Appendix A. Methods and Assumptions

Significant steps to improve California's sustainable water management practices have been implemented since the content for *California Groundwater Update 2013* (Groundwater Update) was finalized in August 2012. Extended drought, significant declines in surface water and groundwater storage, high rates of land subsidence, and loss of ecosystem habitat resulted in the implementation of several statewide initiatives to improve water resource reliability and restore critical ecosystem habitat. Development of the 2014 *California Water Action Plan* and the implementation of the 2014 Sustainable Groundwater Management Act (SGMA) have elevated the findings of this report by incorporating or addressing many of the recommendations into new statewide programs to improve sustainable water resource management.

Although the scope of this report does not permit a comprehensive update of the methods and assumptions appendix to reflect the new aspects of the 2014 sustainability actions, a short reference to the new sustainability initiatives has been provided under the appropriate sections to highlight significant changes and new sources of information. The latest information regarding California groundwater is available on the California Department of Water Resources' (DWR's) Groundwater Sustainability Web site (http://water.ca.gov/groundwater/sgm/index.cfm) and DWR's Groundwater Information Center (http://water.ca.gov/groundwater/gwinfo/index.cfm).

The following section provides an overview of the methods and assumptions for the collection and reporting of data in the Groundwater Update. The update draws upon multiple sources of existing and readily available data that commonly have been generated under separate assumptions and methods for data collection and reporting. Investigations that combine multiple sources of independently collected data can sometimes limit the degree and extent of analysis and interpretation when compared with investigations using coordinated data sources designed for an integrated purpose. Descriptions of the methods, assumptions, and potential limitations of the data provide a broader understanding of the data quality and help to guide appropriate use and interpretation of the data findings.

This appendix is organized according to the order of subject content provided in the Groundwater Update. Description of the methods and assumptions for some subject areas required a longer and more focused presentation. Expanded descriptions of the methods and assumptions for these subject areas have been provided in a separate appendix and are highlighted by bold italic text in the following outline:

- Introduction/ Findings/Gaps/ Recommendations.
- Groundwater Supply and Development.
    - Alluvial and Fractured-Rock Aquifers.
    - Well Infrastructure and Distribution.
    - ***CASGEM Groundwater Basin Prioritization.***
- ***Groundwater Use.***
    - Urban Water Use.
    - Agricultural Water Use.
    - Managed Wetland Water Use.

    - Average Annual Groundwater Use.
    - Change in Annual Groundwater Use.
- Groundwater Monitoring.
    - Groundwater-Level Monitoring.
    - Groundwater Quality Monitoring.
    - Land Subsidence Monitoring.
- Aquifer Conditions.
    - Groundwater Contour Maps.
    - Groundwater-Level Trends.
    - ***Change in Groundwater in Storage.***
    - Groundwater Quality.
    - ***Land Subsidence.***
- Groundwater Management Planning.
    - Groundwater Management Plan Inventory.
    - Groundwater Management Plan Assessment.
    - Groundwater Ordinances.
    - Special Act Districts.
    - Court Adjudication of Groundwater Rights.
    - Other Groundwater Management Planning Efforts.
- ***Conjunctive Management Inventory.***

Groundwater Supply and Development

This section provides an overview of the methods and assumptions used to identify alluvial and fractured-rock aquifers, characterize local well infrastructure, and determine groundwater-basin prioritization.

Alluvial Aquifers

Alluvial aquifers are comprised of sand and gravel or finer-grained sediments having groundwater stored within the voids, or pore space, among the alluvial sediments. Alluvial aquifer descriptions were derived primarily from DWR Bulletin 118-2003. In some basins, additional alluvial aquifer information was derived from local groundwater investigations and referenced appropriately.

The distribution and extent of California's alluvial and fractured-rock aquifers is defined by the latest update of DWR's Bulletin 118. The most recent Bulletin 118 update was published in 2003 and is available online through DWR's Groundwater Information Center (http://www.water.ca.gov/groundwater/). Appendix G of Bulletin 118-2003 provides a description of groundwater basin and subbasin development.

New regulations associated with SGMA establish a process for local agencies to request that DWR revise boundaries of a groundwater basin, including possible establishment of a new subbasin. Updated information regarding basin boundaries is available on DWR's Sustainable Groundwater Management Web site (http://water.ca.gov/groundwater/sgm/basin_boundaries.cfm#regs).

Groundwater basin boundaries identified in Bulletin 118-2003 were defined primarily through evaluation of geologic contacts and hydrogeologic barriers. The identification of the groundwater basins was initiated by determining the presence and areal extent of unconsolidated alluvial sediments identified on 1:250,000-scale geologic maps published by the California Department of Conservation's Division of Mines and Geology. Secondarily, the lateral extent or depth of the groundwater basins and the features that commonly affect groundwater flow were evaluated through review of regional-scale geologic and hydrogeologic reports, and through review of well completion reports. Specifically, the additional evaluation of basin boundaries looked for the following features:

- **Impermeable Bedrock:** Impermeable bedrock includes consolidated rocks of continental and marine origin and crystalline/or metamorphic rock. These rocks typically have lower water yielding capacity.
- **Constrictions in Permeable Materials:** A lower permeability material, even with openings that are filled with more permeable stream channel materials, generally forms a basin boundary for practical purposes. While groundwater may flow through the sediment-filled gaps, the flow is restricted to those gaps.
- **Fault:** A fault that crosses permeable materials may form a barrier to groundwater movement if movement along the fault plane has created fine material that impedes groundwater movement, or juxtaposed low-permeability material adjacent to an aquifer. This is usually indicated by noticeable difference in water levels in wells and/or flow patterns on either side of the fault. Not all faults act as barriers to groundwater flow.
- **Low Permeability Zone:** Areas of clay or other fine-grained material that have significant areal or vertical extent generally form a barrier to groundwater movement within the basin but do not form basin boundaries.
- **Groundwater Divide:** A groundwater divide serves as a barrier to groundwater movement. It is often expressed as a high point in the water table, characterized by divergent groundwater flow directions on either side of the groundwater divide. The location of the divide may change as the water level in one or both basins changes. This type of boundary is often used for subbasins.
- **Adjudicated Basin Boundaries:** The basin boundaries established by court order were used for all adjudicated basins. These court-decided boundaries affect the location of natural boundaries of adjoining basins. Some adjudicated basins are represented as subbasins in Bulletin 118-2003.

Various types of groundwater basins and their boundary conditions are provided in Table A-1. Basin boundaries that are specified in each of the court decisions have been used for the boundaries of adjudicated basins.

Although large-scale mapping and regional studies provide a good statewide approximation of alluvial basin boundaries, additional refinement of alluvial basin boundaries using local-scale studies, exploration, and mapping are recommended and encouraged.

Irrigation Pump Performance

Alluvial aquifer performance characteristics were evaluated based on studies conducted by the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo (Burt 2011). The ITRC studies evaluated thousands of electric irrigation pump test records

Table A-1 Types of Groundwater Basins and their Boundary Characteristics

Groundwater Basin Type	Typical Boundary Conditions
Single simple basin	• Basin surrounded on all sides by less permeable rock. • Higher permeability near the periphery. Clays near the center. • Unconfined around the periphery. Confined near the center. • May have artesian flow near the center.
Basin open at one or more places to other basins	• Many desert basins. • Merged alluvial fans. • Topographic ridges on fans. • Includes some fault-bounded basins.
Basin open to Pacific Ocean	• 260 basins along the coast. • Water-bearing materials extend offshore. • May be in contact with sea water. • Vulnerable to seawater intrusion.
Single complex basin	• Basin underlain or surrounded by older water-bearing materials and water-bearing volcanics. • Quantification is difficult because of unknown contacts between different rock types within the basin.
Groundwater in areas of volcanic rocks	• Basin concept is less applicable in volcanic rocks. • Volcanic rocks are highly variable in permeability.
Groundwater in weathered crystalline rocks (fractured hard rock) -- not considered a basin	• Small quantities of groundwater. • Low yielding wells. • Most wells are completed in the crystalline rock and rely on fractures to obtain groundwater.
Political boundaries or management area boundaries	• Usually not related to hydrogeologic boundaries. • Formed for convenience, usually to manage surface water storage and delivery.

within the Sacramento, San Joaquin, and Salinas valleys, and provided summaries of average flow rate, static groundwater level, and pumping drawdown for each groundwater basin. The Groundwater Update utilized the ITRC pump test results to estimate the average specific capacity of wells within the study area's groundwater basins. The range of average specific capacity estimates provided in the Groundwater Update were calculated based on the average flow rate and drawdown reported by ITRC. Although a portion of the pumping well drawdown is related to well performance and inefficiencies, much of the drawdown and related specific capacity can be directly correlated to the aquifer's ability to freely transmit water. Accuracy of the specific capacity estimates are constrained by the average reporting of the pump test data by IRTC. Additional accuracy could be obtained through analysis of the individual pump test records. Because of data confidentiality issues, individual pump test records from ITRC were not available. Additional information regarding the ITRC study is available online at http://www.itrc.org/reports/characteristics.htm.

Fractured-Rock Aquifers

Fractured-rock aquifers consist of impermeable granitic, metamorphic, volcanic, or hard sedimentary rocks, with groundwater being stored within fractures or other void spaces. Characterization of fractured-rock aquifers is challenging because of the high degree of variability in the size, spacing, interconnection, and orientation of fractures. Fractured-rock aquifers can also be a challenge to accurately monitor because of the typically deep nature of groundwater levels and issues with cascading water across variably spaced fracture zones.

The California Statewide Groundwater Elevation Monitoring (CASGEM) Program focuses groundwater-level data collection on alluvial aquifers. The DWR Land and Water Use Program focuses primarily on agricultural crops grown within alluvial basins. Because of the general lack of regional fractured-rock aquifer data, little information was generated for California's fractured-rock aquifers. Supplemental information regarding fractured-rock aquifers can be obtained through the following sources:

- DWR Bulletin 118-2003: http://www.water.ca.gov/groundwater/bulletin118/index.cfm.
- DWR *Water Facts 1*: http://www.water.ca.gov/waterconditions/docs/water_facts_1.pdf.
- USGS Water Supply Paper 2220: http://pubs.er.usgs.gov/publication/wsp2220.

Well Infrastructure and Distribution

Estimates of well infrastructure and distribution were developed using well completion reports (well logs) submitted to DWR. Well logs associated with water well installation from 1977 through 2010 were used to evaluate the distribution and types of groundwater well uses in California. Despite California Water Code requirements for wells drillers to submit wells logs to the State, DWR does not receive well logs for all newly installed wells. As a result, information on some of the wells installed between 1977 and 2010 is not available for this analysis. In addition, accurate characterization of well location and type of use were limited because of incomplete or missing information provided on the log, and because of the variability and level of completeness of the well-log information managed at each of DWR's four region offices.

At the time this report was generated, information included in well logs was not available to the general public without written permission of the current well owner. In 2015, Senate Bill (SB) 83 amended California Water Code Section 13752 to allow public access to well completion reports. DWR is currently in the process of making well logs publically available. Updated information regarding implementation of SB 83 is available on DWR's Web site on well completion reports: http://water.ca.gov/groundwater/wells/well_completion_reports.cfm.

Well uses were grouped according to the six most common well-use types: domestic, irrigation, public supply, industrial, monitoring, and other. Wells identified as "other" include the less common types of wells, such as stock wells, test wells, or unidentified wells (no information listed on the well log). DWR well log databases do not differentiate between newly installed wells and deepened wells;

for that reason, some of the irrigation well logs may be attributed to the deepening of existing irrigation wells. The small diameter of domestic wells tends to limit the ability to deepen them.

Because of limited information regarding detailed well location, the number and distribution of California wells were aggregated and reported according to county and by hydrologic region. The number and type of wells listed by county are not necessarily indicative of the number and type of wells within the entire hydrologic region. Well-log data for counties that fall within multiple hydrologic regions were assigned to the hydrologic region containing a majority of alluvial groundwater basins within the region.

CASGEM Groundwater Basin Prioritization

As part of the California 2009 Comprehensive Water Package legislation (SB X7-6), DWR implemented the CASGEM Program. The SB X7-6 groundwater-monitoring legislation added Part 2.11 to Division 6 of the California Water Code (Section 10920 et seq.), which established provisions and requirements for local agencies to develop and conduct groundwater-level monitoring programs. The legislation required DWR to identify the extent of groundwater-elevation monitoring within each of the alluvial groundwater basins defined in Bulletin 118-2003, and to prioritize those basins to help identify, evaluate, and determine the need for additional groundwater-level monitoring. The basin prioritization process (California Water Code Section 10933[b]) directs DWR to consider, to the extent data are available, the following eight components:

1. The population overlying the basin.
2. The rate of current and projected growth of the population overlying the basin.
3. The number of public supply wells that draw from the basin.
4. The total number of wells that draw from the basin.
5. The irrigated acreage overlying the basin.
6. The degree to which persons overlying the basin rely on groundwater as their primary source of water.
7. Any documented impacts on the groundwater within the basin, including overdraft, subsidence, saline intrusion, and other water quality degradation.
8. Any other information determined to be relevant by the department.

A detailed explanation of the basin prioritization process is provided in Appendix B. Updated information regarding the CASGEM Program is available online through DWR’s Groundwater Information Center: http://www.water.ca.gov/groundwater/casgem/basin_prioritization.cfm.

Groundwater Use

Groundwater use estimates for this report are based on water supply and balance information derived from DWR land use surveys, coupled with water supply and balance information, and from groundwater-use information voluntarily provided to DWR by water purveyors or other State agencies.

DWR land- and water-use data are first compiled and analyzed by detailed analysis units. Water supply and balance analyses are then compiled into larger planning areas, then into hydrologic regions, and finally into a statewide water supply and balance estimate. To assist local resource planning, DWR also generates water supply and balance information by county. Although some local

groundwater management groups independently develop groundwater extraction estimates for their groundwater basins, at the time of this report, DWR did generate groundwater extraction information by groundwater basin area. New approaches to characterizing the data components for CASGEM basin prioritization resulted in new estimates of groundwater use by groundwater basin. A detailed explanation of the methods associated with estimating groundwater use by groundwater basin is documented in the *CASGEM Basin Prioritization Process, 2014* report provided in Appendix B and available through DWR's Groundwater Information Center:
http://water.ca.gov/groundwater/casgem/pdfs/CA_GW%20Basin%20Prioritization_07-10-14.pdf.

A brief explanation of the methods for determining water use for urban areas, agriculture, and managed wetlands is provided in the following paragraphs. Additional information and data regarding water use and water balance methods are provided in *California Water Plan Update 2013*, Volume 4, *Reference Guide*, and Volume 5, *Technical Guide* (http://www.waterplan.water.ca.gov/cwpu2013/final/index.cfm). A tabular breakdown of groundwater-use information by planning area, county, and hydrologic region is provided in Appendix C.

Urban Groundwater Use

Groundwater pumpage for urban use is based on actual measured volumes reported by service districts within each study area. For rural residential use, groundwater pumpage is based on the per-capita water use from a neighboring service area that represents the housing development. Another name for rural water use, used in the California Water Plan, is "self-producing."

Agricultural Groundwater Use

Estimates of agricultural groundwater use are based on a combination of DWR land-use surveys, interviews with irrigation district personnel, farm advisors, and application of the land-use method. The land-use method identifies crop types and irrigation methods and then applies the appropriate water-use coefficients to ascertain the applied water demand, by water source. In areas where conjunctive use of groundwater and surface water are employed, developing an accurate estimate of the amount of applied groundwater versus surface water can be challenging. In these situations, land- and water-use methods typically assume that local surface-water supplies are used first to meet applied water demand. Once surface-water supplies have been fully allocated, if crop demand and water balance information indicate that additional water supplies are needed, groundwater supplies are assumed to be applied until the full applied water demand is met and the overall supply for the area is balanced. During drought water years, the estimated percentage of groundwater extraction in conjunctive use areas is increased according to the associated reduction or limitations in surface-water supplies.

Managed Wetlands

Groundwater use for managed wetlands and wildlife areas is estimated using a combination of urban and agricultural approaches. In managed wetland areas where wells are equipped with flow meters, DWR strives to collect the actual groundwater pumpage by area. In managed wetland areas without well meters, groundwater extraction volumes are estimated using the land-use method, similar to the agricultural water-use estimates.

Average Annual Groundwater Use

Average annual groundwater-use estimates are based on annual land- and water-use data compiled by water year (October 1 through September 30) and averaged over the 2005-2010 period. Average annual groundwater use is reported by (1) county, planning area, and hydrologic region; (2) the amount of use across urban, agriculture, and managed wetlands sectors; and (3) the amount that groundwater pumping contributes to the area's total water supply. Total water supply for a region represents the sum of surface water, groundwater, and reused/recycled water supplies. Reused/recycled water supplies include desalinated water supplies.

Groundwater use is reported in units of thousand acre feet (taf). To assist with accounting between the various use areas and sectors, tabular reporting of groundwater pumping estimates is provided to the 0.1-taf level. This degree of accuracy may be appropriate for some of the smaller planning areas, but the accuracy of groundwater-use estimates reported at the county and hydrologic region level can vary considerably based on accuracy and availability of recent land- and water-use data. Overall accuracy of groundwater-use information for the larger reporting areas is estimated to range between ±1.0 taf and ±10.0 taf.

Change in Annual Groundwater Use

Comparison of annual groundwater and surface water use is based on 2002-2010 annual land- and water-use data compiled by water year and by hydrologic region. Similar to the average annual groundwater-use data, water-use estimates were further compiled and reported according to urban, agriculture, and managed wetlands uses. To assist in analyzing the annual variability and trends associated with water use, charts were developed to help illustrate the volume and percent of water use, year, water source, and water-use sector. Additional information regarding water year type includes the amount of precipitation recorded as a percentage of the previous 30-year average for the hydrologic region.

Information provided in the previous section, regarding the accuracy of annual groundwater-use data, similarly applies to the 2002-2010 data evaluated for water-use comparisons. Some additional reduction in the accuracy of water-use reporting for the 2002-2005 period is expected because of limitations in the older land-use information.

Groundwater-Monitoring Data

Groundwater-Level Monitoring

California groundwater-level monitoring-well information was compiled from groundwater-level monitoring programs conducted by DWR, U.S. Geological Survey (USGS), U.S. Bureau of Reclamation (USBR), and local monitoring cooperators. At the time of report preparation, much of groundwater-level data associated with the CASGEM Program was not available. The groundwater-level information presented in the report is available online from DWR's Water Data Library (http://www.water.ca.gov/waterdatalibrary/), and the USGS National Water Information System (http://waterdata.usgs.gov/nwis/gw). Privately collected and locally maintained groundwater-level data were not included in this report.

Groundwater-level monitoring information represents data from those wells that have been measured since January 1, 2010, and have had data entered into DWR's Water Data Library or USGS online databases as of July 2012. Updated groundwater-level information may be obtained online from the DWR's Water Data Library and through the USGS National Water Information System. Additional groundwater-level data is now also available online from DWR's CASGEM Web site: http://www.water.ca.gov/groundwater/casgem.

The type of monitoring well, methods, and frequency of monitoring, and the approach for determining well location and elevation commonly vary according to the monitoring entity and the objective of the monitoring network. General information regarding monitoring-well location and measurement frequency is available on the DWR and USGS monitoring information Web sites mentioned in previous paragraphs. Detailed information regarding well ownership, construction, monitoring methods, and qualification of monitoring data is maintained by the lead monitoring entities responsible for the each monitoring network. A summary of the types, methods, frequency, and accuracy of monitoring of monitoring wells, and the information associated with groundwater-level data used in this report, is summarized in the following paragraphs.

Groundwater-level data utilized in this report includes monitoring networks comprised of active and inactive domestic and irrigations wells, various types of abandoned wells, and a smaller subset of dedicated observation wells. Many of the dedicated observation wells are constructed to include a nested set of individual monitoring wells discretely perforated across shallow, intermediate, and deep aquifer zones. The clustered set of individual monitoring wells are commonly placed within a single large-diameter borehole and vertically separated by thick annular seals designed to fully isolate the individual aquifer zone monitoring.

Monitoring-well location (latitude and longitude) accuracy varies according to the entity establishing the monitoring grid. Most groundwater-level monitoring wells have been field surveyed using hand held global positioning system (GPS) devices. Depending on site conditions and satellite coverage, latitude and longitude estimates using hand-held GPS devices are commonly accurate within about 10 feet. Latitude and longitude coordinates for some monitoring well locations are translated from field mapping by using aerial photography and field location descriptions, and are considered accurate to within 100 feet.

The frequency of groundwater-level monitoring also varies by monitoring entity and well type. At a minimum, groundwater levels are collected semi-annually to capture the seasonal fluctuations in groundwater levels (maximum and minimum). Monthly and continuous recordings of groundwater levels are also conducted for some monitoring wells. Most of DWR's dedicated observation wells are equipped with pressure transducers and dataloggers set to record groundwater levels every hour. Continuous groundwater-level data associated with dedicated monitoring wells is available through DWR's Water Data Library by clicking on the "continuous data" link at http://water.ca.gov/waterdatalibrary/docs/Hydstra/index.cfm.

Groundwater levels are typically measured to the nearest 0.1 foot by using an electric sounder or a steel tape. Dedicated monitoring wells with pressure transducers and dataloggers are commonly calibrated to record groundwater-level measurements to the nearest 0.01 foot. To help facilitate quality control, when appropriate, each groundwater-level measurement may also be annotated with a qualification code to help guide application of the data. For example, qualification codes are included at the time of monitoring to reflect whether a well is pumping, has recently pumped, or if nearby wells are being pumped. Additional qualifications are included to reflect cascading or falling groundwater within the well, or to identify when the measurement device encounters oil on top of the water table column within the well. Agricultural wells equipped with vertical turbine pumps sometimes accumulate oil on top of the water table because of excessive oiling of the impeller shaft bearings. A full listing of questionable measurement codes is available from DWR's Water Data Library.

Groundwater-level measurements are taken at a consistent datum or reference point (RP) that is typically located along the well casing, sounding tube, or base of a well. The RP for each well is unique. The RP location, elevation, and height above ground surface for each monitoring well is documented and included as part of the basic site information for each monitoring-well station. The RP elevation can be determined by several methods. Those methods may vary according to the entity establishing the monitoring-well station and the period from which the groundwater-level monitoring station was established.

Some typical approaches for determining RP elevation include land-level surveying to a benchmark include using a USGS 7.5 minute quadrangle map, a digital elevation model (DEM), or GPS. Reference point elevations established through land survey methods are considered accurate to ±0.1 foot. Reference point elevations established using USGS quadrangle ground-surface contours are accurate to about ± one-half of the contour interval. As a result, for a contour interval of 5 feet to 10 feet (which are available for many of the updated Central Valley USGS quadrangle maps), the accuracy of the RP elevation would be about ±2.5 feet to ±5.0 feet. The contour interval of high-quality DEMs is currently about 30 feet. Therefore, the accuracy associated with using DEMs to determine RP elevation is about ±15 feet. Handheld GPS units are typically less accurate for determining elevation than for determining latitude and longitude. Handheld GPS units are more accurate if they use the Wide Area Augmentation System (WAAS) to process elevation information. Handheld GPS units with WAAS data processing can typically achieve an accuracy of ±10 feet to ±20 feet, depending on satellite coverage, weather conditions, topography, and overhead vegetative or interfering structures.

DWR methods for groundwater-level monitoring utilize guidelines documented under the CASGEM Program. In addition to establishing monitoring methods, the CASGEM monitoring guidelines provide suggested criteria for selection of monitoring wells and frequency of monitoring needed to define seasonal and long-term trends in groundwater elevations. The groundwater-level monitoring guidelines are available through DWR's Groundwater Information Center (http://www.water.ca.gov/groundwater/casgem/index.cfm).

USGS methods and techniques for measurement of groundwater levels are included in the 2011 report, *Groundwater Technical Procedures of the U.S. Geological Survey*. It is available online at http://pubs.usgs.gov/tm/1a1/.

Groundwater Quality Monitoring

Groundwater quality monitoring information consists of publically available data from the DWR Water Data Library, the State Water Resources Control Board's (SWRCB's) Groundwater Ambient Monitoring and Assessment (GAMA) Program Web site, and from the SWRCB's GeoTracker GAMA Web site.

Groundwater quality data in DWR's Water Data Library primarily includes baseline minerals, metals, and nutrient data associated with regional monitoring. The GAMA Web site includes a description of the GAMA Program and also provides links to published GAMA documents and related reports. The GeoTracker GAMA Web site is a groundwater information system that provides the public with access to groundwater quality data. Groundwater quality records within GeoTracker are obtained from various sources such as regional water quality control board cleanup sites, California Department of Public Health, California Department of Pesticide Regulation, DWR's Water Data Library, USGS GAMA Priority Basin Project, SWRCB GAMA Domestic Well Project, and the Lawrence Livermore National Laboratory GAMA Special Studies projects.

Land Subsidence Monitoring

Land subsidence monitoring information was compiled from elevation surveys along the California Aqueduct, borehole extensometer monitoring, satellite remote-sensing studies by using interferometric synthetic aperture radar (InSAR), continuous and conventional GPS measurements, and spirit-leveling surveys.

A comprehensive description of land subsidence caused by groundwater pumping in California is provided in Appendix F.

Aquifer Conditions

The aquifer conditions section regionally examines aquifer system response to varying supply, demand, hydrologic conditions, and management practices by evaluating spring groundwater levels, spring-to-spring change in groundwater levels, groundwater-level trends over time, spring-to-spring change in groundwater in storage, and recent land subsidence information.

Aquifer conditions were analyzed using a combination of tools and methods, including:

- Groundwater contour maps.
- Groundwater-level trends.
- Change in groundwater in storage.
- Groundwater quality.
- Land subsidence.

The evaluation of aquifer conditions focuses on groundwater basins located within the Central Valley. Publically available spatial and temporal groundwater-level data outside the Central Valley was generally insufficient to allow for the level of analysis conducted for the Central Valley.

Groundwater contour maps, hydrographs, and change in storage analysis were developed using groundwater-level data that is available online from DWR's Water Data Library (http://www.water.ca.gov/waterdatalibrary/), and the USGS National Water Information System (http://waterdata.usgs.gov/nwis/gw).

Groundwater Contour Maps

Groundwater elevation, depth to groundwater, and change in groundwater-elevation contours were developed using groundwater-level measurements selected primarily from wells constructed within the unconfined or semiconfined portion of the alluvial aquifer system. Groundwater elevations from wells specifically constructed within perched or confined portions of the aquifer system were excluded from groundwater-level contouring. The lack of well-perforation data for many monitoring wells limited the application and use of specific well-construction criteria for selection of monitoring wells used for contouring. In addition, thousands of large-diameter Central Valley production wells screened over multiple aquifer zones have resulted in extensive vertical aquifer mixing of the unconfined and semiconfined aquifer systems, and similarly make systematic exclusion of groundwater contour data based solely on well construction difficult and impractical. In general, groundwater contours represent wells perforated within the upper 400 feet of the aquifer system. Wells having the upper perforation deeper than 400 feet, or groundwater elevations significantly higher than nearby wells constructed in known unconfined or semiconfined aquifer zones, were eliminated from the contouring set of wells. Some additional review of local recharge programs and land use practices were also conducted to make sure that abnormally high groundwater elevations resulting from recharge or land use practices were included in the contouring data.

Groundwater contours were developed using spring groundwater-level data and an ESRI ArcGIS geoprocessing tool described in Appendix E. Spring groundwater levels were selected for evaluation because they typically depict the highest groundwater levels of the year, represent a time when groundwater demands are at the annual minimum, and aquifer recharge from winter rainfall is at or near the annual maximum. Most of the spring groundwater-contour data represents measurements taken during March and April. To accommodate regional variations in precipitation and peak spring groundwater levels, groundwater-level measurements collected between January and April were evaluated, with the peak groundwater level during this period selected to represent “spring” groundwater conditions.

The spatial extent and accuracy of groundwater contours are limited by the location and distribution of monitoring-well data, changes in land-surface topography, and interpolation methods applied in the ArcGIS contouring tool. Central Valley areas having sufficient monitoring-well data were contoured and characterized as “reporting areas.” Alluvial basins areas not covered by contours are identified as “non-reporting areas,” because of the lack of sufficient groundwater-level data.

Spring 2010 depth-to-groundwater contours represents the depth from the ground surface to the unconfined groundwater table. The depth to groundwater was calculated by subtracting the RP height above ground surface from the depth to groundwater-level reading. Depth-to-groundwater contours are generated and referenced to the National Geodetic Vertical Datum 1988 (NGVD 88). Depth-to-groundwater contours are intended to represent regional aquifer conditions. The correlation between regional and local depth-to-groundwater information will depend on the location, distribution, construction, and accuracy of the local data compared with the regional data.

Spring 2010 groundwater-elevation contour maps provide a snapshot of regional groundwater occurrence, distribution, and direction of movement. Groundwater-level measurements recorded as depth to the groundwater table were converted to groundwater elevation by using RP information for the individual monitoring wells, and by referencing measurements to sea level using NGVD 88. The estimated horizontal direction of groundwater movement, from higher to lower elevations, is represented as a series of arrows drawn approximately perpendicular to groundwater-elevation contours. Arrows highlighting the direction of groundwater flow do not provide information regarding the direction of vertical flow within the aquifer system. Groundwater-elevation contours represent regional aquifer conditions. The correlation between regional and local groundwater-elevation information will depend on the location, distribution, construction, and accuracy of the local data compared with the regional data.

Groundwater-Level Trends

Groundwater-well hydrographs are graphical plots of depth to groundwater versus time. Groundwater-well hydrographs for each hydrologic region were selected to help tell a story of how the local aquifer systems respond to changing groundwater demands and implementation of local resource management practices. Groundwater-well hydrographs are identified according to the State Well Number (SWN) system. The SWN identifies a well by its location using the U.S. Public Lands Survey System of township, range, and section. More information on the SWN system is provided in DWR's *water facts* No. 7 information brochure: (http://www.water.ca.gov/pubs/conservation/waterfacts/numbering_water_wells_in_california__water_facts_7_/water_facts_7.pdf).

To help visualize changes in groundwater levels, groundwater hydrographs illustrate the series of individual groundwater-level measurements as a solid line within the graph. Solid lines are discontinued, and groundwater-level data are represented as a single dot, when one or more groundwater measurements are missing from the data series for the groundwater-level monitoring well. When evaluating groundwater hydrographs, it is important to remember that the line connecting a series of individual groundwater-level measurements does not represent a continuous recording of groundwater levels. Rather, it serves to approximate groundwater levels between the two groundwater-monitoring intervals.

Groundwater-level monitoring points on the hydrograph represented as blue dots indicate static groundwater-level measurements. Groundwater-level monitoring points represented by red dots indicate the measurement is qualified as questionable. Questionable measurement codes are used, as appropriate, to qualify the groundwater-level measurement that is subject to conditions that could affect the accuracy of the reading. A full listing of questionable measurement codes is available from DWR's Water Data Library.

Change in Groundwater in Storage

Change in groundwater in storage is the difference between the volumes of groundwater held in storage, within the unconfined aquifer, between two time periods. Change in groundwater in storage is calculated by multiplying the difference in groundwater elevation between two time periods, by the overlying basin area, and by the average specific yield (or volume of pore space from which water may be extracted).

Change in groundwater in storage is directly related to change in groundwater levels and depends on many factors, including climatic conditions, the annual rate of groundwater extraction, and the annual rate of groundwater recharge. Groundwater storage commonly fluctuates within a given year and from year to year. Groundwater in storage will typically decline during periods of drought and rebound during periods of above-normal precipitation. Within the same year, groundwater in storage will decline through the summer months because of extraction for municipal and agricultural uses, and then recover as extraction slows and seasonal precipitation increases the amount of recharge. In basins where the amount of annual groundwater extraction is at or below the amount of normal-year recharge, the long-term change in groundwater in storage will remain the same. In basins where the annual amount of groundwater extraction exceeds the amount of normal-year recharge, the long-term change in groundwater in storage will decline in relation to declining groundwater levels.

Annual and cumulative spring-to-spring changes in groundwater in storage were calculated for the Central Valley over a five-year period from 2005 to 2010. The change in spring-to-spring groundwater in storage was estimated using readily available groundwater-level data coupled with an ESRI ArcGIS geoprocessing tool. The ArcGIS tool provided a standardized, repeatable, and transparent methodology to estimate the volumetric changes associated with annual spring groundwater-elevation data. The change in total aquifer storage volume for each area was then converted to an estimated range of groundwater volume change by applying representative minimum and maximum specific yield values for the aquifer.

Aquifer-texture data from the 2013 DWR California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) and the 2009 USGS Central Valley Hydrologic Model (CVHM) were used to identify an appropriate range of specific yield data for the Central Valley. Based on data included in C2VSim and CVHM, minimum and maximum specific yield values of 0.07 and 0.17 were determined to be good approximations of the range of aquifer storage parameters for the unconfined aquifers in the Central Valley.

Similar to the process for developing groundwater-contour maps, areas having sufficient monitoring-well data were contoured and characterized as “reporting areas.” Areas lacking in data were identified as “non-reporting areas.”

The annual range of groundwater in storage change calculated using the ESRI ArcGIS geoprocessing tool represent a good approximation of the actual range of groundwater volume changes within the reporting areas. Further information regarding the methods, assumptions, and approximate accuracy of the change in groundwater in storage estimates is in the technical memorandum provided in Appendix E.

Groundwater Quality

Groundwater quality monitoring information consists of publically available data from DWR’s Water Data Library, the SWRCB’s GAMA program Web site, and from the SWRCB’s GeoTracker GAMA Web site.

DWR and SWRCB protocols and procedures for collection and analysis of water quality samples follow the protocols and procedures outlined in the basin water quality plans established by the SWRCB. The online links that follow provide specific information regarding the methods and assumptions of SWRCB water quality programs.

General Groundwater Quality Information

- SWRCB Programs: http://www.waterboards.ca.gov/water_issues/programs/#groundwater.
- Communities that Rely on a Contaminated Groundwater Source for Drinking Water: http://www.swrcb.ca.gov/gama/ab2222/docs/ab2222.pdf.
- Addressing Nitrate in California's Drinking Water: http://groundwaternitrate.ucdavis.edu/.
- Hydrogeologically Vulnerable Areas: http://www.waterboards.ca.gov/gama/docs/hva_map_table.pdf.
- Aquifer Storage and Recovery: http://www.waterboards.ca.gov/water_issues/programs/asr/index.shtml.
- Central Valley Salinity Alternatives for Long-Term Sustainability (CV-Salts): http://www.waterboards.ca.gov/centralvalley/water_issues/salinity/.

GAMA Program

- GeoTracker GAMA (Monitoring Data): http://www.waterboards.ca.gov/gama/geotracker_gama.shtml.
- Domestic Well Project: http://www.waterboards.ca.gov/gama/domestic_well.shtml.
- Priority Basin Project: http://www.waterboards.ca.gov/water_issues/programs/gama/priority_basin_projects.shtml.
- Special Studies Project: http://www.waterboards.ca.gov/water_issues/programs/gama/.
- California Aquifer Susceptibility Project: http://www.waterboards.ca.gov/water_issues/programs/gama/special_studies.shtml.

Contamination Sites

- Land Disposal Program: http://www.waterboards.ca.gov/water_issues/programs/land_disposal/.
- Department of Defense Program: http://www.waterboards.ca.gov/water_issues/programs/dept_of_defense/.
- Underground Storage Tank Program: http://www.waterboards.ca.gov/ust/index.shtml.
- Brownfields: http://www.waterboards.ca.gov/water_issues/programs/brownfields/.

Land Subsidence

Evaluation of land subsidence included review of information from elevation surveys along the California Aqueduct, borehole extensometer monitoring, satellite remote-sensing studies using InSAR, continuous and conventional GPS measurements, and spirit-leveling surveys.

Information regarding the process and procedures for spirit-leveling surveys can be found on the Web site for the U.S. Geological Survey, California Water Science Center: http://ca.water.usgs.gov/land_subsidence/california-subsidence-measuring.html.

InSAR is a remote sensing tool that uses satellite radar signals to measure deformation of the earth's crust at a high degree of spatial detail and measurement resolution. Under optimum conditions, the measurement resolution of InSAR monitoring is estimated to be 5 millimeters to 10 millimeters (U.S. Geological Survey 2003).

DWR monitors and maintains several borehole extensometers within the Sacramento Valley. The DWR Sacramento Valley subsidence grid consists of both cable and pipe extensometers. Pipe extensometers have an accuracy of ±0.001 foot. The accuracy of cable extensometers varies depending on individual well construction methods, but the extensometers are generally considered to have an accuracy of ±0.01 foot. DWR extensometers are equipped with instrumentation that continuously records (every 15 minutes) fluctuations of land subsidence, along with changes in groundwater level over multiple aquifer zones. Land subsidence data collected by DWR is available online at: http://www.water.ca.gov/groundwater/data_and_monitoring/land_subsidence_data.cfm.

A detailed overview of the land subsidence in California is provided in Appendix F.

Groundwater Management Information

The summary of California's groundwater management methods provided an inventory and assessment of groundwater management plans (GWMPs), county ordinances, groundwater-basin adjudications, and other groundwater-planning activities in California that were compiled as of August 2012. Passage of SGMA has created a new set of authorities, goals, and requirements for local agencies to implement sustainable groundwater management. It also elevated DWR's role to improve technical assistance and develop regulations for SGMA implementation. Updated information regarding implementation of SGMA is available on DWR's sustainable groundwater management Web site: http://water.ca.gov/groundwater/sgm/index.cfm.

Groundwater Management Plan Inventory

Groundwater management information included in this study is based on documents that were readily available, or submitted to DWR, as of August 2012. The inventory of GWMPs identifies adopting and signatory agencies, the date of plan adoption, the location of plans by county and hydrologic region, and the groundwater basins the plans cover.

The inventory also identified how many of the GWMPs were developed based on older Assembly Bill (AB) 3030 (1992) legislation and how many were developed or updated to meet the additional requirements established by SB 1938 (2002). Groundwater management plans developed prior to the AB 3030 legislation were identified as "inactive." Plans developed or updated after SB 1938 was enacted were identified as "active." Although some GWMPs were labeled inactive for the purposes of the statewide GWMP assessment, it does not necessarily mean that the lead agencies associated with these plans are not implementing the pre-1992 requirements of these plans.

Groundwater Management Plan Assessment

To build a better understanding of existing regional groundwater management efforts in California, DWR partnered with the Association of California Water Agencies (ACWA) in 2011 and 2012 to survey local water agencies about their groundwater management, conjunctive management, and water banking practices. The survey was submitted to ACWA member agencies and included questions on various topics covering groundwater management. The survey participants were not asked to rank their responses in terms of importance, but were asked to provide additional insights and list additional components. Overall, 58 ACWA member agencies responded to some or all of the survey.

In addition to the information gathered from the DWR/ACWA groundwater management survey, DWR independently reviewed the GWMPs to assess the following:

- How many of the post-SB 1938 GWMPs meet the six required components included in SB 1938 and incorporated into California Water Code Section 10753.7.
- How many of the post-SB 1938 GWMPs include the 12 voluntary components included in California Water Code Section 10753.8.
- How many of the implementing or signatory GWMP agencies are actively implementing the seven recommended components listed in DWR Bulletin 118-2003.

Before reporting the findings from the GWMP assessment, DWR contacted each of the lead GWMP agencies to convey the results of its GWMP assessment and provide the opportunity to respond to the assessment findings. Final results from the DWR/ACWA GWMP survey, and from DWR’s individual GWMP review, were aggregated prior to reporting so as not to be punitive in nature. At the time of the assessment, it was widely understood that the application of effective groundwater management in California was rife with jurisdictional, institutional, technological, and fiscal challenges. The overall intent of the GWMP assessment was to help identify groundwater management challenges and successes, and provide recommendations for local and statewide improvements in California groundwater management. Many of the findings and recommendations from the 2012 assessment were addressed and incorporated into the SGMA legislation.

Groundwater Ordinances

Groundwater ordinances are laws adopted by local authorities, such as cities or counties, to manage groundwater. This report expands on earlier efforts in Bulletin 118-2003 to identify groundwater-related ordinances to include ordinances pertaining to the following activities: groundwater management; formation of groundwater advisory committees; conducting water transfers that incorporate groundwater substitution pumping; implementing recharge programs; and the permitting of well construction, abandonment, and destruction.

Special Act Districts

Special act districts are established by the California State Legislature. They can cover a wide range of various authorities, including some relating to increasing local groundwater management authority. It was not within the scope of the Groundwater Update to research and identify all the individual special act districts related to groundwater management. The inventory and assessment of GWMPs in this report include plans that were prepared by special act districts and submitted to DWR.

Court Adjudication of Groundwater Rights

As part of the Groundwater Update, an inventory of court-ordered groundwater adjudications was conducted for California. The primary objective of most adjudications is to provide a proportionate share of the available groundwater to the users within the basin so that it can be extracted without having adverse effects to existing groundwater supplies. Because many of the adjudications were developed before implementation of California's resource sustainability goals outlined in the *California Water Action Plan* and SGMA, groundwater dependent ecosystems and environmental consequences of groundwater extraction were not considered when these judgments were written.

The inventory of adjudications includes court orders, judgments, and decrees. It builds on the list of adjudicated basins first published in Bulletin 118-2003. Findings from the inventory indicate, as of August 2012, there were 24 groundwater adjudications in California. Several additional adjudications are in process.

Other Groundwater Management Planning Efforts

Groundwater management also occurs through the planning efforts associated with integrated regional water management (IRWM) plans, urban water management plans (UWMPs), and agricultural water management plans (AWMPs). An inventory and review of California's 48 IRWM plans was conducted to identify how individual IRWM water resource management groups approach the implementation of local groundwater management strategies, and to identify if the local goals and objectives of local GWMPs were being incorporated into the broader goals of the IRWM plans. The source of IRWM planning information was DWR's IRWM Web site: http://www.water.ca.gov/irwm/grants/index.cfm. Reporting of groundwater-related IRWM planning was provided at the hydrologic region level.

Urban use of groundwater is one of the few uses that meter and report annual groundwater extraction volumes. The groundwater-extraction data is currently submitted with the UWMP and then manually translated by DWR staff into a database. The source of UWMP information was DWR's UWMP Web site: http://www.water.ca.gov/urbanwatermanagement/. Reporting of groundwater-related urban water management planning was provided at the hydrologic region level.

AWMPs provide another avenue for local groundwater management. At the time of report preparation, new and updated AWMPs meeting the SB X7-7 requirements were being actively submitted to DWR. As a result, no reviews of groundwater-related agricultural water management planning efforts were included in the report. Information regarding the 2012 AWMPs can be found on DWR's AWMP Web site: http://www.water.ca.gov/wateruseefficiency/agricultural/awmp_reviews.cfm.

Conjunctive Management Inventory

As part of *California Water Plan Update 2013*, an inventory and assessment of conjunctive management programs in California was conducted. The overall intent of this effort was to (1) provide a statewide summary of conjunctive water management program locations, operational methods, and capacities, and (2) identify their challenges, successes, and opportunities for growth to share with policy-makers and other stakeholders to enable an informed decision-making process regarding groundwater and its management. Additional information regarding conjunctive management in California, as well as a discussion on associated benefits, costs, and issues, can be found in *California Water Plan Update 2013*, Volume 3, Chapter 9, "Conjunctive Management and Groundwater Storage."

The statewide conjunctive management inventory and assessment consisted of literature research, an online survey, personal communication with local agencies, and a documented summary of the conjunctive management programs in California. Statewide, 89 conjunctive management and groundwater recharge programs were identified. Information from these efforts was compiled into a comprehensive spreadsheet of projects and historic operational information that was updated and enhanced with data from a coordinated DWR/ACWA survey.

The online survey administered by ACWA requested the following conjunctive management program information from its member agencies:

- Location of conjunctive use project.
- Year project was developed.
- Capital cost to develop the project.
- Annual operating cost of the project.
- Administrator/operator of the project.
- Capacity of the project in units of acre-feet.

Because of the limited response to the DWR/ACWA survey, DWR augmented the inventory by contacting, either by telephone or through email, each of the 89 entities identified as having a conjunctive water management program. DWR's follow-up efforts requested additional details regarding:

- Source of water received.
- Put and take capacity of the groundwater bank or conjunctive use project.
- Type of groundwater bank or conjunctive use project.
- Program goals and objectives.
- Constraints on development of conjunctive management or groundwater banking (recharge) program.

Because of confidentiality concerns expressed by some local agencies, information for some existing conjunctive management programs was not reported. Also, conjunctive management and groundwater recharge programs that were in the planning and feasibility stage were not included in the inventory. Tables listing all of the conjunctive management projects identified by DWR are reported by hydrologic region. A detailed overview of the conjunctive management inventory is provided in Appendix D.

References

Burt, C. 2011. *Characteristics of Irrigation Pump Performance in Major Irrigated Areas of California*. Irrigation Training and Research Center, ITRC Report No. R11-004. Viewed online at: http://www.itrc.org/reports/characteristics.htm.

U.S. Geological Survey. 2003. *Measuring Human-Induced Land Subsidence from Space. Fact Sheet 069-03*. Viewed online at: http://pubs.usgs.gov/fs/fs06903/pdf/fs06903.pdf.