# Statewide Water Analysis Network

# Scenario Analysis Technical Approach

# Workshop Notes

June 19, 2008

## General questions and comments on scenarios and use of WEAP

- Question: How do the Water Plan scenario factors relate to specific geographic locations?
    - Response: In general, scenario factors are quantified at the Hydrologic Region or Planning Area scales that are used for the Water Plan studies. However, most factors are aggregated up from a finer resolution data. For example, future population estimates are aggregated up from county estimates.

- Question: How will the Water Plan scenarios be used to identify uncertainty in water management?
    - Response: Uncertainty is identified in the scenario approach by use alternative values of key uncertainty factors in each scenario. For example, because future population is an uncertain factor each scenario includes an alternative projection.

- Questions: How is the proposed analysis of many scenarios different from sensitivity analysis?
    - Response: A sensitivity analysis evaluates how modeled results would change under different assumptions about model inputs. Often it is used after a particular solution is identified. In this case, the solutions performance would be evaluated under different assumptions. If these changes are deemed not to be significant then the identified solution is viewed as "robust". If the solution performs poorly, then one may revisit available options. A key feature of this approach is that assumptions about model factors (or uncertainties) are made at the beginning of the analysis and then only after solutions are identified are those assumptions tested. This can be problematic when there are significantly different views about what these initial assumptions ought to be. In other words, the initial specification of uncertain model factors can drive the results in certain ways, even if a sensitivity analysis is done. The water plan analysis, instead, integrates the sensitivity analysis directly into the process of evaluating strategies, and thus eliminates the need to make contentious assumptions at the beginning of the analysis. By creating scenarios, a wide range of plausible assumptions are evaluated, so there is no bias in the analysis towards any specific world view. The analysis then evaluates how well different strategies perform against these scenarios and identifies vulnerabilities (assumptions which lead the strategies to perform poorly). These vulnerabilities then suggest ways to develop more robust strategies. Stated another way, scenario analysis identifies a strategy and then

tests the assumptions that led to that choice. Our methods will evaluate the assumptions though the generation of many scenarios and then seek robust strategies.

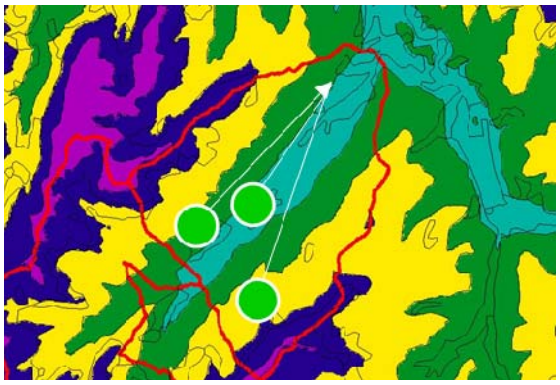
- Question: How will the basic data and assumptions of the WEAP analysis be made available for use by other agencies and the public? Is the WEAP model and data available to the public? Is WEAP a proprietary model?
    - Response: At minimum the WEAP application used for Water Plan scenarios will be made available in a free player version that allows anyone to run the application and view results. In addition, the Stockholm Environment Institute has indicated they will provide a working copy of the WEAP application to those actively involved in the Water Plan stakeholder process.

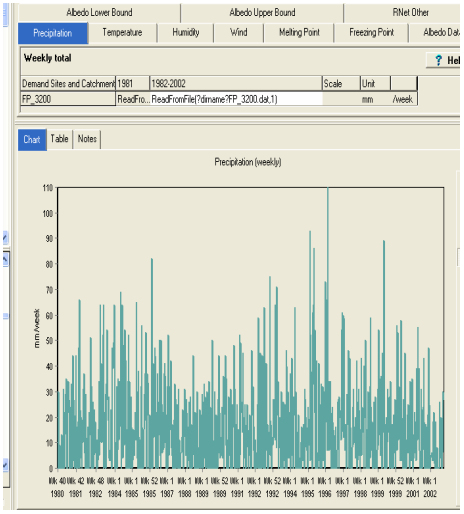
- Question: Will the Water Plan scenarios evaluate uncertainty using probability approaches?
    - Response: The Water Plan will not determine the probability that particular future scenarios will occur. The Water Plan scenarios are intended to serve as an alternative to a formal probability based approach.

- Comment: With the proposed approach, you do not know how likely each scenario will be. It would be nice if you can say there is X percent chance that scenario A will happen or there is Y percent chance that scenario B will occur. In the future, when and if you decide to move more towards a performance based, probabilistic method, you may be able to find the most likely scenario through your thousands of combinations. Around the optimum scenario, you can add uncertainties in term of deviations or exceedance intervals so people can have a feel for how likely it will be.
    - Response: The Water Plan will not determine the probability that particular future scenarios will occur. The Water Plan scenarios are intended to serve as an alternative to a formal probability based approach.

- Question: How will the WEAP model be validated? How accurately can you model catchments in WEAP?
    - Response: There are a variety of validation criteria that will be used to establish model credibility. These include classical comparisons of modeled vs. observed streamflow at various locations throughout the region. We will use a split-sample approach that uses two separate periods (e.g. 1970 through 1985 calibration and 1986 through 200 for validation) for calibration and validation. In addition, we will evaluate the model's ability to reproduce both local and regional water balances, including managed and unmanaged streamflow, reservoir storage, agriculture and urban water demands, and the allocation of ground water and surface water supplies to various uses. The state has created detailed mass balance estimates at the Planning Level, including inflows to individual PA's, and a break-down of consumptive use and supplies by type. To be credible, WEAP should be capable of reproducing these mass balances.
    - We will be representing catchments as geo-located objects based on a set of fixed areas defined by individual 500 meter elevation bands. The sum of the area in

each band will total the area of each individual catchment. Each band will make use of a unique climate sequence of precipitation, temperature, relative humidity and wind speed. Each catchment will also be defined by with land uses for each catchment defined through GIS analysis, which do not have spatial specificity. The two figures below show a catchment (red-outline), with elevations bands (colors) underlain by land use (dark lines). The 'green-dots' represent WEAP hydrologic objects, where unique land use and climate are defined for each. The accuracy of the hydrologic simulation will be determined through statistical analysis of the modeled vs. observed streamflows. WEAP has been shown to be quite capable of reproducing observed hydrographs (Yates et al. 2005).

o 




- Comment: The Water Plan scenarios need to perform a basic threshold analysis to determine limits or breaking points of the system.
    - Response: This is a goal of the scenario analysis for Update 2009.

- Question: How does Planning Area scale analysis in WEAP relate to the statewide scale?
    - Response: For Update 2009 we are testing the application of scenarios for two Hydrologic Regions that further breakdown the detail to the finer resolution Planning Areas. This approach may be expanded statewide in future Water Plans if resources are available.

- Comment: Water Plan scenarios need to provide "concrete" rather than "abstract" answers/solutions to present to the public and decision makers. For example: What are the critical thresholds? What are the critical impacts? Possibly use RAND work done with Inland Empire to model this approach?
    - Response: This is a goal of the scenario analysis for Update 2009.

- Comment: Water Plan scenario analysis needs to look at developing cost estimates for different response packages.
    - Response: This is a goal of the scenario analysis for Update 2009.

- Comment: Water Plan scenarios needs to inform local agencies about the State role in local and regional water plans.
    - Response: This is a goal of the scenario analysis for Update 2009.

- Comment: Water Plan scenarios need to include local land use information.
    - Response: This is a longer term goal for the Water Plan.

- Question: How will the Water Plan be addressing resource sustainability?
    - Response: Resource sustainability will primarily be addressed through evaluation criteria used to describe the performance of resource management strategies. Specific evaluation criteria have not been developed so far.

- Question: Can the Water Plan scenario analysis in WEAP show how groundwater is used during dry years?
    - Response: The representation of groundwater in the Water Plan scenarios will be different depending on the resolution of the analysis performed. At the coarser Hydrologic Region scale performed for the entire state, only simple groundwater storage and withdrawal will be described. This approach will likely show a simple wet and dry year operation. The finer resolution Planning Area analysis performed for the Sacramento and San Joaquin Hydrologic Regions will include a simplified interaction with surface water and infiltration of applied water in addition to the storage and withdrawal. This approach will also include wet and dry year operation.

- Comment: It would be good if Water Plan WEAP applications were provided at various geographic scales. This is imperative for local area buy-in.
    - Response: A longer term goal for the Water Plan is to work more closely with local and regional groups to develop common information sources and planning objectives.

- Comment: Need to develop a user group for all WEAP users and watershed groups.
    - Response: This is an excellent suggestion.

- Comment: The State needs to develop/encourage protocols that would allow the nesting or integration of different models by different agencies in a way that is compatible with the Water Plan scenario analysis.
    - Response: This is a longer term goal for the Water Plan.

- Question: How are plant consumptive use and soil moisture accounting performed in WEAP?
    - Response: WEAP uses a one-dimensional soil moisture accounting method to calculate the partitioning of effective precipitation (i.e. precipitation plus applied water and snow melt) between surface and sub-surface fluxes for a watershed unit, which is typically divided into several fractional areas that represent different land use (e.g. crop types) and/or soil type conditions. A water balance is computed for each fractional area. Changes in soil moisture are determined by

calculating fluxes into and through the soil – infiltration, evapotranspiration, interflow, and deep percolation – at each timestep. These fluxes are dependent upon antecedent soil moisture conditions and represented using the governing equation

$$R_d \frac{dz}{dt} = P_e(t) - PET(t)k_c(t)\frac{5z - 2z^2}{3} - P_e(t)z^{RRF/2} - fk_s z^2 - (1-f)k_s z^2$$

The left hand side of the equation represents the change in soil water storage. The terms on the right hand side of the equation represent effective precipitation, evapotranspiration, surface runoff, interflow, and deep percolation, respectively. Because each of the storage and flux terms are dependent upon soil moisture, $z$, an iterative solution is used to determine $z$ at each timestep.

In this equation, $z$ is the relative soil water storage given as a fraction of the total effective storage in the root zone, $R_d$; $P_e$ is the effective precipitation; $PET$ is the Penman-Montieth reference crop potential evapotranspiration; $k_c$ is the crop coefficient; $RRF$ is the runoff resistence factor of the land cover (higher values lead to less runoff); $k_s$ is an estimate of the root zone saturated hydraulic conductivity; and $f$ is a partitioning coefficient that fractionally partitions water horizontally (interflow) and vertically (deep percolation).

- Question: Will the Water Plan scenarios account for changing crop patterns over time?
  - Response: Yes. Each of the hand crafted scenarios will include different projections of future agricultural land use.

- Question: How does WEAP simulate surface water – groundwater interaction?
  - Response: WEAP models groundwater-surface water interactions using a stylized representation of the system. Groundwater can be represented as a wedge that is symmetrical about a river, such that the flux from one side of the wedge represents half of the total rate. The flux volumes are calculated using the Darcy equation and are dependent on hydraulic conductivity, a representative distance to the river, and the elevation between the groundwater table relative to the wetted depth of the river.

- Question: Does WEAP employ Optimization solver? If not, how the constraints are handled in WEAP?
  - Response: Yes. WEAP uses an optimization routine to allocate available supplies to all demands, according to priorities and preferences and other constraints. WEAP will try to allocate equal amounts of water (as a percentage of their demand) to all demands with the same priority—these demands are considered to be in the same "equity group." This is accomplished in the linear program (LP) with the use of shadow prices to determine which demands are constrained from receiving their full requirement, so that other demands in the same equity group can receive more than the constrained demand. Because the LP optimizes allocations across the entire system for one time step, upstream and downstream

demands and supplies can be balanced. This means that upstream demands do not automatically have priority over downstream demands for allocations of supply.

Physical flow constraints can be specified for diversions and wastewater treatment plants. Reservoir operating rules include constraints (no releases from the dead pool) as well as rule curves that specify target storage levels. WEAP converts these target storage levels into demands for water that can be prioritized among the other consumptive and non-consumptive demands in the system for allocation of water.

## Climate related questions and comments

- Question: How do the California Energy Commission (CEC) climate projections/scenarios relate to the Water Plan scenarios planned for use in Update 2009?
    - Response: The scenario analysis will directly use the CEC climate scenarios. We will use monthly downscaled projections of temperature and precipitation from the global models simulations corresponding to the 12 CEC scenarios (6 models x 2 global emissions scenarios). We may also evaluate additional scenarios from other GCM simulations not included in the CEC set or crafted to reflect particular conditions of interest (e.g. significant drought at a particular time in the simulation).

- Comment: There needs to be a statistical evaluation of the hydrologic variation contained in the CEC climate projections/scenarios, specifically to see if there are drought periods.
    - Response: Excellent suggestion.

- Question: How were the 12 CEC climate projections/scenarios chosen?
    - Response: See appended document on the selection of the projections developed by the Climate Action Team.

- Comment: The Water Plan scenarios needs to provide a feedback loop with the Governor's climate assessment report.
    - Response: This is a goal of the scenario analysis for Update 2009.

- Comment: Need to look at the work Ed Maurer has done to project climate parameters (in addition to temperature and precipitation) and use as appropriate.
    - Response: Excellent suggestion.

- Question: What will be done to address the problem of bias in climate parameters from down scaled data?
    - Response: Our climate scenarios will come directly from the 12 CEC climate projects/scenarios. The bias correction and spatial downscaled has already been done for us.
- Question: How will abrupt climate change events be addressed in the Water Plan, and specifically in the Water Plan scenarios planned for use in Update 2009?

  - Response: Our primary focus is on the CEC climate scenarios, but we may also develop additional scenarios that are reflect some notion of what would happen to precipitation and temperature over California under abrupt climate change

- Question: Is salinity in the Delta the only sea level rise factor to be considered in the Water Plan scenarios planned for use in Update 2009?
  - Response: Yes.

- Question: What assumptions (what specific level) will be used for sea level rise considered in the Water Plan scenarios planned for use in Update 2009?
  - Response: To date, we have not settled on specific sea level rise elevations. However, the final levels used in the analysis will be consistent with those used in the Governor's report.

- Question: Will the Water Plan scenarios look at more extreme ranges of future climate variability? Answer: There is the potential to use information on extreme droughts from tree ring studies.
  - Response: Our primary focus is on the CEC climate scenarios, but we may also develop additional scenarios that are reflective of conditions of interest in the paleorecord.
- Comment: Need to develop a visualization program for WEAP to look specifically at climate change issues.
  - Response: Stockholm Environment Institute is currently working with Google Earth in this regard.

- Comment: The Water Plan scenarios need to address or plan ahead for climate change and such things as shifting of the timing (magnitude, frequency, duration) of the hydrological cycle.
  - Response: This is a goal of the scenario analysis for Update 2009.

- Comment: Consider using the Delta ANN's developed for the CALSIM model. Currently 4 Ann's have been trained to handle 4 sea level rise scenarios (1ft SLR, 2ft SLR, 1ft SLR + 4inch amplitude and 2 ft SLR +4inch amplitude). There is an ANN for the X2 standard.
  - Response: This is an excellent suggestion. We may not include this feature for Update 2009 due to resource and schedule contraints.

- Comment: It is imperative to show local extremes in Water Plan scenarios.
  - Response: Accurately capturing local details is a longer term goal for the Water Plan. This will require significant integration and cooperation between the Water Plan and local planning efforts.

## Flood management related questions and comments

- Question: Can the proposed Water Plan scenario analysis with WEAP be used to tell decision makers how much excess water will be available for use or the reservoir capacity needed to manage flood events?
    - Response: The Water Plan scenarios for Update 2009 will have limited ability to evaluate flood management actions because we are using a monthly time step and are not routing flood flows. Integrating the Water Plan scenarios with flood management is a longer term goal for the Water Plan.

- Comment: Monthly and weekly time steps in the proposed Water Plan scenario analysis with WEAP are too coarse to answer many questions related to flood management and system reoperation.
    - Response: The Water Plan is interested in exploring how a finer time step can be used. One option may be to link the monthly scenario model with more detailed models developed and maintained by related planning efforts. Integrating the Water Plan scenarios with flood management is a longer term goal for the Water Plan.

- Comment: Suggest you use historic data to compare a daily to a monthly reservoir operation and evaluate how significant the differences are. Need to look at operation of flood control rules and significance of daily variability as they relate to peak storage estimates. You could use WEAP for a shorter time span, say 5 years instead of 30 years and use different time intervals, say one day or one week to check out how they affect the results.
    - Response: Excellent suggestion. Integrating the Water Plan scenarios with flood management is a longer term goal for the Water Plan.

- Comment: Identifying water management strategies in the Water Plan scenarios will be helpful to flood managers.
    - Response: The Water Plan is interested in developing information that is useful to related planning efforts.

- Comment: Water Plan needs to strive for a model that can utilize shorter time steps.
    - Response: The Water Plan is interested in exploring how this might be done. One option may be to link the monthly scenario model with more detailed models developed and maintained by related planning efforts.

- Comment: Water Plan scenarios need to consider other flood impacts besides reservoir storage and releases (like levee vulnerabilities and inundation areas).
    - Response: Integrating the Water Plan scenarios with flood management is a longer term goal for the Water Plan.

- Question: Will the Water Plan scenario analysis with WEAP evaluate frequency of flows in flood bypasses?

  - Response: The Water Plan scenarios will only represent flood bypasses for the finer resolution Planning Area analysis performed for the Sacramento and San Joaquin Hydrologic Regions using a monthly time step. The coarser Hydrologic Region scale performed for the entire state will not include operation of flood bypasses.

- Question: Will the Water Plan scenario analysis evaluate seepage and infiltration of water in the flood bypasses?
  - Response: The Water Plan scenarios will only represent flood bypasses for the finer resolution Planning Area analysis performed for the Sacramento and San Joaquin Hydrologic Regions using a monthly time step. The flood bypass operation can include a simple representation of infiltration as a function of the total bypass flow. The coarser Hydrologic Region scale performed for the entire state will not include operation of flood bypasses.

## Environmental / Water Quality related questions and comments

- Question: Can the Water Plan scenario analysis with WEAP show how often bypasses (such as Yolo) can be utilized for environmental and ground water needs; irrespective of flood control and water supply needs?
  - Response: The Water Plan scenarios will only represent flood bypasses for the finer resolution Planning Area analysis performed for the Sacramento and San Joaquin Hydrologic Regions using a monthly time step. The flood bypass operation can include a simple representation of infiltration as a function of the total bypass flow. The coarser Hydrologic Region scale performed for the entire state will not include operation of flood bypasses.

- Comment: The Water Plan scenarios should consider adaptive instream flow requirements that can change due to hydrologic and other conditions.
  - Response: This is a goal of the scenario analysis for Update 2009.

- Comment: Need a finer time step than monthly to simulate daily water quality and instream flow requirements.
  - Response: The Water Plan is interested in exploring how a finer time step can be used. One option may be to link the monthly scenario model with more detailed models developed and maintained by related planning efforts. Integrating the Water Plan scenarios with environmental water needs is a longer term goal for the Water Plan.

- Comment: Environmental flow data are being developed through the FERC process which might be useful for the WEAP system.
  - Response: Excellent suggestion.

- Comment: The Water Plan scenarios should explore various flow and habitat availability relationship scenarios for various aquatic species - with focus on critical lifestage requirements (including such environmental variables as water temperature.

  - Response: This is a longer term goal for the Water Plan scenarios.

- Comment: The Water Plan scenarios should evaluate the effects of climate change on cold water reservoir releases made for fisheries.
  - Response: This is a longer term goal for the Water Plan scenarios.

- Comment: the USFWS has instream flow data for a number of Central Valley waterways that have anadromous species - possibly something useful to the WEAP system. They also have a 10 yr workplan that they could provide, so you know what instream flow data will be available in the future.
  - Response: Excellent suggestion.

- Comment: DFG Water Branch is developing a priority stream list, which will be finalized Sept 1, 2008 - and will be used to guide future instream flow studies.
  - Response: Excellent suggestion.

- Question: In addition to the Wanger Decision, will there be additional demand factors/drivers for instream flow requirements?
  - Response: We have not determined how the Wanger Decision will be included in the Water Plan scenarios. We have identified many of the existing instream flow requirements as part of the Water Plan Water Portfolios. We have also identified many recommendations for additional instream flows by regulatory agencies that will be used to for the future scenarios.

**Overview of Climate-change Scenarios being Analyzed (and provided)**
by the California Climate Action Team

In 2005, to meet California's greenhouse gas reduction targets, Governor Arnold Schwarzenegger directed the Secretary of the California Environmental Protection Agency (CalEPA) to coordinate with several agencies, forming the Climate Action Team -- CAT). CAT releases a bi-annual report on the progress made toward meeting the statewide greenhouse gas targets and towards identifying significant risks and challenges that climate change will impose upon the State. See http://meteora.ucsd.edu/cap/pdffiles/CA_climate_Scenarios.pdf for a summary of the results of the first biennial assessment, in 2006.

Now, in summer 2008, the CAT is again in the process of completing a second biennial assessment of potential climate change impacts in the State. At the core of this effort are climate-change scenarios derived from six global climate models:

- From France: CNRM CM3
- From USA: GFDL CM2.1
- From Japan: MIROC3.2 (med)
- From Germany: MPI ECHAM5
- From USA: NCAR CCSM3
- From USA: NCAR PCM1

These models were chosen on the basis of the availability of detailed outputs for use in various parts of the assessment process and upon consideration of certain aspects of their performance. The availability of daily simulation outputs of surface-air temperatures and precipitation were required so that the scenarios could be used to drive hydrologic models over the State; sub daily outputs were also valued for use in coastal wave models and sea-level projections. In some cases, models were chosen because they were preferred by the original model groups (e.g., the GFDL CM2.1 model was chosen over the GFDL CM2.0 model at the recommendation of the GFDL modeling group) or because they were better documented than alternatives. Data was obtained via the model centers and not just from the Intergovernmental Panel on Climate Change (IPCC) web pages, to acquire the most recent data and more complete data in many cases. Models were assessed in terms of their abilities to reproduce El Nino-Southern Oscillation (ENSO)-like climate variations and their tendency to produce periods of drought over California. Models needed to yield reasonably realistic annual cycles of monthly temperature and precipitation over California. The models chosen also had to perform on reasonably detailed global grids (e.g., models with grid spacing greater than about 5º were not included). Finally models chosen had to provide historical and future climate simulations under specific greenhouse-gas emissions scenarios, so that all the model outputs could be directly compared. (More model details can be found at http://meteora.ucsd.edu/cap/ipcc4.html.)

Simulations of historical climates under historical greenhouse-gas concentrations in the atmosphere and future climates under A2 and B1 emissions scenarios provide inputs to impact assessments being completed by a multidisciplinary collection of scientists, economists, and engineers around the State. These emissions scenarios are products of the IPCC activities and reflect possible futures with generally higher emissions (A2) and lower emissions (B1) in the 21st

Century. The A2 scenario is a "storyline" of future global emissions and economic growth based on strong economic priorities (somewhat at expense of environmental priorities) and more regional than global economic coordination, but with strong emphasis on self-reliance of nations, large population increases and relatively slow economic growth overall; the result is rapid growth of greenhouse-gas emissions throughout the 21st Century. The B1 scenario reflects a possible future in which there is more global economic coordination and a stronger emphasis on environmental sustainability. Under this scenario, populations peak and then steady and growing economies are based more on services and information. The result is that emissions during the 21st Century are less than under A2, although most of the differences in the emissions emerge after about 2050.

With two emissions scenarios and six climate models, a total of 12 climate-change scenarios are at the focus of the 2008 assessment activities. The figure below shows projected mean water-year precipitation totals (as percentages of historical normals) and winter temperatures from the various models under the A2 emissions scenario. See http://meteora.ucsd.edu/cap/cat2008_peak.html for more broad comparisons of the changes projected for northern California's climate in the 21st Century by the various models.

The climate scenarios can be accessed directly through http://meteora.ucsd.edu/cap/scen08_data.html .

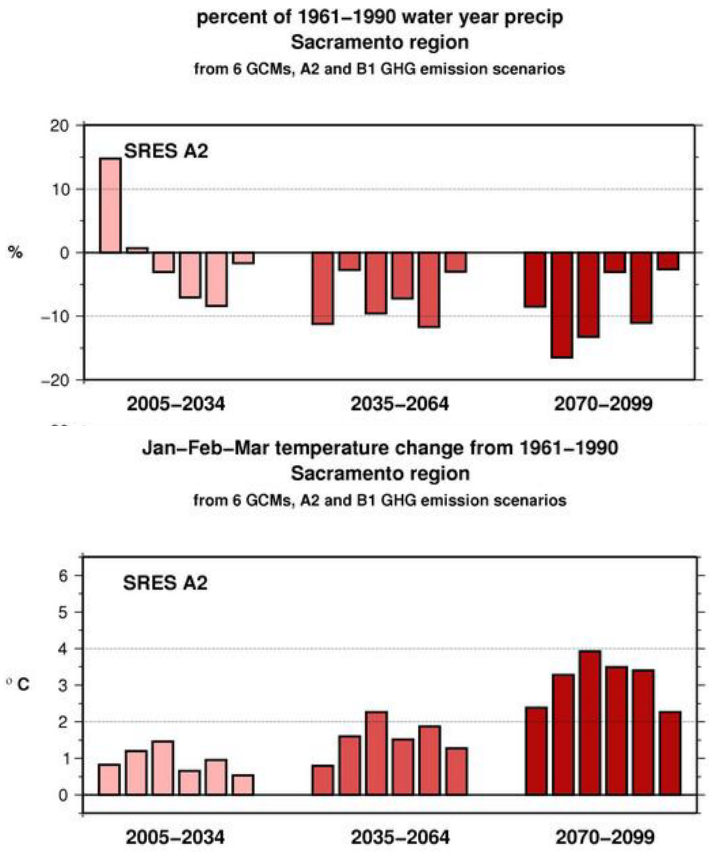



*Fig. 1—Changes in water-year precipitation (as percentage of historical normal) and January-March temperatures projected for the Sacramento area by various climate models during several 30-yr periods in the 21st Century; the model results are presented in this order: 1, CNRM CM3; 2, GFDL CM2.1; 3, MIROC3.2; 4, MPI ECHAM5; 5, NCAR CCSM3; and 6, NCAR PCM1. Changes are relative to conditions during 1961-1990.*