An Interagency Work Team's Plan for Assessing Risks of Climate Change on Management of California's Water Resources

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AN INTERAGENCY WORK TEAM'S PLAN FOR ASSESSING RISKS OF CLIMATE CHANGE ON MANAGEMENT OF CALIFORNIA'S WATER RESOURCES

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Abstract
The California Department of Water Resources and the U.S. Bureau of Reclamation have formed a joint Climate Change Work Team to provide qualitative and quantitative information to managers on potential impacts and risks of climate change to California's water resources. This paper describes the goals of the work team, accomplishments to date, and future directions.

INTRODUCTION

More than 20 million Californians rely on the State Water Project (SWP) and federal Central Valley Project (CVP) for their water supply. SWP and CVP water irrigates nearly 3.6 million acres of farmland. The two projects deliver an average of 10 million acre-feet of water annually. These complex water storage and conveyance systems are operated by the California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (Reclamation) for water supply, flood management, environmental protection and recreational uses.

Climate change and its impact on urban, agricultural, and environmental water supply has become a significant concern to California's water planners. In California, the ability of the SWP and the CVP to meet the water demands of its customers and the environment depends heavily on the accumulation of winter mountain snow melting into abundant spring and summer runoff. In essence, the snow pack is winter precipitation carried over to the subsequent dry season. A warming planet may reduce this natural water storage mechanism. Projected increases in air temperature may lead to changes in the timing, amount and form (rain or snow) of precipitation, changes in runoff timing and volume, sea level rise impacts on Delta water quality, and changes in the amount of irrigation water needed due to modified evapotranspiration rates.

In the past climate change was typically considered qualitatively in this planning process. Legislative mandates in California including a climate change Executive Order (S-3-05) by Governor Schwarzenegger and updates to the California Water Plan (Bulletin 160) call for more quantitative assessments of climate change impacts. To address these concerns, DWR and Reclamation have formed a joint Climate Change Work Team to provide qualitative and quantitative information to managers on potential impacts and risks of climate change to California's water resources. This paper describes the goals, work to date, and future directions of the Climate Change Work Team.

MISSION STATEMENT AND GOALS

The mission of the Climate Change 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 to the decision making process on potential impacts and risks of climate change, flexibility of existing facilities to accommodate climate change, and possible mitigation measures.

Typically climate change investigations result in impacts assessments referencing one or more climate scenarios, but without any estimates of scenario probabilities. It is difficult for water resources managers to weigh decisions using impacts information without complementary information on scenario probability. Estimating climate projection uncertainty among currently available models and emissions scenarios is an initial step to providing probabilistic information, and facilitates a major goal of the Climate Change Work Team: developing methodologies that inform decision-makers on risks rather than impacts (Figure 1).

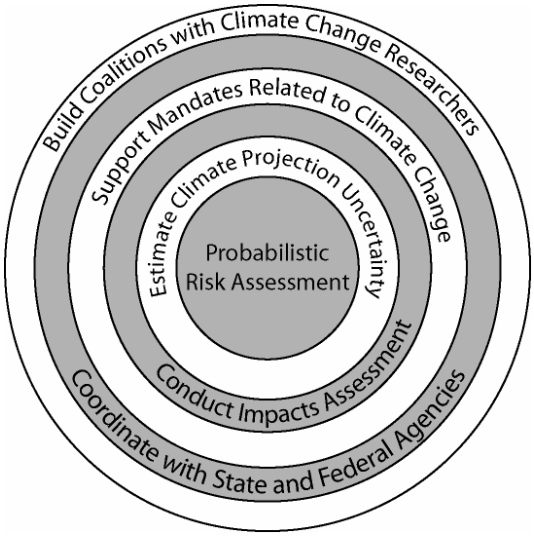

Figure 1: Goals of the DWR-Reclamation Climate Change Work Team

Team goals include:

- ❑ State/Federal coordination with other agencies to determine mutual areas of interest, common methodologies, and comparable results
- ❑ Build coalitions with experts in climate change and seek their guidance in climate scenario selection and estimation of climate projection uncertainty
- ❑ Support mandates on climate change
  - Governor Schwarzenegger's Executive Order # S-3-05, June 1, 2005
  - California Water Plan Bulletin 160
- ❑ Assess impacts to operations of the SWP and CVP for several climate change scenarios
- ❑ Assess risk for the SWP and CVP systems based on combined results from impacts assessment and estimated climate projection uncertainty
- ❑ Evaluate risk mitigation options ranging from adaptation using current infrastructure to more extensive measures involving water supply development

WORK PLAN-ONGOING TASKS

The Climate Change Work Team continues to develop and evolve its work plan to meet the needs of management. Progress to date and future directions are presented below.

Coordination and Coalitions

Two of the goals of the Climate Change Work Team are to coordinate with other state and federal agencies and to build coalitions with climate change researchers. Formation of the work team has enhanced coordination between DWR and Reclamation on planning issues related to climate change. For DWR, work team members represent diverse sections of the organization including Modeling Support, Planning and Local Assistance, Flood Management, and Environmental Services. A productive working relationship has also been established with the California Energy Commission. The work team has also developed working relationships with several climate change research groups including the California Applications Center, Lawrence Berkeley Laboratory, Lawrence Livermore Laboratory, Scripps Institute of Oceanography, U.S. Geological Survey, the University of California at Berkeley and at Davis, and the University of Washington Climate Impacts Group.

Support Mandates

Executive Order S-3-05

On June 1, 2005, Governor Schwarzenegger issued Executive Order (EO) S-3-05 on climate change. The EO establishes targets for reductions in green house gas emissions and mandates biannual reporting on five areas related to climate change, including water supply. The first climate change reports are due in January 2006.

To meet the goals of the EO, a Climate Action Team (CAT) was formed with representatives from various state agencies. The CAT selected four climate change scenarios for initial analysis for the January 2006 reports. The climate change scenarios were produced for the United Nations' Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report due out in 2007. The four scenarios represent two greenhouse gas (GHG) emissions scenarios, A2 and B1 from IPCC, each represented by two different Global Climate Models, the Geophysical Fluid Dynamics Lab model (GFDL) and the Parallel Climate Model (PCM). The A2 emissions scenario assumes slow technological changes and high population growth which results in significantly higher GHG emissions. The B2 scenario represents sustainable development and results in the lowest increase of GHG emissions of the IPCC scenarios. Both the GFDL and PCM models project future warming, with GFDL indicating more warming than PCM.

Since water resources is only one area out of five considered in California's mandated climate change report, the DWR-Reclamation Climate Change Work Team is writing a supplemental report expanding on incorporating climate change into planning and management of California's water resources. The work team is analyzing the same four scenarios selected by the CAT. The supplemental report has a target publication date of January 2006 to coincide with the publication of the mandated report. The work team is coordinating its analysis with researchers working on the mandated report in order to share data and produce results that are comparable and complementary.

California Water Plan-Bulletin 160

The Water Plan is updated every five years and provides specific water management recommendations for the next 25 years. These recommendations are directed to decision makers within the Executive and Legislative branches of California government, DWR and other State agencies, and to local government. Climate change is a key consideration for many of the 14 recommendations identified in the 2005 California Water Plan, and it is specifically addressed in an individual recommendation as follows: "State government should help predict and prepare for the effects of global climate change on our water resources and water management systems."

The 2005 California Water Plan includes qualitative discussion of climate change, and the next Water Plan update will include quantitative analysis. The Climate Change Work Team includes a member from the Water Plan update staff. The methodologies and analysis being developed by the work team will produce quantitative assessments of climate change risks for various aspects of California's water resources that could be used for the next Water Plan update.

Develop Impacts Assessment Methodologies

The Climate Change Work Team is conducting impacts assessments for the four climate change scenarios selected by the CAT. The four climate change scenarios represent two green house gas emissions scenarios (A2 and B1 from IPCC) simulated by two different Global Climate Models (GFDL and PCM). Global results include air temperature, precipitation and radiation fluxes. Results from the global simulations were then dynamically downscaled to California at 1/8th degree latitude/longitude resolution using the Variable Infiltration Capacity (VIC) model (Maurer, 2005). The downscaled data provide precipitation, air temperature, wind speed, surface air humidity, soil moisture, and streamflows. The work team is using the global and downscaled data to develop impacts analyses in areas including: reservoir inflows, SWP-CVP operations, Delta water quality, flood management and water supply, and evapotranspiration (Figure 2).

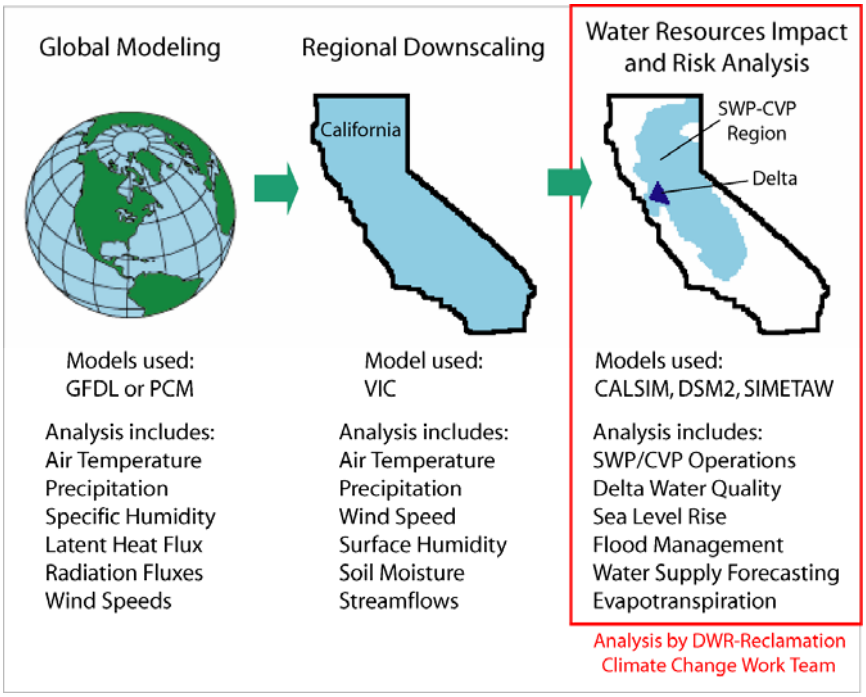

Figure 2: Climate Change Impacts and Risk Assessment Methodology

Reservoir Inflows

Streamflow data have been obtained for several locations for the four climate change scenarios. Based on this data, monthly average changes in reservoir inflows were computed for each scenario for projections around the year 2050. The projected inflow changes were used to modify historical reservoir inflows for important Sacramento and San Joaquin Valley reservoirs to create time series of reservoir inflow reflective of the 2050 projections. The resulting reservoir inflow data are used to simulate the SWP and CVP operations using CalSim-II.

Changes in reservoir inflows for the 2050 projections for the four climate change scenarios are shown in Figure 3. All four scenarios show an increase in reservoir inflows due to increases in winter precipitation. This is likely due to warmer air temperatures shifting more of the precipitation from snow to rain. Consequently, all four scenarios show a decrease in reservoir inflows in the spring due to decreased snow pack and thus decreased spring runoff.

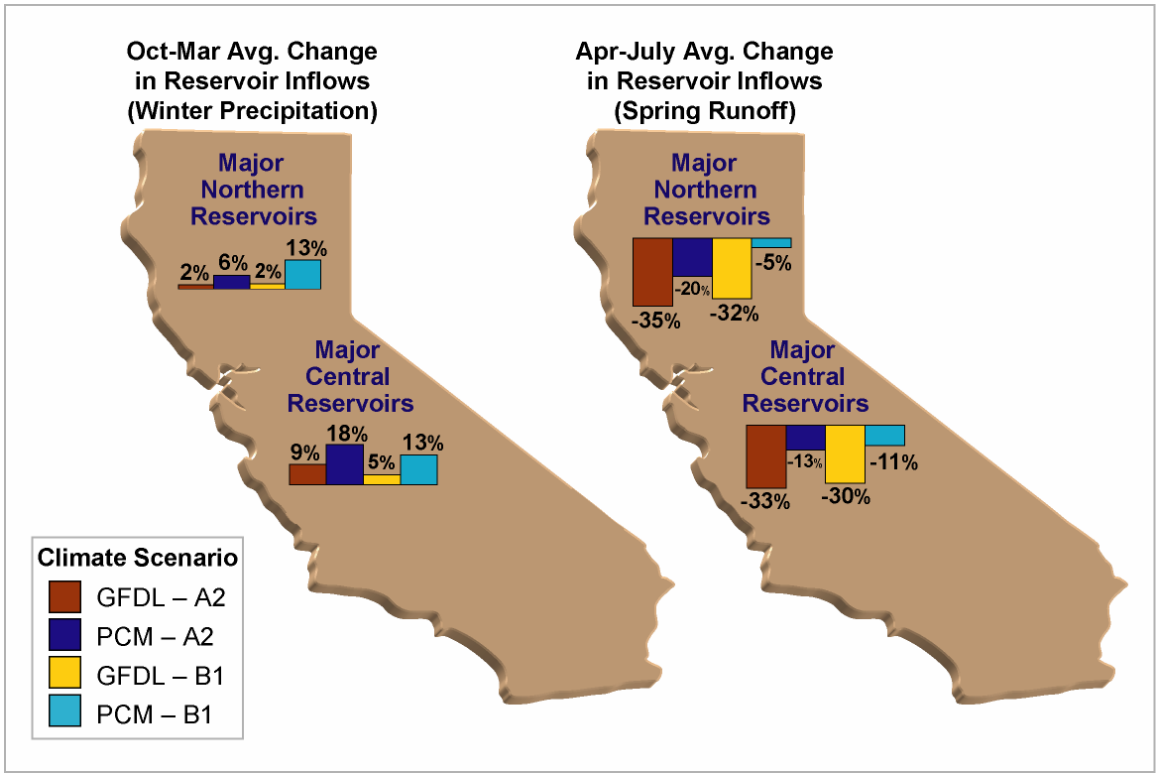

Figure 3: Preliminary Estimations of Reservoir Inflows for 2050 Climate Change Projections

SWP-CVP Operations

The work team has begun to study potential climate change impacts to the SWP and CVP for the four climate change scenarios identified previously. CalSim-II, a joint SWP/CVP planning model, was used simulate project operations for each climate change scenario and a base case. Inflow input to CalSim-II was modified to reflect changes in seasonal and annual runoff into major project reservoirs as discussed above. No operational adaptations were made in these simulations to lessen the impacts of climate change on water supply. The rules and regulations in place today are assumed to be in place in 2050. Analysis of the simulations will include

changes in delivery reliability and annual average carryover storage. Also, we will discuss the interaction of various operating rules and regulations such as water allocations, flood control, in-stream flow requirements, and Delta water quality requirements with the climate altered runoff to suggest potential mitigating operational flexibilities for future study.

Delta Water Quality including Sea Level Rise

The Sacramento-San Joaquin Delta is an integral part of California's water resources management system. Releases from SWP and CVP reservoirs flow through the Sacramento and San Joaquin Rivers into the Delta. Pumping stations in the southern Delta pump water into canals for distribution to central and southern California. The Delta also provides drinking water, irrigation water for local agriculture and habitat for several species. Delta water quality is influenced by the interactions between tidal inflows from San Francisco Bay and freshwater inflows from the Sacramento and San Joaquin Rivers.

The Delta Simulation Model 2 (DSM2) is being used to evaluate changes in water quality due to climate change for the four scenarios selected by the CAT. Modified reservoir releases are provided by output from the CalSim-II model as described above. Similar to the SWP/CVP impacts studies, operations were not modified to try to mitigate for climate change impacts. Initial analyses are focusing on impacts to meeting water quality standards. Two studies are being conducted for each scenario: one for present sea level conditions and one for a one foot increase in sea level.

Flood Management and Water Supply Forecasting

In order to better understand the risks associated with global climate change on California's water resources, it is important to be able to quantify climate change impacts on the ability to provide adequate flood control and the impacts on seasonal water supply. In order to make such quantifications of risk, it is necessary to produce datasets suitable for such analyses.

For flood frequency analysis synthetic future daily flow datasets could be produced from model output for performing traditional flood frequency analyses. These peak daily and peak 3-day flows at key points would provide a basis for comparison with the historical record. At this time however, there is no such dataset sufficient to provide meaningful results. In the absence of such a dataset, two types of surrogate analyses can be performed. The first examines long-term historical data (~100 years) and analyzes changes in the flood frequency that have occurred with time. Such changes would be presumed to be the result of an approximately one degree Fahrenheit warming of the global mean temperature. These results then can be extrapolated to future warming levels. Such extrapolations are based on many assumptions which must be evaluated in order to quantify the uncertainty in the process. The second approach examines historical data in order to identify critical atmospheric circulation parameters and their threshold values associated with extreme flooding events. Analyses of global climate model simulations can then be made of projected future flood producing circulation patterns.

For water supply analyses, it is important to identify potential changes to the land covered by snow pack and to identify changes to the magnitude and timing of snow pack growth and decay. Earlier melt patterns may necessitate new forecast bulletins such as a March to May snow pack status being created to complement existing April-July water supply forecasts. The inclusion of

March in the forecast process introduces a large element of variability. Uncertainties related to this variability would have to be quantified as part of the water supply forecast product. Improved understanding of the potential future changes to the magnitude and timing of water supply runoff will enable better forecast products which can improve adaptive strategies for water supply operations in the state.

Evapotranspiration

California agriculture produces over 350 crops which provide over half of the nuts, fruits and vegetables in the United States (USDA, 2003). California's agricultural production in 2003 was 29.4 billion dollars. Shifts in agricultural production due to climate change could have a profound affect on both California's economy and the nation's food supply.

Increasing air temperature and carbon dioxide (CO_2) concentrations could affect evapotranspiration (ET) rates for crops, and thus affect agricultural production. Analysis of the influence of climate change on evapotranspiration is based on the Penman-Monteith equation for reference evapotranspiration (ETo), which is commonly used as a measure of evaporative demand. We assume the stomatal resistance will increase with rising CO_2 concentration based on studies of stomatal response to CO_2, and that this will also increase canopy resistance to transpiration. There is, however, limited literature available on in-situ measurements of canopy resistance in elevated CO_2 conditions. A literature search is being completed to obtain the canopy resistance data. Special attention is being given to the free air CO_2 enrichment (FACE) studies in our data search. Nitrogen control of stomata limitations of photosynthesis, leaf area responses and water use efficiencies are included in the initial survey. Evapotranspiration relationships reflecting climate change will be incorporated into the SIMulation of Evapotranspiration of Applied Water (SIMETAW) model. SIMETAW will then be used to estimate potential impacts of climate change on evapotranspiration rates for selected crops.

Changes in evapotranspiration rates could lead to changes in the amount of water consumed in agricultural production. Crop shift patterns and population changes that are expected to influence agriculture production in the future are being addressed. DWR's Consumptive Use (CU) model is being modified to account for climate change. This model provides information on consumptive use for other analysis tools including the CalSim-II and DSM2 models.

WORK PLAN-FUTURE DIRECTIONS

Mitigation Measures

Once impacts assessments have been completed, mitigation measures can be explored. Flexibility of existing discretionary operating rules to compensate for climate change impacts will be examined. Additional mitigation measures examined may include changes to operating rules and structural modifications such as changes in storage and conveyance capacity.

Modeling Tool Integration

Several different mathematical models are being used to assess impacts of climate change by translating changes in factors such as sea level, crop evapotranspiration, and precipitation into water supply changes. Currently, there are various models developed and/or used within DWR and Reclamation in different aspects or stages of SWP and CVP water supply planning. In order

to efficiently evaluate the overall impact of climate change on the water supply, these models need be streamlined and integrated by creating a climate change model suite. Within the model suite, models are linked through automatic data conversion and transfer from one model to another. The model suite features plug-n-play and is flexible enough to add or remove any model easily. Due to the limitations of individual models, initial integration efforts for the model suite will focus on the SWP and the CVP, and areas tributary to the Sacramento-San Joaquin Delta. A pilot study linking the CU and CalSim-II models is underway for the model suite.

Probabilistic Risk Assessment

A major goal of the work team is to extend the analysis prospective for long-term water resources planning from "assessing impacts" to "assessing risk." Decision makers require estimates of the likelihood of potential impacts in order to create appropriate response strategies.

The work team plans to collaborate with climate change research groups on the selection of an ensemble of climate change scenarios for analysis, representing a spectrum of climate models and emission scenarios. The ensemble uncertainty would then be quantified at the region-scale in terms of annual shifts in precipitation and air temperature. Ensemble uncertainty would then be used to classify ensemble members probabilistically, with caveats duly noted. These scenario probabilities would then be combined with associated impacts assessed using the previously discussed methodologies in order to produce risk information on a variety of system metrics (e.g., annual water deliveries, end-of-September storage, summer stream temperature). This risk information becomes the baseline for subsequent mitigation studies

SUMMARY

The Climate Change Work Team has demonstrated growth in Agency capability to provide planners with relevant information on potential climate change effects. Additional products from work team activities include identification of data and technology gaps and development of innovative analytical approaches using familiar Agency planning tools. Team interactions with California climate research groups are improving Agency knowledge on climate modeling and projection uncertainties. The work team will continue to evolve to meet the needs of water resources managers and to utilize new information and methodologies as they become available. Future activities include system flexibility analyses and risk assessments, each potentially contributing to management activities such as updates to the California Water Plan (Bulletin 160) and the Governor’s executive order on climate change.

REFERENCES

Maurer, E.P., 2005. Uncertainty in hydrologic impacts of climate change in the Sierra Nevada Mountains, California under two emissions scenarios, Climatic Change (submitted 4-29-05)

U.S. Department of Agriculture, 2003. California Agricultural Statistics 2003.