APPENDIX J

Climate Change Analysis

1. INTRODUCTION TO CLIMATE CHANGE SURVEY

For purposes of assessing the sufficiency of the City of Banning's (City) water supply to satisfy future demands, under all hydrologic conditions, and to support its planning efforts, this report presents a survey of recent climate change reports published by international organizations, state agencies and nongovernmental organizations to examine the potential impact that climate change may have on western water supplies, and more specifically California's supplies. Each of the reports surveyed and described in this report assumes that increased concentration of greenhouse gases in the atmosphere is linked to changes in the Earth's temperature.

2. SURVEY OF CLIMATE CHANGE REPORTS

2.1 Katharine Hayhoe, et al., *Emissions Pathways, Climate Change, and Impacts on California,* Proceedings of the National Academy of Science, Volume 101, No. 34 (August 2004)

Range and Assumptions: This report examines the implications of the highest and lowest Intergovernmental Panel on Climate Change (IPCC) emissions pathways for climate change and associated impacts on California. The report recognizes that because California has many climate zones it is difficult to accurately analyze impacts of regional-scale climate change under different emissions pathways.

Potential Impacts of Climate Change on California: (a) Decreases in winter precipitation from 15 to 30 percent with reductions concentrated in the Central Valley and along the Pacific Coast; (b) Decreasing Sierra Nevada snowpack, reduced spring and summer streamflows which will likely affect surface water supplies and shift reliance to groundwater resources; (c) Earlier runoff; and (d) Report Summary: "By the end of the century under the B1 [lower emissions] scenario, heatwaves and extreme heat in Los Angeles quadruple in frequency…; alpine/subalpine forests are reduced by 50-75%; and Sierra snowpack is reduced 30-70%. Under A1fi [higher emissions] scenario heatwaves in Los Angeles are six to eight times more frequent…; alpine/subalpine forests are reduced by 75-90%; and snowpack declines 73-90%, with cascading impacts on runoff and streamflow that, combined with projected modest declines in winter precipitation, could fundamentally disrupt California's water rights system." (p. 12422.)

2.2 Pacific Institute for Studies in Development, "Climate Change and California Water Resources: A Survey and Summary of the Literature," prepared for the California Energy Commission, Public Interest Energy Research Program (July 2003), republished in *California Water Plan Update* (2005)

Range and Assumptions: (a) Climate change is a reality, as evidenced by consensus in the scientific community. (p. 5.)

Potential Impacts of Climate Change on Western Water Resources in General: (a) Impact on climate change in California's hydrology is uncertain; (b) There is a high confidence that higher temperatures will lead to dramatic changes in snowfall, including increasing the ratio of rain to snow, delaying the beginning of the snow season, increasing the rate of spring snowmelt, and shortening the overall snow season, which will lead to earlier and more rapid runoff; (c) El Niño events may increase, leading to increased flooding; (d) Changes in large-area runoff will occur, but it is unclear how this will affect specific regions; (e) Decreased rainfall and increased temperature could lead to decreases in soil moisture; (f) Temperature increase could lead to adverse changes in water quality; (g) Increased runoff will provide additional recharge to groundwater basins, but runoff may occur when some basins are already full; (h) Sea level rise will affect coastal ecosystems and groundwater aquifers; and (i) Sea level rise could affect salinity levels in the Bay-Delta. (pp. 6-29.)

Planning Recommendations: (a) Water decision makers should improve understanding of the impacts of climate change on the state's water resources; (b) The height of levees should be raised to accommodate sea level rise (cost of $1.28 billion); (c) Operation of existing facilities should be studied to determine if they can handle impacts of future climate change; (d) New construction should be designed to operate under a wide range of conditions and should consider climate change impacts; (e) Water planners should concentrate on increasing efficiency and focusing on conservation; (f) Water should be priced to reflect the true cost of water resources; (g) Hydrologic and environmental monitoring should continue and gaps in data should be closed; (h) Flexibility in decision making should be encouraged, along with flexible institutions to allocate water such as water markets. (pp. 2-3, 34-36.)

2.3 Awwa Research Foundation (AwwaRF) and University Corporation for Atmospheric Research (UCAR), *Climate Change and Water Resources: A Primer for Municipal Water Providers* (2005)

Range and Assumptions: (a) Climate change is occurring and will continue to occur; (b) This report relies on the IPCC Third Assessment Report's estimates that the average global temperature will rise by 1.4 to 5.8 degrees Celsius by the year 2100. (pp. 31-35)

Potential Impacts of Climate Change on Water Supply in General: (a) Average global precipitation will increase because a warmer atmosphere will hold more moisture (regional amounts and intensity of precipitation will vary geographically with some areas becoming wetter and some areas becoming drier); (b) Total evaporation will increase; (c) Variation in levels of runoff will result in changes in aquifer levels and base flows entering surface streams; (d) Warmer climates will result in more precipitation falling as rain, which will increase winter runoff and reduce winter snowpack; (e) Saltwater intrusion may occur in coastal aquifers; (f) Sea level rise may displace wetlands and cause saltwater to intrude into estuaries; (g) Water quality will be adversely impacted by flooding and drought cycles. (pp. 37-54)

Planning Recommendations: The Primer recommends using a bottom-up approach to incorporate climate change data into the planning process by first identifying a water utility's largest vulnerabilities and researching how climate change may impact existing vulnerabilities. Next, a water utility should design a process to lessen the threat of the vulnerability in the face of climate change. (pp. 55-56)

2.4 California Department of Water Resources [Maurice Roos], "Accounting for Climate Change," in California Water Plan Update, Bulletin 160-05 (2005)

Range and Assumptions: (a) This report relies on the IPCC Third Assessment Report's estimates that the average global temperature will rise by 1.4 degrees to 5.8 degrees by the year 2100, but notes that this range is still quite large; (b) This Report also relies on the IPCC Third Assessment Report's estimates that sea level is projected to rise around 0.5 meters (1.6 feet) by 2100, with an estimated ranged between 0.1 and 0.9 meters. (pp. 2-3)

Potential Impacts of Climate Change on Western Water Resources in General: (a) Rising temperatures will affect the amount of snowpack; (b) Sea levels will likely rise (a minimum of 0.2 meters by 2100); (c) An increase in flooding due to extreme precipitation is likely; (d) There will likely be an increase in water requirements for crop and urban vegetation; and (e) Cold water fisheries will be adversely impacted by rising river and estuary temperatures. (pp. 4-11)

Planning Recommendations: (a) Additional hydrologic monitoring and climate change modeling is necessary, especially at the local level; and (b) Monitoring of evapo-transpiration rates should continue. (pp. 12-13)

2.5 Intergovernmental Panel on Climate Change, *2007 Report on Climate Change: The Physical Science Basis & Climate Change, Adaptation and Vulnerability*, Fourth Assessment Report (AR4), Working Groups I & II Contribution to the Intergovernmental Panel on Climate Change (2007)

The Intergovernmental Panel on Climate Change (IPCC) is considered the key international body related to issues surrounding climate change. It has developed climate change projections based on greenhouse gas emission scenarios and climate change models. The IPCC was created by the United Nations Environmental Programme and the World Meteorological Organization to study scientific, technical and socio-economic information related to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. To date, the IPCC has produced four reports, in three categories: (1) The Physical Science Basis; (2) Impacts, Adaptation and Vulnerability; and (3) Mitigation of Climate Change. It published its Fourth Assessment Report in 2007.

Range and Assumptions: (a) Global warming is indisputable as is evident from historical increases in global air and water temperatures; (b) There is a very high confidence that most warming is due to human activities since 1750 which have led to increased greenhouse gases in the atmosphere; (c) The IPCC has developed six scenarios based on future rates of economic growth and global population; (d) The IPCC is projecting an increase of 0.2 degrees Celsius per decade for the next two decades; (e) The IPCC predicts that by the end of the 21st century temperatures will increase by 1.8 degrees Celsius (likely range is 1.0 – 2.9 degrees Celsius), and the high scenario is 4 degrees Celsius (likely range is 2.4 – 6.4 degrees Celsius); (f) The IPCC predicts that global mean sea level rise will be between 14 and 44 cm within this century. IPCC, 2007: Summary of Policymakers.[1]

Potential Impacts of Climate Change on Water Resources in General: (a) Snow pack is projected to decline, which will reduce water supplies in areas that receive runoff from major mountain ranges; (b) Coastal wetlands and irrigation water will likely be adversely impacted by sea level rise, which will lead to a decrease in the amount of freshwater available to humans and ecosystems; (c) Warmer temperatures in western mountains will result in less snowpack, increased winter flooding, and reduced summer flows, leading to increased competition for scarce water supplies; (d) Increased temperatures will lead to water quality issues such as algal blooms; (e) Semi-arid areas such as the Western USA are particularly susceptible to the impacts of climate change on freshwater; (f) Climate change will affect groundwater recharge rates and accordingly, groundwater levels; (g) Sea level rise may increase incidents of saltwater intrusion in aquifers; (h) Increased amounts and variability of precipitation may lead to increased risks of flooding and drought periods; (i) Increased water temperatures and additional periods of low flow may have adverse impacts on water quality; (j) Major uncertainties in quantitative projections of changes in water resources in particular basins exist.[2]

Planning Recommendations: (a) Adaptation is necessary to address impacts that are unavoidable due to past emissions of greenhouse gases; (b) Adaptation measures should be included in future land-use planning and infrastructure design; (c) Integrated management of water resources should be used to reshape the current planning process by integrating land and water resources management, conjunctively managing groundwater and surface water, identifying water quantity and quality relationships and protecting natural systems. (pp. 196-200)

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[1] *See* IPCC, *Climate Change 2007: The Physical Science Basis. Contribution of Working Group to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (2007).

[2] *See* Kundzewicz, et al., “Freshwater Resources and Their Management,” in *Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (2007).

2.6 Brad Udall, "Climatic and Hydrologic Trends in the Western U.S.: A Review of Recent Peer Reviewed Research," in *Intermountain West Climate Summary* (January 2007)

Range and Assumptions: (a) This article reviews the findings of five peer-reviewed studies that address recent trends in: temperature and precipitation trends, streamflow amounts and timing, snow water equivalent and the proportion of rain versus snowfall over the past three years.

Findings: (a) Majority of weather stations revealed a trend toward earlier spring warming period; (b); Found no precipitation trends in California or the Rocky Mountains; (c) Studies show a one- to four-week earlier snowmelt and streamflow in recent decades caused by increases in winter and spring temperatures; (d) Widespread warming in the West; and (e) Declining snowpack in California.

2.7 Michael Dettinger, Western Ground Water and Climate Change — Pivotal to Supply Sustainability or Vulnerable in its Own Right?, National Groundwater Association (June 2007)

Range and Assumptions: This report relies on conclusions by the IPCC authors in the 2007 report which conclude that while precipitation trends are complicated, there is a growing consensus that there will be modestly drier conditions in the southwestern United States.

Potential Impacts of Climate Change on Groundwater: (a) mountain recharge of groundwater basins may decline due to thinning snowpack and precipitation falling as rain rather than snow; (b) in contrast, while mountain recharge may decline, much of this recharged water may run off onto the region's fans and basins and potentially increase recharge on fans and groundwater basin floors; (c) at present, whether the overall recharge will increase, decrease or stay the same is unknown at any scale in the West. Similarly, the impacts to ground water supplies due to changed conditions of the location and timing of recharge are also insufficiently understood." (p. 4); (d) "It is possible that ground water supplies will fare well, overall, in a warming world, but they may also fare poorly." (p. 5.)

2.8 Natural Resources Defense Council, In Hot Water: Water Management Strategies to Weather the Effects of Global Warming (July 2007)

Range and Assumptions: (a) The science is clear, and climate change will affect water management; (b) This report cited the IPCC's Fourth Assessment Report that projected the rate of warming over the 21st century could be up to 11.5 degrees Fahrenheit. (p. 1.)

Potential Impacts of Climate Change on Western Water Resources in General: (a) Rising temperatures could mean earlier snowmelts and runoff; (b) Greater extremes in precipitation will challenge flood control and water storage operations; (c) Reduced snowpack and earlier snowmelt will disrupt streamflows; (d) Increased evapo-transpiration reduces total streamflows; (e) A warmer climate increases the risk of fires; and (f) Sea level rise will threaten water supply, water quality and wetlands. (pp. 1-2, 4-15.)

General Planning Recommendations: (a) Evaluate the vulnerability of water systems to global warming impacts (conduct agency assessments of climate change impacts on water supply; work with other managers to evaluate regional vulnerability); (b) Develop response strategies to reduce future impacts of global warming (consider the impact of climate change on future water management tools, put conservation first, incorporate climate and energy issues into statewide water planning, consider integrated regional water management strategies, collaborate with energy utilities, consider climate change when making commitments about future water deliveries, factor in flood management, and protect and restore aquatic ecosystems); (c) Prevent future impacts by reducing greenhouse gas emissions; and (d) Increase awareness of global warming and water impacts. (pp. vi-x.)

Planning Recommendations for Water Decision Makers: (a) Strengthen Institutional Capacity; (b) Develop flexible strategies that will allow for correction and redirection of investments; (c) Increase ability to meet future needs in the face of increased uncertainty; (d) Choose a "no regrets" policy; (e) Address multiple pressures on water resources; (f) Collaborate with regional water agencies to manage resources; (g) Incorporate climate change into project design; and (h) Communicate with the scientific community. (pp. vi-x, 21-57.)

2.9 Water Replenishment District of Southern California, *Will Climate Change Affect Groundwater in the Central and West Coast Basins?*, Technical Bulletin Volume 10 (Winter 2007)

Range and Assumptions: This report relies on 2006 and 2007 reports conducted by the California Department of Water Resources and the NSF Center for Sustainability of Semi-Arid Hydrology and Riparian Areas, at the University of Arizona. The report starts with the assumption that climate change is caused by humans, and looks to the effects on groundwater in the Central and West Coast basins.

Potential Impact on Water Resources in the Central and West Coast Basins: The report identifies reduction of annual snowpack, changes in the timing and intensity of precipitation, sea level rise and increased water temperatures as the most likely impacts. (p. 2.) From these impacts, the report expects increased salinity intrusions into coastal aquifers and loss of water storage. (p. 2.) The report also expects changes in the intensity and timing of runoff, with potential adverse changes in water quality.

Planning Recommendations: Close monitoring, planning, and responses to changes will likely be necessary. Warmer summers may cause drought, an increase in water demand, and a decrease in water supply. The state should plan accordingly. Warmer winters may result in precipitation falling as rain instead of snow, reducing the snow pack that is a natural reservoir for spring and summer snowmelt, and may increase the intensity of storm runoff that may overflow stream channels, cause flooding, and cause more runoff losses to the oceans. Sea level rises could threaten the Central and West Coast Basins with increased saltwater intrusion.

Additional scientific information and modeling are needed to reduce the climate change uncertainties so that planning can be performed to implement the necessary projects to meet future water needs. (p. 2.) The importance of maintaining and expanding the use of the Central and West Coast Basins as water supply reservoirs is crucial. (p 2.) New and improved spreading grounds and conservation pools will help capture as much storm water as possible to ensure a local supply of replenishment water. Finding ways to decrease our reliance on imported water, increasing the use of recycled water, maximizing groundwater storage, conserving water, and protecting the basins from contamination due to salt water intrusion or other pollutants will ensure a reliable supply of locally-derived groundwater. (p. 2)

2.10 California Department of Water Resources, Progress on Incorporating Climate Change into Management of California's Water Resources (March 2008)

Range and Assumptions: This study uses 2050 climate change projections for runoff and precipitation. DWR used four climate change scenarios from the IPCC's Fourth Assessment Report and then applied its existing analytical tools to quantify possible effects of climate change on California's water resources. (p. 3-1.)

Potential Impacts of Climate Change on Western Water Resources in General: (a) Climate change could lead to extremes of a different nature than current systems were designed to manage; (b) Climate change may produce changes in timing, location, quantity and variability of precipitation, which may be outside of the range for which current infrastructure was designed; (c) Possible loss of five million or more acre-feet of annual water storage in California's snowpack; (d) Increased wildfires and long-term changes in vegetation; (e) Sea-level rise; (f) Increases in water temperatures; and (g) Variations in evapotranspiration rates. (pp. 2-1 to 2-80.)

Potential Impacts of Climate Change on the State Water Project (SWP) and Central Valley Project (CVP): (a) Based on three of the four simulated climate scenarios, there were considerable shortages in CVP north-of-Delta reservoirs during droughts; (b) SWP south-of-delta Table A deliveries will range from an increase of 1 percent in a wetter scenario to a 10 percent reduction for one of the drier climate change scenarios; (c) Increased winter runoff may result in slightly higher annual Article 21 deliveries in the three drier climate change scenarios (but would not fully offset lower Table A deliveries);

(d) Changes in annual average CVP south-of-Delta deliveries ranged from an increase of 2.5 percent for a wetter scenario and up to a 10 percent decrease for drier climate change scenarios; (e) Carryover storage for both the SWP and CVP was negatively impacted in the drier climate change scenarios and positively impacted in the wetter scenario; (f) Under all four climate change scenarios, inflows into the Sacramento-San Joaquin Bay-Delta (Bay-Delta) will increase during the late winter and early spring and decrease during the summer and fall; and (g) Increased salt water intrusion into the Bay-Delta (pp. 2-1 to 2-80, 4-1 to 4-51).

Planning Recommendations: (a) System flexibility may mitigate climate change effects on the CVP and SWP; (b) The effects of rising sea level and salt water intrusion on the Bay-Delta should be studied further; and (c) State climate change research activities by the California Energy Commission should be coordinated with other studies (pp. 8-1 to 8-10).

2.11 Climate Change Science Program, Synthesis and Assessment Product 4.3 (SAP 4.3): The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States (May 2008)

The U.S. Climate Change Science Program (CCSP) report integrates the Federal research efforts of 13 agencies on climate and global change. The report has 38 authors from universities, national laboratories, nongovernmental organizations and Federal service. SAP 4.3 has undergone expert peer review by 14 scientists through a Federal Advisory Committee formed by the USDA, and includes over 1,000 references. USDA was the lead agency for this report as part of its commitment to CCS. (pp. 11-12.) The report focuses on the next 25 to 50 years, and finds that climate change is already affecting U.S. water resources, agriculture, land resources and biodiversity, and will continue to do so.

Range and Assumptions: There is robust scientific consensus that human-induced climate change is occurring. Records of temperature and precipitation in the United States show trends consistent with the current state of global-scale understanding and observations of change. The report asked: (a) What factors influencing agriculture, land resources, water resources and biodiversity in the United States are sensitive to climate and climate change? (b) How could changes in climate exacerbate or ameliorate stresses on agriculture, land resources, water resources and biodiversity? What are the indicators of these stresses? (c) What current and potential observation systems could be used to monitor these indicators? (d) Can observation systems detect changes in agriculture, land resources, water resources and biodiversity that are caused by climate change, as opposed to being driven by other causes? (pp. 11-12.)

Potential Impact on Water Resources in the West: Consistent with streamflow and precipitation observations, most of the continental United States experienced reductions in drought severity and duration over the 20th Century. However, there is some indication of increased drought severity and duration in the western and southwestern United States. (p. 141.) Water quality is sensitive to both increased water temperatures and changes in precipitation, particularly in the West. However, most water quality changes observed so far across the continental United States are likely attributable to causes other than climate change. (pp. 144-45.) Stream temperatures are likely to increase as the climate warms, and are very likely to have both direct and indirect effects on aquatic ecosystems. Changes in temperature will be most evident during low flow periods, when they are of greatest concern. (pp. 145-46.)

Planning Recommendations: The reliance on past conditions as the foundation for current and future planning and practice will no longer be tenable as climate change and variability increasingly create conditions well outside of historical parameters and erode predictability. (pp. 19, 150.) Declining per capita (and for some cases total) water consumption will help mitigate the impacts of climate change on water resources. (pp. 20, 150.) No aspect of the current hydrologic observing system was designed specifically to detect climate change or its effects on water resources. Recent efforts have the potential to make improvements, although many systems remain technologically obsolete, incompatible or have significant data collection gaps in their operations and maintenance structures. Improvements across the board are vital. (pp. 149-50.)

2.12 Intergovernmental Panel on Climate Change, *Climate Change and Water*, Technical Paper VI (June 2008)

Range and Assumptions: This Technical Paper deals only with freshwater. Sea-level rise is dealt with only insofar as it can lead to impacts on freshwater in the coastal zone. (p. 7.) Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes and parts of the tropics, and decreases in some sub-tropical and lower mid-latitude regions. Outside these areas, the sign and magnitude of projected changes varies between models, leading to substantial uncertainty in precipitation projections. Thus projections of future precipitation changes are more robust for some regions than for others. Projections become less consistent between models as spatial scales decrease. (p. 2.3.1.)

By the middle of the 21st century, annual average river runoff and water availability are projected to increase as a result of climate change at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropics. Many semi-arid and arid areas (e.g., the Mediterranean Basin, western USA, southern Africa and northeastern Brazil) are particularly exposed to the impacts of climate change and are projected to suffer a decrease of water resources due to climate change. (p. 2.3.6.)

Water supplies stored in glaciers and snow cover are projected to decline in the course of the century, thus reducing water availability during warm and dry periods (through a seasonal shift in streamflow, an increase in the ratio of winter to annual flows, and reductions in low flows) in regions supplied by melt water from major mountain ranges, where more than one-sixth of the world's population currently live. (pp. 2.1.2, 2.3.2, 2.3.6.)

Globally, the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits (*high confidence*). By the 2050s, the area of land subject to increasing water stress due to climate change is projected to be more than double that with decreasing water stress. Areas in which runoff is projected to decline face a clear reduction in the value of the services provided by water resources. Increased annual runoff in some areas is projected to lead to increased total water supply. However, in many regions, this benefit is likely to be counterbalanced by the negative effects of increased precipitation variability and seasonal runoff shifts in water supply, water quality and flood risks. (p. 3.2.5.)

Impacts to Groundwater Supplies: With climate change, availability of groundwater is likely to be influenced by three key factors: withdrawals (reflecting development, demand, and availability of other sources), evapotranspiration (increases with temperature) and recharge (determined by temperature, timing and amount of precipitation, and surface water interactions). (p. 5.6.) Simulated annual groundwater base flows and aquifer levels respond to temperature, precipitation and pumping – decreasing in scenarios that are drier or have higher pumping and increasing in scenarios that are wetter. In some cases there are base flow shifts; increasing in winter and decreasing in spring and early summer. (p. 5.6.) Increased evapotranspiration or groundwater pumping in semi-arid and arid regions of North America may lead to salinisation of shallow aquifers. (p. 5.6.) In addition, climate change is likely to increase the occurrence of saltwater intrusion into coastal aquifers as sea level rises.

Reduced water supplies coupled with increases in demand are likely to exacerbate competition for over-allocated water resources. (pp. 7.2-7.3.) Vulnerability to climate change is likely to be concentrated in specific groups and regions, including those dependent on narrow resource bases, and the poor and elderly in cities. (pp. 7.2-7.3.) Implementing important mitigation options such as afforestation, hydropower and bio-fuels may have positive and negative impacts on groundwater resources, depending on site- specific situations. The report suggests studies of site-specific joint evaluation and optimization of (the effectiveness of) mitigation measures and water-related impacts. (pp. 7.2-7.3.)

Planning Recommendations: Because of the uncertainties involved, probabilistic approaches are required to enable water managers to undertake analyses of risk under climate change. Techniques are being developed to construct probability distributions of specified outcomes. Further development of this research, and of techniques to communicate the results, as well as their application to the user community, are required. (pp. 136-37.)

Further work on detection and attribution of present-day hydrological changes is required; in particular, changes in water resources and in the occurrence of extreme events. The development of indicators of climate change impacts on freshwater, and operational systems to monitor them, are required. (pp. 136-37.)

There remains a scale mismatch between the large-scale climatic models and the catchment scale – the most important scale for water management. (p. 136.) Higher-resolution climate models, with better land-surface properties and interactions, are therefore required to obtain information of more relevance to water management. Statistical and physical downscaling can contribute.

Most of the impact studies of climate change on water stress in countries assess demand and supply on an annual basis. Analysis at the monthly or higher temporal resolution scale is desirable, since changes in seasonal patterns and the probability of extreme events may offset the positive effect of increased availability of water resources. (p. 136.)

There is a need to develop local-scale data sets and simple climate-linked computerized watershed models that would allow water managers to assess impacts and to evaluate the functioning and resilience of their systems, given the range of uncertainty surrounding future climate projections. Methane emissions have to be estimated. Also, the net effect on the carbon-budget in the affected region has to be evaluated. (p. 136.)

2.13 Richard P. Allan and Brian J. Soden, *Atmospheric Warming and the Amplification of Precipitation Extremes*, SCIENCE, Vol. 321, No. 5895, pp. 1481 – 1484 (September 12, 2008)

Climate models suggest that extreme precipitation events will become more common in an anthropogenically warmed climate. However, observational limitations have hindered a direct evaluation of model-projected changes in extreme precipitation. This study conducted at the University of Miami and the University of Reading (U.K.) made a more direct analysis of precipitation rate changes in the future.

Range and Assumptions: The authors used satellite observations and model simulations to examine the response of tropical precipitation events to naturally driven changes in surface temperature and atmospheric moisture content. (pp. 1481-82.) Both observations and models indicated an increase in heavy rainstorms in response to a warmer climate. However, the observed amplification of global rainfall extremes was found to be substantially larger in the observations than what is predicted by current models.

Potential Impact on Water Resources in General: The observations reveal a distinct link between rainfall extremes and temperature, with heavy rain events increasing during warm periods and decreasing during cold periods. As global temperatures rise, so will extreme rainfall. (pp. 1483-84.) Global warming is also increasing the incidence of heavy rainfall at a rate greater than predicted by current climate models. (pp. 1483-84.)

Planning Recommendations: The observed amplification of rainfall extremes is found to be larger than predicted by models, implying that projections of future changes in rainfall extremes due to anthropogenic global warming may be underestimated. In short, global warming will make extreme weather even more extreme than previous studies have thought. (p. 1484.)

2.14 California Department of Water Resources, Managing an Uncertain Future: Climate Change Adaptation Strategies for California's Water (October 2008)

Range and Assumptions: Climate change is already affecting California's water resources. Bold steps must be taken to reduce greenhouse gas emissions. However, even if emissions ended today, the accumulation of existing greenhouse gases will continue to impact climate for years to come. (p. 2.) Warmer temperatures, altered patterns of precipitation and runoff, and rising sea levels are increasingly compromising the ability to effectively manage water supplies, floods and other natural resources. Adapting California's water management systems in response to climate change presents one of the most significant challenges of this century.

- Historic hydrologic patterns can no longer be solely relied upon to forecast the water future;
- Precipitation and runoff patterns are changing, increasing the uncertainty for water supply and quality, flood management, and ecosystem functions;
- Significant and ongoing investments must be made in monitoring, researching, and understanding the connection between a changing climate, water resources and the environment;
- Extreme climatic events will become more frequent, necessitating improvements in flood protection, drought preparedness and emergency response;
- Water and wastewater managers and customers — businesses, institutions, farms, and individuals — can play a key role in water and energy efficiency, the reduction of greenhouse gas emissions, and the stewardship of water and other natural resources;
- Impacts and vulnerability will vary by region, as will the resources available to respond to climate change, necessitating regional solutions to adaptation rather than the proverbial one-size-fits-all approach; and
- An array of adaptive water management strategies must be implemented to better address the risk and uncertainty of changing climate patterns. (pp. 2-3.)

Potential Impact on California Water Resources: Warming temperatures, combined with changes in rainfall and runoff patterns will exacerbate the frequency and intensity of droughts. Regions that rely heavily upon surface water (rivers, streams, and lakes) could be particularly affected as runoff becomes more variable, and more demand is placed on groundwater. Combined with urbanization expanding into wildlands, climate change will further stress the state's forests, making them more vulnerable to pests, disease and changes in species composition. Along with drier soils, forests will experience more frequent and intense fires, resulting in subsequent changes in vegetation, and eventually a reduction in the water supply and storage capacity benefits of a healthy forest. (p. 5.)

Climate change will also affect water demand. Warmer temperatures will likely increase evapotranspiration rates and extend growing seasons, thereby increasing the amount of water that is needed for the irrigation of many crops, urban landscaping and environmental water needs. Reduced soil moisture and surface flows will disproportionately affect the environment and other water users that rely only on annual rainfall such as non-irrigated agriculture, livestock grazing on non-irrigated rangeland and recreation. (p. 5.)

Changes in the timing of river flows and warming atmospheric temperatures may affect water quality and water uses in many different ways. At one extreme, flood peaks may cause more erosion, resulting in turbidity and concentrated pulses of pollutants. This will challenge water treatment plant operations to produce safe drinking water. Flooding can also threaten the integrity of water works infrastructure. At the other extreme, lower summer and fall flows may result in greater concentration of contaminants. These changes in streamflow timing may require new approaches to discharge permitting and non-point source pollution. Warmer water will distress many fish species and could require additional cold water reservoir releases. Higher water temperatures can also accelerate some biological and chemical processes, increasing growth of algae and microorganisms, the depletion of dissolved oxygen, and various impacts to water treatment processes. An increase in the frequency and intensity of wildfires will also affect watersheds, vegetation, runoff and water quality. (p. 6.)

Planning Recommendations: DWR recommends that the state accomplish the following overarching objectives: (1) Provide Sustainable Funding for Statewide and Integrated Regional Water Management (p. 10); (2) Fully Develop the Potential of Integrated Regional Water Management (p. 11); (3) Aggressively Increase Water Use Efficiency (p. 13); (4) Practice and Promote Integrated Flood Management (p. 16); (5) Enhance and Sustain Ecosystems (p. 21); (6) Expand Water Storage and Conjunctive Management of Surface and Groundwater Resources (p. 23); (7) Fix Delta Water Supply, Quality and Ecosystem Conditions (p. 25); (8) Preserve, Upgrade and Increase Monitoring, Data Analysis and Management (p. 27); (9) Plan for and Adapt to Sea Level Rise (p. 28); (10) Identify and Fund Focused Climate Change Impacts and Adaptation Research and Analysis (p. 29.)

Building upon the recommendations and strategies set forth in this document, the California Resources Agency is also coordinating the development of a statewide, cross-sector Climate Adaptation Strategy (CAS). The CAS will synthesize up-to-date information on expected climate change impacts to California, provide preliminary strategies to reduce the state's vulnerability to these impacts and develop plans for short and long-term actions.

2.15 Ellen Hanak and Jay Lund, The Public Policy Institute of California, *Adapting California's Water Management to Climate Change* (November 2008)

Range and Assumptions: (a) This report relies on existing studies by Luers and Mastrandrea (2008), the IPCC, Lund and Hanak and Moreno and reports that "[m]any of California's water managers are now working with projections of a one foot [sea level] rise by mid-century and a three to four foot rise by 2100." (pp. 3-4.)

Potential Impacts of Climate Change on California: (a) Sea level rise; (b) Warmer temperatures shifting mountain runoff from spring to winter; (c) Changes in precipitation and temperature affecting average runoff volume; (d) Changes in drought persistence; (e) Higher water temperatures in streams and reservoirs that could adversely affect fish species; (f) Changes in water demands from higher temperatures and CO_2 concentrations; (g) Increased water demand; and (g) Increased flood flows and flood frequencies. (p. 3.)

Planning Recommendations: This report recognizes that California's water supply managers have already been using water transfers, conservation, recycling, groundwater storage and desalination to respond to changing demands and limit vulnerability to changing conditions. The PPIC recommends the following: (a) Improve scientific understanding and obtain better information on potential climate impacts. Commission studies to understand the implications of climate change for flood management; (b) Implement a no regrets policy for new infrastructure, especially for stormwater and wastewater that accounts for future problems of peak runoff, and encourage low impact development; (c) Improve information on flood risk; (d) Expand conjunctive use; (e) Shift drought storage from surface reservoirs to groundwater basins; (f) Develop a long-term strategy to repair the Delta ecosystem and make it less vulnerable to climate change.

2.16 GRAPHIC Series No. 2, Groundwater Resources Assessment, *Under the Pressures of Humanity and Climate Change*, A Framework Document (2008)

Purpose: The Groundwater Resources Assessment Under the Pressures of Humanity and Climate Change (GRAPHIC) Project was initiated by UNESCO-International Hydrological Programme to evaluate the effects of human activities and climate change on global groundwater resources because "little is known about how subsurface waters in the vadose zone and groundwater might respond to climate change and affect the current availability and future sustainability of groundwater resources." (p. 1.) Further, the "potential effect of climate change on the quality of groundwater resources has received relatively little attention to date compared with the potential effects on the quantity of water resources." (p. 10.)

Potential Impacts of Climate Change on Groundwater: GRAPHIC recognizes that "[a]quifer recharge can be difficult to quantify because it can be affected by many climatic and human factors, including the amount of precipitation; the density of streams that lose water to the aquifer; the ambient temperature, wind speed, and amount of solar radiation (potential evaporation); the type and amount of vegetative cover; the surface soil type and sub-surface geology; and depth to water." (p. 9.)

2.17 United States Department of the Interior and United States Geological Survey, Circular 1331, *Climate Change and Water Resources Management: A Federal Perspective* (February 2009)

Purpose and Assumptions: The purpose of this interagency report prepared by the U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), Bureau of Reclamation (USBR) and National Oceanic and Atmospheric Administration (NOAA) was to investigate strategies to "improve water management by tracking, anticipating, and responding to climate change." (p. 1.) This report recognized that climate change will impact all sectors of water resources management and that this may necessitate alterations in design and operational assumptions about resource supplies, system demands or performance requirements, and operational constraints.

Planning Recommendations: Generally, the historical record has been used to make water resources decisions but given a changing climate, the authors suggest that it may be appropriate to evaluate the system response for a range of hydroclimatic variability wider than in the historical record. Planning assumptions should be based on projections of future temperature and rainfall instead of solely on past conditions. (p. 2.) This expanded variability may allow a more vigorous evaluation of planning alternatives, particularly when there is concern that study outcomes and decisions may be sensitive to climate assumptions. This report recommends adopting flexible water resource alternatives that perform well over a wide range of future scenarios. It also recommends that adaptive management be used to make decisions over time and to allow adjustments to be made as more information is known. This approach may be useful in dealing with the additional uncertainty introduced by potential climate change. Lastly, knowledge gaps need to be filled through additional research and monitoring. Although research and monitoring will not eliminate all uncertainties, they will provide key improvements in "understanding the effects of climate change on water resources, including quantity and quality, and in evaluating associated uncertainties and risks required for more informed decisionmaking." (p. 3.)

2.18 United Nations Global Compact and Pacific Institute, Climate Change and the Global Water Crisis: What Businesses Need to Know and Do (May 2009)

Purpose and Assumptions: This paper summarized the potential impacts of climate change on energy and water and the resultant impacts on businesses. It also offered recommendations on how companies can respond to the challenges in an integrated way. It focuses on regions that will experience the most severe impacts of climate change. This report relies on the IPCC's VI Technical Paper on "Climate Change and Water." (p. 1.)

Potential Impacts of Climate Change on Water Supply: Climate change will increase water scarcity by decreasing supply. More specifically, it will: (a) Increase water shortages due to modifications in precipitation patterns and intensity; (b) Reduce precipitation in some arid regions that could trigger reduction in groundwater tables; (c) Decrease natural water storage capacity in glaciers and mountain ranges, and subsequently reduce long-term water availability for populations living in glacial- or snowmelt-fed river basins, including major regions of China, India, Pakistan and the western U.S.; (d) Increase the vulnerability of ecosystems due to temperature increases, changes in precipitation patterns, frequent severe weather events, and prolonged droughts; (e) Alter the reliability and existing capacity of water supply infrastructure due to flooding, extreme weather, and sea level rise as most existing water treatment plants and distribution systems were not built to withstand expected sea level rise and increased frequency of severe weather due to climate change; (f) Concentrate snowmelt and precipitation into shorter time frames, making both water releases more extreme and drought events more sustained. Existing infrastructure often does not have the capacity to fully capture this larger volume of water, and therefore will be inadequate to meet water demands in times of sustained drought; (g) Increase water demand for agriculture, primarily for irrigation, due to prolonged dry periods and severe drought.

Business risks of water and climate change: Climate change will exacerbate water and energy related risks. For example, water scarcity "directly affects business operations, raw material supply, intermediate supply chain, and produce use in a variety of ways. Declines or disruptions in water supply can undermine industrial and manufacturing operations where water is needed for production, irrigation, material processing, cooling and/or washing and cleaning." Further, changes in precipitation patterns can directly "affect power generation" and businesses "that depend on highly reliable energy" from these sources. (p. 5.) Water prices will rise as water becomes more scarce and products and services that use large amounts of water could face increased socio-economic risk as scarcity becomes a problem and people become more aware of their rights to access water. (p. 6.)

2.19 US Global Change Research Program, Global Climate Change Impacts in the United States (June 2009)

This report synthesizes information from a wide variety of scientific assessments and recently published research to summarize in plain language what is known about the observed and projected consequences of climate change in the United States. The report was prepared with the goal of informing public and private decision making at all levels. The relationship of climate change to water, energy, agriculture and human health in the US are explored. The importance of mitigation of climate change is emphasized by comparisons of impacts resulting from higher vs. lower emission scenarios.

Potential Impacts of Climate Change on Water Resources in the United States: Global temperature has increased over the past 50 years. This observed increase is due primarily to human induced emissions of heat-trapping gases. (p. 13.) Climate-related changes are already observed in the United States and its coastal waters. These include increases in heavy downpours, rising temperature and sea level, rapidly retreating glaciers, thawing permafrost, lengthening growing seasons, lengthening ice-free seasons in the ocean and on lakes and rivers, earlier snowmelt, and alterations in river flows. These changes are projected to grow. (p. 27.)

Climate change will stress water resources. Water is an issue in every region, but the nature of the potential impacts varies. Drought, related to reduced precipitation, increased evaporation, and increased water loss from plants, is an important issue in many regions, especially in the West. Floods and water quality problems are likely to be amplified by climate change in most regions. Declines in mountain snowpack are important in the West and Alaska where snowpack provides vital natural water storage. (pp. 41, 129, 135, 139.)

Runoff, which accumulates as streamflow, is the amount of precipitation that is not evaporated, stored as snowpack or soil moisture, or filtered down to groundwater. The proportion of precipitation that runs off is determined by a variety of factors including temperature, wind speed, humidity, solar intensity at the ground, vegetation, and soil moisture. While runoff generally tracks precipitation, increases and decreases in precipitation do not necessarily lead to equal increases and decreases in runoff. For example, droughts cause soil moisture reductions that can reduce expected runoff until soil moisture is replenished. Conversely, water-saturated soils can generate floods with only moderate additional precipitation. During the last century, consistent increases in precipitation have been found in the Midwest and Northeast along with increased runoff. (pp. 149, 150.) Climate models consistently project that there will be substantial declines in the interior West, especially the Southwest. Projections for runoff in California and other parts of the West also show reductions, although less than in the interior West. In short, wet areas are projected to get wetter and dry areas drier. Climate models also consistently project heat-related summer soil moisture reductions in the middle of the continent. (pp. 115, 142, 146, 149.)

Potential Impacts on Groundwater Resources in the West: How climate change will affect groundwater is not well known, but increased water demands by society in regions that already rely on groundwater will clearly stress this resource, which is often drawn down faster than it can be recharged. (p. 164.) In many locations, groundwater is closely connected to surface water and thus trends in surface water supplies over time affect groundwater. Changes in the water cycle that reduce precipitation or increase evaporation and runoff would reduce the amount of water available for recharge. Changes in vegetation and soils that occur as temperature changes or due to fire or pest outbreaks are also likely to affect recharge by altering evaporation and infiltration rates. More frequent and larger floods are likely to increase groundwater recharge in semi-arid and arid areas, where most recharge occurs through dry streambeds after heavy rainfalls and floods. (p. 142.)

Sea-level rise is expected to increase saltwater intrusion into coastal freshwater aquifers, making some unusable without desalination. (p. 146.) Increased evaporation or reduced recharge into coastal aquifers exacerbates saltwater intrusion. Shallow groundwater aquifers that exchange water with streams are likely to be the most sensitive part of the groundwater system to climate change. Small reductions in groundwater levels can lead to large reductions in streamflow and increases in groundwater levels can increase streamflow. (p. 165.) Further, the interface between streams and groundwater is an important site for pollution removal by microorganisms. Their activity will change in response to increased temperature and increased or decreased streamflow as climate changes, and this will affect water quality. Like water quality, research on the impacts of climate change on groundwater has been minimal. (p. 149.) Overall, climate change will add another factor to existing water management challenges, thus increasing vulnerability. (p. 170.)

2.20 Climate Change Research Center, The Copenhagen Diagnosis — Updating the World on the Latest Climate Science (2009)

The Copenhagen Diagnosis is an interim report prepared by the Intergovernmental Panel on Climate Change (IPCC) which evaluates the evolving, policy-relevant, climate science written for a broad audience of policy-makers, stakeholders, the media, and the public. This report presents the most significant climate change findings related to greenhouse gas (GHG) emissions, melting of glaciers and ice-caps, Arctic sea-ice decline, current and projected sea level rise, and risks associated with crossing critical thresholds resulting in irreversible damage. The science used in this report is based on the most credible and significant peer-reviewed literature available at the time of publication and the report addresses some common misconceptions in climate change science.

Over the past 25 years temperatures have increased at a rate of 0.190C per decade, in every good agreement with predictions based on greenhouse gas increases. Even over the past ten years, despite a decrease in solar forcing, the trend continues to be one of warming. Natural, short-term fluctuations are occurring as usual but there have been no significant changes in the underlying warming trend. (p. 7.)

Satellites show great global average sea-level rise (3.4 mm/yr over the past 15 years) to be 80% above past IPCC predictions. (p. 7.) This acceleration in sea-level rise is consistent with a doubling in contribution from melting of glaciers, ice caps and the Greenland and West-Antarctic ice-sheets. By 2100, global sea-level is likely to rise at least twice as much as projected by Working Group 1 of the IPCC, for unmitigated emissions it may well exceed one meter. The upper limit has been estimated as two meters sea-level rise by 2100. Sea-level will continue to rise for centuries after global temperature have been stabilized and several meters of sea level rise must be expected over the next few centuries. (p. 7.)

Planning Recommendations: While global warming can be stopped, it cannot easily be reversed due to the long lifetime of carbon dioxide in the atmosphere. (p. 50.) Even a thousand years after reaching a zero-emission society, temperatures will remain elevated, likely cooling down by only a few tenths of a degree below their peak values. Therefore, decisions taken now have profound and practically irreversible consequences for many generations to come, unless affordable ways to extract CO2 from the atmosphere in massive amounts can be found in the future. The chances of this do not appear to be promising. (p. 50.)

The temperature at which global warming will finally stop depends primarily on the total amount of CO2 released to the atmosphere since industrialization. This is again due to the long life-time of atmospheric CO2. Therefore if global warming is to be stopped, global CO2 emissions must eventually decline to zero. (p. 50.) From a scientific point of view, a cumulative CO2 budget for the world would thus be a natural element of a climate policy agreement. Such an agreed global budget could then be distributed amongst countries, for example on the basis of equity principles. An important consequence of the rapidly growing emissions rate, and the need for a limited emissions budget, is that any delay in reaching the peak in emissions drastically increases the required rapidity and depth of future emissions cuts. (p. 51.)

2.21 California Department of Water Resources, Using Future Climate Projections to Support Water Resource Decision Making in California (May 2009)

This document describes advances in climate projection information in California water resource planning since the 2006 climate change assessment by DWR, *Progress on Incorporating Climate Change into Management of California's Water Resources*. Advances include a better understanding of how well current models represent historical climate conditions and refined technologies represent streamflows, outdoor urban and agricultural water demands, and sea level rise. Twelve climate projections are used to assess the reliability of Central Valley Project and the State Water Project operations.

This information is particularly useful for addressing the implications and considerations of climate change on changing hydrology.

Range and Assumptions: This paper presents several advances in using future climate projection information in water resources planning, such as an improved understanding of how well selected climate models represent historical climate conditions and refined methodologies for representing streamflows, outdoor urban and agricultural water demands, and sea level rise in planning tools. Twelve climate projections were used to assess the future reliability of California's main water supply projects. (p. 2.2.) Mid-century and end-of-the-century impacts were estimated for Sacramento-San Joaquin Delta exports, reservoir carryover storage, groundwater pumping, power supply, and the Delta salinity standard known as X2. (p. 5.2.3.) The vulnerability of the system to operational interruption was also examined. A sensitivity analysis was also conducted to examine the effects of air temperature on runoff in the Upper Feather River basin, the main inflow source to Lake Oroville. (p. 5.1.)

Potential Impacts on Water Resources: Increases in air temperature are expected to have significant impacts on watersheds that traditionally receive at least some of their precipitation in the form of snow. One of the key results from the sensitivity analysis for the upper Feather River basin is that the day in the water year when 50% of the annual inflow arrives in Lake Oroville moves earlier in the year as air temperatures increase. (p. 26.) The average day that 50% of the annual inflow arrives at Lake Oroville decreased from March 18 for the base scenario to February 10 for an air temperature increase of 4°C, a change of 36 days. The range of days when 50% of the annual inflow arrives at Lake Oroville also shifts earlier in the year. (p. 26.) For the base case the range was January 7 to April 29, and in the +4°C scenario the range was December 24 to March 14. (p. 26.) Thus, in the +4°C scenario case, the latest day that 50% of the annual inflow arrived at Lake Oroville was earlier than the average day that 50% of the inflow arrived for the base scenario. These results indicate that increases in air temperature will have a significant impact on the timing of runoff for the upper Feather River basin. (p. 26.) These results are consistent with findings from other research studies that show earlier runoff in California due to projected warming in the future.

Increased air temperatures are expected to change the amount and timing of annual runoff. The fraction of runoff that occurs during the traditional period of April through July was examined for the base and the increased air temperature scenarios. (p. 27.) In the climate models, the fraction of runoff that occurs from April through July decreases through time for all scenarios (including the base scenario), and it also decreases as air temperatures increase. This indicates that snowmelt is occurring before April 1 and that the fraction of snowmelt that occurs before April 1 will increase as air temperatures increase. (p. 27.) The 30-year trend indicates that the fraction of annual runoff occurring from April through July decreases from about 35% for the base scenario to about 15% for the +4°C scenario. (p. 27.) In addition to the water supply and flood management impacts of earlier snowmelt, these changes could also require changes to the current water year classifications and their associated regulatory standards because those classifications are partly based on April–July runoff.

The report also examined impacts to the Central Valley water systems. Those projections were based on climate simulations from two GCMs that were each used to represent two GHG emissions scenarios. For the 2008-2009 climate change assessment, a total of 12 projections were used that were based on climate simulations from six GCMs for two GHG scenarios. (p. 5.2.1.) Potential impacts of climate change on the operation of the SWP and CVP were assessed for 12 future climate projections at both the middle and the end of the century. The water supply reliability indicators analyzed were annual Delta exports, reservoir carryover storage, groundwater pumping, power supply, position of a Delta salinity indicator known as X2, and the frequency and extent of system vulnerability to operational interruption. In analyzing the study results, it was assumed that each future climate projection was equally likely to occur.

For all exceedance levels, annual Delta exports were less than the base case for both the mid-century and end-of-century analysis periods. This indicates that SWP and CVP deliveries south of the Delta will be less reliable under projected future climate conditions using the current system infrastructure and operating rules. At mid-century, Delta exports are reduced by 7% for the lower GHG emissions scenario and by 10% for the higher GHG emissions scenario. By the end of the century, the Delta exports are reduced by 21% and 25% respectively. (p. 32.)

Carryover storage for the 12 future climate projections was used to estimate exceedance probabilities for both the mid-century and end-of-century analysis periods. For all exceedance levels, carryover storage is less than the base case for both the mid-century and end-of-century periods. This indicates that SWP and CVP water supplies will be less reliable under projected future climate conditions using the current system infrastructure and operating rules. (p. 34.) At mid-century, reservoir carryover storage is reduced by 15% for the lower GHG emissions scenario and by 19% for the higher GHG emissions scenario. By the end of the century, carryover storage is reduced by 33% and 38% respectively. (p. 34.)

Average annual groundwater pumping for the Sacramento Valley was used to estimate exceedance probabilities for both the mid-century and end-of-century analysis periods for the 12 future climate projections. For all exceedance levels, annual groundwater pumping is greater than the base case for both the mid-century and end of the century. (p. 36.) This indicates that groundwater pumping is likely to increase to augment surface water supplies under future climate change using the current system infrastructure and operating rules. (p. 36.) At mid-century, Sacramento Valley groundwater pumping increases by 5% for the lower GHG emissions scenario and by 9% for the higher GHG emissions scenario. (p. 36.) By the end of the century, Sacramento Valley groundwater pumping increases by 13% and 17% respectively. (p. 36.)

Planning Recommendations: The report makes a series of recommendations, summarized below:

- Improved understanding of the uncertainties associated with future climate projections including relative likelihoods of future greenhouse gas emissions scenarios and sea level rise estimates.
- Improve understanding about how uncertainties and unknowns in each step of developing the simulations, scaling the data, and representing system operations affect the final information provided to decision makers.
- Develop and apply enhanced downscaling techniques that can account for the physical processes as well as statistical properties.
- Develop a dynamical downscaling technique for the state.
- Develop and apply a meso-scale model (such as MM5) or Weather Research and Forecasting (WRF) Model for California, and archive the data for public dissemination.
- Explore methods for incorporating possible changes in variability in future climate and hydrologic conditions (non-stationarity) into impact analyses.
- Further enhance existing management decision support tools or develop new tools for assessing risks of climate change on California's water systems and for exploring adaptation measures such as possible re-operation of existing or projected future water resources systems to reduce the impacts of climate change.
- Develop guidelines for climate change analysis for selection of future climate projections, proper length of planning horizon, etc.
- Improve cross-sector coordination and integration of climate change related analyses.

(p. 46.)

2.22 California Climate Change Center, The Future is Now: An Update on Climate Change Science Impacts and Response Options for California (May 2009)

Range and Assumptions: The California Energy Commission Public Interest Energy Research (PIER) Program prepared this interim summary to demonstrate that the effects of climate change are already being felt in California. The report provides recommendations that encompass both mitigation and adaption for decision makers in California. This report, for use by state agencies and the Legislature, is intended to supplement the PIER Program biennial reports that are focused on impacts related to climate change. Therefore it synthesizes the most recent findings, from published literature, outlines a response strategy, and highlights the benefits to California from implementing actions now.

The project's objectives are:

- Document how climate change in California is now occurring, has already affected public health, the economy, and natural ecosystems, and is likely to accelerate in the future (Chapter 2);
- Explain the evidence attributing past and current observations of climate change to direct human causes such as emissions of greenhouse gases (Chapter 3);
- Examine what would happen to California's climate under hypothetical emissions scenarios, including a scenario of drastically reduced emissions more stringent than any studied previously (Chapter 4);
- Summarize the most up-to-date scientific understanding of how future climate change will affect California's economy and ecosystems (Chapter 4);
- Describe the necessity of a two-pronged response strategy that includes both mitigation of emissions and adaptation to that climate change that is already underway. (Chapter 5).

2.23 California Department of Water Resources, California Water Plan Update 2009 (October 2009)

The 2009 California Water Plan Update emphasizes the need to act now to provide integrated, reliable, sustainable, and secure water resources and management systems for the economy, ecosystems, and human health. Aging infrastructure, impaired water bodies, and declining ecosystems are serious problems that must be addressed in the face of climate change and a rapidly growing human population.

Update 2009 promotes IRWM as a strategy to maximize water supply security, protect water quality and ecosystems, and adapt to changing conditions. The report contains a thorough discussion of impacts that have already occurred, and additional changes that are expected, which will be useful to IRWM planners as they prepare climate change-related portions of their documents. A sustainable, resilient infrastructure with high levels of regional involvement and coordination is presented as the best way to deal with the challenges to come.

Potential Impacts on California Water Resources: Population growth promises to compound water management challenges under climate change. By 2030, the population of California is expected to grow by 14 million overall. (p. 54.) Most of this growth will occur in Southern California, resulting in a geographic disconnect between demand and supply. Dry Southern California imports water from the wetter north, yet the population in Southern California is growing faster than elsewhere in the state. (p. 54.)

In future decades, some areas in the western United States, especially the southwest, may experience greater drought, necessitating more interaction in regional water markets. (p. 57.) In the southern part of the state, water supplies from the Colorado River may decrease in the future. A recent comprehensive modeling study projected an 8-11% decrease in runoff by 2100 for the Colorado River Basin depending on the emissions scenario. This study also found that water shortages for the basin became more frequent. (p. 57.) This reduction in water availability will require that all states within the Colorado River watershed collaborate to share the diminishing water resources fairly. Groundwater access and rights among multiple regional players in the Western United States is subject to debate. (p. 57.) Both the physical and social trends require a better understanding of the full implications for resource management at the regional scale.

Planning Recommendations: In 2006, California elected to take decisive action on mitigation via Assembly Bill 32, the Global Warming Solutions Act of 2006 (Núñez, Chapter 488, Statutes of 2006; AB 32), a comprehensive cap on greenhouse emissions. The report identifies a need for a complementary pathway of adaptation measures to ensure that potential harm and burden to the economy and environment of California is minimized. The Resources Agency has started a new initiative to develop a statewide adaptation strategy that will be updated every other year.

Additional recommendations include: (1) Preparing for change via forward-looking, well-designed adaptation plans; (2) Understanding connections between climate change and land use decisions, and understanding how climate change affects multiple sectors of the economy; (3) Understanding accelerating climate change trends and examining the risks of abrupt climate change; and (4) Managing climate change efforts via private and public sector channels and promoting cooperation among local and regional stake-holders.

2.24 California Climate Action Team, Climate Action Team Biennial Report (May 2010)

Executive Order S-05-05 mandates the preparation of biennial science assessment reports on climate change impacts and adaptation options for California. This draft report is the second such report and differs from the first 2006 policy-based assessment in that the joint effect of increased urbanization and climate impacts are examined. Six model simulations under two emissions scenarios were run to generate a range of possible future conditions. Impacts of climate change on public health, infrastructure, natural resources, energy, water, transportation, forestry, agriculture and the economy are all explored in depth. State efforts to study and adapt to current and future effects of climate change are described.

Range and Assumptions: There were six global climate models (GCMs) run for the recent IPCC Fourth Assessment (IPCC 2007) using the A2 and B1 emission scenarios. The models were employed to assess climate changes and their impacts for the 2008 California Climate Change Assessment. For the assessment, the NCAR Parallel Climate Model (PCM), the NOAA Geophysical Fluids Dynamics Laboratory (GFDL) version 2.1, the NCAR Community Climate Model (CCSM), the Max Plank Institute’s ECHAM3, the Japanese Model for Interdisciplinary Research on Climate (MIROC), and the French Centre National de Recherches Météorologiques (CNRM) models were selected. The set of GCMs expand the ones used in the 2006 California Scenarios Assessment. (p. 1.5.)

Potential Impacts on California Water Resources: Two groups conducted studies of water resources under changing climate conditions using two different models: CALVIN and CalSim-II. The CALVIN model is an engineering-economic optimization model that has been enhanced for climate change studies. Since the model assumes perfect water markets with water being delivered where it is needed to minimize economic losses or increase benefits to the overall water sector, results from CALVIN should be interpreted with caution and representative of minimum impacts given physical constraints only (i.e., as best case scenarios). By comparison, the CalSim-II model is a simulation model that accounts for the existing rules and regulations governing the water system in California. The model assumes that current rules, regulations, and practices remain unchanged in this century. Since climate change will undoubtedly result in changes in water management, results from CalSim should be considered conservative. (p. 1.17.)

The CALVIN work conducted for this assessment (Medellin-Azuara et al. 2008) explored water supply adaptation strategies under two climate scenarios, assuming 2050 levels of socioeconomic development. The first climate scenario used a warmer drier climate with high GHG emission levels and low precipitation levels; the second climate scenario (warmer only) includes historic patterns of precipitation with high levels of emissions and increased temperature. The warmer-drier scenario comes from the downscaled outputs from the GFDL model for the A2 emissions scenario while the warmer-only scenario retains the warming from the GFDL model but assumes no changes in average precipitation levels from the historical record. (p. 1.17.) The CALVIN model integrates economic costs in agricultural and urban locations, operating costs, and water storage and conveyance infrastructure within the network connecting and transporting water resources within and across the state. CALVIN suggests economically promising water management strategies, such that water is allocated to minimize total scarcity and operating costs in California considering a set of physical and operating constraints. (pp. 1.17-1.18.)

The report determined that small shortages close to 28 thousand acre-feet (TAF) per year are most likely in Southern California in historical and warmer-only scenarios. (p. 1.17.) Affected urban centers include some parts of the Metropolitan Water District of Los Angeles and some cities east of Los Angeles within the Mojave and Imperial Valley regions. This finding assumes that current infrastructure development projects will be in operation. A warmer-drier scenario doubles shortages for urban locations to 59 TAF/year. (p. 1.17.) The CALVIN model estimates that urban areas are basically able to receive the water they need from water transfers from the agricultural sector.

The report explained, “It is important to point out that the warmer-drier climate scenario comes at a cost to some environmental flows.” (p. 1.18.) Reductions in environmental flow requirements for the Trinity River, Clear Creek, and the Sacramento River, the San

Joaquin/Mendota refuges, and Pixley were required to achieve model feasibility under this drier scenario. A reduction of roughly 11 percent of the average annual minimum streamflow requirement was applied to Mono Lake water releases from Grant Lake. Changes in end-of-period storage policies in selected reservoirs (such as Shasta) were also needed to accommodate reductions in required minimum streamflows. "Such reductions in streamflow would need to be reviewed for potential environmental impacts, and the respective costs and benefits carefully weighed." (p. 1.18.)

Planning Recommendations: The report identified the following early action items: (1) Executive Order (EO) S-13-08 requires the development of the first California Sea-Level Rise Assessment Report, to be completed no later than December 1, 2010. The result of this study will be used to develop coastal management planning guidance for sea-level rise through the state's coastal management agencies, offices, and commissions, thereby ensuring preservation of terrestrial and aquatic species in coastal areas (p. 4.16); (2) The California Ocean Protection Council will coordinate with the Coastal States Organization to continue to ensure climate change adaptation is a priority for State and federal partners (p. 4.17); (3) The California Department of Fish and Game has identified climate change as a key threat in its core planning document, the State Wildlife Action Plan, and is actively working to determine the climate impacts faced by their managed lands and the species residing on those lands. All of California's land management agencies will adjust plans and expenditures based on updated climate science (p. 4.17); and (4) The Department of Water Resources has completed the 2008 State Water Plan Update that will guide water expenditures and planning for the next century and has climate change as a major planning priority. (p. 4.17.)

2.25 NRDC and Terra Tech, *Climate Change, Water, and Risk: Current Water Demands are Not Sustainable* (July 2010)

A new analysis, performed by consulting firm Tetra Tech for the Natural Resources Defense Council (NRDC), examined the effects of global warming on water supply and demand in the contiguous United States. The study found that more than 1,100 counties — one-third of all counties in the lower 48 — will face higher risks of water shortages by mid-century as the result of global warming. More than 400 of these counties will face extremely high risks of water shortages.

The report concludes that climate change will greatly increase the risk that water supplies will not be able to keep pace with withdrawals in many areas of the United States. This conclusion has significant implications for future water management and climate change adaptation planning efforts. The pressure on public officials and water users, such as farmers, to manage demand and supply will be greatest in the areas facing these higher risks.

Range and Assumptions: Tetra Tech performed an analysis for NRDC which combined water demand projections based on current growth trends with renewable water supply projections based on 16 leading climate models. (p. 2.) The report develops a new water supply sustainability index. The risk to water sustainability is based on the following criteria:

(1) Projected water demand as a share of available precipitation;
(2) Groundwater use as a share of projected available precipitation;
(3) Susceptibility to drought;
(4) Projected increase in freshwater withdrawals; and
(5) Projected increase in summer water deficit.

(p. 2.) The risk to water sustainability for counties meeting two of the criteria are classified as "moderate," while those meeting three of the criteria are classified as "high," and those meeting four or more are classified as "extreme." Counties meeting less than two criteria are considered to have low risk to water sustainability. (p. 2.)

Potential Impacts on Riverside County: Residents in Riverside and San Bernardino counties are at an "extremely high risk" of not having enough water to meet demands by mid-century if changes are not made to combat climate change and curb water use. Two of the principal reasons for the projected water constraints are shifts in precipitation and potential evapotranspiration (PET). Evapotranspiration is the sum of evaporative loss of water from the ground surface and transpiration losses through vegetation. PET is a calculated metric used to represent evapotranspirative losses under idealized conditions, where a full water supply is available for evapotranspiration. Together, changes in precipitation and potential evapotranspiration have significant effects on *available precipitation*, estimated as water falling either as rain or snow that would not be consumed by the potential evapotranspiration. (p. 2.)

Increases in water withdrawals, from groundwater, lakes, rivers, streams, and manmade structures like dams, are also a primary reason for increasing vulnerability. The three categories of water use with the greatest demand are agricultural use, power plant cooling, and domestic use. Under the business-as-usual scenario assumed in this analysis, total water demand is projected to increase by as much as 12.3 percent between 2000 and 2050. (pp. 2-3.) Demand for municipal use and electric cooling is projected to grow along with the U.S. population, while use for irrigation, livestock, aquaculture and mining is assumed to remain at the same levels as 2005, as withdrawals in those sectors have remained relatively flat in the last two decades. The analysis found that total freshwater withdrawals in 2030 and 2050 are anticipated to be significant in the major agricultural and urban areas throughout the nation.

Planning Recommendations: While water management and climate change adaptation plans will be essential to lessen the impacts, they cannot be expected to counter the effects of a warming climate. One reason is that the changes may simply outrun the potential for alternatives such as modifying withdrawals, increasing water use efficiency, increased water recycling, enhancing groundwater recharge, rainwater harvesting and inter-basin or inter-county transfers to make up for water deficits.

The widespread nature of the risk of water shortages may also limit the effectiveness of local solutions — such as acquiring more water from a neighboring county or basin — since many other localities will be trying to get control of the same resource. (p. 4.) Further, the pressure on water supplies will not cease in 2050. If climate warming continues to increase, we can expect the risks of water shortages to increase with it. There is no way to truly manage the risks exposed by this report other than taking the steps necessary to slow down and reverse the warming trend.

2.26 California Climate Action Team, *Climate Action Team Report to Governor Schwarzenegger and the California Legislature* (Dec. 2010)

Potential Impacts to Water Resources: This report to the Governor and the Legislature reviews climate change milestones and legislation across the state. With regards to water resources, the report notes that water resources are essential to support both agricultural and urban areas of the state, while also protecting ecosystems and the environment. "Satisfying these water needs requires substantial energy resources. The California Energy Commission estimates that conveyance, storage, treatment, distribution, use, wastewater collection, wastewater treatment, and discharge account for approximately 19 percent of the state's use of electricity." (pp. 21-22.) Consequently, the report concludes that improved efficiency in water supply and use can both improve resiliency to climate changes and mitigate the emission of green-house gases. The report reviewed the following efforts across the state:

- The Department of Water Resources and other water authorities will implement the 20x2020 Water Conservation Plan to reduce per-capita urban water use 20 percent statewide by 2020, and implement measures promoting agricultural water use efficiency.

- The State Water Resources Control Board and other agencies are developing policies to promote the recycling of water, reducing both the need for new supply and reducing the energy requirements to deliver water to customers.

- The use of low impact development techniques are being encouraged to either infiltrate storm water flows or to capture, store and use storm water onsite. Infiltration and/or onsite use of stored storm water is expected to offset the need to import water from remote locations, thus saving energy and reducing emissions.

- Improved water use and water diversion measurement reporting systems are being developed, including systems for tracking conservation, water recycling, storm water and water rights diversion.

(p. 22.)

Recommendations: An array of adaptive water management strategies must be implemented to better address the risks and uncertainties of changing climate patterns. Coupled water and energy strategies must focus on both greenhouse gas emission reductions and adaptation actions. Both are needed to ensure a sufficient supply of water and the necessary energy for the storage, transport and delivery of water for cities and farms, and to maintain healthy ecosystems. (p. 22.)

2.27 California Natural Resources Agency, Department of Water Resources, *Climate Change Characterization and Analysis in California Water Resources Planning Studies* (Dec. 2010)

Range and Assumptions: This paper surveys planning studies in which DWR was the sole conducting agency and studies in which DWR participated with other agencies to develop joint documents. In the studies under way or completed since 2006, DWR generally considered future climate and hydrology change by following one of four approaches: (1) a scenario approach based on selection of a limited number of Global Climate Models simulations; (2) an ensemble-informed approach based on 112 available downscaled simulations from the Intergovernmental Panel on Climate Change Fourth Assessment Report (2007); (3) relative change approaches that apply perturbations to historical data to simulate the potential impacts of climate change; or (4) qualitative approaches. (p. v.)

This report is a comprehensive survey of all DWR planning studies that have addressed the impact of climate change in predicting future climate conditions and impact on water resources. Thirteen ongoing and past planning studies are reviewed in detail. Seventeen different analysis characteristics are highlighted for each study including planning horizon, spatial coverage, climate analysis approach, number of Global Climate Models (GCMs) used, scenario selection, sea level rise, hydrologic simulation period, and streamflow sequence for operations modeling. Of the 13 projects, more than half were completed solely by DWR; the rest were completed in partnership with DWR, often with multiple State and federal agencies. (p. xiv.) DWR reviewed studies including: CWP Update 2009, 2006 SWP/CVP Impacts Report, 2009 SWP/CVP Impacts Report, SWP Delivery Reliability Report 2009, Management Response Status Report, DRMS Phase 1 Report, Monterey Plus FEIR 2010, Salton Sea Ecosystem Restoration Program, Oroville Facilities Relicensing, BDCP and DHCCP Operations and Planning, CVP/SWP OCAP BA, Los Vaqueros Reservoir Expansion EIR/EIS, and the CVP IR(p. (Table ES-1.)

Characterization of future climate conditions including temperature, precipitation, and humidity was only the first step in the analysis of climate change impacts in the planning studies. Most of the studies proceed to use future climate scenarios to analyze expected future hydrology. (p. xv.) This step typically involved using the downscaled GCM data to generate projection of future streamflow. The studies surveyed for this report used two general methods for developing streamflow projections: adjusted observed hydrologic sequences and unadjusted model generated sequences. (p. xv.) Adjusted observed hydrologic sequences use the observed record of streamflows as a baseline to which adjustments are made to reflect potential climate changes. Unadjusted model generated sequences use climate models to generate input parameters for a hydrologic model which generates streamflow sequences that are used without adjustment. (p. xv.)

Lack of Data: There is a lack of analysis of potential drought conditions that are more extreme than have been seen in our relatively short hydrologic record. There is significant evidence to suggest that California has historically been subject to very severe droughts and that climate change could result in droughts being more common, longer, or more severe. (p. xvi.) However, most current DWR approaches rely on an 82-year historical hydrologic record (1922-2003) on which GCM-generated future climate changed-hydrologic conditions are superposed. This record is likely too short to incorporate the possibility of a low frequency, but extreme, drought.

Potential Impacts to California Water Resources: DWR concludes that snowpack storage in the Sierra Nevada is predicted to diminish by 25 percent by 2050. (p. 2.) Sea level rise increases salinity intrusion into the Delta, making it more difficult to maintain the freshness of the water pumped out of the Delta. The 1,100 miles of earthen levees that protect the Delta are also at increased risk of failure because of sea level rise as higher seas place more pressure on levees in the estuary. (p. 2.) The risk of flooding in California, particularly in the Central Valley, may also increase as a result of climate change. (p. 2.)

Thousands of miles of river throughout the state are controlled by dams and reservoirs, and thousands of acres of land adjacent to those rivers are protected by levees and bypasses. Climate change is likely to increase storm frequency and severity with some increase in winter runoff in mountain basins due to higher-elevation snow levels during storms. (p. 2.) Also, the snowpack will melt earlier in the season with less late-season runoff. All of these factors will further stress the state's levees and reservoir operations. (p. 2.)

2.28 Daniel R. Cayan, et al., Proceedings of the National Academies of Science, *Future Dryness in the Southwest U.S. and the Hydrology of the Early 21st Century*, Vol. 107, No. 50, pp. 21271-21276 (Dec. 13, 2010)

Range and Assumptions: The authors used observed temperature and precipitation to force the Variable Infiltration Capacity (VIC) hydrological model on a 1⁄8° × 1⁄8° grid across the western U.S. This allows the authors to analyze VIC's estimates of key hydrological fields, such as soil moisture, that are poorly observed over the historical time period. (p. 21271.)

The authors used twelve global climate models (GCMs) used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report to investigate effects of climate change on the Southwestern United States. The authors further analyzed the output of two of the twelve models, Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1 and Centre National de Recherches Météorologiques (CNRM) CM3. These two models produce temperature and precipitation simulations falling within the larger ensemble of changes from the set of 12 GCMs, and were among the few models that provided the continuous daily output necessary to drive VIC. (p. 21271.)

Impacts to Future Water Southwestern Water Supplies: The recent drought in the Colorado basin has seen the lowest accumulated deficit in flows at Lees Ferry in over a century of measurements, and has only a 60% chance of occurring in a century. (p. 21275) However, given the amount of natural variability in the region's runoff, the current drought is not outside the realm of droughts likely to be encountered due to natural variability. Downscaled climate model projections show longer and more intense future droughts in the Colorado basin, and a high likelihood of worst-in-century droughts with multi-year flow deficits that exceed any in the observational record by 60–70%. (p. 21275.) If these climate scenarios materialize, the Southwest will have to prepare for deeper and historically more unusual water shortages, and the sustainability of current water deliveries from the Colorado River will become problematical. (p. 21275.)

In summary, a view from a small, but representative selection of climate simulations downscaled to 1⁄8° × 1⁄8° and applied to a hydrological model suggests a future where drought becomes more extreme by the mid to late 21st century. Inevitably, there will be precipitation shortages, and during these times, the resulting hydrological drought is aggravated by a trend toward much less snowpack, warmer temperatures (especially in summer) and diminished runoff and soil moisture. (p. 21275.)