CALIFORNIA DEPARTMENT OF WATER RESOURCES

SUSTAINABLE GROUNDWATER MANAGEMENT PROGRAM

July 2018

Guidance Document for the Sustainable Management of Groundwater

Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development

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The objective of this Guidance Document is to provide Groundwater Sustainability Agencies (GSAs) and other stakeholders with information regarding climate change datasets and related tools provided by the California Department of Water Resources (DWR) for use in developing Groundwater Sustainability Plans (GSPs). The datasets and methods are provided as technical assistance to GSAs to develop projected water budgets.

Information pertaining to the use of climate change datasets to develop projected water budgets may be found in Section 354.18(c)(3) of the GSP Regulations, which describes projected water budget assessments. The water budget and modeling best management practices (BMPs)[1] describe the use of climate change data to compute projected water budgets and simulate related actions in groundwater/ surface water models.

The information provided in this Guidance Document describes the approach, development, application, and limitations of the DWR-provided climate change datasets. However, GSAs may choose not to use the DWR-provided Data, Tools and Guidance to develop projected water budgets.

[1] https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents

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Executive Summary

This *Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development* (Guidance Document) explains the California Department of Water Resources (DWR)-provided climate change data, including how the data were developed, the methods and assumptions used for data development, and how they can be used in the development of a projected water budget. This Guidance Document also describes tools and processes relevant to perform climate change data analysis (i.e., incorporating climate change analysis into projected water budgets, with and without numerical surface water/groundwater models).

DWR provides processed climate change datasets related to climatology, hydrology, and water operations. The climatological data provided are change factors for precipitation and reference evapotranspiration gridded over the entire State. The hydrological data provided are projected stream inflows for major streams in the Central Valley, and streamflow change factors for areas outside of the Central Valley and smaller ungaged watersheds within the Central Valley. The water operations data provided are Central Valley reservoir outflows, diversions, and State Water Project (SWP) and Central Valley Project (CVP) water deliveries and select streamflow data. Most of the Central Valley inflows and all of the water operations data were simulated using the CalSim II model and produced for all projections.

These data were originally developed for the California Water Commission's Water Storage Investment Program (WSIP). However, additional processing steps were performed to improve user experience, ease of use for GSP development, and for Sustainable Groundwater Management Act (SGMA) implementation. Data are provided for projected climate conditions centered around 2030 and 2070. The climate projections are provided for these two future climate periods, and include one scenario for 2030 and three scenarios for 2070: a 2030 central tendency, a 2070 central tendency, and two 2070 extreme scenarios (i.e., one drier with extreme warming and one wetter with moderate warming). The climate scenario development process represents a climate period analysis where historical interannual variability from January 1915 through December 2011 is preserved while the magnitude of events may be increased or decreased based on projected changes in precipitation and air temperature from general circulation models.

These climate change data are available for download on the SGMA Data Viewer (under the Water Budget section), which is an online geographic information system (GIS)-based interactive map for downloading spatial data and associated time-series (temporal) data in accordance with a user-defined region. In addition, DWR provides several desktop tools that can be downloaded and used by Groundwater Sustainability Agencies (GSAs) to process the climate change datasets for their water budget or to incorporate into a groundwater/surface water model. These and the other tools listed in this Guidance Document can be downloaded from DWR's Data and Tools website. These tools can help GSAs analyze projected climate change.

While DWR is providing these climate change resources to assist GSAs in their projected water budget calculations, the data and methods described in this Guidance Document are optional. Other local analysis and methods can be used, including existing climate change analysis. If the DWR-provided datasets are used, the Guidance Document describes two paths that may be followed to develop a projected water budget. The intent is to provide guidance on a possible method to help GSAs include the effects of climate change into their projected water budget calculations, especially if no local climate change analysis has been done before.

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Acronyms and Abbreviations

1995 HTD	1995 historical temperature detrended
BMP	best management practice
C2VSim	California Central Valley Simulation Model
CalSim	California Water Resources Simulation Model
CCTAG	Climate Change Technical Advisory Group
CDF	cumulative distribution function
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CVP	Central Valley Project
DEW	drier with extreme warming
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
ET	evapotranspiration
ET_o	reference evapotranspiration
GCM	general circulation model
GIS	geographic information system
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
HUC	hydrologic unit code
IWFM	integrated water flow model
LOCA	localized constructed analog
METRIC	mapping evapotranspiration at high resolution using internal calibration
NRC	National Research Council
RCP	representative concentration pathway
SGMA	Sustainable Groundwater Management Act
SGMP	Sustainable Groundwater Management Program
SWP	State Water Project
SVSim	Sacramento Valley Simulation Model
VIC	variable infiltration capacity
WMW	wetter with moderate warming
WSIP	Water Storage Investment Program

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SECTION 1

Purpose and Scope

This Guidance Document was developed to help Groundwater Sustainability Agencies (GSAs) incorporate California Department of Water Resources (DWR)-provided climate change and related data into their Groundwater Sustainability Plans (GSPs).

The purpose of this Guidance Document is as follows:

- Provide relevant data and tools for GSAs to incorporate climate change into their GSPs.
- Provide an analysis approach using the provided data and tools that incorporates the best available science and best available information to date.

This Guidance Document focuses on the use of DWR-provided climate change data and provides documentation about the following:

- Climate change data development approach
- Climate change data development methods and processes
- Applications for using the provided climate change data
- Climate change data assumptions and limitations

This Guidance Document provides a process for using DWR-provided climate change data for computing projected water budgets and serves as a companion document to the water budget best management practices (BMPs)[2] and the modeling BMP[3]. For Sustainable Groundwater Management Act (SGMA) implementation purposes, the use of climate change data can help with the following:

- Developing projected water budgets
- Long-term planning of groundwater basin sustainability
- Assessing projects and management actions by performing sensitivity analyses of projected conditions
- Adaptive Management

[2] https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-4-Water-Budget.pdf

[3] https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-5-Modeling.pdf

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Approach Used for DWR-Provided Climate Change Analysis

2.1 Introduction

The Sustainable Groundwater Management Program (SGMP) is providing the California Water Commission's Water Storage Investment Program (WSIP) climate change datasets for use by GSAs. The WSIP dataset is provided for the following reasons:

- Consistent with other DWR programs
- Based on best available science
- Builds on previous efforts and incorporates latest advances
- Follows Climate Change Technical Advisory Group (CCTAG) guidance

This dataset is the first that includes all necessary climate, hydrology, and water supply variables for the entire state. The inclusion of these variables in the dataset allows any GSA or other local water management entity to conduct water resources planning analysis under projected climate change conditions. These recently developed climate datasets are consistent with CCTAG recommendations, use the latest climate data (i.e., Coupled Model Intercomparison Project Phase 5 [CMIP5]), and have been developed using recommended analysis methods.

Available datasets from WSIP have been reviewed, formatted as needed, and additional datasets were developed specifically for SGMA as described further in this Guidance Document.

2.2 DWR-Provided Climate Change Dataset

In 2016, the California Water Commission, assisted by DWR as the technical lead, published climate change datasets to be used for WSIP grant application analysis. The WSIP climate change data development process resulted in recommendations for Steps 3, 4, and 5 (described in Section 2.1.1), as further detailed below.

WSIP climate projections for 2030 and 2070 conditions were derived from a selection of 20 global climate projections recommended by the CCTAG as the most appropriate projections for California water resources evaluation and planning (CCTAG, 2015). Scripps Institution of Oceanography downscaled the 20 climate projections using the localized constructed analog (LOCA) method at 1/16th degree (approximately 6-kilometer [km], or approximately 3.75-mile) spatial resolution (Pierce et al., 2014; 2015). The climate projections for 2030 and 2070 future conditions were derived using a quantile mapping approach that adjusts changes in historical air temperature and precipitation fluxes previously developed by Livneh et. al., 2013.

Adjusted air temperature and precipitation time series for 2030 and 2070 future conditions were used as input to the Variable Infiltration Capacity (VIC) hydrologic model (Liang et al., 1994; 1996) to generate projections of future streamflows. Future streamflow and sea-level rise projections (15 centimeters and 45 centimeters for 2030 and 2070, respectively) were used as inputs to California Water Resources Simulation Model II (CalSim II) and Delta Simulation Model 2 (DSM2) to generate projections of future State Water Project (SWP) and Central Valley Project (CVP) performance and Sacramento–San Joaquin Delta (Delta) conditions. Figure 2-1 illustrates the WSIP climate change dataset development and modeling process. A detailed description of the dataset development process is provided in the WSIP Technical Reference Document's Appendix A (California Water Commission, 2016) as well as Appendix A associated with the SGMA Guidance Document.

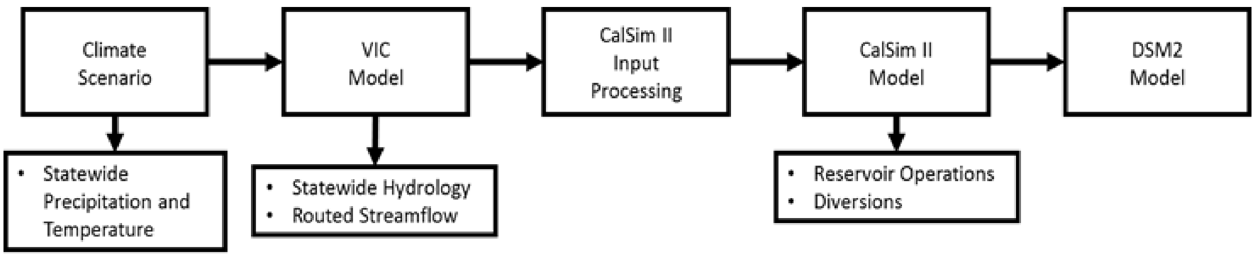

Figure 2-1. Sequence of Models Used for Climate Change Analysis Based on WSIP Approach

2.3 Overview of Climate Change Data and Tool Development Methods

This section describes components of climate data development and information on the modeling approaches used.

2.3.1 Climate Simulation Approach

The provided dataset was developed using climate period analysis. Climate period analysis provides advantages because it isolates the climate change signal from the inter-annual variability signal. In a climate period analysis, inter-annual variability is based on the reference period from which change is being measured, meaning that all differences between the future simulation and the reference period are the result of the climate change signal alone. For additional information on the climate period analysis method and comparison to the transient analysis method, see the provided factsheet on the DWR SGM Data and Tools webpage.

2.3.2 Simulation Period

DWR is providing two future climate period conditions for GSAs to use, including one scenario for 2030 and three scenarios for 2070:

- 2030 (near future):
  - Central tendency of the ensemble of general circulation models (GCMs)
- 2070 (late future):
  - Central tendency of the ensemble of GCMs
  - Drier with extreme warming (2070 DEW) conditions (extreme scenario, single GCM: HadGEM2-ES with representative concentration pathway [RCP] 8.5)
  - Wetter with moderate warming (2070 WMW) conditions (extreme scenario, single GCM: CNRM-CM5 with RCP 4.5)

The 2030 and 2070 central tendency projections, were developed using cumulative distribution functions (CDFs) produced for monthly temperature and monthly precipitation for the reference historical period (1981-2010) and each of the future climate periods (2016-2045 and 2056-2085, for 2030 and 2070, respectively). The CDFs for the central tendency scenarios were developed using an ensemble of climate models such that the entire probability distribution at the monthly scale was transformed to reflect the mean of the 20 climate projections. The extreme scenarios were developed using only the most extreme single model from the ensemble such that the entire probability distribution at the monthly scale was transformed to reflect the change indicated by the single model projection.

Datasets are developed for each climate period to enable GSAs to evaluate a sequence of hydrology with historical variability. The concept of analyzing a hydrological sequence at a projected future time using a climate period analysis is described in Appendix A.

The climate scenario development process represents a climate period analysis with which historical variability from January 1915 through December 2011 is preserved while the magnitude of events may be dampened or amplified based on projected changes in precipitation and air temperature from GCMs.

2.3.3 Climate Model Selection and Spatial Downscaling

DWR used an ensemble of 20 global climate projections (i.e., a combination of 10 GCMs and two RCPs) for the 2030 and 2070 central tendency scenarios from CMIP5. See Appendix A for more information about RCPs.

DWR determined that LOCA, a statistical downscaling technique, was appropriate for use in California water resources planning for the following reasons:

- LOCA is one of the recommended techniques mentioned in the Perspectives Document by CCTAG (CCTAG, 2015)
- LOCA is used in WSIP data development
- LOCA is also being used for California’s Fourth Climate Change Assessment analyses

As a result, LOCA was used to downscale the 20 global climate projections used to develop this dataset.

Please refer to the WSIP Technical Reference Document’s Appendix A (California Water Commission, 2016) for detailed information on the use of LOCA. Appendix A of this Guidance Document also provides more information on the various downscaling methods generally used in California.

2.3.4 Hydrological Model and Systems Operations Model

The VIC model was used for macroscale hydrologic modeling the downscaled climate data. The VIC model developed for WSIP and configured at 1/16th degrees (approximately 6-km, or 3.75-mile) spatial resolution throughout California was used in this data development process. CalSim II, the SWP and CVP operations model developed by DWR and the Bureau of Reclamation (Reclamation), is used to simulate potential changes in California water system operations, such as changes in project deliveries or reservoir releases.

2.3.5 Sea-Level Rise Approach

The sea-level rise estimates by the National Research Council (NRC) suggested projections at three future times relative to 2000 (i.e., at 2030, 2050, and 2100), along with upper- and lower-bound projections for San Francisco (NRC, 2012). The NRC’s projections have been adopted by the California Ocean Protection Council as guidance for incorporating sea-level rise projections into planning and decision making for projects in California. By 2030 and 2070, the median range of expected sea-level rise, as estimated by the NRC, is around 15 and 45 centimeters, respectively. For the provided climate change datasets, projections of 15 and 45 centimeters were selected as representative of 2030 and 2070 future sea-level rise conditions for use in CalSim II and other models.

Development of the Provided Climate Change Datasets

The following sections describe how the existing datasets were compiled and processed for GSAs.

3.1 Overview of Climate Data and Application Processes

The water budget BMP[4] defines and describes the types of data that are typically used to develop a comprehensive water budget, and provides source information. The modeling BMP[5] describes the methods and processes to apply existing and new models for GSP development. The data and tools described in these BMPs can be modified for incorporation of climate change assumptions, future water budgets, and groundwater conditions, as described below.

Figure 3-1 summarizes the various models used as part of the DWR-provided climate change datasets and how they can be linked to groundwater models. Details of model data linkages are provided in the following sections.

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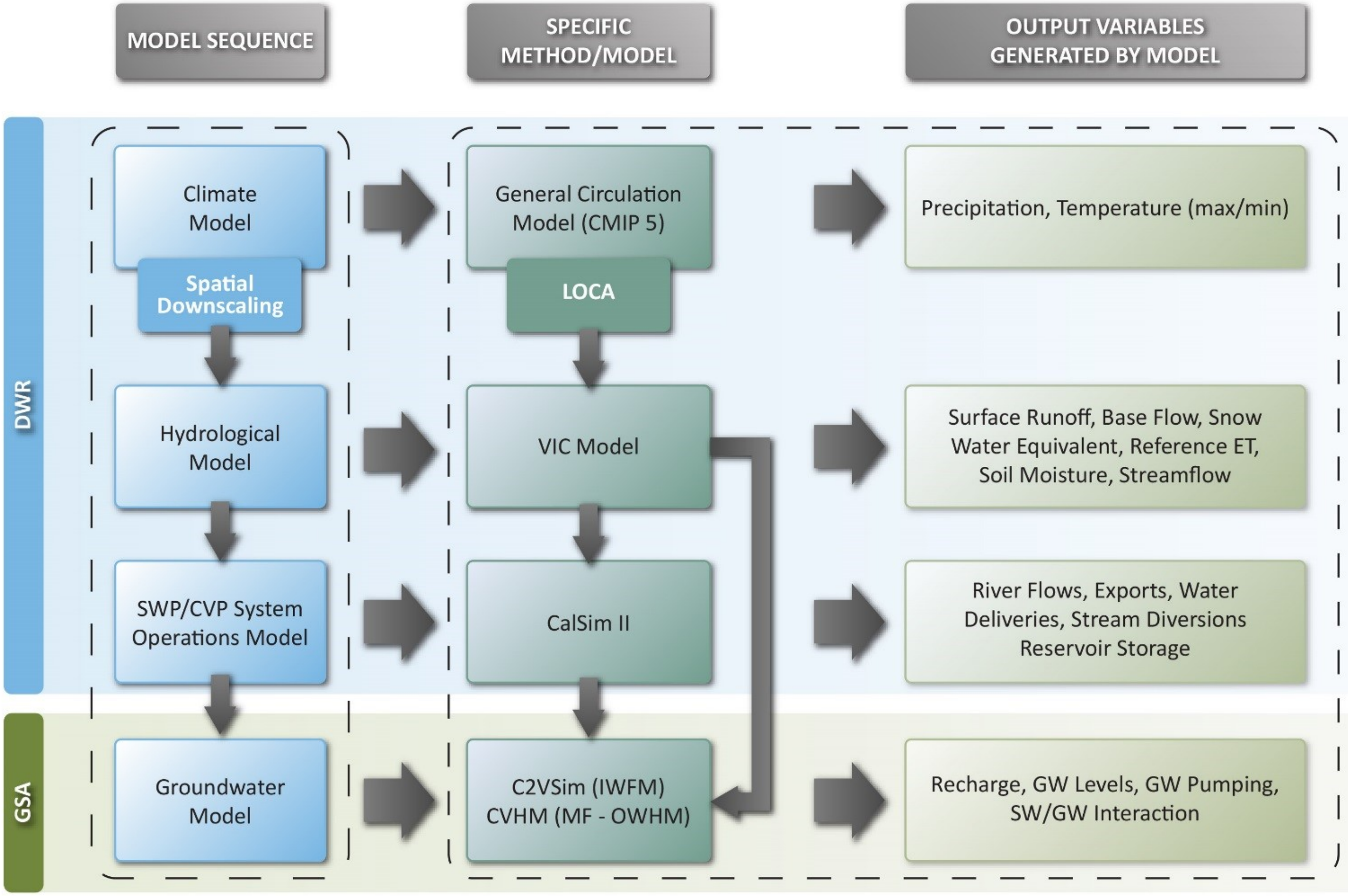
[4] https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-4-Water-Budget.pdf

[5] https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-5-Modeling.pdf

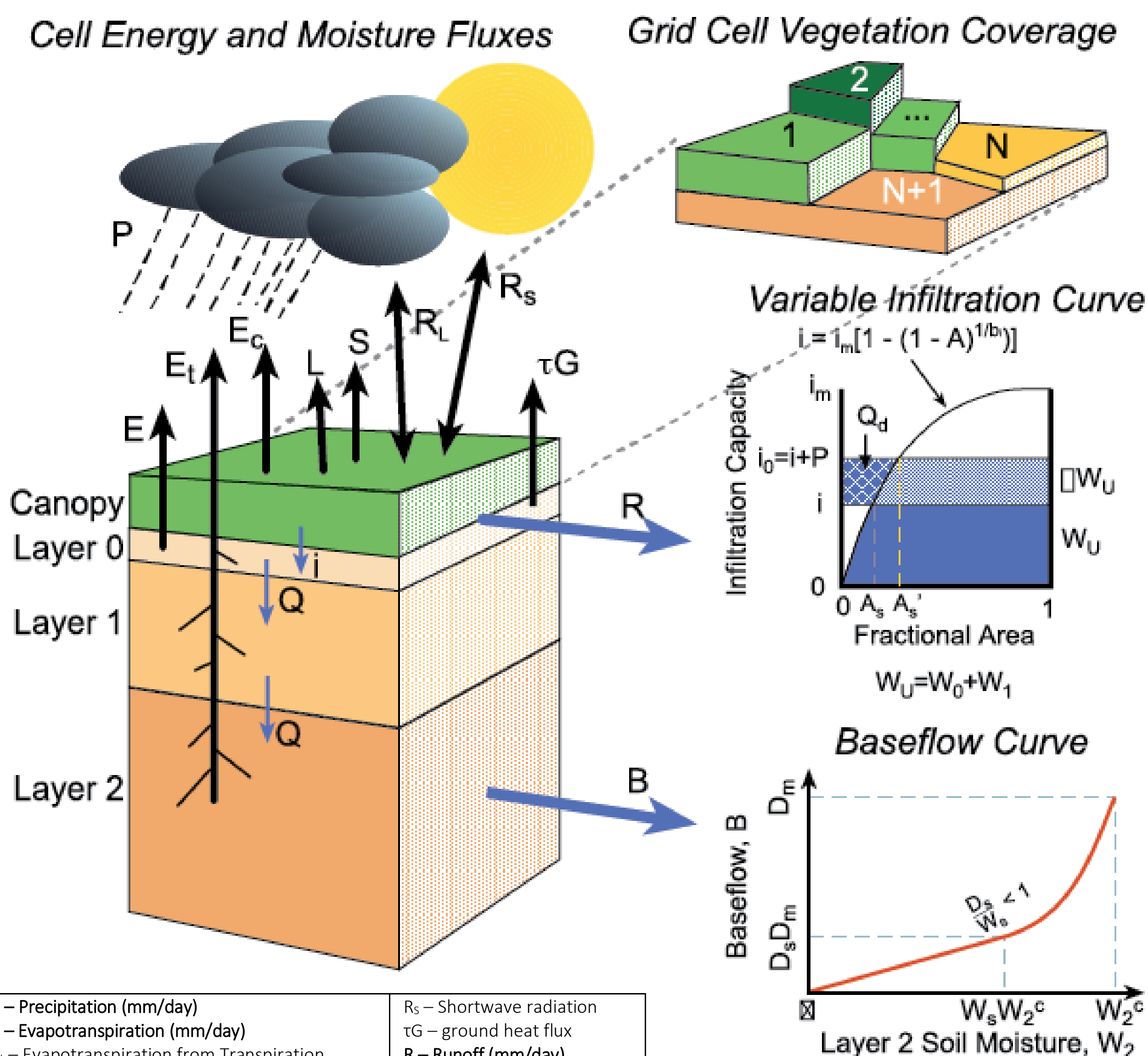


DWR: Department of Water Resources; GSA: Groundwater Sustainability Agency; SWP: State Water Project; CVP: Central Valley Project; LOCA: Localized Constructed Analogs; VIC: Variable Infiltration Capacity; CalSim: SWP & CVP Operations Model; C2VSim: California Central Valley Groundwater - Surface Water Simulation Model; IWFM: Integrated Water Flow Model; CVHM: Central Valley Hydrologic Model; MF - OWHM: MODFLOW One Water Hydrologic Flow Model; ET: Evapotranspiration, SW: Surface Water; GW: Groundwater; CMIP 5: Coupled Model Intercomparison Project

Figure 3-1. General Framework of Linking Climate/Hydrologic Models with Groundwater Models for SGMA Application

3.2 Data from the Variable Infiltration Capacity Hydrologic Model

The VIC model (Liang et al., 1994, 1996; Nijssen et al., 1997) simulates land-surface atmosphere exchanges of moisture and energy at each model grid cell. The VIC model incorporates spatially distributed parameters describing topography, soils, land use, and vegetation classes. It accepts input meteorological data directly from global or national-gridded databases or from global climate model projections. To compensate for the coarseness of the discretization, the VIC model is unique in its incorporation of subgrid variability to describe variations in the land parameters, as well as precipitation distribution. Figure 3-2 shows the hydrologic processes included in the VIC model.



P – Precipitation (mm/day)	R_S – Shortwave radiation
E – Evapotranspiration (mm/day)	τG – ground heat flux
E_t – Evapotranspiration from Transpiration (mm/day)	**R – Runoff (mm/day)**
E_c – Evapotranspiration from Vegetation Canopy (mm/day)	**B – Baseflow (mm/day)**
S and L - related to heat flux	i – infiltration capacity (mm/day)
R_L – Longwave radiation	W – soil moisture

Figure 3-2. Graphical Representation of VIC Model.
Source: University of Washington, 2016

The major parameters of Figure 3-2 are defined above (after Liang et al., 1994). The bolded parameters are the ones primarily used for determining the hydrologic response to projected climate change conditions.

Input and output parameters from the VIC model have been compiled and processed for GSAs to use to assess how changes in climatological conditions could affect hydrologic conditions within their groundwater basins. Detailed descriptions of the climate scenario development process are available in the Technical Reference Document's Appendix A (California Water Commission, 2016).

Precipitation and reference evapotranspiration (ET) for the 2030 and 2070 climate scenarios are available at 1/16th degree (approximately 6-km, or 3.75-mile) spatial resolution throughout California. Using these data, GSAs will be able to incorporate changes in precipitation and ET into groundwater models and water budget calculations to assess changes in the land surface water budget under projected conditions.

Two additional climate datasets are also available that represent extreme projections of climate change at the 2070 climate period. These climate scenarios represent projected conditions from a single GCM for the following conditions, respectively:

- 2070 DEW conditions, as represented by the GCM: HadGEM2-ES with RCP 8.5
- 2070 WMW conditions, as represented by the GCM: CNRM-CM5 with RCP 4.5

These two scenarios can be used to further explore the range of uncertainty in future climate conditions and the impacts of such uncertainty on future water budgets and potential management strategies.

Precipitation and reference ET datasets for each of the four scenarios are packaged as monthly change factor ratios that can be used to perturb historical data to represent projected future conditions. Change factor ratios are calculated as the future scenario (2030 or 2070) divided by the 1995 historical temperature detrended (1995 HTD) scenario. The 1995 HTD scenario represents historical climatic conditions where the increasing temperature trend observed later in the century is added to the data in the earlier part of the century. The result of the temperature detrending process produces a historical record with no observed warming trend in the temperature data. Removing the temperature trend is important to isolate projected changes in climate from the GCMs to establish a basis for projected future conditions. Further discussion about applying change factors and tools to help facilitate this process is provided in Section 4.

3.3 Output Data from the CalSim II Model

CalSim II model runs were produced at 2030 and 2070 projected future conditions for the four scenarios. CalSim II uses projected hydrology from the VIC model, including unimpaired watershed inflows to the Central Valley reservoirs. Based on projected hydrology, CalSim II estimates projected reservoir outflows based on operational constraints, as well as diversions and deliveries for SWP and CVP water. Various input and output datasets are available to GSAs to define predicted reservoir inflows/outflows, river channel flows, streamflow diversions, and SWP/CVP water project deliveries. Reservoir inflows, outflows, river channel flows, and diversions have all been spatially referenced to improve the ease of use of these datasets in groundwater models (Figure 3-3).

Reservoir inflows and local inflows are presented in Table B-1 of Appendix B. CalSim II outputs, including reservoir outflows, river channel flows, and streamflow diversions are presented in Table B-2 of Appendix B. SWP/CVP contractor delivery timeseries data are provided in table format where entities can query data by region and contracting agency. This information will be available on the DWR SGMA Data Viewer online and is further described in Appendix B.

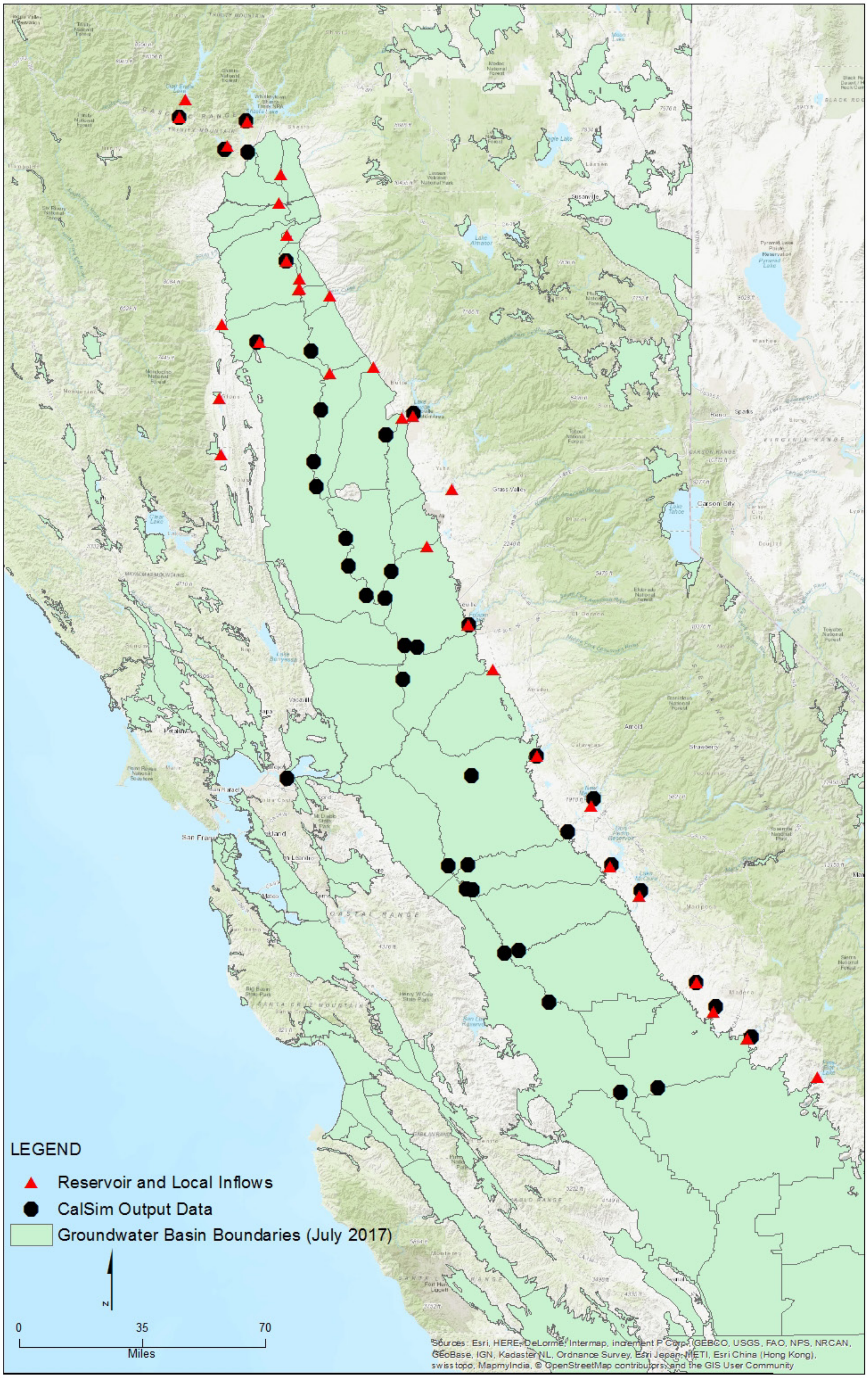


Figure 3-3. Map Displaying Spatially Referenced CalSim II Datasets

3.4 Additional Dataset Development

For WSIP, streamflow datasets primarily included major tributaries in the Central Valley that are represented in the CalSim II model. For SGMA purposes, additional streamflow datasets are needed for areas outside of the area modeled by CalSim II. This section describes the methods adopted to develop these statewide unimpaired streamflow datasets. Note that these are not entirely new datasets, but were developed through further post-processing of existing data provided by WSIP.

3.4.1 Unimpaired Streamflow Data

Three different methodologies were applied to develop datasets that can be used to assess changes in unimpaired streamflow under 2030 and 2070 projected climate conditions. The three methods are as follows:

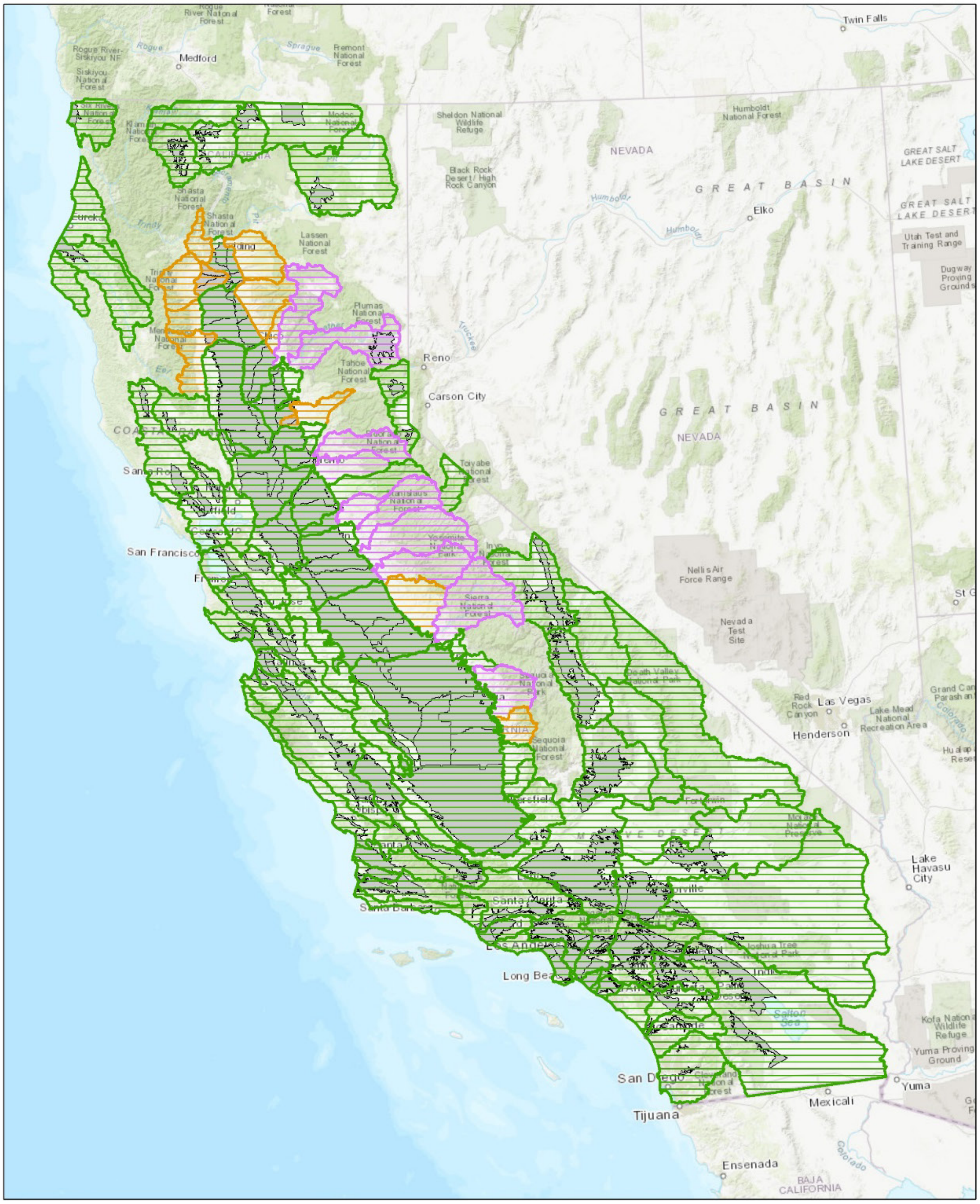
- **Method 1:** Direct VIC routed streamflow with bias correction
- **Method 2:** VIC routed streamflow change factor (no bias correction)
- **Method 3:** Basin average change factor based on average runoff and baseflow computed over Hydrologic Unit Code (HUC) 8 watershed boundaries

Figure 3-4 presents the distribution of each method across California as they apply to specific watershed areas.

Methods 1 and 2 were developed under WSIP for select locations throughout the Central Valley. Both Methods 1 and 2 use the VIC routing model (Lohmann et al., 1996; 1998) to route streamflow to user selected locations. The difference between Method 1 and Method 2 is that Method 1 uses direct streamflow, and Method 2 uses change factors to perturb historical streamflow conditions. Locations were chosen to represent inflow to the major reservoirs that are part of the CVP/SWP system. For further details about the datasets produced under WSIP, refer to Appendix A of the WSIP Technical Reference Document (California Water Commission, 2016). Methods 1 and 2 were applied for additional locations within the Tulare Lake Region that were not considered as part of WSIP. The applicability of Method 1 versus Method 2 is dependent upon available historical unimpaired data, which is required to correct biases in the VIC routing model. As part of this effort, Method 1 was applied to the Kings River and the Kaweah River watersheds, because extended unimpaired streamflow data are available from the California Data Exchange Center. Method 2 was applied to the Tule River and Kern River watersheds.

A third method was devised using the existing statewide gridded data produced from the VIC model to provide unimpaired streamflow change factors for groundwater basins and subbasins outside of the Central Valley. Runoff and baseflow were aggregated based on an area-weighted sum over CalWater 2.2.1 watersheds throughout California. Change factors were then calculated for each of these watersheds based on the combined runoff and baseflow calculation.

The applicability of Method 2 versus Method 3 is dependent on the size of the watershed and the representation of the physical constraints of the watershed within the VIC model. The resolution of the VIC model's flow direction and flow accumulation raster would also constrain the representative delineation of neighboring watersheds, where one grid cell may overlay multiple watersheds but could only contribute flow to one watershed or the other. This constraint would limit the representation of the potential contributing area of watersheds. Refer to Appendix C for a more detailed comparison of Methods 2 and 3 in the Upper Tule Watershed.



LEGEND

Applicable Climate Change Methods for SGMA

- Method 1 - Direct Use of VIC Runoff
- Method 2 - Change Factor from VIC Runoff
- Method 3 - Change Factor from Basin Average
- Groundwater Basins

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Miles

Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Notes:
1. Sustainable Groundwater Management Act (SGMA)
2. Variable Infiltration Capacity (VIC)

Figure 3-4. Unimpaired Streamflow Data Development Methods

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SECTION 4

Application of Climate Change Data for Groundwater Sustainability Plan Development

DWR is providing the necessary and relevant climate change datasets generated from climate modeling and hydrological modeling studies for GSAs to assess projected groundwater conditions and water budgets considering specific groundwater management projects. These datasets should be used as input variables to the appropriate tool to simulate the response to projected water conditions. The climate change data provided for SGMA implementation include the following:

- Climatological data (i.e., precipitation and reference ET) on a state-wide gridded basis
- Hydrological data (i.e., unimpaired streamflow) as point data
- Central Valley project operations data

Table 4-1 summarizes the specific input variable data to be used for projected future water budget development and groundwater modeling. All these datasets are climate transformed according to the method described in Section 3. These datasets are available on DWR's SGMA Data Viewer website,[6] which provides data and information relevant to GSP development and water budget analysis.

Table 4-1. Summary of Data to be Used for Future Water Budget Development and Groundwater Modeling

Gridded Datasets[a]	Selected Flows and Deliveries[b]
• Precipitation • Reference ET	• SWP/CVP imports (Delta exports) • SWP/CVP diversions • SWP/CVP deliveries • SWP/CVP reservoir releases • Routed streamflow for select Central Valley watersheds • Routed streamflow change factor for other watersheds • Non-project reservoir outflows—change factors to modify historical unimpaired flow data into reservoirs

[a] California-wide at 6 km by 6 km resolution in VIC model hydrological analysis, as change factors
[b] CalSim II and VIC model data

4.1 Climate Data Applied at Local Model Scale

The statewide VIC hydrological gridded dataset provides important hydrologic parameters (i.e., precipitation and reference ET) for use in water budget development and groundwater modeling. These datasets are provided as a time series representing monthly change factors over the VIC simulation period of 1915 to 2011. These change factors have been computed for precipitation and reference ET under 2030 and 2070 future conditions.

To use these monthly change factor time-series, GSAs need to multiply their respective historical data with these change factors to obtain a perturbed precipitation and reference ET rate. This rate should then be used in the groundwater model to project future water budgets.

The statewide VIC hydrological dataset is on a 6 km by 6 km resolution. Most of the regional and local groundwater models that will be used by GSAs contain grid cells at a much smaller resolution. Due to inconsistencies in scale, change factors from the VIC model grid cell will need to be mapped spatially to

[6] https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer

the grid cells of the groundwater model. Figure 4-1 illustrates applying climate perturbation factors for groundwater modeling by mapping a VIC model grid with groundwater model grids. The change factor from one VIC model grid cell will be applied to intersecting elements of the groundwater model that fall within the VIC model grid. For elements that fall within two or more VIC model grid cells, an area-weighted average change factor is calculated and applied to the corresponding groundwater model element. A model input file development tool is provided for both integrated water flow model (IWFM) and MODFLOW models to aid in the selection and assigning of appropriate change factors to model grid elements or cells, respectively. This geographic information system (GIS)-based tool can be used to map corresponding cells and apply the appropriate precipitation and evapotranspiration change factor.

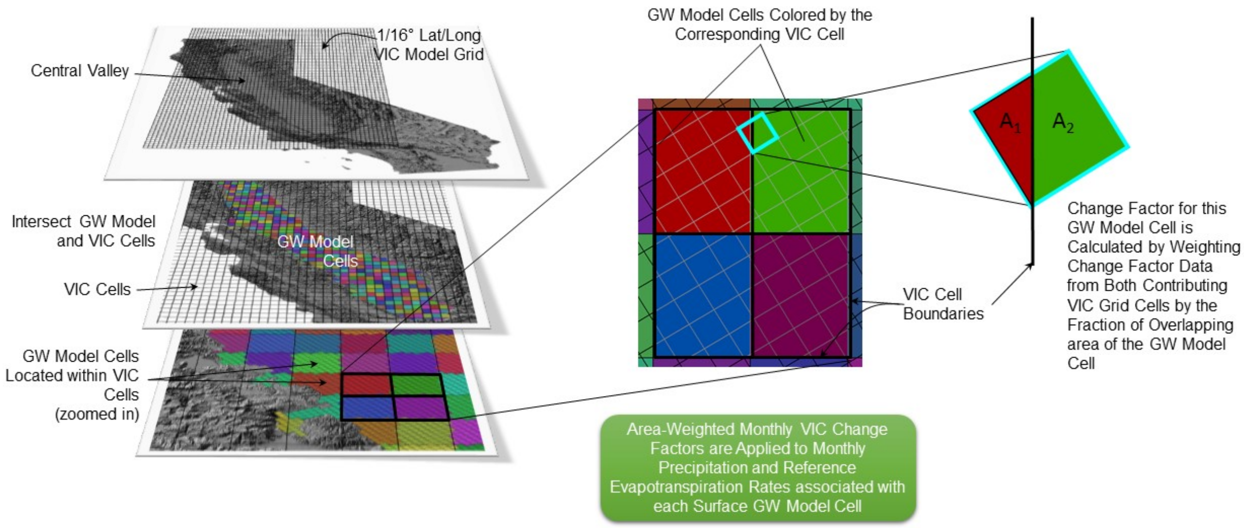


Figure 4-1. Applying Precipitation and ET Change Factors

4.2 Streamflow Data

In addition to precipitation and ET datasets, the calibrated VIC model routing tool processes the individual cell runoff and baseflow terms, and routes flow to simulate unimpaired streamflow at various locations in the modeled watersheds. The hydrology of the Central Valley and operation of the CVP and SWP systems are critical elements toward any assessment of changed conditions throughout the Central Valley. To evaluate the impact of climate change on CVP and SWP operations, the climate-transformed unimpaired streamflows generated from the VIC model were provided as inputs to the CalSim II model, a planning and operational model that simulates the CVP and SWP operations and areas tributary to the Delta. The climate-transformed data were processed within CalSim II to provide modified data on reservoir releases in the Central Valley (impaired flow data). In addition to the generation of perturbed flows, CalSim II also provides datasets on climate-transformed SWP/CVP deliveries, stream diversions and Delta exports for their subsequent application as input variables to the groundwater model. These datasets, provided as monthly time series, can be directly used as inputs to a water budget calculation spreadsheet or a groundwater model.

For watersheds outside of the Central Valley, impaired flow data are not available. Instead, unimpaired streamflow data from Method 3 described in Section 4.4 can be used. Figure 4-2 shows a schematic for applying projected streamflow in a groundwater model or water budget spreadsheet.

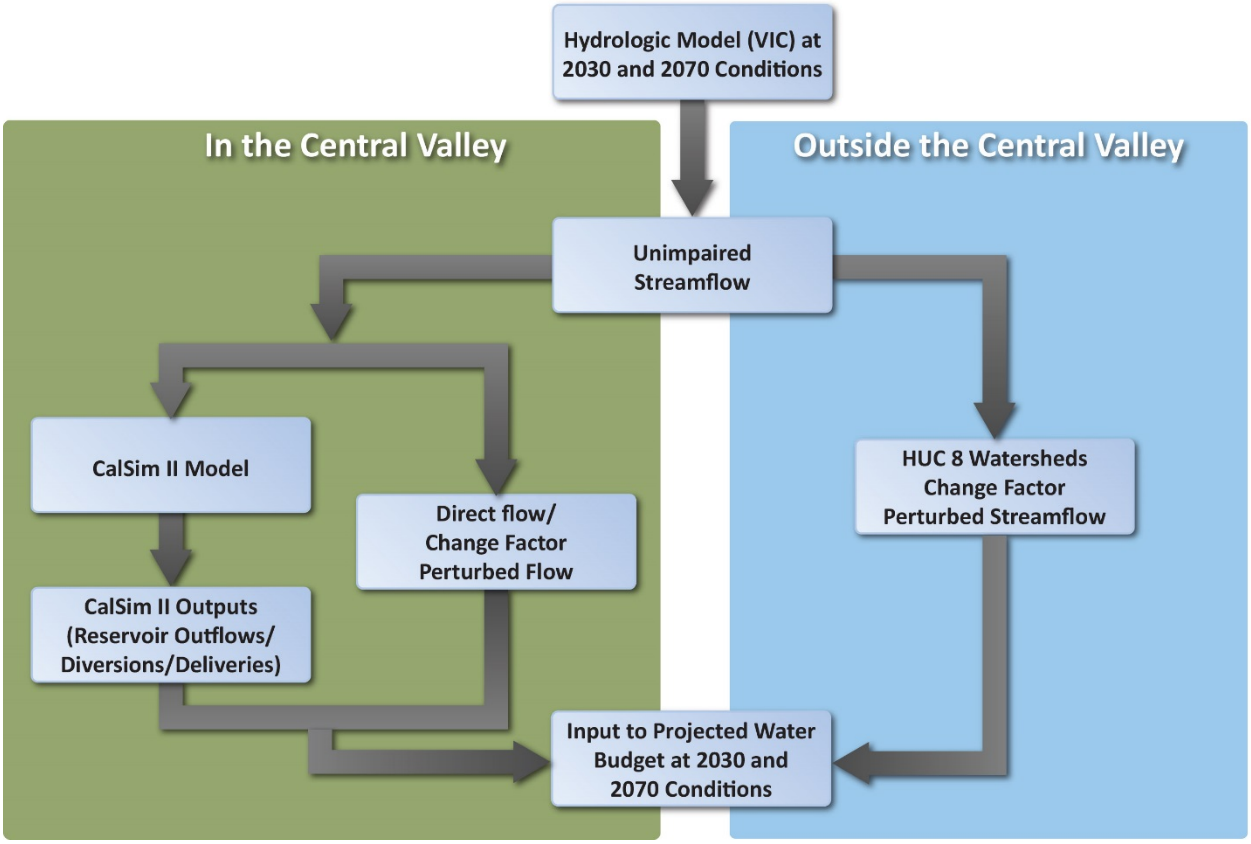


Figure 4-2. Streamflow Data to Use in Projected Water Budget

4.3 Sea-Level Rise Information

As described previously, projections of 15 and 45 centimeters were selected to represent 2030 and 2070 future sea-level rise conditions, respectively, for use in CalSim II and other models. For SGMA implementation, the incorporation of sea-level rise estimates in three-dimensional, physically-based, integrated groundwater/surface-water models can be implemented using one of the following methods, where appropriate:

- Include a specified-head boundary condition in the model cells or elements that are located adjacent to the coast or in the San Francisco Bay, and set the specified-head value at the 2030 projected sea-level rise (i.e., 15 centimeters or 5.9 inches) for the 2030 projected conditions model run. Set the specified-head value at the 2070 projected sea-level rise (i.e., 45 centimeters or 17.7 inches) for the 2070 projected conditions model run.
- A similar method can be used by incorporating a general-head boundary instead of a specified-head boundary.

4.4 Tools for Climate Change Data Integration

DWR developed several tools that are provided to GSAs along with the datasets described in this Guidance Document. These tools can help GSAs perform climate change analysis, and are as follows:

- **SGMA Data Viewer and data portal.** This is an interactive, web-based mapping tool for downloading spatial data and associated time-series data.

- **Model input file development tool(s).** This tool helps map VIC model gridded precipitation and reference ET data to the correct groundwater model cells or elements. One tool will be provided for MODFLOW-OWHM based models, and one will be provided for IWFM-based models.
- **Spreadsheet tool for basin average unimpaired streamflow change factor corrections**. This tool is required whenever unimpaired streamflow is perturbed using monthly change factors. The tool will require unimpaired streamflow and monthly and annual change factors to complete the calculations. The purpose of the tool is to modify monthly change factors to more accurately reflect annual streamflow patterns present in the historical data. Additional information on this method and additional assumptions are included in Appendix C.
- **Contractor deliveries search table.** These tables summarize contractor deliveries within a spreadsheet table that reports the contractor and region of delivery.

Other general modeling tools provided by DWR include the integrated surface-water/groundwater models (IWFM and its Central Valley applications, California Central Valley Simulation Model [C2VSim] and Sacramento Valley Groundwater-Surface Water Simulation Model [SVSim]) to facilitate simulation of current and future groundwater conditions.

4.5 Incorporating Climate Change Analysis Into Water Budgets

As described in the GSP regulations, the Water Budget BMP and earlier in this Guidance Document, the following water budgets are required as part of GSP development:

- Water budget representing historical conditions extending back a minimum of 10 years
- Water budget representing current conditions
- Water budget representing projected conditions over the 50-year SGMA planning and implementation horizon

Based on the available climate change data provided by DWR and described in this Guidance Document, projected water budget could be developed for two future conditions using a climate period analysis as follows:

- Water budget representing conditions at 2030 with uncertainty (using 50 years of historical record representative of the range of inter-annual variability as baseline). Projected 2030 central tendency data will be useful to evaluate projects and actions to achieve sustainability in the early future.
- Water budget representing conditions at 2070 with uncertainty (using 50 years of historical record representative of the range of inter-annual variability as baseline). Projected 2070 central tendency data will be useful to show that sustainability will be maintained into the planning and implementation horizon (i.e., late future), within 50 years after GSP approval.

4.5.1 Projected Water Budget Development Without a Numerical Model

For projected water budgets developed without a numerical groundwater flow model, the datasets described above can be incorporated into a spreadsheet-type water budget where the monthly time series of change factors and direct flow values are used to generate projected future conditions. The 50-year baseline condition timeseries is modified using the change factors from the 2030 projections and 2070 projections, respectively. The resulting timeseries would represent a 50-year projection to understand the uncertainty of what climate and hydrologic conditions could look like in 2030 and the uncertainty of what the climate and hydrologic conditions could look like in 2070. These timeseries include a range of variability in hydrology and temperature as projected for the 2030 and 2070 conditions. The resulting projected water budgets developed for 2030 and for 2070 conditions can be reviewed and interpreted through statistical analysis using water year type averaging and describing ranges in conditions to describe uncertainties in projected water budgets, as further discussed in Section 4.6 below.

When developing a water budget without a numerical model, a few limiting assumptions need to be made, particularly regarding subsurface groundwater inflows from adjacent basins and subsurface groundwater outflow to adjacent basins. For more information on general water budget development, refer to the water budget BMP.[7]

Figure 4-3 illustrates the types of data that would need to be replaced in the historical water budget to develop a projected water budget for 2030 and 2070 conditions including climate change assumptions, to satisfy SGMA requirements.

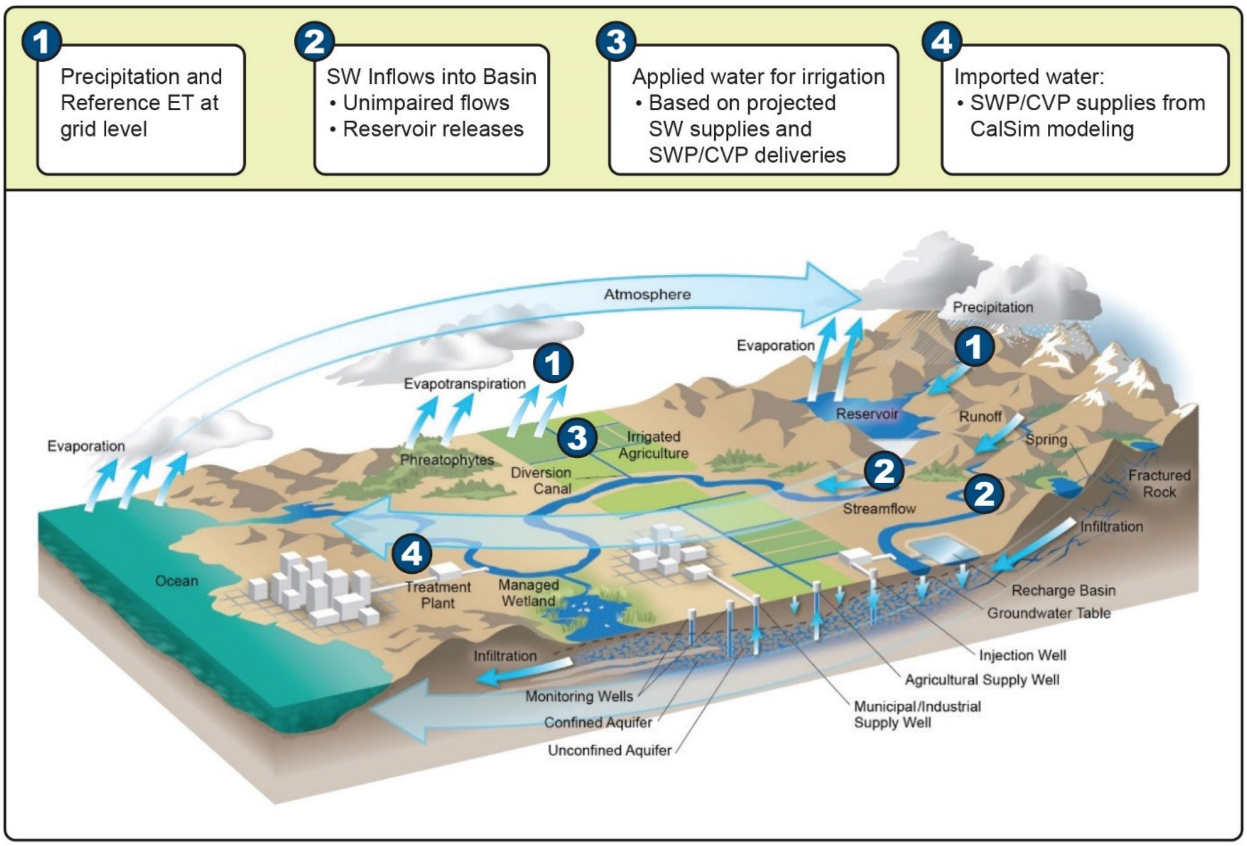


Figure 4-3. Water Budget Components to Modify for Projected Climate Change based Computations

For the precipitation and ET information that is provided at the grid level, an average monthly time series of change factors can be computed for the entire basin and each of the factors can then be applied to the corresponding historical time series to develop the projected time series at 2030 and at 2070. Monthly time series can then be aggregated at the annual level.

[7] https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-4-Water-Budget.pdf

4.5.2 Projected Water Budget Development Using a Numerical Model

If a numerical groundwater model or integrated hydrologic model is used for water budget development, the initial step in the climate change analysis is to choose an existing local groundwater model or a DWR-provided groundwater model (see Modeling BMP).[8] Alternatively, if no model exists that satisfies the requirements of the groundwater basin GSP, a GSA can develop a new groundwater or integrated hydrologic model following the modeling BMP recommendations.

Gridded VIC model hydrological data can be applied, or mapped as Figures 4-1 and 4-4 illustrate, to the groundwater model cells or elements.

The next step would be to modify the input variables in the overlapping groundwater elements located in the VIC model grid in accordance with the climate-transformed data of the corresponding VIC model element. Gridded precipitation and reference ET data should be applied to the surface layer of the model that accounts for land use and water demands due to varying climate. If an integrated hydrologic model is used, these data can be directly applied to the model input files. The water demand is automatically scaled due to changes in air temperature with the reference ET provided and a crop coefficient assumed in the model. If the groundwater model does not include an integrated module that computes surface-water budgets, a pre-processing tool can be used to compute the net recharge to groundwater.

Land use and water demand projection approaches for groundwater modeling should take into consideration existing projections from state or local planning agencies, modified as needed to represent a specific study area and future conditions in the planning period. Water use projections for municipal and agricultural uses should be consistent with the most current local understanding of the groundwater basin. Information can also be developed or obtained from sources such as DWR land-use surveys, county general plans, and satellite-based estimates of ET rates (e.g., mapping evapotranspiration at high resolution using internal calibration [METRIC] calculations).

Stand-alone models that estimate crop water use are also available from DWR.[9] Another approach uses stand-alone modules that can be used in conjunction with groundwater model codes, or modules built into existing groundwater model codes; examples of such modules are as follows:

- **IDC.** IDC is the stand-alone demand calculator used in many IWFM-based models, including C2VSim, which computes agricultural water demands external to a groundwater model; outputs from IDC can be used as inputs to a groundwater model.
- **FMP.** FMP is the farm process module for MODFLOW-based models (now integrated in MODFLOW-OWHM), including CVHM.

These modules compute crop-consumptive use, which translates into agricultural water demand. They also compute limited urban water demand. Based on the crop water demand, irrigation efficiency, and available supply, these modules estimate the deep percolation of applied water to groundwater past the root zone, which is used by the groundwater flow model simulation. Therefore, these modules provide estimates of important components of the overall water demand and supply projections used in groundwater flow modeling.

[8] https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/BMP-5-Modeling.pdf

[9] https://www.water.ca.gov/Library/Modeling-and-Analysis/Statewide-models-and-tools

Unimpaired and impaired streamflow data also need to be modified to account for varying flows with climate change conditions. The modified groundwater model is then run for 2030 and 2070 climatic conditions to simulate the projected water budget. Figure 4-4 shows the groundwater model components to modify for future climate change based projections to simulate projected water budgets.

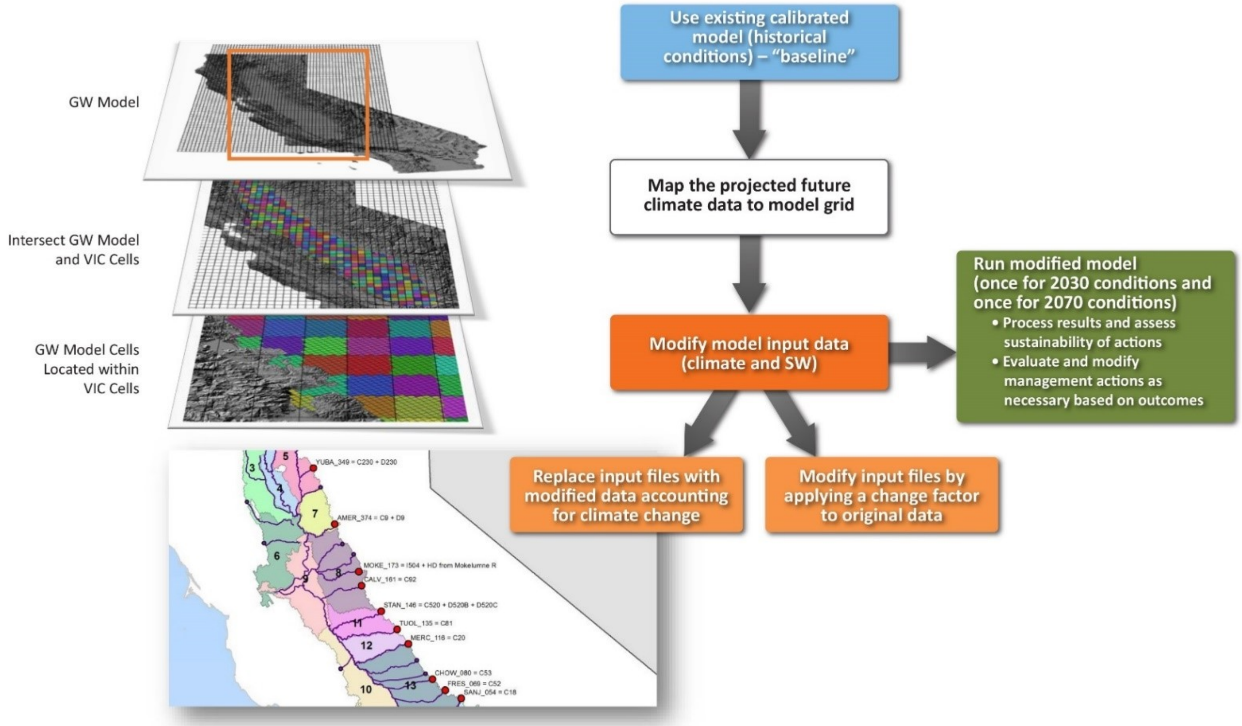


Figure 4-4. Groundwater Model Components to Modify for Future Climate Change-Based Projections

Water budget computation tools are available as noted below for the following integrated hydrologic models:

- DWR's IWFM Z-budget tool[10]
- U.S. Geological Survey's MODFLOW-OWHM zone budget tool[11]

4.5.3 Turning a Calibrated Historical Model into a Projection Model

A historical calibrated model can be applied in a predictive mode to compute projected water budgets with consideration of climate change and assess projects and management actions for long-term sustainability. The climate change datasets described in this Guidance Document represent projected climatologic, hydrologic, and water operations due to climate change for 2030 and 2070 conditions. To apply this dataset to a water budget or model, the 2030 and 2070 climate period condition results from VIC and CalSim II can be used to modify and replace the original historical data as described above.

[10] http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/IWFMv3_02/IWFMv3_02_36/downloadables/ZBudget_Doc.pdf

[11] https://water.usgs.gov/nrp/gwsoftware/zonebud3/zonebudget3.html

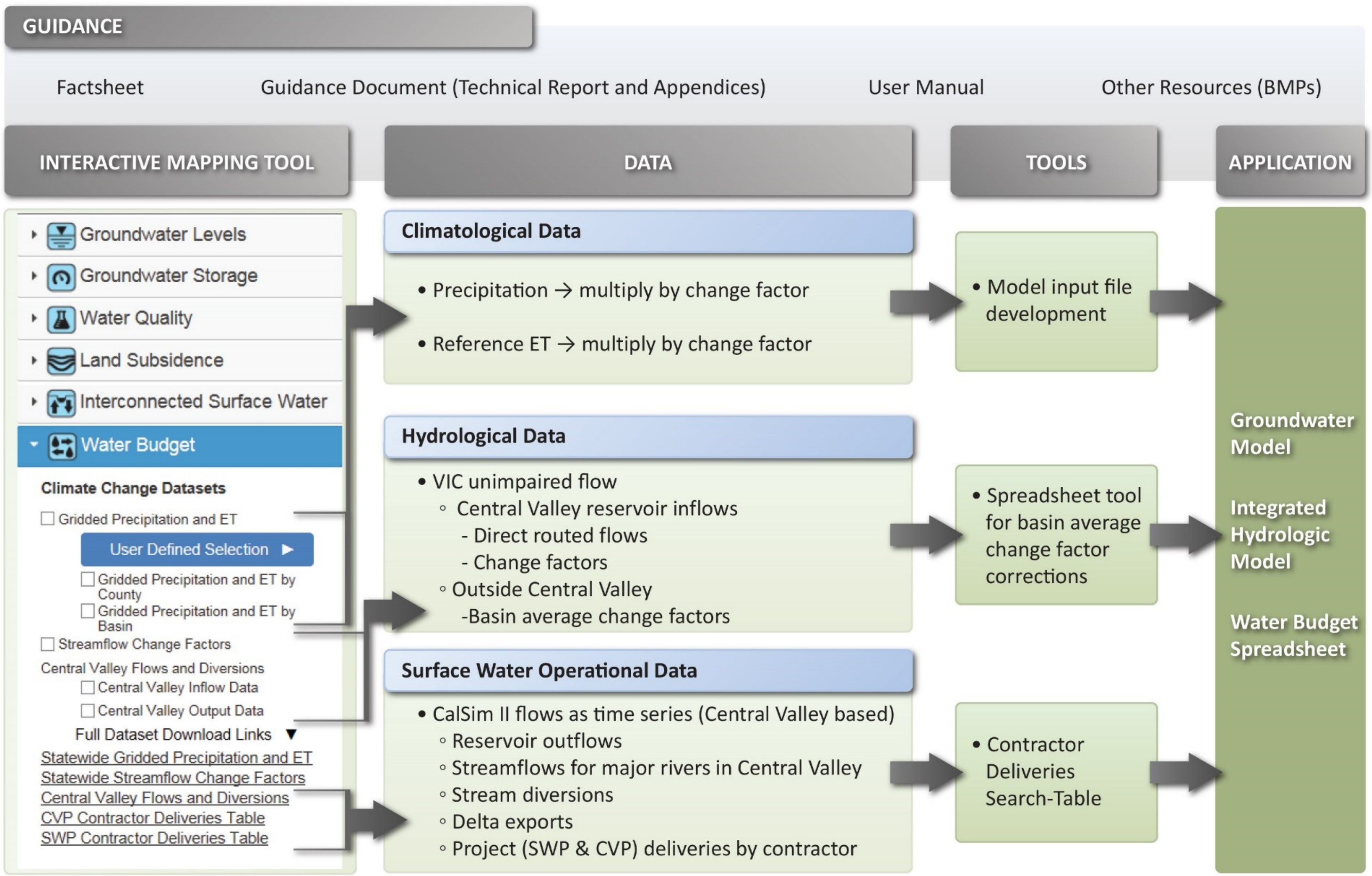
Possible steps to develop projected water budgets using a historical calibrated model are as follows:

1. Use heads at the end of the calibration simulation as the starting heads for the projection model (including subsidence conditions) to start the predictive model at current conditions.
2. Use the most recent available land use data (e.g., provided by DWR) and impose it onto the model for the entire projected simulation period.
3. Impose projected climate, hydrology, water operations, and demands from population and land use onto the existing model.
4. Run for 2030 (baseline and projected actions and projects) and for 2070 (baseline and projected actions and projects) simulations.
5. Aggregate results to develop projected water budgets without and with future projects and management actions.

Figure 4-5 illustrates the process for data download, manipulation and application.

The time series of monthly change factors for the VIC gridded data and the unimpaired streamflow data are from 1915 through 2011. The CalSim II flow time series data are provided over the period from 1921 through 2003. Versions of these time series that account for the effects of climate change are available for each of the 2030 and 2070 future scenarios. To apply these time series to a water budget spreadsheet or numerical model that have to include a minimum 50-year historical dataset, use one of the following methods (dates are shown for illustration purposes only):

- If a groundwater model has a 50-year simulation period between 1965 and 2015, then the common hydrology between these models is 38 years, which is 12 years shy of the required 50-year future planning and implementation horizon. One solution to remedy this issue would be to identify the sequence of water-year types within the historical 12 years and append 12 years of similar future water-year type sequencing to the common type period. DWR will provide a listing of water year types for the historical hydrology, and the 2030 and 2070 hydrology sequences in a separate document.
- If a groundwater model has a simulation period that spans more than 50 years and encompasses the 82 years of common simulation period for VIC and CalSim II, then that sequence can be used for groundwater modeling at 2030 and at 2070 even if it does not encompass the last 12 years of historical hydrology. The projected water budget needs to include a sequence of water-year types, similar to the past, over a 50-year planning horizon.



ET: Evapotranspiration; VIC: Variable Infiltration Capacity; SWP: State Water Project; CVP: Central Valley Project;
CalSim: SWP and CVP Operations Model System

Figure 4-5. Summary of Climate Change Data Download, Processing and Application.

Table 4-2 summarizes the various model outputs and respective timelines.

Table 4-2. Model Data Outputs and Related Simulation Periods

Model	Output Data	Simulation Period
VIC	Precipitation, Reference ET, Unimpaired flows	1915–2011
CalSim II	Reservoir outflows, river flows, diversions, deliveries	1921–2003
Common Simulation Period for Models at 2030 and at 2070		1921–2003 (82 years of projected hydrology)

4.6 Data Interpretation and Results

Simulation models that project climate conditions are inherently uncertain in nature. The outputs from these models are best used for sensitivity analysis to better understand the resiliency of a groundwater basin under projected climate change constraints and to assess potential projects and management actions to achieve or maintain sustainability in a groundwater basin over the long term.

The interpretation of results from these models and subsequent integrated surface-water/groundwater models used to generate outputs related to groundwater conditions necessitates caution. As such, outputs from projection models are best aggregated and interpreted using summary statistics rather than specific points in time. Because the future is uncertain when it comes to climate change, population growth and land-use development, statistical post-processing can help analyze data in a broader sense for planning purposes.

For example, from a water management perspective in California, extreme weather conditions are important aspects, because water years are rarely considered “average” or “normal.” When considering a 50-year simulation period, extracting and summarizing results for each water-year type can help reveal tendencies during these different types of water years and an understanding of these tendencies will help inform project planning and management actions. Evaluating data in terms of bookends could also be useful for looking at extreme conditions and analyzing the potential for flexibility based on the range of operating conditions that could be undertaken in a groundwater basin. These bookends could be representative of the average of all critically dry years and the average of all wet years during the simulation period for capturing the range of extreme conditions within the 50-year water budget analysis period.

An additional constraint on data interpretation for projected water budgets is linked to limitations of applying a time-period analysis with a physical transient model. For example, the following considerations apply when using a numerical model:

- Conditions at the end of the simulation and each year in between are not the expected conditions at those years.
- Comparing projected models with historical models to estimate changes is likely more appropriate than interpreting actual simulated physical values of the projected model.
- Time-period analysis is a statistical simplification that provides a range of possible outcomes representative of the historical interannual variability with the expected future climate trend and provides a method to assess uncertainty in future projected outcomes.

4.7 Disclaimer for Climate Change Data Use

4.7.1 Assumptions and Limitations of the Data and Methods

DWR provides climatological and hydrological data for use in GSP water budget development and modeling. It is the GSA's responsibility to use the data and tools appropriately. Using DWR-provided data and tools does not guarantee that a GSA's projected water budget is acceptable; nor does it guarantee that a projected water budget meets GSP requirements.

Although it is not possible to predict future hydrology and water use with certainty, the models, data, and tools provided here are considered current best available science and, when used appropriately should provide GSAs with a reasonable point of reference for future planning.

GSAs should understand the uncertainty involved in projecting future conditions. The recommended 2030 and 2070 central tendency scenarios describe what might be considered most likely future conditions; there is an approximately equal likelihood that actual future conditions will be more stressful or less stressful than those described by the recommended scenarios. Therefore, GSAs are encouraged to plan for future conditions that are more stressful than those evaluated in the recommended scenarios by analyzing the 2070 DEW and 2070 WMW scenarios.

Note that mathematical (or numerical) models can only approximate physical systems and have limitations in how they compute data. Models are inherently inexact because the mathematical depiction of the physical system is imperfect, and the understanding of interrelated physical processes incomplete. However, mathematical (or numerical) models are powerful tools that, when used carefully, can provide useful insight into the processes of the physical system.

Specific assumptions and limitations for particular models described in this document are provided below.

4.7.2 Model Data Limitations

All models have limitations in their interpretation of the physical system and the types of data inputs used and outputs generated, as well as the interpretation of outputs. The climate models used to generate the climate and hydrologic data for use in water budget development were recommended by CCTAG for their applicability to California water resources planning (CCTAG, 2015).

4.7.2.1 VIC Model Outputs and Limitations

The VIC model generates the following key output parameters on a daily and monthly time step:

- Temperature
- Precipitation
- Runoff
- Base flow
- Reference ET
- Soil moisture
- Snow water equivalent on a grid-cell and watershed basis
- Routed streamflow at major flow locations to the Sacramento and San Joaquin valleys

For purposes of projected water budget development, only a subset of these outputs was used to provide water budget data, as described in earlier sections.

The regional hydrologic modeling described using the VIC model is intended to generate changes in inflow magnitude and timing for use in subsequent CalSim II modeling. Although the VIC model contains several subgrid mechanisms, its coarse grid scale should be considered when interpreting results and analysis of local-scale phenomenon. The VIC model is currently best applied for regional-scale hydrologic analyses. Several limitations to long-term gridded meteorology related to spatial-temporal interpolation and bias correction should be considered. In addition, inputs to the VIC model do not include transient trends in the vegetation or water management that may affect streamflows; thus, they should only be analyzed from a naturalized flow (unimpaired flow) change standpoint.

Finally, the VIC model includes three soil zones to capture the vertical movement of soil moisture, but does not explicitly include groundwater. The exclusion of deeper groundwater is not likely a limiting factor in the upper watersheds of the Sacramento and San Joaquin river region that contribute approximately 80 to 90 percent of the runoff to the Delta. However, on the valley floor, groundwater management and surface water regulation is considerable. Water management models such as CalSim II should be used to characterize the heavily managed portions of the system in the Central Valley.

4.7.2.2 CalSim II Model Outputs and Limitations

CalSim II is a monthly model developed for planning level analyses. The model is run for an 82-year historical hydrologic period, at a projected level of hydrology and demands, and under an assumed framework of regulations. Therefore, the 82-year simulation does not provide information about historical conditions, but it does provide information about variability of conditions that would occur at the assumed level demand with the assumed operations, under the same historical hydrologic sequence. Because it is not a physically based model, CalSim II is not calibrated and cannot be used in a predictive manner, rather, in a comparative manner, of projected scenarios.

In CalSim II, operational decisions are made on a monthly basis, based on a set of predefined rules that represent the assumed regulations. The model has no capability to adjust these rules based on a sequence of hydrologic events such as a prolonged drought, or based on statistical performance criteria such as meeting a storage target in an assumed percentage of years.

Although there are certain components in the model that are downscaled to daily time step (simulated or approximated hydrology) such as an air-temperature-based trigger for a fisheries action, the results of those daily conditions are always averaged to a monthly time step (for example, a certain number of days with and without the action is calculated and the monthly result is calculated using a day-weighted average based on the total number of days in that month), and operational decisions based on those components are made on a monthly basis. Therefore, reporting sub-monthly results from CalSim II or from any other subsequent model that uses monthly CalSim II results as an input is not considered an appropriate use of model results.

Appropriate use of model results is important. Despite detailed model inputs and assumptions, the CalSim II results may differ from real-time operations under stressed water supply conditions. Such model results occur due to the inability of the model to make real-time policy decisions under extreme circumstances, as the actual (human) operators must do. Therefore, these results should only be considered an indicator of stressed water supply conditions under projected conditions.

4.7.3 Appropriate Use of Data

While DWR is providing these climate change resources to assist GSAs in their projected water budget calculations, the data and methods described in the Guidance Document are optional. Other local analysis and methods can be used, including existing climate change analysis. If the DWR-provided datasets are used, the Guidance Document describes two paths that may be followed to develop a projected water budget. The intent is to provide guidance on a possible method to assist GSAs with including climate change into their projected water budget calculations, especially if no local climate change analysis has been done before.

GSAs are not required to use DWR-provided climate change data or methods, but they will need to adhere to the requirements in the GSP Regulations. Local considerations and decisions may lead GSAs to use different approaches and methods than the ones provided by DWR for evaluating climate change. For example, the use of a transient climate change analysis approach may be appropriate where local models and data have been developed that include the best available science in that watershed or groundwater basin.

However, if DWR-provided data are used, GSAs should be careful not to mix and match these data with other locally developed climate change data, as the climate change methods could be different. In other words, the data used to represent climate perturbed model information need to be developed using a consistent approach. For example, it is not appropriate to mix data produced by a transient analysis climate change method with data developed using a climate period analysis method.

The use of change factors instead of actual model simulated values for projected conditions are more appropriate for the DWR-provided data because each of the models that were used have slightly different mathematical assumptions. Therefore, comparing these outputs directly can lead to misinterpretation of results.

Using change factors for gridded precipitation and ET data is a more representative method for local scale analyses with the DWR-provided data because of the discretization of the VIC model and the statistical processing associated with the historical temperature detrending.

The use of CalWater 2.2.1 watershed streamflow change factors requires special consideration when applying the data to a groundwater model or general water budget calculation. For example, this method is applicable to small watersheds because runoff likely occurs in less than the one-month time scale. A thorough explanation on the development of this dataset and the use of the dataset including applicability, limitations, and assumptions are included in Appendix C. This appendix also provides a discussion of the differences between the streamflow runoff methods used.

4.7.4 Evolution of Future Climate Change Data

As climate science develops further, it will be important to use the data that reflects the current understanding and best available science at the time of future GSP updates. For example, CMIP models are updated every 8 to 10 years with new climate science. DWR will release new data as deemed appropriate at the time of model updates to help GSAs stay current on their climate change analysis.

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SECTION 5

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Appendix A
Methods and Approaches for Climate Change Modeling and Analysis, and California Applications

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Methods and Approaches for Climate Change Modeling and Analysis, and California Applications

A.1 Introduction

Climate change is impacting California water resources, as evidenced by reductions in snowpack, altered timing of river flows, rising sea levels, warmer temperatures and altered patterns of precipitation. Figure A-1 illustrates example watershed features that can be impacted by climate change.

Climate-induced changes pose challenges to long-term water resource sustainability planning and management by increasing the uncertainty associated with future climate conditions. California water planners and managers have been among the first in the nation to consider and study these uncertainties through improvements in scientific research related to global-scale climate downscaling models and the development of other regional hydrological and operations models.

This appendix describes observed changes in California climate over the recent past, the need for climate change analysis for sustainability planning, the approach used by the California Department of Water Resources (DWR) to develop a set of climate change datasets, and provides an overview of the methods and approaches used to project changes in future climate and the resulting effects on hydrology. California-specific examples and applications of these methodologies are also provided.

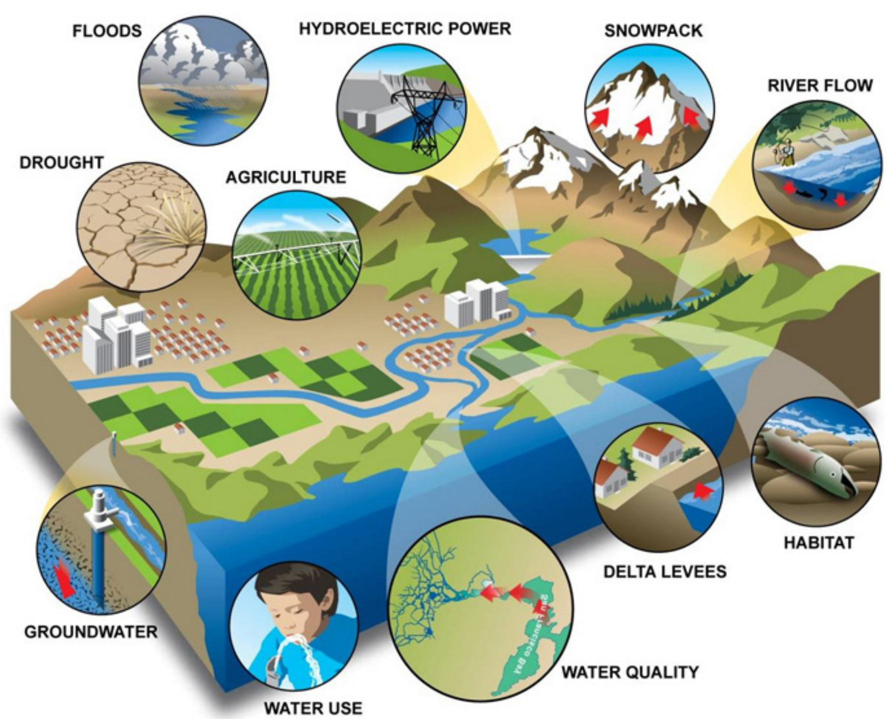


Figure A-1. Example Watershed Features That Can Be Impacted by Climate Change
Source: DWR, 2008

A.2 Observed Changes in California Climate

A.2.1 Precipitation and Temperature

Average annual temperature throughout California is highly variable due to variability in terrain and elevation (Figure A-2). In general, the northern part of the state is often cooler than the southern portion of the state. Cold temperatures down to -1.4 degrees Celsius (°C) can be observed in the Sierra Nevada mountain range due to the high elevation of these peaks. Significant warming can be observed in the Mojave Desert region of the state with temperatures up to 24.8 °C.

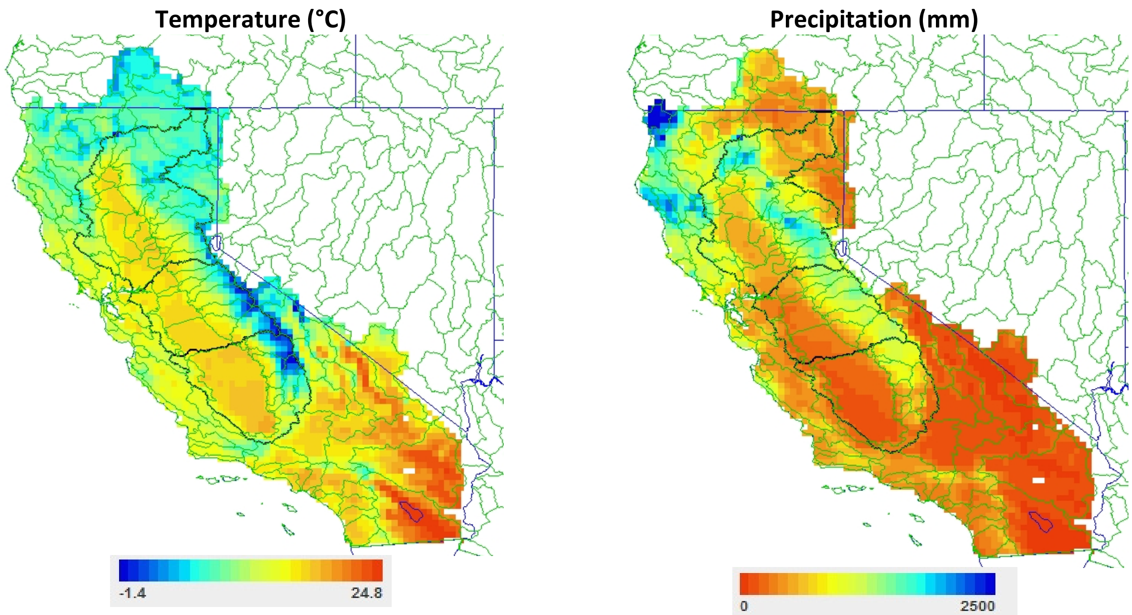


Figure A-2. Average Annual Temperature and Precipitation for 1981 to 2010
Source: Livneh et al., 2013; adapted from Reclamation, 2015

Precipitation in most of California is extremely variable, both spatially and temporally. Higher precipitation can be observed in the North Coast of California while little precipitation is often observed throughout the Mojave Desert and southern portions of California. In general, decreases in precipitation can be observed in moving from north to south through the Central Valley of California. Information from the State's longest observed precipitation records suggest that California's climate can transition from wet to dry or dry to wet within a few decades—well within typical water-resource planning periods (DWR Climate Change Technical Advisory Group [CCTAG], 2015).

California's Office of the State Climatologist provides information about California's climate trends; this office also releases publications related to California climate.[1] The Office of the State Climatologist also publishes an annual *Hydroclimate Report* (Office of the State Climatologist, 2016), which includes key indicators for hydrology and climate in California. This report is updated annually with the newest available data for tracking trends, provides a compilation of indicators, and offers graphical visualization of data trends. Pertinent information from the *Hydroclimate Report* for 2016 is summarized below.

[1] https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Flood-Management/Flood-Data/Files/Water-Year-2016-Hydroclimate-Report.pdf

The annual average air temperature departure for California from water year 1896 to water year 2016 is shown in Figure A-3.

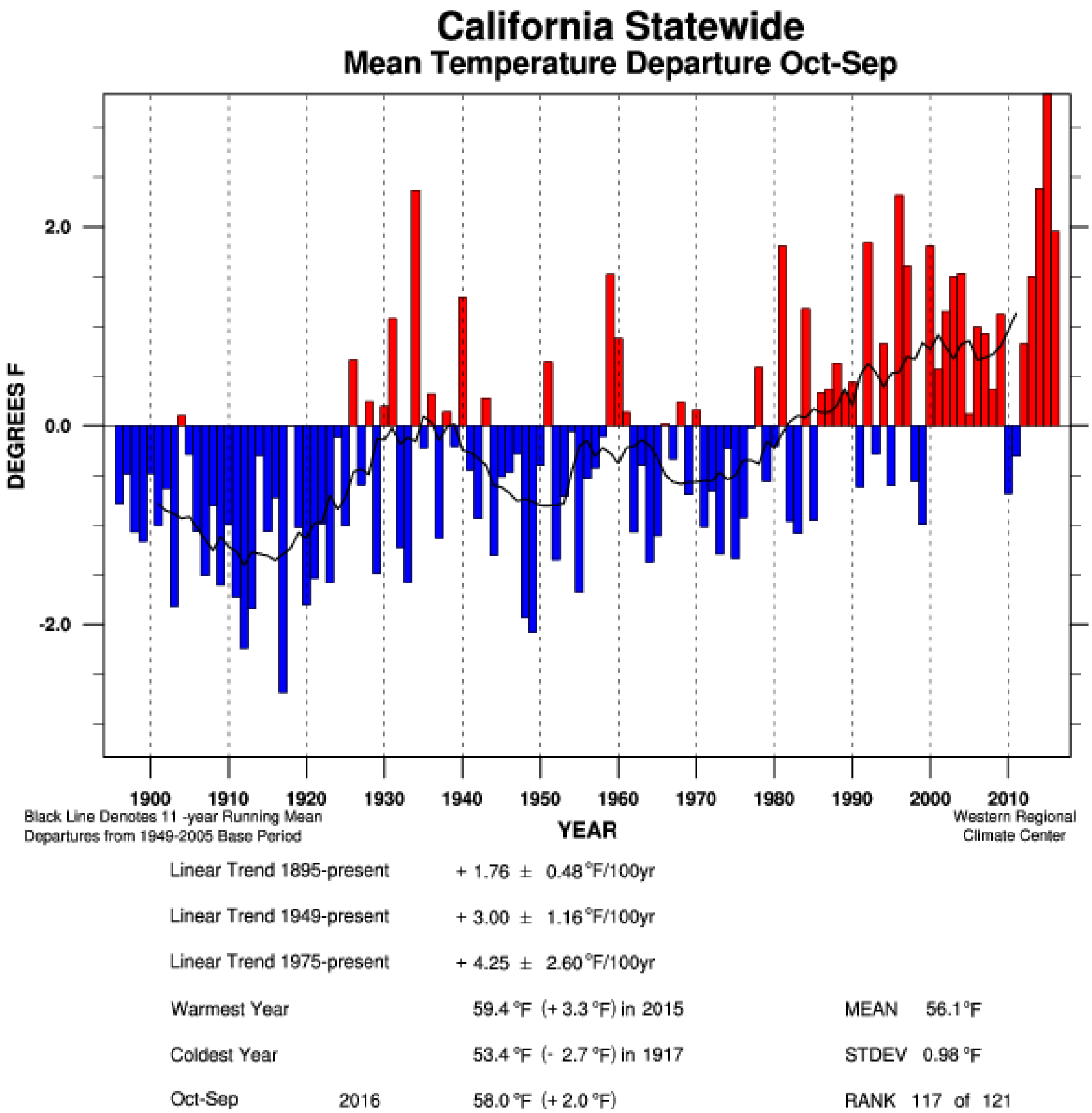


Figure A-3. California Statewide Mean Temperature Departure (October to September)

Source: Western Regional Climate Center, 2016

Notes:

Departure of annual water year average surface air temperature, 1896-2016. Bars: annual values; solid curves: 11-year running mean. Departure for temperature is computed for 1949-2005.

According to the Western Region Climate Center, California has experienced an increase of 1.2 to 2.2 degrees Fahrenheit (°F) in mean air temperature over the past century. Both the minimum and maximum annual air temperatures have increased, but the minimum temperatures (+1.7 to 2.7 °F) have increased more than the maximums (+0.6 to 1.8 °F) (Western Region Climate Center, 2016).

A significant increase in air temperature is apparent beginning from about 1985, although periods of cooling have occurred historically. Most notable is the warming trend that has occurred since the late 1970s. This warming trend has also been observed generally in North America, and follows global trends.

Annual precipitation shows substantial variability and periods of dry and wet conditions (Figure A-4). Most notable in the precipitation record is the lack of a significant long-term annual trend; however, annual variability appears to be increasing. More years with larger than long-term annual precipitation seem to appear in the most recent 30-year record.

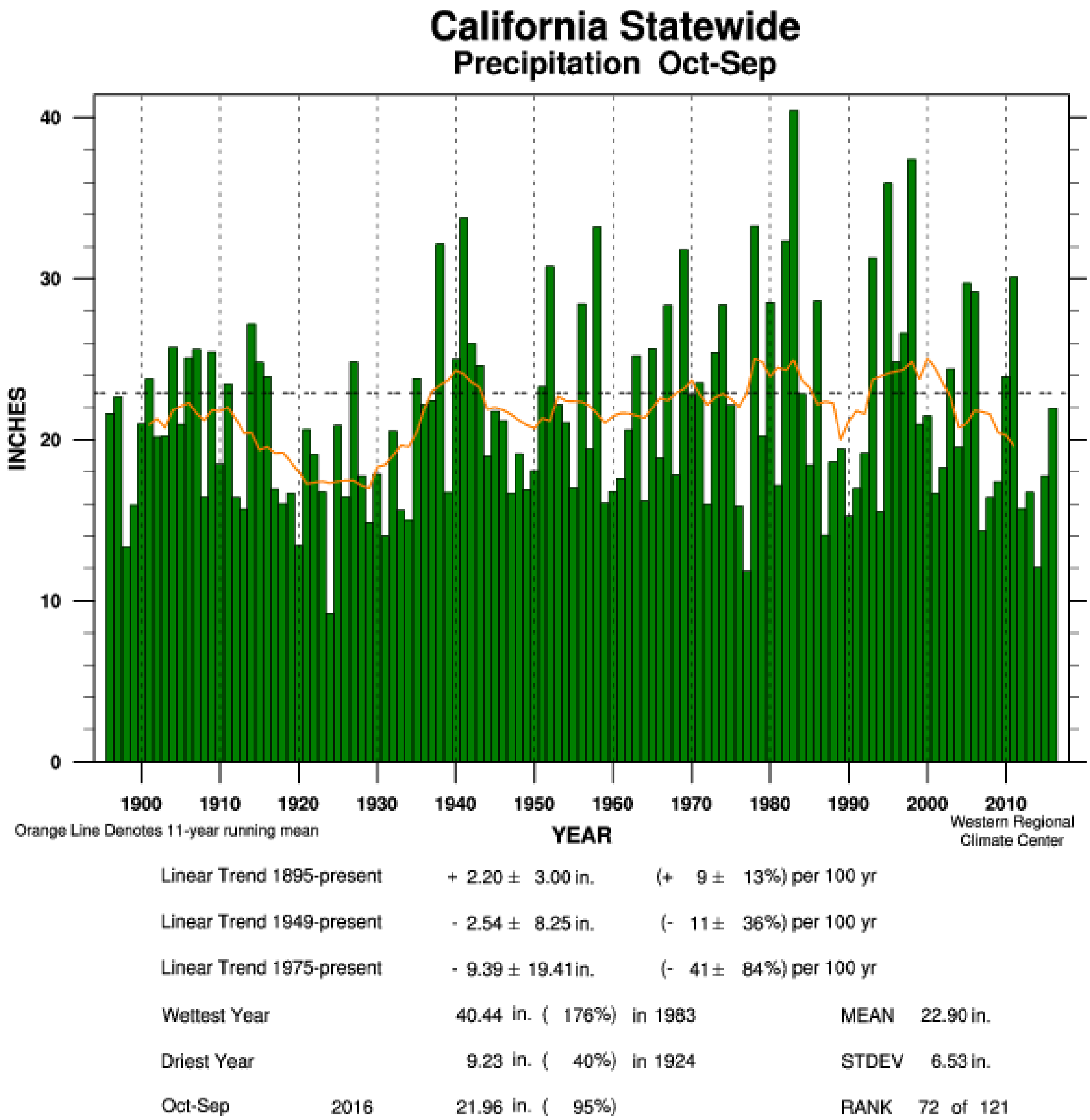


Figure A-4. California Statewide Precipitation (October to September)

Source: Western Regional Climate Center, 2016

Notes:

Annual water year average precipitation for the entire state. Bars: annual values; solid curves: 11-year running mean.

Observed climate and hydrologic records indicate that more substantial warming has occurred since the 1970s and that this is likely a response to the increases in greenhouse gas emissions during this period.

A.2.2 Sierra Snowpack

Snowpack in the Sierra Nevada mountain range is one of the main sources of water supply to streams feeding the Central Valley and California water supply infrastructure. Snowpack is heavily dependent on precipitation and air temperature and has decreased over the past 60 years. Figures A-5 and A-6 show snowpack trends in the Northern and Southern Sierra 13 snow courses. They are measured on April 1 of each year. Data from the 13 northern Sierra snow courses are at a lower elevation and show a steeper snowpack decrease since 1950 as compared to snowpack observed at the 13 southern station snow courses. The northern Sierra Nevada snowpack has decreased by 8.9 inches since 1950 and the southern Sierra Nevada snowpack decreased by 3.6 inches since 1950 (Office of the State Climatologist, 2016).

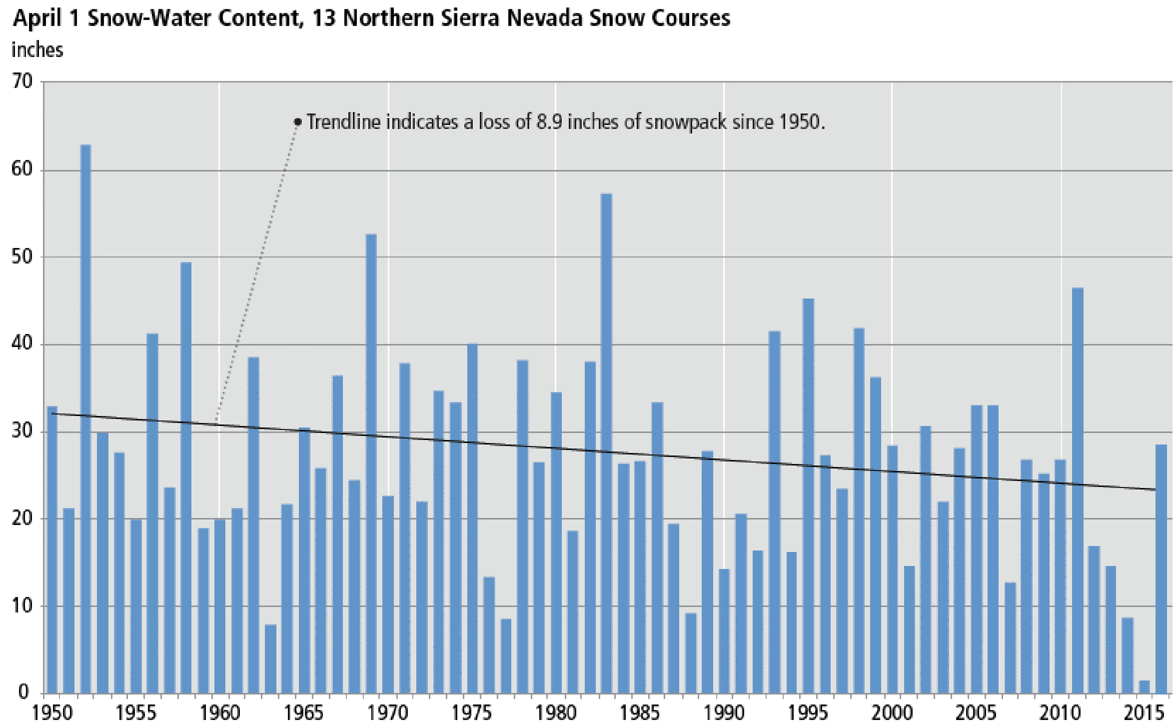


Figure A-5. April 1 Snow-Water Content, 13 Northern Sierra Nevada Snow Courses
Source: Office of the State Climatologist, 2016

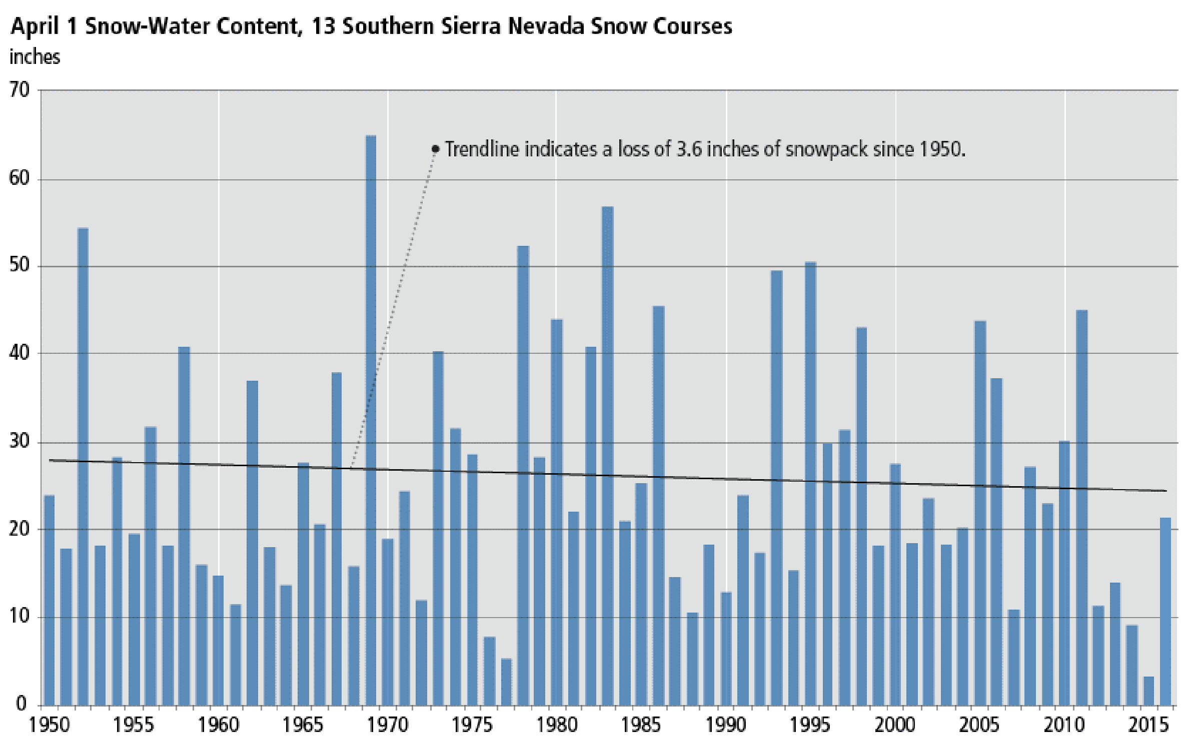


Figure A-6. April 1 Snow-Water Content, 13 Southern Sierra Nevada Snow Courses
Source: Office of the State Climatologist, 2016

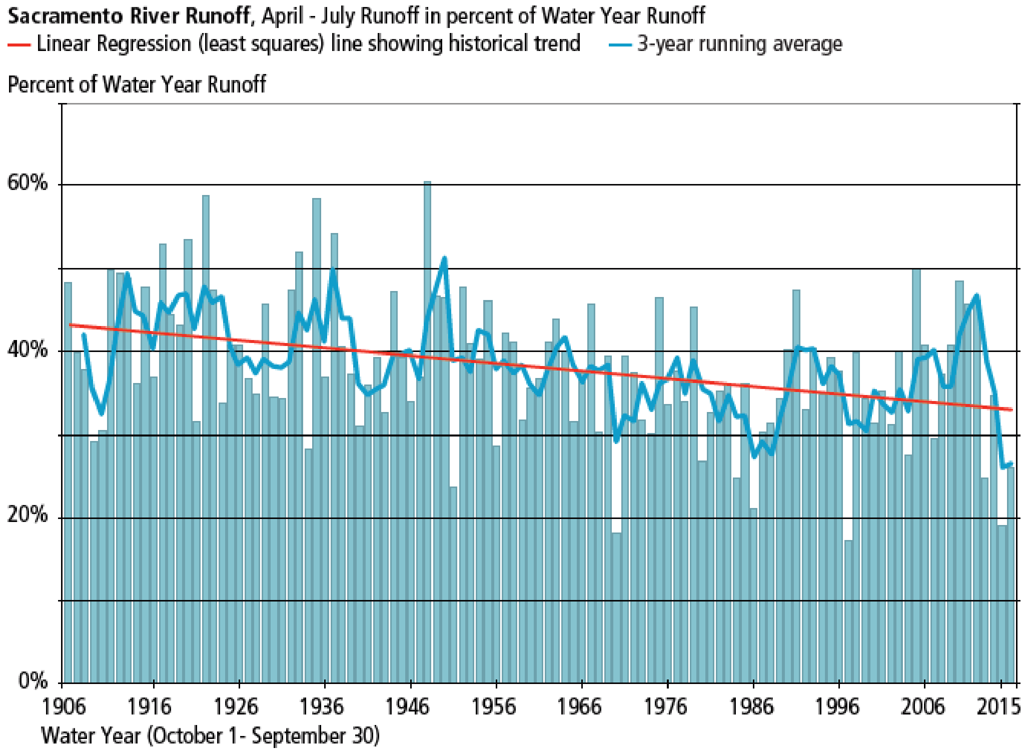
A.2.3 Unimpaired Streamflow: Sacramento and San Joaquin River Systems

Figure A-7 shows a historical comparison of natural hydrology flows or unimpaired flow (i.e., runoff)[2] occurring during the April through July snowmelt season in the Sacramento River from 1906 to 2016, and the San Joaquin River from 1901 to 2016. Unimpaired flows during the snowmelt season show a 9 percent decline per century in the Sacramento River system, whereas the San Joaquin River system shows a decline of 6 percent in unimpaired flow per century. The decline in runoff during this season correlates to the decrease in snowpack in the mountain ranges for watersheds feeding the Sacramento and San Joaquin rivers, as shown in Figures A-5 and A-6.

A.2.4 Effects on Groundwater Resources

Climate variation affects the quantity and timing of groundwater recharge. Increases in air temperature statewide have led to earlier snowmelt and less precipitation falling as snow. This has led to greater rates of direct runoff that likely exceeded soil infiltration capacities in some regions, thereby decreasing groundwater recharge in these regions. Variability in precipitation causing extended dry periods will also lead to less groundwater recharge and therefore less available groundwater for pumping. In addition, changes in the timing of streamflow can affect groundwater/surface-water interaction, which can provide opportunities and risk depending on the magnitude and timing of the change relative to the magnitude and timing of water demand.

[2] Not accounting for the changes in watershed flows due to water development projects such as dams and diversions.



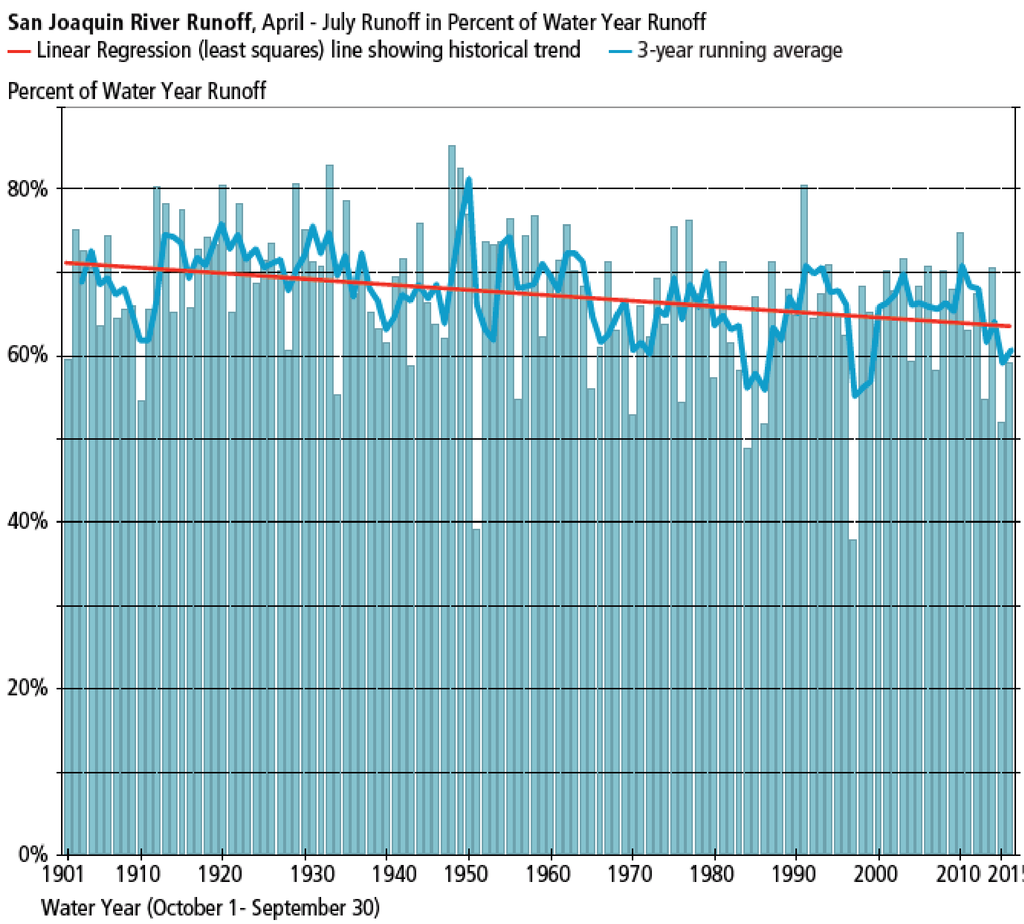


Figure A-7. Unimpaired Streamflow of Sacramento and San Joaquin River Systems
Source: Office of the State Climatologist, 2016

A.2.5 Sea-Level Rise

Global and regional sea levels have been increasing over the past century and are expected to continue to increase throughout this century. Over the past several decades, sea level measured at tide gages along the California coast has risen at a rate of about 17 to 20 centimeters per century (Cayan et al, 2009). There is considerable variability among tide gages along the Pacific Coast, primarily reflecting local differences in vertical movement of the land and the duration of the gage record. Figure A-8 shows the mean sea level trend for three key representative National Oceanic and Atmospheric Administration (NOAA) coastal tide gages in California.

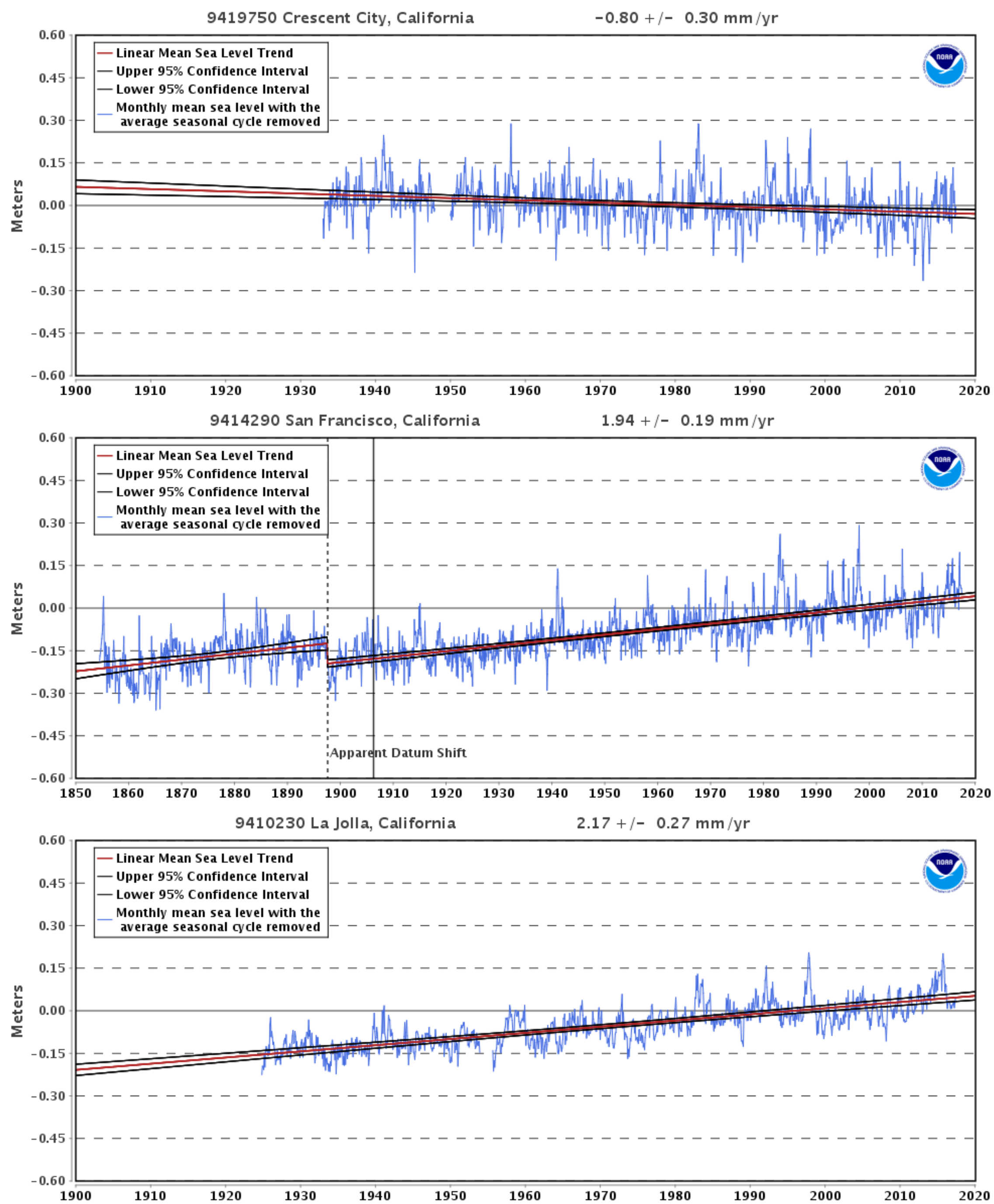


Figure A-8. Mean Sea Level Trend at Three NOAA Coastal Tide Gages on the California Coast

Source: Office of the State Climatologist, 2016

Sea-level rise is an important consideration for coastal groundwater basins that are hydraulically connected to the ocean water. Sea water intrusion along coastal plains is often observed due to increases in reliance on groundwater and pumping's influence on hydraulic gradients. Sea-level rise may exacerbate instances and magnitude of seawater intrusion due to increases in hydraulic gradients from the ocean to the inland groundwater basins. Therefore, sea-level rise is an important consideration for the management of water resources in coastal groundwater basins.

A.3 Using Climate Change Modeling for Groundwater Sustainability Planning

Given the uncertainty about future climate, water demand, and water supply, climate change analysis is a crucial component of long-term water planning activities for ensuring the sustainable management of groundwater resources as mandated by the Sustainable Groundwater Management Act (SGMA). Due to the spatial and temporal complexities associated with evaluating groundwater basin response to changing climate, land use, and proposed projects, it is anticipated that many Groundwater Sustainability Agencies (GSAs) will use hydrologic models to project future groundwater basin conditions. Incorporating climate change analysis in these hydrologic models often requires projections of climate resulting from the simulation of global circulation models.

Global climate change models provide the most scientifically robust information about likely future changes to climate conditions across the globe. Additional information about localized conditions is also typically required to understand how large-scale climate changes could manifest at the smaller watershed or groundwater basin scales. Downscaling of large-scale climate trends is often done by using historical observational data and physically-based regional climate models, or through other techniques. For water resource analysis, information about streamflows, groundwater recharge, and evapotranspiration (ET) is often important, and climate variables like air temperature and precipitation from climate models must be input into a hydrologic model (also known as rainfall-runoff model). Typical steps for developing a scenario for water resources planning are shown in Figure A-9.

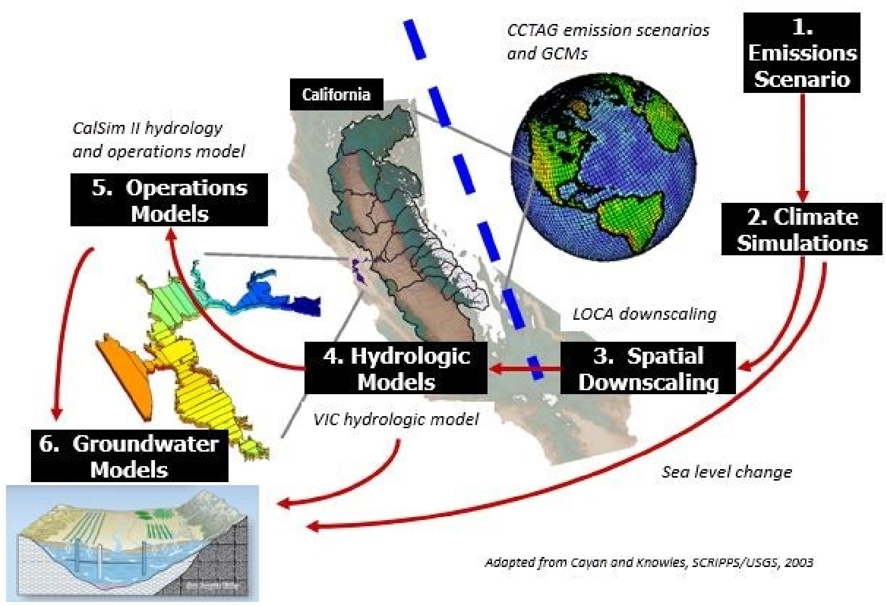


Figure A-9. Climate Change Data Downscaling to Groundwater Model

As shown on Figure A-9, the six steps of climate change modeling for water resources planning are as follows:

1. Select emissions scenario(s)
2. Select global climate model(s) and perform climate simulations using selected emissions scenarios
3. Spatially downscale global climate model results or select already spatially-downscaled data
4. Select hydrologic model and simulate unimpaired flows from downscaled climate model results
5. Select water system operations model(s), include climate change data and use unimpaired flows from the selected hydrologic model to simulate system operations, if applicable
6. Select groundwater/surface water model and use data from downscaled climate model(s), hydrologic model, and operations model(s) to simulate groundwater and surface water response to climate change

A general discussion on the purpose of these steps and the available methodologies are discussed generally in the proceeding sections. Further detail on how each of these climate change modeling steps have been applied to California are described later in Section A.4 of this Appendix.

A.3.1 Climate Simulation Approach

There are two general approaches that can be used to simulate climate change in water resource modeling: transient or climate period analysis. Each approach has advantages and disadvantages, and each may be more or less appropriate depending on the application. More information on this type of analysis is provided in the callout box below. For water resource modeling, particularly in California where inter-annual precipitation variability is extreme, transient analysis can be difficult to interpret. In a transient analysis, inter-annual variability can completely obscure the climate change signal—because each year of the simulation has both inter-annual variability and a climate change signal making it difficult to determine which is causing shifts in precipitation. Climate period analysis provides advantages in this situation because it isolates the climate change signal from the inter-annual variability signal. In a climate period analysis, inter-annual variability is based on the reference period from which change is being measured, meaning that all differences between the future simulation and the reference period are the result of the climate change signal alone.

Transient Climate Simulations versus Climate Period Simulations

Simulation methods are compared below.

Transient Climate Simulations	Climate Period Simulations
• Climate change signal strengthens incrementally over time, similar to the way climate change has been occurring in recent decades. In general, years further in the future are warmer than years closer to the beginning of the simulation, and the most severe changes to climate tend to occur toward the later years of the simulation. • Inter-annual variability can completely obscure the climate change signal—because each year of the simulation has both inter-annual variability and a climate change signal, making it difficult to determine which is causing shifts in precipitation. Climate period analysis provides advantages in this situation because it isolates the climate change signal independent of the inter-annual variability signal.	• Climate change is modeled as a shift from a baseline condition (usually historical observed climate) where every year of the simulation is shifted in a way that represents the climate change signal at a future 30-year climate period. • Inter-annual variability is based on the reference period from which change is being measured, meaning that all differences between the future simulation and the reference period are the result of the climate change signal alone.

One drawback of a climate period analysis is that it provides information about climate impacts at only one future climate period—usually a 30-year window. Therefore, multiple simulations need to be run to understand how climate changes will unfold over time.

A climate period analysis might represent future conditions for 2036 through 2065 or more generally mid-century/2050 future conditions, for example. Therefore, if one needed to evaluate future conditions throughout the 21st century, multiple simulations would have to be run to evaluate conditions at a number of climate periods between current conditions and the end of the century.

Additionally, the climate period analysis that DWR has typically used relies on the perturbation of historical observed climatology (or hydrology) to represent potential future conditions. This approach preserves historical inter-annual variability but also limits the exploration of future changes in inter-annual variability.

The figures below provide a graphical representation of the difference between transient and climate period analysis.

Figure A-10 shows a general conceptual representation of the transient analysis and the climate (or time) period analysis. As shown in the transient analysis, the projected temperature and precipitation follow a historical trend, while land use and other hydrological parameters continue to change over these projected years. A snapshot of climate variables and land use is used to simulate historical hydrological pattern.

Figure A-11 illustrates some of the differences in transient and climate period simulations for both temperature changes and precipitation changes. Figures A-11a (transient analysis) and A-11b (climate period analysis) compare the difference in the ways that these two approaches represent changes in temperature. Figure A-11a (transient analysis) shows the clear increasing trend in temperature over time. Figure A-11b (climate period analysis) shows that a step change in temperature occurs between 2015 conditions and 2030 or 2070 conditions.

Figure A-11c (transient analysis) illustrates how noisy the precipitation data are for transient climate simulations but also how each run explores novel examples of inter-annual variability. Conversely, Figure A-11d (climate period analysis) illustrates how a climate period simulation follows the historical pattern of inter-annual variability and the only differences come from the ways in which climate models project certain year-types will shift to wetter or drier conditions.

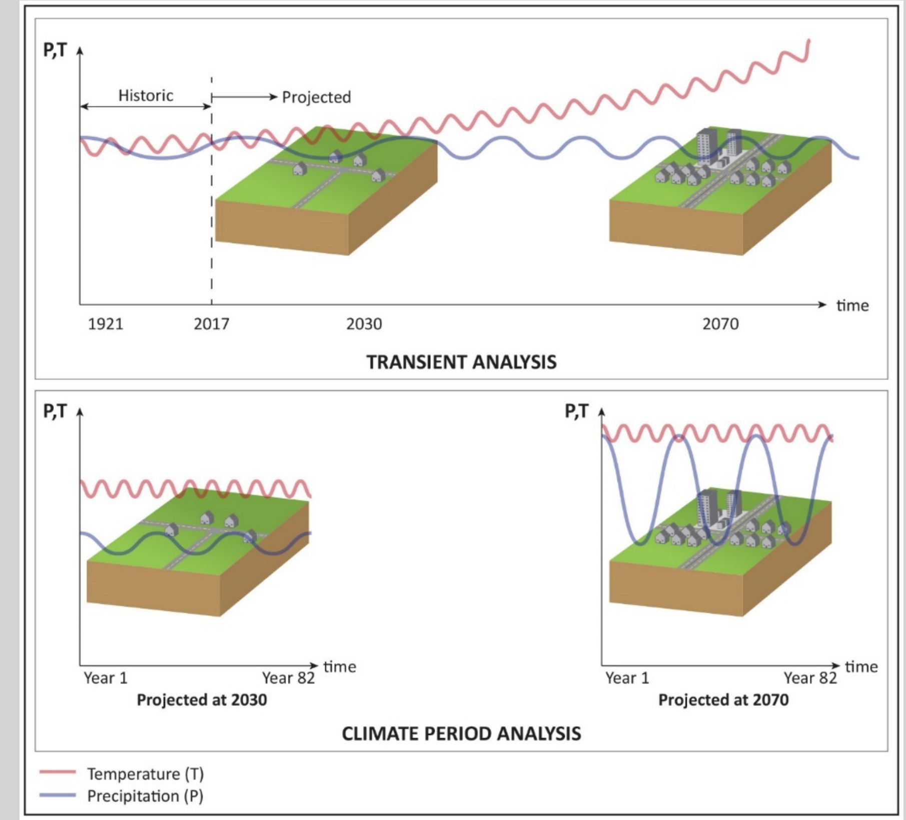


Figure A-10. Conceptual Representation of Transient and Climate Period Analysis

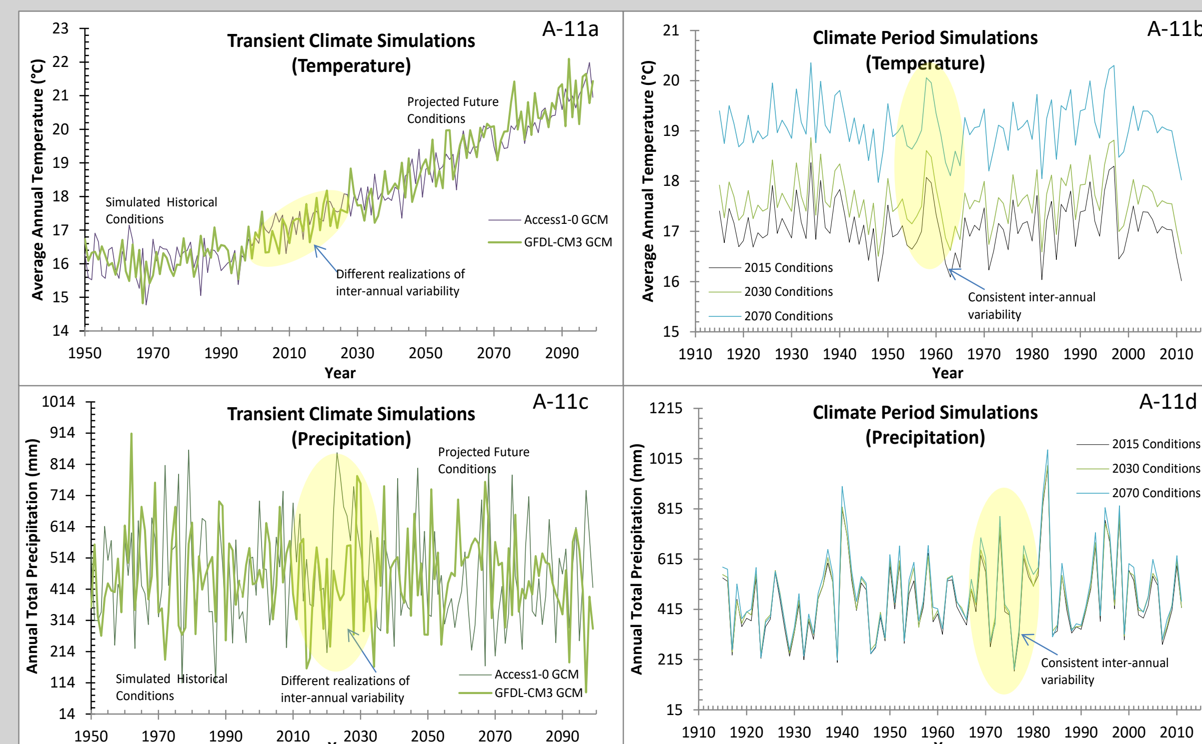


Figure A-11. Transient and Climate Period Simulations of Temperature and Precipitation

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A.3.2 Spatial Downscaling of General Circulation Model Data

A.3.2.1 Purpose and Need

Despite continuing improvements in the development and application of general circulation models (GCMs) and the improvements in computational resources, the spatial resolution of the current suite of GCMs is too coarse for direct use in watershed-scale impact assessments. For example, the spatial resolution of the GCMs that participated in the most recent Coupled Model Intercomparison Project Phase 5 (CMIP5) ranged approximately from 0.5 degree[3] to 4 degrees for the atmosphere component, and ranged approximately from 0.2 degree to 2 degrees for the ocean component (Taylor et al., 2012). To overcome the resolution issues, downscaling is a common approach for translating macro-scale climate changes that are either observed or identified in climate models to changes in meteorological parameters at the regional and local scales.

A.3.2.2 Commonly Used Techniques

Multiple downscaling approaches exist for translating coarse resolution climate model outputs to regional climate patterns. The two broad categories of approaches are statistical downscaling (i.e., using the relationship developed for the observed climate, between the large-scale and smaller-scale to climate model output) and dynamical downscaling (i.e., using physically based regional climate models). In statistical methods, the statistical properties between observed meteorological parameters at various stations or grid locations are related to broader-scale climate parameters at GCM-scale (i.e., a 2-degree grid scale). The relationship, based on historical observations, becomes a mapping-function for use in transferring projected climate conditions. One of the advantages of the statistical downscaling method is that they are computationally inexpensive. However, the major drawback is that the basic assumption in the statistical methods is that the statistical relationship developed for the historical period also holds at the future change conditions is not verifiable.

Dynamical downscaling involves the use of a regional climate model to translate the coarse-scale GCM projections to the regional or local scale (Mearns et al., 2009). Regional climate models use the GCM output as boundary conditions and simulate regional/local projections. This method of downscaling is founded on explicit representations of the laws of thermodynamics and fluid mechanics, so dynamical downscaling output can be seen as a true simulation of high-resolution climate conditions. Some disadvantages of this method are that it is computationally intensive and requires precise calibration of model parameters. Dynamical downscaling has not been widely applied, largely due to the extremely high computing requirements for long-term climate projections. The following summarizes some commonly applied methods used in California for downscaling GCM results*:*

- **Bias Correction Spatial Downscaling (BCSD):** BCSD is a statistical downscaling method. BCSD uses two steps: bias correction and spatial downscaling. The bias correction process uses a quantile-mapping technique to resolve monthly bias in the GCMs at a coarse scale. The spatial downscaling step uses interpolated pattern maps derived from historical climate to downscale climate to the regional or local scale.[4]
- **Localized Constructed Analogs (LOCA):** The LOCA method produces daily downscaled estimates of surface meteorological fields (i.e., minimum temperature, maximum temperature, and precipitation) suitable for hydrological simulations using a multiscale spatial matching scheme to

[3] 1 degree is equivalent to approximately 96 km or 60 mi

[4] http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

pick appropriate analog days from observations. This spatial downscaling method includes a bias-correction process based on frequency-dependent correction of the coarse resolution GCM daily temperature and precipitation fields prior to spatial downscaling.[5]

- **U.S. Geological Survey (USGS) Statistical Downscaling Method and Hydrologic Simulations**: This approach spatially downscales 12-kilometer resolution data from 1950 to 2000 (i.e., current climate) and 2000 to 2100 (i.e., future climate) to 4-kilometer resolution using a method called spatial gradient and inverse distance squared (GIDS) (Flint and Flint, 2012). These 4-kilometer data are designed to match grids from the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) dataset developed by Daly et al. (Daly et al., 1994). Then, bias-correction coefficients (i.e., mean and standard deviation) are developed using the historical monthly 4-kilometer data from both the PRISM and the downscaled GCM data. These historical bias-corrections are then applied to the 2000 to 2100 monthly data to produce bias-corrected 4-kilometer monthly data. These data are further downscaled using GIDS to 270-meter scale for use in the basin characterization model (BCM), a water balance model, to simulate a set of hydrologic variables at a 270-meter scale. The California Basin Characterization Model Downscaled Climate and Hydrology effort (CA-BCM 2014) produced downscaled climate data based on the BCSD statistical downscaling method at an 800-meter spatial resolution, and are further downscaled using the GIDS approach to 270 m[6] for model application.

A comparison of the three major downscaling techniques utilized in California is shown in Figure A-12, summarizing the principal steps for each technique.

All methods result in downscaled climate information for temperature and precipitation for use as input into hydrologic models to assess the local hydrology changes due to climate change as projected by the GCMs. LOCA was used as the downscaling technique for the California Water Commission's Water Storage Investment Program (WSIP), and the resulting data were used to develop the 2030 and 2070 climate scenarios for use by GSAs during Groundwater Sustainability Plan (GSP) development.

[5] http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html; http://loca.ucsd.edu/

[6] http://climate.calcommons.org/bcm

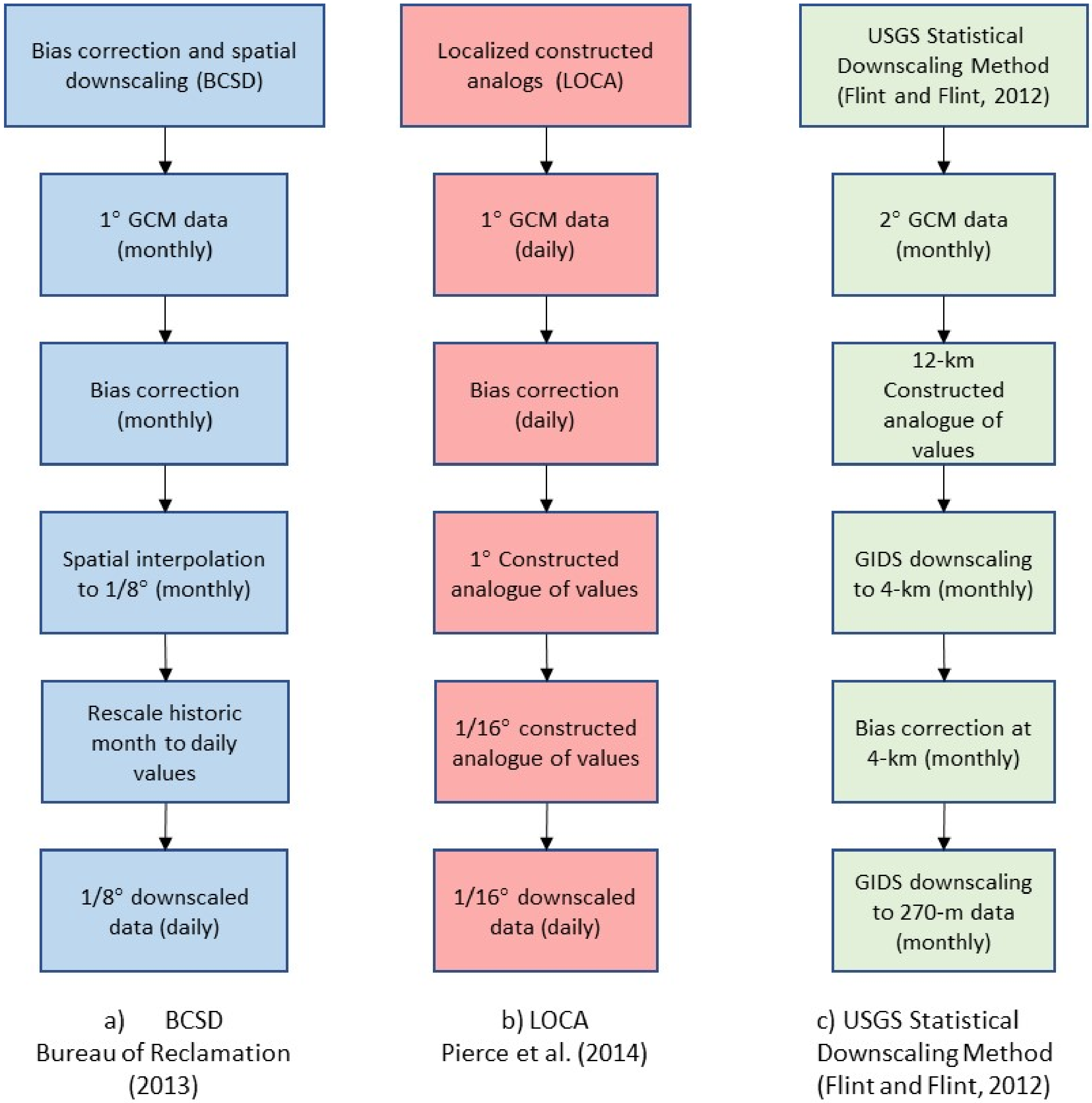


Figure A-12. Different Processing Sequences of BCSD, LOCA, and USGS Downscaling

A.4 Development of DWR-Provided Climate Change Analysis Data

DWR has been at the forefront of developing methods to analyze effects of climate change in California. As climate change science continues to evolve rapidly, DWR has developed methodologies to apply this new and changing information in California water resources planning. With several parallel programs needing to analyze climate change from different perspectives, and to meet the need for consistency across these planning efforts, DWR established the DWR CCTAG in 2012. The CCTAG was empaneled in February 2012 to advise DWR on the scientific aspects of climate change, its impact on water resources, and associated tools for water resources planning. The CCTAG was comprised of scientists, engineers, practitioners, and other water resources experts and was focused on providing guidance on climate data and analysis methods that are best-suited for California. CCTAG members worked collaboratively for

3 years to develop different alternatives for scenarios and approaches in a changing climate before publishing *Perspectives and Guidance for Climate Change Analysis* (Perspectives Document) (CCTAG, 2015). The Perspectives Document consolidates the CCTAG's guidance and perspectives, including its interpretation of scientific information produced by the National Climate Assessment and the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014).

California's recent and most significant effort toward sustainable management of the State's most vulnerable groundwater resources came through passage and implementation of SGMA. The GSP regulations that were developed by DWR require GSAs to incorporate climate change analysis in their GSPs to assess projected water availability and groundwater conditions through a 50-year planning period. CCTAG recommendations are both supportive of and considered in SGMA-required products.

A.4.1 Projected Climate Scenario Development

The following section discusses the methods and assumptions implemented by DWR to develop 2030 (i.e., near-future climate conditions) and 2070 (i.e., late-future climate conditions) climate change scenarios using various techniques and data available from global circulation models (GCMs).

A.4.1.1 Selection of Emission Scenarios and GCMs

As described in the *Water Storage Investment Program Technical Reference Document* (and its Appendix B), 10 GCMs were selected by the CCTAG as the most appropriate projections for water resources planning and analysis in the state of California. Climate change projections are made primarily on the basis of coupled atmosphere-ocean general circulation model simulations under a range of future emission scenarios. Climate projections used in this climate change analysis are based on climate model simulations from CMIP5. The 10 GCMs selected are combined with two emission scenarios, one optimistic (representative concentration pathway [RCP] 4.5) and one pessimistic (RCP 8.5), as identified by the Intergovernmental Panel on Climate Change (IPCC) for the Fifth Assessment Report (AR5) (IPCC, 2014) for 20 projections that apply to California. Table A-1 presents the 10 GCMs and associated RCPs used to develop ensemble climate projection scenarios for the WSIP.

Table A-1. Climate Model and RCP Combinations Used During Analysis

Model Name	Emissions Scenarios (RCPs) Used
ACCESS-1.0	4.5, 8.5
CanESM2	4.5, 8.5
CCSM4	4.5, 8.5
CESM1-BGC	4.5, 8.5
CMCC-CMS	4.5, 8.5
CNRM-CM5	4.5, 8.5
GFDL-CM3	4.5, 8.5
HadGEM2-CC	4.5, 8.5
HadGEM2-ES	4.5, 8.5
MIROC5	4.5, 8.5

A.4.1.2 Development of Future Climate Sequence

Development of a future climate scenario requires construction of a future climate sequence based on data obtained from the applied downscaling technique. For SGMA planning purposes, climate period analysis is most appropriate and recommended as an application for groundwater modeling with climate change.

To develop the climate scenarios, a technique called quantile mapping is applied, where cumulative distribution functions were produced for monthly temperature and monthly precipitation for the reference historical period (from 1981 to 2010) and each of the future climate periods (from 2016 to 2045 and from 2056 to 2085) for the ensemble of the 20 climate projections at each grid cell across the state. For further details on quantile mapping refer to the WSIP *Technical Reference Document* Appendix A (California Water Commission, 2017).

A.4.2 Projected Changes in California Climate Conditions

Based on the developed climate change scenarios, variations in average air temperature and precipitation at the year 2030 and at 2070 for the nine hydrologic regions of California as compared to 1995 historical data are presented in Figures A-13 and A-14, respectively.

On average, statewide precipitation is projected to increase by 2.9 percent at year 2030, and increase by 5.3 percent at year 2070. Temperature is predicted to increase by 2.4°F on average statewide at year 2030, and increase by 5.4°F at 2070. Figures A-13 and A-14 show that the impacts of climate change are projected to be variable across the state with some areas getting wetter and some getting drier. All areas are projected to experience warming, but the degree of warming varies significantly by hydrologic region.

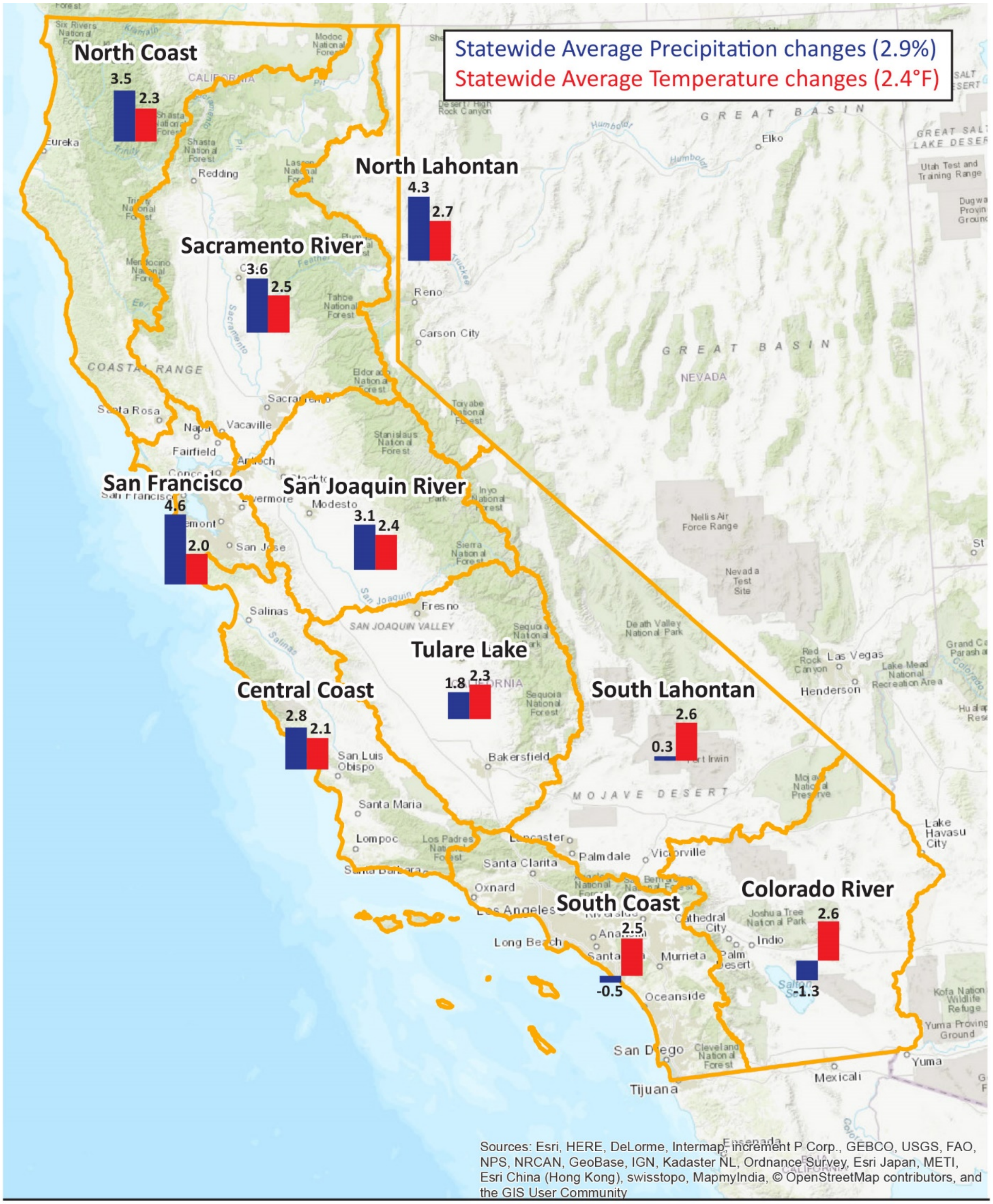
Figures A-13 and A-14 show that, at both the 2030 and 2070 projected climate conditions, the northern and central regions of California are expected to experience an increase in precipitation, as compared with the southern region. The southernmost regions of California (i.e., along the south coast and Colorado River) may experience much drier periods with decreasing precipitation overall. Air temperature trends for southern California are projected to be larger than those in northern or central California under both 2030 and 2070 future conditions, as compared to 1995 base historical conditions. This increase in air temperature means there could be more snowmelt (and potentially earlier snowmelt) and less snowpack in California in the future.

A.4.3 Simulating California Hydrology and Operations under Climate Change

A.4.3.1 Rainfall-Runoff Modeling

As a macro-scale model, variable infiltration capacity (VIC) modeling is well suited for incorporating climate data from downscaled GCM data to simulate statewide hydrologic responses to climate conditions. VIC modeling has been used for numerous DWR studies due to the availability of model inputs and the spatial coverage of the model, which allows for assessing hydrologic conditions throughout the State. The VIC model has also been applied to many major basins in the United States, including large scale applications to the following:

- California's Central Valley (Liang et al., 1994; Maurer et al., 2002, 2007; Maurer, 2007; Hamlet and Lettenmaier, 2007; Barnett et al., 2008; Cayan et al., 2009; Raff et al., 2009; Dettinger et al., 2011a, 2011b; Das et al., 2011a, 2013; DWR, 2014; Bureau of Reclamation [Reclamation], 2014)
- Colorado River Basin (Christensen and Lettenmaier, 2007; Das et al., 2011b; Vano and Lettenmaier, 2014; Vano et al., 2012, 2014)
- Columbia River Basin (Hamlet and Lettenmaier, 1999; Hamlet et al., 2007)
- Several other basins (Maurer and Lettenmaier, 2003; CH2M HILL, 2008; Livneh et al., 2013)



Average Precipitation Change (%)

Average Temperature Change (°F)

Hydrologic Region

HTD: Historical Temperature Detrended

Reference: Water Storage and Investment Program Technical Reference, California Water Commission, 2016.

Figure A-13. Projected Changes in Climate Conditions for 2030
Source: California Water Commission, 2016

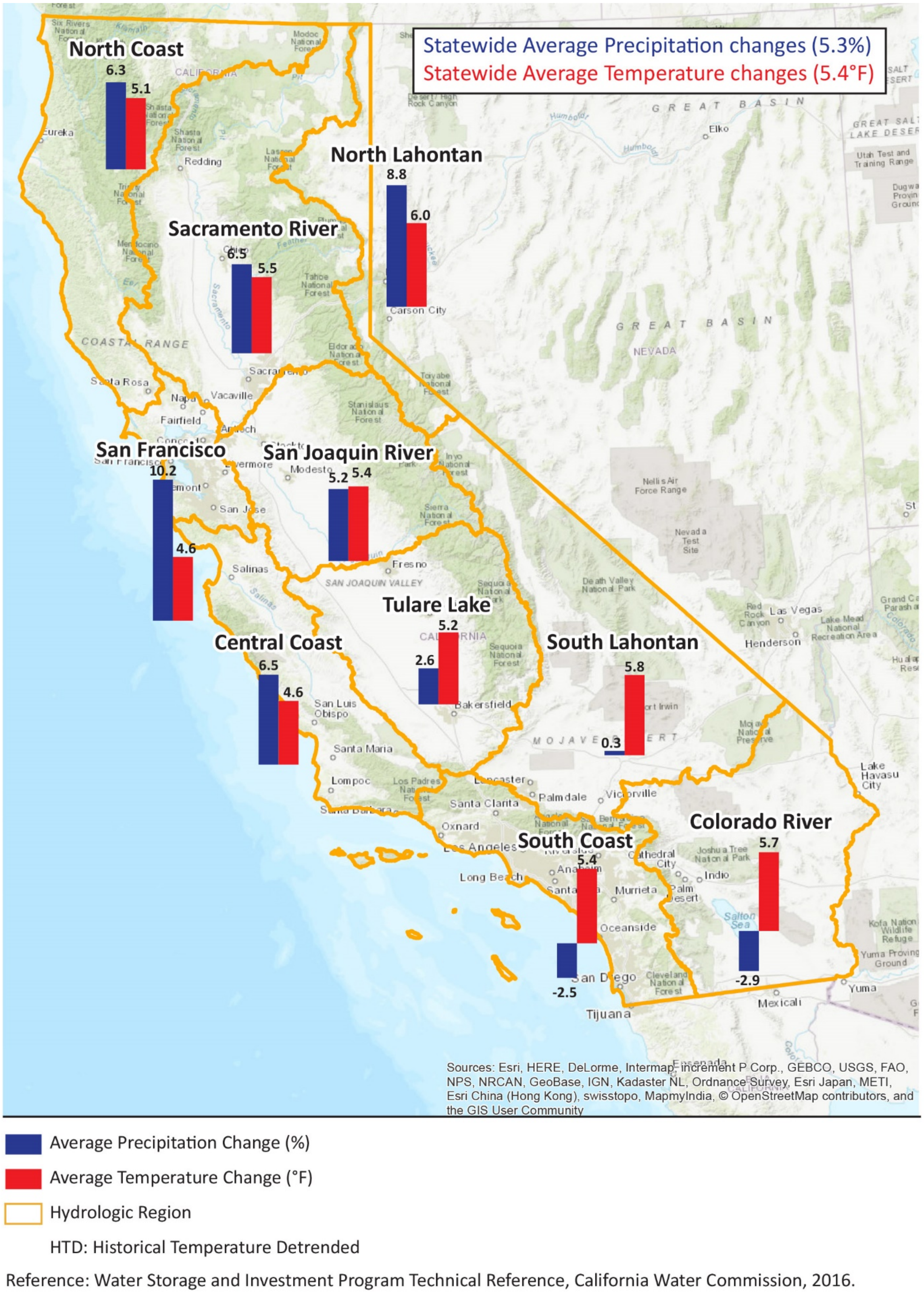


Figure A-14. Projected Changes in Climate Conditions for 2070
Source: California Water Commission, 2016

A.4.3.2 Water Operations Modeling

The hydrology of the Central Valley and operation of the Central Valley Project (CVP) and State Water Project (SWP) systems are critical elements in any assessment of changed conditions throughout the Central Valley and in the Delta, such as for future water supply planning under projected climate change conditions. Changes to system characteristics, such as flow patterns, demands, regulations, and Delta configuration will influence the operation of the CVP and SWP reservoirs and export facilities. The operation of these facilities, in turn, influence Delta flows, water quality, river flows, and reservoir storage. The interaction between hydrology, operations, and regulations is not always intuitive, and detailed analysis of this interaction often results in a new understanding of system responses. Modeling tools are required to approximate these complex interactions under projected conditions. CalSim II is a planning model developed by DWR and Reclamation. It simulates the CVP and SWP and areas tributary to the Delta. CalSim II provides quantitative hydrologic-based information to those responsible for planning, managing, and operating the CVP and SWP. As the official model of those projects, CalSim II is typically the system model used for interregional or statewide analysis in California.

CalSim II model simulations based on the SGMP recommended projected hydrologic conditions for 2030 and 2070 timeframes provide potential SWP and CVP operations under climate change conditions, to assess projected water supply changes through the simulated facilities (i.e., reservoirs, canals) under projected climate change conditions.

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Appendix B
Reservoir and Local Inflows, CalSim II Output Data, and CVP/SWP Contractor Deliveries

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Purpose and Scope

The following appendix provides information regarding CalSim II input and output data provided by the California Department of Water Resources (DWR) for use as part of Sustainable Groundwater Management Act (SGMA) requirements. These datasets represent surface water conditions under 2030 and 2070 projected conditions based on CalSim II model simulations as developed under the California Water Commission's (CWC's) Water Storage Investment Program (WSIP). Time series data corresponding with the information presented in this appendix are available for download via the SGMA Data Viewer.[1] Information presented here provides Groundwater Sustainability Agencies (GSAs) with various water budget components that depend on State Water Project (SWP) and Central Valley Project (CVP) operations under projected future hydrologic conditions. According to the requirements of SGMA, GSAs would incorporate these data into a groundwater model or water budget calculation to assess water budgets under the effects of climate change.

This appendix presents information pertaining to the following datasets:

- Reservoir Inflows and Local Tributary Inflows
- CalSim II Output Data
- SWP Contractor Deliveries
- CVP Contractor Deliveries

B.1 Reservoir Inflows and Local Tributary Inflows

Various reservoir and local tributary inflows have been compiled from the 2030 and 2070 CalSim II model simulations to assist GSAs in development of groundwater sustainability plans (GSPs). Table B-1 presents the locations for reservoir inflows and local tributary inflows that have been produced and the associated CalSim II variable name, where applicable.

Table B-1. List of Reservoir and Local Inflow Data

Description	CalSim II Variable Name
Reservoir Inflows	
Sacramento River Inflow to Shasta Dam	I4
Cosumnes River at Michigan Bar	I501
American River Inflow to Folsom Dam	I300 + I8
Merced River Inflow to Lake McClure	I20
San Joaquin River Inflow to Millerton Lake	I18_SJR + I18_FG
Calaveras River Inflow to New Hogan Lake	I92
Feather River Inflow to Lake Oroville	I6
Trinity River Inflow to Trinity Reservoir	I1
Tuolumne River Inflow to Don Pedro Reservoir	I81
Stanislaus River Inflow to New Melones Lake	I10

[1] https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer

Table B-1. List of Reservoir and Local Inflow Data

Description	CalSim II Variable Name
Yuba River at Smartville	I230
Kings River Inflow to Pine Flat Reservoir	N/A
Kaweah River Inflow to Kaweah Lake	N/A
Local Tributary Inflows	
Butte Creek Local Inflow	I217
Stony Creek Inflow to Black Butte Lake	I42
Cow Creek Local Inflow	I10801
Cottonwood Creek local inflow	I10802
Thomes Creek Local Inflow	I11304
Deer Creek Local Inflow	I11309
Bear River Local Inflow	I285
Fresno River Inflow to Lake Hensley	I52
Inflow to Whiskeytown Lake	I3
Paynes Creek Local Inflow	I11001
Antelope Creek Local Inflow	I11307
Mill Creek Local Inflow	I11308
Elder Creek Local Inflow	I11303
Big Chico Creek Local Inflow	I11501
Stony Creek Inflow to East Park Reservoir	I40
Stony Creek Inflow to Stony Gorge Reservoir	I41
Kelly Ridge Tunnel/Powerhouse	I200
Red Bank Creek Local Inflow	I112
Lewiston Inflow	I100
Chowchilla River Inflow to Eastman Lake	I53

B.2 CalSim II Output Data

Various CalSim II outputs have been compiled from the 2030 and 2070 CalSim II model simulations. Table B-2 presents a compiled list of locations of reservoir outflows, streamflow, and river channel diversions and the associated CalSim II variable name.

Table B-2. List of Reservoir Outflows, River Channel Streamflow, and River Channel Diversions

Description	CalSim II Variable Name
Reservoir Outflows	
Millerton Lake Outflow	C18
Hensley Lake Outflow	C52
Eastman Lake Outflow	C53
Lake McClure Outflow	C20
New Don Pedro Reservoir Outflow	C81
New Melones Reservoir Outflow	C10
New Hogan Reservoir Outflow	C92
Lake Oroville Outflow	C6
Shasta Lake Outflow	C4
Lewiston Lake Outflow	C100
River Channel Streamflow	
Stanislaus River at Goodwin	C520
American River below Nimbus Dam	C9
Sacramento River below Keswick Dam	C5
San Joaquin River below Gravelly Ford	C603
San Joaquin River below Salt Slough	C614
Merced River near Stevinson	C566
Tuolumne River U/S of San Joaquin Confluence	C545
San Joaquin River below Merced River Confluence	C620
San Joaquin River below Tuolumne River Confluence	C630
Stanislaus River near Ripon	C528
Calaveras River Inflow to Delta	C508
American River at Sacramento River Confluence	C303
Sacramento River at Freeport	C169
Feather River below Thermalito Diversion Dam	C203
Delta Outflow	C407
Feather River near Nicolaus	C223
Sacramento River at Red Bluff	C112
Sacramento River at Knights Landing	C134
Sacramento River at Wilkins Slough	C129
Sacramento River at Verona	C160

Table B-2. List of Reservoir Outflows, River Channel Streamflow, and River Channel Diversions

Description	CalSim II Variable Name
San Joaquin River at Vernalis	C639
Clear Creek Tunnel	C3
San Joaquin River below Mendota Pool	C607
River Channel Diversions	
Sacramento River at Red Bluff	D112
Glenn Colusa Canal	D114
Friant-Kern Canal Diversion	D18
Feather River below Thermalito Diversion Dam	C203
Black Butte Outflow	C42

B.3 SWP Contractor Deliveries

SWP contractor delivery data for 2030 and 2070 projected conditions have been compiled for various contractors as represented in the CalSim II model. Table B-3 lists SWP contractors, the associated delivery type, and the associated CalSim II delivery variable name for that contractor. For more information about SWP deliveries and contractor information, refer to the *SWP Delivery Capability Report*.[2]

Table B-3. List of SWP Contractors, Delivery Type, and Associated CalSim II Variable Name

Contractor	Delivery Type	CalSim II Variable Name
Feather River		
Western Canal	FRSA Contractor Delivery	D7A_PAG
Joint Board Canal	FRSA Contractor Delivery	D7B_PAG
Feather WD	FRSA Contractor Delivery	D206A_PAG
Butte County	Table A	SWP_TA_BUTTE
Yuba City	Table A	SWP_TA_YUBA
North Bay		
Napa County FC & WCD	Table A	SWP_TA_NAPA
Solano County WA	Table A	SWP_TA_SOLANO
Napa County FC & WCD	Article 21	SWP_IN_NAPA
South Bay		
Alameda County FC & WCD, Zone 7	Table A & Carryover	SWP_TA_ACFC + SWP_CO_ACFC
Alameda County WD	Table A	SWP_TA_ACWD

[2] http://baydeltaoffice.water.ca.gov/swpreliability/

Table B-3. List of SWP Contractors, Delivery Type, and Associated CalSim II Variable Name

Contractor	Delivery Type	CalSim II Variable Name
Santa Clara Valley WD	Table A	SWP_TA_SCV
Alameda County FC & WCD, Zone 7	Article 21	SWP_IN_ACFC
Alameda County WD	Article 21	SWP_IN_ACWD
Santa Clara Valley WD	Article 21	SWP_IN_SCV
San Joaquin Valley		
Oak Flat WD	Table A	SWP_TA_OAK
Kings County	Table A	SWP_TA_KINGS
Dudley Ridge WD	Table A	SWP_TA_DUDLEY
Empire West Side ID	Table A	SWP_TA_EMPIRE
Kern County WA	Table A	SWP_TA_KERNAG + SWP_TA_KERNMI
Tulare Lake Basin WSD	Table A	SWP_TA_TULARE
Dudley Ridge WD	Article 21	SWP_IN_DUDLEY
Empire West Side ID	Article 21	SWP_IN_EMPIRE
Kern County WA	Article 21	SWP_IN_KERN
Tulare Lake Basin WSD	Article 21	SWP_IN_TULARE
Central Coast		
San Luis Obispo County FC & WCD	Table A	SWP_TA_SLO
Santa Barbara County FC & WD	Table A	SWP_TA_SB
Southern California		
Castaic Lake WA	Table A	SWP_TA_CLWA1 + SWP_TA_CLWA2
Metropolitan WDSC	Table A & Carryover	SWP_TA_MWD + SWP_CO_MWD
San Bernardino Valley MWD	Table A & Carryover	SWP_TA_SBV + SWP_CO_SBV
San Gabriel Valley MWD	Table A	SWP_TA_SGV
San Gorgonio Pass WA	Table A	SWP_TA_SGP
Ventura County FCD	Table A	SWP_TA_VC
Antelope Valley-East Kern WA	Table A	SWP_TA_AVEK
Coachella Valley WD	Table A & Carryover	SWP_TA_CVWD + SWP_CO_CVWD
Crestline-Line Arrowhead WA	Table A	SWP_TA_CLA
Desert WA	Table A & Carryover	SWP_TA_DESERT + SWP_CO_DESERT
Littlerock Creek ID	Table A	SWP_TA_LCID
Mojave WA	Table A	SWP_TA_MWA
Palmdale WD	Table A	SWP_TA_PWD

Table B-3. List of SWP Contractors, Delivery Type, and Associated CalSim II Variable Name

Contractor	Delivery Type	CalSim II Variable Name
Castaic Lake WA	Article 21	SWP_IN_CLWA1
Metropolitan WD of Southern California	Article 21	SWP_IN_MWD
Antelope Valley-East Kern WA	Article 21	SWP_IN_AVEK
Coachella Valley WD	Article 21	SWP_IN_CVWD
Desert WA	Article 21	SWP_IN_DESERT

FC & WCD = flood control and water conservation district

FCD = flood control district

FRSA = Feather River Service Area

ID = irrigation district (ID)

MWD = municipal water district

WA = water agency

WD = water district

Feather River Service Area (FRSA) contractors are grouped into one CalSim II variable. Table B-4 presents the contractors that fall under the FRSA contractor delivery, the associated CalSim II variable name, the annual contract amount, and a ratio that was calculated and applied to the CalSim II time series data. The ratio was calculated as the annual contract amount divided by the total contract amount to determine how to split the CalSim II time series amongst each contractor.

Table B-4. Feather River SWP Contractor Deliveries that Require Disaggregation from CalSim II Variable

Contractor	Delivery Type	CalSim II Variable Name	Annual Contract Amount (AF/year)[a]	Ratio Applied to Timeseries Data
Feather River				
Garden	FRSA Contractor Delivery	D206B_PAG	12.87	0.20
Oswald	FRSA Contractor Delivery	D206B_PAG	2.85	0.04
Joint Board	FRSA Contractor Delivery	D206B_PAG	50	0.76
Plumas	FRSA Contractor Delivery	D206C_PAG	8	0.61
Tudor	FRSA Contractor Delivery	D206C_PAG	5.09	0.39

Notes

[a] Annual Contract Amounts Listed as Modeled in CalSim II

AF =- acre feet

B.4 CVP Contractor Deliveries

CVP contractor delivery information was adapted from the *Coordinated Long-Term Operation of the CVP SWP Environmental Impact Statement*'s Appendix 5A.[3] The information presented here corresponds to the CVP delivery timeseries data available for use under SGMA through the SGMA Data Viewer.[4]

Table B-5 presents the North of Delta CVP contractors, Table B-6 presents American River CVP contractors, Table B-7 presents South of Delta CVP contractors, and Table B-8 presents Sacramento River miscellaneous users. Each table contains the contractor geographic location, CalSim II diversion variable name and service area region, and the contract amount by contract type (i.e., CVP, Settlement/Exchange, or Level 2 Refuges).

Annual contract limits are presented by CVP contractor and contract type (i.e., CVP, Settlement/Exchange, or Refuges). Representation of the deliveries corresponding to these contracts may be aggregated in a way that represents the delivery to multiple contractors. Because of this, annual contract limits can be used to distribute CalSim II data among CVP contractors by using a fraction of annual contract amount per contractor divided by the total annual contract amount.

Table B-5. CVP North-of-the-Delta—Future Conditions

CVP Contractor	Geographic Location	CalSim II Variable Name		CVP Water Service Contracts (TAF/year)		Settlement/ Exchange Contractor (TAF/year)	Level 2 Refuges[a] (TAF/year)
		Diversion	Region	Ag	M&I		
Anderson Cottonwood ID	Sacramento River Redding Subbasin	D104_PSC	DSA 58			128.0	
Clear Creek CSD		D104_PAG	DSA 58	13.8			
		D104_PMI			1.5		
Bella Vista WD		D104_PAG	DSA 58	22.1			
		D104_PMI			2.4		
Shasta CSD		D104_PMI	DSA 58		1.0		
Sac R. Misc. Users		D104_PSC	DSA 58			3.4	
Redding, City of		D104_PSC	DSA 58			21.0	
City of Shasta Lake		D104_PAG	DSA 58	2.5			
		D104_PMI			0.3		
Mountain Gate CSD		D104_PMI	DSA 58		0.4		
Shasta County Water Agency		D104_PAG	DSA 58	0.5			
		D104_PMI			0.5		
Redding, City of/Buckeye		D104_PMI	DSA 58		6.1		
			Total	**38.9**	**12.2**	**152.4**	**0.0**
Corning WD	Corning Canal	D171_AG	WBA 4	23.0			
Proberta WD		D171_AG	WBA 4	3.5			
Thomes Creek WD		D171_AG	WBA 4	6.4			
			Total	**32.9**	**0.0**	**0.0**	**0.0**

3 https://www.usbr.gov/mp/nepa/nepa_project_details.php?project_id=21883

4 https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer

Table B-5. CVP North-of-the-Delta—Future Conditions

CVP Contractor	Geographic Location	CalSim II Variable Name		CVP Water Service Contracts (TAF/year)		Settlement/ Exchange Contractor (TAF/year)	Level 2 Refuges[a] (TAF/year)
		Diversion	Region	Ag	M&I		
Kirkwood WD	Tehama-Colusa Canal [a]	D172_AG	WBA 4	2.1			
Glide WD		D174_AG	WBA 7N	10.5			
Kanawha WD		D174_AG	WBA 7N	45.0			
Orland-Artois WD		D174_AG	WBA 7N	53.0			
Colusa, County of		D178_AG	WBA 7S	20.0			
Colusa County WD		D178_AG	WBA 7S	62.2			
Davis WD		D178_AG	WBA 7S	4.0			
Dunnigan WD		D178_AG	WBA 7S	19.0			
La Grande WD		D178_AG	WBA 7S	5.0			
Westside WD		D178_AG	WBA 7S	65.0			
			Total	**285.8**	**0.0**	**0.0**	**0.0**
Sac. R. Misc. Users [b]	Sacramento River	D113A	WBA 4			1.5	
Glenn Colusa ID	Glenn-Colusa Canal	D143A_PSC	WBA 8NN			441.5	
		D145A_PSC	WBA 8NS			383.5	
Sacramento NWR		D143B_PRF	WBA 8NN				53.4
Delevan NWR		D145B_PRF	WBA 8NS				24.0
Colusa NWR		D145B_PRF	WBA 8NS				28.8
Colusa Drain MWC	Colusa Basin Drain	D180_PSC	WBA 8NN			7.7	
		D182A+D18302	WBA 8NS			62.3	
			Total	**0.0**	**0.0**	**895.0**	**106.2**
Princeton-Cordova-Glenn ID	Sacramento River	D122A_PSC	WBA 8NN			67.8	
Provident ID		D122A_PSC	WBA 8NN			54.7	
Maxwell ID		D122A_PSC	WBA 8NN			1.8	
		D122B_PSC	WBA 8NS			16.2	
Sycamore Family Trust		D122B_PSC	WBA 8NS			31.8	
Roberts Ditch IC		D122B_PSC	WBA 8NS			4.4	
Sac R. Misc. Users [b]		D122A_PSC	WBA 8NN			4.9	
		D122B_PSC	WBA 8NS			9.5	
			Total	**0.0**	**0.0**	**191.2**	**0.0**
Reclamation District 108	Sacramento River	D122B_PSC	WBA 8NS			12.9	
		D129A_PSC	WBA 8S			219.1	
River Garden Farms		D129A_PSC	WBA 8S			29.8	
Meridian Farms WC		D128_PSC	DSA 15			35.0	
Pelger Mutual WC		D128_PSC	DSA 15			8.9	
Reclamation District 1004		D128_PSC	DSA 15			71.4	
Carter MWC		D128_PSC	DSA 15			4.7	
Sutter MWC		D128_PSC	DSA 15			226.0	

Table B-5. CVP North-of-the-Delta—Future Conditions

CVP Contractor	Geographic Location	CalSim II Variable Name		CVP Water Service Contracts (TAF/year)		Settlement/ Exchange Contractor (TAF/year)	Level 2 Refuges[a] (TAF/year)
		Diversion	Region	Ag	M&I		
Tisdale Irrigation & Drainage Company		D128_PSC	DSA 15			9.9	
Sac R. Misc. Users [b]		D128_PSC	DSA 15			103.4	
		D129A_PSC	WBA 8S			0.9	
			Total	**0.0**	**0.0**	**722.1**	**0.0**
Sutter NWR	Sutter Bypass Water for Sutter NWR	C136B	DSA 69				25.9
Gray Lodge WMA	Feather River	C216B	DSA 69				41.4
Butte Sink Duck Clubs		C221	DSA 69				15.9
			Total	**0.0**	**0.0**	**0.0**	**83.2**
Sac. R. Misc. Users [b]	Sacramento River	D163_PSC	DSA 65			56.8	
City of West Sacramento		D165_PSC	DSA 65			23.6	
			Total	**0.0**	**0.0**	**80.4**	**0.0**
Sac R. Misc. Users	Lower Sacramento River	D162A_PSC	DSA 70			4.8	
Natomas Central MWC		D162B_PSC	DSA 70			120.2	
Pleasant Grove-Verona MWC		D162C_PSC	DSA 70			26.3	
			Total	**0.0**	**0.0**	**151.3**	
			Total CVP North-of-Delta	**357.6**	**12.2**	**2193.8**	**189.4**

Notes:

[a] Level 4 Refuge water needs are not included.

[b] Refer to Sac Misc. Users Table for a Breakdown by DSA and River Mile

Ag = agricultural

CSD = community services district

ID = irrigation district

M&I = municipal and industrial

MWC = mutual water company

NWR = national wildlife refuge

TAF = thousand acre-feet

WC = water company

WD = water district

WMA = wildlife management area

Table B-6. CVP for American River—Future Conditions

CVP Contractor	CalSim II Variable Name	CVP Water Service Contracts (TAF/year) M&I[a]
City of Folsom (includes P.L. 101-514)	D8B_PMI	7.0
San Juan Water District (Sac County) (includes P.L. 101-514)	D8E_PMI	24.2
El Dorado Irrigation District	D8F_PMI	7.55
City of Roseville	D8G_PMI	32.0
Placer County Water Agency	D8H_PMI	35.0
El Dorado County (P.L. 101-514)	D8I_PMI	15.0
	Total	**120.8**
California Parks and Recreation	D9AB_PMI	5.0
SMUD (export)	D9B_PMI	30.0
	Total	**35.0**
Sacramento County Water Agency (including SMUD transfer)	D167B_PMI	10.0
	D168C_FRWP_PMI	20.0
Sacramento County Water Agency (P.L. 101-514)	D168C_FRWP_PMI	15.0
Sacramento County Water Agency - assumed Appropriated Water[a]	D168C_FRWP_PMI	
EBMUD (export)[b]	D168B_EBMUD	133.0
	Total	**178.0**
	Total CVP for American River	**333.8**

Notes:

[a] SCWA targets 68 TAF of surface water supplies annually. The portion unmet by CVP contract water is assumed to come from two sources:

1) Delta "excess" water- averages 16.5 TAF annually, but varies according to availability. SCWA is assumed to divert excess flow when it is available, and when there is available pumping capacity.

2) "Other" water- derived from transfers and/or other appropriated water, averaging 14.8 TAF annually but varying according remaining unmet demand.

[b] EBMUD CVP diversions are governed by the Amendatory Contract, stipulating:

1) 133 TAF maximum diversion in any given year

2) 165 TAF maximum diversion amount over any 3 year period

3) Diversions allowed only when EBMUD total storage drops below 500 TAF

4) 155 cfs maximum diversion rate

EBMUD = East Bay Municipal Utilities District

M&I = municipal and industrial

P.L. = Public Law

SMUD = Sacramento Municipal Utilities District

TAF = thousand acre-feet

Table B-7. CVP South-of-the-Delta—Future Conditions

CVP Contractor	Geographic Location	CalSim II Variable Name	CVP Water Service Contracts (TAF/year) Ag	CVP Water Service Contracts (TAF/year) M&I	Exchange Contractor (TAF/year)	Level 2 Refuges[a] (TAF/year)
Byron-Bethany ID	Upper DMC	D700_AG	20.6			
Banta Carbona ID		D700_AG	20.0			
		Total	**40.6**	**0.0**	**0.0**	**0.0**
Del Puerto WD	Upper DMC	D701_AG	12.1			
Davis WD		D701_AG	5.4			
Foothill WD		D701_AG	10.8			
Hospital WD		D701_AG	34.1			
Kern Canon WD		D701_AG	7.7			
Mustang WD		D701_AG	14.7			
Orestimba WD		D701_AG	15.9			
Quinto WD		D701_AG	8.6			
Romero WD		D701_AG	5.2			
Salado WD		D701_AG	9.1			
Sunflower WD		D701_AG	16.6			
West Stanislaus WD		D701_AG	50.0			
Patterson WD		D701_AG	16.5			
		Total	**206.7**	**0.0**	**0.0**	**0.0**
Panoche WD	Lower DMC Volta	D706_PAG	6.6			
San Luis WD		D706_PAG	65.0			
Laguna WD		D706_PAG	0.8			
Eagle Field WD		D706_PAG	4.6			
Mercy Springs WD		D706_PAG	2.8			
Oro Loma WD		D706_PAG	4.6			
		Total	**84.4**	**0.0**	**0.0**	**0.0**
Central California ID	Lower DMC Volta	D707_PEX			140.0	
Grasslands via CCID		D708_PRF				81.8
Los Banos WMA		D708_PRF				11.2
Kesterson NWR	Lower DMC Volta	D708_PRF				10.5
Freitas - SJBAP		D708_PRF				6.3
Salt Slough - SJBAP		D708_PRF				8.6
China Island - SJBAP		D708_PRF				7.0
Volta WMA		D708_PRF				13.0
Grassland via Volta Wasteway		D708_PRF				23.2
		Total	**0.0**	**0.0**	**140.0**	**161.5**
Fresno Slough WD	San Joaquin River at Mendota Pool	D607A_PAG	4.0			
James ID		D607A_PAG	35.3			
Coelho Family Trust		D607A_PAG	2.1			
Tranquillity ID		D607A_PAG	13.8			
Tranquillity PUD		D607A_PAG	0.1			

Table B-7. CVP South-of-the-Delta—Future Conditions

CVP Contractor	Geographic Location	CalSim II Variable Name	CVP Water Service Contracts (TAF/year) Ag	CVP Water Service Contracts (TAF/year) M&I	Exchange Contractor (TAF/year)	Level 2 Refuges[a] (TAF/year)
Reclamation District 1606		D607A_PAG	0.2			
Central California ID		D607B_PEX			392.4	
Columbia Canal Company		D607B_PEX			59.0	
Firebaugh Canal Company		D607B_PEX			85.0	
San Luis Canal Company		D607B_PEX			23.6	
M.L. Dudley Company		D607B_PEX				
Grasslands WD		D607C_PRF				29.0
Mendota WMA		D607C_PRF				27.6
		Total	**55.5**	**0.0**	**560.0**	**56.6**
San Luis Canal Company		D608B_PRJ			140.0	
Grasslands WD		D608C_PRF				2.3
Los Banos WMA		D608C_PRF				12.4
San Luis NWR		D608C_PRF				19.5
West Bear Creek NWR		D608C_PRF				7.5
East Bear Creek NWR		D608C_PRF				8.9
		Total	**0.0**	**0.0**	**140.0**	**50.6**
San Benito County WD (Ag)	San Felipe	D710_AG	35.6			
Santa Clara Valley WD (Ag)		D710_AG	33.1			
Pajaro Valley WD		D710_AG	6.3			
San Benito County WD (M&I)		D711_PMI		8.3		
Santa Clara Valley WD (M&I)		D711_PMI		119.4		
		Total	**74.9**	**127.7**	**0.0**	**0.0**
San Luis WD	CA reach 3	D833_PAG	60.1			
CA, State Parks and Rec		D833_PAG	2.3			
Affonso/Los Banos Gravel Company		D833_PAG	0.3			
		Total	**62.6**	**0.0**	**0.0**	**0.0**
Panoche WD	CVP Dos Amigos PP/CA reach 4	D835_PAG	87.4			
Pacheco WD		D835_PAG	10.1			
		Total	**97.5**	**0.0**	**0.0**	**0.0**
Westlands WD (Centinella)	CA reach 4	D836_PAG	2.5			
Westlands WD (Broadview WD)		D836_PAG	27.0			
Westlands WD (Mercy Springs WD)		D836_PAG	4.2			
Westlands WD (Widern WD)		D836_PAG	3.0			
		Total	**36.7**	**0.0**	**0.0**	**0.0**
Westlands WD: CA Joint Reach 4	CA reach 4	D837_PAG	219.0			
Westlands WD: CA Joint Reach 5	CA reach 5	D839_PAG	570.0			
Westlands WD: CA Joint Reach 6	CA reach 6	D841_PAG	219.0			
Westlands WD: CA Joint Reach 7	CA reach 7	D843_PAG	142.0			
		Total	**1150.0**	**0.0**	**0.0**	**0.0**

Table B-7. CVP South-of-the-Delta—Future Conditions

CVP Contractor	Geographic Location	CalSim II Variable Name	CVP Water Service Contracts (TAF/year)		Exchange Contractor (TAF/year)	Level 2 Refuges[a] (TAF/year)
			Ag	M&I		
Avenal, City of	CA reach 7	D844_PMI		3.5		
Coalinga, City of		D844_PMI		10.0		
Huron, City of		D844_PMI		3.0		
		Total	**0.0**	**16.5**	**0.0**	**0.0**
Cross Valley Canal - CVP	CA reach 14					
Fresno, County of		D855_PAG	3.0			
Hills Valley ID-Amendatory		D855_PAG	3.3			
Kern-Tulare WD		D855_PAG	40.0			
Lower Tule River ID		D855_PAG	31.1			
Pixley ID		D855_PAG	31.1			
Rag Gulch WD		D855_PAG	13.3			
Tri-Valley WD		D855_PAG	1.1			
Tulare, County of		D855_PAG	5.3			
Kern NWR		D856_PRJ				11.0
Pixley NWR		D856_PRJ				1.3
		Total	**128.3**	**0.0**	**0.0**	**12.3**
		Total CVP South-of-Delta	**1937.1**	**144.2**	**840.0**	**281.0**

Notes:

[a] Level 4 Refuge water needs are not included

Ag = agricultural

CA = California

CCID = Central California Irrigation District

DMC = Delta-Mendota Canal

ID = irrigation district

M&I = municipal and industrial

NWR = national wildlife refuge

PUD = public utility district

SJBAP = San Joaquin Basin Action Plan

TAF = thousand acre-feet

WD = water district

WMA = wildlife management area

Table B-8. Sacramento River Miscellaneous Users Breakdown by CalSim II Variable Name Location—Future Conditions

CalSim II Variable Name		Geographic Location		
Diversion	**DSA**	**River Mile**	**Bank (Left, Right)**	**Supply Total (AF/year)**
D104F	58	240.8	L	280
		240.3	L	20
		240.2	L	205
		221	R	780
		221	R	700
		207.5	L	820
		197	L	510
		196.6	L	100
		196.55	L	12
			Total	**3,427**
D113A	58	191.5	R	425
	10	168.85	R	780
		166.8	R	16
		156.8	R	180
		156.1	R	30
		155.6	R	40
		155.6	R	22
			Total	**1,493**
D122A	15	106	R	890
		106	R	880
		103.9	R	390
		103.7	R	180
		99.3	R	460
		93.15	R	2,070
			Total	**4,870**
D122B	15	89.2	R	19
		89.2	R	26
		88	R	35
		87.7	R	180
		83	R	1,310
		70.4	R	190
		70.4	R	210
		70.4	R	300
		69.2	R	30

Table B-8. Sacramento River Miscellaneous Users Breakdown by CalSim II Variable Name Location—Future Conditions

CalSim II Variable Name		Geographic Location		Supply Total (AF/year)
Diversion	DSA	River Mile	Bank (Left, Right)	
D122B	65	30.6	R	120
		29.7	R	3,640
		29.2, 30.3	R	430
		28.1	R	3,020
			Total	**9,510**
D128	15	140.8, 141.5	L	17,956
		104.8	L	730
		102.5	L	490
		99.8	L	2,285
		98.9	L	1,815
		98.6	L	1,560
		95.8	L	2,760
		95.6	L	6,260
		95.25	L	2,804
		92.5	L	164
		92.5	L	246
		89.26	L	36
		89.24	L	95
		88.7	L	204
		88.7	L	640
		88.7	L	76
		88.2	L	150
		86.8	L	380
		82.7	L	210
		82.5	L	450
		82.5	L	90
		81.5	L	2,700
		79.5	L	130
		79	L	65
		79	L	130
		79	L	75
		77.9	L	280
		76.2	L	85
		76.15	L	700
		72.1	L	3,620
		72	L	650

Table B-8. Sacramento River Miscellaneous Users Breakdown by CalSim II Variable Name Location—Future Conditions

CalSim II Variable Name		Geographic Location		Supply Total (AF/year)
Diversion	DSA	River Mile	Bank (Left, Right)	
		67.5	L	7,110
		67.1	L	237
D128	15	67.1	L	1,155
		63.9	L	3,200
		63.3	L	10
		62.3	L	820
		60.5, 61.8	L	460
		60.4	L	2,760
		59.8	L	1,000
		58.9	L	355
		58.3	L	417
		58.3	L	839
		57.75	L	520
		55.1	L	10,070
		53.9	L	325
		52.3	L	160
		52	L	136
		50	L	3,160
		49, 49.7	L	1,485
		49	L	584
		48.7	L	4,740
		46.5	L	935
		44.2, 45.6, 46.45	L	4,040
		38.8	L	200
		37.75	L	155
		37.2	L	170
		36.45	L	230
		36.45	L	16
		36.2	L	500
		36.2	L	1,610
		35.85	L	36
				870
				255
		33.75	L	560
		33.75	L	60
		33.75	L	1,470

Table B-8. Sacramento River Miscellaneous Users Breakdown by CalSim II Variable Name Location—Future Conditions

CalSim II Variable Name		Geographic Location		Supply Total (AF/year)
Diversion	DSA	River Mile	Bank (Left, Right)	
		33.2	L	2,780
		32.5, 33.2	L	920
		26.8, 30.5	L	1,255
			Total	**103,441**
D129A_PSC	65	33.85	R	104
		32.5	R	160
		32.5	R	160
		31.5	R	520
			Total	**944**
D162A_PSC	70	19.6	L	630
		18.7	L	300
		18.45	L	950
		18.2	L	490
		18.2	L	40
		18.2	L	350
		10.75	L	130
		10.75	L	95
		10.25	L	1,060
		9.3	L	750
			Total	**4,795**
D163	65	16.6, 17.0, 22.5	R	4,000
		16.1	R	630
		12	R	50,862
		11.1	R	370
		9.35	R	404
		5.25	R	500
			Total	**56,766**

AF = acre feet

DSA = depletion study area

Appendix C
Basin Average Streamflow Change Factor Method

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Introduction

This appendix provides further detail about the methodology used to develop streamflow change factors throughout the watersheds of the State of California. Additional discussion is provided to inform Groundwater Sustainability Agencies (GSAs) on how to implement provided data and the considerations required for incorporating streamflow change factors into a groundwater model or general water budget calculation.

Streamflow change factors are available for download from the Sustainable Groundwater Management Program (SGMP) Data Viewer.[1] Users can select individual hydrologic unit code (HUC) 8 watersheds that are of interest to their area and download the associated change factor data.

This appendix also discusses the following information to help GSAs implement streamflow change factor data:

- Methodology for developing streamflow change factors
- Comparison of streamflow change factor methods
- Resulting statewide change factor data
- Application of streamflow change factors and limitations of this methodology

Data Development Methodology

Background

Under the California Water Commission's Water Storage Investment Program (WSIP), the primary focus of climate change analysis and modeling efforts were on California's Central Valley through the application of the CalSim II model. The CalSim II model simulates Central Valley Project (CVP)/State Water Project (SWP) operations that operate within the Central Valley. For Groundwater Sustainability Plan (GSP) development, as required by the Sustainable Groundwater Management Act (SGMA), additional information needs to be developed for the groundwater basins that fall outside of the Central Valley and are unable to leverage streamflow information available from CalSim II. Using the statewide variable infiltration capacity (VIC) dataset, runoff and baseflow were aggregated for WSIP at the 8-digit HUC 8 level watersheds. The HUC 8 dataset was obtained through the U.S. Geological Survey (USGS) as a means of delineating watersheds throughout California.

The intent of the basin average streamflow change factors is to provide Groundwater Sustainability Agencies (GSAs) with a streamlined product that can be used to assess changes in streamflow conditions at the 2030 and 2070 timeframes for watersheds outside of the Central Valley. Many streams outside of the Central Valley, in remote areas, are not gaged and do not have sufficient resolution of streamflow records for appropriate calibration of the VIC model to accurately represent the hydrologic response of these watersheds. An additional limitation to using the VIC model for streamflow routing methods is due to the relatively coarse resolution of the VIC grids, which may not be able to accurately represent the physical characteristic and size of the watershed. Due to these limitations, an alternative method was devised to develop streamflow change factors that could be applied to tributaries within the HUC 8 watershed boundary.

[1] https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer

2.1 Statewide HUC 8 Methodology

After downloading HUC 8 watershed data, geoprocessing techniques were used to develop streamflow change factors for select HUC 8 watersheds. HUC 8 watershed boundaries were overlaid with the VIC grid. Analysts performed a grid and a clip function to determine the contributing area of each VIC grid cell within each of the HUC 8 boundaries (Figure C-1). Area fractions for each VIC grid were then calculated as the clipped VIC grid area divided by the area of the full VIC grid cell. These area fractions were then used to calculate a weighted average runoff plus baseflow to produce an estimate of streamflow for each HUC 8 watershed. Weighted average runoff plus baseflow was calculated for the 1995 historical temperature detrended (1995 HTD), the 2030, and the 2070 climate scenarios as developed for the WSIP. Streamflow change factors were then calculated as a future climate scenario (2030, 2070) divided by the 1995 HTD scenario.

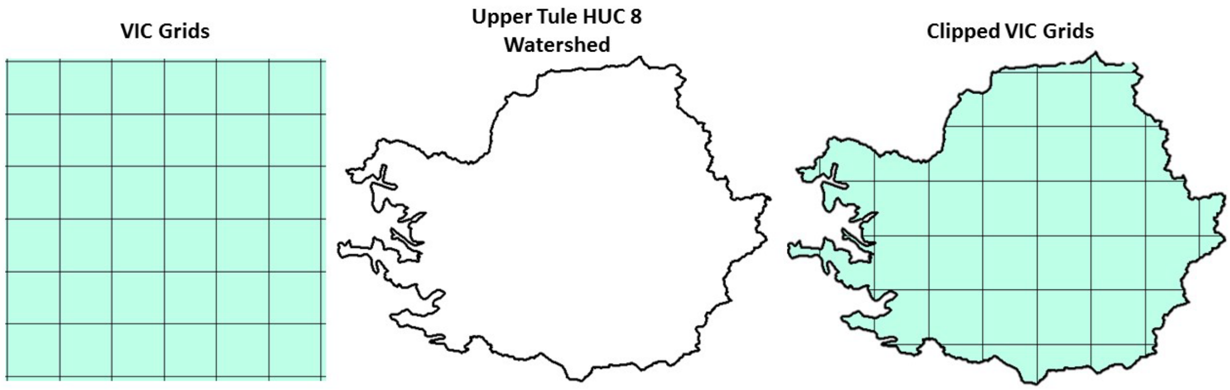

Figure C-1. Example of Clipping the VIC Grids to a HUC 8 Watershed Boundary

2.2 Comparison with VIC Routing Method

As a validation for the basin average streamflow change factor methodology, the basin average streamflow change factors for the Upper Tule Watershed were compared to streamflow change factors produced by the VIC routed streamflow method. Figure C-2 is a representation of the two methods compared for the Upper Tule watershed. Using the VIC routing model, streamflow was routed approximately to the location of the California Data Exchange Center (CDEC) station at Success Dam, with the watershed area roughly coinciding to the reported drainage area at the gaging station. The black/red points presented in Figure C-2 represent the VIC grid cells that contribute flow to the routed streamflow location based on VIC's representation of the watershed delineation.

Figure C-2. Map Comparing Application of VIC Routing Method and Basin Average Method for the Upper Tule Watershed

Table C-1 presents a comparison of results from the basin average method and the VIC routing method. When comparing results from the two methods, the difference in change factors statistics are within 10 percent. Based on these results, the methodology applied to calculate change factors for all HUC 8 watersheds is deemed appropriate for use in the other watersheds of the state.

Watershed delineation using the VIC routing model is limited by the resolution of the VIC grid cells and the associated physical parameterization that dictate watershed response. Delineation of neighboring watersheds needs to be considered as the VIC grid cell may overlap multiple watersheds and can cause calibration issues. Also presented in Figure C-6 are the clipped VIC grids for the Upper Tule watershed, as previously discussed, to estimate basin average streamflow change factors. Based on the delineation capabilities of the VIC routing model and the basin average method, the two methods can produce different estimates of the contributing area for that watershed. This result is likely due to the relative nature of the change factor calculation, where large differences may be observed in the absolute streamflow values between the two methods. Change factors represent the relative change in climate, and the hydrologic response, that is observed between the 1995 HTD climate scenario and the two future climate scenarios.

Table C-1. Comparison of Streamflow Change Factor Results from Basin Average and VIC Routing Methods

Change Factor/ Contributing Area	2030		2070	
	Basin Average Method	VIC Routing Method	Basin Average Method	VIC Routing Method
Monthly Minimum Change Factor	0.16	0.14	0.06	0.16
Monthly Maximum Change Factor	1.65	1.75	2.88	2.94
Monthly Average Change Factor	0.96	0.96	0.91	0.90
Contributing Area (Acres)	285,786	204,603	285,786	204,603

Figure C-3 presents a comparison of projected streamflow at Success Dam based on the basin average and VIC routing methods of calculating change factors. As discussed previously, small discrepancies have been observed when comparing change factor data from each method. When applying these change factors to the historical timeseries, the result produces projected streamflow conditions that are similar.

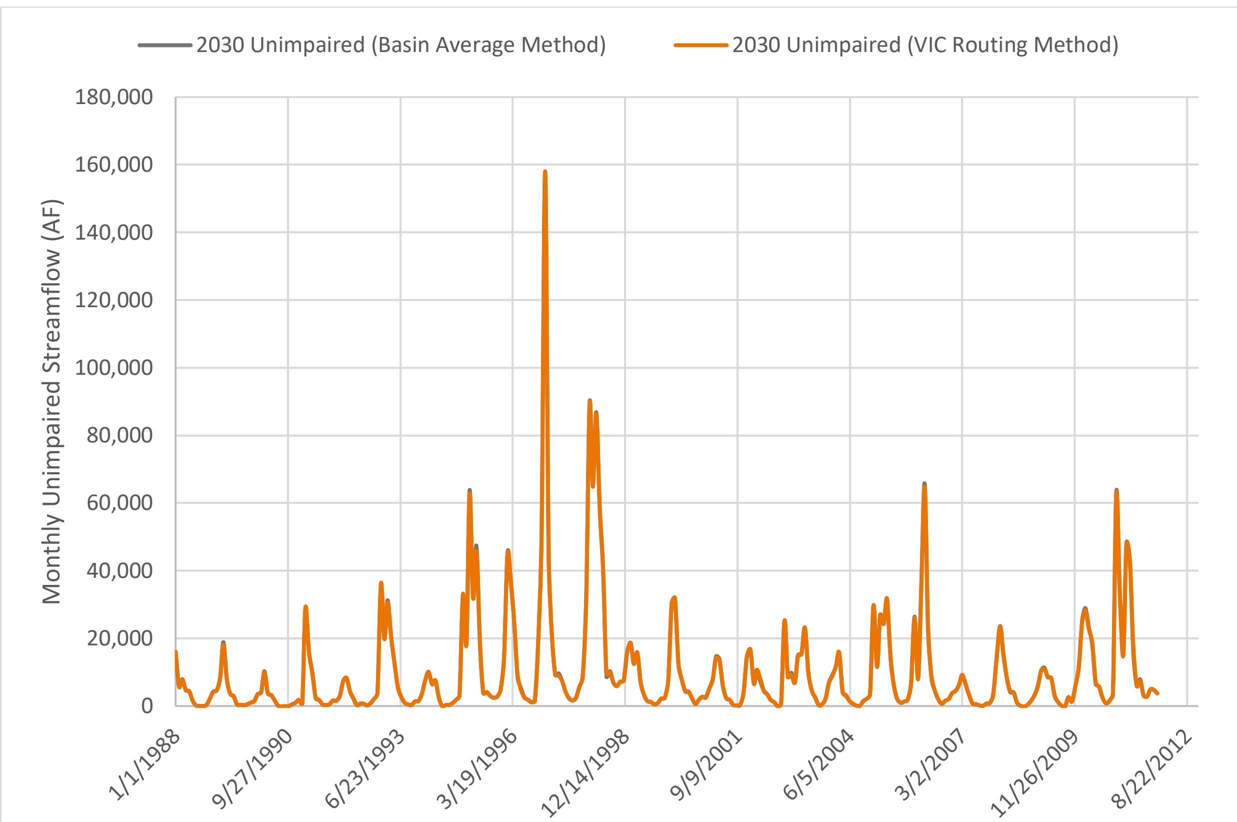

Figure C-3. Comparison of Projected Unimpaired Streamflow Using Change Factors from the Basin Average Method and the VIC Routing Method

Statewide Change Factor Results and Discussion

Streamflow change factor data were calculated for all HUC 8 watersheds in California for 2030 and 2070 future conditions. Statistics (i.e., monthly minimum, monthly maximum, and annual average) for each HUC 8 watershed were calculated to assess spatial trends of the change factor data throughout the state.

On an annual average basis, under 2030 future conditions (compared to 1995 HTD conditions), streamflow change factors in the South Coast, South Lahontan, and Tulare Lake regions show slight decreases (less than 4 percent) in some of the watersheds, and slight increases (less than 5 percent) in others (Figure C-4). All other regions show a less than 10 percent increase in streamflow with a few exceptions along the coast, where watersheds are experiencing up to an 11 percent increase in streamflow. Under 2070 conditions, annual average change in streamflow is larger with a decrease of 14 percent in the South Coast region (Figure C-5). Larger increases are observed in the San Francisco Bay and portions of the North Coast and Sacramento River regions (up to 27 percent). Otherwise, most of the North Coast and Sacramento River regions portray changes in streamflow that are less than 10 percent.

Table C-2 presents the range in monthly streamflow change factor values for 2030 and 2070 future conditions, summarized by hydrologic region. The values presented in Table C-2 reflect the minimum and maximum change factor of the watersheds that fall in that region over the entire VIC simulation period. Monthly minimum and maximum values give an understanding of the range in change that is projected to occur in any given month in HUC 8 watersheds throughout the state. Large change factors are observed in the North Lahontan Region under 2030 and 2070 future conditions. The watersheds in this region are snowmelt dominated watersheds and the maximum change factor result portrayed in these areas is a result of the shift in timing of the snowmelt hydrograph, where more runoff is observed earlier in the year under projected future conditions. Due to this shift in timing, the application of these change factors needs to be scrutinized based on the limitations of the methodology, as discussed in the following sections.

Table C-2. Monthly Minimum and Maximum Streamflow Change Factors by Hydrologic Region for 2030 and 2070 Projected Conditions

Hydrologic Region	2030		2070	
	Min	Max	Min	Max
North Coast	0.2	3.4	0.1	6.7
Sacramento River	0.1	3.1	0.0	4.77
North Lahontan	0.1	9.1	0.0	27.1
San Francisco Bay	0.7	1.6	0.6	4.05
San Joaquin River	0.2	2.4	0.0	5.76
Central Coast	0.7	2.2	0.5	6.39
Tulare Lake	0.2	3.1	0.1	6.17
South Lahontan	0.4	3	0.1	9.38
South Coast	0.5	2.3	0.2	9.28
Colorado River	0.6	1.8	0.2	2.17

Considerations for Change Factor Data Application

Due to the significant variability of watersheds throughout the state of California, no one approach of applying change factor data is appropriate for all watersheds. Analysts should consider the following when determining an appropriate methodology:

- Purpose and key metrics of the analysis being performed (i.e, quantifying surface water and groundwater interactions along a river reach)
- Scope and spatial/temporal resolution of model used
  - Does the modeling effort require operations modeling, streamflow routing, streamflow diversion or depletion estimates?
  - Does the model work on a time scale other than monthly?
- Specific input that drives results
  - Does the streamflow dataset being projected drive the results being analyzed?
- Comparability of VIC baseline versus historical baseline flows
  - Hydrologic process and context similarity
  - Numerical similarity (relatively similar in volume from month-to-month and range of annual volumes)

4.1 Application of Timeseries Change Factor Data

Streamflow change factors are provided as a monthly timeseries format for 2030 and 2070 projected climate conditions. Monthly timeseries values are calculated as the ratio of the month-by-month VIC result with climate change divided by the VIC result without climate change. Application of streamflow change factor timeseries data includes various assumptions and limitations. Analysts should apply these with careful scrutiny of the baseline dataset for which the ratios are being applied.

When applying monthly timeseries change factors, there is the assumptions that an aspect of climate change will have an effect on the timing of the hydrograph. Using a monthly timeseries allows this shift in timing and the sequence of events to be preserved from month to month, as well as being sensitive to variations between years and months in sequence. One limitation of applying the monthly change factors is that this method presumes that the calculated change factors are based upon a similar baseline condition as to which they are applied. Due to this limitation, the applicability of the timeseries method requires that there should be a similarity in the flow pattern and the source of flows (i.e., rain or snow-melt) between the baseline data used for ratio calculations (Livneh, 2013) and the baseline data for which ratios are applied (local observational data). For example, the response of a snow-melt dominated watershed versus a rain dominated watershed is very different in pattern.

Annual streamflow change factors are being provided through SGMA in addition to the monthly change factors. When applying the timeseries method, a second order correction of the monthly change factors is required. This correction uses annual change factors to ensure that the annual change in volume is preserved based on the results of the VIC modeling. A spreadsheet tool has been developed and is provided by the SGMP to assist GSAs in applying the second order correction for their watersheds of interest.

The first step in applying monthly change factors is concerned with the shift in the monthly timing of the hydrograph as observed in the simulated VIC results. Applying a monthly change factor distributes the change due to climate to the pattern of the hydrograph and results in a change in the annual volume of the hydrograph. The second step is concerned with the shift in annual volume of the hydrograph as observed in the VIC results. Applying an annual adjustment factor based on the second order correction methodology ensures that the annual volume change is consistent with the simulated VIC results.

Figure C-3 below presents an example application of the monthly timeseries, for an example water year, before and after the second order correction. A shift in timing can be observed by applying the monthly change factors to the historic dataset (i.e., Historical → Perturbed Before Correction). Implementing the second order correction with the annual adjustment a shift in the volume of the hydrograph can be observed (i.e., Perturbed Before Correction → Perturbed After Correction). This additional step is important to ensure that the response of the watershed due to projected changes in climate are reflected in hydrologic analysis.

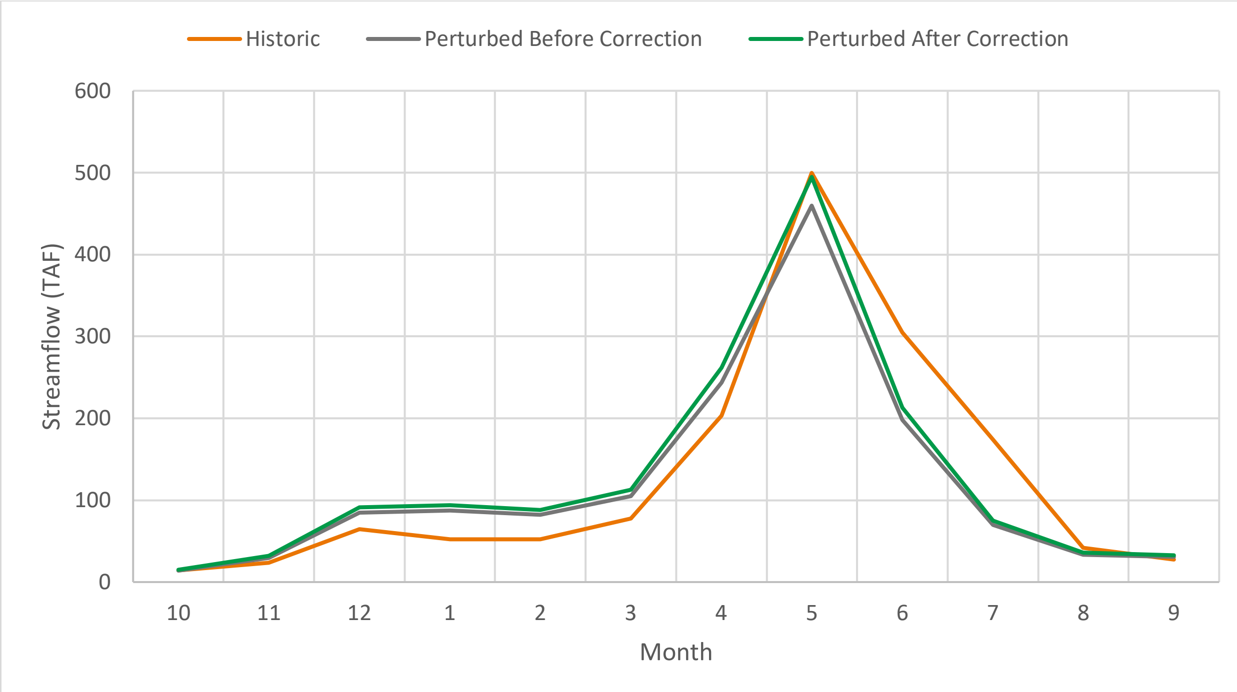

Figure C-7. Comparison of Applying Monthly Timeseries Change Factors Before and After Second Order Correction

While the timeseries application provides a robust methodology to project changes in streamflow due to climate change, there are special considerations that may require a separate approach. As previously discussed, the limitation of the timeseries methodology presumes that the calculated ratios are based upon a similar baseline condition as to which they are applied. In some circumstances, such as in a smaller tributary watershed, the application of the timeseries method may not suffice.

4.2 Alternative Methodology Using Monthly Average Change Factors

If the limitations of the timeseries methods suggest that the method may not be applicable, alternative methodologies should be considered.

An alternative methodology that may be useful is through the use of average monthly change factors. Average monthly change factors are calculated as the ratio of monthly average VIC results under climate change divided by monthly average VIC results without climate change. This methodology implies that seasonality is an important indicator of the relative impact due to climate change where climate change has a similar impact on the hydrograph each year. The timing of runoff events under this methodology is assumed to be similar each year. As a limitation, this method presumes that the change for each month is relatively independent of what happened the month before and varies in the same way from year to year.

4.3 Change Factor Application Summary

In summary, careful consideration should be taken when applying change factor data, depending on the watershed being analyzed. Table C-2 summarizes the proposed and alternative change factor application methodologies, and highlights the implications, limitations, and specific applicability of each of these methods. The methodology presented in Table C-2 serve as bookends of possible methods that could be considered in developing projected streamflow conditions.

Table C-2. Considerations in Determining the Appropriate Implementation of Streamflow Change Factors

Method[1]	Calculation	Implications	Limitations	Applicability
Timeseries (provided)	Monthly timeseries of the ratio of the month-by-month VIC result under climate change divided by the VIC result without climate change.	There is an aspect of climate change impact on a hydrograph that depends upon the timing of the hydrograph. Through this method the sequence of events is preserved from month to month. This method is sensitive to variations between years and months in sequence.	This presumes that the ratios are based upon a similar baseline condition as to which they are applied.	There should be a similarity in the flow pattern between the baseline data used for ratio calculations and the baseline data for which ratios are applied. For example, snow-melt versus rain fed runoff is not similar in pattern.
Monthly Averages	Average monthly values calculated as the ratio of monthly average VIC results under climate change divided by monthly average VIC results without climate change.	Season is an important indicator of the relative impact of climate change. Climate change has similar impact on the hydrograph each year and the timing of events in the hydrograph is similar for each year. This method is not sensitive to variations between years and months in sequence.	This presumes that the change for each month is relatively independent of what happened the month before and varies little from year to year.	Dissimilarity in pattern in the hydrograph is acceptable between the baseline data used for ratio calculations and the baseline data for which ratios are applied. For example, in a watershed where the response of the watershed is similar from year-to-year in terms of timing of the hydrograph.

[1]All methods rely on a timeseries of VIC results under climate change and a companion timeseries of VIC results without climate change.

Some watersheds in California that exhibit more extreme climate phenomena, such as monsoonal events or large changes in snowpack, can produce large spikes in change factors. Significant changes in pattern due to climate change as compared to historical conditions can cause challenges in developing projected conditions. Therefore, these types of watersheds need higher scrutiny when developing the appropriate method for applying projected streamflow changes.

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