Chapter 5.9 Climate Change

This IRWMP complies with all climate change standard requirements established in the Proposition 84 Guidelines. As of the publishing date, the IRWMP Climate Change Handbook to be developed by the State of California DWR in conjunction with US EPA Region 9, USACE and Resources Legacy Fund was under development, and as such, is anticipated to further improve some of the quantitative tools used for the analysis of climate change vulnerabilities. The evolving nature of the OWOW Plan will allow SAWPA and its stakeholders to update the Plan in the future to strengthen the analysis of climate change implications and strategies for the watershed.

Climate change is already having a profound impact on the State of California and on the Watershed. Warmer temperatures, altered patterns of precipitation and runoff, and rising sea levels are increasingly compromising water and environmental resources and, in turn, the sustainability of our communities. Adapting the State's infrastructure to respond to climate change presents one of the most significant challenges of this century. Impacts and vulnerability will vary by region, as will the resources available to respond to climate change. Regional solutions, such as proposed through OWOW and associated integrated solutions, are vital to the future of the Watershed.

Current Conditions

There is broad scientific agreement that climate change is occurring and that emissions of heat-trapping pollution are the primary cause. The United Nations Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report in 2007 estimated that the rate of warming is averaging 1.3 degrees Fahrenheit over the past century. The report also confirmed that "11 of the last 12 years (1995 to 2006) rank among the twelve warmest years since 1850."[i] IPCC predicts the project rate of warming over the 21st century will increase and could peak at 11.5 degrees Fahrenheit above 1990 levels. Global warming and its probable consequent changes in precipitation, storm intensity, increased evaporation and transpiration, greater risk of fires and floods, and a rise in sea level pose a significant danger to the world's environment, health and economy.

The IPCC has identified three major components of a changing climate that will have the most serious impact on communities: 1) increased temperature; 2) more variable precipitation, and; 3) a rising sea level. Each of these components likely will have a significant impact on the Watershed.

Climate Change Projections for the Watershed

Climate change-related impacts already have taken place in California, and are having an effect on the Watershed. According to DWR, historic hydrologic patterns can no longer be relied upon to forecast the water future. As such, the reliability of the system of imported water that provides significant supply to the region has been lessened. Precipitation and associated runoff patterns are changing, increasing the uncertainty for water supply and quality, flood management, and ecosystem functions. The average early snowpack in the Sierra Nevada has decreased by about ten percent during the last century, representing a loss of 1.5 million AF of snowpack storage.[ii] During the same period, the sea level rose seven inches along California's coast. The State's temperature also has risen 1 degree Fahrenheit. Most of the increased temperature readings are at night and during the winter season, with higher elevations showing the greatest increase. Rainfall has become increasingly variable, with southern California experiencing both its driest and wettest years on record within the past decade.

However, projections about future impacts of climate change on the Watershed region remain, like all projections, uncertain. Current temperature and precipitation forecasts are derived from large scale atmosphere-ocean general circulation models that are not easily applied to discrete geographic regions such as the Watershed. More than 20 of these models exist worldwide, and most give quantitatively different forecasts for southern California.[iii] There is value in using predictive models to develop scenarios that aid in planning for the future. Impacts of climate change are likely to occur, and there are risks associated with not planning for future impacts because predictive models are imprecise.

Methodology

With the assistance of the RAND Corporation, an evaluation of the key climate change drivers and the Watershed's vulnerabilities were developed. In 2006, the RAND Corporation partnered with the National Science Foundation to prepare and evaluate case studies addressing water management decision making under conditions of abrupt climate change.

Weather projections for the Watershed region, reflective of climate changes predicted by the scientific community's global climate models, were developed. These data were then used with a water management model to evaluate how various water management scenarios for the region would perform under different scenarios of climate and other management options.

The probable scenarios affecting water supplies in the Watershed included increased temperature, but variable precipitation levels. It also was recognized that the statewide climate trends likely would result in reduced snowpack and runoff amounts, in turn, reducing the amount of water that was likely to be available for imports into the region.

The baseline case for water management was IEUA's 2005 Urban Water Management Plan (UWMP). This plan emphasizes development of local supplies and a reduced dependence on imported water supplies. Under base year conditions, approximately 70% of the water supplies are from local sources (e.g., groundwater, recycled water, and desalted groundwater supplies). These ratios of potential water supply sources are relatively common throughout the Watershed, but some regions are more dependent on imported water and a few, less so. However, the UWMP projects the ability to meet nearly 80% of the service area water demands by 2025.

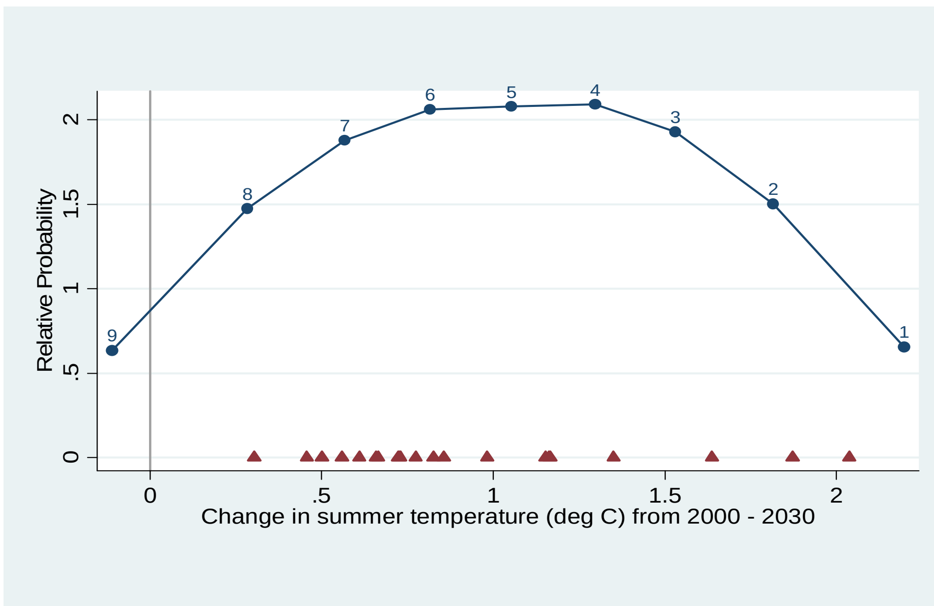
The RAND study showed that the 2005 UWMP performs well under many potential climate change scenarios. However, significant risks to water supply exist if nothing more is done now or in the future to develop additional local supplies. The core vulnerability in the UWMP was the region's continued reliance on imported water supplies, when climate change scenarios showed that imported supplies were severely impacted by declines in precipitation statewide. The most cost-effective scenarios were those which included significant improvements in local water use efficiency along with the development of additional conjunctive use and recycled water programs.

Using the large-scale models to run thousands of possible scenarios, RAND generated probabilistic forecasts for southern California which was the smallest geographic scale to which these probabilistic models can be applied. Based on these model projections, RAND concluded the following regional impacts were likely to occur within the Watershed over the next 30 years.

Temperature

Figure 5.9-1 shows that average summertime temperatures are likely to increase between 0.1 degree and 2.1 degree Celsius. The RAND temperature forecast for southern California, including the Watershed region, is consistent with the IPCC 2007 report that projects warmer temperatures for the western states. It is important to note that the increase in peak summer temperature predicted for the region will intensify heat island effects from the watershed's existing extensive urban development.

Figure 5.9-1 Average summertime temperature changes

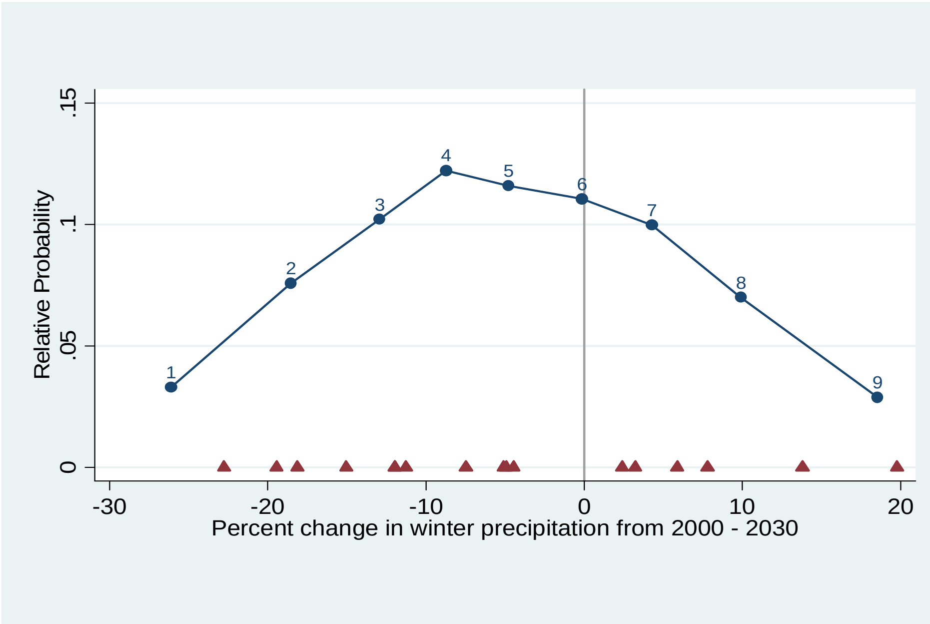


Rainfall

Figure 5.9-2 shows that average wintertime precipitation within the Watershed is likely to be exceedingly variable, ranging from a probable 19% decrease in rainfall (drier) to a possible 8% increase (wetter).

The RAND precipitation forecast suggests that rainfall that will occur in the Watershed region is still very uncertain, but certainly variable. There are many possible changes to the Watershed's precipitation patterns, including a shift to summer monsoon-type (hotter, muggier) weather events. The modeling underscores greater variability of precipitation combined with an expected greater intensity of precipitation events. Dry periods are predicted to last longer and rain storms, when they do occur, will be more powerful. The past three years of precipitation can provide an excellent example of highly variable rainfall patterns as the Watershed had the wettest (2005) and driest (2007) years ever recorded.

Figure 5.9-2 Average wintertime precipitation within the Watershed



Sea Level Rise

RAND recognized that sea level rises associated with increased temperature scenarios shown in the models would increase sea level along the Orange County Coast between 22 and 35 inches.

Actual sea level rises have varied among locations. However, over the past 100 years, sea levels already have risen about seven inches along the California coast. If greenhouse gases and temperatures continue to rise, the ocean could rise an additional 22 to 35 inches by the end of the century. There are implications for coast development and for the provision of groundwater from coastal aquifers.[iv]

Implications of Climate Change for the Watershed

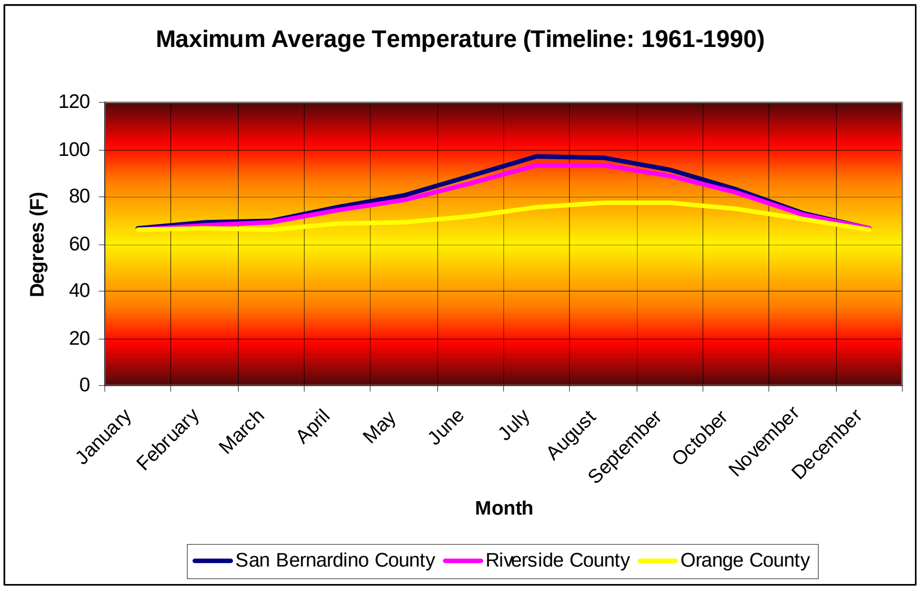
Warmer Temperatures

Increased Evaporation and Transpiration, Increased Water Needs

Overall, higher temperatures will increase levels of evaporation and transpiration, which in turn, increases water demand, primarily for outdoor irrigation. As needs for irrigation water increase, there also may be increasing needs for environmental water, and a greater potential for conflict and competition between these uses.

Figure 5.9-3 shows the maximum average temperatures for San Bernardino County, Riverside County, and Orange County from the 1960s through the 1990s.[v]

Figure 5.9-3 Maximum average temperature in Watershed region



Heat waves are likely to be longer, hotter and more frequent; intensifying wildfire risks and increasing summer peak energy demands

The RAND prediction that summer peak temperatures will increase in the Watershed is a major impact, as it exacerbates a heat island effect that already takes place in developed areas that have minimal vegetation (roof tops, roads) to reduce the concentrated heat. The higher temperatures will exacerbate wildfire concerns by drying out vegetation earlier in the year and increase the potential for extreme wildfire events, especially during annual Santa Ana wind conditions.

Rising temperatures will cause an increase in energy demand, particularly electric cooling demand. However, reduced energy supply reliability is a likely result of the rise in temperature. The lack of snow pack, which usually leads to lower reservoir levels, may reduce hydroelectric power production.

Air quality will be diminished, especially during summer peak temperatures

Southern California already has poor air quality, especially during hot summer months when smog, ozone, and other air pollutants tend to concentrate. The expected increase in summer peak temperatures due to climate change will intensify these problems and create a larger impact on sensitive populations (e.g., young, elderly, and poor) within the Watershed.

Temperature of interior stream, ponds and lakes will increase, creating water quality problems and causing environmental stress for Watershed biota.

Increased temperature can impact water quality several ways. First, warmer water is unable to hold as much dissolved oxygen (DO) as cooler water. This DO is essential for fish and macro-invertebrates that do not breathe at the surface of the water. At times when DO levels decrease, native fish congregate in the deeper cooler areas of a lake or stream. In these areas, they are more susceptible to imported predators such as bass. Where areas of cooler water are not available, the fish become physiologically stressed resulting in reduced survival and decreased fecundity. Increases in water temperature also increase the growth of algae. While algal growth is natural in healthy ecosystems, excessive growth can further decrease DO and produce serious water quality impacts.

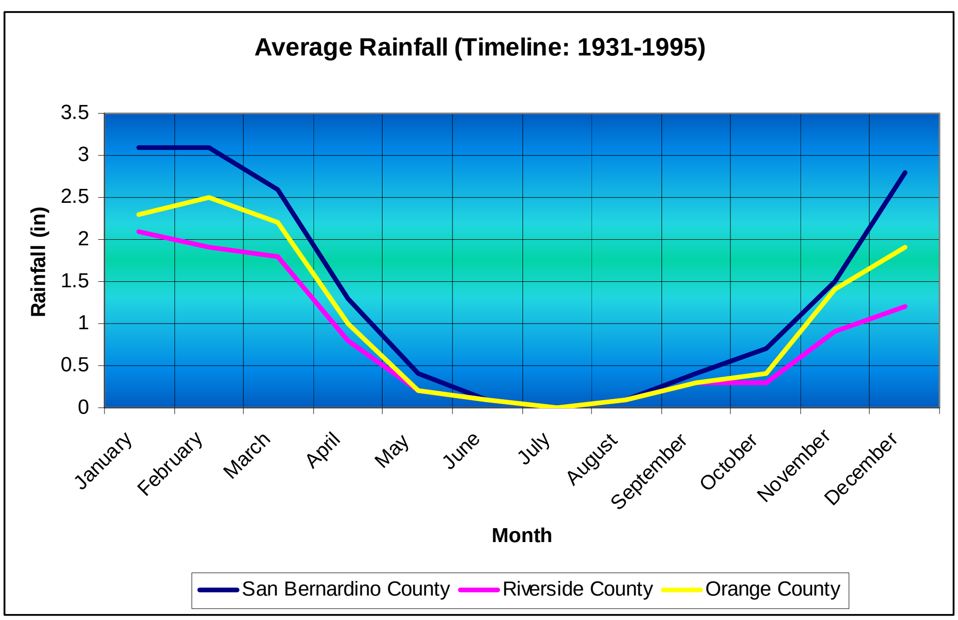
Statewide increase in temperature impacts available imported water supplies

A significant portion of the water currently used within the Watershed is imported into the region either from the Colorado River or from northern California via the SWP. The greatest volume of water imported into the region arrives from northern California, and those deliveries are dependent of the snowpack in the Sierra Nevada Mountains. Decreased snowfall related to climate change or a change from snow to rain, which often flows down the mountains too rapidly to collect, can have significant impacts on the availability of water in southern California.

In the northern part of the State, since rainfall occurs over a short seasonal interval, California's water infrastructure is dependent on the build-up of snow in the mountains of the Sierra Nevadas. Snow acts as a natural reservoir by releasing water into streams and man-made reservoirs after winter and early spring rains and snowfall have ceased.

Warmer temperatures may cause rivers to carry a heavier flow during wet months, possibly triggering floods. During summer months, river flows would be reduced, resulting in water shortages that could affect agricultural areas. **Figure 5.9-4** depicts the average rainfall, in inches, for San Bernardino, Riverside, and Orange Counties during 1931-1995.

Figure 5.9-4 Average rainfall for San Bernardino, Riverside & Orange Counties during 1931-1995

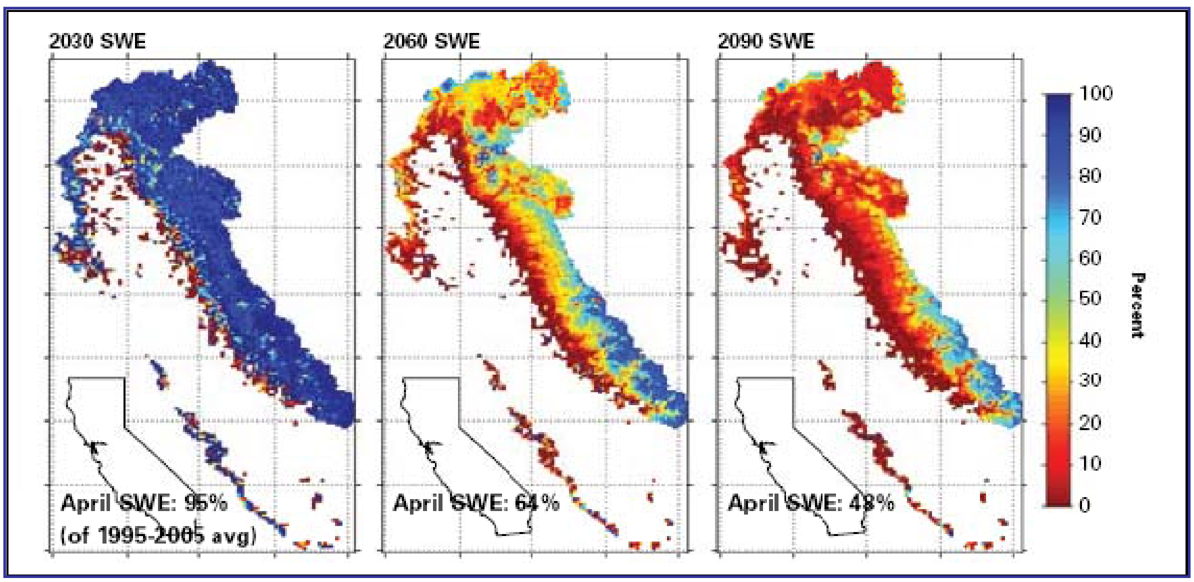


Snowpack and Streamflows

"In the West, streamflow is often strongly influenced by runoff from melting winter snowpacks. Streamflow is characterized by timing, magnitude, frequency, and duration of water flows, all of which are affected by climate change…Recent studies indicate that changes have already occurred in snowmelt and spring runoff throughout the western region of North America." (NRDC)

No matter what amount of precipitation California ends up with, an increase in temperature will result in a reduction in snowpack. This, in turn, will adversely affect the runoff that the California water supply has become so dependent upon. One study projected that snow levels will retreat 500 feet in elevation in California for every rise of one degree Celsius.[vi] The United States Geological Survey (USGS) has observed "that flows in many western streams arrive a week to almost three weeks earlier than they did in the middle of the 20th Century."[vii] For example, (**Figure 5.9-5**) one study shows that the Sacramento and San Joaquin Rivers have declining flows during the critical April to July period, over the last century. Any and all of these changes will affect the water supply, flood control management, and could cause major erosion which would lead to fires and major health hazards.[viii]

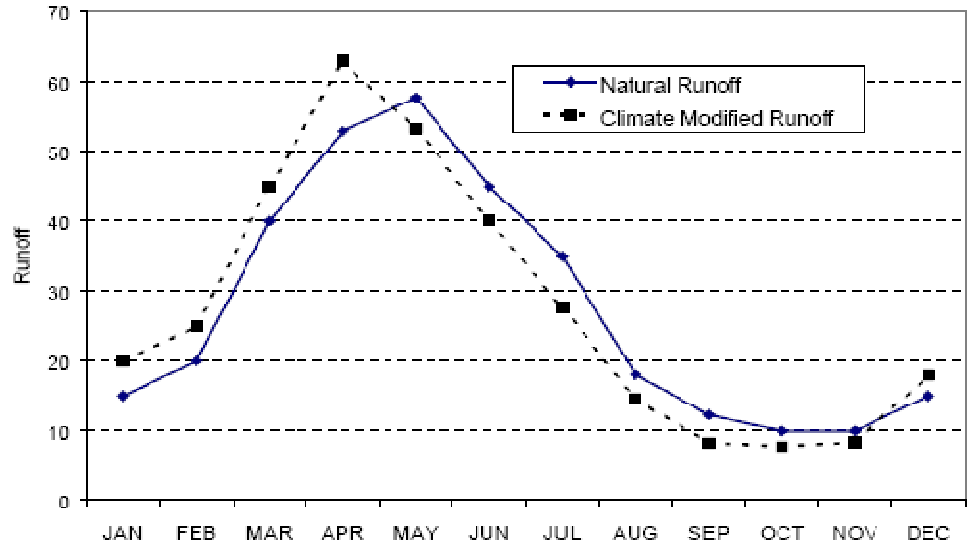
Figure 5.9-5 Evolution of average annual snow water equivalent as a percentage of average 1995-2005 values



Source: Knowles, N. and Dan Cayan. Potential effects of global warming on the Sacramento/San Joaquin Watershed and the San Francisco estuary. September 28, 2002. Geophysical Research Letters. Vol. 29, No. 18.

A study by the Pacific Institute showed that rising temperatures will affect snowfall patterns, as well as the timing and rate of snowmelt. **Figure 5.9-6** shows hypothetical changes in hydrographs that can be expected with changing snow dynamics in the Sierra Nevada.

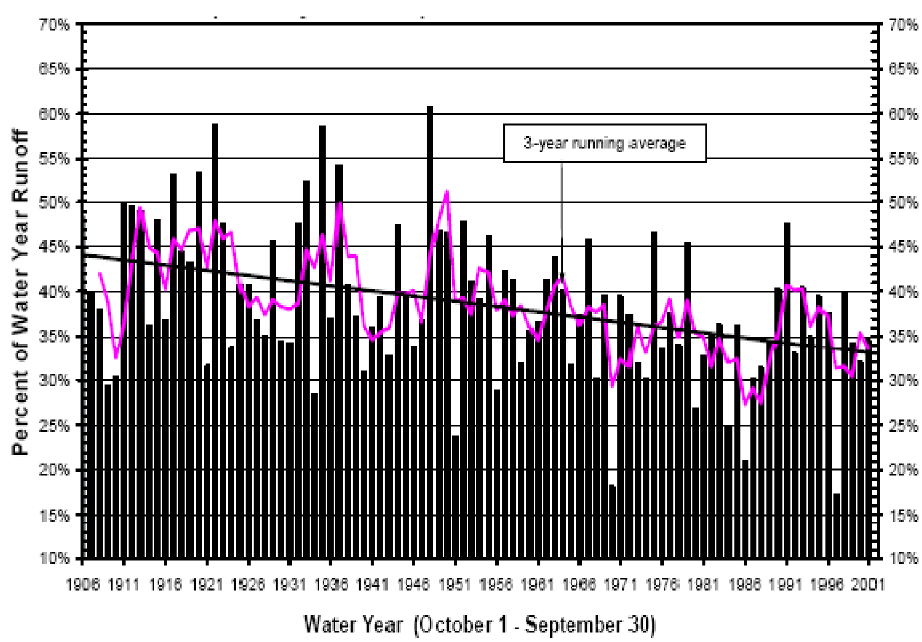
Figure 5.9-6 Hypothetical natural and modified average hydrograph for basins with snowfall and snowmelt in the Sierra Nevada



Warming-induced change in the timing of streamflow, including both the intensity and timing of peak flows, is quickly becoming a reality. As temperatures rise, a declining proportion of total precipitation falls as snow, more winter runoff occurs, and remaining snow melts sooner and faster in spring (see, for example, Gleick, 1986, 1987a,b; Lettenmaier and Gan, 1990; Nash and Gleick, 1991b; Miller *et al.,* 1999; Knowles and Cayan, 2002; VanRheenen *et al.*, in press). In some basins, spring peak runoff may increase; in others, runoff volumes may significantly shift to winter months. Shifts in runoff timing in snowmelt-fed basins are consistent in all studies that considered daily or monthly runoff. These studies show with very high confidence that increases in winter runoff, decreases in spring and summer runoff, and higher peak flows will occur in such basins as temperatures and hence, both snowline and melt rates, rise.

Figure 5.9-7 depicts the historical trend in seasonal runoff for the Sacramento River. The decreasing percentage of runoff indicates an earlier melting seasonal snowpack.

Figure 5.9-7 Sacramento River runoff in percent of Water Year runoff



Increased flood risk and reduced ability for groundwater replenishment

As temperatures warm, more rain than snow falls at higher elevations. In areas that do have snowpack, melting occurs sooner. In the Watershed, this would increase peak flows after winter storms making rainfall more difficult to capture. This scenario could be more severe in El Niño years, which generally feature warmer winters and produce higher amounts of precipitation. Further, climate model studies performed in the last few years indicate that additional levels of carbon dioxide will lead to fewer, but more potent storms as has been the case in the last 50 years.[ix] These intensified storms produce intense run-off (flash-flood type storms) that do not have the necessary time for groundwater replenishment. Intensifying storms combined with the booming population growth in the Watershed region (increased paved land) will only reduce groundwater replenishment even more.

Increased risk to local supplies

Local water supplies are much more reliable than imported supplies, but also will be affected by a changing climate. Increased temperatures, uncertain precipitation patterns, reduced groundwater replenishment, and possible sea-water intrusion are all realistic scenarios that may decrease the reliability of local resources. Local water supplies may consist of surface water, groundwater, recycled water, and desalinated water.

The reliability of surface water can be affected by increased evaporation, changes in precipitation, changes in stormwater run-off, and degrading water quality. These issues also may have a direct impact on groundwater supplies. Rising sea level associated with climate change may increase salt water intrusion into the Orange County groundwater basins, necessitating expensive measures to protect the basins. Continuous replenishment of groundwater is necessary to keep that barrier between the sea water and the coast's fresh water aquifers.

Decreased water quality

Water quality depends on a wide range of variables, including temperature, flow, run-off rates and timing, and the ability of watersheds to assimilate pollutants. Changes in stormflows will have direct water quality impacts. Higher winter flows could reduce pollutant concentrations or increase erosion of land surfaces and stream channels, leading to higher sediment, chemical, and nutrient loads in rivers. Lower summer flows could reduce DO concentrations, reduce dilution of pollutants, and increase zones with high temperatures (Eheart *et al.*, 1999).

Increased wildfire risk

Ecosystems in the West are dependent upon fire to maintain the region's unique ecology. However, a study conducted by the American Water Works Association (AWWA) emphasized that whether or not fire is an ecological benefit or a threat to society, it has a serious impact on water supply in terms of both reduced water quality and possible storage capacity, due to sedimentation.[x] Recent research at Scripps Institute suggests that there are two primary ways that climate change will increase fire risk. The first is varying periods of increased precipitation followed by sustained drought creates high fire-risk fire conditions. And second, higher temperatures reduce moisture levels in soils drying vegetation and creating increased fire risk. A combination of bark beetle infestation and a prolonged drought resulted in extremely severe fire conditions in 2003. According to historical tree-ring analysis, patterns of one or more wet El Niño years followed by a dry La Niña year produces a higher risk of wildfires, in the southwest.[xi]

Management Strategies for a Changing Climate

In order to mitigate green house gas emissions and increase the watershed's ability to adapt to climate change, several strategies and adaptation actions that water managers can take were developed.

Understand that the Past is Not the Future: Resource management planners, including water agencies, have traditionally planned for the future assuming that historical weather patterns will persist without change into the future. Planning within the Watershed must include consideration of the potential impacts of climate change, such as reduced precipitation, more intense storm patterns, increased flooding, reduced snow pack decreasing the reliability of imported water, greater evaporation of surface water, sea level rise and associated impacts on coastal groundwater basins, and increased stress on natural habitats.

Develop Watershed-wide Programs: Time, money and water can be saved through coordinated program implementation within the Watershed. Changing management strategies to meet a changing climate will require that all interests work together to ensure that there are no unintended consequences of our actions. Already, such work has been done in developing regional water management plans and in the development of Basin Plans that feature salt and nitrogen management. The OWOW process continues this effort and considers all stakeholder communities dependent on water.

Incorporate Climate Considerations into Land Use Planning: The development of Smart Growth Communities, the implementation of LID, and improved water efficiency standards will play a significant role in helping the Watershed to adapt to climate change impacts.

Factor in Flood and Fire Management in Planning Decisions: The steep mountains and alluvial flood plans of the Watershed, combined with its historical proclivity towards intense storm events, makes the region more vulnerable to climate changed induced flooding and fires, as the intensity of flood and fire events may increase further.

Protect and Restore Aquatic Ecosystems: The Watershed has a rich array of biological resources that are critical to the quality of life in the region. Healthy ecosystems are more resistant to climate impacts, and enhancement of these systems provides other benefits including water quality, recreation, and flood protection.

Make Water Use Efficiency and Local Water Supply Development a Top Priority: Increased investment in water use efficiency, recycled water, stormwater capture, and groundwater storage are vital to the long-term reliability of water supplies for the Watershed. Imported water supplies are likely to become much less reliable in the future.

Promote Investment in Renewable Energy, Building Efficiency, and Vehicle Efficiency: Transportation, power generation, and heating are primary sources of controllable carbon emissions, and constitute early implementation opportunities for the reduction of greenhouse gases. Wind and solar energy could both become significant sources of renewable energy within the Watershed and numerous projects already are underway. The U.S. Green Building Council has implemented a LEED certification program for green buildings where significant energy savings can be found. There have been several significant LEED projects within the Watershed, but the region lags behind in the implementation of LEED projects. Encouragement of LEED building would result in significant energy savings and an associated reduction in carbon emissions.

Recognize the Energy Intensity of Water Supplies: Development of local supplies is acknowledged by the California Air Resources Board as a core adaptation strategy, as well as a way to reduce greenhouse gas emissions under California's Assembly Bill 32 Scoping Plan. A 2008 Study completed by the California Sustainability Alliance on recycled water estimates that energy savings from the use of 100,000 AFY of currently unused tertiary treated recycled water within the Watershed over the next five years would reduce energy usage by 340,000 MWh/year and achieve an annual reduction of 129,000 tons of carbon dioxide.

In 2006, the California Energy Commission released a report, Refining Estimates of Water Related Energy Use in California, in which they concluded that water supply/conveyance is the most energy intensive source of water, with imported water supplies in southern California requiring almost five times the energy than water supplied to northern California (average 3200 kWh/AF in southern California versus 700 KWh/AF in northern California). Clearly, development of local supply could yield enormous carbon savings.

The California Governor recently issued an Executive Order calling for a 25% reduction in greenhouse gas emissions (from 1990 levels) by 2020. In the same year, the California legislature passed Assembly Bill 32, the Global Warming Solutions Act, which provides for the development of mandatory reporting requirements, greenhouse gas emission targets, and a cap and trade system for achieving the Governor's greenhouse gas emissions goal. The California Air Resources Board is responsible for the development of an implementation plan and adoption of regulatory requirements that will achieve the greenhouse gas reduction goal. In December 2008, the Air Resources Board adopted a scoping plan that lays out the programs that will become requirements statewide.

With emissions currently at 492 metric tons of greenhouse gases annually, California is the second largest emitter in the United States and about the twelfth largest in the world. Reducing California's "carbon footprint" to meet the Assembly Bill 32 goals will require approximately a 29% cut in emissions below the 2020 levels the state's current trajectory would produce.

Increase Public Education: An understanding of the impacts of climate change on the Watershed and California is critical to making the informed choices for water management, land use, ecosystem protection, and infrastructure investments.

Perform Carbon Footprint Assessment and Use the Tool to Identify Additional Opportunities for Reducing Carbon Emissions: A carbon footprint is a measure of the impact human activities have on the environment in terms of the amount of green house gases produced, measured in units of carbon dioxide. The measure is usually expressed as tons of carbon dioxide equivalent. Carbon dioxide accounts for about 84% of human-caused greenhouse gas emissions in California, with methane, nitrous oxide, hydroflorocarbons, sulfur hexafluoride, and perflorocarbons contributing the remainder of the gases.

The California Climate Action Registry provides criteria for measuring carbon emissions from water, wastewater, local government, industry, and other sectors. Carbon emission accounting is expected to be one of the primary tools that the State of California will use to measure progress towards its greenhouse gas emission reduction goals. **(Annual Emissions Report)**. This Report can be found in the Appendices.

EMWD recently has completed an excellent carbon footprint analysis for their facilities that can be a model for others to complete a similar analysis.

Current Implementation

Recognizing the importance of climate change to IRWM planning, assessment and implementation of the plan, climate change was included among the criteria approved by the OWOW Steering Committee for priority ranking of projects submitted to implement the OWOW plan and in the Call for Projects information form. The Call for Projects information form included a requirement that all projects provide data to describe how effectively the proposed project would reduce greenhouse gas emissions from water management activities. The projects were then given a performance measure to determine how effectively this criteria was addressed which in turn was used as part of the criteria to rank projects.

To assure that climate change implementation is addressed, the project proponent for all projects funded under the Prop 84 IRWM Implementation grant program as well as other projects funded by this process will be required to track the effectiveness and performance of the project greenhouse gas emissions during and after implementation or construction.

As a part of climate action registration, SAWPA has joined the California Climate Action Registry (CCAR) which is now operated by the non-profit national organization, Climate Action Registry (CAR). Further, we have encouraged all our partner agencies to do the same in the Santa Ana River watershed.

To stay current with developments, SAWPA has closely tracked the developments under State legislation dealing with climate change as it relates to IRWM planning efforts. Staff has analyzed the legislation and policy context of Executive Order S-3-05 and the California Global Warming Solutions Act of 2006 (AB 32), Senate Bill 97, and EO S-13-18. Further, the following publications and presentation on Climate Change have been thoroughly reviewed and monitored as they have been developed.

- The Climate Change Scoping Plan, California Air Resources Board, 2008
- DWR White Paper, Managing an Uncertain Future: Climate Change Adaption Strategies for California's Water (2008)
- California Climate Adaptation Strategy, California Natural Resources Agency, Dec. 2009
- DWR Power Point Presentations, July 2010, Climate Change Handbook, Incorporating Climate Change into Integrated Regional Water Management Plans, CDM, sponsored by US EPA Region 9, DWR, Resources Legacy Fund, USACE
- IRWM Planning- Climate Change Document Clearinghouse for IRWM Plan support

Next Steps

It is recognized that the tools to mitigate and adapt to climate change impacts are still evolving and will be applied to the region as they develop. Future updates to the OWOW plan will require the application of lessons learned from the latest Climate Change science, the yet to be published Climate Change Handbook, further application of quantitative tools for vulnerability analysis and more detailed and comprehensive assessment of greenhouse emissions in a quantitative fashion from the entire water resource industry in the region. Despite the needs for the future, it is believed that this region has taken the most progressive steps in climate change impacts, mitigation and adaptation within any IRWM plan across the State.

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[i] IPCC see Wilkinson paper

[ii] DWR Report

[iii] Page 10 of Grove Study

[iv] http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2006/08/01/WARMING.TMP

[v] http://www.worldclimate.com/

[vi] Roos, Maurice, 2005. "Accounting for Climate Change" in *California Water Plan Update 2005,* Vol. 4, Reference Guide, Public Review Draft, California Department of Water Resources, p.5.

[vii] USGS, National Streamflow Information Program, March 2005, "Changes in Streamflow Timing in the Western United States in Recent Decades." Fact Sheet, 2005-3018.

[viii] Dettinger, Michael D., and Dan R. Cayan, 1994. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. *Journal of Climate 8: 606-23.*

[ix] http://earthobservatory.nasa.gov/Newsroom/NasaNews/2006/2006030921864.html

[x] Miller, Kathleen, and David Yates, 2005. *Climate Change and Water Resources: A Primer for Municipal Water Providers.* AWWA Research Foundation and University Corporation for Atmospheric Research. http://www.awwarf.org/research/TopicsAndProjects/projectSnapshot.aspx?pn=2973.

[xi] Swetnam, T.W. and J.L. Betancourt, 1998. "Mesoscale Disturbance and Ecological Response to Decadal Climatic Variability in the American Southwest." *Journal of Climate* 11, 3128-3147; Swetnam, T.W. and J.L. Betancourt, 1990. Fire-Southern Oscillation Relations in the Southwestern United States. *Science* 249, 1017-1020.