Progress on Incorporating Climate Change into Management of California's Water Resources

July 2006
Technical Memorandum Report
California Department of Water Resources

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Progress on Incorporating Climate Change into Planning and Management of California's Water Resources

Technical Memorandum Report

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Department of Water Resources

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elevations. Such changes are a function of channel geometry and the distance of open water with respect to wind direction, referred to as "fetch."

Subsidence also must be considered as a risk to Delta levees. The surfaces of many of the Delta's islands and tracts are dominated by soils rich in peat. Peat is a complex organic material that is principally composed of degraded plant matter. Subsidence in the Delta primarily occurs when peat soils are exposed to oxygen and undergo microbial decomposition due to agricultural practices. Subsidence also occurs when peat soils are lost by wind erosion and occasional peat fires. The peat soils of the Sacramento-San Joaquin Delta have subsided at rates of up to about 2 inches per year in the past. Subsidence rates have been the highest in the central Delta islands (Mount, 2004).

Subsidence increases the threat of flooding in the Delta by increasing the differential forces that levees experience. Subsidence also increases the volume of water that can inundate an island or tract when a levee fails. Together, the continued subsidence of Delta islands and rising sea level pose a double-sided threat for Delta levees and flooding. Other factors such as possible increases in peak river flows as the result of climate change further increase the threat to Delta levees.

2.7 Future Water Demand

California's water supply future will be determined by two principal factors, the condition of the State's water resources and water demand. Climate change will likely have a significant effect on California's future water resources, as discussed elsewhere in this report. Climate change will likely also have an effect on future water demand. However, many other factors such as population, land development and economic conditions that are not directly related to climate change will also affect future demand. Table 2-7 provides a summary of some of the potential effects of climate change on future water demand. Table 2-8 lists selected factors that could affect future water demand that will not be directly affected by climate change.

Today there is much uncertainty about future water demand, especially those aspects of future demand that will be directly affected by climate change and warming. While climate change is expected to continue through at least the end of this century, the magnitude and, in some cases, the nature of future changes are uncertain. This uncertainty serves to complicate the analysis of future water demand, especially where the relationship between climate change and its potential effect on water demand is not well understood.

Of the water demand factors that could be directly affected by climate change, potential changes in evapotranspiration, agronomic practices, and environmental water demand might be the most significant for California. Of the changes in demand not directly affected by climate change, changes in demand related to population growth and technological innovation could be the most significant. The following discussion is mostly limited to these aspects of future water demand. Chapter 7 provides additional discussion on evapotranspiration and possible changes in evapotranspiration due to climate change.

Table 2-7 Summary of the Potential Effects of Climate Change on Future Water Demand

Type of Demand	Potential Effect
Crop Irrigation	Increasing temperatures will increase evapotranspiration rates and related water demand where all other factors remain unchanged. Increasing concentrations of atmospheric carbon dioxide may act to reduce increases in plant transpiration (a component of evapotranspiration) in response to increased temperatures. Other factors related to climate change, such as possible changes in humidity, cloudiness and wind could also affect evapotranspiration rates. Evaporation rates from soil and plant surfaces may rise due to temperature increase, depending on changes in other factors that affect evaporation rates. Increased evaporation rates could increase salt accumulation on plant surfaces, especially where overhead irrigation is used. Salt accumulation in surficial soils could also increase. Additional irrigation water demand may result because of possible increased salt control requirements. Some changes in crop type, planting cycles, time of planting, and crop productivity will likely occur as the result of increased temperatures. Statewide and regional irrigation water demand may increase or decrease as the result of these changes. Use of water for frost protection will likely be reduced with increasing temperatures and projected reductions in the annual number of days when frost occurs. Frost protection is typically an important consideration for orchards and vineyards.
Landscape Irrigation	Increased temperatures, as well other atmospheric/climatic factors related to climate change, will affect landscape irrigation in manner similar to that described for crop irrigation, above.
Domestic Water Uses (excluding landscape irrigation)	Domestic water use typically increases with increasing temperature. Increased water demand can occur due to the use of evaporative cooling, increased laundering of clothing, increased bathing, increased drinking water requirements for humans and pets and recreational uses of water.

Table 2-7 Summary of the Potential Effects of Climate Change on Future Water Demand (continued)

Type of Demand	Potential Effect
Commercial and Industrial Water Use (including agro-industrial facilities such as dairies, poultry farms, packing plants, etc.)	Commercial and industrial water use will likely increase as the result of warming due to such factors as increased evaporative cooling demand. Increased consumption of water by concentrated animal feeding facilities, such as dairies and poultry farms, would also likely occur.
Evaporation Losses from Natural Water Bodies and Open Water Storage and Conveyance Facilities	Evaporation losses from water bodies and open conveyances will probably increase as the result of rising temperatures especially in arid portions of the State with low humidity and limited cloud cover.
Environmental Water Requirements	Delta outflow requirements will likely increase to maintain Delta salinity conditions in response to sea level rise; if the Delta's existing configuration, operation of its water supply facilities, and its ecosystem conditions are to remain as they are now. Higher temperatures will likely result in increased environmental water demand for controlling water temperatures for sensitive aquatic species, including anadromous fish. Increased use of reservoir storage and thermal control releases from reservoirs will be required for controlling aquatic habitat temperatures.

Table 2-8 Selected Factors Affecting Future Water Demand in California that are Not Directly Related to Climate Change

Factor	Potential Effect
Population Change	Future increases in population will affect water demand, depending on the location and types of development needed to support an increased population. The conversion of agricultural lands into housing and related community development may not result in a significant increase in water use for a given area, depending on the agricultural use(s) that existed prior to land conversion, and on the type of housing and other facilities constructed. Redevelopment and densification of existing urban land may result in increased water demand in some areas. Development of raw, uncultivated land will directly increase water demand. In general, increases in California's population will tend to increase future water demand.
Changes in Agriculture	Changes in the type and amount of crops grown due to changes in agricultural markets and government crop subsidy programs may help increase or decrease agricultural water demand.
Changes in Landscaping Practices	Changes in consumer preferences and changes in land use ordinances relating to landscaping may affect future landscape water demand.
Changes in Environmental Water Use Requirements	The findings of continuing scientific research related to the condition and preservation of aquatic ecosystems in the State, including the Delta, may affect environmental water demand.
Water Law and Policy	Changes in water law and policy could affect water demand.
Technological Innovation	Lowered consumption rates could result from improvements in water use efficiency for irrigation, domestic, commercial, and industrial uses. Increased reuse of wastewater could help reduce demand on existing and future sources of water. Advances in desalinization technology may reduce demands on the State's freshwater resources, especially in areas along the south coast.

2.7.1 Evapotranspiration

The collective term *evapotranspiration* refers to the vaporization of water from soil and plant surfaces (i.e., evaporation) and vaporization that occurs in plant leaves with water diffusing through pores (stomata) to ambient air (i.e., transpiration). Transpiration is controlled by water availability from the soil, plant morphological and physiological characteristics, and atmospheric conditions which determine how much energy is available to vaporize water inside leaves. Climate and plant type are important determinants of evapotranspiration rates. Even small increases in evapotranspiration rates from crops and landscaping as the possible result of climate change could affect California's overall water demand. This is because of the relatively large amount of the State that is dedicated to irrigated agriculture and the significant amount of landscaping in urban areas.

Increased temperature and atmospheric carbon dioxide concentrations are the two most consistently projected aspects of climate change that will impact evapotranspiration rates for crops and landscaping in California. Hidalgo and others (2005) concluded that a temperature increase of 3 degrees Celsius will result in a 5 percent increase in plant transpiration, unless there is a compensating decrease in solar radiation or other component of the plant energy budget. Increasing carbon dioxide concentrations in the atmosphere may tend to reduce transpiration losses from plants. Other important factors affecting evapotranspiration include wind, dew point (humidity), cloudiness and minimum temperature.

A number of studies related to physiological, biochemical and phenological plant responses to increased atmospheric carbon dioxide concentrations have been published including those studies using data from the 18 free-air carbon dioxide enrichment research sites around the world (Long, 2004). Stomatal responses at elevated atmospheric carbon dioxide concentrations seem to decrease water vapor diffusion; however, more information is needed to better understand the effects of increasing concentrations of atmospheric carbon dioxide on transpiration.

Increased atmospheric carbon dioxide concentrations may also serve to increase vegetal production. Possible increases in production could, in turn, serve to increase total transpiration from individual plants, as well as increase the per-plant water demand for tissue production and direct evaporation from vegetal surfaces. Long and others (2004) found that carbon dioxide concentrations expected by mid-century would increase dry matter production about 20 percent and seed yield by 24 percent for some plant types, including most crops and trees.

Urbanization can affect local evapotranspiration rates through regional greenhouse gas emissions, increasing amounts of plant physiological stressors such as atmospheric ozone, and through higher temperatures associated with urban island heat effects. Slone and others (2005) reported that temperatures over urban centers can be elevated while temperatures over irrigated land tend to be lower than temperatures over undeveloped areas. A significant increase in urbanization in California is expected by the end of this century.

2.7.2 Agronomic Practices

As noted in Table 2-7, climate change and increasing temperatures can affect total crop water demand by inducing changes in crop type, planting cycles and time of planting. Few studies have assessed the possible impacts of climate change on crop patterns in California (Hayhoe, 2004).

Plant physiological responses to increasing temperature will be mixed, therefore there are likely to be varying agronomic responses to climate change. For example, fewer frost days would allow citrus production to extend to higher latitudes and elevations, including in the Central Valley. However, fewer frost days would be detrimental for tree crops having a chill requirement.

There has been a long-term shift toward planting permanent crops in many parts of California, such as trees and vines. Climate change may increase the variability in precipitation and increase the frequency of droughts. Since agricultural water supplies tend to be curtailed before urban supplies during droughts, the possible consequences of increased droughts for agriculture could become more severe because of increased planting of permanent crops. Droughts typically do not cause lasting damage where crops are planted annually.

2.7.3 Changes in Environmental Water Demand

Climate change could have a significant effect on environmental water demand in California. Two aspects of environmental water demand that will likely be impacted the most are salinity control requirements for the Sacramento-San Joaquin River Delta and temperature control demand for various rivers and the Delta.

2.7.3.1 Delta Salinity Control

The Delta is a key component of California's water supply infrastructure. A major portion of the State's agricultural and urban water supply passes through the Delta to State Water Project and Central Valley Project water diversion facilities.

Salinity levels in the Delta depend on outflow from the Delta to the San Francisco Bay and Pacific Ocean. Saline water from the San Francisco Bay is pushed out of the Delta during periods of high Delta outflow. Saline water can enter the Delta and increase salinity a significant distance inland during low outflow.

Delta outflow primarily depends on the amount of freshwater entering the Delta and the diversion of water from the Delta for the Central Valley Project, the State Water Project, and in-Delta uses which collectively reduce outflow. Most of the inflow to the Delta comes from the Sacramento, Cosumnes, Mokelumne, and San Joaquin rivers. Flows from these rivers are typically highest during the winter and spring in response to annual precipitation and snowmelt. The lowest flows typically occur in the late summer and fall.

The greatest challenge for maintaining salinity levels in the Delta typically comes in the late summer and fall when natural Delta inflow is usually the lowest. Reservoir releases during this time help maintain river flows into the Delta in the absence of enough natural runoff. The rate of pumping from the Delta can be reduced during this period to help maintain Delta outflow and prevent salinity intrusion. Pumping operations have been severely cut back during dry years; especially when reservoir storage levels are very low due to drought.

As discussed in Section 2.5, climate change is expected to cause more precipitation in the form of rain rather than snow, reductions in water storage in annual snowpack, earlier snowmelt and sea level rise. Each of these factors could present significant reservoir management challenges, particularly for reservoirs in the Sierra foothills. These reservoirs will likely experience changes in the rate and timing of inflow. Changes in reservoir operations and reduced annual storage in snowpack could result in less water being available in the summer and fall to meet Delta outflow and salinity control requirements.

2.7.3.2 Water Temperature Control

Increased air temperatures as the result of climate change will likely increase water temperatures in the State's lakes and waterways. Increased water temperatures pose a threat to aquatic species that are sensitive to temperature, including anadromous fish. Increased water temperatures will also cause decreased dissolved oxygen concentrations in water and other water quality changes, and will likely increase production of algae and some aquatic weeds.

Intermittent temperature problems now exist for some aquatic species in some Central Valley rivers and streams, and in portions of the Delta. Intermittent temperature problems also occur in other areas of the State; including in the Klamath, Eel, and Russian river basins. High water-temperature problems typically occur during the summer and early fall.

Water resource managers often release cold water stored in reservoirs to control downstream water temperatures for aquatic life. Most of the water held in the State's reservoirs is accumulated in the winter and spring when temperatures are lower than at other times of the year. Reservoirs that are downstream of significant snowpack receive cold water from snowmelt through the spring and sometimes into the summer.

Climate change and rising temperatures will increase demand for temperature control releases from many reservoirs. However, coldwater storage in reservoirs needed to supply releases may decrease as the result of climate change due to:

- diminished snowpack and less inflow of late-season cold snowmelt, especially for lower elevation reservoirs in the Sierra Nevada
- increased heating of reservoir inflow
- increase heating of reservoir content and releases
- possible loss of reservoir storage for thermal control releases due to changes in reservoir operations in response to changes in runoff timing

Increased temperature control requirements together with a possible decreased capacity to provide temperature control releases from reservoirs as the result of climate change, could pose a double-sided threat for some aquatic species.

2.7.4 Population

California has experienced rapid population growth since the mid 1800s. This growth is due in part to California's strong economy, natural beauty and relatively mild climate.

California's population is approaching 37 million. The California Department of Finance projects the State's population to be about 44 million by 2020 and about 55 million by 2050 (DOF, 2004). California's population could be as high as 90 million by the end of the century (Landis, 2003). Figure 2-33 depicts growth in the State's population from 1850 to 2005, and projected growth to 2050.

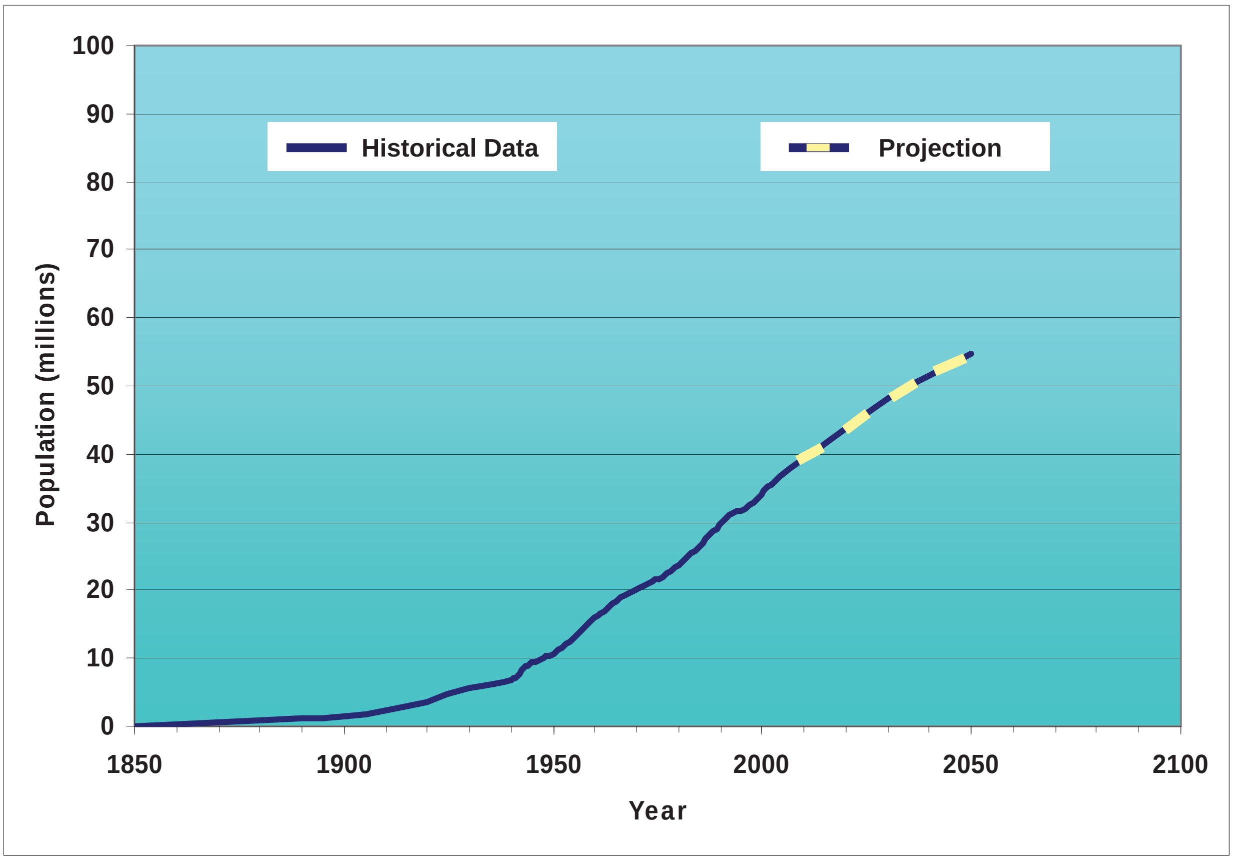

Figure 2-33 Historical and Projected Future Population Growth in California

Data source: DOF (2005)

Future increases in population will affect water demand, depending on the location and types of land development that occur to support an increased population. Much of California's future development is projected to occur on valley floor areas, including in the Central Valley along major transportation systems (Landis, 2003). While climate change is generally not expected to have a major effect on future population growth in California, it could have some effect on the where development occurs.

The conversion of agricultural lands into housing, commercial and industrial uses may not result in an increase in water use for a given area, depending on the agricultural use(s) that existed before conversion and on the specific type of development. Redevelopment and densification of existing urban land may result in increased water demand in some areas. Urbanization of undeveloped land will serve to increase water demand directly. While there is much uncertainty about California's future population growth and development, an increase in the State's population is generally expected to increase the State's total water demand, absent additional measures to conserve water.

2.7.5 Technological Innovation

Technological innovation could play a significant role in determining California's future water demand, as well as future supply. Innovation in water conservation practices could serve to reduce water demand by allowing water to be used more efficiently. Innovation in water resource management could allow California's water resource systems to be managed more efficiently and allow more water supply yield with the same or less environmental impact. Innovation in water resource management and water use would occur with or without climate change. However, given the potential impacts of climate change, there will be an increased impetus for innovation.

A key area for future technological innovation is agricultural water use efficiency. Tanaka and others (2005) have determined that by the year 2100, agricultural water use will fall by 24 percent, while loss of income from agriculture will decrease only 6 percent. This discrepancy between water use and income comes from a predicted shift to higher-value crops and more efficient use of water. A theoretical body of work suggests that horticultural breeding improvements alone can attain a maximum increase in water use efficiency of about 15 percent (Cowan, 1977).

An area of innovation that could affect future water supply conditions, at least in some parts of the State, is sea water desalinization. The unit cost of desalinization has fallen in recent years, however, desalinization remains a relatively expensive and energy-intensive means of obtaining water compared to other water sources. More improvements in desalinization technologies could reduce costs and energy requirements. Desalinization could become a more competitive source of water, especially in coastal areas of Southern California where water is often imported from long distances and at high cost partly because of energy requirements.

2.8 Colorado River Basin

This report is primarily focused on the potential effects of climate change on the Central Valley and associated water resource systems. This is because the Central Valley and its water resource systems supply most of California's water, and because much of the effort to assess the impacts of climate change on the State's water resources has been directed toward the Central Valley. Climate change will affect water resource systems that obtain water from areas outside of the Central Valley. While the timing and scope of this report preclude substantive discussion of most of these systems, it is important to mention the single largest source of water supply for California outside of the Central Valley, the Colorado River.