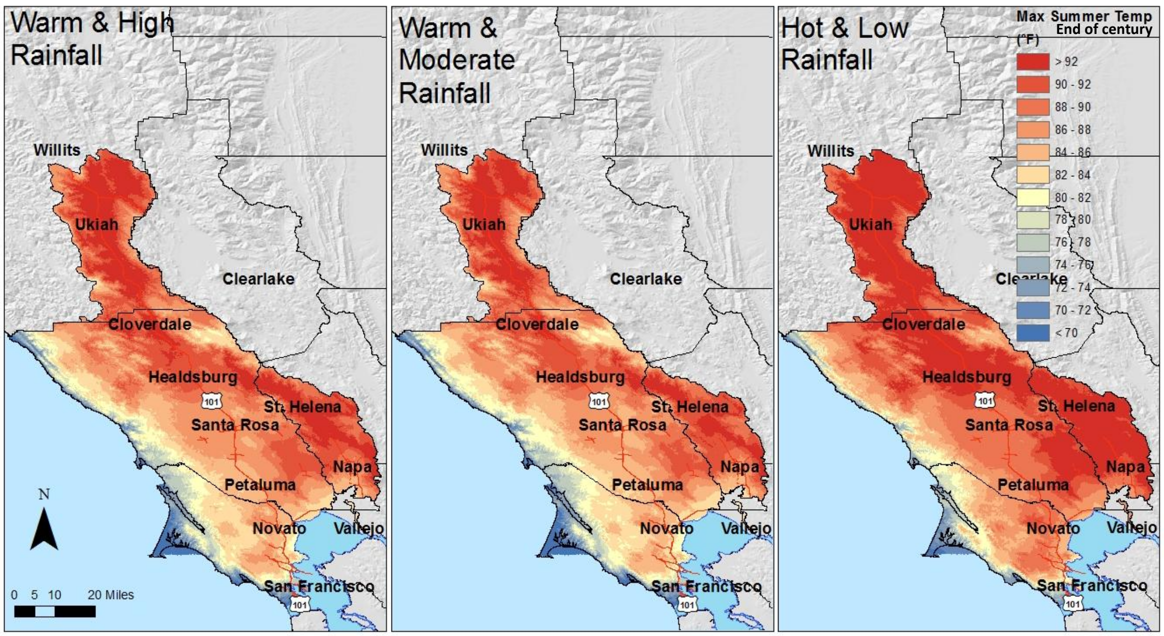
Climate Ready North Bay
Vulnerability Assessment Data Products

North Bay Region Summary

January 2016



Elisabeth Micheli,* Lorraine Flint (USGS), Sam Veloz (Point Blue Conservation Science), Kelley (Higgason) Johnson* and Nicole Heller*

(*Dwight Center for Conservation Science at Pepperwood)

A Dwight Center for Conservation Science

Technical Memorandum

Table of Contents

Citation: Micheli E., L. Flint, S. Veloz, K. Johnson (Higgason), and N. Heller. 2016. *Climate Ready North Bay Vulnerability Assessment Data Products: 1. North Bay Region Summary.* A technical memorandum prepared by the Dwight Center for Conservation Science at Pepperwood, Santa Rosa, CA, for the California Coastal Conservancy and Regional Climate Protection Authority, 38 pp.

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.

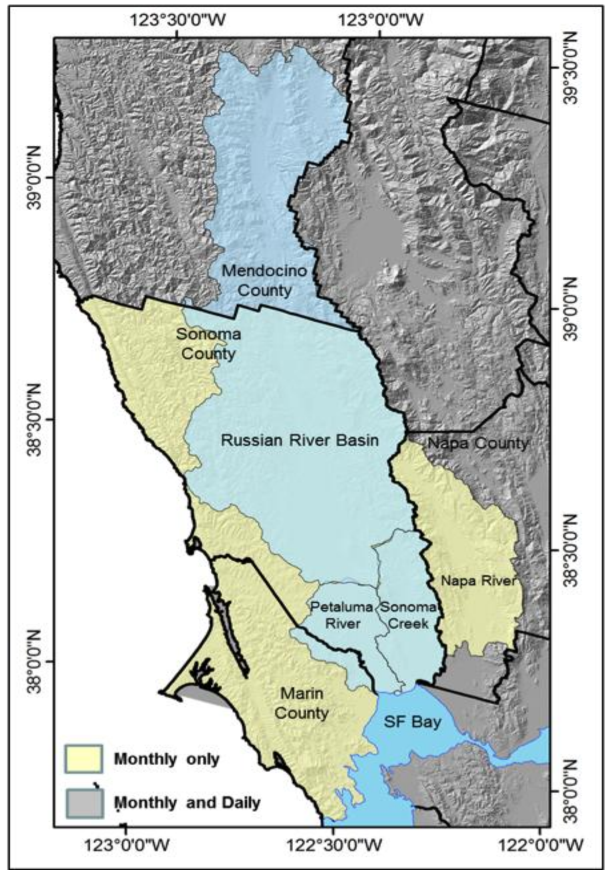


Figure 1. Map of study region, including regions where daily data is available (blue) and where monthly data is available (yellow)

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 core regional data sets used by *Climate Ready North Bay* collaboration as a starting point for understanding potential climate stressors facing North Bay open spaces and watersheds in the decades to come. This memo summarizes the stakeholder engagement process and the basic regional data sets. Data sets 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 and summary tables, and a list of regional data products generated. A PowerPoint deck is also provided that showcases sample data products and take home messages for the region (see *CRNB North Bay Region deck.ppt).* Companion technical memoranda and supporting materials for each engaged agency respond to their specific management questions (for companion user-group Technical Memoranda citations, see Micheli et al. 2016 Parts 2-6 in References Cited). The North Bay Region data sets described here are the foundation of vulnerability assessment products co-created with user groups comprised of engaged Marin, Sonoma, and Napa resource agencies.

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 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 1-11 illustrate the project overview in the companion *CRNB North Bay Region.ppt.*

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 details on the 18 GCMs selected by TBC3 for downscaling.

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,* see slides 12-16 of *CRNB North Bay Region.ppt)*.

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)

Basin Characterization Model
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), 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 water 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 17-23 in the companion *CRNB North Bay Region.ppt* illustrate the Basin Characterization Model methods*.*

Climate Ready North Bay Projected Vegetation Model (PVM)
Projected transitions in dominant vegetation types in response to future climates were modeled based on movement of the 'climate envelopes' occupied by each vegetation type. This analysis compares current vegetation cover that projected under mid- and end-century conditions for each of the six future climate scenarios. The model projects the equilibrium response of vegetation in response to future climates, assuming vegetation maintains currently observed distributions in relation to climate gradients, but is not able to predict how long it will take for these changes to unfold (i.e. decades vs. centuries) (Ackerly et al. 2015). Model results are summarized for the entire region and in selected "landscape units" (as defined by the Bay Area Open Space Council's Conservation Lands Network), and are presented in companion North Bay Climate Ready Vegetation reports.

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

- → *Rising temperatures across the region will generate unprecedented warm conditions for both summer and winter seasons*
- → *Rainfall is likely to be more variable in the future in term of both low and high annual extreme*
- → *The North Bay region is becoming more arid (subject to drier soil conditions) due to rising temperatures*
- → *Runoff may be increasingly flashy, with rates of groundwater recharge relatively less variable over time*
- → *Protecting available 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 more aggressive fuels management*
- → *Vegetation may be in transition, meriting additional monitoring and consideration of a more drought-tolerant planting palette for restoration*

Key findings for the North Bay region 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 rainfall, with direct implications for runoff, recharge, stream-flow and soil moisture. The climate suitability for vegetation types in the North Bay 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, strategies should 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. More aggressive approaches to the reduction of forest fuel loads should be considered.

Summary of Regional Vulnerability Assessment Data

Introduction

This section summarizes the vulnerability assessment data products available for temperature, rainfall, runoff, groundwater recharge, climatic water deficit, vegetation transitions, and fire risk for long-term average trends at the scale of the entire Climate Ready North Bay Region (Figure 1). 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 referenced for figures supporting the data summaries below, which include slides 23-60 in the companion *CRNB North Bay Region.ppt.*

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, (see Appendix C also references 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 consider 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 quantified as the 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 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.

Increasing Temperatures

Throughout the North Bay region, 30-year averages for summer and winter air temperatures are projected to increase. Maximum monthly summer air temperatures are projected to increase by as much as 11°F and minimum monthly winter air temperature to increase by as much as 7.6°F by the end of century for the "worst case" hot and low rainfall Scenario 6

Table 1: Basin Characterization Model Outputs, North Bay Region, 1951-2099

		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	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

For the 30-year average representing 1981-2010, defined as "current conditions," the average maximum monthly average summer air temperature was 82.2°F. For the mid-century period 2040-2069, under "business as usual" scenarios, potential 30-year averages for monthly maximum summer air temperatures are estimated to span the range below.

Scenario 3: Warm, moderate rainfall - 86.0°F, equivalent to an increase of 3.8°F
Scenario 5: Warm, high rainfall - 86.4°F, equivalent to an increase of 4.2°F
Scenario 6: Hot, low rainfall - 89.2°F, equivalent to an increase of 7.0°F

For 2070-2099, under "business as usual" scenarios, potential changes in maximum monthly average summer air temperature by end-century are estimated to span the range below.

Scenario 3: Warm, moderate rainfall - 88.5°F, equivalent to an increase of 6.3°F
Scenario 5: Warm, high rainfall - 89.4°F, equivalent to an increase of 7.2 °F
Scenario 6: Hot, low rainfall - 93.4°F, equivalent to an increase of 11.2°F

From 1981-2010, the 30-year average for minimum monthly winter air temperatures was 39.7°F. For 2040-2069, under "business as usual" scenarios, potential changes in minimum monthly average winter air temperatures by mid-century are estimated to span the range below.

Scenario 3: Warm, moderate rainfall - 43.0°F, resulting in an increase of 3.3°F
Scenario 5: Warm, high rainfall - 43.0°F, resulting in an increase of 3.3°F
Scenario 6: Hot, low rainfall - 44.1°F, resulting in an increase of 4.4°F

Figure 2. Maximum summer temperature, North Bay Region, 1981-2100, 30-year averages, warm and moderate rainfall scenario

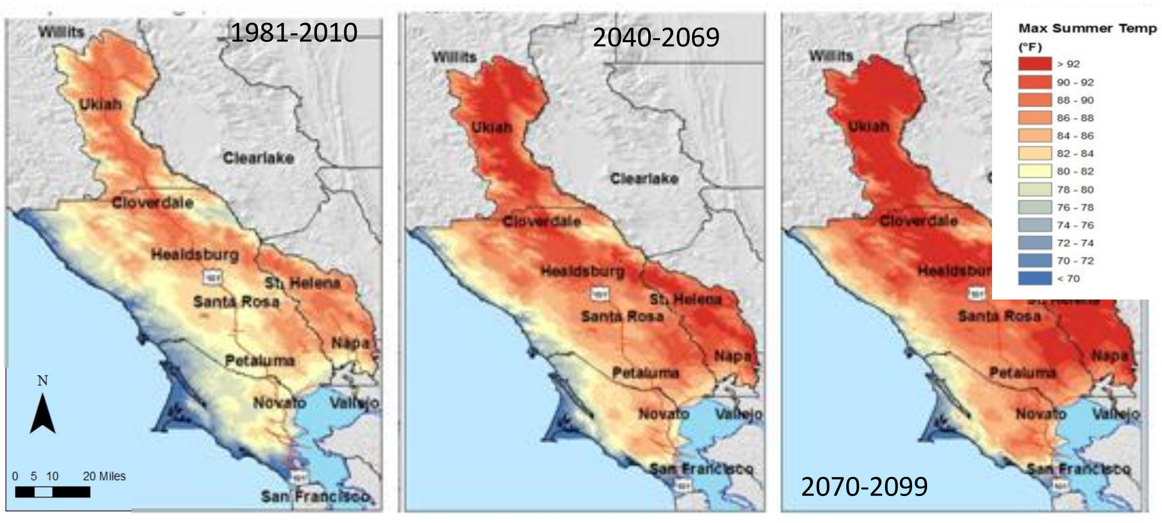
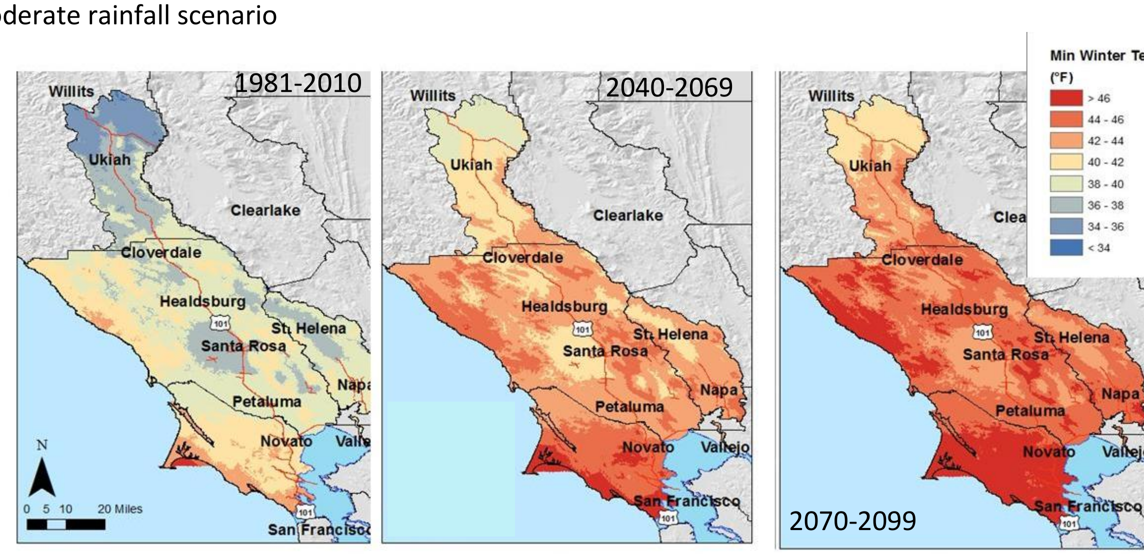


Figure 3. Minimum winter temperature, North Bay Region, 30-year averages, 1981-2099, warm and moderate rainfall scenario



For 2070-2099, under "business as usual" scenarios, potential changes in minimum monthly average winter air temperatures are estimated to span the range below by end-century.

Scenario 3: Warm, moderate rainfall - 44.8°F, resulting in an increase of 5.1°F
Scenario 5: Warm, high rainfall - 45.9°F, resulting in an increase of 6.1°F
Scenario 6: Hot, low rainfall - 47.3°F, resulting in an increase of 7.6°F (2.5°F greater than the moderate warming scenario)

Increases in monthly maximum and minimum temperatures estimated for 30-year time periods represent underlying significant increases in the frequency and intensity of warmer conditions at the monthly and daily time scales. For example, for the Santa Rosa Plain, there is up to a five-fold projected increase in the total number of days exceeding 95°F, with an average of 26 per year measured over 1981-2010, compared to 146 per year projected by the end of the century. In the Alexander Valley, averaged across four future scenarios, there is an overall decrease in the number of springtime (February, March, April) days that are at or below freezing by both mid- and end-century. By the end of the century, on average, the number of days that are at or below freezing are projected to decrease on the order of 50% in February (from 52 to 27), over 60% in March (from 8 to 5), and 100% in April (from 5 to 0). (Please refer to slides 68-70 in the companion *CRNB North Bay Region.ppt* for illustration.)

Projected increases in temperature result in increased rates of evapo-transpiration 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.

Slides 41-46 in the companion *CRNB North Bay Region.ppt* illustrate the data findings above.

Increasing Variability in Rainfall

The future of rainfall quantity and variability for the North Bay region over the next century is perhaps the greatest uncertainty in efforts to project future conditions. Global models vary widely in their estimates of how climate change will impact rainfall patterns. This is because the potential effect of increased temperatures on the dynamic circulation of the oceans and atmosphere, which produces local rainfall, is not well understood in terms of mechanics. Therefore, some models estimate that for the North Bay region global warming will result in a major increase in available rainfall (Scenario 5), while others project little change (Scenarios 1, 2, 3), or moderate to major reductions (Scenario 4 and Scenario 6). Interestingly, for both mid-century and end-century values, projected changes in precipitation in the negative and positive directions essentially cancel each other out in the ensemble average, with no net average change in precipitation when the six models are averaged together. However, an examination of annual values underlying these long-term averages does show, in most projections, a trend of increasing variability in rainfall from year to year.

For 1951-1980 and 1981-2010, both the historic and current regional average rainfall was approximately 43 inches per year. For 2040-2069, average annual rainfall is projected to span the range below.

Scenario 3: Warm, moderate rainfall - 42.1 in/y, 2% less than the current average
Scenario 5: Warm, high rainfall - 53.6 in/y, 25% greater than the current average
Scenario 6: Hot, low rainfall - 34.8 in/y, 19% less than the current average

For 2070-2099, potential changes in average annual rainfall are projected to span the range below.

Scenario 3: Warm, moderate rainfall - 44.8 in/y, 6% greater than the current average
Scenario 5: Warm, high rainfall - 57.9 in/y, 35% greater than the historic/current average
Scenario 6: Hot, low rainfall - 33.9 in/y, 21% less than the historic/current average

Figure 4. Precipitation, 30-year averages, current (1981-2010), and projected (2040-2069) hot and low rainfall and warm and high rainfall scenarios

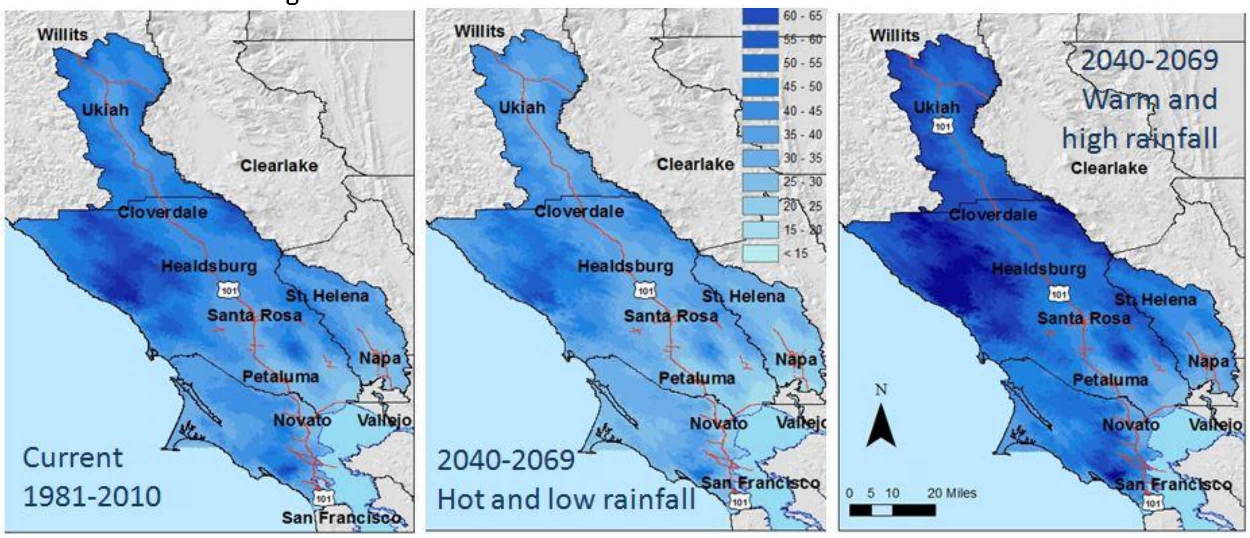
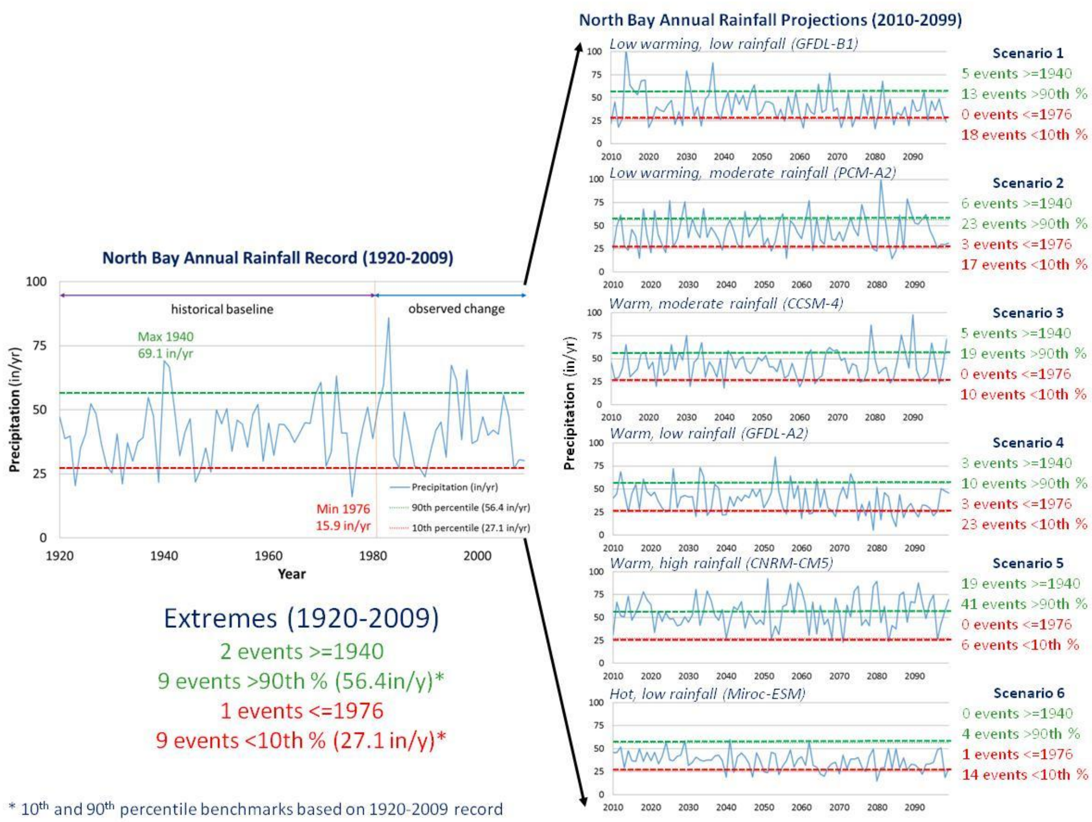


Figure 5. North Bay Region annual rainfall, comparison historic and projected 90-year periods, six scenarios



A comparison of extreme rainfall years 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. Changes in frequency of annual rainfall extremes per decade, historic/current conditions (1920-2009) and six climate ready scenarios (2010-2099)

Exceedances 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		0.22	1.00	1.00	0.11
1	GFDL_B1	2010-2099	Low warming, Low rainfall	0.56	1.44	2.00	0.00
2	PCM_A2	2010-2099	Low warming, Mod rainfall	0.67	2.56	1.89	0.33
3	CCSM4_rcp85	2010-2099	Warm, Mod rainfall	0.56	2.11	1.11	0.00
4	GFDL_A2	2010-2099	Warm, Low rainfall	0.33	1.11	2.56	0.33
5	CNRM_rcp85	2010-2099	Warm, High rainfall	2.11	4.56	0.67	0.00
6	MIROC_rcp85	2010-2099	Hot, Low rainfall	0.00	0.44	1.56	0.11

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%***

We recommend that at this point natural resource managers plan for both high rainfall and low fall rainfall scenarios. For Climate Ready North Bay partners, this has meant taking the worst case drought scenarios and analyzing whether or not current infrastructure would still allow agencies to meet projected demand. It is also suggested for flooding, and with more certainty fire, increased resources may need to be dedicated to hazard mitigation.

Slides 29-35 in the companion *CRNB North Bay Region.ppt* illustrate the data findings above.

Impacts on Watershed Functions: Runoff, Recharge, and Climatic Water Deficit
The benefit of utilizing the Basin Characterization Model is that it takes projected values for rainfall and temperature and tests how these climatic patterns would interact with local

topography, soils, and underlying geology. The model achieves this by calculating a water balance for every 18-acre unit in the North Bay domain. This memorandum summarizes results at the scale of the entire region, while companion memoranda developed for partner agencies isolate results for source watersheds and other regions of interest. These variables are critical to shaping climate smart strategies focused on maintaining water yields and sustainable patterns for future urbanization.

Recharge and runoff both vary with projected precipitation, yet recharge proves more resilient (less variable) than runoff in response to major fluctuations in rainfall, as described below. The spatial variability of high and low groundwater recharge zones can be estimated using the model, a valuable input for sustainable groundwater management. Climatic water deficit projections show what portions of the landscape are vulnerable to drought stress, and also serve as an indicator of irrigation demand. Taken together, this integrated water balance approach to estimating the impacts of future climate change on the local hydrology is a potent tool for determining vulnerabilities and potential adaptation strategies.

Runoff

The amount of runoff is estimated on the amount of incoming rainfall combined with how pervious the watershed is given local soils and bedrock. Climate Ready North Bay data products are capable of estimating the relative variable "flashiness" of watersheds in the study area. Runoff can be used to estimate yield into reservoirs or streams, as well as to provide an indicator of flooding risks.

From 1981-2010, the average amount of runoff for the North Bay region was 14.2 inches per year, per unit area. From 2040-2069, the range of potential change in average amount of annual runoff is projected as follows.

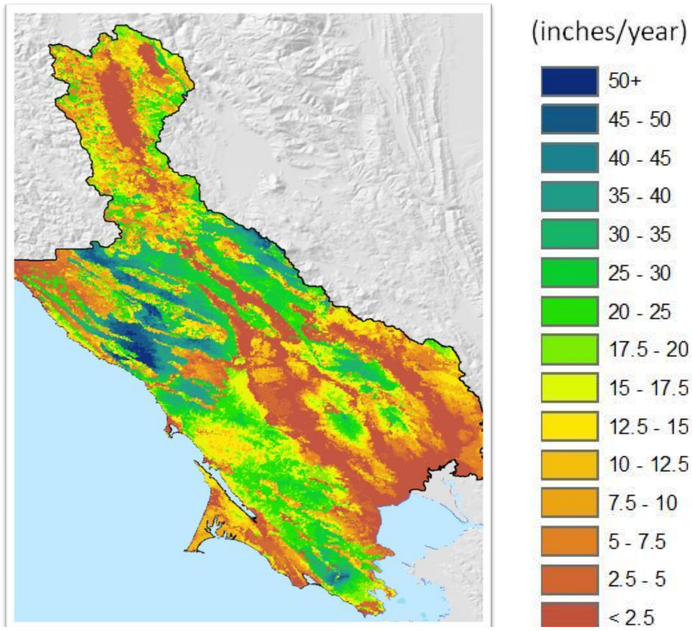
Scenario 3: Warm, moderate rainfall - 14.0 in/y, 1% less than the current average
Scenario 5: Warm, high rainfall - 22.8 in/y, 61% greater than the current average
Scenario 6: Hot, low rainfall - 9.7 in/y, 32% less than the current average

For 2070-2099, the range of potential change in average amount of annual runoff is projected as follows.

Scenario 3: Warm, moderate rainfall - 17.3 in/y, 22% greater than the current average
Scenario 5: Warm, high rainfall - 26.9 in/y, 90% greater than the current average
Scenario 6: Hot, low rainfall - 9.3 in/y, 34% less than the current average

Slides 29-33 in the companion *CRNB North Bay Region.ppt* illustrate the data findings below.

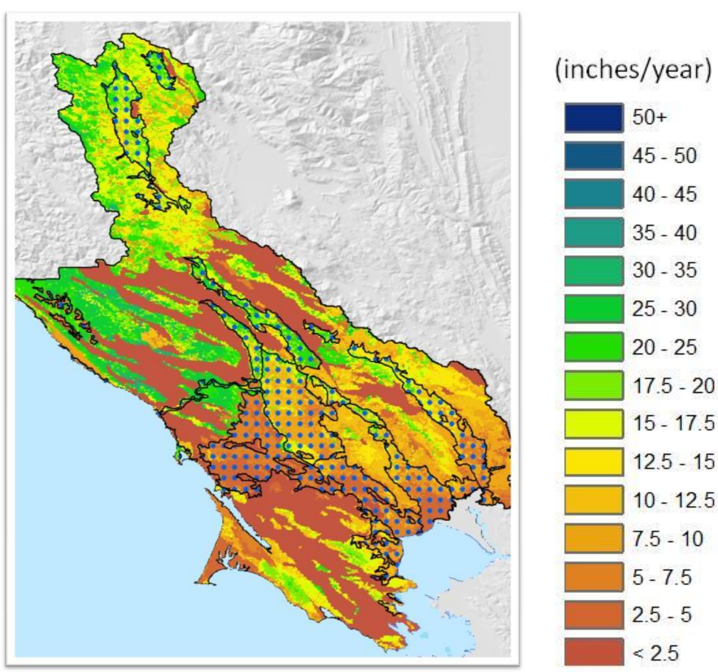
Figure 6. Estimated runoff, North Bay Region, 30-year average, 1981-2010



Groundwater Recharge

The Basin Characterization Model was specifically designed to estimate subsurface recharge using empirical watershed characteristics. Summaries of historic and projected recharge across the North Bay as a whole are summarized below.

Figure 7. Estimated groundwater recharge, North Bay Region, 30-year average, 1981-2010



For 1981-2010, the average amount of groundwater recharge was 10.2 inches per year per unit area. For 2040-2069, the range of potential change in average amount of annual recharge is projected as follows.

Scenario 3: Warm, moderate rainfall - 10.7 in/y, 4% greater than the current average
Scenario 5: Warm, high rainfall - 12.8 in/y, 25% greater than the current average
Scenario 6: Hot, low rainfall - 8.2 in/y, 20% less than the current average

For 2070-2099, the range of potential change in average amount of annual recharge is projected as follows.

Scenario 3: Warm, moderate rainfall - 10.8 in/y, 6% greater than the current average
Scenario 5: Warm, high rainfall - 13.2 in/y, 29% greater than the current average
Scenario 6: Hot, low rainfall - 8.5 in/y, 17% less than the current average

Slides 36-40 in the companion *CRNB North Bay Region.ppt* illustrate the data findings above.

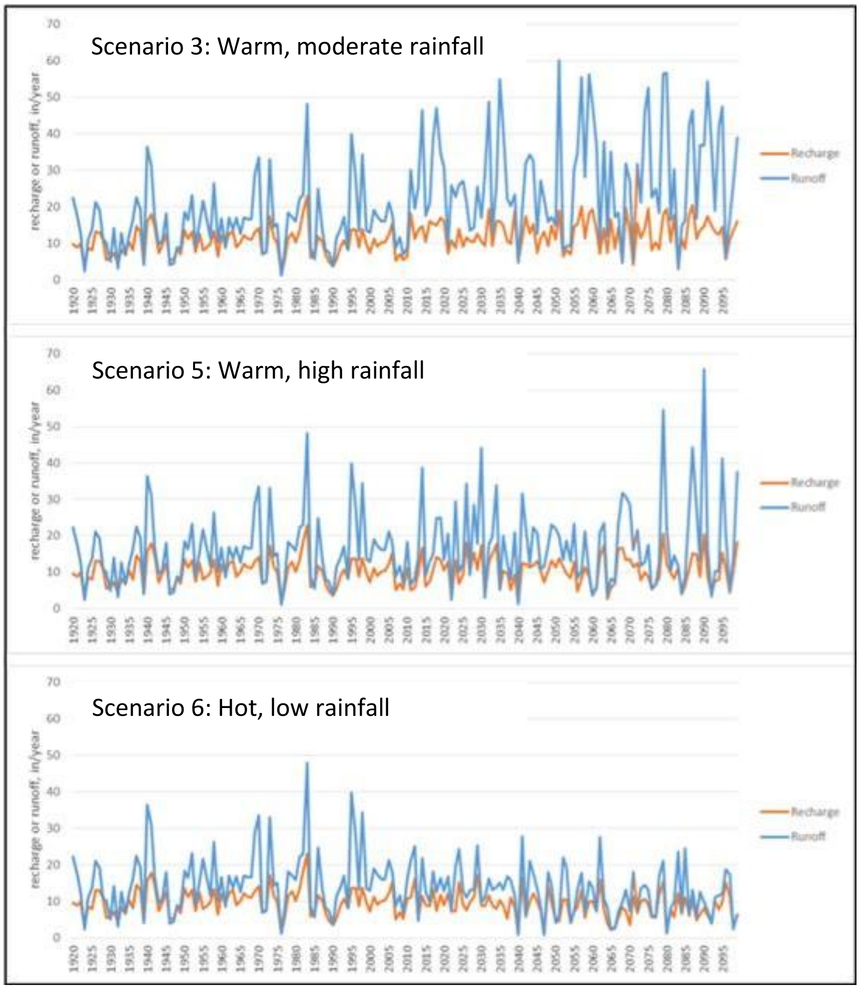
Relationship of Runoff to Recharge

The North Bay Climate Ready project area is highly variable in terms of the spatial distribution of potential surface runoff and recharge. While Sonoma, Mendocino, and Napa counties include significant groundwater recharge basins, the geology of Marin provides for very little ground water and therefore its supply is runoff-dominated. However, for regions with significant recharge storage potential there is also high variability in potential groundwater recharge within a particular basin, such as the Sonoma and Napa Valleys and the groundwater basin of the Russian River Basin.

Figure 8 demonstrates the relatively variability of runoff compared to recharge for a given rainfall quantity. The plot compares total runoff and recharge estimated for the entire area of Sonoma County using Scenarios 3, 5, and 6. The average historic values are 14.2 inches per year for runoff and 10.2 inches per year for recharge. The three future scenarios range from a minimum of 9.3 inches per year to a maximum of 26.9 inches per year for runoff (corresponding to -34% to +90% compared to current). Corresponding recharge values range from only 8.2 to 130.2 inches per year (-17% to +29% compared to current). Based on this analysis, recharge is shown to be a more consistent component of water yield over time relative to runoff. This is not to discount, however, the importance of big runoff years in supplying critical supply to reservoirs, streams, and aquifers. However the relative consistency of groundwater recharge even in low rainfall years suggests where groundwater is available, that sustainable groundwater management is a good investment in water security.

A simple metric that facilitates categorizing watersheds by their relative flashiness is the ratio of recharge to runoff for the North Bay—this value ranged from 0.79-.072 for the historic to current time periods, respectively. The concept of "conjunctive use" in water resources planning refers to looking at the relationship of surface and groundwater supplies as one resource that requires coordinated management. Climate Ready North Bay products may help facilitate conjunctive use approaches where feasible, including groundwater recharge protection and passive or active recharge of aquifers. In terms of watershed mechanics climatic water deficits, addressed below, interface with runoff and recharge by increasing more subsurface storage potential and thus creating more “room” in the soils for subsurface storage.

Figure 8: Estimated annual runoff and recharge, North Bay Region, 1920-2100, three future scenarios



Climatic Water Deficit

Climatic water deficit is an attribute of the landscape that integrates the combined effects of available rainfall, temperature, and watershed structure. It 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 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. As discussed below, it turns out to be an excellent indicator of native vegetation cover or agricultural irrigation demand and fire risks.

An important aspect of climatic water deficits is that, in comparison to rainfall for example, all of the future scenarios project a uni-directional trend in water deficits into the future. From 1981-2010 the average climatic water deficit over the study area was 28.4 inches per year. 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 is projected, with an average of 14% across all scenarios, as is described below.

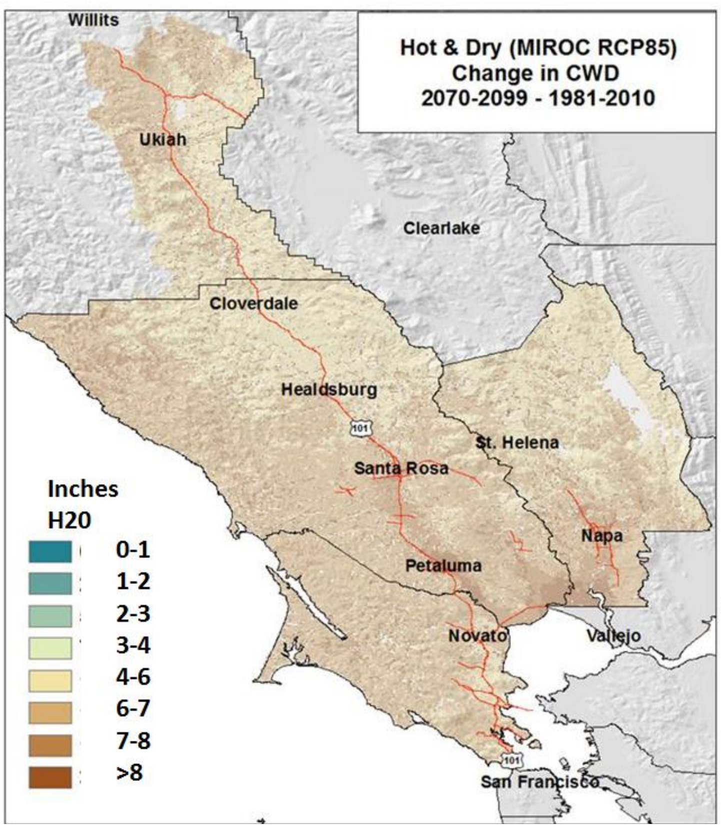
From 2040-2069, the range of potential change in climatic water deficit is projected as follows.

Scenario 3: Warm, moderate rainfall - 30.3 in/year, 7% greater than the current average
Scenario 5: Warm, high rainfall - 29.8 in/year, 5% greater than the current average
Scenario 6: Hot, low rainfall - 32.0 in/year, 12% greater than the current average

For 2070-2099, the range of potential change in climatic water deficit is projected as follows (Figure 3).

Scenario 3: Warm, moderate rainfall - 31.4 in/year, 11% greater than the current average
Scenario 5: Warm, high rainfall - 31.3 in/year, 10% greater than the current average
Scenario 6: Hot, low rainfall - 34.6 in/year, 22% greater than the current average

Figure 9. Projected change in 30-year averages for climatic water deficit, 1981-2010 v. 2070-2099, hot and low rainfall scenario



The magnitude of projected change in climatic water deficit is limited by the total subsurface soil storage potential in a given area. In other words, deeper soils with high soil moisture storage potential may be subject to larger changes than landscapes with thinner soils since they hold relatively more soil moisture. In addition, the impact of increased water deficit needs to be considered in the context of site-specific temporal variability. Regions that have historically been exposed to large variability in water deficits may be more resilient to future deficit increases then regions with historically low variability. The Climate Ready North Bay hypothesizes that small increase in water deficits in traditionally cooler and moister coastal areas this may pose a more significant impact than similar magnitudes of change inland, where watershed and ecosystem have adapted to high variability.

Slides 41-46 in the companion *CRNB North Bay Region.ppt* illustrate the data findings above.

Native Vegetation Response

For 22 dominant vegetation types, the probabilities for each vegetation type to occur in a given location within the study 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, though the sensitivity to climate change was somewhat higher under warm winter conditions (i.e., closer to the coast), on north-facing slopes and in areas of historic higher precipitation. While cool or moist sites may serve as refugia for species adapted to cool and moist conditions, the model suggests these sites will still be highly dynamic and relatively sensitive to climate-driven vegetation transitions (Ackerly et al. 2015). Model results have been summarized for each of the Conservation Lands Network landscape units, and can be accessed (BAOSC 2011).

Across the North Bay counties we observe the following trends, with the caveat that these trends represent the long-term equilibrium response that may be expected in response to varying magnitude of climate change. The modeling does not address the mechanisms of vegetation change (e.g., drought, fire, etc.), and does not incorporate the potential effects of dispersal limitation (i.e. absence of mature populations nearby producing seeds that can disperse to new locations). While we don’t know how quickly changes may occur, the fossil record since the last Ice Age in California and elsewhere demonstrates that periods of major climate change result in significant shifts in vegetation over time.

For Marin County significant reductions in suitable conditions for Redwood and Douglas-fir forests, and Montane Hardwood woodlands, are projected, especially for more than 4-5 °F warming. Grassland conditions may also decline, but the extent of grassland is heavily dependent on management actions (fire, grazing, etc.). Suitable climate for chamise chaparral and other shrublands, coast live oak woodlands, and knobcone pine are projected to expand. Establishment of knobcone pine and some chaparral species are promoted by fire; the extent and severity of wildfire in coming decades will likely have a strong impact on future vegetation.

In Sonoma County, similar reductions in suitable conditions for Redwood and Douglas-fir forests and Montane Hardwoods are projected. Oregon oak woodlands and montane chaparral are also projected to decline. Conditions suitable for coast live oak woodlands, chamise chaparral and other shrublands increase substantially, especially for scenarios above +4°F warming.

In Napa County, conditions suitable for Montane Hardwoods decline at higher temperatures, and montane chaparral also shrinks considerably. Conditions suitable for Chamise Chaparral, other shrublands, Coast Live Oak, and Interior Live Oak all increase in extent. The area suitable for blue oak varies, declining under higher rainfall scenarios, and otherwise remaining stable.

Slides 49-56 in the companion *CRNB North Bay Region.ppt* illustrate the data findings above.

Increasing Fire Frequency

The fire frequency model used in Climate Ready North Bay expresses potential increases in fire risk as a function of probability of a burn or fire return estimated in years. 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. In the attached CRNB North Bay deck.ppt results for the North Bay region as a whole are summarized below.

From 1971-2000, the average historic fire return interval was every 172 years. By the end of the century, fire return intervals are projected to be reduced by approximately 30% throughout the region.

Scenario 3: Warm, moderate rainfall - 120 yr average projected return interval
Scenario 6: Hot, low rainfall - 117 yr average projected return interval

From 1971-2000, the average historic probability of burning with a 30 year period was 17%. From 2070-2099, the probability of burning occurring one or more times within 30 years doubles in some locations, with the probability throughout the region projected to increase to 23% under both the warm, moderate rainfall and hot, low rainfall scenarios.

Figure 10. Historic and projected fire return intervals, 1971-2000 versus 2070-2099, two future scenarios

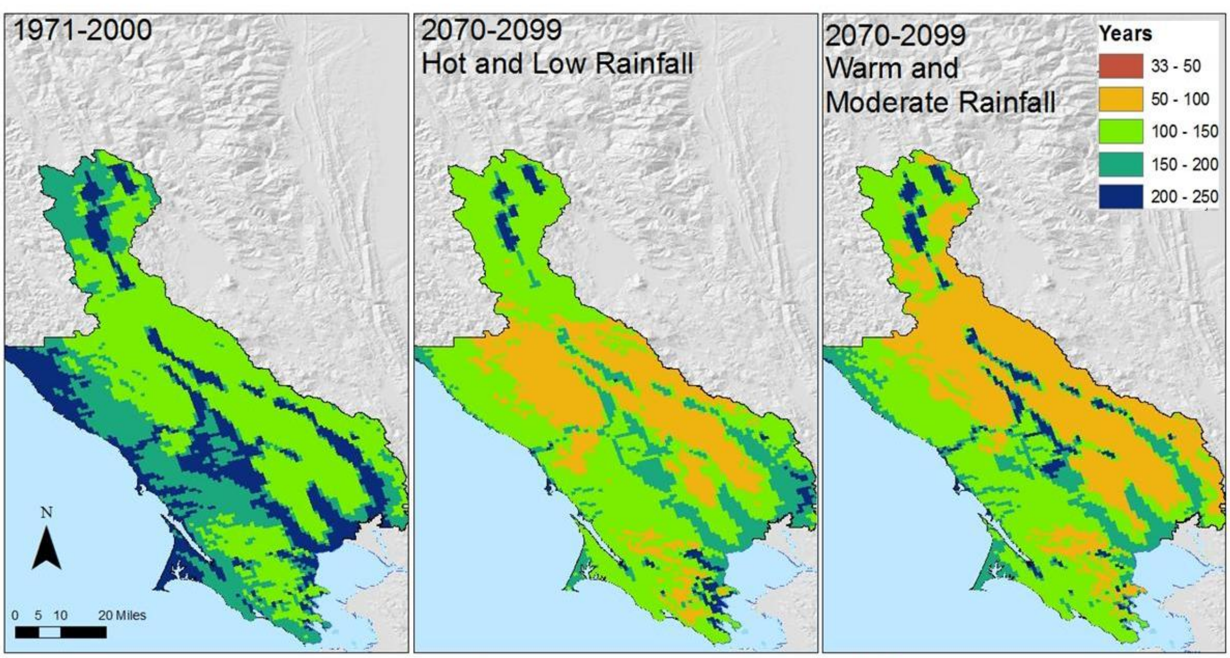
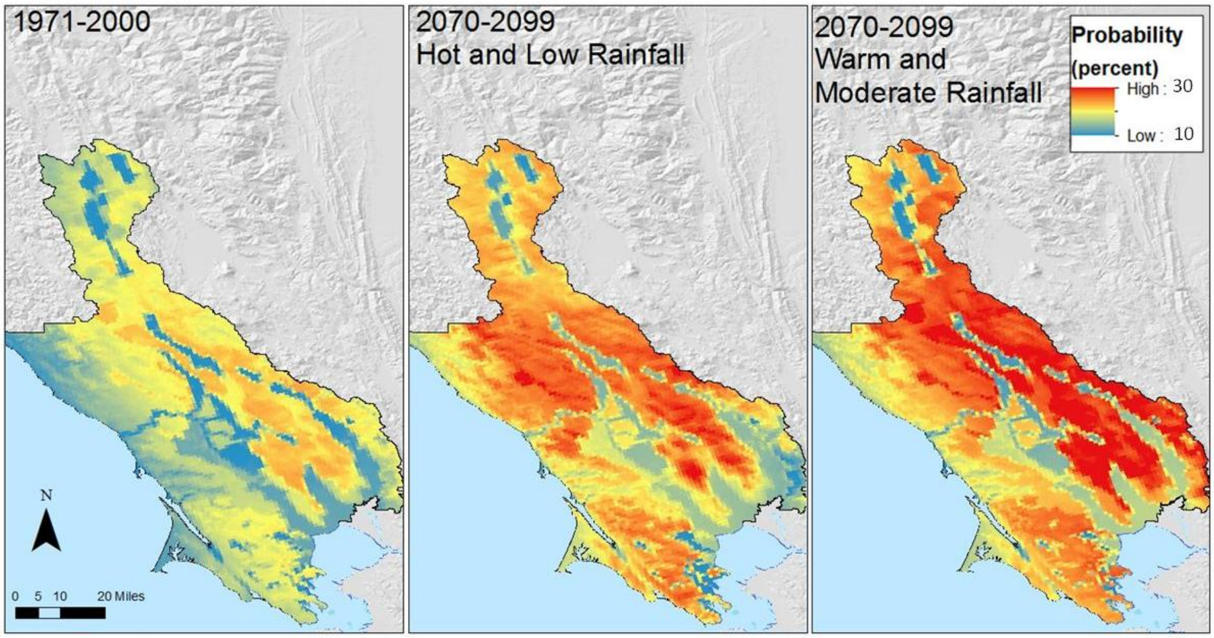


Figure 11. Probability of a burn within a 30-year period, 1971-2000 versus 2070-2099, two future scenarios



Slides 57-60 in the companion *CRNB North Bay Region.ppt* illustrate the data findings above.

Bridging Science and Management

Lessons Learned

Meaningfully translating global change models to local management applications is an emerging practice. We provide the observations below to help inform other climate adaptation planning efforts applying high-resolution climate data at a regional scale for specific management applications.

- Co-creation of data products and tools by scientists working with managers requires an extended dialog (12+ months) and multiple in-person exchanges.

- A critical member of the team is an "information broker" who understands both "science" and "management" perspectives to facilitate discussions.

- Framing resource-specific management questions at project kickoff is a good way to guide the process.

- Managers need to participate in scenario selection to ensure relevancy, and to learn why consideration of multiple scenarios (an ensemble approach) is needed in order to capture model uncertainties Regional data sets capable of servicing multiple agencies and resource issues increase the potential for coordinated or at least consistent adaption planning.

- Managers who have the skill set to actually manipulate the data, for example to generate plots for a given time period of interest, gain significant understanding from completing this kind of exercise.

- Consistent trends across multiple scenarios are important to identify, but the temptation should be resisted to average model results. Physical watershed processes are only accurately characterized within a single scenario.

- Once results are available, many managers needed additional support in scoping how to translate results to specific planning applications and requested follow up meetings to transfer the approval to perform agencies and consultants.

- Agencies see the value of using Climate Ready North Bay results to raise public awareness of resource challenges and conflicts that may lie ahead for communities as a whole.

- More resources are needed to craft effective outreach tools and trainings that are tailored towards diverse audiences.

In the context of the literature on scenario-based climate adaptation planning, we believe our results reflect what Prudhomme (2010) termed a *scenario neutral* approach by not classifying any particular scenario(s) as more likely than another, but rather defining the broadest range possible of viable models. This allowed engaged managers to start to assess the vulnerabilities of their systems.

We had originally hoped in some cases participating agencies might have already defined climate thresholds above or below which their service delivery would be compromised, what Brown and Wilby (2012) and Brown et al. (2012) termed a *climate response function.* However, using our managers' survey and follow up communications, we confirmed that, for the majority of agencies, critical environmental thresholds or climate response functions were unknown. For this reason we focused on primarily a historic analog approach to define thresholds (for example the lowest rainfall year or peak flood of record) in concert with managers.

The value of this project is therefore to provide a relatively simple framework for managers to start to explore what kind of future climate, and which climate variables in particular, could trigger critical sensitivities in their systems. Examples could include rainfall thresholds that compromise watershed services such as water supply or flooding attenuation or increases in climatic water deficit that cause ecosystems to transition in terms of vegetation community or fire regime. Under this Climate Ready framework, managers can compare and contrast additional existing or new models as they come on line, with a growing understanding of the specifics of their systems' vulnerabilities as the planning assessments proceed listed in the *Applications* session below.

While the literature also compares what is termed *top-down* versus *bottom up* approaches to vulnerability assessments, with the former driven by climate model selection on the part of scientists, and the latter driven by vulnerabilities defined at the ground level by managers, our experience may be best described as a hybrid of the two. We believe that by engaging managers from the outset in selecting climate futures based on management needs, while our technical team did narrow the options from an original 100 scenarios to 18 that captured essentially a comparable range, from that point on ground-based management considerations drove the process. We look forward to tracking the evolution of partner agencies' *climate response functions* as they proceed to the next stages of adaptation planning. We also remain strong advocates of getting effective real time hydrology-ecosystem monitoring in place, as is currently being piloted at Pepperwood, to refine our understanding of key mechanisms linking climate, water, and ecosystem response.

Potential Climate Ready Applications

There are a number of current or future planning processes throughout the North Bay region that integration of this climate vulnerability assessment data could benefit that include the following.

- Environmental impact reports
- Local hazard mitigation plans
- Safety elements of general plans
- Reservoir operations and urban water sustainability planning
- Parks, trails, and open space parcel master plans
- Open space acquisition plans
- Stormwater, urban water, and flood management plans and ordinances
- Groundwater sustainability plans
- Public health monitoring procedures
- Street tree and water efficient landscaping ordinances
- Zoning, building, and fire codes
- Climate action plans
- Agency-specific climate adaptation plans
- Parcel or jurisdiction-specific stewardship plans

Agency-specific applications are summarized in companion technical memorandum generated for each user group. Immediate applications of *Climate Ready* data underway include the following pilots.

- MMWD is exploring the use of Climate Ready North Bay hydrology projections as part of an Urban Water Management Plan update to assess supply reliability for the next 40 years.

- Sonoma County Water Agency is using Climate Ready North Bay Russian River flow projections as the foundation of their Climate Adaptation Plan for storage and delivery system operations.

- Napa County is using Climate Ready North Bay recharge maps as an input to its Groundwater Management planning efforts underway.

- Sonoma County Regional Parks is using Climate Ready North Bay vegetation and fire analyses to prioritize the development of forthcoming parcel-specific management plans.

Acknowledgements

We'd like to acknowledge support from Lisa Ames and Matt Gerhart at the California Coastal Conservancy plus key members of the RCPA-NBCAI Climate Ready North Bay partnership, including Suzanne Smith and Lauren Casey (RCPA) and Caitlin Cornwall and Genevieve Taylor (NBCAI) for their support of this initiative as a whole. Thanks to TBC3 members and affiliates for co-creation and technical review of Climate Ready tools including Dr. David Ackerly and his lab at UC Berkeley, Dr. Stuart Weiss of Creekside Center for Earth Observation, and Dr. Max Moritz of UC Santa Barbara. In particular thanks to Naia Morueta-Holmes of UC Berkeley for development of landscape unit Vegetation Reports using her California-wide model. With appreciation for data analysis support and complementary on-line tool development from Dennis Jongsomjit, Michael Fitzgibbon, Deanne DiPietro, and Zhahai Stewart (Point Blue Conservation Science and the California Landscape Conservancy Cooperative) and Michelle Halbur (Pepperwood). And thanks to Tom Greco and Mia Centeno for document formatting support and to Cassandra Liu for contract management (Pepperwood).

References

Ackerly, D. D. 2012. *Future climate scenarios for California: freezing isoclines, novel climates, and climatic resilience of California's protected areas.* California Energy Commission.

Ackerly, D., M. Oldfather, M. Britton, M. Halbur, and L. Micheli. 2013. *Establishment of woodland vegetation research plots at Pepperwood Preserve.* Terrestrial Biodiversity Climate Change Collaborative. Dwight Center for Conservation Science at Pepperwood, Santa Rosa, CA.

Ackerly, D.D., W.K. Cornwell, S.B Weiss, L.E. Flint, and A.L. Flint. 2015. *A geographic mosaic of climate change impacts on terrestrial vegetation: which areas are most at risk*? PLoS ONE 10(6): e0130629. doi:10.1371/journal.pone.0130629.

Brown, C, Y. Ghile, M. Laverty, and K. Li. 2012. *Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sectors*, Water Resources Research, 48, W09537.

Brown, C. and R.L. Wilby. 2012. *An alternate approach to assessing climate risks*. Eos 92(41):401-402.

Cornwell, W.K., S.A. Stuart, A. Ramirez, C.R. Dolanc, J.H. Thorne, and D.D. Ackerly. 2012. *Climate change impacts on California vegetation: physiology, life history, and ecosystem change.* California Energy Commission Publication. CEC-500-2012-023.

Daly, C., M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, B.J. Curtis, and P.P. Pasteris. 2008. P*hysiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States*. Int. J. Climatol., 28:2031-2064.

Deas, M. 2015. *Cal-Adapt and the Usability of Climate Adaptation Tools*. Masters Thesis, Massachusetts Institute Of Technology.

Flint, L.E., and A.L. Flint. 2012. *Downscaling future climate scenarios to fine scales for hydrologic and ecological modeling and analysis*. Ecological Processes, 1:2.

Flint, L.E., A.L. Flint, J.H. Thorne, and R. Boynton. 2013. *Fine-scale hydrological modeling for climate change applications; using watershed calibrations to assess model performance for landscape projections.* Ecological Processes, 2:25.

Flint, L.E. and A.L. Flint. 2014. *California Basin Characterization Model: A dataset of* historic *and future hydrologic response to climate change.* U.S. Geological Survey Data Release. doi:10.5066/F76T0JPB.

Flint, A.L., M.A. Stern, and L.E. Flint. *in prep*. Improved mapping of daily precipitation and air temperature using spatial downscaling.

Krawchuk, M. and M. Moritz. 2012. *Fire and climate change in California: changes in the distribution and frequency of fire in climates of the future and recent past (1911-2099)*. California Energy Commission Publication. CEC-500-2012-026.

Mastrandrea, M. D., N. E. Heller, T. L. Root, and S. H. Schneider. 2010. *Bridging the gap: Linking climate-impacts research with adaptation planning and management.* Climatic Change 100:87-101.

Meehl, G.A., Covey, C., Delworth, T., Latif, M., McAvaney, B., Mitchell, J.F.B., Stouffer, R.J., and Taylor, K.E. 2007. *The WCRP CMIP3 multi-model dataset: A new era in climate change research.* Bulletin of the American Meteorological Society, 88, 1383-1394.

Micheli E., L. Flint, S. Veloz, K. Johnson (Higgason), and N. Heller. 2016. *Climate Ready North Bay Vulnerability Assessment Data Products: 1. North Bay Region Summary.* A technical memorandum prepared by the Dwight Center for Conservation Science at Pepperwood, Santa Rosa, CA, for the California Coastal Conservancy and Regional Climate Protection Authority.

Micheli E., L. Flint, S. Veloz, K. Johnson (Higgason), and N. Heller. 2016. *Climate Ready North Bay Vulnerability Assessment Data Products: 2. Marin Municipal Water District User Group*. A technical memorandum prepared by the Dwight Center for Conservation Science at Pepperwood, Santa Rosa, CA, for the California Coastal Conservancy and Regional Climate Protection Authority.

Micheli E., L. Flint, S. Veloz, K. Johnson (Higgason), and N. Heller. 2016. *Climate Ready North Bay Vulnerability Assessment Data Products: 3. Napa County User Group*. A technical memorandum prepared by the Dwight Center for Conservation Science at Pepperwood, Santa Rosa, CA, for the California Coastal Conservancy and Regional Climate Protection Authority

Micheli E., L. Flint, S. Veloz, K. Johnson (Higgason), and N. Heller. 2016. *Climate Ready North Bay Vulnerability Assessment Data Products: 4. Sonoma County Agricultural and Open Space and Regional Parks User Group*. A technical memorandum prepared by the Dwight Center for Conservation Science at Pepperwood, Santa Rosa, CA, for the California Coastal Conservancy and Regional Climate Protection Authority.

Micheli E., L. Flint, S. Veloz, K. Johnson (Higgason), and N. Heller. 2016. *Climate Ready North Bay Vulnerability Assessment Data Products: 5.Sonoma County Water Agency User Group*. A technical memorandum prepared by the Dwight Center for Conservation Science at Pepperwood, Santa Rosa, CA, for the California Coastal Conservancy and Regional Climate Protection Authority.

Micheli, E., L.E. Flint, A.L Flint, S.B. Weiss, and M. Kennedy. 2012. *Downscaling future climate projections to the watershed scale: a North San Francisco Bay Estuary case study.* San Francisco Estuary and Watershed Science, 10(4).

Micheli, L., and D. DiPietro. 2013. *North Bay vital signs: An integrated ecosystem-climate monitoring framework for Sonoma County*. A report of the North Bay Climate Adaptation Initiative to Community Foundation Sonoma County. Available from www.northbayclimate.org.

Parisien, M.-A., S. Snetsinger, J.A. Greenberg, C.R. Nelson, T. Schoennagel, S.Z. Dobrowski, and M.A. Moritz. 2012. *Spatial variability in wildfire probability across the western United States. International Journal of Wildland Fire* 21:313-327.

Prudhomme, C., R.L. Wilby, S. Crooks, A.L. Kay, and N.S. Reynard. 2010. *Scenario-neutral approach to climate change impact studies: application to flood risk*. J. Hydrol. 390:198-209.

Taylor, K.E., R.J. Stouffer, and G.A. Meehl. 2011. *An Overview of CMIP5 and the experiment design*. Bull. Amer. Meteor. Soc., 93, 485-498, doi:10.1175/BAMS-D-11-00094.1.

Weiss, S.B, L.E. Flint, A.L. Flint, and E. Micheli. in prep. *Choosing your futures: high resolution climate-hydrology scenarios for San Francisco Bay Area, California*.

APPENDICES

Appendix A: List of Climate Ready Analyses Conducted for the North Bay Region

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 historical 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 historical 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*

NORTH BAY CLIMATE-HYDROLOGY VARIABLES

Data Product: Basin Characterization Model Outputs—North Bay 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 North Bay BCM summary.xls*

IMPACTS OF CLIMATE CHANGE ON VEGETATION-NORTH BAY REGION

Data Product: Standardized 4-page landscape unit vegetation reports

Based on a vegetation transition model (Ackerly et al. 2015) for all Conservation Lands Networklandscape units included in the project area.

Filename: *CRNB North Bay Regional Vegetation Reports.pdf*

NORTH BAY FIRE MODELING

Data Product: North Bay Region 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.

Filename: *CRNB fire probability and return intervals.xls*

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%**

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: North Bay Regional Basin Characterization Model Summary Data Tables

Table 1: Basin Characterization Model, North Bay Regional: Three "business as usual" models used for map products, 1951-2099, average values.

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

Table 2: Basin Characterization Model, North Bay Regional: Three "business as usual" models used for map products, 1951-2099, 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