Chapter 10. Climate Change and California's Water Challenges

A major research objective of this study was to engage water agency stakeholders in Southern California in a strategic planning exercise that considered the impact of climate change on the reliability of Southern California's water supply under a range of plausible future scenarios. This involved preparation for the scenario workshops. Part of this preparation included the review of the research available on the potential impact of climate change on Southern California's water supply. This chapter summarizes the review, while the next two chapters focus on the scenario planning process and the results of the scenario workshops.

California Water Challenges

Demographic and economic development in Southern California in the last century has occurred thanks to water from underground basins and abundant water transfers from outside the area. The Los Angeles aqueduct, the Colorado River aqueduct and the State Water Project contribute to about 60% of the water supply of the area while local groundwater basins, local surface water and limited recycling constitute the remaining 40% (MWD, 2010).

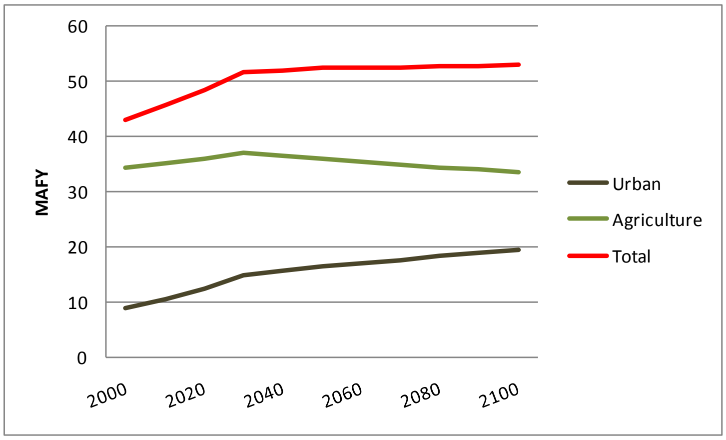
In recent years, a combination natural and human factors has rendered the availability of these resources in the near and far future increasingly uncertain. Although population in the area will likely continue to grow, it is not certain whether the amount of water needed to support the related urban and agricultural uses will be available. See Table 10.1 for a list of trends and factors and their potential impact on water resources, and Figure 10.1 for current and projected water demand in California through mid-century. Water available to Southern California through the State Water Project is strictly constrained by the amount of water needed to maintain the Bay-Delta area ecologically healthy. The amount of water available through the Colorado River Aqueduct has to be reduced to comply with court rulings and interstate obligations. Water available through the Los Angeles Aqueduct is constrained by the need to mitigate environmental damage in the Mono and Owens lake basins; while underground aquifers and surface water quality is increasingly threatened by salt water intrusion, urban runoff and pollution contamination (MWD, 2010; LADWP, 2010).

Climate change is going to exacerbate the ongoing uncertainty. Increased temperatures, reduced snow precipitations, increased weather extremes and sea level rise are the most likely effects of climate change in California (California Natural Resources Agency, 2009). California's water supply as a whole is critically dependent on the extent and depth of the snowpack in the Sierra Nevada. Under climate change, precipitation could dwindle or melt early and move water peaks earlier by as much as a month. It is not known how this will influence ecological and inflow water needs in the Bay Delta area and, conversely, how this will constrain water availability in Southern California. Estimates on the effects of climate change on the Colorado River suggest that the impacts will be even more severe. Current research suggests that actual water sharing agreements have been signed taking into account data which refers to an unusually wet decade, while the river's long term flow is much lower (McCabe & Wolock, 2008). Adding the effects of climate change to the current drought, researchers say, is likely to cause severe decline in runoff with shortfalls in scheduled water deliveries (Ackerman & Stanton, 2011). Underground basins will also be affected. Sea level rise will increase the likelihood of salt water intrusion. Increased intense precipitation will influence the rate of aquifer recharge and the quantity of water runoff to the sea. The future amount of water available for human consumption is not likely to be the same, nor is it likely to be a linear projection of past trends.

Table 10.1 California Water Challenges

Factor	Effects on water
Population growth	Increased demand
Decline of agricultural uses and increase of urban uses	Increased urban demand and water transfers
Availability of imported water from Colorado River	Increased uncertainty, likely decreasing supply
Availability of imported water from State Water Project	Increased uncertainty
Availability of local resources	Need to develop recycling, desalination, other regional supply sources
Fiscal condition of the public sector	Declining capacity to raise capital for new projects
Infrastructure maintenance	Increased costs
Energy costs	Increasing costs and increased costs of imported water
Regional climate	Increased uncertainty

Figure 10.1 Water demand in California (2000 – 2050)



Sources: Groves, 2005; Tanaka et al., 2006, Medellin Azuara et al. 2008

Water Resources and Climate Change

Changes in the climate system affect water availability through numerous mechanisms, because the hydrologic cycle of precipitation, freezing, melting, evaporation and condensation is closely interrelated with the climate system, constituted by atmosphere, oceans, rivers and lakes, surfaces covered in ice and snow, land surface and biosphere. Precipitation, whose frequency, intensity and quantity is influenced by the temperature of the atmosphere and available moisture, determine flows in rivers, lakes and reservoirs, as well as ground water basins replenishment. Snow precipitation and extension of ice and snow covered areas not only are linked to the earth's energy budget because wider ice or snow covered areas increase the amount of energy the earth reflects back to the atmosphere; but also constitute about 75% of the freshwater available on the planet and are correlated with current and future sea level. Evotranspiration, the combination of evaporation and transpiration, determines the amount of moisture that the biosphere returns to the atmosphere and the quantity of water the biosphere processes to sustain itself. Water vapor, other than being the basis for rain, is also one of the greenhouse gasses that contribute to climate change.

The analysis of the relations between climate cycle and the hydrologic cycle is full of uncertainties and of unresolved questions (Bates *et al.,* 2008). A fundamental hurdle is the scale at which climate systems and hydrologic cycles are analyzed. Climate models developed to analyze climate change are global in scale, while hydrological models have been mainly developed at the local and regional scale. Some robust correlations between temperature and precipitation in many regions have been empirically tested and this provides evidence that processes controlling the hydrological cycle and temperature are closely coupled. The widespread 20th-century glaciers and ice caps shrinkage has been measured and appears to be correlated with global warming, but it could also be caused by changes in atmospheric moisture at the tropics (Bates *et al.,* 2008). Evopotranspiration is still not measured in a global context and its relations with the other components of climate and of the hydrologic cycle is not well understood.

The complexity of these relations is additionally enhanced by the fact that there is significant natural variability – on interannual to decadal time-scales – in all components of the climate cycle, that often mask long-term trends, such as the El Nino Southern Oscillation (ENSO) or the Pacific Decadal Oscillation (PDO). "There is still substantial uncertainty in trends of hydrological variables because of large regional differences, and because of limitations in the spatial and temporal coverage of monitoring networks" (Bates *et al.,* 2008; p. 15).

To address such uncertainties, the Intergovernmental Panel on Climate Change (IPCC) has summarized the most recent studies analyzing the effects of climate change on water resources world-wide (Bates *et al.,* 2008). The study argues that the consequences of rising temperatures on water resources will be different at different latitudes and in different climatic zones, but the impacts will affect fresh water supply in all localities. A wide majority of climate models project with more than 90% confidence that precipitation will increase at higher latitudes and in parts of the tropics, and they predict with more than 66% confidence that precipitation will decrease in subtropical and lower mid latitude areas. As a consequence of the change in precipitation, by the middle of the 21st century, annual average river runoff and freshwater availability are projected to increase at higher latitudes and decrease at subtropical and mid latitudes. Although projections become less consistent between models as spatial scales decrease, the IPCC (Bates *et al.*, 2008) is highly confident that the Western United States is going to suffer a decrease in water resources. Intensity of precipitation is also going to be affected, with more frequent heavy rains at every latitude and increased risk of flooding. In addition, continental interiors in sub-tropical, low and middle latitudes will have a tendency to be drier (Bates *et al.*, 2008). A further threat to water supply is posed by the projected decline of snow cover, which will reduce water availability during warm and dry periods.

The decline in water supply will have numerous effects on human systems. Food availability, stability and access could be disrupted, especially in central Africa. Water infrastructure such as hydro electrical plans, irrigation systems, flood defenses and other water management practices will be challenged.

Climate Change and Water Resources in California

Predicting climate change effects on the water cycle at local and regional scale is made difficult by the scale of climate modeling. The methodology to evaluate the hydrologic implications of climate change has been addressed by Gleick (1989), and Vicuna and Dracup (2007). The first step is to estimate future GHG emissions, the second is to gauge the effects of increasing concentrations of GHG on climate variables such as temperature, precipitation and snow cover, the third step is to feed hydroclimatic data into hydrologic models that produce estimates of local changes in runoff. Changes in climate variables caused by increasing GHG emissions have been studied through General Circulation Models (GCM) “detailed, time-dependent, three-dimensional numerical simulations that include atmospheric motions, heat exchanges, and important land-ocean-ice interactions” (Gleick, 1989, p. 331). The spatial resolution of their results, however, is about 200 sq. km.: too coarse a resolution to fit into hydrologic models and to model local features that influence precipitation.

Vicuna et al. (2007) describe different methods that have been used to downscale GCMs and report that most recent studies have used the outputs of different GCMs to build a range of possible hydrologic futures and integrate uncertainty in their projections. They also summarize the evolution of the studies that have estimated the impact of climate change on water resources in California and classify them into three groups: those looking for evidence of climate change in California hydrology (mainly concerned with snowmelt, “spring pulse” and snowpack volume); those that predict climate change future impacts on natural stream-flow (they mostly determine or postulate changes in temperature and precipitation and predict changes in runoff) and those that use predicted changes in runoff to predict their economic, ecologic and institutional impacts through existing modeling techniques (CALVIN, PROSIM).

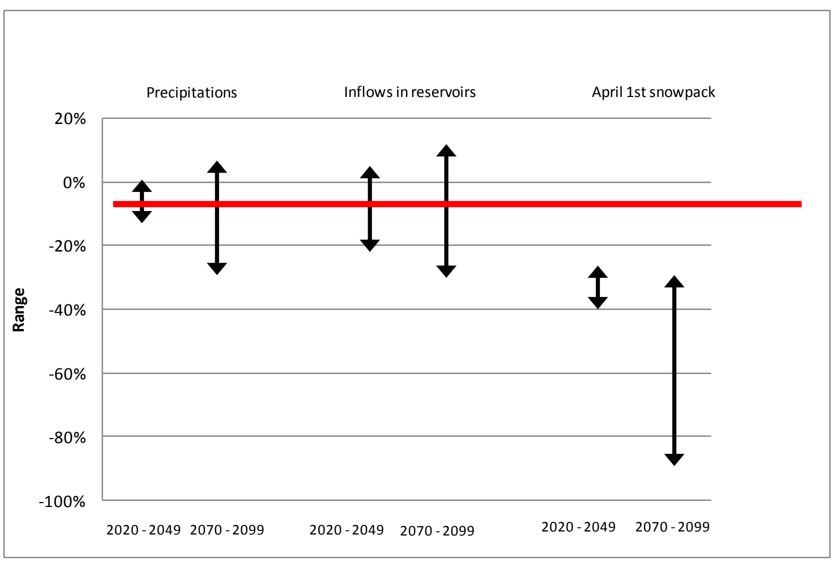
These studies highlight the following conclusions:

- In the last few decades there has been a shift to an earlier spring pulse in the Sierra Nevada Mountains;
- Timing in streamflow runoff will change, but it is not clear whether the total volume of runoff will change, mainly due to the uncertainty about future precipitation projections.
- The forecasted hydrologic impacts of climate change will affect the performance of water infrastructure in California.

Climate Change Projections and Hydrologic Variables in California

In one of the most influential climate change predictions for California, Hayoe et al. (2004) use two different GHG emission projections and 2 different GCMs. They downscale their output with a probabilistic method and estimate ranges of outcomes for a fossil fuels intensive future, with climate very sensitive to GHG emissions and a low fossil fuel intensity future and a less GHG sensitive climate. According to the study, the effects of climate change will be more relevant in North East California than in the South West. They estimate that the possible future of average precipitation in California is included in a range between a slight increase, in case of a low carbon intensive future, if the climate system is not too sensitive to GHG emissions, and a sharp decrease, with a serious drop in the last part of the century that could reach -26%. The change in annual reservoir inflow would follow the same pattern, with a wider range of variability. April 1 snowpack, on the other hand, would decrease under any emission scenario and could possibly be reduced by 89% in case of high GHG emissions and a climate highly sensitive to GHG emissions (Figure 10.2).

Figure 10.2 Changes in California precipitations and inflows in reservoirs caused by climate change



Source: Hayoe et al. 2004

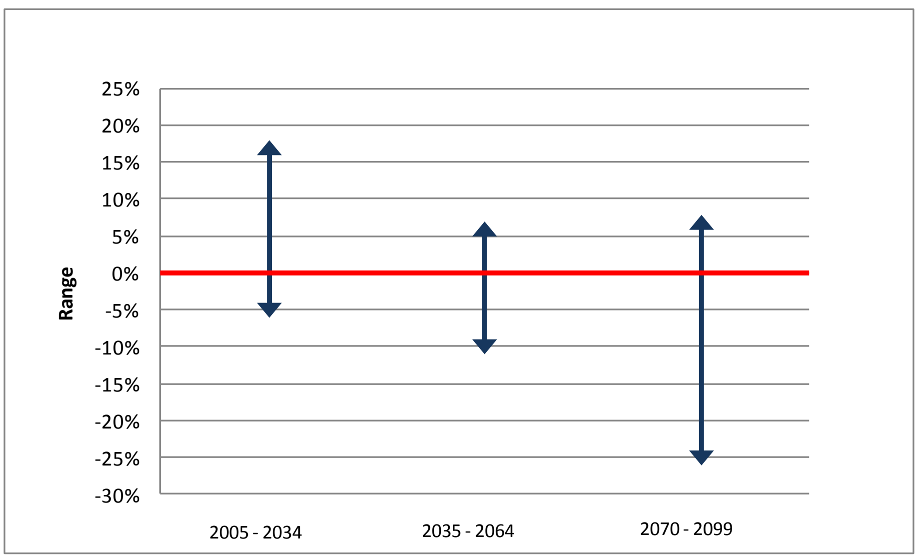
The authors also point out that the nexus of snow-pack, water runoff and water supply is critical to estimate the effects of climate change on water resources in California. They estimate that snow precipitation will decrease in number and volume, that snowpack will be reduced and that snowmelt runoff will shift earlier in the spring. As a consequence, summer and spring stream-flows will be scarcer. At the same time, rain precipitation will increase, making the risk of flooding more frequent.

Using a similar methodology, but using less extreme GHG emissions projections, Cayan et al. (2008) simulate the effects of medium high and low GHG emissions on California's climate for the near future (2005 – 2034), mid century (2035 – 2064) and end of the century (2070 – 2099).

They conclude that there is not a clear trend for the effects of climate change on precipitation in California. The different initial assumptions generate a wide range of possible futures that are not consistent (Figure 10.3).

The effects of climate change on snow-pack, on the other hand, are more consistent with Hayoe et al.'s (2004) findings. In the San Joaquin – Trinity basin the decline of snow cover by 2099 could range between -32% to -79%, with no snow left under 3,000 ft (Cayan et al. 2008).

Figure 10.3 Changes in precipitation in Southern California due to climate change



Source: Cayan et al. 2008

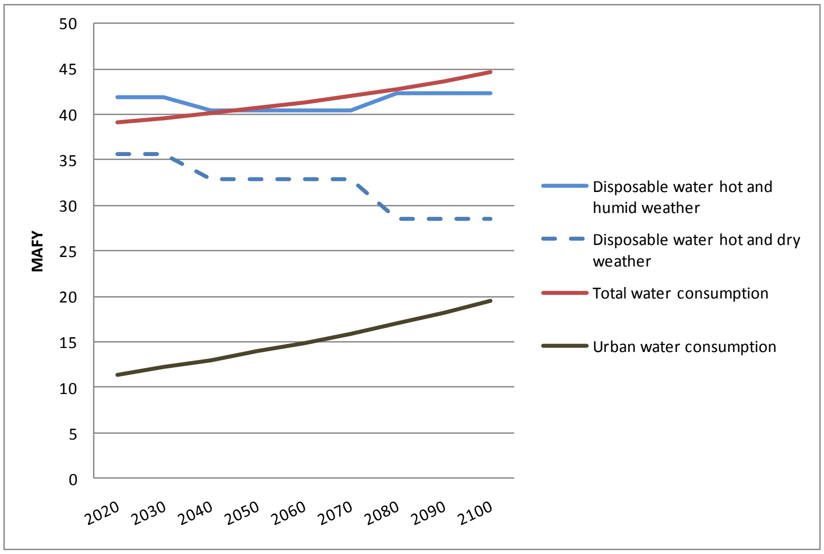
Climate Change and Water Resources in California

A number of studies have applied the hydrologic module of GCMs to the California water management system using the California Value Integrated Network (CALVIN), an integrated economic-engineering optimization model that represents California's inter-tied water system, and have tested whether the infrastructure and management of California waters can economically adapt to respond to climate change, taking into account additional pressures on the water system such as population growth and changes in land use. Focusing on 5 distinct geographic areas, recent studies develop specific hydrological projections for 2020 in an extreme drought scenario based on paleo-drought water data (Harou *et al.*, 2010), for 2050 based on a very dry and warm climate projection (Medellin-Azuara *et al.*, 2008) and for 2100 based on two climate scenarios: hot and humid and warm and dry (Tanaka *et al.*, 2006). Hydrologic projections include inflows from mountain streams, groundwater and local streams, as well as reservoirs evaporation rates and are fed to the optimization model that includes existing reservoirs, groundwater basins, conveyance infrastructure, pumping plants, power plants, rivers, population increase and changes from agricultural to urban land uses.

Harou et al. (2010) estimate the costs of prolonged droughts on the California water system as of 2020. The study starts from the premise that prolonged uninterrupted droughts during which some lakes' capacity was reduced by 40% ~ 60% have occurred frequently in the past thousand years in California and that climate change can occur abruptly, unlike the conditions postulated by most climate models. The authors use a synthetic 72 years drought to simulate extreme drought conditions in which current mean flows in rivers and reservoirs are reduced by 40%~60%. They conclude that a prolonged drought would reduce operating costs, because lower quantities of water will be available for pumping across the state, and would make new reservoirs redundant (with less water even the current reservoirs would not reach capacity). Larger water scarcity, they claim, becomes an opportunity for the development of water markets that will become prevalent in case of prolonged droughts. Willingness to pay for additional water is likely to greatly increase, so much so that priority water rights holders with low value water uses will find it profitable to sell said rights to high water value users. According to the study, water markets and water reuse will be so profitable that additional desalination will lose its attractiveness. Due to the increased willingness to pay and the increased role of water markets, the enlargement of conveyance facilities will also become attractive.

Medellin-Azuara et al. (2008) claim that by 2050 water scarcity, in a dry warming scenario, will be mainly an issue for California's agriculture, specifically in the Central Valley.They argue that in Southern California climate change will not be a big problem as long as the Colorado River Aqueduct continues to operate at maximum capacity and conjunctive management of groundwater basins is implemented.

Figure 10.4 Water demand and water availability in California 2020 – 2100



Source: Tanaka et al. 2006

Tanaka et al. (2006) assume that by 2100 water demand will grow by 14%, and that urban usage's growth will partially be compensated by a reduction of agricultural uses. They estimate that in the worst case scenario, by 2100 water availability could decrease by 25% (Figure 10.4), but they conclude that California's water management system will adapt to extreme water scarcity and increased population with higher operating and scarcity costs. Specifically for Southern California, they argue that water scarcity will be addressed only with more imported water transfers from agricultural to urban uses, increased conjunctive management of groundwater basins and significant use or wastewater reuse.

Findings

Under Climate Change the Future Amount of Water for Human Consumption Will Change. The future amount of water available for human consumption is not likely to be the same, nor is it likely to be a linear projection of past trends. According to most projections, there is wide uncertainty about how water resources will be affected by climate change, but there is wide agreement that every part of the hydrological cycle will be altered.

Uncertainty About Climate Change Impacts on Precipitation in California. One of the possible futures of average precipitation in California is included in a range between a slight increase, in case of a low carbon intensive future, if the climate system is not too sensitive to GHG emissions, and a sharp decrease, with a serious drop in the last part of the century that could reach -26% by 2100.

Projections about the future of California snowpack are quite consistent. Most researchers agree that, snowpack available on April 1st will decrease under any emission scenario and by 2100 could possibly be reduced by 89%. There is also a high degree of confidence that snowmelt runoff will shift earlier in the spring with less water in rivers and streams in spring and summer.

Water Management Will be Key to Climate Change Adaptation. Many researchers agree that water management will be the key to adaptation to climate change. A relative water scarcity is likely to encourage more water transfers, more extensive conjunctive management and a more effective exchange between agricultural and urban uses.

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