculture may increase on the order of 10%*
- → *Fire frequencies are projected to increase on the order of 20%, requiring additional readiness planning and perhaps more aggressive fuels management*
- → *Vegetation may be in transition, meriting additional monitoring and consideration of a drought tolerant planting palette for restoration*

Key findings for Sonoma County include a unidirectional trend, regardless of total rainfall, towards increasing climatic water deficits across model scenarios. Therefore, managers will be facing an increasingly arid environment. Water supply indicators generally increase in variability across all scenarios, with the extreme scenarios ranging from approximately 25% greater to 25% less total watershed supply. The climate suitability for vegetation types in Sonoma County will favor drought-tolerant species, while fire risks are projected to double in especially fire prone regions. The combination of potential drought stress on water supplies and vegetation, with an approximate doubling of fire risks, should inform long-term adaptive management of natural resources. Working with agencies on potential Climate Ready North Bay product applications, the project team is exploring how to build watershed resilience to drought with a focus on protecting groundwater recharge. Drought tolerance also needs to be promoted in forest, rangeland, and agricultural systems, and perhaps more aggressive approaches to the reduction of forest fuel loads should be considered.

Key Management Questions and Summary of Data Products

Introduction

This section summarizes data products developed in response to the key management questions raised by the District and Regional Parks user group. Products include samples of vulnerability assessment data describing temperatures, rainfall, runoff, recharge, climatic water deficit, vegetation transitions, and fire risk. Appendices include a list of data products, summary data tables, and a companion PowerPoint "deck" with slides highlighting these data products (illustrations including maps, tables, and talking points). Corresponding slide numbers are included in this section for figures supporting the data summaries (see deck filenames). Management questions are grouped by resource area with summaries of corresponding vulnerability assessment findings summarized.

Rainfall is the most variable input value to the BCM for the North Bay region as a whole and for Sonoma County, and drives the majority of variability in primary hydrologic response outputs and secondary outputs for potential vegetation transitions and fire risks. Table 1 summarizes BCM projected long-term trends in 30-year time steps from 2010–2099 for temperature, rainfall, runoff, recharge, and climatic water deficit in comparison to current conditions, averaged over 1981–2010, for Sonoma County (see Appendix C for the North Bay region summary data table). Three “business as usual” emissions scenarios are included: Scenario 5: Warm, high rainfall (the highest rainfall model in TBC3’s Bay Area BCM), Scenario 6: Hot, low rainfall (the lowest rainfall model in the TBC3’s Bay Area BCM), and Scenario 3: Warm, moderate rainfall (the closest future to the mean of all rainfall projections for TBC3’s Bay Area BCM). These three scenarios can be considered to “bookend” high and low rainfall extremes (Scenarios 5 and 6 respectively) and a “middle of the road” future (Scenario 3).

This wide variation between model rainfall projections is the greatest source of uncertainty in projected future conditions. With values ranging from approximately *21% less or 35% greater* rainfall by end-century at the scale of 30-year average values, managers need to determine how to plan in the face of this magnitude of uncertainty. Climate Ready North Bay products allow managers to understand the range of physical and ecological impacts caused by variable rainfall, and to “unpack” the annual and seasonal variability underlying these long-term average values.

It is important to point out that, despite this broad range of projected increases or decreases in rainfall, estimated climatic water deficit (which is defined as the quantified amount of evaporative demand exceeding available soil moisture) is expected to increase across all futures. This provides managers with a key landscape condition and water demand indicator that varies only in intensity but not direction. Changes in water deficit are a critical driver of agricultural sustainability, native vegetation response, and fire risk as described in more detail below.

Additionally, all of the climate models show a consistent increase in temperatures for Sonoma County. By century's end, total increases in maximum summer temperatures (30-y averages) range from 5.6 to 9.5°F, while increases in minimum winter temperatures (also 30-y averages) range from 4.8 to 8.4°F. These significant increases in long-term averages represent unprecedented extreme heat events at the scale of days and months. This increase in temperature results in increased rates of evapotranspiration that, in turn, drive changes throughout the hydrologic cycle, which are explored in the following sections. Warmer temperatures effectively generate dryer soil conditions, which then creates more room for storing moisture subsurface in soils and aquifers, potentially reducing the total amount of available surface water.

Table 1: Basin Characterization Model, Sonoma County – Summary of outputs, three scenarios

		Historic	Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Variable	Units	1951-1980	1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in	42.6	43.0	53.6	57.9	42.1	45.6	34.8	33.9
Tmn	Deg F	44.8	45.8	49.2	52.0	48.5	51.3	50.6	54.3
Tmx	Deg F	71.2	71.2	75.0	77.7	74.4	77.1	76.8	80.7
CWD	in	28.0	54.9	57.4	60.1	58.3	60.3	61.5	66.7
Rch	in	11.0	10.2	12.8	13.2	10.7	10.8	8.2	8.5
Run	in	14.0	14.2	22.8	26.9	14.0	17.3	9.7	9.3
				Percent Change from Current or Change in Temperature					
			Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Variable	Units		1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in		43.0	25%	35%	-2%	6%	-19%	-21%
Tmn	Deg F		45.8	3.4	6.2	2.7	5.5	4.8	8.4
Tmx	Deg F		71.2	3.8	6.5	3.2	5.9	5.6	9.5
CWD	in		54.9	5%	10%	6%	10%	12%	22%
Rch	in		10.2	25%	29%	4%	6%	-20%	-17%
Run	in		14.2	61%	90%	-1%	22%	-32%	-34%

Variables: Ppt=precipitation, Tmn=minimum winter temperature (monthly), Tmx=maximum summer temperature (monthly), CWD=climatic water deficit, Rch=recharge, Run=runoff

Slides 34-35in *CRNB SCAPOSD and Regional Parks deck.ppt* illustrate the discussion above.

Water Resources

The following section highlights results generated in response to key management questions regarding water supply from and drought impacts to parcels in the combined Sonoma County parks and open space portfolio.

Management Question: How may climate change impact the inter-annual variability of the region's rainfall?

Sonoma County estimates for long-term rainfall trends can be summarized as follows.

From 1951-1980 the historic Sonoma County average rainfall was 44.9 inches per year.

From 1981-2010, the current Sonoma County average rainfall was 45.5 inches per year. For 2040-2069, Sonoma County average annual rainfall is projected as follows.

> *Scenario 3: Warm, moderate rainfall* – 44.8 in/year 2% less than current
> *Scenario 5: Warm, high rainfall* – 57.2 in/year 26% greater than current
> *Scenario 6: Hot, low rainfall* – 37.2 in/year 18% less than current

For 2070-2099, Sonoma County average annual rainfall is projected as follows.

> *Scenario 3: Warm, moderate rainfall* – 48.6 in/year 7% greater than current average
> *Scenario 5: Warm, high rainfall* – 61.8 in/year 36% greater than current
> *Scenario 6: Hot, low rainfall* – 36.2 in/year 21% less than current

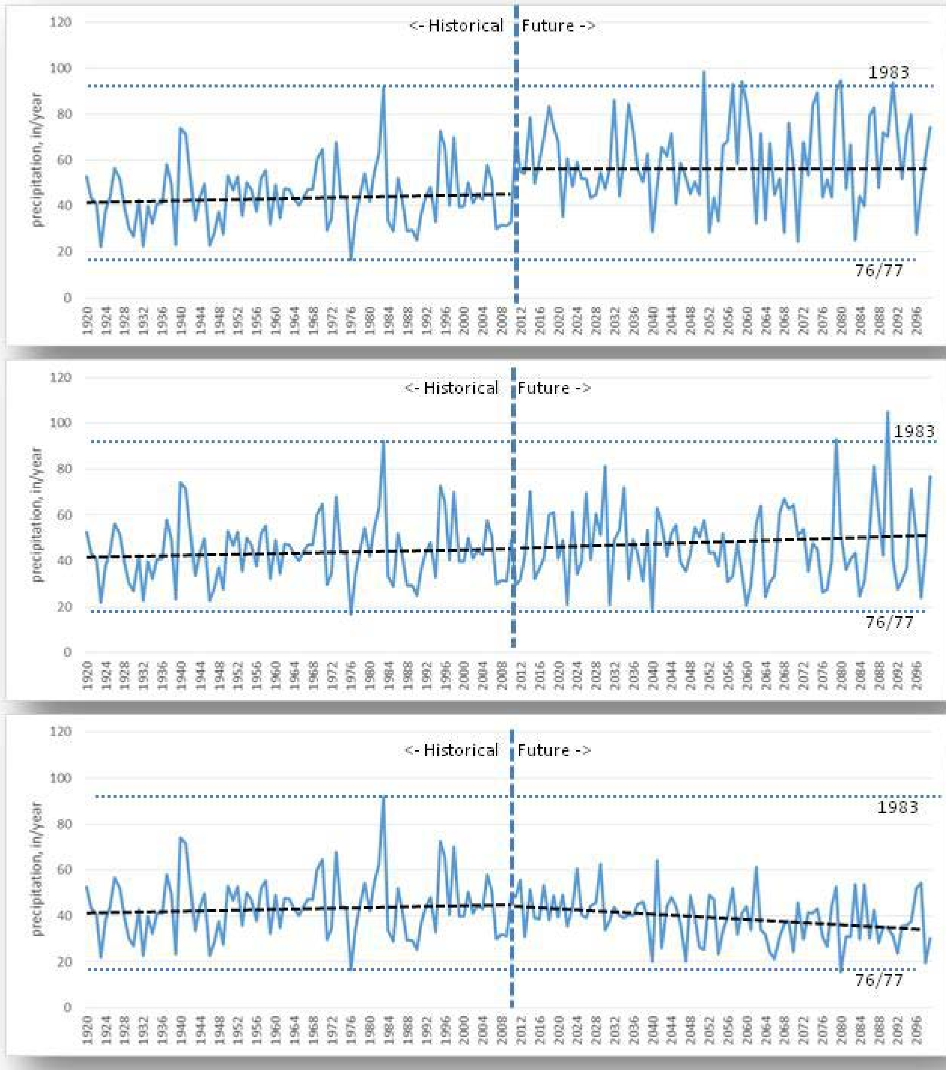
A comparison of extreme rainfall years in the North Bay region, which apply directly to Sonoma County, can be made using annual rainfall totals for the historic period of 1920-2009, including both high rainfall years likely to correspond with flood risks, and low rainfall years likely to correspond with drought risks (Table 2). This comparison shows that if an average is taken across the six projected futures, annual peak rainfall years (defined as exceeding the 90th percentile value of the 1920-2009 period) and low rainfall years (defined as less than the 10th percentile value of the 1920-2009 period) are projected to both increase on the order of 200% and 160%, respectively. However, "worst case scenarios" in terms of high and low rainfall over 30-year periods correspond to more drastic increases in extreme events. For example, under the warm and high rainfall scenario, an approximate five-fold increase in high flood risk years is projected, while under low rainfall scenarios an approximate three-fold increase in potential drought years is projected.

Table 2. Percent changes in frequency of annual rainfall extremes per decade, North Bay Region, current conditions (1920-2009) versus six climate ready scenarios (2010-2099)

Percent increase or decrease per decade				**Annual Peaks (floods)**		**Annual Lows (droughts)**	
Scenario #	**Model**	**Time Period**	**Name**	**>=1940 (69.1 in/yr)**	**>90th % (56.4 in/yr)**	**<10th % (27.1 in/yr)**	**<=1976 (15.9 in/yr)**
	Historic & Observed Change	1920-2009					
1	GFDL_B1	2010-2099	Low warming, Low rainfall	150%	44%	100%	-100%
2	PCM_A2	2010-2099	Low warming, Mod rainfall	200%	156%	89%	200%
3	CCSM4_rcp85	2010-2099	Warm, Mod rainfall	150%	111%	11%	-100%
4	GFDL_A2	2010-2099	Warm, Low rainfall	50%	11%	156%	200%
5	CNRM_rcp85	2010-2099	Warm, High rainfall	850%	356%	-33%	-100%
6	MIROC_rcp85	2010-2099	Hot, Low rainfall	-100%	-56%	56%	0%
			Average	***217%***	***104%***	***63%***	***17%***

In general, for high and moderate rainfall scenarios, variability in annual precipitation and increases in standard deviations over 30-year means, increase in the future. Low rainfall scenario results in decreased high extremes, with slightly more frequent low rainfall years.

Figure 2. A comparison of historic to projected precipitation, Sonoma County. (1920-2099)



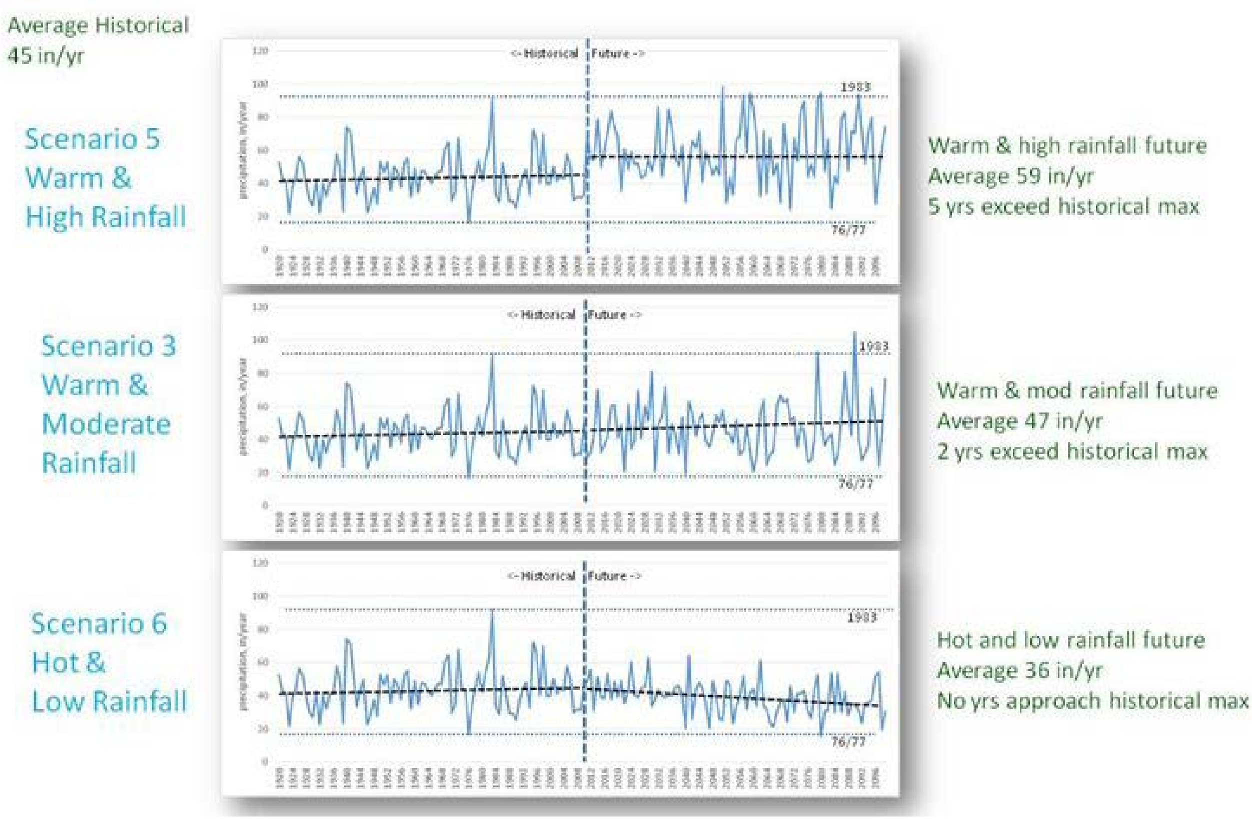
PowerPoint slides 36-39 in the companion *CRNB SCAPOSD and Regional Parks deck.ppt* illustrate the discussion above.

Management Question: Which parcels in the combined parks and open space portfolio provide key water supply benefits?

A comparison of annual values that distinguish the relative contributions of recharge and runoff for Sonoma County, show that, in general, runoff values are far more variable or "flashy" than recharge values. For example, while the variability in the "three scenario set" in runoff ranges from 11.3-30.3 in/year by the end of the century, groundwater recharge values range from only

8.2-12.9 in/year and are therefore more consistent from year to year. The warm-high rainfall scenario shows a trend of continually increasing runoff and recharge values towards the end of century, yet still includes approximately five very low runoff years comparable to the drought conditions of 1976-1977. Although projections for the warm-moderate rainfall scenario are comparable to historic conditions, this scenario shows longer, multi-year low water availability periods than the historic record (for example 2055-2075) and includes some peaks near century's end that are unprecedented in the historic record. The hot-low rainfall scenario shows a dismal trend towards steadily decreasing water availability representative of unprecedented droughts relative to the historic record.

Figure 3. A comparison of historic and projected annual runoff and recharge, Sonoma County (1920-2099)



It should be pointed out that when the combination of recharge and runoff are converted to stream flow, some of the excess runoff will become recharge in locations with deep unsaturated zones, whereas some of the recharge will become base flows contributing to surface water flow.

As a result of these projections, recharge may be considered a more consistent component of water yield over time relative to runoff. However, this is not to discount the importance of big runoff years in supplying critical supply to reservoirs, streams, and aquifers. The relative consistency of recharge even in low rainfall years suggests that sustainable groundwater management is a good investment in water security.

From 1981-2010, the current Sonoma County average annual recharge was 10 inches per year. For 2040-2069, Sonoma County average annual recharge is projected as follows.

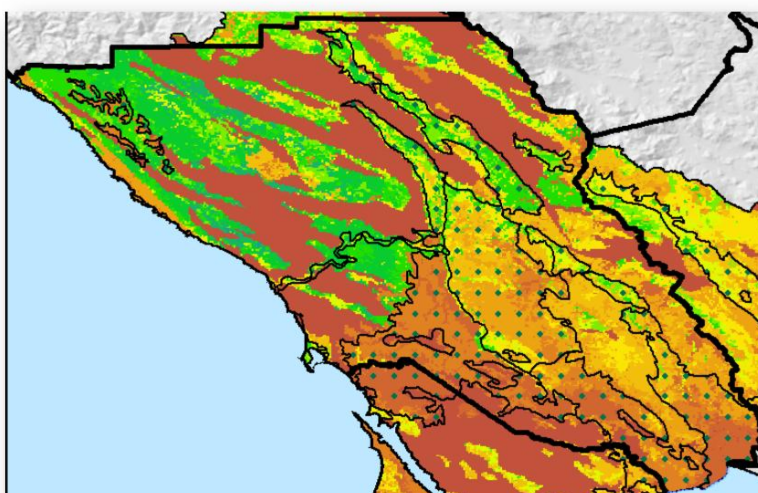
Scenario 3: Warm, moderate rainfall – 10.3 in/year 2% greater than current
Scenario 5: Warm, high rainfall – 12.4 in/year 24% greater than current
Scenario 6: Hot, low rainfall – 7.9 in/year 21% less than current

From 1981-2010, the current Sonoma County average annual runoff was 17 inches per year. For 2040-2069, Sonoma County average annual runoff is projected as follows.

Scenario 3: Warm, moderate rainfall – 16.4 in/year 4% less than current
Scenario 5: Warm, high rainfall – 25.8 in/year 52% greater than current
Scenario 6: Hot, low rainfall – 11.6 in/year 32% less than current

Within Sonoma County, recharge is dominant where soils are thin and bedrock permeability is high, or where the water can penetrate below plant roots in deeper valley soils. Most of the recharge occurs in the higher precipitation mountains surrounding the valleys. Runoff is primarily controlled by soil water holding capacity and geology. High runoff occurs primarily in the mountains where there are shallow soils and higher precipitation. High runoff areas range from 75% of total county runoff in wet scenarios to 25% in dry scenarios by mid-century. Low runoff occurs in the valleys where the soils are thick, or in mountain locations where the bedrock is permeable. The historic range of runoff is very similar to the moderate rainfall scenario by mid-century.

Figure 4. Historic (1981-2010) Sonoma County Groundwater recharge



When evaluating which parcels provide key water supply benefits, areas of high recharge merit further analysis, suggested as follows.

- Map priority recharge areas that target the upper 75% (or an alternative target guided by sustainability thresholds) for recharge potential
- Analyze the existing impermeable footprint, and evaluate where "low impact development" and "green infrastructure" could facilitate watershed resilience
- Analyze optimal siting of proposed build out relative to protected high recharge zones.
- Prioritize siting studies for injection wells.
- Determine what percentage of recharge is currently used in each basin and how much area to protect in order to sustain groundwater demand in the future.

Table 3: Water availability projections (recharge plus runoff in in/year) generated for Sonoma County Regional Parks (1981-2099), 30-year averages

	1981-2010	2040-2069			2070-2099		
Water availability (Recharge + Runoff)	Current	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall
Regional Parks	(in/yr)	% chg	% chg	% chg	% chg	% chg	% chg
Maxwell Farms Regional Park	8.2	82%	-5%	-48%	127%	31%	-55%
Tolay Lake Regional Park	13.3	56%	-5%	-41%	88%	20%	-44%
Sonoma Valley Regional Park	15.3	60%	0%	-36%	90%	23%	-39%
Helen Putnam Regional Park	19.3	41%	-6%	-35%	65%	14%	-36%
Shiloh Ranch Regional Park	19.8	52%	2%	-30%	74%	18%	-30%
Taylor Mountain Regional Park	23.6	41%	-1%	-28%	59%	14%	-28%
Hood Mountain Regional Park	30.5	41%	0%	-26%	58%	14%	-27%
Soda Springs Reserve	30.4	39%	-1%	-27%	55%	10%	-26%
Crane Creek Regional Park	19.8	56%	6%	-24%	79%	25%	-25%
Cloverdale River Park	25.4	46%	2%	-25%	63%	14%	-24%
Average	*20.6*	*51%*	*-1%*	*-32%*	*76%*	*18%*	*-33%*

When evaluating changes in total water availability, represented by combining recharge and runoff values in inches per year, Maxwell Farms, Tolay Lake, and Sonoma Valley have the lowest water availabilities, while Hood Mountain, Soda Springs, and Cloverdale River Park have the highest water availabilities. Table 3 provides a comparison of total water availability for all Sonoma County Regional Parks and Table 4 provides a comparison of total water availability for all Open Space District parcels.

As an attribute of the landscape that integrates the combined effects of available rainfall, temperature, and watershed structure, climatic water deficit takes into account available water, heat exposure, and soil/geology water storage potential to estimate where and by how much potential evapotranspiration exceeds actual evapotranspiration. This term can be thought of as a measure of drought stress, or an estimate of how much more water the landscape would have used had it been available. It captures the effect of limited soil storage to meet evapotranspiration demand.

Table 4: Water availability projections (recharge plus runoff, in/year) generated for Sonoma County Open Space District parcels, 30-year averages, 1981-2099

	1981-2010	2040-2069			2070-2099		
Water availability (Recharge + Runoff)	Current	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall
SCAPOSD parcels	(in/yr)	% chg	% chg	% chg	% chg	% chg	% chg
Dogbane Preserve	7.0	115%	-1%	-50%	170%	39%	-61%
Haroutunian - North	7.7	113%	1%	-47%	167%	40%	-57%
Haroutunian - South	9.6	74%	-9%	-47%	115%	24%	-54%
San Francisco Archdiocese	10.2	75%	-8%	-46%	115%	26%	-53%
Occidental Road Wetland Transfer	11.5	72%	-9%	-45%	110%	24%	-52%
Ho	9.0	97%	6%	-42%	144%	42%	-49%
Wright Preservation Bank	12.9	60%	-9%	-43%	93%	18%	-48%
Oken	14.3	60%	-2%	-38%	90%	21%	-41%
Young/Armos	14.4	60%	1%	-32%	88%	24%	-35%
Calabasas Creek Open Space Preserve	22.9	47%	-1%	-33%	68%	15%	-34%
Healdsburg Ridge Open Space Preserve - Sonoma Land Trust	22.4	45%	-4%	-33%	64%	11%	-33%
Healdsburg Ridge Open Space Preserve	23.4	42%	-4%	-32%	61%	10%	-32%
Paulin Creek Preserve	17.9	43%	-3%	-32%	65%	14%	-32%
McCullough	23.9	43%	-2%	-31%	62%	12%	-31%
Cresta	24.7	41%	-2%	-30%	59%	11%	-30%
Auberge	26.2	44%	0%	-29%	62%	15%	-29%
Carrington Ranch	17.6	60%	6%	-28%	87%	25%	-29%
Keegan and Coppin	25.3	37%	-3%	-29%	55%	11%	-29%
McCrea Fee	36.7	33%	-3%	-27%	49%	9%	-28%
Montini Open Space Preserve	18.1	48%	1%	-28%	70%	21%	-28%
Cresta II	27.5	36%	-3%	-28%	52%	10%	-28%
Coopers Grove	32.4	39%	0%	-25%	56%	13%	-26%
Sonoma Mountain Trail Corridor - Skiles	39.3	34%	-1%	-25%	49%	11%	-26%
Saddle Mountain Open Space Preserve	28.8	42%	1%	-25%	58%	14%	-26%
Sonoma Mountain Trail Corridor - Wilroth Donation	37.6	36%	-1%	-25%	51%	11%	-26%
Sonoma Mountain Ranch	41.2	36%	0%	-24%	51%	12%	-25%
Jacobs Ranch	32.3	41%	1%	-24%	58%	15%	-25%
Wright Hill Ranch	32.8	44%	3%	-23%	62%	17%	-23%
Average	32.7	39%	0%	-25%	56%	13%	-26%

An important aspect of climatic water deficit is that, in comparison to rainfall for example, all of the future scenarios project a unidirectional trend in water deficits into the future. Climatic water deficit in Sonoma County is projected to increase even in high rainfall scenarios. From 1981-2010, the average climatic water deficit for Sonoma County was 28 inches per year per unit area. By the mid-century, water deficits are projected to increase from 5-12%, with an average 8% increase across scenarios. By the end of the century, a range of 10-22% greater water deficit, with an average increase of 14% across all scenarios, is projected. An increase of 10% in climatic water deficit in Sonoma County corresponds to an increased landscape demand in the order of 3 inches of rain per year. Fog could potentially offset these rises, but because future fog patterns are so uncertain, its influence on future climatic water deficit is also uncertain.

Slide 40-48 in the companion *CRNB SCAPOSD and Regional Parks deck.ppt* illustrate the data findings above.

Management Question: Which parcels in the combined portfolio are prone to extreme drought stress?

From 2040-2069, the range of potential change in climatic water deficit is projected as follows.

Scenario 3: Warm, moderate rainfall – 30.1 in/year (with 44.8 in/y rainfall), 6% greater deficit than current average

Scenario 5: Warm, high rainfall – 29.6 in/year (with 57.2 in/y rainfall), 5% greater deficit than current average

Scenario 6: Hot, low rainfall – 31.8 in/year (with 37.2 in/y rainfall), 12% greater deficit than current average

From 2070-2099, the range of potential change in climatic water deficit is projected as follows.

Scenario 3: Warm, moderate rainfall – 31.2 in/year (with 48.6 in/y rainfall), 10% greater deficit than current average

Scenario 5: Warm, high rainfall – 31.1 in/year (with 61.8 in/y rainfall), 10% greater deficit than current average

Scenario 6: Hot, low rainfall – 34.5 in/year (with 36.2 in/y rainfall), 22% greater deficit than current average

Sonoma County Parks are generally located within the drier watersheds in the county, which also have the highest climatic water deficits, while the District parcels span the entire range of climatic water deficits for all watersheds. Maxwell Farms, Sonoma Valley, and Shiloh Ranch are the parks with the lowest deficits, while Cloverdale River, Crane Creek and Taylor Mountain are the parks with the highest deficits. Table 5 provides a comparison of climatic water deficit for all Sonoma County Regional Parks and Table 6 provides a comparison of climatic water deficit for all District parcels.

Table 5: Climatic water deficit (CWD) projections (in/year) generated for Sonoma County Regional Parks, 30-year averages (1981-2099).

	1981-2010	2040-2069			2070-2099		
Climatic Water Deficit	Current	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall
Regional Parks	(in/yr)	% chg	% chg	% chg	% chg	% chg	% chg
Maxwell Farms Regional Park	27.1	5%	7%	18%	11%	12%	26%
Soda Springs Reserve	28.8	8%	10%	14%	13%	13%	25%
Tolay Lake Regional Park	28.3	5%	7%	15%	11%	11%	23%
Sonoma Valley Regional Park	27.8	5%	6%	14%	10%	10%	23%
Shiloh Ranch Regional Park	27.9	4%	6%	12%	9%	10%	21%
Helen Putnam Regional Park	30.4	5%	6%	12%	10%	11%	21%
Hood Mountain Regional Park	29.7	4%	5%	11%	9%	9%	20%
Taylor Mountain Regional Park	31.2	5%	6%	11%	9%	10%	20%
Crane Creek Regional Park	31.4	4%	5%	10%	8%	9%	19%
Cloverdale River Park	31.7	3%	4%	8%	7%	7%	17%
Average	*29.4*	*5%*	*6%*	*12%*	*10%*	*10%*	*21%*

Based on the combined effect of low total water availability and high climatic water deficit, parcels in the combined portfolio that are projected to experience to extreme drought stress in the future could include Dogbane Preserve, Haroutunian, San Francisco Archdiocese and Occidental Road Wetland Transfer District Parcels, and Maxwell Farms, Tolay Lake, and Sonoma Valley Regional Parks.

Fog has the potential to offset some of the patterns of climatic water deficit because of its mediating effect on air temperature and evapotranspiration. Current patterns of fog show more hours per day along the extreme coast and in the inland valleys of Sonoma County. The valley fog overlays those areas with the highest climatic water deficit. However, fog hours have been steadily diminishing over the last 30 years, and while future fog patterns are very uncertain, there is the potential for the trend to continue, providing less relief from landscape stress in the future.

Table 6: Climatic water deficit (CWD) projections (in/year) generated for Sonoma County Open Space District parcels, 30-year averages (1981-2099)

	1981-2010	2040-2069			2070-2099		
Climatic Water Deficit	Current	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall	Warm & high rainfall	Warm & moderate rainfall	Hot & low rainfall
SCAPOSD parcels	(in/yr)	% chg	% chg	% chg	% chg	% chg	% chg
Dogbane Preserve	18.90	5%	12%	31%	13%	16%	41%
Haroutunian - North	18.6	4%	11%	30%	12%	16%	40%
Occidental Road Wetland Transf	20.8	6%	10%	23%	14%	15%	33%
San Francisco Archdiocese	23.1	6%	10%	22%	14%	15%	32%
Haroutunian - South	23.6	7%	10%	22%	14%	15%	31%
Ho	23.1	5%	9%	21%	13%	14%	31%
Wright Preservation Bank	24.2	6%	9%	19%	13%	14%	28%
Carrington Ranch	25.2	6%	8%	15%	12%	12%	26%
Oken	26.7	5%	8%	15%	11%	12%	25%
Wright Hill Ranch	27.0	6%	7%	12%	11%	10%	23%
Calabasas Creek Open Space Pre	26.8	5%	6%	13%	10%	10%	23%
Young/Armos	28.8	5%	6%	14%	10%	11%	22%
McCullough	27.9	5%	6%	12%	10%	10%	22%
Healdsburg Ridge Open Space P	28.0	4%	6%	12%	9%	10%	21%
McCrea Fee	30.1	5%	6%	11%	10%	10%	21%
Sonoma Mountain Trail Corridor	29.0	5%	6%	11%	10%	9%	21%
Sonoma Mountain Ranch	29.3	5%	5%	10%	9%	9%	20%
Cresta	28.4	4%	6%	11%	9%	9%	20%
Coopers Grove	29.2	5%	6%	11%	9%	9%	20%
Sonoma Mountain Trail Corridor	29.3	5%	5%	11%	9%	9%	20%
Auberge	30.5	4%	5%	10%	9%	9%	20%
Healdsburg Ridge Open Space P	28.7	4%	6%	11%	9%	10%	20%
Jacobs Ranch	29.6	5%	5%	10%	9%	9%	20%
Keegan and Coppin	32.8	5%	6%	11%	9%	10%	19%
Paulin Creek Preserve	32.2	4%	6%	11%	9%	10%	19%
Saddle Mountain Open Space Pr	30.7	4%	5%	10%	8%	9%	19%
Cresta II	31.5	4%	5%	10%	8%	9%	18%
Montini Open Space Preserve	35.4	4%	4%	9%	8%	9%	17%
Average	*31.0*	*4%*	*5%*	*10%*	*9%*	*9%*	*19%*

PowerPoint slides 49-55 in the companion *CRNB SCAPOSD and Regional Parks deck.ppt* illustrate the data findings above.

Native Vegetation Response

The following section highlights results generated in response to the key management question regarding changes in climate and resulting impacts on native vegetation composition in the combined portfolio of parks and open space land.

Management Question: What kind of transitions in native vegetation may occur on parks and open space lands?

The TBC3 vegetation model developed by Dr. David Ackerly's lab at UC Berkeley was used to model potential changes in suitability for native vegetation communities in Sonoma County due to climate change. For 22 vegetation types mapped via the Conservation Lands Network, the probabilities for each vegetation type to occur in a given location within the greater San Francisco Bay Area region under the six future climate scenarios were modeled. Overall, the sensitivity of vegetation to climate change was found to be highly heterogeneous across the region, but an unexpected outcome was that sensitivity to climate change is higher closer to the coast, on north-facing slopes and in areas of higher precipitation. While cool or moist sites may be buffered from the impacts of climate change and serve as refugia for the vegetation currently in those locations, the model suggests they will still be highly dynamic and relatively sensitive to climate-driven vegetation transitions (Ackerly et al. 2015).

Changes in vegetation were modeled for 8 Sonoma County "Landscape Units" defined by the Bay Area Upland Habitat Goals Project (BAOSC 2011, see data product in Appendix A). Model results don't project when changes will occur in the future; rather which locations are more or less likely to be suitable for a given vegetation type. In Sonoma County, an overall reduction in suitable conditions for Redwood, Douglas-fir forests, and Montane Hardwoods is projected across the majority of scenarios, with an increase in suitable conditions for Coast Live Oak, Semi-desert Scrub, and Chamise Chaparral projected for all scenarios. Changes in vegetation for the Sonoma Coast Range specifically is also modeled as one of the "Landscape Units" defined by the Bay Area Upland Habitat Goals Project in 2011.

Sonoma Coast Range species level "winners and losers" can also be identified using four-square diagrams, with each color-coded quadrant in the square reflecting higher or lower temperature and rainfall, as well as the direction of change in percent cover in suitable climate for each vegetation type. Coast Live Oak does well in all future scenarios regardless of warming magnitude and rainfall. California Bay is sensitive to rainfall in the Coast Ranges, and therefore does well in the moderate rainfall scenarios, but declines in hot and low rainfall. Tan Oak is sensitive to rainfall and temperature; therefore it shows declines in all scenarios.

PowerPoint slides 56-63 in the companion *CRNB SCAPOSD and Regional Parks deck.ppt* illustrate the data findings above.

Fire Risks

The following section highlights results generated in response to the key management question regarding changes in fire risk in the combined portfolio of parks and open space land. Maps of future climate scenarios are shown for business-as-usual scenarios for end-century projections, and individual parcels and parks are illustrated for mid-century projections.

Management Question: How are fire risks projected to impact the combined portfolio?

From 1971-2000, the average historic fire return interval for Sonoma County was an average of 172 years.

For 2040-2069, fire return intervals are projected as follows.

Scenario 3: Warm, moderate rainfall – 142-year average projected return interval, reduced by 17%

Scenario 6: Hot, low rainfall – 137-year average projected return interval, reduced by 20%

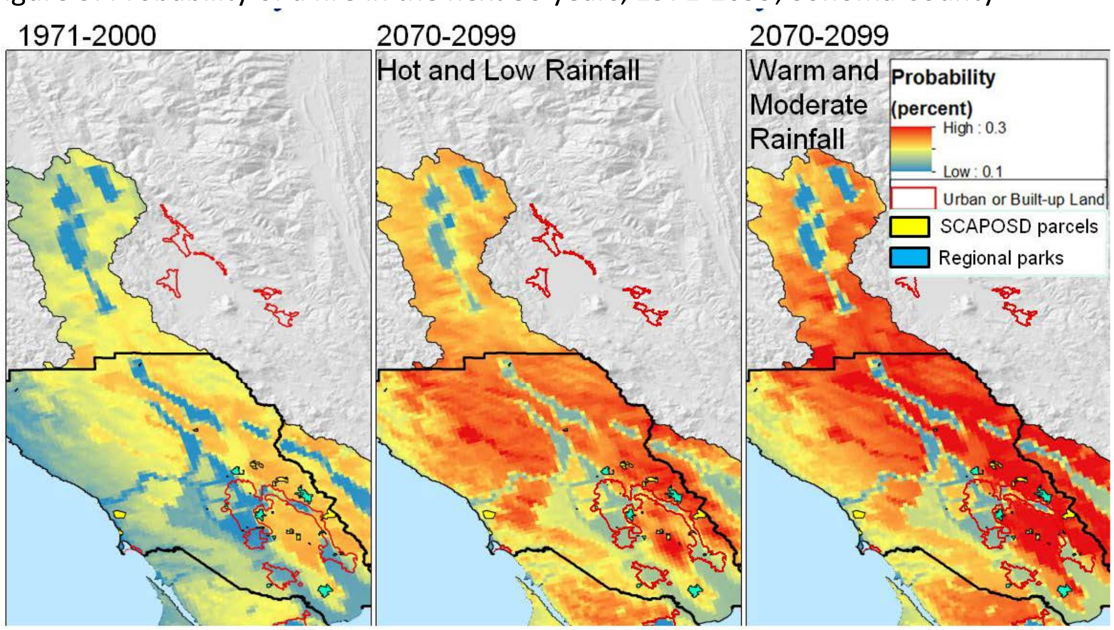
For 2070–2099, fire return intervals are projected as follows.

Scenario 3: Warm, moderate rainfall – 120-year average projected return interval, reduced by 30%

Scenario 6: Hot, low rainfall – 117-year average projected return interval, reduced by 32%

Specifically for the combined portfolio, the fire return interval goes down an average of 18% for Regional Parks and 13% for District parcels by mid-century.

Figure 5. Probability of a fire in the next 30 years, 1971-2099, Sonoma County



From 1971-2000, the average historic probability of burning occurring one or more times within 30 years for Sonoma County was 17%. By the end of the century, the probability of burning doubles in some locations.

From 2040-2069, the probability of burning occurring one or more times within 30 years throughout the region is projected as follows.

Scenario 3: Warm, moderate rainfall – 20% increase in probability
Scenario 6: Hot, low rainfall – 21% increase in probability

Specifically for the combined portfolio of parcels, the probability of burning occurring one or more times within 30 years goes up an average of 18% for Regional Parks and 16% for District parcels by mid-century.

From 2070-2099, the probability of burning occurring one or more times within 30 years is projected as follows.

Scenario 3: Warm, moderate rainfall – 23% probability
Scenario 6: Hot, low rainfall – 23% probability

It's important to note that the probability of fire occurring is actually higher in many locations in the warm and moderate rainfall scenario as opposed to the hot and low rainfall scenario due to the impact of more rainfall on the generation of fuels.

PowerPoint slides 65-70 in the companion *CRNB SCAPOSD and Regional Parks deck.ppt* illustrate the data findings above.

Bridging Science and Management

Climate Ready North Bay data resources developed for Sonoma County are intended to inform specific land and water management actions under the County's Agricultural Preservation and Open Space District and Regional Parks jurisdiction today and in the future. In the process of detailed exchanges with staff, the following potential applications of and audiences for these data sets were identified.

Potential Climate Ready North Bay Data Applications

- Use of hydrology and other model outputs to identify potential acquisitions of high water resource and climate resiliency value
- Consideration of data products in prioritizing which parks need comprehensive management plans, and which ones may be vulnerable to relatively high climate impacts
- Integration of results into specific operational considerations of natural resource plans and fire mitigation planning
- Use of materials for community outreach and education

Potential Climate Ready Data Audiences

- Sonoma County Agricultural Preservation and Open Space District and Regional Parks planners and maintenance and operation staff
- Partner land management agencies
- Adjacent private property owners bordering parks
- Grant funders
- The community at large

Participating Stakeholders

With special thanks to the Sonoma County Agricultural Preservation and Open Space District's Tom Robinson for coordination and all participating managers:

- Tom Robinson, Conservation Planner, Sonoma County Agricultural Preservation and Open Space District
- Sheri Emerson, Stewardship Coordinator, Sonoma County Agricultural Preservation and Open Space District
- John Ryan, Volunteer Coordinator, Sonoma County Regional Parks
- Jen Stanfield, Stewardship Coordinator, Sonoma County Regional Parks
- Bert Whitaker, Park Operations Manager, Sonoma County Regional Parks

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APPENDICES

Appendix A: List of Climate Ready Analyses Conducted for Sonoma County

REGIONAL HYDROLOGY GIS DATABASE

Data Product: TBC3 Bay Area Basin Characterization Model Database

An ESRI Geographical Information System (GIS) raster database. This database includes 18-acre monthly resolution data for Sonoma County, including historic data for 1920-2010 and 18 climate future projections selected to cover the full range of internationally peer-reviewed Global Climate Circulation Models (Flint and Flint 2013). This database is the source of all map products and BCM time series represented in the technical memo and PowerPoint slide deck. It may be queried for future analyses by partner agencies.

Filename: *CRNB TBC3 Bay Area BCM 1920-2099.gdb*

NORTH BAY RAINFALL DATABASE

Data Product: Regional Rainfall Analysis

Spreadsheet of annual rainfall totals for North Bay study region and frequency analysis of exceedence of high and low rainfall relative to benchmarks, including minimum and maximum of historic record and 10^{th} and 90^{th} percentiles of assumed “pre-climate change” conditions. Source data is the California BCM (Flint and Flint 2013).

Filename: *CRNB annual regional rainfall.xls*

SONOMA COUNTY CLIMATE: HYDROLOGY VARIABLES

Data Product: Basin Characterization Model Outputs—Sonoma County Averages

Spreadsheet table of downscaled climate input values (temperature and precipitation) and BCM outputs including runoff, recharge, climatic water deficit, and evapotranspiration averaged over Sonoma County in 30-y time steps for two historic time periods and three projected periods for three “bounding” business-as-usual scenarios (with respect to emissions), including maximum, moderate, and minimum rainfall estimates for the region.

Filename: *CRNB Sonoma County BCM summary.xls*

SONOMA COUNTY PROTECTED PARCELS HYDROLOGY ANALYSIS

Data Product: Comparison of Water Supply and Deficit Indicators by Parcel

This spreadsheet includes calculated estimates of recharge, runoff, and water deficit quantities associated with each parcel used for ranking and plotting parcels with respect to current and projected conditions.

Filename: *CRNB SCPAOSD and Parks parcels-water supply and deficits.xls*

SONOMA COUNTY VEGETATION TRANSITION REPORTS

Data Product: Climate Ready Vegetation Summary Fact Sheets

These fact sheets summarize potential transitions in native vegetation cover using the UC Berkeley Ackerly lab vegetation model (Ackerly et al 2105).

Filename: CRNB Climate Ready Vegetation Reports-Sonoma County.pdf

SONOMA COUNTY FIRE MODELING FOR PROTECTED PARCELS

Data Product: County Summary and Parcel Summaries of Fire Risks

This spreadsheet includes a summary of the risk of a burn within 30 years and an estimated fire return interval from the Krawchuk and Moritz 2012 model.

CRNB SCAPOSD and Parks Fire probability and return interval.xls

IMPACTS OF CLIMATE CHANGE ON VEGEATION: SONOMOA COUNTY

Data Product: Standardized 4-page vegetation reports by landscape

Based on the dynamic vegetation model (Ackerly et al 2015) for all landscape units of the project.

Filename: *CRNB Sonoma County Valley Vegetation Reports.pdf*

Appendix B: Selected Future Climate Scenarios for Detailed Analysis

Table 1. Six Selected Futures for North Bay Regional Vulnerability Assessment (in yellow) in context of original 18 TBC3 scenarios

Graph Label	Model	Emissions Scenario	Assessment Report Vintage	Time Period	Summer Tmax °C	Summer Tmax Increase	Winter Tmin °C	Winter Tmin Increase °C	Annual Precipitation (mm)	% Change Precipitation	% Change Water Deficit
	historic (hst)	N/A	N/A	1951-1980	27.9		3.9		1087		
	current	N/A	N/A	1981-2010	27.9		4.3	0.4	1095	1%	1%
	Assumption: Business as Usual										
6	miroc-esm	rcp85	AR5	2070-2099	34.0	6.1	8.4	4.6	865	-20%	24%
	miroc3_2_mr	A2	AR4	2070-2099	33.0	5.1	7.1	3.2	887	-18%	20%
	ipsl-cm5a-lr	rcp85	AR5	2070-2099	33.0	5.0	9.6	5.7	1325	22%	16%
	fgoals-g2	rcp85	AR5	2070-2099	32.3	4.3	7.1	3.2	1099	1%	22%
5	cnrm-cm5	rcp85	AR5	2070-2099	31.9	4.0	7.7	3.9	1477	36%	12%
4	GFDL	A2	AR4	2070-2099	31.7	3.8	7.7	3.9	861	-21%	21%
3	ccsm4	rcp85	AR5	2070-2099	31.4	3.5	7.1	3.2	1163	7%	12%
2	PCM	A2	AR4	2070-2099	30.6	2.6	6.3	2.4	1159	7%	11%
				Business as Usual Average	**32.2**	**4.3**	**7.6**	**3.7**	**1104**	**2%**	**17%**
	Assumption: Mitigated										
	miroc-esm	rcp60	AR5	2070-2099	32.6	4.7	7.1	3.2	922	-15%	14%
	giss_aom	A1B	AR4	2070-2099	30.9	3.0	6.4	2.5	1104	2%	11%
	csiro_mk3_5	A1B	AR4	2070-2099	30.8	2.8	6.5	2.6	1506	38%	4%
				Mitigated Average	**31.4**	**3.5**	**6.6**	**2.8**	**1177**	**8%**	**10%**
	Assumption: Highly Mitigated										
	mpi-esm-lr	rcp45	AR5	2070-2099	30.1	2.2	5.8	1.9	1148	6%	5%
	miroc-esm	rcp45	AR5	2070-2099	30.1	2.2	6.9	3.0	949	-13%	14%
1	GFDL	B1	AR4	2070-2099	30.1	2.2	6.1	2.2	923	-15%	10%
	PCM	B1	AR4	2070-2099	29.5	1.6	5.5	1.7	1197	10%	5%
				Highly Mitigated Average	**30.0**	**2.1**	**6.1**	**2.2**	**1055**	**-3%**	**8%**
	Assumption: Super Mitigated										
	miroc5	rcp26	AR5	2070-2099	29.8	1.9	5.2	1.3	953	-12%	9%
	mri-cgcm3	rcp26	AR5	2070-2099	29.2	1.3	4.8	0.9	1315	21%	2%
	giss-e2-r	rcp26	AR5	2070-2099	28.4	0.4	4.6	0.7	1344	24%	-4%
				Super Mitigated Average	**29.1**	**1.2**	**4.8**	**1.0**	**1204**	**11%**	**2%**
				ALL Scenarios Average	**31.1**	**3.2**	**6.7**	**2.8**	**1122**	**3%**	**11%**

Table 2. Six Selected Futures for North Bay Regional Analysis: Mid-Century Values

	Model	Emissions Scenario	IPCC Assessment	Short-hand name	Time Period	Summer Tmax °F	Summer Tmax Increase °F	Winter Tmin °F	Winter Tmin Increase °F	Annual Precipitation (in)	% Change Precipitation	% Change Water Deficit
Observed	historical baseline	N/A	N/A		1951-1980	82.2		39.0		42.8		
	current	N/A	N/A		1981-2010	82.2		39.7	0.7	43.1	1%	1%
Projections												
1	GFDL	B1	AR4	low warming-low rainfall	2040-2069	85.2	2.9	42.7	3.7	42.6	-1%	6%
2	PCM	A2	AR4	low warming-mod rainfal	2040-2069	85.0	2.7	41.1	2.1	43.8	2%	7%
3	CCSM-4	rcp85	AR5	warm-mod rainfall	2040-2069	86.0	3.7	42.0	3.0	42.2	-1%	8%
4	GFDL	A2	AR4	warm-low rainfall	2040-2069	86.3	4.0	43.2	4.2	39.8	-7%	12%
5	CNRM-CM5	rcp85	AR5	warm-high rainfall	2040-2069	86.5	4.2	43.0	4.0	53.8	26%	6%
6	MIROC-ESM	rcp85	AR5	hot-low rainfall	2040-2069	89.2	6.9	41.4	2.4	35.0	-18%	14%
Average						**86.3**	**4.1**	**42.2**	**3.2**	**42.9**	**0%**	**9%**

Table 3. Six Selected Futures for North Bay Regional Analysis: End-Century Values

	Model	Emissions Scenario	IPCC Assessment	Short-hand name	Time Period	Summer Tmax °F	Summer Tmax Increase °F	Winter Tmin °F	Winter Tmin Increase °F	Annual Precipitation (in)	% Change Precipitation	% Change Water Deficit
Observed	historical baseline	N/A	N/A		1951-1980	82.2		3.9		42.8		
	current	N/A	N/A		1981-2010	82.2		4.3	0.4	43.1	1%	1%
Projections												
1	GFDL	B1	AR4	low warming-low rainfall	2070-2099	86.2	4.0	6.1	2.2	36.3	-15%	10%
2	PCM	A2	AR4	low warming-mod rainfal	2070-2099	87.0	4.7	6.3	2.4	45.6	7%	11%
3	CCSM-4	rcp85	AR5	warm-mod rainfall	2070-2099	88.5	6.2	7.1	3.2	45.8	7%	12%
4	GFDL	A2	AR4	warm-low rainfall	2070-2099	89.1	6.9	7.7	3.9	33.9	-21%	21%
5	CNRM-CM5	rcp85	AR5	warm-high rainfall	2070-2099	89.5	7.2	7.7	3.9	58.1	36%	12%
6	MIROC-ESM	rcp85	AR5	hot-low rainfall	2070-2099	93.3	11.0	8.4	4.6	34.0	-20%	24%
Average						88.9	**6.7**	**7.2**	**3.3**	**42**	**0.0**	**15%**

Table 4. North Bay Region Basin Characterization Model Outputs, 1920-1999

		Historical	Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Variable	Units	1951-1980	1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in	42.6	43.0	53.6	57.9	42.1	45.6	34.8	33.9
Tmn	Deg F	38.8	39.7	43.0	45.9	41.9	44.8	44.1	47.3
Tmx	Deg F	82.2	82.2	86.4	89.4	86.0	88.5	89.2	93.4
CWD	in	28.0	28.4	29.8	31.3	30.3	31.4	32.0	34.6
Rch	in	11.0	10.2	12.8	13.2	10.7	10.8	8.2	8.5
Run	in	14.0	14.2	22.8	26.9	14.0	17.3	9.7	9.3

				Percent Change from Current or Change in Temperature					
			Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
Variable	Units		1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in		43.0	25%	35%	-2%	6%	-19%	-21%
Tmn	Deg F		39.7	3.2	6.1	2.2	5.0	4.3	7.6
Tmx	Deg F		82.2	4.1	7.2	3.8	6.3	7.0	11.2
CWD	in		28.4	5%	10%	7%	11%	12%	22%
Rch	in		10.2	25%	29%	4%	6%	-20%	-17%
Run	in		14.2	61%	90%	-1%	22%	-32%	-34%

Appendix C: Climate Models Used in the Basin Characterization Model and Glossary of Terms

Table 1. Global Circulation Models used in the California Basin Characterization Model calculation of hydrologic response to future climate projections.

Originating Group(s)	Country	Model Abbreviation	IPCC Assessment Report	Emissions scenario or representative concentration pathway	Downscaling method
National Center for Atmospheric Research	USA	CCSM_4	5	RCP 8.5	BCSD*
Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	France	CNRM-CM5	5	RCP 8.5	BCSD
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS,Tsinghua University	China	FGOALS-G2	5	RCP 8.5	BCSD
NASA / Goddard Institute for Space Studies	USA	GISS-E2	5	RCP 2.6	BCSD
Institut Pierre Simon Laplace	France	IPLS-CM5A-LR	5	RCP 8.5	BCSD
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC-ESM	5	RCP 4.5	BCSD
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	Japan	MIROC-ESM	5	RCP 6.0	BCSD
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	Japan	MIROC-ESM	5	RCP 8.5	BCSD
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	Japan	MIROC5	5	RCP 2.6	BCSD
Max-Planck-Institut für		MPI-ESM-LR	5	RCP 4.5	BCSD

Originating Group(s)	Country	Model Abbreviation	IPCC Assessment Report	Emissions scenario or representative concentration pathway	Downscaling method
Meteorologie (Max Planck Institute for Meteorology)					
Meteorological Research Institute	Japan	MRI-CGCM3	5	RCP 2.6	BCSD
CSIRO Atmospheric Research	Australia	CSIRO_MK3_5	4	A1B	BCSD
NASA / Goddard Institute for Space Studies	USA	GISS_AOM	4	A1B	BCSD
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3_2_MEDRES	4	A2	BCSD
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL	4	A2	CA**
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory	USA	GFDL	4	B1	CA
National Center for Atmospheric Research	USA	PCM	4	A2	CA
National Center for Atmospheric Research	USA	PCM	4	B1	CA

* Bias correction/spatial downscaling (Wood and others, 2004)

** Constructed analogues (Hidalgo and others, 2008)

Table 2. Downscaled climate model input and hydrologic model output variables used in the California Basin Characterization Model.

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

Variable	Code	Creation Method	Units	Equation/model	Description
Snowpack	pck	BCM	mm	Prior month pck + snow – subl –melt	Amount of snow as a water equivalent that is accumulated per month summed annually (if divided by 12 would be average monthly snowpack)
Snowmelt	melt	BCM	mm	Calculated*, applied to pck	Amount of snow that melted summed annually (snow to liquid water)
Excess water	exc	BCM	mm	ppt – pet	Amount of water that remains in the system, assuming evapotranspiration consumes the maximum possible amount of water, summed annually for positive months only

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

Table 3: Glossary of Basin Characterization Model Terms

AET: Actual Evapotranspiration (mm or in H2O per month or per year)
AET is the amount of water transferred from the soil to the atmosphere through vegetation transpiration and direct surface evaporation. Decreased AET means less vegetation productivity. Increased AET means more vegetation productivity.
CWD: Climatic Water Deficit (mm or in H2O per year)
CWD is an integrated measure of seasonal water stress and aridity. It is the additional amount of water that could have been evaporated had it been freely available. It is calculated as a cumulative sum over the dry season. Increased CWD means higher water stress for vegetation, and greater risk of fire. Greatly increased CWD (50-100+ mm/year over 30 years) can lead to death of existing vegetation through drought stress. Decreased CWD means less water stress and potentially lower fire risk.
PET: Potential Evapotranspiration (mm or in H2O per month or per year)
PET is the amount of water that could be evaporated if it were freely available (or, provided an unlimited supply of water). Increased PET means higher evaporative demand. Decreased PET means less evaporative demand.
DJF Tmin: **Average Winter (December-February) daily minimum temperature °C** or **°F**
The average minimum temperature over the coldest months of the year (December- February). DJF Tmin is a prime determinant of frost and freeze frequency, and chilling hours for winter dormant plants.
JJA Tmax: Average Summer (June-August) daily maximum temperature °C or **°F**
The average summer maximum temperature in the three warmest months of the year (June-August). JJA Tmax is a prime determinant of heat wave extremes, and is an important contributor to PET and aridity.
PPT: Precipitation (mm or in H2O per month or per year)
PPT is the total annual precipitation in mm (25.4 mm = 1”). Increased PPT directly increases runoff, may increase recharge if distributed through the rainy season, and can ameliorate aridity if it falls in March-May (higher AET and lower CWD). Decreased PPT directly decreases runoff and recharge, and increases aridity (lower AET and higher CWD).
Recharge: Recharge (mm or in H2O per month or per year)
Recharge is water that percolates below the rooting zone and becomes groundwater for more than a month. Recharge is affected greatly by bedrock permeability and soil depth. Recharge is a precious resource. Recharge provides natural subsurface storage that is the source of stream baseflow in the dry season, and many Bay Area communities depend on well water. Conservation of high recharge areas is a high priority. Increases in recharge results in greater groundwater aquifer storage and maintenance of baseflow (stream flows during periods absent precipitation), especially during multi-year droughts. Decreases in recharge results in less groundwater storage and loss of baseflow, especially during multi-year droughts.
Runoff: Runoff (mm or in H2O per month or per year)
Runoff is the water that feeds surface water stream flow, and generally occurs during storms when the soil is fully saturated with water. Runoff occurs on shallower soils more rapidly than on deeper soils.

Appendix D: Sonoma County Basin Characterization Model Summary Data Tables

Table 1: Basin Characterization Model, Sonoma County: Three "business as usual" models used for map products, 1951-2099.

Variable	Units	Historic	Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
		1951-1980	1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in	42.6	43.0	53.6	57.9	42.1	45.6	34.8	33.9
Tmn	Deg F	44.8	45.8	49.2	52.0	48.5	51.3	50.6	54.3
Tmx	Deg F	71.2	71.2	75.0	77.7	74.4	77.1	76.8	80.7
CWD	in	28.0	54.9	57.4	60.1	58.3	60.3	61.5	66.7
Rch	in	11.0	10.2	12.8	13.2	10.7	10.8	8.2	8.5
Run	in	14.0	14.2	22.8	26.9	14.0	17.3	9.7	9.3

Percent Change from Current

Variable	Units	Historic	Current	Moderate Warming, High Rainfall		Moderate Warming, Moderate Rainfall		Hot, Low Rainfall	
		1951-1980	1981-2010	2040-2069	2070-2099	2040-2069	2070-2099	2040-2069	2070-2099
Ppt	in	42.6	43.0	25%	35%	-2%	6%	-19%	-21%
Tmn	Deg F	44.8	45.8	3.4	6.2	2.7	5.5	4.8	8.4
Tmx	Deg F	71.2	71.2	3.8	6.5	3.2	5.9	5.6	9.5
CWD	in	28.0	54.9	5%	10%	6%	10%	12%	22%
Rch	in	11.0	10.2	25%	29%	4%	6%	-20%	-17%
Run	in	14.0	14.2	61%	90%	-1%	22%	-32%	-34%

Variables: Ppt=precipitation, Tmn=minimum winter temperature (monthly), Tmx=maximum summer temperature (monthly), CWD=climatic water deficit, Rch=recharge, Run=runoff