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Water Storage Investment Program Climate Change Projections for 2030 and 2070

Climate Change Requirements

The draft regulations for the Water Storage Investment Program (WSIP) require applicants to quantify the physical and economic benefits of the public and non-public benefits of water storage projects at two reference points (2030 and 2070). Applicants are required to include climate change in the analysis of the project benefits at the two reference points in order to demonstrate the project's ability to provide public benefits under both "near future" and "late future" conditions. The 2030 ("near future") reference point captures climate conditions for the 30-year period surrounding 2030 (2016-2045) and 2070 ("late future") captures late century climate conditions for the 30-year period surrounding 2070 (2056-2085). With uncertainties expanding greatly with time, the "late future" reference point provides an indication of how the trajectory of benefits might change as the climate continues to warm over the 21st century.

Climate Projections for 2030 and 2070

The climate projections for 2030 and 2070 conditions were derived from the ensemble of 20 global climate projections selected by the DWR Climate Change Technical Advisory Group (CCTAG)[1] as the most appropriate projections for California water resources evaluation and planning. The 20 climate projections were generated from 10 global climate models (GCMs) run with two emission scenarios, one optimistic (RCP 4.5) and one pessimistic (RCP 8.5), identified by the Intergovernmental Panel on Climate Change for the Fifth Assessment Report (2014).

Steps to Develop Climate Inputs

The following steps were used to develop the climate projections (precipitation and temperature) at 2030 and 2070.

- Review and accept the ensemble of 20 climate projections selected by CCTAG
- De-trend the historical, observed temperature data prior to Year 1995
- Use the 20 selected climate projections to develop aggregate cumulative distribution functions (CDFs) for each month and climate period
- Develop ensemble quantile mapping functions
- Apply the quantile mapping function to the historical climate condition

De-trend historical observed temperature data prior to Year 1995

All of the simulations of runoff, streamflow, and system operations are based on an analysis of the 1922-2003 hydrologic sequence adjusted for the amount of climate change expected to occur at each point in

[1] "Perspectives and Guidance for Climate Change Analysis", California Dept. of Water Resources, at http://www.water.ca.gov/climatechange/docs/2015/1_14_16_PerspectivesAndGuidanceForClimateChangeAnalysis_MasterFile_FINAL_08_14_2015_LRW.pdf

time. However, the historical data was observed during a period of climate change. By 1995, approximately 1 degree Celsius (C) of warming had already occurred since 1922. This trend must be removed to create a stationary 1995 climate condition and provide a consistent comparison across the simulations. A linear temperature trend was calculated and applied to the historical observed data from 1922-1995. The trendline value for each year was added to the historical observed temperature. Such a trendline would indicate a different amount of temperature change at different points in the observed record. For example, the trend would indicate that 1 degree C should be added to 1922, 0.5 degree C should be added to 1959, 0 degree C should be added to 1995, and 0.1 degree C should be removed from 2003 values to establish the stationary 1995 climate condition.

Most previous analyses of "current" or "historical" conditions without climate change have neglected to include this de-trending step. By omitting the de-trending step and using unadjusted historical climate data, a scenario would characterize *historical conditions* (roughly centered on a period in the 1960's), not *current conditions* that we would expect today or over the next 10 years.

No trend in the precipitation record from 1922-2003 was detectable, and thus no de-trending was applied to the observed precipitation record.

Use 20 selected climate projections to develop aggregate Cumulative Distribution Functions for each month and climate period

Each of the 20 climate projections used for this analysis provides climate information at monthly time steps for the period 1950-2099 (150 years). Thus, each projection provides 150 observations of January precipitation, 150 observations of February precipitation, 150 observations of March temperature, etc. Thirty years of data were extracted from each of the climate projections for each of the climate periods, using the 30-year span surrounding the period at each of the climate periods, 1995 (1981-2010), 2030 (2016-2045), and 2070 (2056-2085). The 30 years of data for each month for each of the climate projections were ordered from driest to wettest and from hottest to coldest, to create cumulative distribution functions (CDFs). A quantile represents one-thirtieth of the CDF. For example, a quantile of the precipitation CDF is one-thirtieth of its CDF, in order from driest to wettest. An average across all 20 climate projections was calculated for each of the 30 quantiles (e.g., one average of the driest Januarys from all 20 projections). The 30 average values were then used to create new aggregate CDFs for each month and each of the climate periods. By averaging the GCM data only within each quantile and not across quantiles, the variability across the quantiles is preserved.

The procedure to construct the aggregate CDF is illustrated as follows, beginning with a specific month (e.g., January), and climate parameter (e.g., precipitation):

1. Calculate the average across the 20 climate projections of the driest January simulated by each of those projections.
2. Repeat for the second-from-driest January of each climate projection, continuing all the way to the wettest. This creates 30 averages for January.

3. Use the 30 averages to construct an aggregate CDF for all Januarys between 1981 and 2010 (the reference 1995 condition). Do the same for all Januarys between 2016 and 2045 (2030 conditions), and do the same again for all Januarys between 2056 and 2085 (2070 conditions).
4. Repeat this process for other months, for temperature, and for every location in the state that is included in the analysis.

Develop ensemble quantile mapping functions

A quantile mapping function is a relationship between two CDFs, one for the projected climate conditions (e.g. 2030; 2016-2045) and one for the reference climate conditions (1995; 1981-2010). These functions are developed for each month and for both precipitation and temperature at each grid cell of the State at 1/16th degree (~6 km or ~3.75 miles) spatial resolution. The entire State of California is represented in 11,358 grid cells.

These functions are developed using the aggregate CDFs developed from the monthly average of the 20 climate projections, as described above. Thus, 24 quantile mapping functions were developed for each grid cell (12 monthly functions for temperature and 12 monthly functions for precipitation). Each quantile mapping function relates a reference CDF to a projected CDF.

The quantile mapping function is used to project a change in the value of a climate parameter that would be expected to occur over the period of time between the reference and the projected climate periods.

Apply the quantile mapping function to the historical climate condition

For 2030 and 2070 climate projections, an 82-year climate sequence was created by applying the quantile mapping functions to the historic 1922-2003 sequence which was first de-trended for the observed trend in temperature.

Using the quantile mapping function involves these steps:

1. Given a value of a climate parameter, such as temperature, use the reference CDF to determine the probability frequency at which that value occurs.
2. Determine the projected CDF value at that same probability frequency.
3. Compute the change factor, either for temperature or precipitation, between the reference condition value and the resultant projected value.
4. The difference between the reference value and projected value was calculated (in degrees C for temperature and as percent change in precipitation); these change metrics were then applied to the historical observed (de-trended) value for the given grid cell to generate an adjusted future condition value.

These steps were repeated at each grid cell over the entire State to develop 2030 and 2070 climate projections.

Data and Model Products Developed

Commission staff developed climate projections, resulting runoff and streamflow, and model analyses representing water project operations (using the CalSim-II model) and Delta conditions (using the DSM2 model). These datasets and analyses are provided for applicants to use in evaluating proposed water storage projects under 2030 and 2070 future climate and sea level conditions. For each of the near future and late future conditions, staff prepared a CalSim-II and DSM2 model simulation. The inflows used in CalSim-II were based on modeling of rainfall-runoff relationships and streamflow using the Variable Infiltration Capacity (VIC) model. Climate inputs of precipitation and temperature were used as input to the VIC model. Selected climate inputs and VIC model results are provided in the statewide data product published with the CalSim-II and DSM2 models. The representation of each climate condition is based on historical conditions over the 82-year record from 1922-2003 adjusted for the change projected by the selection of climate models.

Uncertainty in Climate Conditions

In addition to quantifying the benefits of the projects with climate conditions at 2030 and 2070, applicants will be required to disclose how the expected public and non-public benefits of the project might change under a wider range of climate conditions and describe how the operations of their projects can be adapted to sustain the benefits claimed. The wide range of climate conditions is described by the range of the 20 individual projections included from wetter/moderate warming conditions to drier/extreme warming conditions. Projects that perform well across a wide range of potential climate conditions will be considered as more resilient. This analysis is a type of stress-test that explores the vulnerability and potential opportunities of projects to future conditions that are less likely, though still within the range of potential expected conditions. These conditions represent the extremes of the ranges of impacts of climate change.

Of the 10 GCMs considered, two GCMs were selected to represent the bounds of the range of climate conditions considered in the ensemble of 20 climate conditions. The GCM CNRM-CM5 is selected as the wetter/moderate warming (WMW)[2] model. The GCM HadGEM2-ES is selected as the drier/extreme warming (DEW) model. CDFs were created based on a combination of two emission scenarios, RCP 4.5 and RCP 8.5 for each of the bounding GCMs, for the 2070 (2056-2085) climate condition. Climate projections for the extreme 2070 climate conditions, VIC and CalSim-II modeling are being prepared based on these GCMs. Even though quantitative analysis of uncertainty in climate change is not required by the regulation, this information will be available for use by applicants in assessing the risks from and ability of their proposed projects to adapt to the wide range of potential climate conditions in the 21st century.

[2]The WMW and DEW extreme climate scenarios directly follow the guidance developed for the California 4th Climate Change Assessment, which has identified HadGEM2-ES as the model to be used for characterization of what they call “warm/dry” conditions and CNRM-CM5 as the model to be used to characterize “cool/wet” conditions.

Summary and Implications of the Climate Change Analysis for WSIP

The approach described above was selected after lengthy consideration of alternative approaches.

- A selected set of 20 climate projections (from those available) were used, based on the recommendation of the CCTAG.
- All 20 climate projections are used to construct the aggregate CDFs and quantile mapping functions. Therefore all projections help to inform the change in climate between the reference and future climate periods.
- Using the individual climate projections directly (without using the quantile mapping steps to adjust historical observed values) was considered by the team and eventually rejected because historical GCM simulations of California climate fail to replicate the inter-annual variability in precipitation that has been observed. Because GCMs are not able to replicate historical inter-annual variability, there is low confidence in their ability to accurately simulate future inter-annual variability. Historical observed inter-annual variability—adjusted to include expected shifts—is still considered by DWR to be the most reliable predictor of future inter-annual variability for California water planning
- These projections make use of the observed historical climate record of California that has been a mainstay of water resource planning in California. A significant advancement in the use of this record has been incorporated in this study by de-trending temperature records to reflect the warming that has already occurred since 1922.
- The variability encompassed by the 20 climate projections is maintained by using the quantile approach, although averaging the values within each of the 30 quantiles moderates the influence of the farthest-outlying predictions.
- The quantile mapping function approach is applied to climate inputs prior to the rainfall-runoff and streamflow modeling in order to maintain the integrity of the physical response of the watersheds at different locations and climate projection periods.
- The quantile mapping functions are applied to modify historically based climate data. Therefore, the approach maintains the climatologic variation in the historical record, including extended periods of drought.
- 2030 and 2070 conditions are slightly wetter than historical conditions on a statewide basis which is consistent with both the ensemble of CCTAG recommended projections and the larger ensemble of all projections in the Coupled Model Inter-comparison Project Phase 5 Database.