"Groundwater Storage Capacity" refers to the volume of void space that can be occupied by water in a given volume of a formation, aquifer, or groundwater basin.

"Safe yield" refers to the maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse effect

"Saturated zone" refers to the zone in which all interconnected openings are filled with water, usually underlying the unsaturated zone.

# 7. Related Materials

This section provides a list of related materials including associated SGMA BMPs, general references, and selected case studies and examples pertinent to the development of water budgets. For the items identified, available links to access the materials are also provided. By providing these links, DWR neither implies approval, nor expressly approves of these documents.

## REFERENCES FOR FURTHER GUIDANCE


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- California Water Plan Update 2013. Department of Water Resources, 2013. Volume 3. Resource Management Strategies. [http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm]

- California's Groundwater Update 2013, Department of Water Resources, 2013.[http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm]

## SELECTED CASE STUDIES AND EXAMPLES

- Development and Calibration of the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG. DWR Technical Memorandum. California Department of Water Resources (DWR) Bay-Delta Office. 2013. [http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/download/C2VSim_Model_Report_Final.pdf]

- Groundwater Availability of the Central Valley, California. Professional Paper 1766. USGS. 2009. [http://pubs.usgs.gov/pp/1766/PP_1766.pdf]

- Scott Valley Integrated Hydrologic Model: Data Collection, Analysis, and Water Budget. Final Report. University of California – Davis, Department of Land, Air, and Water Resources. 2013. [http://groundwater.ucdavis.edu/files/165395.pdf]

- Selected Approaches to Estimate Water-Budget Components of the High Plains, 1940 through 1949 and 2000 through 2009. Scientific Investigations Report 2011–5183. USGS. 2011. [http://pubs.usgs.gov/sir/2011/5183/pdf/sir2011-5183.pdf]

- Simulated Effects of Ground-Water Withdrawals and Artificial Recharge on Discharge to Streams, Springs, and Riparian Vegetation in the Sierra Vista Subwatershed of the Upper San Pedro Basin, Southeastern Arizona. Scientific Investigations Report 2009-5207. USGS. April, 2014.
- [http://pubs.usgs.gov/sir/2008/5207/sir2008-5207.pdf]

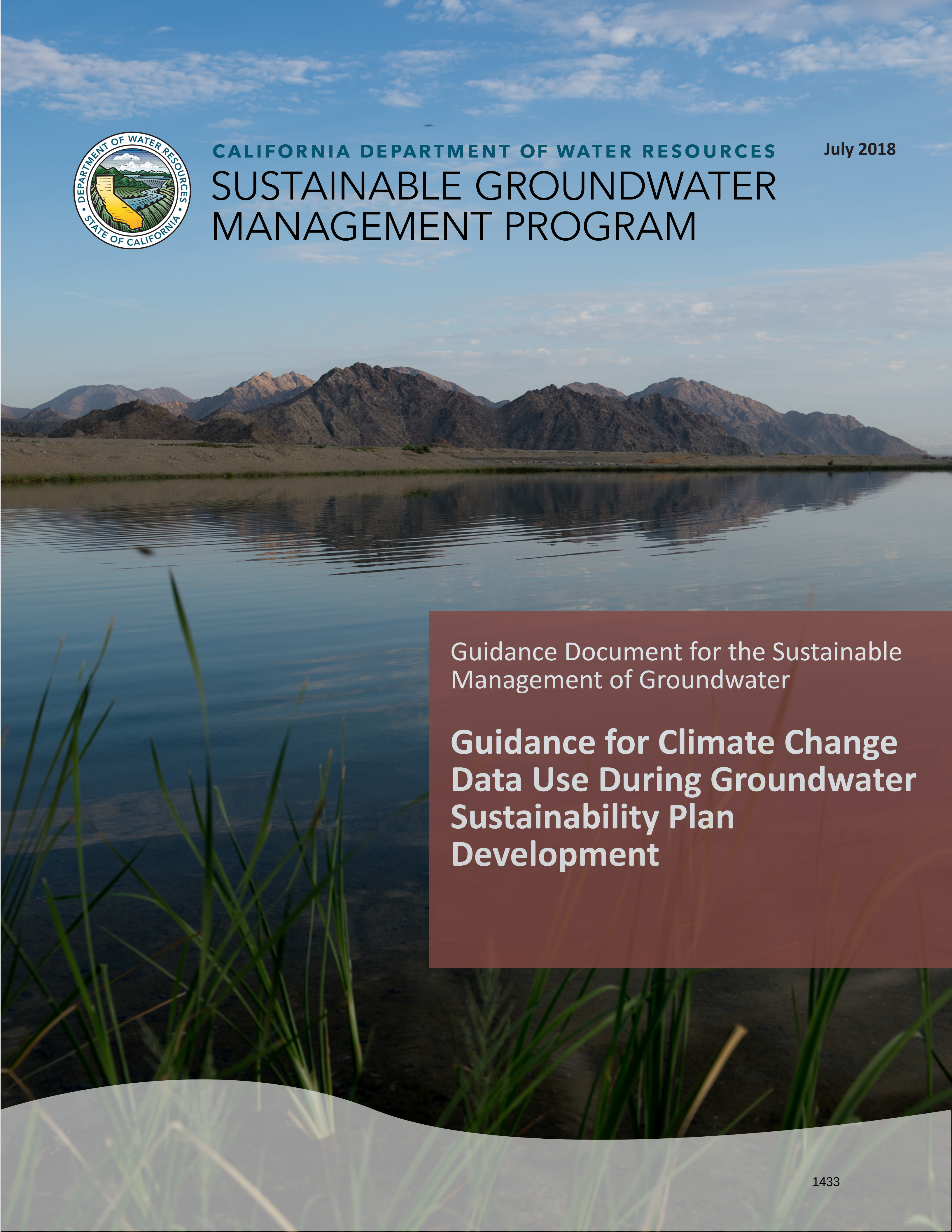
- Evaluation of Simulations to Understand Effects of Groundwater Development and Artificial Recharge on Surface Water and Riparian Vegetation, Sierra Vista Subwatershed, Upper San Pedro Basin Arizona. Open-File Report 2012-1206. USGS. 2012. [https://pubs.usgs.gov/of/2012/1206/of2012-1206.pdf\

## PROFESSIONAL CERTIFICATION RESOURCES

- Professional Engineers Act: http://www.bpelsg.ca.gov/laws/pe_act.pdf
- Professional Geologist and Geophysicist Act: http://www.bpelsg.ca.gov/laws/gg_act.pdf
- Professional License Lookup: http://www.bpelsg.ca.gov/consumers/lic_lookup.shtml

# Appendix 2D

## DWR Resource Guide, Climate Change Data and Guidance for Use during Groundwater Sustainability Plan Development



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

Guidance Document for the Sustainable Management of Groundwater

# Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development

CALIFORNIA DEPARTMENT OF WATER RESOURCES

SUSTAINABLE GROUNDWATER MANAGEMENT PROGRAM

July 2018

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# Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development

July 2018

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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# Contents

**Figures**



**Appendixes**

# 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

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[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.

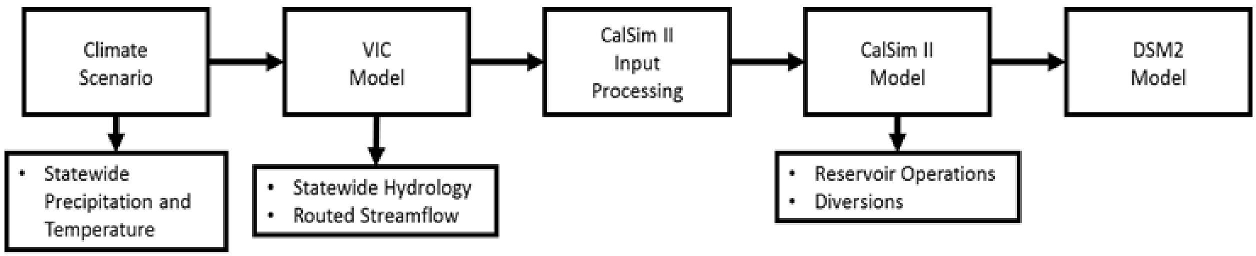



Figure 2-1. Sequence of Models Used for Climate Change Analysis Based on WSIP Approach

## 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.

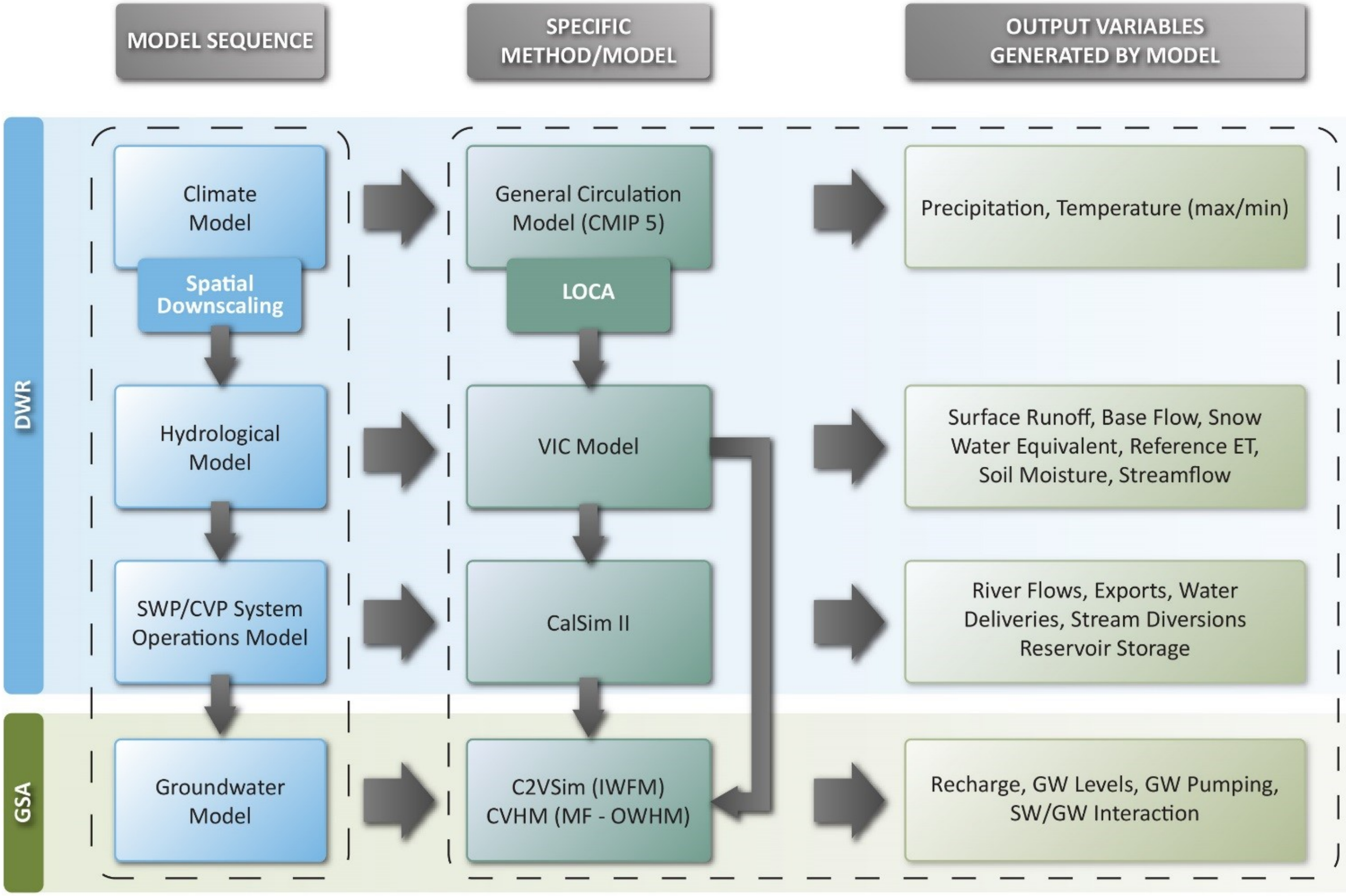
## 3.1 Overview of Climate Data and Application Processes

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.

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

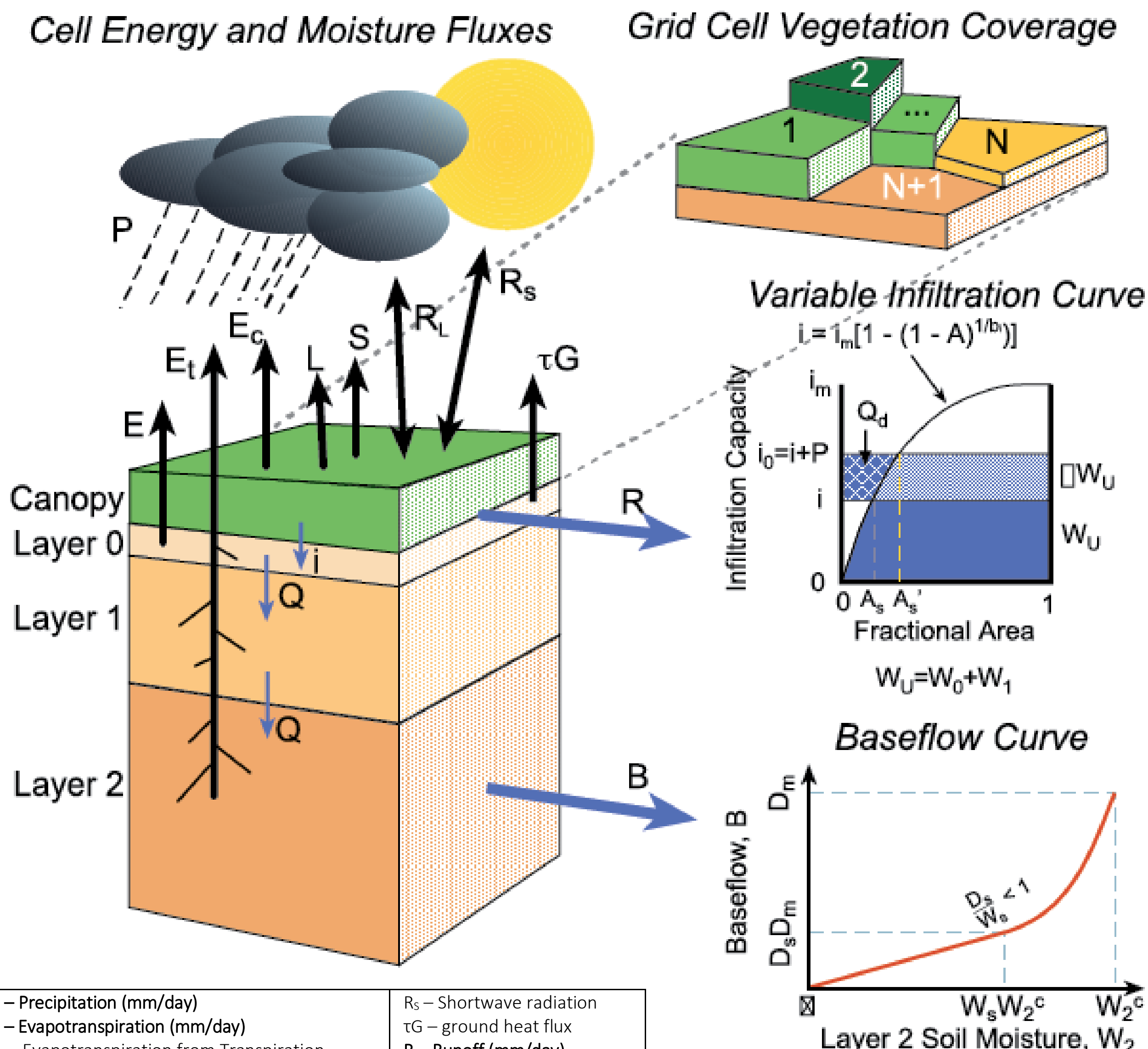



DWR: Department of Water Resources; GSA: Groundwater Sustainability Agency; SWP: State Water Project; CVP: Central Valley Project; LOCA: Localized Constructed Analogs; VIC: Variable Infiltration Capacity; CalSim: SWP & CVP Operations Model; C2VSim: California Central Valley Groundwater - Surface Water 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.

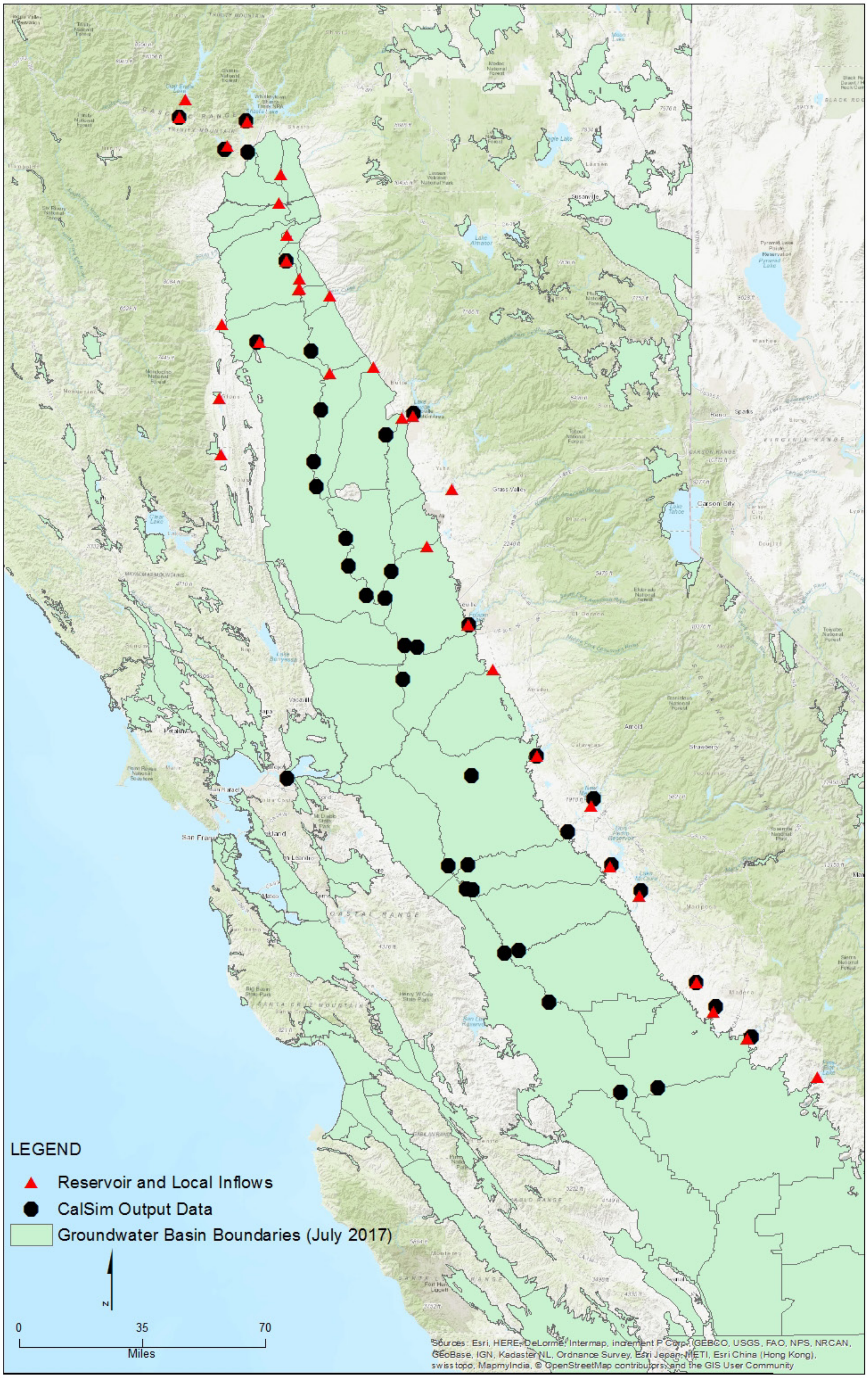



Figure 3-3. Map Displaying Spatially Referenced CalSim II Datasets

## 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:

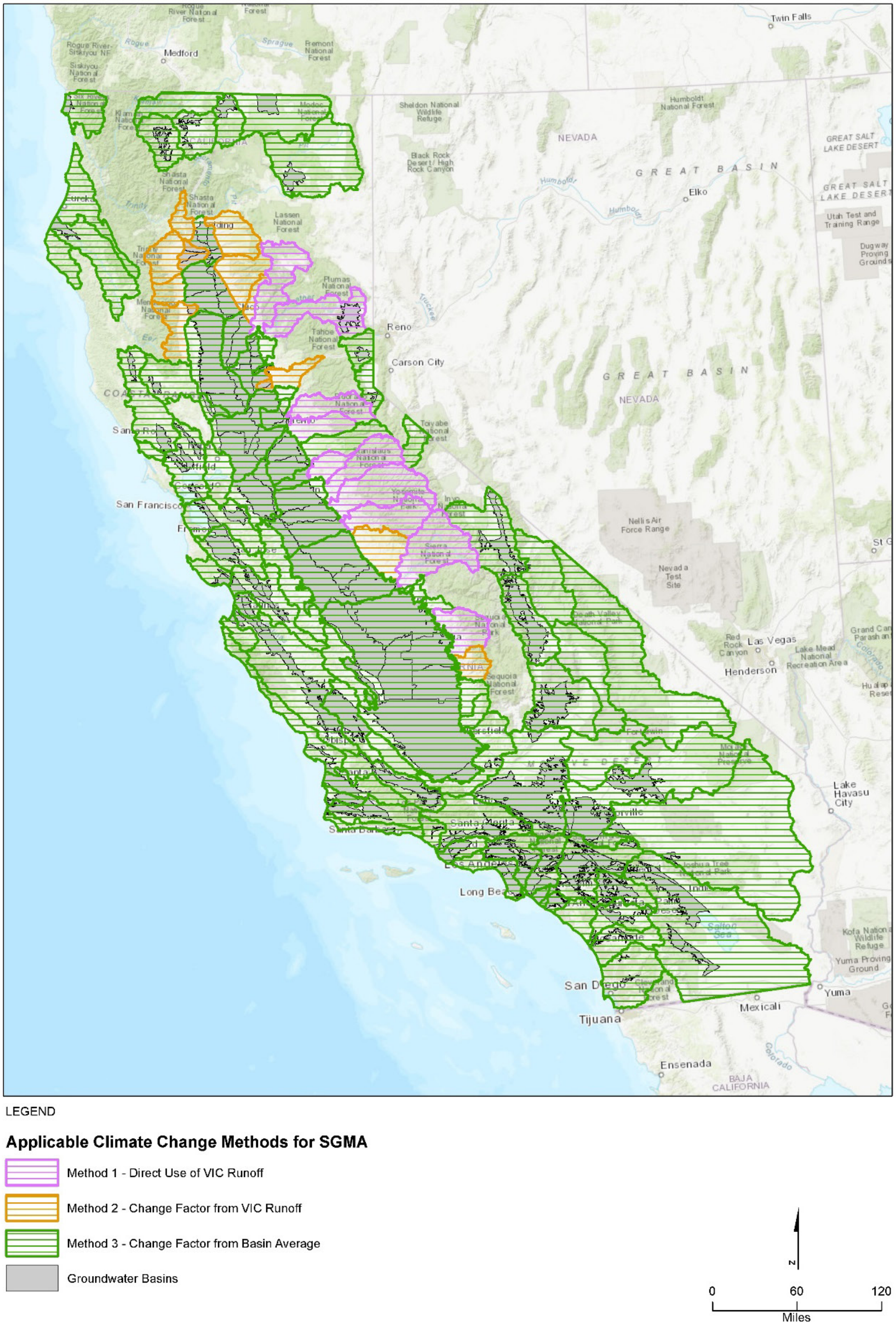
- **Method 1:** Direct VIC routed streamflow with bias correction
- **Method 2:** VIC routed streamflow change factor (no bias correction)
- **Method 3:** Basin average change factor based on average runoff and baseflow computed over Hydrologic Unit Code (HUC) 8 watershed boundaries

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.

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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<br>• Reference ET | • SWP/CVP imports (Delta exports)<br>• SWP/CVP diversions<br>• SWP/CVP deliveries<br>• SWP/CVP reservoir releases<br>• Routed streamflow for select Central Valley watersheds<br>• Routed streamflow change factor for other watersheds<br>• 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.

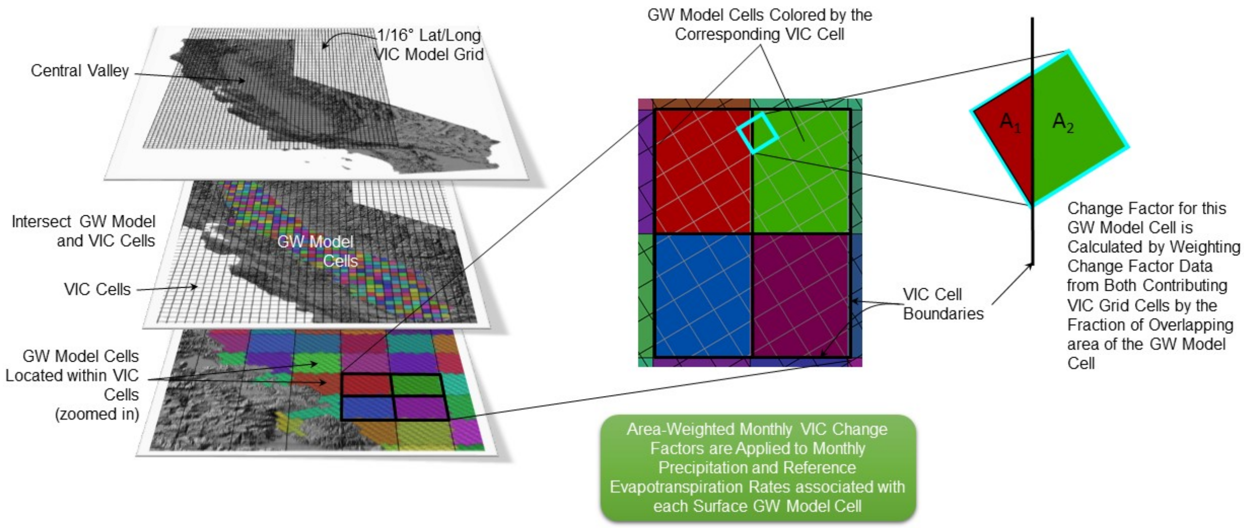


Figure 4-1. Applying Precipitation and ET Change Factors

# 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.

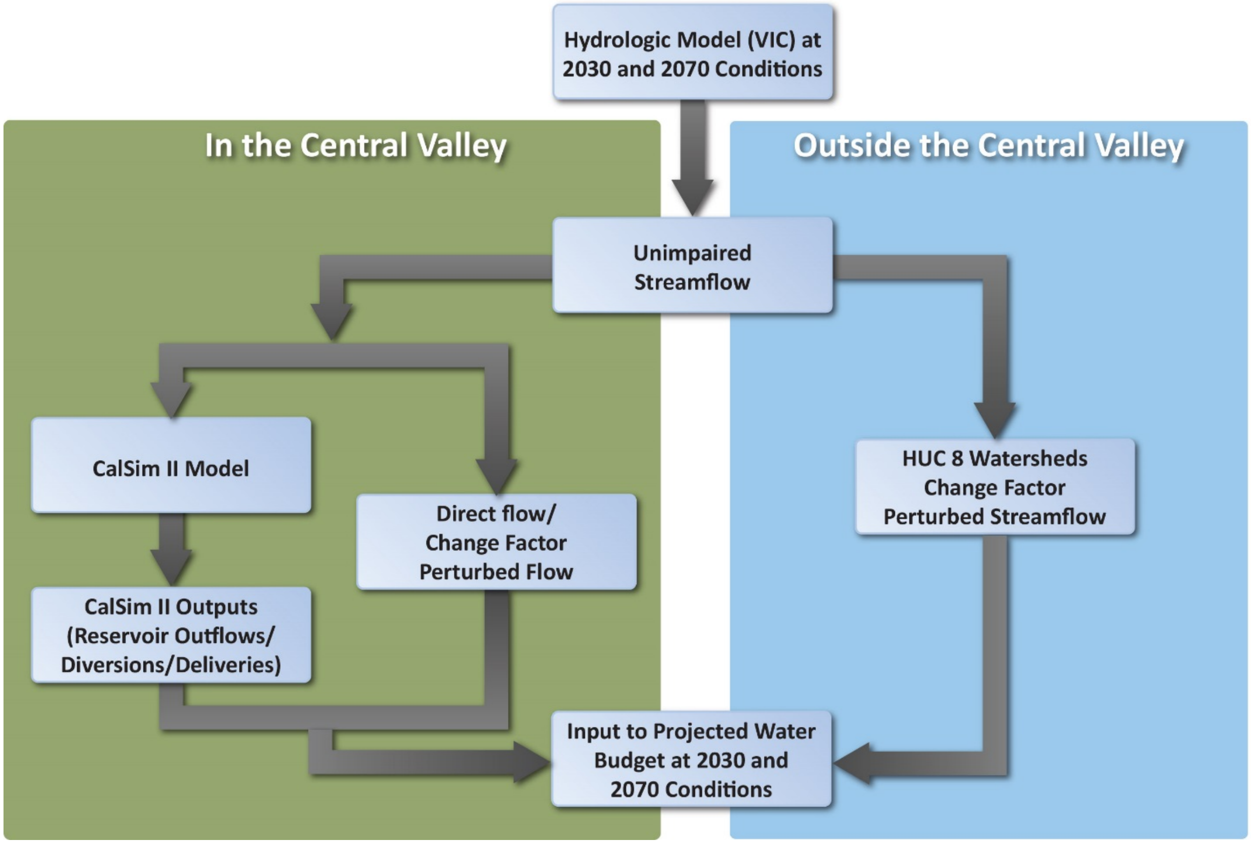


Figure 4-2. Streamflow Data to Use in Projected Water Budget

## 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.

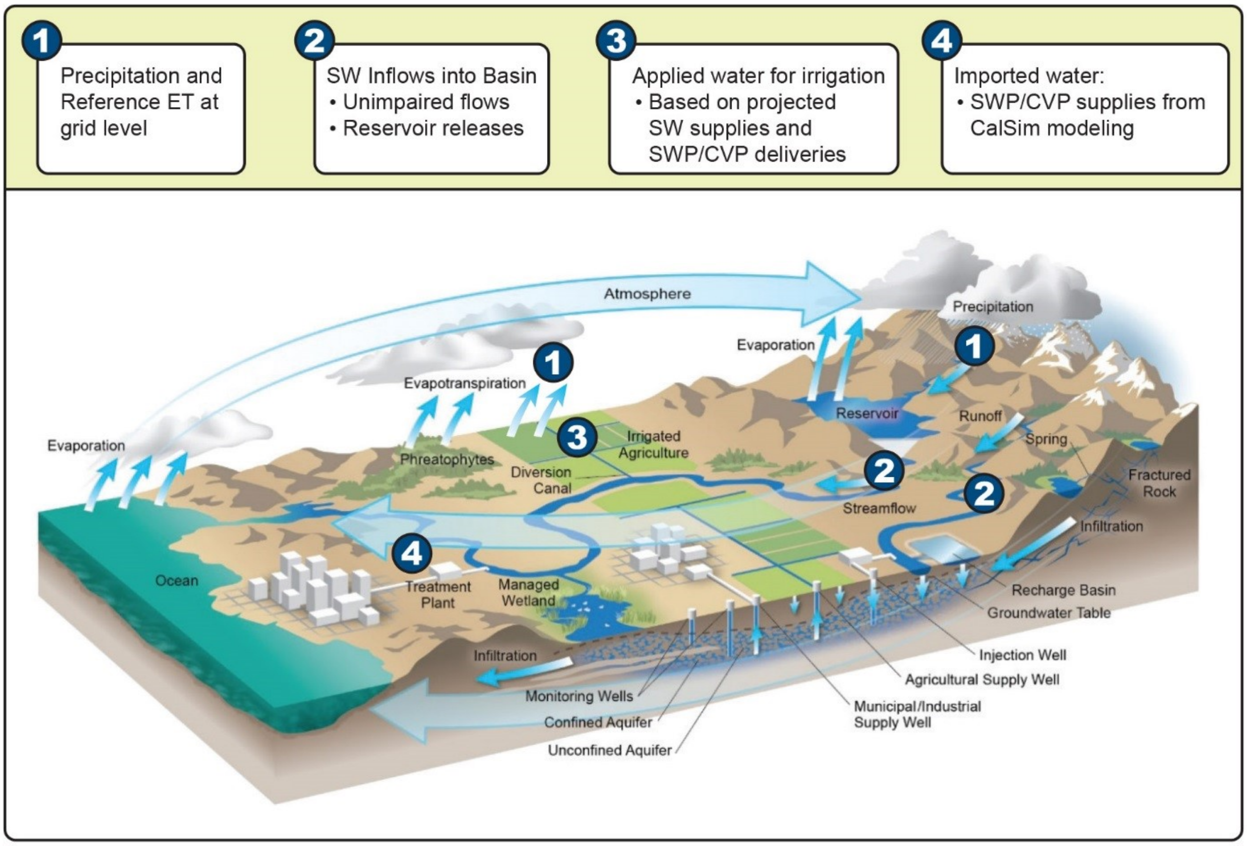


Figure 4-3. Water Budget Components to Modify for Projected Climate Change based Computations

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.

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[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.

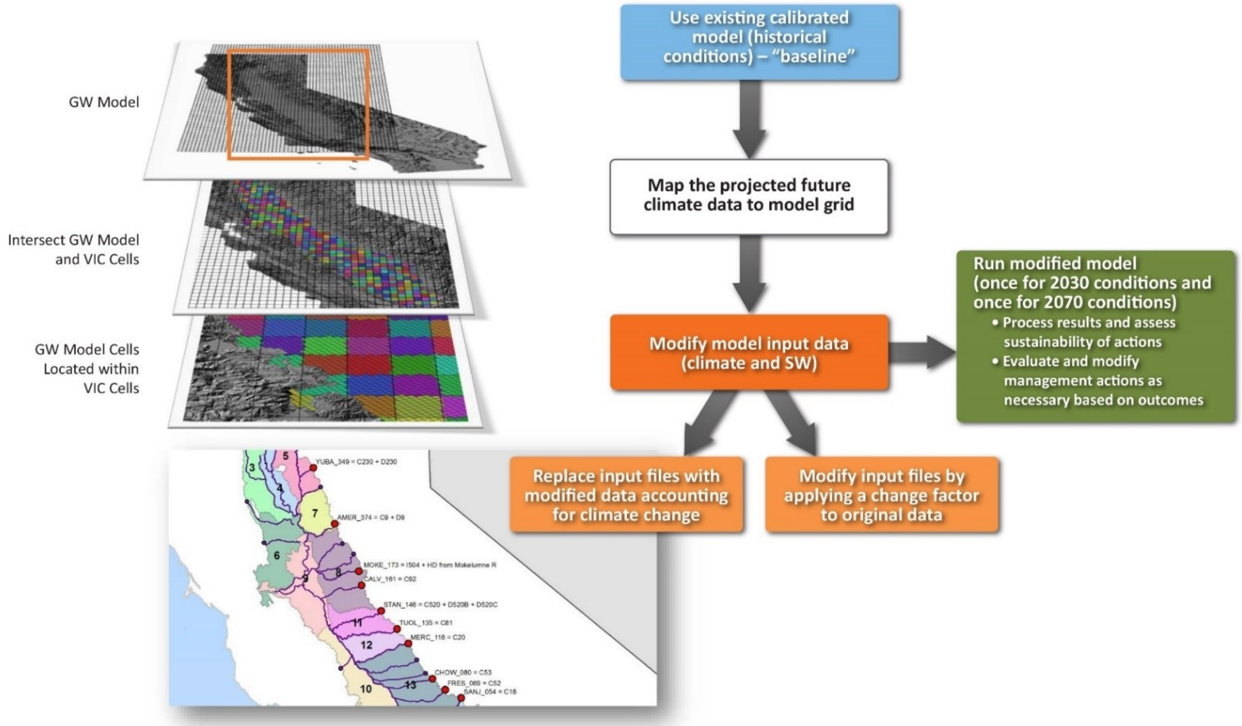



Figure 4-4. Groundwater Model Components to Modify for Future Climate Change-Based Projections

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

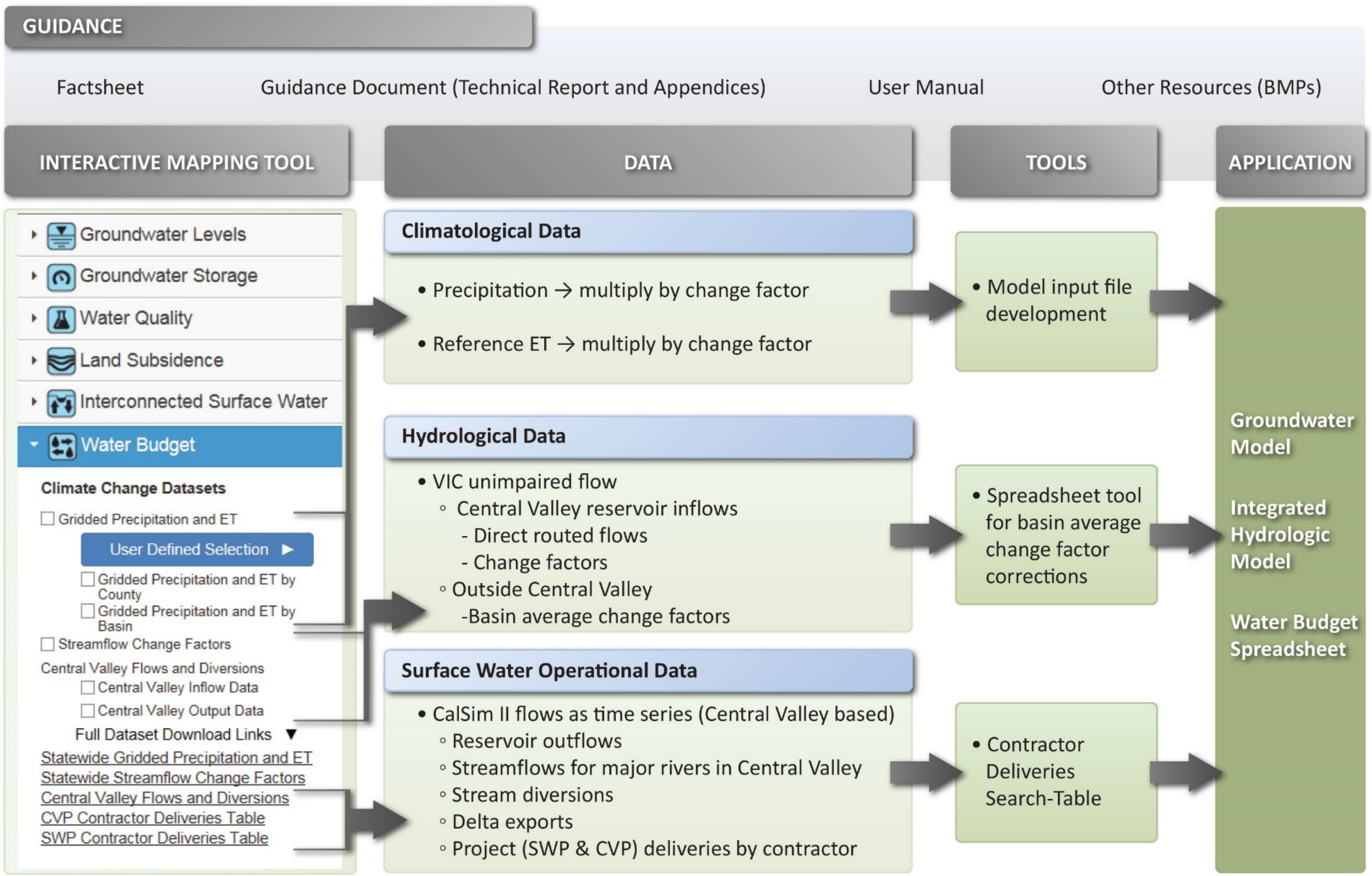
Possible steps to develop projected water budgets using a historical calibrated model are as follows:

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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# 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.

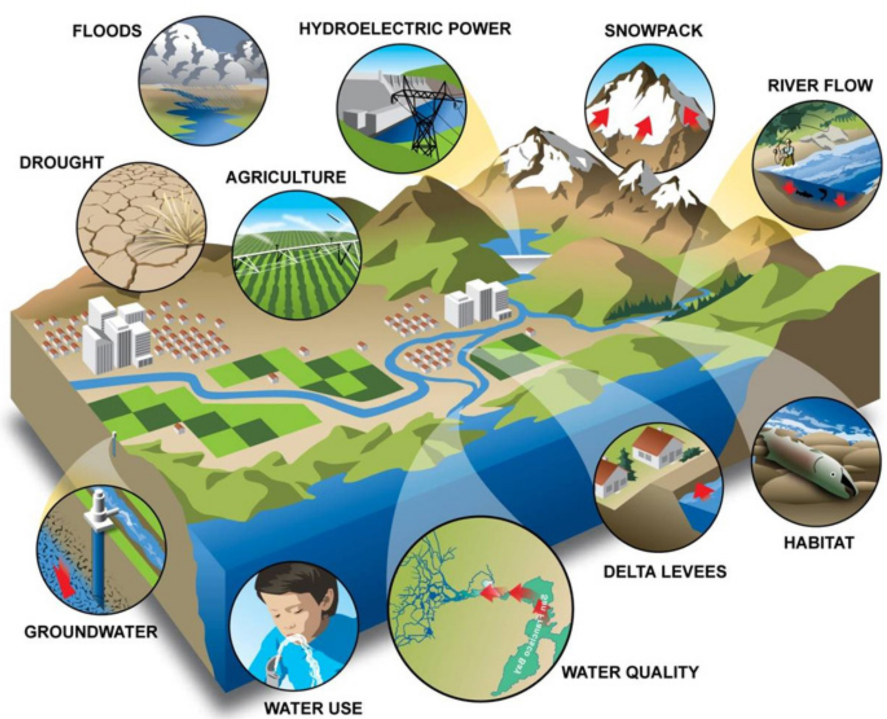



Figure A-1. Example Watershed Features That Can Be Impacted by Climate Change
*Source: DWR, 2008*

# 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.

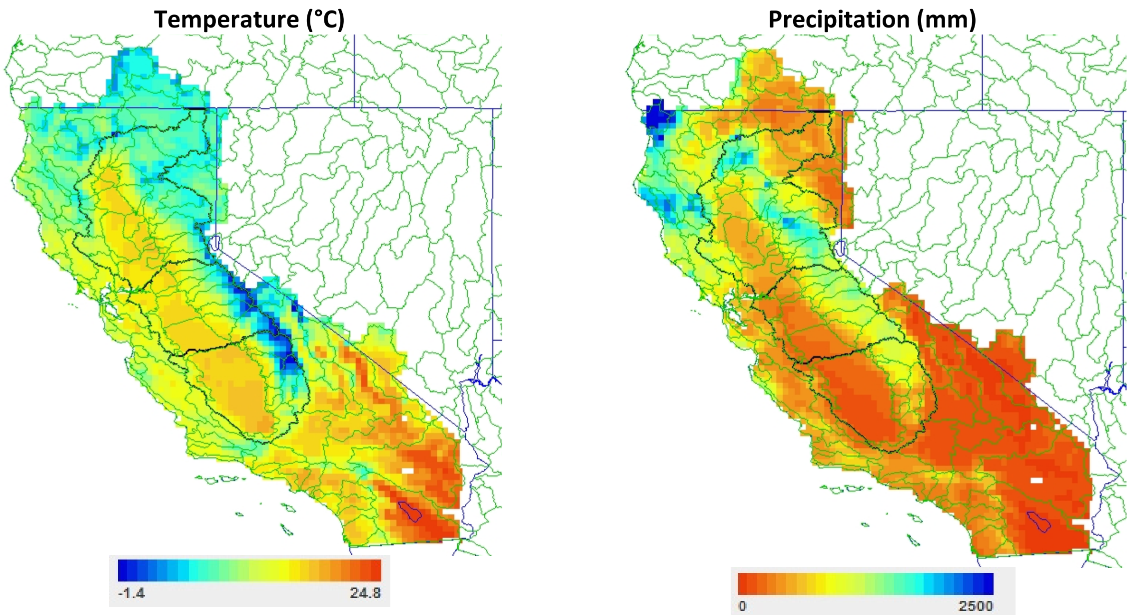



Figure A-2. Average Annual Temperature and Precipitation for 1981 to 2010
*Source: Livneh et al., 2013; adapted from Reclamation, 2015*

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.

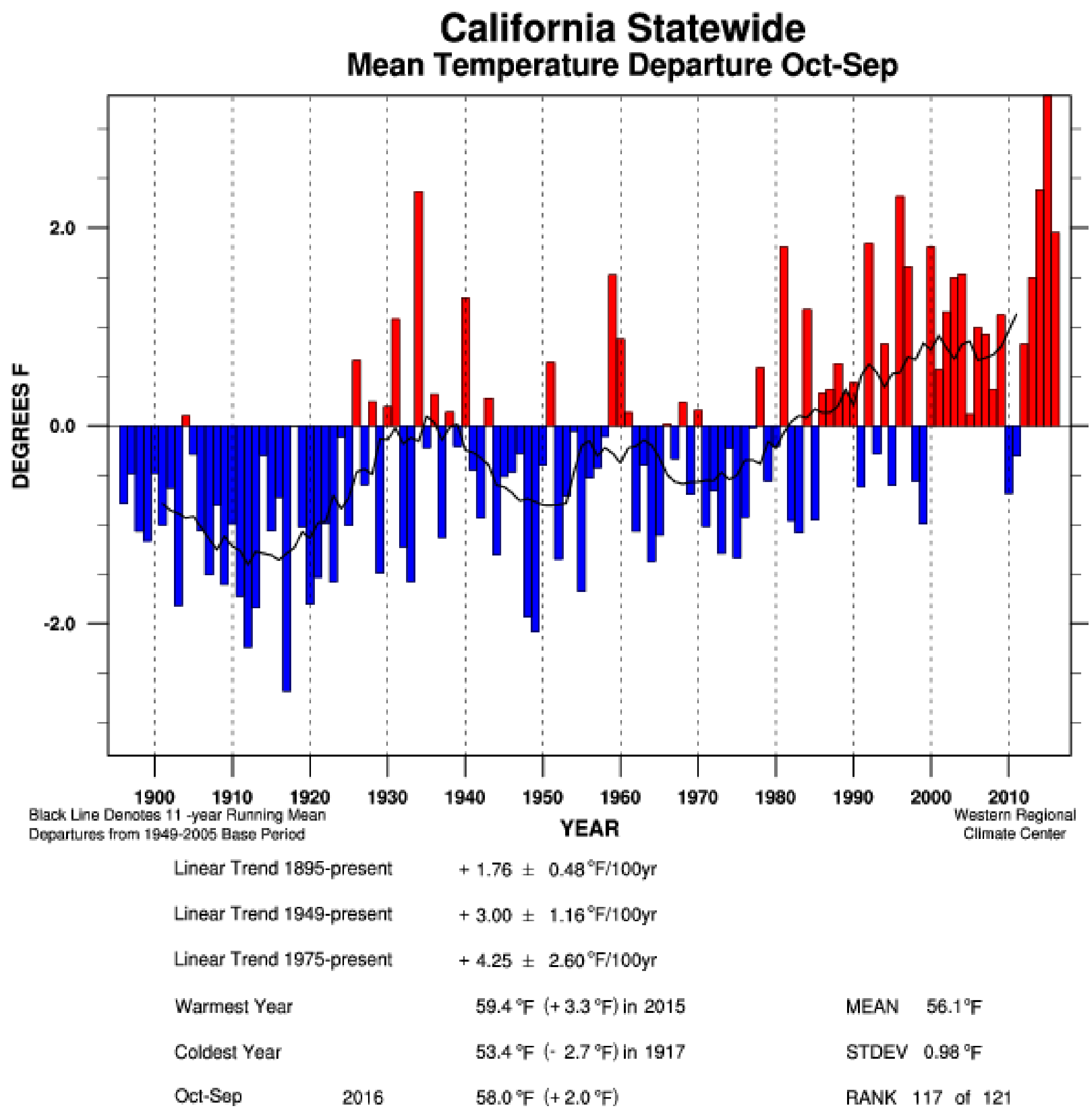



Figure A-3. California Statewide Mean Temperature Departure (October to September)

*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.

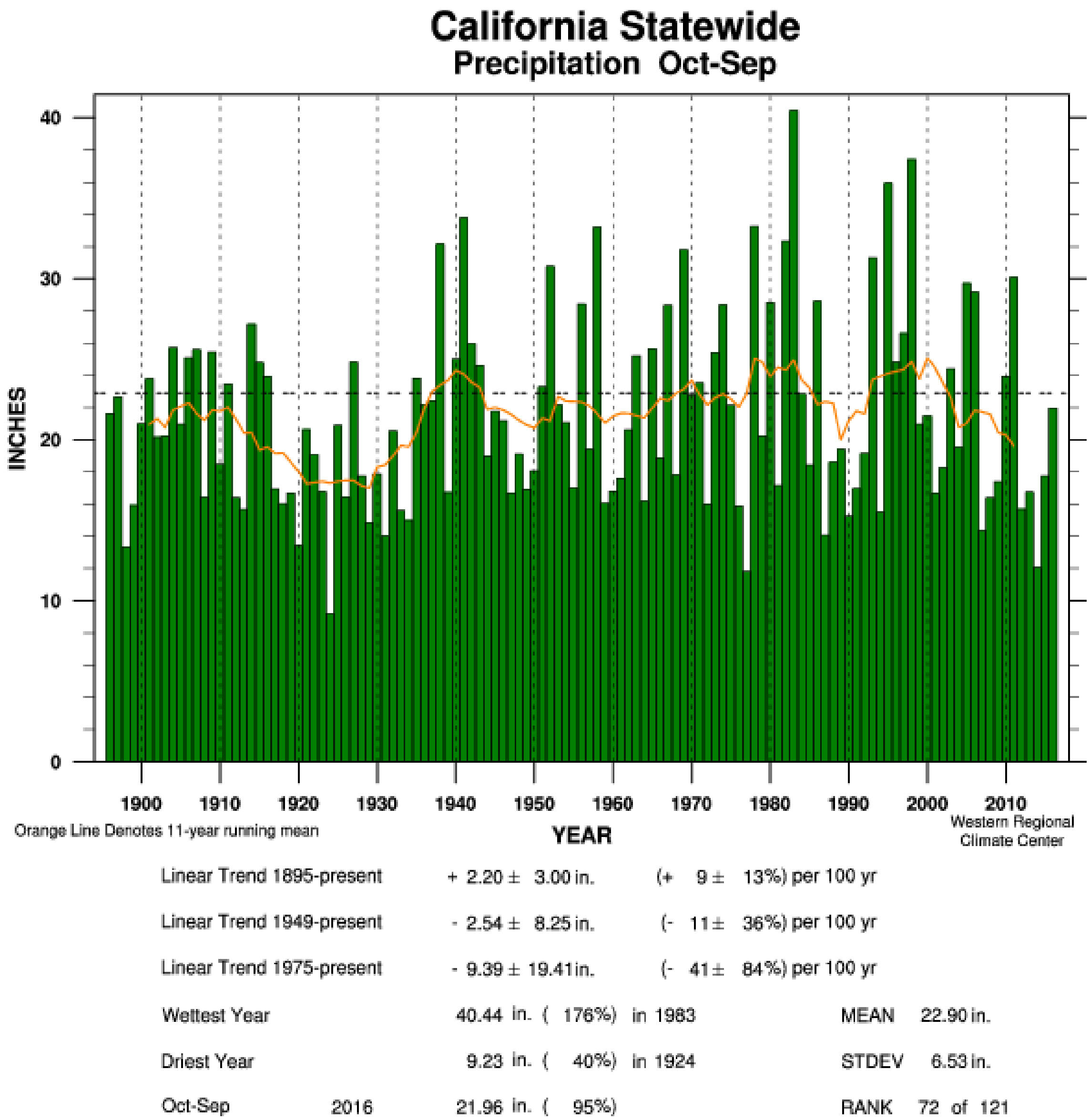



Figure A-4. California Statewide Precipitation (October to September)

*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).

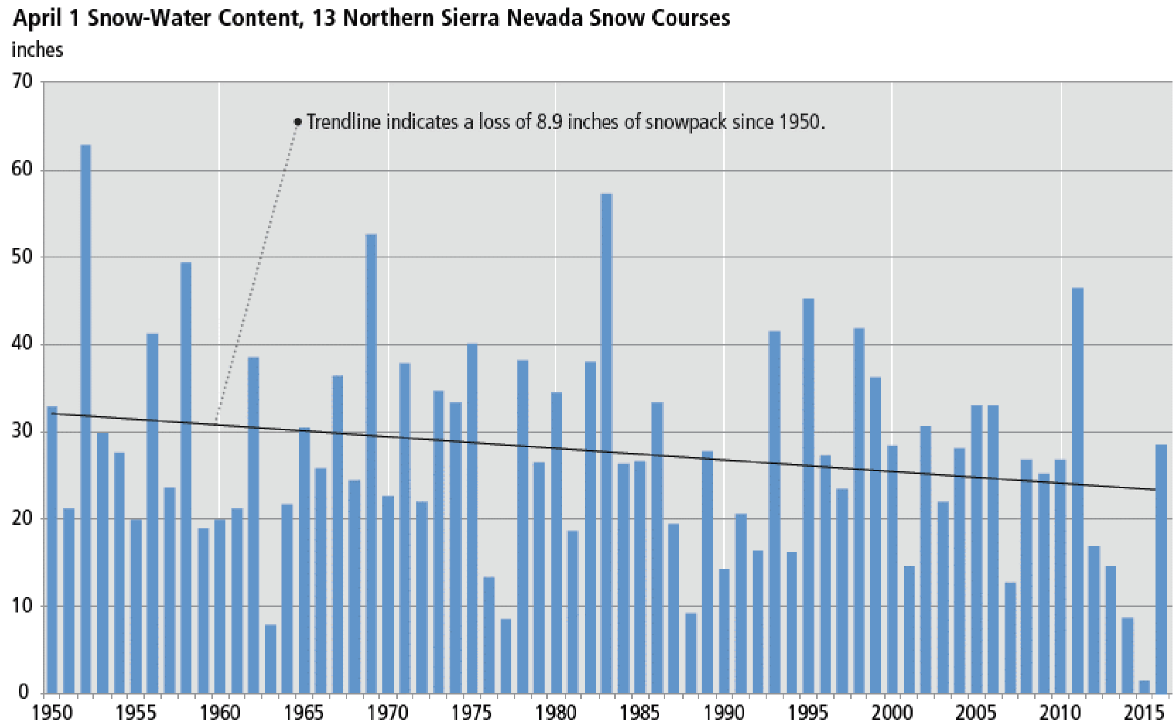



Figure A-5. April 1 Snow-Water Content, 13 Northern Sierra Nevada Snow Courses
*Source: Office of the State Climatologist, 2016*

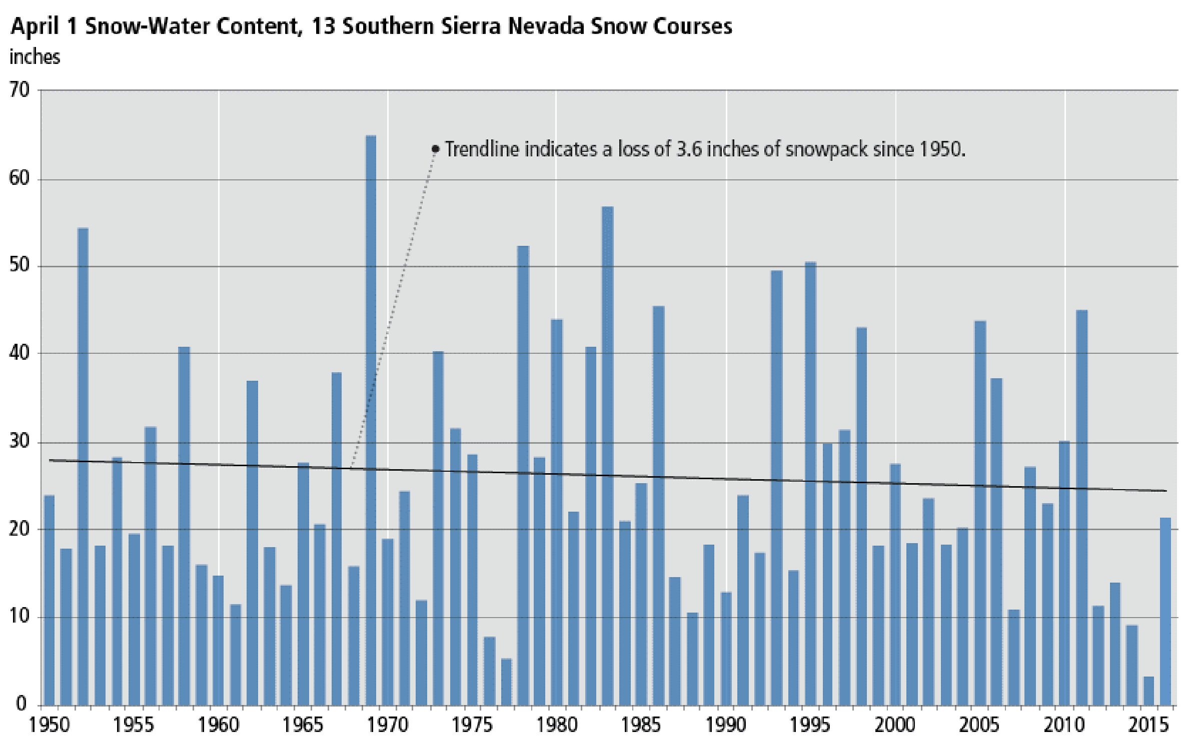



Figure A-6. April 1 Snow-Water Content, 13 Southern Sierra Nevada Snow Courses
*Source: Office of the State Climatologist, 2016*

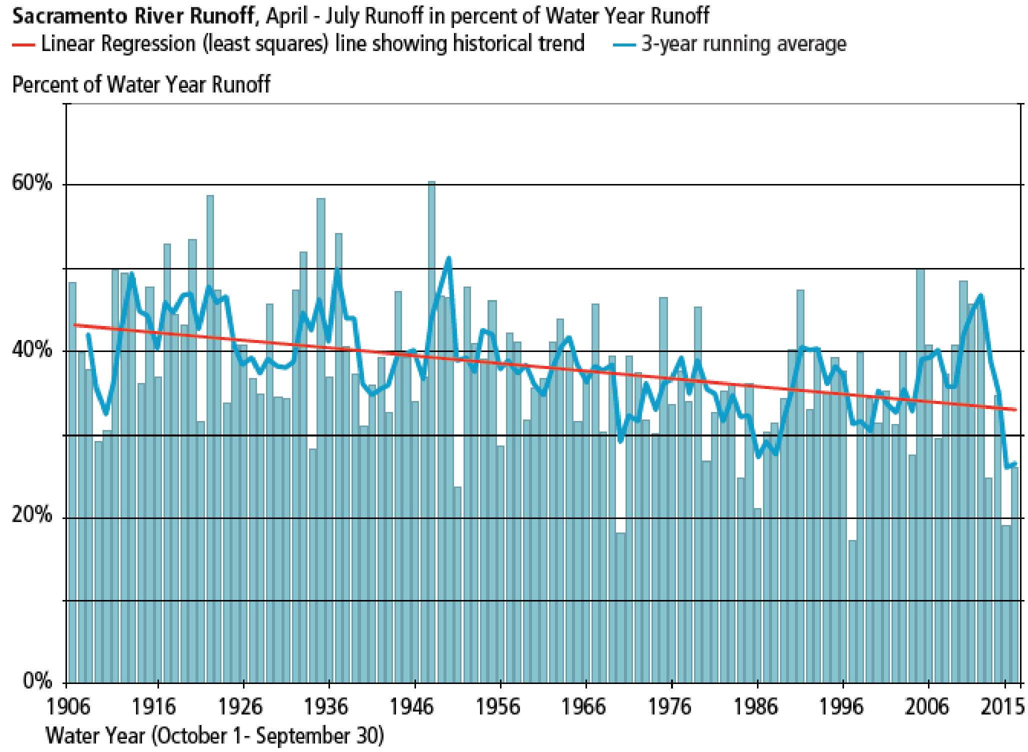
### A.2.3 Unimpaired Streamflow: Sacramento and San Joaquin River Systems

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.



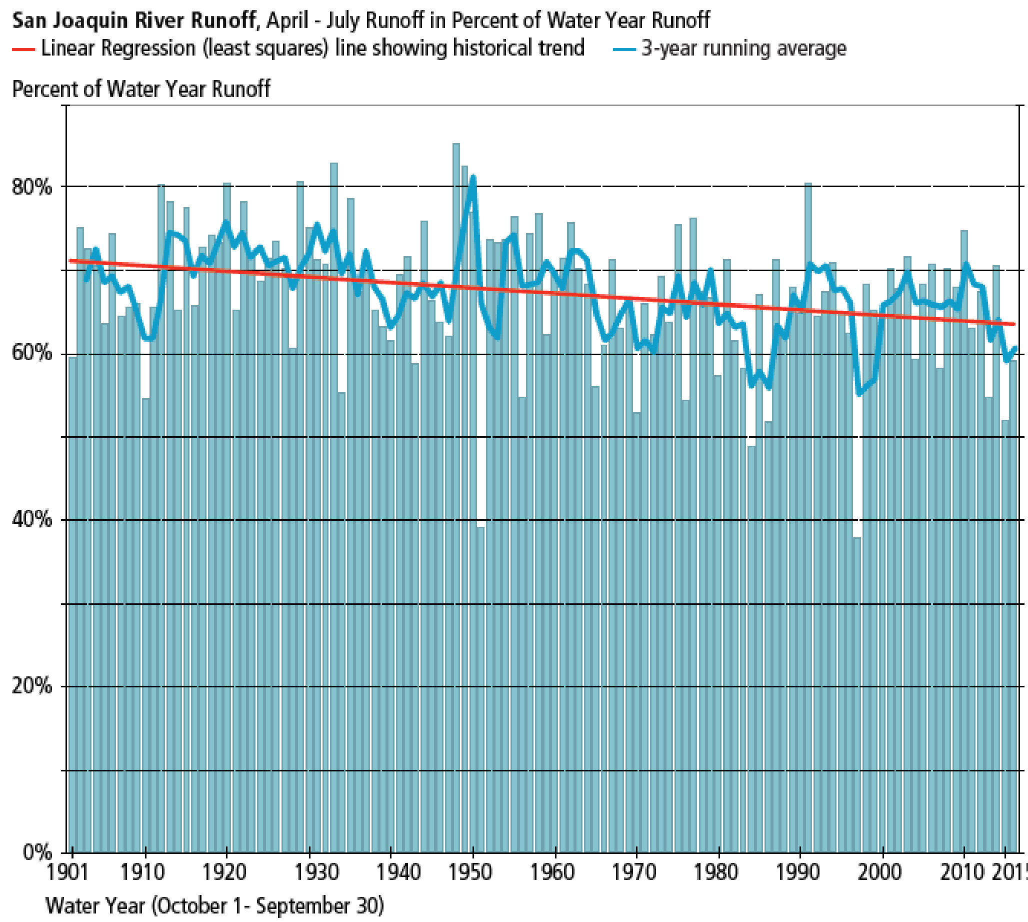




Figure A-7. Unimpaired Streamflow of Sacramento and San Joaquin River Systems
*Source: Office of the State Climatologist, 2016*

## 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.

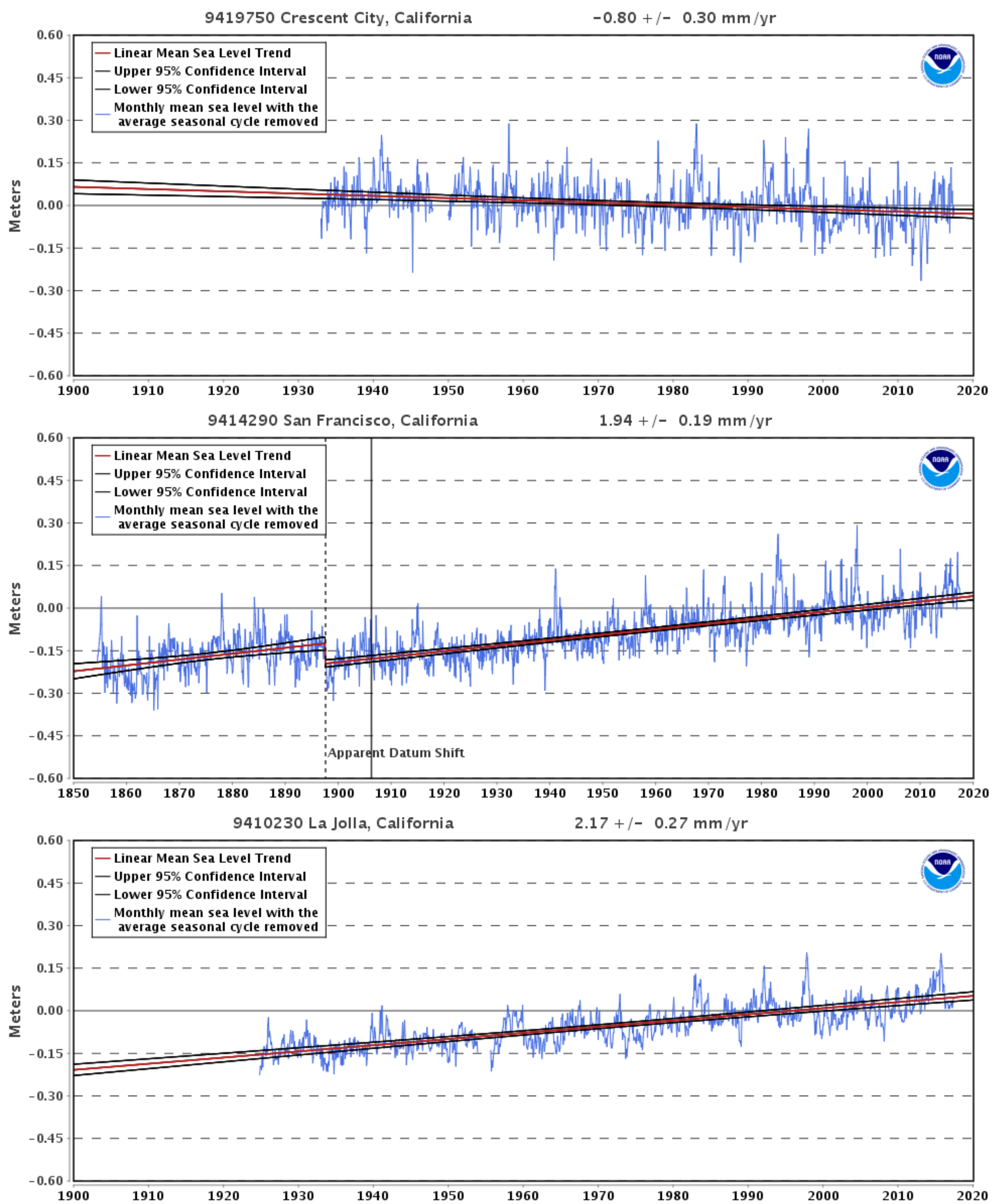



Figure A-8. Mean Sea Level Trend at Three NOAA Coastal Tide Gages on the California Coast

*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.

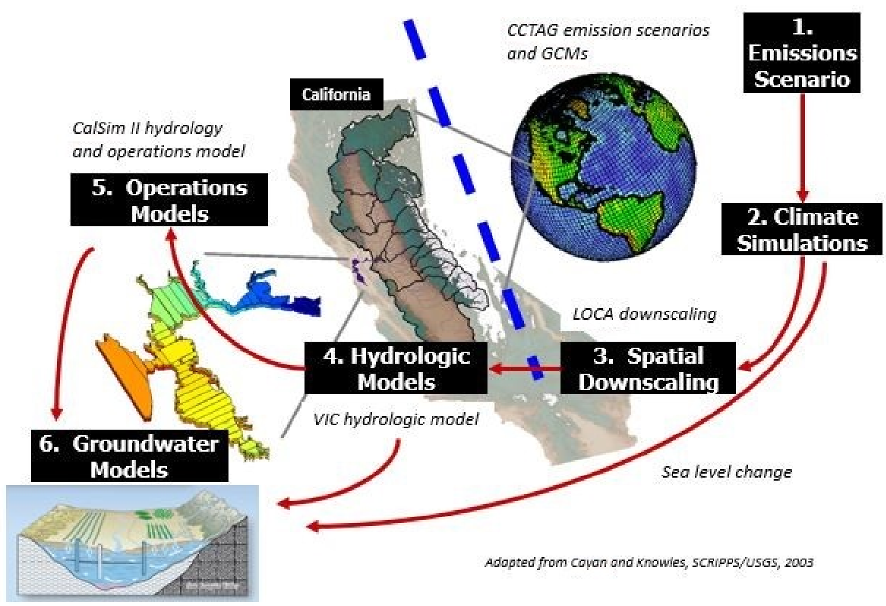



Figure A-9. Climate Change Data Downscaling to Groundwater Model

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.<br>• 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.<br>• 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.

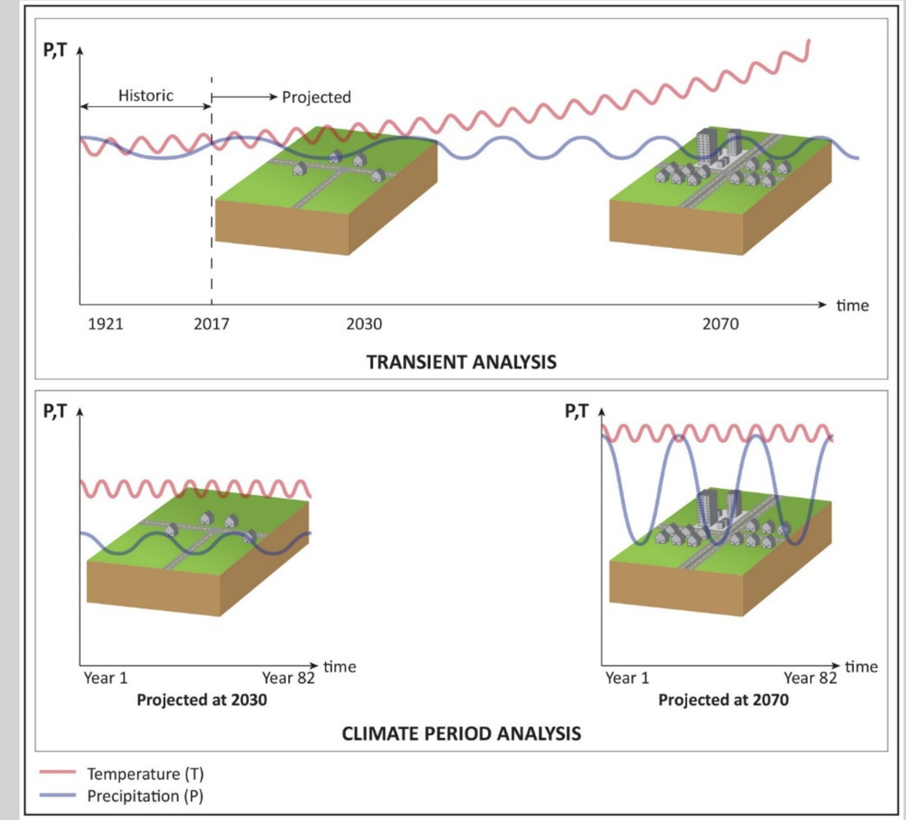



Figure A-10. Conceptual Representation of Transient and Climate Period Analysis

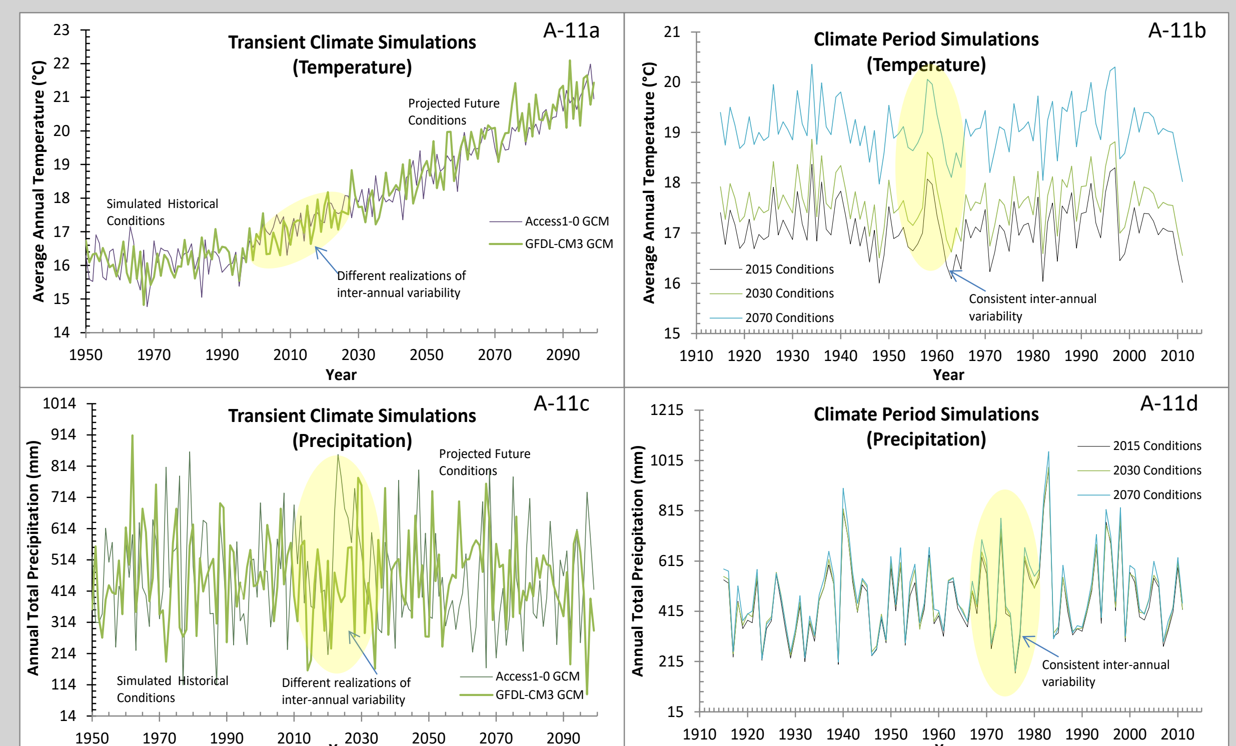



Figure A-11. Transient and Climate Period Simulations of Temperature and Precipitation

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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

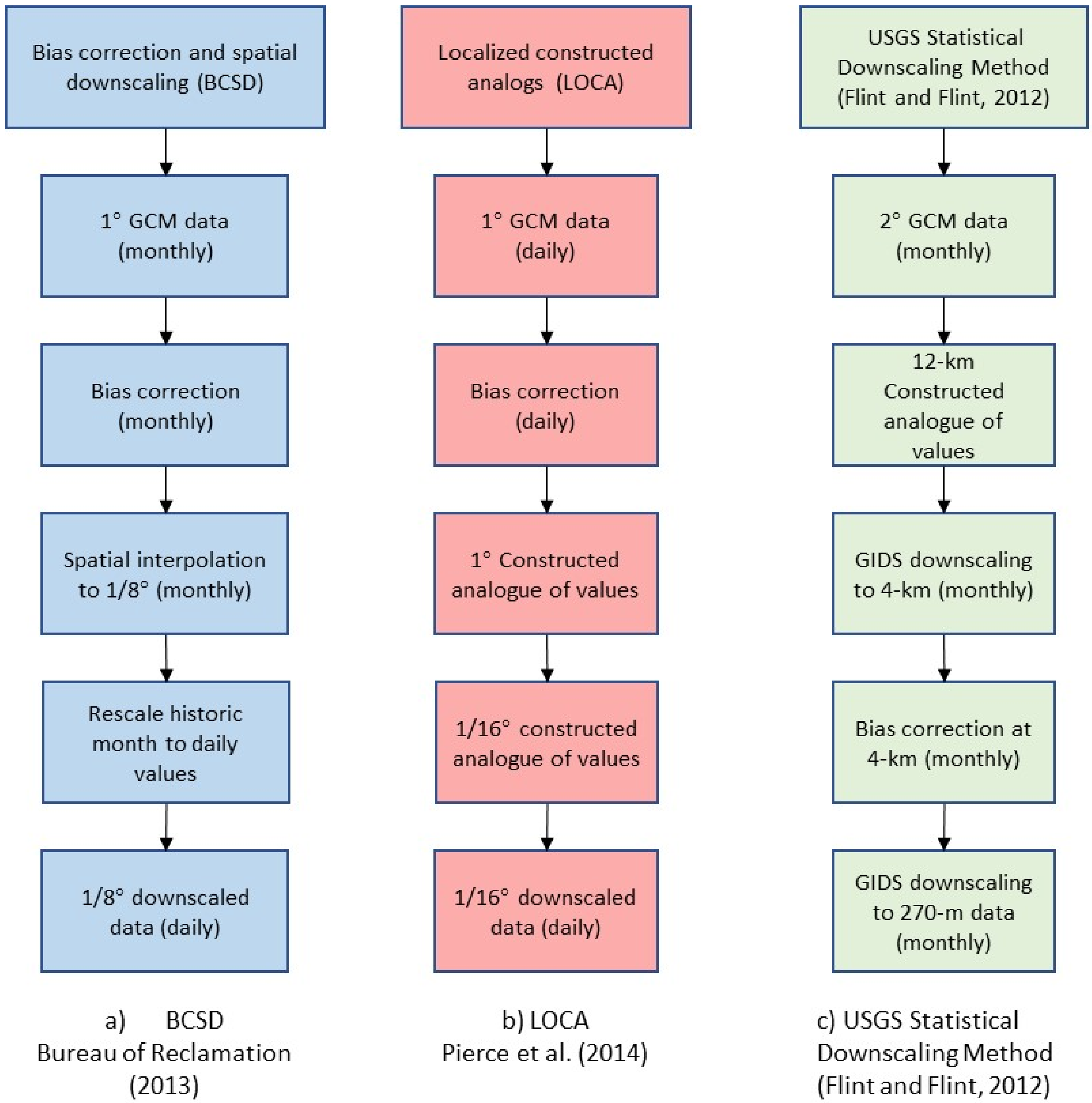



Figure A-12. Different Processing Sequences of BCSD, LOCA, and USGS Downscaling

# 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.

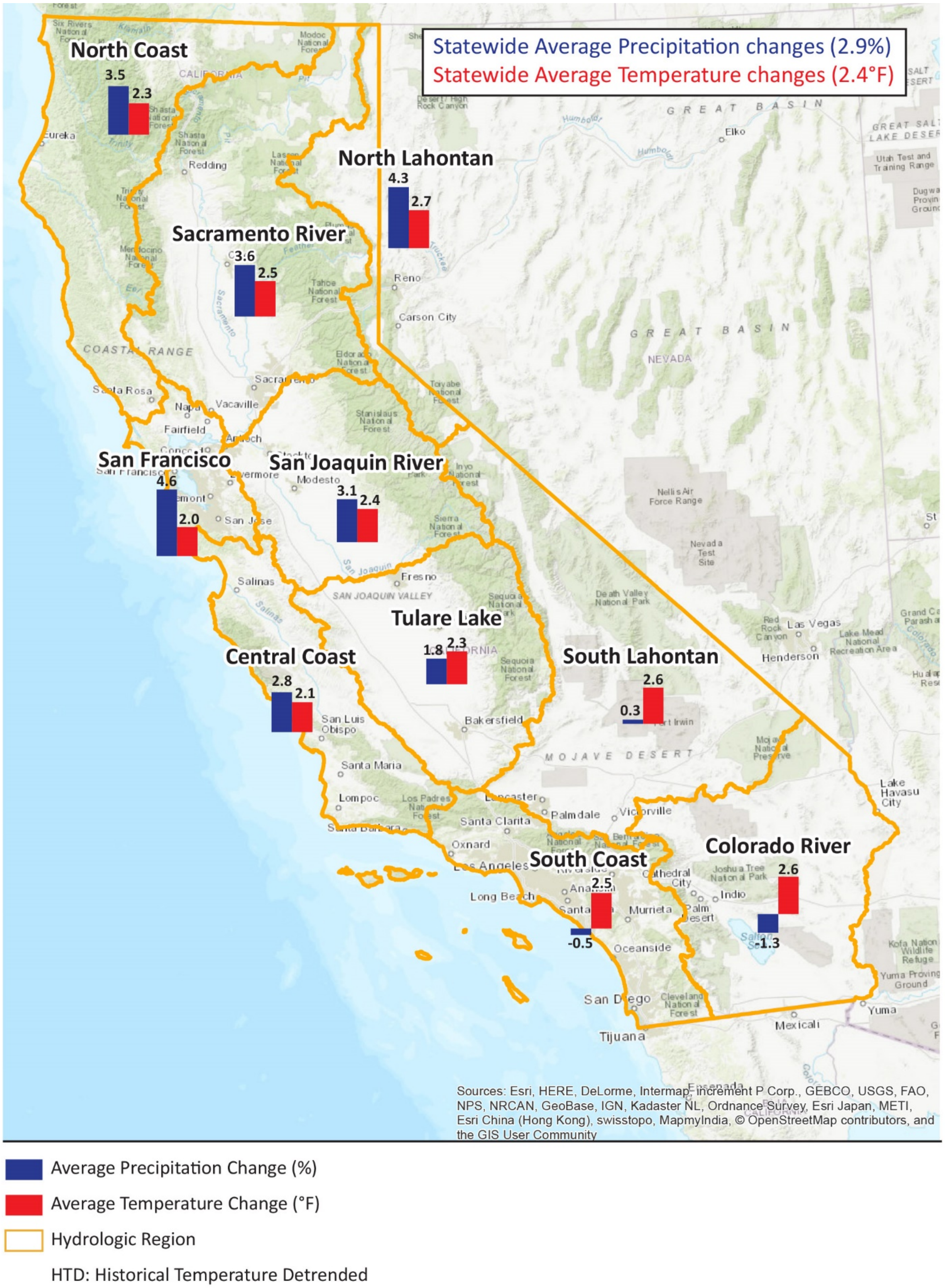
Figures A-13 and A-14 show that, at both the 2030 and 2070 projected climate conditions, the northern and central regions of California are expected to experience an increase in precipitation, as compared with the southern region. The southernmost regions of California (i.e., along the south coast and 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

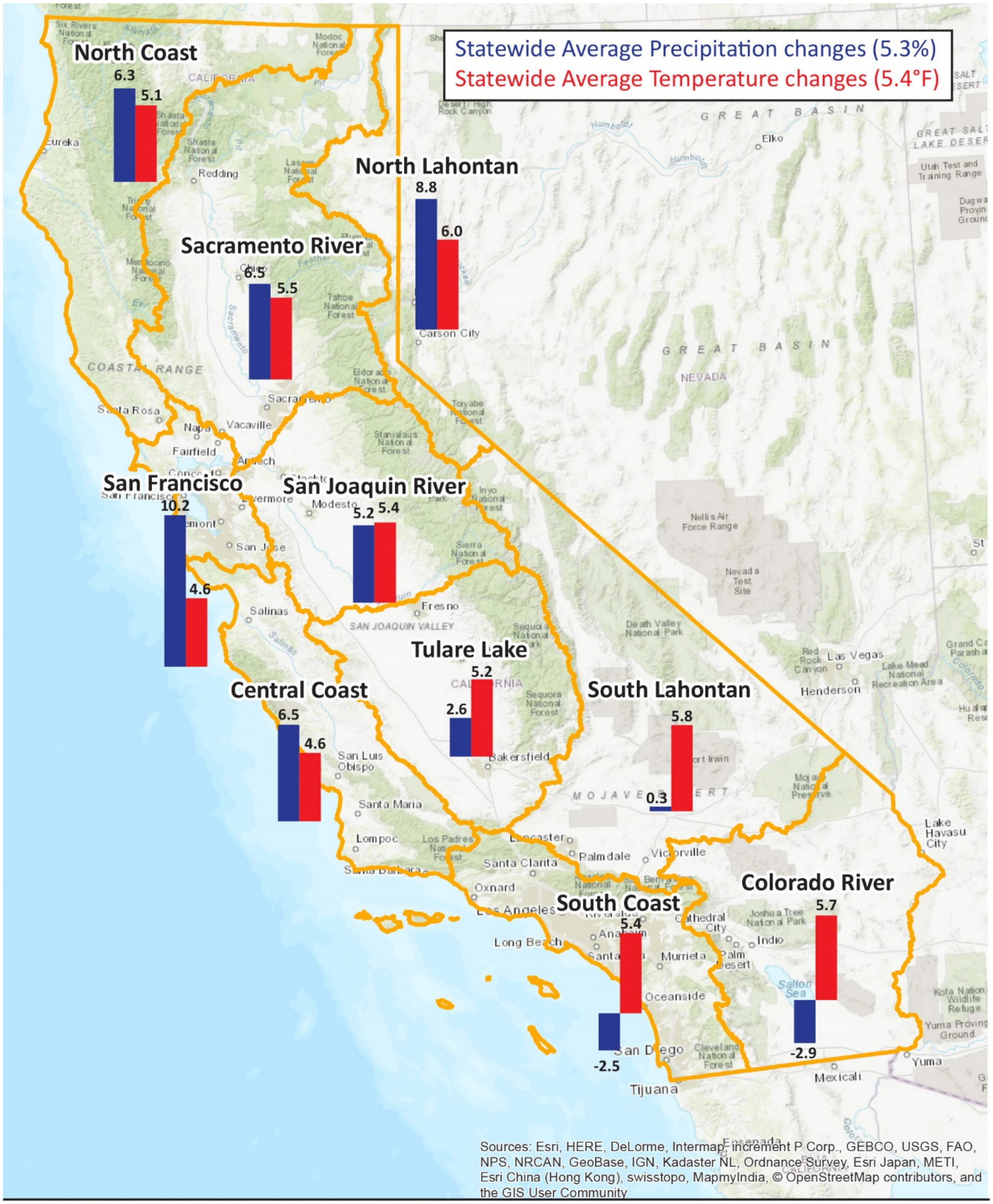
As a macro-scale model, variable infiltration capacity (VIC) modeling is well suited for incorporating climate data from downscaled GCM data to simulate statewide hydrologic responses to climate conditions. VIC modeling has been used for numerous DWR studies due to the availability of model inputs and 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)




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*




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-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) | | Exchange Contractor (TAF/year) | Level 2 Refuges[a] (TAF/year) |
|---|---|---|---|---|---|---|
| | | | Ag | M&I | | |
| 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 | | |
|---|---|---|---|---|
| Diversion | DSA | River Mile | Bank (Left, Right) | Supply Total (AF/year) |
| | | 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.

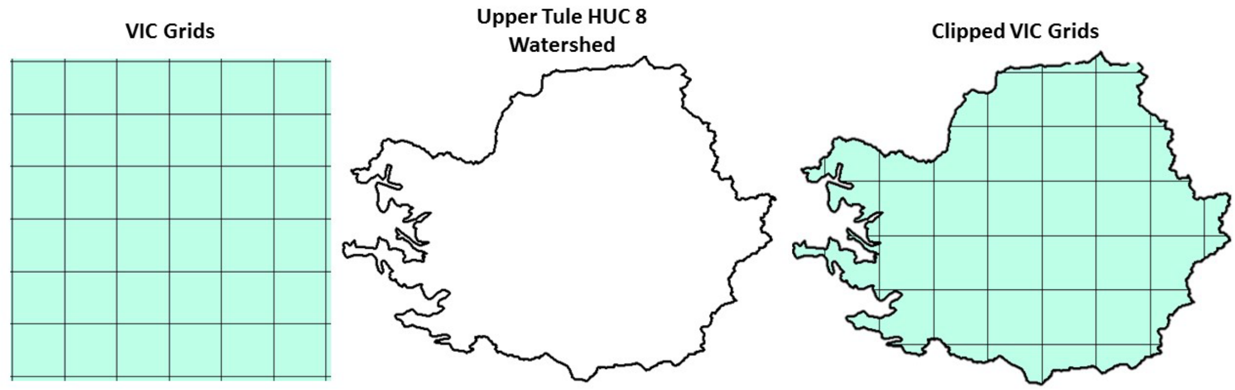


Figure C-1. Example of Clipping the VIC Grids to a HUC 8 Watershed Boundary

## 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.

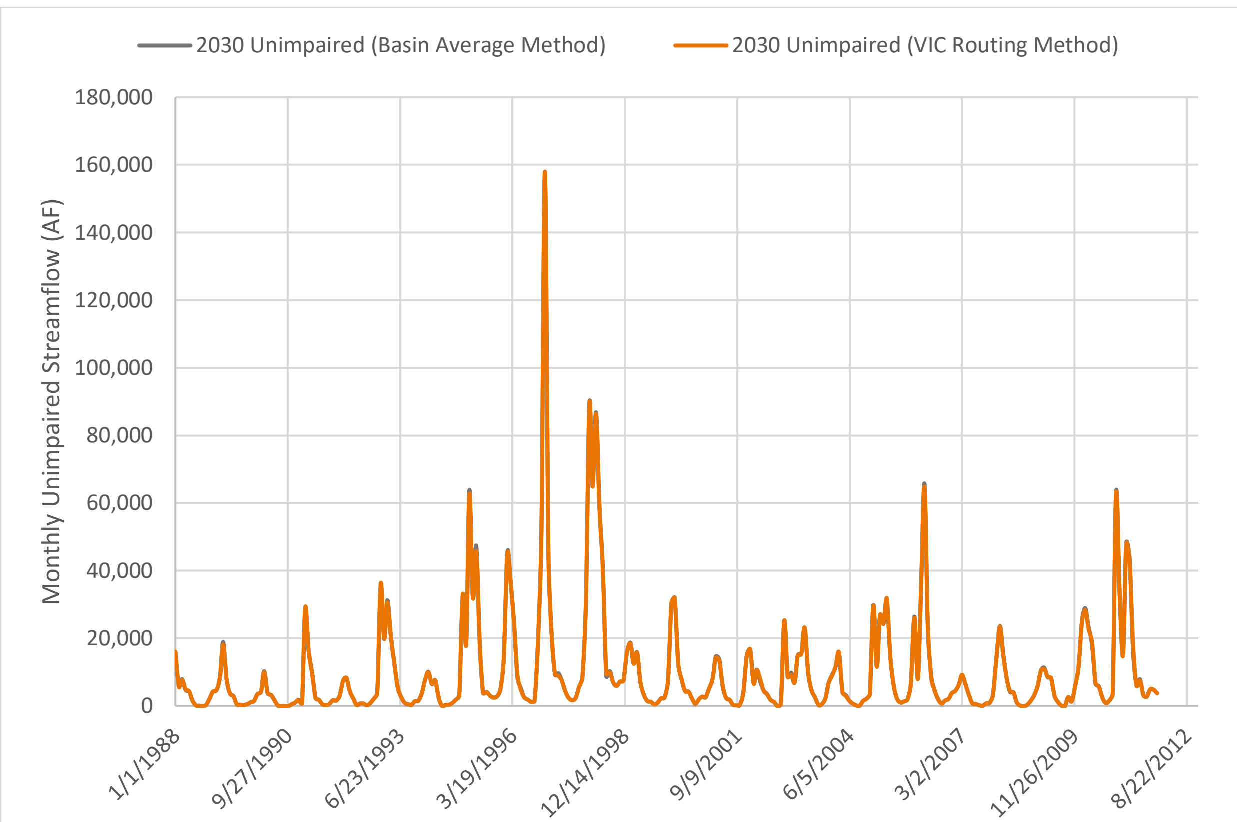


Figure C-3. Comparison of Projected Unimpaired Streamflow Using Change Factors from the Basin Average Method and the VIC Routing Method

# 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.

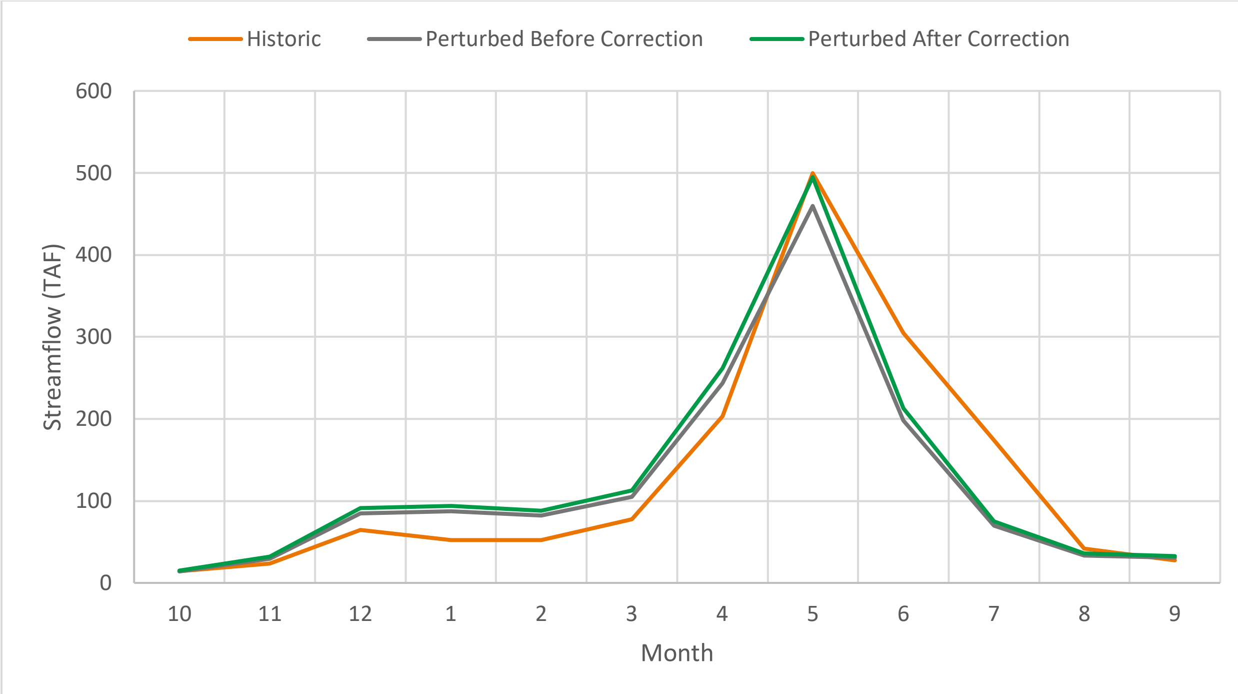


Figure C-7. Comparison of Applying Monthly Timeseries Change Factors Before and After Second Order Correction

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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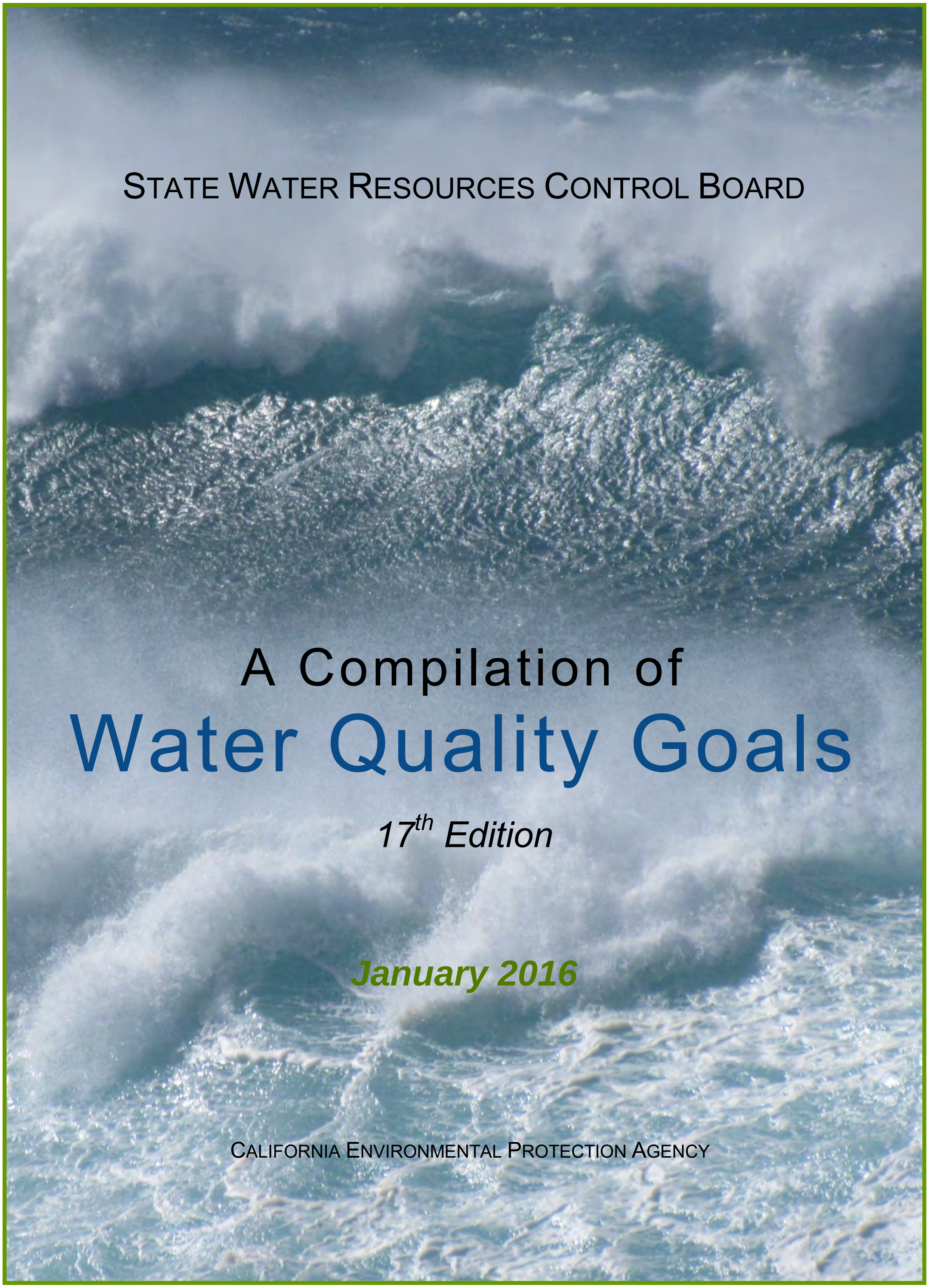
# Appendix 3A

# SWRCB Compilation of Water Quality Goals



STATE WATER RESOURCES CONTROL BOARD

# A Compilation of Water Quality Goals

*17th Edition*

**January 2016**

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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*Edmund G. Brown Jr., Governor*

**California Environmental Protection Agency**
*Matthew Rodriquez, Secretary for Environmental Protection*

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A Compilation of

# Water Quality Goals

*17th Edition*

***January 2016***


REPORT PREPARED BY:

JON B. MARSHACK, D.ENV.
Environmental Program Manager I (Specialist)
Office of Information Management & Analysis
Executive Director, California Water Quality Monitoring Council



STATE WATER RESOURCES CONTROL BOARD

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

# PREFACE TO THE JANUARY 2016 EDITION

This State Water Resources Control Board (State Water Board) staff report, *A Compilation of Water Quality Goals*, supersedes the April 2011 edition and all prior editions and updates published by the State Water Resources Control Board and the Central Valley Regional Water Quality Control Board. Earlier editions and updates should be discarded, as they contain outdated information.

The text of this edition has been updated mainly to reflect the transfer of California's Drinking Water Program from the Department of Public Health (CDPH) to the Division of Drinking Water (DDW) at the State Water Resources Control Board (State Water Board). Information about this transfer is online at http://www.waterboards.ca.gov/drinking_water/programs/DW_PreJuly2014.shtml. Cited examples and hyperlinks to reference materials have also been updated.

*Water Quality Goals* includes an online searchable database of water quality based numeric thresholds available at http://www.waterboards.ca.gov/water_issues/programs/water_quality_goals/. The database contains up-to-date numeric thresholds from a variety of sources for over 860 chemical constituents and water quality parameters, including:

- California and Federal drinking water standards (MCLs)
- California Public Health Goals (PHGs)
- California State Notification and Response Levels for drinking water
- Health Advisories, Water Quality Advisories, and Drinking Water Advisories
- Cancer Risk Estimates
- Health-based criteria from USEPA's Integrated Risk Information System (IRIS)
- California Proposition 65 Safe Harbor Levels
- California Toxics Rule Criteria to protect human health and aquatic life
- California Ocean Plan Water Quality Objectives
- U.S. Environmental Protection Agency (USEPA) Recommended Water Quality Criteria to Protect Human Health and Aquatic Life
- Agricultural use protective thresholds
- Taste and odor based criteria

The narrative *Selecting Water Quality Goals* contains information to help users to understand California's water quality standards adopted to protect the beneficial uses of surface water and groundwater resources, available criteria and guidance for evaluating water quality, and to help users select defensible numeric assessment thresholds based on applicable water quality standards. ***To use this information correctly, it is necessary to read Selecting Water Quality Goals carefully before using numeric thresholds from the database.***

*Water Quality Goals* is a technical report prepared by staff of the State Water Board. It is intended to help identify and assess potential water quality concerns. This report is an informational tool only and does not establish State Water Board policy or regulation. The information presented in this report is not binding on any person or entity, nor does it represent final action of the State Water Board or any Regional Water Board. This report is not intended, nor can it be relied upon, to create any rights enforceable by any party in litigation in the State of California. The overseeing regulatory authority may decide to use the information provided herein, or to act at a variance with the information, based on analysis of site and case-specific circumstances.

If you have questions regarding the *Water Quality Goals* staff report or the online database of numeric thresholds, contact Jon Marshack at (916) 341-5514 or jon.marshack@waterboards.ca.gov.

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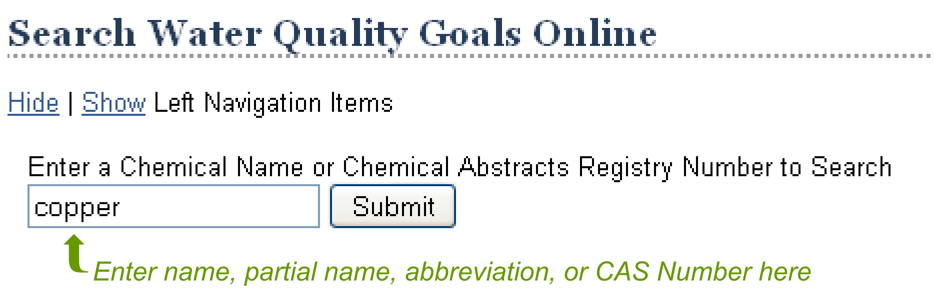
# How to Use Water Quality Goals Online

Previous editions of *Water Quality Goals* included tables of water quality based numeric thresholds, a chemical name cross-reference, footnotes, and references. To provide access to more frequent updates of this information, these tables have been replaced with an online searchable database, located at http://www.waterboards.ca.gov/water_issues/ programs/water_quality_goals. The database allows users to search for numeric thresholds for over 860 chemicals and water quality parameters.

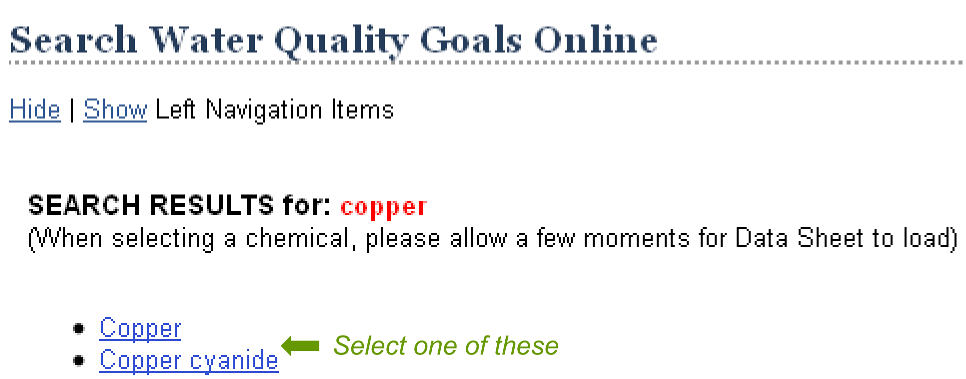
To avoid incorrect use of the numeric thresholds contained in the database, users are strongly encouraged to carefully review the following section, *Selecting Water Quality Goals*.

## Using the Database

Go to the search screen, shown below. In the box, enter a chemical or parameter name, portion of a name, abbreviation, or Chemical Abstracts Service (CAS) Registry Number. Then click the "Submit" button.




The search tool will present you with a list of chemicals and parameters that matches your entry. Click on the one of interest to view a table of numeric thresholds for that chemical or parameter.




An example of the resulting table of numeric thresholds is shown on the following three pages.

*Note: This table is provided as an example and should not necessarily be considered to present current information on numeric thresholds.*

## Search Water Quality Goals Online

Hide | Show Left Navigation Items

New Search  Return to Previous Search Results  Print

**Chemical Name:** Copper
**Chemical Type:** Inorganic    **Chemical Abstracts Service Registry Number:** 7440-50-8
**Synonyms:** Cu

| Source & References | Threshold 1 (ug/L) | Threshold 2 (ug/L) | Units if not ug/L | Notes | Foot note1 | Foot note2 | Adoption Date | Limiting Threshold | |
|---|---|---|---|---|---|---|---|---|---|
| **Drinking Water Standards - Maximum Contaminant Levels (MCLs)** | | | | | | | | | |
| **California Dept of Health Services** | | | | | | | | | |
| **Primary MCL** (health based + technology & economics) | 1300 | | | | 111 | | 6/1/1991 | CC | G;IS |
| **Secondary MCL** (taste & odor or welfare-based) | 1000 | | | | | | | CT | G;IS |
| **U.S. Environmental Protection Agency** (USEPA) | | | | | | | | | |
| **Primary MCL** (health based + technology & economics) | 1300 | | | | 111 | | 12/11/1995 | | |
| **Secondary MCL** (taste & odor or welfare-based) | 1000 | | | | | | 1/1/1977 | | |
| **MCL Goal** (level for no adverse health effects) | 1300 | | | | | | | | |
| **California Public Health Goal or PHG** (Cal/EPA, OEHHA) | 300 | | | | | | 2/8/2008 | TH | G |
| **California Notification Levels** (Department of Health Services) | | | | | | | | | |
| **Source & References** | **Threshold 1 (ug/L)** | **Threshold 2 (ug/L)** | **Units if not ug/L** | **Notes** | **Foot note1** | **Foot note2** | **Adoption Date** | **Limiting Threshold** | |
| **Drinking Water Health Advisories or Suggested No-Adverse-Response Levels for non-cancer health effects** | | | | | | | | | |
| **USEPA IRIS Reference Dose (RfD) as a drinking water level*** | | | | | | | | | |
| **USEPA Health Advisory** | | | | | | | | | |
| **National Academy of Sciences Health Advisory** | | | | | | | | | |
| **One-in-a-Million Incremental Cancer Risk Estimates for Drinking Water** | | | | | | | | | |
| **Cal/EPA Cancer Potency Factor** as a drinking water level** | | | | | | | | | |
| **USEPA Integrated Risk Information System (IRIS)** | | | | | D | | | | |
| **USEPA Health Advisory** | | | | | D | 68 | 1/1/1998 | | |
| **National Academy of Sciences Health Advisory** | | | | | | | | | |
| **California Proposition 65 Safe Harbor Level** as a drinking water level*** | | | | | | | | | |
| **No Significan Risk Level** (one-in-100,000 cancer risk) | | | | | | | | | |
| **Maximum Allowable Dose Level** for Reproductive Toxicity | | | | | | | | | |

| Source & References | Threshold 1 (ug/L) | Threshold 2 (ug/L) | Units if not ug/L | Notes | Foot note1 | Foot note2 | Adoption Date | Limiting Threshold | |
|---|---|---|---|---|---|---|---|---|---|
| **Taste & Odor Threshold** | | | | | | | | | |
| **Agricultural Water Quality Goals** (Food & Ag. Org. of United Nations) | 200 | | | | | | | CC | G;IS |
| **California Inland Surface Waters - California Toxics Rule Criteria** (USEPA) | | | | | | | | | |
| **Human Health Protection** (30-day average) | | | | | | | | | |
| Sources of Drinking Water (water & fish consumption) | 1300 | | | | 2 | 142 | 5/18/2000 | CH | IS |
| Other waters (fish consumption only) | | | | | | | | | |
| **Freshwater Aquatic Life Protection** | | | | | | | | | |
| Continuous Concentration (4-day Average) | | | | see page 23 | 1 | 142 | 5/18/2000 | CA | IS |
| Maximum Concentration (1-hour Average) | | | | see page 23 | 1 | 142 | 5/18/2000 | CA | IS |
| Maximum (Instantaneous) | | | | | | | | | |
| **Source & References** | **Threshold 1 (ug/L)** | **Threshold 2 (ug/L)** | **Units if not ug/L** | **Notes** | **Foot note1** | **Foot note2** | **Adoption Date** | **Limiting Threshold** | |
| **California Enclosed Bays & Estuaries - California Toxics Rule Criteria** (USEPA) | | | | | | | | | |
| **Human Health Protection** (30-day avg; fish consumption only) | | | | | | | | | |
| **Saltwater Aquatic Life Protection** | | | | | | | | | |
| Continuous Concentration (4-day Average) | 3.1 | | | | 1 | 142 | 5/18/2000 | | |
| Maximum Concentration (1-hour Average) | 4.8 | | | | 1 | 142 | 5/18/2000 | | |
| Maximum (Instantaneous) | | | | | | | | | |
| **California Ocean Plan -- Numerical Water Quality Objectives** (State Water Board) | | | | | | | | | |
| **Human Health Protection (30-day average; fish consumption only)** | | | | | | | | | |
| **Marine Aquatic Life Protection** | | | | | | | | | |
| 6- month Median | 3 | | | | 2 | | | | |
| 30-day Average | | | | | | | | | |
| 7-day Average | | | | | | | | | |
| Daily Maximum | 12 | | | | 2 | | | | |
| Instantaneous Maximum | 30 | | | | 2 | | | | |
| **Source & References** | **Threshold 1 (ug/L)** | **Threshold 2 (ug/L)** | **Units if not ug/L** | **Notes** | **Foot note1** | **Foot note2** | **Adoption Date** | **Limiting Threshold** | |
| **National Recommended Water Quality Criteria** (U.S. Environmental Protection Agency) | | | | | | | | | |
| **Human Health & Welfare Protection** | | | | | | | | | |
| Public Health Effects (other than cancer risk) | | | | | | | | | |
| Water & Fish Consumption | 1300 | | | | | | | | |
| Fish Consumption Only | | | | | | | | | |
| One-in-a-Million Incremental Cancer Risk Estimate | | | | | | | | | |
| Water & Fish Consumption | | | | | | | | | |
| Fish Consumption Only | | | | | | | | | |
| Taste & Odor or Welfare | 1000 | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Freshwater Aquatic Life Protection** | | | | | | | | | |
| Recommended Criteria | | | | | | | | | |
| Continuous Concentration (4-day Average) | | | | | 180 | | 2/1/2007 | | |
| 24-hour Average | | | | | | | | | |
| Maximum Concentration (1-hour Average) | | | | | 180 | | 2/1/2007 | | |
| Maximum (Instantaneous) | | | | | | | | | |
| Toxicity Information (Lowest Observed Effect Level) | | | | | | | | | |
| Acute | | | | | | | | | |
| Chronic | | | | | | | | | |
| Other | | | | | | | | | |
| **Saltwater Aquatic Life Protection** | | | | | | | | | |
| Recommended Criteria | | | | | | | | | |
| Continuous Concentration (4-day Average) | 3.1 | 1.9 | | | 1 | 68 | | | |
| 24-hour Average | 3.1 | | | | 1 | 68 | 11/1/2003 | | |
| Maximum Concentration (1-hour Average) | 4.8 | | | | 1 | | | | |
| Maximum (Instantaneous) | | | | | | | | | |
| Toxicity Information (Lowest Observed Effect Level) | | | | | | | | | |
| Acute | | | | | | | | | |
| Chronic | | | | | | | | | |
| Other | | | | | | | | | |
| **Source & References** | **Threshold 1 (ug/L)** | **Threshold 2 (ug/L)** | **Units if not ug/L** | **Notes** | **Foot note1** | **Foot note2** | **Adoption Date** | **Limiting Threshold** | |

**Notes:**

| | |
|---|---|
| * | Assumes 70 kg body weight, 2 liters/day water consumption, and 20% relative source contribution from drinking whater. An additional uncertainty factor of 10 is used for Class C carcinogens. |
| ** | Assumes 70 kg body weight and 2 liters/day water consumption. |
| *** | Regulatory dose level divided by 2 liters/day water consumption. |
| # | Carcinogen / based on cancer risk |
| R | Reproductive toxin / based on reproductive toxicity. |
| CA | First threshold or range is recommended to implement promulgated Criteria to protect Aquatic life. |
| CH | First threshold or range is recommended to implement promulgated Criteria to protect Human health. |
| CC | First threshold or range is recommended to implement the Chemical Constituents objective. |
| CT | First threshold or range is recommended to implement the Chemical Constituents and the Tastes & Odors objectives. |
| TA | First threshold or range is recommended to implement the Toxicity objective to protect Aquatic life. |
| TH | First threshold or range is recommended to implement the Toxicity objective to protect Human health. |
| TO | First threshold or range is recommended to implement the Tastes and Ordors objectives. |
| G | Limiting threshold applies to Groundwater only. |
| IS | Limiting threshold applies to Inland Surface water only. |
| G&IS | Limiting threshold applies to both Groundwater and Inland Surface water. |
| EW | Limiting threshold applies to Estuarine Water only. |
| MW | Limiting threshold applies to Marine Water only. |

**Footnotes**

| | |
|---|---|
| 111 | MCL includes this Action Level to be exceeded in no more than 10% of samples at the tap. |
| D | Class D: Not classifiable as to human carcinogenicity; no data or inadequate evidence. Inadequate information to assess carcinogenic potential (U.S. Environmental Protection Agency, 1986 Guidelines for Carcinogen Risk Assessment). |
| 68 | Draft / tentative / provisional; applies only to second value if two separate values are listed; applies to range if a range of values is listed. |
| 2 | Expressed as total recoverable. |
| 142 | Criteria do not apply to waters subject to water quality objectives in Tables III-2A and III-2B of the San Francisco Bay Regional Water Quality Control Board?s 1986 Basin Plan. See Reference 17. |
| 1 | Expressed as dissolved. |
| 180 | Acute and chronic aquatic life criteria are calculated using the Biotic Ligand Model, a metal bioavailability model. See Reference 25. |

New Search  Return to Previous Search Results  Print

Each table of numeric thresholds contains a number of live links:

- Click on the ***Source & References*** blue underlined headings on the left to see descriptions of and original references for each type of numeric threshold, as in the example shown below. If the reference is available on the Internet, you will be presented with live links to these reference materials.

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**Taste and Odor Thresholds**

Consumers of water do not want to drink water that tastes or smells bad. Therefore, water that contains substances in concentrations that cause adverse tastes or odors may be considered to be impaired with respect to beneficial uses associated with drinking water use (municipal or domestic supply). Adverse tastes and odors may also be associated with nuisance conditions. Taste and odor thresholds are used to translate narrative water quality objectives that prohibit adverse tastes and odors in waters of the State and prohibit nuisance conditions. Taste and odor thresholds form the basis for many secondary drinking water Maximum Contaminant Levels (MCLs) and are also published by the U.S. Environmental Protection Agency in the National Recommended Water Quality Criteria. The values listed here are from sources other than those listed above.

References:

3. U.S. Environmental Protection Agency, Office of Water, *2012 Edition of the Drinking Water Regulations and Health Advisories tables* (April 2012), EPA 822-S-12-001, http://water.epa.gov/drink/standards/hascience.cfm.

7. U.S. Environmental Protection Agency, Office of Water, *National Primary Drinking Water Regulations, Contaminant Specific Fact Sheets - Technical Version* (October 1995), http://www.epa.gov/nscep/index.html or http://water.epa.gov/drink/contaminants/basicinformation/index.cfm.

8. U.S. Environmental Protection Agency, *Federal Register*, Vol. 54, No. 97 (Mon., 22 May 1989), pp. 22138, 22139.

10. California Environmental Protection Agency (Cal/EPA), Office of Environmental Health Hazard Assessment, *Public Health Goals for Chemicals in Drinking Water* (various dates), http://www.oehha.org/water/phg.

11. U.S. Environmental Protection Agency, Office of Drinking Water, *Health Advisory* documents; or Office of Water, *Drinking Water Health Advisory* documents (various dates). Earlier documents were called "Suggested No-Adverse Response Levels", http://water.epa.gov/drink/standards/hascience.cfm.

29. J.E. Amoore and E. Hautala, *Odor as an Aid to Chemical Safety: Odor Thresholds Compared with Threshold Limit Values and Volatilities for 214 Industrial Chemicals in Air and Water Dilution, Journal of Applied Toxicology*, Vol. 3, No. 6, pages 272-290 (1983), http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1099-1263.

30. California State Water Resources Control Board, *Water Quality Criteria*, Second Edition McKee & Wolf (1963, 1978), http://www.waterboards.ca.gov/publications_forms/publications/general/docs/waterquality_criteria1963.pdf.

33. U.S. Environmental Protection Agency, Office of Water, *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis* documents (various dates), http://water.epa.gov/drink/standards/hascience.cfm.

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- ***Footnote1*** and ***Footnote2*** provide you with additional information on the numeric thresholds presented in the table. Clicking on a blue underlined footnote link displays this information, as shown below. Applicable footnotes also appear at the bottom of the table.

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**Footnote 68** Draft / tentative / provisional; applies only to second value if two separate values are listed; applies to range if a range of values is listed.

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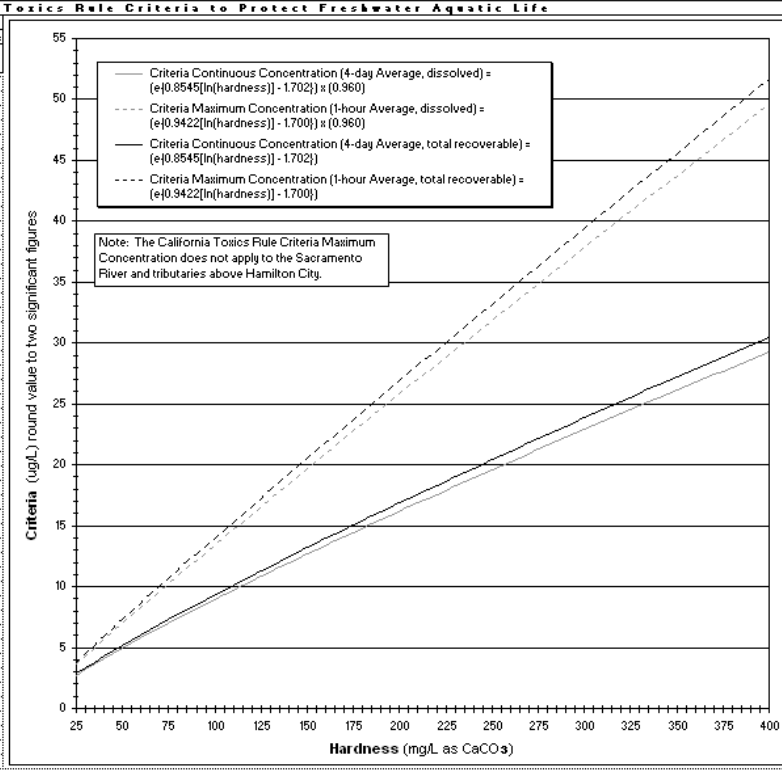
- Where numeric thresholds vary with hardness, pH and other parameters, you will find "***see page...***" links in the ***Notes*** column of the table. Clicking on one of these blue underlined links opens a new window that presents an Excel table and graph of the relationship, such as the copper-hardness relationship shown at the top of the next page. *[Note: You may need to close the **Sources & References** window to be able to open these tables and graphs.]*

**FRESHWATER AQUATIC LIFE - COPPER**

**California Toxics Rule Criteria to Protect Freshwater Aquatic Life**

| Hardness (mg/L as $CaCO_3$) | Copper (ug/L) Dissolved: Continuous Conc. 4-day Average | Copper (ug/L) Dissolved: Maximum Conc. 1-hour Average | Copper (ug/L) Total Recoverable: Continuous Conc. 4-day Average | Copper (ug/L) Total Recoverable: Maximum Conc. 1-hour Average |
|---|---|---|---|---|
| < 25 | use formula | use formula | use formula | use formula |
| 25 | 2.7 | 3.6 | 2.9 | 3.8 |
| 30 | 3.2 | 4.3 | 3.3 | 4.5 |
| 35 | 3.7 | 5.0 | 3.8 | 5.2 |
| 40 | 4.1 | 5.7 | 4.3 | 5.9 |
| 45 | 4.5 | 6.3 | 4.7 | 6.6 |
| 50 | 5.0 | 7.0 | 5.2 | 7.3 |
| 55 | 5.4 | 7.7 | 5.6 | 8.0 |
| 60 | 5.8 | 8.3 | 6.0 | 8.7 |
| 65 | 6.2 | 9.0 | 6.5 | 9.3 |
| 70 | 6.6 | 9.6 | 6.9 | 10 |
| 75 | 7.0 | 10 | 7.3 | 11 |
| 80 | 7.4 | 11 | 7.7 | 11 |
| 85 | 7.8 | 12 | 8.1 | 12 |
| 90 | 8.2 | 12 | 8.5 | 13 |
| 95 | 8.6 | 13 | 8.9 | 13 |
| 100 | 9.0 | 13 | 9.3 | 14 |
| 110 | 9.7 | 15 | 10 | 15 |
| 120 | 10 | 16 | 11 | 17 |
| 130 | 11 | 17 | 12 | 18 |
| 140 | 12 | 18 | 12 | 19 |
| 150 | 13 | 20 | 13 | 21 |
| 160 | 13 | 21 | 14 | 22 |
| 170 | 14 | 22 | 15 | 23 |
| 180 | 15 | 23 | 15 | 24 |
| 190 | 15 | 25 | 16 | 26 |
| 200 | 16 | 26 | 17 | 27 |
| 210 | 17 | 27 | 18 | 28 |
| 220 | 18 | 28 | 18 | 29 |
| 230 | 18 | 29 | 19 | 31 |
| 240 | 19 | 31 | 20 | 32 |
| 250 | 20 | 32 | 20 | 33 |
| 260 | 20 | 33 | 21 | 34 |
| 270 | 21 | 34 | 22 | 36 |
| 280 | 22 | 35 | 22 | 37 |
| 290 | 22 | 37 | 23 | 38 |
| 300 | 23 | 38 | 24 | 39 |
| 310 | 24 | 39 | 25 | 41 |
| 320 | 24 | 40 | 25 | 42 |
| 330 | 25 | 41 | 26 | 43 |
| 340 | 25 | 43 | 27 | 44 |
| 350 | 26 | 44 | 27 | 46 |
| 360 | 27 | 45 | 28 | 47 |
| 370 | 27 | 46 | 29 | 48 |
| 380 | 28 | 47 | 29 | 49 |
| 390 | 29 | 48 | 30 | 50 |
| 400 | 29 | 50 | 30 | 52 |
| > 400 | 29 | 50 | 30 | 52 |




The formulas that control the relationship between the parameter and the numeric threshold are built into these Excel tables, allowing the user to easily calculate the numeric threshold associated with any value of the parameter that is entered by the user.

At the top and bottom of the table:

- ***New Search*** takes you to a new search screen.
- ***Return to Previous Search Results*** takes you back to the list of chemicals and parameters that satisfied your last search.
- ***Print*** allows you to print the table.

Other information included in the table:

- ***Synonyms*** for the chemical or parameter;
- ***Chemical Abstracts Service Registry Number***, if available;
- ***Units*** for each numeric threshold *[Note: The default units are micrograms per liter or "ug/L", equivalent to parts per billion or "ppb"]*;
- Explanatory ***Notes*** with corresponding symbols at the bottom of the table;
- ***Adoption Date*** for most numeric thresholds; and
- ***Limiting WQ Limit*** to indicate recommended assessment thresholds to protect specific beneficial uses in specific water body types (see corresponding symbols at the bottom of the table). An explanation of how these assessment thresholds are selected may be found in the section *Selecting Water Quality Goals*, beginning on the page after next.

The Water Quality Goals online database is periodically updated to reflect newly published and revised numeric thresholds.

# SELECTING WATER QUALITY GOALS

California highly values its water resources, which are significantly limited in quantity and quality. Recurring periods of drought have demonstrated the magnitude and severity of our water quantity limitations. Improper waste management practices and contaminated sites pose significant threats to the quality of California's usable groundwater and surface water resources. The state is experiencing rapid population growth, putting an additional strain on our ability to serve the water needs of our citizens and to protect and restore our valuable fisheries. Therefore, it is imperative that California manage the quality of its water resources in a manner that serves the growing needs of agriculture, cities, and industries without impairing in-stream beneficial uses.

The purpose of this technical report of the State Water Board is to introduce California's water quality standards and to outline a process for selecting assessment thresholds, consistent with these standards. The resulting assessment thresholds may be used to assess impacts from waste management activities or releases of pollutants on the quality of waters of the state and the beneficial uses that they are able to support.

These assessment thresholds are considered to be conservative, because they are determined with a minimum amount of site and case-specific information. These assessment thresholds have been developed to address both narrative and numeric water quality objectives presented in the Water Quality Control Plans of the State Water Board and the nine Regional Water Quality Control Boards (Regional Water Boards), as well as water quality criteria promulgated by the U.S. Environmental Protection Agency (USEPA) for California waters pursuant to Section 303(c) of the federal Clean Water Act (CWA). Under most circumstances, and with the limitations described, the presence of a chemical in surface water or groundwater below the corresponding assessment threshold can be assumed not to impair or threaten the beneficial uses of the water resource. Additional case-by-case evaluation, and in most cases State and/or Regional Water Board action, will generally be necessary to establish an assessment threshold as an appropriate regulatory limitation.

To determine whether a particular waste management activity or discharge may have caused or may threaten to cause adverse effects on water quality, it is necessary to review and apply California's water quality standards. These standards are found in the Water Quality Control Plans, which are adopted by the State Water Board and each of the nine Regional Water Boards (collectively, Water Boards) through a formal administrative rulemaking process, and therefore have the force and effect of law. The discharge or release of waste constituents that causes receiving water concentrations to equal or exceed these standards may unreasonably impair the beneficial uses of the state's water resources and result in pollution.

In many cases, water quality standards include narrative, rather than numeric, water quality objectives. In such cases, numeric thresholds from the literature may be used to evaluate compliance with these standards.

## Terminology

This report uses several terms that may not be familiar to you or may have different meanings in their common usage. Differences in legal definitions necessitate using these terms in specific ways in this report.

***Water Quality Standards*** — pursuant to the CWA, water quality standards are provisions of state or federal law that define the water quality goals of a water body, or portion thereof, by establishing (a) designated uses of water to be protected, and (b) water quality criteria to protect those uses. Water quality standards are enforceable in the bodies of water for which they have been promulgated.

***Water Quality Criteria* —** numeric limitations or levels, e.g. concentrations, or narrative statements that are established to protect uses of a water body under the authority of the CWA. This term has two separate meanings:

1) Water quality criteria promulgated by the USEPA under Section 303(c) of the CWA are enforceable components of water quality standards. Examples include criteria in the National Toxics Rule and the California Toxics Rule.

2) Recommended water quality criteria published under Section 304(a) of the CWA are advisory and may be used by states and tribes to develop their own water quality standards or to implement narrative criteria in water quality standards.

***Beneficial Uses* —** the California term for "designated uses" of water that are components of water quality standards. California law defines "beneficial uses" as uses of surface water and groundwater that may be protected against water quality degradation. Beneficial uses of water may be found in the Water Quality Control Plans adopted by the Water Boards.

***Water Quality Objectives*** — the California term for "water quality criteria." Pursuant to the California Water Code, these are numeric limitations or levels, e.g. concentrations, or narrative statements that are established to protect the beneficial uses of a water body. Water quality objectives may be found in the Water Quality Control Plans adopted by the Water Boards.

***Numeric Threshold*** — as used in this report, this term refers to a numeric value from the literature that was developed to protect one or more beneficial uses of water. Numeric thresholds may be used to implement narrative water quality objectives or criteria.

***Assessment Threshold* —** for a constituent or parameter of concern in a specific body of water, one or more numeric and narrative water quality objectives and promulgated criteria will apply. The most relevant and defensible numeric threshold is selected to implement each applicable narrative objective. As used in this report, the *assessment threshold* refers to the most stringent of this set of

- Numeric water quality objectives,
- Numeric thresholds that implement each narrative objective, and
- Promulgated water quality criteria.

The assessment threshold is one chosen to satisfy all applicable water quality objectives and criteria. So, the *assessment threshold* may be one of several relevant *numeric thresholds*, a numeric objective, or a promulgated criterion.

Additional information about these terms is presented below.

## CALIFORNIA'S WATER QUALITY CONTROL SYSTEM

California has developed a unique system to protect and control the quality of its most valuable resource. The present system of water quality control was established in 1969, when the state legislature passed the Porter-Cologne Water Quality Control Act (Porter-Cologne Act), which is found in Division 7 of the California Water Code. The Porter-Cologne Act recognizes that factors affecting the quality and use of water vary from region to region within the state by establishing a regionally-administered program for water quality control within a framework of statewide coordination and policy. It provides for ten water quality control agencies, the State Water Board and nine Regional Water Boards. The Porter-Cologne Act instructs the Water Boards to preserve and enhance the quality of California's water resources for the benefit of present and future generations.

The Water Boards carry out their water quality protection authority through the adoption of Water Quality Control Plans. Water Quality Control Plans establish water quality standards—beneficial uses and water quality objectives—for particular bodies of water and their tributaries. The Water Quality Control Plans also contain the state's antidegradation policy (State Water Board Resolution 68-16, "Statement of Policy with Respect to Maintaining High Quality of Waters in California") and implementation plans to achieve and maintain compliance with the water quality objectives.

Water Quality Control Plans adopted by the State Water Resources Control Board include:

- The Ocean Plan;
- The Thermal Plan (temperature control in coastal and interstate waters and enclosed bays and estuaries); and
- The Delta Plan (temperature, salinity and flow in the Sacramento-San Joaquin Delta and Suisun Marsh).

Each of the nine Regional Water Boards has adopted one or more Water Quality Control Plans for waters of the state, both surface waters and groundwater, within their region. Regional Water Board boundaries separate the nine major hydrologic basins, called Water Quality Control Regions (see the map on the inside back cover of this report). Water Quality Control Plans adopted by the Regional Water Boards are often called "Basin Plans," since they apply to one or more hydrologic basins within the state.

The State Water Board also adopts regulations and policies for water quality control, which have the force and effect of law, to protect water quality. For example, in the year 2000, the State Water Board adopted the *Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California*. This policy, also known as the State Implementation Policy or "SIP," provides implementation measures for numeric criteria contained in the California Toxics Rule, promulgated by USEPA also in 2000, and for numeric objectives for toxic pollutants in the Basin Plans. The beneficial use designations in the Basin Plans, the California Toxics Rule, and the SIP combine to establish statewide water quality standards for toxic constituents in surface waters that are not covered by the Ocean Plan.

The State and Regional Water Boards implement the statewide and regional Water Quality Control Plans, water quality regulations, and policies for water quality control through the issuance of waste discharge requirements, permits, conditional waivers, prohibitions, and enforcement orders. Under delegated authority from USEPA, the Water Boards also administer most of the federal clean water laws as they apply to California, including the CWA.

The focus of State and Regional Water Boards' water quality control programs is the prevention and correction of conditions of pollution and nuisance. The Porter-Cologne Act (section 13050) defines "pollution" as "an alteration of the quality of the waters of the state by waste to a degree which unreasonably affects (1) such waters for beneficial uses, or (2) facilities which serve these beneficial uses." "Nuisance" is defined as "anything which meets all of the following requirements:

1) is injurious to health, or is indecent or offensive to the senses, or an obstruction to the free use of property so as to interfere with the comfortable enjoyment of life or property, and
2) affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted upon individuals may be unequal, and
3) occurs during or as the result of the treatment or disposal of wastes."

## Water Quality Standards

As stated above, "water quality standards are provisions of state or federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act." [40 Code of Federal Regulations (CFR) Section 130.2(c) and 131.3(I)] Antidegradation policies are also an integral component of federal water quality standards.

Unlike the federal system, California also has water quality standards for groundwater since the term "waters of the state" under the Porter-Cologne Act includes both surface waters and groundwater. In contrast, CWA water quality standards apply to "waters of the United States," a more restrictive term that generally refers to navigable surface waters and their tributaries. California's water quality standards can be found in the Water Quality Control Plans as well as in USEPA's adopted water quality criteria in the National Toxics Rule and the California Toxics Rule. The Water Quality Control Plans specify which beneficial uses apply to each body of surface water and groundwater within each region of the state, and also which water quality objectives must be met to protect those uses. Pursuant to the Porter-Cologne Act, California's water quality standards must be accompanied by implementation programs to achieve and maintain compliance with the water quality objectives. The SIP, discussed above, is an example. To protect both existing and future beneficial uses, California's water quality standards are enforceable throughout the applicable water body, rather than at points of use or discharge.

## Beneficial Uses

The Water Boards' Water Quality Control Plans list the specific beneficial uses designated for California's surface water and groundwater bodies. The following are examples of beneficial uses of water found in the Water Quality Control Plans:

- Municipal and Domestic Supply
- Agricultural Supply
- Industrial Supply (both Service and Process)
- Groundwater Recharge
- Freshwater Replenishment
- Navigation
- Hydropower Generation
- Recreation (both Water Contact and Non-Water Contact)
- Commercial & Sport Fishing
- Shellfish Harvesting
- Subsistence Fishing
- Aquaculture
- Freshwater Habitat (both Warm and Cold)
- Estuarine Habitat
- Inland Saline Water Habitat
- Marine Habitat
- Wetland Habitat
- Wildlife Habitat
- Preservation of Areas of Special Biological Significance
- Preservation of Rare, Threatened, or Endangered Species
- Migration of Aquatic Organisms
- Spawning, Reproduction, and/or Early Development (of Aquatic Organisms)

- Water Quality Enhancement
- Flood Peak Attenuation/Flood Water Storage
- Native American Culture

Under the Porter-Cologne Act, the discharge of waste is not a beneficial use of water, nor is it a right. The discharge of waste is a privilege, subject to specific permit conditions. The Water Boards' mission is to protect the quality of the state's waters from discharges of waste that threaten or cause impairment of designated beneficial uses or cause nuisance.

## SOURCES OF DRINKING WATER POLICY

As mentioned above, California's system of water quality control includes "policies for water quality control" adopted by the State Water Board and incorporated into each Basin Plan. The SIP is an example. Another policy for water quality control fundamentally affects the designation of beneficial uses.

In 1988, the State Water Board adopted Resolution No. 88-63, *Adoption of Policy Entitled "Sources of Drinking Water."* This policy specifies that, except under specifically defined circumstances, all surface waters and groundwater of the state should be protected as existing or potential sources of municipal and domestic supply (a.k.a. sources of drinking water) and should be so designated. The policy lists specific exceptions:

- Waters with existing high total dissolved solids concentrations (greater than 3000 mg/l);
- Waters having low sustainable yield (less than 200 gallons per day for a single well);
- Water with contamination, unrelated to a specific pollution incident, that cannot reasonably be treated for domestic use;
- Waters within specified wastewater conveyance and holding facilities; and
- Regulated geothermal groundwaters.

If a water body has been designated in a Basin Plan for municipal and domestic supply, the use may be de-designated only if one of the exceptions applies and the appropriate Regional Water Board formally amends its Basin Plan.

## WATER QUALITY OBJECTIVES

The second component of California's water quality standards is water quality objectives. The Porter-Cologne Act [CWC, Section 13050(h)] defines "water quality objectives" as "the limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area." Since pollution is defined as an alteration of water quality to a degree which unreasonably affects beneficial uses [CWC, Section 13050(l)], pollution is considered to occur whenever water quality objectives are exceeded.

Water quality objectives established to protect beneficial uses and prevent nuisance are found in the Water Quality Control Plans. As with beneficial uses, water quality objectives are established either for specific bodies of water, such as the Sacramento River between Shasta Dam and the Colusa Basin Drain, or for protection of particular beneficial uses of surface waters or groundwaters throughout a specific basin or region.

In addition, the federally promulgated water quality criteria for toxic pollutants in the National Toxics Rule and the California Toxics Rule apply to nearly all of the state's surface waters that are not covered by the Ocean Plan, i.e., to inland surface waters, enclosed bays and estuaries. Federally-promulgated water quality criteria [under Section 303(c) of the Clean Water Act] legally differ from California's water quality objectives. Water quality objectives must provide *reasonable protection* of beneficial uses or the prevention of nuisance and must consider several factors, including environmental characteristics, economic considerations, and the need to develop housing and recycled water [CWC, Section 13241]. An adopted water quality objective has been determined to be reasonable to achieve. In contrast, CWA 303(c) water quality criteria must protect the most sensitive designated use, regardless of reasonableness or these additional factors. Because water quality objectives for most surface waters require approval by USEPA as CWA 303(c) criteria, the difference between these two terms can be problematic.

Water quality objectives may be stated in either numeric or narrative form. Numeric objectives establish enforceable receiving water concentrations for the indicated constituent(s) or parameter(s). These concentrations are intended to provide reasonable protection of the beneficial uses of the specified body of water. In many cases, water quality objectives are stated in narrative form. Narrative objectives are also enforceable and describe a requirement or prohibit a condition harmful to one or more beneficial uses or that would be considered a nuisance. Both numeric and narrative water quality objectives are found in the Water Quality Control Plans. Examples of narrative objectives, from the Central Valley Region's *Water Quality Control Plan for the Sacramento River and San Joaquin River Basins*, include:

- Chemical Constituents —

  "Waters shall not contain chemical constituents in concentrations that adversely affect beneficial uses.

  "At a minimum, water designated for use as domestic or municipal supply (MUN) shall not contain concentrations of chemical constituents in excess of the maximum contaminant levels (MCLs) specified in … Title 22 of the California Code of Regulations [California's drinking water standards] …

  "To protect all beneficial uses, the Regional Water Board may apply limits more stringent than MCLs."

- Tastes and Odors —

  "Water shall not contain taste- or odor-producing substances in concentrations that impart undesirable tastes or odors to domestic or municipal water supplies or to fish flesh or other edible products of aquatic origin, or that cause nuisance, or otherwise adversely affect beneficial uses."

- Toxicity —

  "… waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life associated with designated beneficial use(s). This objective applies regardless of whether the toxicity is caused by a single substance or the interactive effects of multiple substances."

Similar narrative objectives appear in the Basin Plans of nearly all regions.

Implementation of a narrative toxicity objective depends on the beneficial uses that apply to the water body in question. For waters designated as municipal and domestic supply, concentrations that cause toxicity to humans are of concern. For waters designated as agricultural supply, concentrations that cause toxicity to crops or livestock are at issue. For waters designated for beneficial uses that support aquatic life, toxicity to fish or other aquatic organisms is the concern. For waters designated for beneficial uses that support consumption of aquatic organisms, the main concern is bioconcentration from water and bioaccumulation in the food chain, resulting in concentrations that are toxic to human or wildlife consumers of fish and shellfish.

In addition to direct evidence, such as a fish kill, numeric thresholds designed to prevent these toxic effects are often used to implement the narrative toxicity objective. Examples include the National Recommended Water Quality Criteria from USEPA, which include criteria to protect aquatic life from toxicity, as well as criteria to protect human health from constituents in water that is directly consumed or from constituents that may bioconcentrate and bioaccumulate in fish and shellfish to harmful levels.

The Basin Plans contain water quality objectives for a wide variety of constituents and parameters, including:

- Bacteria
- Biostimulatory Substances
- Color
- Dissolved Oxygen
- Floating Material
- Oil and Grease
- Pesticides
- pH
- Radioactivity
- Salinity
- Sediment
- Settleable Material
- Suspended Material
- Temperature
- Turbidity

Some are expressed as numeric objectives, while others are in narrative form. Narrative water quality objectives may be implemented through the selection of an appropriate numeric threshold, as further described below.

## ANTIDEGRADATION POLICY

Water is a multiple-use resource. A finite supply means that the same water may be used many times from when it falls as rain or snow in the mountains to when it eventually flows into the ocean. Each use of water causes some change in or degradation of water quality. Water quality can also be degraded by discharges of waste and other human activities. If the Water Boards were to allow a single use of water or discharge of waste to degrade water quality to a level just below the water quality objectives, then no capacity would exist for degradation that will be caused by the next downstream or downgradient uses. The ability to beneficially use the water would have been impaired, even though water quality objectives would not yet have been exceeded. An antidegradation policy considers the combined effect of multiple water uses and waste discharges on water quality.

In addition, our understanding of the health and environmental effects of chemicals and combinations of chemicals in water is constantly evolving. What we consider to be safe at 10 ug/L (ppb) today may be found to be harmful at 1 ug/L tomorrow. For these reasons, it is often desirable to prevent or to minimize the degree of water quality degradation to preserve water quality that is better than applicable water quality objectives.

Realizing the need to prevent the degradation of water from multiple uses, in 1968, the State Water Resources Control Board adopted Resolution No. 68-16, *Statement of Policy With Respect to Maintaining High Quality of Waters in California* (California's Antidegradation Policy) for the protection of water quality. Under the Antidegradation Policy, whenever the existing quality of water is better than that needed to protect existing and probable future beneficial uses, such existing high quality shall be maintained until or unless it has been demonstrated to the state that any change in water quality:

- Will be consistent with the maximum benefit to the people of the state;
- Will not unreasonably affect present or probable future beneficial uses of such water; and
- Will not result in water quality less than prescribed in state policies.

Unless these three conditions are met, background water quality—the concentrations of substances in natural waters that are unaffected by waste management practices or pollution—is to be maintained.

If a Water Board determines that some water quality degradation is in the best interest of the people of California, some incremental change in constituent concentrations from background levels may be permitted under the Antidegradation Policy. However, in no case may such degradation cause unreasonable impairment of beneficial uses that have been designated for waters of the state.

The effect of the Antidegradation Policy is to define a range of water quality—between natural background levels and the water quality objectives—that must be maintained. Within this range, the Water Boards balance the need to protect existing high quality water with the benefit of allowing some degradation to occur from discharges of waste, for example the creation of jobs or increased housing.

The Antidegradation Policy also specifies that discharges of waste to existing high quality waters are required to use "best practicable treatment or control," thereby imposing a technology-based requirement on such discharges.

In more recent actions, the State Water Board further delineated implementation of the Antidegradation Policy. These include the adoption of monitoring and corrective action regulations and a site cleanup policy.

## CHAPTER 15, ARTICLE 5 REGULATIONS

In July 1991, the State Water Board adopted revised regulations for water quality monitoring and corrective action for waste management units—facilities where wastes are discharged to land for treatment, storage or disposal. These regulations, contained in Title 23 of the California Code of Regulations, Division 3, Chapter 15, Article 5, contain the only interpretation of the state's Antidegradation Policy that has been promulgated in regulations. Article 5 requires the Regional Water Boards to establish water quality protection standards for all waste management units. Water quality protection standards include concentration limits for constituents of concern, which must be met in groundwater and surface water that could be affected by a release from the waste management unit.

Section 2550.4 of these regulations requires that, in most cases, concentration limits be established at background levels. However, in a corrective action program for a leaking waste management unit, where the discharger of waste has demonstrated that it is technologically or economically infeasible to achieve background levels, the Regional Water Board may adopt concentration limits greater than background. The regulations require that these less stringent limits be set:

- At the lowest concentrations for the individual constituents that are technologically and economically achievable;
- To avoid exceeding the maximum concentrations allowable under applicable statutes and regulations for individual constituents [including water quality objectives and CWA 303(c) water quality criteria];
- To avoid excessive exposure to a sensitive biological receptor [as shown, for example, through health and ecological risk assessments]; and
- To consider the theoretical risks from chemicals associated with the release as additive across all media of exposure and additive for those constituents that cause similar toxicologic effects or have carcinogenic effects.

More recently, the Chapter 15 regulations were amended to limit their applicability to waste management units that manage hazardous waste. New regulations for other waste management units were added in Title 27 of the California Code of Regulations, Division 2, Subdivision 1. Language comparable to Section 2550.4 appears in Section 20400 of these Title 27 regulations.

## SITE INVESTIGATION AND CLEANUP POLICY

In June 1992, the State Water Board adopted Resolution No. 92-49, *Policies and Procedures for Investigation and Cleanup and Abatement of Discharges Under Water Code Section 13304*. This policy for water quality control, which was modified in April 1994 and October 1996, states that the Antidegradation Policy of Resolution No. 68-16 applies to the cleanup of sites contaminated with hazardous or non-hazardous pollutants, and that the criteria in Section 2550.4 of the Chapter 15 regulations are to be used to set cleanup levels for such sites. *[For cleanup of leaking underground fuel tank sites, Section 2550.4 criteria are to be "considered" in setting cleanup levels under Chapter 16 of Title 23, Division 3 of the California Code of Regulations.]* In determining cleanup levels for polluted water and for contaminated soils that threaten water quality, background constituent concentrations in water are the initial goal. If attainment of background concentrations is not achievable, cleanup levels must be set as close to background as technologically and economically feasible. They must, at a minimum, restore and protect all applicable beneficial uses of waters of the state, as measured by the water quality objectives, and must not present significant health or environmental risks.

## NUMERIC THRESHOLDS

To determine whether a particular waste management activity or constituent release has caused or threatens to cause pollution—an alteration of water quality to a degree that unreasonably affects present or probable future beneficial uses—one must refer to California's water quality standards. As described above, the standards consist of one or more beneficial uses of water and water quality objectives or promulgated criteria to protect those uses. Water Boards adopt policies that specify how water quality standards are to be applied. Such policies are normally found in the implementation chapters of the Water Quality Control Plans.

Under most circumstances, compliance with all applicable water quality objectives is required. A narrative objective may be interpreted with respect to a specific pollutant or parameter by selecting an appropriate numeric threshold that meets the conditions of the narrative objective. If used carefully, and if appropriate justification is developed based on site-specific conditions, the numeric thresholds may be used to implement narrative water quality objectives. In general, case-by-case evaluation is necessary to implement narrative objectives for specific pollutants using literature-derived numeric thresholds for the pollutants. *[Note: Normally, State or Regional Water Board action is necessary to establish numeric regulatory limitations that apply narrative water quality objectives.]*

Once all applicable numeric water quality objectives, promulgated water quality criteria, and numeric thresholds to implement each narrative objective have been identified, a single assessment threshold is selected that satisfies them all. The assessment threshold can then be compared with measured or projected constituent concentrations in the water body of interest to determine compliance with water quality standards. This process will be used to select assessment thresholds in the sections below so as to implement all applicable water quality objectives and CWA 303(c) criteria.

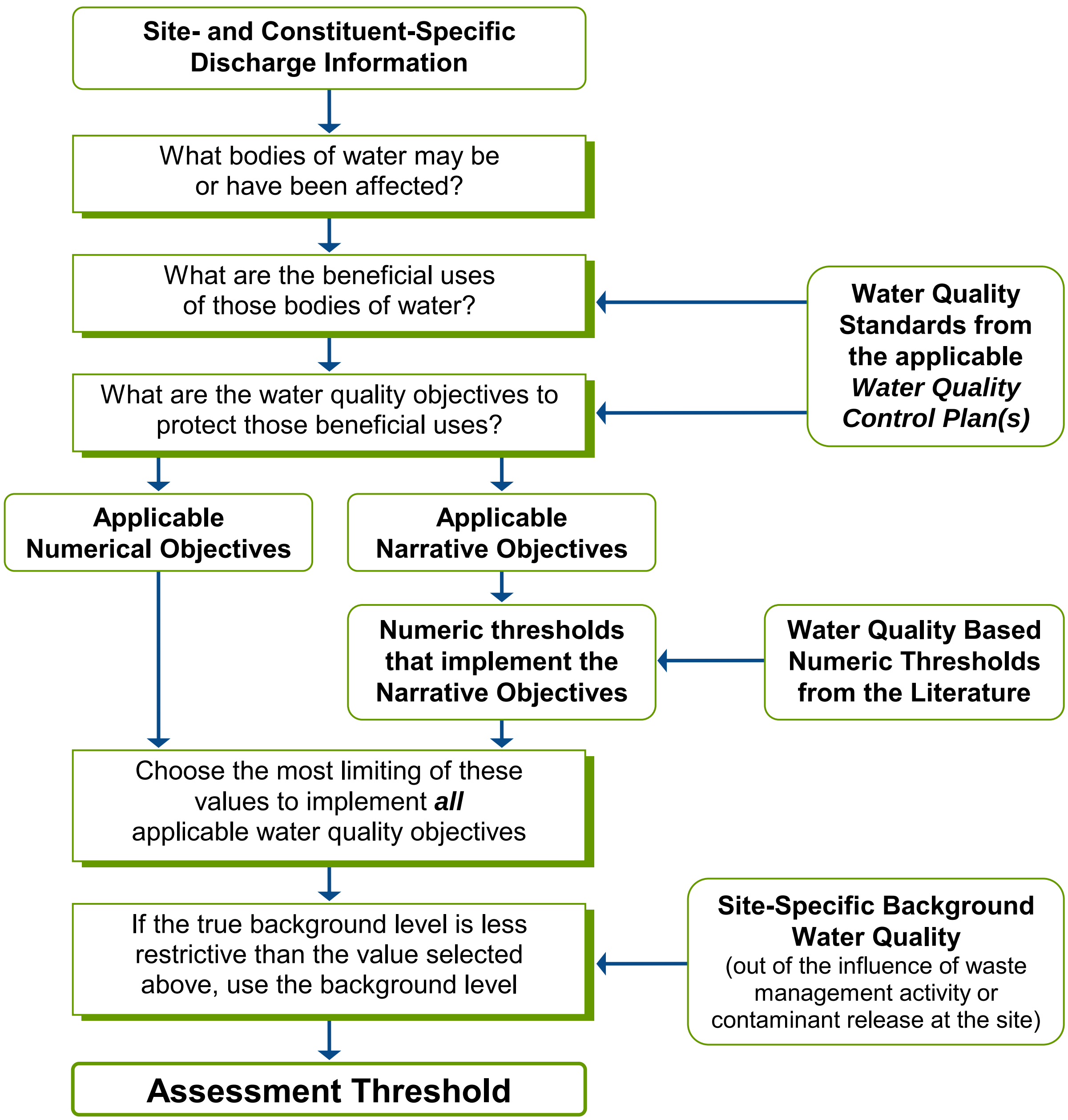
The first step is to identify the bodies of groundwater and/or surface water that have been or may be affected by the particular waste management activity or constituent release. These water bodies are often referred to as "receiving waters." Under California's Antidegradation Policy, it is important to determine natural background constituent levels in the body of water. Discharges of waste can cause unfavorable changes from background levels and *degrade* water quality. Before the Water Boards can authorize any degradation of water quality, specific conditions in the Antidegradation Policy must be satisfied. For additional information on antidegradation see *Controllable Factors and Antidegradation Policies,* below.

The next step is to determine which beneficial uses and water quality objectives from the relevant Water Quality Control Plan(s) apply and which federally promulgated water quality criteria, if applicable, also apply. An assessment threshold is selected for each waste constituent to ensure implementation of all applicable water quality standards. This step is necessary to ensure that all beneficial uses are protected and to prevent pollution and nuisance. A process of selecting assessment thresholds is shown in Figure 1.

If narrative water quality objectives apply to the constituent or parameter of interest in the receiving water, compliance with those objectives may be determined through measurement (e.g., toxicity testing) or other direct evidence of beneficial use impacts. Alternatively, relevant numeric thresholds may be selected from government agency publications and other sources and used to implement the narrative objectives. Numeric thresholds include drinking water standards, recommended water quality criteria, cancer risk estimates, health advisories, recommended water quality criteria, and other numeric thresholds that represent concentrations of chemicals that could limit or impair specific uses of water. An example is the taste and odor threshold for ethylbenzene of 29 ug/L, published by USEPA. This numeric threshold could be used to implement the narrative water quality objective for Tastes and Odors, discussed above.

To select an assessment threshold for each constituent or parameter, first determine all applicable numeric objectives and CWA 303(c) criteria, along with numeric thresholds selected to implement each applicable narrative objective. To ensure that all applicable objectives and criteria are satisfied, the most stringent of this set of values is selected as the assessment threshold. Compliance with water

**FIGURE 1. SELECTING ASSESSMENT THRESHOLDS**



quality objectives occurs if the constituent's concentration in the receiving water falls below the assessment threshold. Exceedance of the assessment threshold may violate the water quality objectives, and beneficial uses may no longer be protected.

An exception to this procedure is where the water's natural background concentration is higher than the assessment threshold, i.e. higher than one or more applicable objective or promulgated criterion. According to implementation language in the Basin Plans, Regional Water Boards' authority to protect water quality from waste discharges is limited to the regulation of "controllable water quality factors," those actions, conditions, or circumstances resulting from human activities that may influence the quality of waters of the state and that may be reasonably controlled. Where the natural background level is higher than an applicable water quality objective, the assessment threshold may need to be adjusted upward to the natural background level. In these cases, other controllable factors are normally not allowed to cause any further degradation of water quality. For additional information, see *Controllable Factors and Antidegradation Policies*, below.

Where the natural background level is higher than an applicable water quality objective or an applicable federal CWA 303(c) criterion, the State or Regional Water Board must take appropriate action to amend the Basin Plan to change the standard.

## TYPES OF NUMERIC THRESHOLDS

Many useful numeric thresholds have been developed to protect specific beneficial uses of water. Some of these numeric thresholds directly apply to constituents and parameters in California waters.

The following is a summary of available types of numeric thresholds, most of which are presented in the Water Quality Goals online database. References in the database present the sources of these numeric thresholds, including Internet addresses where available.

### Drinking Water Standards, Maximum Contaminant Levels (MCLs)

MCLs are components of the drinking water standards adopted by the Division of Drinking Water (DDW) of the California State Water Board pursuant to the California Safe Drinking Water Act. California MCLs may be found in Title 22 of the California Code of Regulations (CCR), Division 4, Chapter 15, *Domestic Water Quality and Monitoring*. USEPA also adopts MCLs under the federal Safe Drinking Water Act. California drinking water standards are required to be at least as stringent as those adopted by the USEPA. If USEPA adopts a federal MCL that is lower than the corresponding state MCL, the state is required by statute to revise its MCL to be at least as stringent as the federal MCL. Some California MCLs are more stringent than USEPA MCLs.

Primary MCLs are derived from health-based criteria (by USEPA from MCL Goals; by DDW from Public Health Goals or from one-in-a-million [$10^{-6}$] incremental cancer risk estimates for carcinogens and threshold toxicity levels for non-carcinogens). MCLs also include technologic and economic considerations based on the feasibility of achieving and measuring these concentrations in drinking water supply systems and at the tap, either throughout California (for MCLs adopted by the State Water Board) or the nation (for those adopted by USEPA). It should be noted that the balancing of health effects with technologic and economic considerations in the derivation of MCLs may result in MCLs that are not fully protective of health. As such, MCLs may not be sufficient to protect beneficial uses of ambient surface water or groundwater resources, as will be discussed below.

Secondary MCLs are derived from considerations of human welfare (e.g., taste, odor, laundry staining) in the same manner as Primary MCLs.

Drinking water MCLs are directly applicable to regulated water supply systems and at the tap. They are enforceable by DDW and local health departments. California MCLs, both Primary and Secondary, are directly applicable to groundwater and surface water resources when they are specifically referenced as water quality objectives in a Water Quality Control Plan. In such cases, MCLs become numeric water quality objectives for ambient waters and enforceable by the State and Regional Water Boards.

Primary MCLs that are also fully health protective may also be used to implement narrative toxicity objectives in water designated as a source of drinking water (municipal and domestic supply) to prevent toxicity to humans. Toxicity objectives in many Basin Plans require that water “shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life.” Similarly, Secondary MCLs that prevent adverse tastes and odors in drinking water may be used to implement narrative water quality objectives that prohibit adverse tastes and odors in water supplies.

## Maximum Contaminant Level Goals (MCL Goals or MCLGs)

MCL Goals are established by USEPA as part of the National Primary Drinking Water Regulations. MCL Goals represent the first step in establishing federal Primary MCLs and are required by statute to be set at levels that represent no adverse health risks. USEPA sets them at “zero” for known and probable human carcinogens, because a single molecule of such a chemical could present some degree of cancer risk. For non-carcinogens and for possible human carcinogens, concentrations that have been determined to pose no health risk, other than cancer, are used. Because they are purely health-based, MCL Goals may be useful to implement narrative water quality objectives that prohibit toxicity to humans. However, MCL Goals that have been set at “zero” may not be good candidates to implement narrative toxicity objectives because they are likely to be perceived as unreasonable to achieve. A more relevant level of risk for carcinogens is discussed below (see *Which Cancer Risk Level?, below*).

## California Public Health Goals (PHGs)

The California Safe Drinking Water Act of 1996 requires that the California Environmental protection Agency (Cal/EPA), Office of Environmental Health Hazard Assessment (OEHHA) adopt Public Health Goals for contaminants in drinking water, based exclusively on public health considerations. PHGs represent levels of contaminants in drinking water that would pose no significant health risk to individuals consuming the water on a daily basis over a lifetime. For carcinogens, PHGs are based on $10^{-6}$ (1-in-a-million) incremental cancer risk estimates. OEHHA and DDW consider the $10^{-6}$ risk level to represent a *de minimis* level of cancer risk for involuntary exposure to contaminants in drinking water. For other contaminants, PHGs are based on threshold toxicity limits, with a margin of safety.

PHGs adopted by OEHHA are used by DDW to develop and revise primary drinking water MCLs. While PHGs are required by statute to be based solely on scientific and public health considerations without regard to economic or technologic limitations, drinking water MCLs are required to consider economic factors and technical feasibility. The California Safe Drinking Water Act requires California MCLs to be reviewed every five years and set as close to the corresponding PHG as feasible, placing emphasis on the protection of public health.

Because they are purely health-based, PHGs may also be appropriate to implement narrative toxicity objectives to address potential toxicity to humans from constituents in water bodies that have been designated as sources of municipal and domestic supply. In addition, where water quality objectives require compliance with drinking water MCLs, the PHGs may provide an indication of whether and the degree to which MCLs are likely to be revised in the future.

## California Drinking Water Notification and Response Levels

DDW publishes California Drinking Water Notification Levels (formerly called “Action Levels”) for chemicals that do not have drinking water MCLs. Notification Levels are based mainly on health effects—an incremental cancer risk estimate of $10^{-6}$ for carcinogens and a threshold toxicity limit for other constituents. As with MCLs, economic factors and the ability to quantify the amount of the constituent in a water sample using readily available analytical methods may cause notification levels to be set at somewhat higher concentrations than purely health-based thresholds. Notification Levels are advisory to water suppliers. If exceeded, DDW requires the supplier to notify local government and recommends notifying customers. When they are purely health-based, Notification Levels may also be appropriate to implement narrative water quality objectives that prohibit toxicity to humans that beneficially use the water resource.

DDW also publishes Response Levels, which are normally set five to ten times higher than their respective Notification Levels. If a chemical exceeds its Response Level, DDW recommends that the drinking water source be taken out of service.

### Cal/EPA Cancer Potency Factors

OEHHA has lead responsibility within Cal/EPA to assess human health risks associated with exposure to toxic substances in environmental media. OEHHA also performs health risk assessments for other California state agencies, such as developing Public Health Goals, which DDW uses to derive primary drinking water standards. As part of these efforts, OEHHA maintains the online Cal/EPA Toxicity Criteria Database of health risk information for chemicals. The health-based criteria presented in this database have been used as the basis for California state regulatory actions. The majority of these criteria has undergone peer review and, in many cases, rigorous regulatory review. The database includes cancer potency factors for inhalation and oral exposures to many chemicals. These Cal/EPA cancer potency factors may be used to calculate concentrations in drinking water associated with specific cancer risk levels, using standard exposure assumptions (see *Threshold Risk Characterization*, below).

### Integrated Risk Information System (IRIS)

The USEPA Office of Research and Development, National Center for Environmental Assessment maintains a chemical database called the Integrated Risk Information System. IRIS is intended to contain USEPA's most current information on human health effects that may result from exposure to toxic substances found in the environment. Two types of criteria are presented in IRIS:

1) Reference doses (RfDs) are calculated as safe exposure levels for health effects other than cancer. They are presented in dose units of milligrams of chemical per kilogram body weight per day of exposure (mg/kg-day). RfDs may be converted into concentrations in drinking water (ug/L or ppb) using standard exposure assumptions (see *Threshold Risk Characterization*, below).
2) IRIS also presents concentrations of chemicals in drinking water that would be associated with specific levels of cancer risk.

### Drinking Water Health Advisories and Water Quality Advisories

Health Advisories are published by USEPA for short-term (1-day exposure or less or 10-day exposure or less), long-term (7-year exposure or less), and lifetime human exposures through drinking water. Health advisories for non-carcinogens and for possible human carcinogens are calculated for chemicals for which sufficient toxicologic data exist. Incremental cancer risk estimates for known and probable human carcinogens are also presented.

The USEPA Office of Pesticide Programs publishes *Registration Eligibility Documents* or *REDs*, which contain similar toxicity information for pesticides.

USEPA Water Quality Advisories contain human health-related criteria that assume exposure through both drinking water and consumption of contaminated fish and shellfish harvested from the same water. Some Water Quality Advisories also contain criteria that are intended to be protective of aquatic life.

These three types of advisories are summarized approximately every two years in the USEPA publication *Drinking Water Standards and Health Advisories tables*.

## Suggested No-Adverse-Response Levels (SNARLs)

SNARLs are human health-based criteria that were published by the National Academy of Sciences (NAS) in the nine volumes of *Drinking Water and Health* (1977 to 1989). USEPA health advisories were also formerly published as “SNARLs.” SNARLs do not reflect the cancer risk that chemical exposure may pose. Incremental cancer risk estimates for carcinogens are also presented in these NAS and USEPA documents. NAS criteria from *Drinking Water and Health* may not contain the most recent toxicologic information. They should only be used to implement narrative water quality objectives if more recent health-based criteria are not available.

## Proposition 65 Safe Harbor Levels

Safe harbor levels are established pursuant to the California Safe Drinking Water and Toxic Enforcement Act of 1986 (adopted by the voters as the initiative “Proposition 65”) for known human carcinogens and reproductive toxins. Proposition 65 made it illegal to expose persons to significant amounts of these chemicals without prior notification or to discharge significant amounts of these chemicals into sources of drinking water. The “significant amounts” are adopted by OEHHA in regulations contained in Title 22 of the California Code of Regulations, Division 2, Chapter 3. The intent of Proposition 65 was not to establish levels in water that are considered to be “safe.”

For carcinogens, No Significant Risk Levels (NSRLs) are set at concentrations associated with a one-in-100,000 ($10^{-5}$) incremental risk of cancer. These are the only California health-based water quality-related thresholds derived from risk levels less stringent than $10^{-6}$. As such, they are not as protective of human health as many other published numeric thresholds (see *Which Cancer Risk Level?*, below). For reproductive toxicants, Maximum Allowable Dose Levels (MADLs) are set at $^{1}/_{1000}$ of the no-observable-effect level (NOEL). The NOEL is the highest dose that was associated with no observed adverse effect in laboratory toxicity experiments or epidemiologic studies.

Proposition 65 levels are doses, expressed in units of micrograms per day of exposure (ug/d). Doses may be converted into concentrations in water by dividing by 2 liters per day water consumption and assuming 100 percent exposure to the chemical through drinking water (see Title 22 of CCR, Sections 12721 and 12821). In cases where significant exposure may also occur from sources other than drinking water, the 100 percent exposure assumption may not be sufficiently health protective.

## California Toxics Rule (CTR) and National Toxics Rule (NTR) Criteria

The federal Clean Water Act requires all states to have enforceable numeric water quality criteria applicable to *priority toxic pollutants* in surface waters. Because the Regional Water Boards’ respective Basin Plans lacked water quality objectives for many of these pollutants, the State Water Board adopted the *Inland Surface Waters Plan* and the *Enclosed Bays and Estuaries Plan* in 1991. These plans contained statewide water quality objectives covering many of the priority toxic pollutants. However, when combined with water quality objectives in the Basin Plans, California still lacked enforceable standards for a number of priority pollutants.

In response to this deficiency in California and in many other states, USEPA promulgated federal regulations called the “National Toxics Rule” in December 1992. The NTR contains chemical-specific numeric criteria for priority (toxic) pollutants. The NTR applies to fourteen states, including California.

As the result of a legal challenge, the State Water Board rescinded the *Inland Surface Waters Plan* and *Enclosed Bays and Estuaries Plan* in 1994, causing California to be, once again, out of compliance with the priority toxic pollutants requirement of the Clean Water Act. In May 2000, USEPA promulgated CWA 303(c) water quality criteria for priority toxic pollutants in California’s inland surface waters and enclosed bays and estuaries in the “California Toxics Rule.” The CTR fills gap in California’s water quality standards necessary to protect human health and aquatic life beneficial uses The CTR criteria are similar to those published in the *National Recommended Water Quality Criteria*, discussed below.

The CTR supplements, and does not change or supersede, the criteria that USEPA promulgated for California waters in the NTR.

The human health NTR and CTR criteria that apply to drinking water sources (those water bodies designated in the Basin Plans as municipal and domestic supply or MUN) consider chemical exposure through consumption of both water and aquatic organisms (fish and shellfish) harvested from the water. For waters that are not drinking water sources (non-MUN waters; e.g., enclosed bays and estuaries), human health NTR and CTR criteria only consider the consumption of contaminated aquatic organisms.

Aquatic life protective criteria are specified at multiple averaging periods (e.g., 4-day, 1-hour) to control acute and chronic toxicity. Different criteria protect freshwater and saltwater aquatic life. In general, the freshwater criteria apply to waters with salinities less than one part per thousand, while the saltwater criteria apply to waters with salinities greater than ten parts per thousand. The more stringent of the freshwater and saltwater aquatic life criteria apply to waters with salinities between one and ten parts per thousand.

The CTR and NTR criteria, along with the beneficial use designations in the Basin Plans and the related implementation policies, are the directly applicable water quality standards for toxic priority pollutants in California waters. Implementation policies for these standards may be found in the *Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California* (SIP), adopted by the State Water Board in March 2000 and updated in February 2005. The SIP includes effluent limit calculations, time schedules for compliance, provisions for mixing zones, analytical methods and reporting levels.

## California Ocean Plan Objectives

One of the statewide Water Quality Control Plans is the *Water Quality Control Plan for Ocean Waters of California* (the *Ocean Plan*). It includes numeric water quality objectives to protect both human health and marine aquatic life from potentially harmful constituents and parameters in waters of California. When combined with beneficial use designations, these objectives constitute directly applicable water quality standards pursuant to Section 303(c) of the federal Clean Water Act. Because some harmful constituents in water concentrate in the tissues of aquatic organisms and bioaccumulate through the food web, objectives to protect human health assume exposure through ingestion of fish and shellfish harvested from the water containing the constituent of concern. Objectives to protect marine aquatic life are specified at multiple averaging periods to protect marine aquatic life against acute and chronic effects.

## National Recommended Water Quality Criteria

These criteria, formerly called the National Ambient Water Quality Criteria, are developed by USEPA under Section 304(a) of the federal Clean Water Act to provide guidance to the states and tribes in developing water quality standards under Section 303(c) of the CWA and to implement narrative toxicity criteria (narrative toxicity objectives in California) in water quality standards. National Recommended Water Quality Criteria are designed to protect human health and welfare and aquatic life from pollutants in freshwater, estuarine, and marine surface waters.

As with CTR and NTR criteria, discussed above, the recommended human health protective criteria assume two different exposure scenarios. For waters that are sources of drinking water, exposure is assumed both from drinking the water and consuming aquatic organisms (fish and shellfish) harvested from the water. For waters that are not sources of drinking water, exposure is assumed to be from the consumption of aquatic organisms only. Aquatic organisms are known to bioconcentrate certain toxic pollutants from water and to bioaccumulate them in the tissues of organisms at higher trophic levels, thereby magnifying pollutant exposures to consumers of fish and shellfish, including humans. Because the recommended human health-based criteria assume exposure through fish and shellfish consumption, the criteria should not be used to implement narrative water quality objectives for groundwater where human exposure would only occur from water consumption-related beneficial uses. The recommended criteria include threshold health protective criteria for non-carcinogens. Incremental cancer risk estimates for carcinogens are presented at a variety of risk levels. Organoleptic (taste- and odor-based) levels are also provided for some chemicals to protect human welfare. Some recommended organoleptic criteria are based on adverse taste or odor of chemicals in water, while others are based on the tainting of the flesh of fish and shellfish from chemicals in ambient water.

As with CTR and NTR criteria, National Recommended Water Quality Criteria also include criteria that are intended to protect freshwater and saltwater aquatic life. Normally, recommended criteria with two different averaging periods are presented for each. Recommended Criteria Maximum Concentrations (CMCs) protect freshwater and saltwater aquatic organisms from short-term or acute exposures (expressed as 1-hour average or instantaneous maximum concentrations) to pollutants. Recommended Criteria Continuous Concentrations (CCCs) are intended to protect aquatic organisms from longer-term or chronic exposures (expressed as 4-day or 24-hour average concentrations). In order to derive recommended criteria, the method used by USEPA, found in *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (1985)*, requires toxicity data for species representing a minimum of eight families of organisms, including both vertebrate and invertebrate species. Toxicity to important aquatic plant species is also considered. The aquatic life criteria derived by USEPA are intended to protect all species, even at sensitive life stages, for which there are reliable measurements in the data set. With the breadth of data required to develop these criteria, USEPA intends the resulting criteria to also protect species for which no data are currently available. Where there is insufficient toxicologic information to develop recommended criteria, the USEPA criteria documents often provide toxicity information, in the form of lowest observed effect levels (LOELs), for species for which data are available.

The National Recommended Water Quality Criteria are found in a number of USEPA documents:

- *Quality Criteria for Water, 1986*, with updates in 1986 and 1987, also known as the "Gold Book";
- *Ambient Water Quality Criteria* volumes on specific pollutants or classes of pollutants (various dates beginning in 1980);
- *Quality Criteria for Water* (1976), also known as the "Red Book";
- *Water Quality Criteria, 1972*, also known as the "Blue Book."

In December 1992, USEPA promulgated the NTR, which updated many of these recommended criteria and made them directly applicable standards for surface waters in many states, including some California waters. These regulations, found in 40 CFR Section 131.36, specify that "[t]he human health criteria shall be applied at the state-adopted $10^{-6}$ risk level" for California. To ascertain compliance with the aquatic life criteria for metallic constituents, water quality samples were to be analyzed for "total recoverable" concentrations. In May 1995, USEPA amended these regulations to express most of these aquatic life criteria for metals as dissolved concentrations.

Approximately every two years beginning in 1999, USEPA publishes tables of *National Recommended Water Quality Criteria* that summarize criteria from the sources discussed above, including more recent updates. Due to their age and changes in methods used to derive the recommended criteria, Blue Book criteria no longer appear in these summary tables. USEPA may no longer support their use.

## Agricultural Water Quality Thresholds

*Water Quality for Agriculture*, published by the Food and Agriculture Organization of the United Nations in 1985, contains numeric thresholds protective of various agricultural uses of water, including irrigation of various types of crops and livestock watering. Above these numeric thresholds, specific agricultural uses of water may be adversely affected. For example, crop yields may be reduced. These numeric thresholds may be used to implement narrative water quality objectives that prohibit chemical constituents in concentrations that would impair agricultural uses of water.

### Taste and Odor Thresholds

Substances in water in amounts that cause adverse tastes or odors may be considered to impair beneficial uses associated with drinking water use (municipal or domestic supply). Adverse tastes and odors may also be associated with nuisance conditions. Taste and odor thresholds may be used to implement narrative water quality objectives that prohibit adverse tastes and odors in waters of the state and prohibit nuisance conditions. Taste and odor thresholds form the basis for many Secondary MCLs and are also published by the USEPA in the *National Recommended Water Quality Criteria* documents and the *Drinking Water Contaminant Fact Sheets*. An extensive collection of odor thresholds in water was published by J.E. Amoore and E. Hautala in the Journal of Applied Toxicology (1983). These latter thresholds were derived by combining air odor thresholds with physical parameters that describe the movement of chemicals between the air and the dissolved-in-water phases.

### Other Numeric Thresholds

Other sources of numeric thresholds include:

- *Hazard Assessments* and *Water Quality Criteria*, published by the California Department of Fish and Wildlife (CDFW) under contract from the California Department of Pesticide Regulation. These documents contain criteria that are protective of aquatic life from exposure to pesticides. CDFW uses the same methods employed by USEPA to derive the National Recommended Water Quality Criteria for freshwater and saltwater aquatic life protection, discussed above. CDFW may modify the data requirements of the USEPA methods, depending on data availability.
- *Water Quality Criteria, Second Edition*, written by McKee and Wolf and published by the State Water Resources Control Board in 1963 and 1978, contains criteria for human health and welfare, aquatic life, agricultural use, industrial use, and various other beneficial uses of water.

Most of the numeric thresholds discussed above are summarized in the Water Quality Goals online database associated with this report.

## RISK CHARACTERIZATION METHODS FOR DRINKING WATER

Methods used by USEPA, OEHHA, and other agencies to derive lifetime health advisories and concentration-based cancer risk estimates for constituents in drinking water may also be used to calculate numeric thresholds from published toxicologic information. These methods are based on the following toxicologic principles.

### Threshold Toxins vs. Non-Threshold Toxins

Relationships between exposure to toxic chemicals and resulting health effects may be roughly divided into two categories, threshold and non-threshold. It is important to recognize that it is not the chemical itself, but the dose (the concentration of the chemical in the media of exposure multiplied by the duration of exposure), that is responsible for the toxic effect. Below a particular threshold dose, many chemicals cause no toxic effects. These chemicals are called threshold toxins. Cyanide, mercury, and the pesticide malathion fall into this category. Some threshold chemicals, like Vitamin A, are beneficial to human health at low doses, but toxic at high doses.

On the other hand, some chemicals have no toxicity threshold. They pose some degree of health risk at any dose. Most carcinogens are thought to fall into this non-threshold category. Essentially, exposure to one molecule is considered to have the potential to cause some finite risk of getting cancer. Health risks for non-threshold toxins are characterized by probabilities—the higher the dose, the higher the probability of experiencing the toxic effect. For example, according to OEHHA, 0.15 microgram of benzene per liter of drinking water is associated with the probability of causing one additional cancer case in a million persons who are exposed through in-home use of this water over their lifetimes. The value of 0.15 ug/L is the estimated drinking water concentration associated with a 1-in-a-million ($10^{-6}$) incremental cancer risk, also known as the "$10^{-6}$ cancer risk estimate" for benzene. Because cancer risk is a probabilistic event, the level of cancer risk is directly proportional to the dose, or the concentration in water if all other factors are held constant. Therefore, the $10^{-5}$ cancer risk level (1 extra case of cancer in 100,000 exposed persons) for benzene would be 1.5 ug/L.

## Weight of Evidence Categories

According to the *1986 Guidelines for Carcinogen Risk Assessment*, USEPA assigned chemicals to five categories, by considering the weight of evidence for causing cancer that exists in the toxicologic record:

- ***Class A*** chemicals are known human carcinogens. There is sufficient evidence relating human exposure to cancer.
- ***Class B*** chemicals are probable human carcinogens. There is limited human evidence, but sufficient animal evidence.
- ***Class C*** chemicals are possible human carcinogens. There is no human evidence and limited animal evidence.
- ***Class D*** chemicals have insufficient cancer risk data to assign them to another category.
- ***Class E*** chemicals have sufficient evidence to indicate that they are not carcinogens.

Because for ethical reasons, toxicologic experiments can not be carried out on humans, very few chemicals fall into *Class A*. Epidemiologic evidence from industrial, accidental, or inadvertent human exposures are used to place chemicals in this category. Arsenic, benzene, vinyl chloride and radioactive substances are examples of *Class A* carcinogens. Unlike experimental animal studies, there is no need to extrapolate the evidence linking chemical exposure and cancer risk from animals to humans. So the highest degree of association between chemical exposure and human cancer risk exists for chemicals in *Class A*.

USEPA publishes cancer risk estimates for *Class A*, *Class B*, and sometimes for *Class C* chemicals. They publish threshold health advisories for lifetime exposure for *Class C*, *Class D* and *Class E* chemicals.

In the *2005 Guidelines for Carcinogen Risk Assessment*, USEPA updated the weight of evidence categories for causing cancer as follows:

- ***Class H*** chemicals are considered to be carcinogenic to humans.
- ***Class L*** chemicals are likely to be carcinogenic to humans.
- ***Class L/N*** chemicals are likely to be carcinogenic above a specified dose but not likely to be carcinogenic below that dose, because tumor formation does not appear to occur below that dose.
- ***Class S*** chemicals have suggestive evidence of carcinogenic potential.
- ***Class I*** chemicals have inadequate information to assess carcinogenic potential.
- ***Class N*** chemicals are not likely to be carcinogenic to humans.

The new system is roughly equivalent to the former *Class A* through *Class E* system, with the addition of the new *Class L/N* to recognize that some chemicals may exhibit a threshold for their carcinogenic effects.

Because of the different ways in which chemicals are believed to cause adverse health impacts, the characterization of health risks for non-threshold toxins is different from that for threshold toxins.

## Non-Threshold Risk Characterization

For non-threshold chemicals, including most carcinogens, the *risk* of a toxic effect is considered to be proportional to the amount or *dose* of the chemical to which a population is exposed. For each carcinogen, risk and dose are related by a cancer potency or slope factor (often abbreviated $q_1$*) which is equal to the risk of getting cancer per unit dose of the chemical. The potency factor is expressed in units of inverse milligrams of chemical per kilogram body weight per day of exposure, $(\text{mg/kg/day})^{-1}$. The cancer risk level, dose, and cancer potency factor are related by equation [1] in Figure 2. Potency factors for carcinogens are calculated by extrapolation from dose-response relationships often developed in laboratory animal exposure studies. For a few chemicals, they are based on human epidemiologic data. Potency factors may be found in the *Cal/EPA Toxicity Criteria Database* maintained by OEHHA, the USEPA *Integrated Risk Information System* (*IRIS*) database, USEPA health advisory documents, and the *Drinking Water and Health* publications of the National Academy of Sciences (NAS).

If one assumes an average drinking water consumption rate of 2 liters per day and an average human body weight of 70 kg, dose and concentration in drinking water may be related by equation [2]. These are standard assumptions used by federal and state drinking water regulatory and advisory programs and by OEHHA in regulations that implement Proposition 65. By combining equations [1] and [2] and rearranging, we obtain equation [3]. This equation allows calculation of a concentration in drinking water associated with a given cancer risk level, if the potency factor is known. For example, the Cal/EPA cancer potency factor for the pesticide 1,2-dibromo-3-chloropropane or DBCP is 7 $(\text{mg/kg/day})^{-1}$. Using equation [3], the concentration in drinking water associated with a 1-in-a-million ($10^{-6}$) lifetime cancer risk level may be calculated as 0.000005 mg/l or 0.005 ug/L. This $10^{-6}$ cancer risk estimate along with other similarly calculated cancer risk estimates for other chemicals may be found in the Water Quality Goals online database associated with this report.

In addition to exposure caused by direct ingestion, volatile chemicals in water may cause additional exposures. Use of water in the home can volatilize these chemicals into indoor air that people breathe.

**FIGURE 2. CALCULATING HEALTH BASED LIMITS**

[1] $\text{Risk Level} = \text{Dose} \times \text{Potency Factor}$

[2] $\text{Dose (mg/kg/day)} = \text{Concentration (mg/l)} \times 2\ \text{liters/day} \div 70\ \text{kg}$

[3] $$\text{Concentration (mg/l)} = \frac{\text{Risk Level} \times 70\ \text{kg}}{\text{Potency Factor} \times 2\ \text{liters/day}}$$

[4] $$\text{RfD} = \frac{\text{NOAEL}}{\text{Uncertainty Factor}}$$

[5] $$\text{DWEL} = \frac{\text{RfD} \times 70\ \text{kg}}{2\ \text{liters/day}}$$

[6] $$\text{Lifetime Health Advisory (mg/l)} = \frac{\text{DWEL} \times 20\%\ \text{RSC}}{\text{Additional Uncertainty Factor}}$$

Bathing with contaminated water may also cause chemical exposure through skin absorption. In recent years, OEHHA has accounted for these added exposures to volatile carcinogens in drinking water in the derivation of Public Health Goals. Assuming greater exposure means that a lower concentration in water is associated with the same level of cancer risk. For example, if exposure to the solvent trichloroethylene (TCE) is assumed only to occur through ingestion of contaminated water, the concentration associated with the 1-in-a-million lifetime cancer risk is 5.9 ug/L, according to OEHHA. If vapor inhalation and dermal exposure are included, the 1-in-a-million risk level drops to 1.7 ug/L. For this reason, Public Health Goals for volatile chemicals are often lower than cancer risk levels from other sources.

## Which Cancer Risk Level?

There is often confusion about which cancer risk level to use in selecting human health-based numeric thresholds. The one-in-a-million ($10^{-6}$) incremental cancer risk level has historically formed the basis of human health protective numeric thresholds in California. It is generally recognized by California and federal agencies as the *de minimis* or negligible level of risk associated with involuntary exposure to carcinogenic chemicals in environmental media.

The $10^{-6}$ risk level has long formed the basis of water-related health-protective regulatory decision-making in California. The following are some of the more significant instances:

- California drinking water program' *Statement of Reasons* documents for Primary MCL regulations for carcinogenic substances use the $10^{-6}$ risk level for lifetime exposure as the basis from which the MCLs were derived. In these documents DDW (and the Department of Public Health before them) describes the $10^{-6}$ risk level as "the *de minimis* excess cancer risk value" which is "typically assumed by federal and state regulatory agencies for involuntary exposures to environmental pollutants." MCLs for carcinogens deviate from the $10^{-6}$ risk level only where technologic or economic factors prevent the attainment of this level in drinking water systems statewide.
- DDW Notification Levels for drinking water are also set at the $10^{-6}$ risk level unless technologic or economic factors prevent attaining that level, as with the Primary MCLs.
- The *Preliminary Endangerment Assessment Guidance Manual* published by the Department of Toxic Substances Control (DTSC) [page 2-26] states that "[i]n general, a risk estimation greater that [sic] $10^{-6}$ or a hazard index greater than 1 indicate the presence of contamination which may pose a significant threat to human health."
- Clean Water Act water quality criteria promulgated for California waters by USEPA in the NTR and the CTR state that "[t]he human health criteria shall be applied at the State-adopted $10^{-6}$ risk level." These criteria, when combined with beneficial use designations in state Water Quality Control Plans are water quality standards for California's inland and estuarine surface waters.
- Substitute Environmental Documents (formerly Functional Equivalent Documents) by the State Water Board that provide background and justification for the California Ocean Plan and the former California Inland Surface Waters and Enclosed Bays and Estuaries Plans cite the $10^{-6}$ risk level as the basis of human health protective water quality objectives for carcinogens.
- Public Health Goals for drinking water, adopted by OEHHA, are based on the $10^{-6}$ risk level for carcinogens, "a level that has been considered negligible or *de minimis*," and a 70-year exposure period.
- In enforcement decisions regarding an off-site chlorinated solvent plume from Mather Air Force Base, the Central Valley Regional Water Board required that a replacement water supply be provided when the level of carcinogenic chemicals is detected and confirmed at or above concentrations that represent $10^{-6}$ lifetime cancer risk levels in individual wells. This decision

implements the narrative toxicity objective for groundwater from the Basin Plan for the Sacramento River and San Joaquin River Basins.

- Cleanup and Abatement Order No. 92-707 adopted by the Central Valley Regional Water Board established cleanup levels for groundwater at the Southern Pacific Transportation Company, Tracy Yard, San Joaquin County at the $10^{-6}$ lifetime cancer risk levels for carcinogens, based on the narrative toxicity objective for groundwater from the Basin Plan for the Sacramento River and San Joaquin River Basins.
  (*Note: The two Central Valley Region enforcement orders are specific to that Region and to the sites mentioned.)*

For consistency with the above, the $10^{-6}$ risk level is used in this document and the Water Quality Goals online database to select human health-protective assessment thresholds based on narrative toxicity objectives.

Regulations implementing Proposition 65 cite the one-in-one-hundred-thousand ($10^{-5}$) risk level for carcinogens. However, Proposition 65's intent is to notify the public before exposure to certain chemicals, and to prohibit specific discharges of these chemicals. It is not the intent of Proposition 65 to establish levels of involuntary environmental exposure that are considered "safe." California has other programs for that purpose (e.g., the PHG program). Therefore, Proposition 65 does not provide a relevant authority for determining the level of cancer risk in order to comply with narrative toxicity objectives.

Site and case-specific factors may cause regulatory levels associated with State and Regional Water Board decisions to deviate from the $10^{-6}$ risk level.

## Threshold Risk Characterization

To calculate a toxin's threshold concentration that is safe enough for humans to consume in drinking water, toxic-dose and safe-dose information is needed. This information is derived from laboratory animal studies or, if available, epidemiologic studies on human populations. In the laboratory studies, animals are exposed to a chemical at specific dose levels. For epidemiologic studies, measured or estimated human exposures are divided into various dose levels. USEPA, OEHHA and other agencies choose one of two dose level results from these studies from which to calculate safe levels of human exposure to the chemical in drinking water. The no observed adverse effect level (NOAEL) is the highest dose that caused no toxic effect in the study. The lowest observed adverse effect level (LOAEL) is the lowest dose that did cause a measurable toxic effect. The LOAEL is a higher dose than the NOAEL. Because the toxic dose of a chemical is usually related to the body weight of the animal or human studied, doses are often reported in units of milligrams of chemical per kilogram of body weight per day of exposure (mg/kg/day or mg/kg-day). Both NOAELs and LOAELs are expressed in these units.

USEPA, OEHHA and other agencies use the NOAEL or LOAEL to calculate a reference dose or RfD for a toxic chemical, using equation [4] in Figure 2. The uncertainty factor in the equation accounts for unknowns in the extrapolation of study data to "safe" levels for human exposure. The minimum uncertainty factor is 10, which accounts for the fact that some people (e.g., children, the elderly, those with compromised immune systems) are more sensitive to toxic chemicals than the average person. The minimum uncertainty factor is normally multiplied by additional factors of 3 to 10 for each of the following conditions, if they apply:

- Extrapolation from animal toxicity studies to human toxicity (not needed when the study is based on human exposure data);
- Using a LOAEL in place of a NOAEL in equation [4], above;
- Using a dose (NOAEL or LOAEL) from a study which examined a less appropriate route of exposure to the chemical (the route of exposure most relevant to drinking water is ingestion);

- Using a dose from a study which exposed test animals for a period of time that is not a significant fraction of the animals' lifetime (subchronic exposure);
- Potential synergism among chemicals (the toxicity of two or more chemicals is greater than additive—the sum of their individual toxicities); and
- Any other toxicologic data gaps.

RfDs have the same units as the NOAELs and LOAELs from which they are derived, mg/kg/day. The USEPA IRIS database contains reference doses for many threshold toxins.

The next step, equation [5], is the calculation of a drinking water equivalent level (DWEL) from the reference dose. For an adult, this step is derived from equation [2] by assuming an average human body weight of 70 kilograms and an average drinking water consumption rate of two liters per day. As with the calculation of cancer risk criteria in water, these are standard assumptions used by federal and state drinking water regulatory and advisory programs. Some agencies make separate calculations for children using a 10 kilogram average body weight and one liter per day average drinking water consumption rate.

One last step, equation [6] in Figure 2, is required to turn the DWEL into the equivalent of a lifetime health advisory concentration. Two additional factors are used. The first is the relative source contribution or RSC. It accounts for the fact that people are usually exposed to chemicals from sources other than drinking water (e.g., in the foods we eat, in the air we breathe). The combined exposure from all sources forms the overall dose that may contribute to toxicity. The default RSC normally used by USEPA to derive lifetime health advisories for threshold toxins is 20%. This means that 20% of the exposure is assumed to come from drinking water and 80% from all other sources combined. Information on exposure to specific chemicals through other media may necessitate the use of a RSC that differs from the default value. California Drinking Water Notification Levels from DDW may differ from health based numeric thresholds published by USEPA, due to differing assumptions about RSC.

The second factor in equation [6] is an additional uncertainty factor, used to provide an extra margin of safety for those chemicals for which limited evidence of cancer risk exists. This uncertainty factor is equal to 10 for *Class C* and *Class S* carcinogens, and 1 for chemicals in *Classes D*, *E*, *I* and *N*. Lifetime health advisories are normally not calculated for chemicals in cancer *Classes A*, *B*, *H* and *L*. Cancer risk estimates are calculated instead.

With equations [5] and [6], one can calculate health protective numeric thresholds for threshold toxins from RfD values published in IRIS and elsewhere in the literature. For example, acetone has an oral exposure RfD of 0.9 mg/kg/day in IRIS. From equation [5], a DWEL of 31.5 mg/l may be calculated. Acetone is in cancer weight of evidence Class D (no evidence of cancer risk); so the additional uncertainty factor is 1. By equation [6], the DWEL may be converted into an expected safe lifetime-exposure limit in drinking water of 6.3 mg/l or 6300 ug/L. This and other similarly calculated numeric thresholds are presented in the Water Quality Goals online database associated with this report.

## SELECTING PROTECTIVE ASSESSMENT THRESHOLDS FROM AMONG AVAILABLE NUMERIC THRESHOLDS

To determine whether the level of a constituent or parameter is impairing or threatens to impair beneficial uses of a water body, a numeric assessment threshold for that constituent or parameter is needed. The procedure for selecting an assessment threshold is discussed above and is based on applicable numeric objectives, CWA 303(c) criteria, and numeric thresholds from the literature to implement each narrative objective.

Because data on the health and environmental effects of chemicals is constantly evolving, one should make sure that current numeric thresholds are used. The original literature should be consulted whenever possible to determine the appropriateness and limitations of the numeric thresholds being considered. Other government agencies, such as the California Division of Drinking Water, the CDFW, OEHHA, and USEPA may need to be consulted for up-to-date information.

In some cases, multiple human health-based numeric thresholds are available for a particular chemical. A decision must be made as to which of these numeric thresholds is the most appropriate to implement narrative toxicity objectives to protect human health. In May 1994, representatives of the State Water Board and the Central Valley Regional Water Board met with toxicologists and other representatives of DTSC and OEHHA to discuss the use of toxicologic criteria in contaminated site assessment and cleanup. The group agreed to use guidance parallel to that given on page 2-20 of DTSC's *Preliminary Endangerment Assessment Guidance Manual* (January 1994). This guidance is relevant when selecting numeric thresholds from the literature to implement health-based narrative water quality objectives or when selecting criteria for use in health risk assessments. Numeric thresholds should be used in the following hierarchy:

1) Cancer potency slope factors and reference doses set forth in California regulations (e.g., an MCL that is based only on health-based information).
2) Cancer potency slope factors and reference doses that were used to develop environmental criteria that are found in California regulations. The health-based slope factors and reference doses should be used instead of the risk management environmental concentration found in the regulation (e.g., the RfD rather than the MCL).
3) Cancer potency slope factors and reference doses from USEPA's Integrated Risk Information System (IRIS).
4) Cancer potency slope factors and reference doses from USEPA's Health Effects Assessment Summary Tables (Health Advisories), the most current edition.

Numeric thresholds in the first two categories may be found in the Cal/EPA Toxicity Criteria Database maintained by OEHHA.

## Caution in Relying on MCLs

The Basin Plans incorporate California Primary MCLs as enforceable, numeric water quality objectives for water bodies designated with the beneficial use of municipal and domestic supply (MUN). And it has become common practice to rely on Primary MCLs to protect human health from chemicals in water. But MCLs are not necessarily the only health protective water quality objectives that apply to the body of water, and in many cases, they are not the most stringent objectives. Primary MCLs are established by balancing health risks with compliance costs and other factors that are germane to water in drinking water distribution systems and at the tap, either on a nation-wide (USEPA) or statewide (DDW) basis. As such, Primary MCLs may not be stringent enough to satisfy the language of narrative water quality objectives that are intended to protect a particular source of drinking water (body of groundwater or surface water).

For example, the total trihalomethane (TTHM) drinking water MCL may not prevent "detrimental physiological responses" an concentrations allowed by the MCL may be "harmful to human health," conditions that do not conform to the narrative water quality objectives for toxicity in all but one of California's Basin Plans. According to the December 1994 staff report supporting amendments to the Sacramento River and San Joaquin River Basin Plan that included adding a narrative toxicity objective for groundwater,

> A common example of incorrect MCL application is the use of the total trihalomethane (TTHM) MCL for the protection of groundwater from chloroform. Chloroform is one of four chemicals covered by the term 'trihalomethanes.' These probable human carcinogens are formed in drinking water by the action of chlorine, used for disinfection, on organic matter present in the raw source water. The total THM federal Primary MCL of 80 ug/L is 44 to 80 times higher than the published one-in-a-million incremental

> cancer risk estimates for chloroform. USEPA has stated that the MCL for total THMs was based mainly on technologic and economic considerations.

Most municipal drinking water systems chlorinate their water to remove pathogens, such as bacteria and viruses, before delivering the water to customers. The 1994 Sacramento/San Joaquin Basin Plan amendment staff report went on to say,

> The MCL for total THMs was derived by balancing the benefit provided by the chlorination process (elimination of pathogens in drinking water) with the health threat posed by the trihalomethane by-products of this process and the cost associated with conversion to other disinfection methods. Since ground water has not yet been chlorinated and may not require chlorination before use, this type of cost/benefit balancing (accepting some cancer risk from chloroform and other THMs in order to eliminate pathogens and avoid conversion costs) is not germane to ground water protection. Therefore, the total THM MCL is not sufficiently protective of the ambient quality of domestic water supply sources.

The staff report concluded that the narrative toxicity objective would provide more appropriate protection against toxicity to humans from chemicals in ambient water than provided by MCLs alone.

Technologic factors also affect the level of health protection afforded by Primary MCLs. To ensure that compliance by drinking water systems statewide can be determined, MCLs are set at or above analytical quantitation limits, the lowest levels that can be quantified by methods commonly used by analytical laboratories. In several cases, DDW and USEPA have established MCLs at concentrations higher than health protective levels, where those levels are below readily available analytical quantitation limits. It is clear from the *Statement of Reasons* documents justifying California drinking water regulations that the intent of DDW was to adopt one-in-a-million cancer risk values as MCLs for several chlorinated solvents (e.g., PCE, carbon tetrachloride) if analytical quantitation limits had been lower at the time of adoption. Since the adoption of these MCLs in the 1980s, analytical quantitation limits have improved, and the health-based levels for these chemicals can be reliably measured at a reasonable cost. The technologic constraint posed by the older analytical quantitation limits is no longer germane. Therefore, it is no longer reasonable to rely on outdated analytical quantitation limits as substitutes for truly health-based thresholds when applying the narrative water quality objective for toxicity.

Public Health Goals adopted by OEHHA are often more stringent than existing Primary MCLs. The California Safe Drinking Water Act of 1996, amended 1999, mandated the establishment of PHGs to inform DDW and the public when California MCLs are less than fully health-protective. The California Safe Drinking Water Act requires DDW to review MCLs every five years and revise them to be as close to PHGs as is technologically and economically achievable. Compliance with health-based PHGs in ambient sources of drinking water not only prevents toxic amounts of chemicals, but also addresses compliance with future MCLs. This may be appropriate for protection of water resources for both existing and future municipal and domestic supply uses.

MCLs are only a subset of the water quality objectives that apply to sources of municipal and domestic supply under most Basin Plans. Narrative objectives for toxicity and beneficial use protection from chemical constituents are also applicable to these waters under most Basin Plans. Due to the constraints discussed above, MCLs that are not fully health protective may not ensure compliance with toxicity or specific chemical constituent water quality objectives. In most cases, purely health-based numeric thresholds, such as one-in-a-million incremental cancer risk estimates and PHGs, are more direct measures of levels that would “prevent detrimental physiologic responses” or that would not be “harmful to human health,” the language found in objectives.

Virtually all Primary MCLs are derived by balancing health effects information with the technologic and economic considerations involved in providing water to customers through conventional drinking water supply systems on a statewide basis. As such, they represent risk management-based levels. Due to the lengthy regulation adoption process, primary MCLs may also not reflect current toxicologic information. Thus, Primary MCLs are not always reliable indicators of the prevention of detrimental physiological responses to users of ambient groundwaters or surface waters.

For the above reasons, primary MCLs may differ significantly from other health-based numeric thresholds. For those chemicals that have primary MCLs, and depending on the case-specific situation, one could assume that either:

1) MCLs are sufficient to protect human health; or
2) Additional health-based numeric thresholds are needed to implement narrative objectives that prohibit detrimental physiological responses in humans that consume the water or are not harmful to human health.

Case-specific information and applicable policies and regulations will govern which assumption to use for a given situation. Users of this document are urged to contact the appropriate regulatory authority before making this determination.

There are additional instances when numeric thresholds that are more stringent than MCLs are applied to protect all of the beneficial uses of a water resource. For example, the Regional Water Boards require surface waters to comply with aquatic life protective criteria for copper, cadmium, and zinc, even when these criteria are more stringent than MCLs. Under some circumstances, agricultural use protective thresholds for several constituents and parameters, including chloride and total dissolved solids, are more stringent than MCLs. For these constituents, sensitive agricultural uses may be impaired at concentrations lower than MCLs. Several chemicals cause water to taste or smell bad at concentrations significantly lower than MCLs. The following are taste and odor thresholds and primary MCLs (in ug/L) for three common constituents of gasoline:

| | ***Taste & Odor Threshold*** | ***Primary MCL*** |
|---|---|---|
| Ethylbenzene | 29 | 300 |
| Toluene | 42 | 150 |
| Xylene(s) | 17 | 1750 |

It is clear that water would be rendered unpalatable and beneficial uses would be impaired at concentrations significantly below MCLs. Taste and odor thresholds may be used to implement narrative water quality objectives for Tastes and Odors to prevent such impairment.

Again, even though MCLs may be applicable water quality objectives for these waters, they may not be the most stringent water quality objectives. Compliance with MCLs will not ensure compliance with all applicable water quality objectives under all circumstances. As such, MCLs may not be sufficiently protective of the most sensitive beneficial uses.

As discussed above, the state's Antidegradation Policy may preclude degrading water quality from background levels, even when applicable water quality objectives are higher.

## Assessment Threshold Algorithms

The above discussion shows how numeric thresholds may be used to develop conservative, beneficial use protective assessment thresholds for surface water and groundwater, based on numeric and narrative water quality objectives, CWA 303(c) water quality criteria, and site-specific conditions. If used as the basis for effluent or receiving water limits in waste discharge requirements, NPDES permits, or enforcement orders, or if used to list a water body as impaired pursuant to CWA Section 303(d), it is imperative that assessment thresholds are selected in a defensible manner and that the rationale for their selection be clearly identified for each site and case.

*[Note: This report focuses on the development of assessment thresholds for receiving waters. It does not provide guidance on the selection of effluent limits, which are derived from both water quality-*

*based and technology-based considerations using discharge-specific factors and according to applicable regulations and policies. Board action is generally required to make such regulatory decisions.]*

To maintain consistency in the selection of assessment thresholds, this report recommends the use of procedures or algorithms for selecting numeric assessment thresholds to comply with water quality objectives and CWA 303(c) water quality criteria. These algorithms are based on a set of guiding principles designed to support the selection of relevant and appropriate water quality-based numeric thresholds. Other policies and regulations, such as the Antidegradation Policy, the *Site Assessment and Cleanup Policy*, and National Pollutant Discharge Elimination System (NPDES) regulations and policies require that technology-based limits and background levels also are considered in determining the final water quality limits appropriate for a particular situation.

## Guiding Principles

The following principles and steps guide the derivation of the assessment threshold selection algorithms that follow. To be defensible, assessment thresholds should be chosen to protect the most sensitive beneficial use by applying all applicable water quality objectives and CWA 303(c) water quality criteria.

For each constituent or parameter, the process of selecting an assessment threshold involves three steps:

1) Select a single numeric threshold to satisfy each water quality objective/303(c) criterion or relevant portion thereof.
2) To satisfy all applicable objectives/criteria and to protect all applicable beneficial uses, select the most restrictive of the numeric thresholds from step (1).
3) To account for controllable factors policy statements, discussed below, select the larger of
    - The numeric threshold chosen in step (2) or
    - The natural background level of the constituent.

As an example of "relevant portions" of an objective in step (1), compliance with the narrative Toxicity objective for surface water normally involves selecting one numeric threshold to protect aquatic life and another numeric threshold to protect human health. Each threshold satisfied a portion of the objective.

*[Note: For the NPDES program and for other situations where it is not clear that background conditions represent true "natural background," (i.e., not influenced by controllable water quality factors), the limit chosen in step (2) should be imposed even where existing background levels are less stringent. According to the SIP the CTR or NTR criterion becomes the effluent limit in such cases.]*

For each constituent, the above steps should result in a numeric assessment threshold that would protect all applicable beneficial uses of the receiving water. If the concentration in ambient water equals or exceeds the assessment threshold, pollution may have occurred or is threatened to occur. Below the assessment threshold, ambient water should be in compliance with applicable water quality objectives and CWA 303(c) water quality criteria. Antidegradation principles may require that more stringent levels be applied.

A variety of factors determine which numeric threshold is selected. The most stringent of all available numeric thresholds is not necessarily appropriate. Certain numeric thresholds may be required by law to be applied or may have greater force of law. If a CTR or NTR criterion for human health protection applies to the surface water body, other human health based numeric thresholds (e.g., Public Heath Goals) are normally not considered. CTR and NTR criteria have been promulgated, while the PHGs are merely advisory. Protection from adverse human health effects has already been satisfied by the applicable CTR or NTR human health criteria. Similarly, Ocean Plan objectives and CTR/NTR criteria to protect human health or aquatic life have greater legal force than National Recommended Water

Quality Criteria (NRWQC) to protect the same beneficial uses. Ocean Plan objectives have been established and CTR/NTR criteria have been promulgated, while the NRWQC are merely advisory.

In step (1) above, especially with respect to toxicity information, the algorithms incorporate a preference for:

- ***Purely risk-based numeric thresholds*** over risk management-based numeric thresholds, unless the water quality objective mandates the use of a risk-management based numeric threshold (e.g., the Chemical Constituent objectives mandates compliance, at a minimum, with California Primary and Secondary drinking water MCLs, some of which are more stringent than other available numeric thresholds). Purely risk based numeric thresholds consider only health risks or other risks to beneficial uses. Risk management based numeric thresholds include economic and/or technologic factors that may not be relevant to protecting beneficial uses of ambient water resources and may not comply with the language of narrative water quality objectives, as discussed above with respect to MCLs.
- ***Numeric thresholds developed and/or published by California agencies***, over those developed by federal agencies or other organizations, to provide consistency within state government.
- ***Numeric thresholds that reflect peer reviewed science***. Avoid using draft or provisional numeric thresholds, unless nothing else is available and sufficient rationale is provided.
- ***Numeric thresholds that reflect current science.*** Select the most recent among available numeric thresholds that address the same beneficial use issues (e.g., Public Health Goals are often more recent than IRIS criteria, which are normally more recent than USEPA health advisories).

These principles are consistent with the manner in which DTSC and OEHHA select toxicity-based criteria for health risk evaluations.

***Avoid using Proposition 65 levels to apply narrative toxicity objectives.*** As discussed above, the intent of Proposition 65 is not to designate “safe” levels of chemicals in drinking water. Proposition 65 levels are not calculated in the same manner as other health-based numeric thresholds for water ingestion in California (i.e., PHGs, other health-based criteria from which MCLs are derived, and CTR and NTR criteria to protect human health).

Based on the above principles, algorithms have been developed to assist users to select protective and defensible assessment thresholds. Because water quality standards for different types of water bodies differ significantly, separate assessment threshold algorithms are presented below for groundwater, inland surface waters, enclosed bays and estuaries, and ocean waters.

## Water Body Types and Beneficial Uses Protected

Considering the variety of situations encountered in California, the assessment thresholds are intended to support a minimum of four categories of sensitive beneficial uses in four different kinds of water bodies, as follows:

- Ground water—
  - Beneficial use is designated as municipal or domestic supply (MUN)
  - Beneficial use is designated as agricultural supply (AGR)
- Inland surface water (salinity less than 10 parts per thousand)—
  - Beneficial use is designated as MUN
  - Beneficial use is designated as AGR
  - Beneficial uses are designated to protect aquatic life

- Beneficial uses are designated to support fish consumption

- Enclosed bays or estuaries (salinity greater than 1 part per thousand)—
  - Beneficial uses are designated to protect aquatic life
  - Beneficial uses are designated to support fish consumption
- Ocean waters—
  - Beneficial uses are designated to protect aquatic life
  - Beneficial uses are designated to support fish consumption

Note: As used in this document and consistent with the CTR and NTR, the term "inland surface waters" is intended to include all surface waters with salinities less than 10 parts per thousand, even though the surface waters being assessed may be an enclosed bay or estuary. The term "enclosed bays/estuaries" is intended to include all non-ocean surface waters with salinities greater than 1 part per thousand, even though surface waters being assessed may appear to be inland surface waters. As defined in the *California Ocean Plan*, ocean waters include territorial marine waters of the state that do not qualify as enclosed bays, estuaries, or coastal lagoons.

## Assessment Threshold Algorithm for Groundwater

For chemicals in groundwater, the following water quality objectives and numeric thresholds normally apply to the water body:

- Chemical Constituents Objective—
  *Each of the following three items apply separately:*
  - Numeric water quality objective from the Basin Plan
  - Drinking Water MCLs—
    *For MUN-designated waters, select the lowest of the following:*
    - California Primary MCL
    - California Secondary MCL
  - Concentrations that indicate impairment of any applicable beneficial use—
    *Select the lowest of the following:*
    - Agricultural use protective threshold
      *[for AGR-designated waters]*
    - Federal Primary MCL, if lower than California Primary MCL [for MUN-designated waters]
      *[Note: Statute requires that the California MCL must be lowered to at least as stringent as the Federal MCL. Compliance with the lower Federal MCL is needed to protect the MUN beneficial use in the longer term.]*
- Toxicity Objective
  - Human health risk-based numeric threshold for drinking water use—
    *For MUN-designated waters, select the first available numeric threshold from the following hierarchy:*
    - OEHHA Public Health Goal
    - Cal/EPA cancer potency factor at the one-in-a-million risk level
      *[Note: For volatile carcinogens, this numeric threshold is likely to be less stringent and less relevant to implement the narrative toxicity objective than the Public Health Goal because it considers only ingestion exposure. PHGs consider ingestion, vapor inhalation*

*and skin adsorption exposures that are likely to occur from the use of drinking water in the household.]*

- ♦ California Drinking Water Notification Level based on toxicity
  *[Note: Concurrence from the State Water Board's Division of Drinking Water may be necessary. Alternatively, cite the original toxicologic threshold used as the basis for the Notification Level.]*
- ♦ USEPA IRIS criteria—
  *Select the lowest of the following:*
  - One-in-a-million cancer risk estimate
  - Reference dose for non-cancer toxicity (as a drinking water threshold)
- ♦ USEPA Health Advisory—
  *Select the lowest of the following:*
  - One-in-a-million cancer risk estimate
  - Lifetime non-cancer numeric threshold
- ♦ USEPA MCL Goal —
  *Use non-zero numeric thresholds only.*
  *[Note: MCL Goals for carcinogens are set at "zero" to represent no health risk. No significant risk is used for the comparable California PHGs.]*
- ♦ Other health risk-based numeric thresholds—
  *[Note: Check the dates and basis for the numeric threshold before using these.]*
  - National Academy of Sciences thresholds
    *Select the lowest of:*
    - ▪ One-in-a-million incremental cancer risk estimate
    - ▪ Drinking water health advisory or SNARL
  - Proposition 65 levels—
    *[Note: Use only if no other health risk-based numeric thresholds are available.]*
    *Select the lowest of:*
    - ▪ No-Significant-Risk Level
    - ▪ Maximum Allowable Dose Level

❖ Tastes and Odors Objective

- ➢ Taste- and odor-based numeric threshold—
  *For MUN-designated waters, select the first available numeric threshold from the following hierarchy:*
  - ♦ California Secondary MCL
  - ♦ Federal Secondary MCL
  - ♦ USEPA National Recommended Water Quality Criterion based on taste & odor
    *[Note: Do not use if numeric threshold is based on tainting of fish flesh.]*
  - ♦ Taste and odor thresholds published by other agencies or from the peer reviewed literature

For each constituent and parameter of interest, first, select one numeric threshold for each of the items above marked with an arrow (➢). Record your selections in a table, such as the one shown in Figure 3. Second, select the most stringent numeric threshold from this table. The result should be an assessment threshold that satisfies all applicable water quality objectives in a conservative manner. Consideration of natural background levels and antidegradation policies may require further modifications to this selection, as discussed below.

### FIGURE 3. GROUNDWATER ASSESSMENT THRESHOLD ALGORITHM TABLE

| Water Quality Objective / Criterion | Relevant Portion of Objective / Criterion | Source | Concentration | Units |
|---|---|---|---|---|
| Chemical Constituents | Drinking Water MCL (lowest) | SWRCB-DDW | | |
| | Numerical Water Quality Objective | Basin Plan | | |
| | Beneficial Use Impairment Numeric Threshold | | | |
| Toxicity | Human Health – Drinking Water | | | |
| Tastes & Odors | Taste & Odor Based Numeric Thresholds for Water | | | |

## Assessment Threshold Algorithm for Inland Surface Waters

Different thresholds apply to surface waters than those that apply to groundwater. Additional beneficial uses—for example, those that protect aquatic life—normally apply. Additional water quality standards apply to surface waters. NTR and CTR criteria apply to California inland and estuarine surface waters. Barring unusual circumstances, CTR or NTR criteria to protect human health or aquatic life should be used in lieu of advisory numeric thresholds to implement the narrative toxicity objective. For example, if the CTR contains a human health protective criterion for the chemical of concern, it should normally be selected instead of a PHG that would be used to implement the narrative toxicity objective to protect human health. Similarly, a CTR aquatic life protective criterion should normally be selected instead of a USEPA-recommended aquatic life criterion for the same chemical.

The CTR, NTR and USEPA National Recommended Water Quality Criteria (NRWQC) for human health protection apply only to surface water, because they are derived assuming exposure through consumption of fish and shellfish from the water.

CTR, NTR and the NRWQC contain different criteria to protect freshwater and saltwater aquatic life. According to the CTR and NTR, only the freshwater criteria should be applied to water bodies with salinities less than 1 part per thousand. Only the saltwater criteria should be applied to waters with salinities greater than 10 parts per thousand. For waters with salinities between 1 and 10 parts per thousand, the more stringent of the freshwater and saltwater criteria should be applied. *Note: Care should be exercised when applying these criteria to inland saline waters (e.g., Salton Sea), as indigenous species may have special needs.*

For constituents and parameters in inland surface waters, the following water quality objectives and numeric thresholds normally apply to the water body:

- USEPA California Toxics Rule and National Toxics Rule—
  *[Note: NTR criteria are listed in the Water Quality Goals online database under "California Toxics Rule Criteria" and footnoted accordingly.]*
  - Criteria for human health protection
    *[Note: Use criteria for drinking water sources, based on consumption of water plus aquatic organisms, unless the MUN beneficial use has specifically been de-listed for the water body.]*
  - Criteria for aquatic life protection
    *[Note: Both the Criteria Continuous Concentration (CCC, 4-day average) and Criteria*

*Maximum Concentration (CMC, 1-hour average) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied. Also note that freshwater criteria should be applied to water bodies with salinities less than 1 part per thousand and saltwater criteria should be applied to waters with salinities greater than 10 parts per thousand. For waters with salinities between 1 and 10 parts per thousand, the more stringent of the freshwater and saltwater criteria should be applied.]*

- Chemical Constituents Objective—
  *Each of the following three items apply separately:*
  - Numeric water quality objective from the Basin Plan
    *[Note: Site-specific objectives may supersede CTR or NTR criteria if approved by USEPA.]*
  - Drinking Water MCLs—
    *For MUN-designated waters, select the lowest of the following:*
    - California Primary MCL
    - California Secondary MCL
  - Concentrations that indicate impairment of any applicable beneficial use—
    *Select the lowest of the following:*
    - Agricultural use protective numeric thresholds
      *[for AGR-designated waters]*
    - Federal Primary MCL, if lower than California Primary MCL
      *[for MUN-designated waters]*
      *[Note: Statute requires that the California MCL must be lowered to at least as stringent as the Federal MCL. Compliance with the lower Federal MCL is needed to protect the MUN beneficial use in the longer term.]*
- Toxicity Objective
  - Human health risk-based numeric threshold for drinking water use—
    *For MUN-designated waters, select the first available numeric threshold from the following hierarchy:*
    *[Note: Applies only if there are no CTR or NTR criteria for human health protection.]*
    - California Public Health Goal
    - Cal/EPA cancer potency factor at the one-in-a-million risk level
      *[Note: For volatile carcinogens, this numeric threshold is likely to be less stringent and less relevant to implement the narrative toxicity objective than the Public Health Goal because it considers only ingestion exposure. PHGs consider ingestion, vapor inhalation and skin adsorption exposures that are likely to occur from the use of drinking water in the household.]*
    - California Drinking Water Notification Level based on toxicity
      *[Note: Concurrence from the State Water Board's Division of Drinking Water may be necessary. Alternatively, cite the original toxicologic threshold used as the basis for the Notification Level.]*
    - USEPA IRIS criteria—
      *Select the lowest of the following:*
      - One-in-a-million cancer risk estimate
      - Reference dose for non-cancer toxicity (as a drinking water threshold)

- USEPA Health Advisory—
  *Select the lowest of the following:*
  - One-in-a-million cancer risk estimate
  - Lifetime non-cancer numeric threshold
- USEPA MCL Goals—
  *Use non-zero numeric thresholds only.*
  *[Note: MCL Goals for carcinogens are set at "zero" to represent no health risk. No significant risk is used for the comparable California PHGs.]*
- Other health risk-based numeric thresholds—
  *[Note: Check the dates and basis for the numeric threshold before using these.]*
  - National Academy of Sciences criteria
    *Select the lowest of:*
    - One-in-a-million incremental cancer risk estimate
    - Drinking water health advisory or SNARL
  - Proposition 65 levels—
    *[Note: Use only if no other health risk-based numeric thresholds are available.]*
    *Select the lowest of:*
    - No-Significant-Risk Level
    - Maximum Allowable Dose Level

- Human health risk-based numeric threshold that includes fish consumption exposure—
  *[Note: Applies only if there are no CTR or NTR criteria for human health protection.]*
  - USEPA National Recommended Water Quality Criteria (NRWQC) for human health protection
    *[Note: Use criteria for drinking water sources, consumption of water plus aquatic organisms, unless the MUN beneficial use has specifically been de-listed for the water body. If based on cancer risk, check that current cancer risk factors are used.]*
- Aquatic life protective numeric thresholds
  *Select the first available numeric threshold from the following hierarchy:*
  *[Note: Applies only if there are no CTR or NTR criteria for aquatic life protection.]*
  - California Department of Fish and Wildlife hazard evaluation or water quality criteria
    *[Note: If available, both the Criteria Continuous Concentration (CCC, normally 4-day average) and Criteria Maximum Concentration (CMC, normally 1-hour average) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied. Also note that freshwater criteria should be applied to water bodies with salinities less than 1 part per thousand and saltwater criteria should be applied to waters with salinities greater than 10 parts per thousand. For waters with salinities between 1 and 10 parts per thousand, the more stringent of the freshwater and saltwater criteria should be applied.]*
  - USEPA NRWQC for aquatic life protection
    *[Note: If available, both the Criteria Continuous Concentration (CCC, 4-day average or 24-hour average) and Criteria Maximum Concentration (CMC, 1-hour average or instantaneous maximum) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied. Also note that freshwater criteria should be applied to water bodies with salinities less than 1 part per thousand and saltwater criteria should be applied to waters with salinities greater than 10 parts per thousand.*

*For waters with salinities between 1 and 10 parts per thousand, the more stringent of the freshwater and saltwater criteria should be applied.]*

- ❖ Tastes and Odors Objective
  - ➢ Taste- and odor-based numeric threshold
    For MUN-designated waters, select the first available numeric threshold from the following hierarchy:
    - ♦ California Secondary MCL
    - ♦ Federal Secondary MCL
    - ♦ USEPA NRWQC based on taste & odor
    - ♦ Taste and odor thresholds published by other agencies or from the peer reviewed literature

For each constituent and parameter of interest, first, select one numeric threshold for each of the items above that begins with an arrow (➢). Record your selections in a table, such as the one shown in Figure 4. Second, select the most stringent numeric threshold from this table. (In the case of aquatic life criteria, both CCC and CMC limits apply, as noted above.) The result should be a conservative assessment threshold that satisfies all applicable water quality objectives and CWA 303(c) criteria. Where aquatic life criteria vary with hardness, pH, or other factors, aquatic life criteria may be the most restrictive under some conditions while other limits in the table may be more restrictive under other conditions. Consideration of natural background levels and antidegradation policies may require further modifications to this selection, as discussed below.

## FIGURE 4. INLAND SURFACE WATERS ASSESSMENT THRESHOLD ALGORITHM TABLE

| Water Quality Objective / Criterion | Relevant Portion of Objective / Criterion | Source | Concentration | Units |
|---|---|---|---|---|
| California Toxics Rule / National Toxics Rule | Human Health Protection | CTR or NTR | | |
| | Aquatic Life Protection – CCC | CTR or NTR | | |
| | Aquatic Life Protection – CMC | CTR or NTR | | |
| Chemical Constituents | Drinking Water MCL (lowest) | SWRCB-DDW | | |
| | Numerical Water Quality Objective | Basin Plan | | |
| | Beneficial Use Impairment Numeric Threshold | | | |
| Toxicity | Human Health – Drinking Water | | | |
| | Human Health – Fish Consumption | USEPA, NRWQC | | |
| | Aquatic Life Protection – CCC | | | |
| | Aquatic Life Protection – CMC | | | |
| Tastes & Odors | Taste & Odor Based Numeric Thresholds | | | |

## Assessment Threshold Algorithm for Enclosed Bays and Estuaries

Much of the information presented above for inland surface waters also applies to enclosed bays and estuaries. Similar constraints involving CTR and NTR criteria apply. Criteria for protection of aquatic life follow the same salinity considerations as presented for inland surface waters. Since municipal and domestic supply (MUN) is not normally a beneficial use of these waters, MCLs and water ingestion-based human health and taste/odor numeric thresholds do not apply. However, human health protective criteria involving ingestion of fish and shellfish do apply. Salinity of these waters normally precludes agricultural supply (AGR) uses.

For constituents and parameters in enclosed bays and estuaries, the following water quality objectives and numeric thresholds normally apply to the water body:

- US EPA California Toxics Rule and National Toxics Rule—
  *[Note: NTR criteria are listed in the Water Quality Goals online database under "California Toxics Rule Criteria" and footnoted accordingly.]*
  - Criteria for human health protection
    *[Note: Use criteria based on consumption of aquatic organisms only.]*
  - Criteria for aquatic life protection
    *[Note: Both the Criteria Continuous Concentration (CCC, 4-day average) and Criteria Maximum Concentration (CMC, 1-hour average) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied. Also note that freshwater criteria should be applied to water bodies with salinities less than 1 part per thousand and saltwater criteria should be applied to waters with salinities greater than 10 parts per thousand. For waters with salinities between 1 and 10 parts per thousand, the more stringent of the freshwater and saltwater criteria should be applied.]*
- Chemical Constituents Objective—
  - Numeric water quality objective from the Basin Plan
    *[Note: Site-specific objectives may supersede CTR or NTR criteria if approved by USEPA.]*
- Toxicity Objective
  - Human health risk-based numeric threshold based on fish consumption exposure—
    *[Note: Applies only if there are no CTR or NTR criteria for human health protection.]*
    - USEPA NRWQC for human health protection
      *[Note: Use criteria based on consumption of aquatic organisms only.]*
  - Aquatic life protective numeric thresholds—
    *Select the first available numeric threshold from the following hierarchy:*
    *[Note: Applies only if there are no CTR or NTR criteria for aquatic life protection.]*
    - California Department of Fish and Wildlife hazard evaluation or water quality criteria
      *[Note: If available, both the Criteria Continuous Concentration (CCC, normally 4-day average) and Criteria Maximum Concentration (CMC, normally 1-hour average) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied. Also note that freshwater criteria should be applied to water bodies with salinities less than 1 part per thousand and saltwater criteria should be applied to waters with salinities greater than 10 parts per thousand. For waters with salinities between 1 and 10 parts per thousand, the more stringent of the freshwater and saltwater criteria should be applied.]*
    - USEPA NRWQC for aquatic life protection
      *[Note: If available, both the Criteria Continuous Concentration (CCC, 4-day average or 24-hour average) and Criteria Maximum Concentration (CMC, 1-hour average or*

*instantaneous maximum) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied. Also note that freshwater criteria should be applied to water bodies with salinities less than 1 part per thousand and saltwater criteria should be applied to waters with salinities greater than 10 parts per thousand. For waters with salinities between 1 and 10 parts per thousand, the more stringent of the freshwater and saltwater criteria should be applied.]*

For each constituent and parameter of interest, first, select one numeric threshold for each of the items above marked with an arrow (➢). Record your selections in a table, such as the one shown in Figure 5. Second, select the most stringent numeric threshold from this table. (In the case of aquatic life criteria, both CCC and CMC values apply, as noted above.) The result should be a conservative assessment threshold that satisfies all applicable water quality objectives and CWA 303(c) criteria. Where aquatic life protective criteria vary with temperature, pH, or other factors, aquatic life criteria may be the most restrictive under some conditions while other numeric thresholds in the table may be more restrictive under other conditions. Consideration of natural background levels and antidegradation policies may require further modifications to this selection, as discussed below.

### FIGURE 5. ENCLOSED BAYS AND ESTUARIES ASSESSMENT THRESHOLD ALGORITHM TABLE

| Water Quality Objective / Criterion | Relevant Portion of Objective / Criterion | Source | Concentration | Units |
|---|---|---|---|---|
| California Toxics Rule / National Toxics Rule | Human Health Protection | CTR or NTR | | |
| | Aquatic Life Protection – CCC | CTR or NTR | | |
| | Aquatic Life Protection – CMC | CTR or NTR | | |
| Chemical Constituents | Numerical Water Quality Objective | Basin Plan | | |
| Toxicity | Human Health – Fish Consumption | USEPA, NRWQC | | |
| | Aquatic Life Protection – CCC | | | |
| | Aquatic Life Protection – CMC | | | |

## Assessment Threshold Algorithm for Ocean (Marine) Waters

Similar to enclosed bays and estuaries, numeric thresholds that apply to ocean waters are mainly focused on protecting aquatic life and protecting human health from consumption of fish and shellfish. While USEPA CTR and NTR criteria apply to inland surface waters and enclosed bays and estuaries, water quality objectives from the *California Ocean Plan* apply to ocean waters. Ocean Plan objectives should normally be applied in lieu of recommended or guidance levels to implement a narrative Toxicity objective. Saltwater aquatic life protective criteria apply to ocean waters. Since municipal and domestic supply (MUN) is not a beneficial use of these waters, MCLs and water-ingestion human health and taste/odor numeric thresholds do not normally apply. Salinity of these waters precludes agricultural supply (AGR) uses.

For chemical constituents and parameters in ocean waters, the following water quality objectives and numeric thresholds normally apply to the receiving water:

- ❖ California Ocean Plan
  - ➢ Objectives for human health protection
  - ➢ Objectives for marine aquatic life protection
    *[Note: Objectives with various averaging periods apply. Sampling frequency should allow determination that all types of objectives are satisfied.]*

- ❖ Chemical Constituents Objective
  - ➢ Numeric water quality objective from the Basin Plan
- ❖ Toxicity Objective
  - ➢ Human health risk-based numeric threshold based on fish consumption exposure
    *[Note: Applies only if there are no Ocean Plan objectives for human health protection.]*
    - ♦ USEPA NRWQC for human health protection
      *[Note: Use criteria based on consumption of aquatic organisms only.]*
  - ➢ Aquatic life protective numeric thresholds
    *Select the first available numeric threshold from the following hierarchy:*
    *[Note: Applies only if there are no Ocean Plan objectives for marine aquatic life protection.]*
    - ♦ California Department of Fish and Wildlife hazard evaluation or water quality criteria
      *[Note: If available, both the Criteria Continuous Concentration (CCC, normally 4-day average) and Criteria Maximum Concentration (CMC, normally 1-hour average) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied.]*
    - ♦ USEPA NRWQC for saltwater aquatic life protection
      *[Note: If available, both the Criteria Continuous Concentration (CCC, normally 4-day average or 24-hour average) and Criteria Maximum Concentration (CMC, 1-hour average or instantaneous maximum) criteria apply. Sampling frequency should allow determination that both types of criteria are satisfied.]*

First, select one numeric threshold for each of the items above that begins with an arrow (➢). Record your selections in a table, such as the one shown in Figure 6. Second, select the most stringent numeric threshold from the table. (In the case of aquatic life criteria, numeric thresholds with various averaging periods may apply, as noted above.) The result should be a conservative assessment threshold that satisfies all applicable water quality objectives and CWA 303(c) criteria. Where aquatic life protective criteria vary with temperature, pH, or other factors, aquatic life criteria may be the most restrictive under some conditions while other numeric thresholds in the table may be more restrictive under other conditions. Consideration of natural background levels and antidegradation policies may require further modifications to this selection, as discussed below.

## FIGURE 6. OCEAN WATERS ASSESSMENT THRESHOLD ALGORITHM TABLE

| Water Quality Objective / Criterion | Relevant Portion of Objective / Criterion | Source | Concentration | Units |
|---|---|---|---|---|
| California Ocean Plan | Human Health Protection | Ocean Plan | | |
| | Marine Aquatic Life Protection – 6-month median | Ocean Plan | | |
| | Marine Aquatic Life Protection – daily maximum | Ocean Plan | | |
| | Marine Aquatic Life Protection – instantaneous maximum | Ocean Plan | | |
| Chemical Constituents | Numerical Water Quality Objective | Basin Plan | | |
| Toxicity | Human Health – Fish Consumption | USEPA, NRWQC | | |
| | Aquatic Life Protection – CCC | | | |
| | Aquatic Life Protection – CMC | | | |

## Limitations and Further Assistance

The above algorithms should be applied carefully, considering the factors of each specific case. Automatically selecting numeric assessment thresholds according to these algorithms will not always generate the most appropriate threshold. If certain beneficial uses do not apply, then numeric thresholds protective of those uses should not be considered. To ensure defensibility, it may be appropriate to deviate from the hierarchies in the algorithms described above in specific cases. For example, a particular numeric threshold may be outdated or is in formal dispute at the agency or authority that published the numeric threshold (as was the case with the former Public Health Goal for chromium at OEHHA).

In another example, a California health-based numeric threshold may be less stringent than a comparable USEPA numeric threshold. As discussed above, consistency within California government would normally favor the California numeric threshold over the one from USEPA. However, if the California and USEPA numeric thresholds are based on the same toxicologic information and the California numeric threshold is higher simply because it was "rounded off" from the USEPA numeric threshold, it may be appropriate to use the more precise USEPA numeric threshold. It may also be that a risk-management decision prevented the California numeric threshold from being set at the same level as the USEPA numeric threshold, which would favor using the USEPA threshold.

What these examples show is that, while an algorithm may be useful to guide the selection process, other information and good judgment are needed to select the most appropriate assessment thresholds. To maintain defensibility, arbitrary selection of numeric thresholds must be avoided. Selection should be based on sound rationale and should consider the circumstances of each case. The *Guiding Principles* section above may be consulted to provide the basis for such rationale. Documentation of the rationale is very important, should the decision to use a particular numeric threshold be challenged or appealed.

Footnotes in the Water Quality Goals online database explain limitations on how the numeric thresholds should be applied and provide other useful information. Before using the numeric thresholds, these footnotes should be reviewed to determine the relevance of the limit for the particular situation of interest.

To assist the user in selecting numeric assessment thresholds based on the above algorithms, a table of limiting thresholds for Step 1 of the selection process (select a single numeric threshold to satisfy each water quality objective/303(c) criterion or relevant portion thereof) has been generated for a number of commonly encountered constituents, based on the format of Figures 3, 4, 5, and 6 above. The table *Water Quality-Based Assessment Thresholds* may be found on the Internet at http://www.waterboards.ca.gov/water_issues/programs/water_quality_ goals/. Limiting numeric thresholds for groundwater, inland surface waters, enclosed bays and estuaries and ocean waters are identified. The table does not include numeric water quality objectives from the Basin Plans, because these vary from location to location and Region to Region. Make sure to consult the appropriate Basin Plan and add numeric objectives applicable to your particular situation. The table also identifies which numeric thresholds apply to each beneficial use category. This table will be updated on a regular basis.

As stated above, conservative assessment thresholds may not be appropriate in all circumstances. A case-by-case evaluation of factors relevant to the individual situation, and in most cases Board action, are needed to establish appropriate regulatory limitations.

## Controllable Factors and Antidegradation Policies

Thus far, the selection of assessment thresholds has only considered compliance with water quality objectives (both numeric and narrative) and CWA 303(c) water quality criteria (CTR and NTR). Additional factors govern the selection of assessment thresholds. According to the Basin Plans' policy statements, controllable water quality factors are not allowed to cause further degradation of water quality in instances where other factors have already resulted in water quality objectives being exceeded. Controllable water quality factors are those actions, conditions, or circumstances resulting from human activities that may influence the quality of the waters of the state, that are subject to the authority of the Water Boards, and that may be reasonably controlled.

Natural background water quality is an example of a water quality factor that is not "controllable." Where natural background water quality exceeds a water quality objective or the numeric threshold chosen to implement a narrative objective, controllable factors policy statements in some Basin Plans do not require improvement over the natural condition. *[Note: This would not apply to federal CWA 303(c) criteria or to any State Water Board-adopted water quality objectives.]* In addition, these policy statements prohibit allowing controllable factors to make the condition worse.

For example, if the natural background concentration of a substance exceeds a water quality objective, the Water Boards would not normally require that these background conditions be improved, and the natural concentration would be chosen as the applicable numeric threshold for the water body. Arsenic presents a common example. Naturally occurring arsenic in groundwater in many places in California exceeds health-based numeric thresholds (e.g., the PHG) and in some locations exceeds the MCL. In such cases, these background concentrations are normally considered to comply with the applicable water quality objectives. This also highlights cases where the Regional Water Board should consider amending beneficial use designations and/or adopting site-specific water quality objectives.

If there is a chance that local background water quality has been influenced by controllable factors (e.g., an upstream or upgradient discharge of waste), then the water quality objective, or numeric threshold chosen to implement the narrative objective, must be implemented. This latter situation is the default assumption for setting effluent limits in the NPDES program, as governed by the SIP, discussed above.

State Water Board Resolution No. 68-16, the state's Antidegradation Policy, requires that the quality of high quality waters be maintained "to the maximum extent possible." High quality means that the water is of better quality than water quality objectives for the constituent or parameter in question. This needs to be evaluated on a constituent-by-constituent basis. The policy allows water quality to be lowered but only if the discharger demonstrates that any change will:

1) be consistent with the maximum benefit to the people of the state;
2) not unreasonably affect the water's present and anticipated beneficial uses; and
3) not result in water quality less than applicable water quality objectives.

In addition, the policy requires that discharges of waste to high quality waters meet "best practicable treatment or control" prior to discharge. If reasonably available technology can achieve constituent concentrations that are better than water quality objectives, then the Water Boards should require that the lower technology-based concentrations be met.

In the NPDES permit program, the state antidegradation policy is implemented consistent with the federal antidegradation policy in 40 CFR Section 131.12. If a decrease in water quality is allowed under the federal policy, the permit must include all applicable technology-based and water quality-based effluent limits for the relevant pollutant or pollutants of concern.

In site cleanup, State Water Board Resolution No. 92-49 affirmed the applicability of the Antidegradation Policy to the process of setting site cleanup levels. Cleanup levels must meet all applicable water quality objectives and must be the lowest concentrations that are technologically and economically achievable. In cases where cleanup technology cannot reasonably meet water quality objectives, Resolution No. 92-49 allows the Regional Water Board to establish a containment zone to manage residual pollution. A further discussion on cleanup levels is presented below.

In summary, if some water quality degradation is not found to be consistent with maximum benefit to the people of the state or does not represent best practicable treatment or control, strict application of California's Antidegradation Policy would require that background levels of chemicals in water be selected as appropriate assessment thresholds. Pursuant to Resolution 92-49, cleanup of water to meet background levels would be required unless attaining such levels is determined to be technologically or economically infeasible. If cleanup levels higher than background are selected, those levels may not exceed applicable water quality standards, i.e., they should not exceed the assessment thresholds.

## Detection and Quantitation Limits

Analytical detection and quantitation limits may provide additional technologic constraints. When the assessment threshold is lower than what can be quantified with appropriate analytical methods, the laboratory should be required to submit both detection and quantitation limits and to report "trace" results—results that are able to be detected but not necessarily quantified. For normal analytical work, quantitation limits may be found in the following references:

1) Minimum Levels (MLs), State Water Board, Policy for Implementation of Toxics Standards for Inland Surface Waters, Enclosed Bays, and Estuaries of California (2005), Appendix 4, available on the Internet at http://www.waterboards.ca.gov/water_issues/programs/state_implementation_policy/.
2) Minimum Levels (MLs), State Water Board, Water Quality Control Plan for Ocean Waters of California (2005), Appendix II, available on the Internet at http://www.waterboards.ca.gov/water_issues/programs/ocean/.
3) Detection Limits for Purposes of Reporting (DLRs), Division of Drinking Water, available on the Internet at http://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Labinfo.shtml.

Detection and quantitation limits may also be found in the analytical method manuals from USEPA. Not all laboratories are equipped to run all of the methods contained in these references.

4) Method Detection Limits (MDLs) Practical Quantitation Limits (PQLs), USEPA analytical method documents, available on the Internet at http://www.nemi.gov/.
   a) SW-846, *Test Methods for Evaluating Solid Waste* (also contains methods for water samples)
   b) *Methods and Guidance for Analysis of Water*

If available methods cannot detect sufficiently low concentrations to determine compliance with the assessment threshold, then it may be necessary to assume that the constituent is not present in the sample. Methods with lower detection and quantitation limits may need to be specified for certain situations. The need for the information should balance the higher cost of such methods. For example, more expensive methods could be reserved for confirmation sampling or be required at a lower frequency. This is in keeping with Section 13267(b) of the California Water Code which instructs that the Water Boards, when requiring dischargers of waste to furnish technical reports, "[t]he burden, including costs, of these reports shall bear a reasonable relationship to the need for the report and the benefits to be obtained from the reports."

## Justification

The selection of assessment thresholds for a particular case should be carefully documented. To be defensible, the assessment threshold selected for each constituent must be tied back to a numeric or narrative water quality objective from the Basin Plan or to a CWA 303(c) water quality criterion. Cite the factors used in selecting numeric thresholds to apply narrative objectives and to address uncontrollable factors and antidegradation policies. Include specific rationale in the documentation (e.g., that the selected numeric threshold is the most recently developed numeric threshold; that its use supports and is consistent with guidance from sister California agencies; that it has been peer reviewed; and that it addresses routes of exposure that are directly related to the beneficial use(s) being protected). The descriptions of the types of numeric thresholds and the *Guiding Principles*, presented above, should be helpful in developing this documentation. The full justification for selected assessment thresholds should be included in the findings and/or the Information Sheet of proposed permits, waste discharge requirements, and other Board orders.

### An Example of Assessment Threshold Selection

Suppose that you are investigating a site where a waste oil tank has leaked into the surrounding soils. Groundwater sampling results indicate that zinc, trichloroethylene (TCE), benzene, and xylene have reached groundwater. You want to know whether the levels of constituents detected in water samples are of concern.

The first step is to look at the Basin Plan for the particular Region in which your site is located. Upon examination of that document, you determine that the beneficial uses designated for groundwater beneath the site are municipal and domestic supply (MUN) and agricultural supply (AGR). No numeric groundwater quality objectives are listed in the Basin Plan for the constituents of concern. However, three narrative objectives apply:

- Chemical Constituents

  Groundwaters shall not contain chemical constituents in concentrations that adversely affect beneficial uses.

  At a minimum, groundwaters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of chemical constituents in excess of the maximum contaminant levels (MCLs) specified in Title 22 of the California Code of Regulations.

- Toxicity

  Groundwaters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life associated with designated beneficial use(s). This objective applies regardless of whether the toxicity is caused by a singled substance or the interactive effect of multiple substances.

- Tastes and Odors

  Groundwaters shall not contain taste or odor-producing substances in concentrations that cause nuisance or adversely affect beneficial uses.

Together, these beneficial uses (MUN and AGR) and the three narrative water quality objectives constitute the water quality standards for groundwater at the site.

The next step is to select assessment thresholds for each constituent, based on the narrative objectives. The Water Quality Goals online database contains an extensive set of numeric thresholds that may be relevant to this example. First, we will review these numeric thresholds to determine those that appear to be most appropriate to implement the identified water quality objectives. Second, we will apply the groundwater algorithm to see whether it achieves an equivalent assessment threshold.

The Chemical Constituents objective from the Basin Plan incorporates by reference California maximum contaminant levels (MCLs) for drinking water. Since the Basin Plans typically do not differentiate between Primary and Secondary MCLs, both types of levels apply. They are:

| | |
|---|---|
| Zinc | 5000 ug/L |
| TCE | 5 ug/L |
| Benzene | 1 ug/L |
| Xylene | 1750 ug/L |

The Chemical Constituents water quality objective also prohibits chemical constituents in concentrations that adversely affect beneficial uses. A review of available numeric thresholds shows that one of the constituents of concern for this site has a numeric threshold that relates to the use of water for the agricultural supply beneficial use. An agricultural water use threshold for zinc is 2000 ug/L. Agricultural use protective numeric thresholds are not available for the organic solvents, TCE, benzene and xylene. Note that the zinc agricultural use threshold (2000 ug/L) is more stringent than the MCL (5000 ug/L). This indicates that MCLs are not necessarily protective of sensitive agricultural uses of water.

To protect long-term municipal water use, federal drinking water MCLs that are lower than California MCLs are also relevant numeric thresholds. However, federal MCLs for benzene (5 ug/L) and xylene (10,000 ug/L) are less stringent than the respective California MCLs. Federal MCLs for zinc and TCE are equivalent to their respective California MCLs.

The water quality objective for Toxicity requires that toxic substances not be present in water in amounts that cause detrimental physiological responses in humans or other organisms associated with beneficial uses. Human health-based numeric thresholds for drinking water exposures are relevant values to consider because humans using the groundwater for municipal or domestic water supply could experience toxic effects if exposed to the chemicals of concern above these numeric thresholds. Health-based NRWQC and CTR/NTR criteria from USEPA are not relevant to consider for this case, since they are based on the assumption that exposure occurs through ingestion of contaminated fish and shellfish in addition to water consumption. The fish and shellfish consumption exposure route is not normally relevant for groundwater.

Relevant health-based numeric thresholds for zinc include the following:

| | |
|---|---|
| USEPA IRIS Reference Dose | 2100 ug/L |
| USEPA Health Advisory | 2000 ug/L |

IRIS numeric thresholds are usually preferred over USEPA health advisories, because IRIS is intended to reflect USEPA's most recent health risk information. In this case, the health advisory was derived from the IRIS reference dose by rounding to one significant figure.

Relevant health-based numeric thresholds for TCE include:

| | | |
|---|---|---|
| Primary MCL | 5 | ug/L |
| California Public Health Goal | 1.7 | ug/L |
| USEPA IRIS Reference Dose | 3.5 | ug/L |
| Cal/EPA Cancer Potency Factor | 5.9 | ug/L |
| USEPA IRIS Cancer Risk Level | 0.5 | ug/L |
| USEPA Health Advisory – cancer | 3 | ug/L |
| NAS cancer risk level | 1.5 | ug/L |
| Prop. 65 No Significant Risk Level | 7 | ug/L |

The MCL is not purely health based because it was set equal to the quantitation limit of an older analytical method. The Proposition 65 no significant risk level is based on the less-appropriate $10^{-5}$ cancer risk level. All of the remaining numeric thresholds are based on the $10^{-6}$ cancer risk level. In USEPA's IRIS database, the reference dose is less stringent than the cancer risk level, indicating that cancer risk is a more limiting health effect. To be consistent with other California government agencies, the California-derived numeric thresholds (the PHG and the Cal/EPA cancer potency factor) are preferred over USEPA and NAS numeric thresholds for use in California. The PHG is more protective than the Cal/EPA cancer potency factor because the PHG includes exposure through inhalation and dermal contact caused by in-home water use in addition to direct ingestion of water. The NAS criterion from *Drinking Water and Health* is least relevant because it is much older than the other numeric thresholds, and because it was "based on limited evidence," as indicated in a footnote in the Water Quality Goals online database.

Relevant health-based numeric thresholds for benzene include:

| | | |
|---|---|---|
| California Primary MCL | 1 | ug/L |
| USEPA Primary MCL | 5 | ug/L |
| California Public Health Goal | 0.15 | ug/L |
| USEPA IRIS Reference Dose | 28 | ug/L |
| USEPA Health Advisory | 3 | ug/L |
| Cal/EPA Cancer Potency Factor | 0.35 | ug/L |
| USEPA IRIS Cancer Risk Level | 1 to 10 | ug/L |
| USEPA Health Advisory – cancer | 1 to 10 | ug/L |
| Prop. 65 No Significant Risk Level | 3.2 | ug/L |
| Prop. 65 Max. Allowable Dose Level | 12 | ug/L |

The USEPA Primary MCL is not purely health based because it was set equal to the quantitation limit of an older analytical method. The Proposition 65 No Significant Risk Level is based on the less-appropriate $10^{-5}$ cancer risk level. The Proposition 65 Maximum Allowable Dose Level, the USEPA IRIS reference dose, and the USEPA health advisory are significantly higher than the cancer based numeric thresholds, so they do not protect against significant cancer risks. The California Primary MCL may not be purely health protective by comparison to the PHG. Of the remaining numeric thresholds, the PHG is the most recent California-derived numeric threshold. The Cal/EPA cancer potency factor is less health protective because it does not account for inhalation and dermal exposures associated with in-home water use that were included in calculation of the PHG.

Health-based numeric thresholds for xylene include:

| | |
|---|---|
| California Primary MCL | 1750 ug/L |
| USEPA Primary MCL | 10,000 ug/L |
| USEPA MCL Goal | 10,000 ug/L |
| California Public Health Goal | 1800 ug/L |
| USEPA IRIS Reference Dose | 1400 ug/L |
| USEPA Health Advisory | 1400 ug/L |

The USEPA IRIS reference doses and health advisory are the most stringent and most recent numeric thresholds. However, California derived numeric thresholds are preferred for consistency within California government. *[Note: When newer USEPA numeric thresholds differ significantly from OEHHA thresholds, it is recommended that OEHHA staff be contacted to determine whether newer information would adjust their recommended threshold.]* The California Primary MCL and the PHG are virtually identical numeric thresholds, with the PHG being published more recently. The difference between these two numeric thresholds reflects only the number of significant figures used.

In summary, appropriate health-based numeric thresholds for use in implementing the Toxicity water quality objective for the constituents of concern in groundwater in our example are as follows:

| | | | |
|---|---|---|---|
| Zinc | 2100 | ug/L | USEPA IRIS RfD |
| TCE | 1.7 | ug/L | California Public Health Goal |
| Benzene | 0.15 | ug/L | California Public Health Goal |
| Xylene | 1800 | ug/L | California Public Health Goal |

The third narrative water quality objective, Tastes and Odors, requires that water not contain substances that could impart objectionable tastes or odors to water supplies. As established earlier, beneficial uses of groundwater beneath our site include municipal and domestic supply. Taste- and odor-based (organoleptic) levels include:

- California and federal Secondary MCLs;
- USEPA National Recommended Water Quality Criteria based on taste & odor or welfare; and
- Other taste and odor thresholds from the scientific and regulatory literature.

For the constituents of concern, taste- and odor- based numeric thresholds are:

| | |
|---|---|
| Zinc | 5000 ug/L |
| TCE | 310 ug/L |
| Benzene | 170 ug/L |
| Xylene | 17 ug/L |

Note that xylene can make water taste or smell bad at a concentration that is more than 100-fold lower than the health-based MCL. The USEPA Secondary MCL for xylene, at 20 ug/L, was actually rounded from and is slightly higher than the taste and odor threshold. However, it should not be cited as it is only a proposed level.

So far, we have reviewed the available numeric thresholds and selected those that appear to be the most appropriate to apply each of the applicable narrative water quality objectives for each constituent of concern. Following the groundwater algorithm achieves the same result. Selecting a numeric threshold for each constituent and for each arrow bullet in the algorithm leads to the list of numeric thresholds in Figure 7.

The most stringent of these numeric thresholds for each constituent of concern would ensure compliance with all water quality objectives and should protect all applicable beneficial uses. Therefore, the assessment thresholds for the constituents of concern in groundwater at our leaking waste oil tank site are:

| | | | |
|---|---|---|---|
| Zinc | 2000 | ug/L | Agricultural Use Limit |
| TCE | 1.7 | ug/L | California Public Health Goal |
| Benzene | 0.15 | ug/L | California Public Health Goal |
| Xylene(s) | 17 | ug/L | Taste & Odor Threshold |

Measured concentrations in groundwater that exceed these assessment thresholds may violate applicable water quality standards.

The reader is cautioned that these assessment thresholds would apply to groundwater at the hypothetical site in this example, and not necessarily to water bodies in other locations. Water resources at other sites may have different beneficial use designations and water quality objectives than presented in this example.

Consideration of natural background levels and antidegradation policies may require further modifications to this selection, as discussed above under *Controllable Factors and Antidegradation Policies*. In the above example, the solvents—TCE, benzene and xylene(s)—are not normally present naturally in groundwater. So, aquifer-specific background levels are not relevant to beneficial use protection and natural background levels are considered to be “zero.”

### FIGURE 7. EXAMPLE NUMERIC THRESHOLDS FOR CONSTITUENTS OF CONCERN (COCs)

| COC | Water Quality Objective / Criterion | Relevant Portion of Objective / Criterion | Source | Concen-tration | Units |
|---|---|---|---|---|---|
| Zinc | Chemical Constituents | Secondary Drinking Water MCL | CA DDW, Title 22 of CCR | 5000 | ug/L |
| | | Numerical Water Quality Objective | Basin Plan | none | |
| | | Beneficial Use Impairment Numeric Threshold | Water Quality for Agriculture | 2000 | ug/L |
| | Toxicity | Human Health -- Drinking Water | USEPA IRIS Reference Dose | 2100 | ug/L |
| | Tastes and Odors | Taste & Odor Based Numeric Threshold | California Secondary MCL | 5000 | ug/L |
| TCE | Chemical Constituents | Primary Drinking Water MCL | CA DDW, Title 22 of CCR | 5 | ug/L |
| | | Numerical Water Quality Objective | Basin Plan | none | |
| | | Beneficial Use Impairment Numeric Threshold | | none | |
| | Toxicity | Human Health -- Drinking Water | California Public Health Goal | 1.7 | ug/L |
| | Tastes and Odors | Taste & Odor Based Numeric Threshold | Amoore and Hautala | 310 | ug/L |
| Benzene | Chemical Constituents | Primary Drinking Water MCL | CA DDW, Title 22 of CCR | 1 | ug/L |
| | | Numerical Water Quality Objective | Basin Plan | none | |
| | | Beneficial Use Impairment Numeric Threshold | | none | |
| | Toxicity | Human Health -- Drinking Water | California Public Health Goal | 0.15 | ug/L |
| | Tastes and Odors | Taste & Odor Based Numeric Threshold | Amoore and Hautala | 170 | ug/L |
| Xylene(s) | Chemical Constituents | Primary Drinking Water MCL | CA DDW, Title 22 of CCR | 1750 | ug/L |
| | | Numerical Water Quality Objective | Basin Plan | none | |
| | | Beneficial Use Impairment Limit | | none | |
| | Toxicity | Human Health -- Drinking Water | California Public Health Goal | 1800 | ug/L |
| | Tastes and Odors | Taste & Odor Based Limit | USEPA | 17 | ug/L |

## ADDITIVE TOXICITY CRITERION FOR MULTIPLE CONSTITUENTS

When multiple constituents have been found together in groundwater or surface waters, their combined toxicity should be evaluated. In the absence of scientifically valid data to the contrary, Section 2550.4(g) of the Chapter 15, Article 5 regulations, which is referenced in the State Water Board's *Site Investigation and Cleanup Policy*, requires that theoretical risks from chemicals found together in a water body "shall be considered additive for all chemicals having similar toxicologic effects or having carcinogenic effects." Some Water Quality Control Plans also require that combined toxicological effects be considered in this manner. This requirement is also found in the California hazardous waste management regulations [Title 22 of CCR, Section 66264.94(f)], and in the USEPA Risk Assessment Guidance for Superfund (RAGS).

The commonly used toxicologic formula for assessing additive risk is:

$$\sum_{i=1}^{n} \frac{[\text{Concentration of Constituent}]_i}{[\text{Toxicologic Threshold in Water}]_i} < 1.0$$

The concentration of each constituent is divided by its toxicologic threshold. The resulting ratios—normalized concentrations—are added for constituents having similar toxicologic effects and, separately, for carcinogens. If the sum is less than one (1.0), no additive toxicity problem is assumed to exist. If the summation is equal to or greater than one, the combination of chemicals is assumed to pose an unacceptable level of health risk unless the State or Regional Water Board is presented with convincing information to the contrary.

For example, in our leaking waste oil tank example discussed above, monitoring shows that groundwater quality beneath the site has been degraded by four constituents of concern in the following concentrations:

| | | |
|---|---|---|
| Zinc | 1300 | ug/L |
| TCE | 1.5 | ug/L |
| Benzene | 0.1 | ug/L |
| Xylene | 9 | ug/L |

None of these concentrations exceeds its respective assessment threshold. However, two of these constituents, TCE and benzene, are associated with cancer risk. The Public Health Goals for TCE and benzene were established at their respective one-in-a-million incremental cancer risk levels:

| | | |
|---|---|---|
| TCE | 1.7 | ug/L |
| Benzene | 0.15 | ug/L |

Individually, no chemical exceeds its toxicologic limit. However, an additive cancer risk calculation shows:

$$\frac{1.5}{1.7} + \frac{0.1}{0.15} = 1.5$$

The sum of the ratios is greater than unity (>1.0); therefore, the additive toxicity criterion has been violated. The chemicals together may present an unacceptable level of toxicity—in this case, an overall cancer risk greater than one-in-a-million.

## Cleanup Levels in Water

If contaminants are found to impair or threaten the beneficial uses of groundwater or surface water resources, cleanup levels in water must be chosen. To satisfy State Water Board Resolution No. 92-49, the Antidegradation Policy, and Section 2550.4 of Title 23 of CCR, cleanup levels for constituents in water are to be chosen at or below applicable water quality objectives and CWA 303(c) criteria. Assessment thresholds, selected using the procedures discussed above, may be used to determine that constituents remaining after cleanup do not exceed these objectives and CWA 303(c) criteria. In addition, cleanup levels must also:

- Not result in excessive exposure to sensitive biological receptors;
- Not pose a substantial present or potential hazard to human health or the environment;
- Not exceed the maximum concentration allowable under applicable statutes or regulations; and
- Be the lowest concentration for each individual constituent that is technologically and economically achievable, toward background levels.

Conventional health and ecological risk assessment procedures can be used to satisfy the first and second of these additional requirements. Feasibility studies provide information that can be used to satisfy the last requirement.

## Conclusion and Status

This staff report and the accompanying Water Quality Goals online database have been developed to provide a uniform method and a convenient source of numeric thresholds for consistently assessing conformity with California's water quality standards. Water Quality Goals has been used by the Water

Boards as a reference for selecting appropriate numeric thresholds to implement narrative water quality objectives.  Three Basin Plans (San Francisco Bay, Sacramento-San Joaquin River, and Tulare Lake) specifically cite *Water Quality Goals* as a source of such information.

*A Compilation Water Quality Goals* will be updated and expanded to account for newly developed numeric water quality information, as needed and as Water Board staff resources are made available for that effort.

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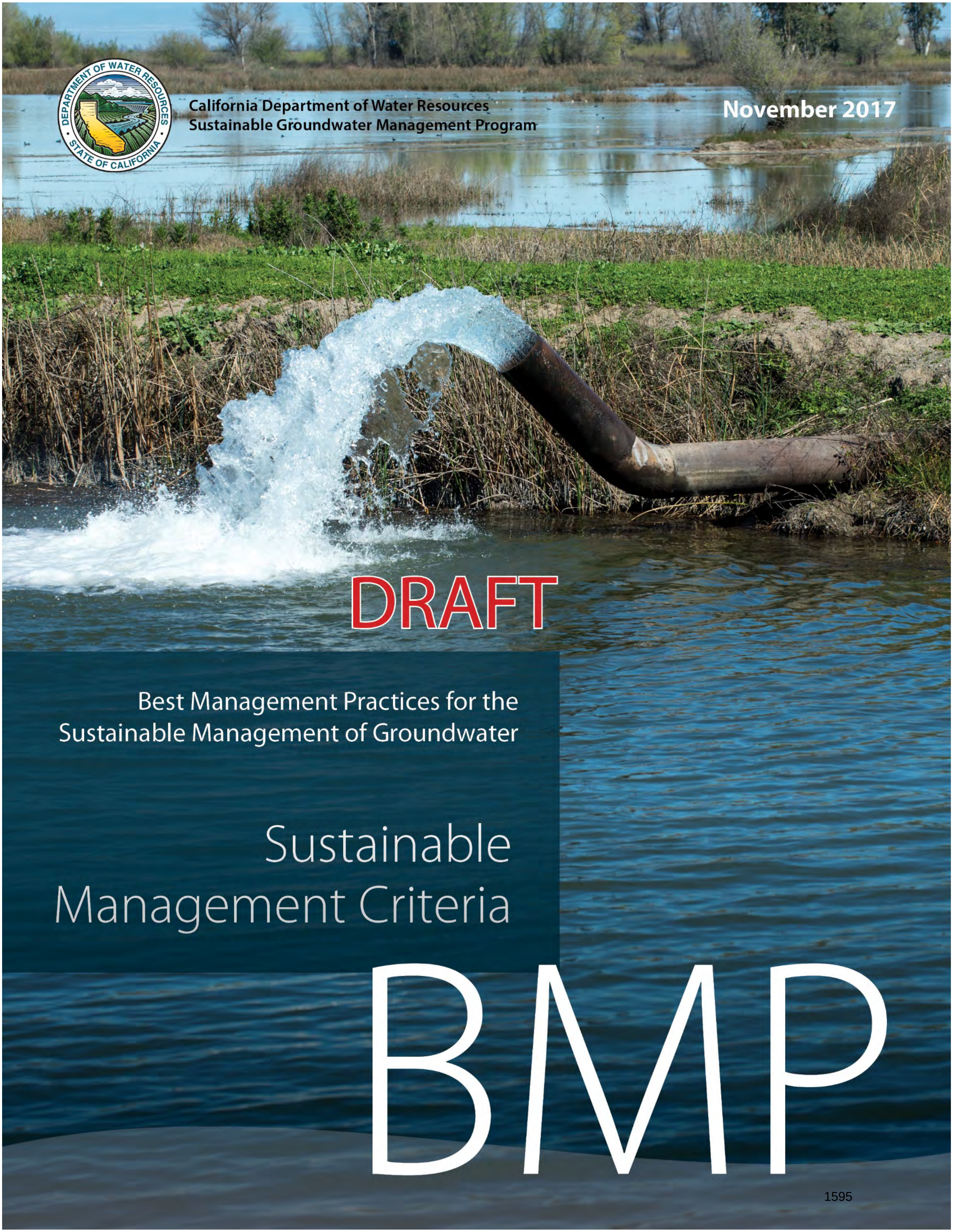
Updated as of: SEPT 2013

# Appendix 3B

## DWR Sustainable Management Criteria BMP



California Department of Water Resources
Sustainable Groundwater Management Program

November 2017

DRAFT

Best Management Practices for the Sustainable Management of Groundwater

# Sustainable Management Criteria

# BMP

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*Sustainable Management Criteria*
*Best Management Practice*

## 1. OBJECTIVE

The Department of Water Resources (the Department) developed this Best Management Practice (BMP) document to describe activities, practices, and procedures for defining the sustainable management criteria required by the Groundwater Sustainability Plan Regulations (GSP Regulations).[1] This BMP characterizes the relationship between the different sustainable management criteria – the *sustainability goal*, *undesirable results*, *minimum thresholds*, and *measurable objectives* – and describes best management practices for developing these criteria as part of a Groundwater Sustainability Plan (GSP).

The Sustainable Groundwater Management Act (SGMA)[2] and GSP Regulations specify the requirements of a GSP. This BMP does not impose new requirements, but describes best management practices for satisfying the requirements of SGMA and the GSP Regulations. A Groundwater Sustainability Agency (GSA) is not required to follow this BMP when developing a GSP, but whatever methodology is adopted by a GSA must be reasonable and supported by the best available information and best available science.[3] While this document describes methods by which a GSA may approach the task of establishing sustainable management criteria recommended as best management practices by the Department, adopting the methods recommended in this BMP does not guarantee approval of the resulting GSP by the Department.

Examples provided in this BMP are intentionally simplified and are intended only to illustrate concepts. GSAs should not consider the level of detail in any of these simplified examples (e.g., the number of minimum thresholds defined in a hypothetical basin, the number of minimum thresholds that constitute an undesirable result, etc.) to be appropriate for their GSP.

## 2. INTRODUCTION

SGMA defines *sustainable groundwater management* as the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.[4] The avoidance of undesirable results is thus critical to the success of a GSP.

GSP Regulations collect together several requirements of a GSP under the heading of "Sustainable Management Criteria" in Subarticle 3 of Article 5.[5] Sustainable management criteria include:

- **Sustainability Goal**

- **Undesirable Results**
- **Minimum Thresholds**
- **Measurable Objectives**

The development of these criteria relies upon information about the basin developed in the *hydrogeologic conceptual model*, the description of current and historical groundwater conditions, and the *water budget*.

Key terms are *italicized* the first time they are presented, indicating that a definition for the term is provided in the Key Definitions section located at the end of this document.

## SGMA Requirement to Quantify Sustainability

The enactment of SGMA in 2014 was a landmark effort to manage California's groundwater in a sustainable manner. The SGMA legislation established definitions of undesirable results, introduced the statutory framework and timelines for achieving sustainability, and identified requirements that local agencies (i.e. GSAs) must follow to engage the beneficial uses and users of groundwater within a basin, among many other important topics. The GSP Regulations developed by the Department specify the documentation and evaluation of groundwater conditions within a basin and the requirements for the development and implementation of plans to achieve or maintain sustainability required by SGMA.

As described in SGMA, sustainable conditions within a basin are achieved when GSAs meet their sustainability goal and demonstrate the basin is being operated within its *sustainable yield*. Sustainable yield can only be reached if the basin is not experiencing undesirable results. The GSP Regulations focus the development of GSPs on locally-defined, quantitative criteria, including undesirable results, minimum thresholds, and measurable objectives. Undesirable results must be eliminated through the implementation of projects and management actions, and progress toward their elimination will be demonstrated with empirical data (e.g., measurements of groundwater levels or subsidence). Quantitative sustainable management criteria allow GSAs to clearly demonstrate sustainability and allow the public and the Department to readily assess progress.

Properly documenting the requirements identified in Subarticle 3, Introduction to Sustainable Management Criteria, in Article 5 of the GSP Regulations, is imperative to maintaining an outcome-based approach to SGMA implementation and must be completed for the Department to consider the approval of a GSP.

# 3. PRELIMINARY ACTIVITIES

A GSA will need to understand the basin's physical condition, the overlying management and legal structures, and the basin's water supplies and demands prior to developing sustainable management criteria. As a result, before a GSA begins the process of developing sustainable management criteria, the following activities should be completed:

### *Understand the Basin Setting*

A thorough understanding of the historical and current state of the basin is necessary before sustainable management criteria can be set. Much of this understanding is gained in the development of a hydrogeologic conceptual model, water budget, and description of groundwater conditions. For more information, see the Hydrogeologic Conceptual Model BMP, Water Budget BMP, and Modeling BMP.

### *Inventory Existing Monitoring Programs*

Minimum thresholds and measurable objectives are set at individual representative monitoring sites. GSAs should compile information from existing monitoring programs (e.g., number of wells and their construction details, which aquifers they monitor). As sustainable management criteria are set, monitoring networks may need to be expanded and updated beyond those used for existing, pre-SGMA monitoring programs. Additional information on monitoring networks is included in the Monitoring Networks and Identification of Data Gaps BMP.

### *Engage Interested Parties within the Basin*

When setting sustainable management criteria, GSAs must consider the beneficial uses and users of groundwater in their basin. Consideration of the potential effects on beneficial uses and users underpin the minimum thresholds. GSAs must explain their decision-making processes and how public input was used in the development of their GSPs. There are specific SGMA requirements for GSAs to engage with interested parties within a basin. For more information about requirements of engagement, refer to the Stakeholder Communication and Engagement Guidance Document.

# 4. SETTING SUSTAINABLE MANAGEMENT CRITERIA

This section describes the development of sustainable management criteria. The section is organized as follows:

- Assessment of *sustainability indicators*, significant and unreasonable conditions, *management areas*, and representative monitoring sites
- Minimum thresholds
- Undesirable results
- Measurable objectives
- Sustainability goal

This organization follows a chronological ordering that GSAs can use as they plan for sustainable management criteria development, although they do not have to proceed in that order. Furthermore, setting sustainable management criteria will likely be an iterative process. Initial criteria may need to be adjusted to address potential effects on the beneficial uses and users of groundwater, land uses, and property interests. The GSA should evaluate whether the sustainable management criteria, as a whole, adequately characterize how and when significant and unreasonable conditions occur, and define a path toward sustainable groundwater management in the basin.

## ASSESSMENT OF SUSTAINABILITY INDICATORS, SIGNIFICANT AND UNREASONABLE CONDITIONS, MANAGEMENT AREAS, AND REPRESENTATIVE MONITORING SITES

### *Sustainability Indicators*

Sustainability indicators are the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, become undesirable results.[6] Undesirable results are one or more of the following effects:

- Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods
- Significant and unreasonable reduction of groundwater storage
- Significant and unreasonable seawater intrusion
- Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies

- Significant and unreasonable land subsidence that substantially interferes with surface land uses
- Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water

The significant and unreasonable occurrence of any of the six sustainability indicators constitutes an undesirable result.

The default position for GSAs should be that all six sustainability indicators apply to their basin. If a GSA believes a sustainability indicator is not applicable for their basin, they must provide evidence that the indicator does not exist and could not occur. For example, GSAs in basins not adjacent to the Pacific Ocean, bays, deltas, or inlets may determine that seawater intrusion is not an applicable sustainability indicator, because seawater intrusion does not exist and could not occur. In contrast, simply demonstrating that groundwater levels have been stable in recent years is not sufficient to determine that land subsidence is not an applicable sustainability indicator. As part of the GSP evaluation process, the Department will evaluate the GSA's determination that a sustainability indicator does not apply for reasonableness.

**Sustainability Indicators in the Context of SGMA versus the California Water Plan**

The term "sustainability indicator" is used in GSP regulations to refer to "any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x)." It is important to note that the term 'sustainability indicator' is not unique to SGMA. The California Water Plan Update 2013 includes a California Water Sustainability Indicators Framework that uses the term 'sustainability indicator' in a way that differs from SGMA. Sustainability indicators in the context of the California Water Plan inform users about the relationship of water system conditions to ecosystems, social systems, and economic systems.

Water managers and users should not confuse sustainability indicators in the context of SGMA with sustainability indicators associated with the California Water Plan or with any other water management programs.

### *Significant and Unreasonable Conditions*

GSAs must consider and document the conditions at which each of the six sustainability indicators become significant and unreasonable in their basin, including the reasons for justifying each particular threshold selected. A GSA may decide, for example, that localized inelastic land subsidence near critical infrastructure (e.g., a canal) and basinwide loss of domestic well pumping capacity due to lowering of groundwater levels are both significant and unreasonable conditions. These general descriptions of significant and unreasonable conditions are later translated into quantitative undesirable results, as described in this document. The evaluation of significant and unreasonable conditions should identify the geographic area over which the conditions need to be evaluated so the GSA can choose appropriate representative monitoring sites.

### *Use of Management Areas*

A GSA may wish to define *management areas* for portions of its basin to facilitate groundwater management and monitoring. Management areas may be defined by natural or jurisdictional boundaries, and may be based on differences in water use sector, water source type, geology, or aquifer characteristics. Management areas may have different minimum thresholds and measurable objectives than the basin at large and may be monitored to a different level. However, GSAs in the basin must provide descriptions of why those differences are appropriate for the management area, relative to the rest of the basin.

Using the land subsidence example from the preceding subsection, GSAs in the hypothetical basin may decide that a management area in the vicinity of the canal is appropriate because the level of monitoring must be higher in that area, relative to the rest of the basin. GSAs may also desire to set more restrictive minimum thresholds in that area relative to the rest of the basin.

While management areas can be used to define different minimum thresholds and measurable objectives, other portions of the GSP (e.g., hydrogeologic conceptual model, water budget, notice and communication) must be consistent for the entire GSP area.

### *Representative Monitoring Sites*

Representative monitoring sites are a subset of a basin's complete monitoring network, where minimum thresholds, measurable objectives, and *interim milestones* are set. Representative monitoring sites can be used for one sustainability indicator or multiple sustainability indicators. **Figure 1** shows how different combinations of representative monitoring sites can be used to assess seawater intrusion and lowering of groundwater levels in a hypothetical groundwater basin.

GSAs can only select representative monitoring sites after determining what constitutes significant and unreasonable conditions in a basin. Using the example discussed in the preceding subsections, the GSA would use a different combination of representative monitoring sites for localized inelastic land subsidence than it would for basinwide groundwater level decline. The GSA must explain how the combination of representative monitoring sites selected for each sustainability indicator can assess the significant and unreasonable groundwater condition.

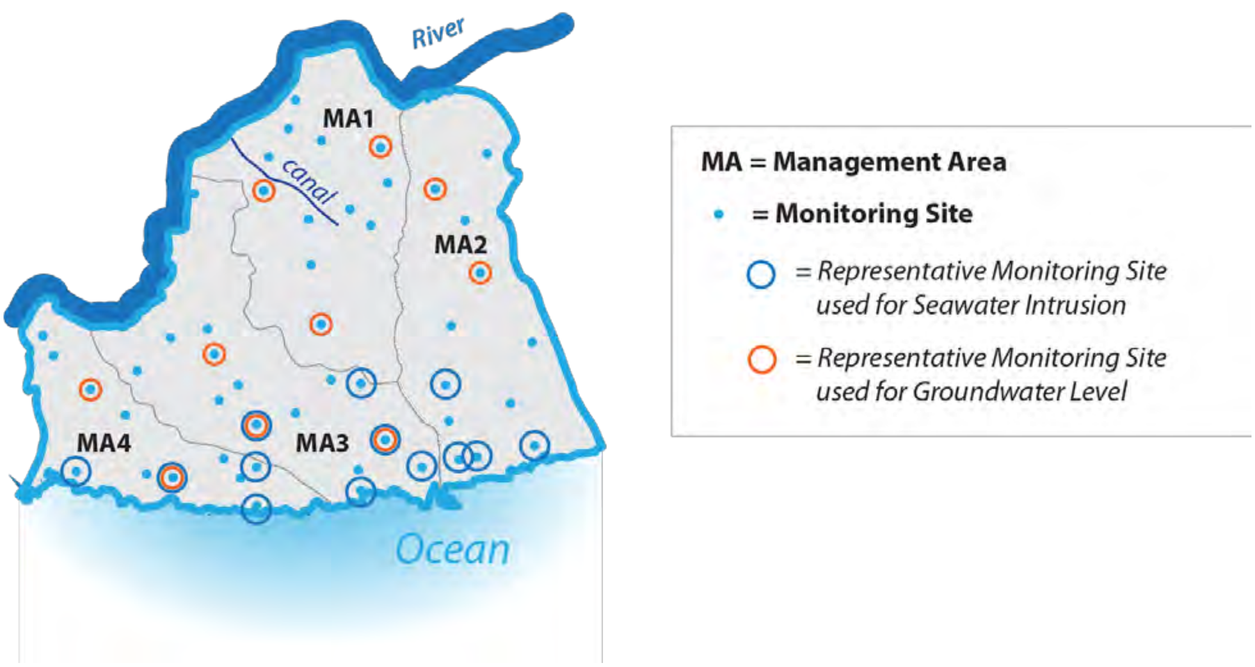



**Figure 1. Example Monitoring Network and Representative Monitoring Sites**

## MINIMUM THRESHOLDS

A minimum threshold is the quantitative value that represents the groundwater conditions at a representative monitoring site that, when exceeded individually or in combination with minimum thresholds at other monitoring sites, may cause an undesirable result(s) in the basin. GSAs will need to set minimum thresholds at representative monitoring sites for each applicable sustainability indicator after considering the interests of beneficial uses and users of groundwater, land uses, and property interests in the basin. Minimum thresholds should be set at levels that do not impede adjacent basins from meeting their minimum thresholds or sustainability goals.

### *Required Components for all Minimum Thresholds*

GSP Regulations require six components of information to be documented for each minimum threshold.[7] The six components (in italicized text) and considerations for how they should be addressed are as follows:

1. *The information and criteria relied upon to establish and justify the minimum thresholds for each sustainability indicator. The justification for the minimum threshold shall be supported by information provided in the basin setting, and other data or models as appropriate, and qualified by uncertainty in the understanding of the basin setting.*

   The GSP must include an analysis and written interpretation of the information, data, and rationale used to set the minimum threshold. For instance, if a groundwater level minimum threshold is set to protect shallow domestic supply wells, the GSA should investigate information such as the depth ranges of domestic wells near the representative monitoring site, aquifer dimensions, groundwater conditions, and any other pertinent information.

2. *The relationship between the minimum thresholds for each sustainability indicator, including an explanation of how the Agency has determined that basin conditions at each minimum threshold will avoid undesirable results for each of the sustainability indicators.*

   The GSP must describe the relationship between each sustainability indicator's minimum threshold (e.g., describe why or how a water level minimum threshold set at a particular representative monitoring site is similar to or different to water level thresholds in nearby representative monitoring sites). The GSP also must describe the relationship between the selected minimum threshold and minimum thresholds for other sustainability indicators (e.g., describe how a water level minimum threshold would not trigger an undesirable result for land subsidence).

3. *How minimum thresholds have been selected to avoid causing undesirable results in adjacent basins or affecting the ability of adjacent basins to achieve sustainability goals.*

   The GSP must describe how the minimum threshold has been set to avoid impacts to adjacent basins. This can be supported by information such as an interbasin agreement, documentation of coordination with GSAs in adjacent basins, and general descriptions of how the minimum threshold is consistent with sustainable management criteria in adjacent basins. Information provided for this component will likely be enhanced beyond the initial GSP in future annual reports and five-year updates. It may be important to inform GSAs in adjacent basins where minimum thresholds are planned and their quantitative values.

4. *How minimum thresholds may affect the interests of beneficial uses and users of groundwater or land uses and property interests.*

   The GSP must discuss how groundwater conditions at a selected minimum threshold could affect beneficial uses and users. This information should be supported by a description of the beneficial uses groundwater and identification of beneficial uses, which should be developed through communication, outreach, and/or engagement with parties representing those beneficial uses and users, along with any additional information the GSA used when developing the minimum threshold.

5. *How state, federal, or local standards relate to the relevant sustainability indicator. If the minimum threshold differs from other regulatory standards, the Agency shall explain the nature of and basis for the difference.*

   The GSP must discuss relevant standards that pertain to the sustainability indicator and justify any differences between the selected minimum threshold and those standards. For instance, the GSP will need to justify why a different level was used if a water quality minimum threshold is set at a different level than a state or federal maximum contaminant level (MCL).

6. *How each minimum threshold will be quantitatively measured, consistent with the monitoring network requirements described in Subarticle 4.*

   Subarticle 4 of the GSP Regulations addresses monitoring networks. The GSP must document the metrics that will be monitored (e.g., groundwater level, groundwater quality) as well as the frequency and timing of measurement (e.g., twice per year in the spring and fall).

Descriptions for these six components are required for all minimum thresholds. However, descriptions for individual components can be shared for multiple minimum thresholds, where appropriate (e.g., in some instances a single description could be provided to describe how a group of minimum thresholds were selected to avoid causing undesirable results in an adjacent basin).

### *Required Minimum Threshold Metrics for Each Sustainability Indicator*

In addition to the six components described above that apply to all minimum thresholds, the GSP Regulations contain specific requirements and metrics for each sustainability indicator.[8] The purpose of the specific requirements is to ensure consistency within groundwater basins and between adjacent groundwater basins.

Specific requirements for the metrics used to quantify each sustainability indicator are listed below and shown in **Figure 2**:

- The minimum threshold metric for the **chronic lowering of groundwater levels** sustainability indicator shall be a groundwater elevation measured at the representative monitoring site.
- The minimum threshold for **reduction of groundwater storage** is a volume of groundwater that can be withdrawn from a basin or management area, based on measurements from multiple representative monitoring sites, without leading to undesirable results. Contrary to the general rule for setting minimum thresholds, the reduction of groundwater storage minimum threshold is not set at individual monitoring sites. Rather, the minimum threshold is set for a basin or management area.
- The minimum threshold metric for **seawater intrusion** shall be the location of a chloride isocontour. Contrary to the general rule for setting minimum thresholds, the seawater intrusion minimum threshold is not set at individual monitoring sites. Rather, the minimum threshold is set along an isocontour line in a basin or management area.
- The minimum threshold metric for **degraded water quality** shall be water quality measurements that indicate degradation at the monitoring site. This can be based on migration of contaminant plumes, number of supply wells, volume of groundwater, or the location of a water quality isocontour within the basin. Depending on how the GSA defines the degraded water quality minimum threshold, it can be defined at a site, along the isocontour line, or as a calculated volume.
- The minimum threshold metric for **land subsidence** shall be a rate and the extent of land subsidence.
- The minimum threshold metric for **depletion of interconnected surface waters** shall be a rate or volume of surface water depletion.

| Sustainability Indicators | Lowering GW Levels | Reduction of Storage | Seawater Intrusion | Degraded Quality | Land Subsidence | Surface Water Depletion |
|---|---|---|---|---|---|---|
| Metric(s) Defined in GSP Regulations | • Groundwater Elevation | • Total Volume | • Chloride concentration isocontour | • Migration of Plumes<br>• Number of supply wells<br>• Volume<br>• Location of isocontour | • Rate and Extent of Land Subsidence | • Volume or rate of surface water depletion |

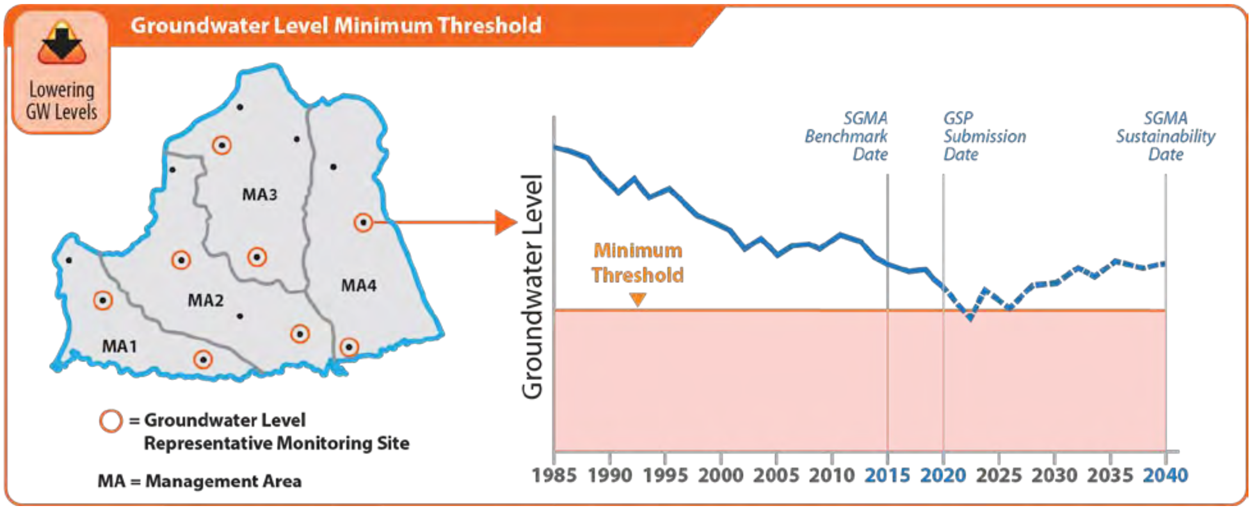
**Figure 2. Minimum Threshold Metrics**

### *Examples and Considerations for Minimum Thresholds*

The following provides graphical examples and considerations for use by GSAs when setting minimum thresholds. The following subsections are organized by sustainability indicator and are illustrative examples only, as GSAs may have other considerations when setting minimum thresholds.

#### Chronic Lowering of Groundwater Levels Minimum Threshold

**Figure 3** illustrates a hypothetical groundwater level hydrograph and associated minimum threshold at a representative monitoring site. In this hypothetical example, the GSA set the minimum threshold at some level below conditions at the time of GSP submission. Note that this and many subsequent examples in this document use 2020 as the hypothetical GSP submission date. The actual GSP submission date required by SGMA varies. GSPs must be submitted by January 31, 2020 for high- and medium-priority basins determined by the Department to be critically overdrafted. All other high- and medium-priority basins must submit GSPs by January 31, 2022.




## Figure 3. Example Groundwater Level Minimum Threshold Established at a Representative Monitoring Site

Considerations when establishing minimum thresholds for groundwater levels at a given representative monitoring site may include, but are not limited to:

- What are the historical groundwater conditions in the basin?
- What are the average, minimum, and maximum depths of municipal, agricultural, and domestic wells?
- What are the screen intervals of the wells?
- What impacts do water levels have on pumping costs (e.g., energy cost to lift water)?
- What are the adjacent basin's minimum thresholds for groundwater elevations?
- What are the potential impacts of changing groundwater levels on groundwater dependent ecosystems?
- Which principal aquifer, or aquifers, is the representative monitoring site evaluating?

**Reduction in Groundwater Storage Minimum Threshold**

**Figure 4** illustrates a hypothetical graph depicting the volume of groundwater available in storage through time, and the associated minimum threshold for the basin.

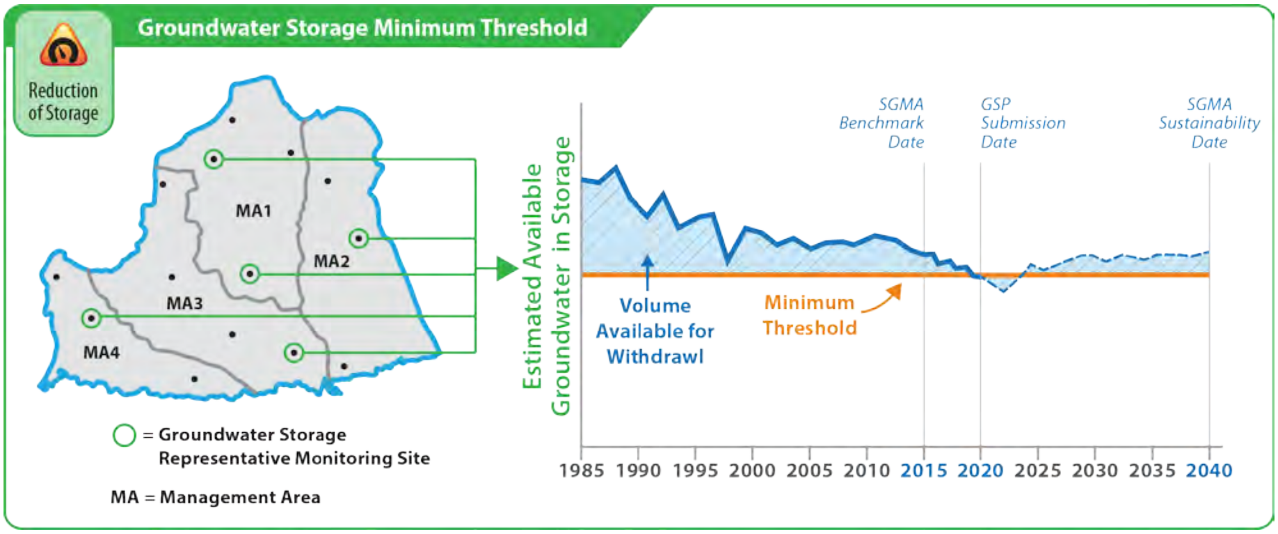



**Figure 4. Example Groundwater Storage Minimum Threshold Established at the Basin Scale**

Considerations when establishing the minimum threshold for groundwater storage may include, but are not limited to:

- What are the historical trends, water year types, and projected water use in the basin?
- What groundwater reserves are needed to withstand future droughts?
- Have production wells ever gone dry?
- What is the effective storage of the basin? This may include understanding of the:
  - Average, minimum, and maximum depth of municipal, agricultural, and domestic wells.
  - Impacts on pumping costs (i.e., energy cost to lift water).
- What are the adjacent basin's minimum thresholds?

**Seawater Intrusion Minimum Threshold**

**Figure 5** illustrates hypothetical chloride isoconcentration contours for two aquifers in a coastal basin. The isoconcentration contours are used as minimum thresholds for seawater intrusion.

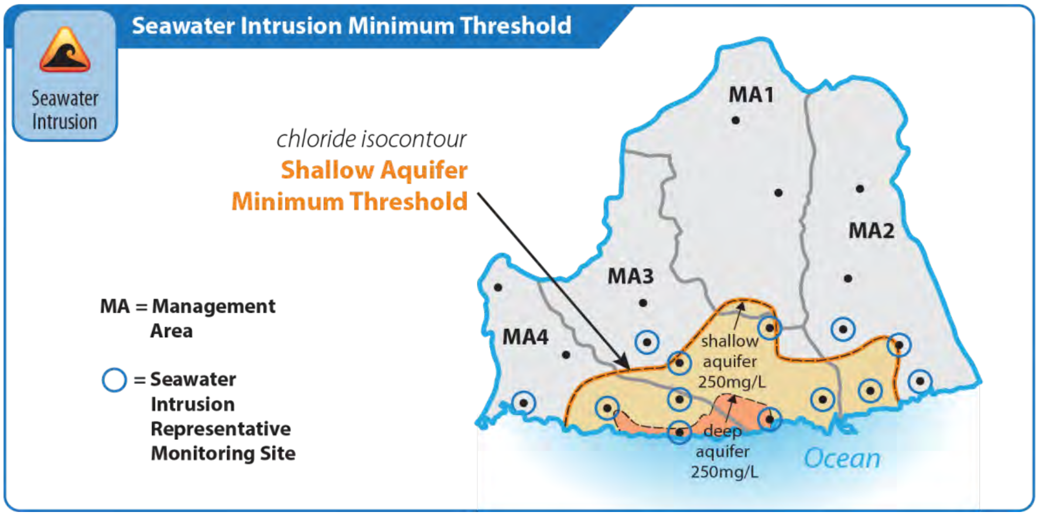



**Figure 5. Example Seawater Intrusion Minimum Threshold Established at the Chloride Isocontour**

Considerations when establishing minimum thresholds for seawater intrusion at a given isocontour location may include, but are not limited to:

- What is the historical rate and extent of seawater intrusion in affected principal aquifers?
- How are land uses in the basin sensitive to seawater intrusion?
- What are the financial impacts of seawater intrusion on agricultural, municipal, and domestic wells?
- What are the Regional Water Quality Control Board Basin Plan objectives?
- What are the adjacent basin's minimum thresholds?

**Degraded Groundwater Quality Minimum Threshold**

**Figure 6** illustrates two hypothetical minimum thresholds for groundwater quality in a basin. The minimum threshold depicted on the top graph is associated with point source contamination (e.g., PCE released from a dry cleaner) and the minimum threshold depicted on the lower graph is associated with nonpoint source contamination (e.g., nitrate in groundwater from regional land use practices).

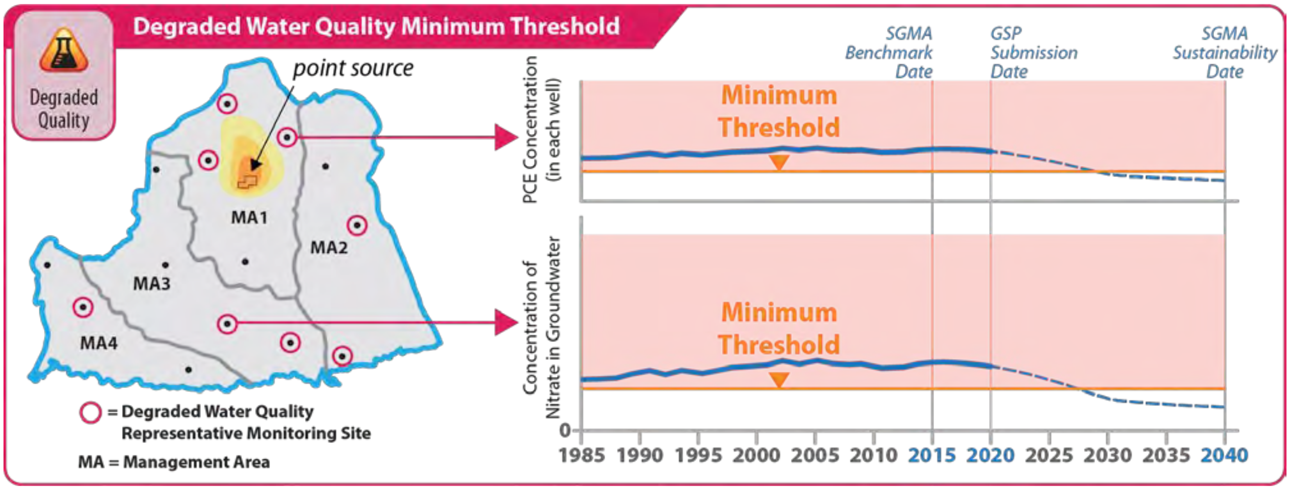



**Figure 6. Example Degraded Water Quality Minimum Threshold Established for Point and Nonpoint Source Pollutants**

Considerations when establishing minimum thresholds for water quality may include, but are not limited to:

- What are the historical and spatial water quality trends in the basin?
- What is the number of impacted supply wells?
- What aquifers are primarily used for providing water supply?
- What is the estimated volume of contaminated water in the basin?
- What are the spatial and vertical extents of major contaminant plumes in the basin, and how could plume migration be affected by regional pumping patterns?
- What are the applicable local, State, and federal water quality standards?
- What are the major sources of point and nonpoint source pollution in the basin, and what are their chemical constituents?
- What regulatory projects and actions are currently established to address water quality degradation in the basin (e.g., an existing groundwater pump and treat system), and how could they be impacted by future groundwater management actions?
- What are the adjacent basin's minimum thresholds?

**Land Subsidence Minimum Threshold**

**Figure 7** illustrates a hypothetical minimum threshold for land subsidence in a basin. The minimum threshold depicts a cumulative amount of subsidence at a given point.

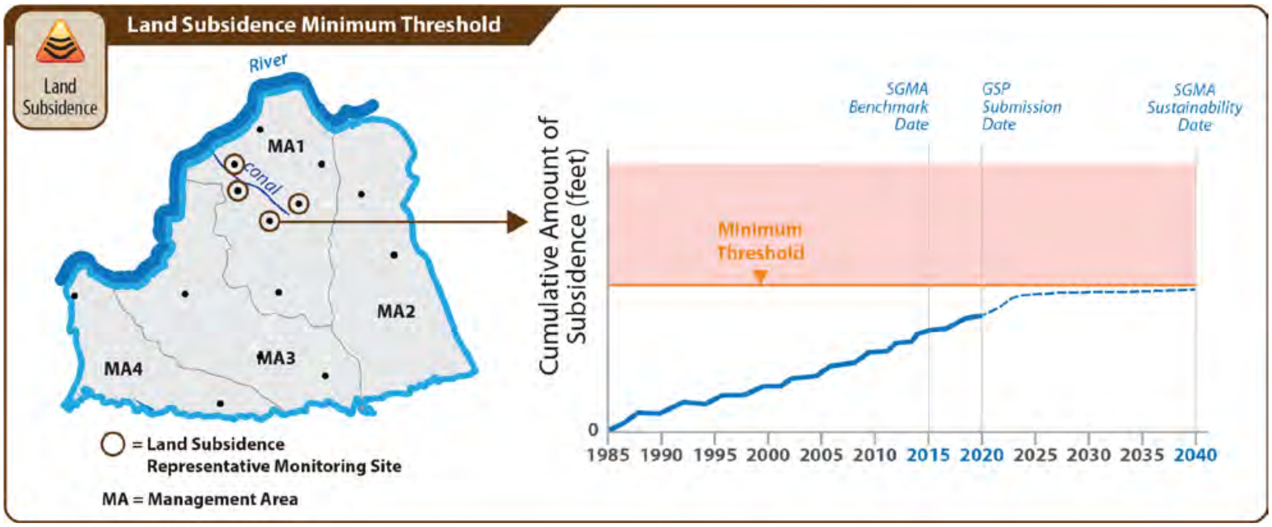



**Figure 7. Example Land Subsidence Minimum Threshold**

Considerations when establishing minimum thresholds for land subsidence at a given representative monitoring site may include, but are not limited to:

- Do principle aquifers in the basin contain aquifer material susceptible to subsidence?
- What are the historical, current, and projected groundwater levels, particularly the historical lows?
- What is the historical rate and extent of subsidence?
- What are the land uses and property interests in areas susceptible to subsidence?
- What is the location of infrastructure and facilities susceptible to subsidence (e.g., canals, levees, pipelines, major transportation corridors)?
- What are the adjacent basin's minimum thresholds?

**Depletion of Interconnected Surface Water Minimum Threshold**

**Figure 8** shows a hypothetical minimum threshold for depletion of interconnected surface waters. This example presents the potential stream depletion rate (or volume) due to groundwater pumping simulated by the basin's integrated hydrologic model. Other approaches for demonstrating stream depletion, instead of the use of a numerical model, may be valid.

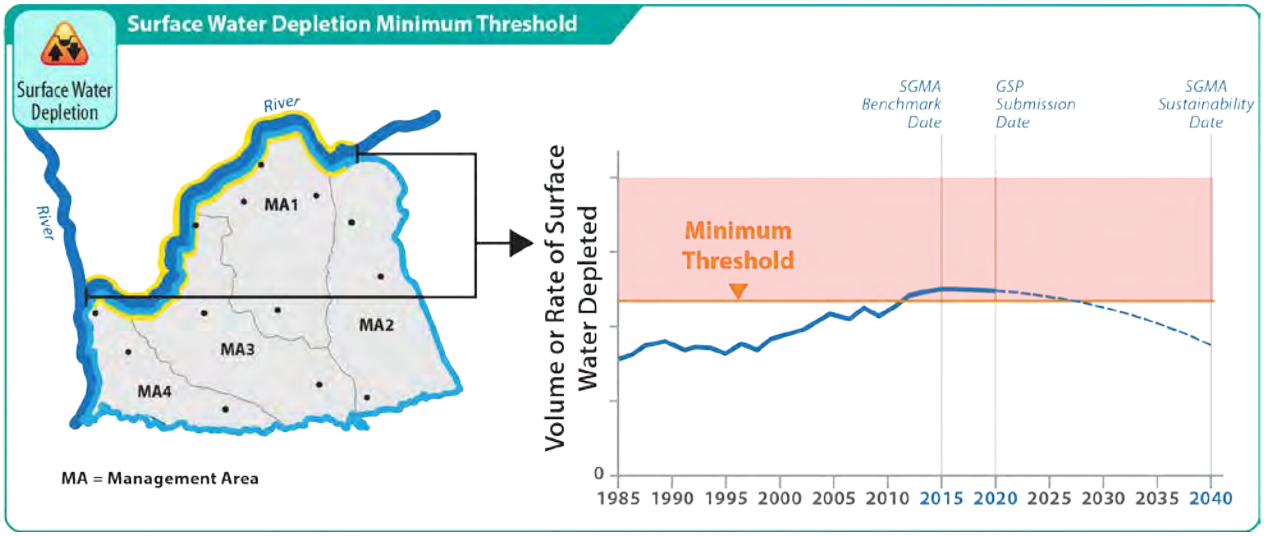



**Figure 8. Example of Depletion of Interconnected Surface Water Minimum Threshold**

Considerations when establishing minimum thresholds for depletions of interconnected surface water may include, but are not limited to:

- What are the historical rates of stream depletion for different water year types?
- What is the uncertainty in streamflow depletion estimates from analytical and numerical tools?
- What is the proximity of pumping to streams?
- Where are groundwater dependent ecosystems in the basin?
- What are the agricultural and municipal surface water needs in the basin?
- What are the applicable State or federally mandated flow requirements?

### *Using Groundwater Elevations as a Proxy*

GSP Regulations allow GSAs to use groundwater elevation as a proxy metric for any (or potentially all) of the sustainability indicators when setting minimum thresholds[9] and measurable objectives[10], provided the GSP demonstrates that there is a significant correlation between groundwater levels and the other metrics.[11]

Two possible approaches for using groundwater elevation as a proxy metric for the definition of sustainable management criteria are:

(1) Demonstrate that the minimum thresholds and measurable objectives for chronic declines of groundwater levels are sufficiently protective to ensure significant and unreasonable occurrences of other sustainability indicators will be prevented. In other words, demonstrate that setting a groundwater level minimum threshold satisfies the minimum threshold requirements for not only

chronic lowering of groundwater levels but other sustainability indicators at a given site.

(2) Identify representative groundwater elevation monitoring sites where minimum thresholds and measurable objectives based on groundwater levels are developed for a specific sustainability indicator. In other words, the use of a groundwater level minimum threshold is not intended to satisfy the minimum threshold requirements for chronic lowering of groundwater but is intended solely for establishing a threshold for another sustainability indicator.

**Subsidence as an Example**

As described below, either approach could be applied to subsidence.

- **Approach 1** – Groundwater level minimum thresholds are above historical low groundwater levels. The GSA determines and documents that avoidance of the minimum thresholds for groundwater levels will also ensure that subsidence will be avoided. In this approach, the GSA would be applying the same numeric definition to two undesirable results – chronic lowering of groundwater and subsidence (**Figure 9**).
- **Approach 2** – The GSA has determined that specific areas are prone to subsidence, knows what the historical low groundwater levels are for those areas, and has demonstrated that no additional inelastic land subsidence will occur as long as groundwater levels remain above historical lows. The GSA develops minimum thresholds for land subsidence based on groundwater levels for the areas prone to subsidence (**Figure 9**). These land subsidence representative monitoring sites are not necessarily included as representative monitoring sites for groundwater level decline.

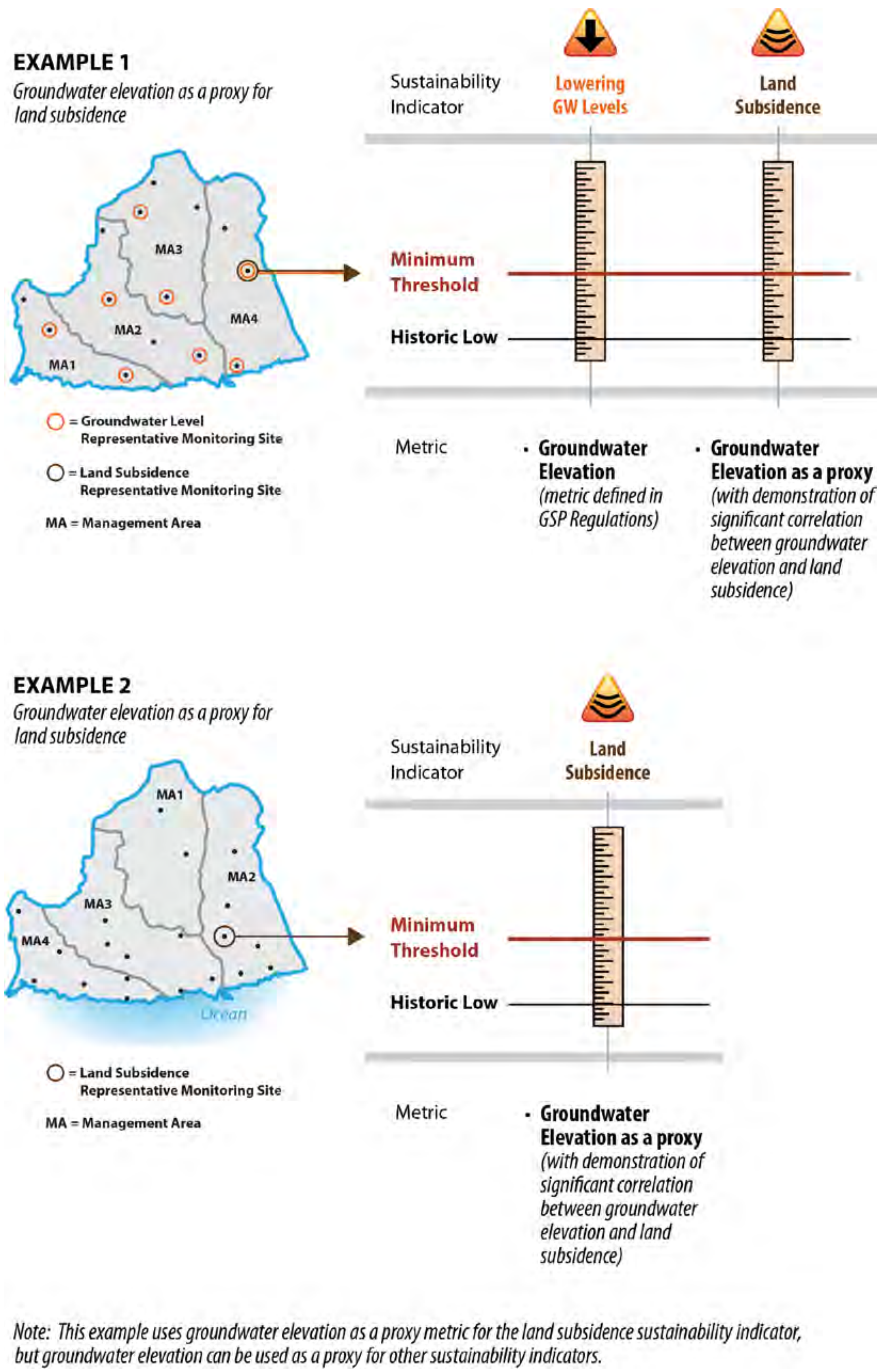



**Figure 9. Example of Using Groundwater Elevation as a Proxy for Subsidence Monitoring**

## UNDESIRABLE RESULTS

Undesirable results occur when conditions related to any of the six sustainability indicators become significant and unreasonable. Undesirable results will be used by the Department to determine whether the sustainability goal has been achieved within the basin.

All undesirable results will be based on minimum thresholds exceedances. Undesirable results will be defined by minimum threshold exceedances at a single monitoring site, multiple monitoring sites, a portion of a basin, a management area, or an entire basin. Exceeding a minimum threshold at a single monitoring site is not necessarily an undesirable result, but it could signal the need for modifying one or more management actions, or implementing a project to benefit an area before the issue becomes more widespread throughout the basin. However, the GSP must define when an undesirable result is triggered.

The GSP must include a description for each undesirable result. Undesirable results must be agreed upon by all GSAs within a basin. If there is more than one GSP in the basin, a single undesirable result description must be agreed upon and documented in the coordination agreement.

GSP Regulations require three components for each undesirable result.[12] The three components (in italicized text) and considerations for how they should be addressed are as follows:

1. *The cause of groundwater conditions occurring throughout the basin that would lead to or has led to undesirable results based on information described in the basin setting, and other data or models as appropriate.*[13]
   The GSP document the factors that may lead to, or have led to, undesirable results. These factors may be localized or basinwide. An example of a localized cause for undesirable results is a group of active wells that are inducing significant and unreasonable land subsidence in a nearby canal. An example of a basinwide cause is general overpumping of groundwater that leads to a significant and unreasonable reduction of groundwater storage. There will often be multiple causes for groundwater conditions becoming significant and unreasonable, and GSAs must investigate each. Even if a basin does not currently have undesirable results, the GSP Regulations require GSAs to consider the causes that would lead to undesirable results and define undesirable results using minimum thresholds.
2. *The criteria used to define when and where the effects of the groundwater conditions cause undesirable results for each applicable sustainability indicator. The criteria*

*shall be based on a quantitative description of the combination of minimum threshold exceedances that cause significant and unreasonable effects in the basin.*[14]

The GSP Regulations require undesirable results to be quantified by minimum threshold exceedances. GSAs have significant flexibility in defining the combinations of minimum threshold exceedances that constitute an undesirable result GSAs should evaluate multiple spatial scales when setting the criteria for undesirable results. Consider an example of two basins. In the first basin, 50 percent of wells have water levels below their assigned minimum threshold. In the second basin, all wells have water levels above their minimum thresholds except for one well where water levels are 800 feet below the minimum threshold. Both basins likely have an undesirable result. GSAs should define their undesirable results to be protective of both scenarios.

3. *The potential effects of the undesirable result on beneficial uses and users of groundwater, land uses, and property interests.*[15]

   The GSA, having acquired information regarding beneficial uses and users of groundwater in the basin, land uses, and property interests tied to groundwater, should describe the effects of each of the potential undesirable results for the basin. The description should make clear how potential effects on beneficial uses and users were considered in the establishment of the undesirable results.

### *Experiencing Undesirable Results*

Avoidance of the defined undesirable results must be achieved within 20 years of GSP implementation (20-year period). Some basins may experience undesirable results within the 20-year period, particularly if the basin has existing undesirable results as of January 1, 2015. The occurrence of one or more undesirable results within the initial 20-year period does not, by itself, necessarily indicate that a basin is not being managed sustainably, or that it will not achieve sustainability within the 20-year period. However, GSPs must clearly define a planned pathway to reach sustainability in the form of interim milestones, and show actual progress in annual reporting.

Failing to eliminate undesirable results within 20 years, or failing to implement a GSP to achieve the sustainability goal established for a basin, will result in the Department deeming the GSP inadequate and could result in State Water Resources Control Board intervention. Failing to meet interim milestones could indicate that the GSA is unlikely to achieve the sustainability goal in the basin.

### *Example of Undesirable Results*

This section provides a simplified example to illustrate the relationship between certain sustainable management criteria. The example is for one sustainability indicator (lowering groundwater levels, using the metric of groundwater elevation. The concepts in the example could be extended to other sustainability indicators using other metrics.

In the example, a hypothetical basin has set minimum thresholds, interim milestones, and measurable objectives for groundwater levels (**Figure 10**) at a network of eight representative monitoring points; to simplify this example, the criteria are assumed to be the same at each well. After considering the conditions at which lowering of groundwater levels would become significant and unreasonable, the GSA has determined that minimum threshold exceedances (i.e., groundwater levels dropping below the minimum threshold) at three or more representative monitoring sites would constitute an undesirable result.

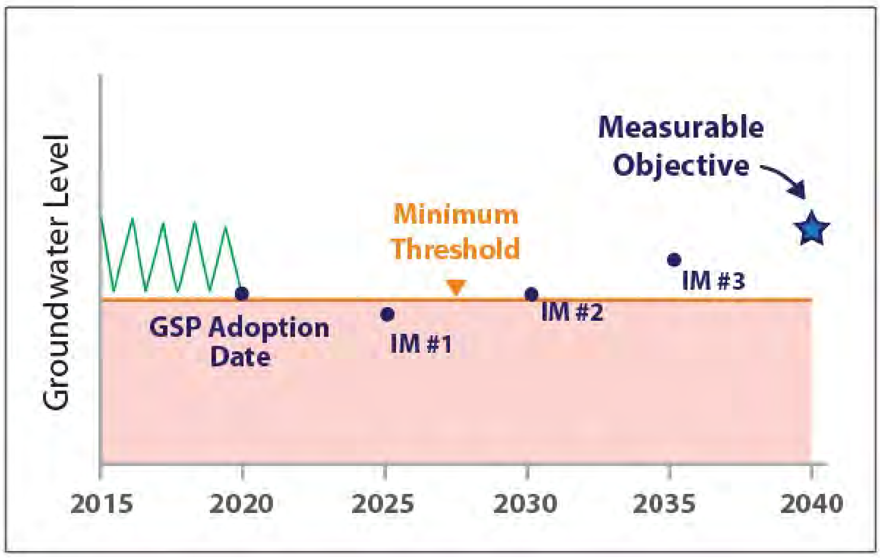



**Figure 10. Example Minimum Threshold, Interim Milestones (IM), and Measurable Objective**

In each of the following scenarios, the GSA monitors groundwater levels at the representative monitoring sites for the 20-year period following GSP submission.

**Scenario 1 – Minimum Threshold Exceedances without an Undesirable Result**

In this scenario (**Figure 11**), one of the eight representative monitoring wells has periodic minimum threshold exceedances over a several-year period after submission of the GSP. After this period, groundwater levels at the representative monitoring site increase and remain above the minimum threshold. Groundwater levels at all other representative monitoring sites remain above the minimum threshold for the entire 20-year period following GSP submission. Groundwater levels at all sites are at or above the measurable objective at the end of the 20-year period. Despite periodic minimum threshold exceedances at one representative monitoring well, the basin never experienced an undesirable result for this sustainability indicator. The original GSP submission foresaw potential minimum threshold exceedances as shown by the first five-year interim milestone set below the minimum threshold.

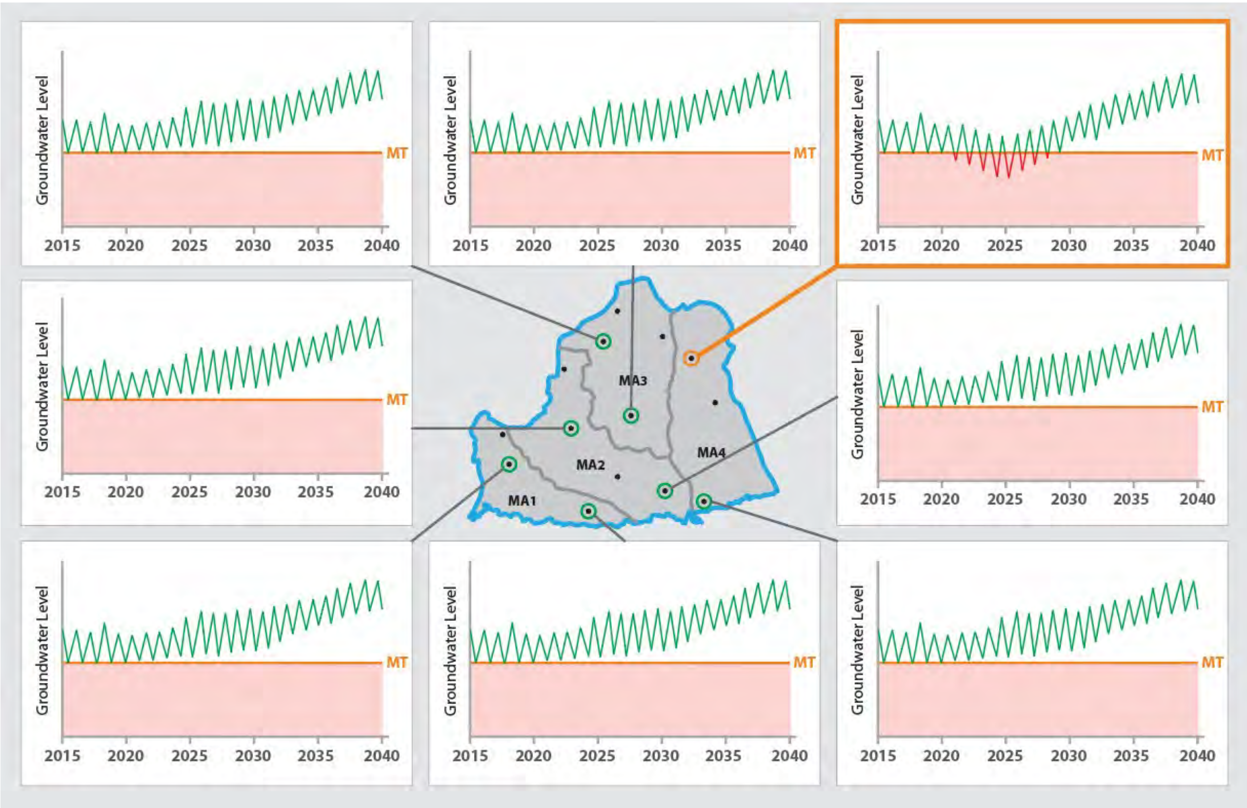



Figure 11. Example Groundwater Level Representative Monitoring Sites – Scenario 1

**Scenario 2 – Minimum Threshold Exceedances with Undesirable Results Eliminated Within 20 Years**

In this scenario (**Figure 12**), three of the eight representative monitoring wells have periodic minimum threshold exceedances over a several-year period after submission of the GSP. After this period, groundwater levels at the three representative monitoring sites increase and remain above their respective minimum thresholds. Groundwater levels at all other representative monitoring sites remain above the minimum threshold for the entire 20-year period following GSP submission. Groundwater levels at all sites are at or above the measurable objective at the end of the 20-year period.

As opposed to Scenario 1, this basin did experience an undesirable result during the period of minimum threshold exceedance at the three representative monitoring wells. However, the basin was sustainably managed because the GSA planned for a period of minimum threshold exceedances via their interim milestones, and because the GSA implemented necessary projects and management actions to eliminate the undesirable result and achieve the measurable objective.

Note that if the GSAs in this hypothetical basin had not planned for continued groundwater level decline via appropriate interim milestones, or had not implemented the necessary projects and management actions to eliminate the undesirable result, the Department could have determined that the GSA was not likely to achieve the sustainability goal for the basin within the 20-year period.

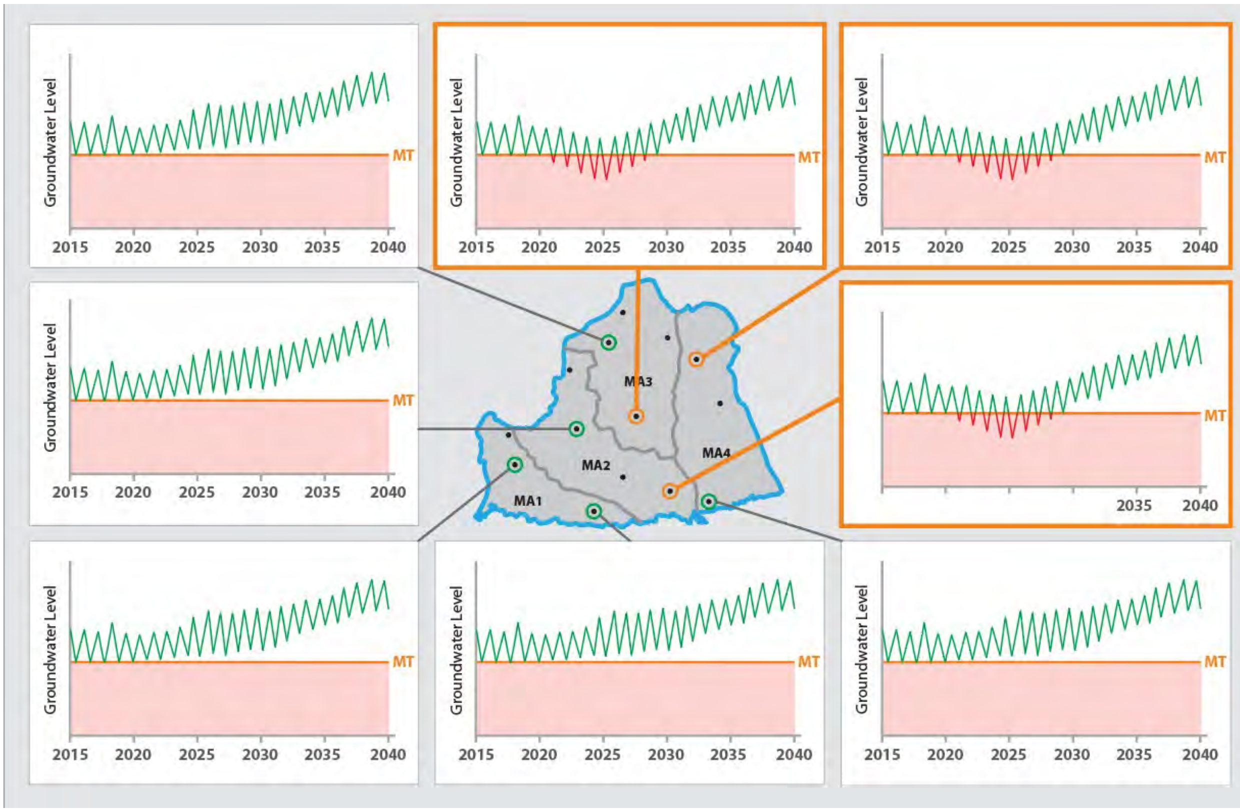



Figure 12. Example Groundwater Level Representative Monitoring Sites – Scenario 2

**Scenario 3 – Minimum Threshold Exceedances with Undesirable Results Not Eliminated Within 20 Years**

In this scenario (**Figure 13**), three of the eight representative monitoring wells have minimum threshold exceedances beginning approximately five years after submission of the GSP. Unlike Scenario 2, groundwater levels continue to decline at the three representative monitoring sites throughout the 20-year period following GSP submission, and are well below both their minimum thresholds and interim milestones. The basin experiences an undesirable result when the three wells begin exceeding their minimum thresholds, and the undesirable result persists throughout the 20-year period. Sustainable groundwater management was not achieved in the basin for this scenario.

Although this example shows undesirable results persisting for the 20-year period, in a real situation the Department would likely determine that the GSA was unlikely to achieve the sustainability goal at one of the interim milestones, thereby triggering State intervention much earlier in the 20-year period. It is beyond the scope of this example or this document to discuss details of State intervention, but it is important to note that State intervention can occur within the 20-year period following GSP submittal.

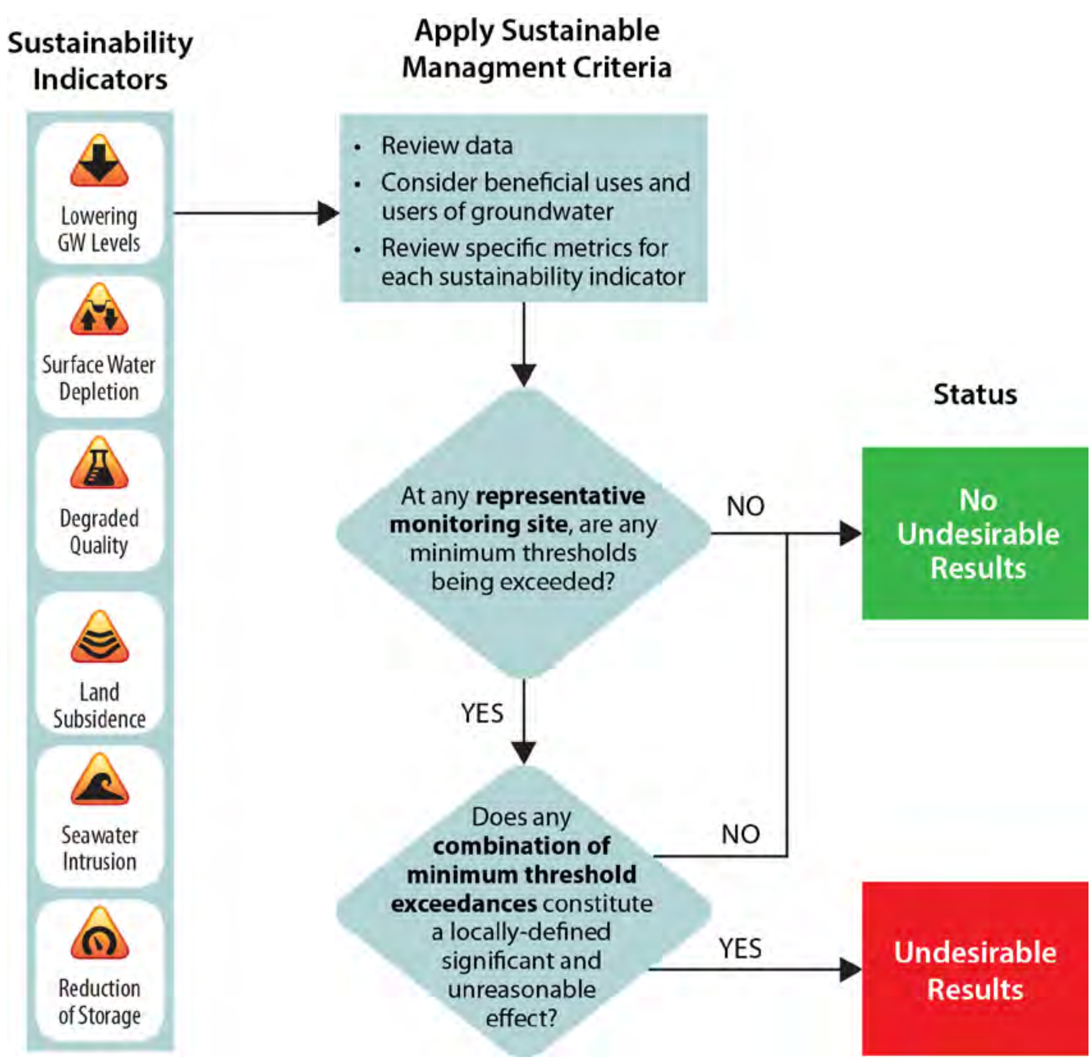

**Figure 13. Example Groundwater Level Representative Monitoring Sites – Scenario 3**

**Relationship between Sustainability Indicators, Minimum Thresholds, and Undesirable Results**

Sustainability indicators are the six effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, are undesirable results. For example, surface water depletion due to groundwater pumping is a sustainability indicator because it is an effect that must be monitored to determine whether it has become significant and unreasonable.

Sustainability indicators become undesirable results when a GSA-defined combination of minimum thresholds is exceeded. Those combinations of minimum threshold exceedances define when a basin condition becomes significant and unreasonable.

The relationship between sustainability indicators, minimum thresholds, and undesirable results is shown in the illustration below.



## MEASURABLE OBJECTIVES

Measurable objectives are quantitative goals that reflect the basin's desired groundwater conditions and allow the GSA to achieve the sustainability goal within 20 years. Measurable objectives are set for each sustainability indicator at the same representative monitoring sites and using the same metrics as minimum thresholds. Measurable objectives should be set such that there is a reasonable margin of operational flexibility (**Figure 14**) between the minimum threshold and measurable objective that will accommodate droughts, climate change, conjunctive use operations, or other groundwater management activities. There are exceptions to this general rule. For example, if the minimum threshold for land subsidence is zero, the measurable objective may also be zero. Projects and management actions included in GSPs should be designed to meet the measurable objectives, with specific descriptions of how those projects and management actions will achieve their desired goals.

In addition to the measurable objective, interim milestones must be defined in five-year increments[16] at each representative monitoring site using the same metrics as the measurable objective, as illustrated in **Figure 14**. These interim milestones are used by GSAs and the Department to track progress toward meeting the basin's sustainability goal. Interim milestones must be coordinated with projects and management actions proposed by the GSA to achieve the sustainability goal. The schedule for implementing projects and management actions will influence how rapidly the interim milestones approach the measurable objectives (i.e., the path to sustainable groundwater management).

The Department will periodically (at least every five years) review GSPs to determine, among other items, whether failure to meet interim milestones is likely to affect the ability of the GSA(s) in a basin to achieve the sustainability goal.[17]

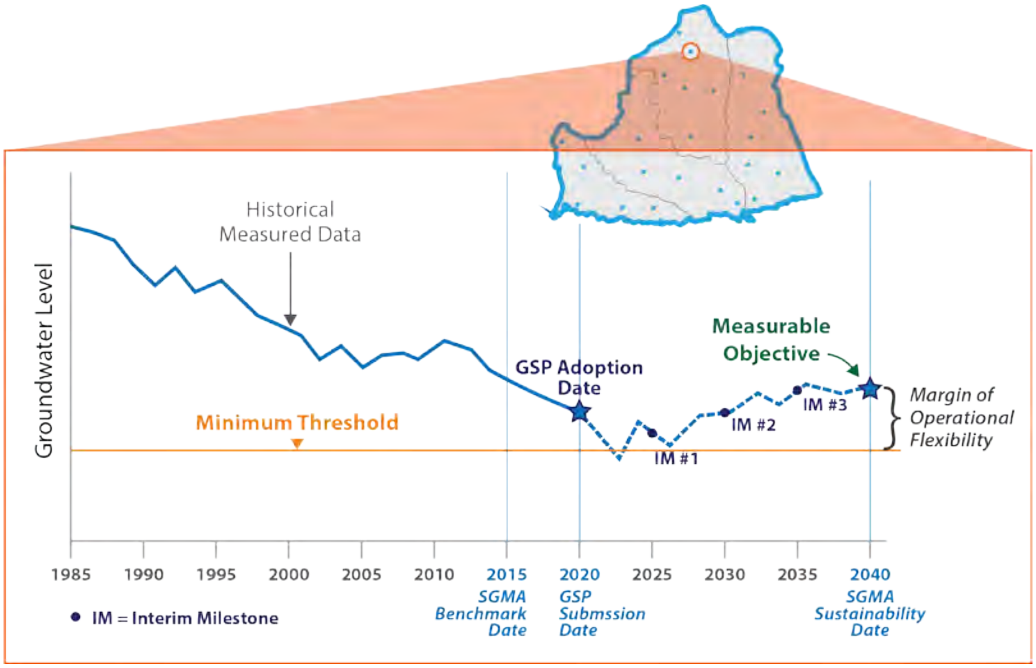



**Figure 14. Relationship between Minimum Thresholds, Measurable Objectives, Interim Milestones (IM), and Margin of Operational Flexibility for a Representative Monitoring Site**

### *The Path to Sustainable Groundwater Management*

There will be many paths to sustainable groundwater management based on groundwater conditions and locally-defined values. **Figure 14** shows the relationship between minimum thresholds, measurable objectives, interim milestones, and margin of operational flexibility for a hypothetical basin. In the example used for **Figure 14**, groundwater levels are predicted to initially decline for the first five years after GSP adoption, and then rise over the subsequent 15 years to meet the measurable objective. At five-year increments, there are interim milestones to check the basin's progress towards the measurable objective. In **Figure 14**, the measured data never drops below the minimum threshold. This is just one example of a path towards reaching sustainability. The Department recognizes that there are different sustainability paths based on basin conditions, future supply and demand forecasts, and implementation of groundwater improvement projects. Three additional potential paths to sustainability are illustrated in **Figure 15**.

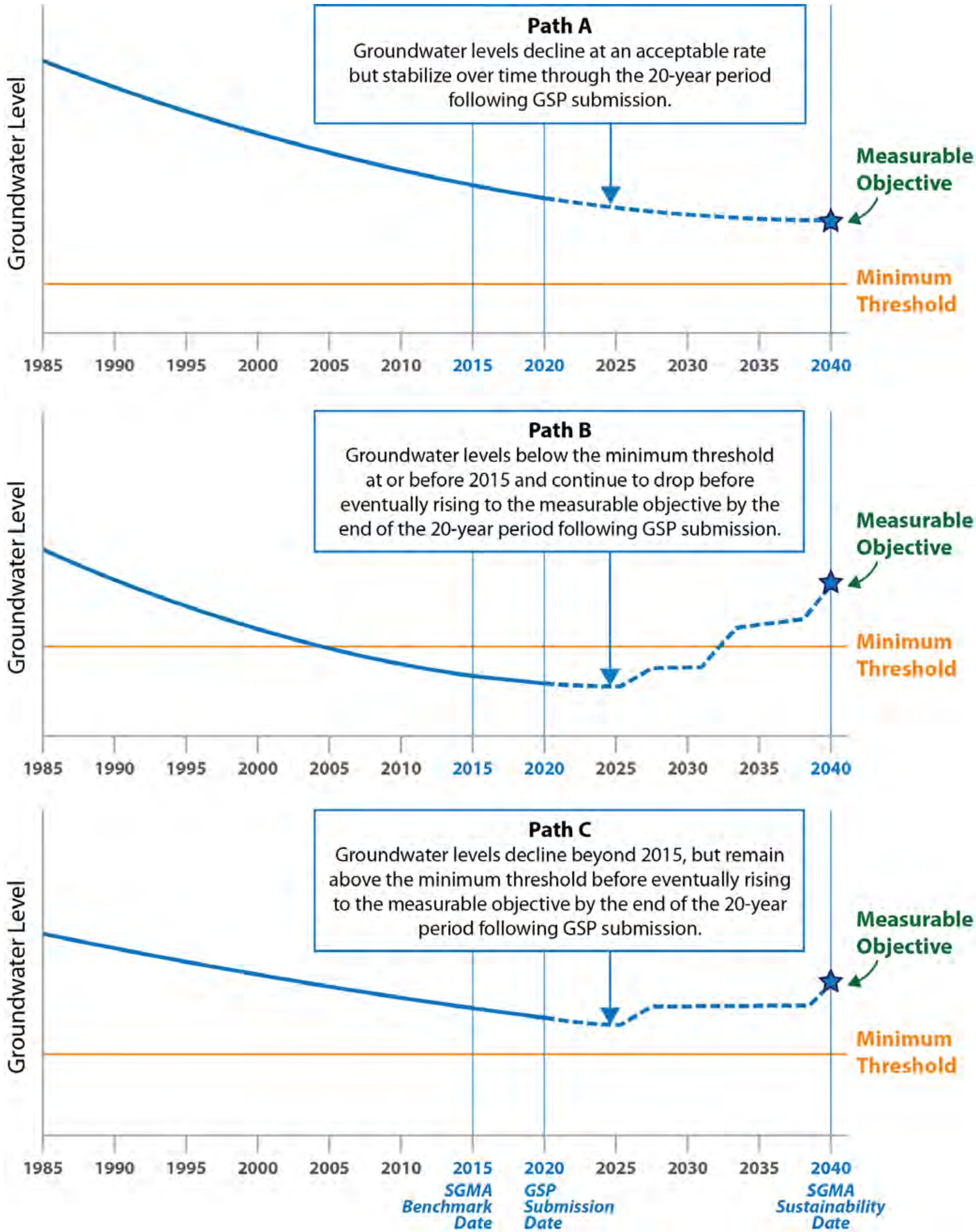



**Figure 15. Potential Paths to Sustainability**

### *Measurable Objectives when an Undesirable Result Occurred before January 1, 2015*

SGMA states that a GSP "may, but is not required to, address undesirable results that occurred before, and have not been corrected by, January 1, 2015." Once minimum thresholds have been developed and an undesirable result numerically defined, the GSA may evaluate whether that undesirable result was present prior to January 1, 2015. This evaluation is not possible until the GSA has defined what constitutes a significant and unreasonable condition (an undesirable result).

If the evaluation indicates that an undesirable result occurred prior to January 1, 2015, the GSA must set measurable objectives to either maintain or improve upon the conditions that were occurring in 2015. The GSA must plan a pathway, indicated by appropriate interim milestones, to reach and maintain the 2015 conditions within the 20-year implementation timeline.

## SUSTAINABILITY GOAL

GSAs must develop a sustainability goal that is applicable to the entire basin. If multiple GSPs are developed for a single basin, then the sustainability goal must be presented in the basinwide *coordination agreement*.

The sustainability goal should succinctly state the GSA's objectives and desired conditions of the groundwater basin, how the basin will get to that desired condition, and why the measures planned will lead to success.

Unlike the other sustainable management criteria, the sustainability goal is not quantitative. Rather, it is supported by the locally-defined minimum thresholds and undesirable results. Demonstration of the absence of undesirable results supports a determination that basin is operating within its sustainable yield and, thus, that the sustainability goal has been achieved.

GSA's should consider the following when developing their sustainability goal:

- **Goal description**. The goal description should qualitatively state the GSA's objective or mission statement for the basin. The goal description should summarize the overall purpose for sustainably managing groundwater resources and reflect local economic, social, and environmental values within the basin.
- **Discussion of measures**. The sustainability goal should succinctly summarize the measures that will be implemented. This description of measures should be consistent with, but may be less detailed than, the description of projects and management actions proposed in the GSP. Examples of measures a GSA could implement include demand reduction and development of groundwater recharge projects. The goal should affirm that these measures will lead to operation of the basin within its sustainable yield.
- **Explanation of how the goal will be achieved in 20 years**. The sustainability goal should describe how implementation of the measures will result in sustainability. For example, if the measures include demand reduction and implementation of groundwater recharge projects, then the goal would explain how those measures will lead to sustainability (e.g., they will raise groundwater levels above some threshold values and eliminate or reduce future land subsidence).

Note that most of the sustainability goal can only be finalized after minimum thresholds and undesirable results have been defined, projects and management actions have been identified, and the projected impact of those projects and management actions on groundwater conditions have been evaluated. Therefore, completion of the sustainability goal will likely be one of the final components of GSP development.

**Role of Sustainable Yield Estimates in SGMA**

In general, the sustainable yield of a basin is the amount of groundwater that can be withdrawn annually without causing undesirable results. Sustainable yield is referenced in SGMA as part of the estimated basinwide water budget and as the outcome of avoiding undesirable results.

Sustainable yield estimates are part of SGMA's required basinwide water budget. Section 354.18(b)(7) of the GSP Regulations requires that an estimate of the basin's sustainable yield be provided in the GSP (or in the coordination agreement for basins with multiple GSPs). A single value of sustainable yield must be calculated basinwide. This sustainable yield estimate can be helpful for estimating the projects and programs needed to achieve sustainability.

SGMA does not incorporate sustainable yield estimates directly into sustainable management criteria. Basinwide pumping within the sustainable yield estimate is neither a measure of, nor proof of, sustainability. Sustainability under SGMA is only demonstrated by avoiding undesirable results for the six sustainability indicators.

# CONCLUSIONS

The key to demonstrating a basin is meeting its sustainability goal is by avoiding undesirable results. Sustainable management criteria are critical elements of the GSP that define sustainability in the basin.

Before setting sustainable management criteria, the GSA should understand the basin setting by establishing a hydrogeological conceptual model, engage stakeholders, and define management areas as applicable. This document addresses best management practices for developing sustainable management criteria, including minimum thresholds, undesirable results, measurable objectives, and the sustainability goal.

Setting sustainable management criteria can be a complex, time consuming, and iterative process depending on the complexity of the basin and its stakeholders. GSAs should allow sufficient time for criteria development during the GSP development process. The public should be engaged early in the process so their perspectives can be considered during sustainable management criteria development. To ensure timely stakeholder participation, it may be useful for GSAs to set a timeline for development of the sustainable management criteria.

# 5. KEY DEFINITIONS

The key definitions related to sustainable management criteria development outlined in applicable SGMA code and regulations are provided below for reference.

**SGMA Definitions (California Water Code 10721)**

(d) "Coordination agreement" means a legal agreement adopted between two or more groundwater sustainability agencies that provides the basis for coordinating multiple agencies or groundwater sustainability plans within a basin pursuant to this part.

(r) "Planning and implementation horizon" means a 50-year period over which a groundwater sustainability agency determines that plans and measures will be implemented in a basin to ensure that the basin is operated within its sustainable yield.

(u) "Sustainability goal" means the existence and implementation of one or more groundwater sustainability plans that achieve sustainable groundwater management by identifying and causing the implementation of measures targeted to ensure that the applicable basin is operated within its sustainable yield.

(v) "Sustainable groundwater management" means the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.

(w) "Sustainable yield" means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result.

(x) "Undesirable result" means one or more of the following effects caused by groundwater conditions occurring throughout the basin:

(1) Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

(2) Significant and unreasonable reduction of groundwater storage.

(3) Significant and unreasonable seawater intrusion.

(4) Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.

(5) Significant and unreasonable land subsidence that substantially interferes with surface land uses.

(6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

**Groundwater Sustainability Plan Regulations (California Code of Regulations 351)**

(g) "Basin setting" refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the Agency in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5.

(h) "Sustainability indicator" refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x).

(q) "Interim milestone" refers to a target value representing measurable groundwater conditions, in increments of five years, set by an Agency as part of a Plan.

(r) "Management area" refers to an area within a basin for which the Plan may identify different minimum thresholds, measurable objectives, monitoring, or projects and management actions based on differences in water use sector, water source type, geology, aquifer characteristics, or other factors.

(s) "Measurable objectives" refer to specific, quantifiable goals for the maintenance or improvement of specified groundwater conditions that have been included in an adopted Plan to achieve the sustainability goal for the basin.

(t) "Minimum threshold" refers to a numeric value for each sustainability indicator used to define undesirable results.

(x) "Plan" refers to a groundwater sustainability plan as defined in the Act.

(y) "Plan implementation" refers to an Agency's exercise of the powers and authorities described in the Act, which commences after an Agency adopts and submits a Plan or Alternative to the Department and begins exercising such powers and authorities.

(ag) "Statutory deadline" refers to the date by which an Agency must be managing a basin pursuant to an adopted Plan, as described in Water Code Sections 10720.7 or 10722.4.

# NOTES

[1] See 23 CCR § 350 *et seq*.

[2] See Water Code § 10720 *et seq*.

[3] See 23 CCR § 355.4(b)(1)

[4] See Water Code § 10721(v)

[5] See 23 CCR § 354.22 *et seq*.

[6] See 23 CCR § 351(ah); *see also* Water Code § 10721(x).

[7] See 23 CCR § 354.28(b)

[8] See 23 CCR § 354.28(c)

[9] See 23 CCR § 354.28(d)

[10] See 23 CCR § 354.30(d)

[11] See 23 CCR § 354.36(b)

[12] See 23 CCR § 354.26(b)

[13] See 23 CCR 354.26(b)(1)

[14] See 23 CCR 354.26(b)(2)

[15] See 23 CCR 354.26(b)(3)

[16] See 23 CCR § 354.30(e)

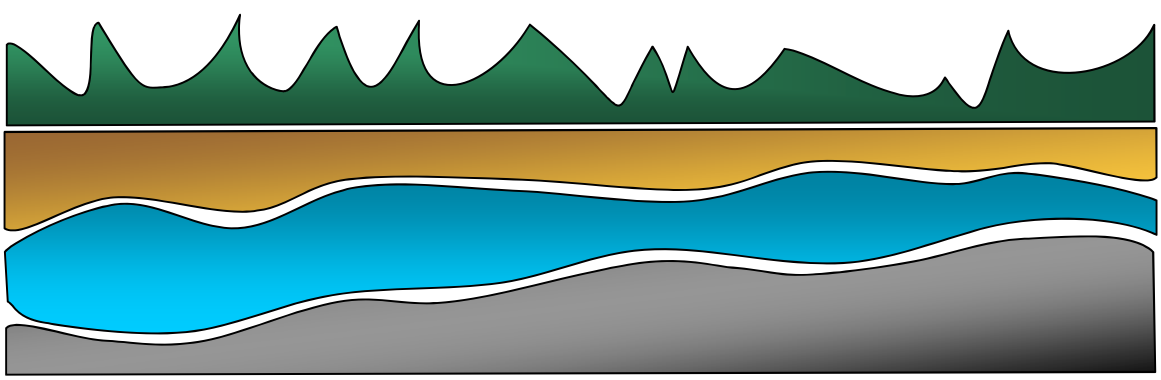
[17] See 23 CCR § 355.6(c)(1)

# Appendix 4A

## KDWCD 2018 Annual Groundwater Report

KAWEAH DELTA
Water Conservation
DISTRICT

# 2018
# ANNUAL GROUNDWATER REPORT



# 2018 ANNUAL
# GROUNDWATER REPORT

This report has been prepared by Kaweah Delta Water Conservation District and presents groundwater measurements that were taken throughout the District. This information is intended to provide the District Board of Directors and participants with groundwater data that will allow for the evaluation of past and current groundwater conditions within the District.

The groundwater measurements were taken in the months of February and October for spring and fall, respectively, at wells located within the Kaweah Delta Water Conservation District boundaries. The data was collected by Kaweah Delta Water Conservation District, Lakeside Irrigation Water District, Kings County Water District and Tulare Irrigation District.

Many groundwater measurements were taken, but only the groundwater depths from well sites in each respective season of 2017 and 2018 were compared within the District. The spring 2018 average comparable depth to groundwater was approximately 133.0 ft., which reflected a groundwater level rise of 7.3 ft. from the prior year. The fall 2018 average comparable depth to groundwater was approximately 142.8 ft., which reflected a groundwater level decline of 7.8 ft. from the prior year.

It should be noted that a majority of the measurements are obtained from active agricultural production wells. Also, there presently is a lack of available well construction data for the wells included in this report. Thereby, the groundwater conditions presented in this report reflect a degree of uncertainty that is commensurate with the complexity of aquifer and measurement conditions.

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