DRAFT

1.3. Climate Change

There is mounting scientific evidence that global climate conditions are changing and will continue to change as a result of the continued build-up of greenhouse gases (GHGs) in the Earth's atmosphere. Changes in climate can affect municipal water supplies through modifications in the timing, amount, and form of precipitation, as well as water demands and the quality of surface runoff. These changes can affect all elements of water supply systems, from watersheds to reservoirs, conveyance systems, and treatment plants.

Planning for and adapting to anticipated changes in climate will be essential to ensuring water supply reliability for all users and to protecting sensitive infrastructure against more frequent and extreme precipitation and wildfire events. This technical memorandum (TM) summarizes anticipated climate change impacts on the State of California and the Mokelumne/Amador/Calaveras (MAC) Integrated Regional Water Management (IRWM) region, evaluates the impacts of those changes with regards to water resource management, assesses the vulnerability of regional infrastructure to anticipated climate change impacts, and provides recommended adaptation and mitigation strategies to address uncertainty and reduce GHG emissions. In addition, a plan for ongoing data collection to fill data gaps and monitor the frequency and magnitude of local hydrologic and atmospheric changes is provided.

1.3.1. Background

Research conducted by the California Department of Water Resources (DWR), the American Water Works Association (AWWA), and the Intergovernmental Panel on Climate Change (IPCC), among others, indicates that North America will likely experience increased land and water temperatures and greater climatic variability in this century. While the impacts of climate change will be experienced differently by different regions and watersheds, water supply systems that exhibit the following characteristics are most likely to be impacted by climate change:

- Depend on surface storage for water supply and flood control;
- Depend on late spring snowmelt;
- Are sensitive to climatic variability;
- Contain biological habitats that are sensitive to water temperatures, quality and runoff timing;
- Are located in arid parts of western North America.

Because the primary sources of water in the MAC Region are the Mokelumne and Calaveras River watersheds, which rely on snowmelt and rainfall from the Sierra Mountain Range, the water supply systems within the Region display many of these characteristics. However, predicting future climate conditions and potential impacts on water resources is not an exact science. Detailed analysis relies on assumptions about future carbon emissions and coarse disaggregation of data from global and regional climate models into regional weather patterns.

1.3.2. Statewide Observation and Projections

In 2005, Governor Arnold Schwarzenegger signed Executive Order S-3-05, ordering the State of California to assess the impacts of climate change on various sectors of the California economy, including the State's water supply. In response to the Governor's order, DWR, in collaboration with recognized industry and academic experts, prepared a report describing the progress made to incorporate climate change into water resources planning (DWR, 2006). The report presented empirical evidence that the State's climate has indeed been changing over the course of the 20th century, and documented a methodology for forecasting future climate conditions by downscaling information from general circulation models (GCMs) to assess potential climate change impacts on the State's water resources. At the same time, the California Energy Commission's Public Interest Energy Research (PIER) and the California Climate Change Center (CCCC) prepared the first biennial science report (CEC, 2006) to evaluate and present potential impacts of climate change on specific sectors of the California economy, including water resources. This report presented a methodology similar to DWR's methodology, but also included approaches that are specific to the resource(s) being impacted by climate change (e.g. agriculture versus public health).

Predicting future climate conditions and the potential associated impacts on water resources is not an exact science and relies on several key assumptions. A number of studies have been conducted to-date to project possible future changes in temperature and precipitation, and many more are currently underway. While it is generally accepted that temperatures will increase in California over the next century, the rate of temperature rise and specific changes in regional precipitation patterns are less certain.

The DWR methodology for evaluating climate change impacts on water resources is summarized in Figure 1. This methodology, as published in the 2006 DWR report entitled *Progress on Incorporating Climate Change into Management of California Water Resources*, is a scenario-planning approach that uses two representative GCMs: the Geophysical Fluid Dynamic Lab model (GFDL) and the Parallel Climate Model (PCM). These models were selected from a multitude of available models currently being run at 18 modeling centers around the world to calculate future global climate conditions. The GFDL model was selected because it is relatively sensitive to GHGs in modeling global and regional temperatures, while the PCM was selected as a counterpoint as it is less sensitive. Both models, however, were within the mid-range of GHG predictions by GCMs in use at that time.

DRAFT

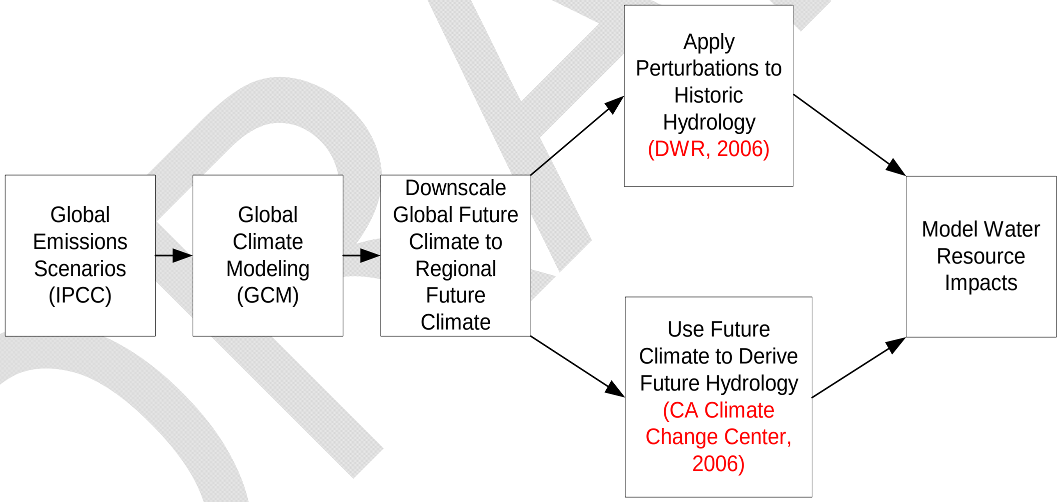


Figure 1: Summary of Climate Change Modeling

Additionally, both GCMs (GFDL and PCM) were evaluated under two emissions scenarios: the A2 emissions scenario and the B1 scenario. The A2 scenario is characterized by an increasing population, regionally oriented economic development and independently operating self-reliant nations with slow technological changes resulting in significantly higher GHG emissions. The B1 scenario reflects a more integrated and ecologically friendly future, combining a high level of environmental and social consciousness with global cooperation for sustainable development. This scenario is characterized by rapid economic growth, but with equally rapid changes toward a service- and information-based economy. This methodology again reflects the central range of modeling results, rather than the extremes.

The resulting changes in global climate were downscaled to obtain regional climate data relevant to the MAC IRWM planning program. Regional climate data were then used to predict regional streamflow runoff using an established hydrologic model (the Variable Infiltration Capacity or VIC model) relating regional temperature and precipitation to streamflow runoff. The model was calibrated by comparing historical streamflow data to modeled streamflow data generated using historic climate conditions. A comparison of monthly average model-generated flows under future climate conditions were then compared to historic streamflows to established monthly perturbation ratios or factors (a perturbation ratio is the ratio of the value of the relevant variable – in this case, streamflow – to the corresponding value of the same variable in the same month under baseline or historical conditions). The resulting perturbation factors were then applied to the historic hydrology of local watersheds to set up a perturbed (or modified) hydrology reflecting potential future conditions under a climate change scenario. In the DWR study, perturbation factors were developed for eleven key California watersheds for use in the state-wide modeling.

The CCCC, under the direction of Governor Schwarzenegger, developed an alternative methodology to assess impacts on several sectors of the California economy (including water resources, agriculture, and public health). For the agricultural sector in the Sacramento Valley, the methodology employed differed from the DWR approach mainly in how streamflows were generated from downscaled GCM data. In the DWR methodology, perturbed historic hydrology modified the magnitude of monthly streamflows but preserved the historic sequence of wet years and dry years (i.e. frequency and length of droughts remained constant). The CCCC methodology stipulated that, because the global climate is changing, past climate patterns are no longer an accurate guide for future patterns (Joyce et al, 2006). Like the DWR approach, the CCCC approach downscaled the GCM data to obtain regional climate data; however, these data were then input into a regional hydrologic model generating streamflow data for future years. The resulting climate-derived hydrologic conditions differ from the perturbed historic hydrologic conditions in that the historic annual and decadal patterns (e.g. length, magnitude, and frequency of droughts) were not preserved. The results of the two methods are summarized in Table 1.

Table 1: Summary of Predicted Water Resources Impacts in Northern California

	Predicted Impacts			
Method	**Snow Pack and Stream Flow Timing**	**Total Annual Precipitation**	**Drought Frequency**	**Drought Length**
Perturbed Historic Hydrology (DWR, 2006)	Decreased Snow pack, Snowmelt earlier in year	Inconclusive – no major trends identified	None – historic patterns are preserved	Greater climate variability predicted (including potentially longer droughts)
Climate-Derived Hydrology (CCCC, 2006a)	Decreased Snow pack, Snowmelt earlier in year	Inconclusive – no major trends identified	Inconclusive - but some scenarios predict more frequent droughts	Inconclusive - but some scenarios predict longer droughts

Both methods (DWR and CCCC) relied on several assumptions, and neither can be used to exactly predict future conditions. Additionally, while projected temperature increases are significant, even as early as 2011-2040, and are consistent between models, the magnitude of annual precipitation has been shown to vary, sometimes significantly, between GCMs (Maurer, 2005). However, the use of scenario planning reduces variance by producing a bracketed range of results, and general trends are beginning to emerge from the modeling. The most consistent findings are that a predicted increase in surface temperature will

DRAFT

cause a decrease in total annual snowpack and that snowmelt, and therefore spring runoff, will occur earlier in the year. Additionally, there is no conclusive evidence from either approach as to the frequency or severity of droughts, but DWR acknowledges the potential for increased climate variability (including the potential for more severe droughts) and some scenarios under the climate-derived hydrology method predict longer and more frequent droughts.

Temperature and Precipitation Changes

While California's average temperature has increased by 1°F in the last one hundred years, trends are not uniform across the state. The Central Valley has actually experienced a slight cooling trend in the summer, likely due to an increase in irrigation (CEC, 2008). Higher elevations have experienced the greatest temperature increases. Many of the State's rivers have seen increases in peak flows in the last 50 years (DWR, 2008).

GCMs project that in the first 30 years of the 21st century, overall summertime temperatures in California will increase by 0.9 to 3.6°F (CAT, 2009) and average temperatures will increase by 3.6 °F to 10.8°F by the end of this century (Cayan et al, 2006). Increases in temperature are not likely to be felt uniformly across California. Model projections generally project that warming will be greater in California in the summer than in the winter (CAT, 2009) and inland areas will experience more extreme warming than coastal areas (CNRA, 2009). These non-uniform warming trends are among the reasons that regional approaches to addressing climate change are important.

While historical trends in precipitation do not show a statistically significant change in average precipitation over the last century, regional precipitation data show a trend of increasing annual precipitation in Northern California (DWR, 2006) and decreasing annual precipitation throughout Southern California over the last 30 years (DWR, 2008). A key change in precipitation patterns has been more winter precipitation falling as rain instead of snow (CNRA, 2012), leading to increased streamflow in the winter and decreased streamflow in the spring and summer, when water demands are the greatest. This increased streamflow variability could lead to increased risks of flooding, levee failure, saline water intrusion and flood-induced habitat destruction.

While temperature projections exhibit high degrees of agreement across various models and emissions scenarios, projected changes in precipitation are more varied. Taken together, downscaled GCM results show little, if any, change in average precipitation for California before 2050 (DWR, 2006), with a drying trend emerging after 2050 (BOR, 2011 and CCSP, 2009). While little change in precipitation is projected by the GCMs as a group, individual GCM results are considerably varied. Climate projections therefore imply an increase in the uncertainty of future precipitation conditions.

Sea level Rise, Snowpack Reduction, and Extreme Events

In the last century, the California coast has seen a sea level rise of seven inches (DWR 2008). The average April 1st snowpack in the Sierra Nevada region has decreased in the last half century (Howat and Tulaczyk, 2005, CCSP, 2008), and wildfires are becoming more frequent, longer, and more widespread (CCSP, 2008).

As the climate warms, snowpack in the Sierra Nevada (a primary storage mechanism for California's water supply) is anticipated to continue to shrink. Based on simulations conducted to date, Sierra Nevada snowpack is projected to shrink by 30% between 2070 and 2099, with drier higher warming scenarios projecting that number as high as 80% (Kahrl and Roland-Holst 2008). Additionally, extreme events are expected to become more frequent, including wildfires, floods, droughts, and heat waves. In contrast, freezing spells are expected to decrease in frequency over most of California (CNRA, 2009). While GCM projections may indicate little, if any, change in average precipitation moving into the future, extreme

DRAFT

precipitation events are expected to become more commonplace (CBO, 2009). The combination of drier and warmer weather compounds expected impacts on water supplies and ecosystems in the Southwestern United States with wildfires expected to continue to increase in frequency and severity (CCSP, 2009).

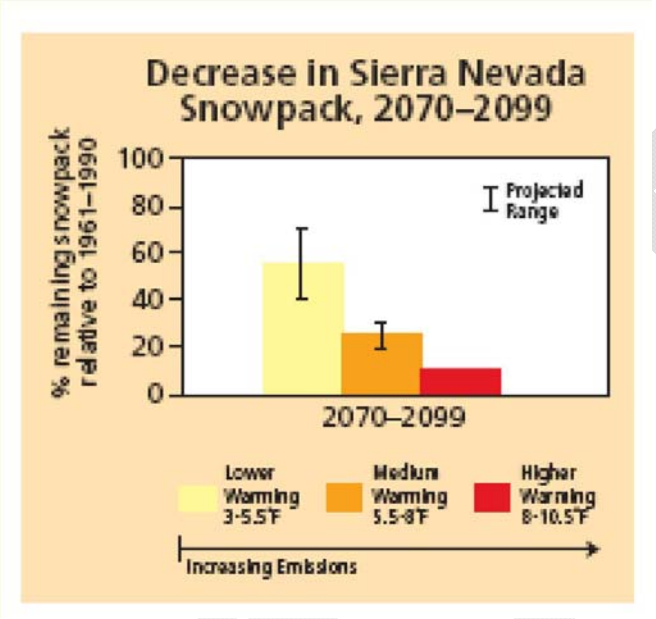


Figure 2: Projected Temperature and Precipitation Changes in California (Hopmans et al., 2008)

1.3.3. Legislative and Policy Context

In order to address currently-predicted climate change impacts to California's water resources, DWR's IRWM Grant Program Guidelines require that IRWM Plans describe, consider, and address the effects of climate change on their region, and consider reducing GHG emissions when developing and implementing projects. Part of this process involves framing the IRWM analysis and response actions in the context of State legislation and policies that have been formed to address climate change. The following summarizes the legislation and policies that were considered as part of this IRWM Plan.

Executive Order (EO) S-3-05 (2005)

EO S-3-05, signed on June 1, 2005 by Governor Arnold Schwarzenegger, is a key piece of legislation that has laid the foundation for California's climate change policy. This legislation recognized California's vulnerabilities to the impacts of climate change, including vulnerabilities of water resources. EO S-3-05 established three GHG reduction targets for California:

- By 2010, reduce GHG emissions to 2000 California levels
- By 2020, reduce GHG emissions to 1990 California levels
- By 2050, reduce GHG emissions to 80 percent below 1990 California levels

In addition to establishing GHG reduction targets for California, EO S-3-05 required the head Secretary of the California Environmental Protection Agency (CalEPA) to establish the Climate Action Team (CAT) for State agencies to coordinate oversight of efforts to meet these targets. As laid out in the EO, the CAT submits biannual reports to the governor and State legislature describing progress made toward reaching the targets.

DRAFT

There are currently 12 sub-groups within CAT, one of which is the Water-Energy group (also known as WET-CAT). WET-CAT was tasked with coordinating the study of GHG effects on California's water supply system, including the development of GHG mitigation strategies for energy consumption related to water use. Since the adoption of the Assembly Bill 32 Scoping Plan (see the following section), WET-CAT has been working on the implementation and analyses of six water-related measures identified in the Scoping Plan:

1. Water Use Efficiency
2. Water Recycling
3. Water System Energy Efficiency
4. Reuse Urban Runoff
5. Increase Renewable Energy Production
6. Public Goods Charge for Water

Assembly Bill 32: The California Global Warming Solutions Act of 2006 (2006)

Assembly Bill 32 (AB 32), the California Global Warming Solutions Act of 2006 laid the foundation for California's response to climate change. In 2006, AB 32 was signed by Governor Schwarzenegger to codify the mid-term GHG reduction target established in EO S-3-05 (reduce GHG emissions to 1990 levels by 2020). AB 32 directed the California Air Resources Board (CARB) to develop discrete early actions to reduce GHG emissions by 2007, and to adopt regulations to implement early action measures by January 1, 2010.

Climate Change Scoping Plan (2008)

AB 32 required CARB to prepare a Scoping Plan to identify and achieve reductions in GHG emissions in California. The Climate Change Scoping Plan, adopted by CARB in December 2008, recommends specific strategies for different business sectors, including water management, to achieve the 2020 GHG emissions limit.

Senate Bill 97 (2007)

Senate Bill 97 (SB 97) recognized the need to analyze greenhouse gas emissions as part of the California Environmental Quality Act (CEQA) process. SB 97 directed the Governor's Office of Planning and Research (OPR) to develop, and the Natural Resources Agency to adopt, amendments to the CEQA Guidelines to address the analysis and mitigation of greenhouse gas emissions. On December 31, 2009, the Natural Resources Agency adopted amendments to the CEQA Guidelines and sent them to the California Office of Administrative Law for approval and filing with the Secretary of State (http://www.ceres.ca.gov /ceqa/guidelines/). The CEQA Guidelines are not prescriptive; rather they encourage lead agencies to consider many factors in performing a CEQA analysis, and maintain discretion with lead agencies to make their own determinations based on substantial evidence.

Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water (2008)

DWR, in collaboration with the State Water Resources Control Board (SWRCB), other state agencies, and numerous stakeholders, has initiated a number of projects to begin climate change adaptation planning for the water sector. In October 2008, DWR released the first state-level climate change adaptation strategy for water resources in the United States, and the first adaptation strategy for any sector in California. Entitled *Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water*, the report details how climate change is currently affecting the state's water supplies, and sets forth ten adaptation strategies to help avoid or reduce climate change impacts to water resources.

DRAFT

Central to these adaptation efforts will be the full implementation of IRWM plans, which address regionally-appropriate management practices that incorporate climate change adaptation. These plans will evaluate and provide a comprehensive, economical, and sustainable water use strategy at the watershed level for California.

Executive Order S-13-08 (2008)

Given the potentially serious threat of sea level rise to California's water supply and coastal resources, and the subsequent impact it would have on our state's economy, population, and natural resources, Governor Schwarzenegger issued EO S-13-08 to enhance the state's management of climate impacts from sea level rise, increased temperatures, shifting precipitation, and extreme weather events. This order required the preparation of the first California Sea Level Rise Assessment Report (by the National Academy of Sciences) to inform the State as to how California should plan for future sea level rise; required all state agencies to consider a range of sea level rise scenarios for the years 2050 and 2100 in order to assess potential vulnerabilities of proposed projects and, to the extent feasible, reduce expected risks and increase resiliency to sea level rise; and required the Climate Action Team to develop a state strategies for climate adaptation, water adaptation, ocean and coastal resources adaptation, infrastructure adaptation, biodiversity adaptation, working landscapes adaptation, and public health adaptation.

California Climate Adaptation Strategy (2009)

In response to the passage of EO S-13-08, the Natural Resource Agency wrote the report entitled *2009 California Climate Adaptation Strategy* (CAS) to summarize the best known science on climate change impacts in the state, to assess vulnerability, and to outline possible solutions that can be implemented within and across the state agencies to promote climate change resilience. The document outlined a set of guiding principles that were used in developing the strategy, and resulted in the preparation of 12 key recommendations as follows:

1. Appoint a Climate Adaptation Advisory Panel (CAAP) to assess the greatest risks to California from climate change and to recommend strategies to reduce those risks, building on the Climate Change Adaptation Strategy.
2. Implement the 20x2020 water use reductions and expand surface and groundwater storage; implement efforts to fix Delta water supply, quality and ecosystems; support agricultural water use efficiency; improve statewide water quality; improve Delta ecosystem conditions; and stabilize water supplies as developed in the Bay Delta Conservation Plan.
3. Consider project alternatives that avoid significant new development in areas that cannot be adequately protected from flooding, wildfire, and erosion due to climate change.
4. Prepare, as appropriate, agency-specific adaptation plans, guidance or criteria.
5. For all significant state projects, including infrastructure projects, consider the potential impacts of locating such projects in areas susceptible to hazards resulting from climate change.
6. The CAAP and other agencies will assess California’s vulnerability to climate change, identify impacts to state assets, and promote climate adaptation/mitigation awareness through the Hazard Mitigation Web Portal and My Hazards Website, as well as other appropriate sites.
7. Identify key California land and aquatic habitats that could change significantly during this century due to climate change.
8. The California Department of Public Health will develop guidance for use by local health departments and other agencies to assess mitigation and adaptation strategies, which include impacts on vulnerable populations and communities, and assessment of cumulative health impacts.

DRAFT

9. Communities with General Plans and Local Coastal Plans should begin, when possible, to amend their plans to assess climate change impacts, identify areas most vulnerable to these impacts, and develop reasonable and rational risk reduction strategies using the CAS as guidance.
10. State fire fighting agencies should begin immediately to include climate change impact information into fire program planning to inform future planning efforts.
11. State agencies should meet projected population growth and increased energy demand with greater energy conservation and an increased use of renewable energy.
12. New climate change impact research should be broadened and funded.

GHG Reporting Rule (2009)

While California has taken the lead in climate change policy and legislation, there have been several recent developments at the federal level affecting climate change legislation. On September 22, 2009, the U.S. Environmental Protection Agency (USEPA) released the Mandatory Reporting of Greenhouse Gases Rule (74FR56260, Reporting Rule) which requires reporting of GHG data and other relevant information from large sources and suppliers in the United States. Starting in 2010, facility owners that emit 25,000 metric tons of GHGs or more per year are required to submit to the USEPA an annual GHG emissions report with detailed calculations of facility GHG emissions. These activities will dovetail with the AB 32 reporting requirements in California.

Senate Bill 375 (2008)

The Sustainable Communities and Climate Protection Act of 2008 (Senate Bill [SB] 375) was passed to enhance the State's ability to reach its AB 32 goals by promoting good planning with a goal of more sustainable communities. SB 375 required the CARB to develop regional greenhouse gas emission reduction targets for passenger vehicles and 2020 and 2035 GHG emission targets for each region covered by one of the State's 18 California's metropolitan planning organizations (MPOs). Each of the MPOs then prepare a sustainable communities strategy that demonstrates how the region will meet its GHG reduction target through integrated land use, housing and transportation planning. Once adopted, these sustainable communities strategies are incorporated into the region's federally enforceable regional transportation plan.

California Water Plan Update (2009)

The *California Water Plan* (CWP) provides a collaborative planning framework for elected officials, agencies, tribes, water and resource managers, businesses, academia, stakeholders, and the public to develop findings and recommendations and make informed decisions for California's water future. The plan, updated every five years, presents the status and trends of California's water-dependent natural resources, water supplies, and agricultural, urban, and environmental water demands for a range of plausible future scenarios and evaluates different combinations of regional and statewide resource management strategies to reduce water demand, increase water supply, reduce flood risk, improve water quality, and enhance environmental and resource stewardship. Last updated in 2009, the CWP Update provided statewide water balances for eight water years (1998 through 2005), demonstrating the state's water demand and supply variability. The updated plan built on the framework and resource management strategies outlined in the CWP Update 2005 promoting IRWM and improved statewide water and flood management systems. The CWP Update 2009 provided the following 13 objectives to help achieve the CWP goals:

1. Expand integrated regional water management
2. Use and reuse water more efficiently
3. Expand conjunctive management of multiple supplies
4. Protect surface water and groundwater quality

DRAFT

5. Expand environmental stewardship
6. Practice integrated flood management
7. Manage a sustainable California Delta
8. Prepare Prevention, Response and Recovery Plans
9. Reduce energy consumption of water systems and uses
10. Improve data and analysis for decision-making
11. Invest in new water technology
12. Improve tribal water and natural resources
13. Ensure equitable distribution of benefits

The plan acknowledges an uncertain future with respect to population, land use, irrigated crop area, environmental water, background water conservation, water demands and climate change variability. To address this, the CWP Update 2009 presents 27 resource management strategies to provide a range of choices and building blocks to address future uncertainty. Finally, the *2009 CWP Update* provided regional reports that summarize regional settings and water conditions, provide regional water balance summaries, and describes regional water quality, flood management, and regional water and flood planning and management. The summaries also provide a summary of challenges facing each of the hydrologic regions and provided future scenarios for the region.

Climate Ready Utilities (2010)

In the fall of 2009, the USEPA convened a Climate Ready Water Utilities (CRWU) Working Group under the National Drinking Water Advisory Council (NDWAC). This working group prepared a report that documents 11 findings and 12 recommendations relating to the development of a program enabling water and wastewater utilities to prepare long-range plans that account for climate change impacts. The report, delivered to the USEPA in 2010, also included an adaptive response framework to guide climate-ready activities, and the identification of needed resources and possible incentives to support and encourage utility climate readiness. This report resulted in the preparation of the USEPA's Climate Ready Water Utilities Program and the development of tools and resources to support water and wastewater utilities in their planning. These tools and resources include:

- Climate Resilience Evaluation and Awareness Tool (CREAT) – a software tool to assist utility owners and operators in understanding potential climate change impacts and in assessing the related risks to their utilities.
- Climate Ready Water Utilities Toolbox – a searchable toolbox that contains resources that support all states of the decision process, from basic climate science through integration of mitigation and adaptation into long-term planning.
- Adaptation Strategies Guide – an interactive guide to assist utilities in gaining a better understanding of what climate-related impacts they may face in their region and what adaptation strategies can be used to prepare their system for those impacts.
- Climate Ready Water Utilities and Climate Ready Estuaries – USEPA initiative working to coordinate their efforts and support climate change risk assessment and adaptation planning.

National Water Program 2012 Strategy: Response to Climate Change (2012)

The USEPA has prepared and released its Draft *National Water Program 2012 Strategy: Response to Climate Change* to address climate change impacts on water resources and the USEPA's water programs. The report identifies core programmatic elements of the strategy in the form of programmatic visions, goals and strategic actions, with each long-term vision (or outcome) documented with an identified set of goals that reflect the same long-term time frame as the vision and several strategic actions to be implemented in the next three to eight years to pursue the longer-term goals and visions. The draft report

DRAFT

also includes ten guiding principles for implementing the strategy outlined in the vision, goals and strategic actions and recommendations for cross-cutting program support.

1.3.4. Regional Climate Change Projections and Impacts

The regional climate change projections and impacts described herein were developed through a detailed climate change impact analysis conducted by the East Bay Municipal Utility District (EBMUD) as part of the Water Supply Management Program (WSMP) 2040. Because the Upper Mokelumne River Watershed is the primary source of EBMUD's water supply, the approach, methodology, and results focused on the Upper Mokelumne River Watershed. Additionally, the EBMUD study focused on climate change impacts to the central portion of the Sierra Nevada. Given the breadth of GCM regionalization, anticipated climatic changes in temperatures and/or precipitation as modeled for the Upper Mokelumne River Watershed can also be considered applicable to the adjacent Calaveras River watershed and to the MAC IRWM region as a whole.

A key goal of EBMUD's WSMP was to develop solutions ensuring that EBMUD has the necessary water supply to meet its current and future demands through the year 2040 under a variety of hydrologic conditions. In deciding on the methodology for evaluating climate change impacts on the water supply system, methodologies used by other water agencies in the State of California for evaluating both climate change and drought impacts on their water systems were first explored. Then, considering these data in conjunction with additional information on the current state of climate change impact analysis science, a "Bottom-Up" approach was selected as the appropriate approach for use in the WSMP. The goal of this method was to test the watershed's sensitivity to a range of possible climate scenarios and then use this information to guide future water supply planning.

A Bottom-Up approach is a sensitivity analysis using historic hydrology to evaluate climate change impacts. Currently, neither global climate change models nor regional downscaling models offer concrete conclusions as to how California will be impacted by climate change; current methodologies only provide initial evaluations of the potential effects of climate change. In a Bottom-Up approach, the most critical vulnerabilities of the water supply system are identified, the causes of those vulnerabilities are articulated to suggest how climate change might or might not exacerbate those vulnerabilities, and steps are taken to address the vulnerability in the face of climatic uncertainty. The Bottom-Up approach is in contrast to a Top-Down approach which begins with climate-derived hydrology under various emission scenarios; these data are then downscaled to a local hydrologic model and water system model (Figure 3).

DRAFT

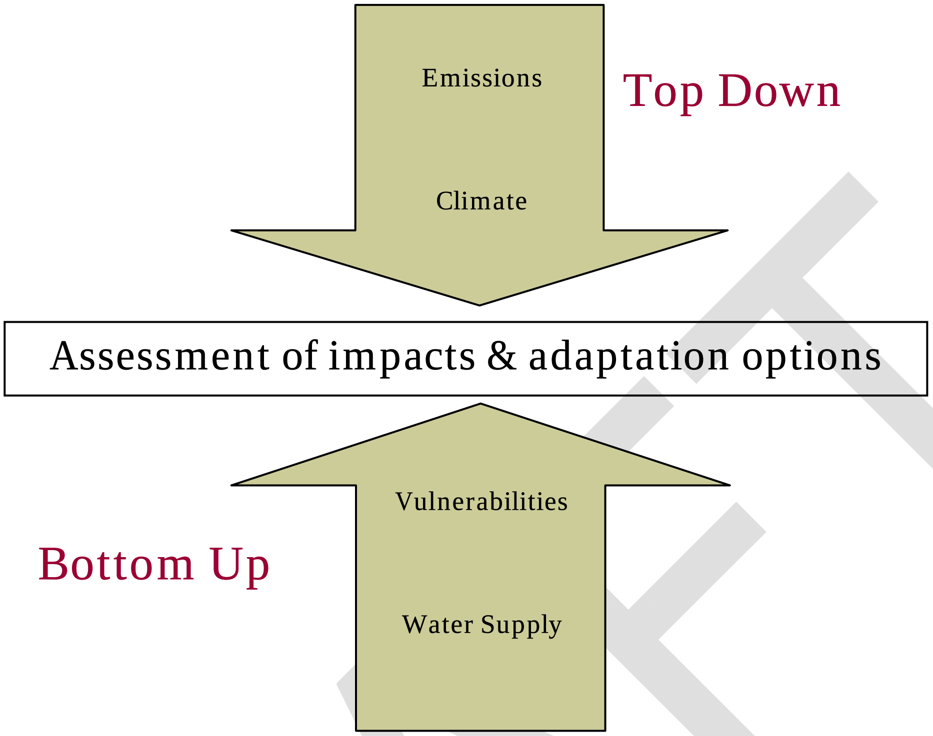


Figure 3: Methods for Assessing Climate Change Impacts

To expedite the analysis of possible climate change impacts to future water supplies, both under historic hydrologic conditions and a range of anticipated future climate scenarios, an integrated combination of the Water Evaluation And Planning (WEAP) system model and the EBMUD's operations model, called EBMUDSIM, was developed. This integrated model, referred to as the 'W-E model', was used as part of the process to evaluate climate change impacts. As part of the WSMP 2040 climate change analysis, the model of EBMUD's current water supply system was 'stressed' by systematically changing pre-identified factors and simulating results using the W-E model. The climate change scenarios were then compared to a baseline scenario to determine how sensitive the system was to each of the factors and to identify critical vulnerabilities. The identified sensitivities were then compared to the general predicted range of climate change affects.

For the sensitivity evaluation, the following three parameters were each individually modified in the W-E model:

- Mokelumne River annual runoff volume
- Mokelumne River runoff timing and pattern
- Length and frequency of multi-year droughts

Temperature Changes

Climate change is expected to cause an increase in regional air temperatures in future years, likely leading to an increase in water temperature in the Mokelumne River and watershed reservoirs. The effects of climate change have already been directly observed on the Mokelumne River watershed. Figure 4 shows maximum and minimum temperature at Camp Pardee, adjacent to Pardee Reservoir in Amador County (EBMUD, 2006). The data shown in this graph clearly depicts an upward trend in both minimum and maximum annual temperatures.

DRAFT

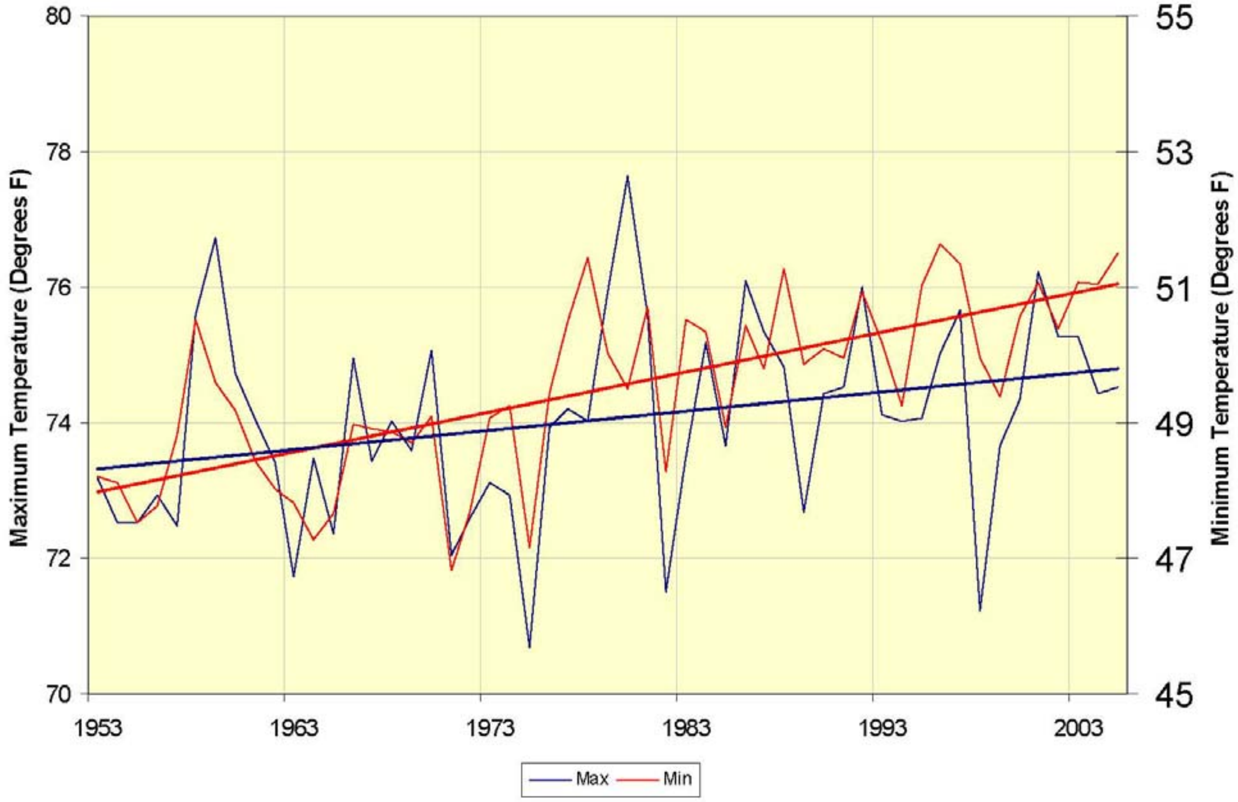


Figure 4: Camp Pardee Average Annual Temperature

Evidence of warming trends is also apparent in winter temperatures in the Sierra Nevada; an increase of almost 2°C (4°F) was observed during the second half of the 20th century. Unless there is a significant decrease in greenhouse gases, the incremental increase of an additional 2°C (4°F) is expected over the next half-century. In 2007, the IPCC released their Fourth Assessment Report. In this report, the IPCC presented best estimates and likely ranges for global average surface air warming. For the 'high' scenario (A1F1), the best estimate is an increase of 2°C to over 9°C, with a likely range between 2.4°C and 6.4°C.

Using similar ranges for global temperature increases, Michael Dettinger of the United States Geological Society (USGS) presented projected changes in annual precipitation in his 2004 paper entitled *From Climate-Change Spaghetti to Climate-Change Distribution* (Dettinger, 2004). This document presented the results of California-specific analyses conducted on behalf of the California Energy Commission which, in general, predict a +5°C warming between the years 2000 and 2100, with very little change in precipitation. This document also presents a detailed summary of studies conducted specifically for Northern California (including the Mokelumne and Calaveras River watersheds), presenting the range of anticipated changes in both temperature and precipitation. Based on this summary, Northern California can expect temperatures increases between +2°C to +6°C and precipitation changes between +20% to -20% by the year 2010. Precipitation is discussed in more detail in Section 0. Using Dettinger's graphs, as shown in Figure 5, this translates to a +4°C increase in air temperatures by the year 2040.

DRAFT

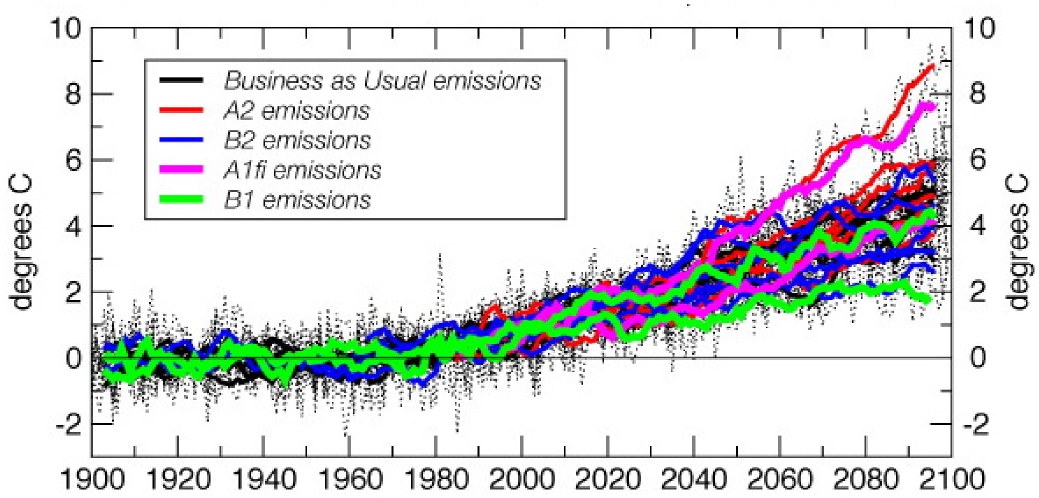


Figure 5: Projected Future Changes in Annual Temperature in Northern California (Dettinger, 2005)

Precipitation Changes

Global climate change models that have been downscaled to California regional areas have shown a greater degree in variability for predicted changes in precipitation than for temperature. Figure 6 shows the variability in projected changes in annual precipitation for Northern California (Dettinger, 2005), including the Mokelumne and Calaveras River watersheds. In general, based on the global climate change modeling published to date, precipitation volumes could increase by as much as 77% or decrease by as much as 25% by the year 2100, depending upon the future emissions scenario.

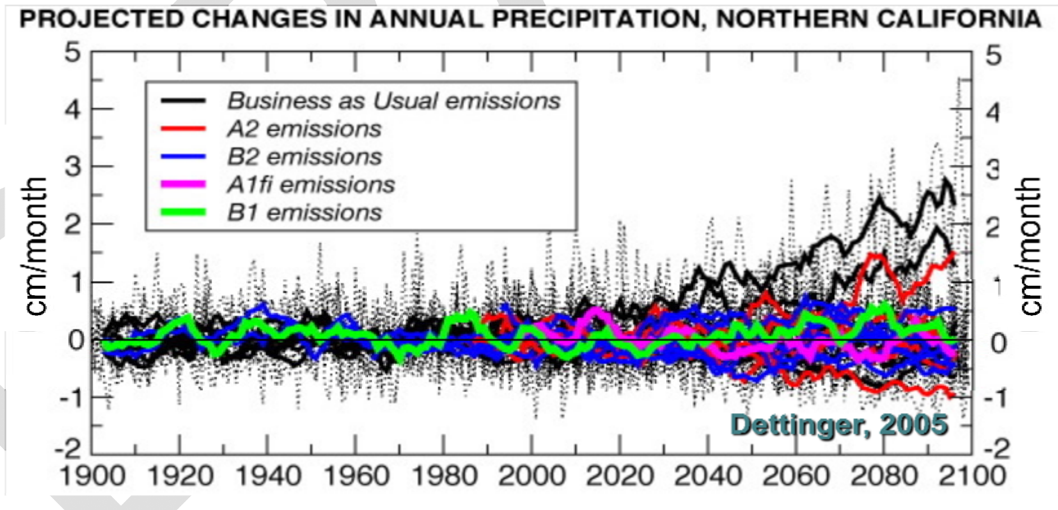


Figure 6: Projected Future Changes in Annual Precipitation in Northern California (Dettinger, 2005)

Precipitation increases can only enhance the volume of water available for supply. As the purpose of water supply planning is to ensure an available future water supply under a variety of dry conditions, potential future increases in precipitation in the Mokelumne River watershed were not part of the analysis

DRAFT

conducted for EBMUD's WSMP 2040 and only future decreases in precipitation were considered in the sensitivity analysis modeling. To that end, impacts of 10% and 20% decreases in precipitation in the Mokelumne River watershed were evaluated with the W-E model assuming that the 10%- and 20%-decrease in precipitation volumes correspond directly to 10% and 20% decreases in river runoff. This potential future trend appears to correspond with observed data, as shown in Figure 7, which shows the April to July Mokelumne River flows as a fraction of a water year. In this figure, there is a downward trend in the fraction of river flows occurring during the spring runoff period (EBMUD, 2006); similar responses would be expected in the Calaveras River. Table 2 in Section 5.3 presents the estimated future decreases in precipitation (and therefore matching decrease in the historic Mokelumne and Calaveras River runoff) in five-year intervals with the corresponding anticipated changes in air temperature.

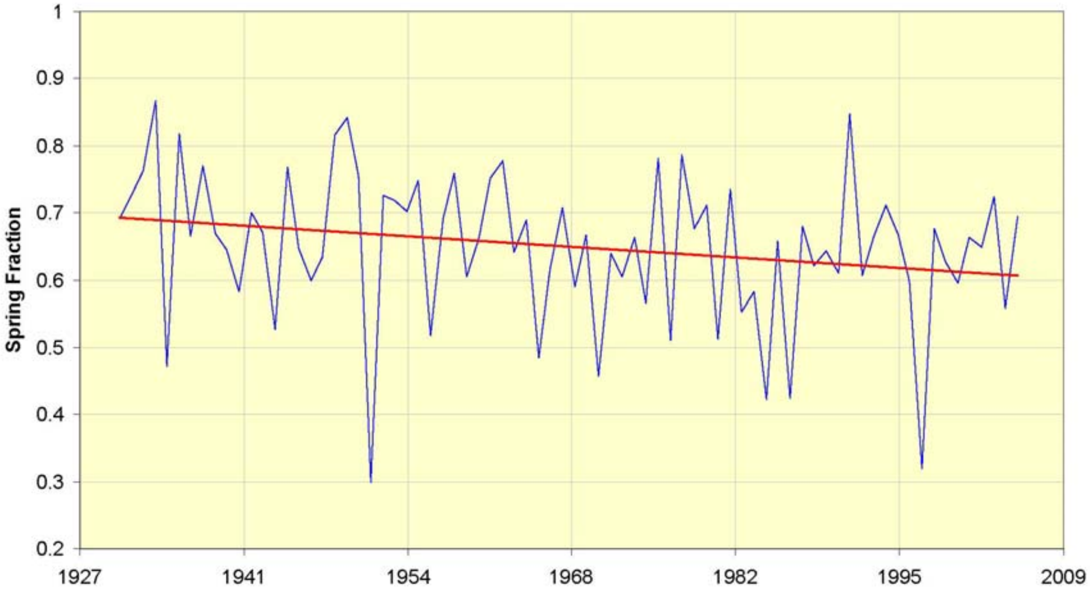


Figure 7: April – July Flow as Fraction of water Year – Mokelumne River

Historically, there have been three significant droughts of note on the Mokelumne River: 1929 to 1934, 1976 and 1977, and 1987 to 1992. Unfortunately, there is no historical regularity in the timing of the droughts that allows future drought frequency to be projected. In general, developing a protocol to simulate future droughts under a variety of climate change scenarios is challenging. By changing the timing of the river runoff and/or decreasing the volume of runoff in the W-E model, new 'artificial' droughts were generated in the EBMUD WSMP 2040 analysis that were then examined for their potential impacts on the Mokelumne River's water supply system. It is assumed (conservatively) that all of Northern California will experience drought conditions at the same time, and therefore drought impacts on the Mokelumne River will also be experienced simultaneously on the Calaveras and other Northern California rivers.

Methodology

In addition to increasing air temperatures, climate change is anticipated to affect weather patterns in a variety of ways. For example, precipitation is anticipated to increase in some locations and decrease in others. Storms are expected to increase in severity, such that a greater percentage of annual precipitation is experienced in a smaller number of events. The precise nature of these changes is currently unknown and cannot be accurately simulated. The simulations described herein assume that air temperature will uniformly increase while other weather patterns and characteristics remain stable. The simulations do not adequately simulate changes to other meteorological parameters, and therefore cannot be considered

DRAFT

to simulate the impacts of climate change. The results of the simulations present only estimates of the potential impacts to water temperature resulting from changes in ambient temperatures.

Although climate changes will most likely not occur in a steady and predictable fashion, it is better to prepare for the worst case scenario. A recent report from the National Research Council, *Abrupt Climate Change: Inevitable Surprises*, shows some major and widespread climatic changes have occurred with startling speed in the past, and can be expected to occur similarly in the future.

By the end of the 21st century, most scientists agree there will be a 3^{o}C to 6^{o}C increase in temperature in the western United States; projections for precipitation vary from 10% wetter to 20% drier. Therefore, based on this and other research available in published literature, the following anticipated changes were used to evaluate climate change impacts on EBMUD's system as part of their WSMP 2040 analysis:

- Increase in average daily temperatures by up to 4^{o}C from 1980 by the year 2040 (2.15^{o}C from 2005 by 2040)
- Decrease in precipitation rates by up to 20% from historical values by the year 2040

These values were selected to test the extreme predictions of climate change effects by the year 2040, thus defining the edges of the envelope of possible change. Intermediate values were also tested to determine if there were breakpoints in the response of the water supply system within that envelope.

In general, projected customer demands are expected to vary under climate change scenarios depending predominantly on temperature changes. While indoor water use is not expected to change significantly under climate change scenarios, changes in outdoor water use may have significant impacts on projected future customer demands. Past studies by Santa Clara Valley Water District (SCVWD) determined that, in general, a 1^{o}C increase in temperature resulted in an approximate 1% increase in demands. For the purposes of modeling climate change impacts during the WSMP 2040 project, a revised demand estimate for the Year 2040 was prepared to incorporate climate change impacts assuming a 4^{o}C increase in temperature, but no change in precipitation. Although a decrease in precipitation with an increase in air temperatures may seem to represent the most extreme climate change conditions, the analysis of projected future demands under such a scenario indicated that a 20% reduction in precipitation had little influence on overall customer demands in comparison to a 4^{o}C increase in air temperature; therefore, only the 4^{o}C increase in air temperatures was considered in the WSMP 2040 analysis.

Table 2: Temperature and Precipitation Changes for Use in Assessing Climate Change Impacts[a]

	1980[b]	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
Temperature Change (in ^{o}C)	0	1.85	2	2.25	2.4	2.5	3	3.5	4	4.21	4.43	4.64	4.85
Temperature Change (in ^{o}F)	0	3.33	3.6	4.05	4.32	4.5	5.4	6.3	7.2	7.58	7.97	8.35	8.73
Precipitation Change (%)	0	-15	-15	-15	-20	-20	-20	-20	-20	-25	-25	-25	-25

Source: RMC, 2008.

Footnotes:

a. Data estimated from ensembles of future temperature and precipitation projections from six coupled ocean-atmosphere general circulation models (Dettinger, 2005).

b. 1980 is the 'start' of recorded temperature increases associated with climate change per Dettinger, 2004.

Procedure for Climate Change Sensitivity Analysis

For the EBMUD WSMP 2040 project, EBMUD's water supply system (including its Mokelumne River reservoirs) was assessed both qualitatively and quantitatively with respect to these vulnerabilities and potential impacts. The analysis for EBMUD was completed specifically for the Upper Mokelumne River watershed, as approximately 90% of the EBMUD's current water supply comes from this watershed. Therefore, the climate change analysis completed for the WSMP 2040 is directly applicable to the portion of the MAC Region that lies within the Upper Mokelumne River watershed, and the analysis is considered to be reflective of similar changes that would likely occur on the Calaveras River watershed due to the extent of regionalization of the GCMs (all of Northern California).

Additionally, a 2010 study conducted by Null et al. of the University of California Davis evaluated the hydrologic response and watershed sensitivity to climate change for the Sierra Nevada watersheds, including the Mokelumne and Calaveras Rivers. This study used a climate-forced rainfall-runoff model to explicitly simulate intra-basin hydrologic dynamics and understand localized sensitivity to climate warming. Using the WEAP model, the researchers simulated anticipated 2^{o}C, 4^{o}C and 6^{o}C temperature increases and evaluated changes from baseline for three key parameters – mean annual flow, centroid timing, and low flow duration – to highlight relative differential responses across the Sierra Nevada watersheds and in relation to water resource development (water supply, hydropower and mountain meadow habitat, respectively).

EBMUD W-E Model

The first step in the WSMP 2040 climate change sensitivity analysis was to develop the scenarios to be modeled using the W-E model. As previously described, the current global climate models and corresponding regional models have indicated, for Northern California, future increases in temperatures accompanied by uncertain future precipitation rates. Additionally, studies have indicated the potential for a more unstable future hydrology, resulting in longer and more frequent droughts. Based on this information, the following scenarios were selected for variation in the W-E model:

- Change in customer demands resulting from a 4^{o}C increase in air temperatures;
- Change in the timing of Mokelumne River runoff corresponding to 2°C, 3°C and 4°C increases in air temperature;
- Reductions in Mokelumne River runoff corresponding to a 10% and 20% reduction in precipitation.

While climate change could result in higher average runoff, only reduced runoff was evaluated because it would have an adverse effect on water supply.

Separate runs for evaluating a future with longer and more frequent droughts was not prepared as the runs evaluating decreases in Mokelumne River runoff inherently also include changes in future drought scenarios. The climate change sensitivity modeling studies changed only one variable at a time and did not evaluate combinations of changes, such as higher customer demand and reduced runoff. Compounding of climate change effects could have a greater overall impact on water supplies from the Mokelumne and Calaveras River watersheds.

For the WSMP 2040 climate change analysis, each proposed scenario was run (including a baseline scenario) through a Visual Basic script (VBS) that approximates Pacific Gas and Electric Company (PG&E) operations under the assumed conditions. Output from VBS provided the necessary hydrologic inputs to the EBMUDSIM model, including regulated inflow to Pardee and updated PG&E reservoir storage values. These results were then incorporated as model input to scenario-specific EBMUDSIM dynamic link libraries for use by WEAP in the sensitivity study. WEAP was then run for each specific

DRAFT

scenario using EBMUD's baseline conditions. Following the W-E model simulations, the Upper Mokelumne River WARMF model was run to evaluate impacts of air temperature changes on Mokelumne River water. Again, while simulations were not conducted for the Calaveras River, the results of the analyses conducted on the Mokelumne River can be considered to qualitatively reflect likely impacts that may occur on the Calaveras River under similar changes in climatic conditions.

Simulation of the climate change scenarios required the development of assumptions regarding future hydrology and its correlation with the river flow and operations of facilities (i.e., powerhouses) on the river (in addition to case-specific climate change effects). Assumptions used in the climate change sensitivity study include:

- Reduction in precipitation is assumed to correspond to an equivalent reduction in runoff designated as true natural flow (TNF), the natural pattern of high and low flows.
- Snow depth and water content at elevations above Highland Meadow (greater than 8700 feet mean sea level) are assumed unchanged.
- Precipitation at snow courses is approximated with the Mokelumne Basin 4-Stations Average Index.
- At unmeasured snow courses, air temperature record is interpolated from observed relationship between Salt Springs Powerhouse on the Mokelumne River and Caples Lake, south of Lake Tahoe.
- Operating assumptions applied with respect to PG&E operation are the following:
    - When monthly unimpaired flow at Mokelumne Hill is less than historical, PG&E storage is not adjusted. The routine attempts to conserve as much water as possible without violating the flow requirements as required by the Lodi Decrees.
    - When monthly unimpaired flow at Mokelumne Hill is more than historical, the routine attempts to store as much as possible.
    - Hydrologic inputs required for executing VBS to approximate PG&E operations required modifications to year 1978 to be consistent with EBMUD's Drought Planning Sequence.
- Hydrologic period from 1953 to 2002 is used in the climate change sensitivity analysis.
- Negative flow values are rounded up to zero.
- Reduction in April through July runoff was deducted from the May to July period to be consistent with Maurice Roos' 1994 study.
- Existing flood control capacity requirement is applied in all simulations.

University of California, Davis Model

As previously noted, modeling by the University of California, Davis (UC Davis) was completed using the WEAP model. Unlike the model version used in the EBMUD modeling, the UC Davis modeling utilized the WEAP model's hydrologic programming to simulate snow accumulation, snowmelt, runoff, soil moisture storage, evapotranspiration, interflow, deep percolation and baseflow for each watershed simulated. Precipitation was partitioned as snow, runoff or infiltration depending on air temperature, land cover, soil depth and previous soil moisture conditions. Climate data (air temperature, precipitation and vapor pressure deficits) for the 1981-2001 period were used to generate modeled hydrology, while interpolated weather data from DAYMET was used in the model to represent temperature and precipitation variability caused from orographic effects. Climate conditions were assumed to be uniform within each watershed, but varied between watershed.

Unimpaired historic hydrology and uniform air temperature increases of 2^{o}C, 4^{o}C and 6^{o}C were modeled in this study as sensitivity analyses of discharge characteristics with respect to temperature. These temperature increases were selected to represent progressively severe warming over the projected period, with the 2^{o}C warming roughly representing climate warming projections from the HadCM3, a medium sensitive GCM utilizing the A1fi scenario for 2020 to 2049 or the PCM using the B1 scenario for the period

DRAFT

from 2070 to 2099. The 4°C warming approximately represents projections from 2070-2099 PCM GCM using the B1 scenario, while the 6°C warming approximately the 2070-2099 Had CM3 GCM using the A1fi scenario.

Model Results

EBMUD W-E Model Results

Seven separate analyses were conducted during the EBMUD WSMP 2040 project to test the sensitivity of the current water supply system to variables that will likely be affected by future changing climate. Table 3 presents the context of each climate change analysis, and the results of each case are presented in Table 4.

Table 3: Summary of Climate Change Analysis Scenarios

Reference	Description	Explanation
CC 0	Baseline	No adjustment to True Natural Flow (TNF) (required to model approximate operation of PG&E operations). Assumes 267 MGD of demand and a 50-year hydrologic record between 1953 and 2002.
CC 1	Normalized Demand	The baseline case with an increased demand of 277 MGD, reflecting increased outdoor water use resulting from a 4°C temperature increase.
CC 2-1	Spring Runoff Shift	Models a18.7% shift in April to July TNF runoff to the November-March period due to a 2°C temperature increase.
CC 2-2	Spring Runoff Shift	Models a 28.3% shift in April to July TNF runoff to the November-March period due to a 3°C temperature increase.
CC 2-3	Spring Runoff Shift	Models a 37.9% shift in April to July TNF runoff to the November-March period due to a 4°C temperature increase.
CC 3-1	Decrease in Precipitation	Models a 10% reduction in TNF runoff resulting from a 10% decrease in precipitation.
CC 3-2	Decrease in Precipitation	Models a 20% reduction in TNF runoff resulting from a 20% decrease in precipitation.

In general, the results of the climate change sensitivity analyses identified that Mokelumne River supplies are most vulnerable to:

- A more extreme shift in spring-time runoff from the April-to-July period to winter months relative to what has been observed in historic years, further lowering spring runoff volumes.
- Decreases in annual runoff volumes (especially reductions of 20% or more in runoff).

Impacts to storage (measured at Pardee Reservoir) are expected to be moderately susceptible to shifts in early springtime runoff and increased customer demands, and very susceptible to decreases in annual runoff volumes. Shifts in springtime runoff on the Mokelumne River could result in an approximate 5% decrease in effective system storage. Additionally, decreasing Mokelumne River runoff by 10% and 20% could result in average decreases in effective system storage of 12% and 24%. Finally, the modeling results indicate that increases in water temperature can be expected with increases in air temperature; however, the severity of the impacts will depend on both the magnitude of air temperature increases and the hydrologic year type.

Overall, based on the W-E modeling results, additional storage combined with source diversity will provide water purveyors dependent upon the Mokelumne River and Calaveras River with the maximum amount of flexibility and the ability to adapt to unknown future conditions.

DRAFT

Table 4: Climate Change Analysis Results

Ref	Description	Explanation	October 1st Pardee Reservoir Storage
CC 0	Baseline	No adjustment to TNF (required because of the pre-processor)	Baseline
CC 1	Normalized Demand	The "baseline" case from above with a demand increase of 3.6% to reflect a 4°C temperature increase between 1980 and 2040	Storage decreased in 27 years; average decrease was 5%. Increases in storage were negligible.
CC 2-1	Spring Runoff Shift	Models a 18.7% shift of April to July runoff to the November to March period due to a 2°C temperature increase	Storage decreased in 26 years and increased in 15 years; average decrease was 3%, and average increase was also 3%
CC 2-2	Spring Runoff Shift	Models a 28.3% shift of April to July runoff to the Nov to March period due to a 3°C temperature increase	Storage decreased in 25 years and increased in 19 years; average decrease was 5%, and average increase was 3%
CC 2-3	Spring Runoff Shift	Models a 37.9% shift of April to July runoff to the November to March period due to a 4°C temperature increase	Storage decreased in 28 years and increased in 18 years; average decrease was 6%, and average increase was 4%
CC 3-1	Decrease in Precipitation	Models a 10% reduction in TNF runoff	Storage decreased in 31 years and increased in 19 years; average decrease was 12%, and average increase was 1%
CC 3-2	Decrease in Precipitation	Models a 20% reduction in TNF runoff	Storage decreased in 36 years and increased in 14 years; average decrease was 24%, and average increase was 0.4%

DRAFT

University of California, Davis Model Results

Modeling conducted by UC Davis researchers simulated anticipated 2^{o}C, 4^{o}C and 6^{o}C temperature increases and evaluated changes from baseline for three key parameters – mean annual flow, centroid timing, and low flow duration – to highlight relative differential responses across the Sierra Nevada watersheds and in relation to water resource development (water supply, hydropower and mountain meadow habitat, respectively). The response of the Mokelumne and Calaveras River watersheds to these temperature changes is discussed below.

The Mokelumne River experienced a higher change in mean annual flow due to climate change compared to other Sierra Nevada watersheds and is considered to be more vulnerable based on its relatively small amount of water storage and changes in mean annual flow.

Modeled changes to climate warming in the Mokelumne and Calaveras River watersheds resulted in reductions in mean annual flow (MAF). Specifically, there were approximately 3%, 6% and 9% decreases in mean annual flow on both the Mokelumne and Calaveras Rivers resulting from 2^{o}C, 4^{o}C and 6^{o}C increases in air temperature, respectively. These reductions in MAF impacts instream conditions and habitat for aquatic and riparian ecosystems.

Compared to other Sierra Nevada watersheds, the Mokelumne River experienced a higher change in MAF due to climate change, and given its relatively little total water storage relative to the American or Yuba Rivers, was therefore considered to be more vulnerable to climate warming based on total water stored and changes in MAF. This, in turn, may lead the watershed to having the most altered aquatic and riparian ecosystems under all climate alternatives. The Calaveras River, in contrast, had more moderate changes in MAF with respects to climate change, and therefore would be considered to be less vulnerable.

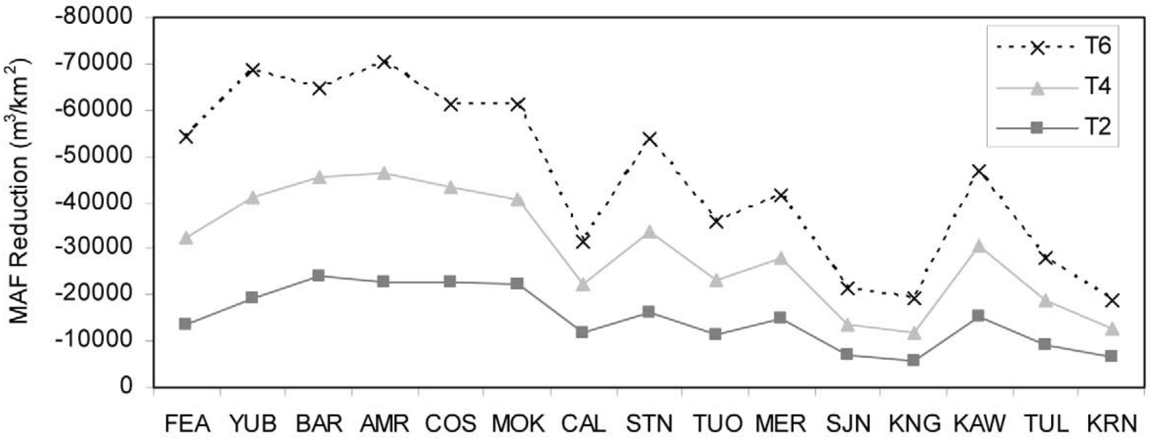


Figure 8: Reduction in Mean Annual Flow from Basecase by Watershed (Null et al., 2010)

The modeling also showed that runoff centroid timing (CT) was 2 weeks, 4 weeks, and 6 weeks earlier given the respective 2^{o}C, 4^{o}C and 6^{o}C increases in air temperature in the Mokelumne River watershed. Changes in seasonal runoff timing may affect electrical generation capabilities, flood protection, water storage and deliveries. The Calaveras watershed, in contrast, had one of the smallest runoff timing shifts observed, with an average CT approximately one day earlier for each 2^{o}C rise in air temperature. This is primarily due to the low elevation of this watershed and associated low snowpack potential.

The Mokelumne River currently contains seven hydropower facilities with a total online capacity of 374 MW. In contrast, the Calaveras River has only one hydropower facility with a total online capacity of 2

MW. CT shifts are one indication of potential future climate impacts to hydropower generation capacity as a result of substantial changes in runoff timing with climate warming. Hydropower is often generated during high demand periods, which may be compromised if facilities are forced to spill due to higher magnitude flows or to accommodate early arrival of flows. The Mokelumne River demonstrated changes in CT due to climate warming will result in impacts to generating capacity on the river, making it one of the more vulnerable watersheds statewide. The Calaveras River is considered not to be vulnerable to CT shifts due to small changes in CT and relative little online hydropower capacity.

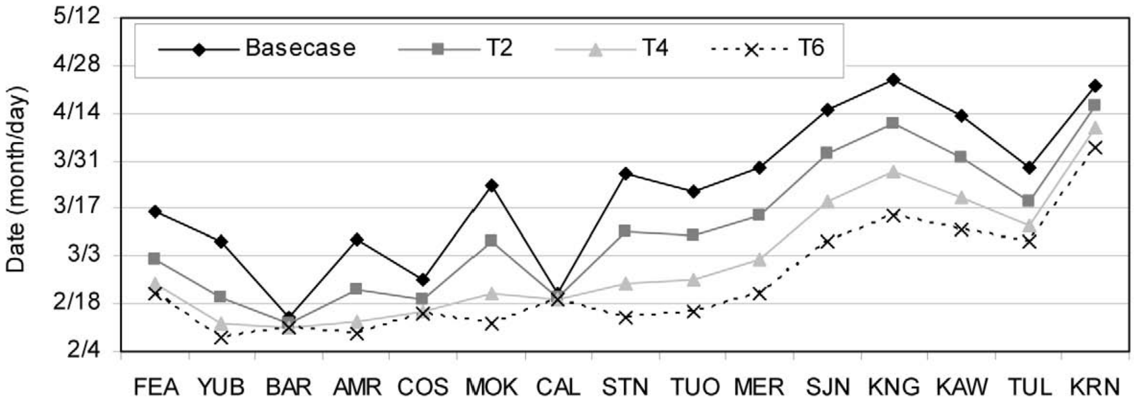


Figure 9: Average Annual Centroid Timing by Watershed (Null et al., 2010)

Finally, the study evaluated the average low flow duration (LFD) for the Sierra Nevada watersheds relative to climate change. The Mokelumne River had the greatest increase in LFD weeks (from basecase conditions to 6^{o}C warming). In general, average low flow duration lasted 2, 3 and 4 weeks longer for the 2^{o}C, 4^{o}C and 6^{o}C increases in air temperature, respectively. This suggests that as precipitation shifts from snowfall to rainfall, summer and autumn flows during wet years will be relatively drier as a result of flashier storms that do not replenish soil moisture from snowmelt. The Calaveras River, in contrast, had one of the shortest periods of low flow conditions of the watersheds studied.

Changes in LFD were considered a surrogate for montane ecosystems in the study as persistent low flow conditions deplete meadow groundwater reserves and soil moisture, reducing the downstream benefits of meadows. Meadows provide ecosystem services such as maintaining summertime flow during dry periods and reducing floods in winter; providing aquatic and riparian habitat for birds, fish, amphibians, and insects; promoting riparian vegetation rather than conifer or dry shrub vegetation that increases wildfire risks; and improving downstream water quality. The Mokelumne River watershed was considered vulnerable to LFD, and as a result, could experience habitat loss as a result of climate change. The Calaveras River watershed, having relatively little meadow area, was considered to be more resilient to LFD.

DRAFT

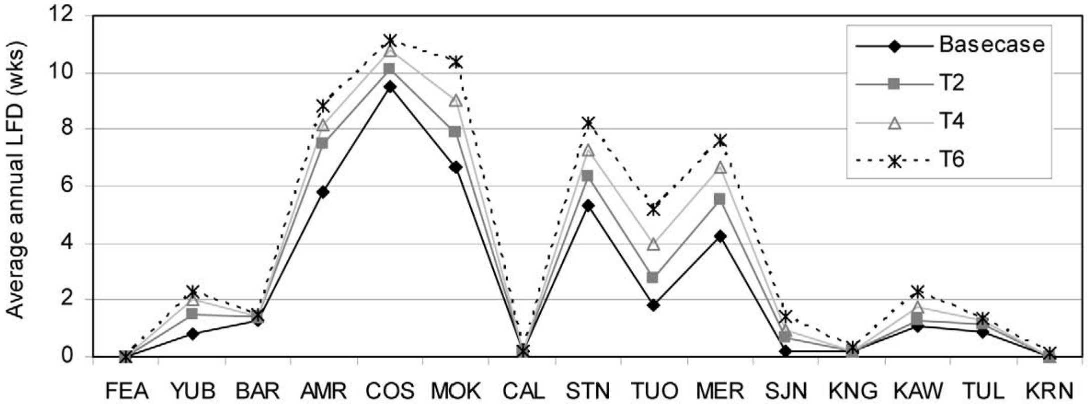


Figure 10: Average Annual Low Flow Duration by Watershed (Null et al., 2010)

1.3.5. Regional Water Resource Vulnerability

Primary water users in the MAC Region include agriculture, the environment, and urban users. Water supplies are derived from groundwater, surface water, and some recycled water, with surface water from the Mokelumne and Calaveras Rivers providing the majority of water supply in the Region. Groundwater is used in some areas of the MAC region, but quantity and quality vary considerably due to small and unpredictable yields from the fractured rock system and limited alluvial basins that typify the underlying geology. Groundwater accounts for approximately 2% of Amador Water Agency's (AWA)'s total water supply and is only used in the communities of La Mel Heights and Lake Camanche Village. Wells serving Lake Camanche Village are located within the Cosumnes Subbasin of the San Joaquin Valley Groundwater Basin. A portion of western Calaveras County overlies the Eastern San Joaquin Subbasin (also of the San Joaquin Valley Groundwater Basin), which is overdrafted due to extraction of groundwater for irrigation and municipal purposes exceeding the basin's safe yield.

Declining Sierra Nevada snowpack, earlier springtime runoff, and reduced spring and summer streamflows will likely affect the availability and quality of surface water supplies and may potentially shift reliance to groundwater resources, which are already of limited quantity and quality in many places.

Other anticipated regional impacts resulting from climate change (increased air temperatures and variable precipitation) include changes to water quality; increased flooding, wildfires and heat waves, and impacts to ecosystem health. Earlier springtime runoff will increase the risk of winter flooding as capturing earlier runoff to compensate for future reductions in snowpack would take up a large fraction of the available flood protection space, forcing a choice between winter flood prevention and maintaining water storage for use during dry periods in summer and fall.

The identified vulnerabilities within the MAC Region are summarized in Table 5 and further described in the following sections.

DRAFT

Table 5: MAC Region Vulnerabilities

Vulnerability	Description
Water Demand	Vulnerable to increased agricultural demands due to longer growing season, increased temperatures and evapotranspiration rates, and more frequent/severe droughts. Vulnerable to increased urban and commercial, industrial and institutional (CII) demand due to increased outside temperatures.
Water Supply and Quality	Vulnerable to decreased snowpack in the Sierra Nevada, shifts in timing of seasonal runoff, degraded surface and groundwater quality resulting from lower flows and increased overdraft conditions, a reduction of meadows that can provide contaminant reduction, and more frequent/severe droughts and storm events increasing turbidity in surface supplies.
Flood Management	More severe/flashier storm events and earlier springtime runoff leading to increased flooding, and a reduction of meadows which help reduce floods in the winter.
Hydropower	Vulnerable to increased customer demand combined with changes in timing of seasonal runoff and flashier storm systems affecting reservoir storage.
Ecosystem and Habitat	Vulnerable to decreased snowpack, more frequent/severe droughts and wildfires, shift in seasonal runoff, increased low flow periods and increased water temperatures (degraded water quality).

DRAFT

Water Demand

Land use / land cover in the MAC Region is dominated by forested areas and agricultural uses, including grazing, wine grapes, and timber harvesting. In general, irrigation water demand varies based on precipitation, and may or may not increase under future climate change conditions depending on precipitation changes. The effects of increased air temperatures on agriculture will include faster plant development, shorter growing seasons, changes to reference evapotranspiration and possible heat stress for some crops. Without accounting for evapotranspiration rates, agricultural crop and urban outdoor demands are expected to increase in the Sacramento Valley by as much as 6% in the future (Chung et al., 2009). The agricultural community will respond to these climate-induced changes primarily by increasing the acreage of land fallowing and retirement, augmenting crop water requirements by groundwater pumping, improving irrigation efficiency, and shifting to high-value and salt-tolerant crops (Hopmans et al., 2008).

The seasonal variability of water demands is projected to increase with climate change as droughts become more common and more severe. Other seasonal uses such as landscape irrigation cooling demands are also expected to increase as a result of climate change (DWR, 2008 and CNRA, 2009).

Water Supply and Quality

The MAC Region's water supplies consist of groundwater, local surface water, and recycled water. In general, impacts on urban users will be a function of behavioral response of individuals and organizations as well as hydrology. Currently, approximately 75% of total water use statewide occurs between April and September when lawns and crops are being irrigated (Hayhoe et al., 2004). Decreased summertime flows will likely result in increased groundwater pumping, where possible, and greater overdraft conditions, especially in the Eastern San Joaquin Subbasin due to increased groundwater use as a means of offsetting surface water shortages. Additionally, rising temperatures are projected to increase the frequency of heat waves, which could also lead to increased water use, further exacerbating low flow conditions (Hayhoe et al., 2004).

Changes in water availability and timing may also affect the value of water rights statewide as mid- and late-season natural stream flow become more variable (and therefore less valuable) and the value of rights to stored water (which has a higher degree of reliability) increase. Senior users without access to storage could face unprecedented water shortages due to reduced summertime flows (Hayhoe et al., 2004). These same changes will also affect the level of hydropower generation in the MAC Region, especially in the summer, when hydropower generation is needed most to meet peak demand (Moser et al., 2012).

Finally, climate change impacts may affect water quality in a multitude of ways.

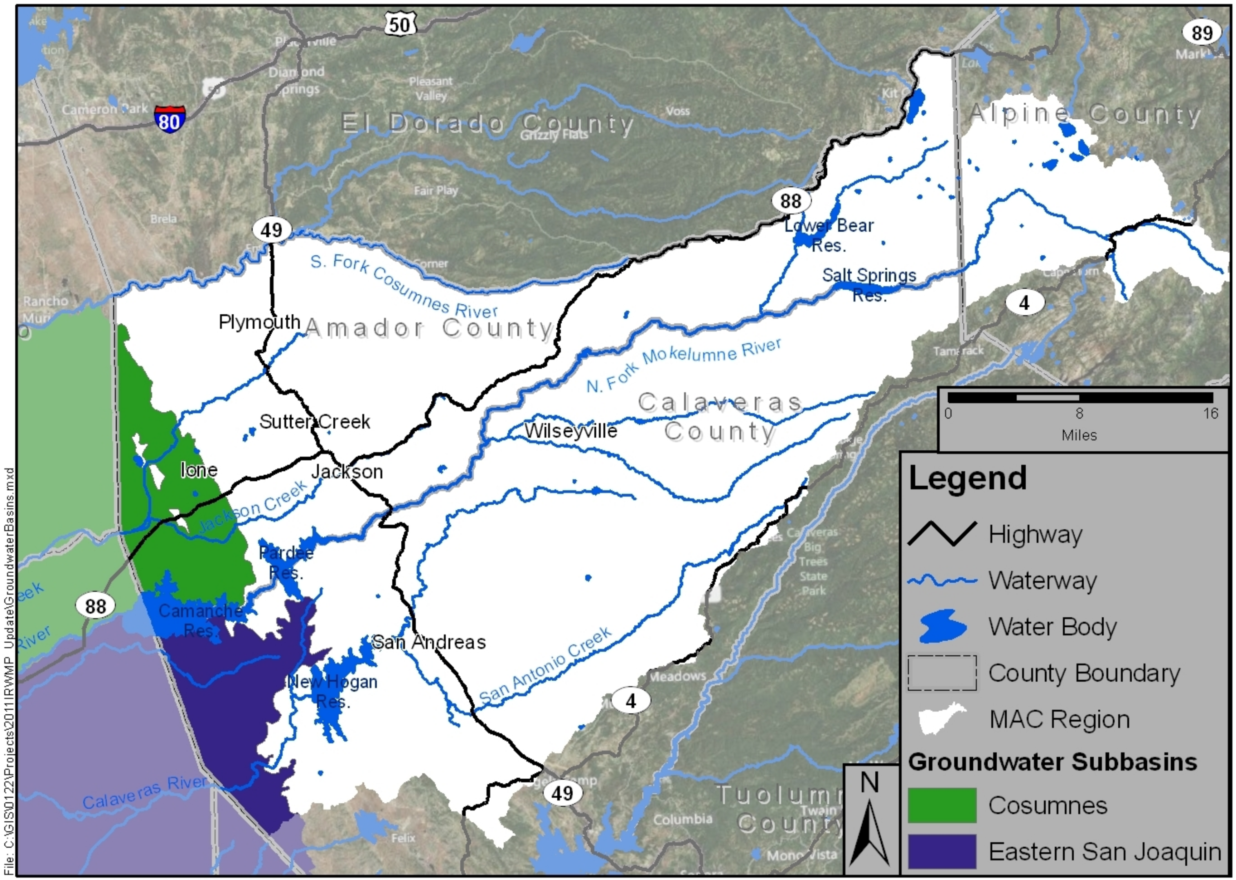
- Water quality can be impacted by both extreme increases and decreases in precipitation. Increases in storm event severity may result in increased turbidity in surface water supplies while decreases in summertime precipitation may leave contaminants more concentrated in streamflows (DWR, 2008).
- Higher water temperatures may exacerbate reservoir water quality issues associated with reduced dissolved oxygen levels and increased algal blooms (DWR, 2008).

Water quality concerns not only impact drinking water supplies, but also environmental uses and wastewater treatment processes. The altered assimilative capacity of receiving waters may increase wastewater treatment requirements, and wastewater collection systems could be inundated in flooding events. More prevalent wildfires could result in aerial deposition and runoff of pollutants into water bodies, impacting surface water quality. Declining Sierra Nevada snowpack, earlier springtime runoff and reduced spring and summer stream flows will likely affect surface water supplies and shift reliance to groundwater resources, which are already overdrafted in many places.

Groundwater Supply and Quality

The MAC Region partially overlies the San Joaquin Valley Groundwater Basin, specifically the Cosumnes and Eastern San Joaquin Subbasins as shown in Figure 11. Groundwater quantity and quality vary significantly from well site to well site due to the fractured rock system that typifies the foothill geology. AWA uses groundwater to serve only La Mel Heights and Lake Camanche Village. CCWD is in the process of annexing the Wallace area, which relies on groundwater supplies. The larger communities included in Calaveras County are served by public water systems (e.g. CCWD), while the remainder of the County is served either by small public water systems (less than 200 service connections) or individual domestic wells.

DRAFT



Source: Cal-Atlas; DWR; ESRI

Figure 11: Groundwater Basins in the MAC Region

The Eastern San Joaquin Subbasin is known to be in a state of overdraft due to excessive pumping. Overpumping has caused depressions near Stockton and Lodi, outside of the MAC Region. Extended low flow conditions due to climate change and future variations in precipitation and streamflow will influence how and when the groundwater subbasins are recharged. It is also possible that groundwater pumping could increase in the areas of the MAC Region that currently use groundwater, further exacerbating water quality and quantity issues.

Surface Water Supply and Quality

The primary source of water in the MAC Region is surface water from the Mokelumne and Calaveras Rivers. Sierra Nevada snowpack serves as the primary source of water for the Mokelumne River. Many of the water systems in and outside the MAC Region rely on this supply as their primary source.

DRAFT

Table 6: Water Systems' Reliance on the Mokelumne River

Water System	Reliance on Mokelumne River
Amador Water System	15,000 AFY from Mokelumne River
Central Amador Water Project	1,150 AFY from Mokelumne River
JVID	3,800 AFY from Pardee Reservoir
CPUD	920 AFY from South Fork of Mokelumne River
EBMUD	364,072 AFY from the Mokelumne River
CCWD	Uses Bear Creek, tributary to the Mokelumne River as primary source of water
West Point, Wilseyville, Bummerville	Rely on Mokelumne River as backup source

Unlike the Mokelumne River, the primary source of supply to the Calaveras River is rainfall. Reduced snowpack, variations in precipitation, and the shift in the timing of spring snowmelt have the potential to significantly impact surface water supplies from both rivers.

As the occurrence of wildfires increases, additional sediment could also be deposited into water bodies and turbidity may become a greater concern. Sediment and pollutants collected from upstream could be concentrated downstream and in reservoirs, leading to water quality issues and the disturbance of critical habitats. In addition, earlier snowmelt and more intense precipitation events may increase source water turbidity. Shifts in the timing of runoff have already been observed; the fraction of total annual runoff occurring between April and July has decreased by 23% in the Sacramento Basin and by 19% in San Joaquin Basin over the past 100 years (CEC, 2008). Increased flooding may lead to sewage overflows, resulting in higher pathogen loading in the source waters. Increased water temperatures and shallower reservoirs may result in more prevalent eutrophic conditions in storage reservoirs, increasing the frequency and locations of cyanobacterial blooms. These potential changes could result in challenges for surface water treatment plants and require additional monitoring to quantify changes in source water quality and better control of finished water quality (CUWA, 2007).

Flood Management

Sea level rise is not a direct climate change impact to the MAC Region; therefore, there are no related vulnerabilities. However, in addition to increased coastal flooding resulting from sea-level rise, the severity of non-coastal flooding will also increase in the future due to climate change. Extreme precipitation events may become more common, increasing the likelihood of extreme weather events and floods. Rising snowlines will also increase the surface area in watersheds receiving precipitation as rain instead of snow (DWR, 2008), thereby increasing storm-related runoff. Sea level rise may indirectly affect the MAC Region through future required stream releases from upstream rivers (such as the Mokelumne and Calaveras Rivers) necessary to maintain salinity fronts in the Sacramento-San Joaquin Delta.

There are multiple reservoirs operated within the MAC Region for both water supply and flood control purposes. Camanche Reservoir is primarily operated for flood control and to meet downstream flow requirements and riparian needs. New Hogan Dam was constructed on the Calaveras River in 1963 for flood control, as well as municipal, industrial, and irrigation purposes. Flood control releases are controlled by the U.S. Army Corps of Engineers, with Stockton East Water District operating the reservoir at all other times. Flooding is a concern in the MAC Region; many cities and communities are included in Federal Emergency Management Agency (FEMA) designated 100-year and 500-year flood zones. Flooding can occur from heavy rainfall, rapid snowmelt, saturated soils, or a combination of these

DRAFT

conditions. In some cases, flooding may due to an inadequate storm drainage system, unable to handle heavy, more intense storms during winter and springtime.

Ecosystem and Habitat

The MAC Region is a largely natural area containing two national forests and significant areas designated as rural or open space, providing habitat for numerous species and a wide variety of plant and animal life in many different environments including riparian, wetland, forest, and alpine habitats. Temperature-induced declines in alpine/subalpine forest are expected to occur, in addition to major shifts from evergreen conifer forest to mixed evergreen conifer forests and expansion of grasslands (Hayhoe et al., 2004). Increasing stress on ecosystems resulting from rising temperatures will reduce trees' capacity to resist pest attacks while increasing pest survival rates, accelerating their development and allowing them to expand their range. And these same increases in temperatures will also result in warmer freshwater temperatures which, along with changes in seasonal stream flows, are projected to cause sharp reductions in salmon populations and increased risks of extinction for some Central Valley subpopulations (Ackerman and Stanton, 2011).

Projected hotter and possibly drier future conditions will also increase the frequency and extent of wildfires, worsen pest outbreaks, and stress precarious sensitive populations. Wildfires will play a significant role in converting woodlands to grassland as decreases in moisture shift the competitive balance in favor of the more drought-tolerant grasses and increases in grass biomass provide more fine fuels to support more frequent fires. Increased wildfires also favor grasses, which re-establishes more rapidly than slower growing woody life forms after burning (Hayhoe et al., 2004)

Finally, variations in precipitation and the changes in springtime snowmelt will directly affect both surface water and groundwater quality. Warmer surface water affects the chemical composition of these waters (for example, decreasing levels of dissolved oxygen) in addition to directly impacting aquatic and riparian habitats. Decreased precipitation, and associated decreased groundwater percolation, will result in increased dissolved concentrations in groundwater.

Hydropower

Pacific Gas and Electric Company (PG&E) owns and operates the Mokelumne River Hydroelectric Project (FERC license no. 137), which consists of a series of storage and regulating reservoirs and associated tunnels and pipelines that supply water to four hydropower generating units located primarily on the North Fork of the Mokelumne River. The Mokelumne River Project has a generating capacity of 206 MW. In October 2011, FERC issued the Mokelumne River Project a 30-year license. EBMUD also generates electricity at its dams at Pardee and Camanche reservoirs. The Pardee Hydropower Powerhouse typically generates approximately 140 million KWh of energy during years of median runoff, and the Camanche Powerhouse generates approximately 45 million KWh annually. EBMUD sells this energy to the Sacramento Municipal Utility District (SMUD).

The primary source of water for hydropower generation in the MAC Region is snowmelt from the Sierra Nevada. Changing volumes of snowfall and snowpack in the Sierra Nevada and the changing seasonal melting patterns may require changes in reservoir operations. As the timing of snowmelt shifts in the spring, hydroelectric power generation may also shift to accommodate enhanced flood control operations. Additionally, increasing temperatures will also increase energy demands, especially during peak demand times (DWR, 2008). As previously described, the modeling completed as described in the *Hydrologic Response and Watershed Sensitivity to Climate Warming in California's Sierra Nevada* (Null et al., 2010), showed that runoff centroid timing (CT) on the Mokelumne River was 2 weeks, 4 weeks, and 6 weeks earlier given the respective 2°C, 4°C, and 6°C increases in air temperature. Change in seasonal runoff timing may affect electrical generation capabilities, flood protection, water storage and deliveries.

DRAFT

Hydropower is often generated during high demand periods, which may be compromised if facilities are forced to spill due to higher magnitude flows or to accommodate early arrival of flows (Null et. al., 2010).

Other

Climate change will also affect the MAC Region in other ways, including impacting recreation and tourism industries (and therefore the Region's economy). Projections of decreased snowpack have the potential to affect the ski industry in Alpine County (part of the MAC Region) since the ski resorts are within the elevations impacted by reduced snowpack due to temperature increases. These temperature increases will also delay the beginning of ski season and impact the economic viability of the industry (Hayhoe et al., 2004).

Prioritized Vulnerabilities

To be completed after discussion at meeting.

1.3.6. Adaptation and Mitigation

Global climate modeling carries a significant degree of uncertainty resulting from varying sensitivity to changes in atmospheric forcing (e.g. CO_2, aerosol compounds), unpredictable human responses, and incomplete knowledge about the underlying geophysical processes of global change. Even though current scenarios encompass the "best" and "worst" cases to the greatest degree possible based on current knowledge, significant uncertainty associated with future global GHG emission levels remains, especially as timescales approach the end of the century. Historical data for calibrating GCMs is not available worldwide, and is spatially biased towards developed nations.

Considering the great deal of uncertainty associated with climate change projections, the prudent approach to addressing climate change incorporates a combination of adaptation and mitigation strategies. Climate adaptation includes strategies (policies, programs or other actions) that seek to bolster community resilience in the face of unavoidable climate impacts (CNRA and CEMA, 2012), where mitigation strategies include best management practices (BMPs) or other measures that are taken to reduce GHG emissions.

There are eight categories of RMS considered for the MAC Plan Update:

1. *Reduce Water Demand*
2. *Improve Operational Efficiency and Transfers*
3. *Increase Water Supply*
4. *Improve Water Quality*
5. *Urban Runoff Management*
6. *Practice Resource Stewardship*
7. *Improve Flood Management*
8. *Other Strategies*

Adaptation Strategies

The Prop 84 IRWM Guidelines require consideration of the *California Water Plan* (CWP) resource management strategies (RMS) in identifying projects and water management approaches for the region. RMS are being considered in the MAC IRWM planning process to meet the region's objectives and as part of the project review process.

A wide range of RMS will be required to achieve the MAC Region's goals and objectives. As such, a comprehensive range of RMS were evaluated for their ability to assist the region in achieving its goals and objectives. Application of various RMS diversifies water management approaches, and many of the RMS apply to climate change adaptation and mitigation.

Within each RMS category is a variety of specific RMS that have been identified for the region (Table 7). For example, reducing water demand can be completed through agricultural water use efficiency and/or urban water use efficiency. As described in the *Climate Change Handbook for Regional Planning* (CDM, 2011), not all of the RMS directly apply to climate change adaptation or mitigation, but instead are

DRAFT

directed at overall system resiliency. And any approach that improves a system's resilience to the uncertain conditions climate change could bring will provide the Region with the flexibility and adaptability to meet future water supply challenges.

The following table summarizes the ability of individual RMS to aid in climate change adaption. The application of RMS relevant to the MAC Region as climate change adaptation strategies are described in the following sections. Examples of performance metrics are identified for the RMS. These metrics can be used to measure the effectiveness of the adaptation strategy as they are implemented in response to climate change.

DRAFT

Table 7: Applicability of RMS to Climate Change Adaptation

Resource Management Strategies	Habitat Protection	Flood Control	Water Supply Reliability	Additional Water Supply	Water Demand Reduction	Sea Level Rise	Water Quality Protection	Hydropower
Reduce Water Demand								
Agricultural Water Use Efficiency	✓		✓	✓	✓			✓
Urban Water Use Efficiency	✓		✓	✓	✓			✓
Improve Operational Efficiency and Transfers								
Conveyance-Regional/Local	✓	✓	✓	✓			✓	
System Reoperation		✓	✓	✓				✓
Water Transfers			✓	✓				
Increase Water Supply								
Conjunctive Management and Groundwater Storage	✓	✓	✓	✓			✓	
Precipitation Enhancement	✓			✓				✓
Recycled Municipal Water	✓		✓	✓				
Surface Storage-Regional/Local	✓	✓	✓	✓			✓	✓
Improve Water Quality								
Drinking Water Treatment and Distribution			✓	✓			✓	
Groundwater Remediation/Aquifer Remediation			✓	✓			✓	
Matching Quality to Use	✓		✓	✓	✓		✓	
Pollution Prevention	✓		✓				✓	
Salt and Salinity Management	✓		✓				✓	
Urban Runoff Management	✓	✓	✓	✓			✓	
Practice Resource Stewardship								
Agricultural Lands Stewardship	✓				✓		✓	
Economic Incentives	✓		✓		✓	✓	✓	✓
Ecosystem Restoration	✓	✓	✓			✓	✓	✓
Forest Management	✓	✓	✓				✓	✓
Land Use Planning and Management	✓	✓	✓		✓	✓	✓	✓
Recharge Area Protection	✓	✓	✓	✓			✓	
Water-dependent Recreation	✓	✓					✓	
Watershed Management	✓	✓	✓	✓		✓	✓	✓
Improve Flood Management								
Flood Risk Management	✓	✓	✓	✓		✓	✓	✓

Reduce Water Demand

Reducing existing and future water demands can reduce pressure on limited water supplies and help the region adapt to the potential climate change impacts of less precipitation, shifting of springtime snowmelt, and overall water-related uncertainties. The Reduce Water Demand RMS includes both agricultural and urban water use efficiency. Opportunities for increased water conservation and water use efficiency measures for urban and agricultural water use are identified in multiple documents, including the *CWP Update*, the Agricultural Efficient Water Management Practices, the *California 20x2020 Water Conservation Plan* (20x2020 Plan), and by the California Urban Water Conservation Council. These recommendations could potentially be incorporated into the existing framework already developed by cities and water agencies within the MAC Region. Performance metrics that could be used to measure the effectiveness of Reduce Water Demand adaptation include average water demand reduction per year and peak water demand reduction per month (CDM, 2011).

Improve Operational Efficiency and Transfers

Water supply system operations need to be optimized in order to maximize efficiency, both in terms of water usage and energy usage. Improving operational efficiency and transfers can be achieved through the RMS: conveyance – regional/local, system reoperation, and water transfers.

- Existing infrastructure for regional and local conveyance must be maintained and improved as their useful lives are reached. Well-maintained conveyance infrastructure improves water supply reliability and enhances regional adaptability to climate change impacts. Addressing aging infrastructure, increasing existing capacity, and/or adding new conveyance facilities can improve existing conveyance systems and operational efficiency.
- System reoperation consists of modifying existing operation and management procedures for existing reservoirs and conveyance facilities to increase water related benefits from these facilities. Through system reoperation, the MAC Region may be able to adapt to less reliable water supplies and/or increased water demands by maintaining conveyance infrastructure, as well as adapting to potential climate change impacts on hydropower production, flooding, habitats, and water quality.
- Similar to system reoperation, water transfers can help the MAC Region improve water supply reliability and provide flexibility in the future when there are increased water demands and potentially less reliable water supplies.

An example of a performance metric to quantify this RMS, Improve Operational Efficiency and Transfers, includes amount of new supply created through regional water transfers (CDM, 2011).

Increase Water Supply

As water demands increase due to longer growing seasons, higher temperatures, and longer droughts, the future of existing water supply sources becomes less certain. The MAC Region will need to enhance existing water supplies and improve its flexibility in managing those supplies to meet demands. Increasing water supply can be accomplished through the implementation of conjunctive management of surface and ground water supplies, groundwater storage, recycled water use, and increased surface water storage, as appropriate to the different areas of the region. Diversifying the region's water supply portfolio and adding drought-resistant sources is an adaptation measure that will help address increased water demands and/or decreased supply reliability. Performance metrics for measuring the effectiveness of the Increase Water Supply RMS could include additional supply created, amount of potable water offset, and supply reliability (CDM, 2011).

Implementing conjunctive management and groundwater storage helps coordinate the use of both surface and groundwater resources to maximize the availability and reliability of water supplies. In the future, when timing and availability of supplies are less certain, conjunctive management could help the region to adapt to climate changes. Another adaptation strategy to Increase Water Supply is developing a project to provide additional local surface storage as a means of helping a water system adjust to altered streamflow timing resulting from earlier snowpack melting. Additional storage capacity could also help the MAC Region adapt to the anticipated increased precipitation variability. Increased surface storage could allow ecosystem and water managers to make real-time decisions that are not available otherwise. Added

DRAFT

storage provides greater flexibility for capturing surface water runoff, managing supplies to meet seasonal water demands, helping manage floods from extreme storm events, and responding to extreme weather conditions such as droughts. Rehabilitation and possible enlargement of existing dams and infrastructure can potentially eliminate the need for new reservoir storage.

The California Recycled Water Policy, developed by the State Water Resource Control Board in 2009, includes a goal of offsetting as much potable water with recycled water for nonpotable uses as possible by the year 2030. Recycled water is a sustainable, climate-resilient local water resource that could significantly help the MAC Region meet its water management goals and objectives while also assisting in meeting the seasonal water demands of agriculture. Water recycling provides a local supply that may use less energy than other water supplies, helping to mitigate climate change impacts through associated GHG emissions. Recycled water is already used in the MAC Region to irrigate golf courses and some agricultural irrigation; agencies are interested in continuing to use recycled water and expanding its use for agricultural purposes and urban landscape irrigation.

Improve Water Quality

Improving drinking water treatment and distribution, groundwater remediation, matching water quality to use, pollution prevention, salt and salinity management, and urban runoff management can help improve water quality. These strategies may help the region adapt to drinking water- and ecosystem-related water quality impacts from climate change. They may also contribute to providing additional supplies; for example, stormwater capture and reuse would reduce pollution runoff to riparian and aquatic habits, but could also provide a seasonal source of irrigation water for urban landscaping or groundwater recharge. Water quality performance metrics for this RMS could include stream temperature, dissolved oxygen content, and pollutant concentrations (CDM, 2011).

Climate change impacts can pose a number of challenges for surface water treatment plants, including increased monitoring and treatment flexibility necessary to quantify and treat for source water quality changes in order to maintain finished water quality. Continued growth statewide will result in increased stress on the limited water resources available for domestic, agricultural, and industrial uses. Improving water treatment technologies and matching quality to end use can provide the flexibility required to meet uncertain future conditions.

Removing naturally-occurring and anthropogenic contaminants in current groundwater sources will provide additional water supply by increasing the use of groundwater in the MAC and neighboring regions. Local government and agencies with land use responsibility should limit potentially contaminating activities in areas where recharge takes place (recharge zone protection) and work together with entities currently undergoing long-term groundwater remediation to develop a sustainable, long-term water supply for beneficial reuse.

In recent years, as point sources of pollution have become regulated and controlled, “non-point source” (NPS) pollution has become a primary concern for water managers. NPS pollution is generated from land use activities associated with agricultural development, forestry practices, animal grazing, uncontrolled urban runoff from development activities, and discharges from marinas and recreational boating activities, and other land uses that contribute pollution to adjacent surface and groundwater sources. Pollution prevention and management of water quality impairments should incorporate a watershed approach to protect water supply sources and help to ensure the long-term sustainability of those supplies.

Urban runoff management, including Low Impact Development (LID) encompasses a broad range of activities to manage both stormwater and dry weather runoff. Stormwater capture and reuse projects can reduce the burden on wastewater treatment plants and augment water supplies, helping a region adjust to

DRAFT

climate change impacts on water quality and water supply (CDM, 2011). The MAC Region should investigate and implement LID techniques and opportunities, where appropriate, and integrate urban runoff management with other RMS.

Improve Flood Management

The MAC Region does not currently experience major flood issues, but with increased frequency and severity of storm events predicted for the future, the MAC Region will need to collaborate and accelerate flood protection projects in order to prepare for increased flooding risk due to climate changes. Flood management involves emergency planning, general planning activities, and policy changes. Improving flood management can help a region adapt to not only potential flooding but many other related climate change impacts, including ecosystem and water quality vulnerabilities. Performance metrics could include acres of meadows restored or volume of natural flood storage provided (CDM, 2011).

Practice Resource Stewardship

Resource stewardship includes overseeing and protecting land, wildlife, and water by way of conservation and preservation, ecosystem restoration and forest management, watershed management, flood attenuation, and water-dependent recreation. Restoring and preserving habitat and wetlands has multiple benefits, including promoting biodiversity and habitat enhancement, as well as improving flood management as the natural storage provided by riparian wetlands can serve as buffers that absorb peak flows and provide slow releases after storm events (DWR, 2008). Because the scope of resource stewardship includes all resources, these strategies can help adapt to climate change impacts in various ways, depending on project-specific details (CDM, 2011). For example:

- Climate changes are predicted to result in additional fragmentation and shrinking of California's ecosystems. Appropriate corrective actions should be designed to expand and reconnect them, preventing or reversing these effects. As water managers in the region identify adaptation strategies for water and flood management, they should consider strategies that will also benefit ecosystems.
- Improved and enhanced aquatic and riparian habitats can provide significant water resource benefits through promoting groundwater recharge, protecting and improving water quality, and contributing to flood protection.
- Proper forest management would improve water quality, help reduce wildfires, and improve ecosystem and habitat within the Region.
- Additional stream gages and precipitation stations in the Region could provide data needed to determine climate trends and evaluate hydroclimatic and geologic conditions. Water quality and sediment monitoring stations would allow quantification of the effects of climate change as well as forest management activities on surface water quality (CDM, 2011).

Appropriate corrective actions should be designed to expand and reconnect important ecosystems, preventing or reversing impacts from climate change. Water managers in the region should identify adaptation strategies for water and flood management, considering strategies that will also benefit ecosystems. For example, these strategies may include:

1. Establishing large biological reserve areas that connect or reconnect habitat patches.
2. Promoting multidisciplinary approaches to water and flood management.
3. Providing financial incentives for farmers or ranchers to grow and manage habitat.
4. Improving instream flow needs (CDM, 2011).

Improved and enhanced aquatic and riparian habitats can provide significant water resource benefits through promoting groundwater recharge, protecting and improving water quality, and contributing to flood protection.

DRAFT

The MAC Region contains significant upland forest areas that drain to the region's water supplies. While the Upper Mokelumne River Watershed Authority, as the Regional Water Management Group, is not responsible for managing these upland forested areas, protection of those lands is important to ensure high quality surface runoff supplies. Proper forest management would improve water quality, help reduce wildfires, and improve ecosystem and habitat within the Region. Additional stream gages and precipitation stations could help establish and confirm climate trends and evaluate hydroclimatic and geologic conditions. Water quality and sediment monitoring stations would allow quantification of the effects of climate change as well as forest management activities on surface water quality (CDM, 2011).

Other Strategies

Additional conservation and demand reduction measures, such as crop idling, irrigated land retirement, and rainfed agriculture could be implemented as adaptive management strategies under this RMS. Adaptation strategies in this category may require significant amounts of energy for implementation, and would need to be analyzed to determine the benefit versus additional GHG emissions. The RMS included in this category were not deemed applicable for the MAC region and were therefore, not included.

No Regret Strategies

No regret adaptation strategies are those that make sense for current hydrologic conditions, while also helping the region to adapt to anticipated climate change impacts. The following table presents the No Regrets adaptation strategies for the MAC Region. At present, the region is either already implementing these strategies or plans to implement them in the foreseeable future.

DRAFT

Table 8: No Regret Strategies in the MAC Region

Resource Management Strategies	No Regrets Strategy
Agricultural Water Use Efficiency	✓
Urban Water Use Efficiency	✓
Conveyance-Regional/Local	✓
System Reoperation	
Water Transfers	
Conjunctive Management and Groundwater Storage	✓
Precipitation Enhancement	
Recycled Municipal Water	✓
Surface Storage-Regional/Local	✓
Drinking Water Treatment and Distribution	✓
Groundwater Remediation/Aquifer Remediation	✓
Matching Quality to Use	✓
Pollution Prevention	✓
Salt and Salinity Management	✓
Urban Runoff Management	
Agricultural Lands Stewardship	✓
Economic Incentives	
Ecosystem Restoration	✓
Forest Management	✓
Land Use Planning and Management	✓
Recharge Area Protection	✓
Watershed Management	✓
Flood Risk Management	✓

Mitigation/GHG Reduction Strategies

Water distribution can require significant energy. In California, 19% of the state's electricity and 30% of its natural gas is used for water-related activities (DWR, 2010a). As the MAC Region solicits and prioritizes projects for inclusion in its IRWM Plan, it must consider GHG emissions from the projects and ways to potentially mitigate climate change.

As described in Section 1, increasing GHG concentrations contribute to warming trends and climate change impacts. Because the water industry is a significant GHG contributor, reducing GHGs generated in the conveyance, treatment, and distribution of water and wastewater poses a significant opportunity to help achieve the GHG emission goals set by AB32.

The variation in temperature and precipitation projections from different emissions scenarios simulated using the GCMs illustrates the importance of implementing adaptation measures now to address climate impacts already taking place. GHG emission reductions must be achieved through cooperation at the global, national, regional, and local levels to prevent or mitigate continued climate change impacts later in the century. Major components of climate change mitigation strategies include:

1. Improve Energy Efficiency
2. Reduce Emissions
3. Carbon Sequestration

DRAFT

Almost all resource management strategies identified by the *2009 CWP Update* can potentially reduce GHG emissions and mitigate climate change impacts. A list of applicable strategies is included in Table 9.

The following briefly summarizes how the applicable RMS could contribute to GHG emissions mitigation in the MAC Region.

- Reduce Water Demand – implementing urban and agricultural water use efficiency measures will help save water and energy by reducing the volume of water treated and distributed (pumped) throughout regional water systems.
- Improve Operational Efficiency and Transfers – optimizing water system operations will maximize efficiency and potentially reduce energy use. Reducing system losses will also reduce emissions by reducing the volume of water treated and distributed (pumped) throughout regional water systems.
- Increase Water Supply – depending on the method used to increase water supply, there may be a net increase or decrease in GHG emissions. Increasing storage could have GHG emissions associated with construction, but relatively low operational emissions.
- Improve Water Quality – GHG emissions depend on the specific project implemented to improve water quality. Matching quality to use generally has lower emissions than using potable water for the specified nonpotable uses by limiting water treatment. Additionally, protecting water sources from future water quality degradation may offset the future need for water treatment.
- Improve Flood Management – where flood management encourages vegetation growth (e.g. ecosystem or floodplain restoration), carbon sequestration may help reduce net carbon emissions.
- Practice Resource Stewardship – implementing ecosystem restoration or forest management can contribute to carbon sequestration and potentially reduce net emissions.

DRAFT

Table 9: Applicability of CWP Resource Management Strategies to GHG Mitigation

Resource Management Strategies	Greenhouse Gas Mitigation		
	Energy Efficiency	Emissions Reduction	Carbon Sequestration
Reduce Water Demand			
Agricultural Water Use Efficiency	✓	✓	
Urban Water Use Efficiency	✓	✓	
Improve Operational Efficiency and Transfers			
Conveyance-Regional/Local	✓	✓	
System Reoperation	✓	✓	
Water Transfers	*	*	
Increase Water Supply			
Conjunctive Management and Groundwater Storage	*	*	
Desalination	-	-	-
Precipitation Enhancement	✓		
Recycled Municipal Water	*	*	
Surface Storage-Regional/Local	*	✓	
Improve Water Quality			
Drinking Water Treatment and Distribution	✓	✓	
Groundwater Remediation/Aquifer Remediation	*	*	
Matching Quality to Use	*	*	
Pollution Prevention		✓	
Salt and Salinity Management		✓	
Urban Runoff Management	✓	✓	
Improve Flood Management			
Flood Risk Management			✓
Practice Resource Stewardship			
Agricultural Lands Stewardship			✓
Economic Incentives	✓	✓	✓
Ecosystem Restoration			✓
Forest Management			✓
Land Use Planning and Management	✓	✓	✓
Recharge Area Protection			✓
Water-dependent Recreation			✓
Watershed Management	✓	✓	✓

Source: CDM, 2011.

Key:

✓ indicates that, in general, this will provide a beneficial effect

X indicates that, in general, this will provide an adverse effect

* indicates that this may provide either beneficial or adverse effects

DRAFT

1.3.7. Plan for Further Data Gathering

Identifying and implementing appropriate adaptation strategies requires having the data necessary to (1) understand the magnitude of climate change impacts and associated vulnerabilities and (2) plan for strategy implementation in a timely manner. To aid in this understanding, the MAC Region has developed a data gathering and analysis approach to collecting and assimilating data related to the prioritized climate change vulnerabilities. This data collection plan is summarized in the table on the following pages.

As part of IRWM project implementation, numerous types of data will be collected as part of the project performance and monitoring program. Project-specific data collection could contribute to the data collection described herein for further vulnerability assessment. Additionally, the plan presented below provides a preliminary approach to collecting climate change-related data. This approach may need to be modified to align with available resources and to minimize duplication of efforts.

DRAFT

Table 10: Data Collection and Management for Vulnerability Assessment

Vulnerability	Vulnerability Indicators	Vulnerability Measurement Tools & Methods				Adaptation Goal(s)	Possible Near-Term Adaptation Actions
		Measure	Method	Frequency	Responsible Entity		
Water Demand	Increased urban demand	Water meter data	Flow meters	Monthly	Water agencies	- Minimize urban demand - Sufficient storage to meet unexpected needs	Participate in community planning and regional collaborations relating to climate change adaptation Develop programs to encourage installation of advanced irrigation equipment Develop water conservation and demand management programs through water metering and rebate programs Demand management through public education on conservation Establish a relationship with local power utility and work jointly on strategies to reduce seasonal or peak water and energy demand
		Groundwater use reporting (unmetered systems)	Individual reporting to basin management authority	Annual	Basin management group		
		Annual evaluation of meter records	Electronic data compilation	Annual	RWMG		
	Increased agricultural demand	Water meter data	Flow meters	Monthly	Water agencies & irrigation districts	- Minimize urban demand - Sufficient storage to meet unexpected needs	Participate in community planning and regional collaborations relating to climate change adaptation Reduce agricultural water demand by working with irrigators to install advanced irrigation equipment Develop water conservation and demand management programs through water metering and rebate programs Establish a relationship with local power utility and work jointly on strategies to reduce seasonal or peak water and energy demand Model agricultural water demand under future scenarios of climate change and projections of cropping types
		Groundwater use reporting (unmetered systems)	Individual reporting to basin management authority	Annual	Basin management group		
		Annual evaluation of meter records	Electronic data compilation	Annual	RWMG		
	Increased CII demand	Water meter data	Flow meters	Monthly	Water agencies	- Minimize urban demand - Sufficient storage to meet unexpected needs	Participate in community planning and regional collaborations relating to climate change adaptation Demand management through public education on conservation Develop water conservation and demand management programs through water metering and rebate programs Work with power companies to evaluate feasibility of using recycled water or alternative cooling methods to meet power plant needs Optimize operations by restricting some energy-intensive activities during the summer to times of reduced electricity demand and work with energy utility on off-peak pricing
		Groundwater use reporting (unmetered systems)	Individual reporting to basin management authority	Annual	Basin management group		
		Annual evaluation of meter records	Electronic data compilation	Annual	RWMG		
	Increased demand for firefighting (wild and other)	Public records compared with meter records; statistical analyses	Electronic data compilation	Every five years	RWMG	- Minimize likelihood of wildfires through land management - Plan and managed supplies to meet fire fighting needs	Use fire models and develop fire management plans for water supply sources in fire-prone watersheds Practice fire management plans in watersheds

		Vulnerability Measurement Tools & Methods					
Vulnerability	**Vulnerability Indicators**	**Measure**	**Method**	**Frequency**	**Responsible Entity**	**Adaptation Goal(s)**	**Possible Near-Term Adaptation Actions**
Water Supply and Quality	More frequent droughts	Historical data tracking with statistical analyses	Electronic data compilation	Every five years	RWMG	- Minimize urban, agricultural and CII demands - Sufficient storage to cover drought periods	Conduct climate change impacts and adaptation training for staff Participate in community planning and regional collaborations relating to climate change adaptation Expand current resources through developing regional water connections for sharing during shortages
	Reduced surface water availability	Streamflow measurements	Stream gages or weirs	Monthly	California Department of Water Resources (CDEC), U.S. Geological Survey, water agencies, irrigation districts	- Minimize urban, agricultural and CII demands - Sufficient storage to cover drought periods	Use hydrologic models to project runoff and incorporate model results in water supply planning Diversify water portfolio to include drought-proof supplies like recycled water Practice conjunctive use and construct or expand infrastructure to support such use Construct infrastructure for additional surface and/or ground water storage (i.e. recharge facilities) Increase water storage capacity (i.e. silt removal from reservoirs) Retrofit intakes to accommodate lower water levels in reservoir and decreased late season flow
		Water stage at dam sites	Water level gages	Monthly	Water agencies, irrigation districts		
	Increased groundwater salinity	Groundwater samples (Specific Conductance, Total Dissolved Solids)	Laboratory and in-field analyses	Quarterly	Water agencies, groundwater management organizations	- Track and mitigate groundwater quality impacts through basin management activities	Simulate climate change scenarios/projections in groundwater models
	Increased groundwater overdraft	Groundwater elevations	Elevation monitoring data	Monthly or Seasonally	Water agencies, groundwater management organizations	- Track and mitigate groundwater overdraft through basin management activities	Simulate climate change scenarios/projections in groundwater models Diversify water portfolio to include drought-proof supplies like recycled water Practice conjunctive use and construct or expand infrastructure to support such use Construct infrastructure for additional surface and/or ground water storage (i.e. recharge facilities)
	Decreased surface water quality	Water quality parameters such as dissolved oxygen, total suspended solids, etc.	Laboratory and in-field analyses	Seasonally	Water agencies, resource conservation districts, volunteers	- Track and mitigate surface water quality impacts through watershed management activities	Manage reservoir water quality by investing in practices such as lake aeration Monitor surface water conditions, including water quality in receiving bodies Implement watershed practices to limit pollutant runoff to surface water Increase capacity for wastewater and storm water collection, treatment and discharge
		Ability of surface water treatment plants to treat diverted water	Number of violations	Annual	California Department of Public Health	- Maintain ability to treat surface water to drinking water standards	Develop models to understand potential water quality changes and costs of resultant changes in treatment Increase or modify treatment capabilities to address treatment needs of marginal water quality Implement or retrofit source control measures at treatment plants to deal with altered influent flow and quality

		Vulnerability Measurement Tools & Methods					
Vulnerability	**Vulnerability Indicators**	**Measure**	**Method**	**Frequency**	**Responsible Entity**	**Adaptation Goal(s)**	**Possible Near-Term Adaptation Actions**
	Increased cost of imported supplies (indicator of regional and statewide demand)	Average market value of one acre-foot of water	Market survey	Annual	RWMG, water agencies, irrigation districts	- Minimize the need for imported water	
Flood Management	Increased frequency of high flow events / shift in timing of snowmelt	Streamflow measurements	Stream gage	Monthly at a minimum; continuous preferred	California Department of Water Resources (CDEC)	- Plan for sufficient flood storage space under a variety of hydrologic conditions	Increase water storage capacity (i.e. silt removal from reservoirs) Develop plans for reoperation of reservoirs Monitor flood events and drivers that may impact flood and water quality models Set aside land for future flood-proofing needs (e.g. berms, dikes) Implement or retrofit source control measures that address altered influent flow and quality at treatment plants Build flood barriers, flood control dams, levees and related structures

DRAFT

		Vulnerability Measurement Tools & Methods					
Vulnerability	**Vulnerability Indicators**	**Measure**	**Method**	**Frequency**	**Responsible Entity**	**Adaptation Goal(s)**	**Possible Near-Term Adaptation Actions**
	Increased areas of inundation	Area flooded during storm events	Insurance reports	Annual	California Department of Insurance	- Plan for and minimize potential flood-related damage	Participate in community planning and regional collaborations relating to climate change adaptation Develop and implement emergency response plans to deal with natural disasters Implement green infrastructure on site and in municipalities to reduce runoff and associated pollutant loads into waterways Integrate flood management and modeling into land use planning Conduct extreme precipitation events analysis with climate change to understand the risk of impacts to water and wastewater infrastructure Plan for alternative power supplies to support operations in case of loss of power Establish mutual aid agreements with neighboring utilities Identify and protect vulnerable facilities Integrate climate change risks, including flooding, into CIPs to build facility resilience against current and potential future risks Implement policies and procedures for post-flood repairs Monitor and inspect the integrity of existing infrastructure Set aside land for future flood-proofing needs (e.g. berms, dikes) Implement or retrofit source control measures that address altered influent flow and quality at treatment plants Build flood barriers, flood control dams, levees and related structures Relocate facilities to higher ground Study response of nearby wetlands to storm surge events
Ecosystem and Habitat	Impacted fisheries and other habitats	Fish count	Field studies	Seasonally	California Department of Fish and Game	- Track and mitigate fisheries impacts through watershed management activities	Acquire and manage ecosystems, such as wetlands Monitor vegetation changes in watersheds
	Degradation of surface water quality	Water quality parameters such as dissolved oxygen, total suspended solids, etc.	Laboratory and in-field analyses	Seasonally	Water agencies, resource conservation districts, volunteers	- Track and mitigate surface water quality impacts through watershed management activities	Develop models to understand potential water quality changes Monitor surface water conditions, including water quality in receiving bodies Implement watershed practices to limit pollutant runoff to surface water
	Increased water temperatures	Water temperature	Thermometer	Monthly	Water agencies, resource conservation districts, volunteers	- Track and mitigate surface water quality impacts through watershed management activities	Develop models to understand potential water quality changes Monitor surface water conditions, including water quality in receiving bodies

		Vulnerability Measurement Tools & Methods					
Vulnerability	**Vulnerability Indicators**	**Measure**	**Method**	**Frequency**	**Responsible Entity**	**Adaptation Goal(s)**	**Possible Near-Term Adaptation Actions**
Hydropower	Decrease in power generation	Number of kilowatt hours produced	Data generation records	Annual	Pacific Gas and Electric Company California Public Utilities Commission	- Reduce energy demand - Maximize hydroelectric generation	Develop plans for reoperation of reservoirs Work with power companies to coordinate energy conservation programs (such as rebate programs) Establish a relationship with local power utility and work jointly on strategies to reduce seasonal or peak water and energy demand Work with power companies to evaluate feasibility of using recycled water or alternative cooling methods to meet power plant needs Optimize operations by restricting some energy-intensive activities during the summer to times of reduced electricity demand and work with energy utility on off-peak pricing
	Increase in power demands	Number of kilowatt hours delivered	Data transmission and metering records	Monthly	Pacific Gas and Electric Company California Public Utilities Commission	- Reduce energy demand	
Other	Increased frequency of wildfires	Historical data tracking with statistical analysis	Electronic data compilation	Annual	California Department of Forestry and Fire Protection	- Land management to minimize wildfire	Monitor current weather conditions Use fire models and develop fire management plans for water supply sources in fire-prone watersheds Practice fire management plans in watersheds
	Reduced snowpack	Snowpack survey (depth of snowpack)	Snowpack measurements (depth and water content)	Seasonal	California Department of Water Resources	- Sufficient surface and/or ground water storage to replace lost snowpack storage	Monitoring current weather and hydrologic conditions Use hydrologic models to project snowpack and runoff, and incorporate results into planning

DRA

References

Ackerman, Frank and Elizabeth A. Stanton. 2011. *The Last Drop: Climate Change and the Southwest Water Crisis*. Stockholm Environmental Institute – U.S. Center. February.

Bureau of Reclamation (BOR). 2011. *SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, 2011*. April.

California Air Resources Board (CARB). 2011. *Attachment D, Final Supplement to the AB 32 Scoping Plan Functional Equivalent Document*. August 19.

California Climate Action Team (CAT), Water-Energy Sector Sub Group. 2009. *Water-Energy Sector Summary, AB 32 Scoping Plan, GHG Emissions Reduction Strategies*. March 4.

California Climate Change Center (CCCC). 2006a. *Our Changing Climate: Assessing the Risks to California*. CEC-500-2006-077. July

CCCC. 2006b. *Climate Warming and Water Supply Management in California*. March.

CCCC. 2006c. *Climate Change Impacts of Water for Agriculture in California: A Case Study in the Sacramento Valley*. March.

California Department of Water Resources (DWR). 2012a. *Proposition 84 & 1E Integrated Regional water Management Draft Guideline*. July.

DWR. 2012b. *State Water Project Delivery Reliability Report 2011*. June.

DWR. 2012c. *Draft Climate Action Plan*. March.

DWR. 2010a. Proposition 84 & 1E Integrated Regional water Management Guidelines. August.

DWR 2010b. 20x2020 Water Conservation Plan. February.

DWR. 2009. California Water Plan Update 2009 - Integrated Water Management. DWR Bulletin 160-09.

DWR. 2008. Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water. October.

DWR. 2007. *Drought Preparedness, Background – Droughts in California* as viewed at http://watersupplyconditions.water.ca.gov/background.cfm on June 11, 2007.

DWR. 2006. *Progress on Incorporating Climate Change into Management of California's Water Resources*. Technical Memorandum Report. Accessed April 24, 2011.

DWR. Various Dates. *Water Conditions in California, Bulletin 120*. As viewed at http://cdec.water.ca.gov/snow/bulletin120.

California Energy Commission (CEC) Public Interest Energy Research Program (PIER). 2008.

The Future Is Now: An Update on Climate Change Science, Impacts, and Response Options for California. Publication # CEC-500-2008-077.

CEC. 2006. *Climate Action Team Report to Governor Schwarzenegger and the Legislature*. 1st Biennial Report to the Climate Action Team by the Public Interest Energy Research (PIER) Program. As viewed at http://www.climatechange.ca.gov/research/2008_assessment/index.html. March.

California Natural Resources Agency (CNRA) and the California Emergency Management Agency (CEMA). 2012. Draft *California Climate Change Adaptation Policy Guide*. April.

CNRA. 2009. *2009 California Climate Change Adaptation Strategy: A Report to the Governor of the State of California in Response to Executive Order S-13-2008*. As viewed at http://www.climatechnage.ca.gov/adaptation/

California State Assembly. 2006. *Assembly Bill No. 32 (Chapter 488).*

California State Senate. 2007. *Senate Bill No. 97 (Chapter 185).*

California State Senate. 2008. *Senate Bill No. 375 (Chapter 728).*

California Urban Water Agencies (CUWA). 2007. *Climate Change and Urban Water Resources.*

Camp Dresser McKee. 2011. *Climate Change Handbook for Regional Water Planning*. Prepared for the U.S. Environmental Protection Agency Region 9 and the California Department of Water Resources. November.

Cayan, Dan, Mary Tyree, Mike Dettinger, Hugo Hidalgo, Tapash Das, Ed Maurer, Peter Bromirski, Nicholas Graham and Reinhard Flick. 2009. *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. CED-500-2009-014-F. California Climate Change Center. As viewed at www.energy.ca.gov/2009publications/CEC-500-2009-014/CEC-500-2009-014-D.pdf

Cayan, Dan. Amy Lynd Luers, Michael Hanemann, Guido Franco, Bart Croes. 2006. *Scenarios of*

Climate Change in California: An Overview. California Energy Commission publication CEC-500-2005-186-SF.

Chung, F., J. Anderson, S. Arora, M. Ejeta, J. Galef, T. Kadir, K. Kao, A. Olson, C. Quan, E. Reyes, M. Roos, S. Seneviratne, J. Wang, H. Yin. 2009. *Using Future Climate Projections to Support Water Decision Making in California. California Energy Commission publication CEC-500-2009-52-F.*

Congressional Budget Office (CBO). 2009. *Potential Impacts of Climate Change in the United States.* May.

Dettinger, Michael. 2005. *From Climate Change Spaghetti to Climate Change Distributions for 21st Century California*. San Francisco Estuary and Watershed Science. Vol. 3, Issue 1, Article 4. March.

Dettinger, Michael. 2004. *From Climate Change Spaghetti to Climate Change Distribution*. Discussion paper prepared for the CA Energy Commission, Public Interest Energy Research Program by the United States Geologic Survey and Scripps Institute of Oceanography. Publication No. 500-04-028. February.

East Bay Municipal Utility District (EBMUD). 2012. *WSMP 2040, Water Supply Management Program 2040 Plan*. April.

EBMUD. 2006. *Climate Change and EBMUD's Water Supply*. Presentation to the EBMUD Board of Directors, February 14, 2006.

Hayhoe, Katharine, Daniel Cayan, Christopher B. Field, Peter C. Frumhoff, Edwin P. Maurer, Norman L. Miller, Susanne C. Moser, Stephen H. Schneider, Kimberly Nicholas Cahill, Elsa E. Cleland, Larry Dale, Ray Drapek, R. Michael Hanemann, Laurence S. Kalkstein, James Lenihan, Claire K. Lunch, Ronald P. Neilson, Scott C. Sheridan and Julia H. Verville. 2004. *Emissions Pathways, climate change and impacts on California*. Published in the Proceedings of the National Academy of Sciences of the United States of America, Volume 101, Number 34. August 24. pp 12422-12427.

Hopmans, Jan, Gerrit Schoups, and Ed Maurer. 2008. *Global Warming and its Impacts on Irrigated Agriculture in the San Joaquin Valley (SJV).* As viewed at https://sunsite.berkeley.edu/WRCA/WRC/pdfs/GW26thHopmans.pdf. August 22.

Howatt, Ian M. and Slawek Tulaczyk. 2005. *Climate sensitivity of spring snowpack in the Sierra Nevada*. As seen in the Journal of Geophysical Research, Volume 110, F04021, 9 pp. December 8.

Howitt, Richard, Josué Medellin-Azuara, and Duncan MacEwan. 2009. *Estimating the Economic Impacts of Agricultural Yield Related Changes for California*. CED-500-2009-042-F. California Climate Change Center, as viewed at http://www.energy.ca.gov/2009publications/CED-500-2009-042/CED-500-2009-042-F.pdf

Hydropower Reform Coalition. 2009. *Hydropower Reform Coalition Success Story, Mokelumne River Project, North Form of the Mokelumne River, California.*

Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: Synthesis Report.*

IPCC. 2007b. *Climate Change 2007*. Fourth Assessment Report of the IPCC.

IPCC. 2001. *Summary for Policymakers: A Report of Working Group 1 of the Intergovernmental Panel on Climate Change.*

Joyce, Brian, Sebastian Vicuna, Larry Dale, John Dracup, Michael Hanemann, David Purkey, and David Yates. 2006. *Climate Change Impacts on Water for Agriculture in California: A Case Study in the Sacramento Valley*. California Climate Change Center (CCCC). March.

Kahrl, Fredrich and David Roland-Holst. 2008. *California Climate Risk and Response*. November.

Leung, L. Ruby, and William I. Jr. Gustafson. 2005. *Potential Regional Climate Change and Implications to U.S. Air Quality*. As published in the Geophysical Research Letters, 32:L16711.

Loáiciga, Hugo A. 2003. *Climate Change and Groundwater*. As published in the Annals of the Association of American Geographers. 93(1), pp 30-41.

Lobell, David B., Kimberly Nicholas Cahill, and Christopher B. Field. 2007. *Historical effects of temperature and precipitation on California Crop Yields*. As published in Climate Change, 81:2, pp187-203. As viewed at http://www.escholarship.org/uc/item/3d53x9mc

Lobell, David B., Kimberly Nicholas Cahill, and Christopher B. Field. 2006. *Weather-based yield forecasts developed for 12 California Crops*. As published in California Agriculture, 60:4, pp211-15. As viewed at http://dx.doi.org/10.1007/s1-10584-006-9141-3

Lundquist, Jessica D. and Daniel R. Cayan. 2002. *Seasonal and Spatial Patters in Diurnal Cycles in Streamflow in the Western United States*. As published in Journal of Hydrometerology, by the American Meterological Society, Volume 3, pp. 591-603. October.

Maurer, Edwin P. 2005. *Uncertainty in Hydrologic Impacts of Climate Change in the Sierra Nevada Mountains, California Under Two Emissions Scenarios.* April 29.

Moser, Susanne, Julia Ekstrom and Guido Franco. 2012. *Our Changing Climate 2012, Vulnerability & Adaptation to the Increasing Risks from Climate Change in California*. A Summary Report on the Third Assessment from the California Climate Change Center. CEC-500-2012-007. July.

Null, Sarah E., Joshua H. Viers, and Jeffery F. Mount. 2010. *Hydrologic Response and Watershed Sensitivity to Climate Warming in California's Sierra Nevada*. April 1.

RMC Water and Environment (RMC). 2008. *Estimated Impact of Air Temperature Increase on Mokelumne River Water Temperature.* Technical Memorandum prepared for EBMUD as part of the WSMP 2040 project. March 23.

Roos, Maurice. 1994. *Potential Effect on Water Project Yield of Changed Snowmelt Runoff Patterns*. Presented at the Western Snow Conference, Santa Fe, New Mexico. April.

Schlenker, Wolfram, W. Michael Hanemann, and A. C. Fisher. 2007. *Water availability, degree days and the potential impact of climate change on irrigated agriculture in California*. As viewed in Climate Change, 81:1, pp 19-38. As viewed at http://dx.doi.org/10.1007/s10584-005-9008-z

Schoups, Gerrit, Ed Maurer, and Jan Hopmans, et al. 2009. *Climate Change Impacts on Subsurface Hydrology, Crop Production, Water Use and Salinity in the San Joaquin Valley, CA*. As presented at the DWR-UC Workshop on Climate Change Impacts, January 26.

Schoups, G., E.P. Maurer and J.W. Hopmans. 2005. *Climate change impacts on water demand and salinity in California's irrigated agriculture*.

Treidel, Holger, Jose Luis Martin-Bordes, and Jason J. Gurdak (ed.). 2012. *Climate Change Effects on Groundwater Resources, A Global Synthesis of Findings and Recommendations*. CRC Press.

United States Climate Change Science Program (CCSP). 2009. *Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decision Making.* Synthesis and Assessment Product 5.2. January.

CCSP. 2008. *Weather and Climate Extremes in a Changing Climate. Regions of Focus: North American, Hawaii, Caribbean and U.S. Pacific Islands.* Synthesis and Assessment Product 3.3. June.

United States Environmental Protection Agency (USEPA). 2012a. *Climate Ready Water Utilities Adaptation Strategies Guide for Water Utilities*. EPA 817-K-11-003. January.

USEPA. 2012b. *Planning for Sustainability, A Handbook for Water and Wastewater Utilities*. EPA-832-R-12-001. February.

USEPA. 2012c. *National Water Program 2012 Strategy: Response to Climate Change, Public Comment Draft*. March.

United States Geological Survey (USGS), Office of Global Change. 2009. *Effects of Climate Variability and Change on Groundwater Resources of the United States*. Fact Sheet 2009-3074. September.

University of California, Davis. 2012. *Vulnerability and Adaptation to Climate Change in California Agriculture*. A White Paper from the California Energy Commission's California Climate Change Center. CEC-500-2012-031. July.