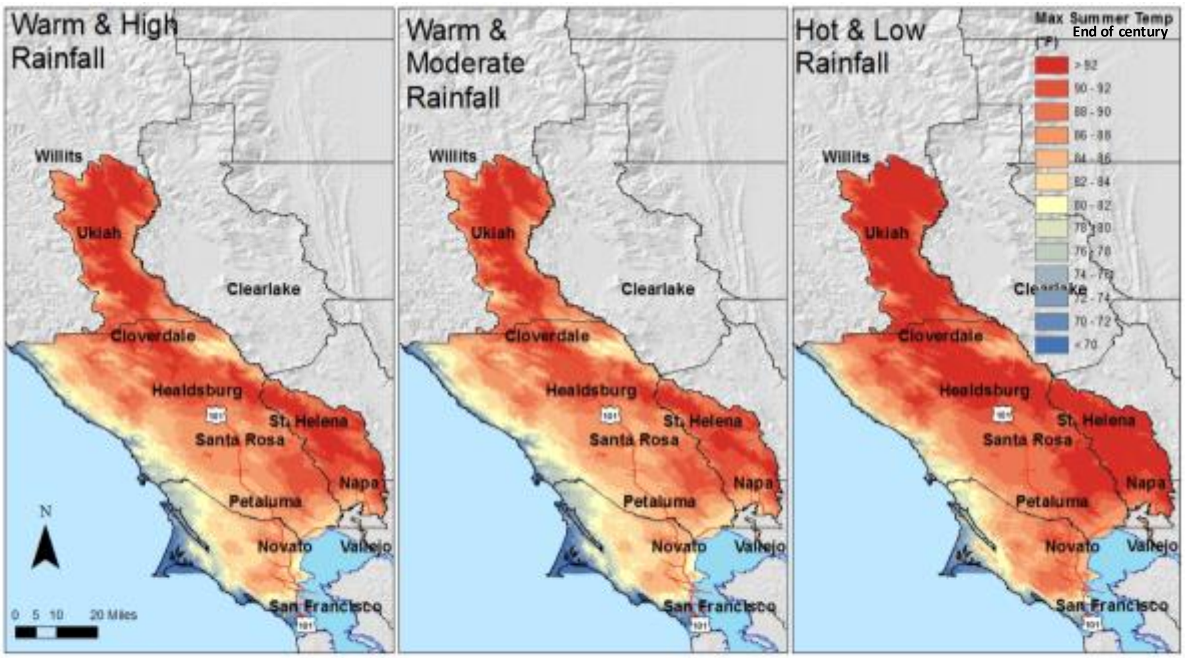
Climate Ready North Bay
Vulnerability Assessment Data Products

Marin Municipal Water District User Group

May 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

The work upon which this publication is based was funded in part through a Climate Ready Grant awarded by the California State Coastal Conservancy.

***Citation*:** 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, 33 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.

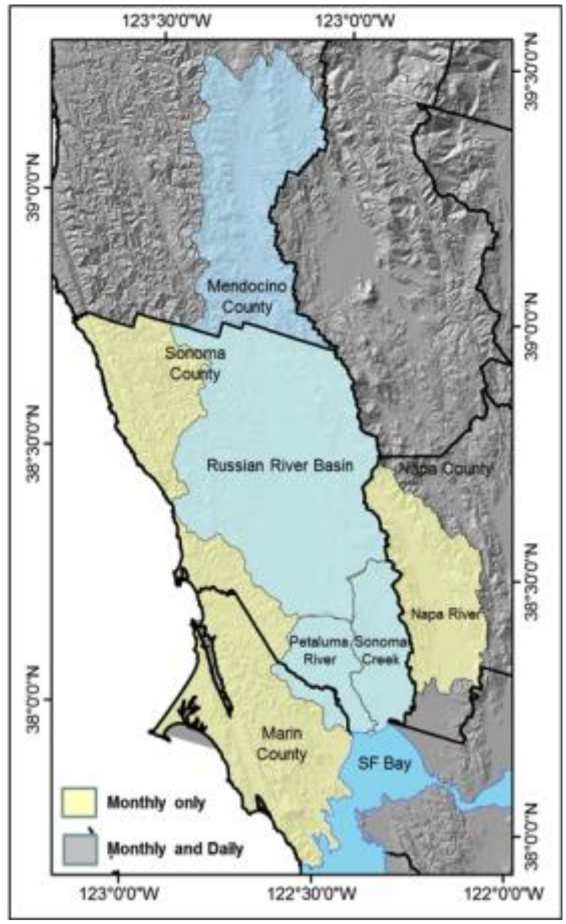


Figure 1: Map of study region shown in blue and yellow, including regions where daily data is available for analyses (blue) and those where monthly data is available (yellow). *Climate Ready North Bay 2015*.

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 Marin Municipal Water District (MMWD) in the *Climate Ready North Bay* collaboration to develop customized climate vulnerability assessment data products for the Marin County study area. The goal is to provide a starting point for understanding potential climate stressors facing the County in the decades to come. A companion technical memorandum summarizes results for the North Bay region as a whole (see Micheli et al. 2016, *Climate Ready North Bay: 1. North Bay Region Summary Technical Memorandum*). This memo summarizes engaged MMWD departments' jurisdiction and climate-related concerns, articulates key management questions, and provides take home messages regarding Marin's climate future. MMWD's management concerns are grouped into three resource areas: 1) Regional Rainfall Annual Variability; 2) Marin County Surface Water Supply (including drought risks, water quality, demand, and fisheries habitat); and 3) Land Cover and Fire Risks. Appendices include a glossary, details on climate models, summary tables, and a list of data products generated and provided to MMWD. A companion PowerPoint deck (*CRNB MMWD deck.ppt*) was also provided to the agency to showcases sample data products and take-home messages for MMWD's use. 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 1-10 in *CRNB MMWD deck.ppt* illustrate the project overview above.

MMWD Responsibilities and Jurisdictions

The MMWD was established as the first municipal water district in California, with the mission to manage local natural resources in a sustainable manner and to provide customers with reliable, high quality water at a reasonable price. MMWD provides drinking water to 188,200 customers in central and southern Marin County. MMWD's water supply is provided by three integrated water sources: district reservoirs, imported water, and recycled water. On average about 75 percent of Marin County's water supply comes from rainfall collected in the district's seven reservoirs located on Mt. Tamalpais and in west Marin. The water supply provided by four of these reservoirs—Kent, Alpine, Bon Tempe, and Nicasio—is used annually. Water supply from the other three reservoirs—Phoenix, Lagunitas and Soulajule—is held in reserve. Water from the district's reservoirs is conveyed to the district's San Geronimo Water Treatment Plant or Bon Tempe Water Treatment Plant for treatment before entering the distribution system.

Historically, approximately 25 percent of MMWD's water is imported from the Sonoma County Water Agency (SCWA). SCWA water originates from rainfall that flows into Lake Sonoma and Lake Mendocino and is released into the Russian River. The Russian River water is filtered naturally through 80 feet of sand beds adjacent to the river. The Russian River water is blended with MMWD's reservoir water in the distribution system.

MMWD was also the first water supplier in California to use recycled water for car washes, air conditioning cooling towers, and commercial laundries. Up to two million gallons a day are recycled and distributed via a separate pipeline system to more than 350 customers in northern San Rafael during the warmer months. Recycled water is used for irrigation, toilet flushing, and other non-drinking purposes.

The watershed lands owned and protected by MMWD stretch over 21,635 acres, including more than 18,900 on Mt. Tamalpais and 2,700 adjacent to Nicasio and Soulajule reservoirs in west Marin. An additional 35,000 acres of privately owned watershed drains into those two reservoirs. In addition to being a valuable source of water for customers, the Mt. Tamalpais watershed is a natural wild-land of great biological diversity and a popular recreational destination (MMWD 2015).

MMWD Climate-Related Concerns and Management Priorities

MMWD's priority concerns are potential climate change impacts on lake operations and water demand, availability of surface water supply, drought risks, and stewardship of the Mt.

Tamalpais watershed in terms of vegetation management and fire risk.

Marin Municipal Water District is currently developing the *Water Resources Plan 2040*, a long-term plan for improving water supply resiliency under water shortage conditions, thereby providing consistent water to customers into the future. MMWD staff may apply the *Climate Ready North Bay* data findings to this analysis as they work to select water supply resiliency alternatives for further study, in order to ultimately recommend a preferred alternative.

MMWD staff is also considering using *Climate Ready North Bay* products as communication tools to inform the MMWD Board of Directors. An objective for communications would be to foster understanding of why each climate scenario is different and what the implications of each may be. MMWD's goal is to clearly illustrate the challenge of climate change adaptation in the context of historical data.

MMWD's management concerns are grouped into three resource areas: 1) Regional Rainfall Annual Variability; 2) Marin County Surface Water Supply (including drought risks, demand, and fisheries habitat); and 3) Land Cover and Fire Risks.

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 summarizes of the 18 GCMs selected by TBC3.

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, in terms of both rainfall and temperature change (Scenario 3) and lowest (Scenario 4) rainfall scenarios, and in addition to the scenario that landed closest to the center (ensemble mean) of the full set of climate projections, and in particular wanted to capture the highest (Scenario 5). 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)

USGS 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 historical 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 18-acre 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 historical climate input data is downscaled from PRISM (Daly et al. 2008), and the daily data set includes historical 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-year 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 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 historical 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 historical 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 11-14 illustrate the scenario selection discussion above, while slides 16-30 illustrate the BCM methodology and sample results at the scale of the North Bay region.

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).

Fire Risk Model
Statistical models of recent historic burning across the state, at a spatial resolution of 1080m landscapes and a temporal resolution of 30 years (1971-2000) were combined with the BCM outputs (temperature, precipitation, potential evapotranspiration, actual evapotranspiration, and climatic water deficit) to determine how fire activity might change over time. *Climate Ready North Bay* futures used for this analysis include Scenarios 1, 2, and 4. (Appendix B) Fire risk was modeled as the probability of burning occurring at least once within a future 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

- → *Marin County is becoming more arid due to rising temperatures*
- → *Rainfall is likely to be more variable in the future*
- → *Runoff and supply to reservoirs may be increasingly flashy*
- → *Water demand for agriculture and outdoor irrigation 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 Marin 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 Marin 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. 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.

Bridging Science and Management

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

Potential Climate Ready North Bay Data Applications

- Use of localized climate temperature and rainfall data to inform the MMWDs Water Resources Plan 2040
- Presentations to raise public awareness regarding the benefits of greenhouse gas reduction (mitigation) and the need to plan for adaptation
- Use of hydrologic data to inform partner agencies' long-term planning for surface water supply
- Integration of potential vegetation transition risks and fire hazards into natural resource management plans and fire mitigation planning
- Use of hydrologic assessments to evaluate potential high value resource streams and riparian zones at risk, as well as development of strategies to build adaptation into maintenance and restoration planning

Potential Climate Ready Data Audiences

- Other MMWD staff
- Elected and other decision makers, including the MMWD Board of Directors
- Consultants working on other dimensions of natural resource management and climate readiness for the MMWD
- Developers
- Agriculture
- The community at large

Management Questions Beyond Scope of Current Study

Additional management questions were identified in the *Climate Ready North Bay* stakeholder process that the team determined were beyond the scope of this study, and therefore were not addressed as part of the *Climate Ready North Bay* study. However, they are included here to provide a starting point for subsequent climate adaptation work.

- *What are the implications of potential temperature increases for water demand?*
  Historic and projected monthly temperature data have been provided to the MMWD to complete this analysis. *Historic* temperature data can be compared with the *historic* demand record to see if there is a strong enough correlation to merit extrapolation of future demand as a function of monthly temperatures.

- *What are the implications of potential temperature increases on water quality?*
  An original project goal was to try to correlate temperature with algal blooms, but apparently there was an insufficient historic record of bloom timing to facilitate a correlation. However, concerns remain regarding potential impacts of rising temperatures on water quality in reservoirs and storage tanks.

- *Can assessments of sub-areas of interest for vegetation transitions and/or fire address how the frequency of "red flag" days that trigger maintenance restrictions due to fire weather might be impacted? Can a correlation of "red flag" days tracked since 2004 be made to climatic water deficit or other climate indicators?*
  There is currently a companion project at UC Berkeley looking at controls on red flag days and the potential to model these under future climate scenarios.

- *What are the flooding issues specific to Corte Madera?*
  The *Climate Ready North Bay* team recommends exploring the development of higher temporal resolution climate-hydrology products that can look at the interface of watershed runoff and sea level rise projections presently under development for the Marin coast.

- *What are the implications of climate change for site-specific riparian vegetation and restoration projects?*
  The *Climate Ready North Bay* team recommends investigating the Point Blue Conservation Science climate smart planting palette developed for the Students and Teachers Restoring Watersheds (STRAW) program.

Acknowledgements

Funding for this project was in part provided by the Planning Group of MMWD. 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 Dr. 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.

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.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.

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 North Bay Analyses Conducted for Marin Municipal Water District

REGIONAL HYDROLOGY GIS DATABASE

Data Product: TBC3 Bay Area Basin Characterization Model Database-An ESRI Geographical Information System (GIS) raster data base. This database base includes 18-acre resolution monthly 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 bench-marks, 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*

MARIN COUNTY CLIMATE: LONG-TERM SUMMARY HYDROLOGY and FIRE 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-year 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 MMWD county BCM and service area fire summaries.xls

MARIN COUNTY CLIMATE: HYDROLOGY and FIRE 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-year 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 MMWD county BCM and service area fire summaries.xls*

MMWD RESERVOIRS: ANNUAL TIME SERIES AND RUNNING AVERAGES

Data Product: Basin Characterization Model Annual Time Series by Reservoir Drainage Area and Stream Gages

Spreadsheets of downscaled precipitation, reservoir inputs and BCM water supply outputs including runoff and annual 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. These annual values are shown as annual time series plots, as a 2-year running average and in the companion sheet as 3-year running averages.

Filename: *CRNB MMWD reservoir and gage annual time series plots.xls*
Filename: *CRNB MMWD 2 YR AVG PPT RCH RUN DISCHARGE by reservoir and cumulative.xls*
Filename: *CRNB MMWD 3 YR AVG PPT RCH RUN DISCHARGE by reservoir and cumulative.xls*

MMWD SUB: AREAS-MONTHLY RESOLUTION HYDROLOGY-CLIMATE OUTPUTS

Data Products: Monthly climate and hydrology time series for Service Area and Reservoirs

Excel spreadsheet and pivot table data products produced in monthly time steps include temperature (for purposes of correlating with demand), reservoir inflows (for correlation with precipitation or combined runoff and recharge), precipitation, and runoff. All parameters may be queried by reservoir drainage area.

Filename: CRNB MMWD Monthly Temperature Averages.xls
Filename: CRNB MMWD Monthly Reservoir Inflows 1955-2014.xls
Filename: CRNB MMWD Monthly Averages PPT for MMWD reservoir watersheds.xls
Filename: CRNB MMWD Monthly Averages RUNOFF for reservoir watersheds.xls

MARIN COUNTY VEGETATION TRANSITION REPORTS

Data Product: Climate Ready North Bay 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-Marin County.pdf

IMPACTS OF CLIMATE CHANGE ON VEGETATION: MARIN 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 Marin County 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	historica 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	historica 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%

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

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

Table 1. IPCC Global Models used in the TBC3 Bay Area California Basin Characterization Model downscaled climate-hydrology knowledge base

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

Originating Group(s)	Country	Model Abbreviation	IPCC Assessment Report	Emissions scenario or representative concentration pathway	Downscaling method
Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)		MPI-ESM-LR	5	RCP 4.5	BCSD
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.