Appendix E. California's Groundwater Update 2013 Technical Memorandum: Calculating Annual Change in Groundwater in Storage by Using Groundwater-Level Data

This technical memorandum describes the data, assumptions, and methodology used for calculating change in groundwater in storage by using groundwater levels, as developed by the California Department of Water Resources (DWR) for *California Water Plan Update 2013*. Specifically, this technical memorandum describes the data, assumptions, and methods used to analyze groundwater-level measurements, generate regional groundwater-level contour maps, and estimate the annual change in groundwater in storage within a groundwater basin or reporting area. For this analysis, custom geographic information systems (GIS) tools and workflows were developed and applied to groundwater-level data stored in the DWR Water Data Library (WDL). These estimates, prepared for *California Water Plan Update 2013*, are intended for use in evaluating basin-wide issues and not for conducting detailed local analysis that may be required for implementation of specific projects.

Introduction

Recommendations and feedback from *California Water Plan Update 2009* indicated a need for more transparent and reliable methods to estimate change in groundwater in storage. For *California Water Plan Update 2013*, GIS modeling is used to develop a method for estimating change in groundwater in storage by using groundwater-level data.

Summary/Background

Annual change in groundwater in storage, for the purposes of this document, is the difference in the volume of water in an aquifer from one year to the next. Change in groundwater in storage has been reported in past California Water Plan updates. In those updates, the reported change in storage number was the byproduct of calculations from land and water use surveys, that determined overall water use from a complex series of water balance formulas. For *California Water Plan Update 2013*, a standardized, repeatable, and transparent methodology to estimate change in groundwater in storage by using groundwater-level data was developed. This method uses groundwater-level measurements from monitoring wells, instead of estimates based on water demand.

The use of groundwater-level measurement data provides a relatively simple, repeatable, and transparent approach to measuring changes in groundwater levels and estimating change in groundwater storage. This method is intended to augment other ways of calculating change in groundwater in storage and is still being refined.

To make this approach transparent and repeatable, publically available groundwater-level data from the DWR WDL was queried and analyzed by using Environmental Systems Research Institute (ESRI) ArcGIS geoprocessing tools.

Groundwater-Level Data and Geographic Information Systems

A groundwater-level measurement collected from a single well provides groundwater-level information at a particular location, whereas measurements collected from multiple wells (as in a monitoring network) can provide information about the groundwater levels over a larger area or region. Changes in groundwater levels can be determined at a single well from repeated measurements, and changes in the groundwater level over a region can be determined from repeated measurements from multiple wells within that region. Change in groundwater in storage can then be estimated from changes in groundwater levels, if enough additional information is known about aquifer properties and the unconfined nature of the aquifer systems.

GIS is a system designed to manage, manipulate, analyze, and present geographical data, and is well-suited to analyze groundwater-level data collected from wells. Using custom-built GIS tools, a repeatable procedure was developed to process groundwater level measurements and estimate change in groundwater in storage. These GIS tools, along with a systematic process of implementing them, represent a workflow by which groundwater-level data is queried, filtered, and analyzed to determine regional groundwater elevations, annual changes in groundwater elevation, and annual change in groundwater in storage.

Change in Groundwater in Storage

Change in groundwater in storage describes the difference in groundwater volume between two time periods. In general, the change in groundwater storage is calculated by multiplying the difference in groundwater elevation between two monitoring periods, by the area overlying the groundwater basin, and by the average storativity (specific yield in an unconfined aquifer).

Change in Groundwater in Storage = Overlying Area x ($GWE_{t0} - GWE_{t1}$) x Specific Yield,

Where

GWE_{t0} = Groundwater elevation monitoring period one,
GWE_{t1} = Groundwater elevation monitoring period two.

For this application, groundwater-elevation surfaces were created from measured groundwater elevation data by using GIS, where each surface is representative of groundwater levels for a region at a given time period. The volume, or space, created between two different surfaces represents the change in groundwater elevation between the two time periods. This volume was calculated using GIS. The calculated volume was then multiplied by minimum and maximum specific yield values that resulted in the minimum and maximum estimated change in groundwater in storage between two time periods.

Spring-to-spring changes are used because spring months in California generally represent the highest groundwater table conditions for the year.

A more detailed description of estimating the change in groundwater in storage is provided in the "Using Groundwater-Level Data to Estimate Change in Groundwater in Storage" section of this technical memorandum.

Data Types and Availability

The process of calculating the change in groundwater in storage by using groundwater-level data requires well data, groundwater-level measurement data, and hydrogeologic data. Information about the quality of the data is also needed to assess the quality of the results. Data and quality information are obtained from a variety of sources, including well completion reports (WCRs) and other reports filed after the construction of the well, field data collected as part of a monitoring program, and special studies.

Well Data

Well data consist of information describing the well's location, construction details, and type of well use. Other well data may include information about the materials encountered while drilling and more detailed information about specific hydrologic properties of the water-bearing formations.

Well Completion Reports

A WCR (currently DWR Form 188) is required by California Water Code Section 13751(a) to be completed by the driller and submitted to DWR each time a new well is installed. A WCR contains basic information about the well's intended use, location, construction, owner, and driller. A section of the WCR, known as the well log, contains information about the subsurface materials encountered during drilling of the well borehole.

The well location and construction details provide spatial information directly related to the water-level measurements collected at the well. Information about the well type, well use, and construction date, also contained in the WCR, can be important for evaluating the quality of the data collected at the well.

Other Well Information

In addition to WCRs, other well data may be available. This information is sometimes contained in special reports prepared when a well or monitoring network is installed, and may include geophysical surveys, historical information, or other data. This other data can provide useful information about the quality of collected groundwater-level data.

Well Data Availability and Quality

Since 1977, approximately 430,000 WCRs have been submitted to DWR. Only the wells that have been, or are currently being, monitored for groundwater level are entered into the DWR WDL database. For any given well, the available data varies. Ideally, a WCR is completed and filed with DWR, the well location and elevation is surveyed, and there is supplemental information about the hydrogeology (such as a geophysical survey). Unfortunately, few of the more than 40,000 wells entered into the DWR WDL database contain this degree and quality of information. For a typical well, a WCR exists and some of the well construction information is available (such as well depth). The well location data is typically accurate to within 30 feet to 35 feet. Unfortunately, many wells within the database lack well construction data (or the data is not currently loaded into the database) and the exact well location has not been confirmed in the field. For a well with insufficient data, it may be possible to characterize the water-level data by comparing the well's water-level measurements with those of a neighboring well that has more available data. More details are available in the "Using Groundwater-Level Data to Estimate Change in Groundwater in Storage" section.

Groundwater-Level Data

Groundwater levels are a key indicator of groundwater basin and aquifer conditions. Groundwater-level data can be used to make interpretations regarding hydrogeology, groundwater flow, groundwater supply and sustainability, land use, and so forth. Groundwater levels fluctuate seasonally because of various inputs and outputs, such as the amount of precipitation, evapotranspiration, and groundwater pumping. Frequent groundwater-level measurements provide more detail regarding the seasonal groundwater-level fluctuations and aquifer conditions.

Depending on the scope, intent, and goals of a well-monitoring network, the measurement frequency can range from multiple times an hour to once a year, or longer. Some groundwater-level records include years of data gaps or stop altogether because of lack of funding, well conditions, or site and well access issues.

Groundwater-level data are collected by DWR, staff from local agencies, and other individuals. Groundwater-level data consists of water-level measurements collected from wells and qualitative information recorded when the measurement was collected. Water levels are measured from a fixed point on the well casing, known as the reference point, by using one of a variety of instruments such as a steel tape, electronic sounder, acoustic sounder, or pressure transducer. Qualitative information indicates conditions that may make a measurement questionable or record the reason a measurement was not collected during a site visit.

DWR Water Data Library (WDL) Groundwater-Level Database

Groundwater-level data is loaded and managed in an Oracle database referred to as the DWR WDL Groundwater Module. Data that was not loaded into the WDL was omitted from *California Water Plan Update 2013* change in groundwater storage estimates.

California Statewide Groundwater Elevation Monitoring Program Data

The California Statewide Groundwater Elevation Monitoring (CASGEM) Program was implemented by DWR in 2011 after the completion of the change in groundwater in storage analysis described in this technical memorandum. It is important to note that the DWR WDL was updated to accommodate CASGEM data. As a result, future analysis, conducted as described in this technical memorandum, will include CASGEM water-level data in addition to other water-level data collected and stored in the WDL.

Spatial and Temporal Aspects of Groundwater-Level Data

An individual groundwater-level measurement is unique in both space and time, and multiple measurements from a single well depict groundwater-level changes over time at a location. Furthermore, a collection of groundwater-level measurements from a well network are used to assess how groundwater levels change over time and over a region.

It is especially important to consider the spatial and temporal aspects of well data as part of any complicated analysis, such as estimating the change in groundwater in storage, as this can affect the ability to conduct analysis in some regions or for some time periods.

Groundwater-Level Data Availability

The availability of statewide groundwater-level data is variable from region to region over time. For *California Water Plan Update 2013*, spring groundwater-level data was analyzed for the years 2005 through 2010. Water-level data collected from groundwater basins and subbasins was evaluated and it was determined that the WDL did not have sufficient groundwater-level data for regions outside the Central Valley to reliably evaluate change in groundwater in storage. For most areas within the Central Valley, sufficient groundwater-level data exists in the WDL to estimate change in groundwater in storage. Regions within the Central Valley that lack sufficient groundwater-level data include the Delta and portions along the west side and other areas of the San Joaquin Valley.

It is recognized that groundwater-level data may have been collected in these regions, but this data was not provided to DWR.

Hydrogeologic Data

Storage Coefficients and Other Aquifer Properties

Storativity describes the volume of water released from, or taken into, storage in an aquifer per unit surface area per unit change in hydraulic head. Storativity values are unit-less (although sometimes expressed as a percentage) and are influenced by factors such as porosity, mineral grain size, aquifer compaction, cementation, and water quality. In an unconfined aquifer, storativity is approximately equal to the specific yield. *Specific yield* represents the water-yielding capacity of a material and is defined as the ratio of the volume of water that will drain by gravity from a saturated rock or soil compared to the total volume of rock or soil.

Specific yield values can be used to determine the amount of groundwater in storage, or the change in groundwater storage, within a given volume of aquifer material. Specific yield value(s) representative of the aquifer material are required for this type of analysis, since unrepresentative specific yield value(s) would result in an inaccurate determination of the change in groundwater storage.

Methods of Determination

Specific yield values can be determined in the field or laboratory using direct or indirect methods. Direct methods divide the measured volume of water that drains from a volume of saturated material, by the volume of the saturated material. Indirect methods involve determining the specific retention (the percentage of water that will not drain from a saturated material) of a known volume of material after gravity drainage, then subtracting that value from the porosity of the material.

WCRs or driller logs may also be used to estimate aquifer porosity, or specific yield, by evaluating the lithologic log in WCRs. Various methods and assumptions related to determining the specific yield of materials are discussed in DWR Bulletin Number 45 (Eckis, 1934). Estimating specific yield values using driller logs are discussed in DWR Bulletin Number 45 (Eckis, 1934), U.S. Geological Survey (USGS) Water Supply Paper 1497 (Olmsted and Davis, 1961), USGS Water Supply Paper 1662-D (Johnson, 1967), and the Report of Referee (California State Water Rights Board, 1962). The various methods of determining specific yield involve different assumptions and limitations. These assumptions and limitations may produce associated errors in the estimation of specific yield values. USGS Water Supply Paper 1662-D (Johnson, 1967) includes a discussion of these error-related issues.

Availability and Application of Specific Yield Data

Many reports, groundwater models, and other scientific documents publish specific yield data for many of California's groundwater basins. Because of the broad regional scope of estimating annual change in groundwater in storage for *California Water Plan Update 2013*, specific yield data gathered and reported for large regions of the state can be useful in lieu of pulling and aggregating information together from many smaller regions.

After evaluation of existing reports and models, specific yield values from two vetted models were adapted for use for the work described in this technical memorandum; the DWR 2013 California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) and the USGS 2009 Central Valley Hydrologic Model (CVHM). Data from these models were evaluated because they both provide specific yield values for the Central Valley in a geospatial format readily useable in GIS. It was necessary to conduct the change in groundwater in storage analysis using a range of specific yield values (expressed as a minimum and maximum).

Alternative Methods Used to Calculate Change in Groundwater in Storage

A variety of methods exist to estimate change in groundwater in storage. The myriad of methods used to estimate change in groundwater in storage can be generalized into three categories: those that use groundwater-level data exclusively; those based on water balances, water budgets, or modeling; and those that use remote sensing. Examples from each of these categories are provided in the following paragraphs.

Other Methods that use Groundwater-Level Data

USGS Scientific Investigations Report 2012-5291

The USGS report, *Water-Level and Storage Changes in the High Plains Aquifer, Predevelopment to 2011 and 2009-11* (2013, McGuire, Virginia L. USGS Scientific Investigations Report: 2012-5291), uses groundwater-level measurements to present water-level changes in the High Plains aquifer from the time before substantial groundwater irrigation development began (generally before 1950, and termed "predevelopment" in the report) to 2011, and from 2009 to 2011. Similar to the approach outlined in this technical memorandum, groundwater-level data was processed using GIS tools. Groundwater elevations from 2009 and 2011were characterized using rasterized surfaces (developed with GIS) for predevelopment. These rasterized surfaces were processed to determine the saturated thickness and changes in the saturated thickness of the aquifer. Specific yield values of the aquifer were determined and used to process the changes in groundwater storage based on the change in saturated aquifer thickness.

Methods that use Water Balance/Budget/Modeling

DWR C2VSIM (2013) and USGS CVHM (2009)

The C2VSim is an integrated numerical model that simulates water movement through the linked land surface, groundwater, and surface water flow systems in California's Central Valley. The C2VSim model contains monthly historical stream inflows, surface water diversions, precipitation, and land use and crop acreages from October 1921 through September 2009. C2VSim dynamically calculates crop water demands, allocates contributions from precipitation, soil moisture and surface water diversions, and calculates the groundwater pumpage required to meet the remaining demand. The model simulates the historical response of the Central Valley's groundwater and surface water flow system to historical stresses, and can also be used to simulate the response to projected future stresses. C2VSim was developed using the Integrated Water Flow Model Version 3.02. C2VSim is capable of reporting change in groundwater in storage. More information is available online at http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm.

The CVHM was developed by the USGS and is an extensive, detailed three-dimensional (3-D) computer model of the hydrologic system of the Central Valley (Faunt et al. 2009). The CVHM simultaneously accounts for changing water supply and demand across the landscape, and simulates surface water and groundwater flow across the entire Central Valley (http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html). The development of the CVHM comprised four major elements: (1) a comprehensive GIS to compile, analyze, and visualize data, (2) a texture model to characterize the aquifer system, (3) estimates of water-budget components by numerically modeling the hydrologic system with the Farm Process, and (4) simulations to assess and quantify hydrologic conditions. More information is available in the USGS report, *Groundwater Availability of the Central Valley Aquifer, California* (http://pubs.usgs.gov/pp/1766/PP_1766.pdf).

Methods that use Remote Sensing

NASA Gravity Recovery and Climate Experiment

The primary goal of the Gravity Recovery and Climate Experiment (GRACE) (http://science.nasa.gov/missions/grace/) mission is to accurately map variations in the earth's gravity field. The GRACE mission has twin satellites flying about 220 kilometers (137 miles) apart in a polar orbit 500 kilometers (310 miles) above the earth.

As the pair circles the earth, areas of slightly stronger gravity (greater mass concentration) will affect the lead satellite first, pulling it away from the trailing satellite, then as the satellites continue along their orbital path, the trailing satellite is pulled toward the lead satellite as it passes over the gravity anomaly. By making accurate measurements of the distance between the two satellites, using geodetic-quality Global Positioning System (GPS) receivers and a microwave ranging system. This provides scientists all over the world with an efficient and cost-effective way to map the earth's gravity fields with great accuracy. The results from GRACE yield important information about the distribution and flow of mass within the earth and its surroundings.

GRACE can be used to estimate variations in total water storage and groundwater storage changes. But, using GRACE data in the Central Valley aquifer can be challenging because of the coarse spatial resolution. Climate variability also alters precipitation, groundwater recharge, and pumping practices. A statistical downscaling approach was applied to GRACE data at the sub-region level and then applied to the downscaled GRACE estimates to investigate the influence of climate variability, such as from the El Niño Southern oscillation and Pacific Decadal oscillation. Downscaling GRACE-derived groundwater storage estimates using C2VSim data was successful using linear models at the sub-region level. The incorporation of downscaling for estimating variations in groundwater storage in highly productive aquifers may improve water management techniques in California.

More information on downscaling GRACE is available online at http://www.earthzine.org/2012/08/13/downscaling-grace-data-in-the-central-valley-aquifer-in-california/.

Using Groundwater-Level Data to Estimate Change in Groundwater in Storage

Synopsis

DWR is implementing a new process to analyze groundwater-level data, report groundwater levels, report changes in groundwater levels, and calculate change in groundwater in storage over time. This technical memorandum describes the applied methods and assumptions.

Goals and Approach

The primary goal of this process is to analyze groundwater-level data to estimate the annual change in groundwater in storage using groundwater levels measured from wells with a repeatable and transparent workflow. Reports will be comparable, as much as practicable, to other methods of estimating change in groundwater in storage.

To meet the goal, an automated procedure to query, analyze, and report groundwater-level data was developed using ESRI map-based ArcGIS software. Using GIS software also facilitated data quality assurance and quality control by enabling the data to be viewed in a map with associated attribute information. The automated process is the implementation of numerous custom designed GIS geoprocessing tools operated in a highly organized workflow. This approach is intended to provide the most direct depiction of the available groundwater-level data, minimizing bias.

Assumptions and Other Key Concepts

A number of important assumptions allow direct handling of groundwater-level data in the process workflow. These assumptions enable the process workflow to produce more reliable results and ensure the repeatability of the analysis.

Assumptions

1. *All Data must Reside in the DWR Water Data Library*

The DWR WDL is DWR's primary repository for groundwater-level measurements collected from wells. To provide reliable, transparent, and repeatable analysis with the custom built GIS geoprocessing tools, data from outside the WDL are not included in the process workflow.

2. *Wells are not Preselected for Analysis*

All groundwater-level data is initially considered high-quality data, appropriate for inclusion in the analysis. Poor-quality data is filtered or otherwise removed as needed during the process workflow.

The WDL contains information on more than 40,000 wells and millions of groundwater-level data records collected since the 1920s. New wells and new water-level measurements are added to the database regularly. Specific information about each well, and the period of measurement for each well, is variable and prevents the reasonable preselection of wells for the purpose of analyzing groundwater-level changes over time. It is not possible to pick a set of wells to analyze change in groundwater in storage over time based on single set of criteria. The GIS workflow and geoprocessing tools were designed to facilitate evaluating the quality of the groundwater-level data. Wells and/or individual measurements can be flagged and removed, or excluded, from analysis if they do not meet specific analytical requirements. By utilizing this inclusive approach to well and groundwater-level measurement selection, all available data is reviewed, allowing a more robust dataset for conducting analysis.

3. *Groundwater Levels Represent Unconfined, Static, Aquifer Conditions*

Aquifers are dynamic hydrologic systems influenced by surface and subsurface groundwater inflows/outflows, and by groundwater pumping. To minimize the effects of these variable conditions, groundwater elevation measurements are filtered to depict static conditions in the unconfined portion of the aquifer.

4. *Only Spring-to-Spring Changes in Storage are Estimated*

For the purposes of this technical memorandum, and for annual change in groundwater in storage reports in *California Water Plan Update 2013*, "spring" is a term used generally to describe the period of time before the primary irrigation season. Because of variations in irrigation patterns throughout the state, this period may range from January through April. The spring pre-irrigation period best represents static groundwater-level conditions because it typically allows an aquifer the most time to recover from the previous irrigation season (typically summer or fall of the previous year). As a result, spring-to-spring changes in groundwater elevations are used to minimize the effects groundwater pumping and other inflows/outflows have on groundwater levels.

5. *Groundwater-Level Change is Calculated from Two Water-Level Measurements in the Same Well*

Changes in groundwater levels for a basin are derived from the changes in water levels as measured in wells. A groundwater-level measurement from one time period is compared to a measurement collected at the same well at a different time. The calculated difference between these two measurements is the change in groundwater level in that well for the time interval between the first and second measurement.

6. *The Extent, or Geographic Limit, of the Groundwater Basin is Delineated and it is Assumed that no Changes in Groundwater Elevations Occur at this Boundary*

The lateral geographic extent of a groundwater aquifer is defined as the outermost edge of the groundwater basin. In DWR Bulletin 118, this basin boundary is generally defined as the extent of alluvium. It is assumed that groundwater levels do not vary at the basin's edge. In other words, the change in groundwater elevation between any two time periods at the outermost edge of the groundwater basin is equal to zero (this is referred to as the zero boundary).

7. *The Extent, or Geographic Limit, of Available Groundwater-Level Data is Delineated*

It is necessary to describe the extent, or geographic limit, of groundwater-level measurements for any change in groundwater in storage analysis. In most cases, the extent of the available data will lie within the extent of the groundwater basin.

8. *Specific Yield Values are Applied as an Average Range (Average Minimum and Average Maximum) for an Entire Reporting Area*

Reporting areas are user-defined geographic regions. To estimate the change in groundwater storage between any two time periods within a reporting area, the average specific yield for the reporting area is used. For *California Water Plan Update 2013*, average minimum and maximum specific yield values were used to calculate a range in the amount of change in groundwater storage. As a result, the amount of change in groundwater in storage is provided as a range (minimum and maximum) for each reporting area.

Key Concepts

1. *Groundwater Basin and Subbasin Boundaries*

A groundwater basin is defined as an alluvial aquifer as identified in DWR Bulletin 118-2003. Groundwater basins have both lateral and vertical boundaries. Lateral boundaries are features, such as rock or sediments with very low permeability, that significantly impede groundwater flow, or a geologic structure, such as a fault. Vertical boundaries are typically characterized by very low permeability rock or sediments or the base of fresh water.

A subbasin is created by dividing a groundwater basin into smaller units, commonly for the purpose of collecting and analyzing data. The limiting rule for a subbasin is that it should not cross over a groundwater basin boundary.

For the purposes of *California Water Plan Update 2013*, the change in groundwater storage is only estimated for alluvial aquifers. Because of the difficulty of adapting the developed method for fractured-rock aquifers, calculations were not done for such aquifers.

2. Reporting Areas and Non-Reporting Areas

Reporting areas are discrete areas within a groundwater basin or subbasin used to report change in groundwater elevation and change in groundwater storage estimates. A reporting area is typically identified as an area within a groundwater basin or subbasin where sufficient data exists to analyze the change in groundwater in storage. *Non-reporting areas* are areas that may be of interest, but are outside of a reporting area. For example, a non-reporting area may be a part of a groundwater basin where groundwater elevation data is limited or otherwise not available.

3. Groundwater-Level Surfaces

A groundwater-level surface is a virtual surface built with GIS tools using unique groundwater-level measurements collected from wells within a specific time period and region. These unique measurements are imported into a map as point data and used to construct a triangulated irregular network (TIN) with GIS tools. TINs are a form of vector-based digital geographic data and are constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. For each spring time period, two surfaces are built: (1) groundwater levels in an unconfined aquifer (often described as the water table) as the water surface elevation (WSEL), and (2) the depth below ground surface (DBGS). The WSEL and DBGS surfaces are generally depicted in maps as contours and/or with color ramping.

4. Depth to Groundwater and Groundwater Elevation

The *depth to groundwater* is the measured vertical distance to water in a well from a defined reference point. The DBGS is the depth to groundwater minus the distance from the reference point to the ground surface. Often the reference point is the top edge of the well casing, which is commonly above the ground surface. The depth to groundwater and DBGS is commonly expressed as a positive number. The DBGS can be a negative number if the water level in a well casing is above the ground surface.

The *groundwater elevation* or WSEL is the ground surface elevation minus the DBGS. Negative WSEL values indicate that groundwater levels are below mean sea level.

5. Selecting Unique Groundwater-Level Measurements

The measurement frequency among wells is variable and can range from several times a day to once a year (or even once every several years). As a result, an individual well may have none, one, or several measurements for any given time period. The process of building groundwater-level surfaces requires that a single, or unique, groundwater-level measurement is selected from each well. This is accomplished by first selecting all measurements within a defined date range for a given well, then picking the unique measurement that is closest in time to a defined target date. For *California Water Plan Update 2013*, a March 15 target date was used to select water-level measurements collected during the period from January 1 through May 31.

6. Change in Groundwater Level

Groundwater-level changes in an unconfined aquifer can be measured by monitoring the changes in groundwater levels in selected wells that intercept an unconfined aquifer. The change in groundwater levels between two distinct time periods is determined by calculating the difference in the water levels measured in each time period. If water levels rise over time, the difference is expressed as a positive number; if water levels drop, the difference is a negative number. The spring-to-spring annual change in groundwater elevation is calculated by subtracting the later spring measurement (monitoring period 2) from the earlier spring measurement (monitoring period 1).

GIS tools can be used to express the calculated change (or difference) in water-level measurements as a surface, just as the WSEL and DBGS can be expressed as a surface. The change in water levels can be represented in a map with contoured isolines and/or with color ramping indicating the amount of water-level change.

GIS tools can also determine the difference between two TIN surfaces, such as WSEL surfaces. For *California Water Plan Update 2013*, the change in groundwater levels is determined by comparing measurements in wells (represented as points), rather than by comparing groundwater-level surfaces directly.

7. *Change in Groundwater in Storage*

The change in groundwater levels between two time periods (as measured from wells intersecting an unconfined aquifer) represents a thickness within the unconfined aquifer. This thickness, over a defined area, represents a volume of aquifer space, or change volume, in which groundwater levels have changed over time. The amount of groundwater within a volume of aquifer space is estimated by applying the storage coefficient (specific yield, or Sy). For *California Water Plan Update 2013*, a minimum and a maximum specific yield value, 0.07 and 0.17, respectively, is applied to calculate the range representing the change in groundwater within an unconfined aquifer for a defined reporting area. The minimum and maximum specific yield values were based on aquifer texture data developed for DWR C2VSim and USGS CVHM Central Valley groundwater models.

Workflow

Calculating the change in groundwater in storage using groundwater-level data can be divided into several distinct, related steps in the workflow process. For each of these steps, one or more custom GIS geoprocessing tools were developed.

Query and Filter Groundwater-Level Data for Spring Datasets

A spring groundwater-level data set is a list of wells, each with a single unique water-level measurement, and other pertinent information. Wells are not all measured on the same day or at the same frequency, and querying a single measurement per well for the spring dataset is a multistep process. Selecting the well and the unique measurement is accomplished with a series of GIS tools which filter data based on several input parameters, as shown in Table E-1.

For *California Water Plan Update 2013*, each spring dataset was limited to groundwater basins within the Central Valley, as described in DWR's *California's Groundwater: Bulletin 118*. For wells within these areas, groundwater levels between January 1 and May 31 of each year were queried. When more than one measurement for a given well was identified within this date range, the measurement on the date closest to the target date of March 15 was used.

Table E-1 Groundwater-Level Measurement Selection Parameters

Parameter	Data Description	Purpose
Geographic Region	Polygon feature	Limits the geographic scope of the query
Date Range	Minimum date value and maximum date value	Selects only well data within a specific date range
Target Date	Date	Selects the water-level measurement nearest the specified target date
Well Depth	Depth, in feet	Filters wells by depth
Questionable Measurement Code	Coded values (alphanumeric)	Filters out measurements with specific measurement quality codes (such as "well is pumping" or "pumping well nearby")
Excluded Wells	Table identifying selected wells in groups using well group codes	Enables filtering wells by group, as listed on the Excluded Wells table

Numerous checks built into the workflow process help evaluate and ensure the quality of the well and water-level data. Although the workflow queries are designed to minimize the use of poor quality or inappropriate data, occasionally an anomalous data point is discovered during the development of point datasets, groundwater-level surfaces, change surfaces and change in storage estimates. It is important that anomalous data be isolated, evaluated, and removed from the dataset, if necessary. If an anomalous data point is removed, it is added to the excluded wells table, a special list of points that were deemed unacceptable. The excluded wells table catalogs questionable or otherwise inappropriate data points along with a coded value and a comment.

Create Groundwater-Level Surfaces within Defined Basins

Surfaces representing regional groundwater elevations and depth of groundwater below the ground surface are created from the spring dataset. These surfaces are built using a TIN where each water-level measurement represents a point in 3-D space, where latitude and longitude are the X and Y locations, respectively, and the groundwater elevation is the Z location. Contour lines and other surface representations can then be built from the groundwater elevation TIN. Surfaces representing groundwater elevation data in a 3-D map environment provide a powerful tool for evaluating data quality and helping ensure groundwater elevation readings represent similar aquifer zones and monitoring conditions. For example, water-level measurements that are not consistent with nearby measurements will deviate from the 3-D surface model as an anomalous spike or a hole. Specific information about these anomalous points, such as measurement date, well construction, and other attributes, can then be further reviewed. A groundwater elevation point that is inconsistent with the surrounding elevations, or is recorded with a questionable measurement qualification, is removed from the TIN surface and is added to the excluded wells table. The TIN surface is then regenerated without the errant points.

For map presentations and reports, the surface model can then be converted to a raster surface, resulting in smooth contour lines.

Calculate Change in Groundwater Elevation Over Time

The change in groundwater elevation over time is determined by creating groundwater elevation surfaces for each monitoring period and calculating the difference in groundwater elevation at "like points" (wells measured during both monitoring periods). The calculated elevation difference at each of these monitoring points represents the total change in groundwater elevation that occurred between the two monitoring periods at that well. Monitoring points representing the change between two groundwater elevation surfaces are sometimes referred to as change points. Change points are then used to create a new TIN which represents the amount of groundwater elevation change between two monitoring periods at a given location.

Calculate Intermediate Volumes using Surface Models and Basin Boundaries

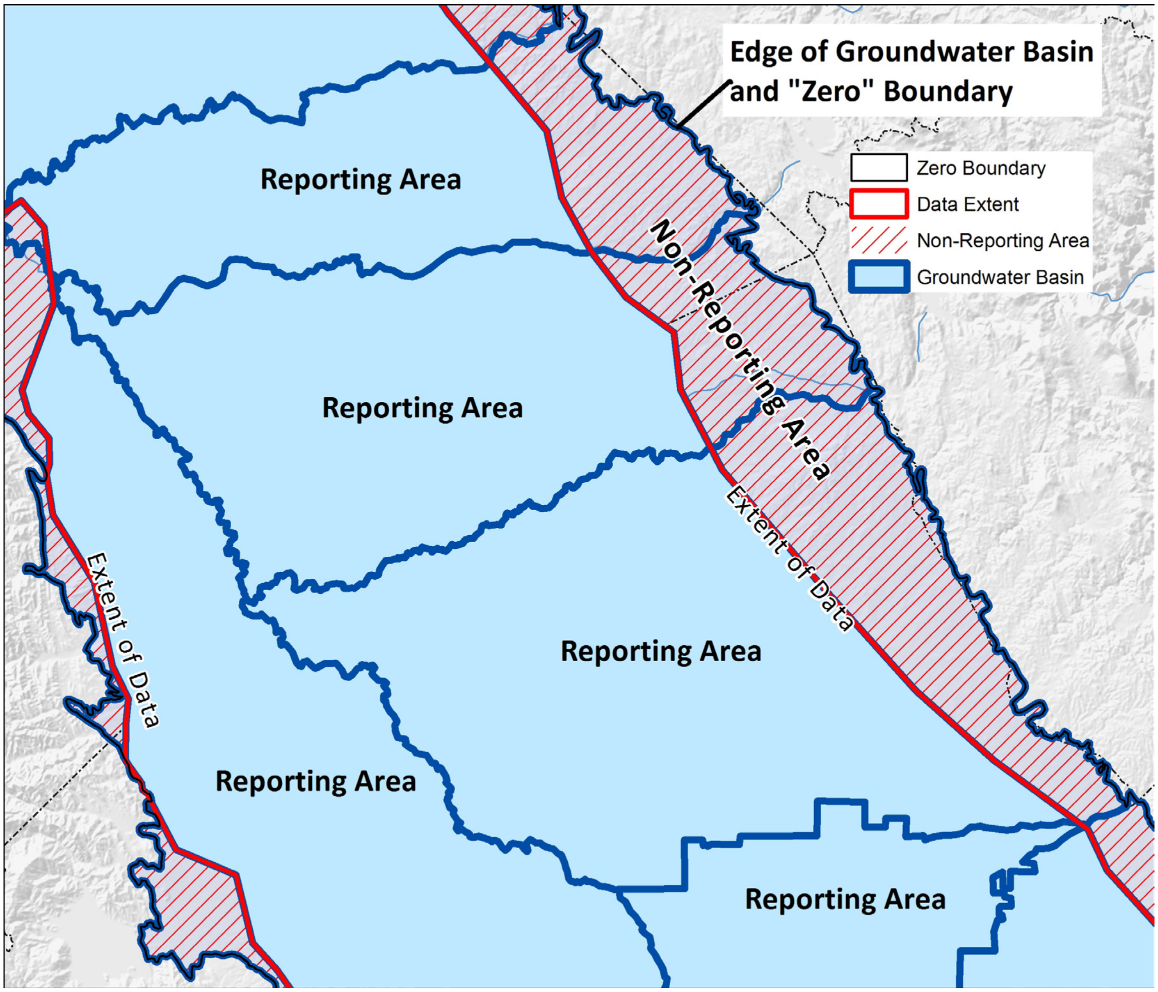
A calculated intermediate volume is the total volume of the space described by the vertical distance (or change) between two groundwater elevation surfaces and a zero boundary (Assumption 6 and Map E-1). The vertical distance between two groundwater elevation surfaces from two different time periods is determined from the change points. The outer extent of groundwater elevation change is characterized as a boundary, called the zero boundary, where changes in groundwater elevation do not occur. The zero boundary typically represents the outer edge of the groundwater basin.

Map E-1 shows the types of boundaries and areas used to calculate the change in groundwater in storage by using groundwater-level measurement data. Groundwater basin/subbasin boundaries, a zero boundary, and the extent of data boundary delineate the reporting and non-reporting areas. The estimated change in groundwater in storage is provided for each reporting area.

The intermediate volume, representing the change in groundwater elevation, is built as a volumetric TIN model using the change points and the zero boundary along the edge of the basin. The change TIN represents a thickness (or distance in Z space) rather than a surface, as with the groundwater elevation surface model TINs. GIS tools are then used to calculate the intermediate change volume for any region, such as a groundwater subbasin, as long as that region exists within the zero boundary. The average groundwater elevation change for a region can also be calculated by dividing the change volume for that region by the area of the region.

Within the Central Valley, there are some areas in groundwater basins, and inside the zero boundary, where groundwater-elevation data is unavailable for analysis. Although interpolation between data points is a common approach for TIN development, in areas where the distance between data points is unacceptable, it was deemed inappropriate to estimate changes in groundwater storage where no supporting groundwater data were available. Groundwater basins and subbasins were subsequently characterized as reporting areas and non-reporting areas based on available data (Key Concept 2). The intermediate change volume, as well as the average change in groundwater elevations, is then estimated for each reporting area within a groundwater subbasin (Map E-1).

Map E-1 Boundary Types Required to Estimate and Report the Change in Groundwater in Storage



Apply Storage Coefficients to Calculate Change in Groundwater Storage Values

Storage coefficients are used to calculate the volumetric change in groundwater storage from the intermediate change volume. In an unconfined aquifer, the storage coefficient is represented as the specific yield of the aquifer (a unit-less number that describes the volume of water that could flow out of a unit volume of aquifer). Large specific yield values generally indicate coarse-grained aquifer materials, while smaller values indicate fine-grained aquifer materials. The estimated volume of groundwater change between two time periods for each reporting area (also see "Assumptions" and "Key Concepts" sections) is calculated by applying a specific yield value to the intermediate change volume.

Because specific yield values cannot be accurately estimated for much of the Central Valley, the estimated change in groundwater in storage for *California Water Plan Update 2013* is given as a range of values by applying a minimum and a maximum specific yield value to the intermediate volume within a reporting area. The minimum and maximum specific yield values selected are

0.07 and 0.17, respectively. As previously mentioned, specific yield estimates are based on estimates derived for DWR C2VSim and USGS CVHM Central Valley groundwater models. For each reporting area a minimum and a maximum estimated change in groundwater in storage, and an average change in groundwater elevation, are calculated.

Summary

Using GIS software and the described workflow to estimate the change in groundwater in storage from groundwater-level measurements can be a useful tool and standardized approach for evaluating change in groundwater storage over time. Using GIS to apply a workflow that implements the assumptions and key concepts as described in this technical memorandum meets the goals of *California Water Plan Update 2013* in that it allows for a transparent and repeatable process of estimating basin-wide change in groundwater in storage. This approach is one of several known techniques to estimate change in groundwater in storage.

Throughout the development and implementation of the assumptions, key concepts, and workflows as described in this technical memorandum, several important considerations and conclusions were revealed. They are summarized in the following paragraphs.

Data Dependency

Estimating change in groundwater in storage using groundwater-level data over time can only be accomplished where data exist. As a result, this process requires many thousands of groundwater-level measurements that cover broad geographic regions horizontally and vertically, and cover a broad range in time.

To select the appropriate water-level records to estimate the change in groundwater in storage, it is necessary to review all available well data, rather than preselected wells based on specific criteria, for each analysis. To ensure that high-quality data is used and questionable data is properly filtered, several quality assurance/quality control (QA/QC) reviews of the data were built into the workflow. Ultimately, the selection of appropriate groundwater-level measurements proved to be the most time-consuming process. The QA/QC requirements are integrated into the assumptions, key concepts, and workflows as described in this technical memorandum.

A byproduct of implementing these analyses is the ability to conduct internal evaluations of the spatial and temporal distribution of data maintained in the DWR WDL. And, QA/QC techniques developed for the change in groundwater in storage analysis can also be used to query and analyze groundwater-level data for other purposes.

Repeatability of Process through GIS Workflows

DWR has used groundwater-level measurements to estimate the regional change in groundwater levels and change in groundwater in storage prior to the development of the process described in this technical memorandum. Unfortunately, because of the required data management and analysis complexities, it is not possible to repeat or update past estimations. The development of specific GIS tools implemented as a clearly defined workflow allows for new analyses to be repeated and updated.

In order to develop an intuitive process, tools and workflows are based on the previous DWR efforts to analyze groundwater-level data and estimate change in groundwater in storage. The overall workflow was first defined, and then divided into several independent process steps. A custom GIS tool was then developed for each process step. The GIS tools can be run independently, adding flexibility to the management and review of groundwater-level data.

Process Transparency

Providing transparency to the process of estimating the change in groundwater in storage is an important goal which requires data availability and a clear description of the process. DWR is providing process transparency using the publically available groundwater-level data managed in the DWR WDL, and implementing the workflow described in this document. Additionally, during the development of *California Water Plan Update 2013*, the process described in this was presented to the California Water Plan Update 2013 Groundwater Caucus and to the general public.

Limitations to Estimating the Change in Groundwater Storage Using Groundwater-Level Data

Estimates of the change in groundwater in storage as described in this technical memorandum are based on groundwater-level data collected in the field. As a result, it is not possible to model predictions of future change in groundwater in storage, nor is it possible to estimate past changes in groundwater storage where data was not collected. These types of analysis must be completed using a different modeling process, such as those described in the "Methods that use Water Balance/Budget/Modeling" section of this technical memorandum.

Limitations exist based on the availability of data and understanding of hydrogeology conditions within a basin. This includes knowledge of specific yield values, water quality, impediments to vertical groundwater flow, and other factors.

Limitations based on the available groundwater-level measurement data and well-construction information are the most obvious types of limitations to this process. Change in groundwater in storage cannot be estimated in areas lacking appropriate groundwater-level measurements. Fortunately, the tools and workflows described in this technical memorandum can assist in identifying areas lacking in appropriate data. They are also used to provide recommendations that help fill data gaps in existing groundwater-monitoring plans and other groundwater-monitoring efforts.

Improvements to Estimating the Change in Groundwater Storage Using Groundwater-Level Data and Other Future Steps

This technical memorandum describes the process of calculating estimates of the change in groundwater in storage for *California Water Plan Update 2013*, which were completed in 2012. Since that time, several improvements were made to the GIS tools used to calculate the estimates. These improvements include general tool refinements, the development of new QA/QC tools, and the ability to make volumetric calculations based on specific yield values that vary spatially. Even with improved GIS tools, the assumptions and workflow remain unchanged.

In addition to GIS tool improvements, the implementation of the DWR CASGEM Program has begun to fill some gaps in groundwater-level monitoring.

Future work will update annual change in groundwater in storage for the Central Valley and explore application of the change in groundwater in storage tool for groundwater basins outside the Central Valley. Also, DWR anticipates working with other agencies to compare change in groundwater in storage estimates using the methods described in this technical memorandum, to those estimates used by the local agencies. These comparisons will provide valuable information toward developing future refinements.

It is also anticipated that DWR will provide regular reports of the estimated yearly spring-to-spring change in groundwater in storage.

Estimated Annual Change in Groundwater in Storage, Spring 2005 through Spring 2010

The annual change in groundwater in storage for spring 2005 to spring 2010 was estimated for *California Water Plan Update 2013* using the assumptions, key concepts, and methods as described in this technical memorandum. The results of this analysis are included as maps, tables, and charts, in the following pages. Because of the lack of data availability for many areas outside the Central Valley, change in groundwater in storage estimates are provided only for basins and subbasins within the Central Valley.

The analysis of groundwater basins within the Redding Basin, Sacramento Valley, and San Joaquin Valley were organized by hydrologic region. Within the Sacramento Valley and Redding basins, subbasins were combined into logical groupings for analysis. Twenty-four subbasins were reorganized into eight grouped reporting areas. Consequently, the total number of areas analyzed for each of the three hydrologic regions is more uniform, with the change in groundwater in storage being estimated for eight areas in the Sacramento River Hydrologic Region, seven subbasins in the San Joaquin River Hydrologic Region, and eight subbasins in the Tulare Lake Hydrologic Region.

Additional analysis results are provided, including change in groundwater in storage estimates summarized for the Redding Basin and Sacramento Valley portion of the Sacramento River Hydrologic Region, the San Joaquin Valley portion of the San Joaquin River Hydrologic Region, the San Joaquin Valley portion of the Tulare Lake Hydrologic Region, and the entire Central Valley. Within the Redding Basin and Sacramento Valley portion of the Sacramento River Hydrologic Region, change in groundwater in storage results are provided for 22 individual subbasins.

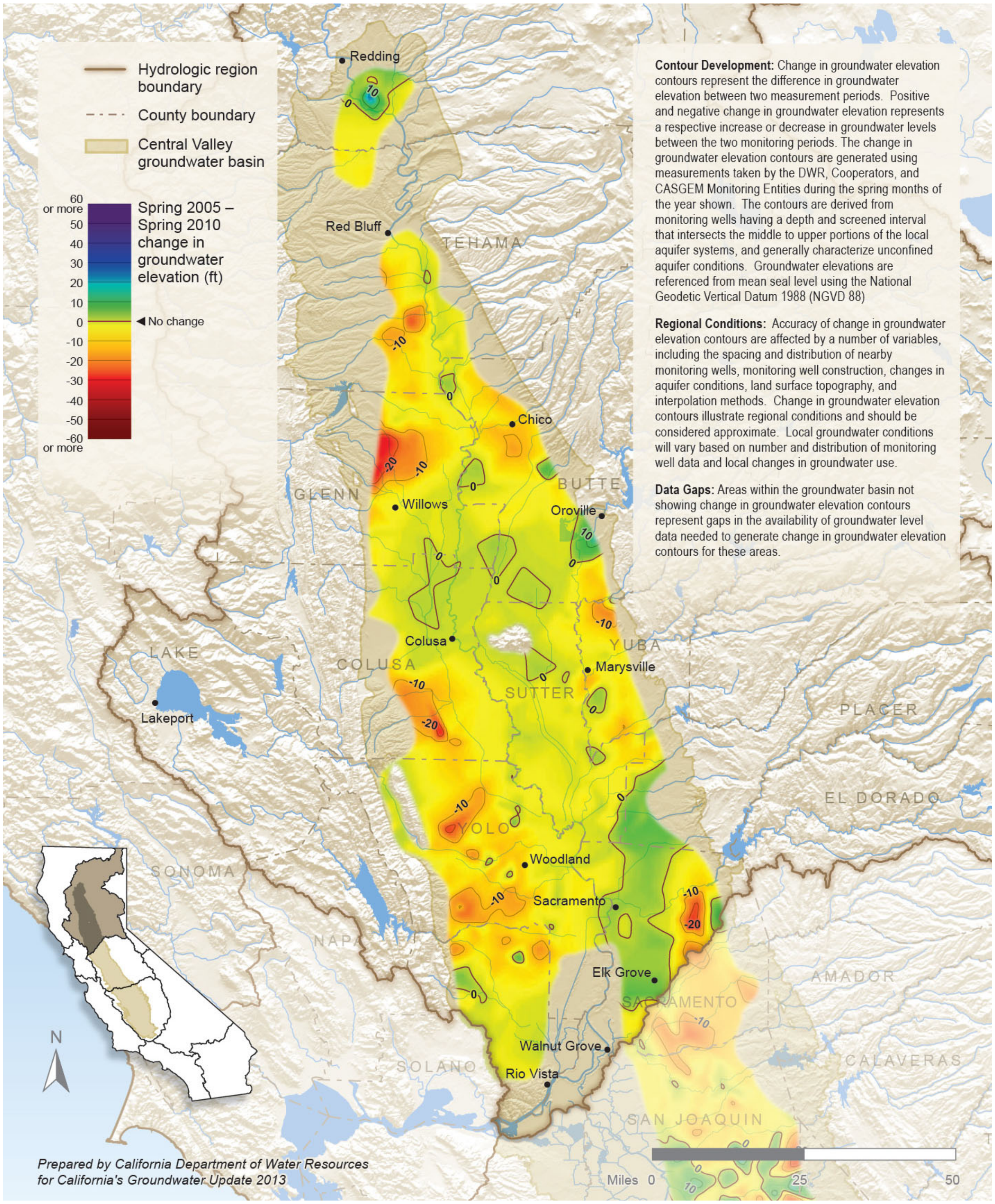
Each analysis provides the estimated annual change in groundwater in storage based on a range of storage coefficients, which are expressed as specific yield values. The high and low range of specific yield values were selected based on aquifer texture mapping of the Central Valley, and are estimated to be 0.07 and 0.17, respectively. The change in groundwater in storage estimates are provided for reporting areas. Reporting areas are regions where sufficient groundwater-level data exists within the groundwater subbasin, groundwater subbasin group, groundwater basin, or hydrologic region, to reasonably contour change in groundwater elevation. Non-reporting areas are locations where groundwater-level data is insufficient to reasonably contour and complete the change in groundwater in storage analysis. Central Valley reporting and non-reporting areas are shown in maps E-2, E-4, and E-6. Analysis of each reporting area includes a table summarizing the average annual change in groundwater level and estimated change in groundwater in storage for the minimum and maximum specific yield values, and a chart depicting the annual and cumulative change in groundwater in storage estimates. Superimposed on each chart is a color coded depiction of the water year type for each annual estimate.

Because estimating changes in groundwater in storage using groundwater levels require an understanding of how groundwater levels change over time, maps (E-3, E-5, and E-7) illustrating the amount of groundwater level change in each Central Valley hydrologic region, are provided.

On September 9, 2015, during a webinar presenting newly released chapters from *California's Groundwater Update 2013,* DWR provided an overview about the groundwater storage tool and its application. This presentation provides detailed information on how the tool was used and it provides information on future development and application on other hydrologic regions in California. The PowerPoint presentation is available online at http://www.waterplan.water.ca.gov/docs/misc/groundwater/update2013/GWU2013_Change_in_Groundwater_in_Storage_Tool_Presentation.pptx, and you can view the video at https://www.youtube.com/watch?v=olqAJImlZr0.

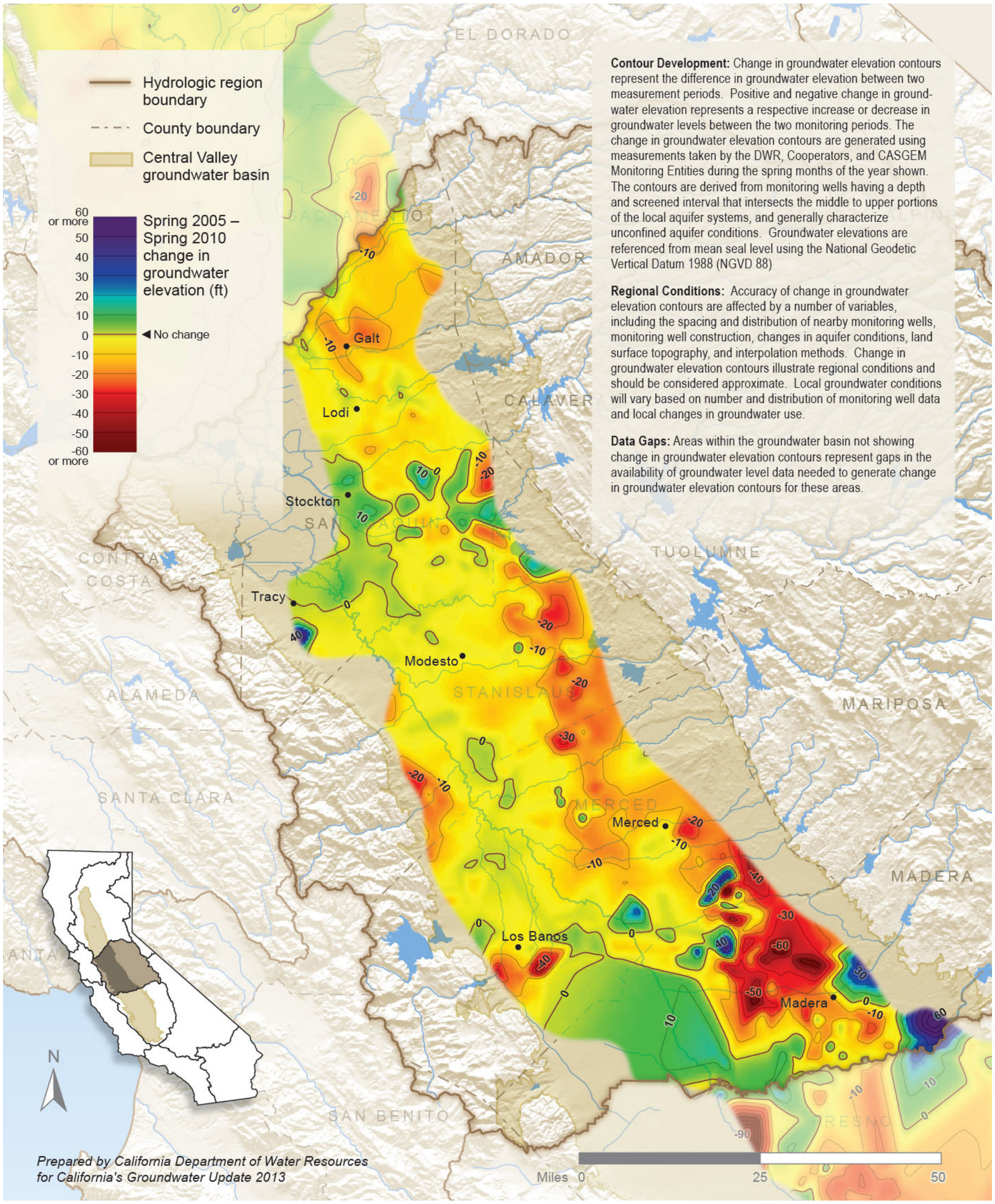
Map E-2 Groundwater Subbasins, Group Areas, Reporting, and Non-Reporting Areas within the Sacramento River Hydrologic Region

Map E-3 Change in Groundwater Elevation Contour Map for Sacramento Valley Portion of the Sacramento River Hydrologic Region (Spring 2005 – Spring 2010)

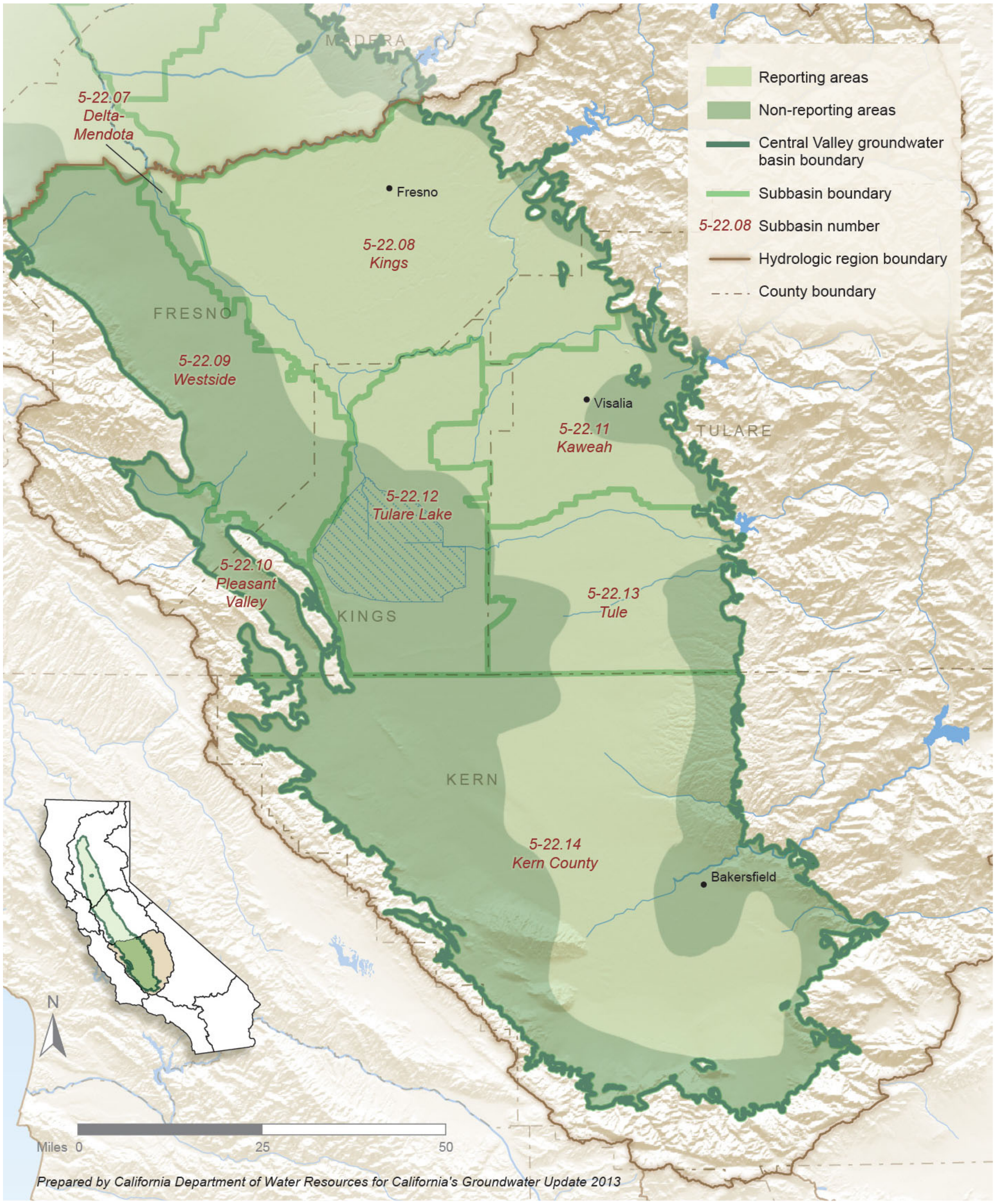


Map E-4 Groundwater Subbasins, Group Areas, Reporting, and Non-Reporting Areas within the San Joaquin River Hydrologic Region

Map E-5 Change in Groundwater Elevation Contour Map for San Joaquin River Hydrologic Region (Spring 2005 – Spring 2010)



Map E-6 Groundwater Subbasins, Reporting, and Non-Reporting Areas within the Tulare Lake Hydrologic Region



Map E-7 Change in Groundwater Elevation Contour Map for Tulare Lake Hydrologic Region (Spring 2005 – Spring 2010)

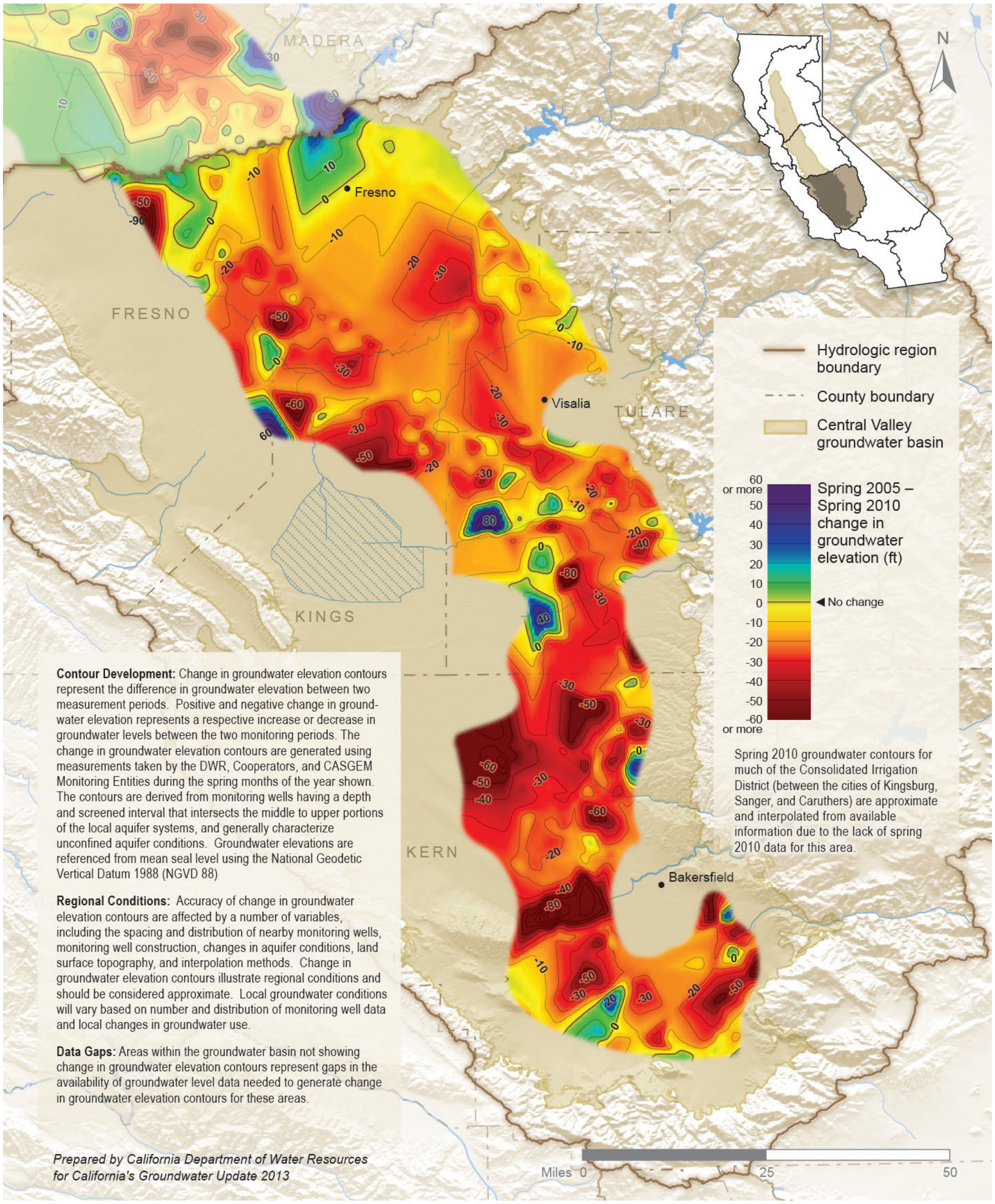
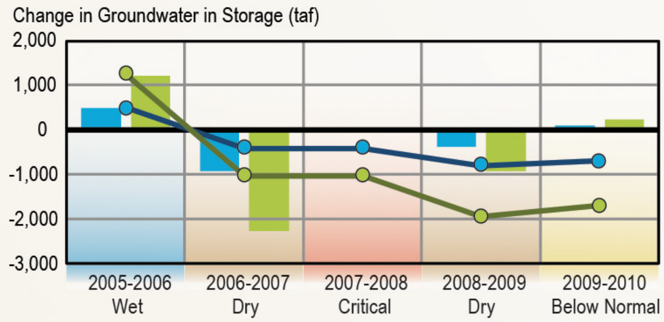
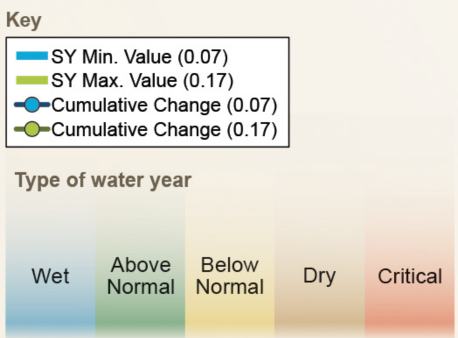


Figure E-1 Annual Change in Groundwater in Storage for the Sacramento Valley Portion of the Sacramento River Hydrologic Region Reporting Area (Spring 2005-2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	2.3	503	1,221
2006-2007	-4.3	-929	-2,255
2007-2008	0.0	-2	-4
2008-2009	-1.8	-378	-918
2009-2010	0.5	103	250
Total (2005-2010)	**-3.3**	**-703**	**-1,706**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 3,070,427 acres
5. Non-Reporting Area: 1,033,705 acres



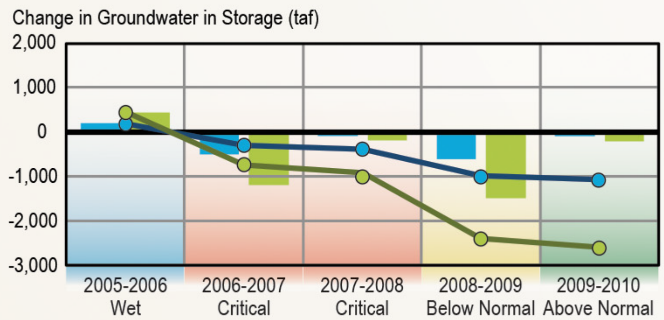


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-2 Annual Change in Groundwater in Storage for the San Joaquin River Hydrologic Region Reporting Area (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.1	189	458
2006-2007	-2.7	-487	-1,183
2007-2008	-0.4	-74	-179
2008-2009	-3.4	-606	-1,473
2009-2010	-0.5	-83	-203
Total (2005-2010)	**-5.9**	**-1,061**	**-2,580**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 2,535,865 acres
5. Non-Reporting Area: 1,180,392 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

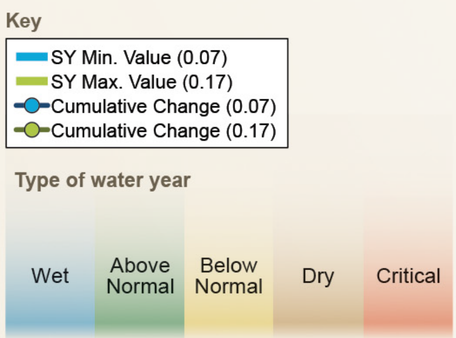
Wet | Above Normal | Below Normal | Dry | Critical

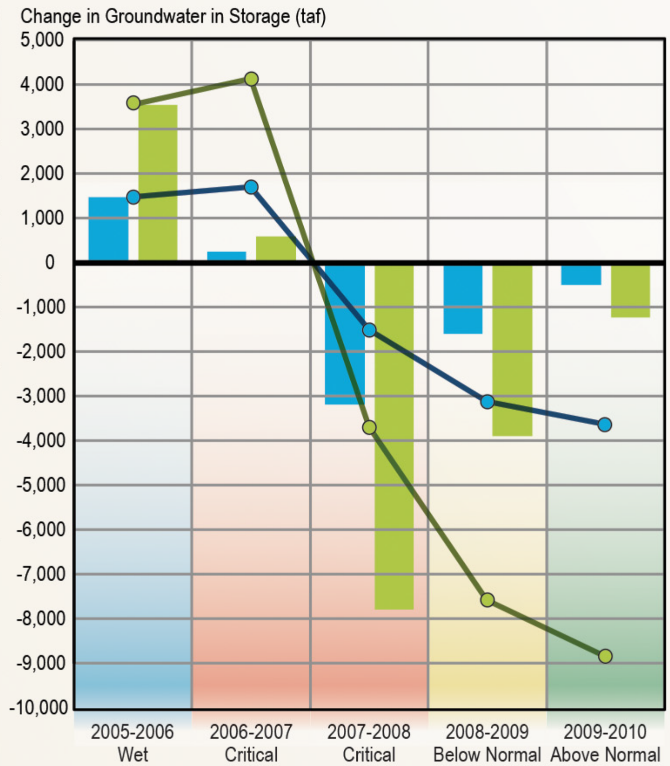
Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-3 Annual Change in Groundwater in Storage for the Tulare Lake Hydrologic Region Reporting Area (Spring 2005-2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	7.0	1,457	3,539
2006-2007	1.1	237	576
2007-2008	-15.4	-3,213	-7,802
2008-2009	-7.7	-1,600	-3,886
2009-2010	-2.5	-517	-1,256
Total (2005-2010)	**-17.5**	**-3,636**	**-8,829**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 2,981,955 acres
5. Non-Reporting Area: 2,018,490 acres





Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-4 Annual Change in Storage for California's Central Valley Reporting Area (Spring 2005-2010)

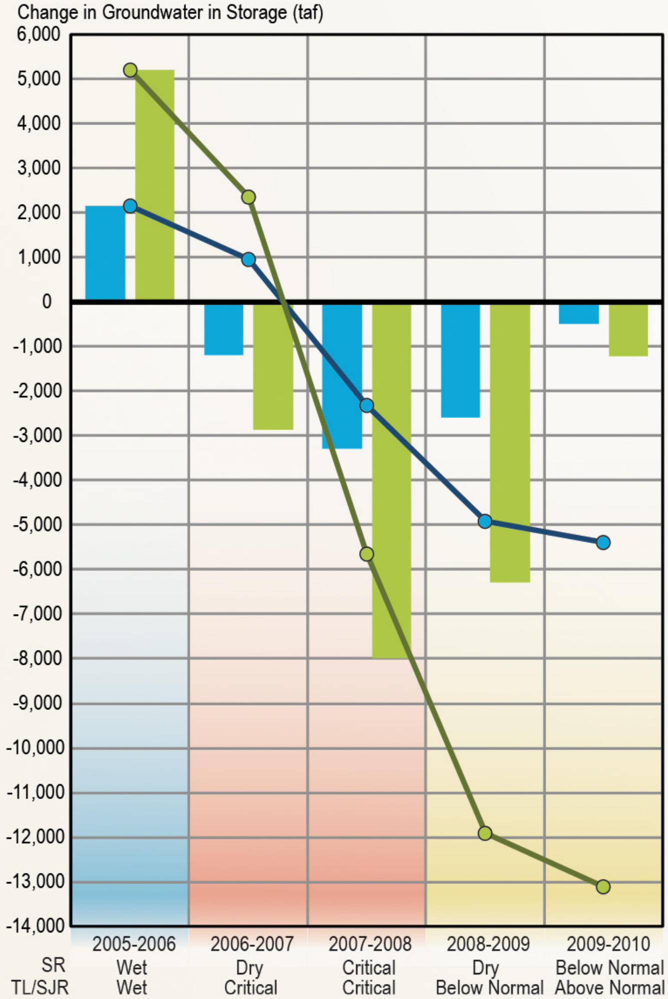
Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.6	2,148	5,218
2006-2007	-2.0	-1,179	-2,863
2007-2008	-5.5	-3,288	-7,984
2008-2009	-4.3	-2,584	-6,276
2009-2010	-0.8	-498	-1,209
Total (2005-2010)	**-9.0**	**-5,401**	**-13,114**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 8,588,247 acres
5. Non-Reporting Area: 4,232,587 acres

Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

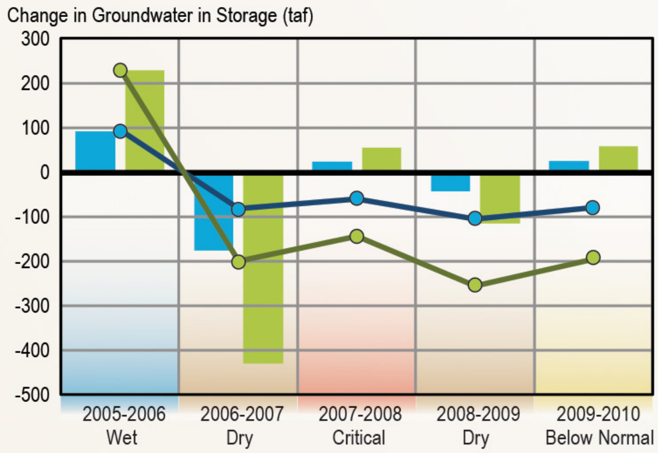


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-5 Annual Change in Groundwater in Storage for the Central Sacramento Valley Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	2.1	95	230
2006-2007	-3.9	-177	-429
2007-2008	0.5	22	55
2008-2009	-1.0	-46	-112
2009-2010	0.6	25	60
Total (2005-2010)	**-1.7**	**-81**	**-196**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 644,291 acres
5. Non-Reporting Area: 37,119 acres
6. Group includes subbasins 5-21.58 (West Butte), 5-21.59 (East Butte), and 5-21.62 (Sutter)



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

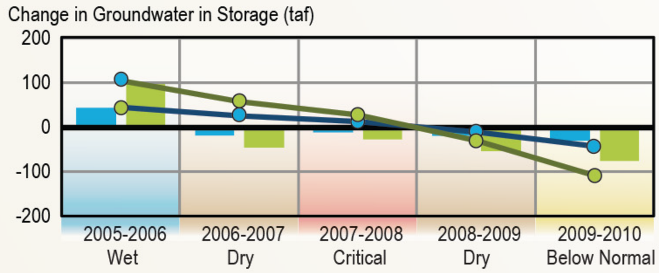
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-6 Annual Change in Groundwater in Storage for the East Sacramento Valley Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.6	43	103
2006-2007	-1.7	-19	-47
2007-2008	-1.1	-12	-30
2008-2009	-2.0	-23	-57
2009-2010	-2.8	-32	-79
Total (2005-2010)	**-4.0**	**-43**	**-110**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 167,590 acres
5. Non-Reporting Area: 40,132 acres
6. Group includes subbasins 5-21.60 (North Yuba), and 5-21.61 (South Yuba)



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

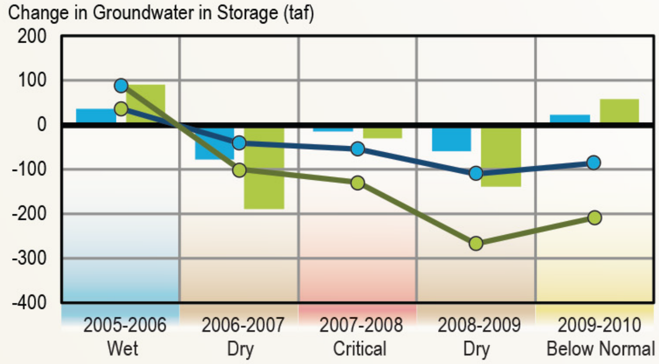
Wet | Above Normal | Below Normal | Dry | Critical

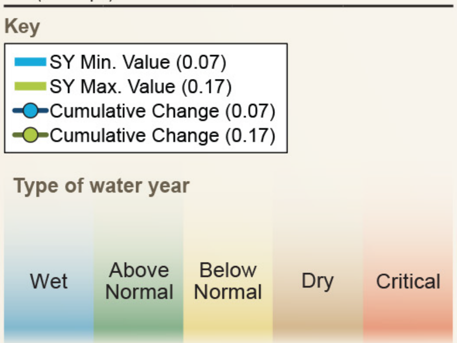
Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-7 Annual Change in Groundwater in Storage for the North Sacramento Valley Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	2.4	37	91
2006-2007	-5.0	-78	-189
2007-2008	-0.8	-12	-29
2008-2009	-3.7	-58	-140
2009-2010	1.6	24	59
Total (2005-2010)	**-5.5**	**-87**	**-208**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 223,187 acres
5. Non-Reporting Area: 275,835 acres
6. Group includes subbasins 5-21.50 (Red Bluff), 5-21.51 (Corning), 5-21.53 (Bend), and 5-21.54 (Antelope)



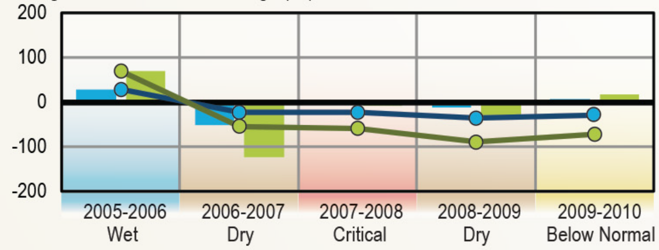


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-8 Annual Change in Groundwater in Storage for the Northeast Sacramento Valley Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.1	28	68
2006-2007	-5.6	-51	-124
2007-2008	-0.2	-2	-4
2008-2009	-1.4	-13	-31
2009-2010	0.8	7	17
Total (2005-2010)	**-3.3**	**-31**	**-74**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 129,669 acres
5. Non-Reporting Area: 55,881 acres
6. Group includes subbasins 5-21.55 (Dye Creek), 5-21.56 (Los Molinos), and 5-21.57 (Vina)



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

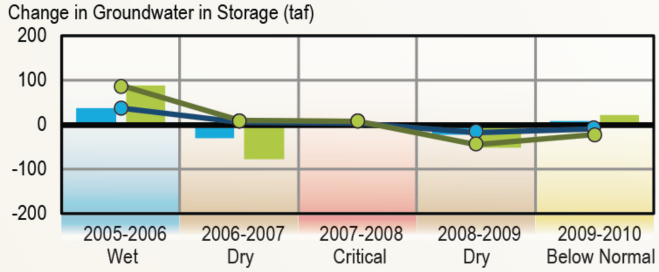
Wet | Above Normal | Below Normal | Dry | Critical

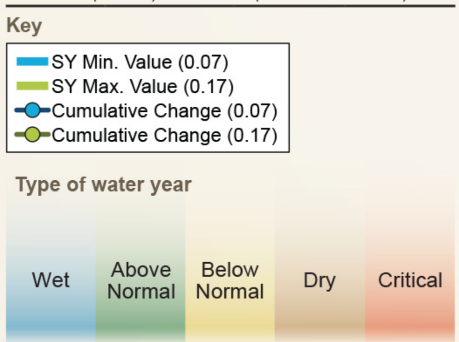
Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-9 Annual Change in Groundwater in Storage for the Redding Area Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.0	36	88
2006-2007	-2.7	-32	-78
2007-2008	-0.1	-1	-2
2008-2009	-1.8	-22	-53
2009-2010	0.8	9	23
Total (2005-2010)	**-0.8**	**-10**	**-22**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 171,568 acres
5. Non-Reporting Area: 176,515 acres
6. Group includes subbasins 5-6.01 (Bowman), 5-6.02 (Rosewood), 5-6.03 (Anderson), 5-6.04 (Enterprise), 5-6.05 (Millville), and 5-6.06 (South Battle Creek)



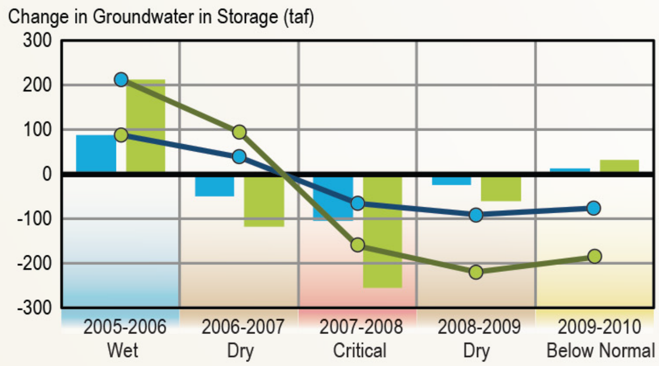


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-10 Annual Change in Groundwater in Storage for the Southeast Sacramento Valley Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	2.4	88	213
2006-2007	-1.3	-49	-118
2007-2008	-2.9	-105	-255
2008-2009	-0.7	-25	-60
2009-2010	0.4	14	33
Total (2005-2010)	**-2.1**	**-77**	**-187**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 520,032 acres
5. Non-Reporting Area: 68,067 acres
6. Group includes subbasins 5-21.64 (North American) and 5-21.65 (South American)



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

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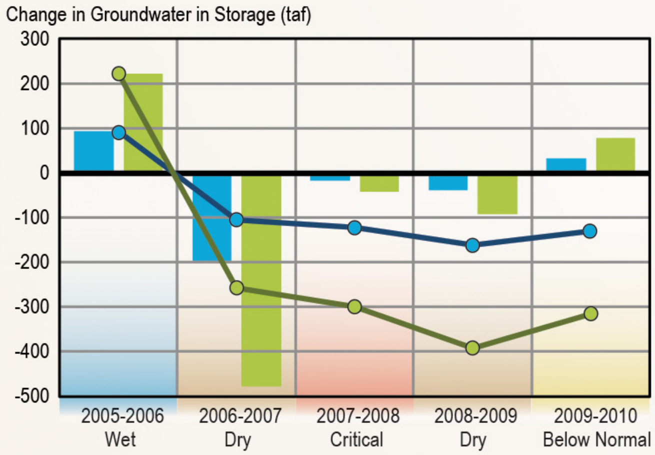
Figure E-11 Annual Change in Groundwater in Storage for the Southwest Sacramento Valley Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	2.8	92	222
2006-2007	-6.1	-197	-479
2007-2008	-0.5	-17	-42
2008-2009	-1.2	-39	-94
2009-2010	1.0	32	77
Total (2005-2010)	**-4.0**	**-129**	**-316**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 461,655 acres
5. Non-Reporting Area: 189,229 acres
6. Group includes subbasins 5-21.66 (Solano) and 5-21.67 (Yolo)



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

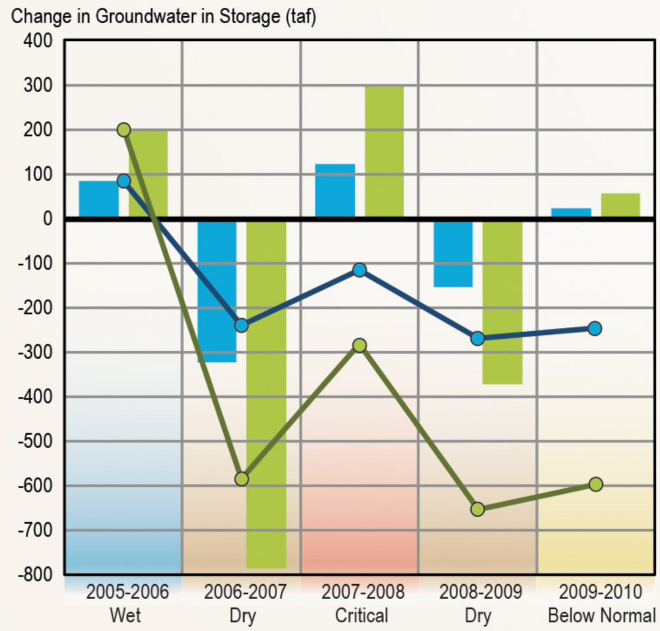
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-12 Annual Change in Groundwater in Storage for the West Sacramento Valley Subbasin Group in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.6	84	203
2006-2007	-6.3	-323	-784
2007-2008	2.4	124	301
2008-2009	-3.0	-153	-371
2009-2010	0.5	23	57
Total (2005-2010)	**-4.8**	**-245**	**-594**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 728,526 acres
5. Non-Reporting Area: 189,852 acres
6. Group includes subbasin 5-21.52 (Colusa)



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

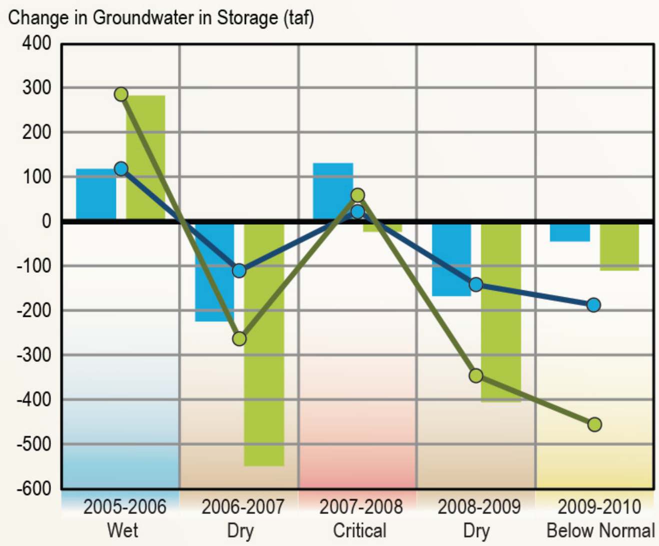
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-13 Annual Change in Groundwater in Storage for the Southeast San Joaquin Valley Subbasin Group in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.5	118	286
2006-2007	-6.7	-227	-551
2007-2008	4.0	134	325
2008-2009	-5.0	-167	-406
2009-2010	-1.3	-45	-110
Total (2005-2010)	**-5.5**	**-187**	**-456**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 480,478 acres
5. Non-Reporting Area: 71,853 acres
6. Group includes subbasins 5-22.05 (Chowchilla) and 5-22.06 (Madera)



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-14 Annual Change in Groundwater in Storage for the Bowman Subbasin (5-6.01) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.3	3	7
2006-2007	-1.0	-2	-5
2007-2008	-0.9	-2	-5
2008-2009	-1.1	-2	-6
2009-2010	-0.5	-1	-3
Total (2005-2010)	**-2.2**	**-4**	**-12**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 30,766 acres
5. Non-Reporting Area: 47,719 acres

Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

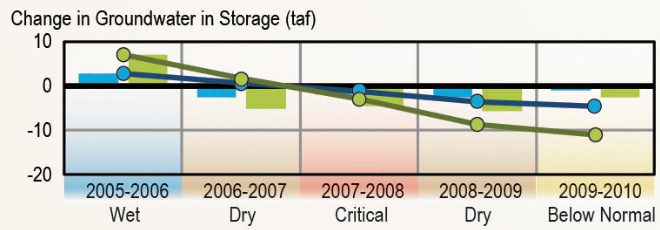


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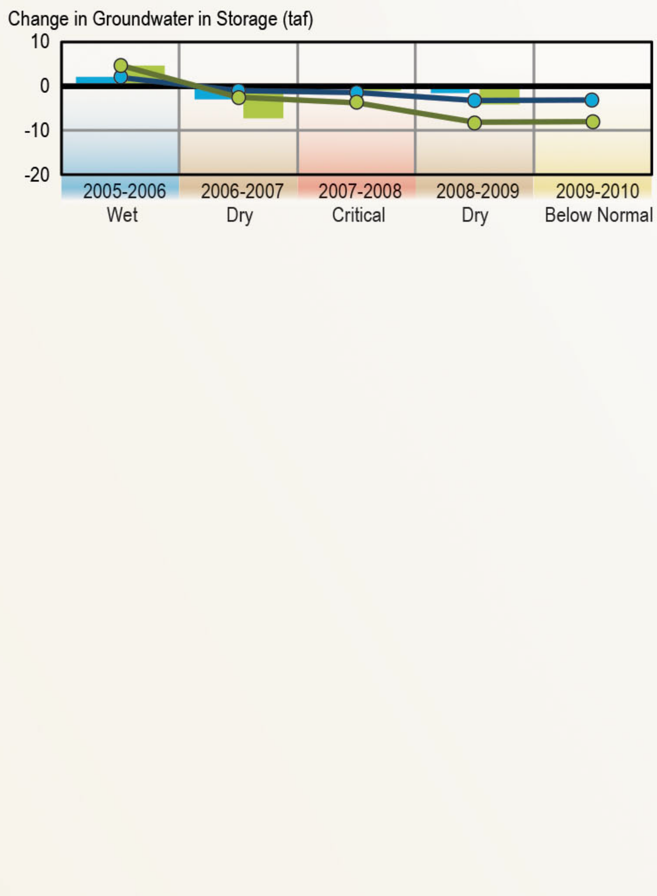
Figure E-15 Annual Change in Groundwater in Storage for the Rosewood Subbasin (5-6.02) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.9	2	5
2006-2007	-3.1	-3	-7
2007-2008	-0.5	-1	-1
2008-2009	-1.8	-2	-4
2009-2010	0.0	0	0
Total (2005-2010)	**-3.5**	**-4**	**-7**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 14,096 acres
5. Non-Reporting Area: 32,394 acres

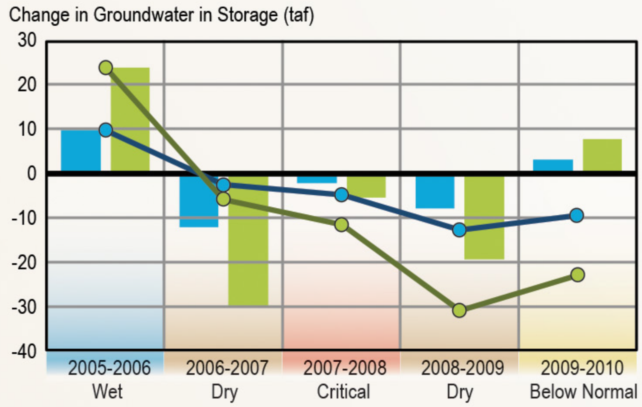


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-16 Annual Change in Groundwater in Storage for the Anderson Subbasin (5-6.03) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	2.1	10	24
2006-2007	-2.6	-12	-30
2007-2008	-0.5	-2	-6
2008-2009	-1.7	-8	-20
2009-2010	0.7	3	8
Total (2005-2010)	**-2.0**	**-9**	**-24**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 67,088 acres
5. Non-Reporting Area: 29,842 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

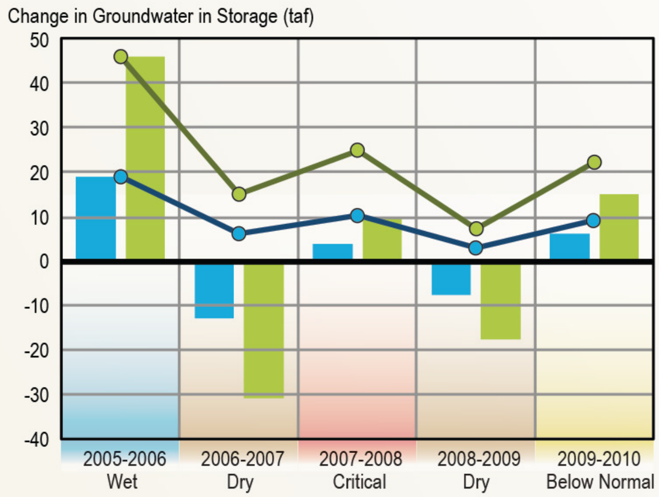
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-17 Annual Change in Groundwater in Storage for the Enterprise Subbasin (5-6.04) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	6.7	19	46
2006-2007	-4.5	-13	-31
2007-2008	1.4	4	10
2008-2009	-2.6	-7	-18
2009-2010	2.2	6	15
Total (2005-2010)	**3.2**	**9**	**22**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 40,260 acres
5. Non-Reporting Area: 20,646 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

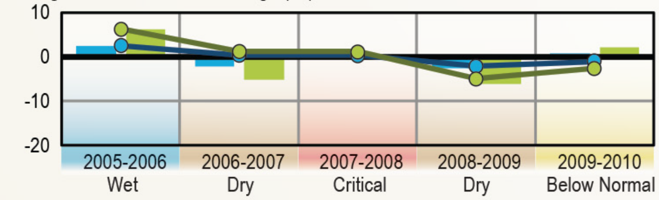
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-18 Annual Change in Groundwater in Storage for the Millville Subbasin (5-6.05) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.9	3	6
2006-2007	-1.5	-2	-5
2007-2008	0.0	0	0
2008-2009	-1.9	-3	-6
2009-2010	0.7	1	2
Total (2005-2010)	**-0.8**	**-1**	**-3**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 19,358 acres
5. Non-Reporting Area: 45,914 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

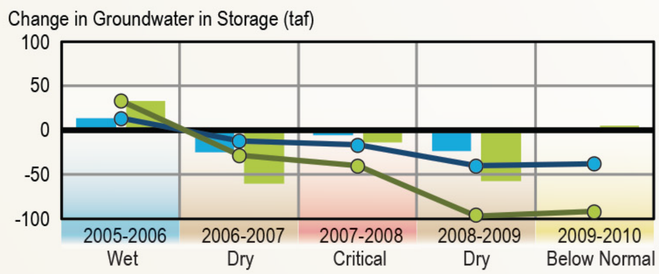
Wet | Above Normal | Below Normal | Dry | Critical

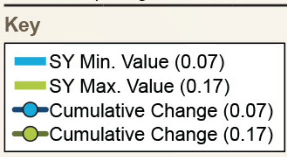
Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-19 Annual Change in Groundwater in Storage for the Red Bluff Subbasin (5-21.50) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	4.5	14	33
2006-2007	-5.6	-25	-61
2007-2008	-1.0	-5	-13
2008-2009	-4.9	-23	-56
2009-2010	-0.5	2	6
Total (2005-2010)	**-7.5**	**-37**	**-91**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 84,133 acres
5. Non-Reporting Area: 190,560 acres





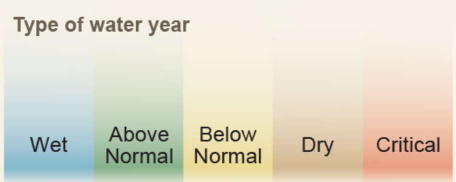


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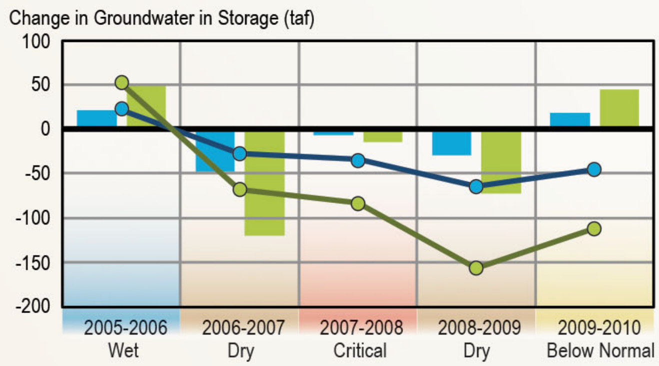
Figure E-20 Annual Change in Groundwater in Storage for the Corning Subbasin (5-21.51) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	2.5	21	51
2006-2007	-5.7	-49	-119
2007-2008	-0.7	-6	-15
2008-2009	-3.5	-30	-74
2009-2010	2.1	18	45
Total (2005-2010)	**-5.3**	**-46**	**-112**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 123,013 acres
5. Non-Reporting Area: 82,606 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

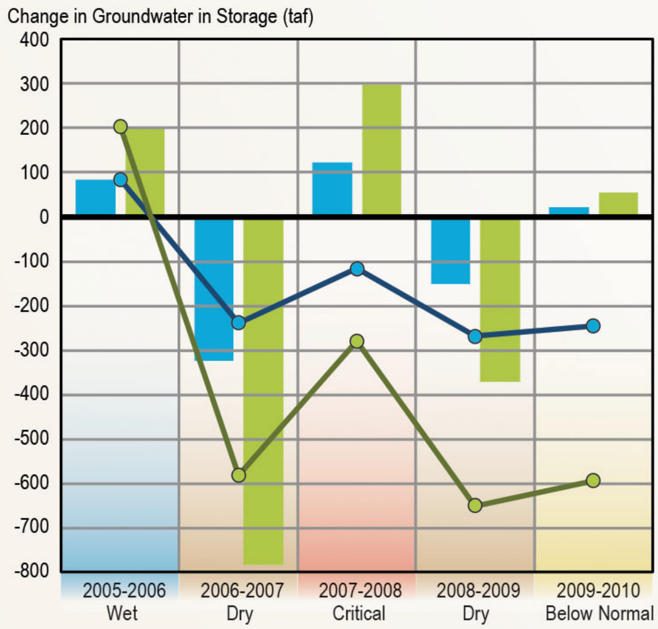
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-21 Annual Change in Groundwater in Storage for the Colusa Subbasin (5-21.52) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.6	84	203
2006-2007	-6.3	-323	-784
2007-2008	2.5	124	301
2008-2009	-3.0	-153	-371
2009-2010	0.5	23	57
Total (2005-2010)	**-4.7**	**-245**	**-594**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 728,526 acres
5. Non-Reporting Area: 189,852 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

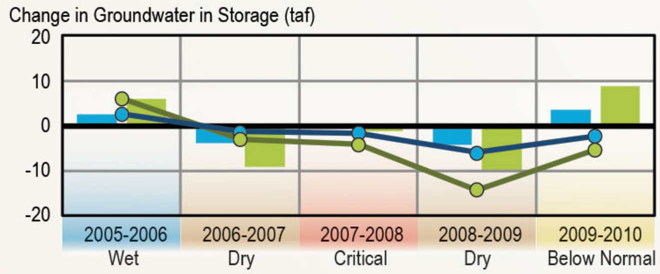
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-22 Annual Change in Groundwater in Storage for the Antelope Subbasin (5-21.54) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	2.3	3	6
2006-2007	-3.3	-4	-9
2007-2008	-0.4	-1	-1
2008-2009	-3.7	-4.	-10
2009-2010	3.2	4	9
Total (2005-2010)	**-1.9**	**-2**	**-5**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 16,040 acres
5. Non-Reporting Area: 2,669 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

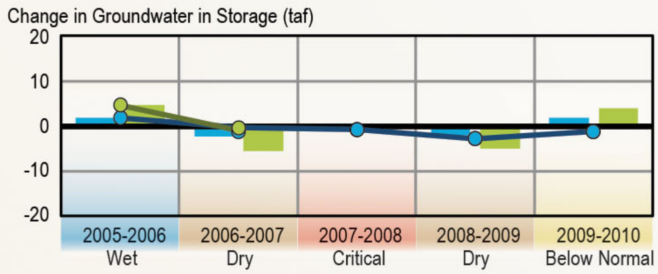
Wet | Above Normal | Below Normal | Dry | Critical

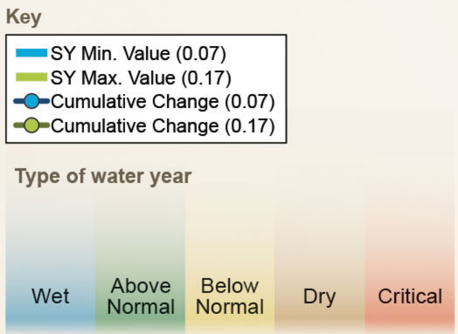
Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-23 Annual Change in Groundwater in Storage for the Dye Creek Subbasin (5-21.55) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.5	2	5
2006-2007	-1.9	-2	-6
2007-2008	-0.3	0	-1
2008-2009	-1.7	-2	-5
2009-2010	1.3	2	4
Total (2005-2010)	**-1.1**	**-1**	**-3**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 17,348 acres
5. Non-Reporting Area: 10,380 acres



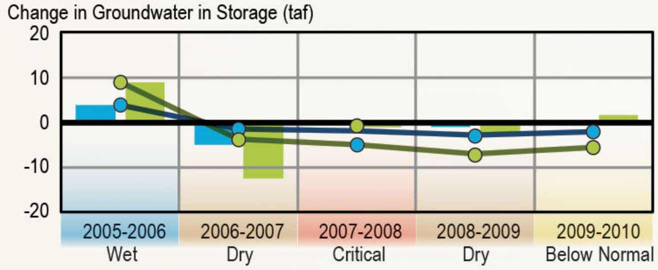


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-24 Annual Change in Groundwater in Storage for the Los Molinos Subbasin (5-21.56) in the Sacramento River Hydrologic Region (Spring 2005-2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	2.3	4	9
2006-2007	-3.2	-5	-13
2007-2008	-0.3	-1	-1
2008-2009	-0.6	-1	-2
2009-2010	0.4	1	2
Total (2005-2010)	**-1.4**	**-2**	**-5**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 22,982 acres
5. Non-Reporting Area: 10,188 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

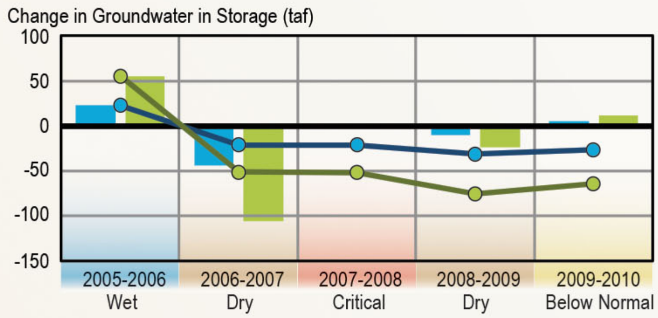
Type of water year

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-25 Annual Change in Groundwater in Storage for the Vina Subbasin (5-21.57) in the Sacramento River Hydrologic Region (2005-2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.6	23	55
2006-2007	-6.9	-43	-105
2007-2008	-0.1	-1	-2
2008-2009	-1.5	-10	-23
2009-2010	0.8	5	11
Total (2005-2010)	**-4.1**	**-26**	**-64**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 89,340 acres
5. Non-Reporting Area: 35,313 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

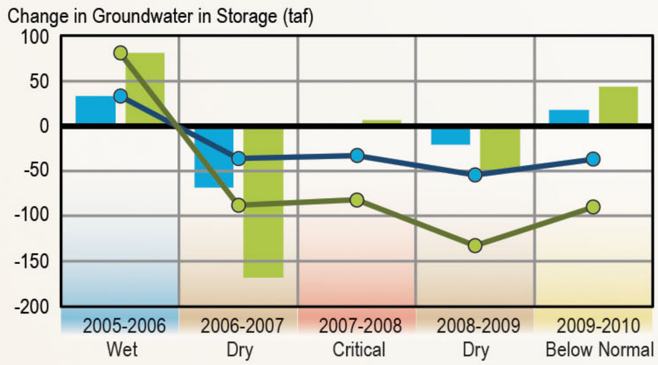
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-26 Annual Change in Groundwater in Storage for the West Butte Subbasin (5-21.58) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	2.7	33	80
2006-2007	-5.6	-70	-168
2007-2008	0.2	3	6
2008-2009	-1.7	-21	-51
2009-2010	1.4	18	43
Total (2005-2010)	**-3.0**	**-37**	**-90**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 175,056 acres
5. Non-Reporting Area: 6,527 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

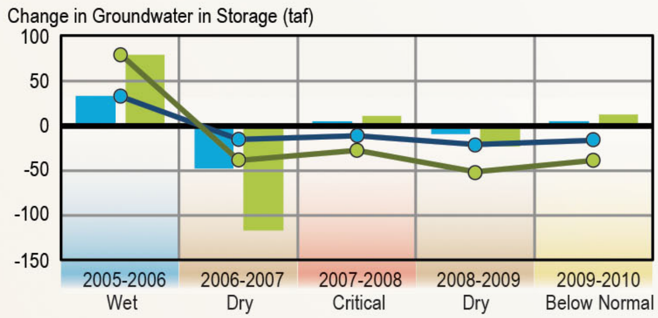
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-27 Annual Change in Groundwater in Storage for the East Butte Subbasin (5-21.59) in the Sacramento River Hydrologic Region (Spring 2005-2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	2.0	32	79
2006-2007	-2.9	-48	-117
2007-2008	0.3	4	11
2008-2009	-0.6	-10	-24
2009-2010	0.3	5	12
Total (2005-2010)	**-0.9**	**-17**	**-39**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 234,856 acres
5. Non-Reporting Area: 30,592 acres



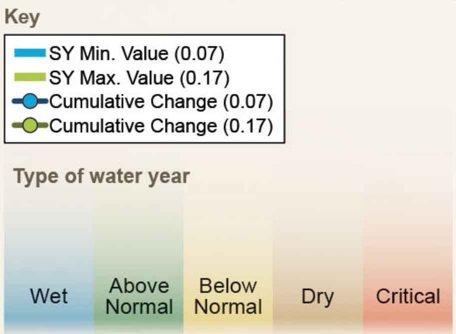


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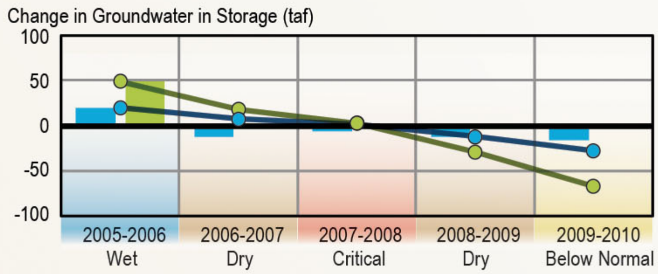
Figure E-28 Annual Change in Groundwater in Storage for the North Yuba Subbasin (5-21.60) in the Sacramento River Hydrologic Region (Spring 2005-2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	3.5	20	49
2006-2007	-2.3	-13	-31
2007-2008	-1.1	-6	-15
2008-2009	-2.3	-13	-32
2009-2010	-2.8	-16	-39
Total (2005-2010)	**-5.0**	**-28**	**-68**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 80,951 acres
5. Non-Reporting Area: 22,244 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

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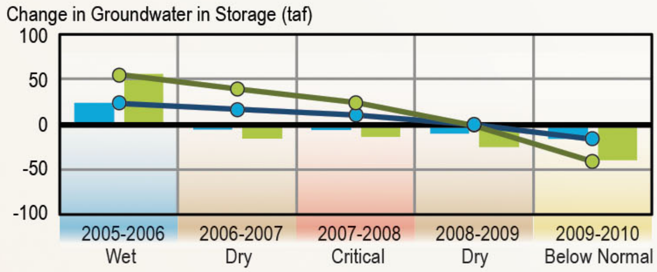
Figure E-29 Annual Change in Groundwater in Storage for the South Yuba Subbasin (5-21.61) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.7	22	55
2006-2007	-1.1	-7	-16
2007-2008	-1.0	-6	-15
2008-2009	-1.7	-10	-25
2009-2010	-2.8	-17	-41
Total (2005-2010)	**-2.9**	**-18**	**-42**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 86,638 acres
5. Non-Reporting Area: 17,889 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

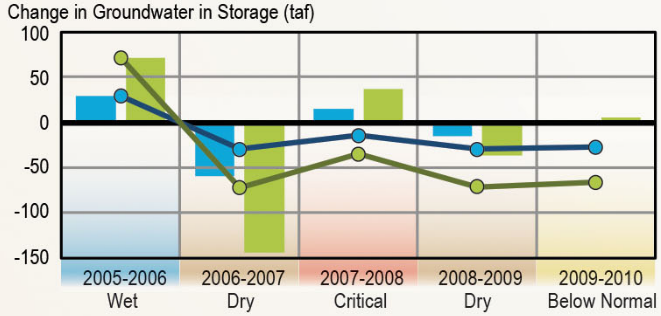
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-30 Annual Change in Groundwater in Storage for the Sutter Subbasin (5-21.62) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.8	29	71
2006-2007	-3.6	-59	-144
2007-2008	0.9	15	37
2008-2009	-0.9	-15	-37
2009-2010	0.1	2	5
Total (2005-2010)	**-1.7**	**-28**	**-68**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 234,379 acres
5. Non-Reporting Area: 0 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

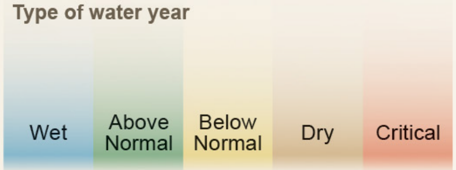
Figure E-31 Annual Change in Groundwater in Storage for the North American Subbasin (5-21.64) in the Sacramento River Hydrologic Region (Spring 2005-2010)

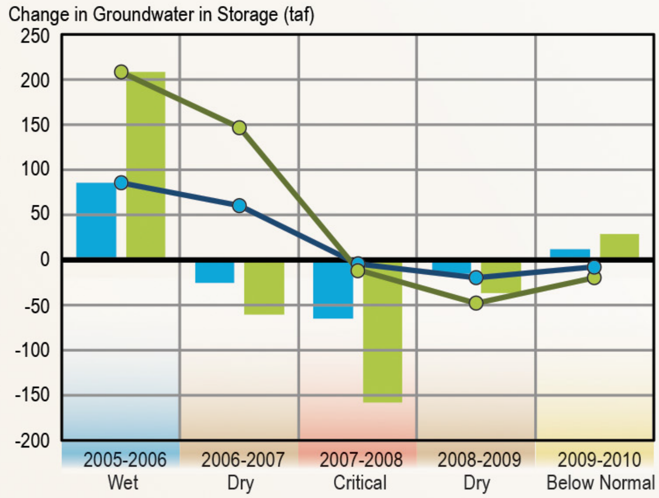
Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.9	86	208
2006-2007	-1.2	-25	-61
2007-2008	-3.0	-65	-158
2008-2009	-0.7	-15	-37
2009-2010	0.5	12	28
Total (2005-2010)	**-0.5**	**-7**	**-20**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 309,500 acres
5. Non-Reporting Area: 30,783 acres

Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year



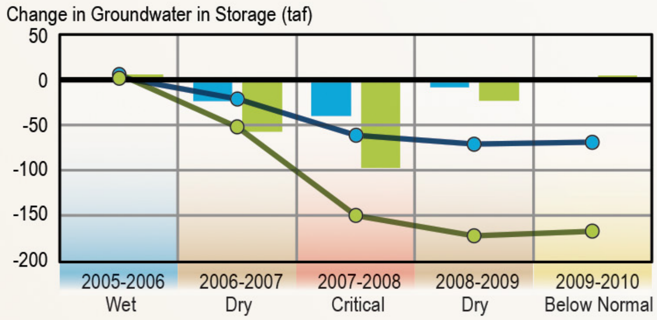


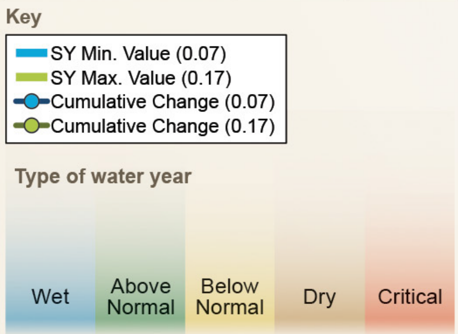
Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-32 Annual Change in Groundwater in Storage for the South American Subbasin (5-21.65) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	0.2	2	5
2006-2007	-1.6	-24	-58
2007-2008	-2.7	-40	-97
2008-2009	-0.6	-9	-22
2009-2010	0.1	2	5
Total (2005-2010)	**-4.6**	**-69**	**-167**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 210,533 acres
5. Non-Reporting Area: 37,283 acres



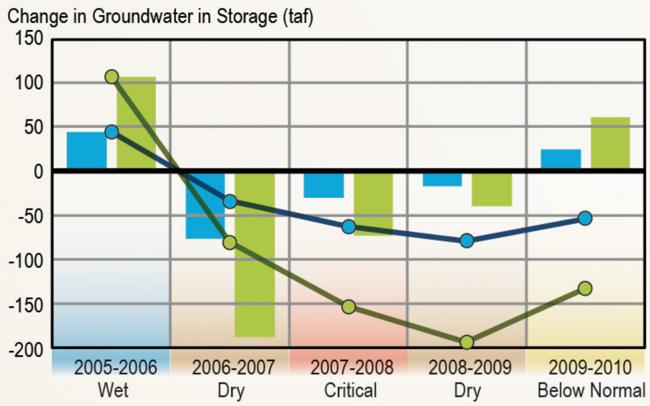


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-33 Annual Change in Groundwater in Storage for the Solano Subbasin (5-21.66) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	2.5	44	107
2006-2007	-4.5	-77	-188
2007-2008	-1.7	-30	-72
2008-2009	-1.0	-17	-41
2009-2010	1.5	25	61
Total (2005-2010)	**-3.2**	**-55**	**-133**

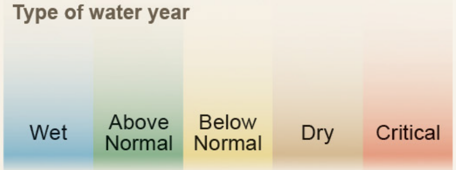
Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 249,157 acres
5. Non-Reporting Area: 175,886 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

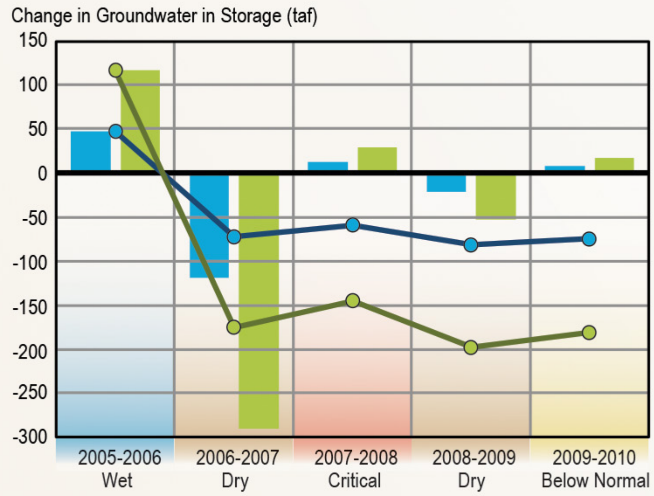


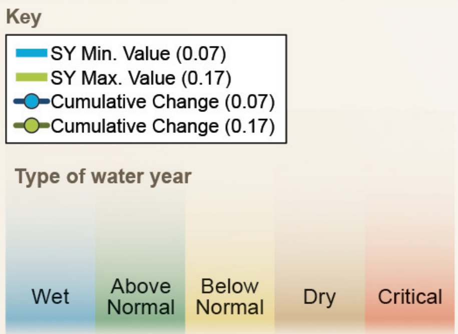
Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-34 Annual Change in Groundwater in Storage for the Yolo Subbasin (5-21.67) in the Sacramento River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.2	48	116
2006-2007	-8.1	-120	-291
2007-2008	0.8	12	30
2008-2009	-1.5	-22	-53
2009-2010	0.5	7	17
Total (2005-2010)	**-5.1**	**-75**	**-181**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 212,498 acres
5. Non-Reporting Area: 13,343 acres



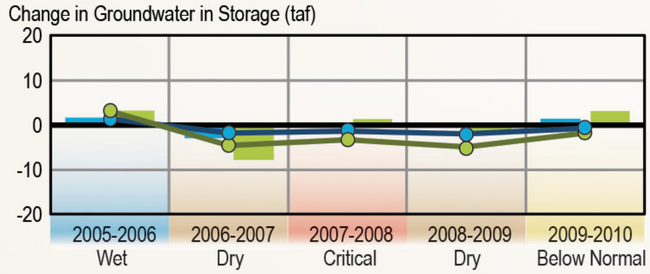


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-35 Annual Change in Groundwater in Storage for the Capay Valley Subbasin (5-21.68) in the Sacramento River Hydrological Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	1.0	1	3
2006-2007	-2.5	-3	-8
2007-2008	0.4	1	1
2008-2009	-0.7	-1	-2
2009-2010	1.2	1	3
Total (2005-2010)	**-0.6**	**-1**	**-3**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 23,910 acres
5. Non-Reporting Area: 1,077 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

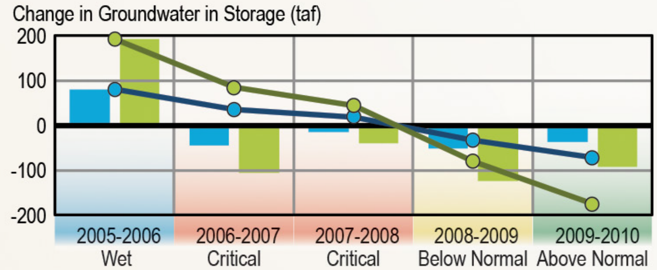
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-36 **Annual Change in Groundwater in Storage for the Eastern San Joaquin Subbasin (5-22.01) in the San Joaquin River Hydrologic Region (Spring 2005-2010)**

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	2.2	79	191
2006-2007	-1.3	-44	-108
2007-2008	-0.5	-16	-40
2008-2009	-1.5	-52	-125
2009-2010	-1.1	-39	-95
Total (2005-2010)	**-2.2**	**-72**	**-177**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 508,142 acres
5. Non-Reporting Area: 199,014 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

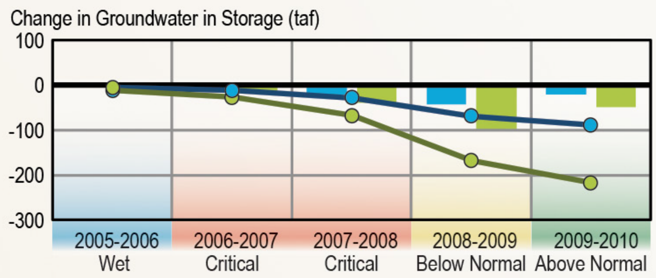
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-37 Annual Change in Groundwater in Storage for the Modesto Subbasin (5-22.02) in the San Joaquin River Hydrologic Region (Spring 2005- Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	-0.3	-4	-11
2006-2007	-0.5	-7	-16
2007-2008	-1.3	-17	-42
2008-2009	-3.3	-41	-101
2009-2010	-1.6	-20	-48
Total (2005-2010)	**-7.0**	**-89**	**-218**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 182,002 acres
5. Non-Reporting Area: 64,493 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

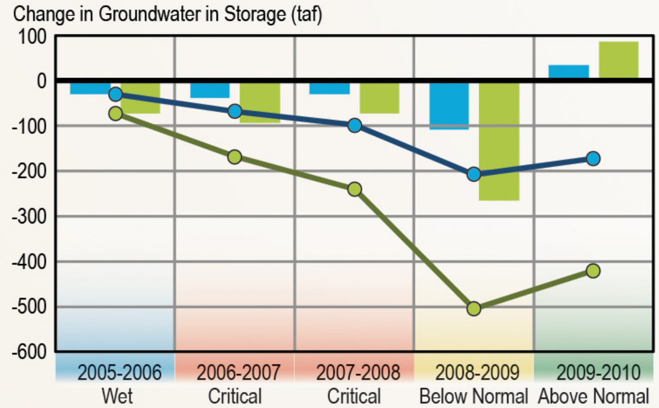
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-38 **Annual Change in Groundwater in Storage for the Turlock Subbasin (5-22.03) in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)**

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	-1.5	-30	-73
2006-2007	-1.9	-39	-95
2007-2008	-1.5	-30	-72
2008-2009	-5.4	-110	-267
2009-2010	1.8	36	87
Total (2005-2010)	**-8.5**	**-173**	**-420**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 288,501 acres
5. Non-Reporting Area: 58,587 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

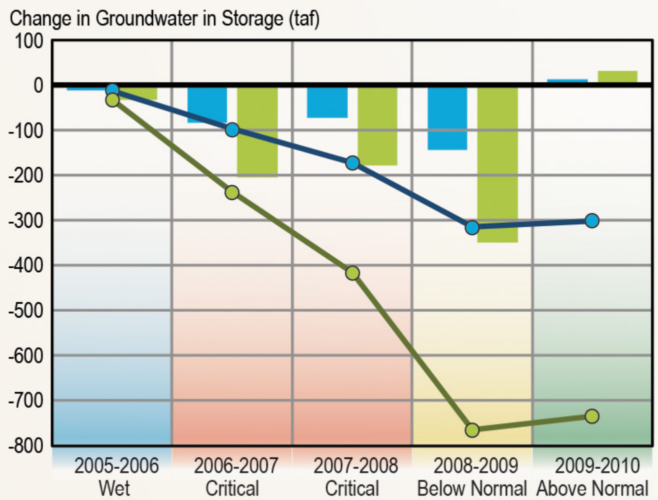
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-39 Annual Change in Groundwater in Storage for the Merced Subbasin (5-22.04) in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	-0.5	-14	-33
2006-2007	-3.2	-84	-204
2007-2008	-2.8	-74	-179
2008-2009	-5.4	-143	-348
2009-2010	0.5	12	30
Total (2005-2010)	**-11.4**	**-303**	**-734**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 377,340 acres
5. Non-Reporting Area: 113,717 acres



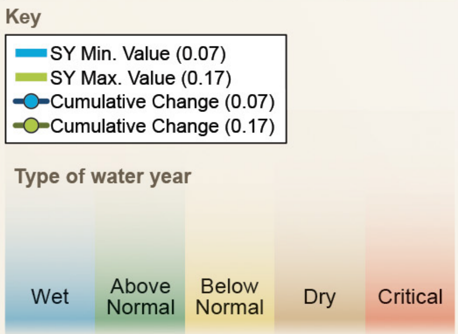


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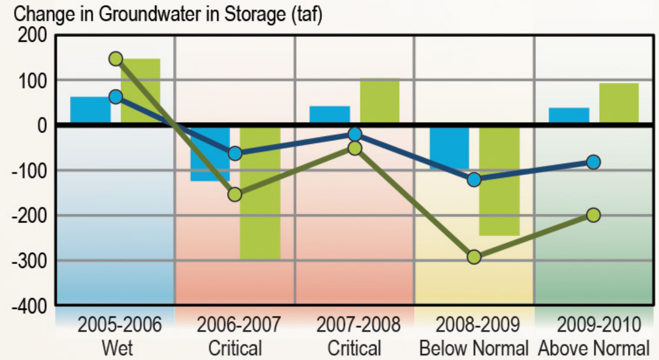
Figure E-40 Annual Change in Groundwater in Storage for the Chowchilla Subbasin (5-22.05) in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	5.6	61	149
2006-2007	-11.3	-125	-302
2007-2008	3.9	43	105
2008-2009	-9.2	-101	-244
2009-2010	3.5	39	94
Total (2005-2010)	**-7.5**	**-83**	**-198**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 157,035 acres
5. Non-Reporting Area: 2,200 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

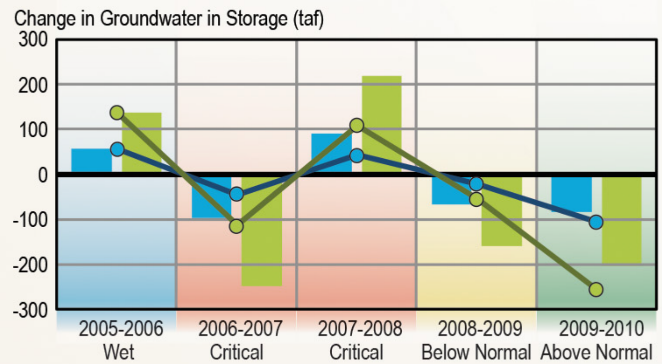
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-41 Annual Change in Groundwater in Storage for the Madera Subbasin (5-22.06) in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf) Assuming Specific Yield = 0.07	Estimated Change (taf) Assuming Specific Yield = 0.17
2005-2006	2.5	56	137
2006-2007	-4.5	-103	-249
2007-2008	4.0	91	220
2008-2009	-2.9	-67	-161
2009-2010	-3.7	-84	-204
Total (2005-2010)	**-4.6**	**-107**	**-257**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 323,443 acres
5. Non-Reporting Area: 69,652 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

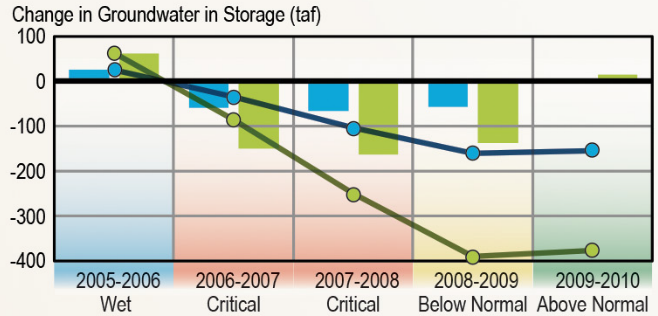
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-42 Annual Change in Groundwater in Storage for the Delta-Mendota Subbasin (5-22.07) in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	0.9	26	62
2006-2007	-2.1	-61	-148
2007-2008	-2.3	-68	-164
2008-2009	-2.0	-58	-140
2009-2010	0.2	5	13
Total (2005-2010)	**-5.3**	**-156**	**-377**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 414,710 acres
5. Non-Reporting Area: 331,880 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

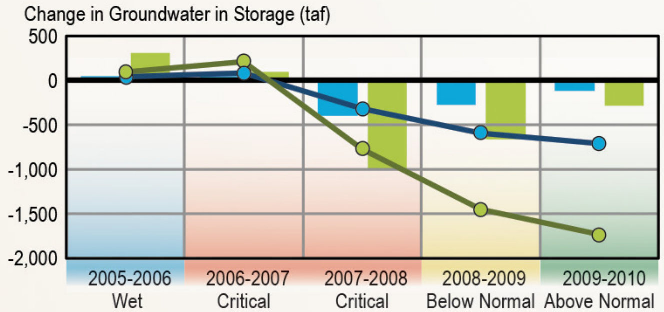
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

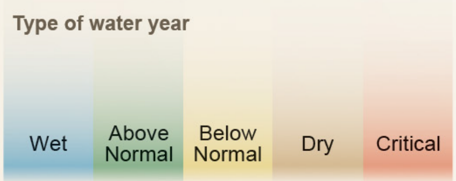
Figure E-43 Annual Change in Groundwater in Storage for the Kings Subbasin (5-22.08) in the Tulare Lake Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	0.6	41	100
2006-2007	0.7	45	109
2007-2008	-6.2	-405	-984
2008-2009	-4.2	-276	-670
2009-2010	-1.8	-118	-286
Total (2005-2010)	**-10.9**	**-713**	**-1,731**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 958,828 acres
5. Non-Reporting Area: 16,980 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

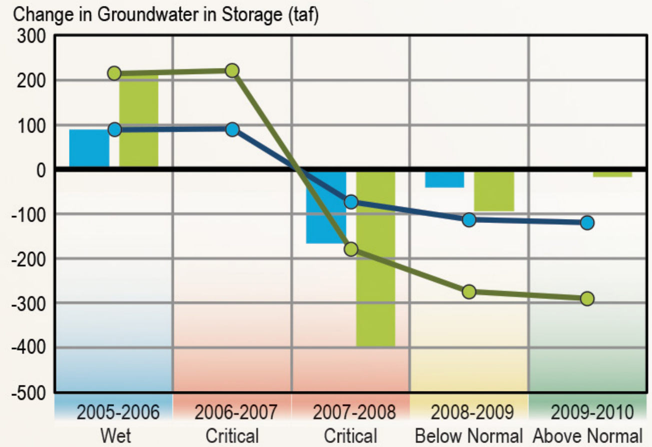


Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-44 Annual Change in Groundwater in Storage for the Westside Subbasin (5-22.09) in the Tulare Lake Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	21.4	88	214
2006-2007	0.8	3	8
2007-2008	-39.8	-165	-400
2008-2009	-9.4	-39	-95
2009-2010	-1.7	-7	-17
Total (2005-2010)	**-28.7**	**-120**	**-290**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 59,070 acres
5. Non-Reporting Area: 581,002 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

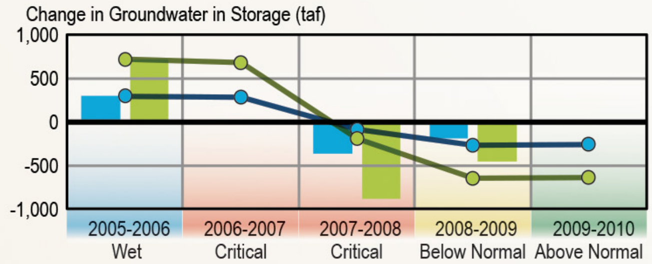
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-45 Annual Change in Groundwater in Storage for the Kaweah Subbasin (5-22.11) in the Tulare Lake Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	10.1	299	727
2006-2007	-0.5	-15	-37
2007-2008	-12.3	-364	-884
2008-2009	-7.0	-186	-451
2009-2010	0.2	5	11
Total (2005-2010)	**-9.5**	**-261**	**-634**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 432,958 acres
5. Non-Reporting Area: 12,484 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

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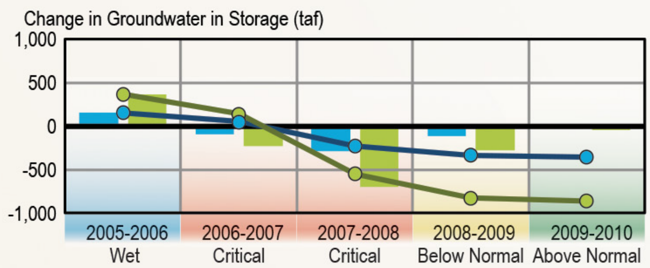
Figure E-46 Annual Change in Groundwater in Storage for the Tulare Lake Subbasin (5-22.12) in the Tulare Lake Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	10.7	152	368
2006-2007	-6.5	-93	-226
2007-2008	-20.1	-286	-694
2008-2009	-7.7	-109	-266
2009-2010	-1.2	-17	-40
Total (2005-2010)	**-24.8**	**-353**	**-858**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 203,140 acres
5. Non-Reporting Area: 320,702 acres



Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

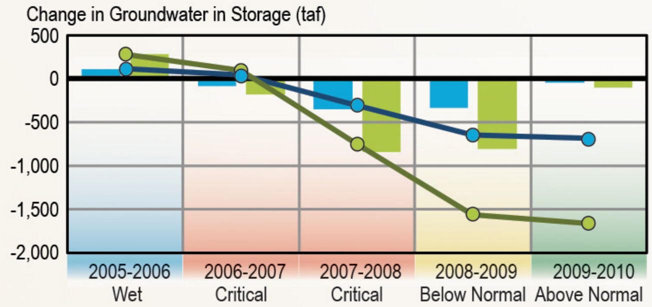
Wet | Above Normal | Below Normal | Dry | Critical

Prepared by California Department of Water Resources for California's Groundwater Update 2013

Figure E-47 Annual Change in Groundwater in Storage for the Tule Subbasin (5-22.13) in the Tulare Lake Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	3.7	114	277
2006-2007	-2.5	-76	-185
2007-2008	-11.3	-344	-836
2008-2009	-11.0	-334	-812
2009-2010	-1.4	-42	-102
Total (2005-2010)	**-22.5**	**-682**	**-1,658**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 439,449 acres
5. Non-Reporting Area: 29,565 acres



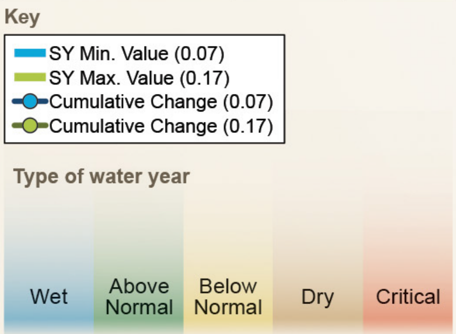


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Figure E-48 Annual Change in Groundwater in Storage for the Kern County Subbasin (5-22.14) in the Tulare Lake Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	12.3	763	1,853
2006-2007	6.1	374	907
2007-2008	-26.6	-1,648	-4,003
2008-2009	-10.6	-656	-1,592
2009-2010	-5.5	-339	-823
Total (2005-2010)	**-24.3**	**-1506**	**-3,658**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 888,510 acres
5. Non-Reporting Area: 1,057,758 acres

Key

- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

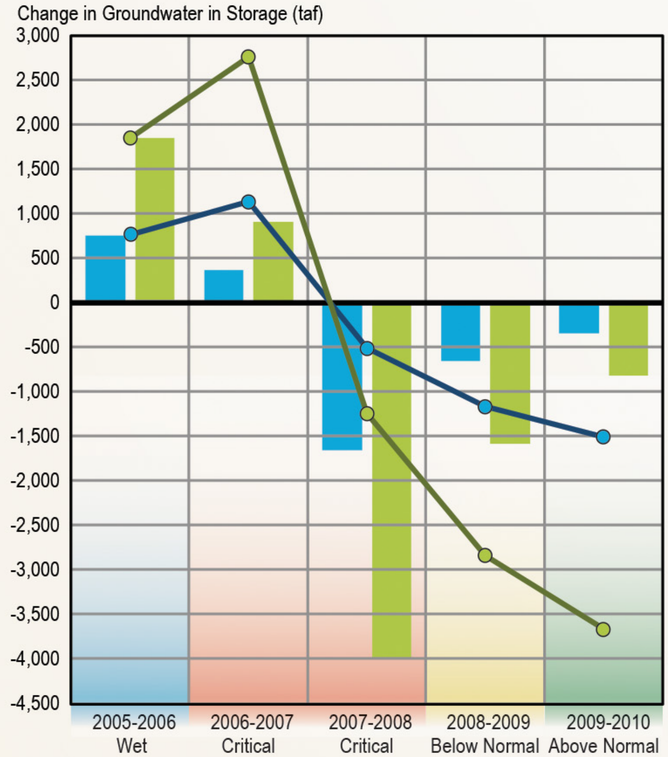

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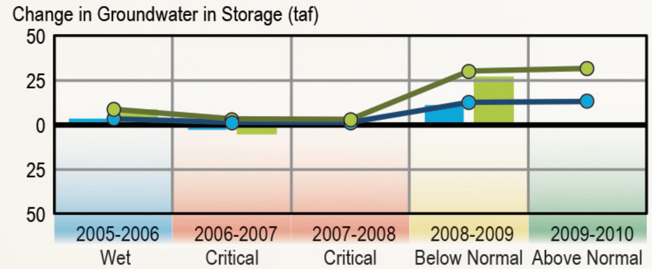
Figure E-49 Annual Change in Groundwater in Storage for the Tracy Subbasin (5-21.15) in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	0.7	4	9
2006-2007	-0.4	-2	-6
2007-2008	0.0	0	0
2008-2009	2.0	11	27
2009-2010	0.1	1	2
Total (2005-2010)	**2.4**	**14**	**32**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 79,356 acres
5. Non-Reporting Area: 265,653 acres



Key
- SY Min. Value (0.07)
- SY Max. Value (0.17)
- Cumulative Change (0.07)
- Cumulative Change (0.17)

Type of water year

Wet | Above Normal | Below Normal | Dry | Critical

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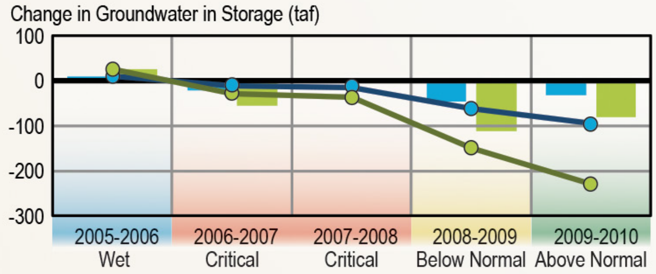
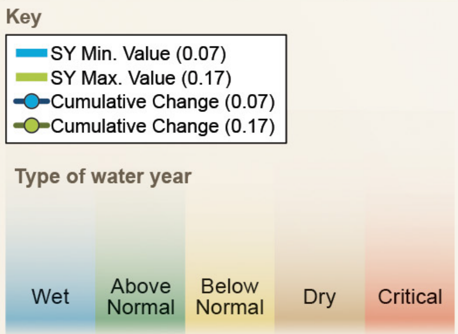
Figure E-50 **Annual Change in Groundwater in Storage for the Cosumnes Subbasin (5-22.16) in the San Joaquin River Hydrologic Region (Spring 2005-Spring 2010)**

Period Spring/ Spring	Average change in groundwater elevation (ft)	Estimated Change (taf)	
		Assuming Specific Yield = 0.07	Assuming Specific Yield = 0.17
2005-2006	0.8	11	27
2006-2007	-1.6	-23	-56
2007-2008	-0.2	-3	-7
2008-2009	-3.2	-47	-113
2009-2010	-2.3	-33	-81
Total (2005-2010)	**-6.5**	**-95**	**-230**

Notes:
1. taf = thousand acre feet
2. ft = feet
3. Groundwater elevation and change in groundwater in storage are estimates and are calculated within reporting area only
4. Reporting Area: 205,336 acres
5. Non-Reporting Area: 75,194 acres





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