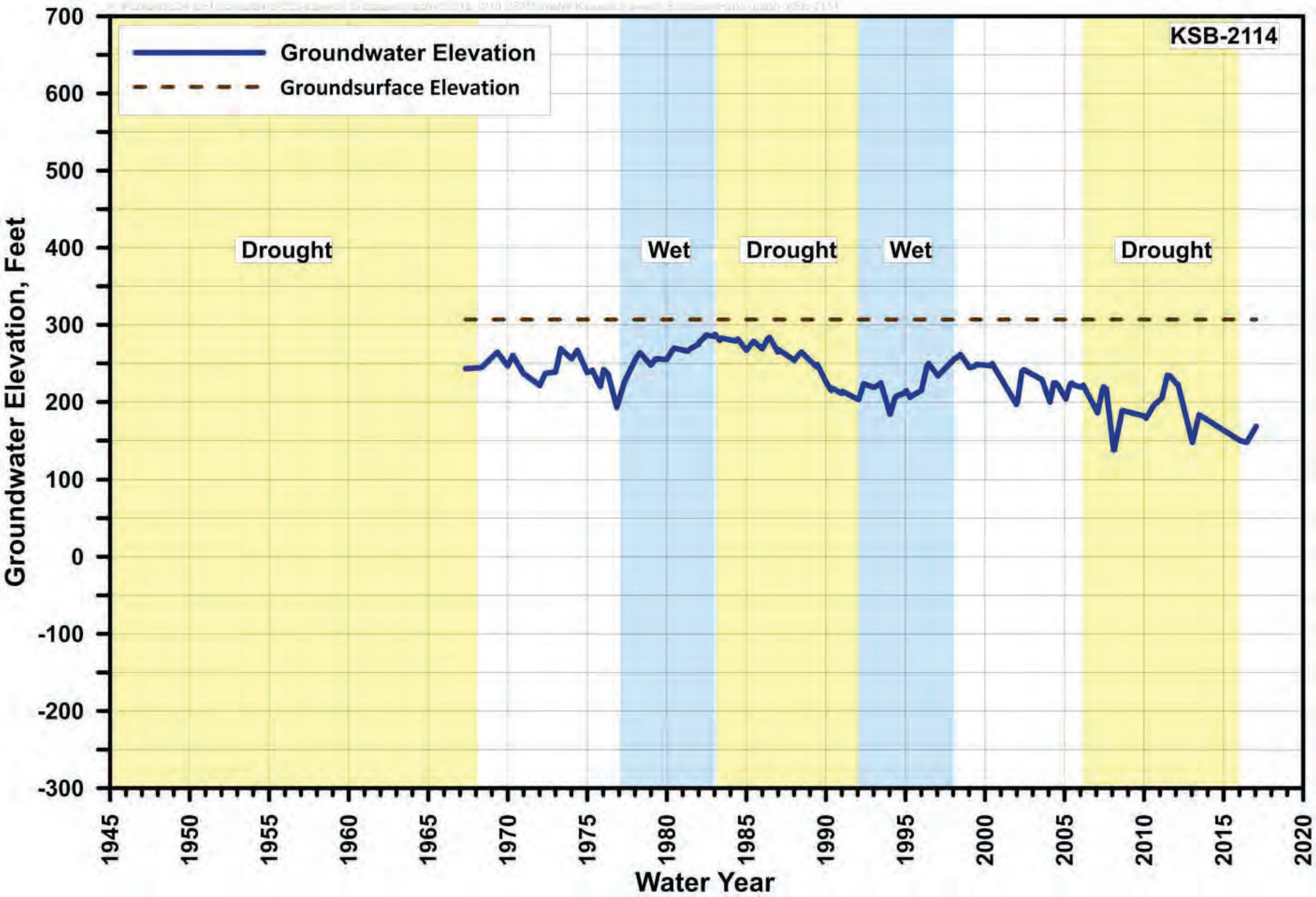
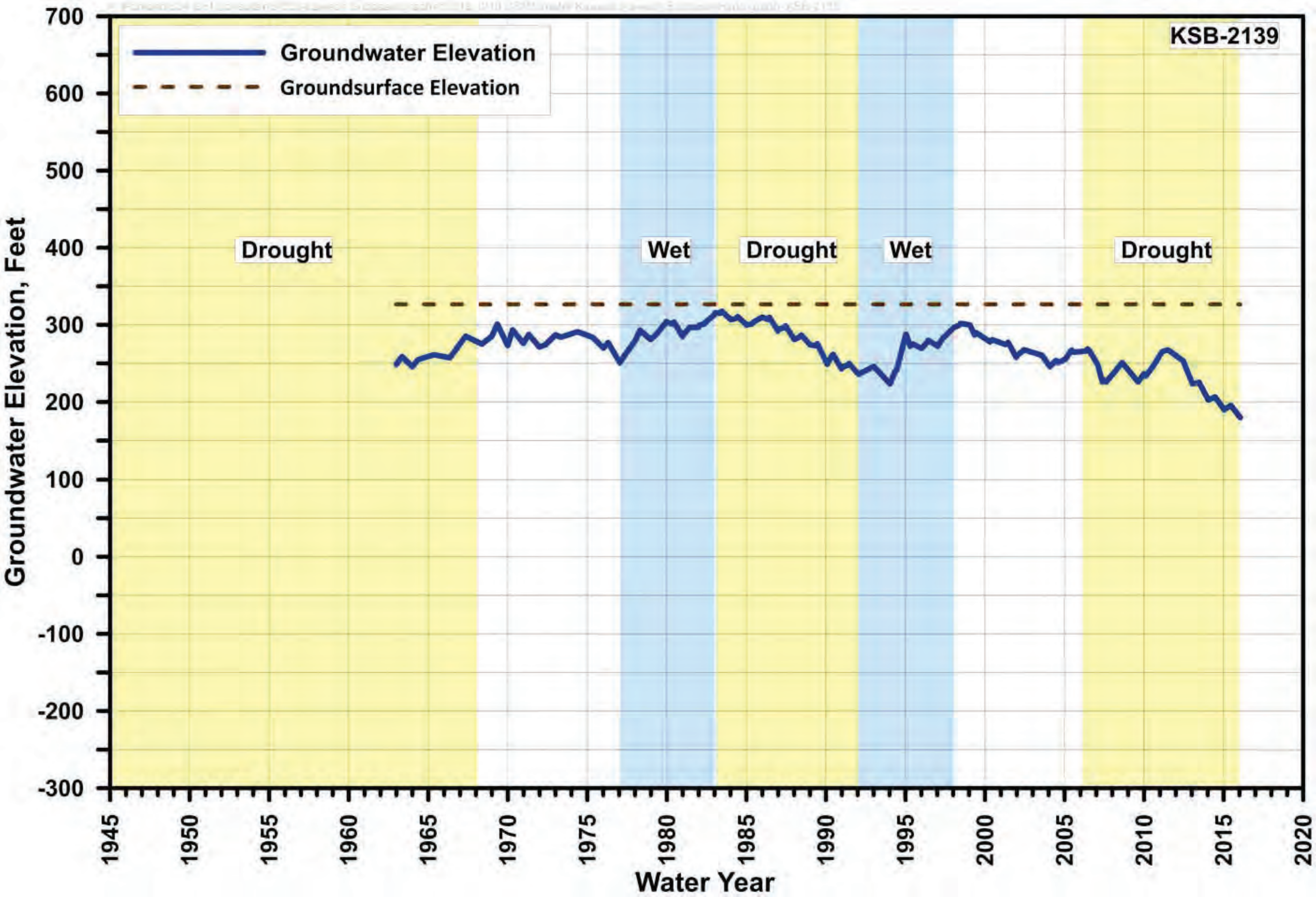
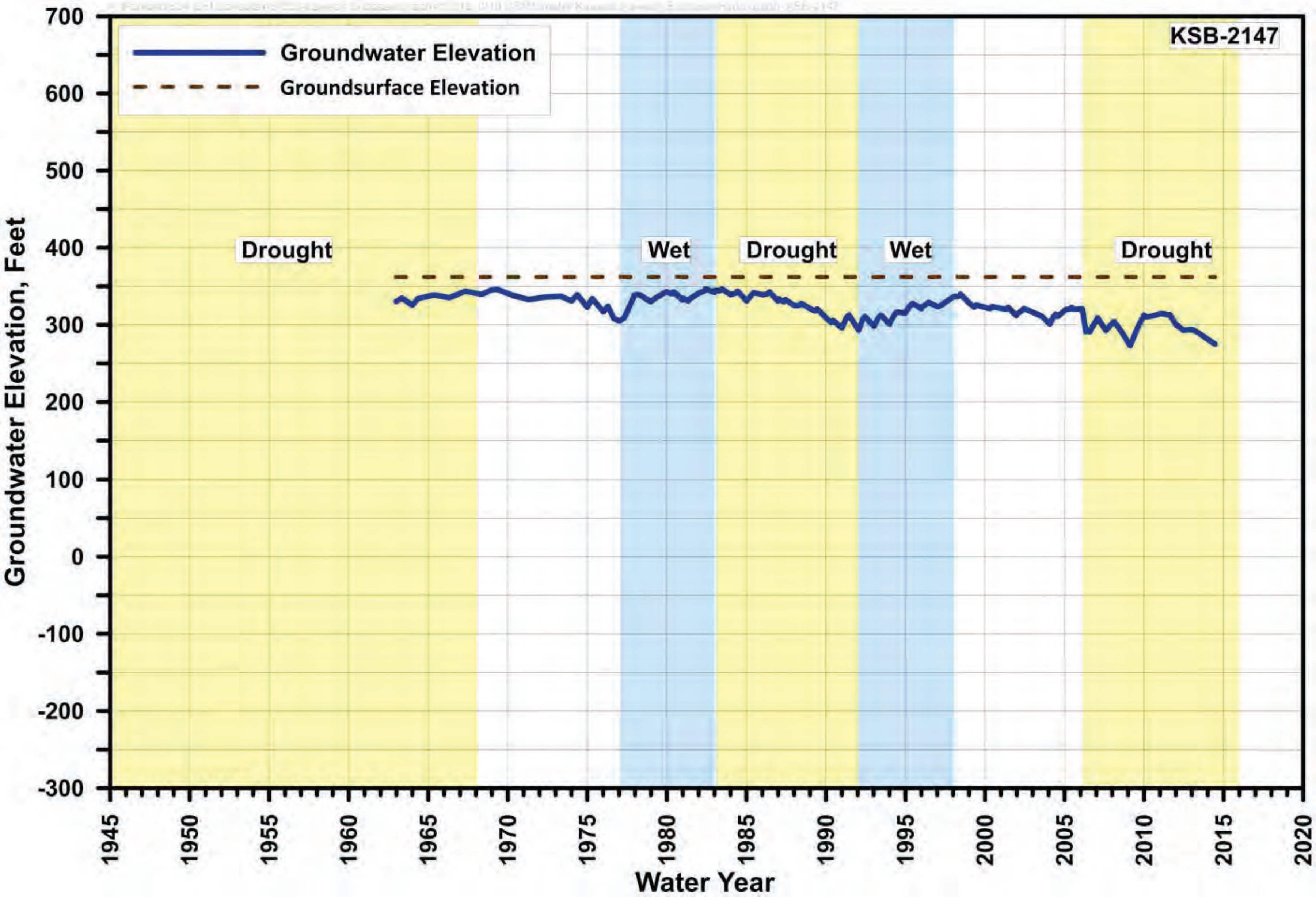


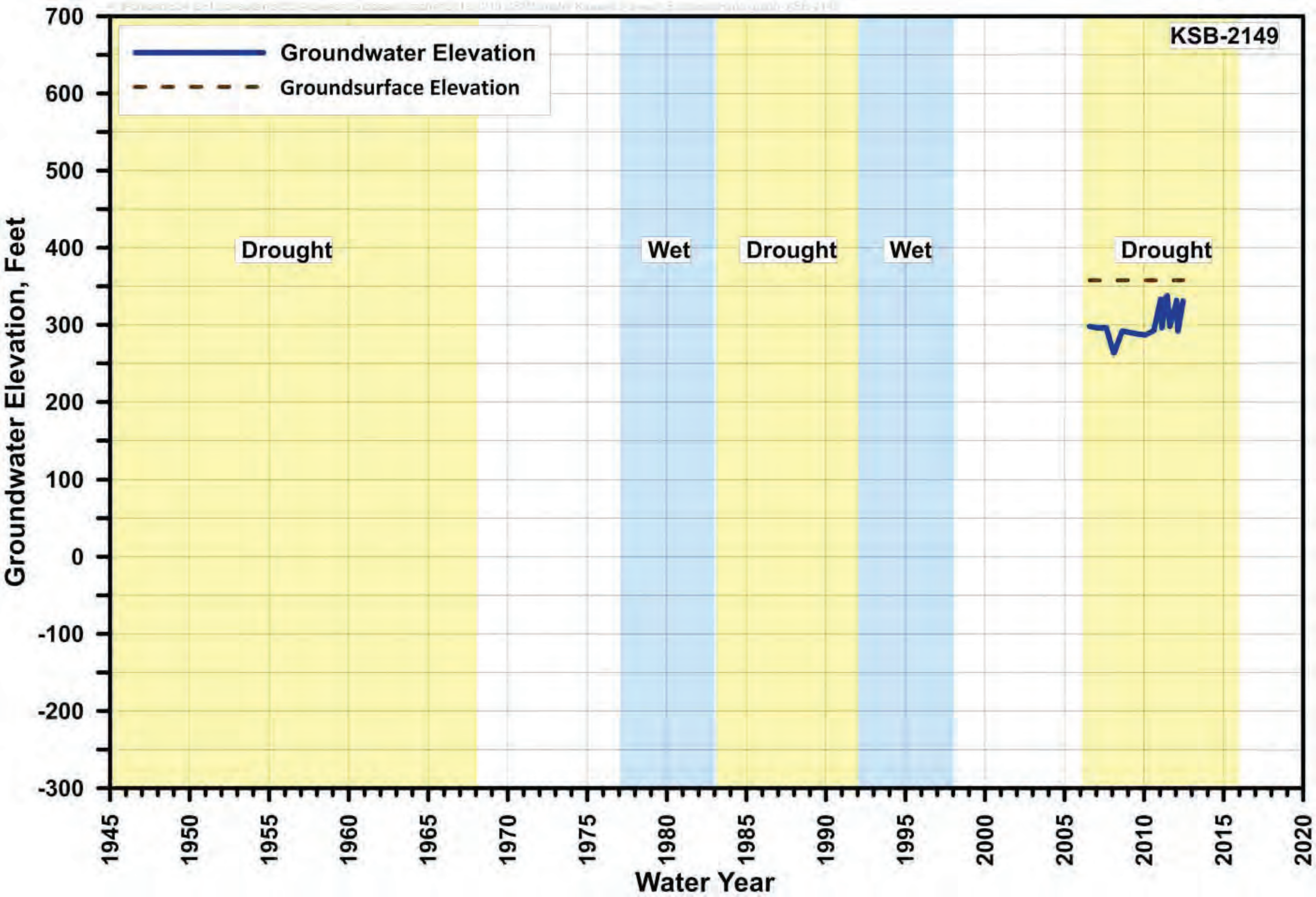
KSB-2114
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year



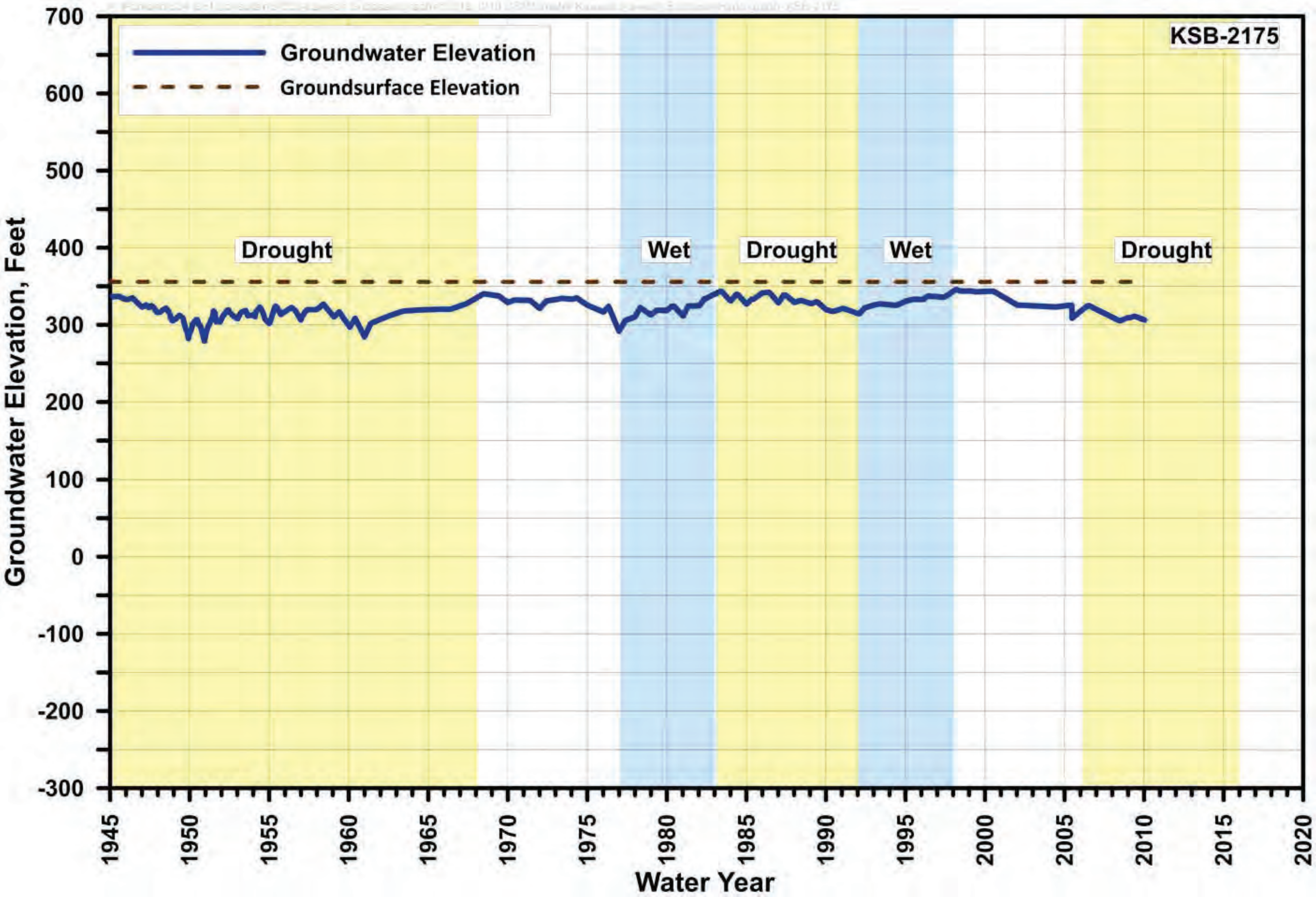
KSB-2139
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year



KSB-2147
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020



KSB-2149
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year



KSB-2175
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
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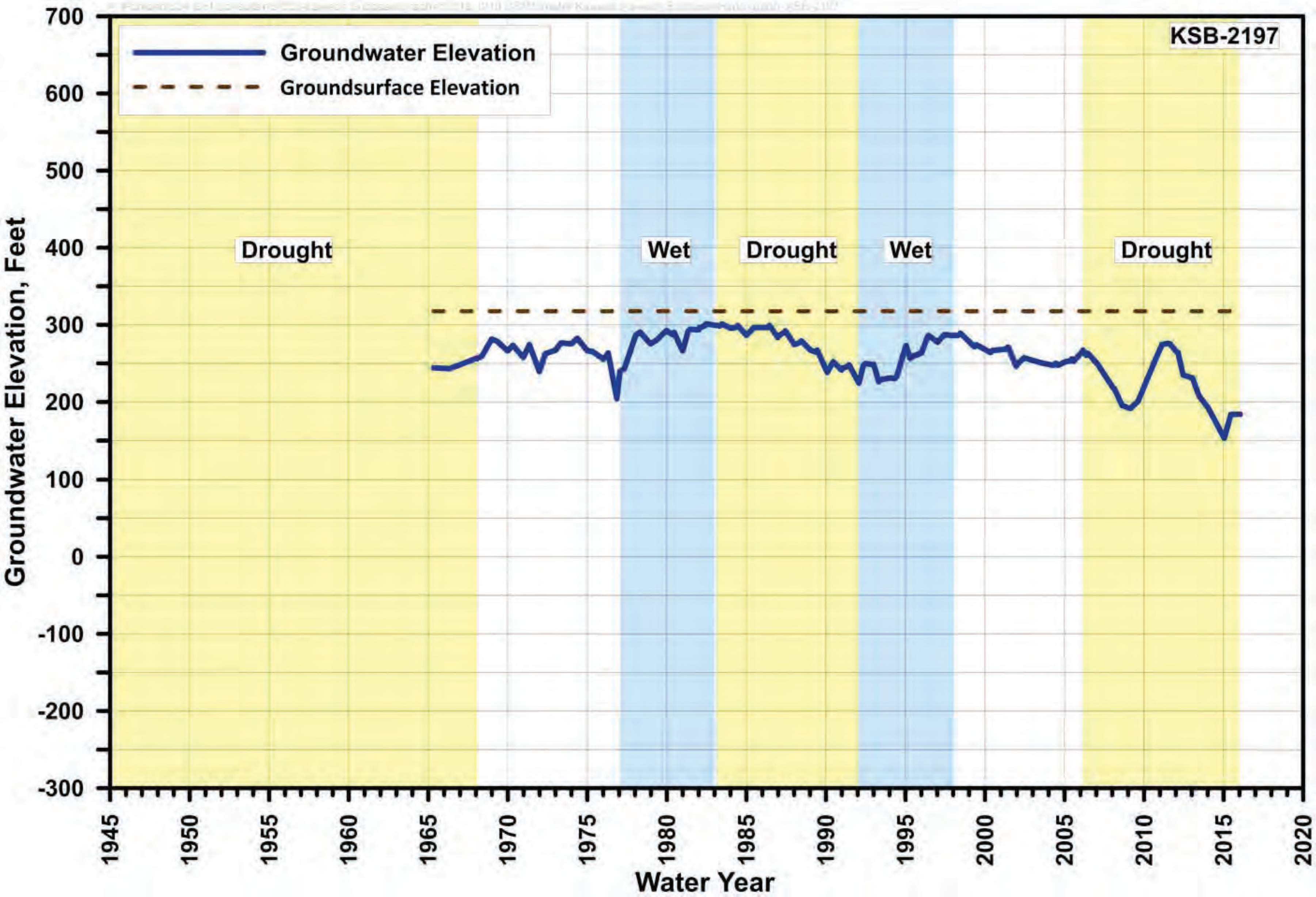
1990
1995
2000
2005
2010
2015
2020



KSB-2197
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
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1980
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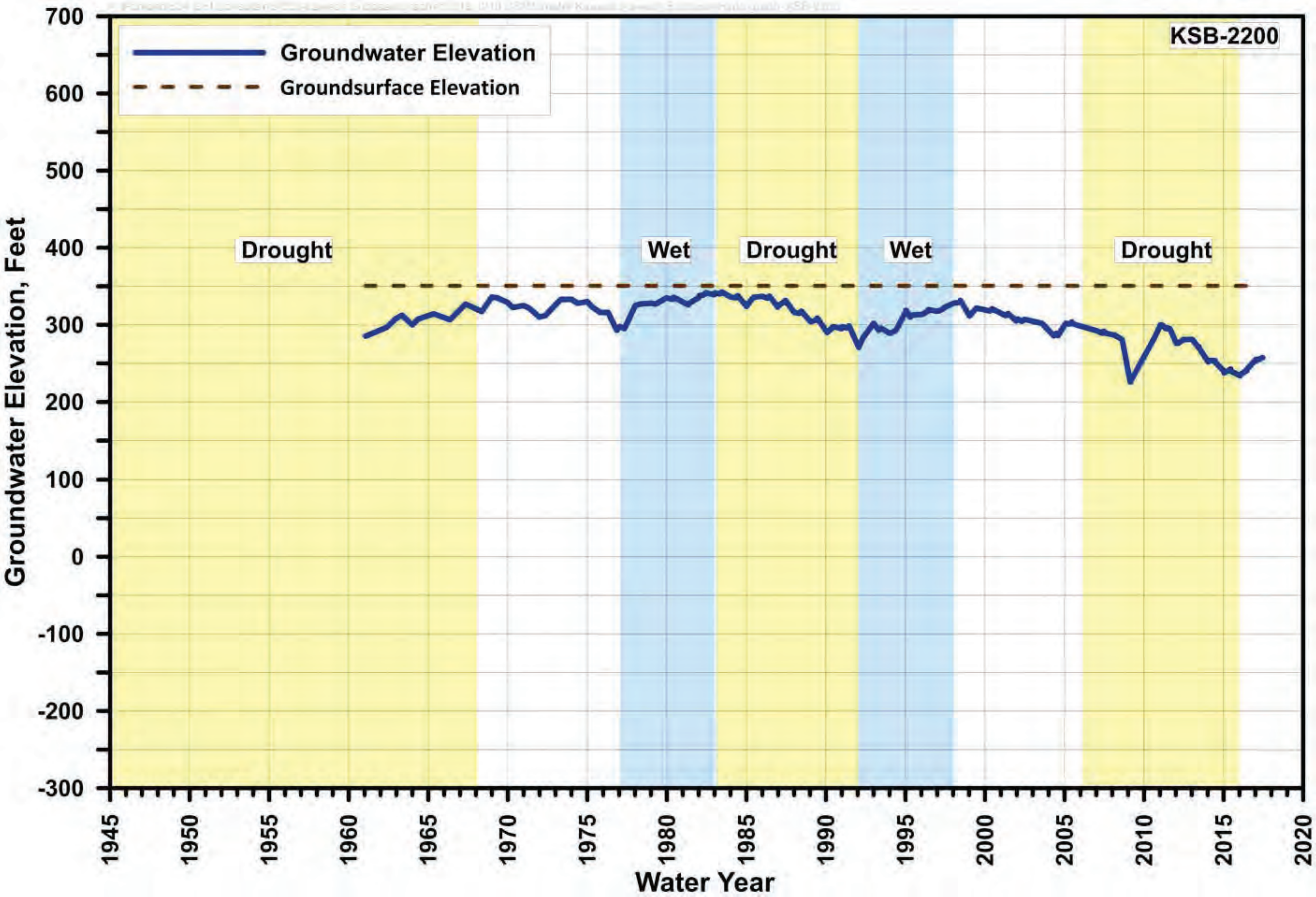
1995
2000
2005
2010
2015
2020
Water Year



KSB-2200
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
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1980
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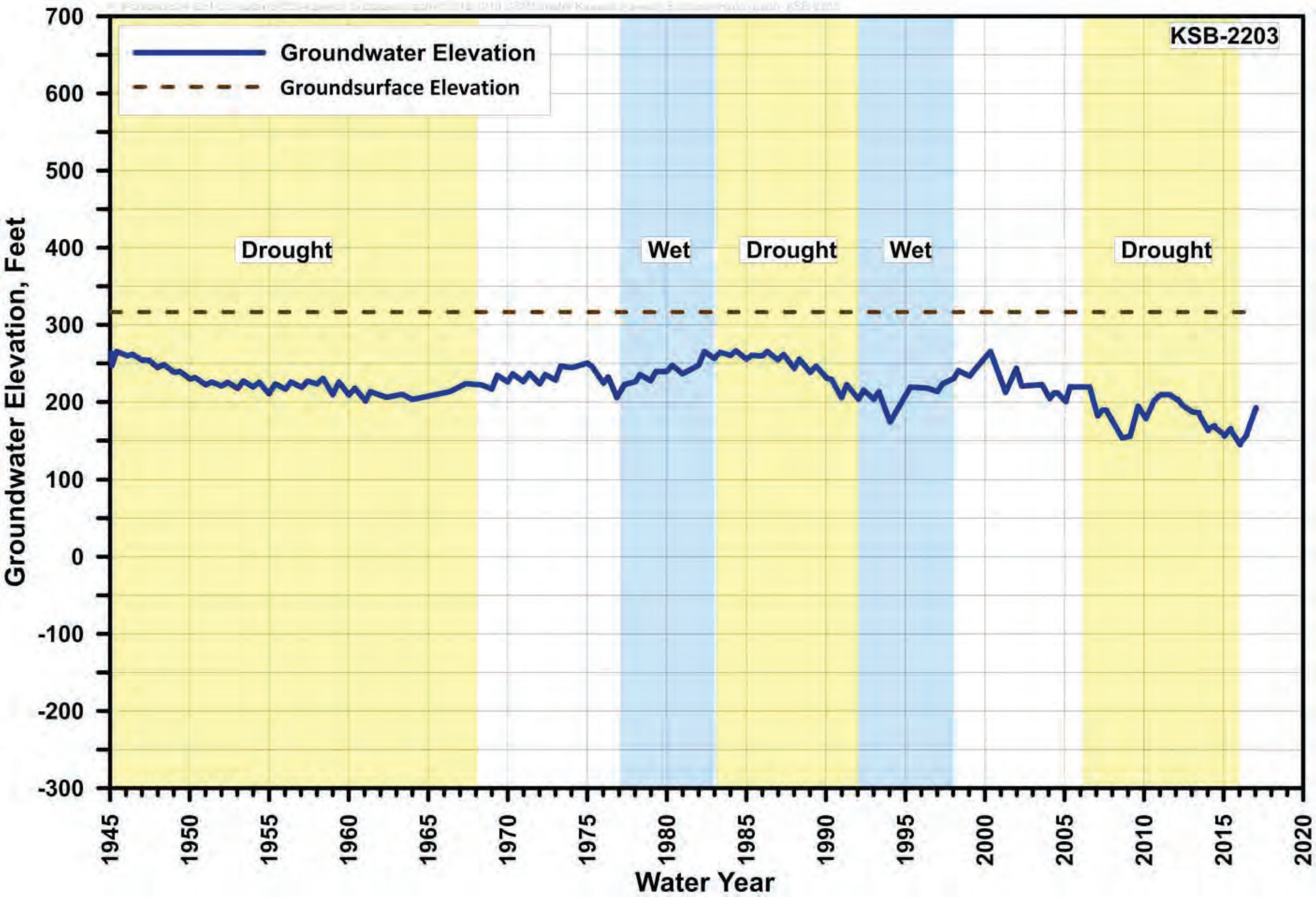
1995
2000
2005
2010
2015
2020
Water Year



KSB-2203
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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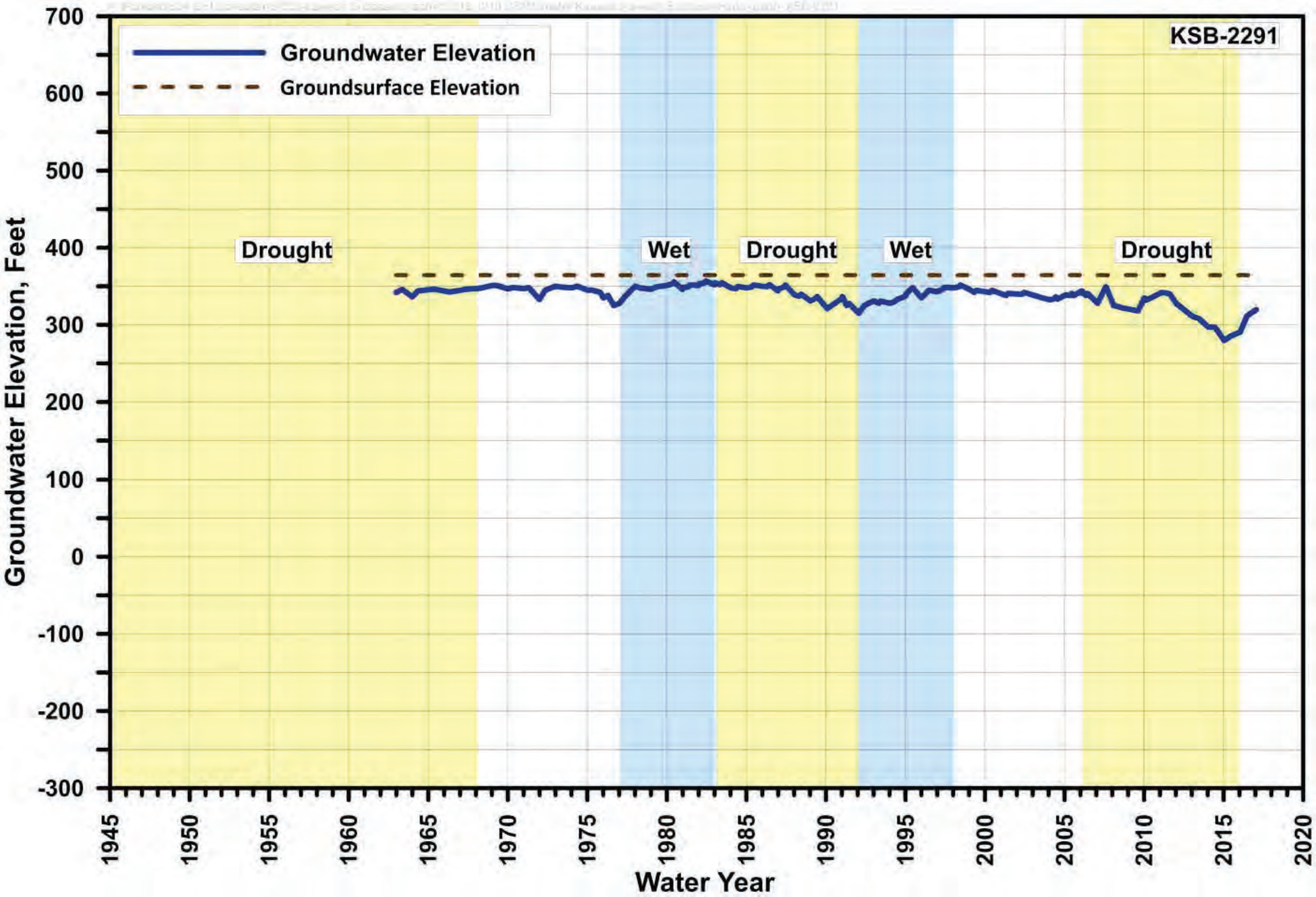
2015
2020



KSB-2291
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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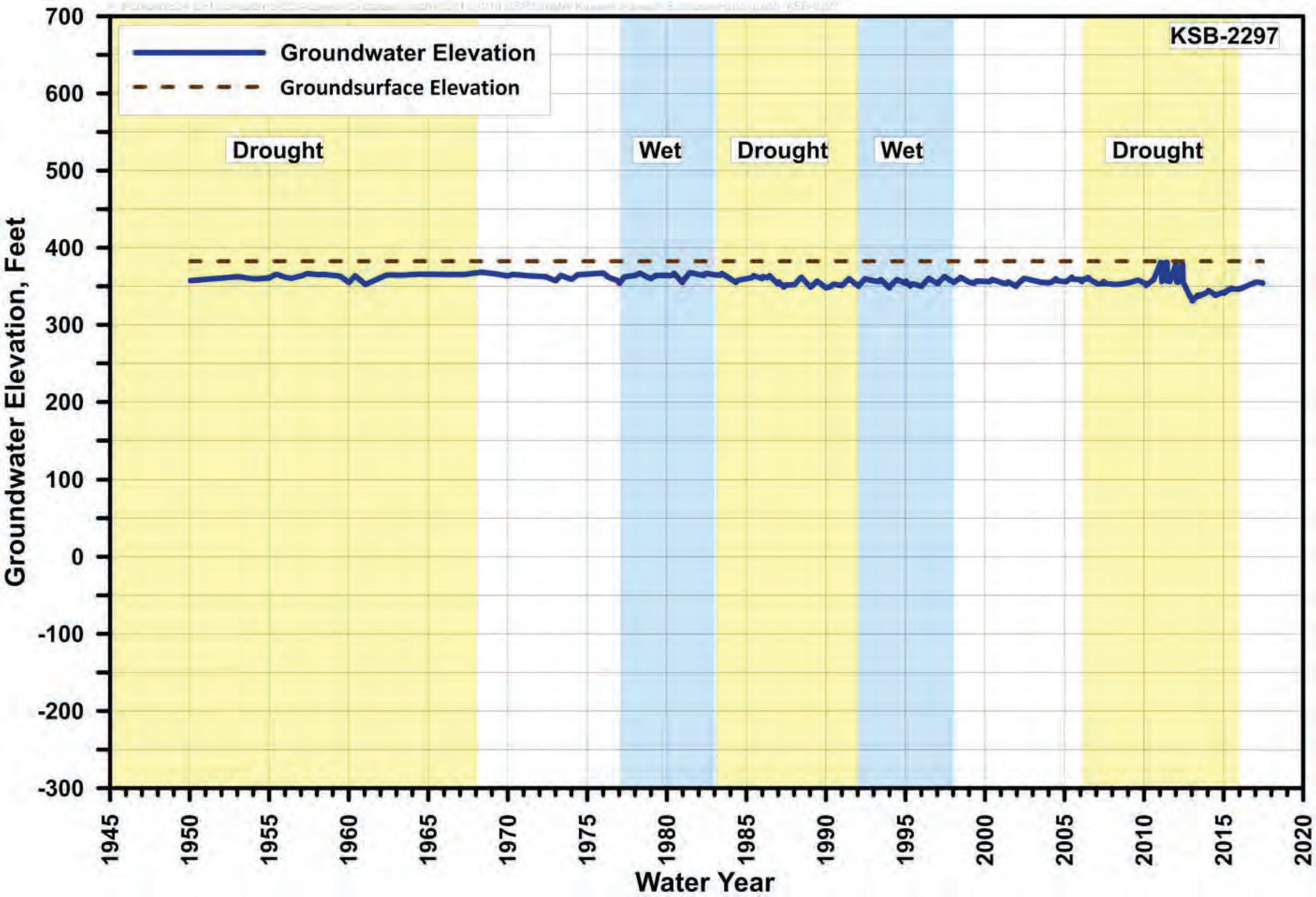
2005
2010
2015
2020
Water Year



KSB-2297
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
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1975
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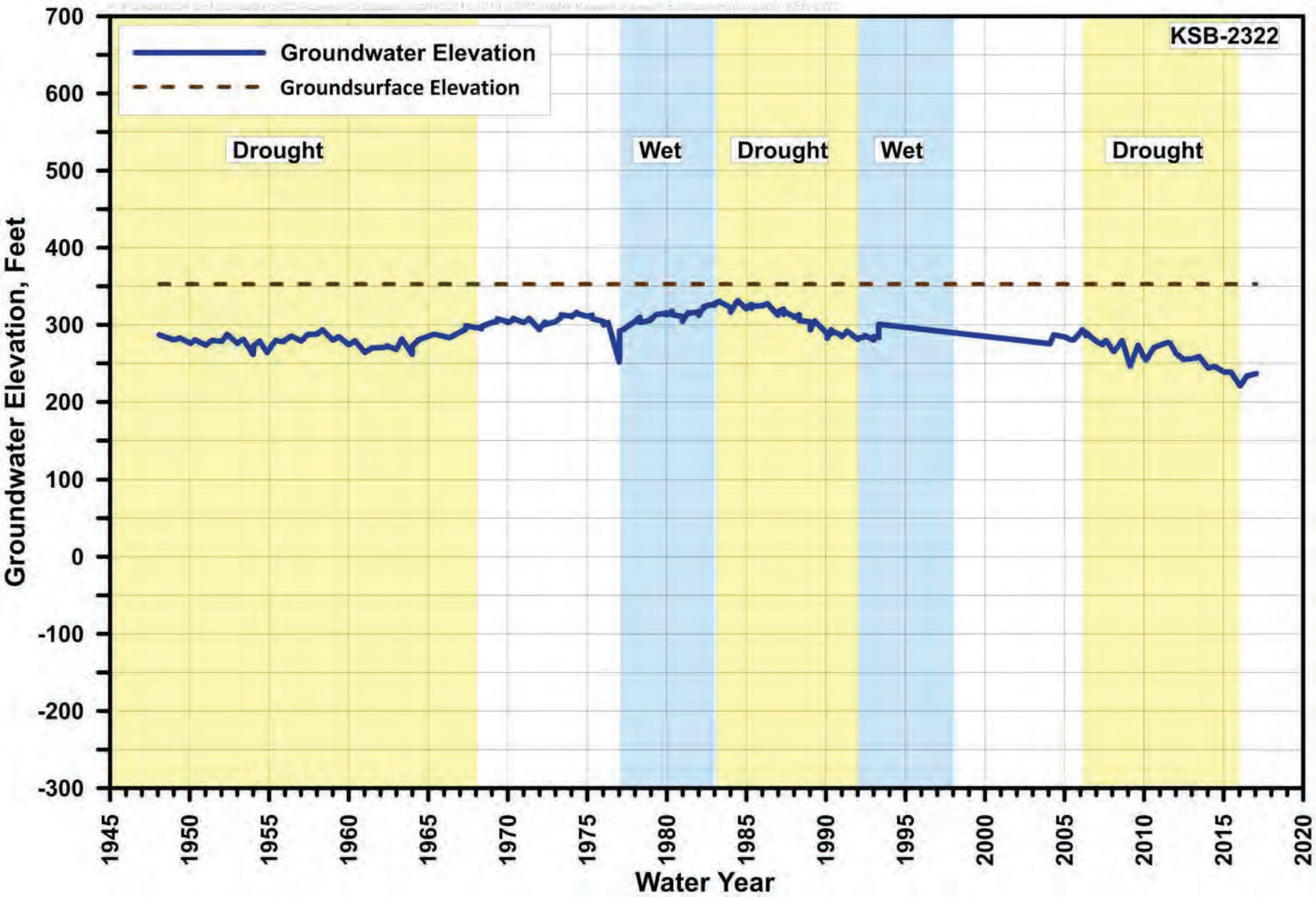
1990
1995
2000
2005
2010
2015
2020



KSB-2322
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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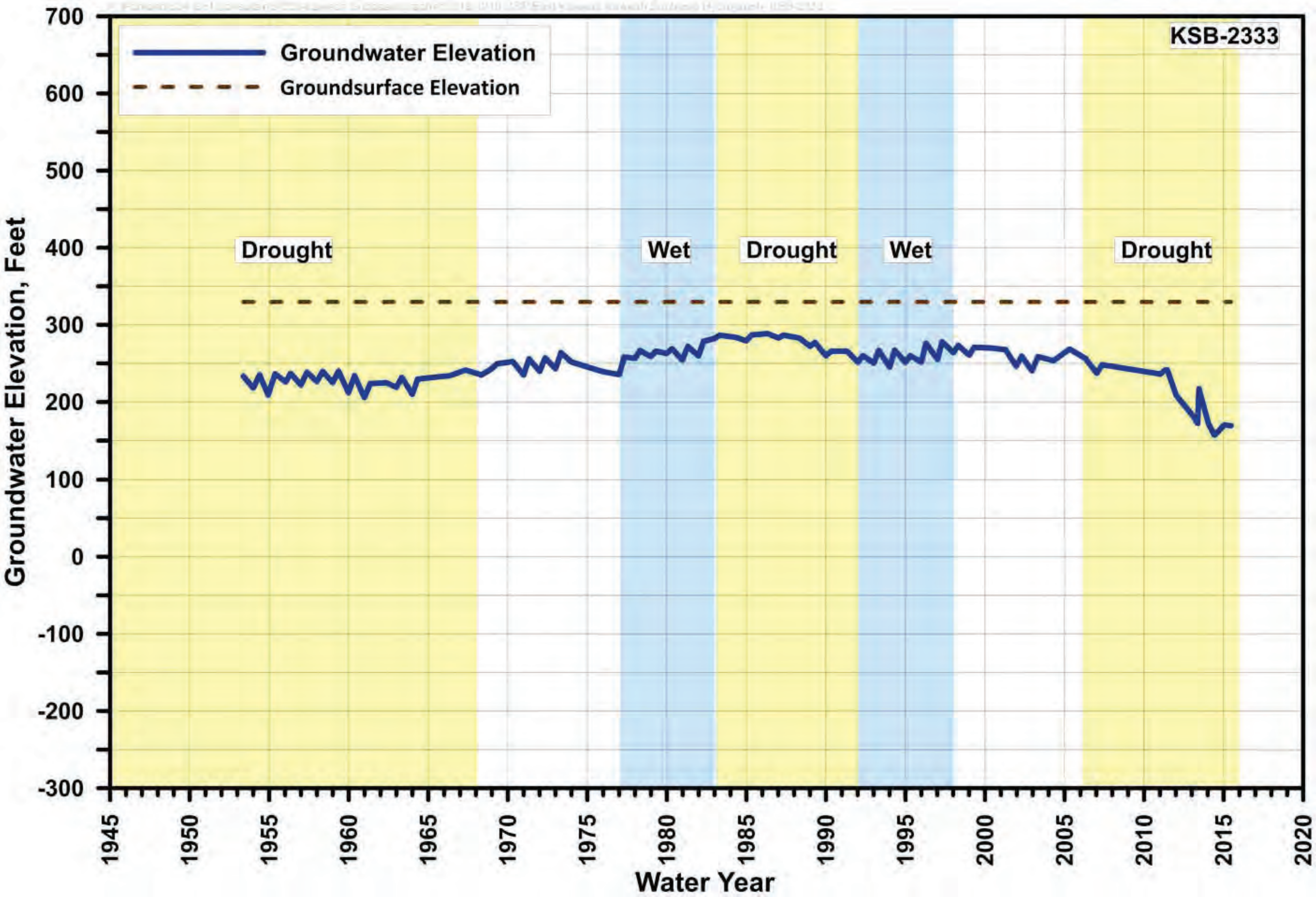
2005
2010
2015
2020


KSB-2333
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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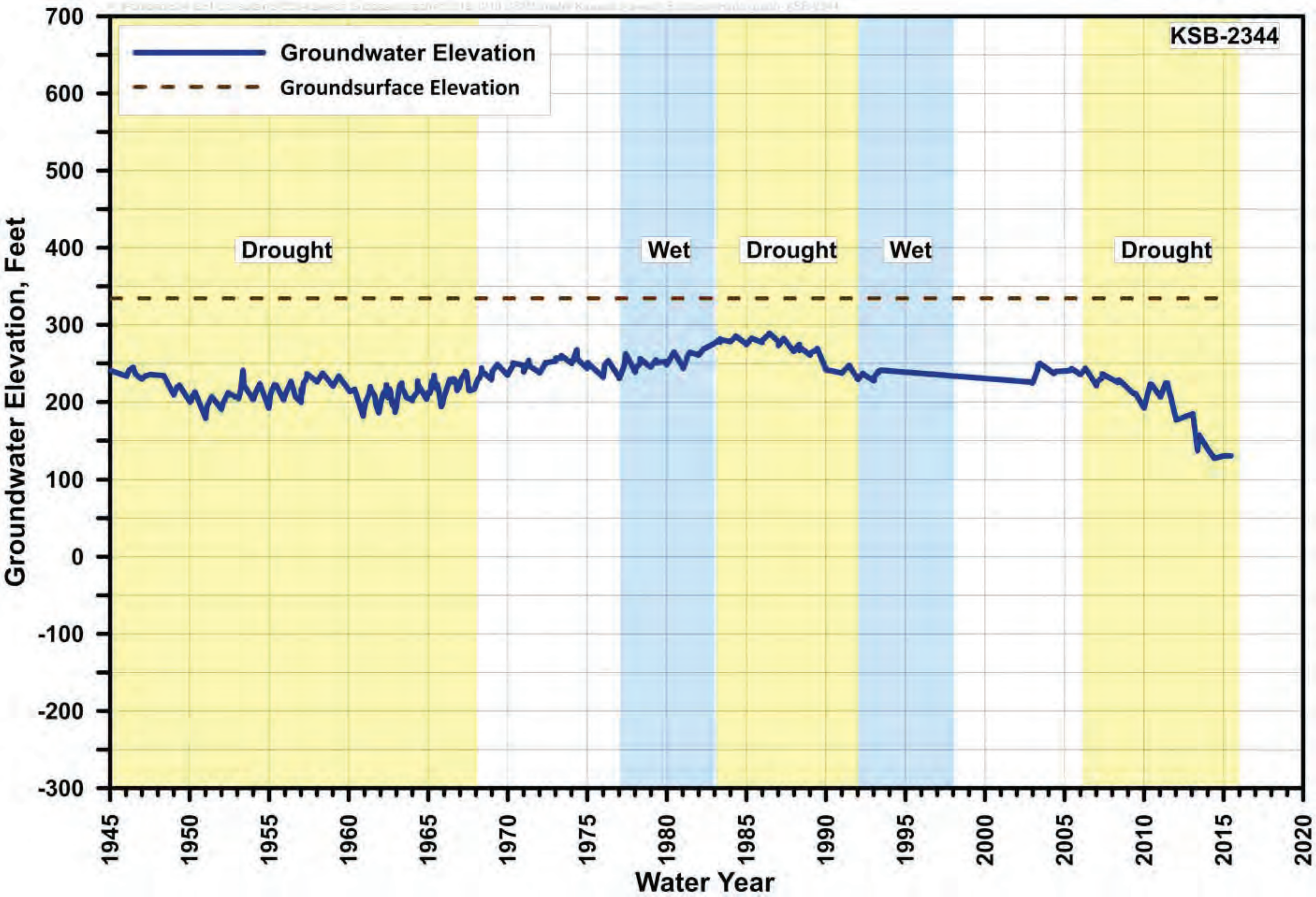
2010
2015
2020
Water Year



Groundwater Elevation
Groundsurface Elevation
KSB-2344
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
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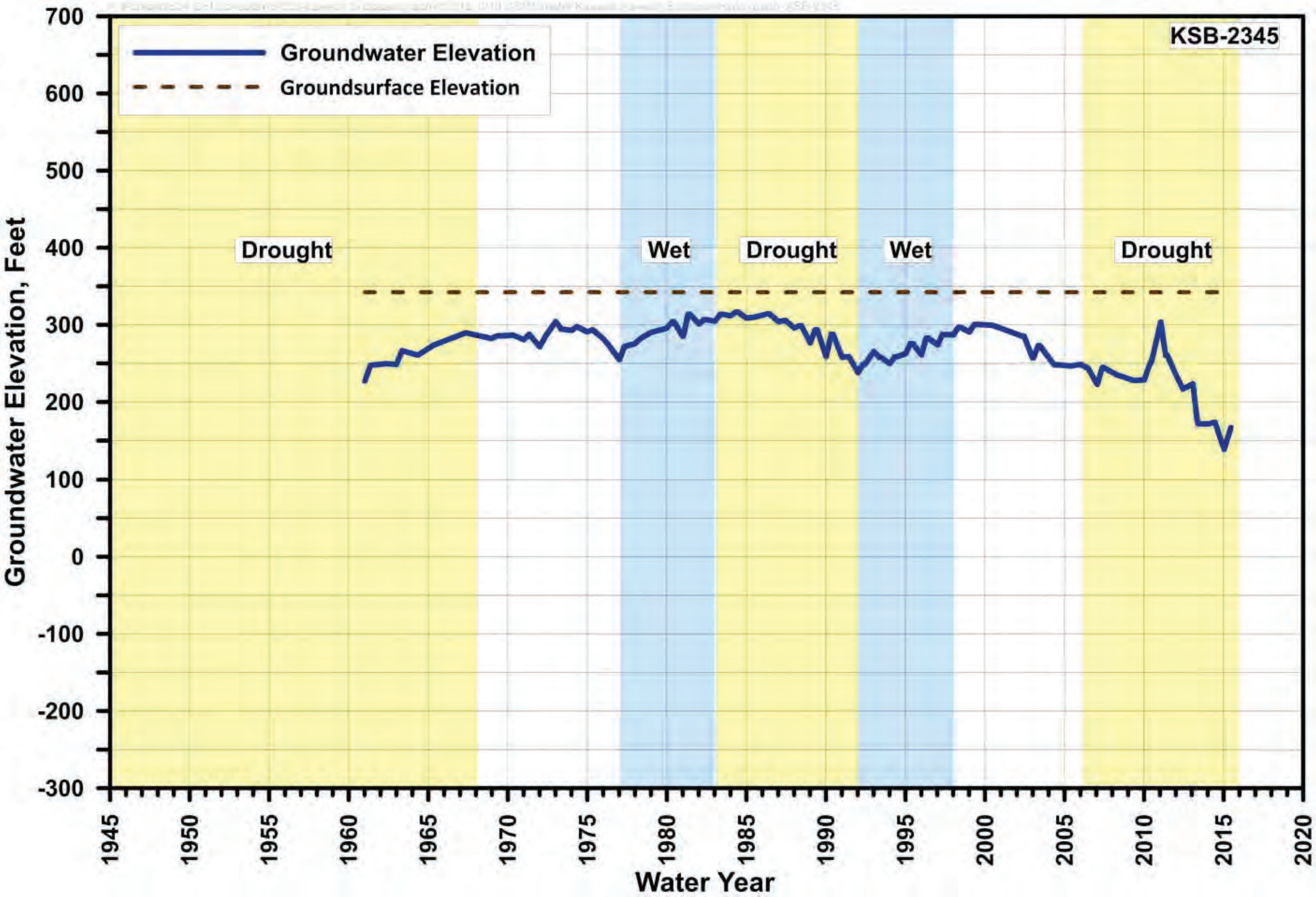
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year



KSB-2345
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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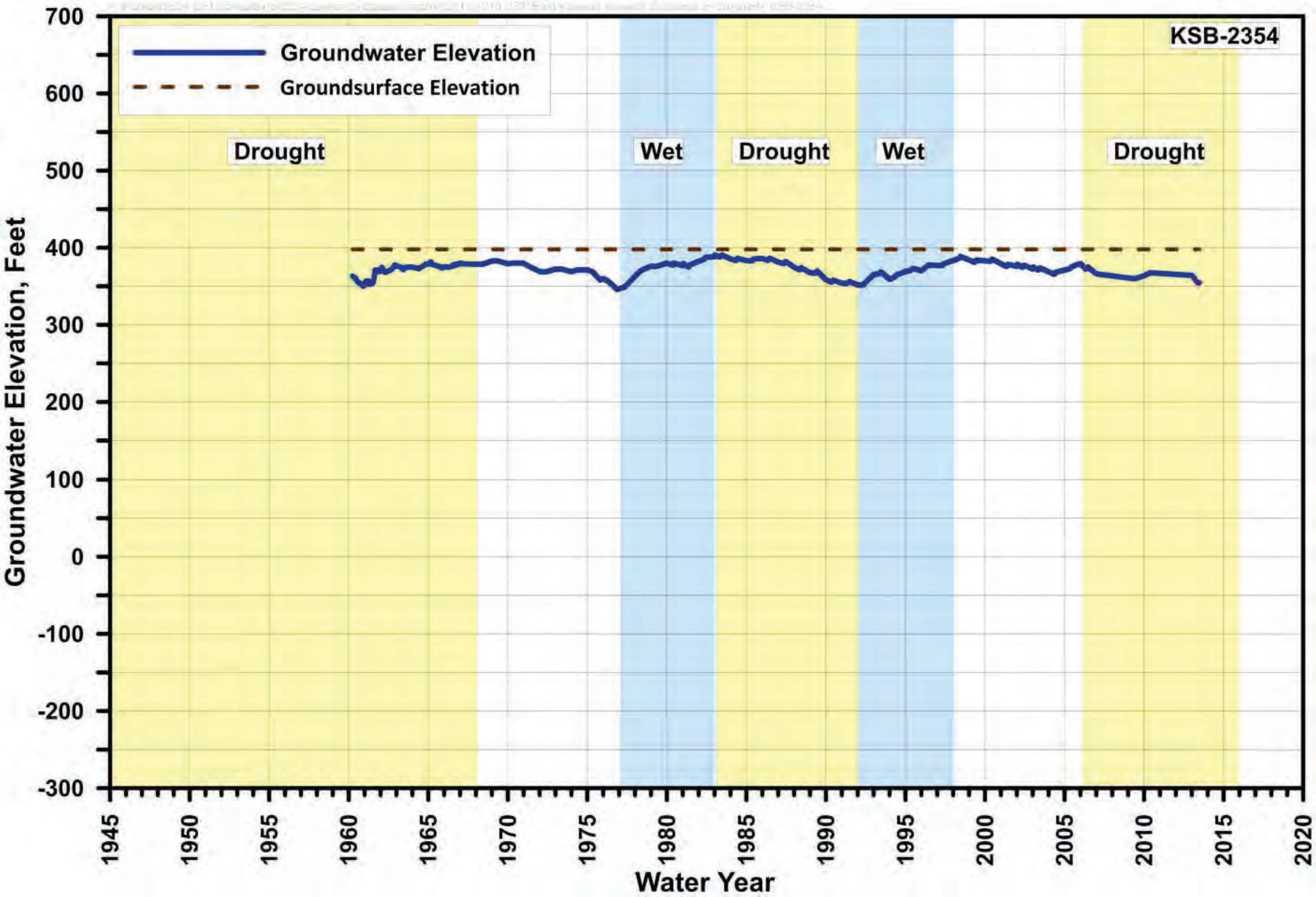
2000
2005
2010
2015
2020



KSB-2354
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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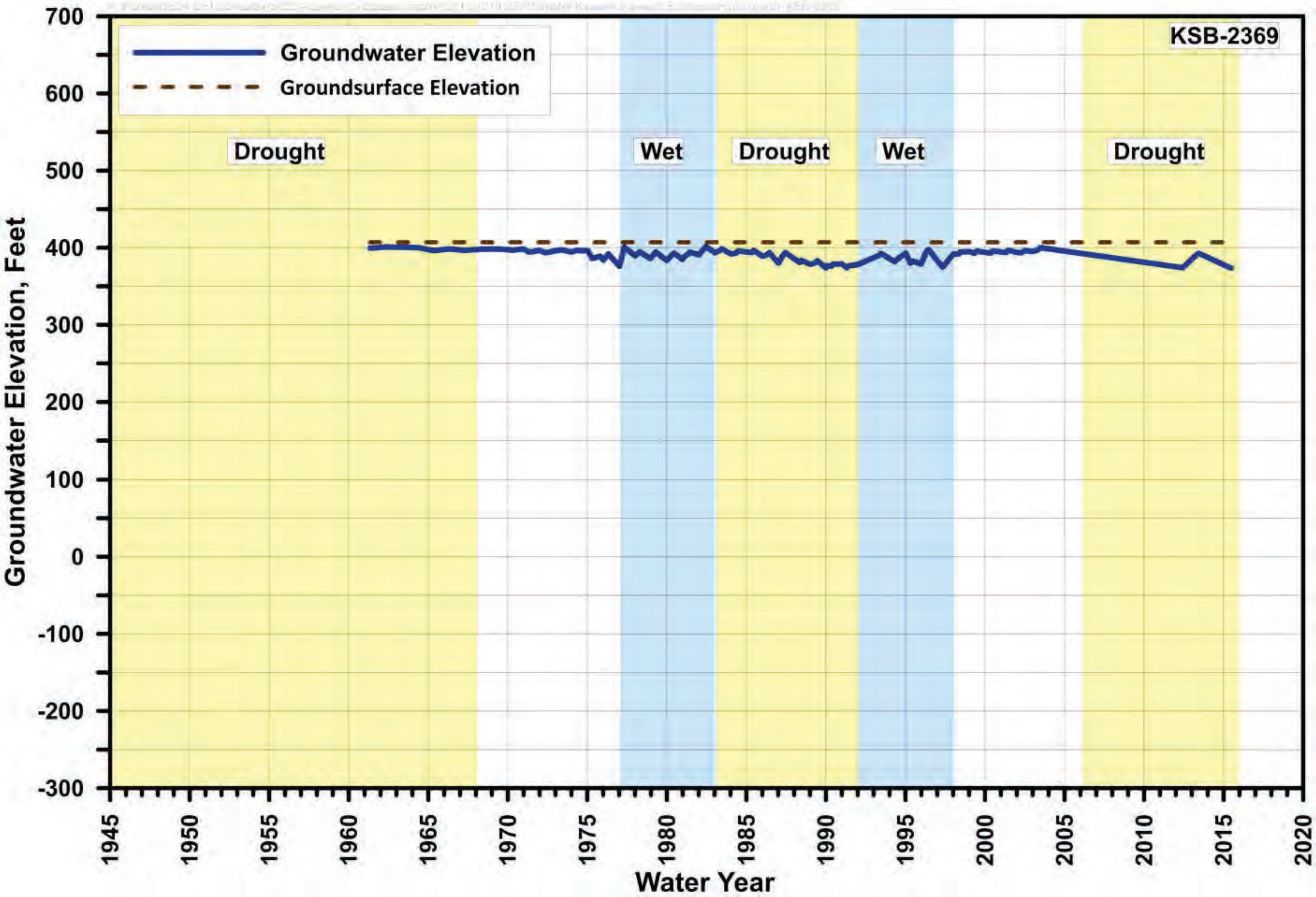
2010
2015
2020



KSB-2369
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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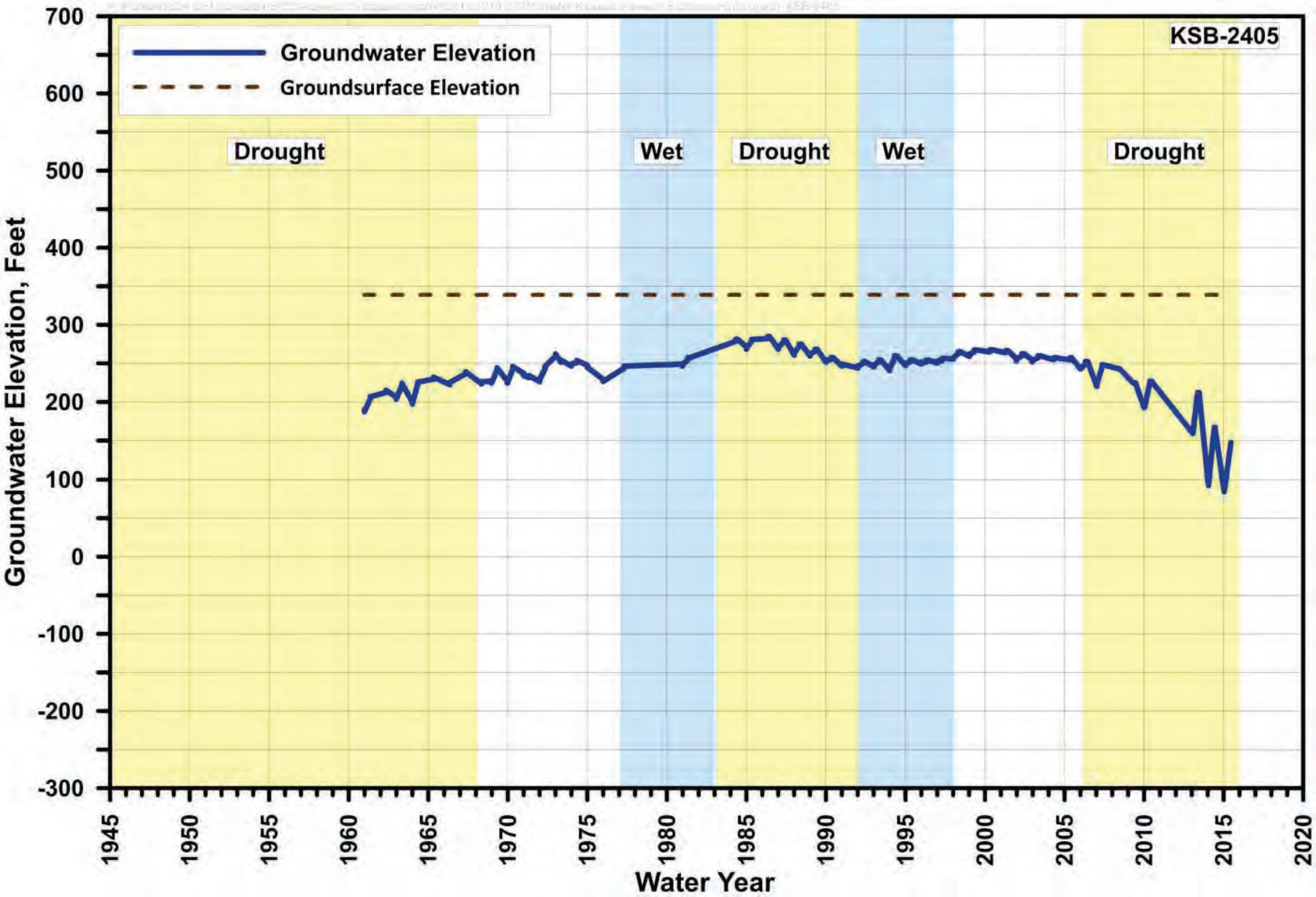
1995
2000
2005
2010
2015
2020
Water Year


KSB-2405
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
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1990
1995
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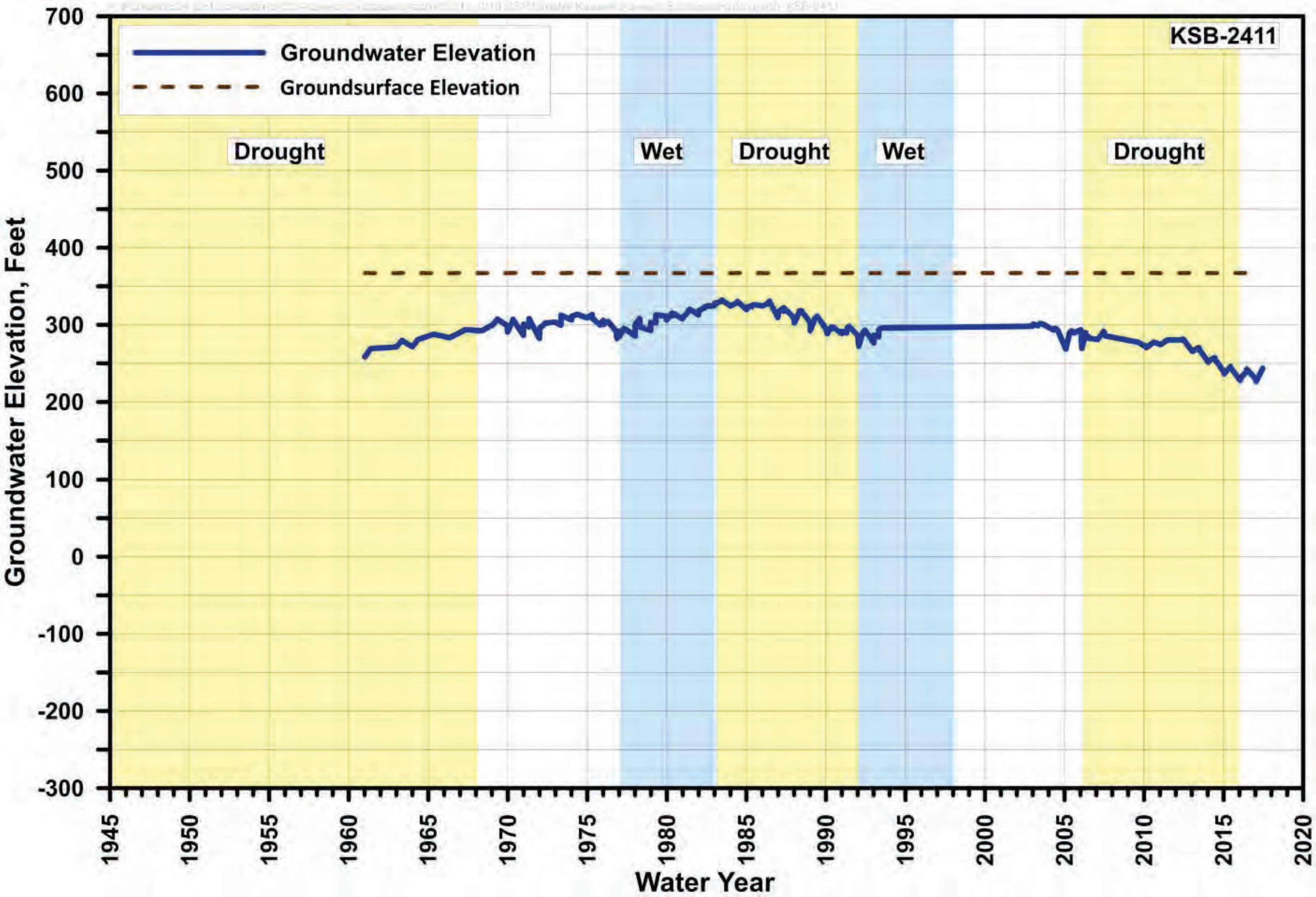
2005
2010
2015
2020


KSB-2411
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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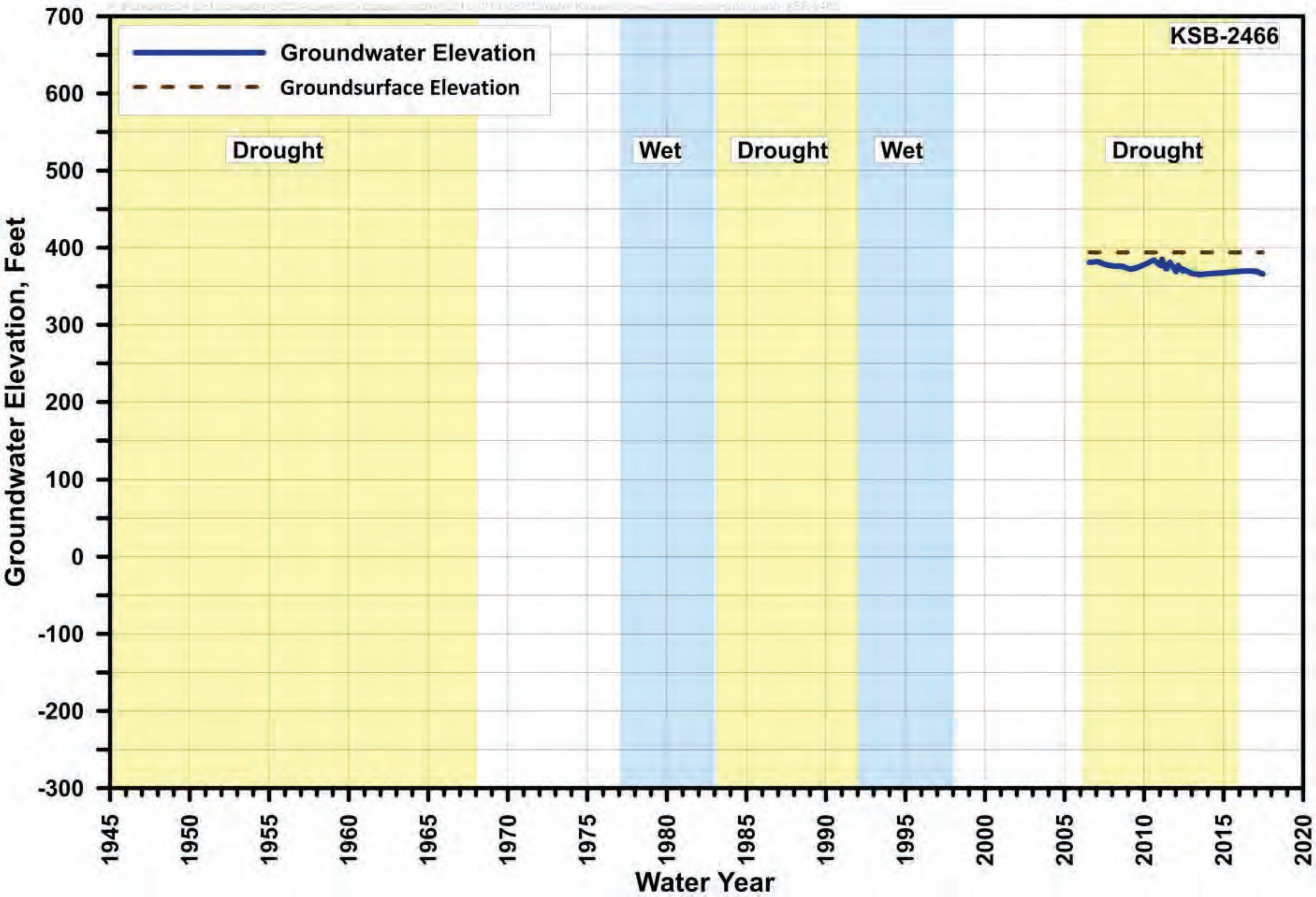
1995
2000
2005
2010
2015
2020
Water Year


KSB-2466
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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1995
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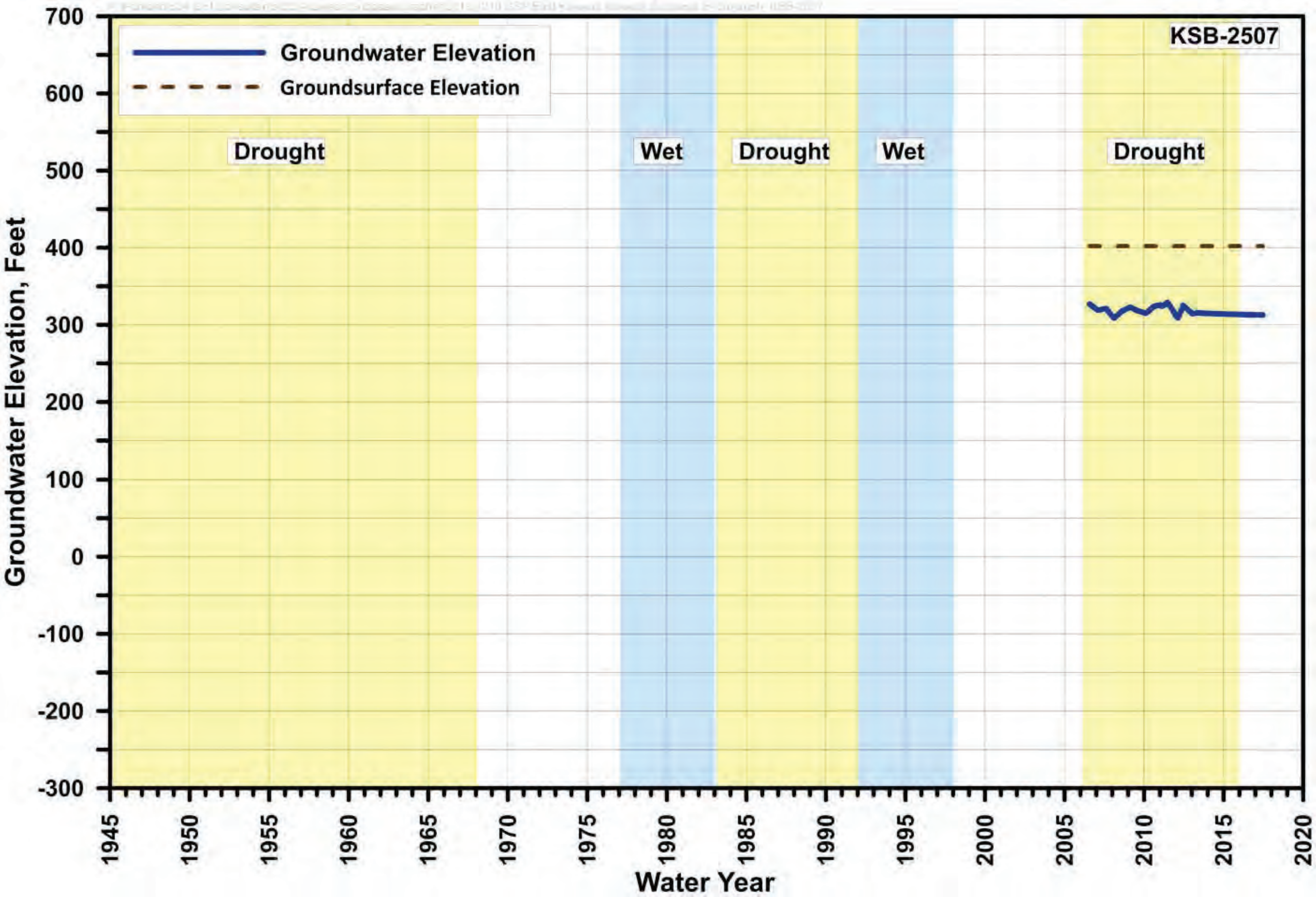
2005
2010
2015
2020
Water Year



KSB-2507
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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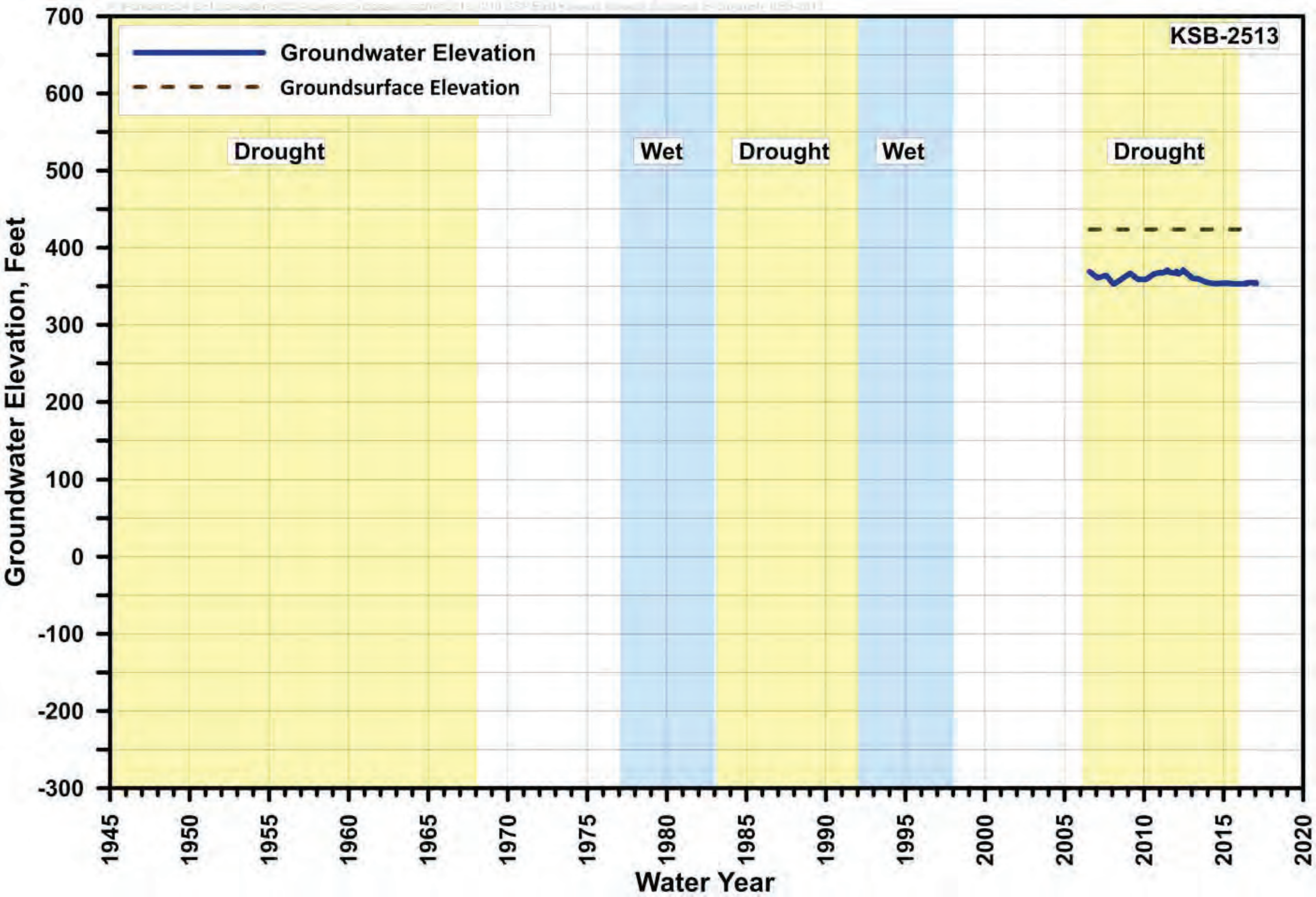
1995
2000
2005
2010
2015
2020
Water Year



KSB-2513
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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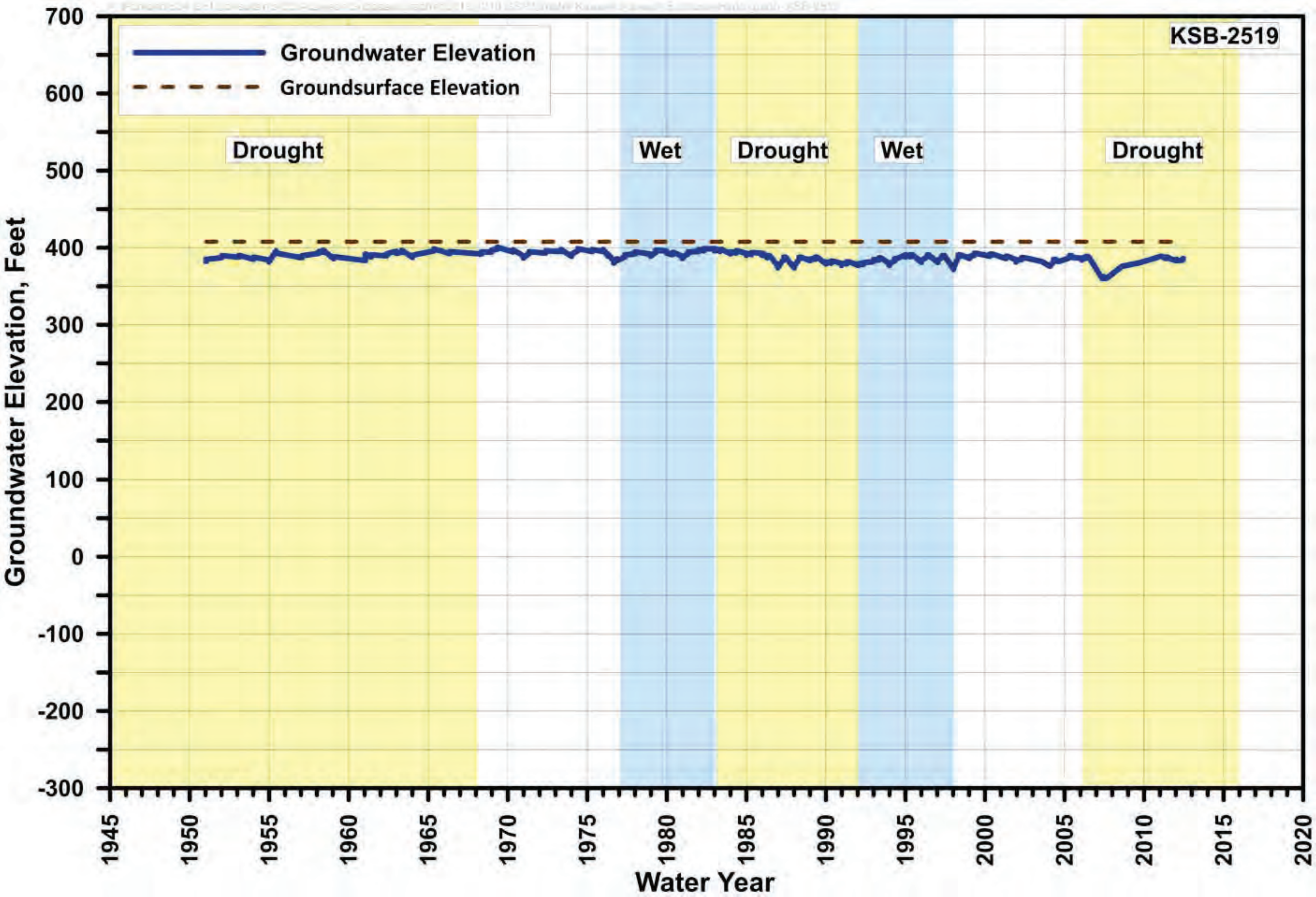
2010
2015
2020
Water Year



KSB-2519
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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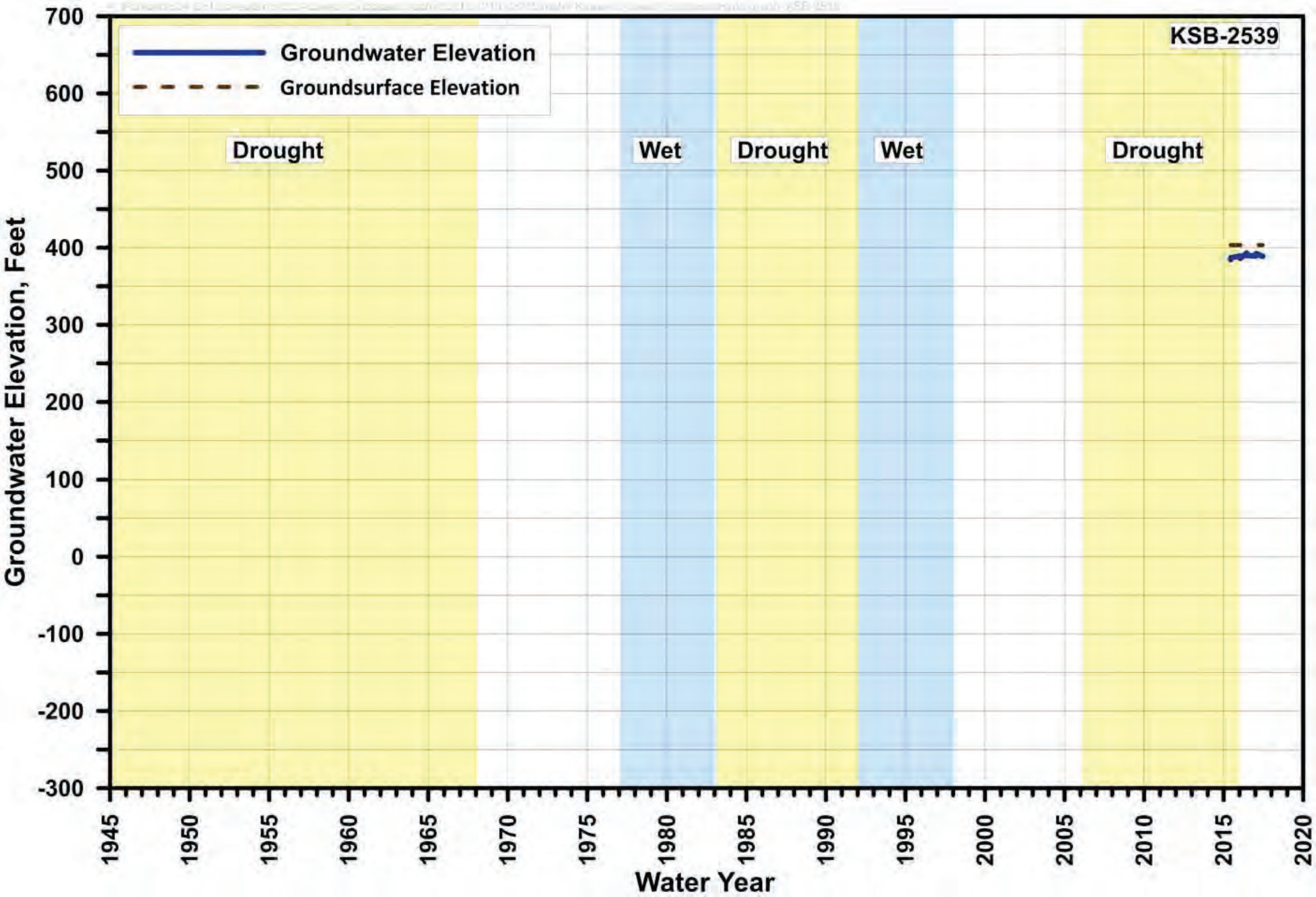

KSB-2539
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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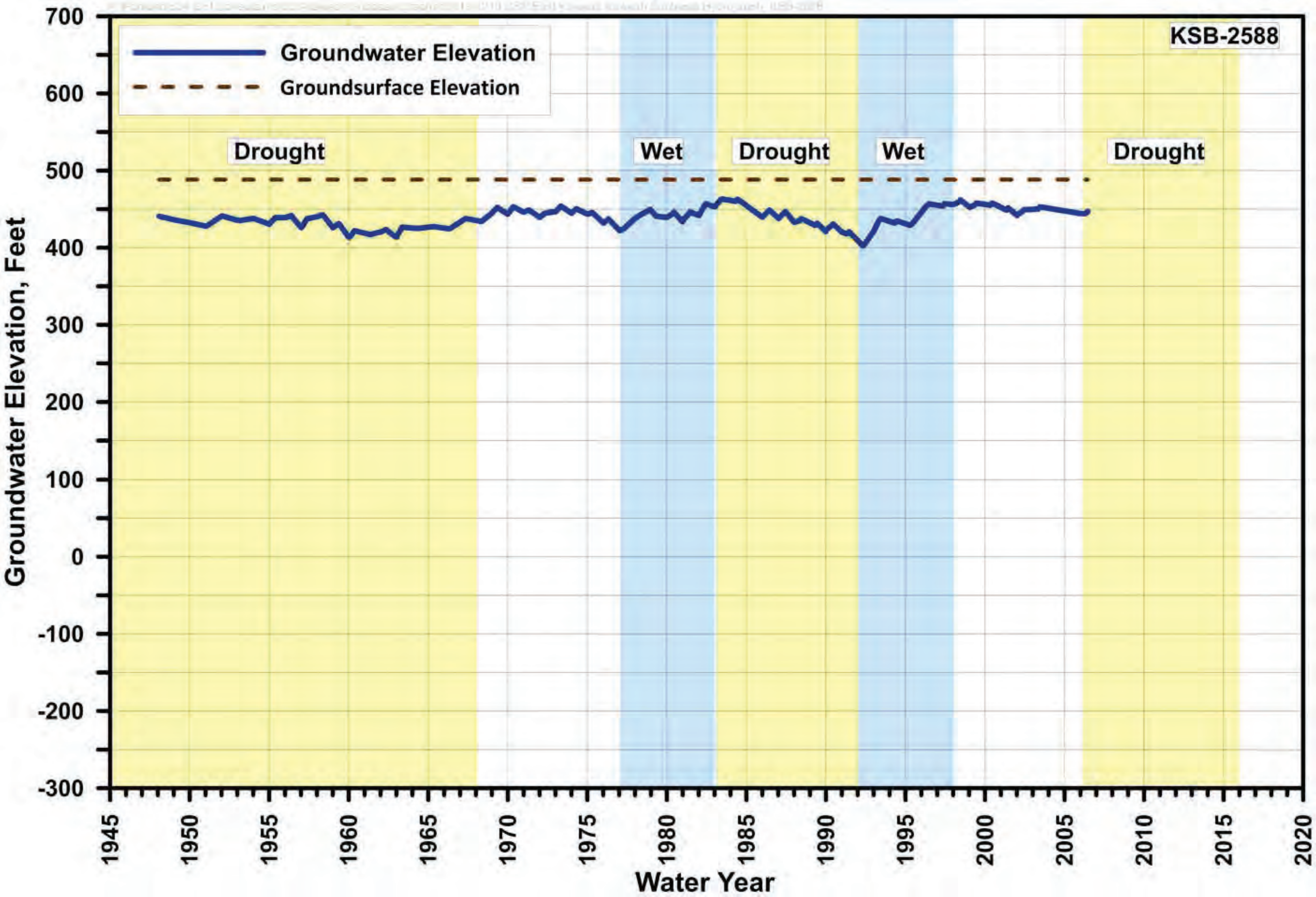
2020
Water Year



KSB-2588
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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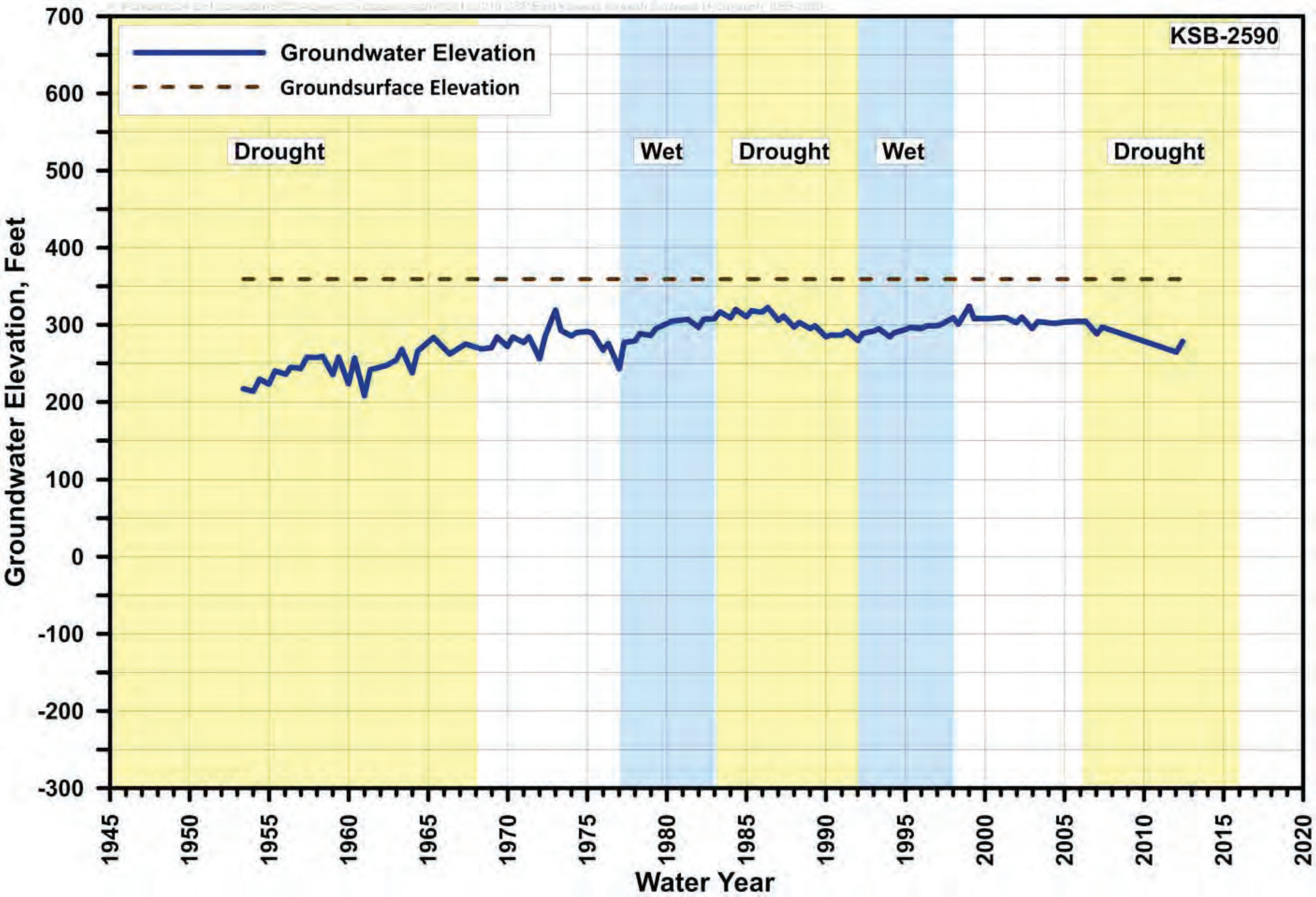
KSB-2590
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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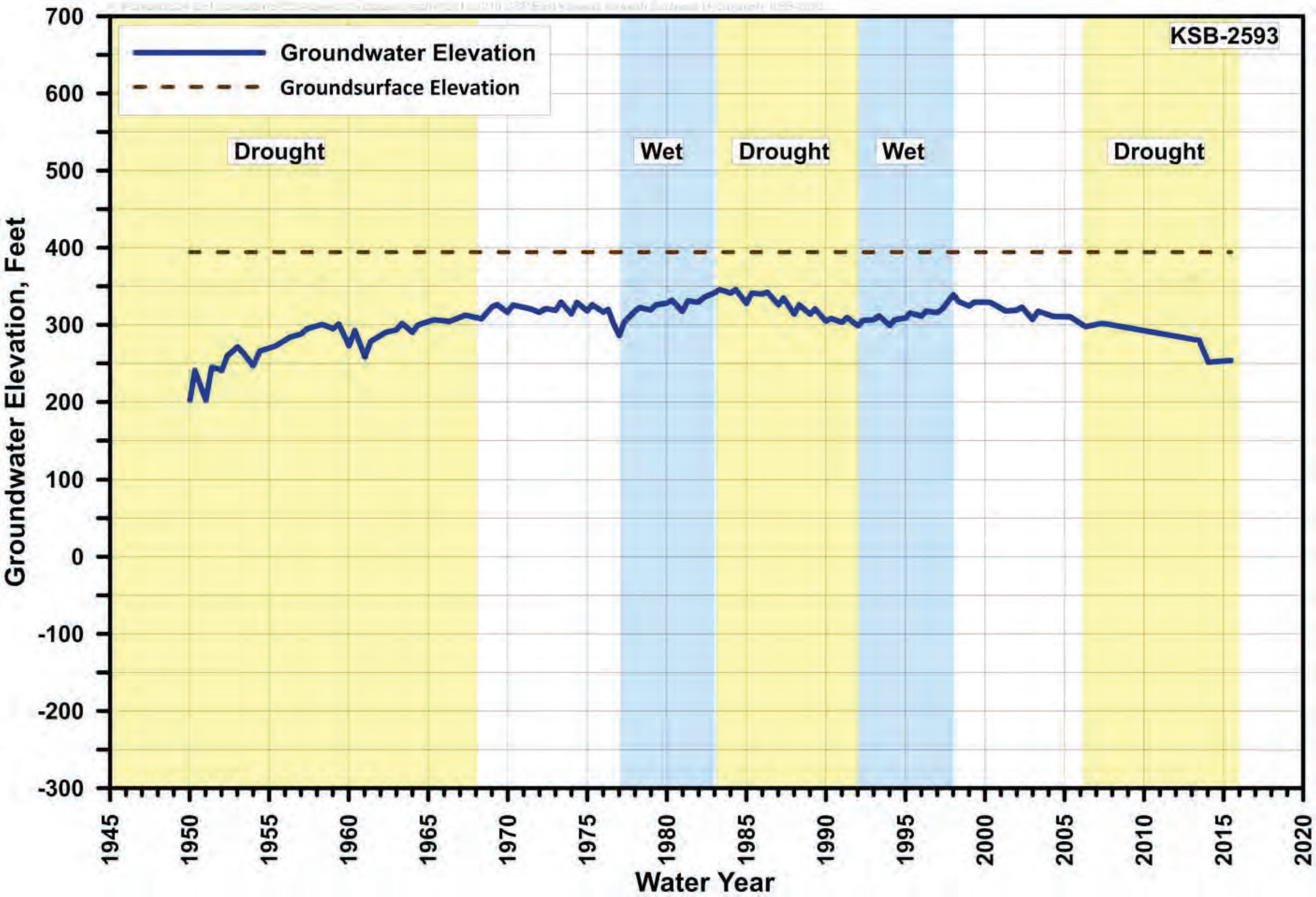
2015
2020
Water Year


KSB-2593
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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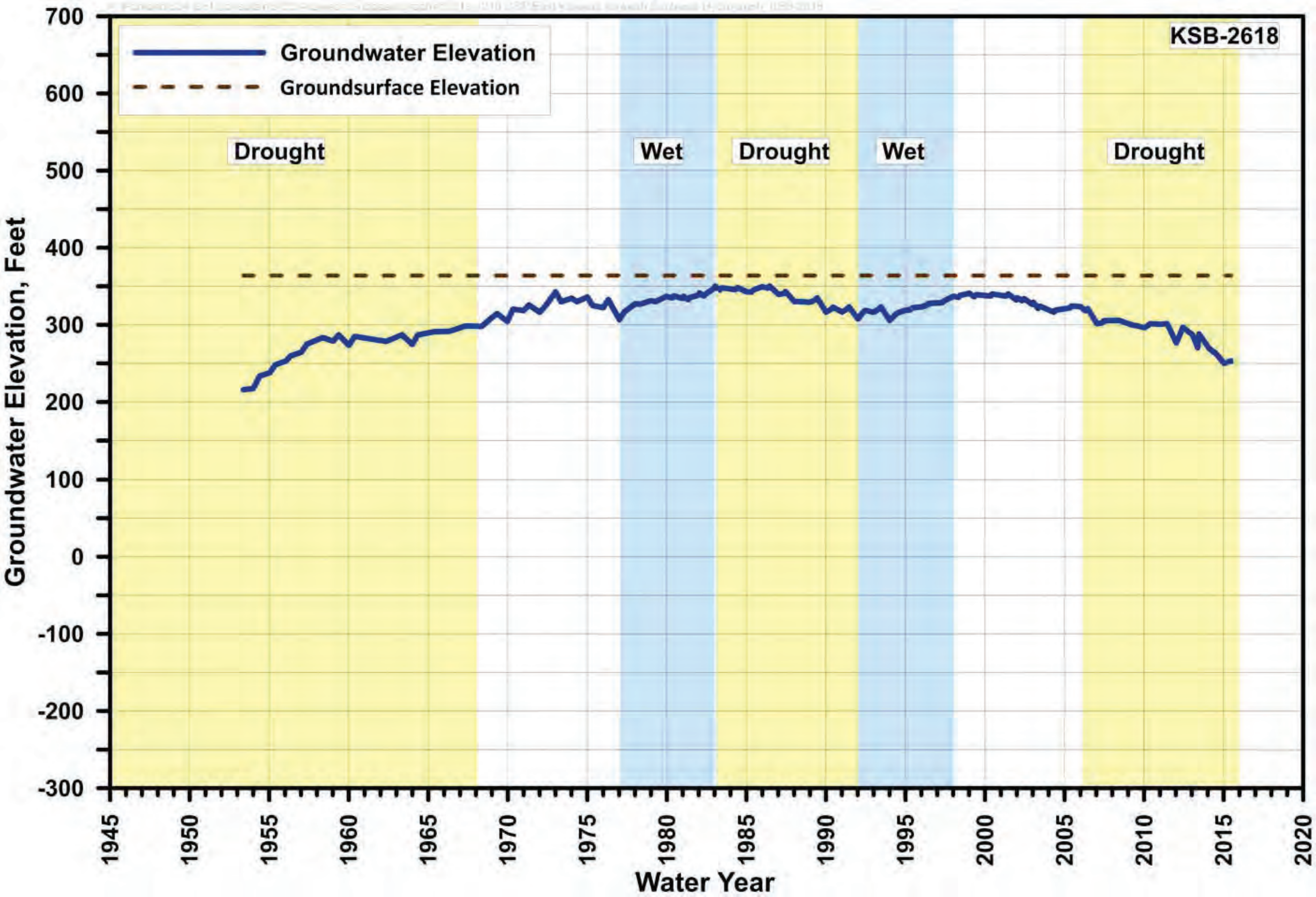
2015
2020
Water Year


KSB-2618
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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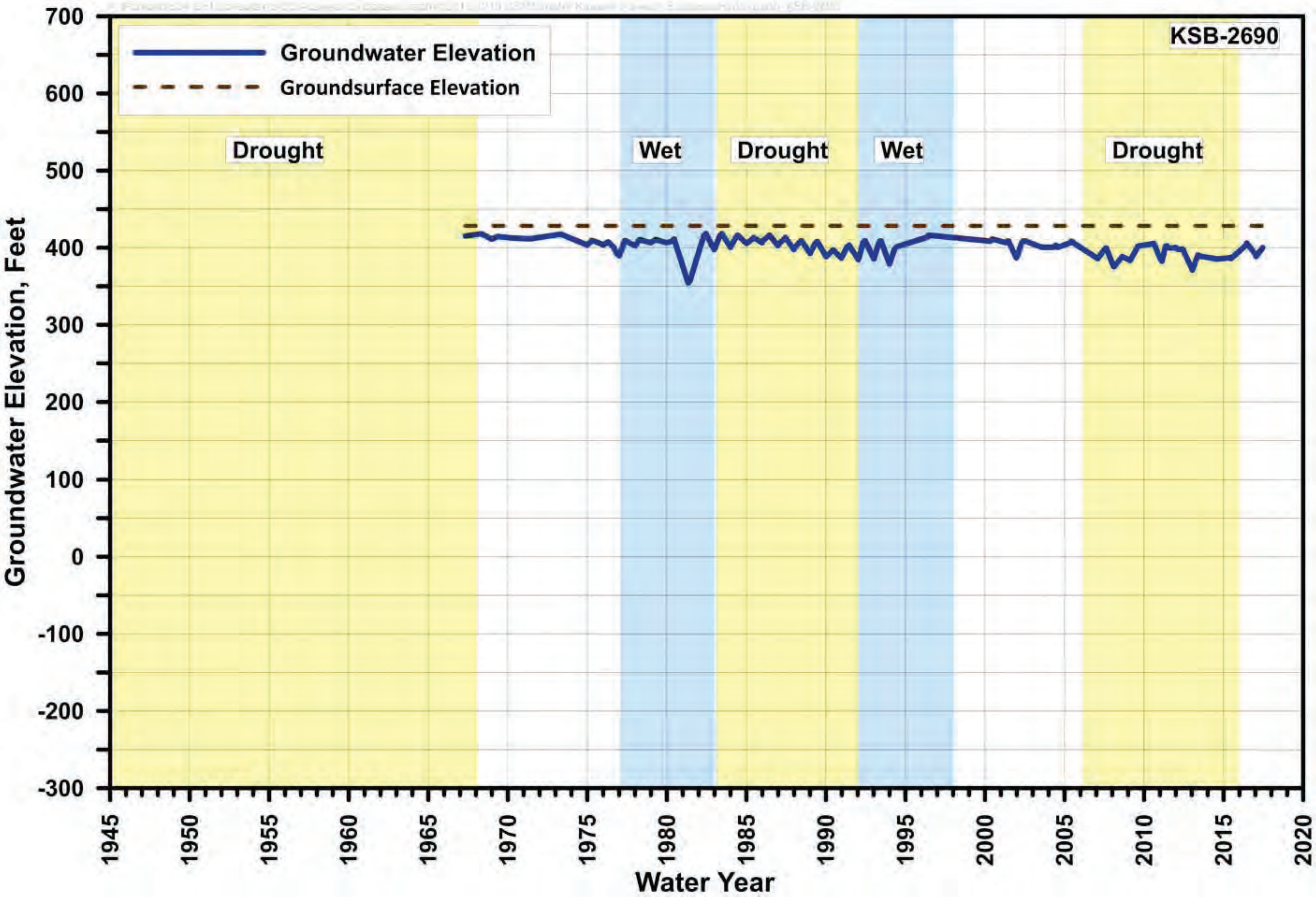

KSB-2690
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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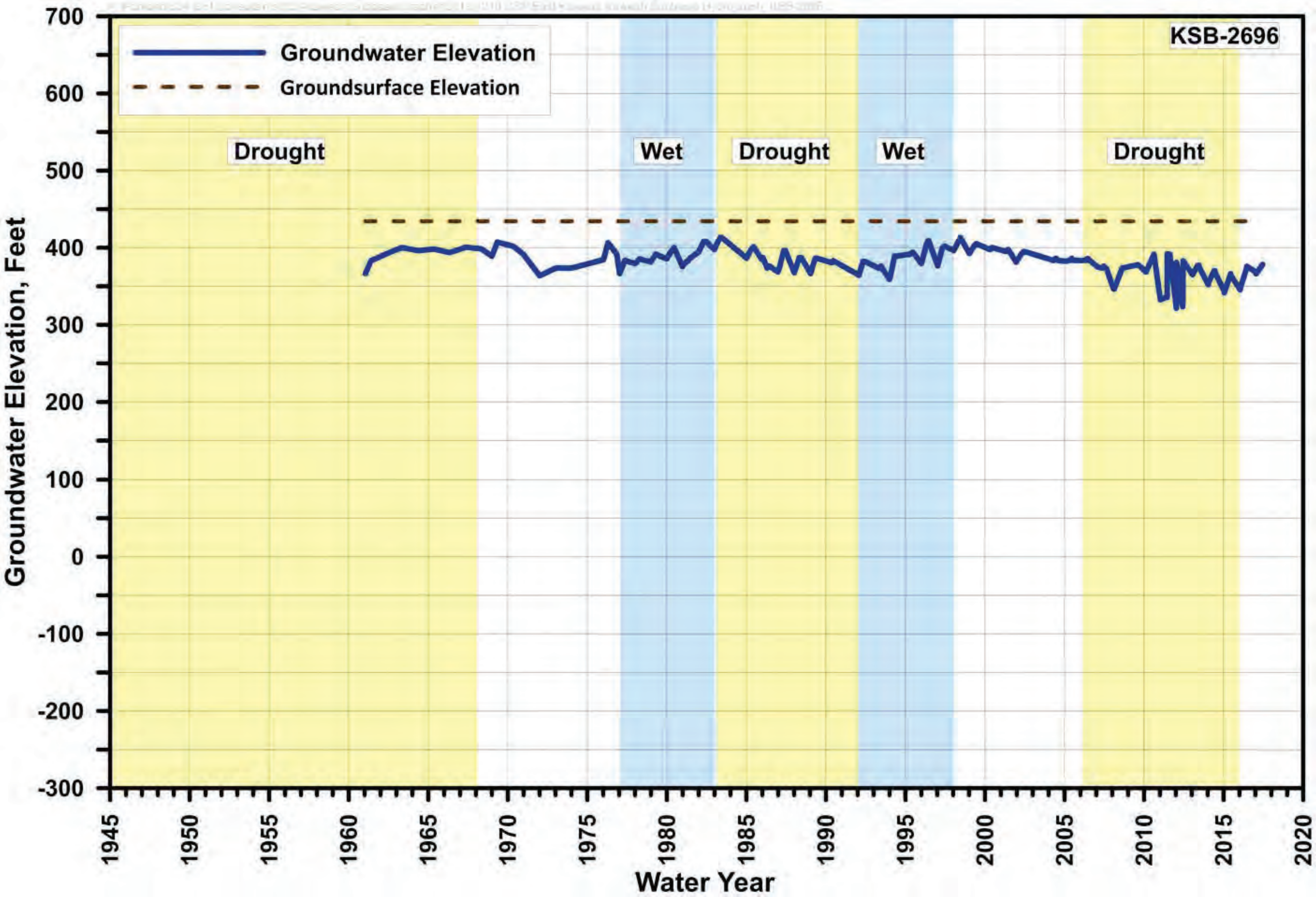
2015
2020
Water Year



KSB-2696
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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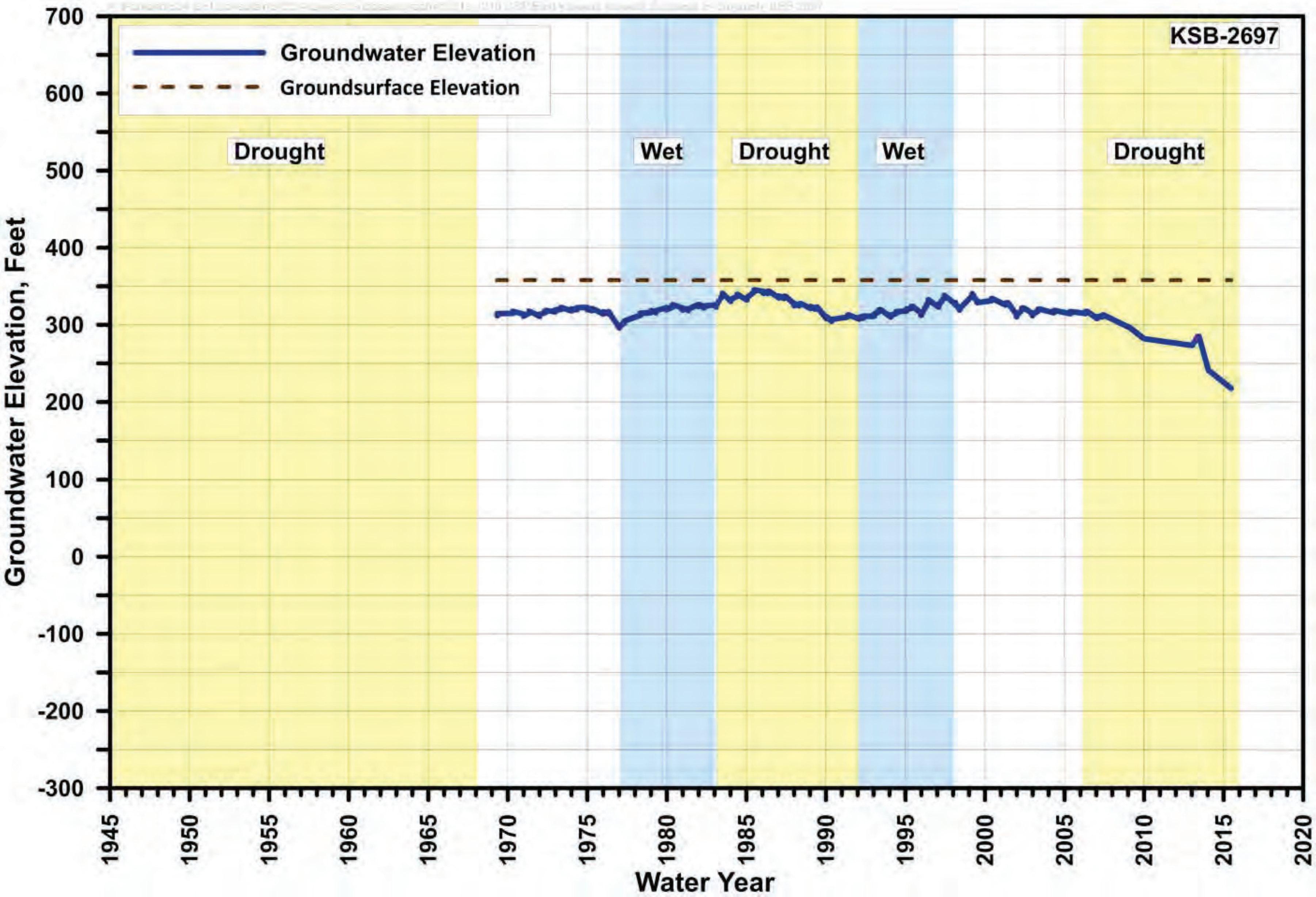
2015
2020
Water Year



KSB-2697
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
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-100
-200
-300
1945
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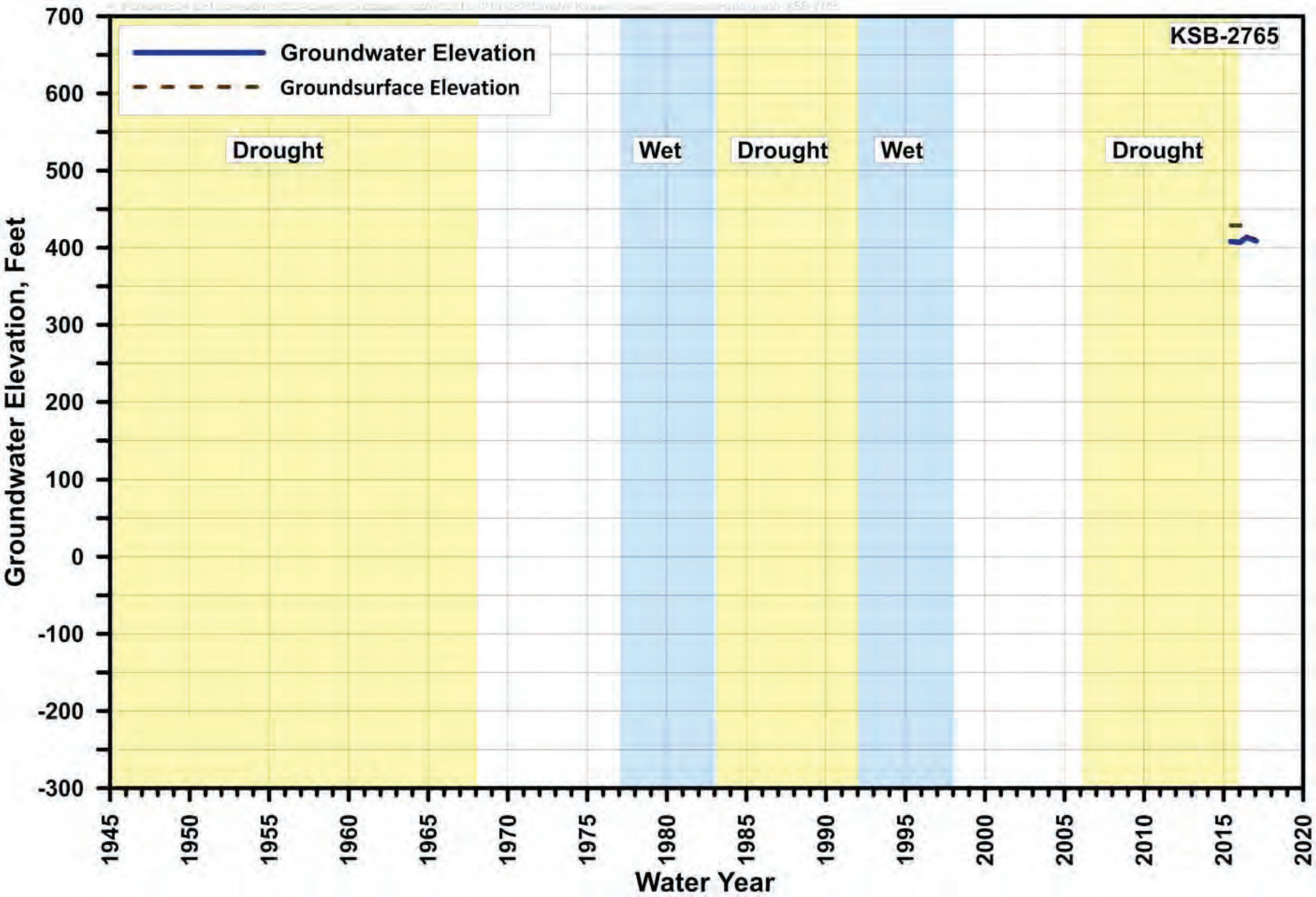
KSB-2765
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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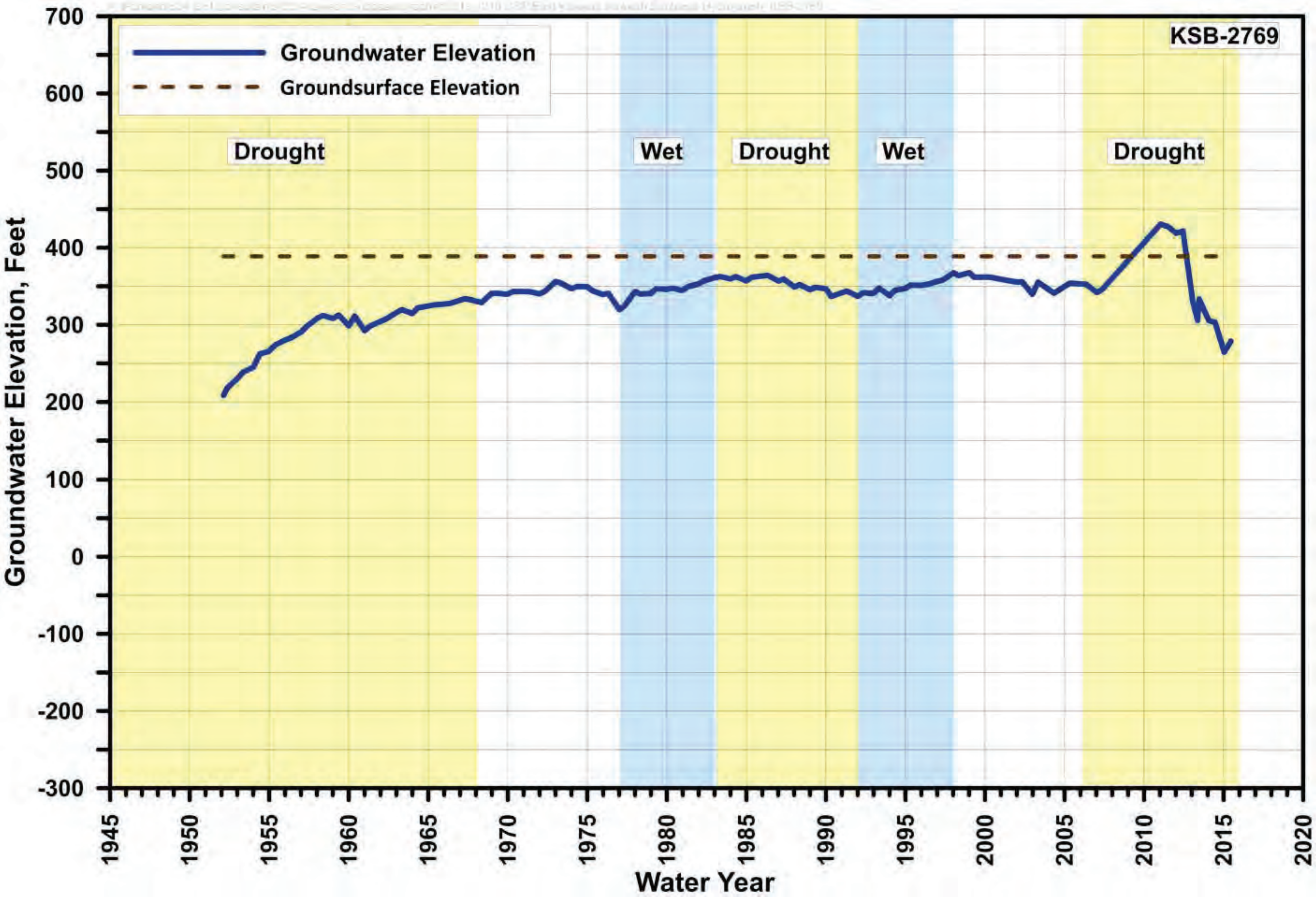
2015
2020
Water Year



KSB-2769
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
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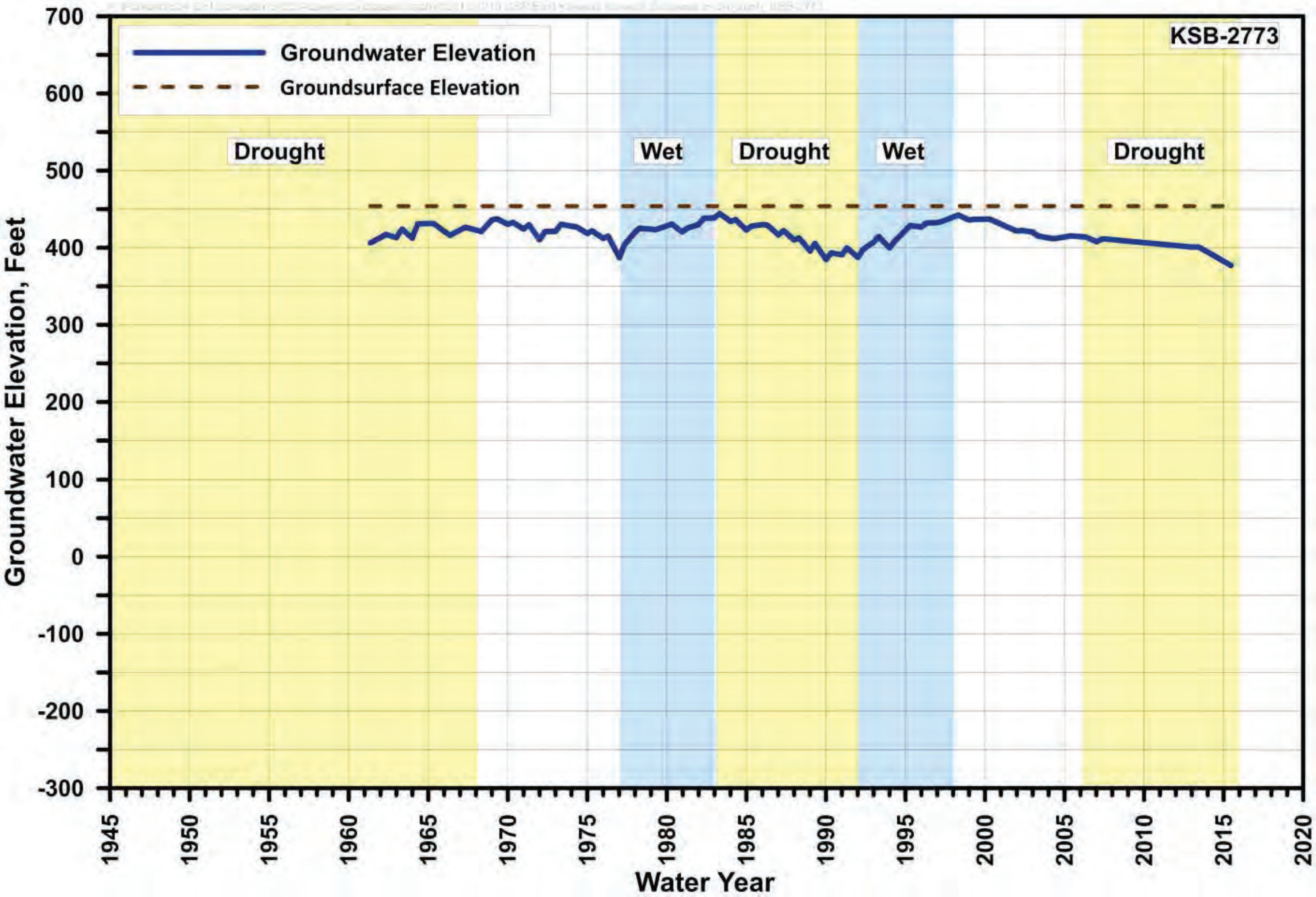
2020
Water Year



KSB-2773
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
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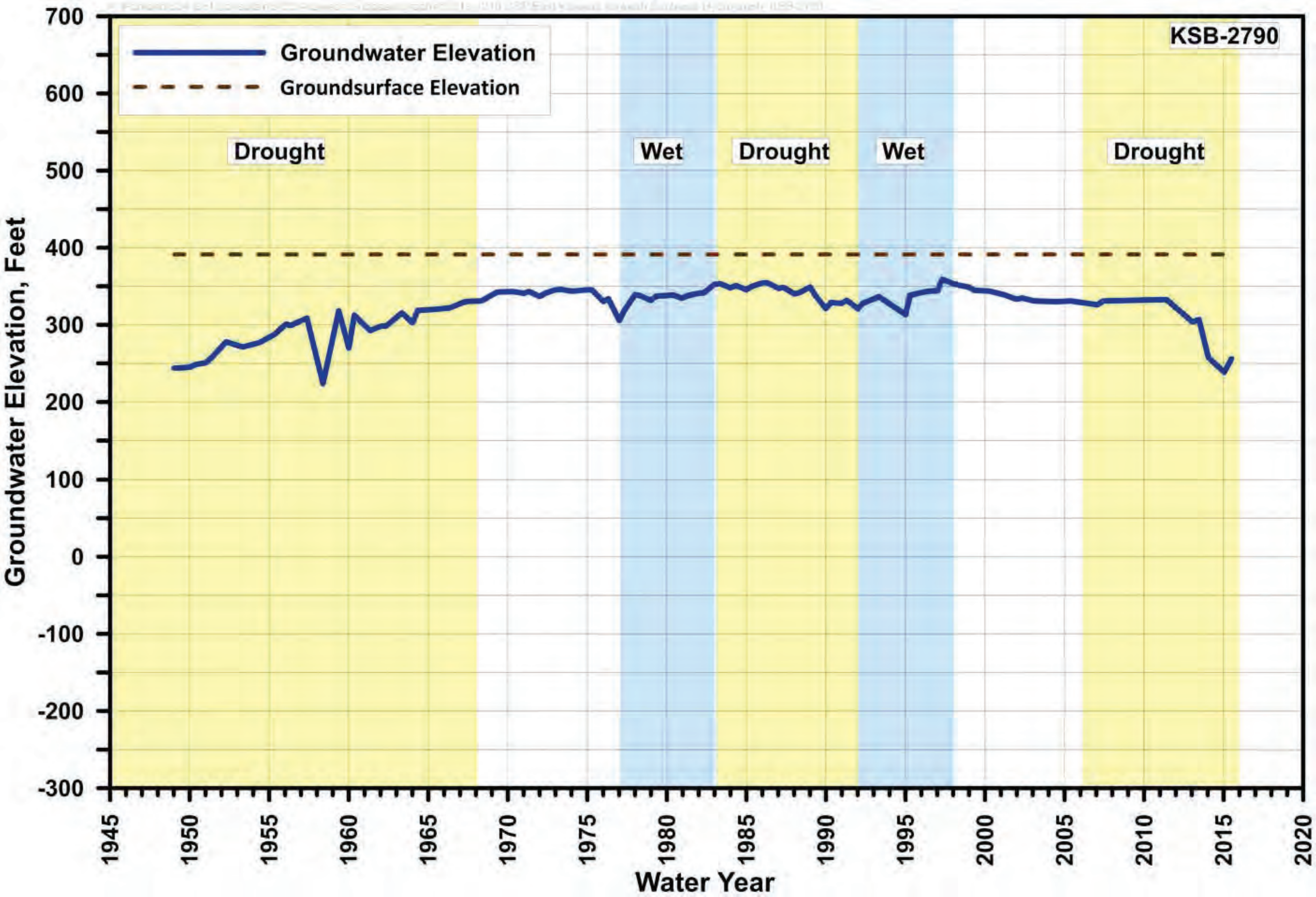
2015
2020
Water Year



KSB-2790
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
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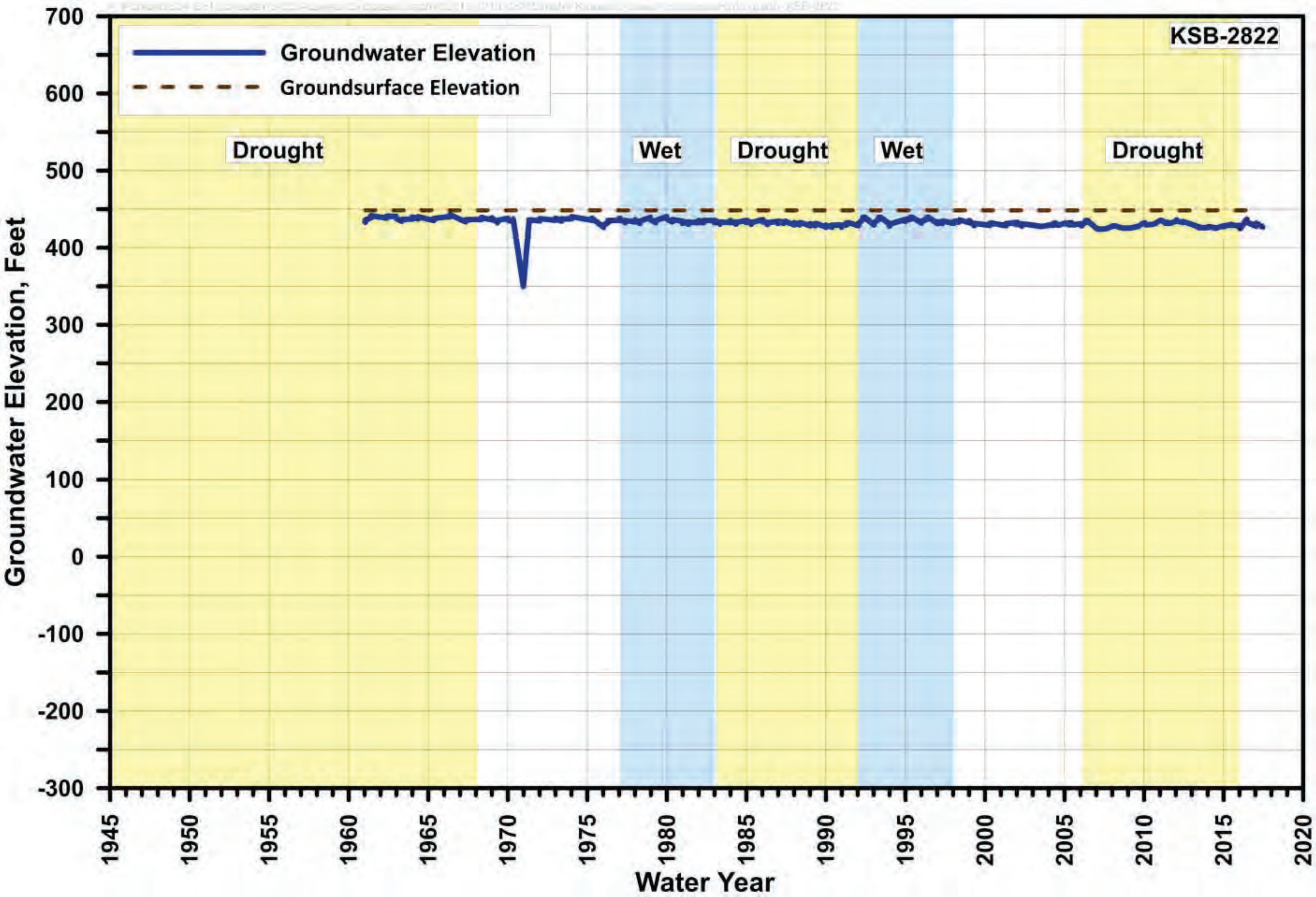

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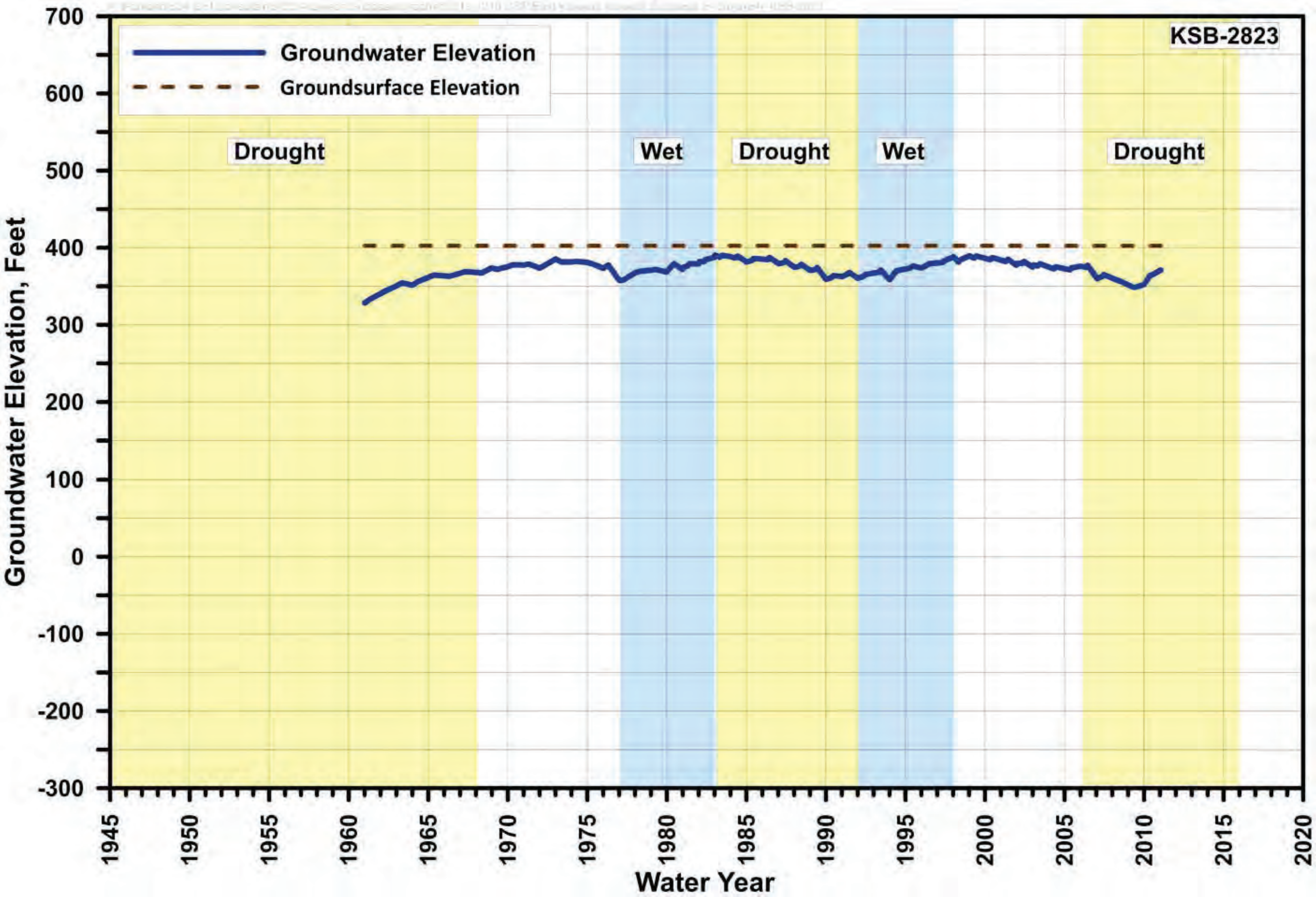
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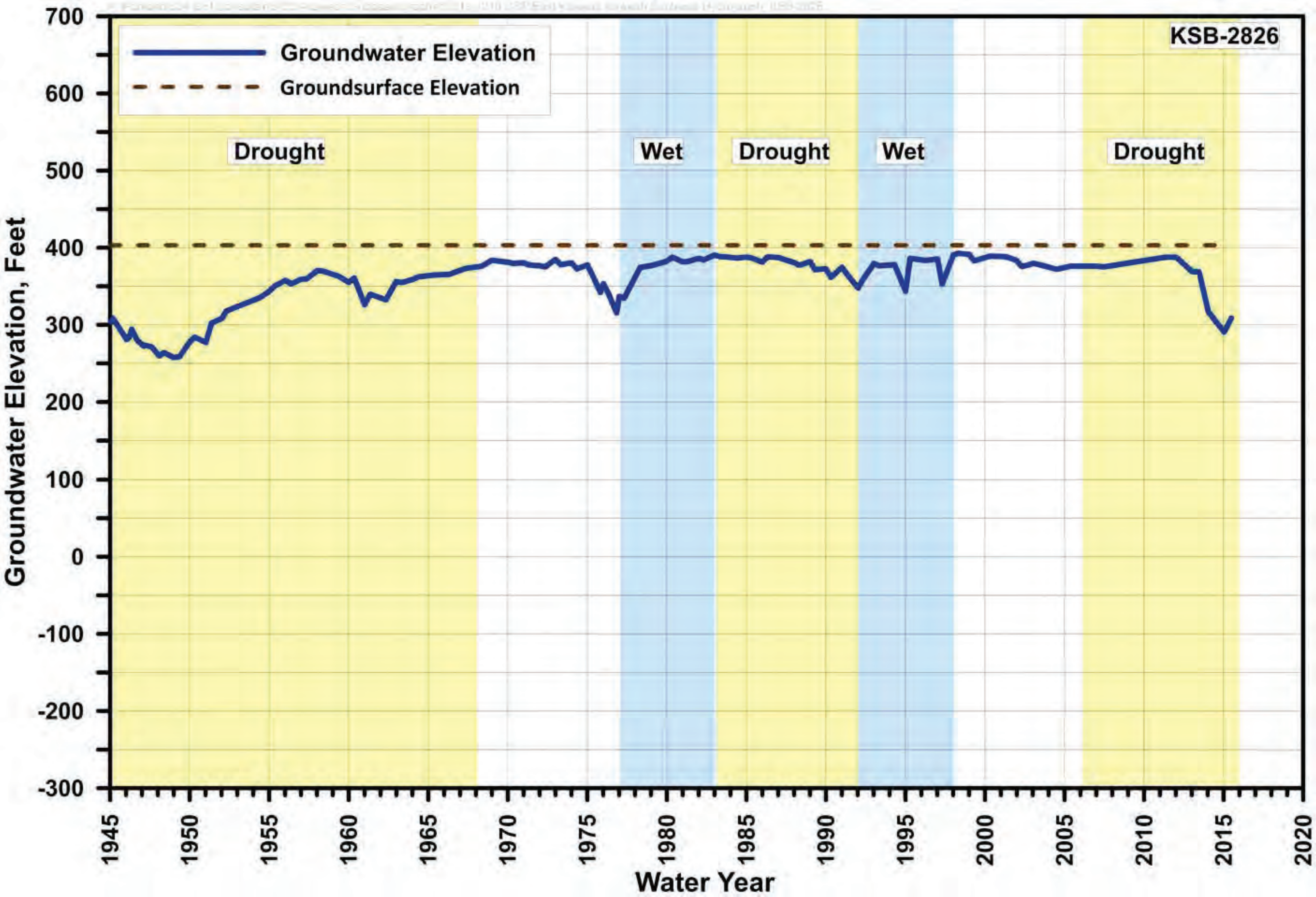

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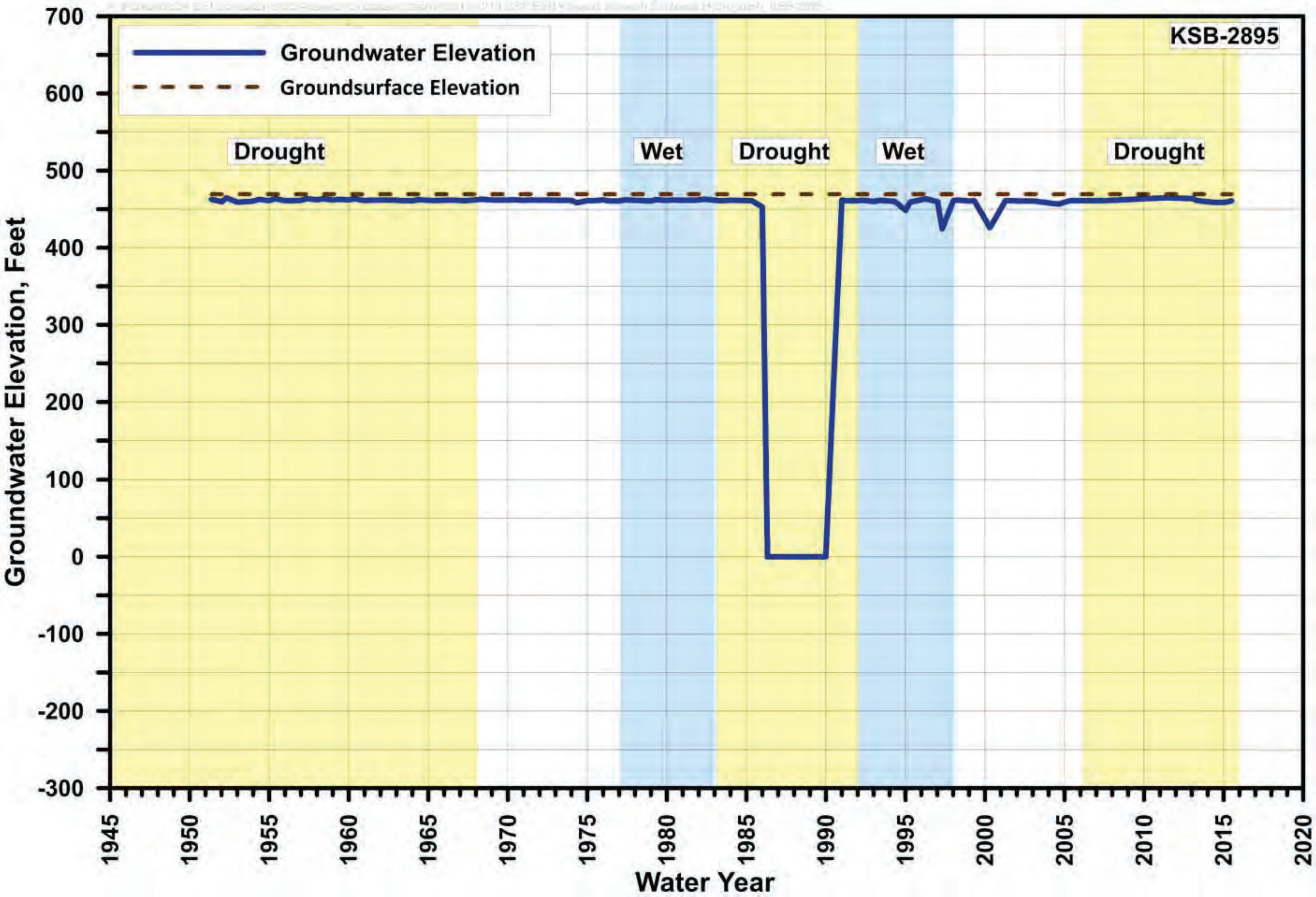

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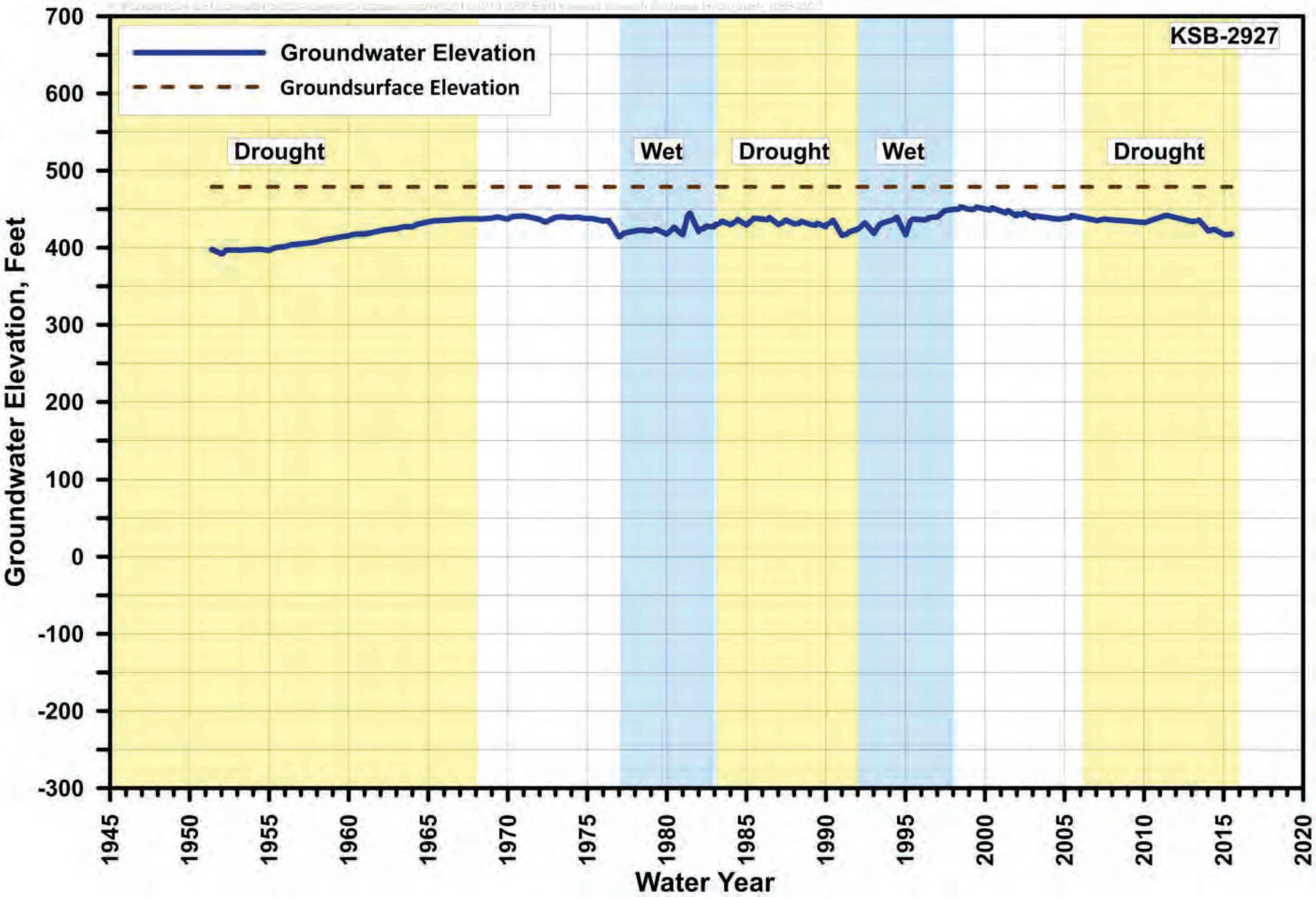

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Appendix C

Davids Engineering
Evapotranspiration and Applied Water Estimates

Technical Memorandum

Technical Memorandum

To: GEI Consultants

From: Davids Engineering

Date: November 30, 2018

Subject: **Kaweah Subbasin Development of Evapotranspiration and Applied Water Estimates Using Remote Sensing**

1 Summary

The purpose of this effort is to develop time series estimates of agricultural water demands for the Kaweah Subbasin from 1999 through 2017. This effort updates a similar analysis previously completed for the Kaweah Delta Water Conservation District (KDWCD) from 1999 through 2016 to include the areas currently not included in the KDWCD area but lying within the Kaweah Subbasin and to extend the estimates through 2017.

The consumptive use of water (i.e., evapotranspiration) is the primary destination of infiltrated precipitation and applied irrigation water within the Kaweah Subbasin. Quantification of consumptive use was achieved by performing daily calculations of evapotranspiration (ET) for individual fields from October 1998 through December 2017. ET was separated into its evaporation (E) and transpiration (T) components. Transpiration was quantified using a remote sensing approach where Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), which was subsequently translated to a basal crop coefficient and combined with referent ET to calculate transpiration over time.

A spatial coverage of field boundaries was developed for the Kaweah Subbasin, and individual field polygons were assigned cropping and irrigation method information over time based on available data. Field boundaries were delineated by combining polygon coverages in GIS format from the United States Department of Agriculture (USDA) and the California Department of Water Resources (DWR). The area encompassed by the field boundary GIS coverage includes the Kaweah Subbasin and the area immediately surrounding but outside of the subbasin.

Crop ET was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. Due to the remote sensing approach crop ET estimates are relatively insensitive to crop type and irrigation method so detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing relatively reliable estimates of crop ET. Crop types and irrigation method were assigned to each field based on a combination of data from DWR and USDA. The amount of green vegetation present over time was estimated for each field polygon based on NDVI, which is calculated using a combination of red and near infrared reflectances as measured using multispectral satellite sensors onboard Landsat satellites. Following the preparation of NDVI imagery spanning the analysis period all images were quality controlled to remove pixels affected by clouds.

Mean daily NDVI values for each field were converted to basal crop coefficients based on cropping information from the 2007 Tulare County crop survey, combined with an analysis of actual evapotranspiration (ET_a) by crop conducted using the Surface Energy Balance Algorithm for Land (SEBAL®) for 2007 (Bastiaanssen et al., 2005; SNA, 2009). Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University[1]. Daily reference evapotranspiration (ET_o) was estimated based on information from California Irrigation Management Information System (CIMIS) weather stations. Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the Kaweah Subbasin.

A summary for the 1999 to 2017 analysis period of the annual ET of applied water (ET_{AW}), ET_c (synonymous with ET_a), applied water (AW), deep percolation of applied water (DP_{AW}) and deep percolation of precipitation (DP_{pr}) estimates based on the root zone water balance model is given in the Results section.

Application of remote sensing combined with daily root zone water balance modeling (RS-RZ model) provides an improved methodology for estimation of surface interactions with the groundwater system including net groundwater depletion through estimation of ET of applied water and other fluxes.

2 Introduction

The purpose of this effort is to develop time series estimates of agricultural water demands for the Kaweah Subbasin from 1999 through 2017. Demand was estimated quantitatively at the field scale using a daily root zone water balance model and aggregated to monthly time steps. It is anticipated that these estimates will be used to support development of an integrated hydrologic model for the Kaweah Subbasin and water budget development for one or more Groundwater Sustainability Plans (GSPs). Crop evapotranspiration (ET), the primary driver of agricultural water demand, was estimated based on a combination of remote sensing and simulation of irrigation events using the water balance model.

This effort updates a similar analysis previously completed for the Kaweah Delta Water Conservation District (KDWCD) from 1999 through 2016 to include the areas currently not included in the KDWCD area but lying within the Kaweah Subbasin. In addition to adding the additional areas within the Kaweah subbasin, this analysis extends the estimates through the end of the 2017 calendar year.

3 Methodology

3.1 Daily Root Zone Simulation Model

A conceptual diagram of the various surface layer fluxes of water into and out of the crop root zone is provided in Figure 3.1. The consumptive use of water (i.e., evapotranspiration or ET) is the primary destination of infiltrated precipitation and applied irrigation water within the Kaweah Subbasin. Quantification of consumptive use was achieved by performing daily calculations of ET for individual fields from October 1998 through December 2017. Evapotranspiration was separated into its evaporation (E) and transpiration (T) components. Additionally, each component was separated into the amount of E or T derived from precipitation or applied water.

[1] http://prism.oregonstate.edu/

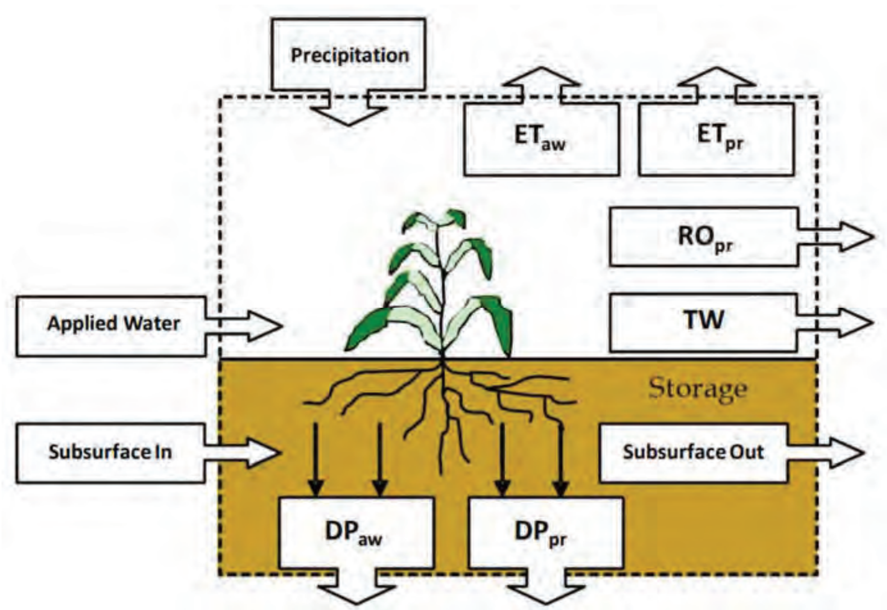

Figure 3.1. Conceptualization of Fluxes of Water Into and Out of the Crop Root Zone

Transpiration was quantified using a remote sensing approach whereby Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), a measure of the amount of green vegetation present. NDVI values were calculated and interpolated for each field over time. NDVI values were then converted to transpiration coefficients that were used to calculate transpiration over time by multiplying daily NDVI by daily reference evapotranspiration (ET_o). Evaporation was quantified by performing a surface layer water balance for the soil based on the dual crop coefficient approach described in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998). On a daily basis, evaporation was calculated based on the most recent wetting event (precipitation or irrigation) and the evaporative demand for the day (ET_o). This methodology is described in greater detail by Davids Engineering (Davids Engineering 2013).

3.2 Development of Field Boundaries

A spatial coverage of field boundaries was developed for the Kaweah Subbasin, and individual field polygons were assigned cropping and irrigation method information. For each field polygon, daily water balance calculations were performed for the 1999 to 2017 analysis period, and irrigation events were simulated to estimate the amount of water applied to meet crop irrigation demands. This section describes the development of the field polygon coverage and assignment of cropping and irrigation method attributes.

3.2.1 Development of Field Boundaries

Field boundaries were delineated by combining publicly available polygon coverages in GIS format from the United States Department of Agriculture (USDA) and the California Department of Water Resources (DWR). For the original KDWCD study area, common land unit (CLU) coverages developed by the USDA Farm Services Administration (FSA) on a county by county basis were combined to develop the base field coverage. Gaps exist in the CLU field coverages for fields not participating in USDA farm programs. These gaps were filled by overlaying the FSA CLU data with field polygons from DWR land use surveys for Kings and Tulare counties.

For the expanded study area encompassing the full Kaweah Subbasin, the original field boundaries were retained, and additional fields were added based on DWR's 2014 statewide spatial cropping dataset.

The area encompassed by the field boundary GIS coverage includes the Kaweah Subbasin and the area immediately surrounding, but outside of, the subbasin. Fields outside of the subbasin were included to provide a more robust dataset for model calibration and validation. Ultimately, results specific to the subbasin as a whole include only those fields with their centroid located within the Kaweah Subbasin.

3.3 Assignment of Cropping and Irrigation Method

As described previously, crop evapotranspiration (ET) was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. A result of the remote sensing approach is that crop transpiration was estimated with little influence from the assigned crop type for each field. Additionally, crop transpiration is the dominant component of ET, meaning that ET estimates are likewise largely independent of the assigned crop type.

Crop evapotranspiration is driven to some extent by the characteristics of the irrigation method and its management, including the area wetted during each irrigation event and the frequency of irrigation. Surface irrigation methods typically wet more of the soil surface than micro-irrigation methods; however, surface irrigated fields are typically irrigated less frequently than their micro-irrigated counterparts. As a result, evaporation rates can be similar among surface and micro-irrigated fields and estimates of evaporation are likewise somewhat independent of the assigned irrigation method. Parameters related to irrigation method were assigned based the predominant irrigation method for each crop, as described by recent historical DWR land and water use surveys.

A key result of the relative insensitivity of the crop ET estimates to crop type or irrigation method (due to the remote sensing approach), is that detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing reliable estimates of crop ET at the field scale and, more importantly, at coarser scales due to the cancellation of errors in individual field estimates as they are aggregated.

Crop types were assigned to each field based on a combination of data from DWR and USDA. DWR data consisted of land use data from 2003 and 2014 for Kings County and from 1999, 2007, and 2014 for Tulare County. USDA data consisted of Cropland Data Layer coverages for 2008 to 2013 and 2015 to 2016. The source of land use data for each year is summarized in Table 3.1.

Table 3.1. Land Use Sources by County and Year.

County	Year(s)	Source
Kings	1999-2007	DWR (2003)
	2008-2013	CDL
	2014	DWR (2014)
	2015-2017	CDL*
Tulare	1999-2002	DWR (1999)
	2003-2007	DWR (2007)
	2008-2013	CDL
	2014	DWR (2014)
	2015-2017	CDL*

* CDL data for 2016 was used for 2017

3.4 NDVI Analysis

The amount of green vegetation present over time was estimated for each field polygon based on the Normalized Difference Vegetation Index (NDVI), which is calculated using a combination of red and near infrared reflectances, as measured using multispectral satellite sensors onboard Landsat satellites. NDVI can vary from -1 to 1 and is typically varies from approximately 0.15 to 0.2 for bare soil to 0.8 for green vegetation with full cover. Negative NDVI values typically represent water surfaces.

3.4.1 Image Selection

Landsat images are preferred due to their relatively high spatial resolution (30-meter pixels, approx. 0.2 acres in size). A total of 682 raw satellite images were selected and converted to NDVI spanning the period from September 1998 to January 2018. Of the images selected, 230 were from the Landsat 5 satellite, 350 were from the Landsat 7 satellite (first available in 2001), and 102 were from the Landsat 8 satellite (first available in 2013). These images were used to process and download surface reflectance (SR) NDVI from the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA)[2].

An example time series of NDVI imagery for 2010 for the Kaweah Delta Water Conservation District (KDWCD) is shown in Figure 3.1 in Davids Engineering (2013). In the figure, areas with little or no green vegetation present are shown in brown, and areas with green vegetation are shown in green.

There was sufficient cloud-free Landsat imagery available that no cloud gap filling as in Davids Engineering (2013) was necessary. The number of days between image dates ranged from 5 to 56, with an average of 10 days. Generally, there was at least one image selected for each month.

3.4.2 Extraction of NDVI Values by Field and Development of Time Series NDVI Results

Following the preparation of NDVI imagery spanning the analysis period, all images were masked using the Quality Assessment Band (BQA) provided by ESPA to remove pixels affected by clouds. Then, mean NDVI was extracted from the imagery for each field for each image date. These NDVI values were then interpolated across the full analysis period from October 1, 1998 to December 31, 2017 to provide a daily time series of mean NDVI values for each field.

[2] USGS ESPA website: https://espa.cr.usgs.gov/

Top of Atmosphere (TOA) NDVI was calculated for several image dates and compared to SR NDVI on the same image dates to establish the following relationship (R^2=0.99):

$$(TOA\ NDVI) = 0.9224*(SR\ NDVI) - 0.0171 \quad [3.1]$$

This regression was applied to all image dates to convert from SR to TOA NDVI to provide consistency with the relationship between NDVI and the transpiration coefficient developed by Davids Engineering (2013) Error! Bookmark not defined..

Landsat 8 bandwidth was adjusted to be consistent with bandwidths from Landsat satellites 5 and 7 using the following empirical relationship:

$$(L7\ mean\ NDVI) = 0.984*(L8\ mean\ NDVI) - 0.0421 \quad [3.2]$$

An example of time varying NDVI for individual fields over time is found in Section 3 of Davids Engineering (2013). Interpolated NDVI values for selected fields are provided for the period 1999 through 2010 on an annual basis, from January 1 to December 31 of each year. These figures illustrate the ability of the remote sensing approach to account for both changes in cropping over time and the presence of double- and triple-cropping.

3.4.3 Development of Relationships to Estimate Basal Crop Coefficient from NDVI

Basal crop coefficients (K_{cb}) describe the ratio of crop transpiration to reference evapotranspiration (ET_o) as estimated from a ground-based agronomic weather station. By combining K_{cb}, estimated from NDVI, with an evaporation coefficient (K_e), it is possible to calculate a combined crop coefficient ($K_c = K_{cb} + K_e$) over time[3]. By multiplying K_c by ET_o, crop evapotranspiration (ET_c) can be calculated. For this analysis, ET_o, K_{cb}, K_e, and ET_c (synonymous to actual ET, ET_a) were estimated for each field on a daily time step from October 1, 1998 to December 31, 2017.

Mean daily NDVI values for each field were converted to basal crop coefficients based on cropping information from the 2007 Tulare County crop survey conducted by DWR, combined with an analysis of actual evapotranspiration (ET_a) by crop conducted using the Surface Energy Balance Algorithm for Land (SEBAL®) for 2007 (Bastiaanssen et al., 2005; SNA, 2009). Specifically, a relationship between actual basal crop coefficients estimated using SEBAL and field-scale mean NDVI values developed by Davids Engineering (2013) was applied to calculate daily basal crop coefficients for each field over time[4].

3.5 Precipitation

Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University[5]. Specifically, each field was assigned estimated precipitation from the 4km PRISM grid cell within which its centroid fell. The update generally results in modest increases in estimated precipitation within the study area, with greater increases moving from west to east due to orographic effects.

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[3] The estimation of Ke is based on a daily 2-stage evaporation model presented in FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998).

[4] This relationship is developed based on comparison of the combined crop coefficient to NDVI for individual fields, but represents only the transpiration component of ET. Thus, the relationship developed predicts the basal crop coefficient, Kcb.

[5] http://prism.oregonstate.edu/

Annual precipitation totals, averaged over the study area for water years 1999 to 2017, are shown in Figure 3.1. Water year precipitation over the study period varied from 4.1 inches in 2014 to 16.1 inches in 2011, with an annual average of 9.1 inches.

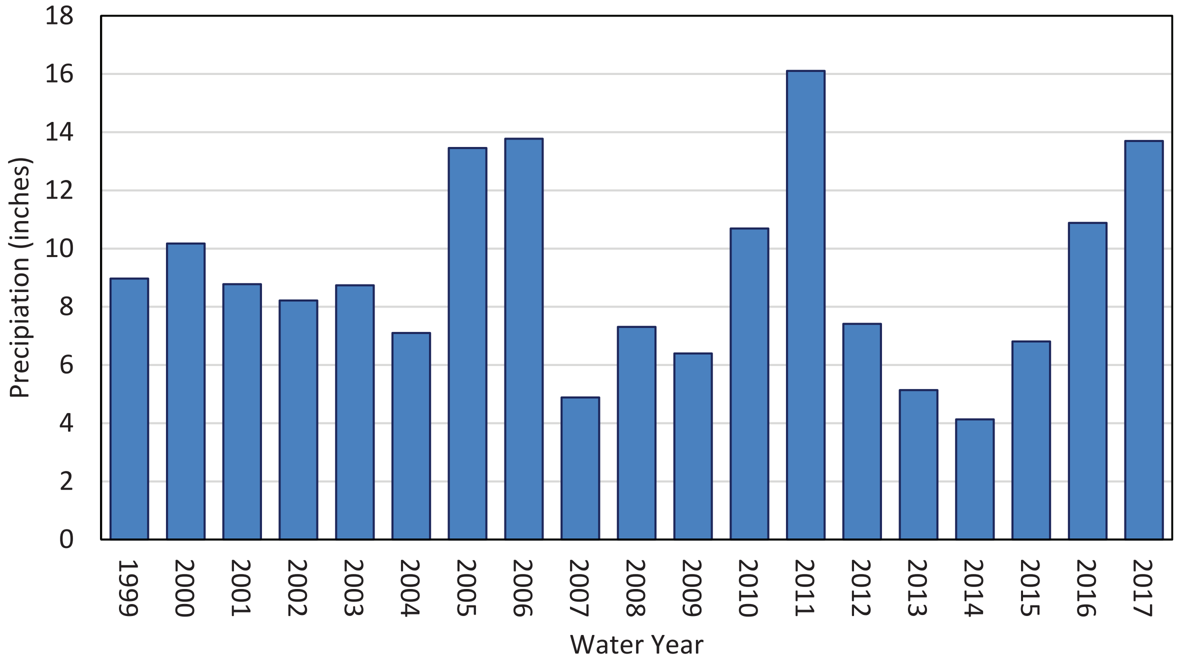


Figure 3.2. Annual Precipitation Totals

3.6 Estimation of Daily Reference Evapotranspiration

Daily reference evapotranspiration (ET_o) was estimated based on information from California Irrigation Management Information System (CIMIS) weather stations. ET_o provides a means of estimating actual crop evapotranspiration over time for each field. Based on review of nearby weather stations with data available during the period of analysis, the Porterville station (169) was selected based on it being relatively close to the Kaweah Subbasin, at a similar elevation to the Kaweah Subbasin, having relatively good fetch, and having available data for the majority of the analysis period.

Individual parameters from the available data including incoming solar radiation, air temperature, relative humidity, and wind speed were quality-controlled according to the procedures of Allen et al. (2005). The quality-controlled data were then used to calculate daily ET_o for the available period of record.

CIMIS data for Porterville were not available prior to August 2000. As a result, it was necessary to estimate ET_o for the period from October 1, 1998 to August 1, 2000. ET_o for Porterville was estimated by developing a linear regression to estimate Porterville ET_o using quality-controlled data from the Stratford CIMIS station for the period of overlapping data availability.

3.7 Estimation of Root Zone Water Balance Parameters

Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the Kaweah Subbasin. Crop parameters of interest include root depth, NRCS curve number[6], and management allowable depletion (MAD). Root depth was estimated by crop group based on published values and a representative mix of individual crops within each crop group for the Kaweah Subbasin. Curve numbers were estimated based on values published in the NRCS National Engineering Handbook, which provides estimates based on crop type and condition. MAD values by crop were estimated based on values published in FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998).

Soil hydraulic parameters of interest include field capacity (% by vol.), wilting point (% by vol.), saturated hydraulic conductivity (ft/day), total porosity (% by vol.), and the pore size distribution index (λ, dimensionless). These parameters were estimated by first determining the depth-weighted average soil texture (sand, silt, clay, etc.) based on available NRCS soil surveys. Then, the hydraulic parameters were estimated using hydraulic pedotransfer functions developed by Saxton and Rawls (2006). Next, hydraulic parameters were adjusted within reasonable physical ranges for each soil texture so that the modeled time required for water to drain by gravity from saturation to field capacity agreed with typically accepted agronomic values. Unsaturated hydraulic conductivity (e.g. deep percolation) within the root zone was modeled based on the equation developed by Campbell (1974) for unsaturated flow.

4 Results

4.1 Crop Evapotranspiration

Estimated annual crop evapotranspiration volumes for fields with their centroid within the Kaweah Subbasin are shown in Figure 4.1. Estimated volumes of ET derived from applied water (ETaw) and precipitation (ETpr) are shown in thousands of acre-feet (taf). Annual ETaw ranged from 721 taf to 916 taf, with an average of 817 taf. Annual ETpr ranged from 87 taf to 260 taf, with an average of 174 taf. Total crop ET ranged from 899 taf to 1,056 taf, with an average of 991 taf.

[6] The curve number runoff estimation method developed the Natural Resources Conservation Service (NRCS) was used to estimate runoff from precipitation in the model. For additional information, see NRCS NEH Chapter 2 (NRCS, 1993).

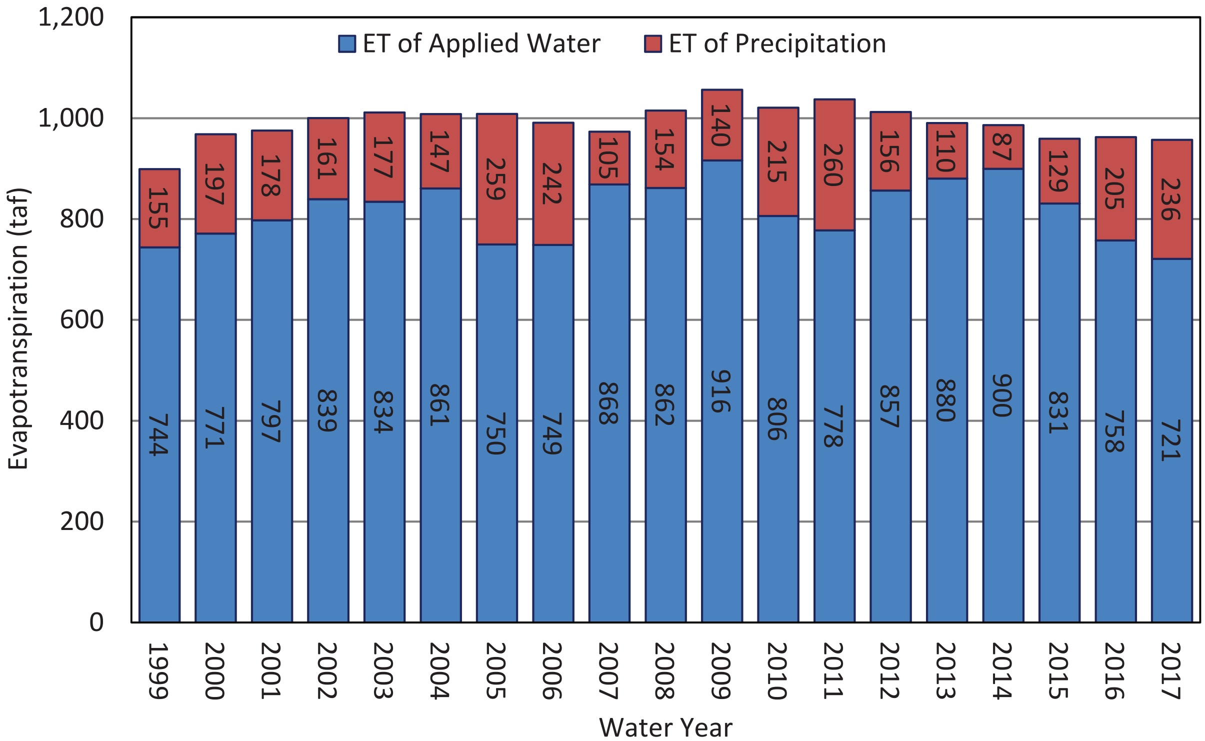


Figure 4.1. Kaweah Subasin Crop ET by Water Year

4.2 Irrigation Demands

Annual estimated irrigation demands for fields with their centroid within the Kaweah Subbasin are shown in Figure 4.2 in thousands of acre feet. Annual demands ranged from 948 taf to 1,149 taf, with an average of 1,042 taf.

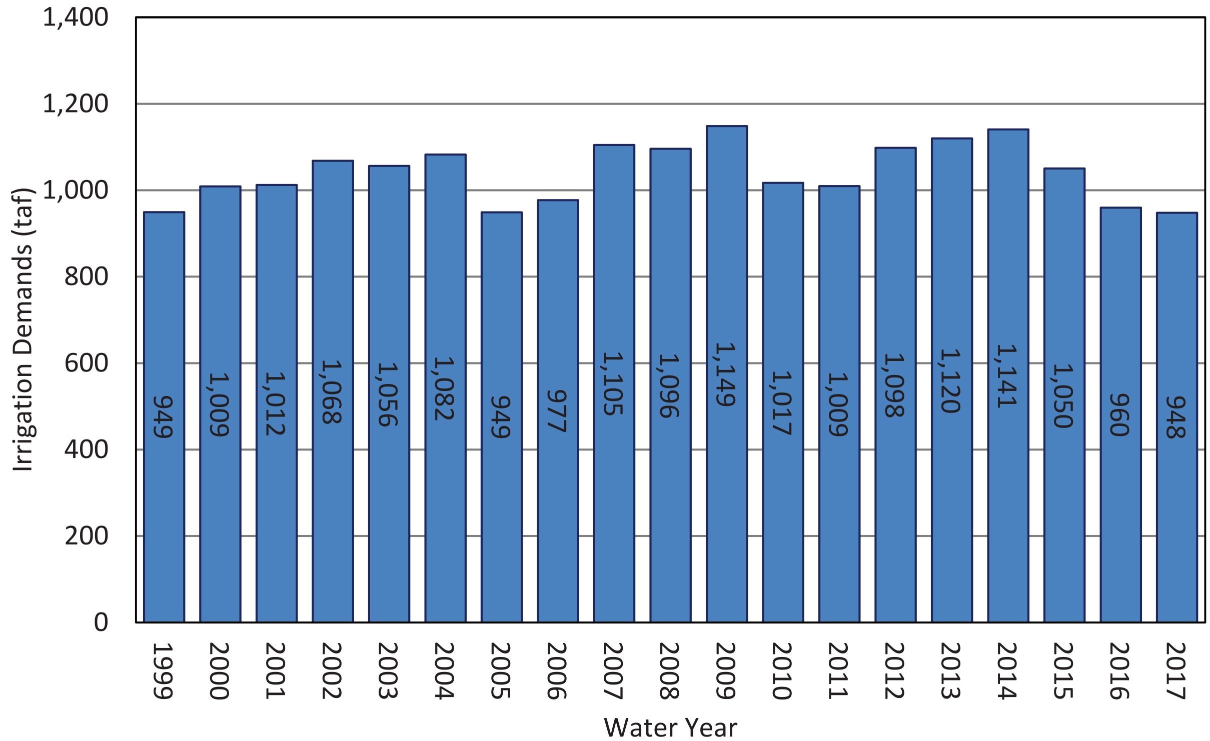


Figure 4.2. Kaweah Subasin Irrigation Demands by Water Year

4.3 Deep Percolation

Estimated annual deep percolation volumes for fields with their centroid within the Kaweah Subbasin are shown in Figure 4.3. Estimated volumes of deep percolation derived from applied water (DPaw) and precipitation (DPpr) are shown in thousands of acre-feet. Annual DPaw ranged from 208 taf to 242 taf, with an average of 227 taf. Annual DPpr ranged from 24 taf to 130 taf, with an average of 60 taf. Total deep percolation ranged from 255 taf to 372 taf, with an average of 287 taf.

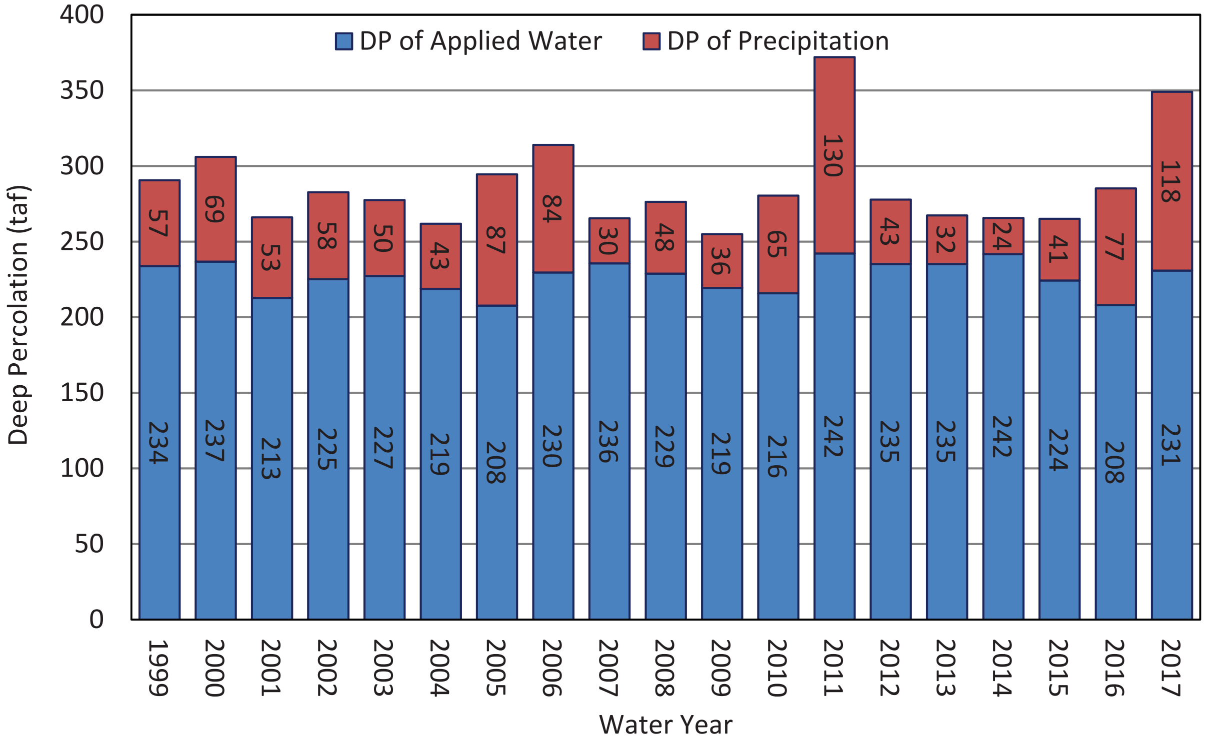


Figure 4.3. Kaweah Subasin Deep Percolation by Water Year

4.4 Annual Evapotranspiration by Crop for 2014

Estimated annual average evapotranspiration by crop is shown in Figure 4.4, along with the estimated acreage for each crop. Figure 4.4 shows the estimated average total ET by crop in inches in 2014. Average ET ranges from 7 inches for miscellaneous grain and hay to 49 inches for walnuts. The primary crops are corn, citrus, alfalfa and walnuts, representing 82, 60,40, and 31 thousand acres, respectively.

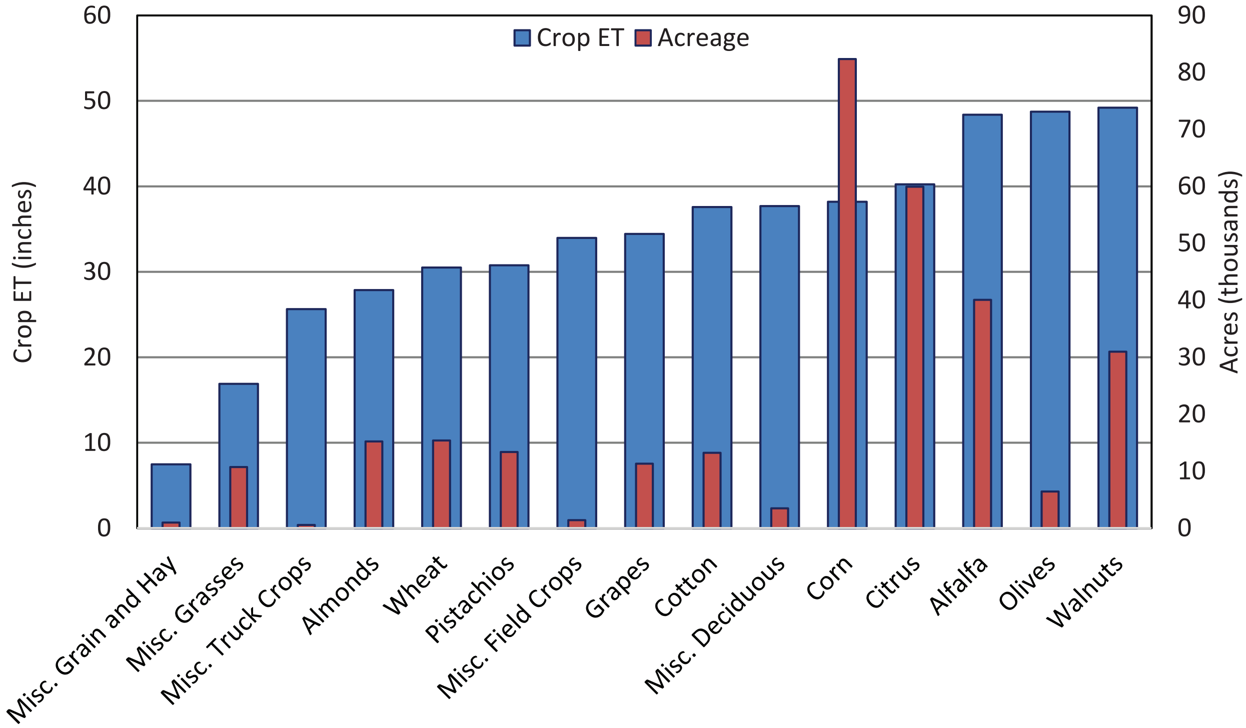


Figure 4.4. Kaweah Subasin 2014 Average ET by Crop and Crop Acreage

Additional monthly plots of ET_{oF}, ET_a and AW by crop for 2014 can be found in the appendix.

5 References

Allen, R.G, L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56. FAO. Rome, Italy.

Davids Engineering. 2013. Time Series Evapotranspiration and Applied Water Estimates from Remote Sensing. Kaweah Delta Water Conservation District. http://www.kdwcd.com/wp-content/uploads/2018/07/KDWCD-NDVI-ET-Analysis-FINAL-REPORT-March-2013.pdf

NRCS. 1993. Chapter 2 - Watershed Project Evaluation Procedures. National Engineering Handbook Part 630, Hydrology.

Saxton, K.E. and W.J. Rawls. 2006. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Sci. Soc. Am. J. 70:1569–1578.

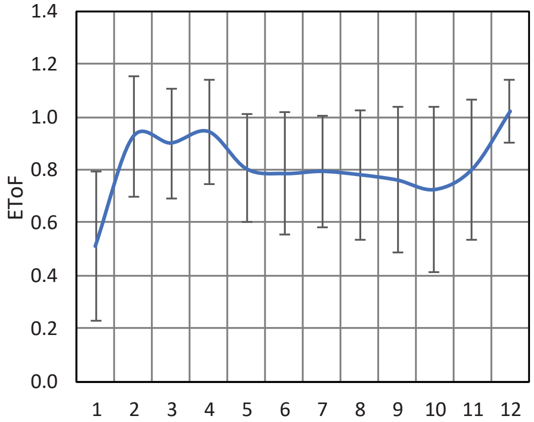
6 Appendix

This appendix includes the following figures:

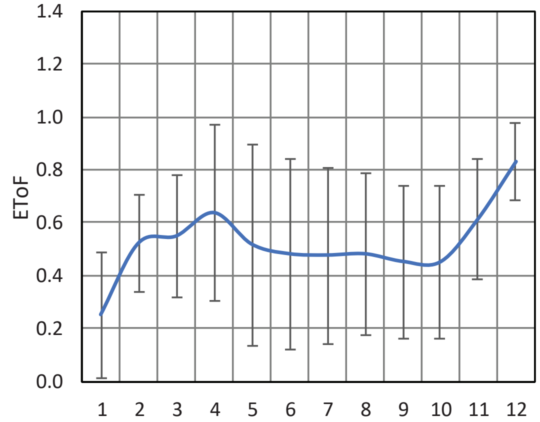
- Average monthly crop water use coefficients or "fraction of reference ET" (EToF) by crop, along with error bars depicting the standard deviation among fields.
- Average monthly crop ET by crop, along with error bars depicting the standard deviation among fields.
- Average monthly applied water by crop, along with error bars depicting the standard deviation among fields.

EToF 2014

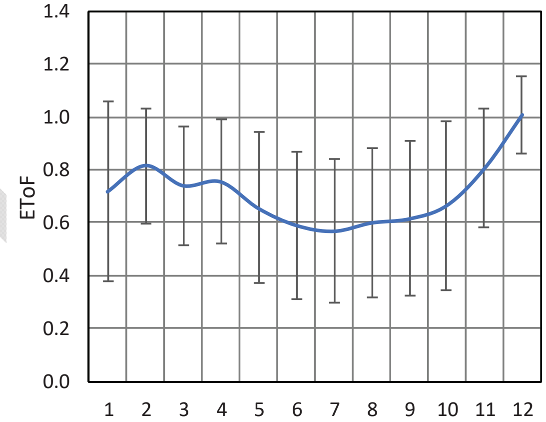
Alfalfa



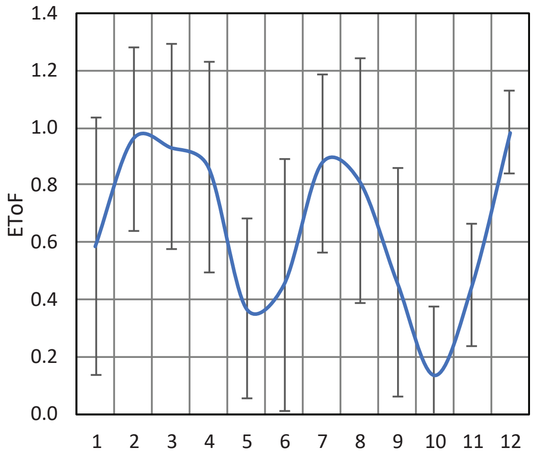
Almonds



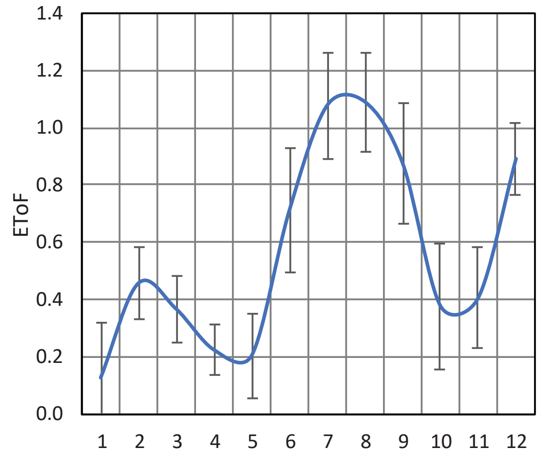
Citrus



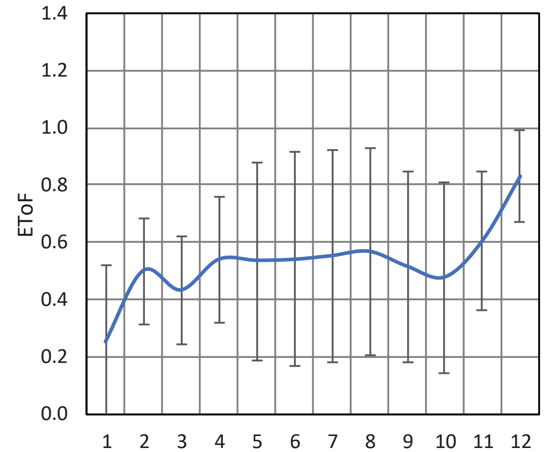
Corn



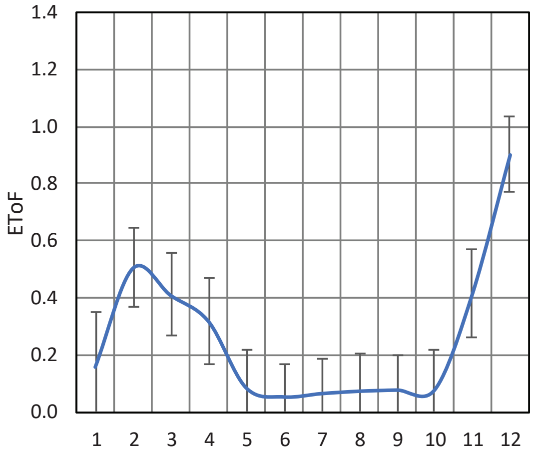
Cotton



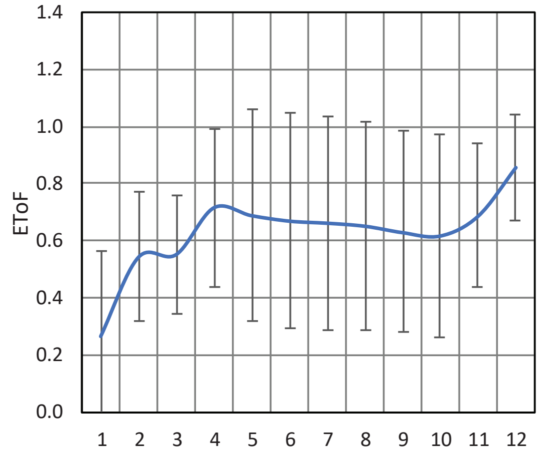
Grapes



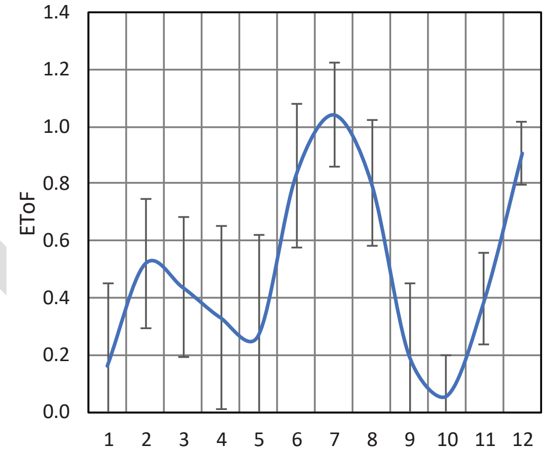
Idle



Misc. Deciduous



Misc. Field



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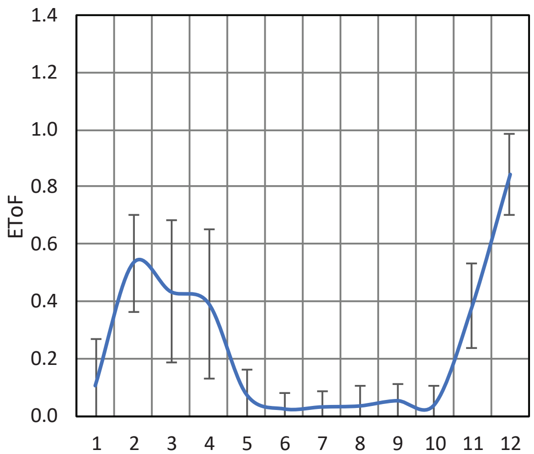

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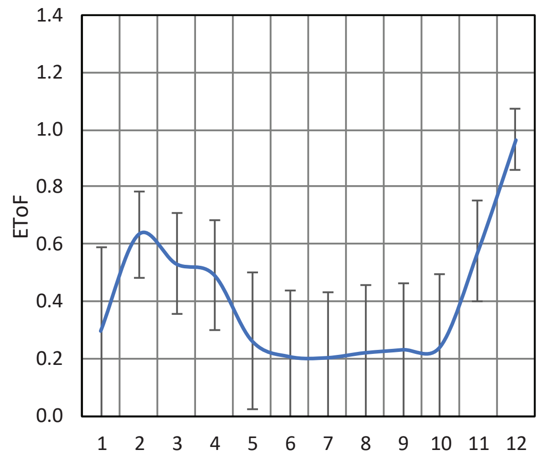

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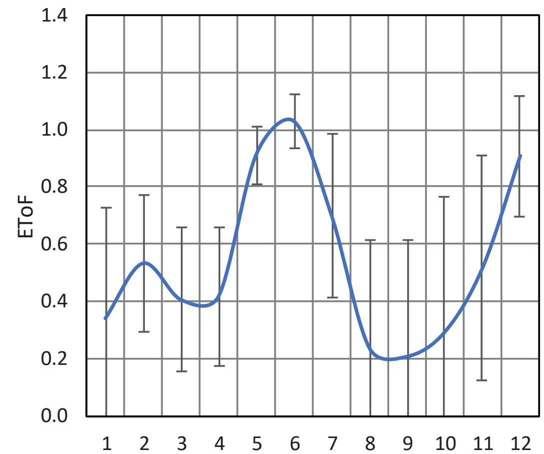

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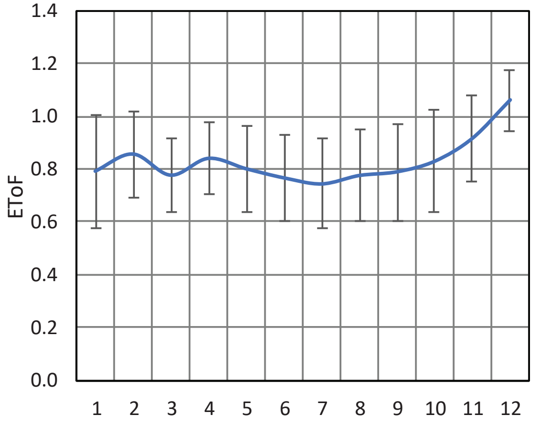

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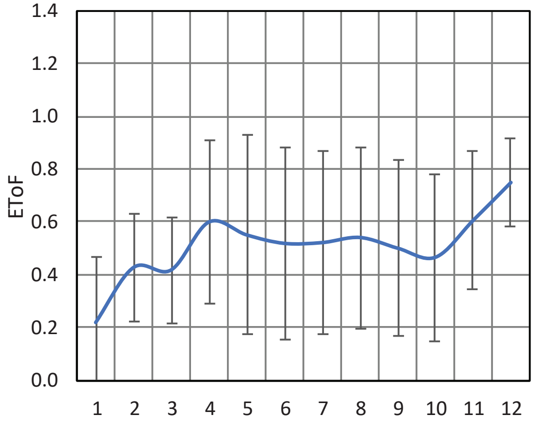

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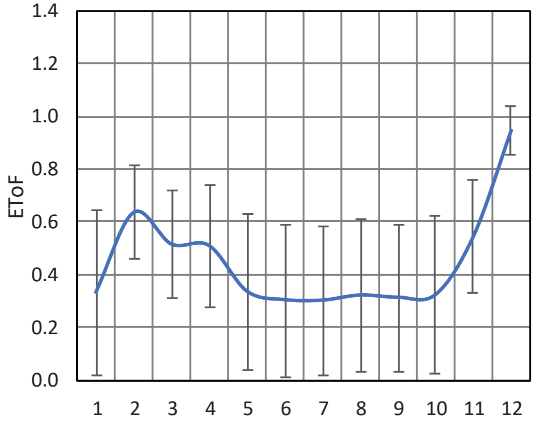

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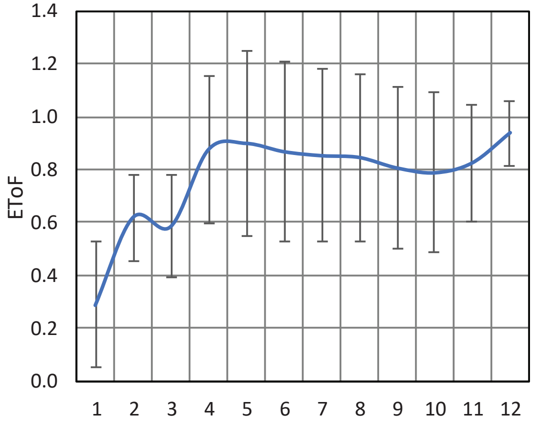

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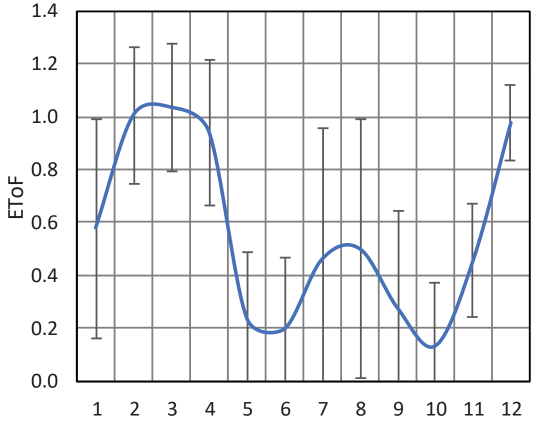

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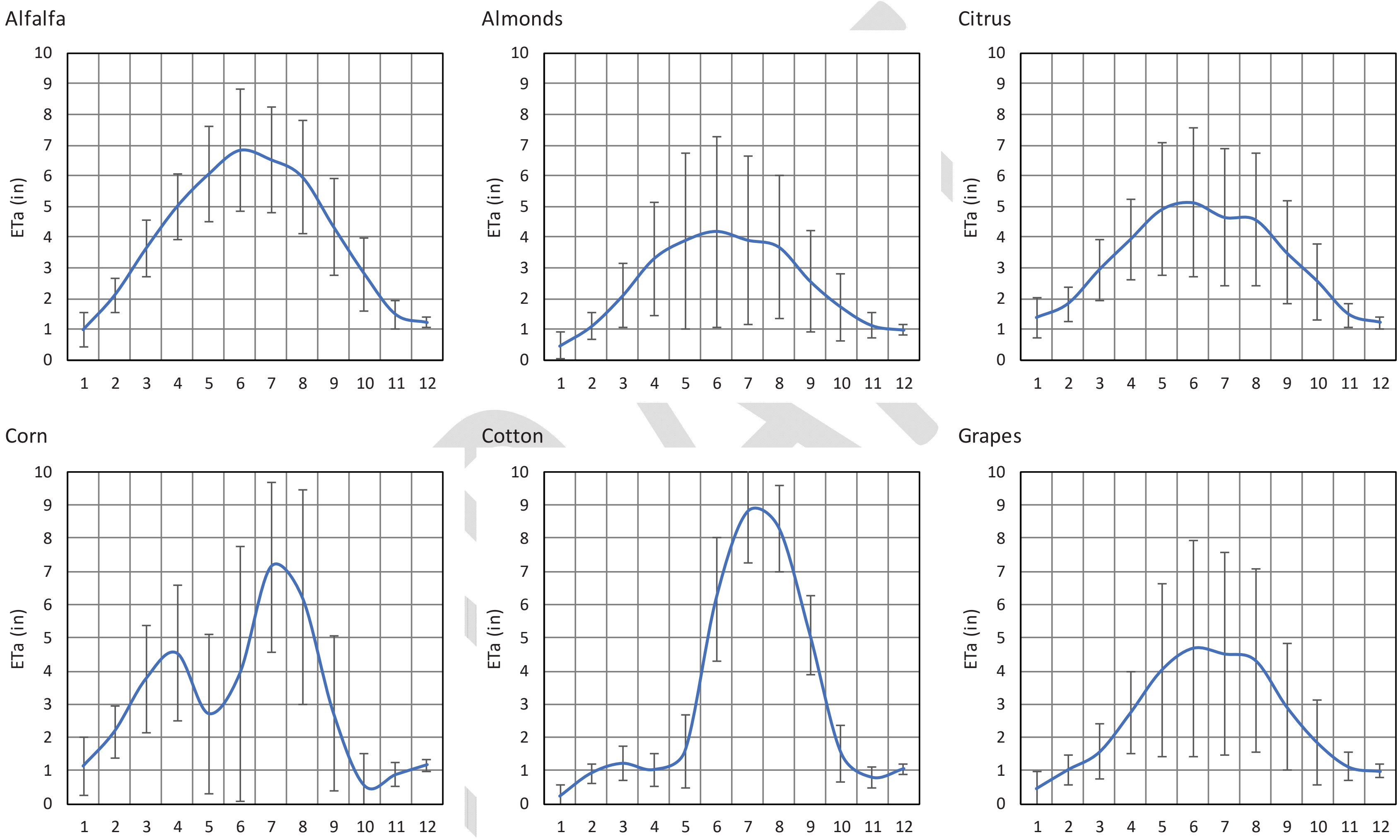
Alfalfa
Almonds
Citrus
Corn
Cotton
Grapes
ETa (in)
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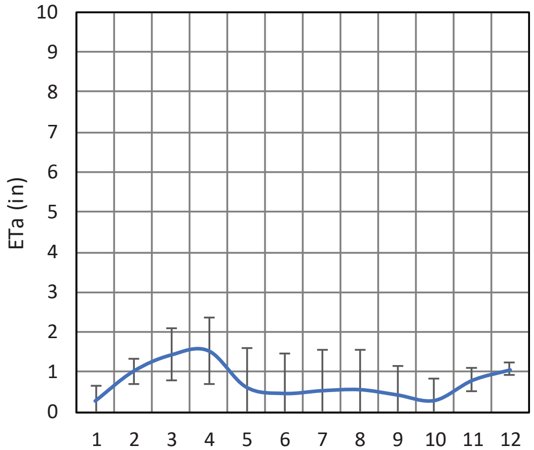
1 2 3 4 5 6 7 8 9 10 11 12

Idle



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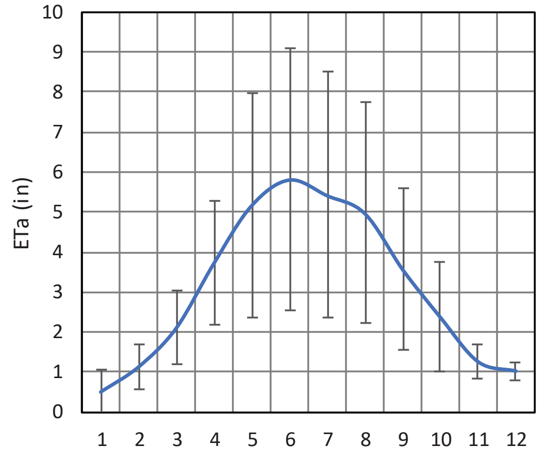

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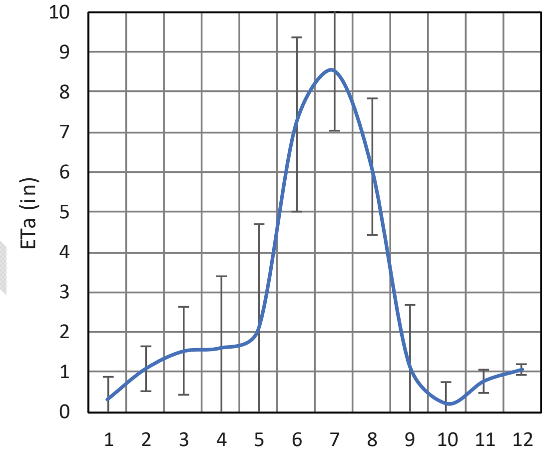

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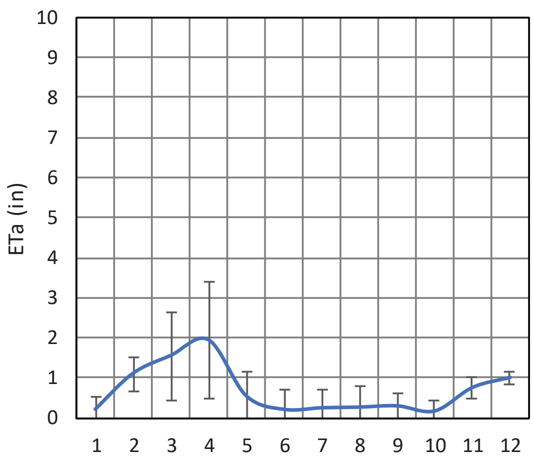

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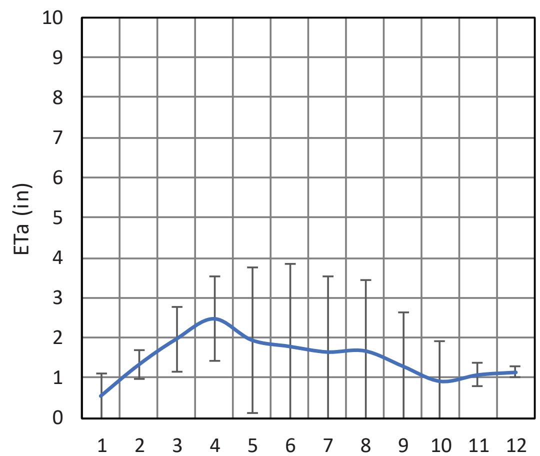

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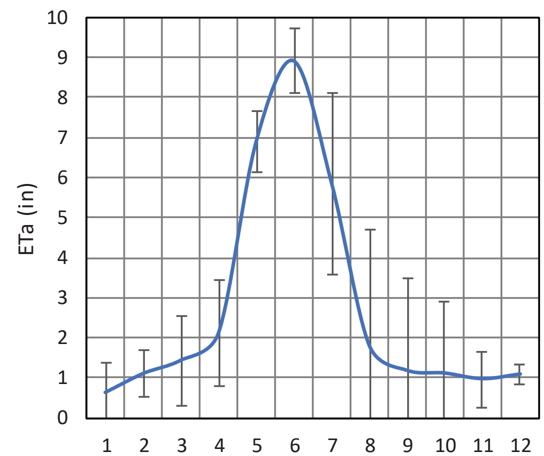

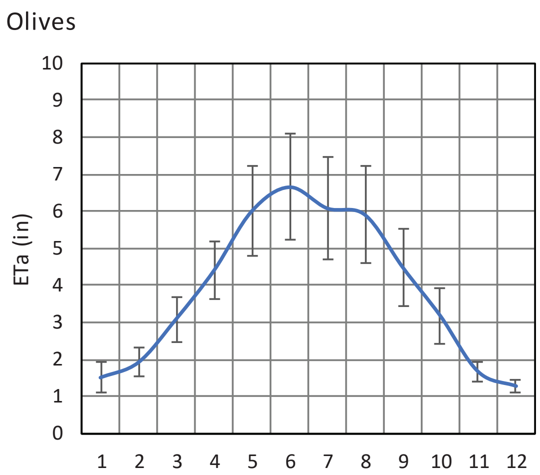
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ETa (in)
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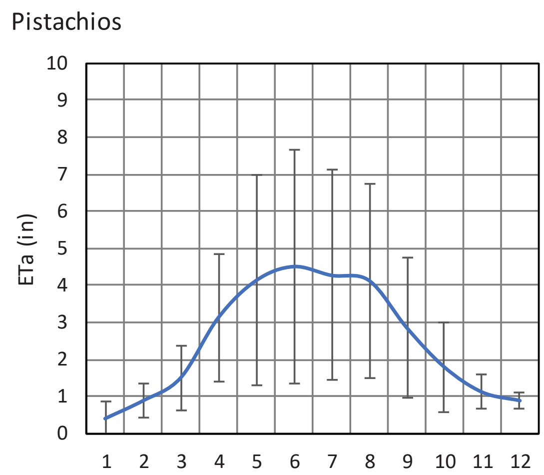
1 2 3 4 5 6 7 8 9 10 11 12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ETa (in)
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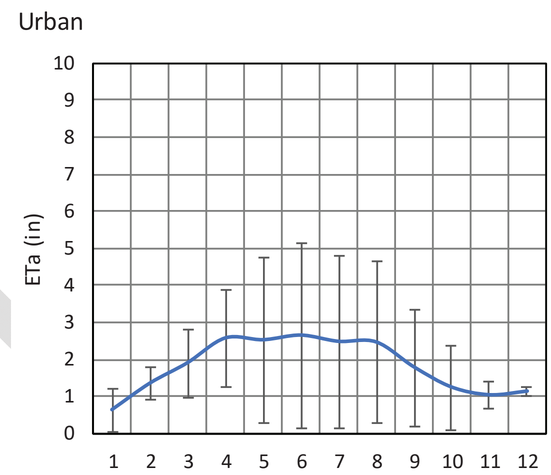
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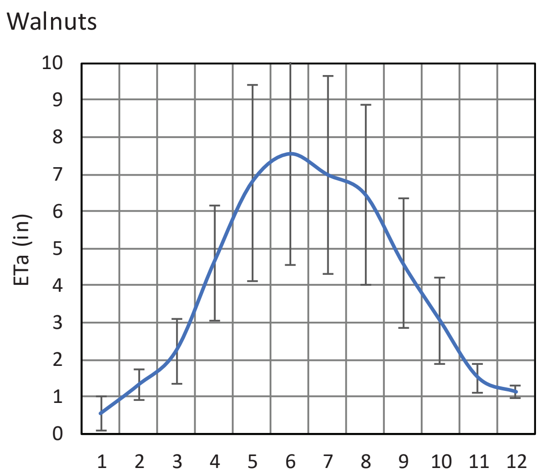
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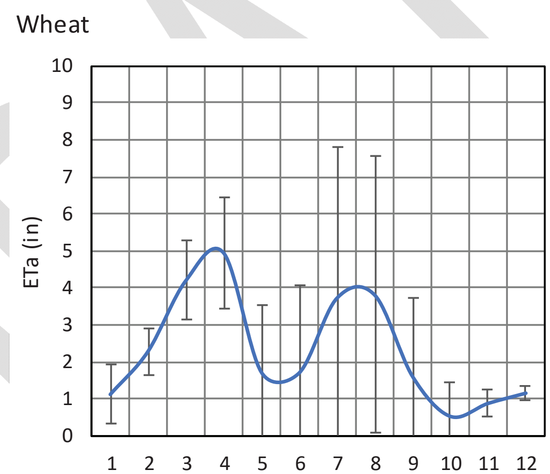
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AW 2014

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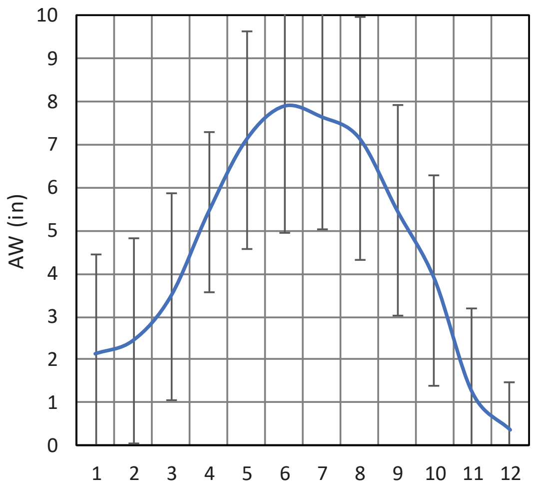

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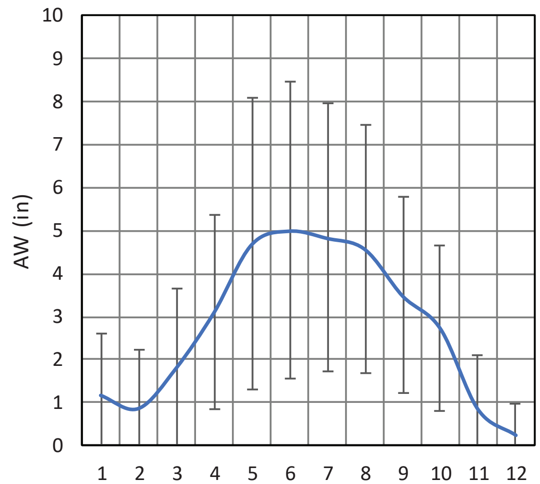

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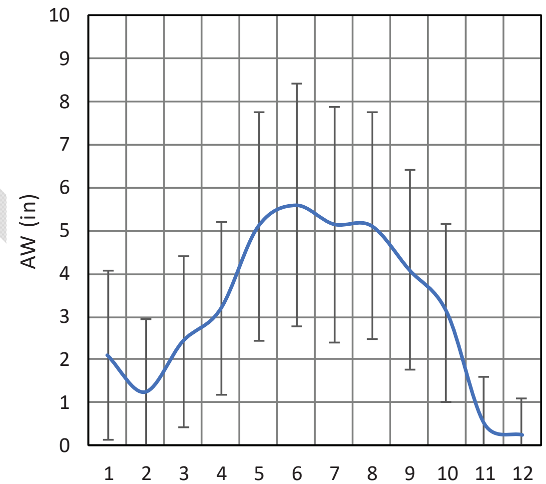

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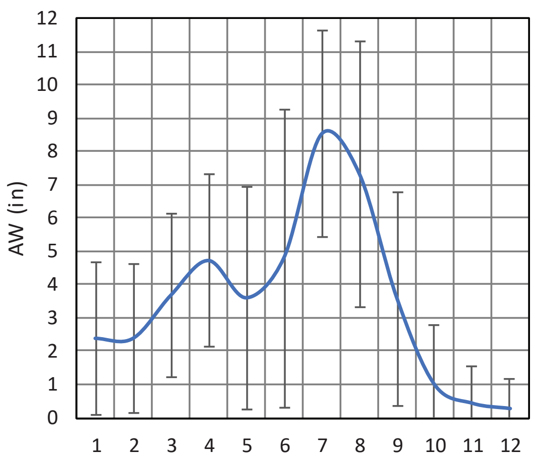

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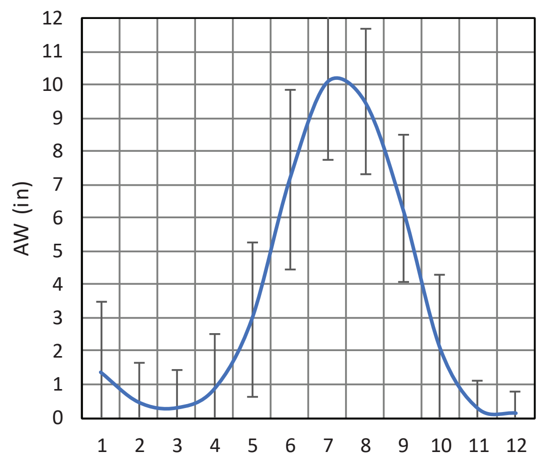

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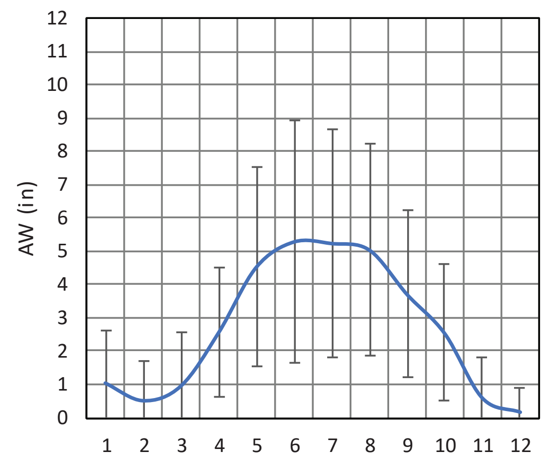

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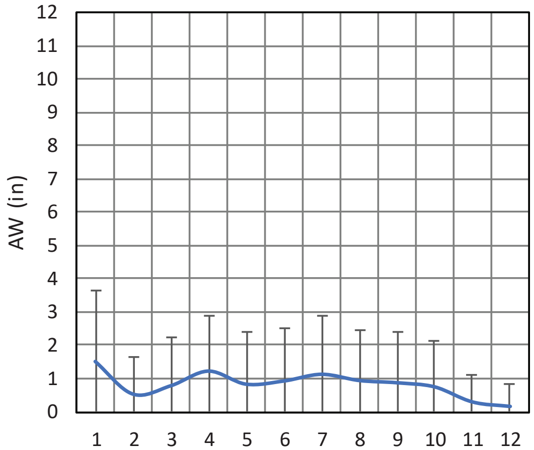

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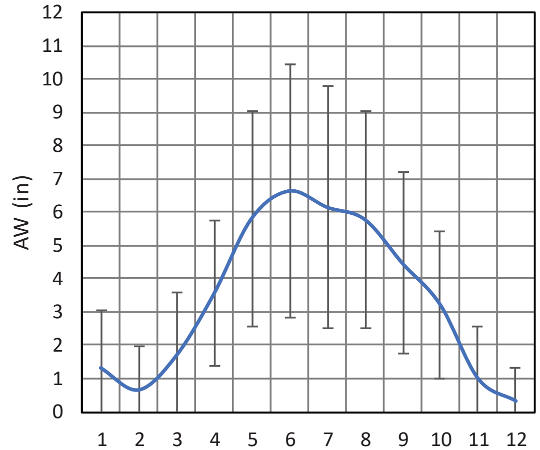

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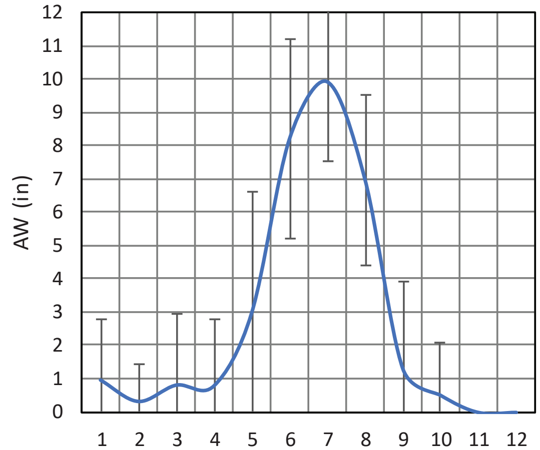

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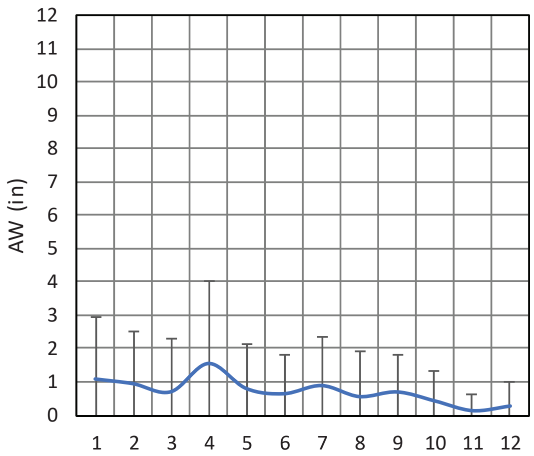

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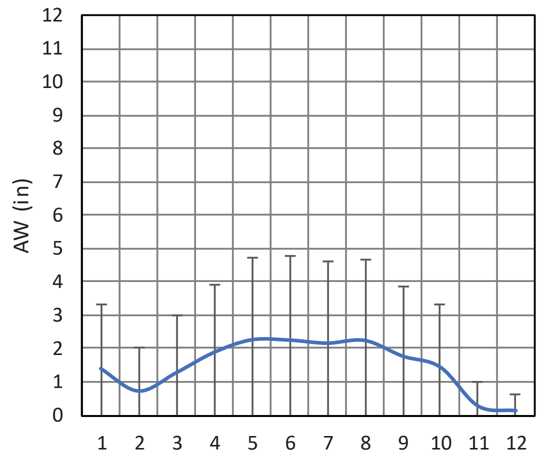

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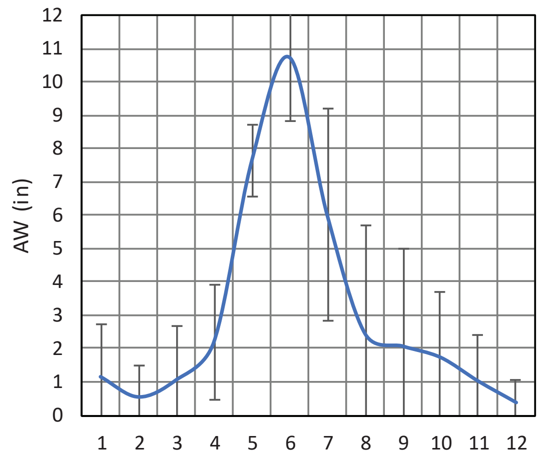

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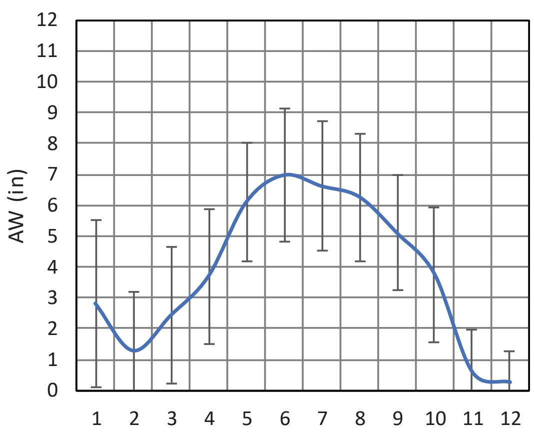

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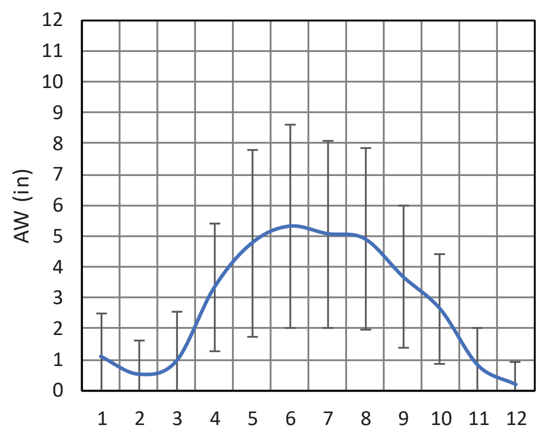

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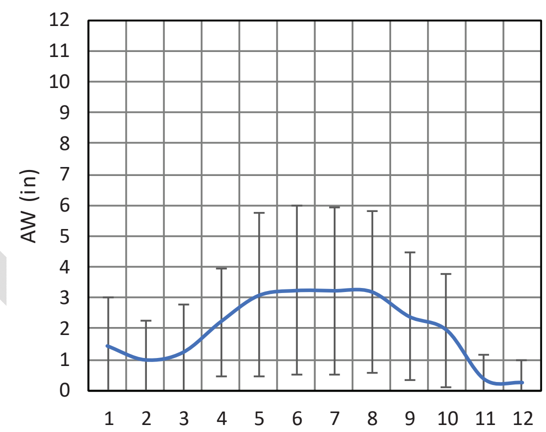

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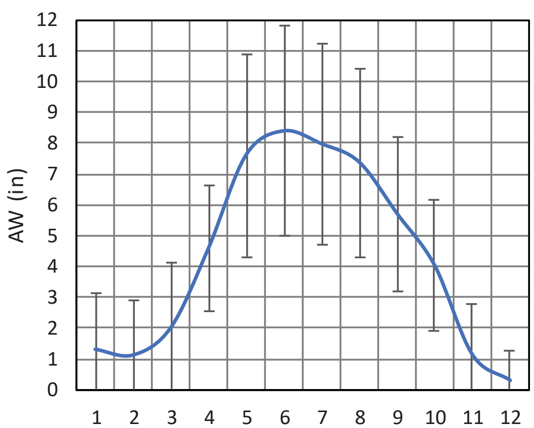

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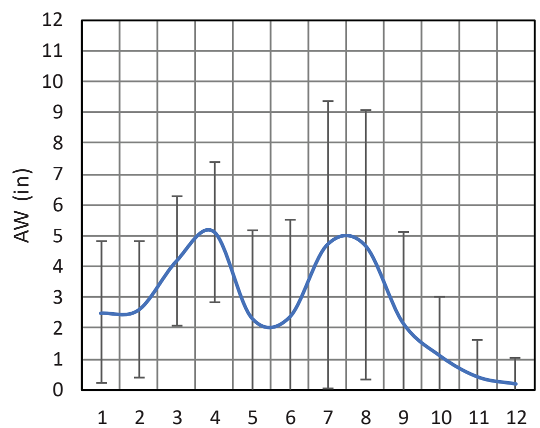

Appendix D

Friant Water Authority

Future Water Supply Study

Friant WATER AUTHORITY

Technical Memorandum

Estimate of Future Friant Division Supplies for use in Groundwater Sustainability Plans, California

CONTENTS

FIGURES

TABLES

ACRONYMS

CFS	cubic feet per second
CVP	Central Valley Project
CWC	California Water Commission
DEW	Drier/Extreme Warming
DWR	California Department of Water Resources
GSA	Groundwater Sustainability Agency
Friant	Friant Water Authority
Friant Contractors	Friant Division long-term contract holders
PEIS/R	Program Environmental Impact Statement/Report
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RWA	Recovered Water Account
SGMA	Sustainable Groundwater Management Act
SJRRP	San Joaquin River Restoration Program
SJRRS	San Joaquin River Restoration Settlement
SWP	State Water Project
TAF	thousand acre-feet
TM	Technical Memorandum
WMW	Wetter, Moderate Warming
WSIP	Water Supply Investment Program

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BACKGROUND

The Friant Water Authority (Friant) was approached by several Groundwater Sustainability Agencies (GSAs) for information about future water supply availability from the Central Valley Project (CVP) Friant Division. Those GSAs include the following, who were subsequently engaged during the development of analysis to meet their request:

- Mid-Kaweah GSA, represented by Paul Hendrix
- White Wolf Sub-basin GSA, represented by Jeevan Muhar
- Kern Groundwater Authority, represented by Terry Erlewine

This Technical Memorandum (TM) was prepared for use by those GSAs and others, in accordance with the expectations set by the Friant Board of Directors in their 2016 Strategic Plan to provide "accurate and up-to-date data needed to manage water supplies through modeling and data collection."

This TM presents five scenarios that were intended to represent a range of potential water supply conditions for the Friant Division through the end of the century, all of which were assembled from existing studies that were recently conducted using the CalSim-II computer model. These scenarios were assembled from pre-existing model runs and analysis and have been compiled and reviewed by Friant for use or consideration in plans developed by GSAs that receive Friant Contract surface water deliveries. The selected scenarios are summarized below and organized by their identification name in the accompanying "Summary_FutureFriantSupplies_Final" spreadsheet file.

1. **Model Run 2015.c (''2015.c'')** was designed to represent current conditions, where implementation of the San Joaquin River Restoration Settlement (SJRRS) is limited by downstream capacity limitations and the climate and hydrology are assumed to be most similar to historical hydrologic conditions.

2. **''2030.c''** was designed to represent near future climate conditions centered around 2030 and uses California Department of Water Resources (DWR's) central tendency climate projection. This scenario assumes implementation of the SJRRS, as described in the Reclamation's Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

3. **''2070.c''** was designed to represent far-future climate conditions centered around 2070 and uses DWR's central tendency climate projection. This scenario assumes implementation of the SJRRS, as described in the Reclamation's Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

4. **''DEW.c''** was included in this TM for completeness, as it represents an extreme climate condition (being: Drier/Extreme Warming, "DEW") that was produced by DWR for planning studies. The DEW scenario was developed by DWR as a means of bracketing the range of potential future climate conditions by 2070, which are highly uncertain. This scenario was modeled with implementation of the SJRRS, as described in the Reclamation's Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

5. **''WMW.c''** was included in this TM for completeness, as it represents an extreme climate condition (being: Wetter/Moderate Warming, "WMW") that was produced by DWR for planning studies. The WMW scenario was developed by DWR as a means of bracketing the range of potential future climate conditions by 2070, which are highly uncertain. This scenario was modeled with implementation of the SJRRS, as described in the Reclamation's Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

For questions, clarifications, or suggestions that will improve this TM or its application with the implementation of the Sustainable Groundwater Management Act (SGMA) for planning purposes, please contact Jeff Payne, Director of Water Policy at jpayne@friantwater.org

STUDY SETTING

The Friant Division includes storage for waters of the San Joaquin River at Friant Dam (Millerton Lake), as well as conveyance and delivery facilities through the Friant-Kern and Madera canals that deliver water to 32 Friant Division long-term contract holders (Friant Contractors) and other water users. Figure 1 shows the location of the Friant Contractors in the San Joaquin Valley. Friant Contractors all have access to waters of the San Joaquin River through their contracts with Reclamation. However, most Friant Contractors have other supplies that include groundwater and surface water supplies that are local to their geography.

Combined, the facilities of the Friant Division span over 180 miles, crossing seven rivers, and conveying water between 16 GSAs as shown in Figure 2. All the basins connected by the Friant Division and its facilities are considered by DWR to be “critically overdrafted” and therefore are each a “high priority” for the implementation of SGMA. Table 1 lists the Friant Contractors with lands overlapping a GSA and 2014 Friant Contractor irrigated lands. A Friant Contractor may appear in more than one GSA. The 2014 irrigated acreage was obtained from remote sensing from DWR (DWR, 2017). Friant Division M&I contractors were assumed to have no agricultural demand. Kaweah-Delta Water Conservation District agricultural demands were not estimated in this analysis. Any agricultural demand within City of Fresno is represented as part of the Fresno Irrigation District.

Figure 1: Location of Friant Contractors in the San Joaquin Valley

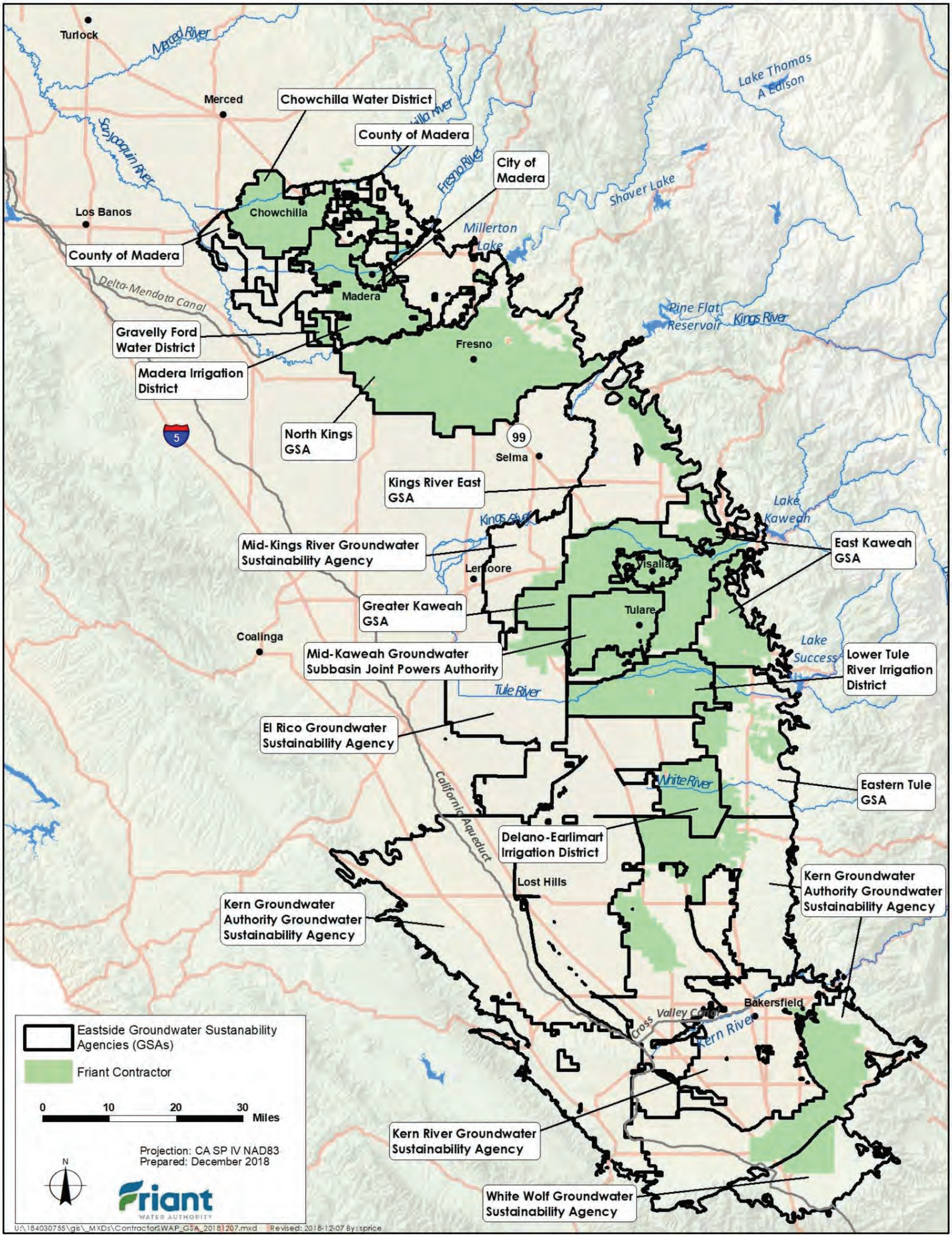

Figure 2: Location of Friant Contractors relative to GSAs

Table 1. Friant Contractors and Estimated Irrigated Acreage relative to GSAs (DWR, 2017)

GROUNDWATER SUSTAINABILITY AGENCY	FRIANT CONTRACTOR[1]	FRIANT CONTRACTOR IRRIGATED LAND[2] (ACRES)
Chowchilla Water District	Chowchilla Water District	67,170
City of Madera	Madera Irrigation District	910
County of Madera	Chowchilla Water District	30
	Madera Irrigation District	90
Gravelly Ford Water District	Gravelly Ford Water District	7,490
Madera Irrigation District	Madera Irrigation District	100,360
North Kings GSA	Fresno Irrigation District[3]	128,330
	Garfield Water District	1,160
	International Water District	540
Kings River East GSA	Hills Valley Irrigation District	2,830
	Orange Cove Irrigation District	24,360
	Tri-Valley Water District	1,040
Mid-Kings River GSA	Kaweah Delta Water Conservation District[2]	NE
East Kaweah GSA	Exeter Irrigation District	10,580
	Ivanhoe Irrigation District	9,630
	Lewis Creek Water District	1,010
	Lindmore Irrigation District	22,760
	Lindsay - Strathmore Irrigation District	10,880
	Lower Tule River Irrigation District	80
	Stone Corral Irrigation District	5,980
Greater Kaweah GSA	Exeter Irrigation District	500
	Ivanhoe Irrigation District	30
	Kaweah Delta Water Conservation District[4]	NE
	Tulare Irrigation District	60
Mid-Kaweah Groundwater Subbasin Joint Powers Authority	Tulare Irrigation District	58,160
El Rico GSA	Kaweah Delta Water Conservation District[4]	NE
Lower Tule River Irrigation District	Lower Tule River Irrigation District	80,480
	Porterville Irrigation District	70
Eastern Tule GSA	Kern - Tulare Water District	8,480
	Porterville Irrigation District	12,470
	Saucelito Irrigation District	18,060
	Tea Pot Dome Water District	3,090
	Terra Bella Irrigation District	9,110
Delano - Earlimart Irrigation District	Delano - Earlimart Irrigation District	49,960
Kern Groundwater Authority GSA	Arvin - Edison Water Storage District	84,280
	Kern-Tulare Water District	14,500
	Shafter - Wasco Irrigation District	30,190
	Southern San Joaquin Municipal Utility District	45,190
Kern River GSA	Arvin - Edison Water Storage District	190
White Wolf GSA	Arvin - Edison Water Storage District	20,830

Key:
GSA = Groundwater Sustainability Agency
NE = Not estimated
Notes:
[1]Only Friant Contractors with agricultural demands shown per GSA, Friant M&I contractors were assumed to have no agricultural demand.
[2] Irrigated lands rounded to nearest 10 acres
[3]Any agricultural lands within City of Fresno is represented as part of the Fresno Irrigation District
[4]Kaweah-Delta Water Conservation District agricultural lands were not estimated

PREVIOUS STUDIES AND REPORTS

The potential range of future Friant Division water supplies from the San Joaquin River have been studied for several recent efforts. This TM relies on computer models, assumptions, and analysis that were initially developed for and reported by the following:

- San Joaquin River Restoration Settlement, and Program (SJRRS and SJRRP)
  - Settlement Agreement (2006)
  - Program Environmental Impact Statement/Report (PEIS/R; Reclamation, 2009)
- Temperance Flat Reservoir studies, including:
  - Federal Feasibility Study (Reclamation, ongoing)
  - Application to California Proposition 1, Water Storage Investment Program (Temperance Flat Reservoir Authority, 2017)

FACTORS AFFECTING FRIANT SUPPLIES THROUGH YEAR 2100

Beyond the natural variability of annual precipitation in the headwaters of the San Joaquin River, several drivers are expected to greatly influence the water supplies of the Friant Division over the coming century. These include:

1. **Changes in the climate and hydrology**: These changes include a warming trend that is expected to reduce winter snow accumulation and hasten spring melt and runoff. Five climate conditions are considered in this report.
2. **Implementation of the SJRRS Restoration Goal:** The SJRRS Restoration Goal is currently limited in its implementation but is expected to be fully implemented by 2030, with the completion of river conveyance enhancements below Friant Dam. When completed, the impact of the SJRRS on Friant Contractor supplies will reach the extent anticipated in the SJRRS.
3. **Implementation of the SJRRS Water Management Goal**: The SJRRS Water Management Goal provides for several mechanisms to reduce or avoid water supply impacts on Friant Contractors. The water supply benefits of two SJRRS provisions are quantified in this analysis, being those described in Paragraphs 16(a) (i.e., recapture and recirculation) and 16(b) (i.e., water sold at $10 per acre foot during wet conditions).
   - Paragraph 16(a) is restricted at this time, being limited to the recapture of flows that can be released from Friant Dam. As implementation of the Restoration Goal progresses, so will recapture and recirculation.
   - Paragraph 16(b) is currently underutilized. At the time of the Settlement, a fixed $10 per acre foot price for wet year supplies was expected to stimulate investments in groundwater infiltration facilities. With subsequent water supply challenges imposed by SGMA on the Eastern San Joaquin Valley, the regional appetite for groundwater infiltration has grown dramatically. At this time, Friant Contractors anticipate considerable interest and ability to divert and infiltrate flows that may have spilled from Friant Dam under historical conditions. The upper end of implementation of 16(b) is expected to occur before 2030.

The technical representations of these conditions were taken from previous studies and reports, in the manner described below.

INVENTORY OF MODEL SIMULATIONS PERFORMED

This report presents simulated operations that account for five climate conditions and the eventual full implementation of SJRRS Restoration and Water Management goals. Table 2 identifies 15 individual modeling runs compiled for this TM, along with the major assumptions for each.

The reader should note that each of the five climate conditions contain three model runs, denoted with a suffix of “a”, “b”, and “c”. To calculate the Restoration Goal for each of these climate conditions, model runs “a” and “b” were conducted to create comparisons that are necessary for explaining effect of SJRRS implementation. Calculation of the Water Management Goal requires a comparison of model runs “a” to model runs “b” and “c” to represent the expected recapture and recirculation for each level of SJRRS implementation. Model runs denoted with “c” are provided for comparative analyses that calculate recapture and recirculation, as well as additional groundwater recharge deliveries during wet conditions.

All simulations were performed using CalSim-II, the State of California’s premiere water supply planning and analysis tool. The primary use of the CalSim model is for estimating water supply exports from the Sacramento-San Joaquin Delta for delivery to CVP and State Water Project (SWP) water users. CalSim-II simulates statewide water supply operations using a continuous 82-year hydrology, traditionally based on the period of historic records beginning October 1921 and running through September 2003.

Table 2. Fifteen model runs simulated for this Report

MODEL RUN	CLIMATE CONDITION	SJRRS SETTLEMENT RESTORATION GOAL	SJRRS SETTLEMENT WATER MANAGEMENT GOAL	BENCHMARK CALSIM-II MODEL USED
2015.a	2015 Conditions (historical modified for recent changes)	Pre-SJRRS	Pre-SJRRS	DWR Delivery Capability Report, 2015 climate
2015.b		Limited SJRRS	Limited Access	
2015.c			Full Access	
2030.a	Near-Future (DWR 2030 Central Tendency)	Pre-SJRRS	Pre-SJRRS	Water Commission, 2030 climate
2030.b		Full SJRRS	Limited Access	
2030.c			Full Access	
2070.a	Late-Future (DWR 2070 Central Tendency)	Pre-SJRRS	Pre-SJRRS	Water Commission, 2070 climate
2070.b		Full SJRRS	Limited Access	
2070.c			Full Access	
DEW.a	Late-Future, 2070 Drier/Extreme Warming	Pre-SJRRS	Pre-SJRRS	Water Commission, 2070 DEW climate
DEW.b		Full SJRRS	Limited Access	
DEW.c			Full Access	
WMW.a	Late-Future, 2070 Wetter/Moderate Warming	Pre-SJRRS	Pre-SJRRS	Water Commission, 2070 WMW climate
WMW.b		Full SJRRS	Limited Access	
WMW.c			Full Access	

Key:
DEW = Drier/Extreme Warming
DWR = California Department of Water Resources
SJRRS = San Joaquin River Restoration Settlement
WMW = Wetter/Moderate Warming

CLIMATE CHANGES EVALUATED

The California Water Commission Water Supply Investment Program (CWC WSIP) developed baseline CalSim-II simulations using several levels of potential climate change to modify input hydrology of the entire system, including the San Joaquin River. These scenarios were developed using the 20 combinations of climate change models and representative concentration pathways recommended by DWR Climate Change Technical Advisory Group as being most appropriate for California water resource planning and analysis. Further details on the specific climate change included in each of the simulations is included in the CWC WSIP Technical Reference (CWC, 2016). The resulting climate change conditions used in this analysis include:

1. **2015 Conditions:** This represents a historical hydrology modified to match climate and sea level conditions for a thirty-year period centered at 1995 (reference climate period 1981 – 2010).
2. **Near-Future 2030 Central Tendency:** This represents a 2030 future hydrology with projected climate and sea level conditions for a thirty-year period centered at 2030 (reference climate period 2016 – 2045).
3. **Late-Future 2070 Central Tendency:** This hydrology represents a 2070 future condition with projected climate and sea level conditions for a thirty-year period centered at 2070 (reference climate period 2056 – 2085).
4. **Late-Future 2070 Drier/Extreme Warming Conditions (DEW):** This hydrology represents a 2070 DEW future condition with projected climate and sea level conditions for a thirty-year period centered at 2070 (reference climate period 2056 – 2085).
5. **Late-Future 2070 Wetter/Moderate Warming Conditions (WMW):** This hydrology represents a 2070 WMW future condition with projected climate and sea level conditions for a thirty-year period centered at 2070 (reference climate period 2056 – 2085).

The seasonal timing of inflow to Millerton Lake is projected to change in response to climate change. Historical inflow to Millerton Lake generally peak during the month of June due to the delayed runoff from a large snow pack. The climate change scenarios for 2030 and 2070 are based on warmer conditions that will produce precipitation events with more rainfall and less snowpack than historically occurred, resulting in peak runoff earlier in the year. Peak runoff into Millerton Lake is projected to occur in May for the 2030 scenario, and in April for the 2070 scenario. Figure 3 shows the general trend of Millerton Lake inflow change due to climate change.

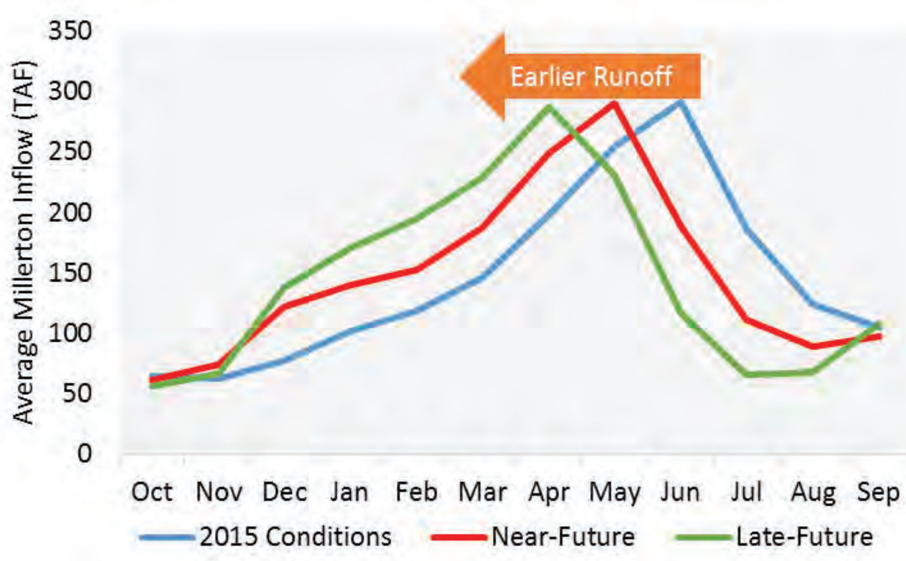

Figure 3. Millerton Lake Inflow Change Due to Climate Change

When analyzing CalSim-II outputs, the results are often summarized by water year type, which classifies groups of years with similar hydrologic characteristics. A water year starts October 1 of the preceding calendar year and ends September 30 of the current year. For example, water year 1922 starts October 1, 1921 and ends September 30, 1922. In this analysis the SJRRS water year type classification was used to summarize the estimated changes in Friant Division supplies. The SJRRS water year types are classified as follows: Wet, Normal-Wet, Normal-Dry, Dry, Critical High and Critical Low. For the CWC WSIP the SJRRP water year type classification remained unchanged between the five climate change conditions. In this TM, the SJRRS water year types were redefined based on Unimpaired Millerton Inflow (consistent with the SJRRS) from the CalSim II SV input files. This was done to update the SJRRS hydrographs to better reflect the anticipated climate change conditions. Table 3 summarizes the SJRRS water year types by climate condition. For reporting purposes, the designation of Critical water year type includes both Critical High and Critical Low SJRRS water year types.

Table 3. SJRRS Water Year Types per Climate Condition by Number of Years and Percentage of Total Years

SJRRS WATER YEAR TYPE	2015 CONDITIONS	NEAR-FUTURE, 2030	LATE-FUTURE, 2070	LATE-FUTURE, 2070 DEW	LATE-FUTURE, 2070 WMW
Wet	16 (20%)	18 (22%)	19 (23%)	21 (26%)	35 (43%)
Normal-Wet	25 (30%)	21 (26%)	20 (24%)	12 (15%)	21 (26%)
Normal-Dry	24 (29%)	25 (30%)	20 (24%)	11 (13%)	15 (18%)
Dry	12 (15%)	11 (13%)	16 (20%)	20 (24%)	9 (11%)
Critical[1]	5 (6%)	7 (9%)	7 (9%)	18 (22%)	2 (2%)
Long-Term[2]	82	82	82	82	82

Key:
DEW = Drier/Extreme Warming
DWR = California Department of Water Resources
SJRRS = San Joaquin River Restoration Settlement
WMW = Wetter/Moderate Warming
Note:
[1]For reporting purposes, the designation of Critical water year type includes both Critical High and Critical Low SJRRP water year types
[2]Long-Term average reflects the 82-year CalSim II simulation period (October 1921 thru September 2003)

SJRRS IMPLEMENTATION

Implementation of the SJRRS includes actions to meet both the Restoration and Water Management Goals. Both goals have a direct effect on Friant Division water supplies, and both are expected to change in implementation over time.

Presently, both goals are implemented in a limited manner because of capacity restrictions in the San Joaquin River below Friant Dam (which constrict releases for the Restoration Goal) and the need for further buildout of groundwater infiltration facilities to take full advantage wet year supplies, when available (for the Water Management Goals). However, Reclamation has plans for implementation that will allow for virtually all SJRRS releases to be made by 2025 (SJRRP, 2018). Further, water users throughout the Friant Division are pursuing a broad array of facilities that will enhance the ability to implement Paragraph 16(b) water supplies, when available.

To represent the current and anticipated future implementation of the SJRRS, the following variations were constructed.

Restoration Goal Implementation

Three levels of Restoration Goal implementation are considered, as follows:

1. **Pre-SJRRS:** This simulation sets the required minimum release from Millerton to the San Joaquin River to the values in the without project baseline conditions (SJRRP, 2009).
2. **Limited SJRRS:** This condition approximates current conditions, which are expected to remain limited until 2025. Simulations of this condition are based on the current channel capacity of 1,300 cubic feet per second (CFS) in Reach 2.
3. **Full SJRRS:** This condition represents the SJRRS hydrograph with capacities identified in the SJRRS Funding Constrained Framework. Under this plan, channel capacity will not exceed the identified 2025 channel capacity of 2,500 CFS in Reach 2. This hydrograph was used in the 2030, 2070, 2070 DEW, and 2070 WMW level of climate change simulations. Flow releases (Flow Schedules) for this condition were approximated with a spreadsheet developed by the SJRRP for the Framework Document (SJRRP, 2018). Table 3 shows the Full SJRRS Implementation hydrograph compared to the Funding Constrained Framework SJRRS hydrograph for the four climate change scenarios. The differences between the four climate change scenarios is due to the different number of years per SJRRS water year type, as shown in Table 3. Table 4 is not the impact of Friant Deliveries, but

represents the SJRRS releases under the Funding Constrained Framework under different climate change conditions.

Table 4 Long-Term Average SJRRS Releases under Full SJRRS Implementation and the Funding Constrained Framework Four Climate Conditions

SJRRS WATER YEAR TYPE	FULL SJRRP IMPLEMENTATION (TAF/YEAR)	FUNDING CONSTRAINED FRAMEWORK			
		NEAR-FUTURE, 2030 (TAF/YEAR)	LATE-FUTURE, 2070 (TAF/YEAR)	LATE-FUTURE, 2070 DEW (TAF/YEAR)	LATE-FUTURE, 2070 WMW (TAF/YEAR)
Wet	674	633	633	628	633
Normal-Wet	474	434	433	428	432
Normal-Dry	365	365	364	363	357
Dry	302	297	296	296	300
Critical High	188	188	188	188	188
Critical Low	117	117	117	117	117
Long-Term[1]	438	417	414	376	483[2]

Key:
DEW = Drier/Extreme Warming
DWR = California Department of Water Resources
SJRRS = San Joaquin River Restoration Settlement
TAF/year = thousand acre-feet per year
WMW = Wetter/Moderate Warming
Note:
[1]Long-Term average reflects the 82-year CalSim II simulation period (October 1921 thru September 2003)
[2] The Long-Term Average SJRRS release for 2070 WMW is higher than the Full SJRRP Implementation because, as Table 3 shows, the number of Wet water years increased from 16 years (20 percent) in the 2015 Condition to 35 years (43 percent) in the 2070 WMW Condition.

The quantification of SJRRS implementation impact is performed by comparing the with and without SJRRS water supplies diverted from Friant Dam.

In the course of compiling these model runs, it was discovered that previous studies had not correctly implemented SJRRS flows under climate change. SJRRS outflow requirements at Friant Dam are determined by the total annual hydrology, which can change enough under climate conditions to alter a given year's release requirements. All scenarios and results in this report have been adjusted to correctly set SJRRS flow requirements, including under climate change.

Water Management Goal Implementation

Three levels of Water Management Goal implementation are considered, as follows:

1. **Pre-SJRRS**: This represents the without SJRRS condition.
2. **Limited Access:** This represents 16(a) supplies available to Friant Contractors as part of the SJRRS that provides for recapture and recirculation of flows released from Friant Dam for the purposes of meeting the Restoration Goal.
3. **Full Access:** This represents supplies anticipated with future ability to divert 16(a) and 16(b) supplies to Friant Contractors. 16(b) stipulates a Recovered Water Account (RWA) that represents water not required to meet SJRRS or other requirements be made available to Friant Contractors who experience a reduction in water deliveries from the implementation of the SJRRS. 16(b) water is made available to those Friant Contractors at $10 per acre-foot during wet condition.

The SJRRS and implementing documents identify several locations for recapture, however modeling conducted for the SJRRP PEIS/R only provided for estimated recapture as the incremental improvement in total Delta Exports that result from the SJRRS. The quantification of water supplies recaptured in the Delta in conformance with 16(a) is performed by comparing simulated Delta exports with and without the implementation of the SJRRS. The net improvement in export is identified as recapturable supply.

The CalSim-II model simulates 16(b) as an additional demand after Class 1 and Class 2 delivery allocations are met and before 215 (“Other”) deliveries are made. The CalSim-II simulated 16(b) delivery via the Friant Kern and Madera canals is based on anticipated development of groundwater infiltration facilities throughout the Friant Division in response to SJRRS implementation. These facilities are not identified and are represented as surrogate water demands in the CalSim-II model. As a result, use of 16(b) water supply availability must be viewed as total opportunity that has not been attributed among individual water users at this time.

The quantification of water supplies diverted from Friant Dam for 16(b) is performed by comparing the with and without SJRRS simulations that allow for added diversions. This required the additional simulation for each scenario, to provide for comparison. The “#.b” scenarios are included in results for reference.

GUIDANCE ON USE OF RESULTS

This TM provides descriptions of potential future water supplies for the Friant Division for five climate change conditions under different levels of SJRRS implementation.

The key outputs of this report are provided in tables by monthly and total volumes by contract year (which begins March 1 of the current calendar year and ends February 28 of the following year), except when noted, and summarized by SJRRS water year type classification and long-term average for each of the following:

- Millerton Lake Inflow
- Total Friant Division deliveries of:
  - Class 1
  - Class 2/Other
  - Paragraph 16(b) water (aka $10 water, or RWA water)
- Friant Dam Spill
- Potential Friant Division Delta Recapture (by year, only), for:
  - Class 1 Delta Recapture
  - Class 2 Delta Recapture
  - Total Delta Recapture

These data are provided in a spreadsheet, entitled: “Summary_FutureFriantSupplies_Final.xlsm”

Table 5 provides a portion of a tabulated output available in the spreadsheet. Tabulated information includes the average monthly and total volumes by SJRRS water year type classification and long-term average. For reporting purposes, the designation of Critical water year type includes both Critical-High and Critical-Low SJRRS water year types. Tabulated information also includes the monthly and total volumes per contract year (Mar-Feb). In the spreadsheet, the tables include the monthly and total volumes per contract year for the entire 82-year CalSim-II simulated period (October 1921 to September 2003).

Table 5. Example Output Table for Class 1 Deliveries

		Class 1 Delivery												
		Mar TAF	Apr TAF	May TAF	Jun TAF	Jul TAF	Aug TAF	Sep TAF	Oct TAF	Nov TAF	Dec TAF	Jan TAF	Feb TAF	Total TAF
Wet		16.1	28.1	51.6	123.4	189.9	181.5	106.3	48.5	12.2	6.4	6.3	29.8	800.0
Normal-Wet		26.2	46.3	75.0	149.8	189.3	165.2	84.0	28.9	4.7	4.5	4.5	21.6	800.0
Normal-Dry		32.9	56.7	92.1	158.6	184.4	152.5	67.9	20.9	3.6	3.6	3.4	19.7	796.3
Dry		29.7	48.8	81.7	143.9	167.1	130.5	55.8	20.9	4.7	2.3	2.3	17.3	705.1
Critical		16.7	19.9	36.4	86.6	111.5	65.2	31.0	19.9	6.6	0.0	0.0	9.9	403.8
Long Term		26.1	44.6	74.1	142.4	179.9	153.4	76.2	28.7	6.0	4.0	3.9	21.3	760.4
2015 SJRRP WY Type	Month Year	Mar TAF	Apr TAF	May TAF	Jun TAF	Jul TAF	Aug TAF	Sep TAF	Oct TAF	Nov TAF	Dec TAF	Jan TAF	Feb TAF	Total TAF
Normal-Wet	1921								0.0	0.0	0.0	0.0	0.0	0.0
Normal-Wet	1922	22.3	37.4	59.8	138.2	189.1	174.0	97.8	36.4	5.5	5.3	5.3	28.9	800.0
Normal-Wet	1923	25.6	42.7	64.4	146.7	187.1	170.7	95.2	33.8	4.9	4.6	4.6	19.7	800.0
Critical	1924	17.9	21.4	39.2	93.2	120.0	72.2	31.6	21.4	7.1	0.0	0.0	10.7	434.7
Normal-Dry	1925	32.8	56.4	89.7	158.4	188.2	152.0	70.7	21.0	3.9	3.9	3.3	19.7	800.0
Normal-Dry	1926	33.2	57.1	98.8	160.4	183.9	151.2	65.6	19.9	3.3	3.3	3.3	19.9	800.0
Normal-Wet	1927	25.7	47.4	80.6	151.2	191.4	163.5	79.8	26.8	4.8	4.6	4.6	19.8	800.0
Normal-Dry	1928	31.6	57.8	92.0	162.4	186.2	153.1	66.4	20.2	3.4	3.4	3.4	20.2	800.0
Dry	1929	26.8	48.2	80.3	132.2	148.5	124.8	53.0	16.1	2.7	2.7	2.7	16.1	654.0
Dry	1930	27.1	48.8	81.1	133.6	150.1	126.2	53.6	16.3	2.7	2.7	2.7	16.3	661.1
Critical	1931	12.9	15.5	28.3	67.4	86.9	52.3	22.9	15.5	5.2	0.0	0.0	7.7	314.5
Normal-Wet	1932	25.6	42.7	64.4	146.7	187.1	170.7	95.2	33.8	4.9	4.6	4.6	19.7	800.0
Normal-Dry	1933	32.8	56.4	89.7	158.4	188.2	152.0	70.7	21.0	3.9	3.9	3.3	19.7	800.0
Dry	1934	24.0	28.7	52.2	124.2	159.9	96.2	42.2	28.5	9.5	0.0	0.0	14.2	579.6
Normal-Wet	1935	28.2	47.3	80.4	150.7	190.7	162.9	79.5	26.7	4.7	4.6	4.6	19.7	800.0
Normal-Wet	1936	28.2	47.2	80.3	150.7	190.7	162.9	79.5	26.7	5.0	4.6	4.6	19.7	800.0
Normal-Wet	1937	28.7	48.0	81.6	159.5	191.1	160.7	74.5	24.0	4.0	4.0	4.0	20.0	800.0
Wet	1938	17.2	28.4	52.1	115.8	193.9	182.0	104.2	49.9	13.0	6.6	6.6	30.4	800.0

CLASS 1 AND CLASS 2 SUPPLY PROJECTIONS

While CalSim-II does produce estimated deliveries of Class 1 water supplies with some confidence, the simulated “Class 2” and “Other” model outputs have always been problematic. This is because CalSim-II approximations of wet year operations were calibrated to mimic total releases – not actual deliveries of Class 2 or (separately) Other supplies. As a result, the modeling outputs provided with this TM do not distinguish between Class 2 and Other modeling categories. These two data outputs have been grouped to describe Class 2 behavior in aggregate. Through previous modeling conducted for SJRRS implementation, Friant Division managers have found the aggregation of Class 2 and Other model outputs performs closer to actual experience with Class 2 deliveries.

CalSim-II does not determine delivery by Friant Contractor, it simulates the annual allocations and then distributes them over the year on a monthly pattern. CalSim- II does approximate the division of flows between the Madera and Friant-Kern canals, but the actual final deliveries simulated in CalSim-II are not to specific Friant contractors or physical locations. Standard practice in interpreting deliveries to Friant Contractors has been to split Class 1 and Class 2/Other deliveries among individual contractors by contract quantity. For example, a district with an 80 thousand acre-feet (TAF) Friant Division Class 1 contract (i.e., 10 percent of total Class 1) and 70 TAF of Class 2 (i.e., five percent of total Class 2), would have access to 10 percent of the Class 1 supplies and five percent of the Class 2/Other supplies in a given year. Table 6 lists the Friant Contractors corresponding Class 1 and Class 2 contract amounts by volume and percentage. These have been incorporated into the spreadsheet to facilitate use.

NOTE: The reader may note that Section 215 water supplies are not discussed. While the factors that produce “215 water” are presumed to exist in the future, the frequency and magnitude of their availability is expected to be greatly diminished by implementation of the SJRRS, which has made available water supplies to Friant Contractors through Paragraph 16(b) of the Settlement. The assumed low availability of 215 water comports with recent experience, even with partial SJRRS implementation. As a result, this analysis makes no attempt to quantify future 215 water supply availability, which may be presumed to be nearly zero for planning purposes. “16(b)” or “RWA” or “$10” water (all the same) is discussed in a later section.

Table 6. Friant Contractor Summary

FRIANT CONTRACTOR	CLASS 1 ACRE-FEET	CLASS 2 ACRE-FEET	CLASS 1 PERCENTAGE	CLASS 2/OTHER PERCENTAGE
Arvin-Edison Water Storage District	40,000	311,675	5.0%	22.2%
Chowchilla Water District	55,000	160,000	6.9%	11.4%
City of Fresno	60,000	0	7.5%	0.0%
City of Lindsay	2,500	0	0.3%	0.0%
City of Orange Cove	1,400	0	0.2%	0.0%
Delano-Earlimart Irrigation District	108,800	74,500	13.6%	5.3%
Exeter Irrigation District	11,100	19,000	1.4%	1.4%
Fresno County Water Works District No. 18	150	0	0.0%	0.0%
Fresno Irrigation District	0	75,000	0.0%	5.4%
Garfield Water District	3,500	0	0.4%	0.0%
Gravelly Ford Water District	0	14,000	0.0%	1.0%
Hills Valley Irrigation District	1,250	0	0.2%	0.0%
International Water District	1,200	0	0.2%	0.0%
Ivanhoe Irrigation District	6,500	500	0.8%	0.0%
Kaweah Delta Water Conservation District	1,200	7,400	0.2%	0.5%
Kern-Tulare Water District	0	5,000	0.0%	0.4%
Lewis Creek Water District	1,200	0	0.2%	0.0%
Lindmore Irrigation District	33,000	22,000	4.1%	1.6%
Lindsay-Strathmore Irrigation District	27,500	0	3.4%	0.0%
Lower Tule River Irrigation District	61,200	238,000	7.7%	17.0%
Madera County	200	0	0.0%	0.0%
Madera Irrigation District	85,000	186,000	10.6%	13.3%
Orange Cove Irrigation District	39,200	0	4.9%	0.0%
Porterville Irrigation District	15,000	30,000	1.9%	2.1%
Saucelito Irrigation District	21,500	32,800	2.7%	2.3%
Shafter-Wasco Irrigation District	50,000	39,600	6.3%	2.8%
Southern San Joaquin Municipal Utility District	97,000	45,000	12.1%	3.2%
Stone Corral Irrigation District	10,000	0	1.3%	0.0%
Tea Pot Dome Water District	7,200	0	0.9%	0.0%
Terra Bella Irrigation District	29,000	0	3.6%	0.0%
Tri-Valley Water District	400	0	0.1%	0.0%
Tulare Irrigation District	30,000	141,000	3.8%	10.1%
Total	800,000	1,401,475	100%	100%

SJRRS WATER SUPPLY PROJECTIONS

The SJRRS Water Management Goal creates two new categories of supplies for Friant Contractors that are described in paragraphs 16(a) and (b) of the Settlement.

Delta recapture (Paragraph 16(a) is quantified in this analysis by taking the difference in Delta Exports between the with and without SJRRS implementation and crediting the net volume of improvement to the SJRRS recapture program. This does not account for the ability to recapture water supplies on the lower San Joaquin River. Delta recapture is reported as an annual quantity to overcome limitations in the simulation of monthly operations, which are not appropriate for use as monthly recapture volumes at this time. This supply represents an upper bound for potential recapture in the Delta. Discussions between Reclamation, DWR, and

Friant are ongoing to establish the availability of this water supply through Delta pumping. At the time of this report, no processes are in place to recapture in the Delta.

In recent practice, recaptured supplies have been split between Class 1 and 2 contractors, using recapture to back-fill for water contract allocations. For this analysis, Delta recapture has been split between Class 1 and Class 2 contractors, based on recent practices by Reclamation. At the request of Friant Contractors, recapture is provided first to Class 1 water users up to the point that the combination of Friant Division deliveries and recapture equal a 100 percent Class 1 allocation. Any volumes in excess are allocated to Class 2 contractors, proportional to their Class 2 contract volumes. The spreadsheet includes summary tables of total Delta recapture, and a breakout of Class 1 and Class 2 recapture by Friant Contractor proportional to their contract amounts as shown in Table 5. Users of this data are encouraged to apply contract quantities (Table 6) to attribute allocations among Friant Contractors.

The second SJRRS water category, Paragraph 16(b) supplies, are quantified in the CalSim II model by assuming a demand for this potential supply and meeting this demand, limited by availability of flood water and channel capacity for delivery. Any remaining flood water is then assumed available for 215/other delivery in the simulation. Specific patterns for the use of this supply do not yet exist and, thus, CalSim-II makes no assertion about anything except for the expectation and potential for these supplies to be delivered.

For consistency with previous efforts to interpret the CalSim II model and its output, 16(b) supplies have been divided among Friant Contractors in proportion to their share of impact from the SJRRS that accumulates to their water supplies. The impact from the SJRRS is estimated by comparison of the total C1 and C2/Other delivery in the Pre-SJRRS and "limited" CalSim II simulations. The allocation to the individual contractors was done based on percentage of impact from the Proposed Implementation Agreement of the Friant Settlement (SJRRP, 2009) and from the percentage impact computed from the new CalSim II simulation performed for this analysis. For example, a Friant Contractor with five percent of reduction in total Class 1 and Class 2/Other is and would have access to five percent of the 16(b) supplies. Table 7 and 8 shows impact of SJRRS under the five climate change conditions and computed impacts from the Mediator's Report for the Friant Contractors.

Table 7. Summary of Friant Contractor Impacts per Climate Change and Mediator's Report (Volume)

FRIANT CONTRACTOR	LONG-TERM AVERAGE CLASS 1 AND CLASS 2/OTHER IMPACTS					
	MEDIATOR'S REPORT	2015 CONDITION	NEAR-FUTURE, 2030	LATE-FUTURE, 2070	LATE-FUTURE, 2070 DEW	LATE-FUTURE, 2070 WMW
	TAF	TAF	TAF	TAF	TAF	TAF
Arvin-Edison Water Storage District	30.342	28.13	28.88	26.54	18.69	28.41
Chowchilla Water District	17.661	15.76	16.58	15.75	12.59	16.04
City of Fresno	3.629	2.30	3.06	3.71	5.22	2.52
City of Lindsay	0.151	0.10	0.13	0.15	0.22	0.11
City of Orange Cove	0.085	0.05	0.07	0.09	0.12	0.06
Delano-Earlimart Irrigation District	13.255	10.53	11.96	12.47	13.10	10.97
Exeter Irrigation District	2.398	2.05	2.20	2.15	1.89	2.10
Fresno County Water Works District No. 18	0.009	0.01	0.01	0.01	0.01	0.01
Fresno Irrigation District	6.719	6.40	6.46	5.79	3.66	6.43
Garfield Water District	0.212	0.13	0.18	0.22	0.30	0.15
Gravelly Ford Water District	1.254	1.19	1.21	1.08	0.68	1.20
Hills Valley Irrigation District[1]	0.000	0.00	0.00	0.00	0.00	0.00
International Water District	0.073	0.05	0.06	0.07	0.10	0.05
Ivanhoe Irrigation District	1.173	0.29	0.37	0.44	0.59	0.32
Kaweah Delta Water Conservation District[1]	0.000	0.000	0.000	0.000	0.000	0.000
Kern-Tulare Water District[1]	0.000	0.000	0.000	0.000	0.000	0.000
Lewis Creek Water District	0.088	0.05	0.06	0.07	0.10	0.05
Lindmore Irrigation District	3.967	3.14	3.58	3.74	3.94	3.28
Lindsay-Strathmore Irrigation District	1.663	1.06	1.40	1.70	2.39	1.16
Lower Tule River Irrigation District	25.024	22.66	23.62	22.16	16.94	22.99
Madera County	0.012	0.01	0.01	0.01	0.02	0.01
Madera Irrigation District	21.805	19.13	20.35	19.61	16.47	19.53
Orange Cove Irrigation District	2.371	1.50	2.00	2.42	3.41	1.65
Porterville Irrigation District	3.655	3.14	3.35	3.24	2.77	3.20
Saucelito Irrigation District	4.221	3.62	3.92	3.86	3.47	3.72
Shafter-Wasco Irrigation District	6.572	5.30	5.96	6.15	6.28	5.50
Southern San Joaquin Municipal Utility District	10.346	7.56	8.82	9.46	10.63	7.94
Stone Corral Irrigation District	0.605	0.38	0.51	0.62	0.87	0.42
Tea Pot Dome Water District	0.454	0.28	0.37	0.44	0.63	0.30
Terra Bella Irrigation District	1.754	1.11	1.48	1.79	2.52	1.22
Tri-Valley Water District[1]	0.000	0.000	0.000	0.000	0.000	0.000
Tulare Irrigation District	14.447	13.18	13.67	12.74	9.49	13.36
Total	**173.945**	**149.13**	**160.26**	**156.49**	**137.14**	**152.67**

Key:
DEW = Drier/Extreme Warming
TAF = thousand acre-feet
WMW = Wetter/Moderate Warming
Note:
[1] Friant Contractor calculated impact as zero because they do not receive a proportion of 16(b) supplies.

Table 8. Summary of Friant Contractor Impacts per Climate Change and Mediator's Report (Percentage)

FRIANT CONTRACTOR	LONG-TERM AVERAGE CLASS 1 AND CLASS 2/OTHER IMPACTS					
	MEDIATOR'S REPORT	2015 CONDITION	NEAR-FUTURE, 2030	LATE-FUTURE, 2070	LATE-FUTURE, 2070 DEW	LATE-FUTURE, 2070 WMW
	%	%	%	%	%	%
Arvin-Edison Water Storage District	17.444%	18.864%	18.020%	16.958%	13.630%	18.611%
Chowchilla Water District	10.153%	10.571%	10.347%	10.066%	9.183%	10.504%
City of Fresno	2.086%	1.544%	1.909%	2.368%	3.806%	1.653%
City of Lindsay	0.087%	0.064%	0.080%	0.099%	0.159%	0.069%
City of Orange Cove	0.049%	0.036%	0.045%	0.055%	0.089%	0.039%
Delano-Earlimart Irrigation District	7.620%	7.063%	7.464%	7.970%	9.553%	7.183%
Exeter Irrigation District	1.378%	1.373%	1.374%	1.376%	1.380%	1.373%
Fresno County Water Works District No. 18	0.005%	0.004%	0.005%	0.006%	0.010%	0.004%
Fresno Irrigation District	3.863%	4.292%	4.030%	3.701%	2.669%	4.213%
Garfield Water District	0.122%	0.090%	0.111%	0.138%	0.222%	0.096%
Gravelly Ford Water District	0.721%	0.801%	0.752%	0.691%	0.498%	0.786%
Hills Valley Irrigation District[1]	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
International Water District	0.042%	0.031%	0.038%	0.047%	0.076%	0.033%
Ivanhoe Irrigation District	0.675%	0.196%	0.234%	0.281%	0.430%	0.207%
Kaweah Delta Water Conservation District[1]	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
Kern-Tulare Water District[1]	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
Lewis Creek Water District	0.050%	0.031%	0.038%	0.047%	0.076%	0.033%
Lindmore Irrigation District	2.281%	2.108%	2.232%	2.388%	2.876%	2.145%
Lindsay-Strathmore Irrigation District	0.956%	0.708%	0.875%	1.085%	1.744%	0.758%
Lower Tule River Irrigation District	14.386%	15.194%	14.736%	14.159%	12.352%	15.057%
Madera County	0.007%	0.005%	0.006%	0.008%	0.013%	0.006%
Madera Irrigation District	12.536%	12.831%	12.699%	12.532%	12.011%	12.791%
Orange Cove Irrigation District	1.363%	1.009%	1.247%	1.547%	2.486%	1.080%
Porterville Irrigation District	2.101%	2.103%	2.089%	2.072%	2.019%	2.099%
Saucelito Irrigation District	2.427%	2.430%	2.446%	2.467%	2.531%	2.435%
Shafter-Wasco Irrigation District	3.778%	3.553%	3.719%	3.927%	4.581%	3.602%
Southern San Joaquin Municipal Utility District	5.948%	5.071%	5.504%	6.048%	7.754%	5.201%
Stone Corral Irrigation District	0.348%	0.257%	0.318%	0.395%	0.634%	0.276%
Tea Pot Dome Water District	0.261%	0.185%	0.229%	0.284%	0.457%	0.198%
Terra Bella Irrigation District	1.008%	0.746%	0.923%	1.144%	1.839%	0.799%
Tri-Valley Water District[1]	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
Tulare Irrigation District	8.305%	8.840%	8.531%	8.141%	6.921%	8.748%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.000%**

Key:
DEW = Drier/Extreme Warming
WMW = Wetter/Moderate Warming
Note:
[1] Friant Contractor does not receive a proportion of 16(b) supplies.

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SJRRP, *see San Joaquin River Restoration Program*

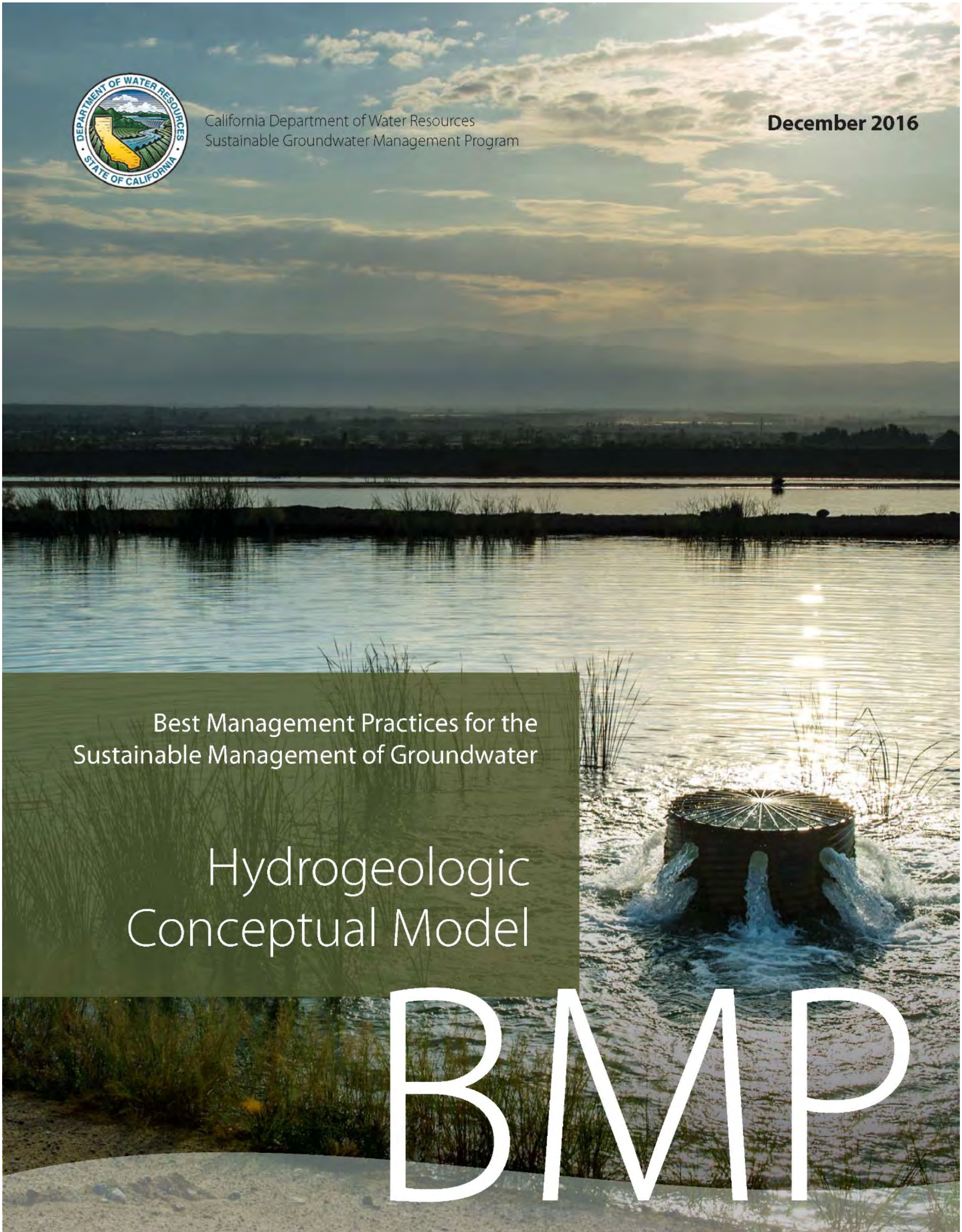
Appendix 2B SGMA DWR Guidance Documentation

2Ba ***Hydrogeologic Conceptual Model Best Management Practices***

2Bb ***Water Budget Best Management Practices***

2Bc ***Resource Guide Climate Change Data and Guidance***

Appendix 2Ba Hydrogeologic Conceptual Model Best Management Practices



California Department of Water Resources
Sustainable Groundwater Management Program

December 2016

Best Management Practices for the Sustainable Management of Groundwater

Hydrogeologic Conceptual Model

BMP

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Hydrogeologic Conceptual Model
Best Management Practice

1. Objective

The objective of this Best Management Practice (BMP) is to assist in the use and development of *hydrogeologic conceptual models* (HCM). The California Department of Water Resources (the Department or DWR) has developed this document as part of the obligation in the Technical Assistance Chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater *basins*. Information provided in this BMP is meant to provide support to Groundwater Sustainability Agencies (GSAs) when developing a HCM in accordance with the Groundwater Sustainability Plan (GSP) Emergency Regulations (GSP Regulations). This BMP identifies available resources to support development of HCMs.

This BMP includes the following sections:

1. Objective. The objective and brief description of the contents of this BMP.
2. Use and Limitations. A brief description of the use and limitations of this BMP.
3. HCM Fundamentals. A description of HCM fundamental concepts.
4. Relationship of HCM to other BMPs. A description of how the HCM relates to other BMPs and is the basis for development of other GSP requirements.
5. Technical Assistance. A description of technical assistance to support the development of a HCM and potential sources of information and relevant datasets that can be used to further define each component.
6. Key Definitions. Definitions relevant for this BMP as provided in the GSP and Basin Boundary Regulations and in SGMA.
7. Related Materials. References and other materials that provide supporting information related to the development of HCMs.

2. Use and Limitations

BMPs developed by the Department are intended to provide technical guidance to GSAs and other stakeholders. Practices described in these BMPs do not replace or serve as a substitute for the GSP Regulations, nor do they create new requirements or obligations for GSAs or other stakeholders. While the use of BMPs is encouraged, use and/or adoption of BMPs does not equate to an approval determination by the Department. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

3. HCM Fundamentals

A HCM:

1. Provides an understanding of the general physical characteristics related to regional hydrology, land use, geology and geologic structure, water quality, *principal aquifers*, and principal aquitards of the *basin setting*;
2. Provides the context to develop water budgets, mathematical (analytical or numerical) models, and monitoring networks; and
3. Provides a tool for stakeholder outreach and communication.

A HCM should be further developed and periodically updated as part of an iterative process as *data gaps* are addressed and new information becomes available. A HCM also serves as a foundation for understanding potential uncertainties of the physical characteristics of a basin which can be useful for identifying *data gaps* necessary to further refine the understanding of the hydrogeologic setting. An example of a HCM depicted as a three-dimensional block diagram is shown in **Figure 1**.

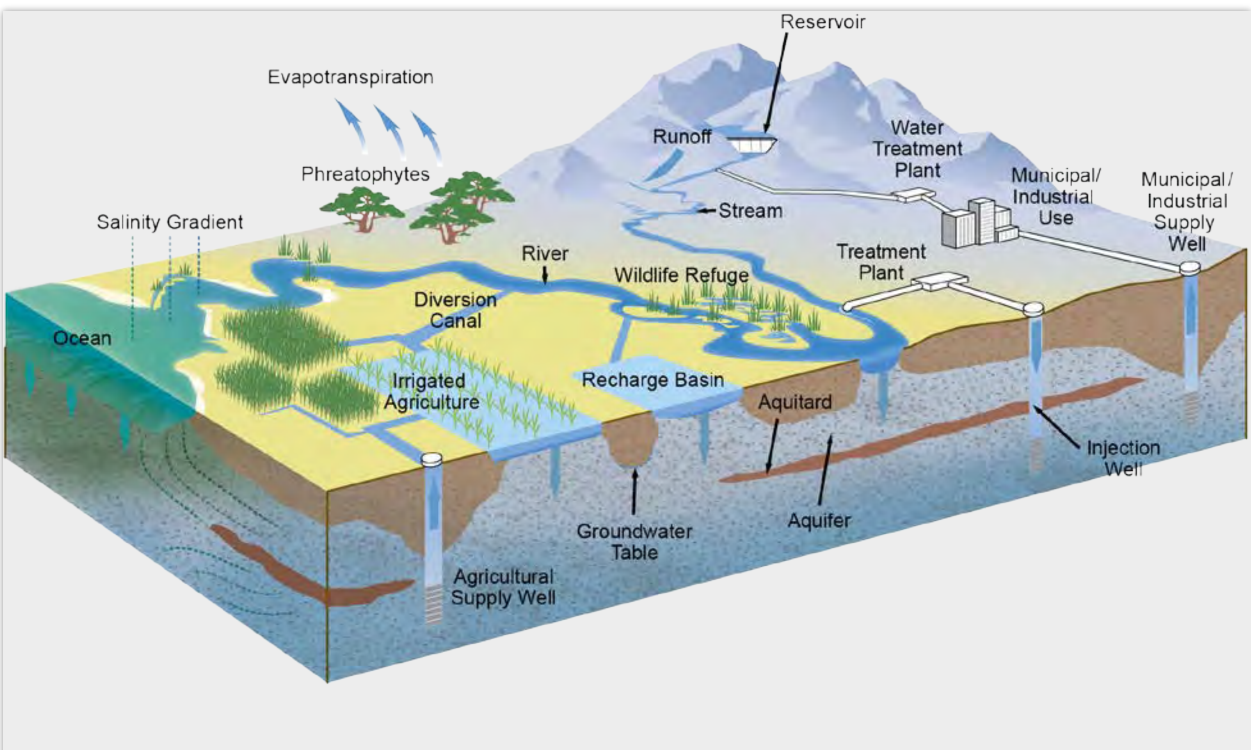

Figure 1 – Example 3-D Graphic Representing a HCM

COMMON HCM USES

The following provides a limited list of common HCM uses:

- Develop an understanding and description of the basin to be managed, specifically the structural and physical characteristics that control the flow, storage, and quality of surface and groundwater
- Identify general water budget components
- Identify areas that are not well understood (*data gaps*)
- Inform monitoring requirements
- Facilitate or serve as the basis for the development, construction, and application of a mathematical (analytical or numerical) model
- Refine the understanding of basin characteristics over time, as new information is acquired from field investigation activities, monitoring networks, and modeling results
- Provide often highly-technical information in a format more easily understood to aid in stakeholder outreach and communication of the basin characteristics to local water users
- Help identify potential projects and management actions to achieve the sustainability goal within the basin

HCM IN REFERENCE TO THE GSP REGULATIONS

23 CCR §354.14 (a): Each Plan shall include a descriptive hydrogeologic conceptual model of the basin based on technical studies and qualified maps that characterizes the physical components and interaction of the surface water and groundwater systems in the basin.

GSP Regulations[1] require that each GSP include a HCM for the basin reported in a narrative and graphical form that provides an overview of the physical basin characteristics, uses of groundwater in the basin, and sets the stage for the *basin setting* (GSP §354.14(a)). The GSP Regulations identify the level of detail to be included for the HCM to aid in describing the *basin setting* for the GSP development and sustainability analysis.

[1] http://www.water.ca.gov/groundwater/sgm/pdfs/GSP_Emergency_Regulations.pdf

The HCM requirements outlined pertain to two main types of information:

1. The narrative description is accompanied by a graphical representation of the basin that clearly portrays the geographic setting, regional geology, basin geometry, general water quality, and consumptive water uses in the basin.
2. A series of geographic maps and scaled cross-sections to provide a vertical layering representation and a geographic view of individual datasets including the topography, geology, soils, *recharge* and discharge areas, source and point of delivery of imported water supplies, and surface water systems that are significant to management of the basin.

A HCM differs from a mathematical (analytical or numerical) model in that it does not compute specific quantities of water flowing through or moving into or out of a basin, but rather provides a general understanding of the physical setting, characteristics, and processes that govern groundwater occurrence within the basin. In that sense, the HCM forms the basis for mathematical (analytical or numerical) model development, and sets the stage for further quantification of the water budget components.

The intent of requiring HCMs in the GSP Regulations is not to provide a direct measure of sustainability, but rather to provide a useful tool for GSAs to develop their GSP and meet other requirements of SGMA.

4. RELATIONSHIP OF HCM TO OTHER BMPS

The purposes of the HCM in the broader context of SGMA implementation include:

- Supporting the evaluation of sustainability indicators, assessing the potential for undesirable results, and development of minimum thresholds;
- Supporting identification and development of potential projects and management actions to address undesirable results that exist or are likely to exist in the future; and
- Supporting the development of monitoring protocols, networks, and strategies to evaluate the sustainability of the basin over time.

The HCM is also linked to other related BMPs as illustrated in **Figure 2**. This figure provides the context of the BMPs as they relate to various steps to sustainability as outlined in the GSP Regulations. The HCM BMP is part of the *Basin Setting* development step in the GSP Regulations.

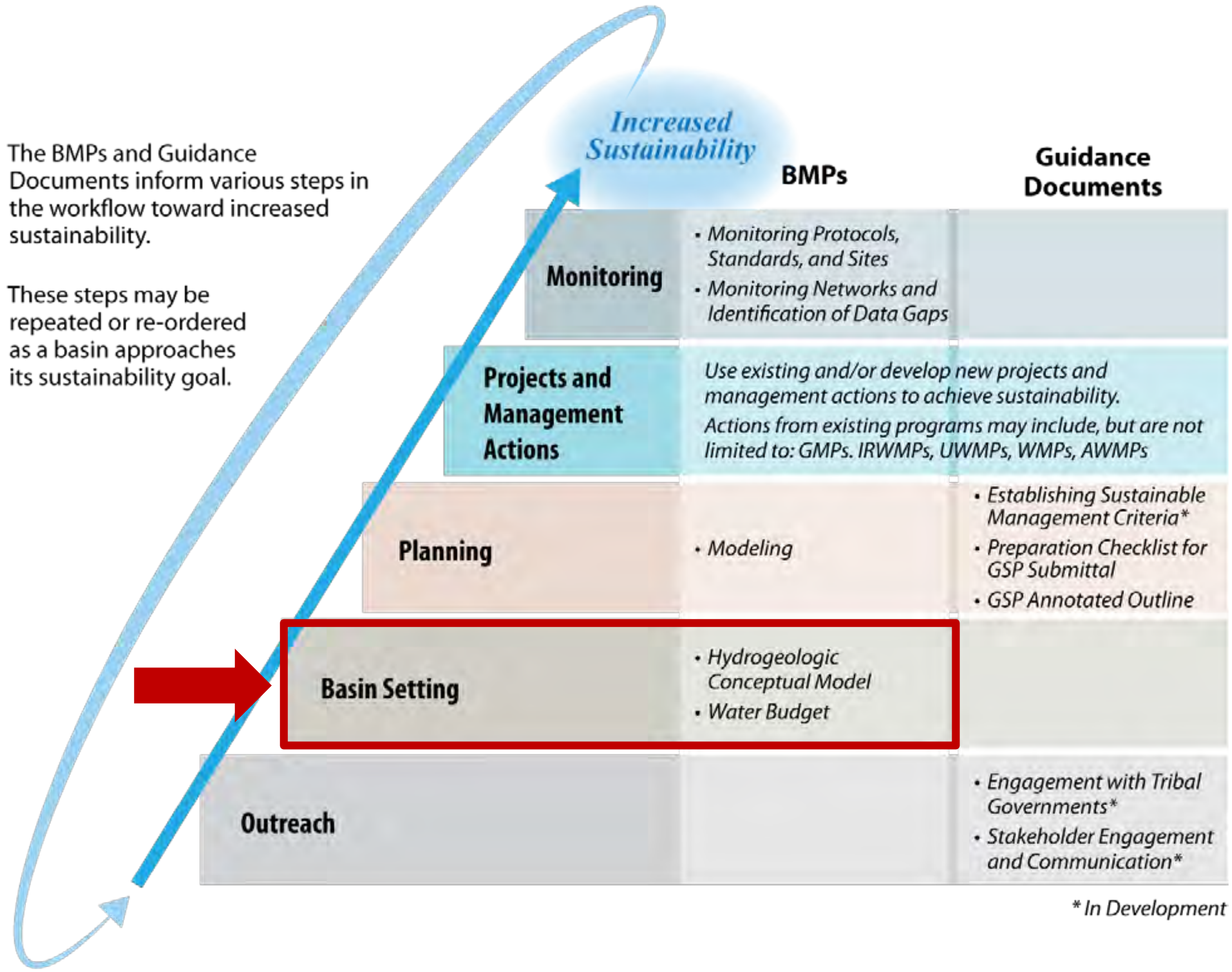

Figure 2 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

HCM development is the first step to understanding and conveying the GSP *basin setting*. The HCM is also linked to other GSP components (and applicable related BMPs) as illustrated **Figure 3**. For example, the HCM supports the development of the monitoring networks and activities needed to better understand the distribution and movement of water within a basin, which leads to the initial development and quantification of a water budget. Once the HCM and water budget have been developed, a mathematical (analytical or numerical) model may be built to further evaluate sustainability indicators, assess the probability of future undesirable results, and support basin management decisions as necessary to avoid the occurrence of undesirable results.

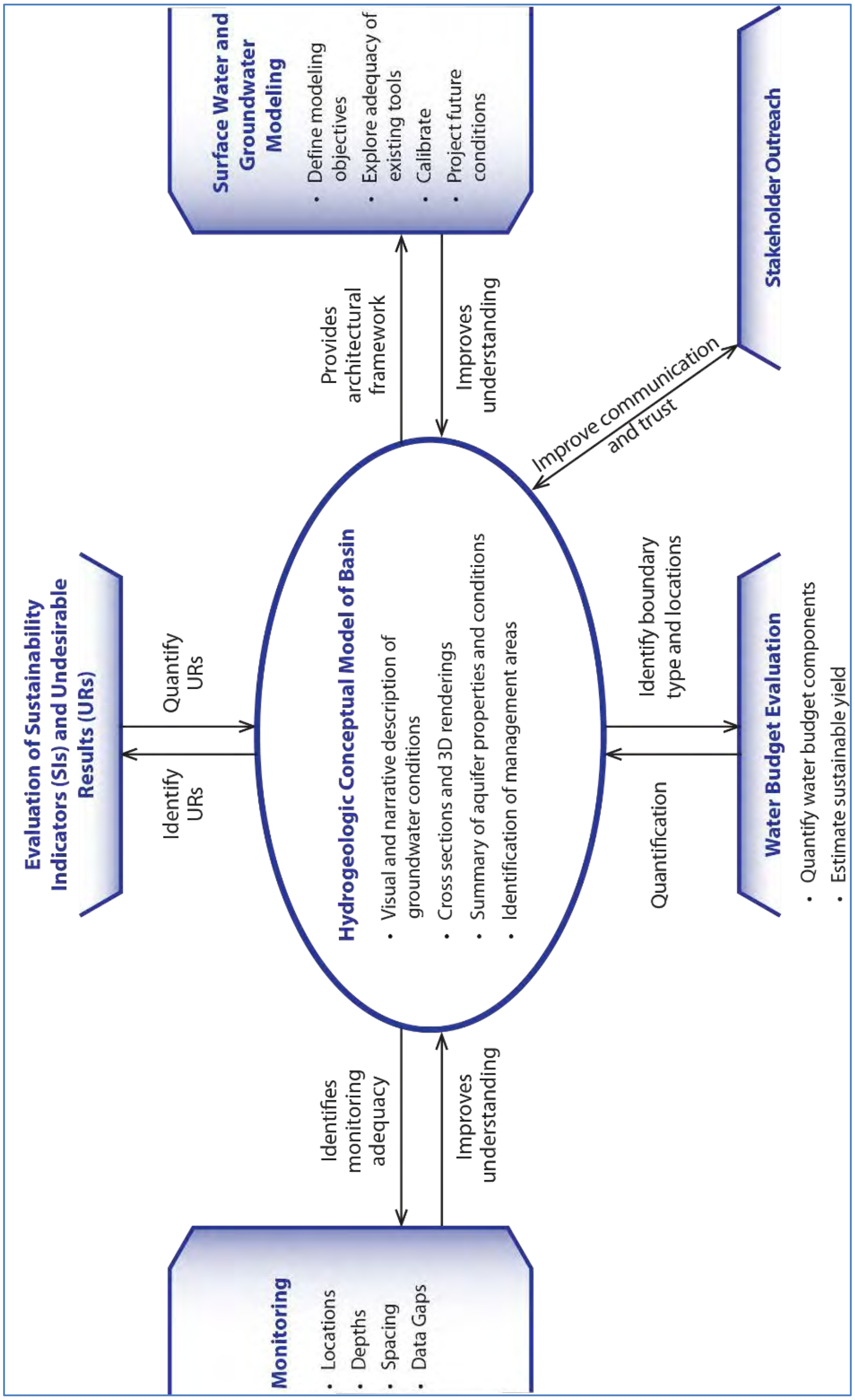

Figure 3 – Interrelationship between HCM and Other BMPs and Guidance Documents

5. Technical Assistance

This section provides technical assistance to support the development of a basin HCM including potential sources of information and relevant datasets that can be used to develop each HCM requirement. As described in the GSP Regulations Section 354.12, the Basin Setting shall be prepared by or under the direction of a professional geologist or professional engineer.

CHARACTERIZING THE PHYSICAL COMPONENTS

Each section below is related to the specific GSP Regulation requirements and provides additional technical assistance for the GSA's consideration.

23 CCR §354.14 (b)(1): The regional geologic and structural setting of the basin including the immediate surrounding area, as necessary for geologic consistency.

The regional geologic and structural setting of a basin describes the distribution, extent, and characteristics of the geologic materials present in the basin along with the location and nature of significant structural features such as faults and bedrock outcrops that can influence groundwater behavior in the basin.

This type of information can often be found in existing geologic maps and documents published by the Department (specifically Bulletin 118 and 160), the United States Geological Survey (USGS), and other local government agencies (references are also provided in Section 7). Groundwater Management Plans and other technical reports prepared for the basin may also include information of this type.

23 CCR §354.14 (b)(2): Lateral basin boundaries, including major geologic features that significantly affect groundwater flow.

Basin boundaries are often geologically controlled and may include bedrock boundaries that define the margins of the alluvial groundwater *aquifer* system, and therefore represent barriers to groundwater flow. For a map of the Department's Bulletin 118 groundwater basins and subbasins refer to the Department's basin boundary website.

Other basin boundaries may include rivers and streams, or structural features such as faults. Additionally, basins on the coast can be subject to seawater intrusion, which creates another type of boundary to the freshwater basin. Information on these types of boundaries can also be found in reports prepared by State (California Geological Survey) or federal agencies (USGS) or by local agencies or districts. In addition, the presence of seawater along the coastal margin can also reflect the boundary of a coastal basin.

23 CCR §354.14 (b)(3): Definable bottom of the basin.

Several different techniques or types of existing information can be used in the evaluation of the definable bottom of the basin and extent of freshwater.

Defining the Basin Bottom based on Physical Properties

The bottom of the basin may be defined as the depth to bedrock also recognized as the top of bedrock below which no significant groundwater movement occurs. This type of information may be found from reviewing geologic logs from wells drilled for water extraction, as well as from oil and gas exploration wells which tend to be drilled deeper than usable aquifer systems.

Defining the Basin Bottom based on Geochemical Properties

In many basins of the Central Valley, freshwater is underlain by saltier or brackish water that is a remnant of the marine conditions that were present when the Valley was flooded in the geologic past. Several standards exist that can be used to define the base of freshwater and the bottom of the basin in the Central Valley:

- Base of freshwater maps in the Central Valley published by the Department and by USGS
- United States Environmental Protection Agency (US EPA) definition for Underground Source of Drinking Water (USDW)

The Department plans to release a freshwater map for the Central Valley that depicts the useable bottom of the alluvial aquifer. This map assumes that the base of freshwater is defined by the Title 22 State Water Resources Control Board (SWRCB) upper secondary maximum contaminant level recommendation of 1,000 milligrams per liter (mg/L) total dissolved solids (TDS).

The USGS has two base of fresh water maps available in the Central Valley based on 3,000 mg/L TDS.

An alternative threshold available to define the bottom of the groundwater basin is the US EPA USDW standard of less than 10,000 mg/L TDS. In some basins, oil and gas *aquifers* underlie the potable alluvial *aquifer* or USDW (defined as less than 10,000 mg/L TDS in Title 40, Section 144.3, of the Code of Federal Regulations). In basins where produced water from underlying oil and gas operations is beneficially used within the basin, or injected into the basin's USDW, the HCM can further characterize the geologic boundaries that separate the USDW from the oil and gas *aquifers*, and identify the "exempted *aquifer*" portion of the groundwater basin that has been permitted for underground injection control by the SWRCB Oil and Gas Monitoring Program or the Division of Oil, Gas and Geothermal Resources (DOGGR).

It should be noted that the definable bottom of the basin should be at least as deep as the deepest groundwater extractions; however, this may not be an appropriate method if it conflicts with other local, State, or Federal programs or ordinances. Finally, consideration should be given to how the bottom of the basin is defined in hydraulically-connected adjacent basins, as this could create additional complexity when developing and implementing GSPs.

Defining the Basin Bottom based on Field Techniques

Common field techniques used to define the bottom of alluvial basins can be subdivided into techniques utilizing direct measurements and those utilizing indirect measurements. The most common ones are listed below.

Direct measurement approaches typically involve drilling of multiple wells through the freshwater-bearing alluvial aquifer sediments and into the underlying lithologic units, whether it is bedrock or alluvium, containing groundwater that does not meet the criteria for potable water or an USDW. Once each borehole has been constructed, several different approaches can be taken to estimate the depth to the basin bottom at that location. Compilation of data from multiple wells can then be used to prepare a contour map of the depth to the basin bottom. Typical direct techniques include:

- Installation of multi-port well systems or installation of a nested well array
- Continuous profiling of lithology/groundwater quality using TDS, conductivity, or other downhole geophysical techniques
- Mapping depth to bedrock from borehole

Indirect measurement approaches are typically employed along the ground surface or from helicopters or fixed-wing aircraft. The most common methods used are geophysical techniques or surveys. Typical geophysical techniques that can be used to estimate bedrock depth or groundwater quality profiles include:

- Seismic refraction/reflection surveys
- Gravity surveys
- Magnetic surveys
- Resistivity surveys
- Radar, including ground penetrating radar
- Other Electromagnetic techniques

> *23 CCR §354.14 (b)(4): Principal aquifers and aquitards, including the following information:*
> *(A) Formation names, if defined.*
> *(B) Physical properties of aquifers and aquitards, including the vertical and lateral extent, hydraulic conductivity, and storativity, which may be based on existing technical studies or other best available information.*
> *(C) Structural properties of the basin that restrict groundwater flow within the principal aquifers, including information regarding stratigraphic changes, truncation of units, or other features.*
> *(D) General water quality of the principal aquifers, which may be based on information derived from existing technical studies or regulatory programs.*
> *(E) Identification of the primary use or uses of each aquifer, such as domestic, irrigation, or municipal water supply.*

Aquifer information is available in geologic reports from the Department and USGS, such as Bulletin 118, and local groundwater management plans and studies. Links to applicable reports are provided below. The USGS maintains very detailed reports and datasets for groundwater quality throughout the state that can be downloaded from their California Water Science Website (http://ca.water.usgs.gov/). The SWRCB also collects and maintains groundwater quality data, accessible through their GeoTracker GAMA website. (http://www.waterboards.ca.gov/gama/geotracker_gama.shtml)

In addition, the Regional Water Quality Control Boards, with coordination from the SWRCB, manage groundwater quality programs and data related to the Irrigated Lands Regulatory Program (http://www.swrcb.ca.gov/water_issues/programs/agriculture/). These programs are in the early phases of development, and data are being collected by local entities. As groundwater quality data become available through these programs, they may be a good source of information for HCM and GSP development. The Central Valley Regional Water Quality Control Board and SWRCB, in cooperation with stakeholders and the Central Valley Salinity Coalition, collaborate to review and update the basin plans for the Sacramento and San Joaquin river basins, the Tulare Lake Basin, and the Delta Plan for salinity management. As part of this program, technical reports are being developed and groundwater quality data are being collected in the Central Valley aquifer that provide other sources of information for those basins (http://www.cvsalinity.org/).

Uses of groundwater can be found within water quality control plans (known as basin plans), agricultural water management plans (AWMP) and urban water management plans (UWMP), which detail the use of water by agency and by types of beneficial uses. In addition, basin plans describe the water quality objectives and beneficial uses to be protected, with a program of implementation to achieve those objectives.

> 23 CCR §354.14 (b)(5): *Identification of data gaps and uncertainty within the hydrogeologic conceptual model.*

An assessment of the uncertainty in the HCM components, along with the identification of data gaps of the physical system and water use practices in the basin, are all necessary elements of the HCM. Typical data gaps and uncertainties related to the HCM include the hydraulic properties of the aquifer and aquitard materials, the depth and thickness of various geologic layers, and adequate geographic distribution of groundwater quality data, among others. It is important to adequately evaluate data gaps and uncertainties within a HCM as these data gaps often drive the types and locations of monitoring that should be conducted to reduce uncertainties in these conceptual model components.

For example, a portion of a groundwater basin may not be well characterized from previous studies and historic monitoring activities; therefore, there is less readily-available information to define the HCM in that portion of the basin. Specific data collection activities to address these *data gaps* could then be considered in the development of the GSP.

GRAPHICAL AND MAPPING REQUIREMENTS

> *23 CCR §354.14 (c): The hydrogeologic conceptual model shall be represented graphically by at least two scaled cross-sections that display the information required by this section and are sufficient to depict major stratigraphic and structural features in the basin.*

In addition to the narrative description of the HCM, another necessary element of a HCM is a graphical representation of the HCM components in the form of at least two geologic cross-sections. A cross-section depicts the vertical layering of the geology and major subsurface structural features in a basin, in addition, but not limited to, other HCM features such as the general location and depth of existing monitoring and production wells and the interaction of streams with the aquifer.

The locations selected for cross-section development in a basin are best informed by the sustainability indicators most critical to that basin, as well as the potential for undesirable results to occur. For example, if subsidence is a known issue in a basin, construction of cross-section(s) may be focused in areas where subsidence has occurred or is at risk of occurring. An example of a scaled cross-section is provided in **Figure 4**.

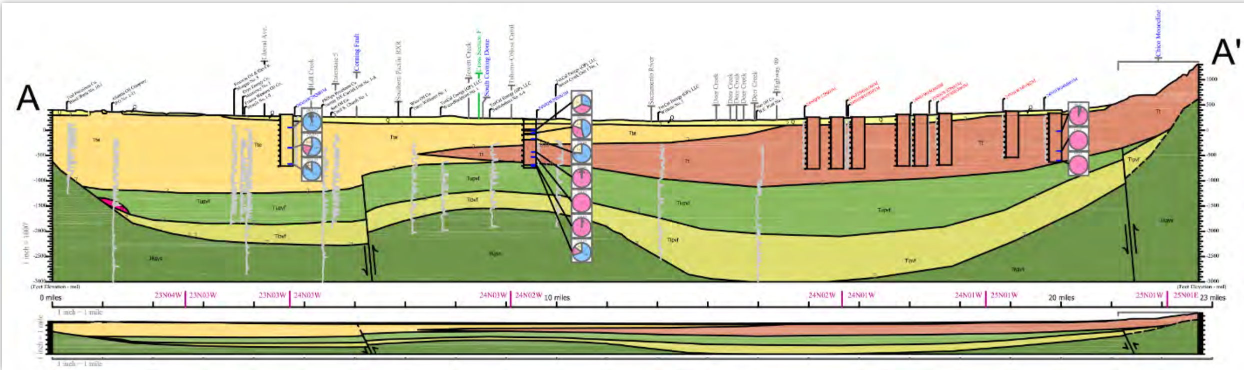

Figure 4 – Example Scaled Cross-Section

Geologic cross-sections should be constructed by a professional geologist, or a person knowledgeable of geologic principles such as the Laws of Superposition, Original Horizontality, cross-cutting relationships, and Walther's Law. The type of cross-section ranges from "conceptual to highly detailed", depending on the intended use. The type of cross-section also depends on the type of subsurface data that is available and the reliability of that data. A full understanding of, and appreciation for, the variety of depositional environments, like sequence stratigraphy, is needed to construct accurate geological cross sections. Cross-section construction considerations include, but are not limited to, the following:

- Geologic cross-sections are often oriented perpendicular to the strike of the regional bedding. If a line of section oblique to the strike of regional bedding is selected, apparent dip of bedding and structural features should be computed and included in the geologic cross-section. It is important to choose a geologically relevant orientation with respect to strike and dip (and to note whether any of the selected orientations depict an apparent dip much different than the true dip).

- The geologic cross-section should not change trend direction, or bend significantly as this can change the relationship of the deposition direction. North and east should be on the right side of the page. If wells logs are projected onto the section the distance they are projected from the section line should be noted.

- The location and orientation of the line of geologic cross-section should be presented in plan view on a geologic map. The horizontal distance between boreholes, geologic contacts, structural features, and surface features is interpreted from the scale of the geologic map. The horizontal scale can be enlarged or reduced, preserving the relative distances, based on cross-section size. The vertical scale of the cross-section can exceed the horizontal scale (vertical exaggeration) in order to more clearly present the subsurface data. However, the scale should be chosen without undue vertical exaggeration.

- Subsurface lithology and structural features should be projected from surface contacts at the dip angle (or apparent dip) reported on the geologic map. Subsurface contacts may be correlated/interpreted between boreholes based on available lithologic logs and professional judgement. The cross-sections should be tied where they cross and to the geologic map at formation contacts.

- Cross-sections should include major aquifer and aquitard units, but it may not be necessary to include all lithologic beds on the cross-section.

- The geologic cross-section should include information provided on lithologic logs for boreholes along the line of section. Information for wells off-set from the line of section can be projected onto the cross-section. The maximum distance for projection of data onto the cross-section will be dependent upon the scale; professional judgement should be used in the selection of the maximum projection distance. The distance for projection of data should be somewhat dependent on the reasonableness one can infer that the units or features continue with some level of certainty. Conversely, if there is uncertainty, dashed lines or question marks are often applied to denote uncertainty.

- The level of detail and quality of available subsurface lithologic logs will vary between boreholes. The quality of individual lithologic logs should be considered when correlating subsurface borehole information.

- Where two cross-section lines intersect, the subsurface interpretations presented on the geologic cross-sections should be consistent at the intersection.

- The data used for horizon boundaries should be shown and posted for reference; and any references used to depict the cross-sections should be cited.

If known, other details should also be included in hydrogeologic cross sections, such as: (1) static water level of each *aquifer*; (2) screened intervals; (3) total depth of the boring/well; (4) availability of geophysical logs; and (5) type of drilling method. Additional notation on the cross-section may also be helpful for illustration.

23 CCR §354.14 (d) Physical characteristics of the basin shall be represented on one or more maps that depict the following:
(1) Topographic information derived from the U.S. Geological Survey or another reliable source.
(2) Surficial geology derived from a qualified map including the locations of cross sections required by this Section.
(3) Soil characteristics as described by the appropriate Natural Resources Conservation Service soil survey or other applicable studies.
(4) Delineation of existing recharge areas that substantially contribute to the replenishment of the basin, potential recharge areas, and discharge areas, including significant active springs, seeps, and wetlands within or adjacent to the basin.
(5) Surface water bodies that are significant to the management of the basin.
(6) The source and point of delivery for imported water supplies.

Geographical representations of the distribution of major data elements in a groundwater basin in map form help illustrate the layout of data and information presented in the HCM. The data for these maps are generally available from various sources such as GIS Shapefiles that can be overlain on a basin-wide base map.

As stated in the GSP Regulations, physical characteristics of the basin need to be displayed on maps. Information is provided on the types of datasets readily available for mapping.

- Topographic information can be found from online USGS topographic maps or more detailed high resolution Digital Elevation Model (DEM) mapping GIS datasets. There are several sources of topographic and DEMs available online, such as the ones provided in Section 7.

- In addition, the ESRI ArcGIS platform also includes DEM data available for use in conjunction with the ESRI GIS software.

- Surficial Geologic information can be downloaded from the California Geological Survey (CGS) and USGS from their interactive mapping tool.
  - CGS - http://maps.conservation.ca.gov/cgs/gmc/
  - USGS - http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

  The map that is produced to illustrate the surficial geology of the basin should also include the location of the cross-sections.

- The National Resource Conservation Service (NRCS) maintains soil data and Shapefiles nationwide on a county basis available at their website: http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.
  For additional related soil characteristics in California, see the UC Davis soil interactive maps (http://casoilresource.lawr.ucdavis.edu/).

- *Recharge* and discharge areas of groundwater are generally not well mapped. This type of information may be available from local and regional groundwater management planning documents, or larger reports form the Department and USGS. Additional *recharge* maps in California have been developed by the California Soil Resource Lab at UC Davis – The following link is to their Soil Agricultural Groundwater Banking Index (SAGBI): http://casoilresource.lawr.ucdavis.edu/sagbi/

- Surface water mapping data can be downloaded from ESRI base maps within ArcGIS, or downloaded from the National Hydrography Datasets (NHD) datasets: http://viewer.nationalmap.gov/viewer/nhd.html?p=nhd

- Water supplies imported into a basin from state, federal, or local projects need to be mapped for the HCM. This information is generally available from the major suppliers of surface water such as the Department, United States Bureau of Reclamation (USBR), and local water and irrigation districts.

Additional useful information to be mapped may include:

- Groundwater elevation contour maps show the spatial distribution of groundwater elevations and help identify areas of low and high groundwater level areas within a basin. Elevation contour maps can be created from water level data collected from wells that are screened within the same principal aquifers. Information on water level data interpolation to create contour maps can be found in Tonkin et. al (2002).

- Land use maps detail the agricultural and urban land uses, and the distribution of natural vegetation, including potentially groundwater-dependent ecosystems. Land use maps shall use the Department land use classification scheme and maps provided by the Department.

An example of a geologic map is provided in **Figure 5**.

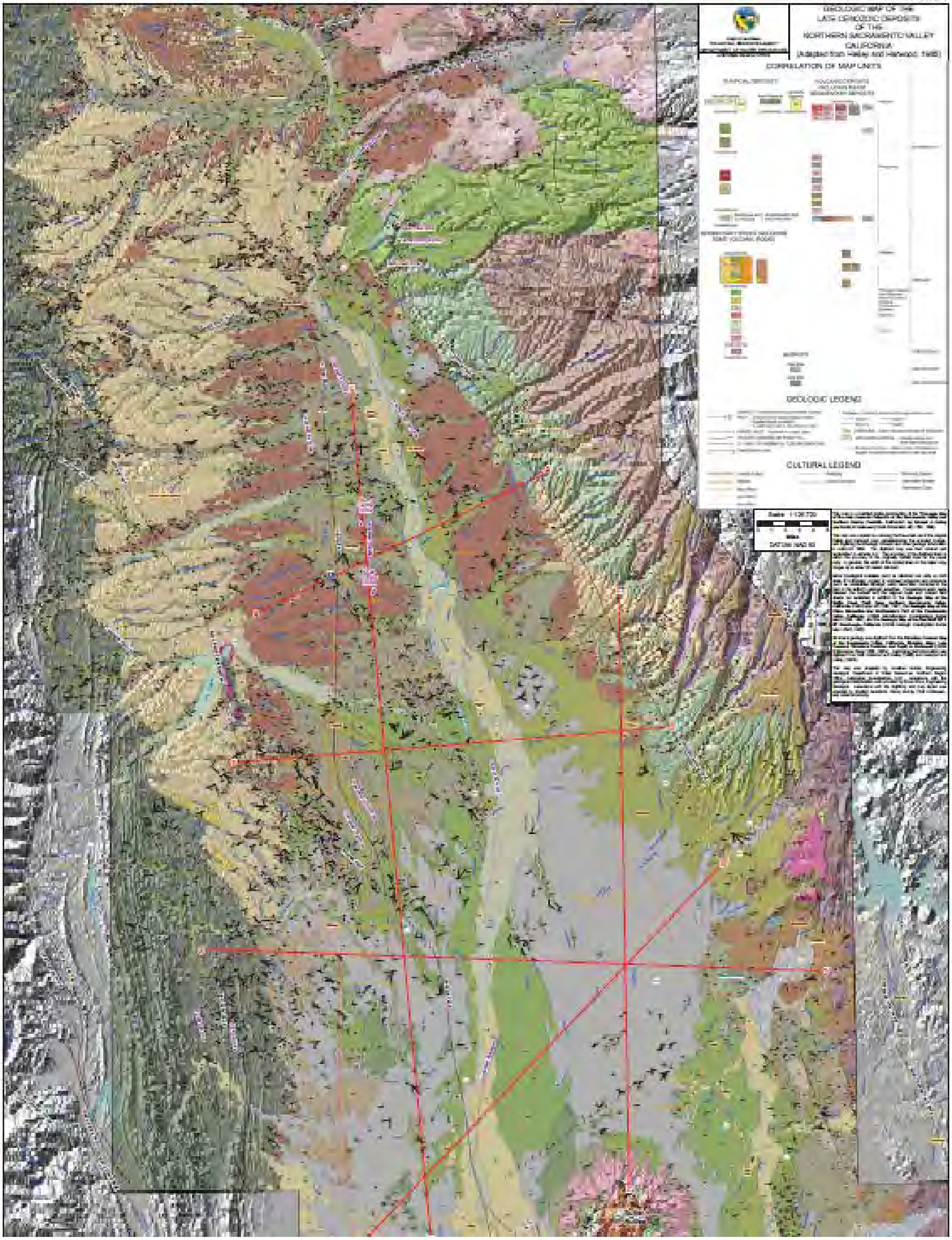

Figure 5 – Example Geologic Map

TYPICAL FLOW OF GRAPHICAL HCM DEVELOPMENT

The HCM requirements outlined in the GSP Regulations pertain to two main types of information:

1. Narrative description of the basin, which can be accompanied by a three-dimensional graphic illustration of the HCM to complement the narrative; and
2. At least two scaled cross-sections and geographic maps to provide vertical layering representation and a geographic view of individual datasets, respectively.

The typical flow of graphical HCM development is presented in **Figure 6**. This figure shows the level of technical representation and detail, from basic cartoon-type representation, to a geographic representation map, to a scaled vertical cross-section that provides more subsurface detail for the HCM.

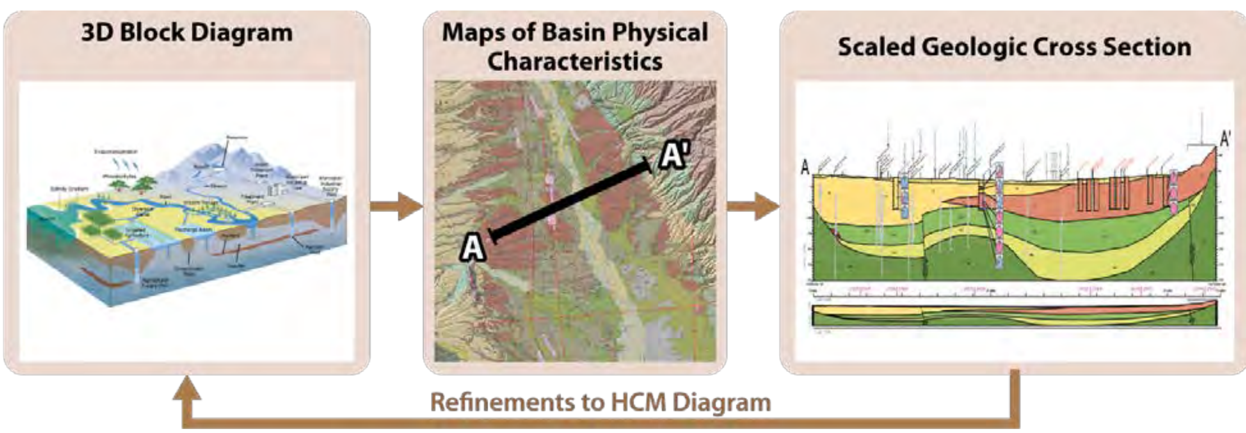

Figure 6 – Steps to Developing Graphic Representations of the HCM

6. Key Definitions

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

SGMA Definitions (California Water Code §10721)

- "Groundwater recharge" or "recharge" means the augmentation of groundwater by natural or artificial means.

- "Recharge area" means the area that supplies water to an aquifer in a groundwater basin.

Groundwater Basin Boundaries Regulations (California Code of Regulations §341)

- "Aquifer" refers to a three-dimensional body of porous and permeable sediment or sedimentary rock that contains sufficient saturated material to yield significant quantities of groundwater to wells and springs, as further defined or characterized in Bulletin 118.

- "Hydrogeologic conceptual model" means a description of the geologic and hydrologic framework governing the occurrence of groundwater and its flow through and across the boundaries of a basin and the general groundwater conditions in a basin or subbasin.

- "Qualified map" means a geologic map of a scale no smaller than 1:250,000 that is published by the U. S. Geological Survey or the California Geological Survey, or is a map published as part of a geologic investigation conducted by a state or federal agency, or is a geologic map prepared and signed by a Professional Geologist that is acceptable to the Department.

- "Technical study" means a geologic or hydrologic report prepared and published by a state or federal agency, or a study published in a peer-reviewed scientific journal, or a report prepared and signed by a Professional Geologist or by a Professional Engineer.

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

- "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.

- "Best available science" refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.

- "Data gap" refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.

- "Principal aquifers" refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.

- "Uncertainty" refers to a lack of understanding of the basin setting that significantly affects an Agency's ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.

- "Water source type" represents the source from which water is derived to meet the applied beneficial uses, including groundwater, recycled water, reused water, and surface water sources identified as Central Valley Project, the State Water Project, the Colorado River Project, local supplies, and local imported supplies.

- "Water use sector" refers to categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed *recharge*, and native vegetation.

7. Related Materials

This section provides a list of related materials including general references, standards, guidance documents, and selected case studies and examples pertinent to the development of HCMs. For the items identified, available links to access the materials are also provided. In addition, common data sources and links to web-materials are also provided. By providing these links, DWR neither implies approval, nor expressly approves of these documents.

It should also be noted that existing Groundwater Management Plans (GMP), Salt & Nutrient Management Plans (SNMP), Urban Water Management Plans (UWMP), Drinking Water Source Assessment Plans (DWSAP), Agricultural Water Management Plans (AWMP), and Integrated Regional Water Management Plans (IRWMP) may be useful references in the development of HCMs. To the extent practicable, GSAs should utilize and build on available information.

STANDARDS

- ASTM D5979 – 96 (2014) Standard Guide for Conceptualization and Characterization of Groundwater Systems

REFERENCES FOR FURTHER GUIDANCE

Basin Boundary Modifications web page. California Department of Water Resources. http://www.water.ca.gov/groundwater/sgm/basin_boundaries.cfm *Accessed December 2016.*

California Geological Survey web page. California Department of Conservation. http://www.quake.ca.gov/ *Accessed December 2016.*

California Soil Resource Lab web page. University of California, Davis. https://casoilresource.lawr.ucdavis.edu/ *Accessed December 2016.*

California Water Plan (Bulletin 160). California Department of Water Resources. http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm *Accessed December 2016.*

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California's Groundwater, Bulletin 118. California Department of Water Resources. http://water.ca.gov/groundwater/bulletin118.cfm *Accessed December 2016.*

Central Valley Salinity Alternatives for Long-term Sustainability web page. Central Valley Salinity Coalition. http://www.cvsalinity.org/ *Accessed December 2016.*

European Commission. 2010. *Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 26. Guidance on Risk Assessment and the Use of Conceptual Models for Groundwater.* Technical Report – 2010-042.

Fulton, J.W., et. al. 2005. *Hydrogeologic Setting and Conceptual Hydrologic Model of the Spring Creek Basin, Centre County, Pennsylvania, June 2005.* USGS Scientific Investigation Report 2005-5091.
http://pubs.usgs.gov/sir/2005/5091/sir2005-5091.pdf

Geologic Map of California (GMC). California Department of Conservation.
http://maps.conservation.ca.gov/cgs/gmc/ *Accessed December 2016.*

Groundwater Ambient Monitoring and Assessment Program (GAMA) web page. State Water Resources Control Board.
http://www.waterboards.ca.gov/gama/geotracker_gama.shtml *Accessed December 2016.*

Interactive Fault Map. U.S. Geological Survey.
http://earthquake.usgs.gov/hazards/qfaults/map/#qfaults *Accessed December 2016.*

Irrigated Lands Regulatory Program web page. State Water Resources Control Board.
http://www.swrcb.ca.gov/water_issues/programs/agriculture/ *Accessed December 2016.*

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Oil and Gas Monitoring Program web page. State Water Resources Control Board.
http://www.waterboards.ca.gov/water_issues/programs/groundwater/sb4/index.shtml
Accessed December 2016.

Teresita Betancur V., Carlos Alberto Palacio T. and John Fernando Escobar M. 2012. *Conceptual Models in Hydrogeology, Methodology and Results - A Global Perspective,* Dr. Gholam A. Kazemi (Ed.), ISBN: 978-953-51-0048-5, InTech, Available from: http://www.intechopen.com/books/hydrogeology-a-globalperspective/conceptual-models-in-hydrogeology-methodologies-and-results

Tonkin, M. and Larson, S. 2002. *Kriging Water Levels with a Regional-Linear and Point-Logarithmic Drift*, Ground Water, March-April 2002.

Toth, J. 1970. *A conceptual model of the groundwater regime and the hydrogeologic environment.* Journal Of Hydrology, Volume 10, Issue 1. February. doi:10.1016/0022-1694(70)90186-1

Web Soil Survey. U.S. Department of Agriculture Natural Resources Conservation Service. http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx *Accessed December 2016.*

REFERENCES FOR CROSS SECTIONS

Suggestions to Authors of the Reports of the United States Geological Survey, Seventh Edition, 1991. See Section named Cross Sections and Stratigraphic Sections and Preparing Maps and Other Illustrations, with a subsection titled Cross Sections.

Manual of Field Geology, Robert Compton, 1962. Chapter 11, Preparing Geologic Reports, Section 11-10 Detailed Geologic Maps and Cross Sections.

Walker, Roger G. (editor), 1981, Facies Models, Geological Association of Canada Publications, Toronto, Canada, 211 pages.

Reading, H.G. (editor), 1978, Sedimentary Environments and Facies, Elsevier Press New York, 569 pages.

Krumbein, K.C. and L.L. Sloss. 1963, Stratigraphy and Sedimentation, W.H. Freeman and Company, San Francisco, 660 pages.

DATA SOURCES

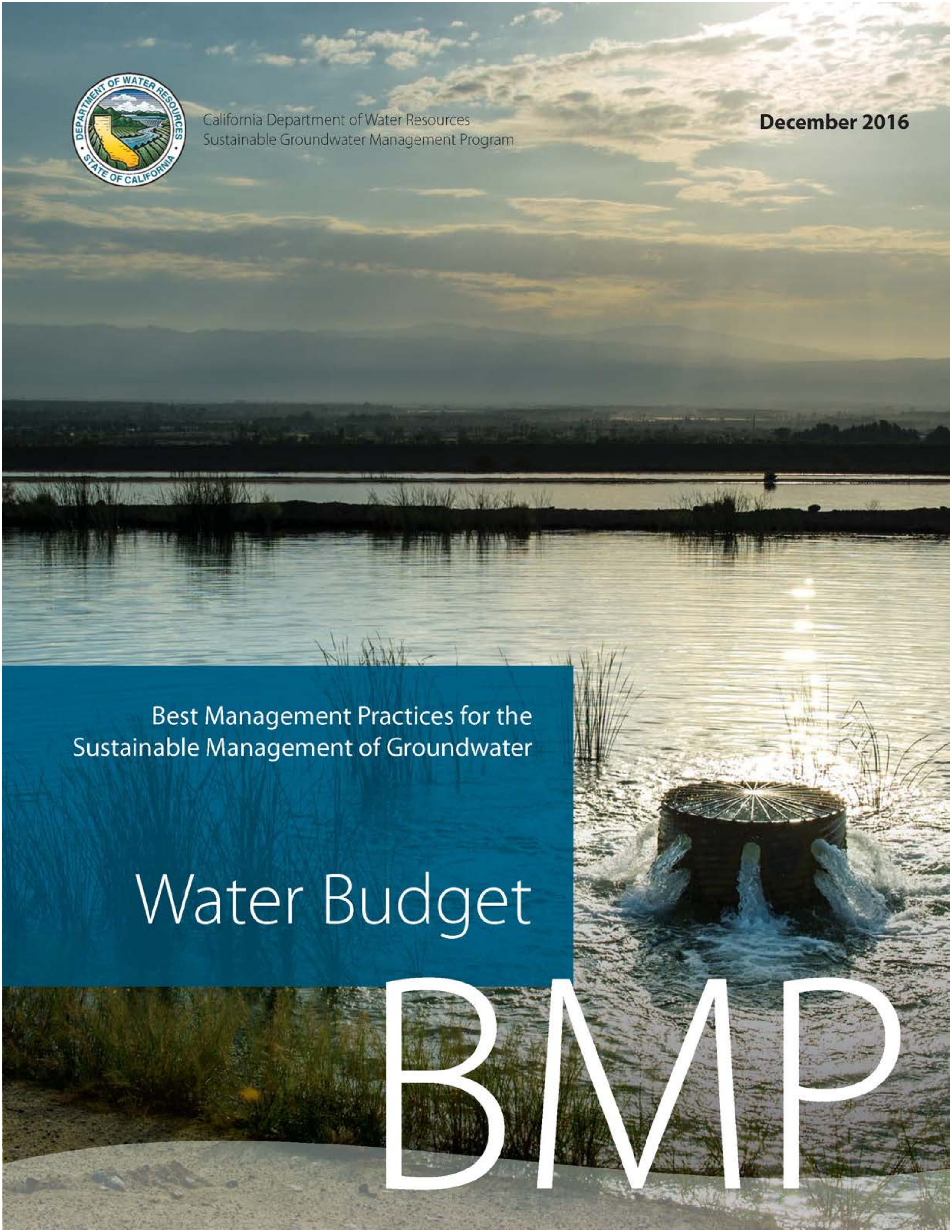
Geology reports:

Geology of the Northern Sacramento Valley, CA:
http://www.water.ca.gov/pubs/geology/geology_of_the_northern_sacramento_valley__california__june_2014-web/geology_of_the_northern_sacramento_valley__california__june_2014__updated_09_22_2014__website_copy_.pdf

Digital Elevation Models (DEMs):

- http://www.opendem.info/opendem_client.html
- http://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View
- http://www.brenorbrophy.com/California-DEM.htm.

Appendix 2Bb Water Budget Best Management Practices



California Department of Water Resources
Sustainable Groundwater Management Program

December 2016

Best Management Practices for the
Sustainable Management of Groundwater

Water Budget

BMP

State of California
Edmund G. Brown Jr., Governor

California Natural Resources Agency
John Laird, Secretary for Natural Resources

Department of Water Resources
Mark W. Cowin, Director

Carl A. Torgersen, Chief Deputy Director

Office of the Chief Counsel
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Water Budget
Best Management Practice

1. OBJECTIVE

The objective of this Best Management Practice (BMP) is to assist the use and development of *water budgets*. The Department of Water Resources (the Department or DWR) has developed this document as part of the obligation in the Technical Assistance Chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater *basins*. Information provided in this BMP provides technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders on how to address water budget requirements outlined in the Groundwater Sustainability Plan (GSP) Emergency Regulations (GSP Regulations). This BMP identifies available resources to support development, implementation, and reporting of water budget information.

This BMP includes the following sections:

1. Objective. The objective and brief description of the contents of this BMP.
2. Use and Limitations. A brief description of the use and limitations of this BMP.
3. Water Budget Fundamentals. A description of fundamental water budget concepts.
4. Relationship of Water Budgets to other BMPs. A description of how the water budget BMP relates to other BMPs and how water budget information may be used to support development of other GSP requirements.
5. Technical Assistance. A description of technical assistance to support the development of a water budget, potential sources of information, and relevant datasets that can be used to further define each component.
6. Key Definitions. Definitions relevant for this BMP as provided in the GSP Regulations, Basin Boundary Regulations, SGMA, and DWR *Bulletin 118*.
7. Related Materials. References and other materials that provide supporting information related to the development of water budget estimates.

2. USE AND LIMITATIONS

This BMP is intended only to provide technical assistance to GSAs and other stakeholders. GSAs and other stakeholders may use this BMP. The BMP does not create any new requirements or obligations for the GSA or other stakeholders. This BMP is not a substitute for the GSP Regulations and SGMA. Those submitting a GSP are strongly encouraged to read the GSP Regulations and SGMA. In addition, using this BMP to develop a GSP does not equate to an approval by the Department. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

3. Water Budget Fundamentals

Earth's water is moved, stored, and exchanged between the atmosphere, land surface, and the subsurface according to the hydrologic cycle (**Figure 1**). The hydrologic cycle begins with evaporation from the ocean. As the evaporated water rises, the water vapor cools, condenses, and ultimately returns to the Earth's surface as precipitation (rain or snow). As the precipitation falls on the land surface, some water may infiltrate into the ground to become groundwater, some water may run off and contribute to streamflow, some may evaporate, and some may be used by plants and transpired back into the atmosphere to continue the hydrologic cycle (Healy, R.W. et al., 2007).

A water budget takes into account the storage and movement of water between the four physical systems of the hydrologic cycle, the atmospheric system, the land surface system, the river and stream system, and the groundwater system. A water budget is a foundational tool used to compile water inflows (supplies) and outflows (demands). It is an accounting of the total groundwater and surface water entering and leaving a basin or user-defined area. The difference between inflows and outflows is a change in the amount of water stored.

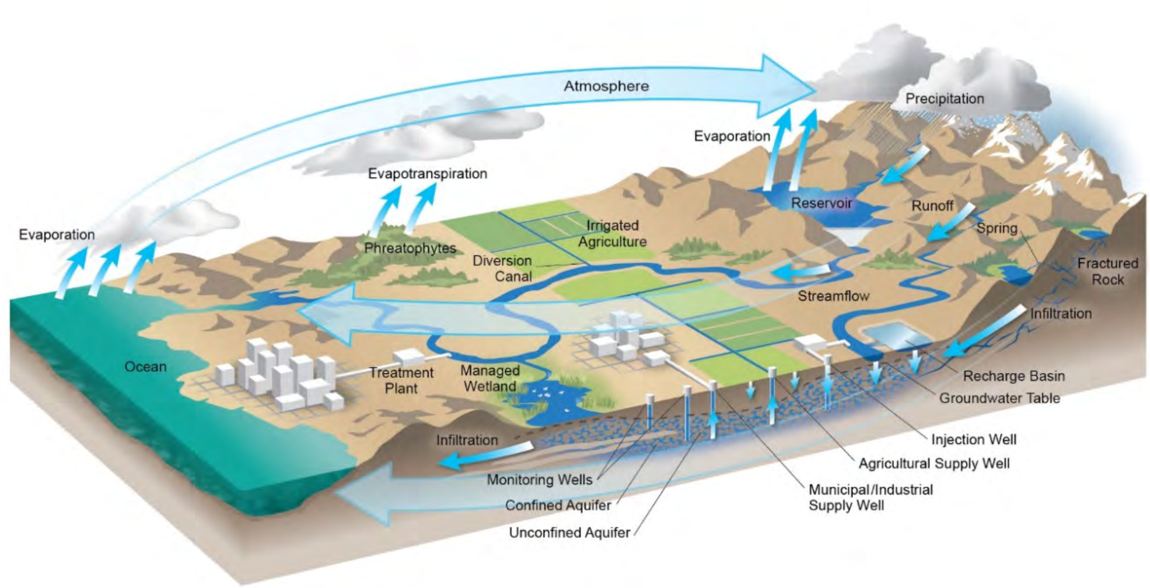


Figure 1 – The Hydrologic Cycle

In resource management it's said, "You can't manage what you don't measure." Similar to a checking account, water budget deposits (inflows) and withdrawals (outflows) are tracked and compared over a given time period to identify if the change in account balance is positive (increase in amount of water stored) or negative (decrease in the amount of water stored). During periods when inflows exceed outflows, the change in volume stored is positive. Conversely, during periods when inflows are less than outflows, the change in storage is negative. Surpluses from previous budget periods can act as a buffer towards isolated annual water budget deficits, but a series of ongoing negative balances can result in long-term conditions of overdraft.

Water budgets can be highly variable between groundwater basins. In some basins, precipitation may be the largest contributor to groundwater recharge. In other basins, leading sources of recharge may stem from infiltration and seepage of irrigation water, conveyance systems, septic systems, and various surface water systems (streams, lakes, reservoirs, etc.). In some areas, high groundwater levels result in seasonal or continuous outflow from the groundwater system to overlying surface water systems. In other basins, lower groundwater levels result in the continuous movement of water from the surface water system to the groundwater system. Assessment and comparison of annual water budget data requires using a consistent, user-defined area and period of evaluation. Under the GSP Regulations, the water budget is developed for the groundwater basin according to the annual *water year* period (October 1 to September 30).

In principle, a water budget is a simple concept that provides the accounting framework to measure and evaluate all inflows and outflows from all parts of the hydrologic cycle – atmospheric, land surface, surface water, and groundwater systems. In reality, it can be difficult to accurately measure and account for all components of the water budget for a given area. Some water budget components may be estimated independent of the water budget, while others may be calculated based on the fundamental principle that the difference between basin inflows and outflows is balanced by a change in the volume of water in storage. This principle is quantified according to the following water budget equation.

$$\text{Inflow (a, b, c)} - \text{Outflow (a, b, c)} = \text{Change in Storage}$$

Equation 1 – Water Budget Equation

Because groundwater basin inflows and outflows are balanced by a change in the amount of water in storage, the above equation may be rearranged to calculate, or "back into", an unknown component of the water budget equation. For example, if one wishes to determine unknown Outflow component "a", and all other components of the water budget for the groundwater system have been determined, Outflow "a" can be calculated by rearranging the above water balance equation as follows:

Outflow (a) = Inflow (a, b, c) – Outflow (b, c) – Change in Storage

To illustrate this example, consider a water budget scenario where total inflow from components "a", "b", and "c" equals 100 units of water; total outflow from all components other than "a" equals 40 units of water; and the annual change in storage identified through groundwater level measurements is approximately equal to +10 units of water. An estimate of outflow "a" during this period may be calculated from the above water budget equation as shown below. Note that "change in storage" is represented as a positive number to denote an increase in storage and a negative number to denote a decrease in storage.

Outflow (a) = Inflow (a, b, c) – Outflow (b, c) – Change in Storage
50 units = 100 units – 40 units – 10 units

Identifying which water budget components are most appropriate to estimate through balancing of the water budget equation will depend on the local ability to independently measure or estimate the remaining water budget components. It also depends on the relative importance, versus *uncertainty*, associated with each component in the overall water budget. A higher level of water budget uncertainty often translates to a higher risk that the projects and management actions being evaluated to achieve sustainability, based on future water budget projections, may not achieve the intended outcome within the intended timeframe.

An important consideration when implementing water resource management is the interaction between groundwater and surface water systems. *Groundwater flow* naturally moves down-gradient, from areas of high groundwater elevation to areas of lower groundwater elevation. In areas where groundwater levels are below the surface water system, the direction of groundwater flow will be from the surface water system to the groundwater system. Streams that receive water from the groundwater system are called "gaining" streams and those that lose water to the groundwater system are called "losing" streams (see **Figure 2**). The gaining or losing character of streamflow may be consistent throughout a stream system or it may be highly variable based on stream reach location and based on seasonal versus annual changes in local climatic conditions and the water inflow (recharge) or outflow (groundwater extraction) for the basin. It is therefore important to clearly identify and characterize stream segments included in the water budget calculation.

Unless additional inflows or supplies are developed, increases in groundwater extraction may eventually result in a hydraulic disconnection between the surface water and groundwater systems in basins where these systems are currently interconnected. Groundwater systems that are disconnected from the surface water system will still receive recharge from the surface water system. However, all further extraction from the groundwater system may be largely balanced through a decline of *groundwater in storage* and/or a reduction of subsurface outflow from the basin over time.

Another important water budget consideration is stream depletion due to groundwater pumping. In basins with *interconnected surface water* systems, if inflows (recharge) to the basin remain fixed while the amount of groundwater extraction increases, the increased volume of groundwater extraction, while initially resulting in a decline in the volume of *aquifer* storage, will eventually be balanced by decreases in the groundwater flow to springs, gaining streams, groundwater-dependent ecosystems or an increase in discharge from losing streams. Shallow production wells in close proximity to surface water systems commonly capture flow directly from the surface water system through induced recharge. Stream depletion associated with pumping wells further removed from surface water systems is more commonly the result of the indirect capture of groundwater flow that would otherwise have discharged to the surface water system sometime in the future. In both situations, streamflow depletion will continue until a new equilibrium between the outflow associated with groundwater extraction and the inflow from surface water depletion is established.

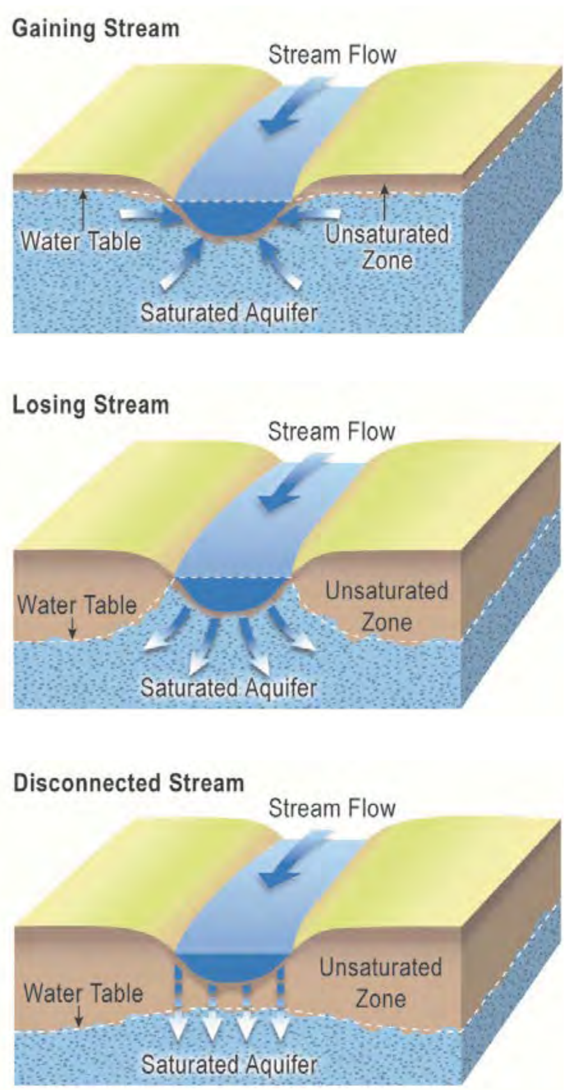


Figure 2 – Gaining, Losing, and Disconnected Streams

The transition from storage depletion to stream depletion will affect water budget accounting over time. The time lag to reach this new equilibrium is directly related to the location and construction of production wells, the thickness and hydrologic conductivity of the aquifer system, and the capacity and timing of the groundwater extraction. In many basins, stream depletion due to groundwater extraction will continue for decades prior to reaching a new equilibrium (Barlow, P.M. and Leake, S.A., 2012). Because of this transitional process, a water budget based on "average conditions" will not reflect this slow and progressive change. It's also important to recognize that water budget accounting during early stages of groundwater basin development will have different storage and basin outflow values than water budget accounting for a later time period, when the basin is approaching equilibrium.

To accurately identify and evaluate the various inflow and outflow components of the water budget, it is important to adequately characterize the interaction between surface water and groundwater systems through sufficient monitoring of groundwater levels and streamflow conditions. The *Monitoring Networks and Identification of Data Gaps* and *Monitoring Protocol, Standards, and Sites* BMPs have additional information regarding GSP monitoring requirements.

Due to the complexities of characterizing stream depletion due to groundwater extraction, integrated groundwater-surface water models are often used to assist with water budget accounting and forecasting. In addition, where *interconnected surface water* systems exist, the quantification and forecasting of streamflow depletion may be extremely difficult without the use of a numerical groundwater and surface water model. Additional information regarding consideration of models under the GSP Regulations is provided in the Modeling BMP and in Section 5 of this BMP.

Water Budget Uses

Water budget accounting may be very general or very detailed, depending on the hydrologic complexities of the basin, the scale and intent of water budget accounting, and the importance of understanding the individual water budget components necessary to support water resource decision making. Some of the general and GSP Regulation-specific water budget uses and applications are provided below.

General Water Budget Uses

- Develop an accounting and characterize spatial and temporal distribution of inflows and outflows to a watershed, groundwater basin, or *management area*.

- Identify the primary *beneficial uses* and users of water and determine which water budget components are most critical to the area.
- Improve communication between the local land use planners and water resource managers.
- Estimate water budget components that are not easily measured or well understood.
- Evaluate how the surface and groundwater systems respond to the seasonal and long-term changes to supplies, demands, and climatic conditions.
- Identify the timing and volume of inflows and outflows that will result in a balanced water budget condition for a management area.
- Develop a water supply assessment of future conditions to better understand the effects of proposed land and water use changes, climate change, and other factors to the local and regional water budget.
- Inform additional monitoring needs.
- Identify the interaction between surface water and groundwater systems, including changes over time.

GSP-Related Water Budget Uses

SGMA requires local agencies to develop and implement GSPs that achieve *sustainable groundwater management* by implementing projects and management actions intended to ensure that the basin is operated within its *sustainable yield* by avoiding *undesirable results*. A key component in support of this effort is an accounting and assessment of the current, historical, and projected water budgets for the basin. The following provides a partial list of GSP-related water budget applications and uses:

- Develop an accounting and characterize spatial and temporal distribution of inflows and outflows to the basin by *water source type* and *water use sector*, to identify the main beneficial uses and users, and determine which water budget components are most critical to achieving sustainable groundwater management (§354.18(b)).
- Assess how annual changes in historical inflows, outflows, and change in basin storage vary by *water year type* (hydrology) and water supply reliability (§354.18(c)(2)).
- Develop an understanding of how historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within the sustainable yield (§10733.6(b)(3)).

- Improve coordination and communication between the GSA and water supply or management agencies, local land use approval agencies, and interested parties who may be subject to sustainable groundwater management fees (§355.4(b)(4)).
- Facilitate coordination of water budget data and methodologies between agencies preparing a GSP within the basin (§357.4) or between basins (§357.2).
- Identify *data gaps* and *uncertainty* associated with key water budget components and develop an understanding of how these gaps and uncertainty may affect implementation of proposed projects and water management actions.
- Evaluate how the surface and groundwater systems have responded to the annual historical changes in the water budget inflows and outflows (§354.18(c)(2)).
- Determine the rate and volume of surface water depletion caused by groundwater use that has adverse impacts on the beneficial uses of the surface water and may lead to undesirable results (§354.16(f) and 354.28(c)(1)).
- Identify which water budget conditions commonly result in *overdraft conditions* (354.18(b)(5).
- Estimate the sustainable yield for the basin (§354.18 and 10727.6(g)).
- Forecast projected inflows and outflows to the basin over the *planning and implementation horizon* (§354.18(c)(3)).
- Evaluate the effect of proposed projects and management actions on future water budget projections (§354.44(b)).
- Evaluate future scenarios of water demand uncertainty associated with projected changes in local land use planning, population growth, and climate (§65362.5(a)).
- Inform monitoring requirements (§354.34(b)(4)).
- Inform development and quantification of sustainable management criteria, such as the *sustainability goal*, undesirable results, *minimum thresholds*, and *measureable objectives* (§354.22).
- Help identify potential projects and management actions to achieve the sustainability goal for the basin within 20 years of GSP implementation (§354.44).

Water Budgets in Reference to the GSP Regulations

With respect to the GSP Regulations, developing a water budget that accurately identifies and tracks changing inflows and outflows to a basin will be a critically important tool to support decision making.

Complexity of water budgets will vary by groundwater basin according to the local complexities of the basin hydrology, physical setting, spatial and temporal distribution of supplies and demands, historical water management practices and the presence or absence of undesirable results. Ongoing parallel efforts to monitor and verify water budget components will help improve accuracy; however, some level of uncertainty is inherent in each water budget. An important objective of water budget accounting under the GSP Regulations is to develop an understanding of what level of water budget certainty and detail is sufficient for making effective basin management decisions.

The GSP water budget requirements are not intended to be a direct measure of groundwater basin sustainability; rather, the intent is to quantify the water budget in sufficient detail so as to build local understanding of how historical changes to supply, demand, hydrology, population, land use, and climatic conditions have affected the six *sustainability indicators* in the basin, and ultimately use this information to predict how these same variables may affect or guide future management actions. Building a coordinated understanding of the interrelationship between changing water budget components and aquifer response will allow local water resource managers to effectively identify future management actions and projects most likely to achieve and maintain the sustainability goal for the basin.

Another important aspect of documenting water budget information in the GSP is to ensure the Department is provided with sufficient information to demonstrate that the GSP conforms to all SGMA and GSP Regulation requirements, and, when implemented, is likely to achieve the sustainability goal within 20 years and maintain sustainability over the 50 year planning and implementation horizon.

4. RELATIONSHIP OF THE WATER BUDGET TO OTHER BMPS

Quantifying the current, historical, and projected water budget for the basin is just one of several interrelated GSP elements the GSAs will use to help understand the basin setting, evaluate groundwater conditions, determine undesirable results, develop sustainability criteria, establish appropriate monitoring networks, and ultimately identify future projects and management actions that are likely to achieve and maintain the sustainability goal for the basin. **Figure 3** illustrates the relationship of the water budget BMP to the other BMPs, and to the overall steps towards achieving sustainability under SGMA and the GSP Regulations.

Figure 3 identifies the water budget BMP as part of the Basin Setting portion of the GSP Regulations (§354.12). However, the water budget BMP also directly supports, or is supported by, several other BMPs and Guidance Documents such as stakeholder outreach, development of the *Hydrogeologic Conceptual Model* (HCM), modeling, monitoring networks, monitoring protocols, and establishing sustainable management criteria. Basin monitoring feeds into the understanding of the HCM and groundwater conditions, which then supports the understanding and quantification of the water budget and model development. It ultimately supports evaluation of sustainability indicators, undesirable results, and basin management decisions to achieve the sustainability goal for the basin.

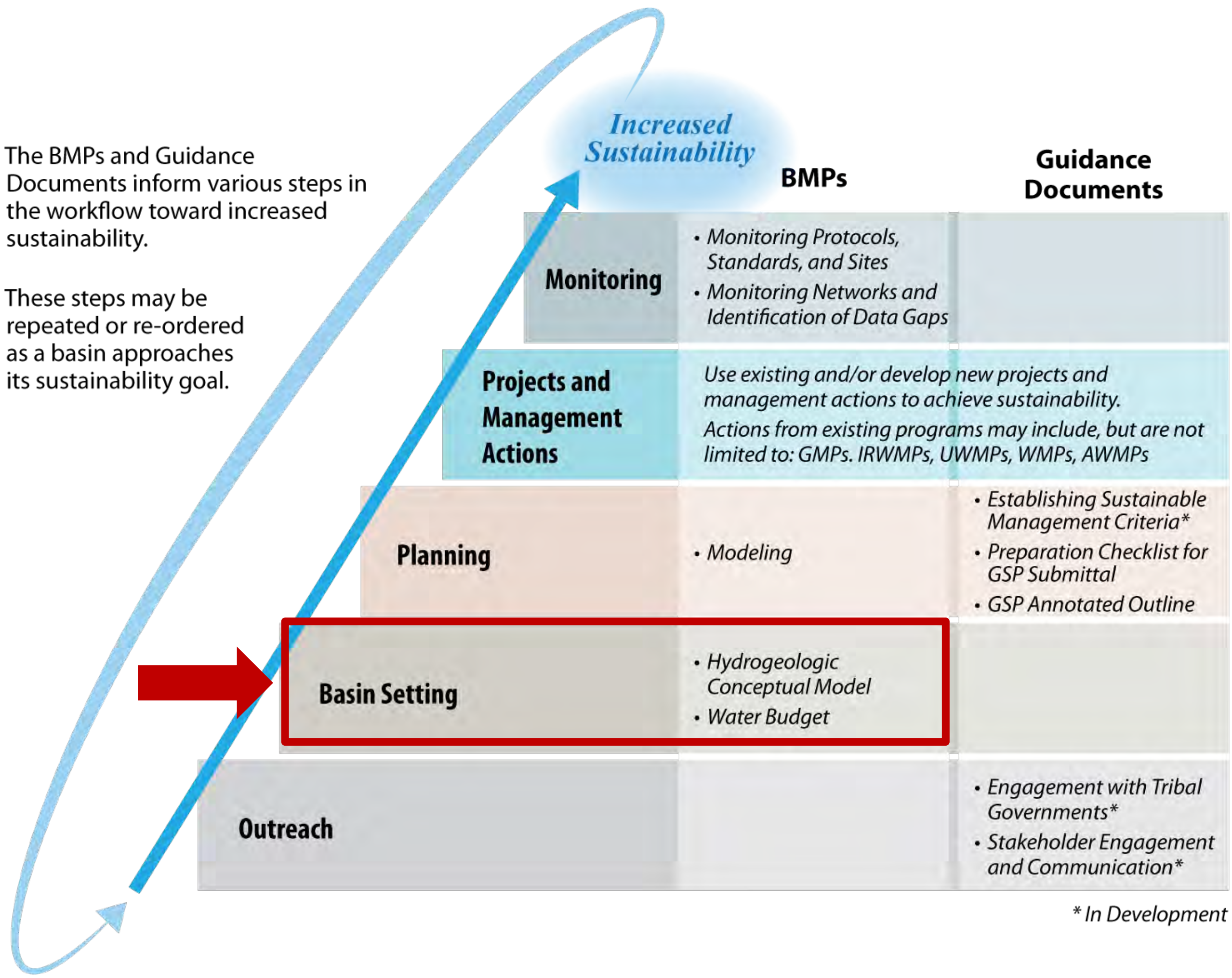


Figure 3 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

5. Technical Assistance

Implementing sustainable groundwater management under SGMA and the GSP Regulations requires development of a water budget. It should identify and account for basin inflows, outflows, and change in storage over changing temporal and spatial conditions of supply, demand, and climate with sufficient accuracy. This section provides guidance for the development of a water budget, including potential sources of information, reporting formats, and relevant datasets that can be used to further quantify and estimate the various water budget components.

GENERAL WATER BUDGET REQUIREMENTS

The following section highlights and provides guidance and technical assistance on the general requirements for all GSP-developed water budgets.

Subarticle 2. Basin Setting
23 CCR §354.12: Introduction to Basin Setting
Information provided pursuant to this Subarticle shall be prepared by or under the direction of a professional geologist or professional engineer.

Professional Certification

Water budget requirements are provided in Subarticle 2, under the Basin Setting portion of the GSP Regulations. Introduction to the basin setting stipulates that GSP water budget information, and all information provided under Subarticle 2 of the GSP Regulations, is to be prepared by or under the direction of a professional geologist or professional engineer. The qualifications and requirements for professional engineers and geologists are governed by the Professional Engineers Act (Business and Professions Code §6700) and the Geologist and Geophysicist Act (Business and Professions Code §8700). Information regarding the professional codes and licensing lookup are provided below.

- **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

Water Budget Data, Information, and Modeling Requirements

> ***23 CCR §354.18(e):*** *Each Plan shall rely on the best available information and best available science to quantify the water budget for the basin in order to provide an understanding of historical and projected hydrology, water demand, water supply, land use, population, climate change, sea level rise, groundwater and surface water interaction, and subsurface groundwater flow. If a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater, the Plan shall identify and describe an equally effective method, tool, or analytical model to evaluate projected water budget conditions.*

Water Budget Data Requirements: GSP Regulations stipulate the need to use the best available information and the *best available science* to quantify the water budget for the basin. Best available information is common terminology that is not defined under SGMA or the GSP Regulations. Best available science, as defined in the GSP Regulations, refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, which is consistent with scientific and engineering professional standards of practice.

It is understood that initial steps to compile and quantify water budget components may be constrained by GSP timelines and limited funding, and may consequently need to rely on the best available information that is obtainable at the time the GSP is developed. Information describing potential sources of data to support the quantification of water budget components is provided later in this BMP under *Water Budget Data Resources*. This section also includes a listing of data to be provided by the Department as part of the Department's technical assistance.

As GSAs compile and assess the various water budget components for the basin, each GSA will work to identify, prioritize, and fill data gaps as an ongoing effort to further refine water budget data and information based on the best available science.

Sustainability will ultimately depend on the GSA's ability to manage the basin within the identified uncertainty of water budget information to meet the locally defined objectives and thresholds of the outcome-based sustainable management criteria identified in §354.22. However, the initial approval of the GSP by the Department requires GSAs to gather and present a level and quality of water budget information that will demonstrate the GSP will likely achieve the sustainability goal for the basin under the substantial compliance requirements in §355.2 of the GSP Regulations.

Use of Models to Determine Water Budgets: GSP Regulations do not require the use of a model to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater. However, if a model is not used, the GSA is required to describe in the GSP an equally effective method, tool, or analytical model to evaluate projected water budget conditions.

Groundwater basins with acceptable water budget conditions, minimal undesirable results, and limited proposed changes to future groundwater demands may be able to identify and describe equally effective methods or tools to quantify and forecast future water budget conditions in sufficient detail.

In basins with *interconnected surface water* systems or complex spatial and temporal variations in water budget components, quantifying and forecasting streamflow depletion and other water budget components may be extremely difficult without the use of a numerical groundwater and surface water model. Modeling results may also be an effective tool for outreach and communication, and can prove useful in analyzing and quantifying some of the more difficult-to-measure water budget components.

Additional information regarding the requirements, application, and availability of models and modeling data is provided in the Modeling BMP.

Defining Basin Area and Water Budget Systems

23 CCR §354.18(a): *Each Plan shall include a water budget for the basin that provides an accounting and assessment of the total annual volume of groundwater and surface water entering and leaving the basin, including historical, current and projected water budget conditions, and the change in the volume of water stored. Water budget information shall be reported in tabular and graphical form.*

Three-Dimensional Basin Area: Prior to developing a water budget for the basin, GSAs must first identify the vertical and lateral extent of the basin as described under the HCM (§354.14) portion of the GSP Regulations. The HCM is based on technical studies and qualified maps that characterize the physical basin area and the interaction of surface water and groundwater systems in the basin. It requires evaluation of the physical systems related to regional hydrology, land use, geology and geologic structure, water quality, *principal aquifers*, and principal aquitards in the basin. Additional information regarding development of the HCM may be found in the HCM BMP.

The lateral boundaries of the basin are determined by the Department and conform to those boundaries provided in Bulletin 118. The vertical basin boundary, or definable bottom of the basin, is determined by the GSA and may be delineated by either, 1) a structural barrier to groundwater flow as determined by local geology, or 2) the base of fresh water as determined by groundwater quality information. In general, deep portions of the basin not part of the groundwater flow path can be excluded from analysis; conversely, if the those portions of the basin are part of the flow path or are being managed, they should be included in the analysis. Basin boundaries may be periodically modified through SGMA under §10722.

In addition to the lateral and vertical basin boundaries, the water budget accounting takes into consideration the exchange of water between subsystems within the hydrologic cycle. **Figure 4** is a generalized schematic illustrating the potential interaction between water budget components and the surface water system and groundwater system for a groundwater basin or management area.

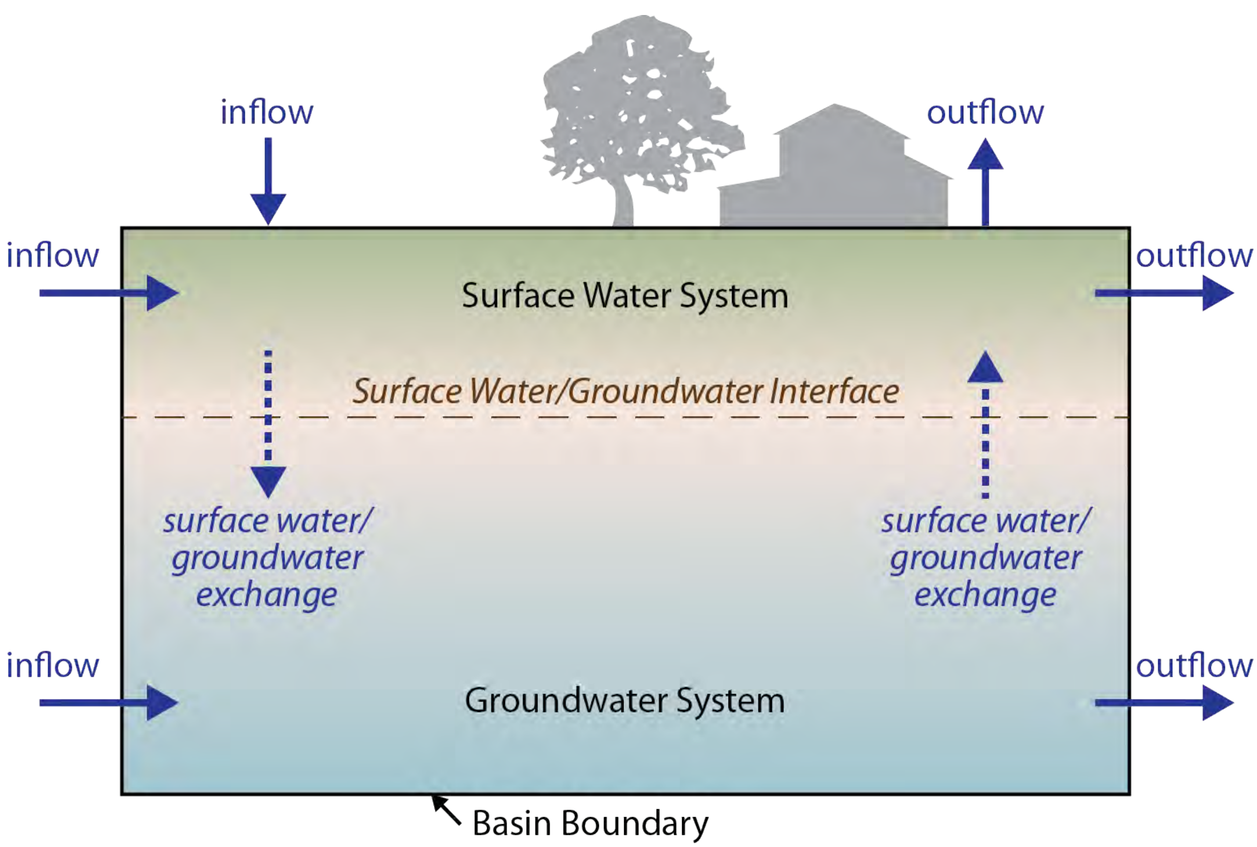


Figure 4 – Conceptual Basin Boundary, Surface Water and Groundwater Systems, and Inflows and Outflows

The surface water system is represented by water at the land surface within the lateral boundaries of the basin. Surface water systems include lakes, streams, springs, and man-made conveyance systems (including canals, drains, and pipelines). Near-surface processes such as stream underflow, infiltration from surface water systems or outflow due to evapotranspiration from the root zone are often included for convenience as part of the surface water accounting. Root zone processes may also be accounted for explicitly by defining a separate land surface system and quantifying exchanges with the surface water system and groundwater system, as well as exchanges with the atmosphere. An example of explicit accounting for the land surface system is provided later in this document based on water budgets prepared as part of the California Water Plan (DWR Bulletin 160).

The groundwater system is represented by that portion of the basin from the ground surface to the definable bottom of the basin, extending to the lateral boundary of the basin. The groundwater system will be characterized by one or more *principal aquifers* and represents the physical basin area used to quantify the annual change in volume of groundwater stored, as required in the water budget. The same three-dimensional basin area should also be used for GSAs to optionally identify the volume of groundwater in storage or the *groundwater storage capacity*, as necessary, to assist in the determination of sustainable yield.

23 CCR §354.20(a). Management Areas: *Each Agency may define one or more management areas within a basin if the Agency has determined that creation of management areas will facilitate implementation of the Plan. Management areas may define different minimum thresholds and be operated to different measurable objectives than the basin at large, provided that undesirable results are defined consistently throughout the basin.*

Management Areas: Although the GSP Regulations only require quantification of water budget components for the basin, each GSA may choose to further subdivide and report the water budget by one or more management areas to help facilitate GSP implementation, and to help demonstrate GSP substantial compliance to the Department under §355.2 of the GSP Regulations (*Department Review of Adopted Plan*). If management areas are developed, additional information and graphics will be needed to define the names, locations, and distribution of management areas within the basin. Graphical representations of the physical setting and characteristics of the basin will be largely provided under HCM requirements in §354.14 of the GSP Regulations.

> ***23 CCR §357.4(a). Coordination Agreements:*** *Agencies intending to develop and implement multiple Plans pursuant to Water Code Section 10727(b)(3) shall enter into a coordination agreement to ensure that the Plans are developed and implemented utilizing the same data and methodologies, and that elements of the Plans necessary to achieve the sustainability goal for the basin are based upon consistent interpretations of the basin setting.*

Coordination of Water Budget Data: When one or more GSPs are being developed by one or more GSAs for the same basin, §10727(b)(3) of SGMA and §357.4 of the GSP Regulations require a coordination agreement between all GSAs developing a GSP within the basin. As stated in the GSP Regulations citation above, the coordination agreement is to ensure that GSPs are developed and implemented using the same data and methodologies. Specifically, the coordination agreements need to describe how the Agencies utilize the same data and methodologies for the following water budget related components:

- Surface water supply
- Total water use
- Change in groundwater storage
- Water budget
- Sustainable yield

Thus, when presenting water budget information for basins with one or more GSPs, all GSPs for the basin need to identify and describe the existing coordination agreements for the basin, the point of contact of each agreement, how the individual coordinating agencies have taken steps to ensure that each GSP for the basin is utilizing the same data and methodologies for the above water budget components, and how the GSP is fulfilling the coordination requirements identified under §357.4 of the GSP Regulations.

For many basins within the Central Valley, Salinas Valley and elsewhere, not all lateral boundaries for contiguous basins serve as a barrier to groundwater or surface water flow. In situations where a basin is adjacent or contiguous to one or more additional basins, or when a stream or river serves as the lateral boundary between two basins, it is necessary to coordinate and share water budget data and assumptions. This is to ensure compatible sustainability goals and accounting of groundwater flows across basins, as described in §357.2 (Interbasin Agreements) of the GSP Regulations.

As described in SGMA, the Department shall evaluate whether a GSP adversely affects the ability of an adjacent basin to implement its GSP or impedes the ability to achieve its sustainability goal. In order to adequately evaluate this condition, in many cases this will necessitate GSA coordination and sharing of water budget data, methodologies, and assumptions between contiguous basins including:

- Accurate accounting and forecasting of surface water and groundwater flows across the basin boundaries
- Application of best available data and the best available science

In these interbasin situations, it is highly recommended that water budget accounting describe how individual agencies took steps to ensure that each GSP for the basin is utilizing compatible data and methodologies for the water budget components identified under interbasin coordination in §357.4 of the GSP Regulations.

Accounting and Quantification of Water Budget Components

23 CCR §354.18(b): The water budget shall quantify the following, either through direct measurements or estimates based on data:

(1) Total surface water entering and leaving a basin by water source type.

(2) Inflow to the groundwater system by water source type, including subsurface groundwater inflow and infiltration of precipitation, applied water, and surface water systems, such as lakes, streams, rivers, canals, springs and conveyance systems.

(3) Outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow.

(4) The change in the annual volume of groundwater in storage between seasonal high conditions.

(5) If overdraft conditions occur, as defined in Bulletin 118, the water budget shall include a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions.

(6) The water year type associated with the annual supply, demand, and change in groundwater stored.

(7) An estimate of sustainable yield for the basin.

Accounting of the water budget components includes: 1) an annual quantification of inflows and outflows across the basin boundaries, 2) the exchange of water between the surface water system and groundwater system, and 3) the change in volume of groundwater in storage. Surface water entering and leaving the basin and inflow to the groundwater system must be accounted for by water source type. Outflows from the groundwater system must be accounted for by *water use sector*. The annual accounting of surface water entering and leaving the basin should also include the annual change in surface water storage within lakes and reservoirs that contribute significant water supplies to the basin.

The GSP water budget components are conceptually illustrated in the water budget schematic shown previously in **Figure 4**. **Figure 5** expands upon **Figure 4** by depicting the individual water budget components identified by the GSP Regulations.

Quantification of the annual water budget inflows, outflows, and change in storage for the basin is to be generated by water year through direct measurements or estimates based on data. As previously discussed, the water budget must also be based on best available information and science. Methods to quantify water budget components may vary depending on basin-specific conditions, best available information, and the consideration of uncertainties associated with each method. Methods may change over time as monitoring networks are improved and data gaps are filled.

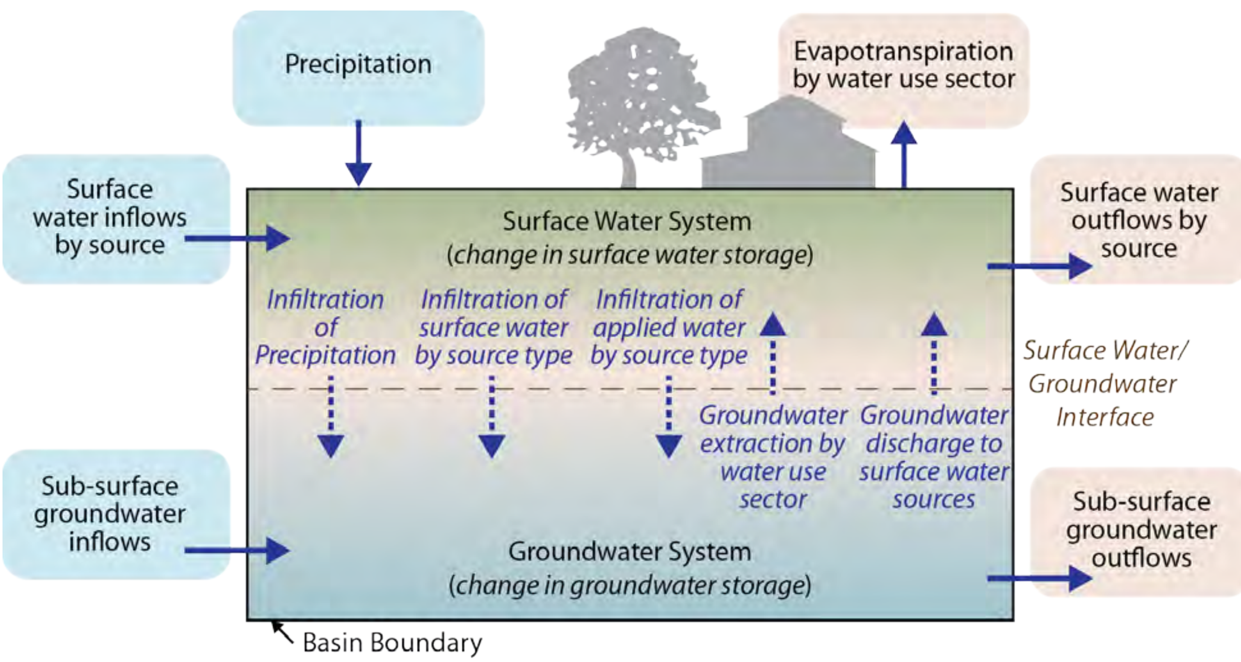


Figure 5 – Required Water Budget Components

Additional discussion regarding consideration of direct and indirect approaches to quantify water budget components is provided under *Identifying and Selecting Methodologies to Estimate Water Budget Components*. Information describing potential data sources to support quantification of change in storage is provided later in this section under *Water Budget Data Resources*, including data to be provided by the Department specifically for the purpose of supporting GSP water budget development.

The following information provides a breakdown of the seven overarching water budget component requirements listed above and included in §354.18(b) of the GSP Regulations.

(1) Total surface water entering and leaving the basin by water source type.

Water budget components associated with the river and stream system include the surface water entering (inflow) and leaving the basin (outflow). The inflow and outflow of surface water to the basin is required to be annually quantified as a total annual volume in acre-feet per year (af/yr) according to the surface water body (name) and the water sources type. Water source type represents the source from which water is derived to meet the applied beneficial uses. Surface water sources should be identified as one of the following:

- Central Valley Project
- State Water Project
- Colorado River Project
- Local supplies
- Local imported supplies

Much of the surface water flowing into the basin is diverted and applied to meet the beneficial uses within the basin. It is recommended that total annual volume of applied surface water (af/yr) also be quantified according to the appropriate water use sector and the total applied water area (acres). For urban water suppliers, the diverted and applied surface water use should include the total annual volume of use for all urban areas within the basin and the average daily gallons of per capita use (gpcd) for the basin. A breakdown of the applied surface water accounting by basin and by water use sector is provided as follows:

- Urban: total annual volume (af/yr) and the average daily per capita use (gpcd)
- Industrial: total annual volume (af/yr) and total applied water area (acres)
- Agricultural: total annual volume (af/yr) and applied water area (acres)
- Managed Wetlands: total annual volume (af/yr) and applied water area (acres)
- Managed Recharge: total annual volume (af/yr) and applied water area (acres)
- Native Vegetation: total annual volume (af/yr) and applied water area (acres)
- Other (as needed): total annual volume (af/yr) and applied water area (acres)

Applied surface water supply may be further subdivided by *management area* as needed to facilitate water budget accounting and to help demonstrate GSP substantial compliance under §355.2 of the GSP Regulations.

***Surface Water Available for Groundwater Recharge or In-Lieu Use*:** In addition to the above GSP Regulation requirement to include an accounting of the total surface water entering and leaving the basin, §10727.2(d)(5) of SGMA requires the GSP include a description of the surface water supply used, or available for use, for groundwater recharge or in-lieu use.

The Department currently estimates the volume of water available for replenishment of the groundwater in the State. The statewide water available for replenishment is being estimated on a regional basis. This regional estimate will not fulfill the SGMA requirement to identify the surface water supply used, or available for use, for groundwater recharge or in-lieu use at the basin level. However, the Department's process, methods, and sources of data for surface water supply availability should provide valuable assistance to GSAs. The Department's report on Water Available for Replenishment is currently under development.

(2) Inflow to the groundwater system by water source type, including subsurface groundwater inflow and infiltration of precipitation, applied water, and surface water systems, such as lakes, streams, rivers, canals, springs and conveyance systems.

Oil & Gas Field-Produced Water

Significant quantities of water are produced as a by-product of oil and gas extraction in some basins. Where applicable, it is important to characterize this water in terms of aquifer depletion, beneficial use, quality, and reliability.

- Aquifer Depletion. Oil and gas-bearing formations are often at a depth below the groundwater flow system. Is the quantity of produced water accounted for in the hydrogeologic conceptual model? Will depletion of this water cause Undesirable Results such as subsidence?
- Beneficial Use. Describe the uses for the produced water. Is the produced water being supplied as a beneficial use such as irrigation or recharge, or is it being evaporated? If so, it should be included as a water supply type in the water budget accounting.
- Quality. Describe the quality of the produced water, existing use permits, and any treatment processes employed. Describe the use or discharge relative to RWQCB Basin Plan Objectives.
- Reliability. Availability of produced water will fluctuate with oil and gas production. Oil fields have limited production durations that may be incompatible with long-term groundwater sustainability. Oil field-produced water will generally not be an acceptable supply for establishing sustainability, but may be a component of an initial basin recovery effort. The reliability of produced water should be characterized in the GSP if it is being use as a source of supply.

Inflows to the groundwater system are to be annually quantified by water year type for the basin as the total annual volume (af/yr) according to the water source type and water use sector.

An accounting of inflows to the groundwater systems should include, but may not be limited to, the following:

- Subsurface groundwater inflow (af/yr)
- Infiltration of precipitation (af/yr)
- Infiltration of applied water (af/yr)
- Infiltration from surface water systems (af/yr)
- Infiltration or injection from managed recharge projects (af/yr)

It is also important to identify and account for inflows or outflows to the groundwater system that may originate from outside the identified basin area. For example, application and infiltration of oil field-produced water should be identified as a separate source of imported water, while the injection of water beneath the definable bottom of the basin should be identified as an outflow from the basin when applicable (see text box discussion of oil field-produced water considerations). In addition, depending on the definable bottom of the basin, groundwater being injected to maintain a *seawater intrusion* barrier may need to be recognized as an outflow from the groundwater basin. Subsurface outflow needed to prevent seawater intrusion should be quantified.

For areas having *Urban Water Management Plans* (UWMP) or *Agricultural Water Management Plans* (AWMP), the GSP water budget assessment of urban and agricultural areas should be consistent with the water budget reporting in the most recent UWMPs and AWMPs, unless more recent information is available.

(3) ***Outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow****.*

An annual accounting of groundwater outflow from the basin should be total volume (ac-ft) by water source type and water use sector. Sources of groundwater outflow should include, but not be limited to, the following:

- Evapotranspiration: (af/yr)
- Groundwater discharge to surface water sources (af/yr)
- Subsurface groundwater outflow (af/yr)

- Groundwater extraction by water use sector:
  - Urban (af/yr) and (gpcd)
  - Industrial (af/yr)
  - Agricultural (af/yr)
- Managed Wetlands (af/yr)
- Managed Recharge (af/yr)
- Infiltration from the following: (af/yr)
  - Native vegetation (af/yr)
  - Other (as needed)

  Note: if oil and gas production wells are producing or applying water within the basin, as defined in the HCM, an accounting of the produced water is to be included as a source of applied water.

Outflows from the groundwater system may be further subdivided by management area as needed to facilitate water budget accounting and to help demonstrate GSP substantial compliance under §355.2 of the GSP Regulations.

(4) The change in the annual volume of groundwater in storage between seasonal high conditions.

In addition to the inflow and outflow components of the water budget, the annual change in the volume of groundwater in storage (af/yr) is required to be provided in tabular and graphical form according to water year type and the associated total annual volume of groundwater extraction for the basin. In addition, the GSP should provide some level of discussion regarding the variation between annual change of groundwater in storage versus annual changes in surface water supply, water year type, water use sector, sustainable yield and overdraft conditions (if present or potentially present).

The change in groundwater in storage is the total change in storage between *seasonal high* conditions, which typically occurs in the spring. It is recommended that the change in storage estimates be based on observed changes in groundwater levels within the basin. However, change in groundwater storage may also be calculated as the difference between annual inflows and outflows according to the water budget equation in Section 3, where all inflows and outflows can be reliably measured or estimated.

Similar to other water budget components, the method to quantify change in storage will likely vary depending on basin-specific conditions and available information, and include consideration of uncertainties associated with each method.

Assessment of change in storage under future water budget projections may require the use and application of a groundwater flow model. If a model is used to estimate future changes in groundwater storage, the Modeling BMP should be followed.

Changes in surface water storage (reservoirs, lakes, and ponds) will also be an important water budget component in some basins. For these basins, change in storage should be identified as change in groundwater storage and surface water storage.

The annual change in groundwater storage may also be further subdivided according to *management areas,* as needed, to help facilitate water budget accounting and to help demonstrate GSP substantial compliance under §355.2 of the GSP Regulations.

(5) ***If overdraft conditions occur, as defined in Bulletin 118, the water budget shall include a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions***.

The GSP water budget must include an assessment of *groundwater overdraft* conditions. Determination of overdraft conditions requires the evaluation of current and historical water budget conditions. As described in DWR Bulletin 118, overdraft occurs when groundwater extraction exceeds groundwater recharge over a period of years, resulting in a decrease in groundwater storage.

Overdraft conditions should be assessed by calculating change in groundwater storage over a period of years during which water year and water supply conditions approximate average conditions. Overdraft conditions should be evaluated as changes in groundwater storage by water year type. For basins without an existing water year index, water year types will be developed, classified, and provided by the Department based on annual precipitation as a percentage of the previous 30-year average precipitation for the basin. Water year classifications will be divided into five categories ranging from wet, above normal, below normal, dry, to critically dry conditions.

Single-year reduction in groundwater storage during critical, dry or below normal water years may not represent overdraft conditions. Reductions in groundwater storage in above normal or wet years or over a period of average water year conditions may indicate overdraft conditions. All annual change in groundwater storage estimates from water budget accounting should be included and discussed in the GSP.

If overdraft conditions are identified, the GSP shall describe projects or management actions, including a quantification of demand reduction or other methods, for the mitigation of overdraft, as required under §354.44(b)(2) of the GSP Regulations.

When evaluating if the GSP is likely to achieve the sustainability goal for the basin, the Department will consider whether the GSP includes a reasonable assessment of overdraft conditions and a reasonable means to mitigate overdraft as required under §354.4(b)(6) of the GSP Regulations.

(6) The water year type associated with the annual supply, demand, and change in groundwater stored.

In order for local resource managers to develop an understanding of the relationship between changing hydrologic conditions and the associated aquifer response to changing water supply, demand, and storage, the GSP water budget accounting must be reported according to water year type. Even though the GSP Regulations only require annual water budget accounting and reporting, in order for local water resource managers to adequately understand the timing and distribution of water supply and demand and to implement effective water management actions, local water budget accounting may need to be conducted on a monthly or more frequent basis. As mentioned previously in the overdraft discussion, water year types will be developed, classified, and provided by the Department for those basins not having an existing water year index. GSP water budgets detailing supply, demand, and change in groundwater stored according to water year type will help facilitate assessment of overdraft conditions and estimates of sustainable yield for the basin.

(7) An estimate of sustainable yield for the basin

Estimating sustainable yield includes evaluating current, historical, and projected water budget conditions. Sustainable yield is defined in SGMA legislation and refers to 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. Water budget accounting information should directly support the estimate of sustainable yield for the basin and include an explanation of how the estimate of sustainable yield will allow the basin to be operated to avoid locally defined undesirable results. The explanation should include a discussion of the relationship or linkage between the estimated sustainable yield for the basin and local determination of the sustainable management criteria (sustainability goal, undesirable results, minimum thresholds, and measureable objectives).

TABULAR AND GRAPHICAL REPRESENTATION OF THE WATER BUDGET COMPONENTS

The water budget information is to be in tabular and graphical form. This presentation of the data may take many forms depending on the sources of water inflow and outflow to the basin and the water use sectors within the basin.

A sample water budget tabulation is illustrated in **Table 1**. **Table 1** includes a listing of required water budget components to support a complete accounting of groundwater basin inflows and outflows. Additional water budget components not explicitly listed in the Regulations may be necessary for some basins in order to adequately evaluate sustainability and to identify and evaluate projects and management actions to address undesirable results. For example, in basins where treated produced water generated from oil and gas operations is used as a source of supply, the annual volume of the produced water being applied for beneficial use should be quantified and described according to water supply type and water use sector.

Additional tables depicting a breakdown of water budget accounting by water use sector and water source type may be needed to better understand the individual supplies and demands for some basins, and the percent of total supply that is met by each water source type.

Multiple graphical depictions of the various water budget components will likely be needed to fully illustrate the water budget accounting in many basins. The graphics should include charts and maps to show the trends and spatial distribution of the various water budget components. A general graphic summarizing the inflows, outflows and change in storage by water year type will be needed to provide an understanding of the overall water balance for the basin by water year type. Graphics and tables should depict complete and separate water budgets for the basin as a whole, the surface water system, and the groundwater system by basin or management area and by water year type. In addition, more detailed maps and figures that separately depict basin inflows and outflows by water source type, water use sector, and water year will likely be needed to better understand the relationship and overall importance of the various water sources and water use sectors.

Water Year:
Water Year Type:

INFLOWS		OUTFLOWS	
Inflow Source	Volume (af/yr)	Outflow Sink	Volume (af/yr)
Surface Water Inflow\1		Surface Water Outflow\1	
Precipitation		Evapotranspiration\4	
Subsurface Groundwater Inflow		Subsurface Groundwater Outflow	
Total Basin Inflow		Total Basin Outflow	
Subsurface Groundwater Inflow		Subsurface Groundwater Outflow	
Infiltration of Precipitation		Groundwater Extraction\1	
Infiltration from Surface Water Systems\2		Discharge to surface water systems\2	
Infiltration of Applied Water\3			
Total Groundwater Inflow		Total Groundwater Outflow	

Change in Surface Storage Volume	
Change in Groundwater Volume	

\1 by water source type
\2 lakes, streams, canals, springs, conveyance systems
\3 includes applied surface water, groundwater, recycled water, and reused water
\4 by water use sector

Table 1 – Simple Water Budget Tabulation Example

A sample paired bar graphic illustrating balanced water budgets for both the basin and the groundwater system including the required water budget components is presented as **Figure 6**. Each pair of bars shows inflows on the left and outflows on the right. In this illustration, more water flows out of the basin than flows in during the water year, resulting in an annual reduction in groundwater storage.

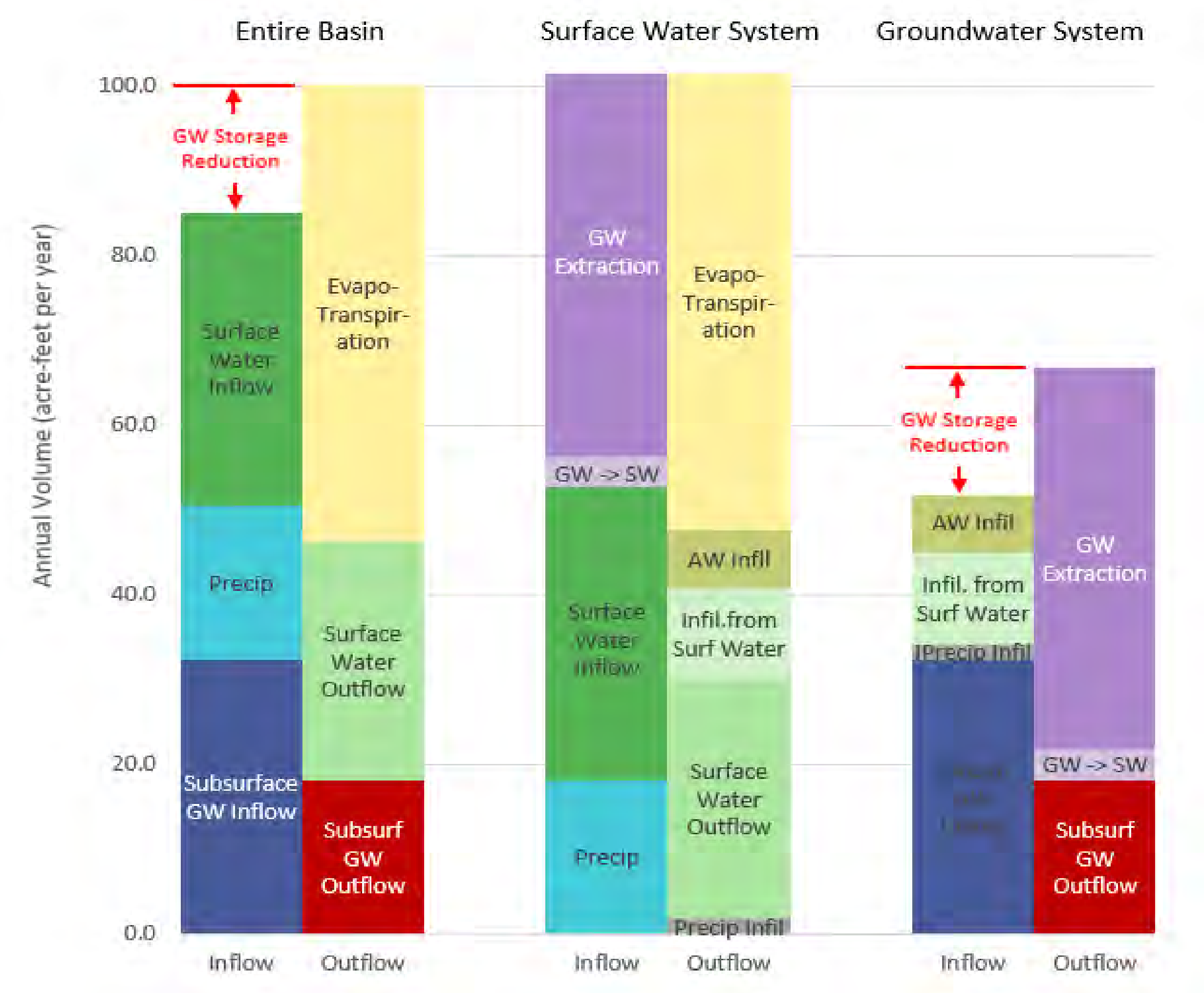


Figure 6 – Paired Bar Water Budgets

Additional graphical examples depicting water supplies and water use by water year type are provided in the Department's *California Water Plan Update 2013* (*Volume 1, Chapter 3, pages 3-33 - 3-40*), and the *California Groundwater Update 2013 (Chapter 2, pages 17-22)*. Online links to these reports are provided in Section 7, under *Guidance and General References*. Supplementary example graphics are being developed and will be provided as part of the Department's technical assistance.

An example of a detailed water budget developed by the Department as part of a pilot project to develop water budgets for future California Water Plan updates is provided in the text boxes on the following pages. The example includes hydrologic systems (e.g., the atmospheric system and land surface system) and other water budget components not explicitly required by the GSP Regulations. Conversely, the example does not explicitly include all of the water budget components required by the GSP Regulations. For example, deep percolation from the land surface to the groundwater system is included in the example, as compared to infiltration of precipitation and infiltration of applied water as required by the GSP Regulations. As discussed previously, more detailed accounting than required by the GSP Regulations, including additional components included in the example, may be necessary in some basins to adequately evaluate sustainability, and to identify and evaluate projects and management actions to address undesirable results.

Example of a Detailed Water Budget Including Additional Components Not Identified in the GSP Regulations

It may be useful in some basins to develop water budgets with additional detail not explicitly identified in the GSP Regulations. The following example, based on water budgets being developed as part of future updates of the California Water Plan, illustrates additional water budget components that may be included. **Figure 6** depicts the water budget as a combination of four hydrologic systems, including the atmospheric system, the land surface system, the river and stream system (also including conveyances and lakes and reservoirs), and the groundwater system. In contrast to the GSP Regulations, wherein the land surface system and river and stream system are, in essence, combined to form the surface water system, these systems are broken out explicitly.

Inflows and outflows to and from the user-defined area are illustrated in **Figure 7** as blue and orange arrows, while the flow of water within the user-defined area is shown as a series of purple arrows. Although not specifically depicted in **Figure 7**, the exchange of water in the root zone is included within the lower portion of the land surface system. The unsaturated zone in **Figure 7** is the portion of the subsurface that lies between the land surface system and the groundwater table, which defines the upper portion of the groundwater system. In reality, the thickness and distribution of the unsaturated zone may vary significantly according to the historical groundwater demand and water management practices in the basin. In areas with shallow groundwater conditions, the groundwater system may connect directly to the land surface system, eliminating the unsaturated zone and causing groundwater to discharge directly to the land surface through seeps, wetlands, or springs.

Short descriptions of the various water budget components within the user-defined area for the example are provided below.

River and Stream System: The river and stream system includes an accounting of water budget components for rivers and streams, lakes and reservoirs, and conveyance systems. Water budget components for the river and stream system include surface water entering and leaving the basin or user-defined area (includes imported or exported surface water), as well as the interaction of surface water with the atmospheric, land surface, and groundwater systems within the basin. **Figure 7** shows that inflows to the river and stream system may include stream flows entering into the basin, inflow from rainfall-runoff and agricultural and urban return flow contributions from the land surface system, inflow from the groundwater system, and direct precipitation to the surface water body. Outflows from the river and stream system primarily include diversions, conveyance seepage, streamflow losses to the groundwater, evaporation to the atmospheric system, and stream flows leaving the user-defined area.

Land Surface System: The land surface system includes an accounting of inflows and outflows associated with the various native and managed land use activities. It includes the exchange of water over the land surface, including the root zone, and the exchange of water with the other hydrologic systems within the user-defined area. The root zone occupies the upper portion the land surface where plants extract moisture to meet their water needs. The unsaturated zone is below the land surface system and represents the portion of the basin that receives percolated water from the root zone and either transmits it as deep percolation to the groundwater system or to reuse within the land surface system, or both. Subsurface soil and geologic conditions will help inform estimates of reuse and deep percolation.

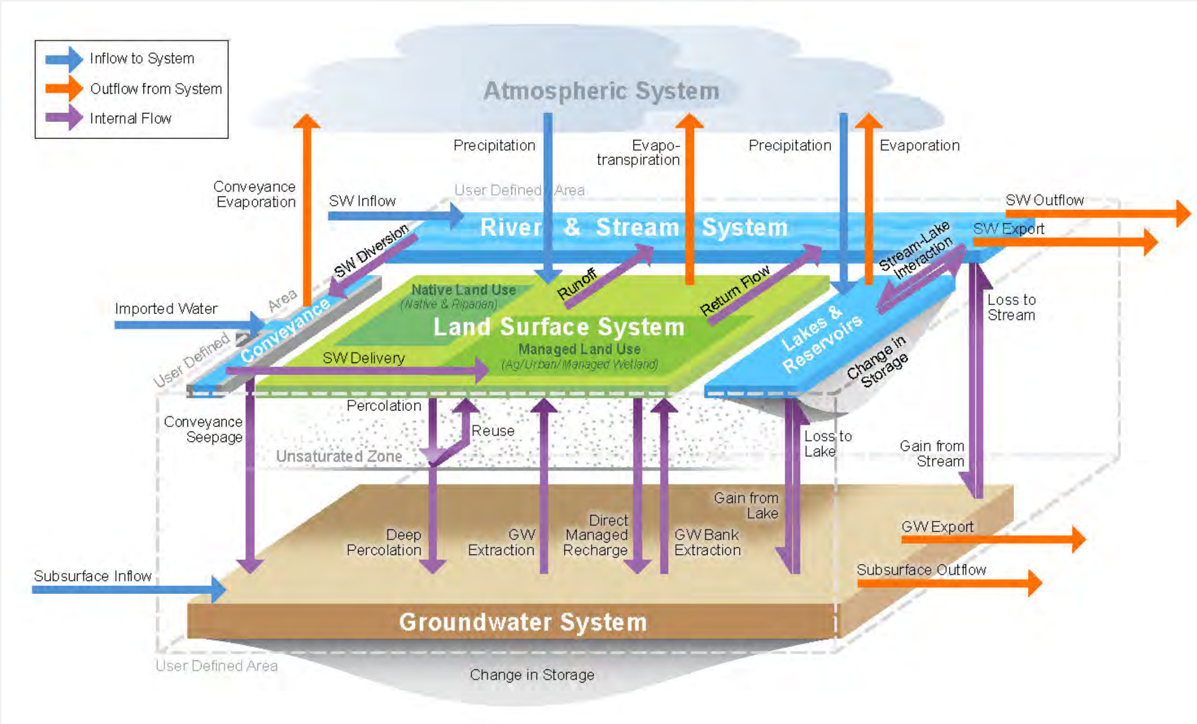


Figure 7 – Water Budget Schematic Showing the Interrelationships among Potential Water Budget Components and the Water Systems that Comprise the Hydrologic Cycle

Inflows to the land surface system may include the inflow of water from diversions from the river and stream system, groundwater extraction, direct precipitation to the land surface, and reuse of percolated water from the unsaturated zone. In areas having a high groundwater table or in locations where the subsurface geology causes outflow from the groundwater system to the land surface, inflows to the land surface system may also come from the capillary movement or direct outflow of groundwater into the land surface system through seeps, wetlands, or springs. Outflows from the land surface system include rainfall-runoff, agricultural and urban return flows to the river and stream system, percolation of precipitation of applied water and direct managed recharge to the groundwater system, and evapotranspiration to the atmospheric system.

Groundwater System: The groundwater system is represented by that portion of the user-defined area extending vertically from the base of the unsaturated zone to the definable bottom of the basin and laterally to the DWR Bulletin 118 basin boundary. In the GSP, the groundwater system will also be characterized by one or more principal aquifers and represent the physical extent of the basin that is used to quantify the annual change in volume of groundwater stored. The same three-dimensional basin should also be used for GSAs to optionally identify the volume of groundwater in storage or the groundwater storage capacity, as necessary, to assist in the determination of sustainable yield.

Inflows to the groundwater system include subsurface groundwater flow entering the user-defined area, deep percolation generated by precipitation and irrigation water infiltrating downward through the root and unsaturated zones, seepage into the aquifer from the river and stream system, and managed recharge through spreading basins or aquifer injection wells. Outflows from the groundwater system primarily include subsurface groundwater outflow leaving user-defined area, groundwater extraction from wells, and discharge to the river and stream system. Additional outflows from the groundwater system may also occur due to shallow groundwater discharge from seeps, wetlands, and springs. In situations where groundwater rises within the root zone of the land surface system, outflows due to evapotranspiration are typically attributed to the groundwater system.

Based on the detailed water budget example, graphics and tables can be developed to depict complete and separate water budgets for the land surface system, the groundwater system, the river and stream system, and a combination of these systems. These graphics and tables can be developed by water year type for the basin as a whole, by management area, or for other user-defined areas of interest. Examples of graphics depicting water budgets over time for the basin as a whole and for the groundwater system are provided in **Figure 8**. In this figure, the outflows are shown to the left, and the inflows are shown on the right. Annual change in storage may be represented as an inflow or an outflow depending on whether the amount of water in storage increases or decreases during a given time period of interest. An increase in storage is represented as an outflow, while a decrease in storage is represented as an inflow.

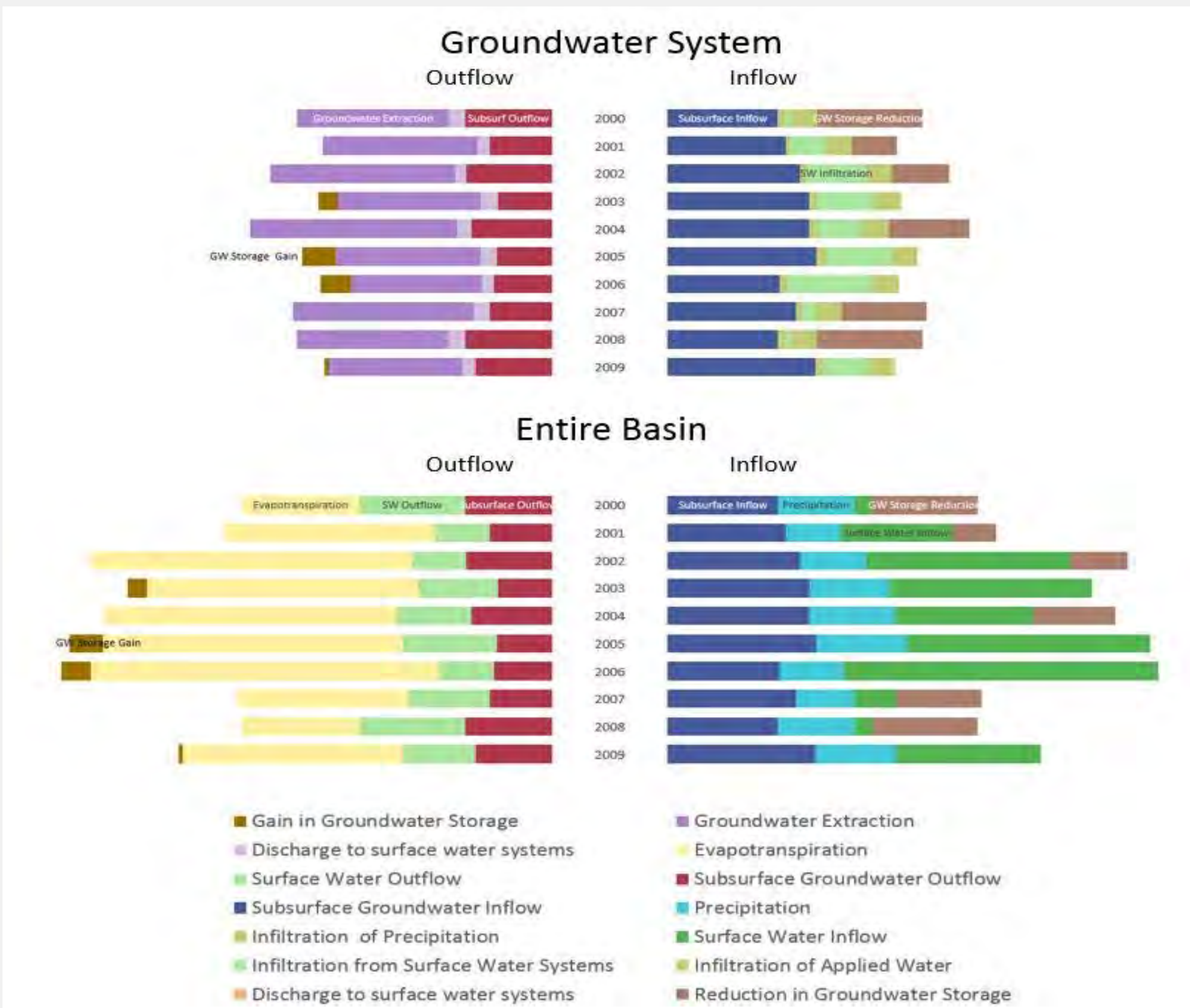


Figure 8 – Water Budget Inflows, Outflows, and Change in Storage by Water Year for Groundwater System and Entire Basin

DEFINING WATER BUDGET TIME FRAMES

> *23 CCR §354.18(c): Each Plan shall quantify the current, historical, and projected water budget for the basin.*

The GSP Regulations require a water budget for current, historical, and projected basin conditions. Descriptions of the water budget requirements are provided below.

Current Water Budget Assessment §354.18(c)(1)

The GSP is required to provide an accounting of current water budget conditions to inform local resource managers and help the Department understand the existing supply, demand and change in storage under the most recent population, land use, and hydrologic conditions. The current water budget is required to quantify all seven of the general water budget requirements listed in §354.18(b).

Historical Water Budget Assessment §354.18(c)(2)

The historical water budget accounting is required to evaluate how past water supply availability or reliability has previously affected aquifer conditions and the ability of the local resource managers to operate the basin within sustainable yield. The historical assessment is specifically required to include the following:

- Use at least the most recent ten years of surface water supply information to quantify the availability of historical surface water supply deliveries. The reliability of historical surface water deliveries is to be calculated based on the planned versus actual annual surface water deliveries, by surface water source, and water year type.
- Quantify and assess at least the most recent ten years of historical water budget information by water year type. The ten years of historical water budget information is to be used to help estimate the projected future water budgets and future aquifer response to the sustainable groundwater management projects and actions being proposed over the GSP planning and implementation horizon. The intent of the historical water budget evaluation is also to provide the necessary data and information to calibrate the tools or methods used to project future water budget conditions. Depending on the historical variability of supplies, demands, and land use; the level of historical groundwater monitoring in the basin; and the type of tool being used to estimate future projects and associated aquifer response; additional historical water budget information may be needed for adequate calibration.

- Use at least the most recent ten years of water supply reliability and water budget information to describe how the historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability of the local agency to operate the basin within sustainable yield. To assist in the evaluation, sustainable yield should be evaluated by water year type, as previously described in (7) *An estimate of sustainable yield for the basin.*

Projected Water Budget Assessment §354.18(c)(3)

The projected water budget accounting is used to quantify the estimated future *baseline conditions* of supply, demand, and aquifer response to GSP implementation. It is also required to evaluate and identify the level of uncertainty in the estimate, and to include historical water budget information to estimate future baseline conditions concerning hydrology, water demand and surface water supply reliability over the 50-year planning and implementation horizon. Methods used to estimate the projected water budget include the following three requirements:

- Use 50 years of historical precipitation, evapotranspiration, and stream flow information as the future baseline hydrology conditions, while taking into consideration uncertainties associated with the estimated climate change and sea level rise projections.
- Use the most recent land use, evapotranspiration, and crop coefficient information as the baseline condition for estimating future water demands, while taking into account future water demand uncertainty associated with projected changes in local land use planning, population growth, and climate.
- Use the most recent water supply information as the baseline condition for estimating future surface water supply, while applying the historical surface water supply reliability identified in §354.18(c)(2) and taking into consideration the projected changes in local land use planning, population growth, and climate.

Time frames required for the evaluation of current, historical, and projected water budget conditions are illustrated graphically in **Figure 9**. The illustration also includes a description of data to be supplied by the Department. Additional discussion of data and data sources is provided in greater detail in subsequent sections of this BMP (*Water Budget Data Resources)*.

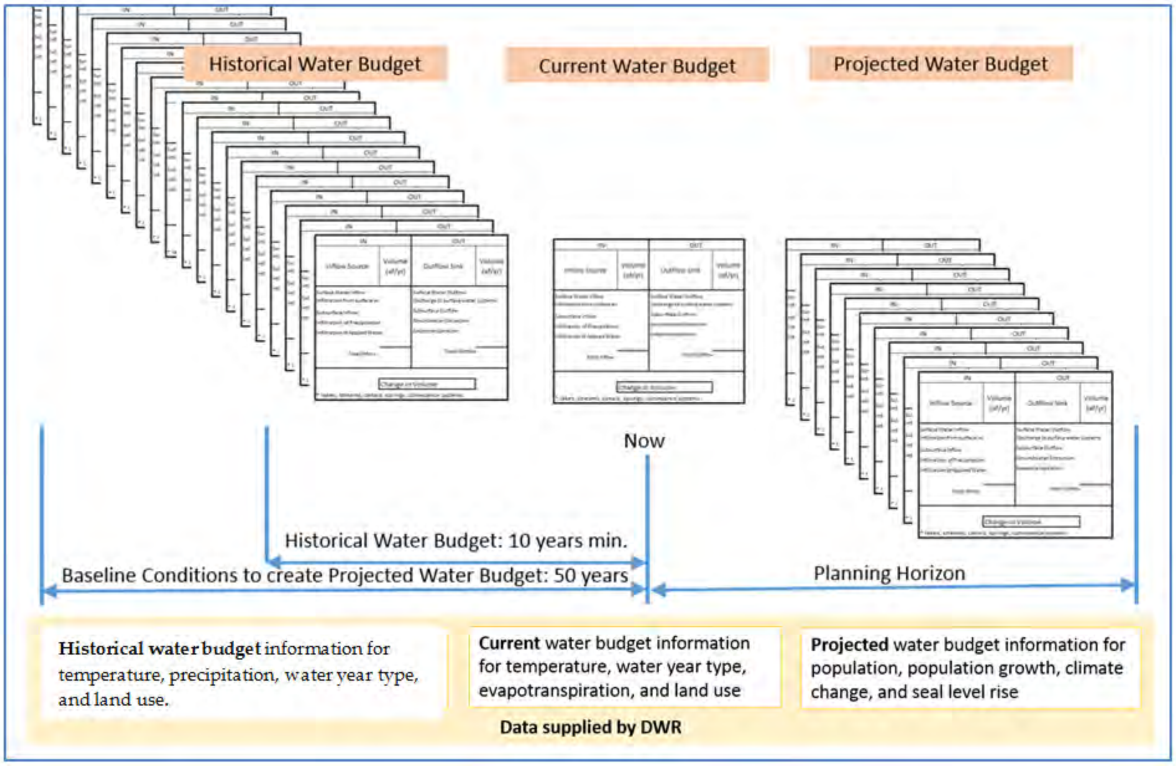


Figure 9 – GSP Water Budget Time Frames

Although the GSP Regulations only require annual quantification of the current, historical, and projected water budget information, in order to adequately assess projected water budget scenarios, GSAs may want to perform water budget accounting on a monthly or even a daily basis, especially if a groundwater model is used to compile and assess future water budget and aquifer conditions. In these situations, model results can be aggregated to annual values to support the GSP and subsequent *annual reporting*. Water budget accounting for shorter than annual time periods provides information necessary to support sustainable management of the basin through more timely evaluation of the water supply and demands by water use sector, of the potential undesirable results, and of the associated need for potential projects and management actions.

IDENTIFYING AND SELECTING METHODOLOGIES TO ESTIMATE WATER BUDGET COMPONENTS

As discussed above, individual components of the water budget may be estimated independently or based on estimates of other water budget components using the water budget equation. A comprehensive review of methodologies for each water budget component is beyond the scope of this BMP; however, the reader is encouraged to review water budget data resources described under *Water Budget Data Resources* and related materials referenced in Section 7. Selection of a methodology for a particular water budget component should consider the following:

- Whether the basin includes multiple GSAs intending to implement multiple GSPs (requires coordination agreement and description of how the same data and methodology are being used).
- How historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within sustainable yield.
- Past and current approaches to quantifying water budget components in the basin.
- Alternative approaches representing the best available information and the best available science.
- Data available to support application of the methodology.
- The methods being used for GSP development in adjacent basins.
- The magnitude of the water budget component relative to other components in the basin.
- Accuracy and uncertainty associated with the methodology and supporting data.

Some water budget components lend themselves to direct monitoring and measurement more than others. For example, physical processes at the ground surface, such as surface water diversion, groundwater extraction, and precipitation can be directly measured with a high degree of accuracy, certainty, and reliability using various meters, data loggers, and other readily available monitoring devices. These approaches to monitoring support utilization of the best available science, reflect industry standards, and result in defensible data that meets the uncodified finding of SGMA to collect data necessary to resolve disputes regarding sustainable yield, beneficial uses, and water rights (SGMA Uncodified Findings (b)(3)).

In contrast, other water budget components such as infiltration from surface water systems, subsurface *groundwater flows* across basin boundaries, and seawater intrusion into the basin cannot be measured directly and must be estimated using other approaches.

The methodologies, assumptions, and data sources used to quantify water budget components are to be documented in the GSP. Much of the information needed to quantify a component of the water budget may be available in existing planning documents and on-line data sources (see *Water Budget Data Resources* below).

As described in the *Coordination of Water Budget Data* section in this BMP, for situations where basin boundaries are adjacent or contiguous to one or more additional basins, or when a stream or river serve as the lateral boundary between two basins, it is recommended that water budget accounting in adjacent basins develop "interbasin" agreements to facilitate exchange of water budget information, as described in §357.2 of the GSP Regulations.

EVALUATING ACCURACY AND UNCERTAINTY OF WATER BUDGET COMPONENTS

Careful consideration should be given to documenting the accuracy and uncertainty of the data being used and in selecting which components are estimated independently versus estimated based on the principle of mass balance, as described above. In all cases, any components estimated based on the water budget equation (Equation 1) should be examined closely for reasonableness. For example, if past experience suggests that a typical value for infiltration of precipitation is around 5 to 10 percent of the total inflow for a given basin, but solution of the water budget equation for infiltration of precipitation results in an estimate of 50 percent of total inflow from infiltration of precipitation, additional examination of the other water budget components is warranted.

Evaluation of accuracy and uncertainty associated with individual water budget components is important because it improves understanding of the sensitivity and range of uncertainty of the various water budget components, which subsequently supports and informs development of GSP sustainable management criteria (§354.22) and projects and management actions (§354.44) that are being implemented and proposed to achieve sustainability.

WATER BUDGET DATA RESOURCES

Data resources to assist in development of a water budget will vary according to past water management studies and water resource investigations conducted in the region. However, several sources of potentially useful information were identified and are described below. These sources include data to be provided by the Department as part of technical assistance to support GSP development and sustainable water management, as well as other available sources of information.

Data Provided by the Department (§354.18(d) and (f))

Data from the Department, as available, to develop the water budget identified in the Regulations includes the following (§354.18(d) and (f)):

- **Historical Information:** Monthly minimum, maximum, and mean temperature and precipitation; water year type for areas outside the Central Valley; and Central Valley land use information.
- **Current Information:** Monthly minimum, maximum, and mean temperature; water year type; evapotranspiration, and statewide land use information.
- **Projected Information:** Population, population growth, climate change, and sea level rise.
- **Modeling Support**: The California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) and Integrated Water Flow Model (IWFM).

Agencies developing a water budget may choose to use other data of comparable quality, as allowed by GSP Regulation §354.18(d). As mentioned previously, if a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions, an equally effective method, tool, or analytical model must be identified and described in the plan (§354.18(e)). A water budget completed outside of a model may be useful as part of model calibration to confirm the reasonableness of water budget produced by the model.

Climate Change and Sea Level Rise. GSP Regulations require future water budget estimates to take into consideration changing climate and sea level rise when evaluating water supply, demand, and reliability for the basin over the planning and implementation horizon. Due to the spatial and temporal complexities associated with evaluating the basin response to changing climate, land use, and proposed projects, it is anticipated that most GSAs will utilize a hydrologic model to evaluate the various potential future basin conditions. In an effort to support consistent GSP analysis of future sustainability conditions, the Department will provide GSAs with a climate change guidance document to qualify data sources and identify acceptable methods for analyzing future climate change conditions for GSP development. These datasets will be publically posted and include future condition estimates of temperature, precipitation, runoff, sea level, and projected SWP and CVP deliveries. The data will not assume implementation of the California WaterFix Program.

Additional Data and Resources

Several other data sources exist in addition to those data specifically identified in the GSP Regulations to be provided by the Department. Some of these include data available from the Department not specifically listed in the GSP Regulations. A summary of data available to support water budget development is provided in **Table 2**. The table is not intended to provide an exhaustive list of data and sources to support water budget development, but rather to provide a reference to data that may be helpful. Specific data selected to support water budget development will depend on methodologies selected to estimate water budget components.

Table 2 – Potential Data Sources to Support Water Budget Development

Data Type	Data Sources	Notes
Air Temperature	DWR, PRISM, CIMIS, NOAA, USBR	Historical and current conditions available from DWR, PRISM, CIMIS, and NOAA. Projected future conditions available from DWR and USBR.
Precipitation	DWR, PRISM, CIMIS, NOAA, NASA, USBR	Historical and current conditions available from DWR, PRISM, CIMIS, NOAA, and NASA. Projected future conditions available from DWR and USBR.
Water Year Type	DWR	
Land Use	DWR, USDA, City, County General Plans, Local Agencies	Historical and current conditions available from DWR, USDA CDL, city & county general plans, and local agencies (including county agricultural commissioners).
Evapotranspiration	DWR, CIMIS, CalSIMETAW, UCCE	Historical and current conditions include reference evapotranspiration, total evapotranspiration, and amount of evapotranspiration derived from applied irrigation water. Could include traditional approaches and/or satellite remote sensing approaches.
Population	DWR, State Dept. of Finance, U.S. Census Bureau, UWMPs	Historical and current conditions from Dept. of Finance, U.S. Census, and UWMPs. Projected future conditions from DWR and UWMPs.
Climate Change	DWR, USBR	May include projected temperature, precipitation, evapotranspiration, streamflows, projected project supplies, etc.
Sea Level Rise	DWR	
Applied Water	AWMPs, UWMPs, UCCE, DWR	Historical and current applied irrigation water demands reported in AWMPs, UCCE publications, and DWR reports. Historical, current, and projected urban demands described in UWMPs.
Groundwater Level	DWR, USGS, Local Agencies	DWR sources include GIC and WDL.
Aquifer Thickness and Layering	DWR, USGS, Local/Regional Studies	DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available.

Data Type	Data Sources	Notes
Aquifer Hydraulic Conductivity	DWR, USGS, Local/Regional Studies	DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available.
Digital Elevation Model	USGS	Utilized to estimate surface water runoff from precipitation.
Streamflow	DWR, USGS, Local Agencies	DWR sources include CDEC and WDL.
Surface Water Diversions	Local Agencies, SWRCB eWRIMS, DWR, USBR	
Municipal/Industrial Groundwater Pumping	UWMPs	
Agricultural Groundwater Pumping	AWMPs, DWR, USGS	
Specific Yield	DWR, USGS, Local/Regional Studies	DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available.
Surface Soil Properties	NRCS	
Per-Capita Water Use	UWMPs, DWR, USGS	

Tabled Acronyms:

AWMP – Agricultural Water Management Plan
C2VSIM – California Central Valley Groundwater-Surface Water Simulation Model
CalSIMETAW – California Simulation of Evapotranspiration of Applied Water Model
CDEC – California Data Exchange Center
CIMIS – California Irrigation Management Information System
CVHM – Central Valley Hydrologic Model
DWR – Department of Water Resources
eWRIMS – Electronic Water Rights Information Management System
GIC – Groundwater Information Center
NASA – National Aeronautics and Space Administration
NOAA – National Oceanic and Atmospheric Administration
NRCS – Natural Resources Conservation Service
PRISM –Parameter-elevation Relationships on Independent Slopes Model
SWRCB – State Water Resources Control Board
UCCE – University of California Cooperative Extension
USBR – United States Bureau of Reclamation
USDA – United States Department of Agriculture
USGS – United States Geological Survey
UWMP – Urban Water Management Plan
WDL – Water Data Library

Additional Data Sources

Additional sources of available information include data from State and federal agencies, research institutions, local water resource management entities, and other local data collection and sharing activities. A partial list of data sources associated with existing water resource management programs are provided below:

- Urban Water Management Plans (UWMPs) http://www.water.ca.gov/urbanwatermanagement/
- Agricultural Water Management Plans (AWMPs), http://www.water.ca.gov/wateruseefficiency/agricultural/agmgmt.cfm
- Groundwater Management Plans (GWMPs), http://water.ca.gov/groundwater/groundwater_management/GWM_Plans_inCA.cfm
- Integrated Regional Water Management Plans (IRWMPs), http://water.ca.gov/irwm/stratplan/
- Groundwater Ambient Monitoring and Assessment Program (GAMA), http://www.swrcb.ca.gov/gama/
- Irrigated Lands Regulatory Program (ILRP) http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/

A comprehensive list of all available sources of water budget data from state and federal agencies, research institutions, and local water management entities is beyond the scope of this BMP. Some additional sources of water budget-related information from select State and federal agencies are provided below.

Department of Water Resources

- Groundwater Information Center (GIC) http://water.ca.gov/groundwater/gwinfo/index.cfm
- California Statewide Groundwater Elevation Monitoring Program (CASGEM) http://water.ca.gov/groundwater/casgem/
- Water Data Library (WDL) http://www.water.ca.gov/waterdatalibrary/
- California Data Exchange Center (CDEC) http://cdec.water.ca.gov/
- California Irrigation Management Information System (CIMIS) http://wwwcimis.water.ca.gov/cimis/welcome.jsp
- Land Use Surveys: http://www.water.ca.gov/landwateruse/lusrvymain.cfm

- Groundwater –Surface Water Simulation Model: The following the Department Bay-Delta site list information for the C2VSim Central Valley Groundwater-Surface water simulation model. This same website contains additional links to the Department water budget tools such as:
    - California Central Valley Groundwater-Surface Water Simulation Model
    - http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm
    - Integrated Water Flow Model (IWFM)
      http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/index.cfm
    - Irrigation Demand Calculator (IDC)
      http://baydeltaoffice.water.ca.gov/modeling/hydrology/IDC/index_IDC.cfm
    - CalLite: Central Valley Water Management Screening Model
      http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalLite/index.cfm
    - Water Resource Intergraded Modeling System (WRIMS) model engine (formally named CALSIM)
      http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/index.cfm
    - Delta Simulation Model II (DSM2)
      http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm
- Bulletin 118
  http://water.ca.gov/groundwater/bulletin118/index.cfm
- California Groundwater Update 2013
  http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm
- Bulletin 160: California Water Plan Update 2013
  http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm
- Bulletin 230-81: Index to Sources of Hydrologic Data
  http://www.water.ca.gov/waterdatalibrary/docs/historic/Bulletins/Bulletin_230/Bulletin_230__1981.pdf
- Additional DWR Data Topics
  http://water.ca.gov/nav/index.cfm?id=106
- Additional DWR Bulletin and Reports
  http://water.ca.gov/waterdatalibrary/docs/historic/bulletins.cfm

State Water Resources Control Board

- Electronic Water Rights Information Management System (eWRIMS)
  http://www.swrcb.ca.gov/waterrights/water_issues/programs/ewrims/
- GeoTracker
  https://geotracker.waterboards.ca.gov/

United States Geological Survey:

- Central Valley Hydrologic Model (CVHM) http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html
- Water Data Discovery: http://water.usgs.gov/data/
- Surface Water Information: http://water.usgs.gov/osw/
- Groundwater Information Pages: http://water.usgs.gov/ogw/

Additional USGS Water Budget Related Materials by Topic

Developing a Water Budget

This USGS Circular is a general reference for developing a water budget; it includes the key components of the water budget, exchanges of water between these components, and case studies of water-budget development and the use of water budgets in managing hydrologic systems. http://pubs.usgs.gov/circ/2007/1308/

Recharge Estimation

Modeling, field-based, and other methods have been used to estimate recharge. Those included here are examples of methods potentially applicable to relatively large areas. A comprehensive overview of recharge estimation methods is available in this book: https://pubs.er.usgs.gov/publication/70156906.

This USGS report is a compilation of methods and case studies for recharge estimation in the arid and semiarid southwestern U.S., including eastern and southeastern California: http://pubs.usgs.gov/pp/pp1703/index.html

Modeling of Recharge

Basin Characterization Model (BCM): developed by USGS for use in estimating natural recharge, and has been applied to all of California and other regions in the western US and internationally. This regional water-balance model differs from rainfall-runoff models because it incorporates estimates of shallow bedrock permeability to spatially distribute in-place natural recharge across the landscape. Content on the website below describes the model and associated methods, and provides links to output datasets available for historical and future projections of climate, and to associated publications of applications. The BCM is currently undergoing revisions to further improve the accuracy of recharge estimates for California; these revisions will be completed in mid-2017.
http://ca.water.usgs.gov/projects/reg_hydro/projects/dataset.html

The Farm Process: a tool developed by the USGS to improve the estimation of recharge (and pumping) associated with irrigated agriculture. It is available in various versions of MODFLOW; the most recent version is in MODFLOW-OWHM.

- Primary documentation, Version 1: http://pubs.usgs.gov/tm/2006/tm6A17/
- Documentation of Version 2: http://pubs.usgs.gov/tm/tm6a32/
- Version 3 is in MODFLOW-OWHM: http://water.usgs.gov/ogw/modflow-owhm/

GSFLOW: a coupled ground-water and surface-water flow model developed by the USGS and based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005). Features of both PRMS and MODFLOW aid in recharge estimation. http://pubs.usgs.gov/tm/tm6d1/

SWB: a modified Thornthwaite-Mather soil-water-balance code developed by the USGS for estimating groundwater recharge. http://pubs.usgs.gov/tm/tm6-a31/

INFIL: a grid-based, distributed-parameter watershed model developed by the USGS, for estimating net infiltration below the root zone. The link below provides documentation of the model, the associated software, and examples of applications.
http://water.usgs.gov/nrp/gwsoftware/Infil/Infil.html

Case Studies for Recharge Estimation using Modeling

MODFLOW: Natural recharge estimates, and uncertainty analysis of recharge estimates, using a regional-scale model of groundwater flow and land subsidence, Antelope Valley, California. https://pubs.er.usgs.gov/publication/70155814

INFIL: Estimating spatially and temporally varying recharge and runoff from precipitation and urban irrigation in the Los Angeles Basin, California.
http://dx.doi.org/10.3133/sir20165068

Geophysical Methods for Estimating Recharge

This USGS report describes many geophysical methods for investigating groundwater recharge; it includes case studies and a list of references for further information.
http://pubs.usgs.gov/pp/pp1703/app2/pp1703_appendix2.pdf

Surface-Water/Groundwater Interactions

- This USGS Circular is a general reference for groundwater and surface water, and their interdependence: http://pubs.usgs.gov/circ/circ1139/

- This USGS Circular describes the process of streamflow depletion by wells, and ways of understanding and managing the effects of groundwater pumping on streamflow: http://pubs.usgs.gov/circ/1376/
- This USGS document outlines *Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water*: http://pubs.usgs.gov/tm/04d02/
- This USGS document identifies methodologies for *Using Diurnal Temperature Signals to Infer Vertical Groundwater-Surface Water Exchange*: http://onlinelibrary.wiley.com/doi/10.1111/gwat.12459/abstract

Baseflow Analysis

- General link to USGS software associated with baseflow analysis http://water.usgs.gov/software/lists/groundwater#flow-based
- U.S. Geological Survey Groundwater Toolbox, A Graphical and Mapping Interface for Analysis of Hydrologic Data (Version 1.0)—User Guide for Estimation of Base Flow, Runoff, and Groundwater Recharge From Streamflow Data: http://pubs.usgs.gov/tm/03/b10/ and http://water.usgs.gov/ogw/gwtoolbox/

Streamflow Trend Evaluation

User Guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval: R Packages for Hydrologic Data: http://pubs.usgs.gov/tm/04/a10/

Water Use

Guidelines for preparation of State water-use estimates for 2005: http://pubs.usgs.gov/tm/2007/tm4e1/

Climate-Related Analysis

HydroClimATe: Hydrologic and Climatic Analysis Toolkit: http://pubs.usgs.gov/tm/tm4a9/

BCM Time Series Graph Tool: Enabling analyses of climate and hydrology variables, including recharge and runoff, for all HUC-8 watersheds in California for historical and future climates:http://climate.calcommons.org/article/about-bcm-time-series-graph-tool

Climate Smart Watershed Analyst: Enabling analyses of climate and hydrology variables, for time series and seasonality for planning watersheds in the San Francisco Bay Area for historical and future climates: http://geo.pointblue.org/watershed-analyst/

6. KEY DEFINITIONS

The key definitions related to Water Budget development outlined in applicable SGMA code and regulations are provided below for reference.

SGMA Definitions (California Water Code §10721)

(b) "Basin" means a groundwater basin or subbasin identified and defined in Bulletin 118 or as modified pursuant to Water Code § 10722.

(c) "Bulletin 118" means the department's report entitled "California's Groundwater: Bulletin 118" updated in 2003, as it may be subsequently updated or revised in accordance with § 12924.

(r) "Planning and implementation horizon" means a 50-year time 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.

(t) "Recharge area" means the area that supplies water to an aquifer in a groundwater basin.

(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.

(y) "Water budget" means an accounting of the total groundwater and surface water entering and leaving a basin including the changes in the amount of water stored.

(aa) "Water year" means the period from October 1 through the following September 30, inclusive

Groundwater Basin Boundaries Regulations (California Code of Regulations §341)

(f) "Aquifer" refers to a three-dimensional body of porous and permeable sediment or sedimentary rock that contains sufficient saturated material to yield significant quantities of groundwater to wells and springs, as further defined or characterized in Bulletin 118.

(q) "Hydrogeologic conceptual model" means a description of the geologic and hydrologic framework governing the occurrence of groundwater and its flow through and across the boundaries of a basin and the general groundwater conditions in a basin or subbasin.

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

(b) "Agricultural water management plan" refers to a plan adopted pursuant to the Agricultural Water Management Planning Act as described in Part 2.8 of Division 6 of the Water Code, commencing with Section 10800 et seq.

(d) "Annual report" refers to the report required by Water Code §10728.

(e) "Baseline" or "baseline conditions" refer to historic information used to project future conditions for hydrology, water demand, and availability of surface water and to evaluate potential sustainable management practices of a basin.

(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) “Best available science” refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.

(l) “Data gap” refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.

(n) “Groundwater flow” refers to the volume and direction of groundwater movement into, out of, or throughout a basin.

(o) “Interconnected surface water” refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.

(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.

(aa) “Principal aquifers” refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.

(ad) “Seasonal high” refers to the highest annual static groundwater elevation that is typically measured in the Spring and associated with stable aquifer conditions following a period of lowest annual groundwater demand.

(ae) “Seasonal low” refers to the lowest annual static groundwater elevation that is typically measured in the Summer or Fall, and associated with a period of stable aquifer conditions following a period of highest annual groundwater demand.

(af) “Seawater intrusion” refers to the advancement of seawater into a groundwater supply that results in degradation of water quality in the basin, and includes seawater from any source.

(ah) “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 §10721(x).

(ai) “Uncertainty” refers to a lack of understanding of the basin setting that significantly affects an Agency’s ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.

(aj) “Urban water management plan” refers to a plan adopted pursuant to the Urban Water Management Planning Act as described in Part 2.6 of Division 6 of the Water Code, commencing with Section 10610 et seq.

(ak) “Water source type” represents the source from which water is derived to meet the applied beneficial uses, including groundwater, recycled water, reused water, and surface water sources identified as Central Valley Project, the State Water Project, the Colorado River Project, local supplies, and local imported supplies.

(al) “Water use sector” refers to categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed recharge, and native vegetation.

(am) “Water year” refers to the period from October 1 through the following September 30, inclusive, as defined in the Act.

(an) “Water year type” refers to the classification provided by the Department to assess the amount of annual precipitation in a basin.

Bulletin 118 Definitions

“Beneficial use” of water in Bulletin 118 references 23 categories of water uses identified by the State Water Resource Control Board and are listed and briefly described in Appendix E.

“Groundwater overdraft” refers to the condition of a groundwater basin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years during which water supply conditions approximate average conditions.

“Groundwater in storage” refers to the quantity of water in the zone of saturation.

"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

- Barlow, P.M., and Leake, S.A., 2012, Streamflow depletion by wells—Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey, Circular 1376. [http://pubs.usgs.gov/circ/1376/]

- Chang, S.W., T.P. Clement, M.J. Simpson, and K.K. Lee. 2011. Does Sea-level Rise Have an Impact on Saltwater Intrusion, Advances in Water Resources 34:1283-1291. [http://www.mj-simpson.com/pdf/ADWR_2011.pdf]

- Healy, R.W., Winter, T.C., LaBough, J.W., and Franke, L.O., 2007, Water Budgets: Foundations for Effective Water-Resources and Environmental Management. U.S. Geological Survey, Circular 1308. [http://pubs.usgs.gov/circ/2007/1308/]

- Loaiciga, H.A., T.J. Pingel, and E.S. Garcia. 2012. Sea Water Intrusion by Sea-level Rise: Scenarios for the 21st Century, Ground Water, 50L37-47 [http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.2011.00800.x/abstract]

- Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground Water and Surface Water, A Single Resource. U.S. Geological Survey, Circular 1139. [http://pubs.usgs.gov/circ/circ1139/#pdf]

- 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

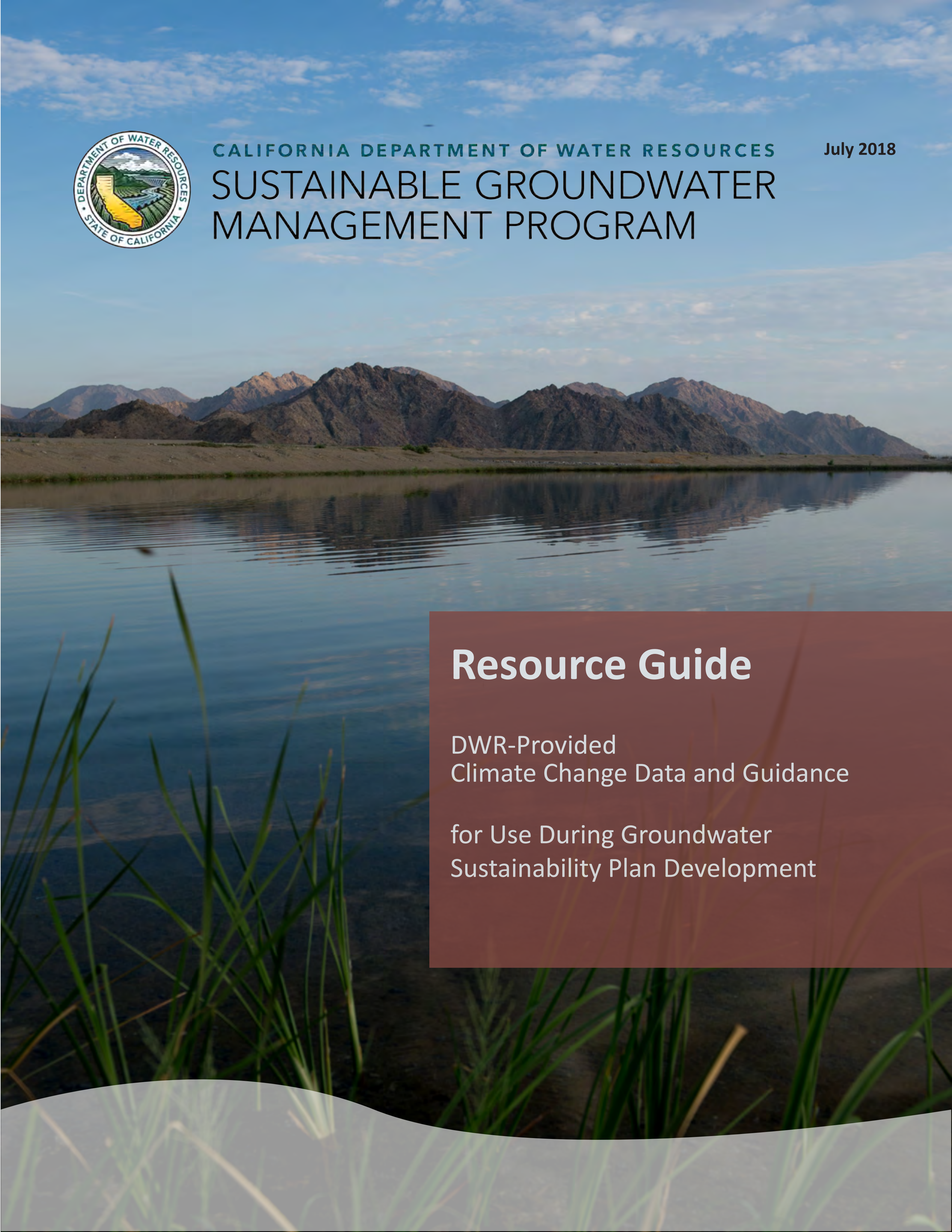
- Professional Engineers Act: http://www.bpelsg.ca.gov/laws/pe_act.pdf
- Professional Geologist and Geophysicist Act: http://www.bpelsg.ca.gov/laws/gg_act.pdf
- Professional License Lookup: http://www.bpelsg.ca.gov/consumers/lic_lookup.shtml

Appendix 2Bc Resource Guide Climate Change Data and Guidance

CALIFORNIA DEPARTMENT OF WATER RESOURCES

July 2018

SUSTAINABLE GROUNDWATER MANAGEMENT PROGRAM



Resource Guide

DWR-Provided Climate Change Data and Guidance

for Use During Groundwater Sustainability Plan Development

Resource Guide

DWR-Provided Climate Change Data and Guidance

for Use During Groundwater Sustainability Plan Development

The California Department of Water Resources (DWR) provides multiple resources related to climate change for Groundwater Sustainability Agencies (GSAs) to use during development of Groundwater Sustainability Plans (GSPs). This document gives GSAs and other stakeholders a high-level overview of these climate change resources including datasets provided by DWR, tools for working with the DWR-provided datasets, and guidance for using DWR-provided data and tools in developing GSPs. The datasets and methods can provide technical assistance to GSAs for developing projected water budgets. GSAs may choose not to use the DWR-provided Data, Tools and Guidance to develop projected water budgets. However, DWR recognizes that assessing impacts of climate change is complex and can take considerable time and effort. As a result, the climate change resources are provided to help reduce the level of effort needed for GSAs to account for climate change impacts in their GSPs.

The climate change resources are designed to complement the GSP regulations and best management practices (BMPs). 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 describe projected water budget assessments. Additional clarification can be found in the water budget and modeling BMPs[1] which describe the use of climate change data to compute projected water budgets and simulate related actions in groundwater/surface water models. The *Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development* (Guidance Document) is the primary source of technical guidance. The Guidance Document explains the DWR-provided climate change data including how the data were developed, the methods and assumptions used, and how they can be used in the development of a projected water budget.

The information in this document briefly summarizes the DWR-provided climate change resources and serves as a roadmap to point the reader toward additional information with the necessary level of detail. This document is organized as follows:

- Overview – provides overall background on the Sustainable Groundwater Management Act (SGMA) and Regulatory requirements as well as information on the DWR-provided climate change datasets.
- Climate Change Data – summarizes the datasets provided including climate, hydrology, and operations for the different climate change projections.
- Climate Change Data Processing Tools – introduces the web and desktop tools for accessing and using the climate change datasets for projected water budget analysis.
- Climate Change Data Analysis Guidance – summarizes the different types of guidance available including the factsheet, Guidance Document and appendices, and user manual.
- Climate Change Data Analysis Process – provides an overview of the approaches detailed in the climate change Guidance Document.
- Resources – summarizes the different data, tools, guidance, and other resources into a reference table with accessible web-links.

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

Overview

Regulatory Background

SGMA requires incorporation of climate change assumptions into the development of projected water budgets, and for the sustainable management of groundwater basins. A select list of SGMA and GSP regulatory requirements are provided below.

SGMA Requirements

- Water Code Section 10727.2, *Required Plan Elements*
- Water Code Section 10733.2, *Department to Adopt Emergency Regulations Concerning Plan Review and Implementation*

DWR GSP Regulations

- Section 354.18, *Water Budget*
- Section 354.18(e), *Use of best available information and best available science*

DWR-Provided Information

DWR-provided climate change data are based on the California Water Commission's Water Storage Investment Program (WSIP) climate change analysis results. The provided climate change data can help GSAs with the following:

- Developing long-term water budgets
- Planning long-term groundwater basin sustainability
- Assessing projects and management actions and performing sensitivity analysis of projected conditions
- Managing resources adaptively

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. These WSIP datasets were derived from a selection of 20 global climate projections recommended by the Climate Change Technical Advisory Group (CCTAG). These WSIP datasets were further processed to include data formats useful for the development of GSPs and related technical analysis to implement the SGMA.

DWR Climate Change Analysis Background

While DWR provides 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. This document provides an overview of DWR-provided data and methods and summarizes additional guidance provided.

Climate Change Data

Datasets provided by DWR were developed based on the WSIP analysis for projected climate conditions centered around 2030 and 2070 (Table 1). 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 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 (GCMs).

- **Climate Data.** The climate data provided include precipitation and reference evapotranspiration as simulated by the VIC model through a downscaling process from global circulation models. Precipitation and reference evapotranspiration (ET) 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 scenario) divided by 1995 historical temperature detrended scenario.

Datasets Provided by DWR's Sustainable Groundwater Management Program (SGMP)

- Climatological Data — Gridded change factors for precipitation and reference evapotranspiration
- Central Valley Project Operations Data — Central Valley diversions, deliveries, and modeled flow data (State Water Project [SWP] and Central Valley Project [CVP] Simulation Model [CalSim II] and variable infiltration capacity [VIC] model)

- **Hydrology Data.** The hydrology data provided include projected Central Valley stream inflows as simulated by the VIC model that can be used directly in a water budget by replacing the historical data with the projected data, and additional streamflow data in the area outside of the Central Valley. In addition, for SGMA purposes, unimpaired streamflow change factor datasets were developed through further post-processing of existing data provided via WSIP.
- **Water Operations Data.** The water operations data provided include Central Valley reservoir outflows, diversions, State Water Project (SWP)/Central Valley Project (CVP) water deliveries and select streamflow data as simulated by the CalSim II model and produced for all future conditions and scenarios.

Table 1. Datasets Provided by WSIP and Modified Datasets Provided by SGMP

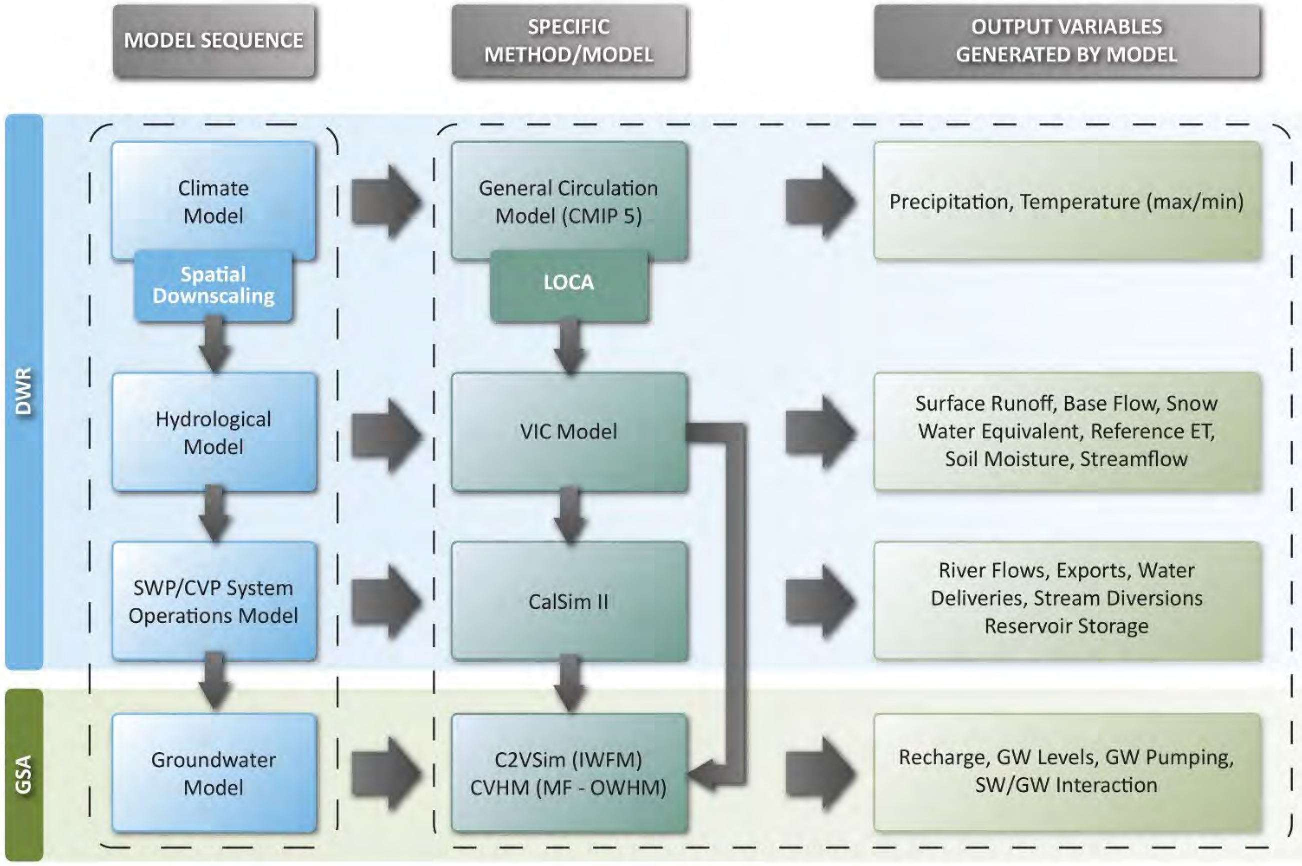
Data Type	Specific Data	WSIP	SGMP[a]
Climate	Precipitation, reference ET	Individual text files for each VIC model grid cell with associated VIC grid GIS data	VIC model grid GIS data with related table of timeseries data for each grid cell (as change factors)
Hydrology	Central Valley stream inflows	Timeseries data developed as input to the CalSim II model	Point locations provided as GIS data with related timeseries data in .csv format for each location
Hydrology	Statewide unimpaired streamflow change factors[b]	N/A; runoff and baseflow provided in individual text files for each VIC grid	Dataset developed by combining VIC runoff and baseflow for each HUC 8 watershed; provided based on HUC 8 GIS data with related table of timeseries data
Water Operations	Diversion/deliveries and reservoir outflow data	Dataset embedded in CalSim II model runs	Point locations provided as GIS data with related timeseries data in .csv format for each location; delivery data available through lookup table of contracted amounts with CalSim II timeseries outputs in Excel format

Notes:
[a]All data are available through SGMA Data Viewer at https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer.
[b]Streamflow change factors are for unimpaired flows (i.e., upstream of dams where reservoir operations have not been included).

Key:
GIS = geographic information system
.csv = comma separated values
HUC 8 = Hydrologic Unit Code 8
N/A = not applicable. developed by SGMP

Climate Change Data

As part of technical assistance, DWR provides climate change datasets that can be readily used by GSAs for projected water budgets. The figure below summarizes the general modeling sequence for evaluating climate change effects on groundwater resources. The center column shows the specific methods and models used if the DWR-provided datasets are used by a GSA in a groundwater model. The data output from each model is shown in the right column. As the figure indicates, DWR provides all but the last step to reduce the level of effort needed for GSAs to incorporate climate change.



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

- **Appropriate use of climate change datasets**

  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 or that the projected water budget meets GSP requirements. GSAs are not required to use DWR-provided climate change data or methods, but GSAs will need to adhere to the requirements in the GSP Regulations. If DWR-provided data are used, GSAs should be careful and use a consistent approach if combining DWR-provided data with other local information. For example, it is not appropriate to mix data produced by a transient climate analysis method with data developed using a climate period analysis method.

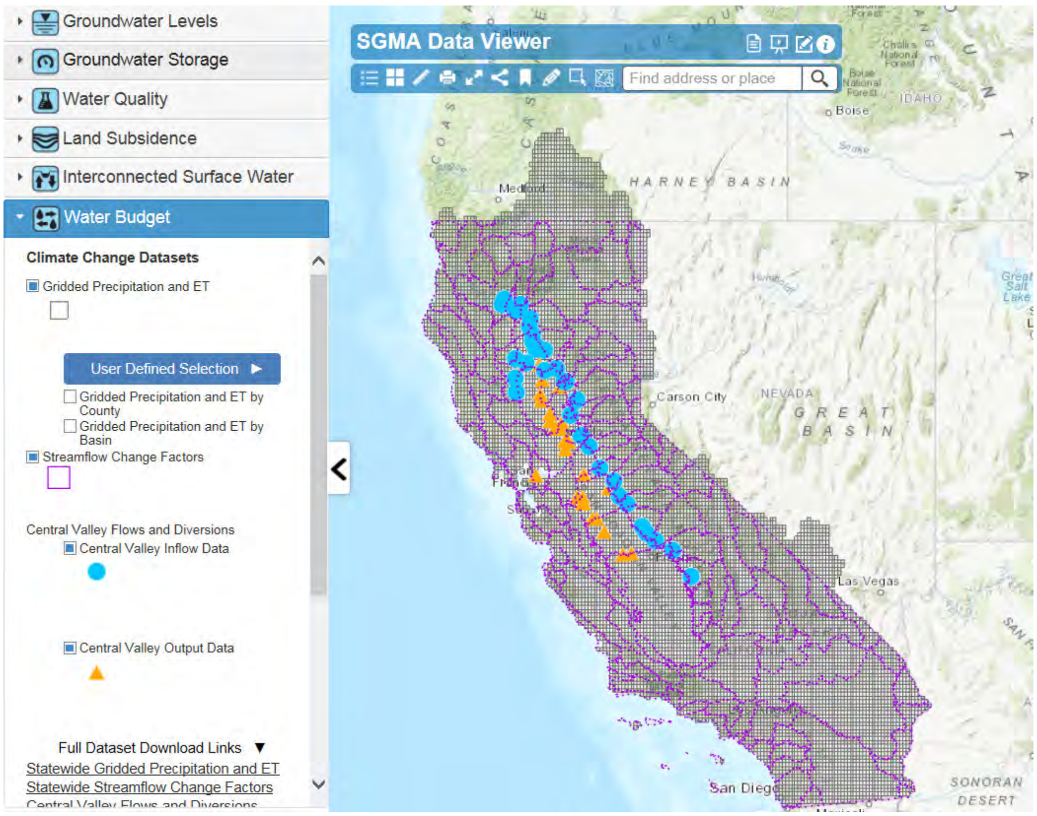
- **Refinement of climate change analysis data and methods in the future**

  As climate science further develops, it will be important to use the data that reflect the current understanding and best available science at the time of future GSP updates. For example, Coupled Model Intercomparison Projects (CMIP) are updated every 8 to 10 years to incorporate the latest developments in 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.

Climate Change Data Processing Tools

DWR developed and provides the SGMA Data Viewer and desktop tools to help GSAs apply data to their hydrologic models and water budget calculations, as follows:

- **SGMA Data Viewer:** this is an online GIS-based interactive map for downloading relevant spatial and associated time-series (temporal) data in accordance with a user-defined region. Data can be visualized and downloaded for the entire state, or subsets of data can be clipped directly from the statewide dataset by drawing polygons or uploading a boundary shapefile (for example representing a model domain). Datasets are also available by county and basin. The snapshot below shows the Data Viewer page with the climate change data download options, under the Water Budget section.



- **Desktop tools** are available to help process relevant datasets for future water budget analysis and integrated hydrologic modeling.
  - **Model input file development desktop tools.** These tools help map VIC model gridded precipitation and reference ET data to the correct groundwater model cells (for MODFLOW-based models) or elements (for Integrated Water Flow [IWFM]-based models).
  - **Spreadsheet tool for basin average unimpaired streamflow change factor corrections.** This tool modifies monthly change factors to more accurately reflect annual streamflow patterns present in historical data.
  - **Contractor deliveries search table.** These tables summarize water contractor deliveries in a spreadsheet format that reports both the name of contractor and region of delivery.

These and the other tools listed below can be downloaded from DWR's Data and Tools website. These tools can help GSAs analyze projected climate change.

Other Related Tools

- **DWR modeling tools.** 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.

Climate Change Data Analysis Guidance

In addition to data and tools, DWR provides several guidance documents to help GSAs apply climate change data to their water budgets and for other GSP requirements. Supporting documents (listed below) may help GSAs understand and incorporate climate change into projected water budgets. The main document, the Guidance Document[2] was developed to help GSAs incorporate DWR-provided climate change and related data into their GSPs.

Climate Change-Specific Guidance

- **Factsheet.** The factsheet provides a one-page reference about the climate change data, tools, and guidance being provided by DWR to assist GSAs with climate change analysis in their GSPs.

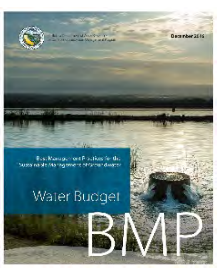
- **Guidance Document.** The Guidance Document provides GSAs and other stakeholders with information regarding climate change datasets and tools provided by DWR for use in developing GSPs. The focus of the guidance document is the DWR-provided data with information about how the climate change data were developed, including the climate change methods used and key assumptions underlying those methods. The Guidance Document describes how the data can be used to develop projected water budgets. The Guidance Document is the primary reference for understanding the DWR-provided climate change data and is written for a more technical audience.

  Three appendices provide additional details on climate change data development and background information on California climate.

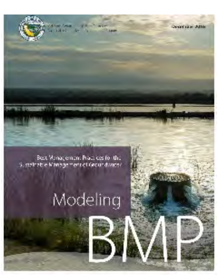
- **User Manual**. The *Climate Change Data User Manual* provides GSAs with instructions for downloading and incorporating DWR-provided climate change data into water budget calculations and numerical groundwater or integrated hydrologic models.

> **Purpose of Guidance Document**
> - 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 incorporate best available science and best available information to date.

Other Related Guidance



- **Water Budget BMP.** The objective of this BMP is to assist in the use and development of water budgets. Information provided in this BMP provides technical assistance to GSAs and other stakeholders on how to address water budget requirements outlined in the GSP Emergency Regulations. This BMP identifies available resources to support development, implementation, and reporting of water budget information.



- **Modeling BMP.** The objective of this BMP is to assist with the use and development of groundwater and surface water models during GSP development. Information in this BMP provides technical assistance to GSAs and other stakeholders on how to address modeling requirements outlined in the GSP Emergency Regulations. This BMP identifies available resources to support the development of groundwater and surface water models. Specifically, a model can be used to predict water budgets at varying scales under future conditions and climate change, as well as with the inclusion of management scenarios.

2 https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/Climate-Change-Guidance---SGMA.pdf

Climate Change Data Analysis Process

Incorporating Climate Change Analysis into Projected Water Budgets

GSP Water Budget Requirements

- For historical conditions
- For current conditions
- For projected conditions over the 50-year planning and implementation horizon

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

- Water budget representing a minimum of 10 years of historical conditions
- Water budget representing current conditions
- Water budget representing projected conditions over the planning and implementation horizon using a 50-year hydrologic baseline condition.

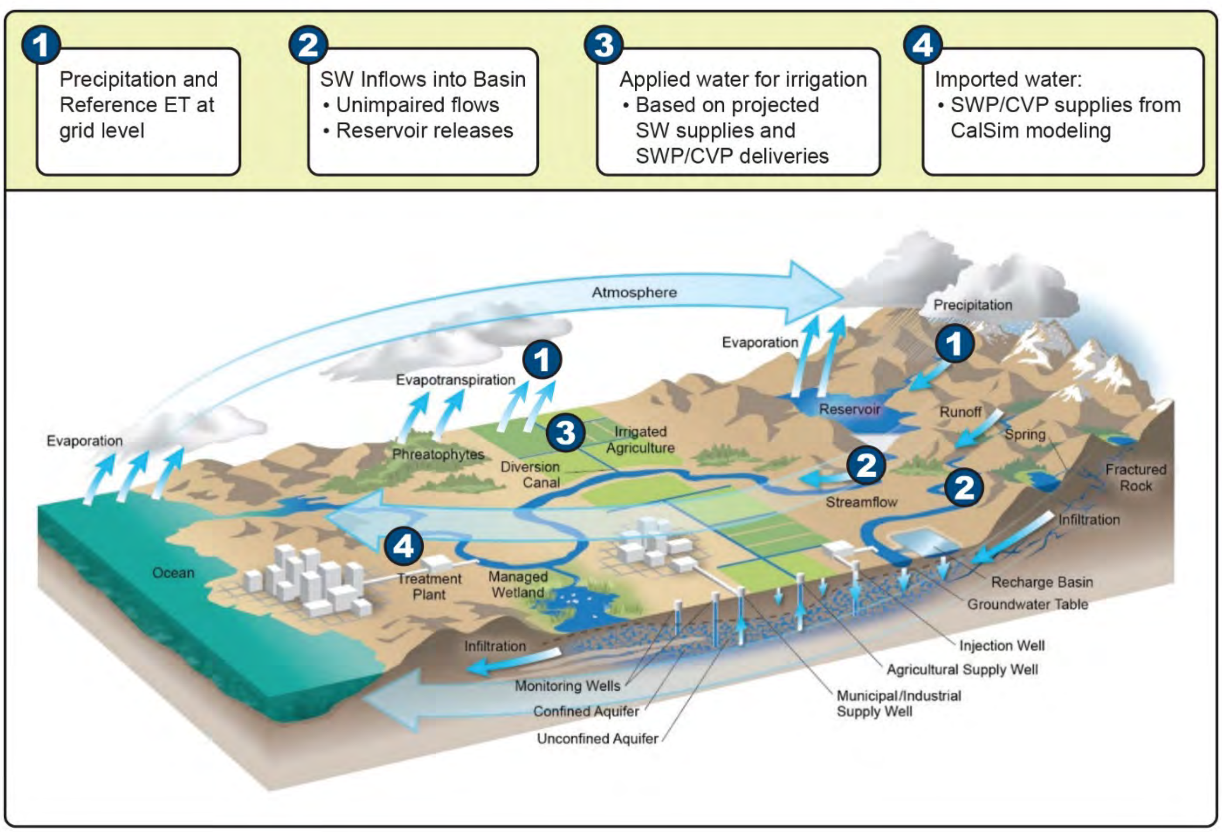
Based on the available climate change data provided by DWR as described in the Guidance Document, the projected water budgets can be developed for two future conditions using a climate period analysis as follows:

- Water budget representing conditions at 2030 with uncertainty (i.e., using 50 years of historical record representative of the range of inter-annual variability as a baseline).
- Water budget representing conditions at 2070 with uncertainty (using the same 50-year period as for 2030).

Projected water budgets will be useful for showing that sustainability will be maintained over the 50-year planning and implementation horizon.

Projected Water Budget Development Without a Numerical Model

The datasets described above can be incorporated into a spreadsheet-type water budget. The figure below illustrates the types of data that would need to be replaced in a historical water budget to develop a projected water budget for 2030 and 2070 conditions, including climate change assumptions, to satisfy SGMA requirements.



Climate Change Data Analysis Process

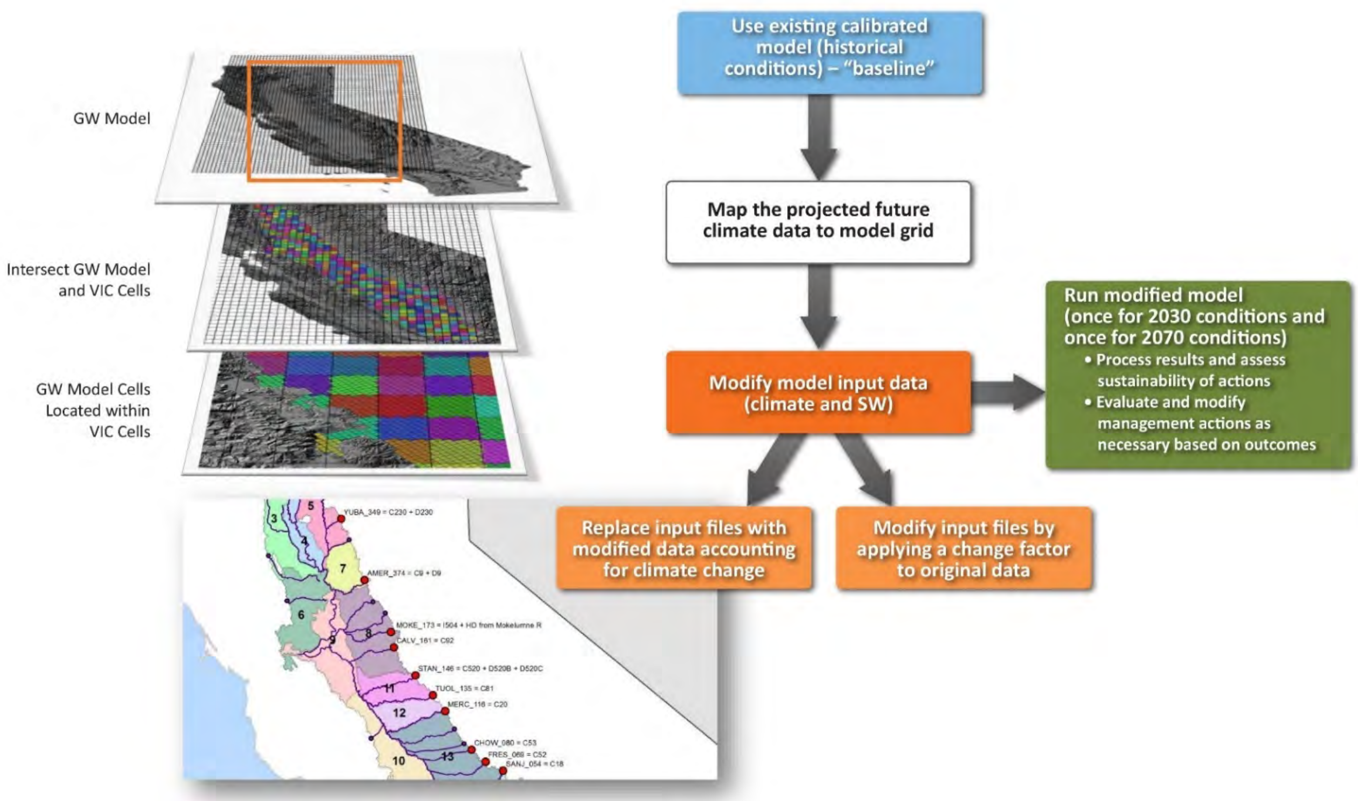
Projected Water Budget Development with a Numerical Model

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. Alternatively, if there is not an existing model for the groundwater basin or subbasin, a GSA can choose to develop a new groundwater or integrated hydrologic model. The modeling BMP provides guidance on the model development process as well as information on available model applications.

Once a numerical model is selected or developed, the next step is to modify the model input datasets for projected conditions. Due to uncertainty about future conditions, projected conditions are typically assessed using a baseline condition representative of a range of possible conditions.

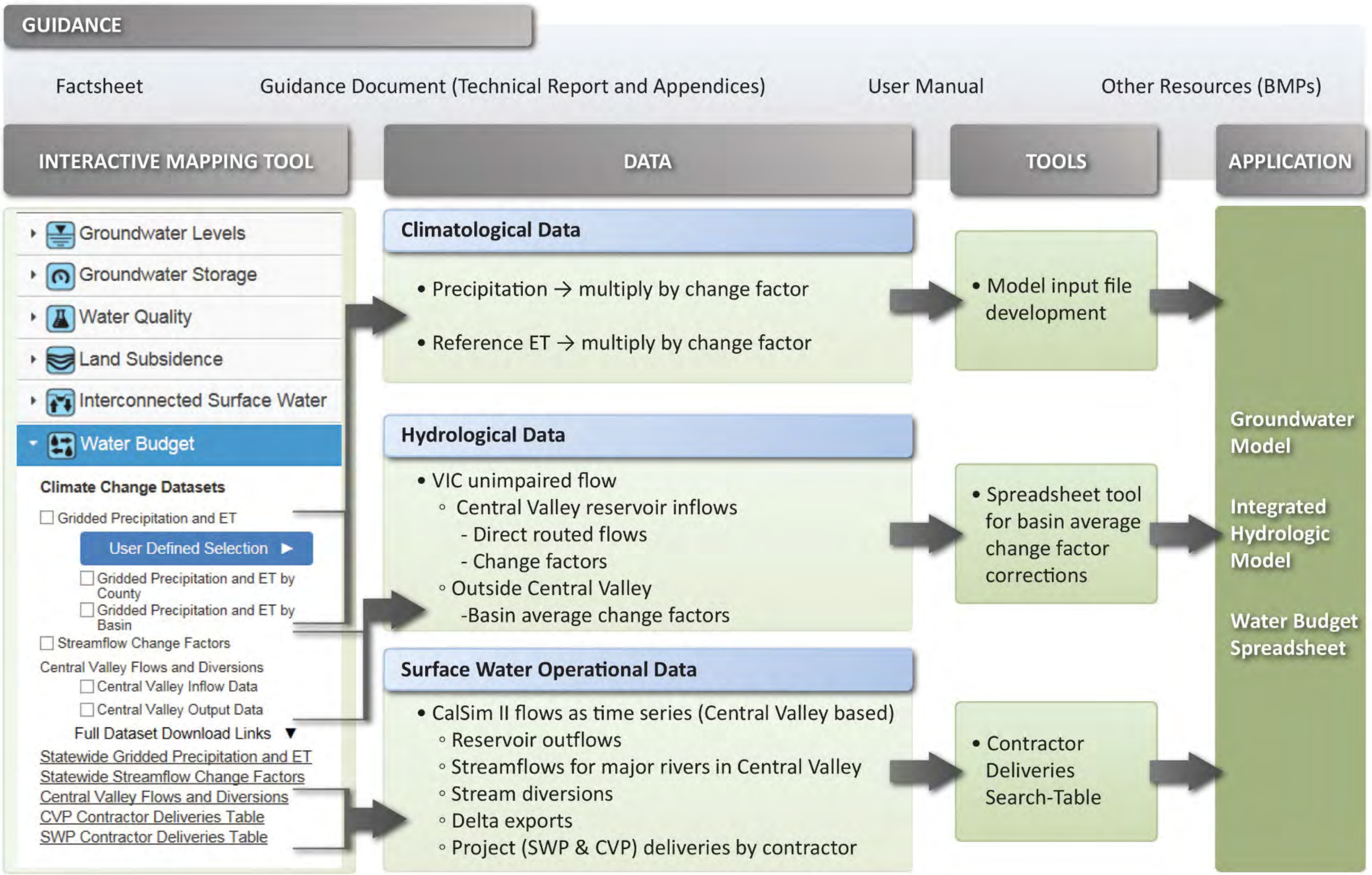
The provided climate change datasets are then used to perturb or replace applicable datasets in the baseline model for projected conditions. For model input datasets such as precipitation and evapotranspiration, all groundwater model grid elements or node locations need to be modified with the change factors from the corresponding VIC model grids. The figure below illustrates the process to incorporate the gridded climate change data (precipitation and ET change factors) into an existing numerical model for future climate change projections to simulate projected water budgets.

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



For input datasets such as stream inflow or surface water operations (diversions and deliveries), corresponding locations in the model need to be modified using the provided Central Valley flows and diversions, if applicable. Stream flow change factors corresponding to state-wide watersheds are also provided. In addition, projected water budgets using numerical models may take into account land use and water demand projection approaches for groundwater modeling and consider existing projections from state or local planning agencies, modified as needed to represent a specific study area and future conditions in the planning period.

Summary of Climate Change Data Analysis Process

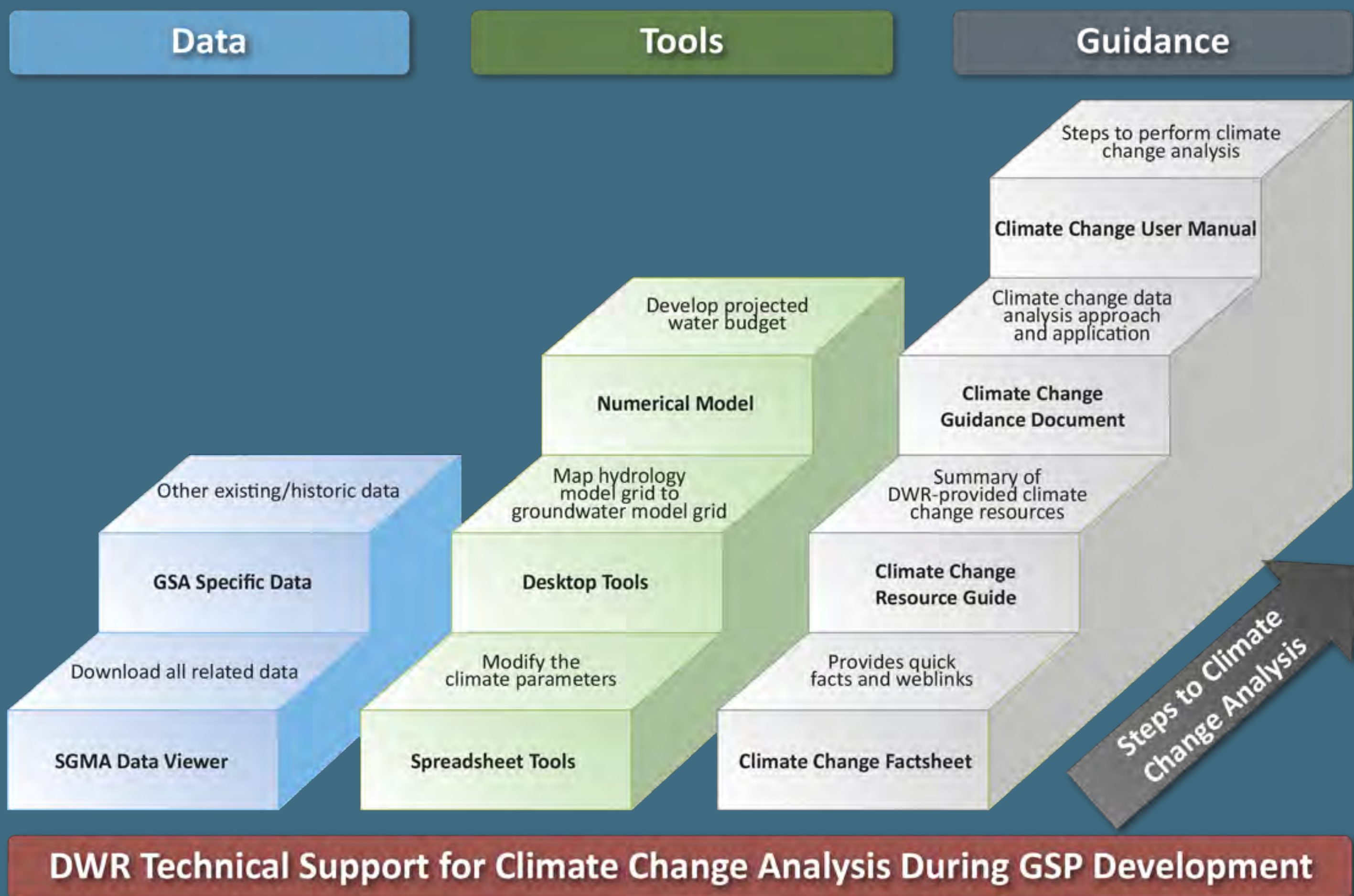


Resources

Table 2 provides an overview of all applicable DWR-provided resources related to climate change analysis under SGMA.

Table 2. Climate Change Data Application Resources

Data	• **SGMA Data Viewer:** This is an interactive, web-based mapping tool for downloading spatial data and associated time-series data. Available at: https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer • **SGMA Data Viewer Factsheet:** https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Data-and-Tools/Files/FAQ-and-Fact-Sheets/SGMA-Data-Viewer-Fact-Sheet.pdf
Tools	• **Second Order Correction Spreadsheet Tool:** This tool helps modify monthly change factors to more accurately reflect annual streamflow patterns present in the historical data • **Desktop IWFM/MODFLOW Tools:** These tools help map VIC model gridded precipitation and reference ET data to the correct groundwater model (for MODFLOW-based models) cells or elements (for IWFM-based models) **Tools are available at**: https://www.water.ca.gov/Programs/Groundwater-Management/Data-and-Tools
Guidance	• **Climate Change Factsheet:** the factsheet can be found online at https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Data-and-Tools/Files/FAQ-and-Fact-Sheets/SGMP-Climate-Change-Fact-Sheet.pdf • ***Guidance for Climate Change Data Use During Sustainability Plan Development***: The Guidance Document provides GSAs and other stakeholders with information about DWR-provided climate change datasets for use in GSPs. The document can be found at: https://www.water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Sustainable-Groundwater-Management/Best-Management-Practices-and-Guidance-Documents/Files/Climate-Change-Guidance---SGMA.pdf **Guidance Document Appendices:** • Appendix A: Methods and Approaches for Climate Change Modeling and Analysis, and California Applications • Appendix B: Reservoir and Local Inflows, CalSim II Output Data, and CVP/SWP Contractor Deliveries • Appendix C: Basin Average Streamflow Change Factor Method • **Climate Change Data User Manual**: This manual provides GSAs with recommendations and instructions for incorporating DWR-provided climate change data into water budget calculations, and numerical groundwater and integrated hydrologic models.
Other Resources	• **Water Storage Investment Program Technical Reference:** WSIP's Technical Reference can be found at https://cwc.ca.gov/Documents/2016/WSIP/WSIP_Data_and_Model_Product_Description_11-1-16.pdf. The Technical Reference supports physical and economic analysis of the public benefits of eligible water storage projects applying for WSIP grant funds. Appendix A includes the development of the climate change data to support this analysis. • **DWR-Provided Models**: Models such as IWFM, C2VSim, SVSim are general modeling tools provided by DWR, and include the integrated surface-water/groundwater models (i.e., IWFM and its Central Valley applications, C2VSim and SVSim) to facilitate simulation of current and future groundwater conditions. **Information on modeling tools is available at**: https://water.ca.gov/Programs/Groundwater-Management/Data-and-Tools



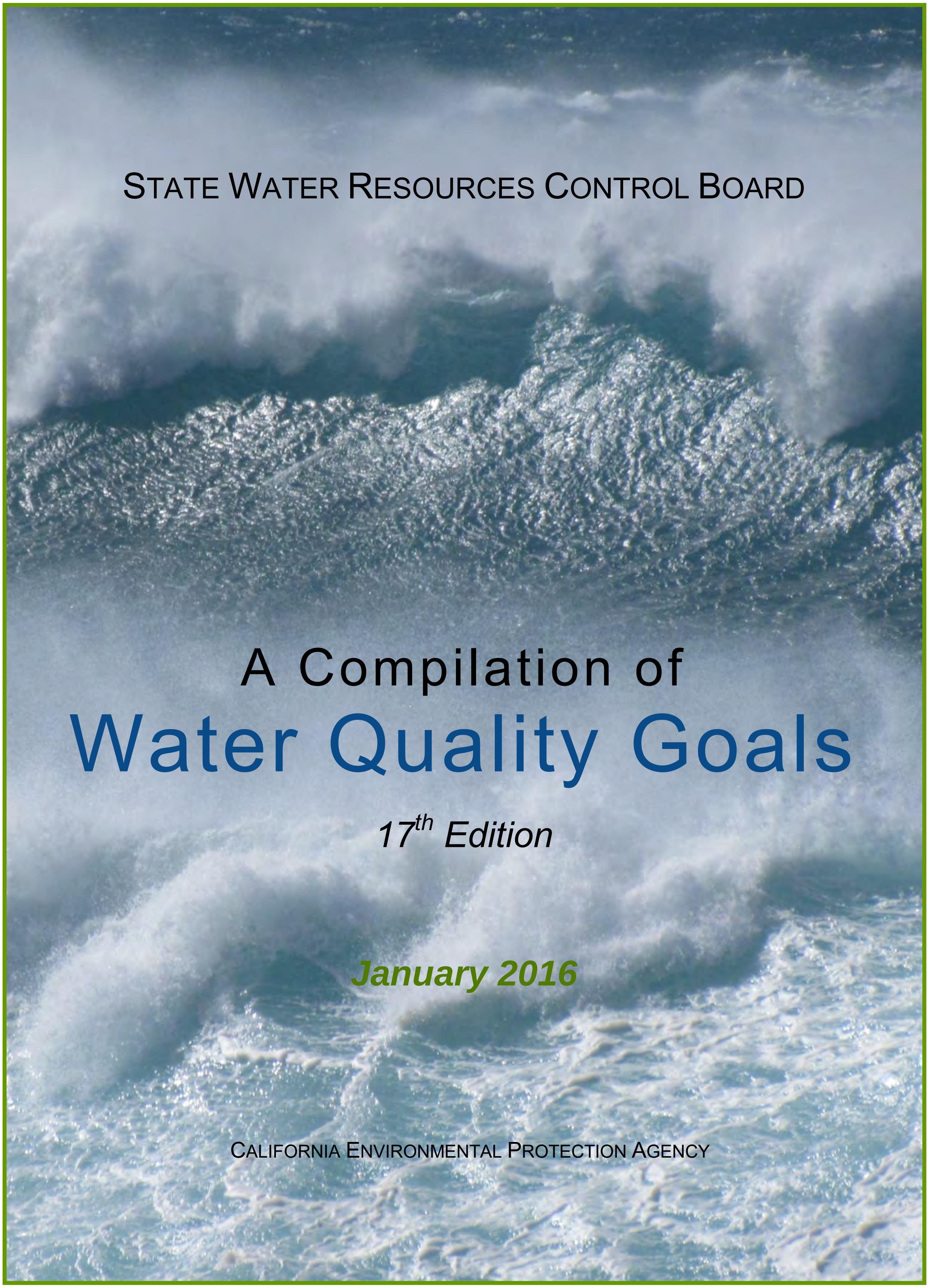
Data
Tools
Guidance
Steps to perform climate change analysis
Climate Change User Manual
Develop projected water budget
Numerical Model
Climate change data analysis approach and application
Climate Change Guidance Document
Other existing/historic data
GSA Specific Data
Map hydrology model grid to groundwater model grid
Desktop Tools
Summary of DWR-provided climate change resources
Climate Change Resource Guide
Download all related data
SGMA Data Viewer
Modify the climate parameters
Spreadsheet Tools
Provides quick facts and weblinks
Climate Change Factsheet
Steps to Climate Change Analysis
DWR Technical Support for Climate Change Analysis During GSP Development

Appendix 3

3A State Water Resources Control Board Water Quality Goals Compilation

3B Sustainable Management Criteria Best Management Practices

Appendix 3A State Water Resources Control Board Water Quality Goals Compilation



STATE WATER RESOURCES CONTROL BOARD

A Compilation of
Water Quality Goals

17th Edition

January 2016

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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A Compilation of

Water Quality Goals

17th Edition

January 2016

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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.

TABLE OF CONTENTS

LIST OF FIGURES

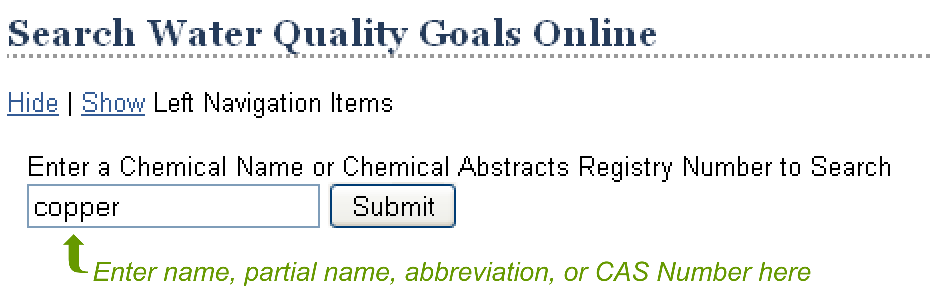
HOW TO USE WATER QUALITY GOALS ONLINE

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 up-dates 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.

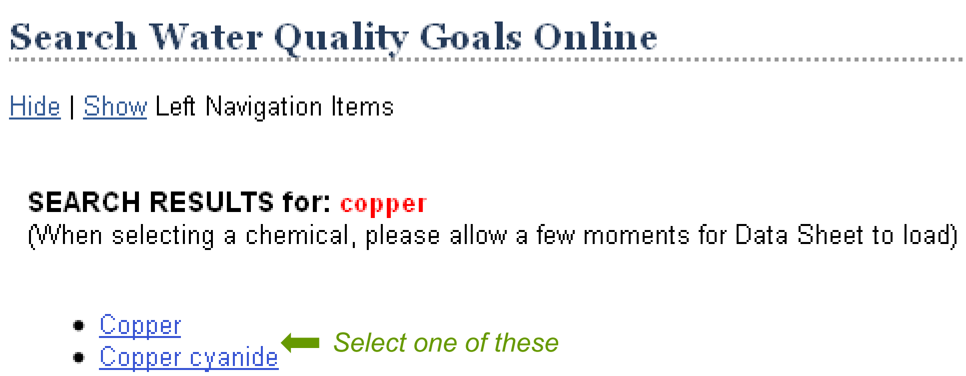
To avoid incorrect use of the numeric thresholds contained in the database, users are strongly encouraged to carefully review the following section, *Selecting Water Quality Goals*.

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.

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.

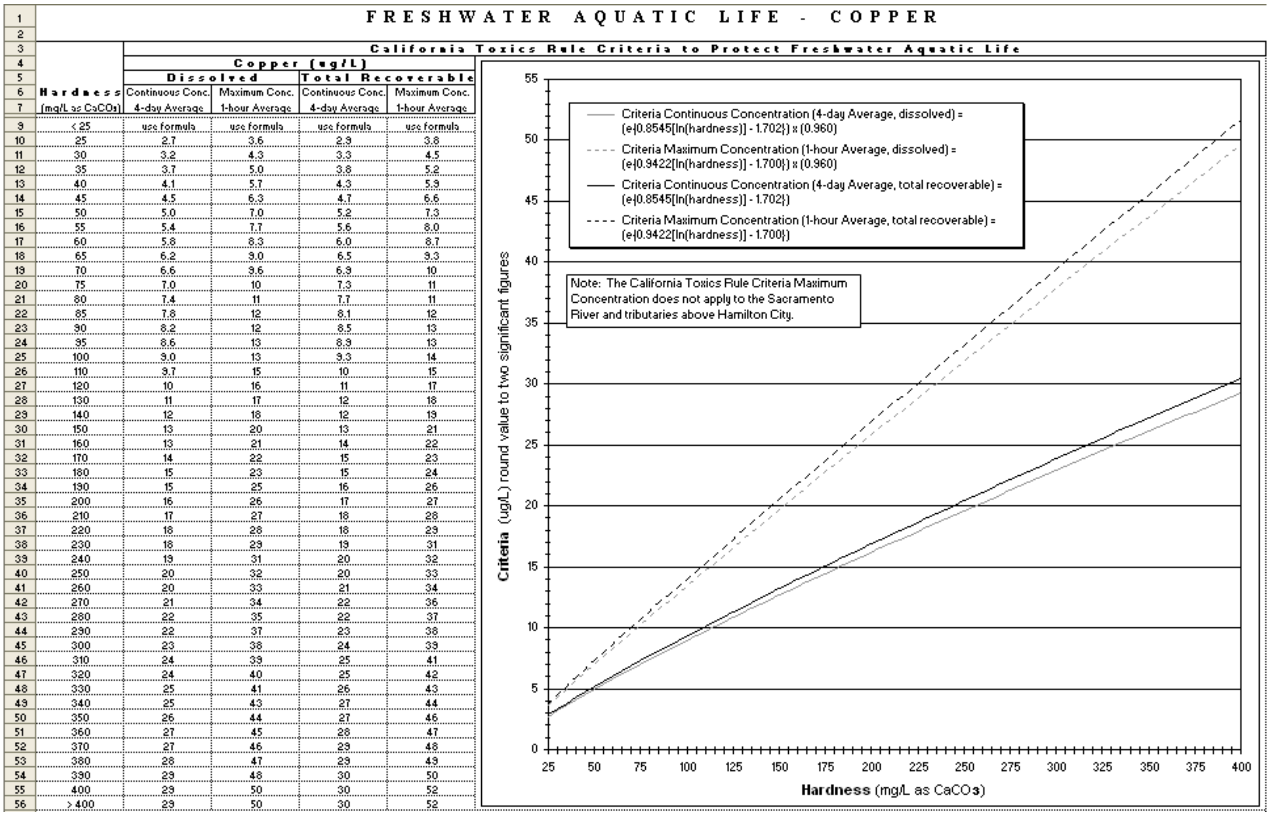
References:

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.

- ***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.

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.

- 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			
		Copper (ug/L)			
		Dissolved		Total Recoverable	
	Hardness (mg/L as CaCO3)	Continuous Conc. 4-day Average	Maximum Conc. 1-hour Average	Continuous Conc. 4-day Average	Maximum Conc. 1-hour Average
9	< 25	use formula	use formula	use formula	use formula
10	25	2.7	3.6	2.9	3.8
11	30	3.2	4.3	3.3	4.5
12	35	3.7	5.0	3.8	5.2
13	40	4.1	5.7	4.3	5.9
14	45	4.5	6.3	4.7	6.6
15	50	5.0	7.0	5.2	7.3
16	55	5.4	7.7	5.6	8.0
17	60	5.8	8.3	6.0	8.7
18	65	6.2	9.0	6.5	9.3
19	70	6.6	9.6	6.9	10
20	75	7.0	10	7.3	11
21	80	7.4	11	7.7	11
22	85	7.8	12	8.1	12
23	90	8.2	12	8.5	13
24	95	8.6	13	8.9	13
25	100	9.0	13	9.3	14
26	110	9.7	15	10	15
27	120	10	16	11	17
28	130	11	17	12	18
29	140	12	18	12	19
30	150	13	20	13	21
31	160	13	21	14	22
32	170	14	22	15	23
33	180	15	23	15	24
34	190	15	25	16	26
35	200	16	26	17	27
36	210	17	27	18	28
37	220	18	28	18	29
38	230	18	29	19	31
39	240	19	31	20	32
40	250	20	32	20	33
41	260	20	33	21	34
42	270	21	34	22	36
43	280	22	35	22	37
44	290	22	37	23	38
45	300	23	38	24	39
46	310	24	39	25	41
47	320	24	40	25	42
48	330	25	41	26	43
49	340	25	43	27	44
50	350	26	44	27	46
51	360	27	45	28	47
52	370	27	46	29	48
53	380	28	47	29	49
54	390	29	48	30	50
55	400	29	50	30	52
56	> 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.

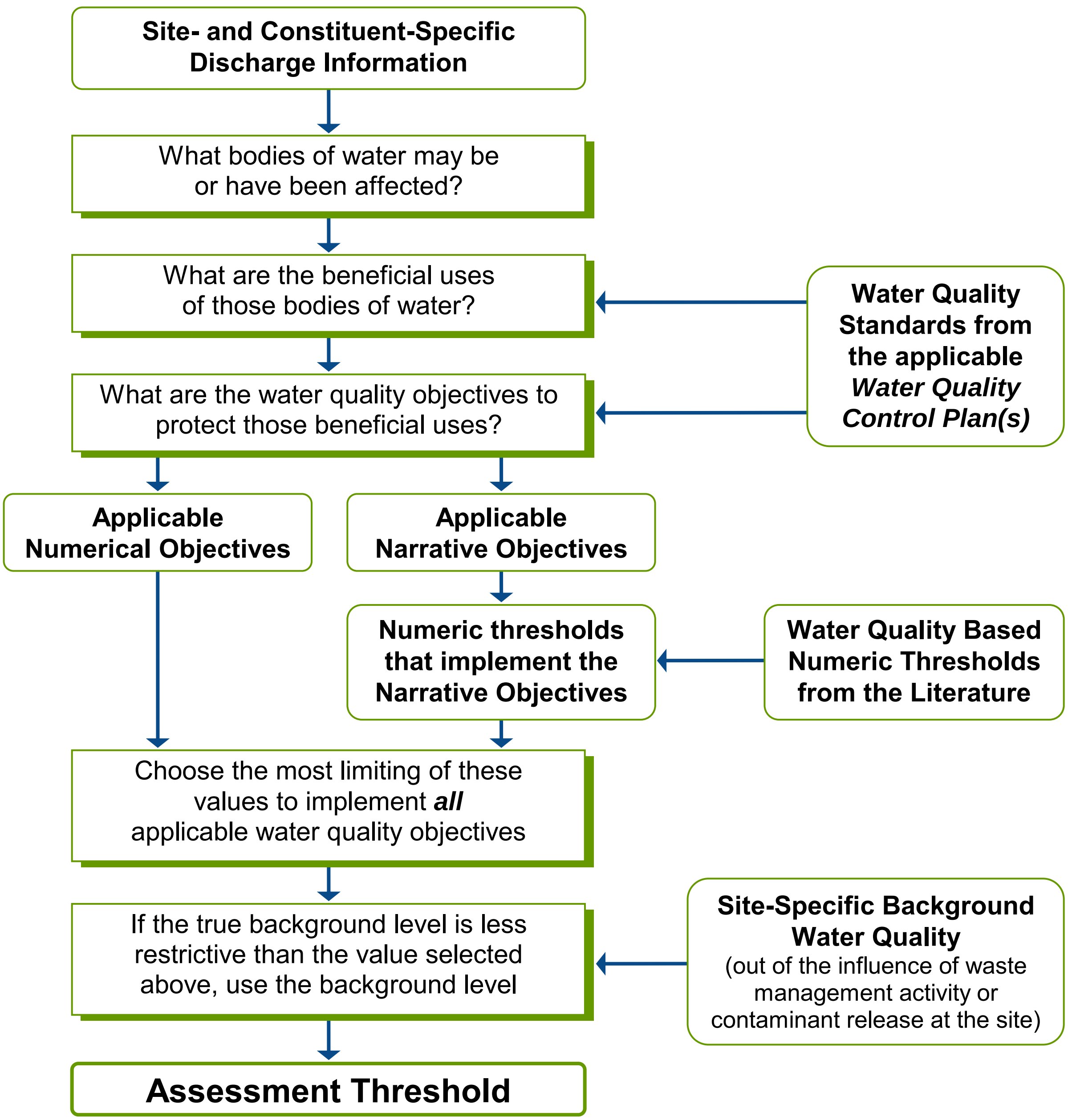
The first step is to identify the bodies of groundwater and/or surface water that have been or may be affected by the particular waste management activity or constituent release. These water bodies are often referred to as "receiving waters." Under California's Antidegradation Policy, it is important 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 $\frac{1}{1000}$ 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, $(mg/kg/day)^{-1}$. 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 $(mg/kg/day)^{-1}$. 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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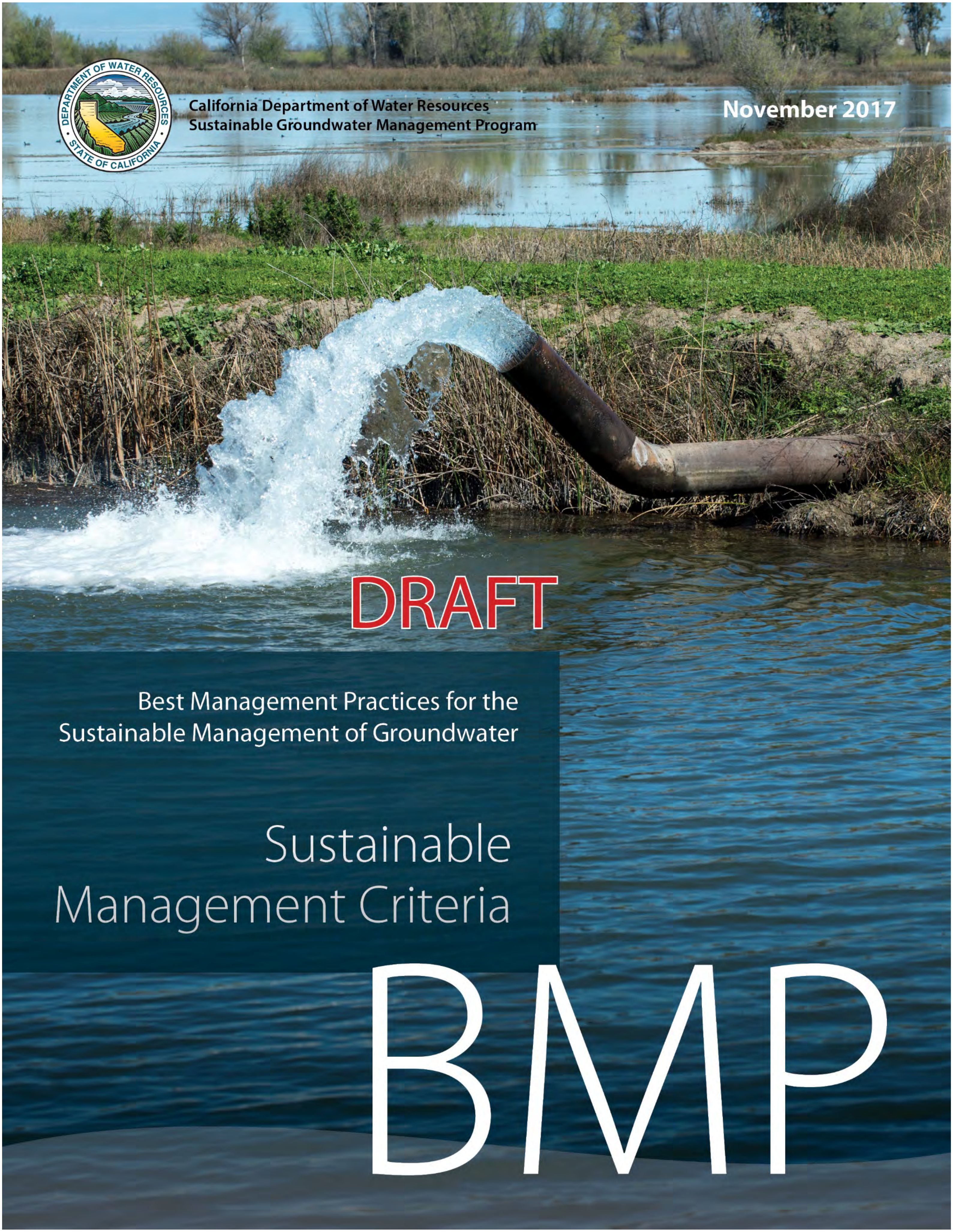
Appendix 3B Sustainable Management Criteria Best Management Practices



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.

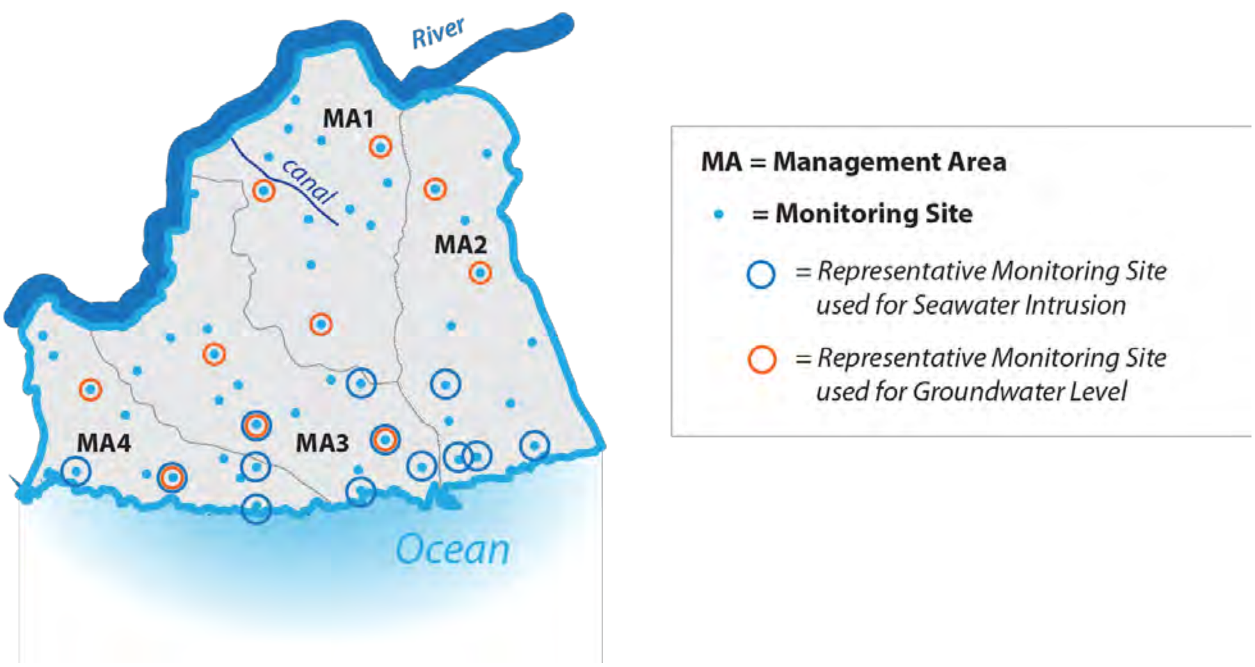

Figure 1. Example Monitoring Network and Representative Monitoring Sites

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.

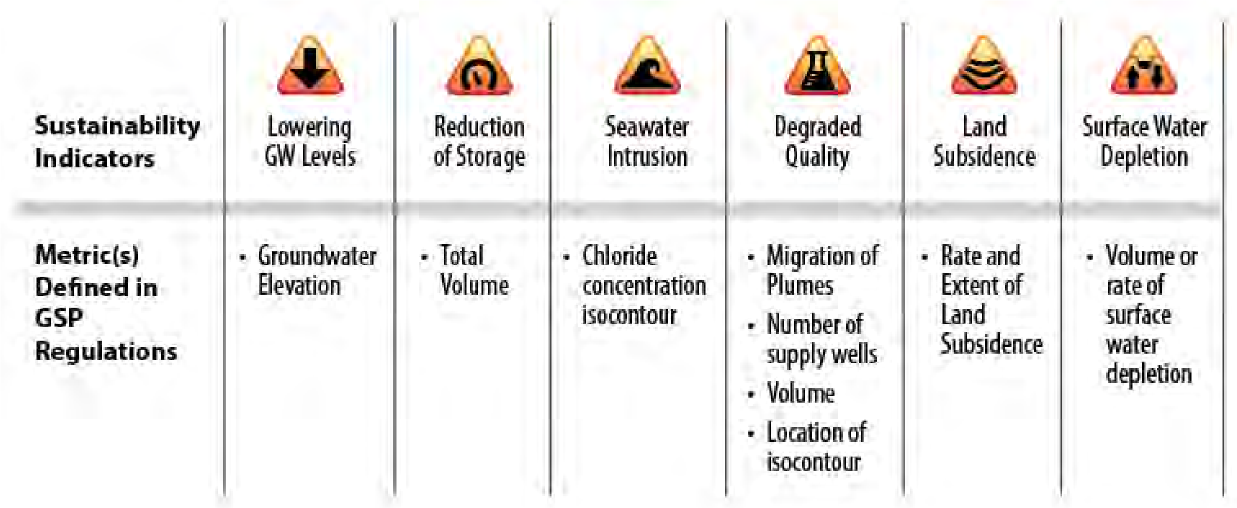

Figure 2. Minimum Threshold Metrics

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.

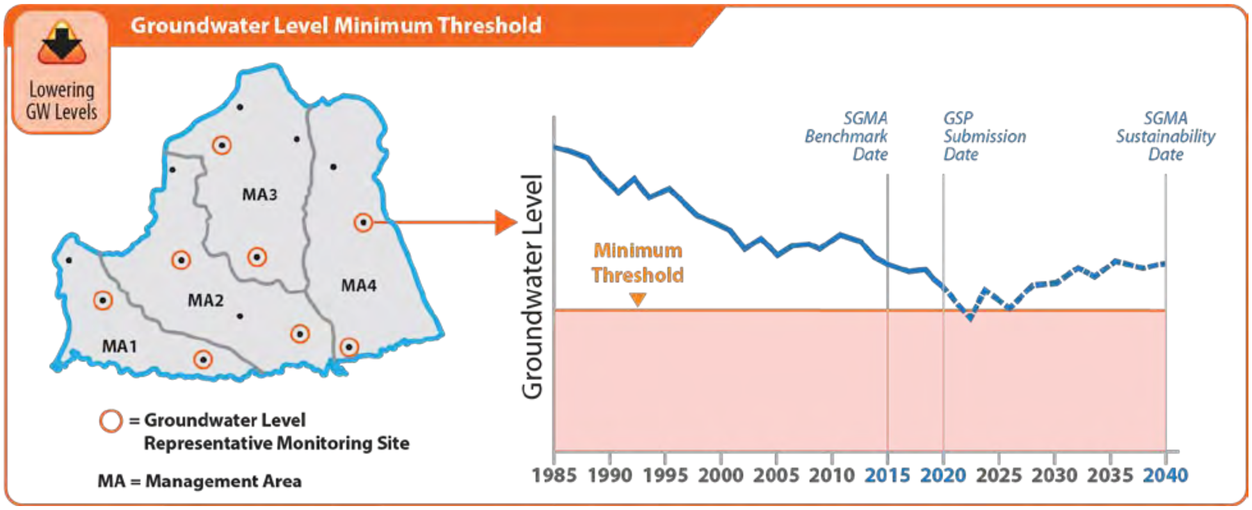

Figure 3. Example Groundwater Level Minimum Threshold Established at a Representative Monitoring Site

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.

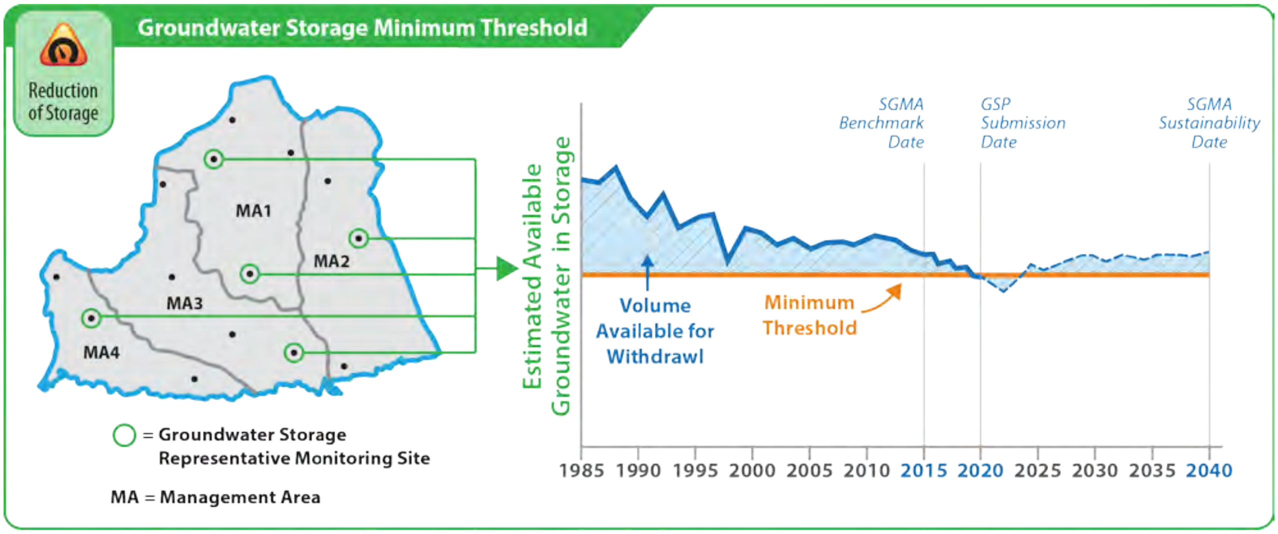

Figure 4. Example Groundwater Storage Minimum Threshold Established at the Basin Scale

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.

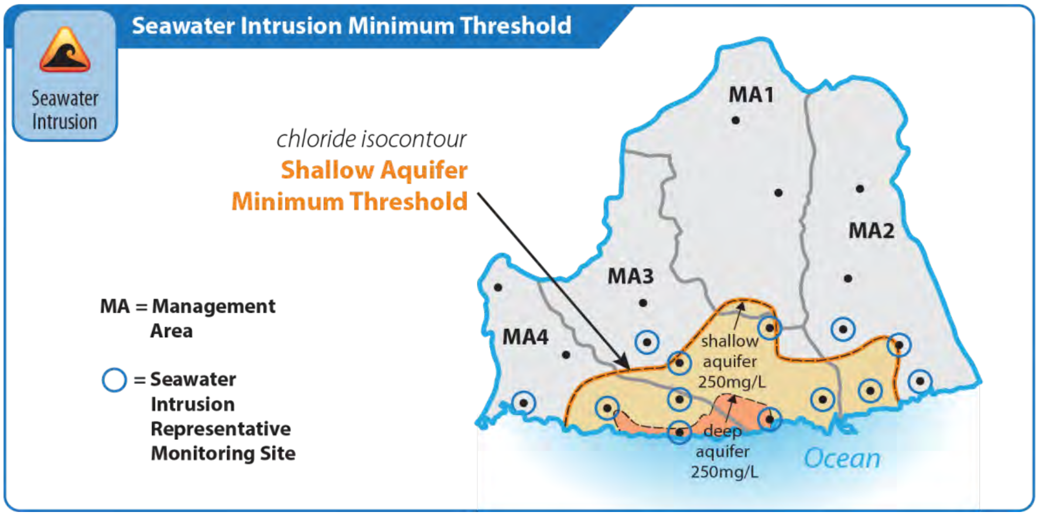

Figure 5. Example Seawater Intrusion Minimum Threshold Established at the Chloride Isocontour

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).

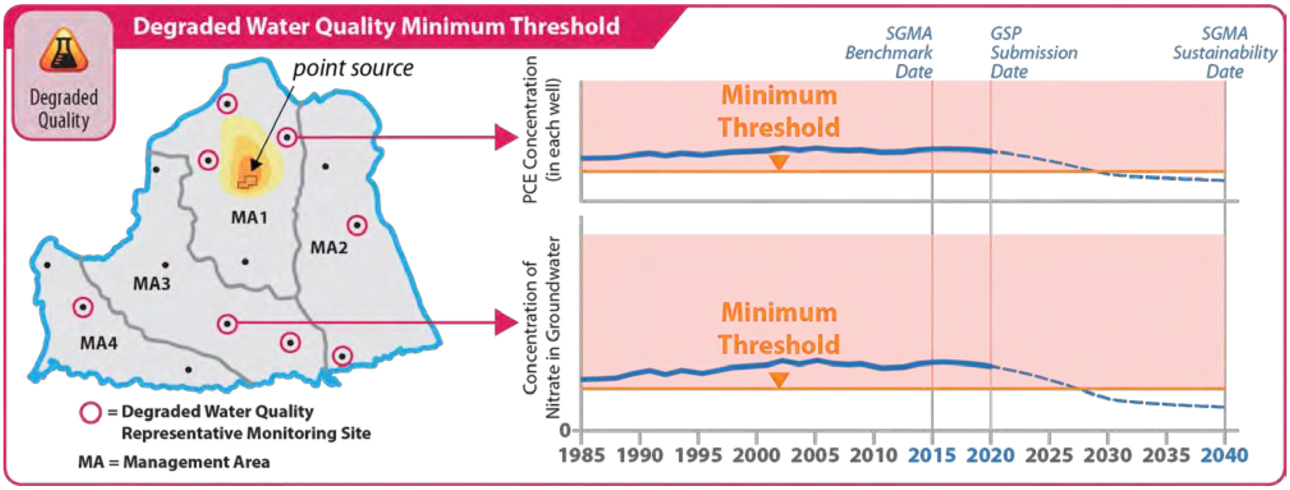

Figure 6. Example Degraded Water Quality Minimum Threshold Established for Point and Nonpoint Source Pollutants

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.

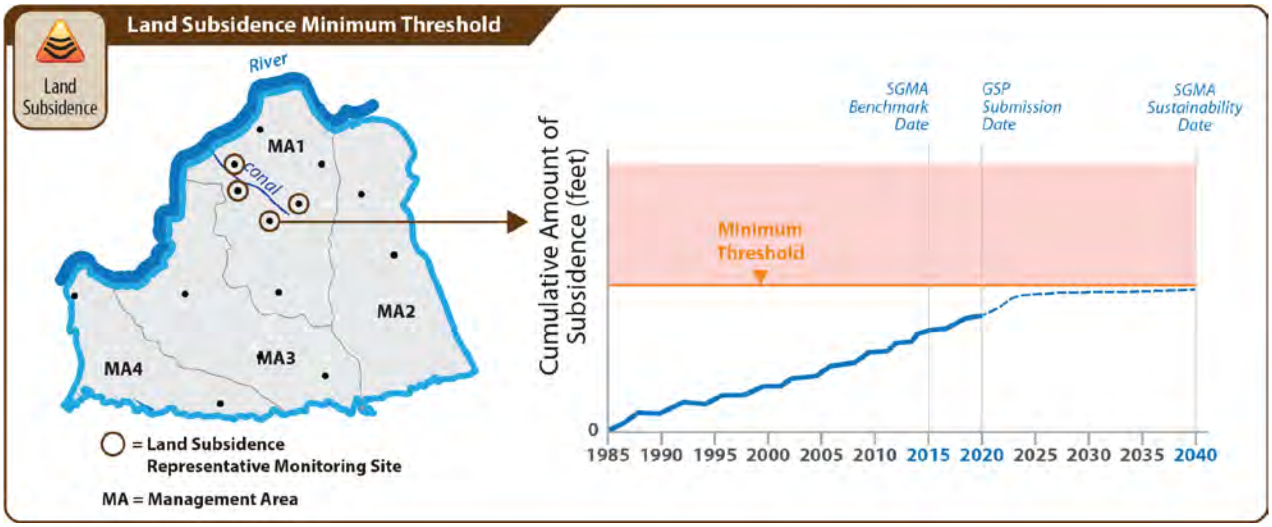

Figure 7. Example Land Subsidence Minimum Threshold

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.

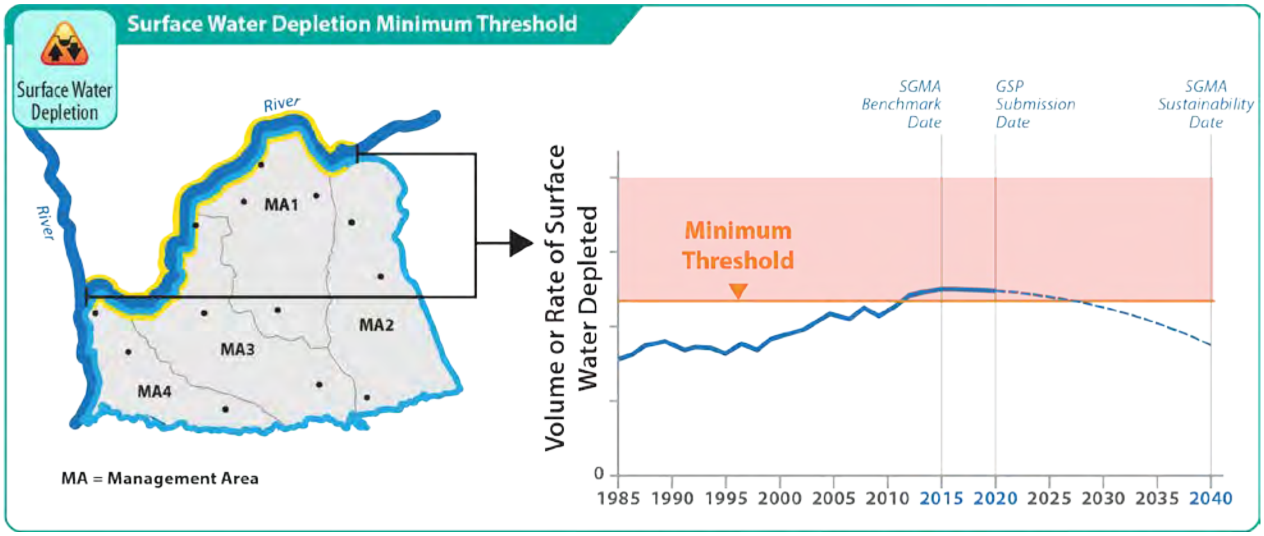

Figure 8. Example of Depletion of Interconnected Surface Water Minimum Threshold

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.

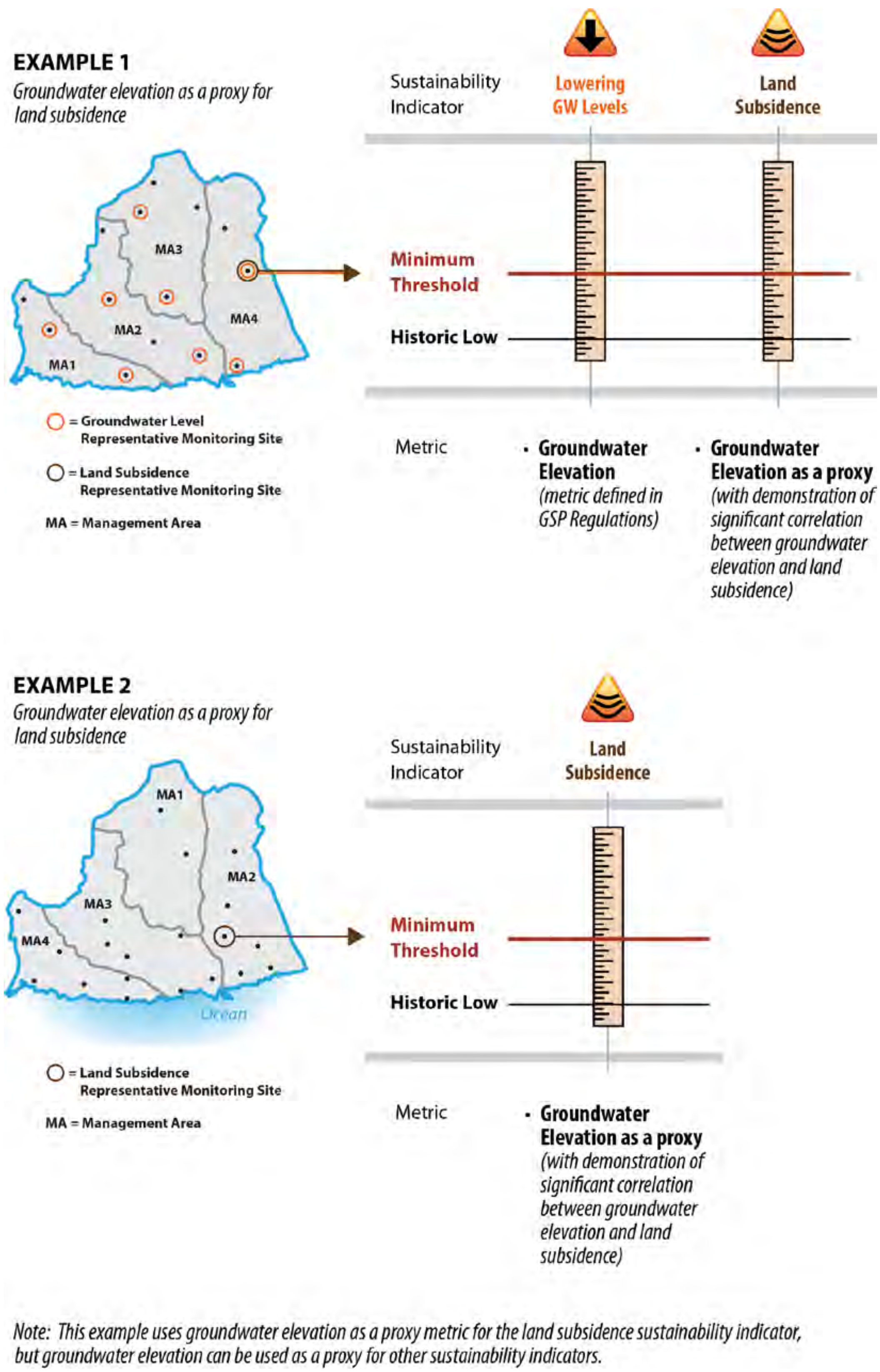

Figure 9. Example of Using Groundwater Elevation as a Proxy for Subsidence Monitoring

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.

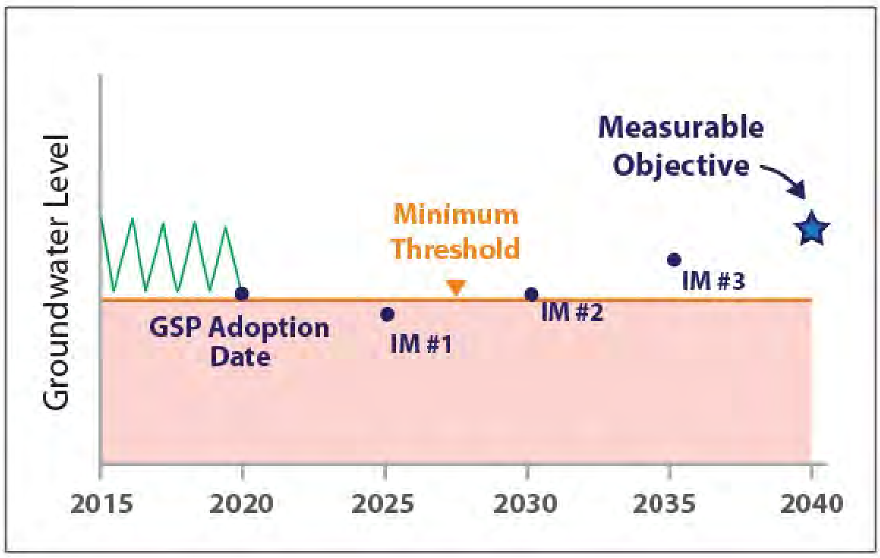

Figure 10. Example Minimum Threshold, Interim Milestones (IM), and Measurable Objective

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.

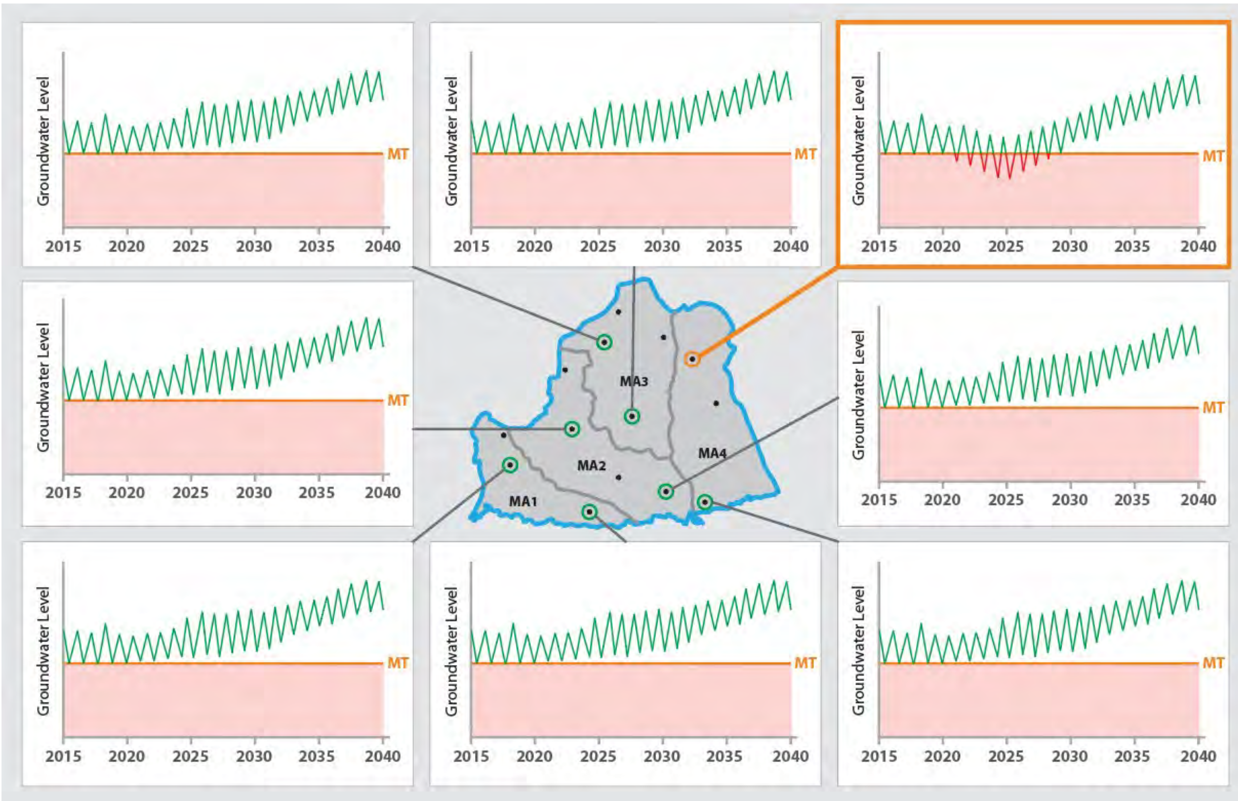

Figure 11. Example Groundwater Level Representative Monitoring Sites – Scenario 1

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.

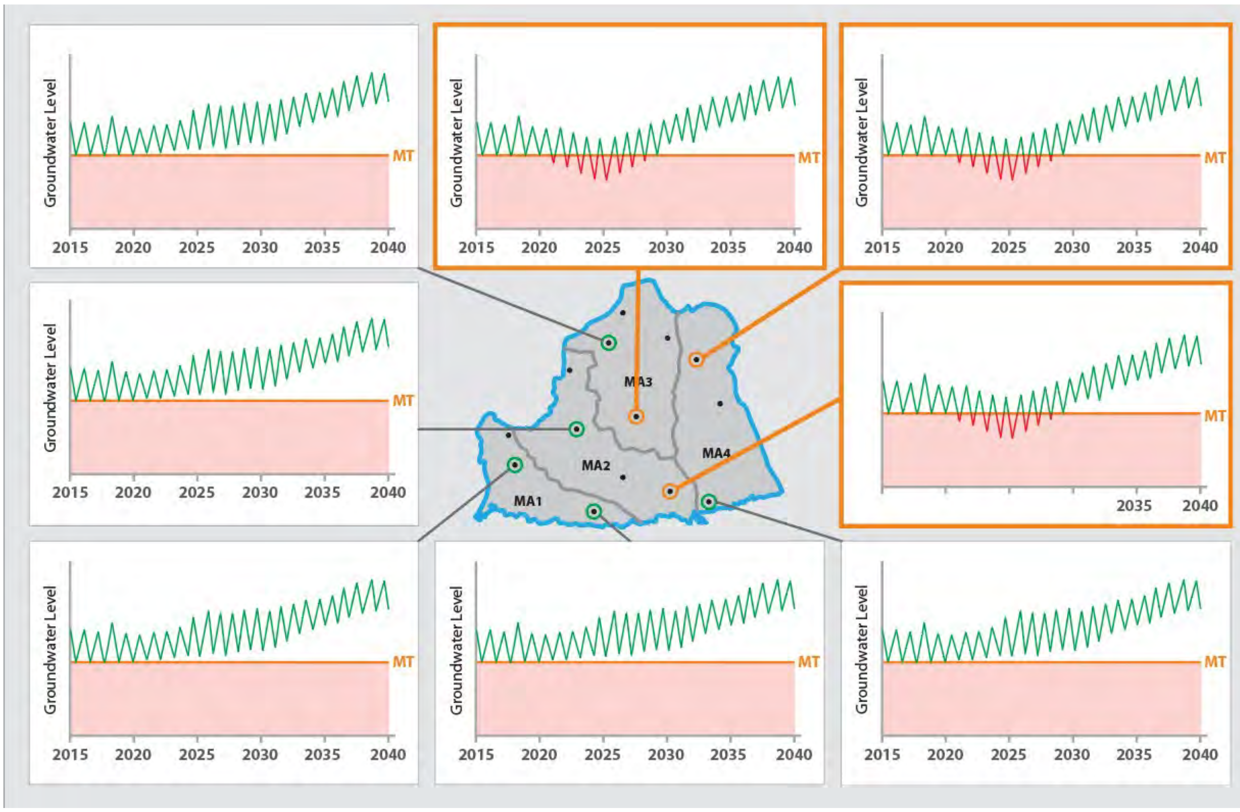

Figure 12. Example Groundwater Level Representative Monitoring Sites – Scenario 2

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.