# GLOBAL CLIMATE CHANGE AND ITS EFFECTS ON CALIFORNIA WATER SUPPLIES

Future global climatic conditions may affect California's water supplies through potential, though uncertain, changes related to air temperatures and precipitation and their resulting effects on water temperatures, water project operations, reservoir operations, stream runoff, and rise in sea levels affecting Delta water quality. Accordingly, in order to better understand the impacts to California's water supply associated with global climate change, a literature survey, as set forth below, was undertaken.

To preface, though, this discussion relies primarily upon information provided by the California Department of Water Resources (DWR). The focus is on DWR's assessment of such global climate change issues because DWR operates the SWP water storage and conveyance system, one of two major water projects that convey potable water to California's population. The other water storage and conveyance project is the federal Central Valley Project (CVP), which is operated by the U.S. Bureau of Reclamation (Reclamation). These two water systems are operated by DWR and Reclamation for water supply, flood management, environmental protection, and recreation.

DWR and Reclamation have formed a work team to address water resources related to issues of global climate change. The mission of the work team is to coordinate with other state and federal agencies to incorporate climate change science into California's water resources planning and management. The team will provide and regularly update information for decision makers on potential impacts and risks of global climate change, flexibility of existing facilities to accommodate climate change, and available mitigation measures.

The first product of the work team's efforts is DWR's technical report titled, "Progress on Incorporating Climate Change into Management of California's Water Resources," dated July 2006 (Progress Report). The report responds to the Governor's Executive Order S-3-05, which requires biennial reports on climate change impacts to various areas, including water resources. It provides information on potential impacts of selected climate change scenarios to operations of the SWP and CVP, Delta water quality, flood management, and evapotranspiration. The technical chapters of the report underwent peer review.

DWR's reporting and assessment on global climate changes and its effects on California's water supplies are important, because California's water supplies depend heavily on the accumulation of winter mountain snow melting into spring and summer runoff. As stated by DWR, "[a] warming planet may reduce this natural water storage mechanism . . . [and] [p]rojected increases in air temperature may lead to changes in the timing, amount and form of precipitation -- rain or snow, changes in runoff timing and

volume, sea level rise effects on [Sacramento-San Joaquin] Delta water quality, and changes in the amount of irrigation water needed due to modified evapotranspiration rates." (Progress Report, p. 1-2.)

In summary, DWR's planning documents, discussed below, address the uncertainties surrounding global climate change and its effects on California's water supplies. According to information currently available, DWR has reported that California's future hydrologic conditions will likely be different from patterns observed over the past century -- although the precise causes, extent, and timing of the changes remain uncertain. And while DWR has acknowledged that better quantification will be possible as more sophisticated tools are developed and additional studies are completed, DWR currently is incorporating the potential effects of global climate change on water resources into its modeling projections and reliability forecasts.

The following discussion primarily summarizes DWR's plans and reports related to potential impacts of global climate change on California's future water supplies. The discussion also lists and describes other selected reports and studies concerning global climate change and its effects on water supplies. In addition, the discussion identifies the previously adopted mitigation measures relative to water supplies, which conserve water supplies and lessen greenhouse gas emissions that contribute to global climate change.

## DWR Plans and Reports

### DWR's SWP Delivery Reliability Report (2005)

DWR's 2005 SWP Delivery Reliability Report, April 2006 (Reliability Report), presents information from computer simulation studies of the operation of the SWP. Using the CalSim-II model, DWR has simulated SWP operations, using historical rainfall and runoff data, which is then adjusted for changes in water and land use that have occurred or may occur in the future. The computer simulations were conducted over a 73-year period (1922-1994) of the adjusted historical rainfall/runoff data. This modeling approach incorporates the assumption that the next 73 years will have the same or similar rainfall/snowmelt amount and pattern, both within-year and from year-to-year, as the historical 1922-1994 period.

Based on this modeling assumption, DWR has noted that, currently, the CalSim-II model does "not incorporate any modifications to account for changes related to climate change" that could disrupt SWP deliveries. (Reliability Report, Chap. 3, p. 7.) Earlier in the Reliability Report, DWR also has acknowledged that that CalSim modeling and study approach includes the assumption that past rainfall-runoff patterns will be repeated in the future and that this assumption has an "inherent uncertainty, especially given the evolving information on the potential effects of global climate change." (*Id.* at p. 4.) Relying upon the 2005 update to the California Water Plan, DWR summarized the potential effects of global climate change on future water supplies, as follows:

> California's water systems have been designed and operated based on data from a relatively short hydrologic record. Mounting scientific evidence suggests that forecasted climate changes could significantly change California's precipitation pattern and amount from that shown by the record. Less snowpack would mean less natural water storage. More variability in rainfall, wetter at times and drier at times, would place more stress on the reliability of existing flood management and water systems. California's high dependence on reservoir storage and snowpack for water supply and flood management makes us particularly vulnerable to these types of projected hydrologic changes.

(*California Water Plan Update*, December 2005, Vol. 1, page 3-15.) DWR also stated in its Reliability Report that:

> Potential changes in climate patterns are becoming better defined and attempts to quantify the resulting impacts to SWP water supply are underway. Broad brush estimates are being developed of the potential impact upon the SWP in 50 to 100 years if no additional conveyance facilities or upstream reservoirs are built. As this information becomes more refined, it will be helpful in guiding the development of statewide strategies for the future management and development of water resources facilities, including the SWP.

(Reliability Report, Chap. 2, p. 4.) In the meantime, however, DWR has confirmed that the results of CalSim-II model studies conducted for the Reliability Report "represent the best available assessment of the delivery capability of the SWP." (Reliability Report, Chap. 3, p. 7.)

In response to concerns about future climate conditions that may affect water supplies, DWR has stated that information pertinent to climate change and its effects on water supplies "is evolving rapidly, but has not reached a level at which it can be quantitatively incorporated into delivery projections of the SWP."[1] Nonetheless, DWR has acknowledged that the published literature and other information are "helpful in developing strategies for the future management and development of the State's water resources, including improvements to the SWP." (*Ibid*.)

**DWR's California Water Plan Update (2005)**

DWR's California Water Plan Update of 2005 (2005 Water Plan) also addresses uncertainties associated with global climate change and its potential effect on water supplies. In Chapter 4 of the 2005 Water Plan, DWR summarizes the "predictions" surrounding global climate change, and they "include increased temperatures, reductions to the Sierra snowpack, earlier snowmelt, and a rise in sea level, although the

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[1] See, DWR letter to Mindy McIntyre, Water Program Manager, Planning and Conservation League, dated April 20, 2006 (DWR's April 20, 2006 letter), which is found in Appendix G to DWR's 2005 SWP Delivery Reliability Report (April 2006).

extent and timing of the changes remain uncertain." (*Id*. at p. 32.) DWR further states that these predicted changes "could have major implications for water supply, flood management, and ecosystem health. The prospect of significant climate change warrants examination of how California's water infrastructure and natural systems can be managed to accommodate or adapt to these changes, and whether more needs to be done." (*Ibid*.) DWR also acknowledges that, for over the past ten years, "scientists have been publishing formal, peer-reviewed recommendations for integrating the results of climate change research into policy." (*Ibid*.)

For example, in conjunction with affected state agencies, the Public Interest Energy Research Program (PIER) administered by the California Energy Commission has developed and is implementing a climate change research plan for California. The PIER program established a regional climate change research center with the goals of: (1) improving the understanding of the possible physical and economic impacts of climate change; and (2) developing robust adaptation and mitigation strategies for California. (See, 2005 Water Plan, p. 32, Box 4-9, PIER Program and Climate Change Research.) In support of future updates of the 2005 Water Plan, the newly-created research center is funding: (1) development and maintenance of a comprehensive climatic database for California and the analysis of meteorological and hydrological trends; (2) monitoring of meteorological and hydrological parameters in some key remote locations using innovative remote sensing devices; (3) development of climate projections for the state using regional climate models at levels of resolution appropriate for water resources impact analyses; and (4) study of water resources impacts under different climatic projections. DWR is a key co-sponsor of these research activities, and DWR staff is participating in the modeling efforts. (*Ibid*.)

**Climate Change Report**

DWR's 2005 Water Plan also referenced the work performed by the Pacific Institute for Studies in Development, Environment and Security (Pacific Institute). The Pacific Institute, in a literature search report for DWR, summarized recommendations for coping with and adapting to climate change from key peer-reviewed publications. The Pacific Institute's report is titled, "Climate Change and California Water Resources: A Survey and Summary of the Literature," by Michael Diparsky and Peter H. Gleick, Pacific Institute, July 2003 (Climate Change Report). This report is included in the Volume 4 Reference Guide to the 2005 Water Plan.

In the Climate Change Report, the Pacific Institute surveyed existing literature on climate change and its impacts on water resources in California. This report reviewed projected effects of climate change on the state's water supply, delivery, and quality, and explored the economics involved in meeting the challenges that those effects could bring about. (Climate Change Report, p. vii.) In general, the report confirmed temperature increases and their effects include a snowpack higher in elevation, with either

lower or higher precipitation depending upon the information source (*id*. at pp. 6, 10); either greater or lesser amounts of runoff depending upon the information source (*id*. at p. 14); a greater number of extreme flood and drought events (*id*. at p. 13); and reductions or increases in projected water use by plants (*id.* at p. 10), again, depending upon the information source. Thus, depending upon the information presented, California could have more water available due to increased humidity and rainfall, or less water available due to reductions in snowpack, greater evaporation, and no change or slightly less rainfall.

The Climate Change Report concluded that managing water resources to address climate changes could prove different than managing for historical climate variability because: (1) climate changes could produce hydrologic conditions and extremes of a different nature than current systems were designed to manage; (2) they may produce similar kinds of variability but outside of the range for which current infrastructure was designed; (3) traditional water resource management assumes that sufficient time and information will be available before the onset of large or irreversible climate impacts to permit managers to respond appropriately; and (4) traditional management assumes that no special efforts or plans are required to protect against such uncertainties.

The Climate Change Report's literature survey resulted in specific recommendations for the following areas:

- Water planning and management
- Sea level concerns
- Modifying operation of existing systems
- New supply options
- Demand management, conservation, and efficiency
- Economics, pricing, and markets
- State water law
- Hydrologic and environmental monitoring.

The Climate Change Report further recommended that a more comprehensive assessment of all of these areas, supported by multiple state agencies and including the participation of a wide range of stakeholders, would be a valuable tool for policymakers and planners, and it was urged that such an assessment to be undertaken in the near future. (*Ibid*.)

The subject of groundwater also was addressed in the Climate Change Report. The report concedes that the impacts of global climate change on groundwater basins, and groundwater recharge characteristics are largely unknown. For example, the report notes that changes in groundwater recharge will result

from changes in effective rainfall as well as a change in the timing of the recharge season. (*Id*. at p. 20.) Increased winter rainfall may be expected in some regions, leading to increased groundwater recharge. Conversely, higher evaporation or shorter rainfall seasons in other regions could mean that soil deficits persist for longer periods of time, shortening recharge seasons, citing Leonard, *et al*., 1999. However, warmer, wetter winters would increase the amount of runoff available for groundwater recharge. This additional runoff in the winter would be occurring at a time when some basins are either being recharged at their maximum capacity or are already "full." (*Ibid*.) On the other hand, reductions in spring runoff and higher evapotranspiration because of higher temperatures, could reduce the amount of water available for recharge.

However, "[t]he extent to which climate will change and the impact of that change are both unknown." (*Ibid*.) Overall, the recommendation is that possible climate changes may require more sophisticated conjunctive management programs in which "the aquifers are more effectively used as storage facilities." (*Ibid*.)

Although the data is still developing, the Climate Change Report has confirmed that a consensus in the literature is emerging to suggest that temperatures globally are increasing. Given that climate change is a complex topic, and that the world's climate has changed in cycles for hundreds of thousands, if not yet millions, of years, according to DWR, the cause of these climate changes and their effects have not reached a level at which such information can be quantitatively incorporated into the delivery projections of the SWP.[2]

**Accounting for Climate Change Report**

In addition, a DWR report on climate change impacts and the recommendations for further research has been prepared and included in the Volume 4 Reference Guide to the 2005 Water Plan. The report is entitled, "Accounting for Climate Change," by Maurice Roos, Chief Hydrologist, DWR (Accounting Report).

The Accounting Report noted that evidence of global climate changes continues to develop, and this developing information has suggested that global climate change can affect the amount, timing, and form of precipitation (whether rain or snow) that California receives, as well as the sea level of the Pacific Ocean. This report disclosed that changes in weather, especially temperature and atmospheric composition, can affect water use and consumption. (Accounting Report, p. 1.) In addition, the Accounting Report indicated that most scientists feel that changes during the last several decades are

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[2] DWR's April 20, 2006 letter, p. 2 (*supra* footnote 2).

likely mostly due to human activities, but natural causes and variability cannot be ruled out as significant components. The Accounting Report also stated that projections of the amount of warming and other climate changes during the 21st century are wide-ranging, depending on assumptions and models. The findings summarized in the Accounting Report provide that:

Whatever the causes, the prospects of significant changes warrant examination of how the State's water infrastructure and natural systems can accommodate or adapt to climate changes and whether more needs to be done to detect, evaluate and respond to water resource system effects. Many uncertainties remain, primarily on the degree of change to be expected. Responsible planning requires that the California water planning community work with climate scientists and others to reduce these uncertainties and to begin to prepare for those impacts that are well understood, already appearing as trends, or likely to appear.

(*Ibid.*)

**Modeling Efforts**

DWR's 2005 Water Plan also has referenced modeling efforts undertaken by the University of California, Davis (with funding from the Resource Agency, CALFED, and the California Energy Commission). The University used the "CALVIN" model to evaluate how California's water system might adapt to long-term climate warming. This preliminary analytical tool was used to integrate "existing surface water, groundwater, and water demand data in an integrated economic-engineering framework for California's inter-tied water system (covering 92 percent of California's population and 88 percent of its irrigated area)." (2005 Water Plan, p. 33.) Although a useful analytical tool, DWR noted that:

In developing the computer model [CALVIN], significant weaknesses and gaps in water data were identified and documented. The model and its results have been peer reviewed and show preliminary insights into economically promising possibilities for California water management. More importantly, the tool demonstrated concepts in advanced data management, documentation, and analysis that may be useful for future statewide and regional water policy and planning analysis. The CALVIN model has been applied preliminarily to examine statewide potential for regional and statewide water markets and how California's water system might adapt to long-term climate warming (through the [PIER] Program).

(*Ibid*.)

In addition, DWR's 2005 Water Plan has referenced computer modeling of global climate change scenarios, which predict significant future reductions in the Sierra snowpack.[3] (*Id.* at pp. 33-34.) The model's simulation of potential changes in snowpack during the 21st century predicts a 52 percent reduction in the annual April through July runoff for a 2.1 degree C (3.8 F) of warming, which, according to DWR, is "well within the 1.4 to 5.8 degrees C (2.5 - 10.4 F) range predicted by global climate models for this century." (*Id*. at p. 34.) According to DWR, "[c]hanges in the timing of snowfall and snowmelt, as a result of climate change, may make it more difficult to fill reservoir flood control space during late spring and early summer, potentially reducing the amount of surface water available during the dry season. . . . Reductions in snowpack may require changes in the operation of California's water systems and infrastructure, and increase the value of additional flood control space in reservoirs." (*Ibid*.)

**DWR's Progress Report (2006)**

As stated above, in July 2006, DWR issued its report titled, "Progress on Incorporating Climate Change into Management of California's Water Resources" (Progress Report). In this report, DWR describes progress made on incorporating climate change into existing water resources planning and management techniques and methodologies. The report was prepared in response to the Governor's Executive Order S-3-05, and as an opportunity to begin addressing limitations identified in DWR's 2005 Update to the California Water Plan.

Chapter 2 provides a statewide overview of California's water resources, and includes a summary of potential causes of global climate change with an emphasis on aspects of climate change that pose a potential threat to California's water supplies, including: (i) observed and projected changes in air temperature, precipitation and runoff, and sea level rise, including potential effects on groundwater and Delta water quality; (ii) potential effects of climate change on future water demands, Colorado River basin, and sensitive fish species; (iii) sudden climate change; and (iv) climate change and water supply planning challenges. Chapter 3 provides an overview of global climate change studies being conducted by DWR. DWR's study efforts, whenever appropriate, focused on the four climate change scenarios selected by the "Climate Action Team" (CAT), which was formed in response to Executive Order S-3-05. Specifically, DWR's initial studies focused on the potential effects of climate change to four main California water resources areas: (i) SWP and CVP operations; (ii) Delta water quality, including possible increases in sea level; (iii) flood management and water supply forecasting; and (iv) changes in evapotranspiration rates and the consumptive use of irrigation water.

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[3] The source of this modeling is cited in the 2005 Water Plan References as: Knowles Noah, and Cayan D. 2002. Global Climate Change: Potential Effects on the Sacramento/San Joaquin Watershed and the San Francisco Estuary. Geophysical Research Letters 29.

Chapters 4 and 5 are of particular importance because they focus on climate change impacts on SWP and CVP operations and on the Delta. The results of the analysis undertaken in Chapter 4 suggest several potential climate change impacts on overall SWP and CVP operations and deliveries. For example, in three of the four climate scenarios simulated, CVP north-of-Delta reservoirs experienced shortages during droughts. DWR recommends that future studies examine operational changes that could avoid these shortages. At present, DWR concludes it is not clear whether such operational changes "will be insignificant or substantial." (Progress Report, p. III.)

The report also found that changes in annual average SWP south-of-Delta Table A deliveries ranged from a slight increase of about 1% for a wetter scenario to about a 10% reduction for one of the drier climate change scenarios. In three drier climate change scenarios, increased winter runoff and lower Table A allocations resulted in somewhat higher annual average Article 21 deliveries (Article 21 of the SWP long-term water supply contracts permits delivery of water excess to the delivery of Table A water and some other water types to those SWP contractors requesting it). The increase in Article 21 deliveries did not fully offset losses to Table A. In contrast, the wetter scenario with higher Table A allocations results in fewer Article 21 delivery opportunities and decreased annual average Article 21 deliveries. Changes in annual average CVP south-of-Delta deliveries ranged from increases of about 2.5% for the wetter scenario and decreases of up to 10% for drier climate change scenarios. Future studies will have to address how north-of-Delta shortages could impact south-of-Delta CVP deliveries. For both the SWP and CVP, carryover storage (*i.e.*, water stored from one year over the next) was negatively affected in the drier climate change scenarios and slightly increased in the wetter scenario.

DWR also pointed out that sea level rise effects on water project operations were not examined due to lack of existing tools for that type of analysis. DWR noted that future work in this area will include the development of the necessary tools to quantify the impacts of sea level rise on saltwater intrusion and the incremental water supply impacts to repulse greater saltwater intrusion forces into the Delta. Chapter 5 focuses on potential impacts of climate change on Delta water quality and water levels. DWR concluded that while tools are being developed to quantify the incremental impacts of sea level rise on water supplies to counteract increased saltwater intrusion, until such tools become available, DWR's preliminary analysis provided an indication of the water project operational challenges due to sea level rise.

DWR's Progress Report (2006) is not without its critics. However, DWR is making progress on incorporating global climate change issues into its management of California's water supplies and DWR's efforts are responsive to the directives of both the Governor and the Legislature to make progress toward assessing the impacts to California on global warming, including impacts to water supplies.

In short, the literature cited by DWR, and the most recent report prepared by DWR, confirm that, over time, California water supply managers will need to modify the methods used to manage water supplies in order to build-in the flexibility needed to address a dynamic water supply environment. However, it appears that more information is needed in order to draw definitive conclusions regarding the implications of climate change on water supplies. DWR has also committed to continue to incorporate new information in successive updates to the California Water Plan. At the same time, though, DWR itself concedes that its latest reporting effort is preliminary, incorporates several assumptions, reflects a limited number of climate change scenarios, and does not address the likelihood of occurrence of each scenario. For those reasons, DWR has concluded that the literature and study results to date are not sufficient by themselves to make "policy decisions." (Progress Report, p. II.)

**Monterey Plus Draft EIR (October 2007)**

In October 2007, DWR issued the Draft EIR for the Monterey Amendments to the State Water Project Contracts (including Kern Water Bank Transfer) and associated actions as part of the Monterey Settlement Agreement (Monterey Plus Draft EIR; SCH No. 2003011118). In Section 12 of the Monterey Plus Draft EIR, DWR considered the impacts of climate change on the proposed project and the impacts of the proposed project on climate change.

When evaluating the potential impacts to water resources in California resulting from global climate change, DWR noted the lack of cohesive results among the various water modeling programs:

> Although current models are broadly consistent in predicting probable increases in global air temperatures and levels of GHGs resulting from human activities, there are considerable uncertainties about precipitation estimates. For example, many regional modeling analyses conducted for the western United States indicate that overall precipitation will increase, but uncertainties remain due to differences among larger-scale General Circulation Models (GCMs). Some researchers believe that climate warming might push the storm track on the West Coast further north, which would result in drier conditions in California. At the same time, relatively newer GCMs, including those used in the National Water Assessment, predict increases in California precipitation.

(Monterey Plus Draft EIR, pp. 12-3 through 12-4.) DWR further noted that while GCMs and hydrologic models (*i.e.*, CALSIM) have been utilized in a number of California climate change studies, many of the studies have failed to "address inter-annual variability or scaling issues inherent in mapping GCM model output to more detailed watershed hydrologic models. As a result, such studies do little more than make qualitative statements about the implications of these changes to environmental impacts (e.g., water quality, agriculture, fisheries.)" (*Id*. at. p. 12-4.)

In light of the lack of uniformity between the modeling programs, and the inconsistent results produced by various modeling program, DWR concluded that "[o]ne of the most important areas of research associated with the potential impacts of climate change on California's water resources is the further development of tools to predict changes in the timing or amount of future water availability." (Monterey Plus Draft EIR, p. 12-9.) According to DWR:

> To effectively assess the potential impacts of climate change on California's water system, a model is needed that represents the operation of the system and has the ability to accept input from climate change impact studies related to the Central Valley. The model requires a descriptive, rather than prescriptive approach. A descriptive approach would use observed data in the model without regulatory limits on operations to represent a more realistic view of the operation of California's water system.

(*Id*. at p. 12-10.) DWR further stated that the "major fault" with CALSIM is its "inability to utilize hydrologic data not related to the 73 years of historical data for which the model has been validated." (*Ibid*.)

Accordingly, as no model currently exists to accurately forecast the impacts to water resources resulting from climate change, and because the "degree to which these [climate change] effects will be felt between now and 2020 has not been studied and remains unknown," the Monterey Plus Draft EIR did not incorporate climate change into the CALSIM II modeling. (Monterey Plus Draft EIR, p. 12-12.) Nonetheless, citing its Progress Report, DWR concluded that it is likely that SWP water supplies will become less reliable "under the trends that have been identified with climate change." (*Id*. at p. 12-14.)

The Monterey Plus Draft EIR also briefly considered its carbon footprint, noting that the proposed project "could result in some added GHG emissions as a result of post-Monterey Amendment SWP operations." (Monterey Plus Draft EIR, p. 12-14.) DWR underscored it commitment to reduce its carbon intensity reliance, noting that: (i) it does not intend to renew its contract for power from a coal-fired power plant; (ii) it recently filed an intent to register with the California Climate Action Registry; and (iii) it is evaluating alternative power sources. (*Ibid*.) However, after concluding that there is no applicable significance threshold, DWR did not prepare an emissions inventory for the proposed project. DWR did conclude in the Monterey Plus Draft EIR, though, that while the proposed project is not significant on a project-specific basis, the proposed project may be cumulatively significant due to "a lack of clear scientific and regulatory criteria for determining the level of significance of the project's contribution." (*Id*. at p. 12-15.)

Citing a recently published California Energy Commission report, titled Climate Change and California Water Resources: A Survey and Summary of the Literature, DWR concluded that managing water

resources in light of the changing climate will likely prove to be different than managing for historic variability, particularly due to the lack of "accurate and consistent information about how precipitation patterns, timing, and intensity will change" and the lack of "methodologies and tools to incorporate future climate change scenarios into current hydrologic models." (Monterey Plus Draft EIR, p. 12-16.)

**DWR's SWP Delivery Reliability Report (2007)**

DWR issued "The State Water Project Delivery Reliability Report 2007" (August 2008) (2007 Reliability Report). The 2007 Reliability Report updates the 2005 Reliability Report, and describes three areas of significant uncertainty to SWP delivery reliability: (a) the recent and significant decline in pelagic organisms in the Delta (open-water fish such as striped bass, Delta smelt, and longfin smelt); (b) climate change and sea level rise; and (c) the vulnerability and potential failure of Delta levees. The inclusion of new areas of uncertainty distinguishes the 2007 Reliability Report from earlier reports by including estimates of the potential reductions to SWP delivery reliability due to the pelagic organism decline and future climate changes.

As described in the 2007 Reliability Report, simulations to evaluate future (2027) SWP delivery reliability incorporate the current interim court-ordered operating rules related to Delta smelt and a range of possible climate change impacts to hydrology in the Central Valley. Therefore, for 2027, ten simulations were used to reflect the four assumed scenarios for climate change and the two levels of operating rules.

The 2007 Reliability Report observes that "climate change can potentially affect SWP delivery by altering the timing and amount of source water." (2007 Reliability Report, p. 31.) In order to evaluate water availability, the report "estimates climate change impact to SWP deliveries by interpolating between future studies that assume no climate change and studies that assume 2050 emissions." (*Id*. at p. 32; see also 2007 Reliability Report, Appendix B.)

**Progress Report Update (2008)**

In 2008, DWR, in connection with Reclamation and the Department of Land, Air and Water Resources at the University of California, Davis, published an article in *Climatic Change* titled "Progress on Incorporating Climate Change into Management of California's Water Resources" (Progress Report Update). The Progress Report Update presents "preliminary efforts by agencies managing California's water resources to incorporate climate change research into their planning and management tools." (Progress Report Update, p. 1.) The Progress Report Update also provides an "overview" of the efforts documented in the original Progress Report (2006), and presents an impact analysis that focuses on five (5) issues: (1) snowpack; (2) runoff; (3) operations of the SWP and CVP; (4) water quality and water levels

in the Sacramento-San Joaquin Delta for both present and future sea level rise conditions; and (5) evapotranspiration rates. (*Ibid*.)

The preliminary impact assessments were conducted using four (4) climate change scenarios that represent two (2) greenhouse gas emission scenarios identified by the Intergovermental Panel on Climate Change that were simulated by two (2) global climate models. (Progress Report Update, p. 5.) In order to examine potential impacts, the authors relied on a sequence of four models -- a global climate model (*i.e.*, GFDL or PCM); a regional downscaling model (*i.e.*, VIC); a SWP-CVP-specific impacts model (*i.e.*, CalSim-II); and a Delta-specific impacts model (*i.e.*, DSM2). (*Ibid*.; see also Figure 6: Approach for Analyzing Potential Water Resources Impacts on Climate Change.)

Anticipated impacts include greater amounts of winter-season runoff, which could lead to greater uncontrolled releases from the SWP and CVP reservoirs (should flood protection rules remain static), and reduced spring-season runoff, which could lead to decreased water supplies and deliveries. (Progress Report Update, p. 16.) The analysis concludes that while there is "general consensus" regarding the expected impacts, "the magnitudes and onset-timing of impacts . . . are uncertain and scenario dependent." (*Ibid*.) Accordingly, the authors recommend that the analytical mindset be expanded from assessing potential impacts to assessing the risk potential associated with individual climate scenarios, and, in that regard, note that DWR, Reclamation, and climate researchers currently are undertaking a project that evaluates how to apply risk assessment principles to the study of climate change impacts. (*Ibid*.)

**Managing An Uncertain Future (2008)**

In October 2008, DWR issued a new white paper, titled "Managing An Uncertain Future: Climate Change Adaptation Strategies for California's Water" (Managing An Uncertain Future), as part of its update to the California Water Plan and in connection with the California Resources Agency's preparation of the draft statewide Climate Adaptation Plan.[4] This white paper is not focused on forecasting specific quantities of future water supply or demands, but instead "recommends a series of adaptation strategies for state and local water managers to improve their capacity to handle change." (Managing An Uncertain Future, p. 1.)

The white paper begins with a bulleted list of "[w]hat we know," which includes findings that: "[h]istoric hydrologic patterns can no longer be solely relied upon to forecast the water future;" precipitation and runoff patterns are changing, increasing uncertainty in water supply; additional monitoring and

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[4] The purpose of the Climate Adaptation Plan is not to develop strategies to reduce GHG emissions, but to develop mechanisms that ensure California is able to efficiently adapt to the changing climate. (See www.climatechange.ca.gov/adaptation.)

researching is required to understand the connection between the changing climate, water resources, and the environment; "[e]xtreme climatic events will become more frequent;" "[i]mpacts and vulnerability will vary by region;" and, an "array" of adaptation strategies is necessary to ensure that the state responds to climate change as best as possible. (Managing An Uncertain Future, p. 2.) In contrast to findings regarding "[w]hat we know," is the white paper's observation that "the exact conditions of future climate change remain uncertain," further evidencing the general conclusion that the exact implications of climate change on water resources is unknown at this time -- the white paper observes that change is coming; however, the parameters of that change are unknown. (*Id*. at p. 3.) Nonetheless, the white paper highlights some anticipated "challenges ahead," which include: the loss of natural snowpack storage; an increase in the frequency and intensity of drought in some regions; an increase in high frequency flood events in some regions; changes in water quality; an increase in the sea level; and, a reduction in the reliability of California's hydroelectricity operations. (*Id*. at p. 4-7.)

The white paper then proceeds to present 10 climate change adaptation strategies, as summarized below:

1. Provide sustainable funding for statewide and integrated regional water management.
2. Fully develop the potential of integrated regional water management, which provides a "comprehensive approach for determining the appropriate mix of water demand and supply management options and water quality actions. (Managing An Uncertain Future, p. 11.)
3. Aggressively increase water use efficiency in order to meet Governor Schwarzenegger's goal to achieve a statewide 20 percent reduction in per capita water use by 2020. (*Id*. at p. 13.)
4. Practice and promote integrated flood management.
5. Enhance and sustain ecosystems because "integrated systems . . . suffer less damage from, and recover more quickly after, severe natural disruptions." (*Id*. at p. 21.)
6. Expand water storage and conjunctive management of surface and groundwater resources.
7. Fix Delta water supply, quality and ecosystem issues.
8. Preserve, upgrade and increase monitoring, data analysis and management in order to remedy the "large gaps in the hydrologic observational network (*e.g.*, rain and snow gauges) in the areas of California most vulnerable to climate change." (*Id*. at p. 27.)
9. Plan for and adapt to sea level rise.
10. Identify and fund focused climate change impacts and adaptation research and analysis.

As noted in the white paper, "[s]everal of the recommendations . . . are ready for immediate adoption, while others need additional public deliberation and development. Some can be implemented under existing resources and authority, while the majority will require new resources, sustained financial investment and significant collaborative investment." (Managing An Uncertain Future, p. 1.)

**Using Future Climate Change Projections (2009)**

In April 2009, DWR issued a draft paper, titled "Using Future Climate Projections to Support Water Resources Decision Making in California" (Using Future Climate Change Projections).[5] The key findings of that report, which are based on 12 modeled climate change scenarios, follow:

Since the 2006 climate change assessment (DWR 2006), several advances have been made in using future climate projection information in water resources planning in California, including 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. The range of impacts presented in this paper indicates the need for adaptation measures to improve the reliability of future water supplies in California (DWR 2008).

Possible climate change impacts to SWP and CVP operations were assessed using 12 future climate projections (Section 2.2). . . . Uncertainties in the results increase as the projections move further into the future. . . . The reliability of the SWP and CVP water supply systems is expected to be reduced for the range of future climate projections studied (Section 5.2.3).[6]

The report also found, however, that the following additional work is needed to better improve the use of future climate change projection information in water resources planning:

- Improve 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.

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5 See http://baydeltaoffice.water.ca.gov/climatechange/ClimateChangeApr09.pdf.

6 *Id*. at pp. 2-3.

- 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.[7]

As such, DWR's Using Future Climate Change Projections report supports the conclusion that while regional modeling efforts have improved over the years, uncertainty still remains regarding potential climate change effects on water supply reliability.

**DWR's SWP Delivery Reliability Report (2009)**

In January 2010, DWR released the "Draft State Water Project Delivery Reliability Report" (2009 Draft Reliability Report).[8] As in previous reports, estimates of SWP deliveries are based on operation simulations run with the CalSim II model using an extended record of runoff patterns; these patterns have been adjusted to reflect the levels of development in the source areas and, for future conditions, possible impact due to climate change accompanying sea level rise. The 2009 Draft Reliability Report also incorporates regulatory requirements for SWP and CVP operations in accordance with recent biological opinions from federal agencies.

Per the 2009 Draft Reliability Report, there are "three significant factors contributing to uncertainty" in SWP delivery reliability, one of which includes the "possible effects from climate change and sea level rise."[9] In order to better understand the potential effects, the 2009 Draft Reliability Report utilized in its modeling a climate change scenario that represents the median effects of 12 scenarios addressed in DWR's Using Future Climate Change Projections report, summarized immediately above. The draft report found that "climate changes have the potential to simultaneously affect the availability of source water, the ability to convey water, and users' demands for water."[10]

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7 *Id*. at p. 46.

8 *See* http://baydeltaoffice.water.ca.gov/swpreliability/DRAFT-DelRelRep2009.pdf.

9 *Id*. at p. 17.

10 *Id*. at p. 18.

## Other Selected Reports and Studies

### Urban Water Management Plan (December 2005)

The 2005 Urban Water Management Plan (UWMP) for the CLWA service area addresses the potential effects of global warming on California's future water supplies. Relying upon DWR's California Water Plan Update (2005), the UWMP identifies some potential impacts of global warming, based on more than a decade of scientific studies on the subject. The potential impacts include the production of hydrologic conditions, variability, and extremes that are different than what current water systems are designed to manage. Other potential impacts consist of questions on how rapidly impacts may occur to water supplies, and whether water planners and managers can protect against sudden changes.

Like other water purveyors, CLWA is relying upon DWR's commitment to continue to update and refine modeling efforts based on on-going scientific data, and to incorporate that information into future plans, reports, and studies issued by DWR. In the interim, however, CLWA and the retail purveyors in the Santa Clarita Valley have thoroughly described the available water resources in the Valley, including available local groundwater supplies, for the 25-year period covered by the UWMP. By law, the UWMP must be updated every five years, with the next update to occur no later than December 2010. The update also may be amended at any time, based on the discretion of CLWA and the retail purveyors in the Santa Clarita Valley. This five-year updating requirement ensures that global climate change and its effects on local and imported supplies will be taken into account and regularly reported.

As to local groundwater supplies, the UWMP summarizes well-established findings from recent studies and groundwater modeling, which confirm that the local groundwater basin (Alluvial aquifer and Saugus Formation) is operating within sustainable yields and, as such, the basin remains in good operating condition and can continue to support pumping in the operating ranges reflected in the 2005 UWMP, or slightly higher, without adverse results (e.g., long-term water level decline, "overdraft," or degradation of groundwater quality). The primary studies that support these findings are as follows:

(a) Richard C. Slade & Associates, LLC, "2001 Update Report, Hydrogeologic Conditions in the Alluvial and Saugus Formation Aquifer Systems," prepared for Santa Clarita Valley Water Purveyors (July 2002);

(b) CH2MHill "Regional Groundwater Flow Model for the Santa Clarita Valley, Model Development and Calibration" (April 2004);

(c) CH2MHill, Technical Memorandum "Calibration Update of the Regional Groundwater Flow Model for the Santa Clarita Valley, Santa Clarita, California" (August 2005);

(d) CH2MHill and Luhdorff & Scalmanini, Consulting Engineers, "Analysis of Groundwater Basin Yield, Upper Santa Clara River Groundwater Basin, East Subbasin, Los Angeles County, California" (August 2005);

(e) UWMP, including Appendix C, "Groundwater Resources and Yield in the Santa Clarita Valley" (December 2005); and

(f) 2006 Santa Clarita Valley Water Report (May 2007).

The August 2005 Basin Yield Report described and modeled the groundwater operating plan for the Valley. The model simulated a 78-year period of groundwater pumping, natural groundwater recharge (from rainfall and river storm flows), and natural groundwater flow and discharge that occurs in the basin. This 78-year rainfall record was derived from historical rainfall records dating back to the 1920s. Based on a review of those historical records, the simulated rainfall pattern was derived with two objectives in mind. First, the record was designed to capture historic cycles in rainfall, alternating periods of below-normal rainfall, then periods of above-normal rainfall, followed by periods of below-normal rainfall, etc. The 78-year rainfall record contained four periods of generally below-normal rainfall (ranging in length from seven to 15 years) and five periods of generally above-normal rainfall (ranging in length from six to eight years). Second, the record was designed to have a long-term volume of rainfall equal to the historic long-term average rainfall over the past several decades.

In summary, the rainfall pattern that was used in the modeling analysis was based on actual historic long-term rainfall and historic dry cycles and wet cycles. Thus, changes in climatic conditions over the past 78-year period were taken into account. If future climate change studies are published by DWR that predict changes in the strengths of future droughts and future wet periods, these effects could then be incorporated into the groundwater model to test the potential influence of climate change on the groundwater system; of course, any future studies that attempt to predict climate change effects on future local rainfall patterns are likely to have significant uncertainties. Nonetheless, when such studies are completed and available, CLWA and the local purveyors will consider them in local water planning efforts. Until then, however, CLWA and the local purveyors are relying upon the best available information presented in the reports and studies referenced above.

**Emissions Pathway Report**

"Emissions Pathways, Climate Change, Impacts on California," by Katharine Hayhoe, *et al*., dated August 24, 2004 (Hayhoe 2004), has discussed the magnitude of future climate changes based on climate projections from the modeling of greenhouse gas emissions scenarios out to the year 2100. This report shows that, by the end of the century, due to increased temperatures, the Sierra snowpack could be reduced by 30-70 percent under one emissions scenario, and as high as 73-90 percent under another

emissions scenario. The increased temperatures, along with impacts on runoff and stream flow, combined with modest declines in winter precipitation, could fundamentally disrupt California's water resources. (Emissions Pathway Report, p. 1.)

**Pondering a Climate Conundrum**

Other literature calls attention to the ongoing debate over global warming and its effects. For example, in an article presented in *Nature* (Online Version) entitled, "Pondering a Climate Conundrum in Antarctic," it has been suggested that there are cooling trends, not necessarily global warming. In that article, the authors noted a "[u]nique, distinct cooling trend discovered on the Earth's southernmost continent Antarctica overall has cooled measurably during the last 35 years - despite a global average increase in air temperature of 0.06 degrees Celsius during the 20th century - making it unique among the Earth's continental landmasses."

**Water Management Strategies**

The Natural Resources Defense Council has prepared a report summarizing the "broad potential water management impacts of climate change, the many existing climate-related activities of water managers around the West, and a full range of recommendations for water managers and staff to consider as they incorporate global warming into the planning and management of their agencies."[11] After generally surveying the potential impacts of global climate change to water supply, flood management, water quality, aquatic ecosystems, and hydropower, and the effectiveness of presently utilized water management strategies to combat climate change impacts, the report proposes a four-part water management strategy for use by water managers that consists of: (i) evaluation of a water system's potential vulnerabilities at both a local and regional level; (ii) development of responsive strategies; (iii) commitment to global climate change prevention and the endorsement of GHG emissions reductions; and (iv) increased public outreach to improve awareness of global warming and climate change. As part of this strategy, and in order to better understand and prepare for the potential impacts to water resources as a result of global climate change, the report calls on various entities and individuals to provide additional funding for research.

**Climate Warming and Water Management Adaptation for California**

Tanaka *et al.* (2006) explore the ability of California's water supply system to adapt to long-term climatic and demographic changes using the California Value Integrated Network (CALVIN), a statewide

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[11] See, Nelson, Barry, et al., July 2007, "In Hot Water: Water Management Strategies to Weather the Effects of Global Warming."

economic-engineering optimization model of water supply management.[12] The results show agricultural water users in the Central Valley are the most sensitive to climate change, particularly under the driest and warmest scenario (*i.e.*, PCM 2100), and predict a 37% reduction of Valley agricultural water deliveries and a rise in Valley water scarcity costs by $1.7 billion. Though the results of the study are only preliminary, they suggest that California's water supply system appears "physically capable of adapting to significant changes in climate and population, albeit at a significant cost." Such adaptation would entail changes in California's groundwater storage capacity, water transfers, and adoption of new technology.

**Trends in Snowfall versus Rainfall in the Western United States**

To better understand the nature of the observed changes in snowpack and streamflow timing in the west, Knowles *et al.* (2006) address historical changes in the relative contributions of rainfall and snowfall.[13] The study documents a regional trend toward smaller ratios of winter-total snowfall water to winter-total precipitation during the period of 1949-2004. The trends toward decreased winter-total snowfall are a response to warming across the region, with the most significant decreases occurring where winter wet-day minimum temperatures were on average warmer than -5° over the study period. The authors suggest that, if warming trends continue, the snowfall fraction of precipitation is likely to continue to decline, which combined with earlier melting of the remaining accumulations of snowpack, will diminish the West's natural freshwater storage capacity. This trend could, in turn, exacerbate tensions between flood control and storage priorities that many western reservoir managers face.

**Climate Change Impacts on Water for Agriculture in California: A Case Study in the Sacramento Valley**

Joyce *et al.* (2006) employ the Water Evaluation and Planning (WEAP) system, a hydrologic model that was developed for the Sacramento River Basin.[14] The study found that increasing temperatures could put a strain on the basin's water resources. Assuming an increasing urban demand for water, the effects of climate change could be mitigated if the agricultural sector adapts to the new environment. The authors considered the effect of increased irrigation efficiency and shifts in cropping and found that groundwater pumping between 2070 and 2100 was reduced when these practices were adopted.

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[12] See, Tanaka, S.K., et al., 2006. "Climate Warming and Water Management Adaptation for California. *Climatic Change*," Vol. 76, No. 3-4, June 10, 2006.

[13] Knowles, N., and D. R. Cayan. 2002. "Potential Effects of Global Warming on the Sacramento/San Joaquin Watershed and the San Francisco Estuary." *Geophysical Research Letters* 29(18):1891, doi:10.1029/2001GL014339.

[14] Joyce, B., et al. 2006. "Climate Change Impacts on Water for Agriculture in California: A Case Study in the Sacramento Valley." California Climate Change Center, State of California. White Paper, CEC-5500-2005-194-SF, March 2006.

**Climate Scenarios for California**

Cayan *et al.* (2006) consider two GHG emissions scenarios, a medium-high and a low.[15] The study found that California will experience a warming trend from 2000 to 2100, with temperatures rising between 1.7 and 5.8E C, depending on the model and the scenario chosen. This increase in temperature could potentially impact snowpack levels as the state experiences less snow and more rain. The results also indicate that snowpack in the Sierra Nevada could be reduced 32-79%, depending on the model and scenario chosen. The study does not consider the ability of California's water supply system to adapt to these potential changes.

**Global Climate Change Impacts in the United States (2009)**

This report summarizes the science of climate change, and the current and projected impacts of climate change on the United States.[16] With respect to water resources, the report concludes that "[t]he impacts of climate change include too little water in some places, too much water in other places, and degraded water quality."[17] With respect to the southwest regional analysis, the report found that "[w]ater supplies are projected to become increasingly scarce, calling from trade-offs among competing uses, and potentially leaded to conflict."[18] With that said, the report underscores:

> One of the main messages to emerge from the past decade of synthesis and assessments is that while climate change is a global issue, it has a great deal of regional variability. There is an indisputable need to improve understanding of climate system effects at these smaller scales, because these are often the scales of decision making in society. Understanding impacts at local scales will also help to target finite resources for adaptation measures. . . Further work is needed on how to quantify cumulative uncertainties across spatial scales and the uncertainties associated with complex, intertwined natural and social systems.[19]

**Analysis of Groundwater Supplies in the Santa Clarita Valley (August 2009)**

The Santa Clarita Valley Purveyors (comprised of the Los Angeles County Waterworks District 36, Newhall County Water District, Santa Clarita Water Division of the Castaic Lake Water Agency and Valencia Water Company) recently analyzed the groundwater development potential and possible

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15 Cayan, D., et al. 2006. "Climate Scenarios for California. California Climate Change Center, State of California. White Paper" CEC-500-2005-203-SF, March 2006.

16 U.S. Global Climate Research Program, 2009, *Global Climate Change Impacts in the United States*.

17 *Id*. at p. 41.

18 *Id*. at p. 129.

19 *Id*. at p. 154.

augmentation of the groundwater operating plan for Santa Clarita Valley. This analysis was undertaken in part for preparation of the next UWMP (anticipated in 2010) and in part because of recent events that are expected to impact the future reliability of the principal supplemental water supply for Santa Clarita Valley (i.e., the State Water Project). The analysis, entitled *Analysis of Groundwater Supplies and Groundwater Basin Yield Upper Santa Clara River Groundwater Basin, East Subbasin*, was published in August 2009.

The primary objective of the updated analysis of groundwater basin yield in the Santa Clarita Valley was to evaluate the planned utilization of groundwater by the Purveyors, after their consideration of potential impacts on traditional supplemental water supplies from the SWP, and with recognition of (i) the ongoing pumping by others for agricultural and other private water supply, (ii) the sustainability of the groundwater resource, and (iii) the physical ability to extract groundwater at desired rates.

A second objective of the updated groundwater basin yield analysis was to investigate and describe potential impacts of expected climate change on the groundwater basin and its yield. A third objective was to consider potential augmentation of basin yield via potential artificial groundwater recharge using storm water runoff in selected areas of the basin as being planned by the Los Angeles County Flood Control District.

With respect to the second objective, and as stated in Section 5.4, Climate Change Summary, of the analysis:

> Examination of the three simulated climate change scenarios was undertaken to provide a level of quantification to the possible impact of climate change on local groundwater basin yield and availability of groundwater as part of overall water supply to the Valley. In light of the range of global climate model output that was considered for development of the local scenarios analyzed herein, it is obvious that there is neither a unique result that can be expected to become a representative hydrologic condition in the Valley, nor is there a unique result that can be expected in terms of basin yield and associated sustainable groundwater supply as an outcome of climate change. Obviously, the Valley does not get to "choose" a future climate scenario, but rather will have to manage within whatever future patterns of rainfall actually occur over time, whether the future rainfall exhibit wet-dry cycles that are similar to or different from historically recorded conditions.
>
> [¶] Perhaps most useful in the consideration of climate change effects analyzed herein is with respect to results over the UWMP planning horizon of 20 to 25 years. For the range of relatively wet to relatively dry conditions analyzed herein, all three scenarios suggest that the 2008 Operating Plan can be considered sustainable and, with the same local exceptions as simulated through a repetition of historical hydrology (e.g. mainly at and above Mint Canyon), achievable over the UWMP planning horizon. Beyond that horizon,

> greater uncertainty exists because the global climate models use different emissions scenarios and also become increasingly uncertain over time because of predictive uncertainty pertaining to the forward-looking representation of the many physical processes that affect climate into the future. As a result, for time periods beyond the UWMP planning horizon, some models predict long-term drying and subsequent sustained declines in groundwater levels, which would result in a smaller local groundwater supply over time, while other models predict hydrologic conditions similar to or wetter than those that have been historically observed, in which case the 2008 Operating Plan can be considered sustainable, albeit with some local issues relative to actual pumping capability at certain times (mainly in the Alluvium at the eastern end of the Valley).

## Conclusions Reached From Literature Survey

In summary, DWR has not yet fully incorporated parameters to account for climate change; however, as the literature and modeling tools continue to develop in order to assess such risks, DWR will incorporate such information into successive updates to the California Water Plan. In addition, DWR is committed to the preparation of the biennial assessment reports of SWP delivery reliability. In the meantime, DWR reports that the results of its updated reports represent the best available information at this time.

Based on the above data, DWR should continue to utilize on-going studies, as they become available, in developing strategies for the future management and development of California's water resources. At this time, however, it is appropriate to terminate any further analysis of potential future global climatic changes and their effects on California's water supplies, consistent with Section 15145 of the CEQA Guidelines.