Appendix J. HCM BMP

Hydrogeologic Conceptual Model Best Management Practice

1. OBJECTIVE

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

This BMP includes the following sections:

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

2. USE AND LIMITATIONS

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

3. HCM FUNDAMENTALS

A HCM:

1. Provides an understanding of the general physical characteristics related to regional hydrology, land use, geology and geologic structure, water quality, principal aquifers, and principal aquitards of the basin setting;

2. Provides the context to develop water budgets, mathematical (analytical or numerical) models, and monitoring networks; and

3. Provides a tool for stakeholder outreach and communication.

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

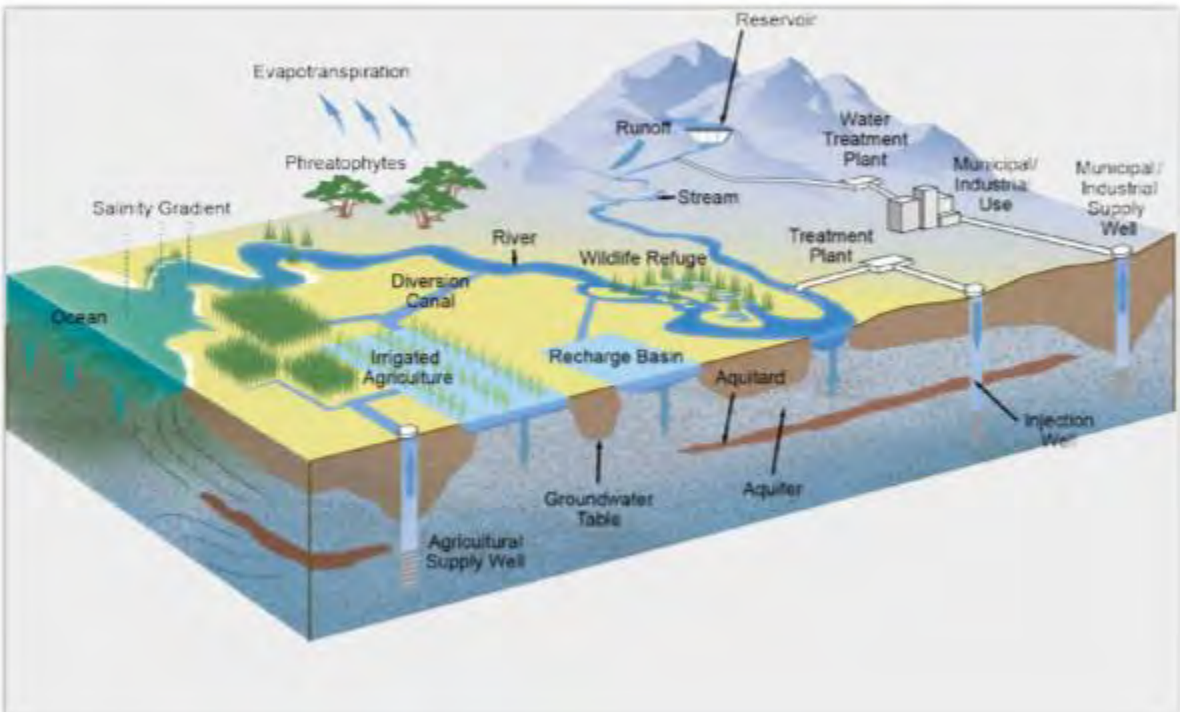


Figure 1 – Example 3-D Graphic Representing a HCM

COMMON HCM USES

The following provides a limited list of common HCM uses:

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

- Help identify potential projects and management actions to achieve the sustainability goal within the basin

HCM IN REFERENCE TO THE GSP REGULATIONS

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

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

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

1. The narrative description is accompanied by a graphical representation of the basin that clearly portrays the geographic setting, regional geology, basin geometry, general water quality, and consumptive water uses in the basin.

2. A series of geographic maps and scaled cross-sections to provide a vertical layering representation and a geographic view of individual datasets including the topography, geology, soils, recharge and discharge areas, source and point of delivery of imported water supplies, and surface water systems that are significant to management of the basin.

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

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

4. RELATIONSHIP OF HCM TO OTHER BMPS

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

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

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

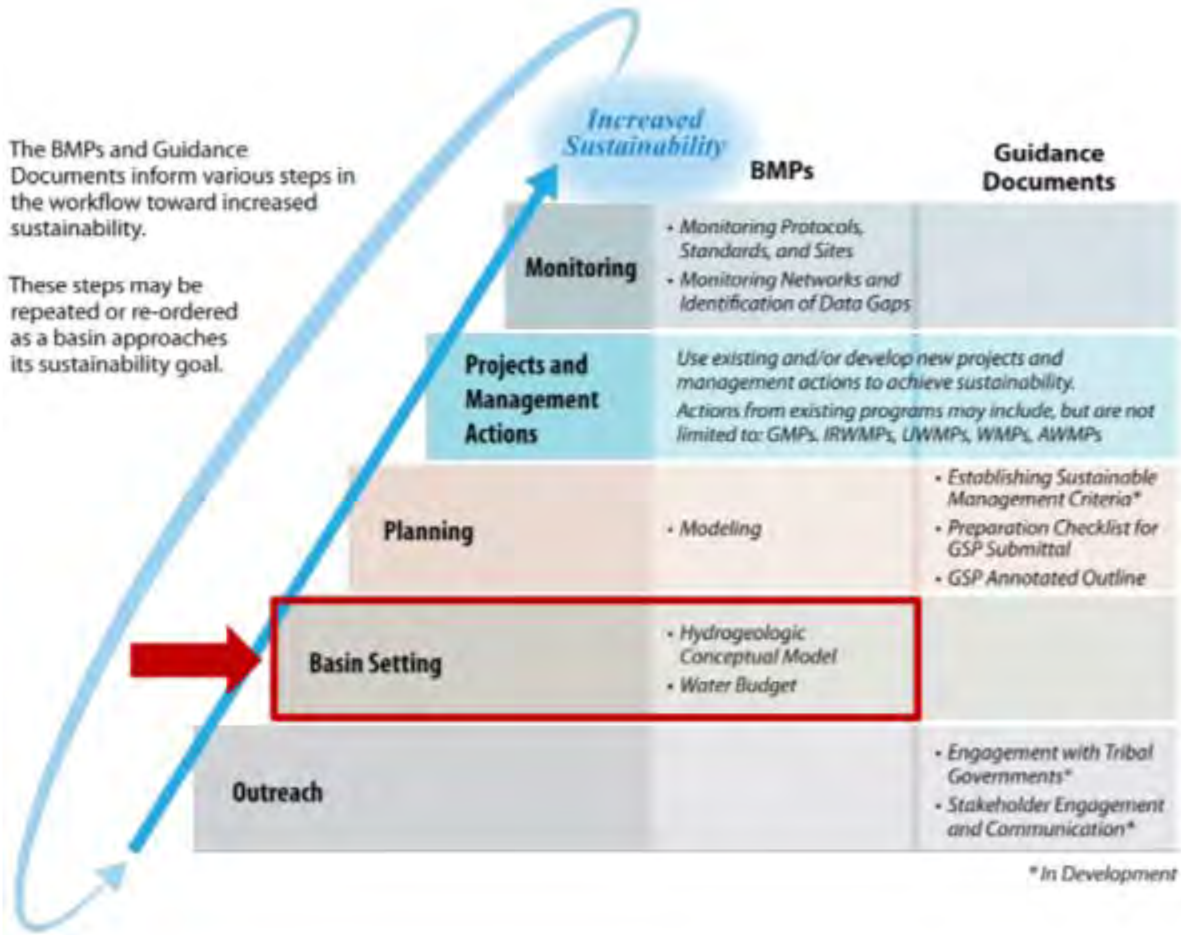


Figure 2 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

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

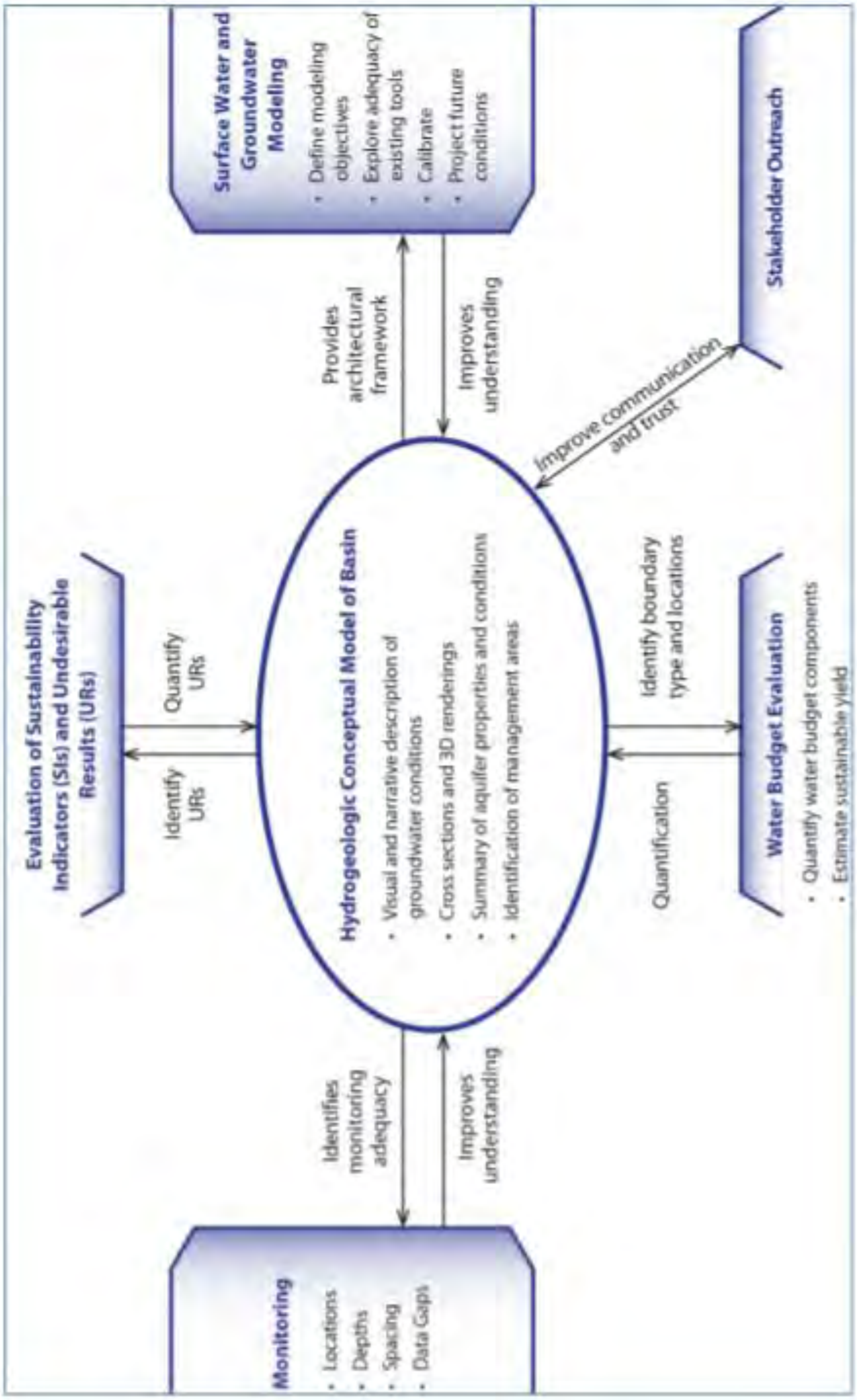


Figure 3 – Interrelationship between HCM and Other BMPs and Guidance Documents

5. TECHNICAL ASSISTANCE

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

CHARACTERIZING THE PHYSICAL COMPONENTS

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

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

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

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

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

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

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

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

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

<u>Defining the Basin Bottom based on Physical Properties</u>

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

Defining the Basin Bottom based on Geochemical Properties

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

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

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

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

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

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

Defining the Basin Bottom based on Field Techniques

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

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

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

- Mapping depth to bedrock from borehole

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

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

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

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

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

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

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

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

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

GRAPHICAL AND MAPPING REQUIREMENTS

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

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

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

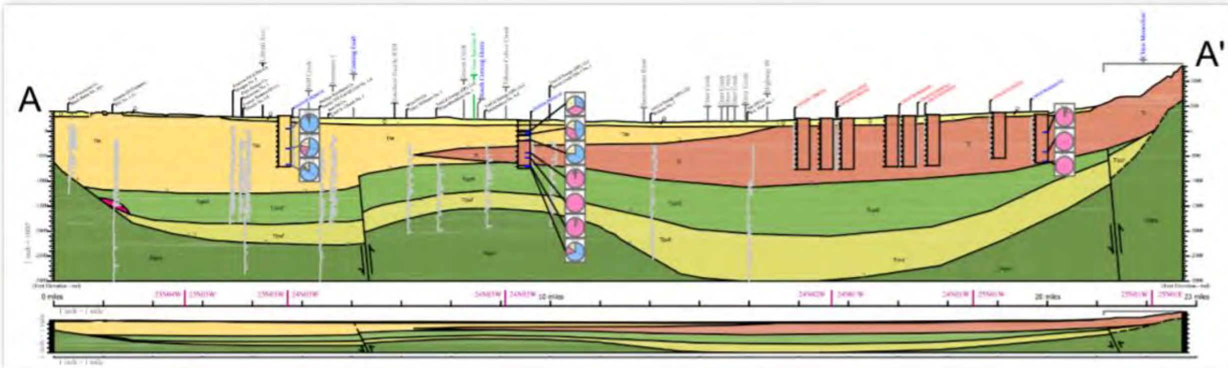


Figure 4 – Example Scaled Cross-Section

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

- Geologic cross-sections are often oriented perpendicular to the strike of the regional bedding. If a line of section oblique to the strike of regional bedding is selected, apparent dip of bedding and structural features should be computed and included in the geologic cross-section. It is important to choose a geologically relevant orientation with respect to strike and dip (and to note whether any of the selected orientations depict an apparent dip much different than the true dip).
- The geologic cross-section should not change trend direction, or bend significantly as this can change the relationship of the deposition direction. North and east should be on the right side of the page. If wells logs are projected onto the section the distance they are projected from the section line should be noted.
- The location and orientation of the line of geologic cross-section should be presented in plan view on a geologic map. The horizontal distance between boreholes, geologic contacts, structural features, and surface features is interpreted from the scale of the geologic map. The horizontal scale can be enlarged or reduced, preserving the relative distances, based on cross-section size. The vertical scale of the cross-section can exceed the horizontal scale (vertical exaggeration) in order to more clearly present the subsurface data. However, the scale should be chosen without undue vertical exaggeration.
- Subsurface lithology and structural features should be projected from surface contacts at the dip angle (or apparent dip) reported on the geologic map. Subsurface contacts may be correlated/interpreted between boreholes based on available lithologic logs and professional judgement. The cross-sections should be tied where they cross and to the geologic map at formation contacts.
- Cross-sections should include major aquifer and aquitard units, but it may not be necessary to include all lithologic beds on the cross-section.

- The geologic cross-section should include information provided on lithologic logs for boreholes along the line of section. Information for wells off-set from the line of section can be projected onto the cross-section. The maximum distance for projection of data onto the cross-section will be dependent upon the scale; professional judgement should be used in the selection of the maximum projection distance. The distance for projection of data should be somewhat dependent on the reasonableness one can infer that the units or features continue with some level of certainty. Conversely, if there is uncertainty, dashed lines or question marks are often applied to denote uncertainty.
- The level of detail and quality of available subsurface lithologic logs will vary between boreholes. The quality of individual lithologic logs should be considered when correlating subsurface borehole information.
- Where two cross-section lines intersect, the subsurface interpretations presented on the geologic cross-sections should be consistent at the intersection.
- The data used for horizon boundaries should be shown and posted for reference; and any references used to depict the cross-sections should be cited.

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

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

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

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

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

- In addition, the ESRI ArcGIS platform also includes DEM data available for use in conjunction with the ESRI GIS software.
- Surficial Geologic information can be downloaded from the California Geological Survey (CGS) and USGS from their interactive mapping tool.
  - CGS - http://maps.conservation.ca.gov/cgs/gmc/
  - USGS - http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

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

- The National Resource Conservation Service (NRCS) maintains soil data and Shapefiles nationwide on a county basis available at their website: http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx. For additional related soil characteristics in California, see the UC Davis soil interactive maps (http://casoilresource.lawr.ucdavis.edu/).
- Recharge and discharge areas of groundwater are generally not well mapped. This type of information may be available from local and regional groundwater management planning documents, or larger reports form the Department and USGS. Additional recharge maps in California have been developed by the California Soil Resource Lab at UC Davis – The following link is to their Soil Agricultural Groundwater Banking Index (SAGBI): http://casoilresource.lawr.ucdavis.edu/sagbi/
- Surface water mapping data can be downloaded from ESRI base maps within ArcGIS, or downloaded from the National Hydrography Datasets (NHD) datasets: http://viewer.nationalmap.gov/viewer/nhd.html?p=nhd
- Water supplies imported into a basin from state, federal, or local projects need to be mapped for the HCM. This information is generally available from the major suppliers of surface water such as the Department, United States Bureau of Reclamation (USBR), and local water and irrigation districts.

Additional useful information to be mapped may include:

- Groundwater elevation contour maps show the spatial distribution of groundwater elevations and help identify areas of low and high groundwater level areas within a basin. Elevation contour maps can be created from water level data collected from wells that are screened within the same principal aquifers. Information on water level data interpolation to create contour maps can be found in Tonkin et. al (2002).
- Land use maps detail the agricultural and urban land uses, and the distribution of natural vegetation, including potentially groundwater-dependent ecosystems. Land use maps shall use the Department land use classification scheme and maps provided by the Department.

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

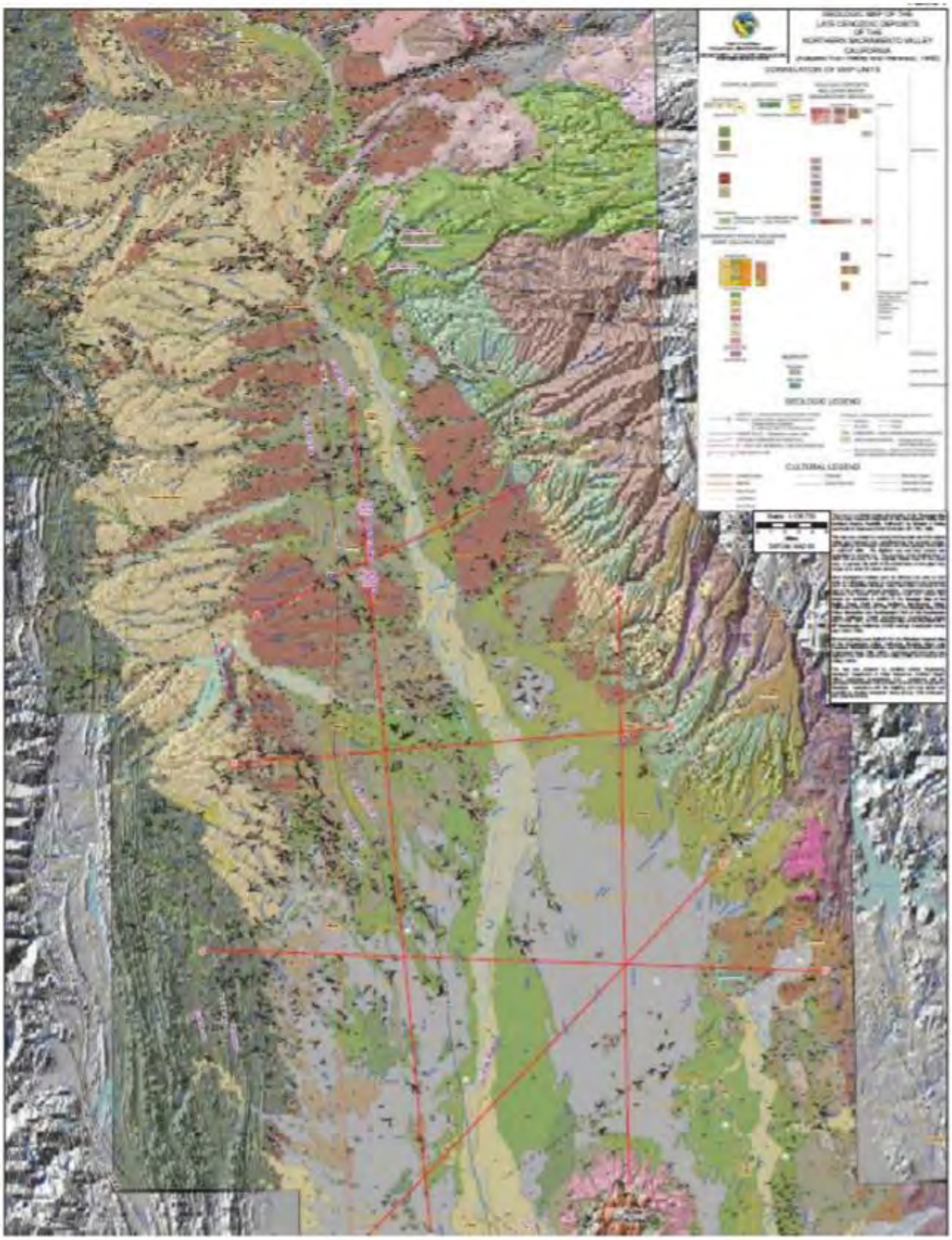


Figure 5 – Example Geologic Map

TYPICAL FLOW OF GRAPHICAL HCM DEVELOPMENT

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

1. Narrative description of the basin, which can be accompanied by a threedimensional graphic illustration of the HCM to complement the narrative; and

2. At least two scaled cross-sections and geographic maps to provide vertical layering representation and a geographic view of individual datasets, respectively.

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

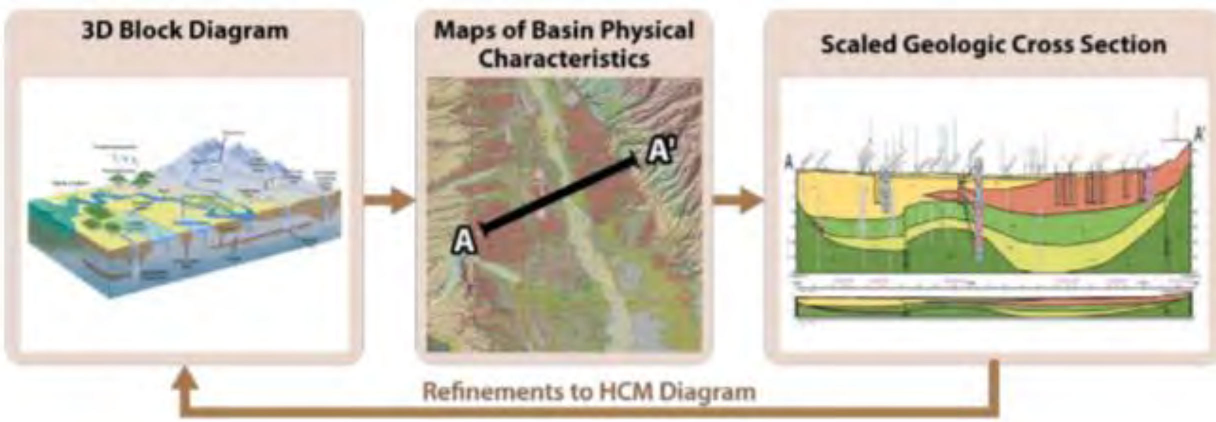


Figure 6 – Steps to Developing Graphic Representations of the HCM

6. KEY DEFINITIONS

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

SGMA Definitions (California Water Code §10721)

- “Groundwater recharge” or “recharge” means the augmentation of groundwater by natural or artificial means.
- “Recharge area” means the area that supplies water to an aquifer in a groundwater basin.

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

- “Aquifer” refers to a three-dimensional body of porous and permeable sediment or sedimentary rock that contains sufficient saturated material to yield significant quantities of groundwater to wells and springs, as further defined or characterized in Bulletin 118.
- “Hydrogeologic conceptual model” means a description of the geologic and hydrologic framework governing the occurrence of groundwater and its flow through and across the boundaries of a basin and the general groundwater conditions in a basin or subbasin.

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

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

- "Basin setting" refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the Agency in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5.
- "Best available science" refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.
- "Data gap" refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.
- "Principal aquifers" refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.
- "Uncertainty" refers to a lack of understanding of the basin setting that significantly affects an Agency's ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.
- "Water source type" represents the source from which water is derived to meet the applied beneficial uses, including groundwater, recycled water, reused water, and surface water sources identified as Central Valley Project, the State Water Project, the Colorado River Project, local supplies, and local imported supplies.
- "Water use sector" refers to categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed recharge, and native vegetation.

7. RELATED MATERIALS

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

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

STANDARDS

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

REFERENCES FOR FURTHER GUIDANCE

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

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

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

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

California Water Science Center. U.S. Geological Survey. http://ca.water.usgs.gov/ Accessed December 2016.

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

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

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

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

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

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

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

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

National Geologic Map Database. U.S. Geological Survey. https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html Accessed December 2016.

National Map Hydrography. U.S. Geological Survey. https://viewer.nationalmap.gov/viewer/nhd.html?p=nhd Accessed December 2016.

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

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

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

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

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

REFERENCES FOR CROSS SECTIONS

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

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

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

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

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

DATA SOURCES

Geology reports:

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

Digital Elevation Models (DEMs):

- http://www.opendem.info/opendem_client.html

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

Appendix K. Water Budget BMP

Water Budget Best Management Practice

1. OBJECTIVE

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

This BMP includes the following sections:

1. Objective. The objective and brief description of the contents of this BMP.

2. Use and Limitations. A brief description of the use and limitations of this BMP.

3. Water Budget Fundamentals. A description of fundamental water budget concepts.

4. Relationship of Water Budgets to other BMPs. A description of how the water budget BMP relates to other BMPs and how water budget information may be used to support development of other GSP requirements.

5. Technical Assistance. A description of technical assistance to support the development of a water budget, potential sources of information, and relevant datasets that can be used to further define each component.

6. Key Definitions. Definitions relevant for this BMP as provided in the GSP Regulations, Basin Boundary Regulations, SGMA, and DWR Bulletin 118.

7. Related Materials. References and other materials that provide supporting information related to the development of water budget estimates.

2. USE AND LIMITATIONS

This BMP does not create any new requirements or obligations for the GSA or other stakeholders. This BMP is not a substitute for the GSP Regulations and SGMA. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

3. WATER BUDGET FUNDAMENTALS

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

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

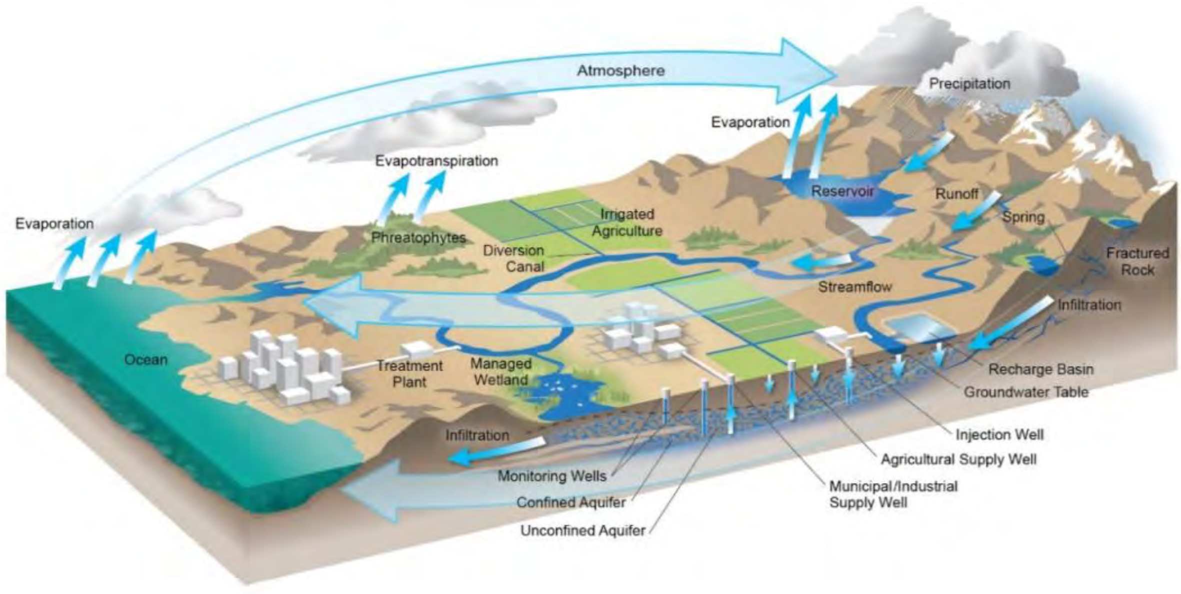


Figure 1 – The Hydrologic Cycle

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

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

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

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

Equation 1 – Water Budget Equation

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

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

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

$$\begin{array}{ccccccc} \text{Outflow (a)} & = & \text{Inflow (a, b, c)} & – & \text{Outflow (b, c)} & – & \text{Change in Storage} \\ \text{50 units} & = & \text{100 units} & – & \text{40 units} & – & \text{10 units} \end{array}$$

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

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

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

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

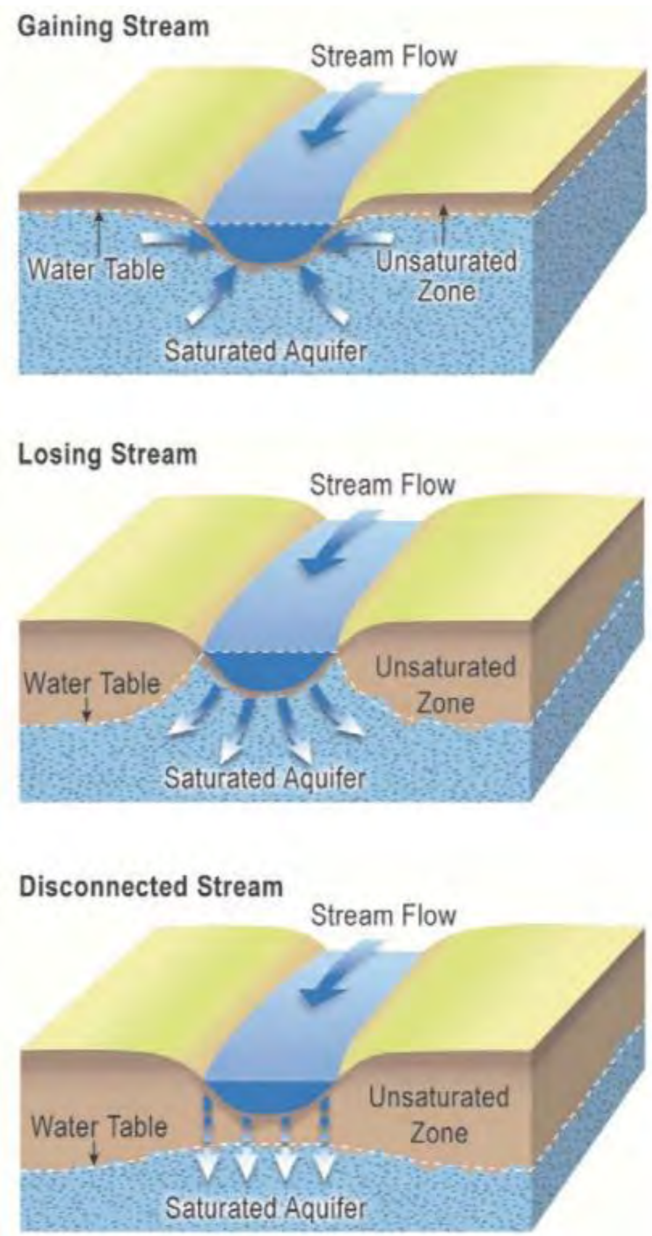


Figure 2 – Gaining, Losing, and Disconnected Streams

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

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

Characterization of stream depletion due to groundwater extraction requires adequate data and analysis. In the absence of adequate data, integrated groundwater-surface water models are often used to assist with water budget accounting and forecasting. Additional information regarding consideration of models under the GSP Regulations is provided in the Modeling BMP and in Section 5 of this BMP.

Water Budget Uses

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

General Water Budget Uses

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

GSP-Related Water Budget Uses

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

- Develop an accounting and characterize spatial and temporal distribution of inflows and outflows to the basin by water source type and water use sector, to identify the main beneficial uses and users, and determine which water budget components are most critical to achieving sustainable groundwater management (§354.18(b)).
- Assess how annual changes in historical inflows, outflows, and change in basin storage vary by water year type (hydrology) and water supply reliability (§354.18(c)(2)).
- Develop an understanding of how historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within the sustainable yield (§10733.6(b)(3)).
- Improve coordination and communication between the GSA and water supply or management agencies, local land use approval agencies, and interested parties who may be subject to sustainable groundwater management fees (§355.4(b)(4)).
- Facilitate coordination of water budget data and methodologies between agencies preparing a GSP within the basin (§357.4) or between basins (§357.2).
- Identify data gaps and uncertainty associated with key water budget components and develop an understanding of how these gaps and uncertainty may affect implementation of proposed projects and water management actions.
- Evaluate how the surface and groundwater systems have responded to the annual historical changes in the water budget inflows and outflows (§354.18(c)(2)).
- Determine the rate and volume of surface water depletion caused by groundwater use that has adverse impacts on the beneficial uses of the surface water and may lead to undesirable results (§354.16(f) and 354.28(c)(1)).
- Identify which water budget conditions commonly result in overdraft conditions (354.18(b)(5).
- Estimate the sustainable yield for the basin (§354.18 and 10727.6(g)).
- Forecast projected inflows and outflows to the basin over the planning and implementation horizon (§354.18(c)(3)).
- Evaluate the effect of proposed projects and management actions on future water budget projections (§354.44(b)).
- Evaluate future scenarios of water demand uncertainty associated with projected changes in local land use planning, population growth, and climate (§65362.5(a)).
- Inform monitoring requirements (§354.34(b)(4)).
- Inform development and quantification of sustainable management criteria, such as the sustainability goal, undesirable results, minimum thresholds, and measureable objectives (§354.22).
- Help identify potential projects and management actions to achieve the sustainability goal for the basin within 20 years of GSP implementation (§354.44).

Water Budgets in Reference to the GSP Regulations

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

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

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

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

4. RELATIONSHIP OF THE WATER BUDGET TO OTHER BMPS

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

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

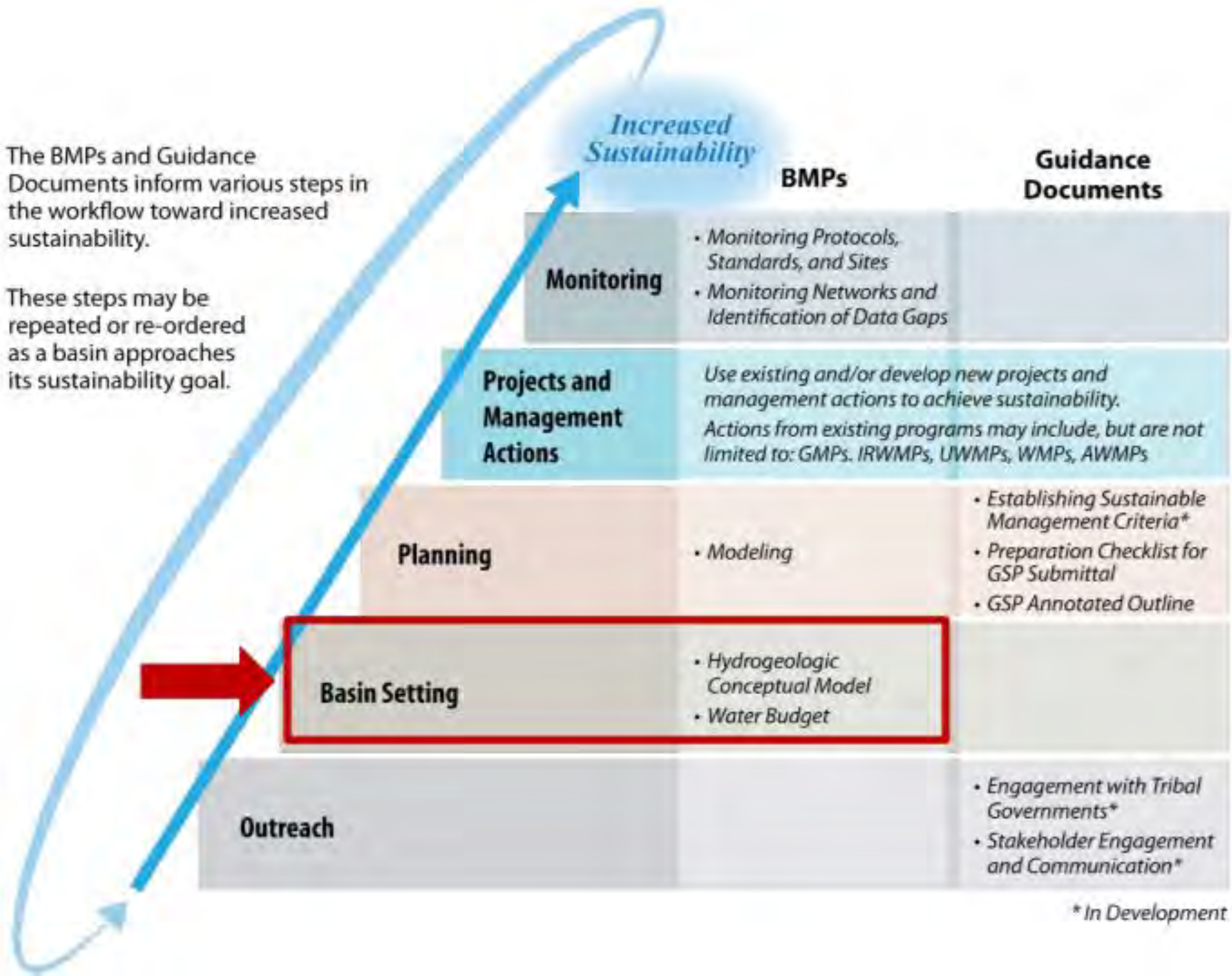


Figure 3 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

5. TECHNICAL ASSISTANCE

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

GENERAL WATER BUDGET REQUIREMENTS

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

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

Professional Certification

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

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

Water Budget Data, Information, and Modeling Requirements

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

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

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

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

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

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

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

In basins with interconnected surface water systems or complex spatial and temporal variations in water budget components, quantifying and forecasting streamflow depletion and other water budget components is best determined from an experienced local professional and/or the use of a numerical groundwater and surface water model. Modeling results may also be an effective tool for outreach and communication, and can prove useful in analyzing and quantifying some of the more difficult-to-measure water budget components.

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

Defining Basin Area and Water Budget Systems

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

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

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

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

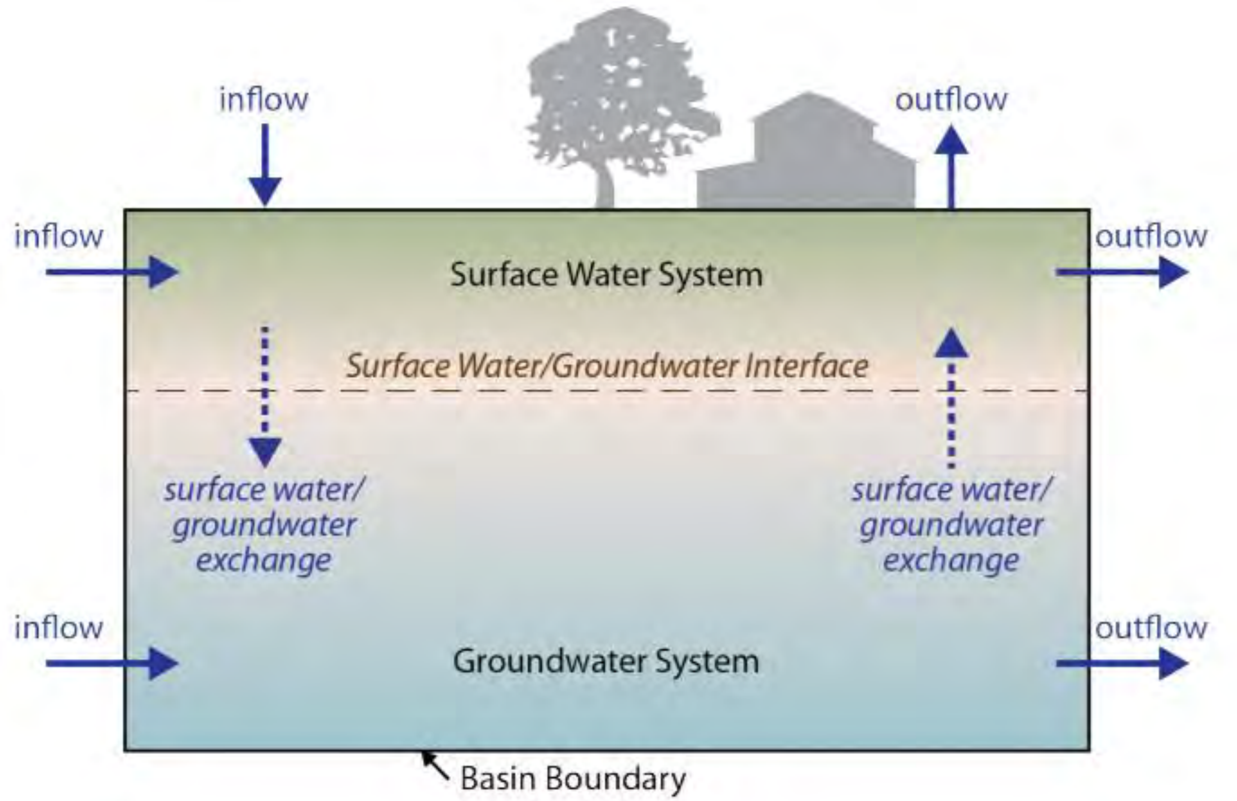


Figure 4 – Conceptual Basin Boundary, Surface Water and Groundwater Systems, and Inflows and Outflows

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

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

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

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

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

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

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

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

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

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

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

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

Accounting and Quantification of Water Budget Components

23 CCR §354.18(b): The water budget shall quantify the following, either through direct measurements or estimates based on data: (1) Total surface water entering and leaving a basin by water source type. (2) Inflow to the groundwater system by water source type, including subsurface groundwater inflow and infiltration of precipitation, applied water, and surface water systems, such as lakes, streams, rivers, canals, springs and conveyance systems. (3) Outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow. (4) The change in the annual volume of groundwater in storage between seasonal high conditions. (5) If overdraft conditions occur, as defined in Bulletin 118, the water budget shall include a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions. (6) The water year type associated with the annual supply, demand, and change in groundwaterstored. (7) An estimate of sustainable yield for the basin.

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

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

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

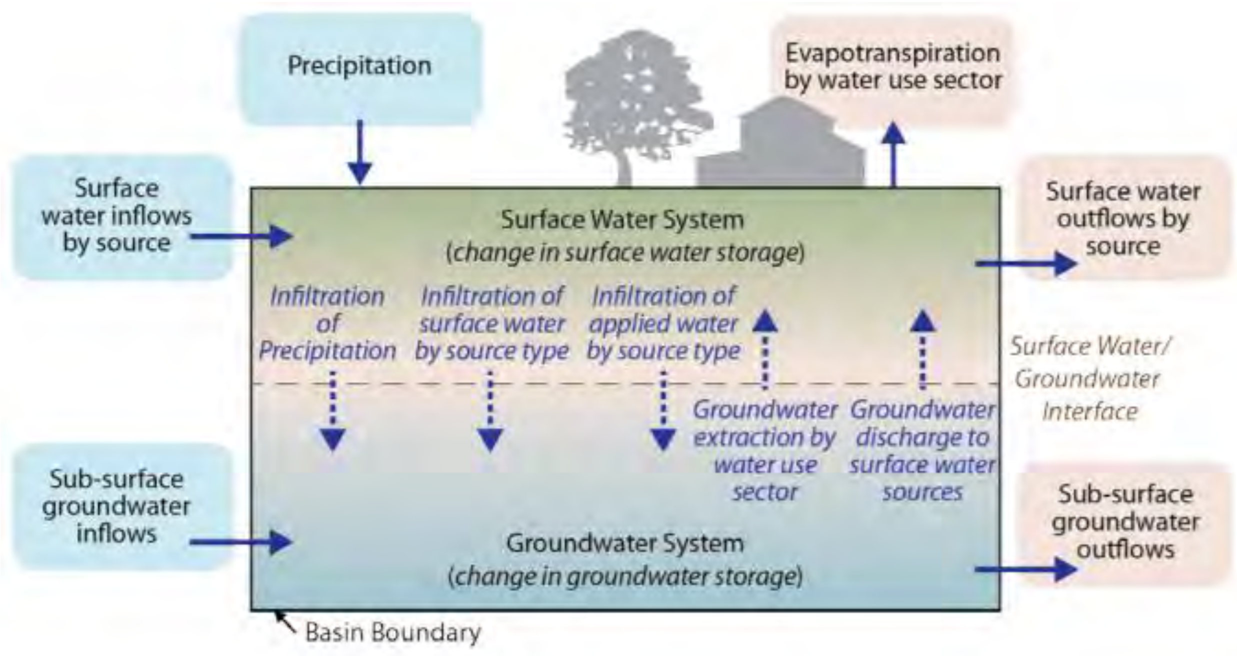


Figure 5 – Required Water Budget Components

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

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

(1) Total surface water entering and leaving the basin by water source type.
Water budget components associated with the river and stream system include the surface water entering (inflow) and leaving the basin (outflow). The inflow and outflow of surface water to the basin is required to be annually quantified as a total annual volume in acre-feet per year (af/yr) according to the surface water body (name) and the water sources type. Water source type represents the source from

which water is derived to meet the applied beneficial uses. Surface water sources should be identified as one of the following:

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

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

- Urban: total annual volume (af/yr)
- Industrial: total annual volume (af/yr) and total applied water area (acres)
- Agricultural: total annual volume (af/yr) and applied water area (acres)
- Managed Wetlands: total annual volume (af/yr) and applied water area (acres)
- Managed Recharge: total annual volume (af/yr) and applied water area (acres)
- Native Vegetation: total annual volume (af/yr) and applied water area (acres)
- Other (as needed): total annual volume (af/yr) and applied water area (acres)

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

Surface Water Available for Groundwater Recharge or In-Lieu Use: In addition to the above GSP Regulation requirement to include an accounting of the total surface

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

• Aquifer Depletion. Oil and gas-bearing formations are often at a depth below the groundwater flow system. Is the quantity of produced water accounted for in the hydrogeologic conceptual model? Will depletion of this water cause Undesirable Results such as subsidence?

• Beneficial Use. Describe the uses for the produced water. Is the produced water being supplied as a beneficial use such as irrigation or recharge, or is it being evaporated? If so, it should be included as a water supply type in the water budget accounting.

• Quality. Describe the quality of the produced water, existing use permits, and any treatment processes employed. Describe the use or discharge relative to RWQCB Basin Plan Objectives.

• Reliability. Availability of produced water will fluctuate with oil and gas production. Oil fields have limited production durations that may be incompatible with long-term groundwater sustainability. Oil field-produced water will generally not be an acceptable supply for establishing sustainability, but may be a component of an initial basin recovery effort. The reliability of produced water should be characterized in the GSP if it is being use as a source of supply.

water entering and leaving the basin, §10727.2(d)(5) of SGMA requires the GSP include a description of the surface water supply used, or available for use, for groundwater recharge or in-lieu use.

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

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

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

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

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

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

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

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

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

- Evapotranspiration: (af/yr)
- Groundwater discharge to surface water sources (af/yr)
- Subsurface groundwater outflow (af/yr)
- Groundwater extraction by water use sector:
  - Urban (af/yr) and (gpcd)
  - Industrial (af/yr)
  - Agricultural (af/yr)
- Managed Wetlands (af/yr)
- Managed Recharge (af/yr)
- Infiltration from the following: (af/yr)
  - Other (as needed)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(7) An estimate of sustainable yield for the basin

Estimating sustainable yield includes evaluating current, historical, and projected water budget conditions. Sustainable yield is defined in SGMA legislation and refers to the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin, and including any temporary surplus that can be withdrawn annually from a groundwater supply without causing an undesirable result. Water budget accounting information should directly support the estimate of sustainable yield for the basin and include an explanation of how the estimate of sustainable yield will allow the basin to be operated to avoid locally defined undesirable results. The explanation should include a discussion of the relationship or linkage between the estimated sustainable yield for the basin and local determination of the sustainable management criteria (sustainability goal, undesirable results, minimum thresholds, and measurable objectives).

TABULAR AND GRAPHICAL REPRESENTATION OF THE WATER BUDGET COMPONENTS

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

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

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

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

Water Year:
Water Year Type:

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

Change in Surface Storage Volume	
Change in Groundwater Volume	

\1 by water source type

\2 lakes, streams, canals, springs, conveyance systems

\3 includes applied surface water, groundwater, recycled water, and reused water

\4 by water use sector

Table 1 – Simple Water Budget Tabulation Example

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

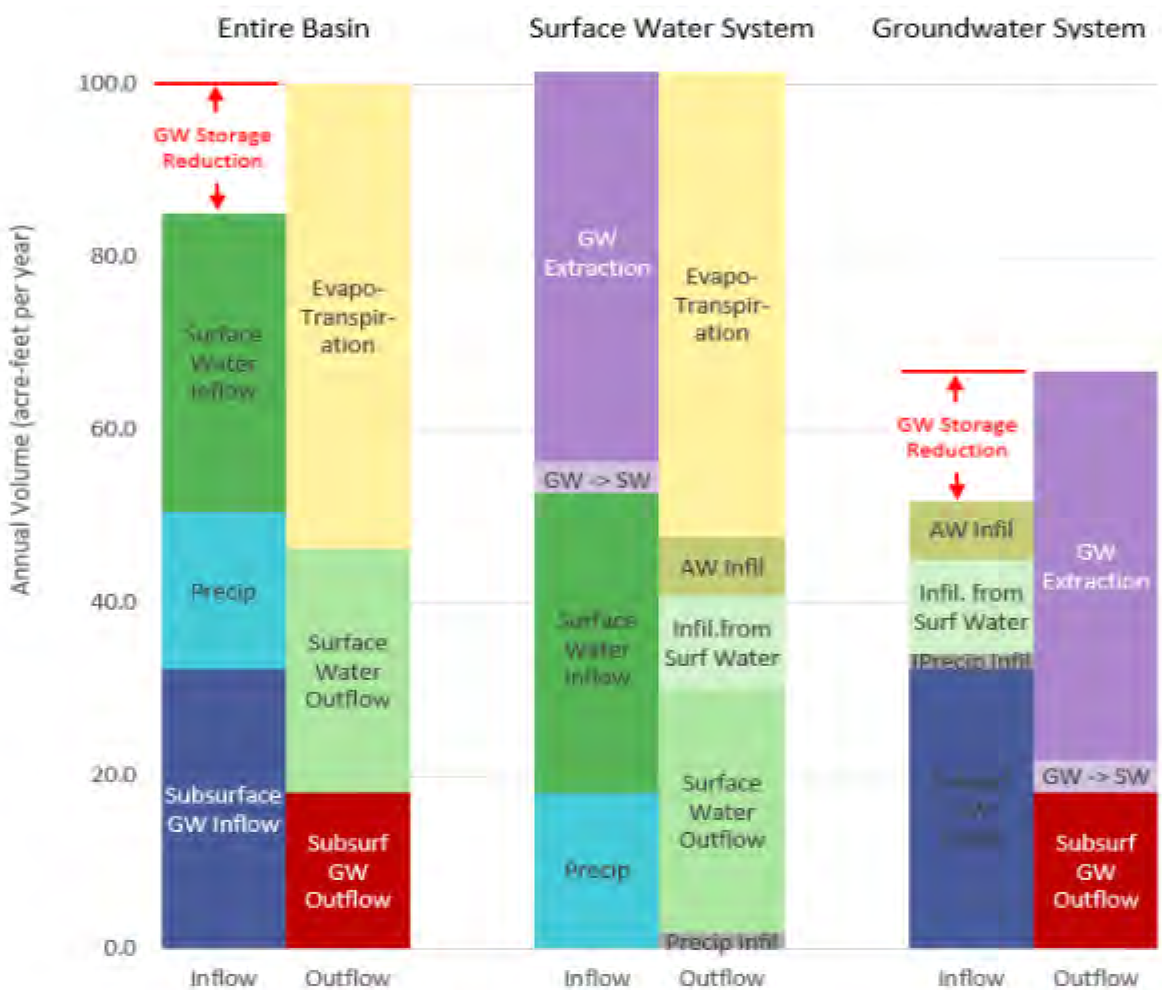


Figure 6 – Paired Bar Water Budgets

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

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

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

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

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

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

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

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

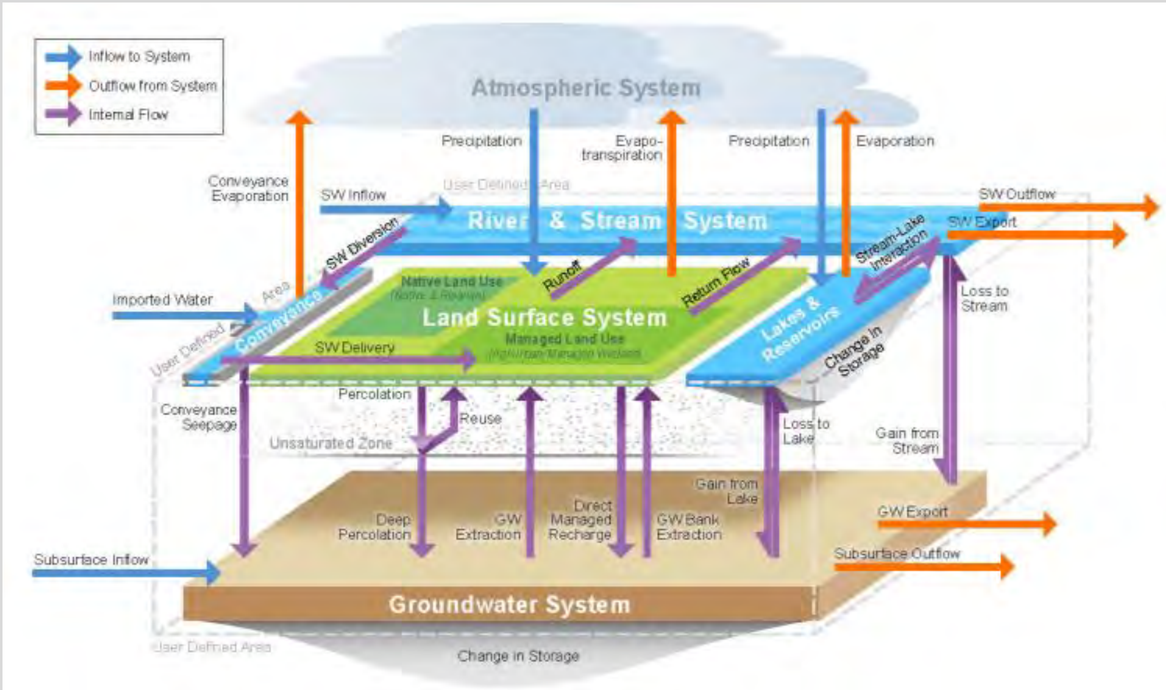


Figure 7 – Water Budget Schematic Showing the Interrelationships among Potential Water Budget Components and the Water Systems that Comprise the Hydrologic Cycle

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

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

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

In situations where groundwater rises within the root zone of the land surface system, outflows due to evapotranspiration are typically attributed to the groundwater system.

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

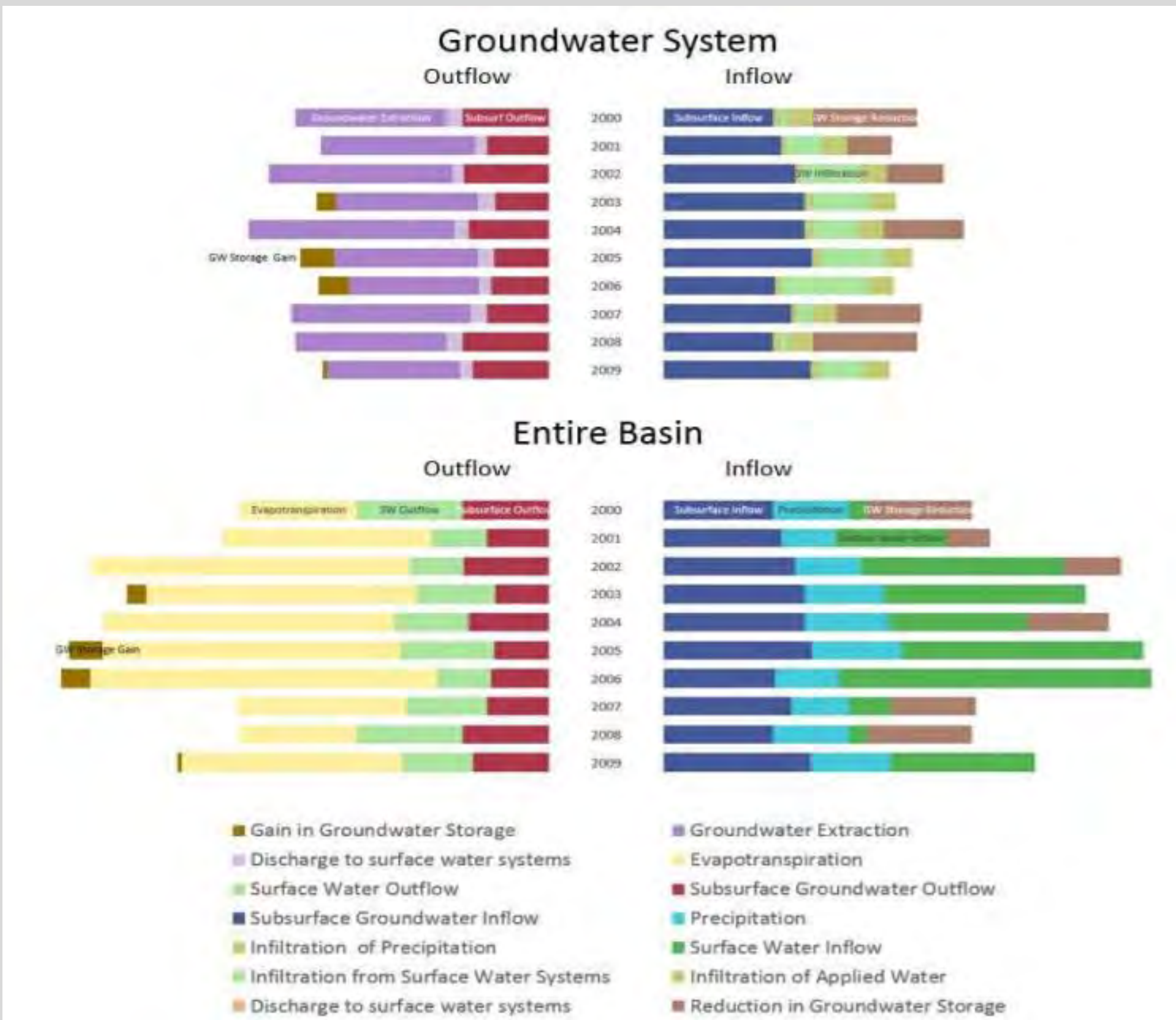


Figure 8 – Water Budget Inflows, Outflows, and Change in Storage by Water Year for Groundwater System and Entire Basin

DEFINING WATER BUDGET TIME FRAMES

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

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

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

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

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

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

- Use at least the most recent ten years of surface water supply information to quantify the availability of historical surface water supply deliveries. The reliability of historical surface water deliveries is to be calculated based on the planned versus actual annual surface water deliveries, by surface water source, and water year type.
- Quantify and assess at least the most recent ten years of historical water budget information by water year type. The ten years of historical water budget information is to be used to help estimate the projected future water budgets and future aquifer response to the sustainable groundwater management projects and actions being proposed over the GSP planning and implementation horizon. The intent of the historical water budget evaluation is also to provide the necessary data and information to calibrate the tools or methods used to project future water budget conditions. Depending on the historical variability of supplies, demands, and land use; the level of historical groundwater monitoring in the basin; and the type of tool being used to estimate future projects and associated aquifer response; additional historical water budget information may be needed for adequate calibration.
- Use at least the most recent ten years of water supply reliability and water budget information to describe how the historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability of the local agency to operate the basin within sustainable yield. To assist in the evaluation, sustainable yield should be evaluated by water year type, as previously described in (7) An estimate of sustainable yield for the basin.

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

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

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

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

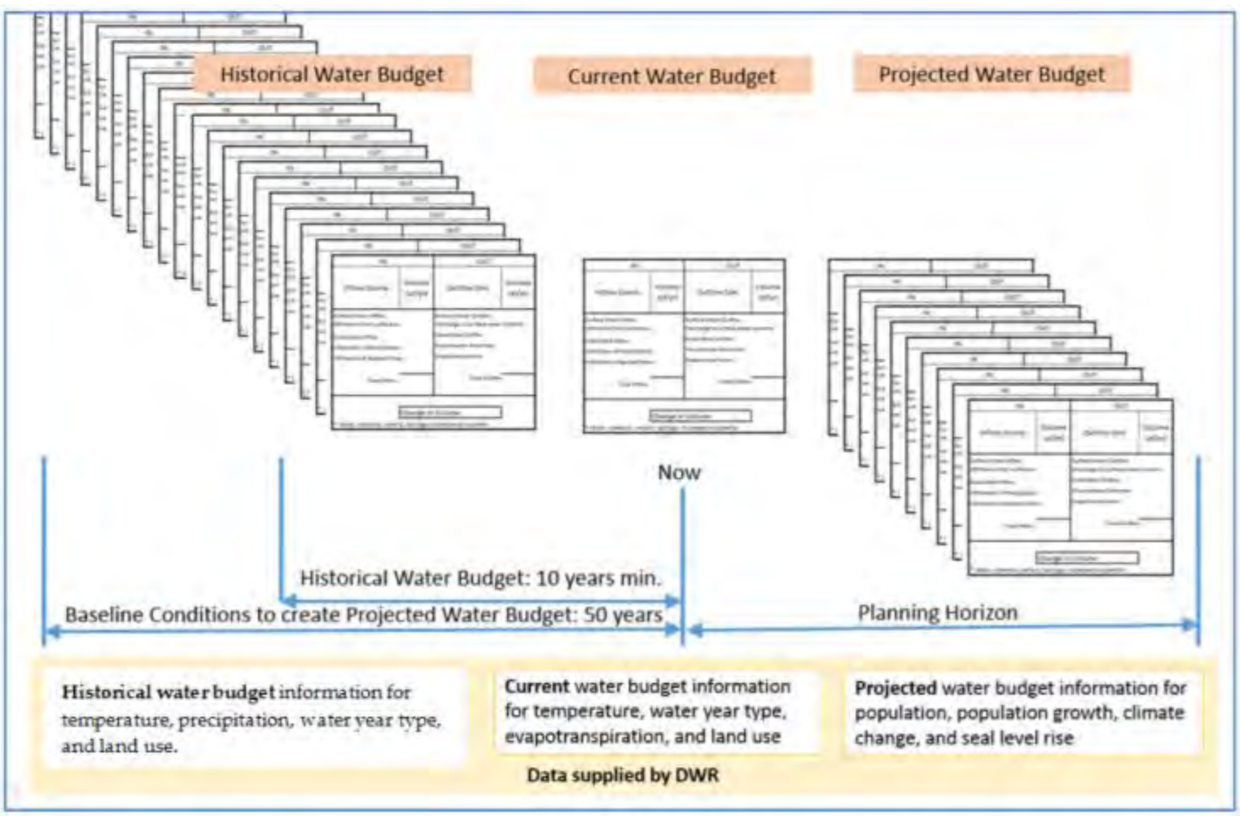


Figure 9 – GSP Water Budget Time Frames

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

IDENTIFYING AND SELECTING METHODOLOGIES TO ESTIMATE WATER BUDGET COMPONENTS

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

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

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

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

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

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

EVALUATING ACCURACY AND UNCERTAINTY OF WATER BUDGET COMPONENTS

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

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

WATER BUDGET DATA RESOURCES

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

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

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

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

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

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

Additional Data and Resources

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

Table 2 – Potential Data Sources to Support Water Budget Development

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

Data Type	Date Sources	Notes
Surface Water Diversions	Local Agencies, SWRCB, eWRIMS, DWR, USBR	
Municipal/Industrial Groundwater Pumping	UWMPs, Local Agencies	
Agricultural Groundwater Pumping	AWMPs, DWR, USGS, Local Agencies	
Specific Yield	DWR, USGS, Local/Regional Studies	DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available.
Surface Soil Properties	NRCS	
Per-Capita Water Use	UWMPs, DWR, USGS, Local Agencies	
Tabled Acronyms:	AWMP – Agricultural Water Management Plan C2VSIM – California Central Valley Groundwater-Surface Water Simulation Model CalSIMETAW – California Simulation of Evapotranspiration of Applied Water Model CDEC – California Data Exchange Center CIMIS – California Irrigation Management Information System CVHM – Central Valley Hydrologic Model DWR – Department of Water Resources eWRIMS – Electronic Water Rights Information Management System GIC – Groundwater Information Center NASA – National Aeronautics and Space Administration NOAA – National Oceanic and Atmospheric Administration NRCS – Natural Resources Conservation Service PRISM –Parameter-elevation Relationships on Independent Slopes Model SWRCB – State Water Resources Control Board UCCE – University of California Cooperative Extension USBR – United States Bureau of Reclamation USDA – United States Department of Agriculture USGS – United States Geological Survey UWMP – Urban Water Management Plan WDL – Water Data Library	

Additional Data Sources

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

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

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

Department of Water Resources

- Groundwater Information Center (GIC) http://water.ca.gov/groundwater/gwinfo/index.cfm
- California Statewide Groundwater Elevation Monitoring Program (CASGEM) http://water.ca.gov/groundwater/casgem/
- Water Data Library (WDL) http://www.water.ca.gov/waterdatalibrary/
- California Data Exchange Center (CDEC) http://cdec.water.ca.gov/
- California Irrigation Management Information System (CIMIS) http://wwwcimis.water.ca.gov/cimis/welcome.jsp
- Land Use Surveys: http://www.water.ca.gov/landwateruse/lusrvymain.cfm
- Groundwater –Surface Water Simulation Model: The following the Department Bay-Delta site list information for the C2VSim Central Valley GroundwaterSurface water simulation model. This same website contains additional links to the Department water budget tools such as:
    - California Central Valley Groundwater-Surface Water Simulation Model
    - http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm
    - Integrated Water Flow Model (IWFM) http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/index.cfm
    - Irrigation Demand Calculator (IDC) http://baydeltaoffice.water.ca.gov/modeling/hydrology/IDC/index_IDC.cfm
    - CalLite: Central Valley Water Management Screening Model http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalLite/index.cfm
    - Water Resource Intergraded Modeling System (WRIMS) model engine (formally named CALSIM) http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/index.cfm
    - Delta Simulation Model II (DSM2) http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

- Bulletin 118 http://water.ca.gov/groundwater/bulletin118/index.cfm
- California Groundwater Update 2013 http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm
- Bulletin 160: California Water Plan Update 2013 http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm
- Bulletin 230-81: Index to Sources of Hydrologic Data http://www.water.ca.gov/waterdatalibrary/docs/historic/Bulletins/Bulletin_230/Bulletin_230__1981.pdf
- Additional DWR Data Topics http://water.ca.gov/nav/index.cfm?id=106
- Additional DWR Bulletin and Reports http://water.ca.gov/waterdatalibrary/docs/historic/bulletins.cfm

State Water Resources Control Board

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

United States Geological Survey:

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

Additional USGS Water Budget Related Materials by Topic

Developing a Water Budget

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

Recharge Estimation

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

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

Modeling of Recharge

Basin Characterization Model (BCM): developed by USGS for use in estimating natural recharge, and has been applied to all of California and other regions in the western US and internationally. This

regional water-balance model differs from rainfallrunoff models because it incorporates estimates of shallow bedrock permeability to spatially distribute in-place natural recharge across the landscape. Content on the website below describes the model and associated methods, and provides links to output datasets available for historical and future projections of climate, and to associated publications of applications. The BCM is currently undergoing revisions to further improve the accuracy of recharge estimates for California; these revisions will be completed in mid-2017.
http://ca.water.usgs.gov/projects/reg_hydro/projects/dataset.html

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

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

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

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

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

Case Studies for Recharge Estimation using Modeling

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

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

Geophysical Methods for Estimating Recharge

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

Surface-Water/Groundwater Interactions

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

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

Baseflow Analysis

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

Streamflow Trend Evaluation

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

Water Use

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

Climate-Related Analysis

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

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

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

6. KEY DEFINITIONS

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

SGMA Definitions (California Water Code §10721)

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

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

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

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

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

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

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

> (1) Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
>
> (2) Significant and unreasonable reduction of groundwater storage.
>
> (3) Significant and unreasonable seawater intrusion.
>
> (4) Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.
>
> (5) Significant and unreasonable land subsidence that substantially interferes with surface land uses.
>
> (6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Bulletin 118 Definitions

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

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

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

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

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

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

7. RELATED MATERIALS

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

REFERENCES FOR FURTHER GUIDANCE

- Barlow, P.M., and Leake, S.A., 2012, Streamflow depletion by wells— Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey, Circular 1376. http://pubs.usgs.gov/circ/1376/
- Chang, S.W., T.P. Clement, M.J. Simpson, and K.K. Lee. 2011. Does Sea-level Rise Have an Impact on Saltwater Intrusion, Advances in Water Resources 34:1283- 1291. http://www.mj-simpson.com/pdf/ADWR_2011.pdf
- Healy, R.W., Winter, T.C., LaBough, J.W., and Franke, L.O., 2007, Water Budgets: Foundations for Effective Water-Resources and Environmental Management. U.S. Geological Survey, Circular 1308. http://pubs.usgs.gov/circ/2007/1308/
- Loaiciga, H.A., T.J. Pingel, and E.S. Garcia. 2012. Sea Water Intrusion by Sea-level Rise: Scenarios for the 21st Century, Ground Water, 50L37-47 http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.2011.00800.x/abstract
- Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground Water and Surface Water, A Single Resource. U.S. Geological Survey, Circular 1139. http://pubs.usgs.gov/circ/circ1139/#pdf
- California Water Plan Update 2013. Department of Water Resources, 2013. Volume 3. Resource Management Strategies. http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm
- California's Groundwater Update 2013, Department of Water Resources, 2013. http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm

SELECTED CASE STUDIES AND EXAMPLES

- Development and Calibration of the California Central Valley GroundwaterSurface Water Simulation Model (C2VSim), Version 3.02-CG. DWR Technical Memorandum. California

Department of Water Resources (DWR) Bay-Delta Office. 2013. http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/download/C2VSim_Model_Report_Final.pdf
- Groundwater Availability of the Central Valley, California. Professional Paper 1766. USGS. 2009. http://pubs.usgs.gov/pp/1766/PP_1766.pdf
- Scott Valley Integrated Hydrologic Model: Data Collection, Analysis, and Water Budget. Final Report. University of California – Davis, Department of Land, Air, and Water Resources. 2013. http://groundwater.ucdavis.edu/files/165395.pdf
- Selected Approaches to Estimate Water-Budget Components of the High Plains, 1940 through 1949 and 2000 through 2009. Scientific Investigations Report 2011– 5183. USGS. 2011. http://pubs.usgs.gov/sir/2011/5183/pdf/sir2011-5183.pdf
- Simulated Effects of Ground-Water Withdrawals and Artificial Recharge on Discharge to Streams, Springs, and Riparian Vegetation in the Sierra Vista Subwatershed of the Upper San Pedro Basin, Southeastern Arizona. Scientific Investigations Report 2009-5207. USGS. April, 2014. http://pubs.usgs.gov/sir/2008/5207/sir2008-5207.pdf
- Evaluation of Simulations to Understand Effects of Groundwater Development and Artificial Recharge on Surface Water and Riparian Vegetation, Sierra Vista Subwatershed, Upper San Pedro Basin Arizona. Open-File Report 2012-1206. USGS. 2012. https://pubs.usgs.gov/of/2012/1206/of2012-1206.pdf\

PROFESSIONAL CERTIFICATION RESOURCES

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

Appendix L. Modeling BMP

Modeling Best Management Practice

1. OBJECTIVE

The objective of this Best Management Practice (BMP) is to assist with the use and development of groundwater and surface water models. The California Department of Water Resources (the Department or DWR) has developed a Best Management Practice for Modeling, as part of the obligation in the Technical Assistance chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater basins. The SJREC GSA has reviewed and updated this BMP for inclusion in the GSP. This BMP provides technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders on how to address modeling requirements outlined in the Groundwater Sustainability Plan (GSP) Emergency Regulations (GSP Regulations). This BMP identifies available resources to support the development of groundwater and surface water models.

This BMP includes the following sections:

1. Objective. The objective and outline of the contents of this BMP.
2. Use and Limitations. A description of the use and limitation of this BMP.
3. Modeling Fundamentals. A description of fundamental modeling concepts.
4. Relationship of modeling to other BMPs. A description of how modeling relates to other BMPs and is a tool used to develop other GSP requirements.
5. Technical Assistance. A description of technical assistance for the development of a model, potential sources of information, and relevant datasets that can be used to further define model components.
6. Key Definitions. Definitions relevant for this BMP as provided in the GSP Regulations, Basin Boundary Regulations, and SGMA.
7. Related Materials. References and other materials related to the development of models.

2. USE AND LIMITATIONS

This BMP was developed by the Department and updated by the SJREC GSA, to provide technical guidance to GSAs and other stakeholders. Practices described in this BMP does not replace the GSP Regulations, nor does it create new requirements or obligations for GSAs or other stakeholders. In addition, using this BMP to develop a GSP does not equate to an approval determination by the Department. The SJREC GSA will use measured data and an analytical model to the greatest extent feasible. This BMP will elaborate on the use of numerical models in such instance that the SJREC GSA relies on a numerical model result as part of the GSP analysis. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

3. MODELING FUNDAMENTALS

As modified from Barnett and others (2012), a model is any computational method that represents an approximation of the hydrologic system. While models are, by definition, a simplification of a more complex reality, they have proven to be useful tools over several decades for addressing a range of groundwater problems and supporting the decision-making process. Models can be useful tools for estimating the potential hydrologic effects of proposed water management activities.

Surface water and groundwater systems are affected by natural processes and human activity. They require targeted and ongoing management to maintain surface water and groundwater resources within acceptable limits, while providing desired economic and social benefits. Sustainable groundwater management and policy decisions must be based on knowledge of the past and present behavior of the surface and groundwater system, the likely response to future changes and management actions, and the understanding of the uncertainty in those responses.

The location, timing, and magnitude of hydrologic responses to natural or human induced events depend on a wide range of factors. Such factors include the nature and duration of the event that is impacting groundwater, the subsurface properties, and the connection with surface water features such as rivers and oceans. Through observation of these characteristics, a conceptual understanding of the system can be developed.

Models provide insight into the complex system behavior and (when appropriately designed) can assist in developing conceptual understanding. Models provide an important framework that brings together conceptual understanding, data, and science in a hydrologically and geologically consistent manner. In addition, models can estimate and reasonably bound future groundwater conditions, support decisionmaking about monitoring networks and management actions, and allow the exploration of alternative management approaches. However, there should be no expectation that a single ‘true’ model exists. All models and model results will have some level of uncertainty. Models can provide decision makers an estimate of the predictive uncertainty that exists in model forecasts. By gaining a sense of the magnitude of the uncertainty in model predictions, decision makers can better accommodate the reality that all model results are imperfect forecasts and actual basin responses to management actions will vary from those predicted by modeling.

GENERAL TYPES OF MODELS AND MODELING SOFTWARE

There are various modeling approaches, methods, and software that can be used for GSP development and implementation. This section provides a general description of a few widely used types of models and the variety of software typically used for modeling. These model types are not mutually exclusive. For example, an integrated groundwater and surface water model can also be described as a numerical model.

Each GSA is responsible for determining the appropriate modeling method, software, and the level of detail needed to demonstrate that undesirable results can be avoided and the sustainability goal in each basin is likely to be achieved within 20 years of GSP implementation. A table of select, currently available, modeling codes (the model computation engine) and applications (the constructed model including inputs) is provided in Appendix A.

TYPES OF MODELS

Conceptual Models

A conceptual model is often considered the first step in understanding the groundwater flow system and developing a mathematical model. A conceptual model includes a narrative interpretation and graphical representation of a basin based on known characteristics and current management actions. Conceptual models do not necessarily include quantitative values. For more details on developing a conceptual model, please refer to the Hydrogeologic Conceptual Model (HCM) BMP.

Mathematical Models

A model that simulates groundwater flow or solute transport by solving an equation, or series of equations, that reasonably represents the physical flow and transport processes is referred to as a mathematical model. Mathematical models differ from conceptual models in that they are capable of providing quantitative estimates of the water budget components. Mathematical models are often divided into two categories: analytical and numerical models or tools.

Analytical Models and Tools

Analytical models generally require assumptions that significantly simplify the physical system being evaluated. For example, topographic boundary conditions are generally limited to simple geometric shapes in these solutions, and aquifer properties are often required to be homogeneous and isotropic. The physical configuration of the management action is also typically idealized for the purposes of analysis and, therefore, influences related to project geometry are ignored. Often only one component (a measured or simulated value or relationship) of the groundwater system is evaluated at a time, and this approach omits the evaluation of potential interactions with other components. For example, a spreadsheet could use a simple equation to estimate the aquifer drawdown in one location based on pumping at another location, without considering the potential influence on nearby streams.

However, analytical models and tools can successfully and inexpensively be employed to gain strong conceptual and general quantitative understanding of groundwater basin dynamics, which includes interactions with pumping, groundwater storage, groundwater quality, seawater intrusion, land subsidence, and interaction with surface water. The applicability of this approach is well suited to initial scoping studies, basins with simple hydrologic conditions or areas operating sustainably. This analysis may be limited when used as the only modeling tool.

Numerical Models and Tools

Numerical modeling tools are widely used in groundwater flow and transport analysis to evaluate the change to the groundwater system caused by changes in conditions due to management actions, changes in population and land use, climate change, or other factors. These numerical models allow for a more realistic representation of the physical system, including geologic layering, complex boundary conditions, and stresses due to pumping, recharge and land use demands. GSPs developed for complex basins with significant groundwater withdrawals and/or surface water - groundwater interaction may use a numerical groundwater - surface water model to demonstrate that the GSP will avoid undesirable results and achieve the sustainability goal within the basin. Several of the available modeling codes and associated applications are discussed in more detail in Appendix A.

Integrated Hydrologic Water Models

A fully integrated surface water and groundwater model refers to a suite of codes that jointly solve the numerical solutions for surface processes (such as irrigation deliveries and stream diversions), surface flows and groundwater heads together. Many models include the ability to simultaneously simulate streamflow and its interconnection with the aquifer system.

Coupled Groundwater and Surface Water Models

A coupled groundwater and surface water model uses separate models for surface water and the groundwater systems. Coupled models are set up such that the solution from one model (i.e., surface water modeling output) can be used as input into the second model (i.e., groundwater model) to solve the groundwater flow equations and to consider the stresses (boundary conditions) imposed by the surface water information.

Transport Models

Transport model codes add a layer of complexity beyond what is provided by groundwater-flow models. These models allow for the assessment of a variety of problems, including the potential migration of existing contaminant plumes due to management actions, or the changes in groundwater quality over time after a remediation project is implemented. These types of models are not as widely used for water resources planning, but need to be considered for basins in which existing contamination impairs the use of groundwater as the source of supply and/or affect other areas of the basin now or as a potential result of future management actions.

TYPES OF MODELING SOFTWARE

Groundwater modeling typically requires the use of a number of software types, including the following (modified from Barnett and others, 2012):

- The model code that solves the equations for groundwater flow and/or solute transport, sometimes called simulation software or the computational engine
- A graphical user interface (GUI) that facilitates preparation of data files for the model code, runs the model code and allows visualization and analysis of results
- Software for processing spatial data, such as a geographic information system (GIS), and software for representing hydrogeological conceptual models
- Software that supports model calibration, sensitivity analysis and uncertainty analysis
- Programming and scripting software that allows additional calculations to be performed outside of or in parallel with any of the above types of software
- A wide range of model codes to solve problems related to groundwater flow and/or transport, such as model codes that simulate farm water management, plant-water interactions, unsaturated zone flow and transport processes, stream flow processes, surface water - groundwater interactions, land subsidence, watershed processes, climate, geochemical reactions, economic water management optimization, or parameter calibration
- Software to process spreadsheets used in an analytical model.

Some software is public domain and open-source (freely available and able to be modified by the user) and some is commercial and closed (proprietary design that is only available in an executable form that cannot be modified by the user).

Some software fits several of the above categories; for example, a model code may be supplied with its own GUI or a GIS may be supplied with a scripting language. Some GUIs support one model code while others support many. Most model codes that solve the groundwater flow and/or transport equation have an integrated capability to also simulate some or many of the related processes listed above, such as surface water - groundwater interaction.

COMMON MODEL USES

The following provides a partial list of general and SGMA-related uses for models

General Uses (modified from Barnett and others, 2012)

- Improving hydrogeological understanding (synthesis of data).
- Aquifer simulation (evaluation of aquifer behavior).
- Calculating and verifying water budget components, such as recharge, discharge, change in storage and the interaction between surface water and groundwater systems (water resources assessment).
- Predicting impacts of alternative hydrological or development scenarios (to assist decision-making).
- Managing resources (assessment of alternative policies).
- Sensitivity and uncertainty analysis (to guide data collection and risk-based decision-making).
- Visualization (to communicate aquifer behavior).
- Providing a repository for information and data that influence groundwater conditions.

GSP-Related Uses

- Developing an understanding and assessment of how historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within sustainable yield.
- Assessing how annual changes in historical inflows, outflows, and changes in basin storage vary by water year type (hydrology) and water supply reliability.
- Evaluating how the surface and groundwater systems respond to the annual changes in the water budget inflows and outflows.
- Identifying which management actions and water budget situations may result in overdraft conditions or undesirable results.
- Facilitating the estimate of sustainable yield for the basin.
- Optimizing proposed projects and management actions and evaluating the potential effects those activities have on achieving the sustainability goal for the basin.
- Evaluating future scenarios of water demand uncertainty associated with projected changes in local land use planning, population growth, and climate.
- Informing monitoring requirements.
- Informing development and quantification of sustainable management criteria, such as the sustainability goal, undesirable results, minimum thresholds, and measureable objectives.
- Helping identify potential projects and management actions and optimizing their design to achieve the sustainability goal for the basin within 20 years of GSP implementation.
- Identifying data gaps and uncertainty associated with key water budget components and model forecasts, and developing an understanding of how these gaps and uncertainty may affect implementation of proposed projects and water management actions.

MODELS IN REFERENCE TO THE GSP REGULATIONS

Developing and applying models to aid in determining sustainable groundwater management results in multiple benefits to GSAs and stakeholders. Constructing and calibrating the model improves understanding of the critical processes that influence sustainability indicators within the basin. The application of the model to forecast the influence of projects and management actions on basin conditions provides a framework within which a GSA can screen and select appropriate projects and management actions that lead to the achievement of the sustainability goal for the basin. Additionally, models can play a critical role in simulating the changing climate conditions that may occur during the 50-year planning and implementation horizon required under SGMA. It should be noted that in general, groundwater and surface water models are more effective at comparing the benefits and impacts of various management strategies with respect to one another rather than predicting exact management outcomes. So while a model can assist in selecting the best alternative from a variety of options, uncertainty will still remain in the forecasted outcome of a particular alternative. Adaptive management will always be a necessary component of program implementation.

A significant consideration that must be addressed by all GSAs is whether modeling is necessary or required for developing and implementing its GSP. In most basins, the spatial and temporal complexity of the data will require some application of modeling to accurately assess the individual and cumulative effects of proposed projects and management actions on avoiding or eliminating undesirable results and achieving the basin's sustainability goal. It is each GSA's role to carefully consider if changing basin conditions and proposed projects and management actions have the potential to trigger undesirable results within the basin or in adjacent basins, and whether a model is necessary to demonstrate that the proposed projects and management actions will achieve the sustainability goal. Therefore, the use of models for developing a GSP is highly recommended, but not required. The use of a model will ultimately depend on the individual characteristics and complexity of the basin setting, the presence or absence of undesirable results, and the presence or absence of interconnected surface water systems. As stated in GSP Regulation sections §354.18 (f) and §354.28(c)(6), "if a numerical groundwater and surface water model is not used to quantify the water budget and depletions of interconnected surface water, the GSP shall identify and describe an equally effective method, tool, or analytical model to accomplish these requirements".

Similar to the question of whether models should be used during GSP development is the question of the appropriate level of model complexity. Simple models require fewer data, less complex software, and are, therefore, often less expensive, and have much shorter run times. These characteristics are advantageous when focusing on a single undesirable result. However, simple models may overlook important system components and the interconnectedness of undesirable results, and may be difficult to calibrate to historical data. Complex models can incorporate more data and professional judgment. Therefore, they often result in a more accurate representation of the groundwater system. However, complex models are more expensive and difficult to build, require more data and more technical expertise, and the complexity can lead to a false impression of accuracy; a complex model may in fact be less accurate.

Fundamentally, a good model strategy is to follow the principle of parsimony: to build the simplest model that honors all relevant available data and knowledge, while providing a reasonable modeling tool to achieve the desired decision support at a desirable level of certainty. It may be necessary to use complex models to assess certain undesirable results, and it may be possible to use simple models to assess other undesirable results.

Some guidance on what might influence model complexity is provided in the modeling considerations section of this BMP. Since significant professional judgment goes into the development of a model, two models of the same basin – even if they are built with the same model code - are likely to differ in their design and their outcome. Where multiple models exist, differences between model outcomes, after a careful assessment of the differences in model design and assumptions, may provide an important opportunity to further assess uncertainty in predicted outcomes and to further direct future data collection programs. Importantly, multiple models with differing outcomes should not be interpreted a priori as one model being (more) right and others being (more) wrong.

While models are useful and often invaluable tools for understanding a basin and predicting future basin conditions, in most cases, they are not the only available means for demonstrating that a basin has met its sustainability goal. Satisfactorily demonstrating that all undesirable results have been avoided and the sustainability goal has been met will be a function of the data collected and reported during GSP implementation.

4. RELATIONSHIP OF MODELING TO OTHER BMPS

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

1. Supporting the development of the water budget

2. Establishing the Sustainable Management Criteria (sustainability goal, undesirable results, minimum thresholds, and measurable objectives)

3. Supporting identification and development of potential projects and management actions to address undesirable results that exist or are likely to exist in the future

4. Supporting the refinement of the monitoring network in the basin over time

Modeling is also linked to other related BMPs as illustrated in **Figure 1**. This figure provides the context of the BMPs as they relate to logical progression to sustainability as outlined in the GSP Regulations. The modeling BMP is part of the planning step in the GSP Regulations.

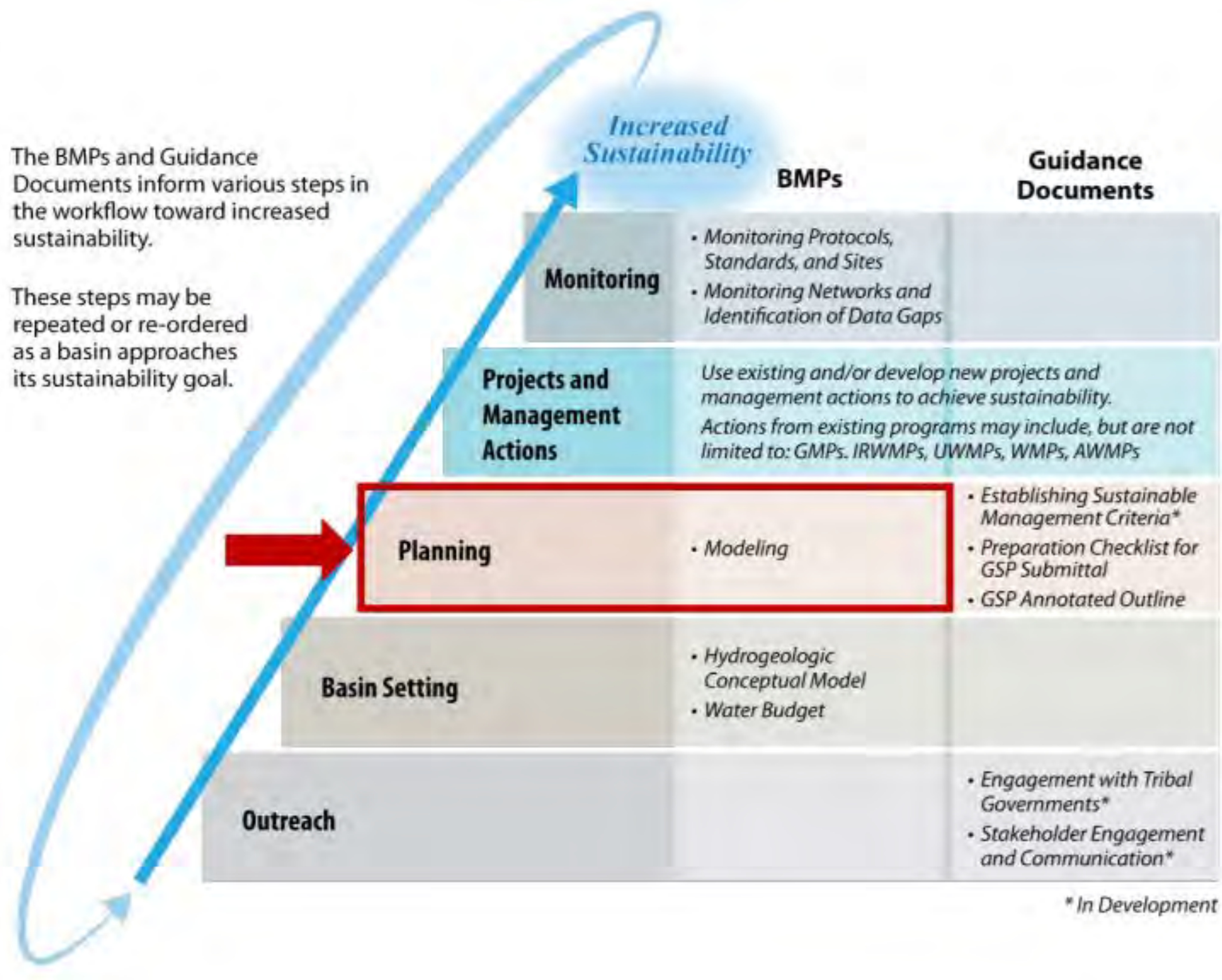


Figure 1 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

5. TECHNICAL ASSISTANCE

This section provides technical assistance and guidance to support the development of models under SGMA and the GSP Regulations, including potential sources of information and relevant datasets that can be used to develop and implement the various modeling components.

GUIDING PRINCIPLES FOR MODELS USED IN SUPPORT OF GSPS

The Department is providing the following four modeling principles to help foster SGMA's intent to promote transparency, coordination, and data sharing. They help guide GSAs in their selection and use of models for sustainable groundwater management, and expedite Department review of GSP-related modeling analysis and findings.

1. Model documentation (documentation of model codes, algorithms, input parameters, calibration, output results, and user instructions) is publicly available at no cost. In particular, the model documentation should explain (or refer to available literature that explains) how the mathematical equations for the various model code components were derived from physical principles and solved, and guidance on limitations of the model code.

2. The mathematical foundation and model code have been peer reviewed for the intended use. Peer review is not intended to be a "stamp-of-approval" or disapproval of the model code. Instead, the goal of peer review is to inform stakeholders and decision-makers as to whether a given model code is a suitable tool for the selected application, and whether there are limits on the temporal or spatial uses of the model code, or other analytic limits.

3. The GSP descriptions of the conceptual model, the site-specific model assumptions, input parameters, calibration, application scenarios, and analytical results demonstrate that the quantification of the forecasted water budget, sustainable management criteria (sustainability goal, undesirable results, minimum thresholds, and measurable objectives), proposed projects and management actions are reasonable and within the range of identified uncertainties, to evaluate the GSP-identified outcomes of sustainability for the basin.

4. If requested, provide the Department with a free working copy of the complete modeling platform (for example native MODFLOW and IWFM input files, output files, and executables) that allows the Department to run the model, create and verify results, view input and output files, or perform any other evaluation and verification.

GENERAL MODELING REQUIREMENTS

23 CCR §352.4(f) Groundwater and surface water models used for a Plan shall meet the following standards:

(1) The model shall include publicly available supporting documentation.

(2) The model shall be based on field or laboratory measurements, or equivalent methods that justify the selected values, and calibrated against site-specific field data.

(3) Groundwater and surface water models developed in support of a Plan after the effective date of these regulations shall consist of public domain open-source software.

The intent of requiring standards for models in the GSP Regulations is to promote a consistent approach to the development and coordination of models in California. This will allow the Department to evaluate these models and related GSPs within basins and between basins across the state. A description of the specific modeling standards listed in §352.4(f) is provided below.

(1) The model shall include publicly available supporting documentation.

Models used for a GSP are required to provide publicly available supporting documentation in the form of:

1. An explanation of the modeling code, the physical processes simulated by the code, associated mathematical equations, and assumptions, which are typically found in publicly available theoretical documentation, user instructions or manuals. This information should be referenced by the model developer in their documentation of the model application.

2. A description of the model application, including the construction of the model by the GSA that describes the conceptual model, simulation model development, assumptions, data inputs, boundary conditions, calibration, uncertainty analysis, and other applicable model application elements. This documentation should be a component of a GSP, and included as an appendix to characterize the technical work that went into developing and applying the model for GSP

development and implementation. The California Water and Environmental Modeling Forum (CWEMF) has developed a framework for documenting and archiving a groundwater flow model application that can be tailored for GSA use (CWEMF, 2000).

(2) The model shall be based on field or laboratory measurements, or equivalent methods that justify the selected values, and calibrated against site-specific field data.

The development of a mathematical model starts with assembling applicable information relevant to the basin or site-specific characteristics. A detailed HCM forms the basis of the model by providing relevant physical information of the aquifer and surface systems, as well as applicable boundary conditions of the basin and stressors (such as pumping and recharge). Previous field evaluations, studies and literature may provide additional data for the model development. For more sitespecific information, field testing can be performed, e.g., targeted aquifer tests to determine parameters such as hydraulic conductivity, transmissivity, and storage coefficients. In addition, field tests allow for the calibration of the model to field data. Calibration of the model should be performed by comparing simulated values to observed field data such as groundwater levels, groundwater flow directions, groundwater discharge rates, water quality concentrations, land subsidence observations, measurements of surface water and groundwater exchange, or chloride concentrations as an indicator for seawater intrusion. Additional information on these topics is provided in the modeling considerations and modeling process sections.

(3) Groundwater and surface water models developed in support of a Plan after the effective date of these regulations shall consist of public domain open-source software.

Public domain codes published through government agencies like the Department, the U.S. Army Corps of Engineers Hydrologic Engineering Center, and United States Geological Survey (USGS), are often widely distributed, relatively inexpensive, and generally accepted model codes with features that can be and have been used to simulate a wide range of hydrogeological conditions. Public domain codes, including many listed in Appendix A, have received extensive peer review, case studies document their general applicability, and their limitations have been published in the scientific literature. Many were originally developed, and are continually being refined, by government agencies such as the Department and USGS. Proprietary codes may share many attributes with public domain codes; however, the source code is not generally available for review, they require the purchase of a license to use the software, and the peer review may be limited.

The GSP Regulations require that all new models developed in support of a GSP after the effective date of the GSP Regulations (August 15, 2016) use public domain open- source software to promote transparency and expedite review of models by the Department. The requirement to use public domain open-source software allows for different agencies, stakeholders, and the Department to view input and output data, and run the model, without using a proprietary code; this requirement may help encourage collaborative actions and data sharing that could lead to increased coordination within and between basins. Models developed and actively used in groundwater basins prior to the GSP Regulations effective date can be used for GSP development and implementation, even if they do not use public domain and opensource software as shown in **Figure 2**.

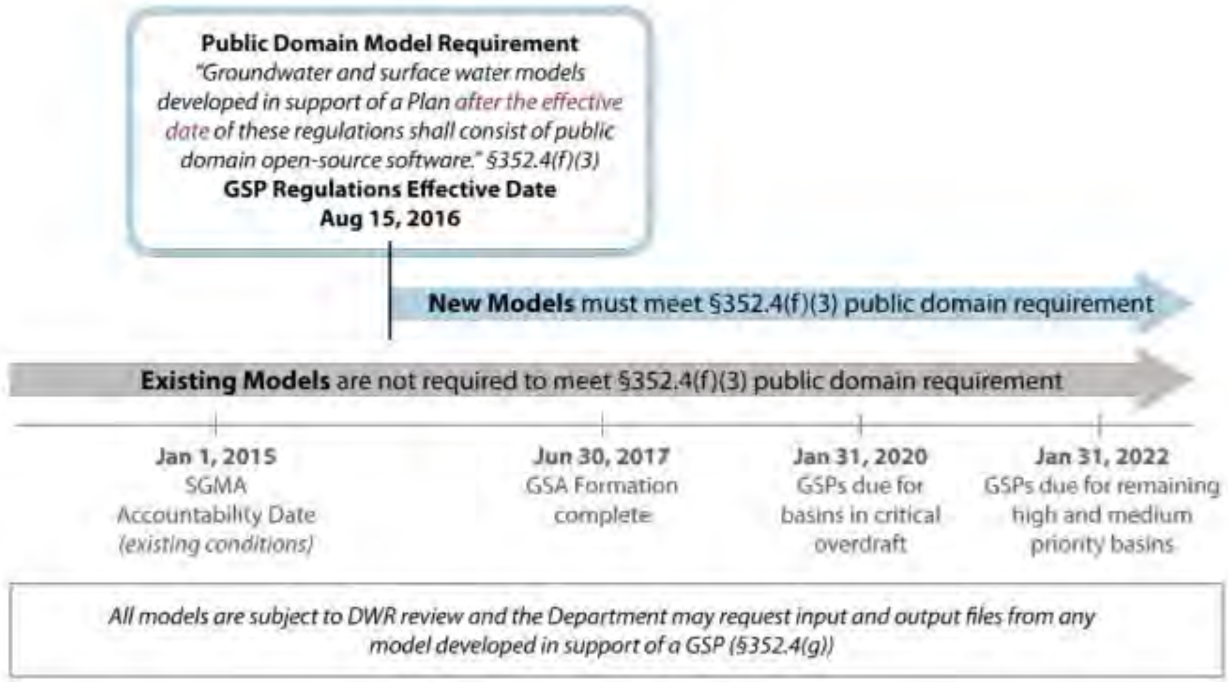


Figure 2 - GSP Regulations Effective Date and Model Development Timeline

The public domain and open-source software requirement only applies to model codes that solve the equations for groundwater flow and transport, and does not apply to other supporting software used to generate model input files or process model output data (such as Microsoft Excel, various GUIs, or GIS mapping software). In addition, the public domain and open-source software requirement does not apply to other boundary evaluation models or tools that provide input to the model or GSP, including watershed evaluation models, estimates of runoff, irrigation demand (if calculated outside the groundwater model), municipal demand (if calculated outside the groundwater model), or other related models.

23 CCR §352.4(g) The Department may request data input and output files used by the Agency, as necessary. The Department may independently evaluate the appropriateness of model results relied upon by the Agency, and use that evaluation in the Department's assessment of the Plan.

All models are subject to Department review and the Department may request input and output files from any model developed in support of a GSP, including any software-specific files.

MODELING CONSIDERATIONS

A model should be selected and developed with clearly defined objectives to provide specific information in support of developing a GSP. Examples of the GSP needs and modeling objectives that should be considered when selecting and developing a model include the following.

Addressing Sustainability Indicators

The management of each sustainability indicator poses unique technical challenges. Each GSA will need to characterize the current and projected status of each sustainability indicator in the basin, and identify the point at which conditions in the basin cause undesirable results. Models must be selected and developed that provide GSAs ample information about the future condition of each sustainability indicator relevant to the basin, and improve the GSA's ability to avoid undesirable results and achieve the Sustainability Goal in the basin.

The need to model each sustainability indicator will be specifically related to the current and potential presence and magnitude of undesirable results in the basin. As the magnitude and distribution of undesirable results increase, the complexity associated with adequately identifying appropriate projects and management actions to achieve sustainability may surpass the ability of simple analytical tools and lead towards the need to apply more complex numerical modeling techniques. Models are also tools that can help establish the Sustainable Management Criteria. Specific modeling considerations for each of the sustainability indicators are described below.

Lowering of Groundwater Levels

One of the most common effects of unsustainable groundwater management is the chronic lowering of groundwater levels. While an assessment of current and/or historical groundwater pumping on groundwater levels can be performed based on groundwater level measurements, forecasting future conditions that may differ from historical conditions will likely require the development of a model, unless the management area can show operating sustainably. All models are capable of simulating the effects of groundwater pumping on groundwater levels and, therefore, forecasts of groundwater level impacts due to basin management actions are readily available from any model of adequate detail and complexity. However in basins where surface water - groundwater interaction plays a significant role in the basin water budget, the groundwater flow model selected to forecast basin conditions resulting from management actions should be capable of accounting for the effects of pumping on streamflow. Addressing this sustainability indicator does not promote or exclude any particular models. Instead, the GSA should assess which modeling tool will provide estimates of groundwater levels at the appropriate spatial distribution to support GSP development and implementation.

Reduction of Groundwater Storage

Estimates of changes in groundwater storage volume can be computed based on observed groundwater level changes, along with knowledge of the geometry and hydraulic and hydrogeologic properties of the aquifer system. Therefore, historical changes in groundwater storage can be estimated from aquifer and groundwater monitoring data. However, forecasting future storage changes due to projects and management actions will likely require a modeling tool of some type. In addition, models are capable of providing the geographic distribution of changes in storage at specific locations. All transient groundwater and surface water models are capable of computing changes in groundwater storage within a basin due to particular management actions and, therefore, estimation of change in groundwater storage is readily available from any transient model of adequate detail and complexity. Addressing this sustainability indicator does not promote or exclude any particular model. Instead, the GSA should assess which modeling tool will provide estimates of groundwater storage changes at the appropriate spatial distribution and accuracy to support GSP development and implementation, particularly based on the types of management actions considered in the basin.

Seawater Intrusion

The Delta-Mendota Subbasin is highly unlikely to have any impacts to Seawater Intrusion. Therefore, modeling of Seawater Intrusion is not required.

Degraded Water Quality

In basins with impaired water quality, the GSP's projects and management actions could cause impaired groundwater to flow towards municipal or other water supply wells. In these basins, the model code or codes (see Appendix A) should be capable of simulating the extent and flow direction of the impaired groundwater. This could require a model with particle tracking capabilities or a model with chemical transport capabilities. To satisfy the requirement that an open-source public domain flow model code be used for all new models under SGMA, groundwater quality will likely be simulated with open source particle tracking or transport codes that can be coupled to the flow model, such as PATH3D or MT3D.

Known contaminants shall be monitored and managed to restrict the migration of contamination plumes in areas where the GSA has control over the migration.

Land Subsidence

Groundwater basins may be subject to subsidence from groundwater pumping. In these basins, the GSA should implement a model code or codes (see Appendix A) capable of accurately simulating significant groundwater level changes over time, the resulting potential for drawdown-induced subsidence, and the loss of inelastic groundwater storage due to sediment compaction. If the historical subsidence has been significant, the GSA may want to select a model code that incorporates land subsidence directly into the groundwater flow process. If the amount of historical subsidence is not significant, controlling and abating subsidence could be estimated with simpler, one-dimensional calculations that are external to the groundwater flow model.

Local expertise shall be used to determine the potential causes and possible mitigation efforts to mitigate land subsidence.

Depletion of Interconnected Surface Water

> 23 CCR §354.28 (b) The description of minimum thresholds shall include the following:
>
> (1) The information and criteria relied upon to establish and justify the minimum thresholds for each sustainability indicator. The justification for the minimum threshold shall be supported by information provided in the basin setting, and other data or models as appropriate, and qualified by uncertainty in the understanding of the basin setting.
>
> (6) Depletions of Interconnected Surface Water. The minimum threshold for depletions of interconnected surface water shall be the rate or volume of surface water depletions caused by groundwater use that has adverse impacts on beneficial uses of the surface water and may lead to undesirable results. The minimum threshold established for depletions of interconnected surface water shall be supported by the following:
>
> (A) The location, quantity, and timing of depletions of interconnected surface water.
>
> (B) A description of the groundwater and surface water model used to quantify surface water depletion. If a numerical groundwater and surface water model is not used to quantify surface water depletion, the Plan shall identify and describe an equally effective method, tool, or analytical model to accomplish the requirements of this Paragraph.

Depletion of interconnected surface water occurs when groundwater levels decline beneath a surface water system that is hydraulically connected at any point by a continuous saturated zone between the underlying aquifer and the overlying surface water system. It should be noted that there is a difference between natural occurring depletion of interconnected surface water and the depletion of interconnected surface water due to local groundwater extractions. While the GSA has no direct control over naturally occurring depletion of interconnected surface water, the GSA will monitor and manage depletion of interconnected surface water due to local groundwater extractions. The pattern of surface water depletion can be complex, both spatially and temporally, depending on the characteristics of the streambed sediments and the distribution of drawdown in the underlying aquifer system. If groundwater in a basin is in hydraulic connection with the surface water system, the selected model code or codes (see Appendix A) used to evaluate basin sustainability must be capable of accurately depicting the effects of changing groundwater levels and stream stages on the resulting depletion of interconnected surface water.

If a numerical groundwater and surface water model is not used to quantify surface water depletions, an equally effective method, tool, or analytical model must be identified and described in the GSP (§354.28(b)(6)(B)).

Developing Water Budgets

> 23 CCR §354.18 (e) Each Plan shall rely on the best available information and best available science to quantify the water budget for the basin in order to provide an understanding of historical and projected hydrology, water demand, water supply, land use, population, climate change, sea level rise, groundwater and surface water interaction, and subsurface groundwater flow. If a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater, the Plan shall identify and describe an equally effective method, tool, or analytical model to evaluate projected water budget conditions.
>
> (f) The Department shall provide the California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) and the Integrated Water Flow Model (IWFM) for use by Agencies in developing the water budget. Each Agency may choose to use a different groundwater and surface water model, pursuant to Section 352.4.

Models are useful tools to develop water budgets as they have the ability to account for all inflows and outflows to the basin and estimate changes in storage over time. Specifically, a model can be used to predict water budgets at varying scales under future conditions and climate change, as well as with the inclusion of management scenarios. The Water Budget BMP includes more details on the development of surface water and groundwater budget and the associated required components.

If a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions, an equally effective method, tool, or analytical model must be identified and described in the GSP (§354.18(e)).

Forecasting Future Conditions

One significant and important benefit of using a model is the computational ability to forecast and evaluate multiple basin conditions over time. Any modeling approach should be capable of readily simulating reductions in available surface water supplies, changes in land use and associated water demands, and the effects of climate change influencing meteorological conditions across the basin, and quantifying the uncertainty in these predictions.

Assessing Impacts of Potential GSP Projects and Management Actions

Each GSP must demonstrate how the selected projects and management actions will achieve the sustainability goal for the basin within 20 years of GSP implementation. Impacts on sustainability indicators from the various projects and management actions in a GSP can be best estimated by an appropriately developed and calibrated model. Model simulations can include a variety of potential projects and management actions, and identify those that appear to be successful at achieving the sustainability goal for the basin. Furthermore, the model simulations can demonstrate sustainability over the range of climatic patterns that may occur in the future. Simulations of future conditions, with or without projects, must include an assessment of prediction uncertainty about these simulated outcomes based on appropriate statistical analysis of parameter/boundary condition uncertainty during the sensitivity analysis and calibration process.

GSAs may additionally want to weigh a number of alternative strategies that can all achieve sustainability and identify those that can be implemented at the lowest cost. The selected model should be accurate and detailed enough to demonstrate the different impacts on various parties from proposed projects and management actions, and allow GSAs to choose among various alternative strategies. Formal groundwater management optimization routines are one type of tool that may be used, in conjunction with groundwater (or integrated hydrologic) models, to achieve this goal.

Identifying Data Gaps and Monitoring Needs

Models can help GSAs identify additional data that could reduce uncertainty in the GSP development and implementation. Models can perform a large number of simulations, each with a different set of hydrogeologic parameters, to assess: 1) which parameters have the greatest sensitivity on model estimates of key sustainability indicators, and 2) the magnitude of variability imparted in model forecasts of sustainability due to the level of uncertainty in the value of key model parameters. Results from a model's uncertainty analysis can be used to prioritize data collection activities according to which parameters are most influential on various sustainability indicators. For example, if modeling results indicate that achieving sustainability is heavily dependent on infiltration of surface water, it will be important to focus characterization activities on better understanding the rate and variability of surface water infiltration, and what actions influence these processes. In addition, focused field studies to estimate the physical values of associated model parameters, such as the streambed hydraulic conductivity for groundwater and surface water exchange, are valuable.

Uncertainty analysis can provide useful input in the following areas:

- Prioritization of data collection efforts to target key basin characteristics driving the potential for undesirable results with the goal of reducing the level of remaining uncertainty.
- The selection of a reasonable margin of operational flexibility in specifying measurable objectives, minimum thresholds, and proposed projects and management actions (allowable surface water diversions, pumping quantities, etc.).
- A platform for integrating the uncertainty of the effects of climate change and sea-level rise on sustainable basin operations.

Assessing Impacts on Adjacent Basins

Coordination of modeling efforts between adjacent basins is critical in assessing the current understanding of the basin inflows and outflows, and evaluating the potential effects from projects and management actions in one basin on adjacent basins. For example, boundary heads and flows computed by different models or methods needs to be checked for consistency. Boundary conditions and general parameter values for adjacent models are expected to be consistent. Interagency coordination agreements, as required under the GSP Regulations (§357.4), stress the importance of basin-wide planning and modeling. Interbasin agreements are optional, but are recommended in the GSP Regulations (§357.2) to help with establishing a consistent understanding of basin conditions across adjacent basins, and to aid in development of models with consistent assumed properties and boundary conditions. Items that may be affected and need to be coordinated among adjacent basins relate to existing undesirable results, basin sustainability goals, water budgets, minimum thresholds and measurable objectives, and general land use plans.

Model Adaptability

Modeling to support sustainable groundwater management is an ongoing effort. The initial model developed to support a sustainability assessment must be based on the best available information, the level of expert knowledge about the basin, and the best available science at the time of model development. As new data are collected and an improved understanding of the basin is developed over time, through either additional characterization, monitoring efforts, or both, the predictive accuracy of the model (or models) should be improved through a refinement of the underlying model assumptions (aquifer properties, stratigraphy, boundary conditions, etc.), as well as more robust calibration due to a larger database of calibration targets (groundwater levels, surface water flows, a more robust climatic dataset, etc.). The model selected to provide long-term support of a groundwater basin should be able to adapt to refined hydrogeologic interpretations and incorporate additional data.

Incorporating model adaptability allows a GSP to start with relatively simple models, and add complexity over time. It may be beneficial to initially defer to simple yet adaptable models. As the amount of information and expert knowledge about a basin increases, complexity can be added to these simple models to reduce the amount of predictive uncertainty.

Spatial Extent of the Model and Model Boundaries

A single GSP or multiple GSPs with a coordination agreement must be developed for an entire basin. Therefore, to predict whether undesirable results currently exist or may occur in the future, the model should at a minimum cover the entire basin. For some sustainability indicators, such as changing groundwater levels causing depletions of interconnected surface water, the model boundaries may need to extend beyond the basin boundary to accurately simulate the effects of pumping. Additionally, the model must be capable of evaluating whether the basin’s projects and management actions adversely affect the ability of adjacent basins to implement their Plan or achieve and maintain their sustainability goals over the planning and implementation horizon. Important areas of consideration that may call for an expanded model domain are: 1) the ability to simulate the magnitude and variability in the exchange of groundwater and surface water systems between a basin of interest and adjacent groundwater basins; and 2) the ability to simulate boundary conditions that may lie outside of the basin of interest, but still have an influence on the water budget of the basin under consideration. In many cases, the model needs to be large enough to encompass the entire area affected by the GSA’s groundwater activities such as pumping and recharge projects that the model is intended to assess.

Regional scale models may not always be appropriate for basin management because the model grid might be too coarse to accurately assess local sustainability indicators. However, in these cases regional scale models can be used as a basis for basin-wide models. Regional models can provide boundary conditions that can be implemented into basin-wide models. Alternatively, fine grid models can be nested into regional models. This can be done by either locally refining the mesh structure of a regional model, or using tools such as the Telescopic Mesh Refinement (TMR) or Local Grid Refinement (LGR) packages.

Data Availability

The availability of basin-specific information may influence model selection and construction. Basins with a large amount of data may support a more complex modeling platform than a basin with a paucity of available data. However, the complexity of the model should be based on the surface water and groundwater use and potential issues in the basin. Hydrologic processes that may affect SGMA undesirable results also need to be considered for model development.

Importance of Land Use Practices in Agricultural Basins

It is important that models developed for basins with significant agricultural water use be responsive to changes in agricultural practices. These changes may entail changes in crop types, irrigation practices, irrigation water source, or other changes related to land use practices. Some model codes, such as the Department Integrated Water Flow Model (IWFM) and the USGS' One Water Hydrologic Model (OWHM) explicitly simulate the effects of changing agricultural practices and surface water uses. Agricultural practices may also be addressed in model pre-processors such as GIS tools or spreadsheets for other model codes.

Model Results Presentation

Models are important tools that can aid with stakeholder engagement and common understanding of the basin, as well as the establishment of sustainable management criteria, and projects and management actions, through the presentation of outputs in graphical and mapping formats. Using model results in coordination with HCM graphical representations provides a means of communication with interested parties in the basin by providing detailed basin information. Where multiple models exist, an informed comparison to results from other models may be useful to confirm results or identify potential additional uncertainties.

Models developed for management support should provide clear information to decision makers, and must be capable of efficiently and effectively conveying simulation output in a format that is understandable by a wide variety of stakeholders with varying levels of technical expertise.

GUIs are commercially available for different types of model codes. These GUIs, in addition to other commonly used software, such as Microsoft Excel and ESRIs software, are powerful tools to help with processing data into model input formats, more efficiently run models, and provide a platform to visualize model outputs and create figures for stakeholder communication and reporting needs. These GUIs are not part of the model code itself, but are an external software that can be used to make the modeling process more streamlined. Therefore, GUIs do not fall under the "public domain and open source" definition that the model codes need to adhere to per the GSP Regulations.

THE GROUNDWATER MODELING PROCESS

Modeling depends on and reflects the judgement and experience of the groundwater modeler(s). There is no formula or discrete set of steps that will ensure that a model is accurate or reliable. However, there are recommended steps and protocols that groundwater modelers should follow. The general steps are shown graphically in **Figure 3**, and discussed below.

1**. Establish the model's purpose and objectives.** Models generally cannot reliably answer all questions about groundwater behavior. For the purposes of SGMA, the GSA should assess which sustainability indicators need to be simulated by the model (or models), and develop the model purpose to address these. GSAs should also establish protocols at this stage for where the model will be housed, how the model will be updated, and the terms of model use by various GSA members. Stakeholder input is an important component of model development; specifically, during the early planning phase of model development when the purpose and objectives of the model are being considered and near the end of the modeling process when various modeling scenarios are being considered.

2. **Collect and organize hydrogeologic data.** The amount of available data and accuracy of available data will drive the complexity and detail included in both the conceptual model and mathematical model. All GSA members should, to the degree possible, provide data of similar accuracy and completeness to ensure that the entire model reflects a similar level of data density and integrity. Raw data collected as part of the basin setting and HCM development should be organized at this stage. Once these data are organized into a database, they are processed into input files for modeling, with specific file formats as required by the chosen code. As an example, the Central Valley Hydrologic Model (CVHM) website has a framework for the organization of the raw data with links to the data sources, as well as related GIS shapefiles and CVHM input files of the processed data (http://ca.water.usgs.gov/projects/central-valley/central-valleyspatial-database.html).

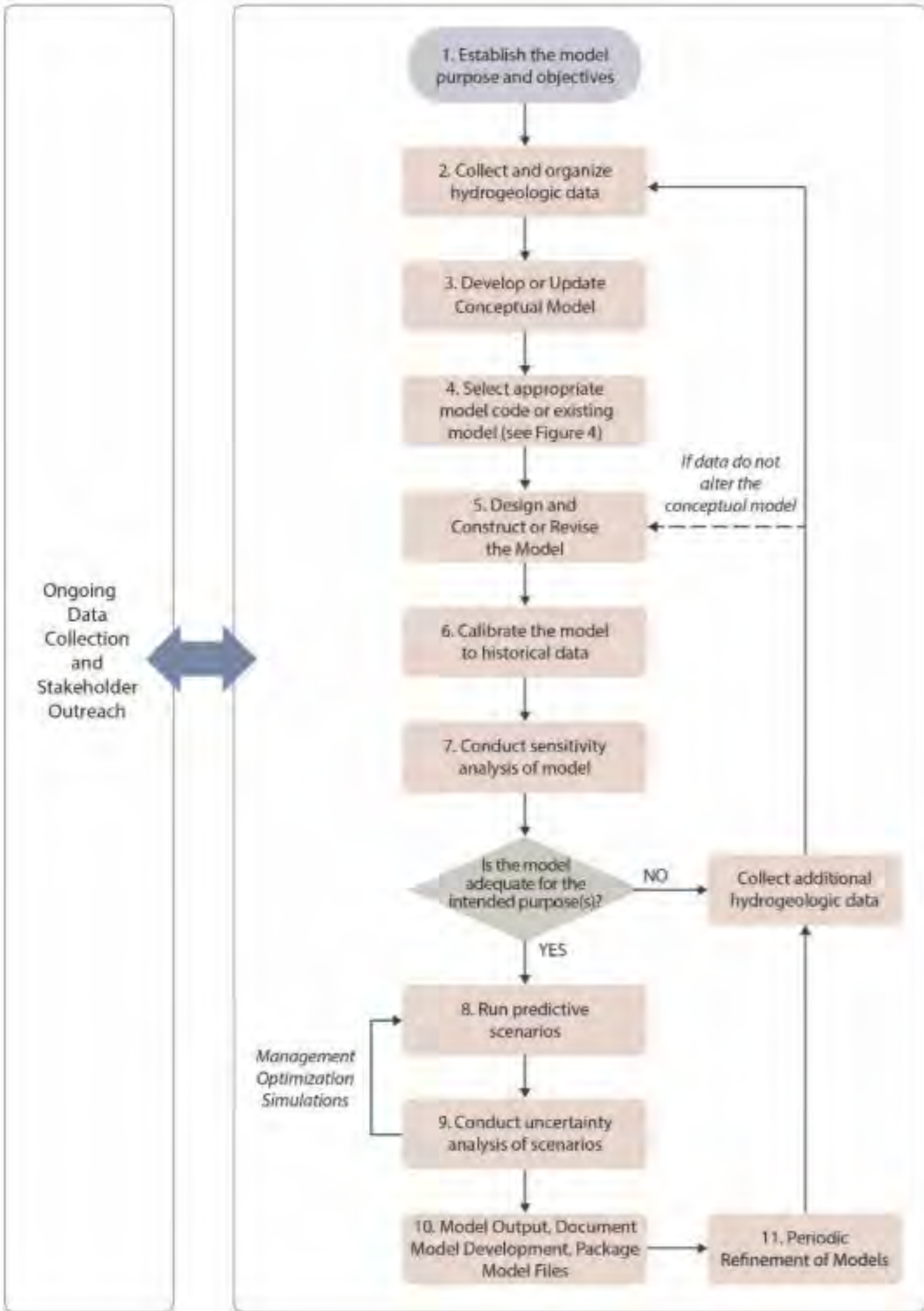


Figure 3: General Modeling Process

3. **Develop a conceptual model of the basin.** The conceptual model forms the structural, hydrogeologic, and hydrologic basis of the mathematical (analytical or numerical) model. The conceptual model identifies the key parameters of physical setting, aquifer structure and range of aquifer parameters, hydrologic processes, and boundary conditions that govern groundwater and surface water occurrence within the basin. The conceptual model provides the technical foundation of the model and an initial interpretation of a basin based on known characteristics and current management actions. In addition to aquifer characteristics and groundwater management activities, the conceptual model includes a conceptual understanding of the surface features, water uses, land uses, water management activities, and any other processes in the basin that affect surface and groundwater uses. Although a conceptual model does not necessarily include quantitative values, it should identify the range of reasonable parameter values for the aquifer materials that occur in the basin and that reflect the scale of the model. A sound and well-developed conceptual model is essential to the development of a reliable mathematical model. For more details on developing a hydrogeologic conceptual model, please refer to the HCM BMP.

4. **Select the appropriate model code or existing model.** The selected model code or existing model must be able to simulate all the processes that might significantly influence the various sustainability indicators. However, modelers should practice pragmatism and avoid unnecessary model complexity. In many basins, there may be one or multiple existing models already in use. It is preferable to avoid competing models that perform similar functions in a single basin. The GSA should compare existing models and decide if one of these models is better suited for GSP development and implementation. If multiple models are used in a basin, GSAs should consider the potential overlap and differences between the models, and how the different model results could inform management uncertainty.

Figure 4 provides a flowchart that may aid in the comparison and selection of an appropriate model if multiple models exist in a basin and GSAs opt to use a single model. In addition, two interactive maps of a select number of existing, available, model applications in California are available at the following links (DWR – http://www.water.ca.gov/groundwater/MAP_APP/index.cfm ; USGS – http://ca.water.usgs.gov/sustainable-groundwater-management/californiagroundwater-modeling.html).

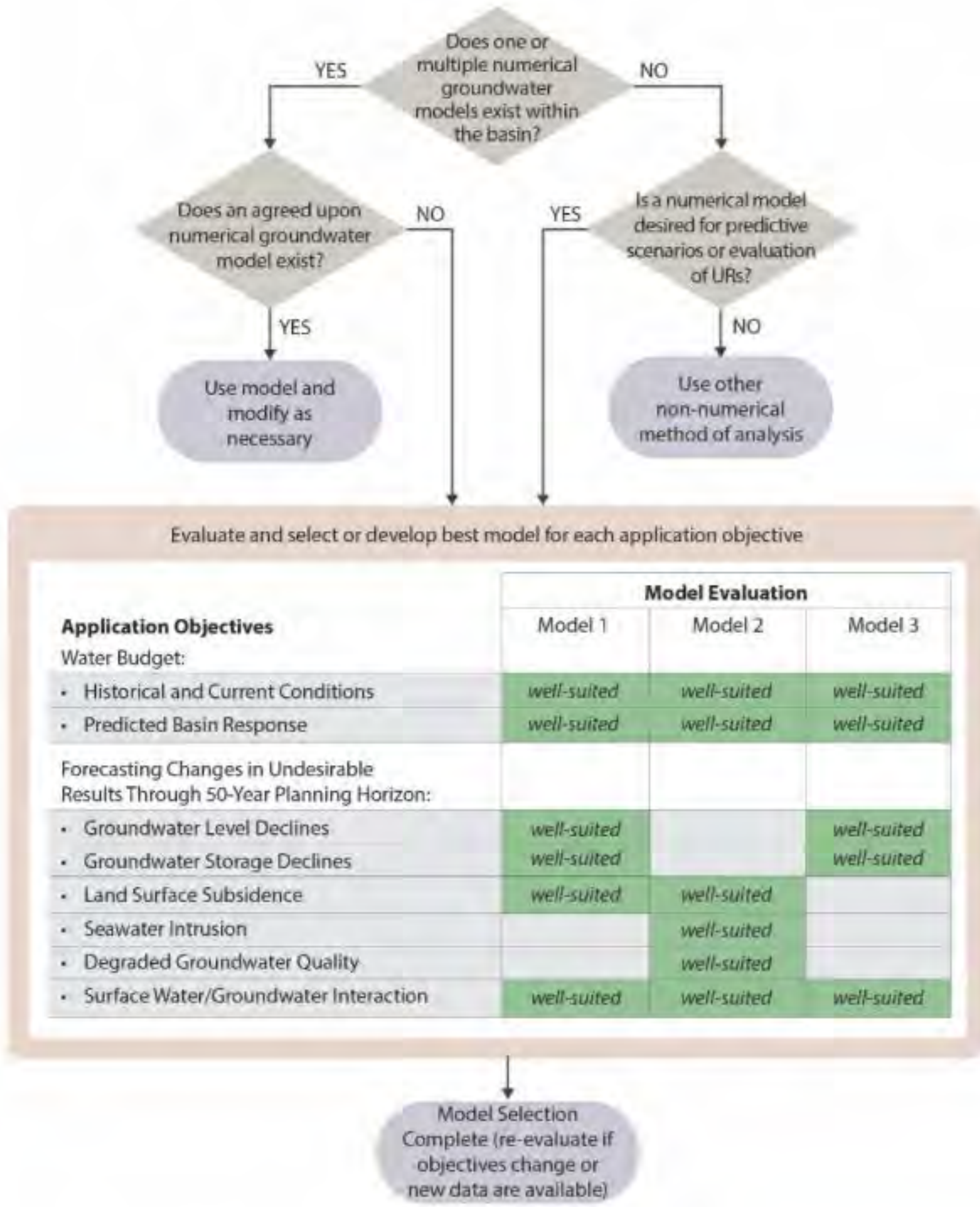


Figure 4: Generalized Model Selection Process
Note: Selected model needs to adhere to the public domain open source requirements.

5. Design and construct (or revise) the model. In this step, the conceptual model developed in step three is implemented in the selected model code. This step includes constructing the model grid, populating the model with hydrogeologic parameters, assigning boundary conditions, and adding water budget components to the model. Models should maintain simplicity and parsimony of hydrogeologic parameters, while simultaneously simulating the important hydrogeologic details that will drive basin sustainability.

6. Calibrate the numerical model to historical data. Model calibration is required by the GSP Regulations (§352.4(f)(2)). Calibration is performed to demonstrate that the model reasonably simulates known, historical conditions. Calibration generally involves iterative adjustments of various model aspects until the model results match historical observations within an agreed-to tolerance. Hydrogeologic parameters such as hydraulic conductivity, specific yield and leakance coefficients are often modified during model calibration. However, adjustment of parameter values must be constrained within the range of reasonable values for the aquifer materials identified in the conceptual model. Aspects of the water budget, such as recharge rate or private pumping rate, may also be modified during calibration.

One of the primary values of model calibration is to identify problems in the hydrogeologic conceptual model. If a model fails to reproduce observed data, then the representation of the conceptual model in the numerical model contains inaccuracies. While the ability to achieve an acceptable calibration does not necessarily prove that a model is a good representation of the physical system, difficulties encountered during calibration can help identify areas where the conceptualization of the physical system is lacking and more data may be needed to improve the model conceptualization.

No model is perfectly calibrated, and establishing desired calibration accuracy a priori is difficult. One criteria that could be considered is whether additional calibration would change a GSA's approach to achieving sustainability. If a more accurate model does not change the decision a GSA would make, then additional calibration is not necessary. The USGS has published calibration guidelines (Reilly and Harbaugh, 2004), and other modeling guidelines exist to help estimate calibration adequacy. For example, the correlation coefficient between the simulated and observed groundwater elevations, for instance, can be used as a statistic to determine how well a model is calibrated. "Generally, a value of R that is greater than 0.90 indicates that the trends in the weighted simulated values closely match those of the weighted observations" (Hill and Tiedeman, 2007).

7. Conduct sensitivity analysis of the model. The model calibration process typically includes or is followed by a sensitivity analysis to identify parameters or boundary conditions to which model forecasts are particularly sensitive. Parameters that are both highly sensitive and poorly constrained may be good candidates for future data collection. Sensitivity analysis provides a measure of the influence of parameter uncertainty on model predictions. By systematically varying parameter values within reasonable ranges, GSAs can assess how sensitive the calibrated model is to uncertainty in these parameters, and where future data collection efforts could be focused. This step of the modeling process can also help to determine whether the calibrated model can conduct required simulations with the desired level of accuracy.

8. Develop and run predictive scenarios that establish expected future conditions under varying climatic conditions, and implementing various projects and management actions. Predictive scenarios should be designed to assess whether the GSP's projects and management actions will achieve the sustainability goal, and the anticipated conditions at five-year interim milestones. Predictive scenarios for the GSP should demonstrate that the sustainability goal will be maintained over the 50-year planning and implementation horizon.

9. Conduct an uncertainty analysis of the scenarios. This is to identify the impact of parameter uncertainty on the use of the model's ability to effectively support management decisions and use the results of these analyses to identify high priority locations for expansion of monitoring networks. Predictive uncertainty analysis provides a measure of the likelihood that a reasonably constructed and calibrated model can still yield uncertain results that drive critical decisions. It is important that decision makers understand the implications of these uncertainties when developing long-term basin management strategies. As discussed in other sections of this BMP, this type of analysis can also identify high-value data gaps that should be prioritized to improve confidence in model outputs, and yield a tool that has an increased probability of providing useful information to support effective basin management decisions. A formal optimization simulation of management options may be employed, taking advantage of the predictive uncertainty analysis to minimize economic costs of future actions, while meeting regulatory requirements at an acceptable risk level.

10. Model output, document model code and model application development, and package model files. Model data outputs are used for GSP development and analysis of sustainability indicators and inform proposed management actions. The GSP needs to include documentation on the modeling tools used for GSP development. This documentation can be provided in the form of a technical appendix to the GSP and should include both information on the model code (i.e., referenced from user manuals) and detailed descriptions of the model application development. Model code information should include an explanation of the model code, associated mathematical equations, and assumptions, which are typically found in publicly available theoretical documentation, user instructions or manuals. This information should be referenced by the model user in their documentation of the model application. The description of the model application should include detailed information on the model conceptualization, assumptions, data inputs, boundary conditions, calibration, sensitivity and uncertainty analysis, and other applicable modeling elements such as model limitations. In addition, final model files used for decision making in the GSP should be packaged for release to the Department.

11. Revise and refine model regularly during implementation. After GSP development and during the implementation of the GSP, new data will be available through monitoring and collection from local agencies. As new data are made available through annual updates and the 5-year review process, models can be updated and refined. These new data will be useful for regular model updates and recalibration to reduce model uncertainties and better assess the future effects of management actions on the basin's sustainability indicators.

6. KEY DEFINITIONS

The key definitions related to surface water and groundwater modeling outlined in this BMP are provided below for reference.

SGMA Definitions (California Water Code §10721)

- "Basin" refers to a groundwater basin or subbasin identified and defined in Bulletin 118 or as modified pursuant to Chapter 3 (commencing with Section 10722).

- “Coordination agreement” means a legal agreement adopted between two or more groundwater sustainability agencies that provides the basis for coordinating multiple agencies or groundwater sustainability plans within a basin pursuant to this part.
- “Condition of long-term overdraft”: The condition of a groundwater basin where the average annual amount of water extracted for a long-term period, generally 10 years or more, exceeds the long-term average annual supply of water to the basin, plus any temporary surplus. Overdraft during a period of drought is not sufficient to establish a condition of long-term overdraft if extractions and recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
- “Groundwater” refers to water beneath the surface of the earth within the zone below the water table in which the soil is completely saturated with water, but does not include water that flows in known and definite channels.
- “Groundwater recharge” refers to the augmentation of groundwater, by natural or artificial means.
- “Planning and implementation horizon” means a 50-year time period over which a groundwater sustainability agency determines that plans and measures will be implemented in a basin to ensure that the basin is operated within its sustainable yield.
- “Sustainability goal” means the existence and implementation of one or more groundwater sustainability plans that achieve sustainable groundwater management by identifying and causing the implementation of measures targeted to ensure that the applicable basin is operated within its sustainable yield.
- “Sustainable groundwater management” means the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.
- “Sustainable yield” means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result.
- “Undesirable result” refers to: One or more of the following effects caused by groundwater conditions occurring throughout the basin:
    - 1. Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.
    - 2. Significant and unreasonable reduction of groundwater storage.
    - 3. Significant and unreasonable seawater intrusion.
    - 4. Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.
    - 5. Significant and unreasonable land subsidence that substantially interferes with surface land uses.
    - 6. Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

- “Water budget” is an accounting of the total groundwater and surface water entering and leaving a basin including the changes in the amount of water stored.
- “Water year” refers to the period from October 1 through the following September 30, inclusive

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

- “Hydrogeologic conceptual model” is a description of the geologic and hydrologic framework governing groundwater flow through and across the boundaries of a basin and the general groundwater conditions in a basin.

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

- “Basin setting” refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the Agency in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5.
- “Best available science” means the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision that is consistent with scientific and engineering professional standards of practice.
- “Best management practice” refers to a practice, or combination of practices, that are designed to achieve sustainable groundwater management and have been determined to be technologically and economically effective, practicable, and based on best available science.
- “Data gap” refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.
- “Groundwater flow” refers to the volume and direction of groundwater movement into, out of, or throughout a basin.
- “Interconnected surface water” refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.
- “Interim milestone” refers to a target value representing measurable groundwater conditions, in increments of five years, set by an Agency as part of a Plan.
- “Measurable objectives” refer to specific, quantifiable goals for the maintenance or improvement of specified groundwater conditions that have been included in an adopted Plan to achieve the sustainability goal for the basin.
- “Minimum threshold” refers to a numeric value for each sustainability indicator used to define undesirable results.
- “Plan implementation” refers to an Agency’s exercise of the powers and authorities described in the Act, which commences after an Agency adopts and submits a Plan or Alternative to the Department and begins exercising such powers and authorities.
- “Sustainability indicator” refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code Section 10721(x).
- “Uncertainty” refers to a lack of understanding of the basin setting that significantly affects an Agency’s ability to develop sustainable management criteria and appropriate projects and

management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.

7. RELATED MATERIALS

The following links provide examples, standards, and guidance related to modeling. By providing these links, the Department neither implies approval, nor expressly approves of these documents.

STANDARDS

- ASTM D5718-95: Standard Guide for Documenting a Groundwater Flow Model Application.
- ASTM D5880-95: Standard Guide for Subsurface Flow and Transport Modelling.
- ASTM D5981-96: Standard Guide for Calibrating a Groundwater Flow Model Application.

REFERENCES FOR FURTHER GUIDANCE

Anderson, M.P., and W.W. Woessner, 1992. Applied groundwater modeling: simulation of flow and advective transport, Academic Press, 381 p.

Barnett B., L.R. Townley, V. Post, R.E. Evans, R.J. Hunt, L. Peeters, S. Richardson, A.D. Werner, A. Knapton, and A. Boronkay, 2012. Australian groundwater modelling guidelines, National Water Commission, Canberra, June, 191 p. http://archive.nwc.gov.au/library/waterlines/82

Brush, C.F., and Dogrul, E.C. June 2013. User Manual for the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim), Version 3.02-CG.

CWEMF (formerly - Bay-Delta Modeling Forum), 2000, Protocols for Water and Environmental Modeling, http://www.cwemf.org/Pubs/Protocols2000-01.pdf

Harter T. and H. Morel-Seytoux, 2013. Peer Review of the IWFM, MODFLOW and HGS Model Codes: Potential for Water Management Applications in California's Central Valley and Other Irrigated Groundwater Basins. Final Report, California Water and Environmental Modeling Forum, August 2013, Sacramento. http://www.cwemf.org

Hill M.C. and C.R. Tiedeman. 2007. Effective Groundwater Model Calibration: With Analysis of Data, Sensitivities, Predictions, and Uncertainty. Wiley. 480 pages. January.

Merz, S.K. 2013. Australian groundwater modelling guidelines: companion to the guidelines, National Water Commission, Canberra, July, 31 p. http://archive.nwc.gov.au/library/waterlines/82

Moran, T., 2016. Projecting Forward, A framework for Groundwater Model Development Under the Sustainable Groundwater Management Act. Final Report, Stanford, Water in the West, November 2016. http://waterinthewest.stanford.edu/publications/groundwater-model-report

Murray–Darling Basin Commission (MDBC) 2001, Groundwater flow modelling guideline, report prepared by Aquaterra, January 2001.

Peralta, R., 2012. Groundwater Optimization Handbook: Flow, Contaminant Transport, and Conjunctive Management 1st edition. Boca Raton, Florida, 474 p.

Reilly, T.E., 2001. System and boundary conceptualization in groundwater flow simulation: Techniques of water resource investigations of the United States geological survey, book 3, applications of hydraulics, Chapter B8, Reston, VA, 38 p. http://pubs.usgs.gov/twri/twri-3_B8/

Reilly, T.E., and A.W. Harbaugh, 2004. Guidelines for evaluating ground-water flow models: USGS scientific investigations report 2004-5038, Reston, VA, 30 p. http://pubs.usgs.gov/sir/2004/5038/PDF.htm

United States Geological Survey (USGS). 2009. Groundwater Availability of the Central Valley Aquifer, California. U.S. Geological Survey Professional Paper 1766. Groundwater Resources Program. Reston, VA.

APPENDIX A - EXISTING MODEL CODES AND MODEL APPLICATIONS

There are many existing model codes and model applications being used in basins throughout the state. The Department and USGS have coordinated and compiled a table of available model codes (see Appendix A) and interactive maps displaying a select number of existing model applications in California.

- DWR: http://www.water.ca.gov/groundwater/MAP_APP/index.cfm
- USGS: http://ca.water.usgs.gov/sustainable-groundwatermanagement/california-groundwater-modeling.html

Currently, there are two existing, calibrated, and actively updated and maintained model applications that cover the Central Valley aquifer system. These models can be a great source of data and provide a good starting point for basins within the Central Valley that currently do not have a model. A brief description of these models is provided below. Other regional applications of these models have also been developed for specific purposes.

California Central Valley Groundwater-Surface Water Simulation Model (C2VSim)

The Department developed, maintains, and regularly updates C2VSim. It has been used for several large-scale Central Valley studies. C2VSim is an integrated numerical model based on the finite element grid IWFM that simulates the movement of water through a linked land surface, groundwater, and surface water flow systems. The C2VSim model includes monthly historical stream inflows, surface water diversions, precipitation, land use, and crop acreage data from October 1921 through September 2009. 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 response to projected future stresses (DWR, 2016). http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm

Central Valley Hydrologic Model (CVHM)

CVHM is a three-dimensional numerical groundwater flow model developed by USGS and documented in Groundwater Availability of the Central Valley Aquifer, California (USGS, 2009). CVHM simulates groundwater and surface water flow, irrigated agriculture, and other key hydrologic processes over the Central Valley at a uniform grid-cell spacing of 1 mile on a monthly basis using data from April 1961 to September 2003. CVHM simulates surface water flows, groundwater flows, and land subsidence in response to stresses from water use and climate variability throughout the Central Valley. It uses the MODFLOW-2000 (USGS, 2000) finite-difference groundwater flow model code combined with a module called the farm process (FMP) (USGS, 2006) to simulate irrigated agriculture. It can be used in a similar

manner to C2VSim to simulate response to projected future stresses.
http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html

Summary of Commonly Used Groundwater Model Codes in California.					
Model Code	**Description**	**Download**	**Documentation**	**Maintained by**	**Applicability to SGMA Sustainability Indicator**
IWFM	Finite-element code for integrated water resources modeling	http://baydeltaoffice.water.ca.gov/modeling/hydrology/I WFM/	DWR, 2016. Integrated Water Flow Model: IWFM -2015, Theoretical Documentation, Central Valley Modeling Unit Support Branch Bay-Delta Office	DWR	Groundwater levels Storage Interconnected SW/GW Subsidence
IDC	Stand-alone executable version of IWFM root zone compotent (iwfm Demand Calculator).	http://baydeltaoffice.water.ca.gov/modeling/hydrology/IDC/index_IDC.cfm	DWR, 2016. IWFM Demand Calculator: IDC-2015, Theoretical Documentation and User's Manual, Central Valley Modeling Unit Support Branch Bay-Delta Office	DWR	Land use water budget
MODFLOW	Finite-difference groundwater flow code; several versions available with related modules.	http://water.usgs.gov/ogw/modfl ow/	Current core version is MODFLOW -2005: USGS. 2005. MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model— the Ground-Water Flow Process. USGS Techniques and Methods 6–A16	USGS	Groundwater levels Storage Interconnected SW/GW Subsidence Seawater intrusion
MODFLOW-OWHM	MODFLOW based integrated hydrologic flow model (One Water Hydrologic Flow Model).	integrated hydrologic flow model (One Water Hydrologic Flow Model). http://water.usgs.gov/ogw/modfl ow-owhm/	USGS. 2014, One-Water Hydrologic Flow Model (MODFLOW-OWHM). U.S. Geological Survey Techniques and Methods 6-A51.	USGS	Groundwater levels Storage Interconnected SW/GW Subsidence Seawater Intrusion

Summary of Commonly Used Groundwater Model Codes in California.					
Model Code	**Description**	**Download**	**Documentation**	**Maintained by**	**Applicability to SGMA Sustainability Indicator**
MODFLOW-USG	MODFLOW-USG: An Unstructured Grid Version of MODFLOW for Simulating Groundwater Flow and Tightly Coupled Processes Using a Control Volume FiniteDifference Formulation	http://water.usgs.gov/ogw/mfusg /	Panday, Sorab, Langevin, C.D., Niswonger, R.G., Ibaraki, Motomu, and Hughes, J.D., 2015, MODFLOW-USG version 1.3.00: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation: U.S. Geological Survey Software Release, 01 December 2015, http://dx.doi.org/10.5066/F7R20ZFJ	USGS	Groundwater levels Storage Interconnected SW/GW Subsidence
GSFLOW	GSFLOW: coupled groundwater and surface-water flow mode	http://water.usgs.gov/ogw/gsflo w/	Regan, R.S., Niswonger, R.G., Markstrom, S.L., Maples, S.R., and Barlow, P.M., 2016, GSFLOW version 1.2.1: Coupled Groundwater and Surface-water FLOW model: U.S. Geological Survey Software Release, 01 October 2016, http://dx.doi.org/10.5066/F7WW7FS0	USGS	Groundwater levels Storage Interconnected SW/GW
MT3D[1]	Modular 3-D MultiSpecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems. Postprocessing code to MODFLOW for transport modeling	http://hydro.geo.ua.edu/mt3d/	Zheng, Chunmiao, 2010, MT3DMS v5.3 Supplemental User's Guide, Technical Report to the U.S. Army Engineer Research and Development Center, Department of Geological Sciences, University of Alabama, 51 p	University of Alabama	Water quality/contaminant plumes

Summary of Commonly Used Groundwater Model Codes in California.

Model Code	Description	Download	Documentation	Maintained by	Applicability to SGMA Sustainability Indicator
RT3D	Modular Code for Simulating Reactive Multi-species Transport in 3-Dimensional Groundwater Systems. Postprocessing code to MODFLOW for transport modeling.	http://bioprocess.pnnl.gov/rt3d.downloads.htm#doc	Clement, P. T, 1997, A Modular Computer Code for Simulating Reactive Multi-species Transport in 3-Dimensional Groundwater Systems, Pacific Northwest National Laboratory	Pacific Northwest National Laboratory	Water quality/contaminant plumes
Path3D	A particle-tracking program for MODFLOW that can simulate advective transport	http://www.sspa.com/software/path3d	Zheng, C., 1992, Path3D, a groundwater pass and travel time simulator, S.S. Papadopulos & Associates, Inc..	S.S. Papadopulos & Associates	Water quality/contaminant plumes
MOD-PATH3DU	Groundwater path and travel time simulator for unstructured model grids	http://www.sspa.com/software/modpath3du	Muffles, C, M. Tonkin, M. Ramadhan, X. Wang, C. Neville, and J.R. Craig, 2016, Users guide for mod-PATH3DU; a groundwater pass and travel time simulator, S.S. Papadopulos & Assoc. Inc, and the University of Waterloo.	S.S. Papadopulos & Associates	Water quality/contaminant plumes
SEAWAT	MODFLOW MT3D based model designed to simulate three-dimensional variable-density groundwater flow.	http://water.usgs.gov/ogw/seawat/	Langevin, C.D., SEAWAT: a computer program for simulation of variable-density groundwater flow and multi-species solute and heat transport: U.S. Geological Survey Fact Sheet FS 2009-3047, 2 p	USGS	Seawater intrusion
MODPATH	Particle-Tracking post-processing tool for MODFLOW.	http://water.usgs.gov/ogw/modpath/	USGS. 2012, User guide for MODPATH version 6—A particle-tracking model for MODFLOW: U.S. Geological Survey Techniques and Methods, book 6, chap. A41	USGS	Groundwater flow path tracking for groundwater quality, Seawater intrusion, and other flowrelated processes

Summary of Commonly Used Groundwater Model Codes in California.					
Model Code	**Description**	**Download**	**Documentation**	**Maintained by**	**Applicability to SGMA Sustainability Indicator**
INFIL 3.0	Watershed model to estimate net infiltration below the root zone.	http://water.usgs.gov/nrp/gwsoftware/Infil/I nfil.html	U.S. Geological Survey, 2008, Documentation of computer program INFIL3.0-A distributed-parameter watershed model to estimate net infiltration below the root zone: U.S. Geological Survey Scientific Investigations Report 2008-5006.	USGS	

Notes:

- Additional DWR modeling tools and resources are available at: http://www.water.ca.gov/groundwater/sgm/index.cfm and http://baydeltaoffice.water.ca.gov/modeling/
- Additional USGS modeling tools and resources are available at: http://water.usgs.gov/software/lists/groundwater
- This list does not contain all available models in California and there are model codes in use in California that are currently proprietary (such as MicroFem, MODFLOW-Surfact, MODHMS) but may be allowed if the model applications were developed and used prior to the effective date of the GSP Regulations.

Appendix M. SMC BMP

Sustainable Management Criteria Best Management Practice

1. OBJECTIVE

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

The Sustainable Groundwater Management Act (SGMA)[2] and GSP Regulations specify the requirements of a GSP. This BMP does not impose new requirements, but describes best management practices for satisfying the requirements of SGMA and the GSP Regulations. This BMP is reasonable and supported by the best available information and best available science.[3]

Examples provided in this BMP are intentionally simplified and are intended only to illustrate concepts. The level of detail in any of these simplified examples (e.g., the number of minimum thresholds defined in a hypothetical basin, the number of minimum thresholds that constitute an undesirable result, etc.) may not represent the actual level of detail required to achieve sustainability.

2. INTRODUCTION

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

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

- **Sustainability Goal**

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

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

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

SGMA REQUIREMENT TO QUANTIFY SUSTAINABILITY

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

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

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

3. PRELIMINARY ACTIVITIES

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

Understand the Basin Setting

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

Inventory Existing Monitoring Programs

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

Engage Interested Parties within the Basin

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

4. SETTING SUSTAINABLE MANAGEMENT CRITERIA

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

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

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

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

Sustainability Indicators

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

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

Significant and unreasonable reduction of groundwater storage

Significant and unreasonable seawater intrusion

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

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

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

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

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

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

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

Significant and Unreasonable Conditions

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

Use of Management Areas

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

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

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

Representative Monitoring Sites

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

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

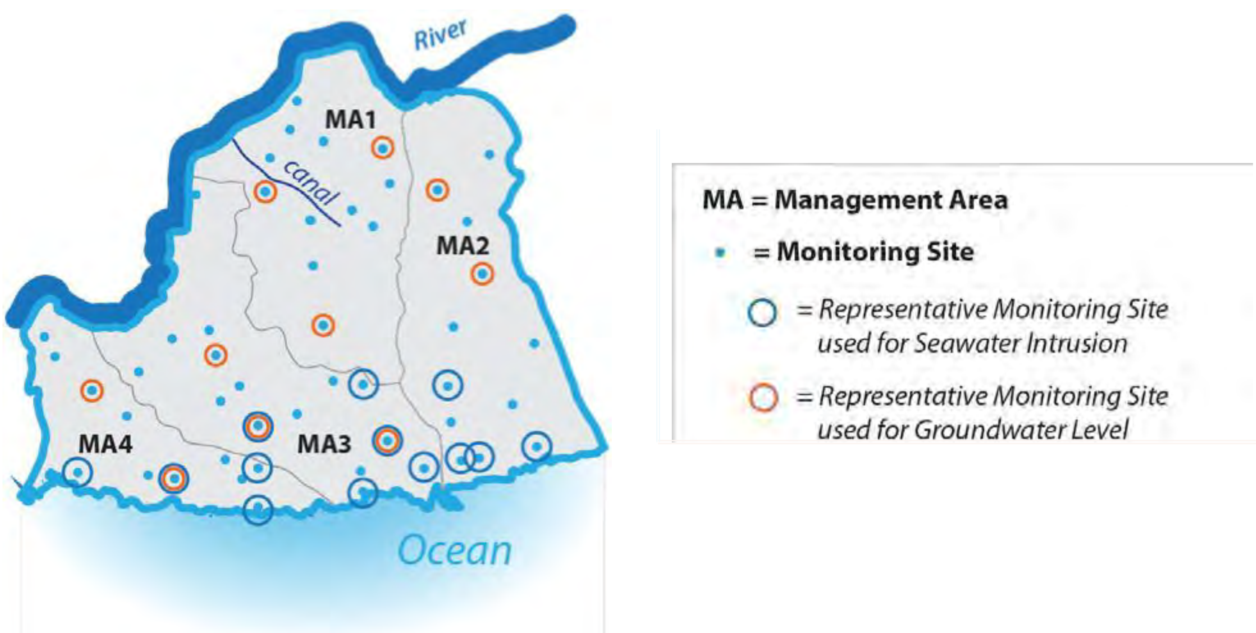


Figure 1. Example Monitoring Network and Representative Monitoring Sites

MINIMUM THRESHOLDS

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

Required Components for all Minimum Thresholds

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

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

   The GSP must include an analysis and written interpretation of the information, data, and rationale used to set the minimum threshold. For instance, if a groundwater level minimum threshold is set to protect shallow domestic supply wells, the GSA should investigate information such as the depth ranges of domestic wells near the representative monitoring site, aquifer dimensions, groundwater conditions, and any other pertinent information.
2. *The relationship between the minimum thresholds for each sustainability indicator, including an explanation of how the Agency has determined that basin conditions at each minimum threshold will avoid undesirable results for each of the sustainability indicators.*

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

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

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

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

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

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

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

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

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

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

Required Minimum Threshold Metrics for Each Sustainability Indicator

In addition to the six components described above that apply to all minimum thresholds, the GSP Regulations contain specific requirements and metrics for each sustainability indicator.[8] The purpose of the specific requirements is to ensure consistency within groundwater basins and between adjacent groundwater basins. In some instances a minimum threshold may be described as a management strategy to mitigate impacts from an adjacent GSP/Subbasin.

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

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

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

Figure 2. Minimum Threshold Metrics

Examples and Considerations for Minimum Thresholds

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

Chronic Lowering of Groundwater Levels Minimum Threshold

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

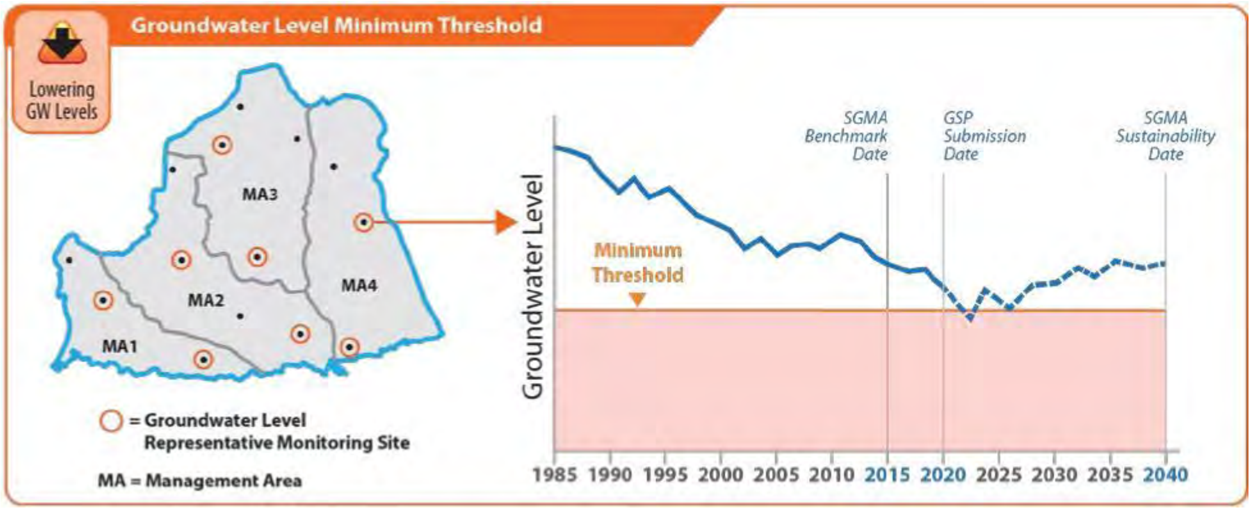


Figure 3. Example Groundwater Level Minimum Threshold Established at a Representative Monitoring Site

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

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

Reduction in Groundwater Storage Minimum Threshold

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

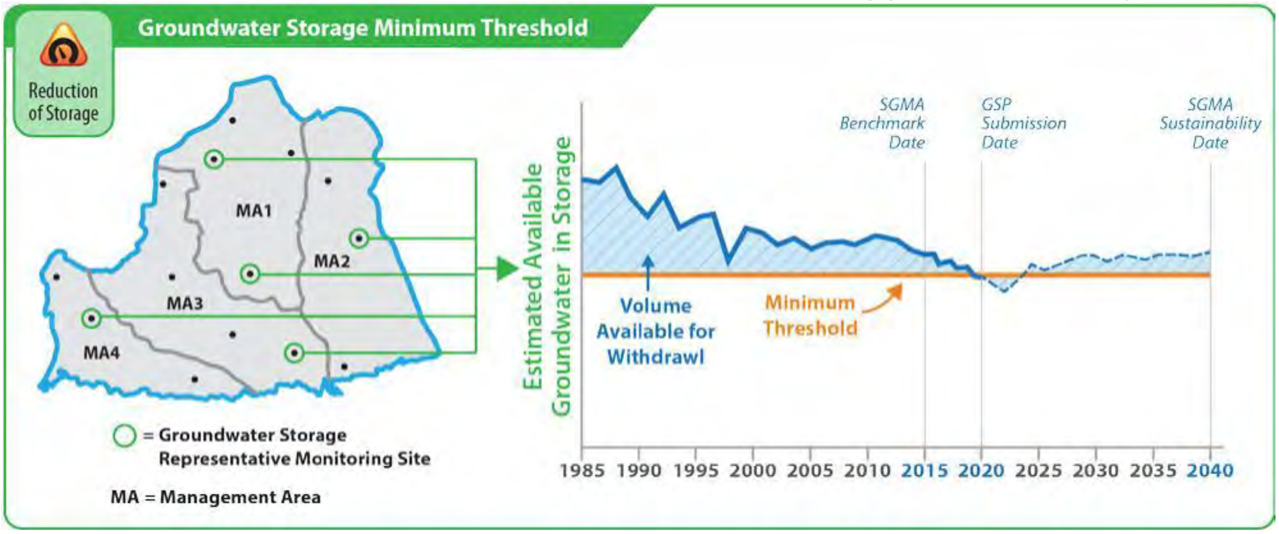


Figure 4. Example Groundwater Storage Minimum Threshold Established at the Basin Scale

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

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

Seawater Intrusion Minimum Threshold

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

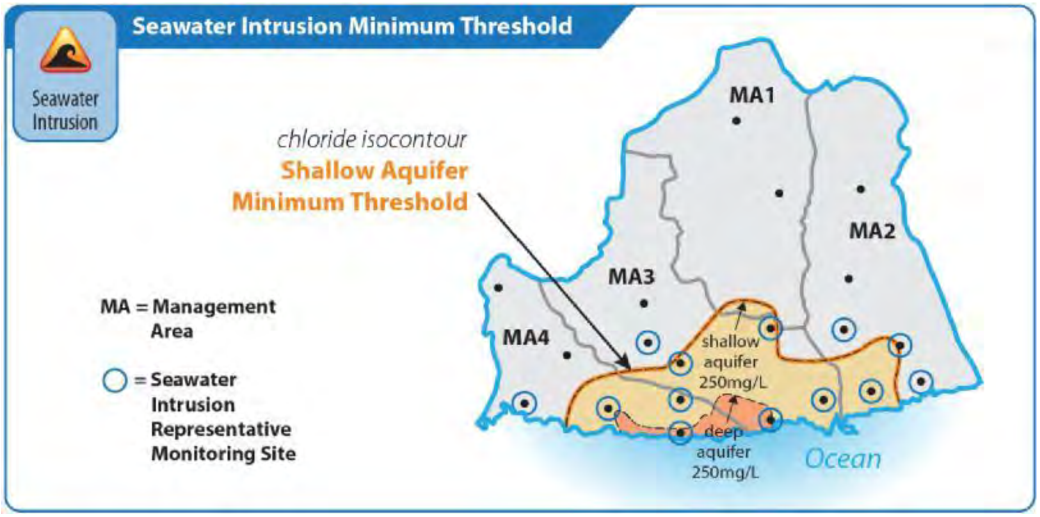


Figure 5. Example Seawater Intrusion Minimum Threshold Established at the Chloride Isocontour

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

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

Degraded Groundwater Quality Minimum Threshold

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

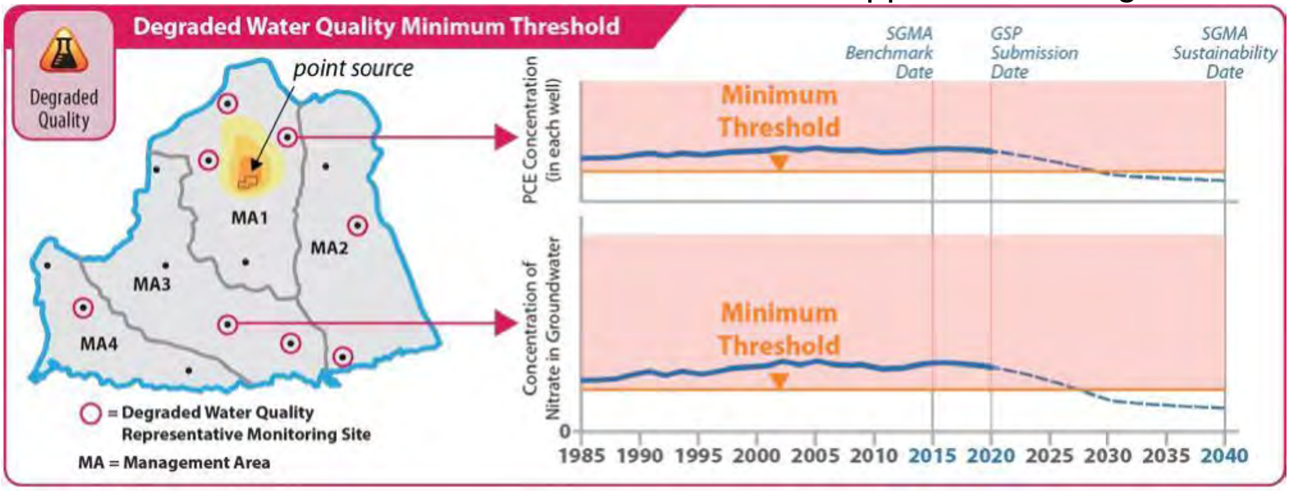


Figure 6. Example Degraded Water Quality Minimum Threshold Established for Point and Nonpoint Source Pollutants

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

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

Land Subsidence Minimum Threshold

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

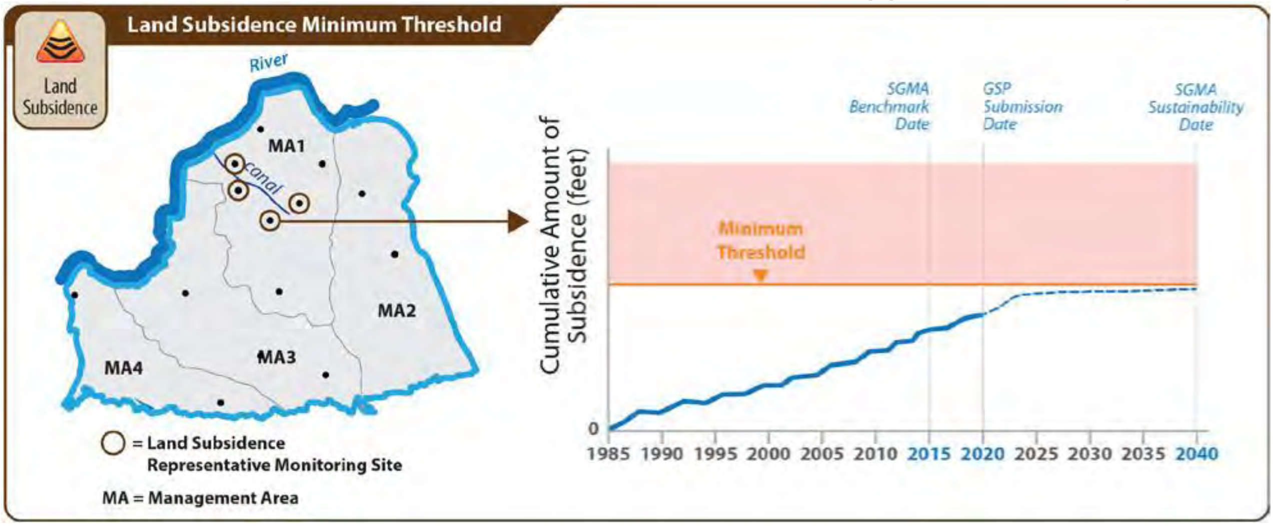


Figure 7. Example Land Subsidence Minimum Threshold

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

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

Depletion of Interconnected Surface Water Minimum Threshold

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

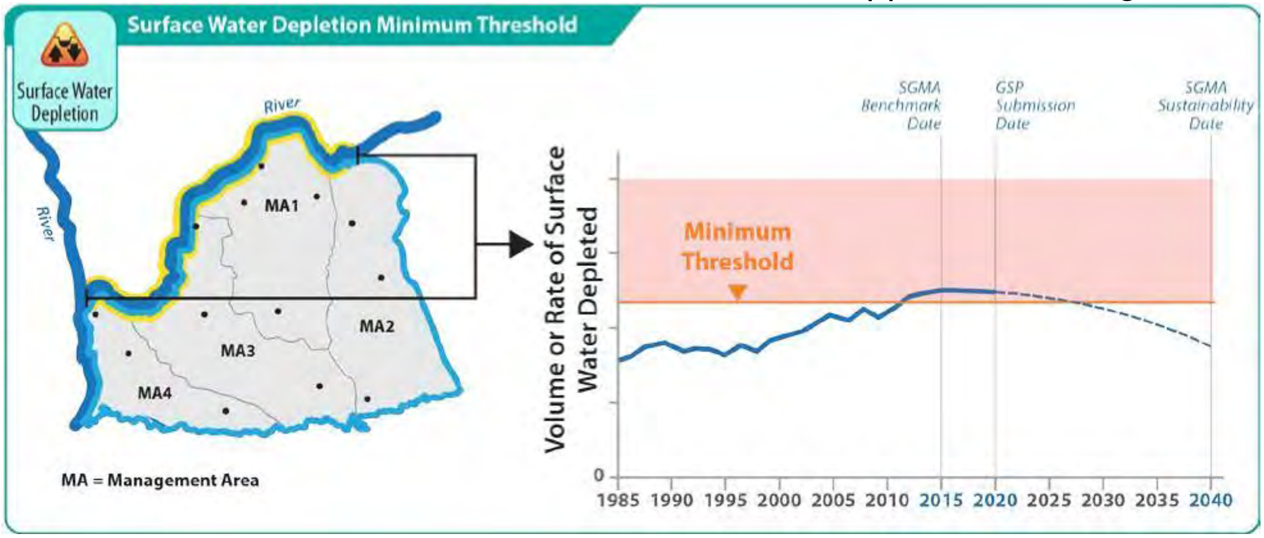


Figure 8. Example of Depletion of Interconnected Surface Water Minimum Threshold

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

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

Using Groundwater Elevations as a Proxy

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

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

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

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

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

Subsidence as an Example

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

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

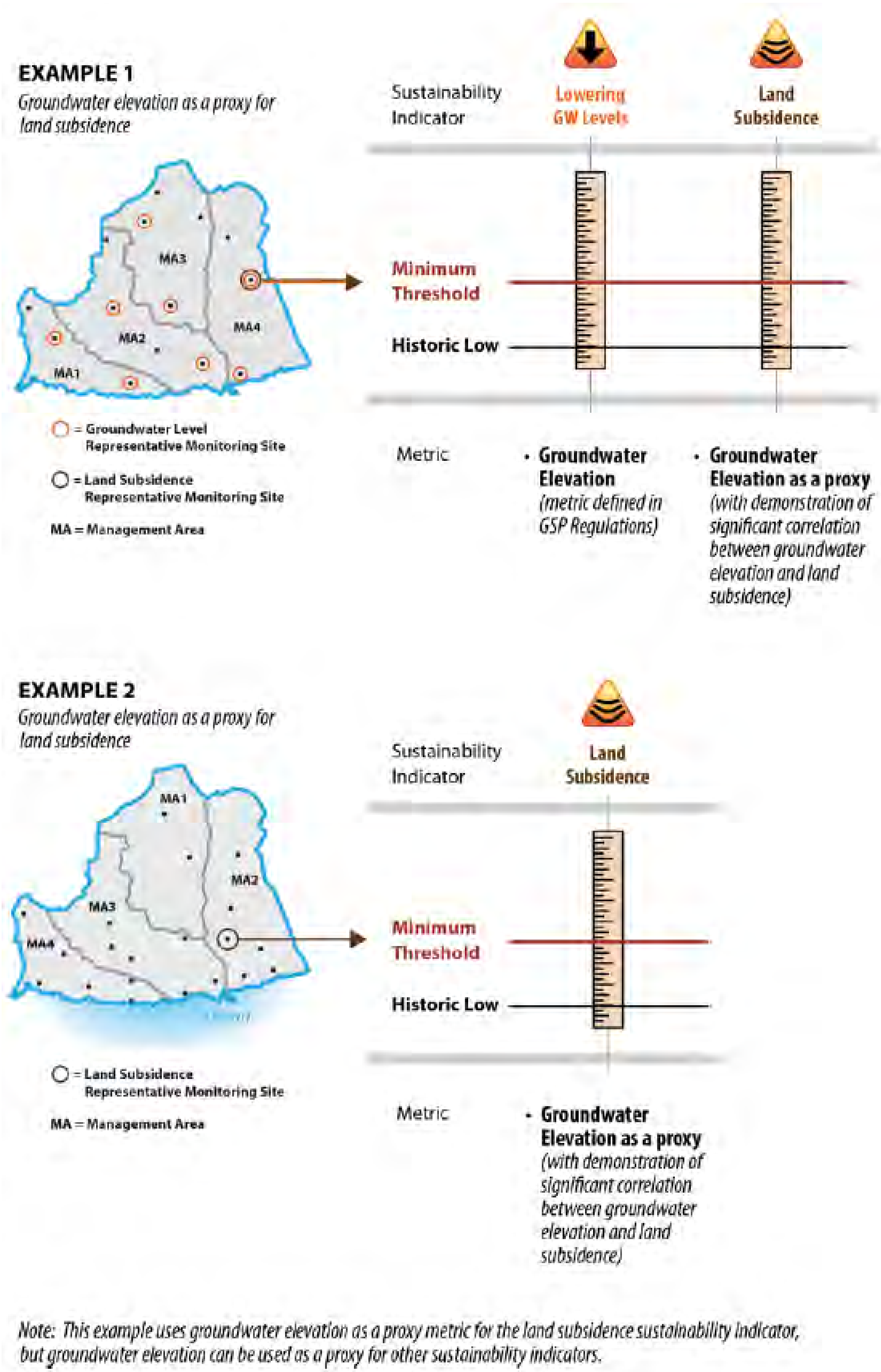


Figure 9. Example of Using Groundwater Elevation as a Proxy for Subsidence Monitoring

UNDESIRABLE RESULTS

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

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

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

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

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

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

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

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

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

Experiencing Undesirable Results

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

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

Example of Undesirable Results

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

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

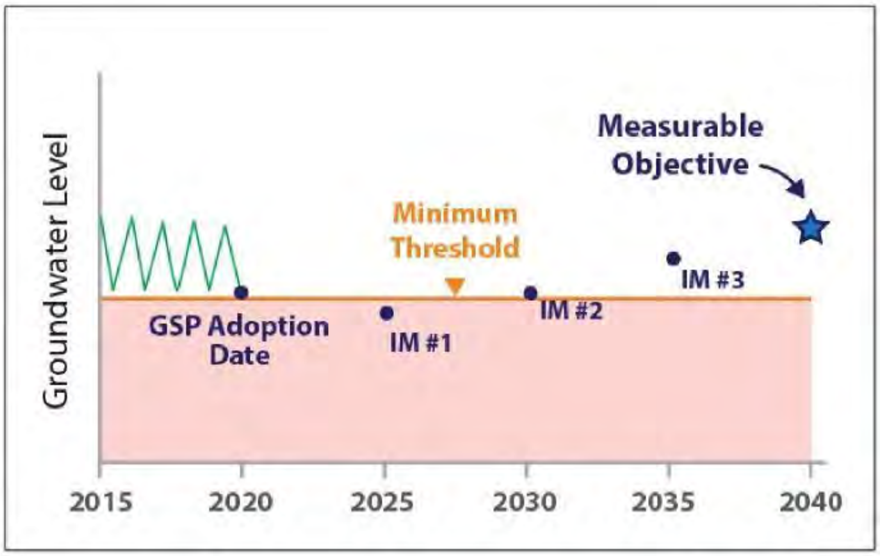


Figure 10. Example Minimum Threshold, Interim Milestones (IM), and Measurable Objective

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

Scenario 1 – Minimum Threshold Exceedances without an Undesirable Result

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

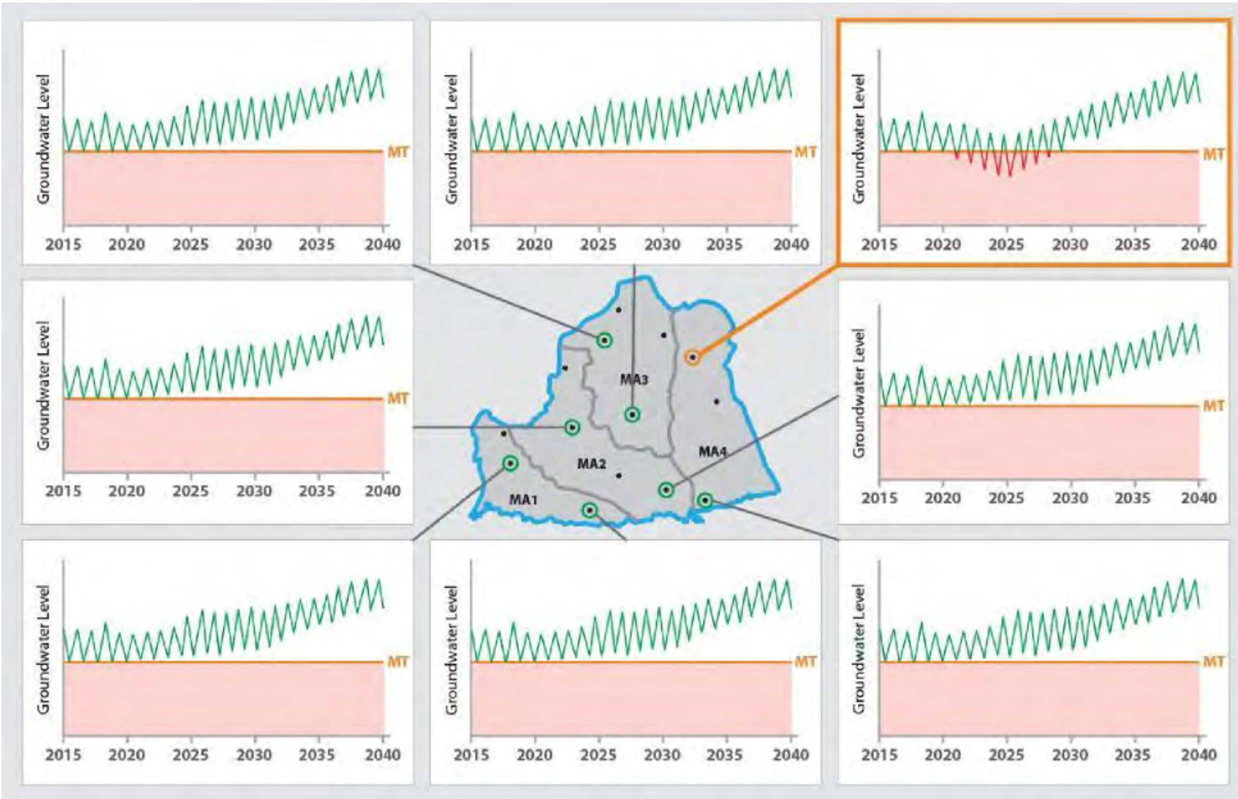


Figure 11. Example Groundwater Level Representative Monitoring Sites – Scenario 1

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

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

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

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

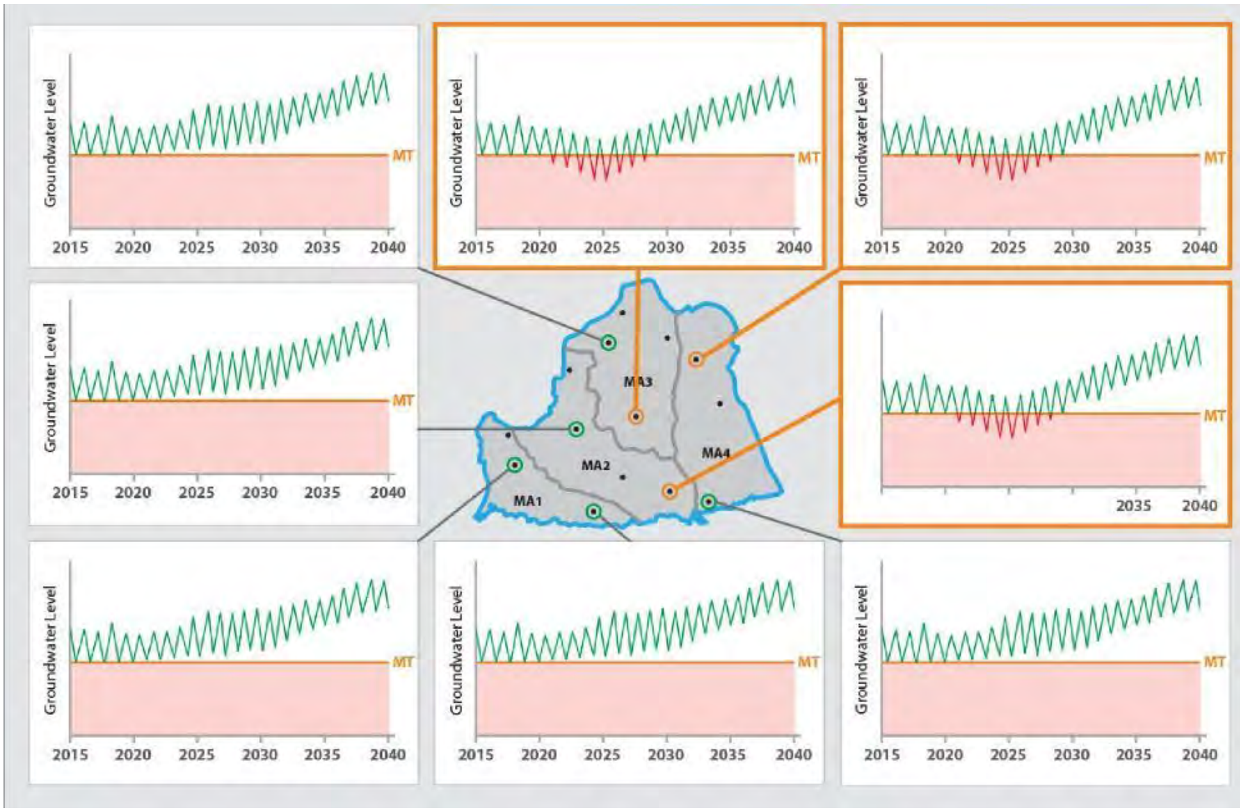


Figure 12. Example Groundwater Level Representative Monitoring Sites – Scenario 2

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

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

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

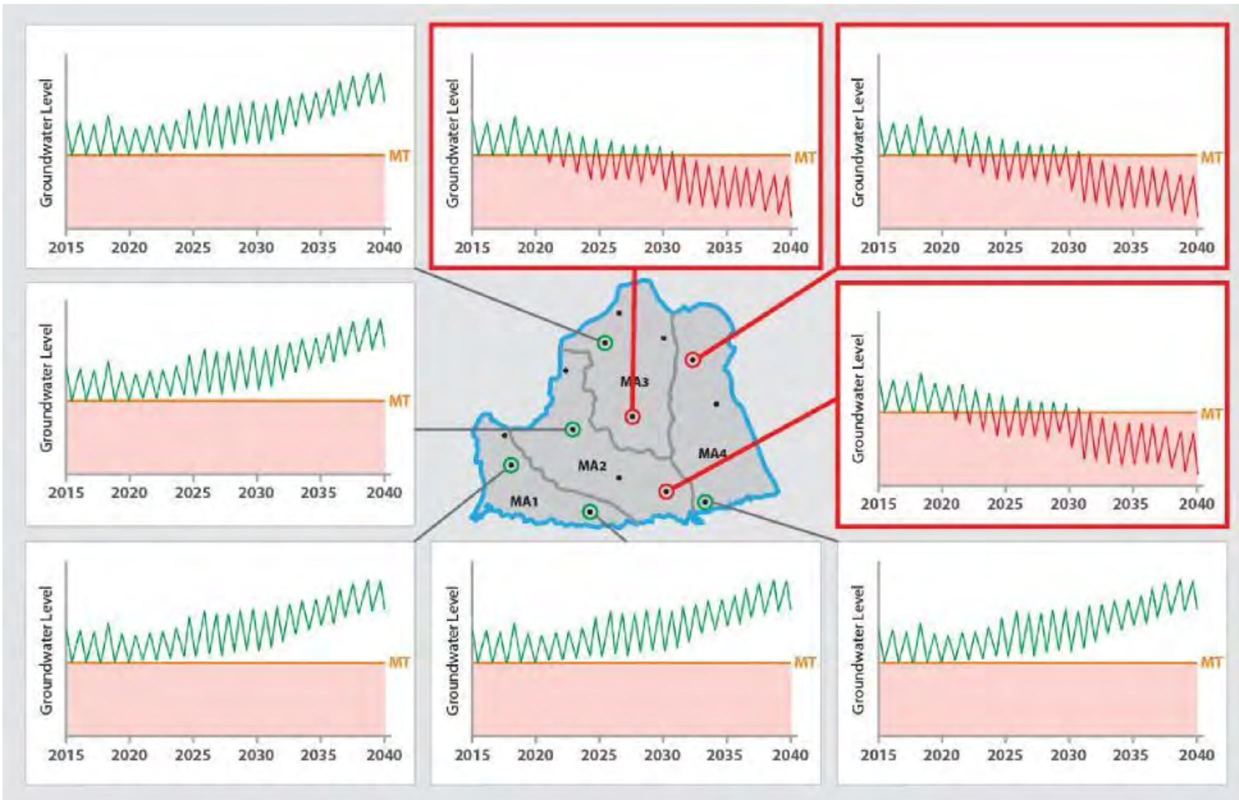


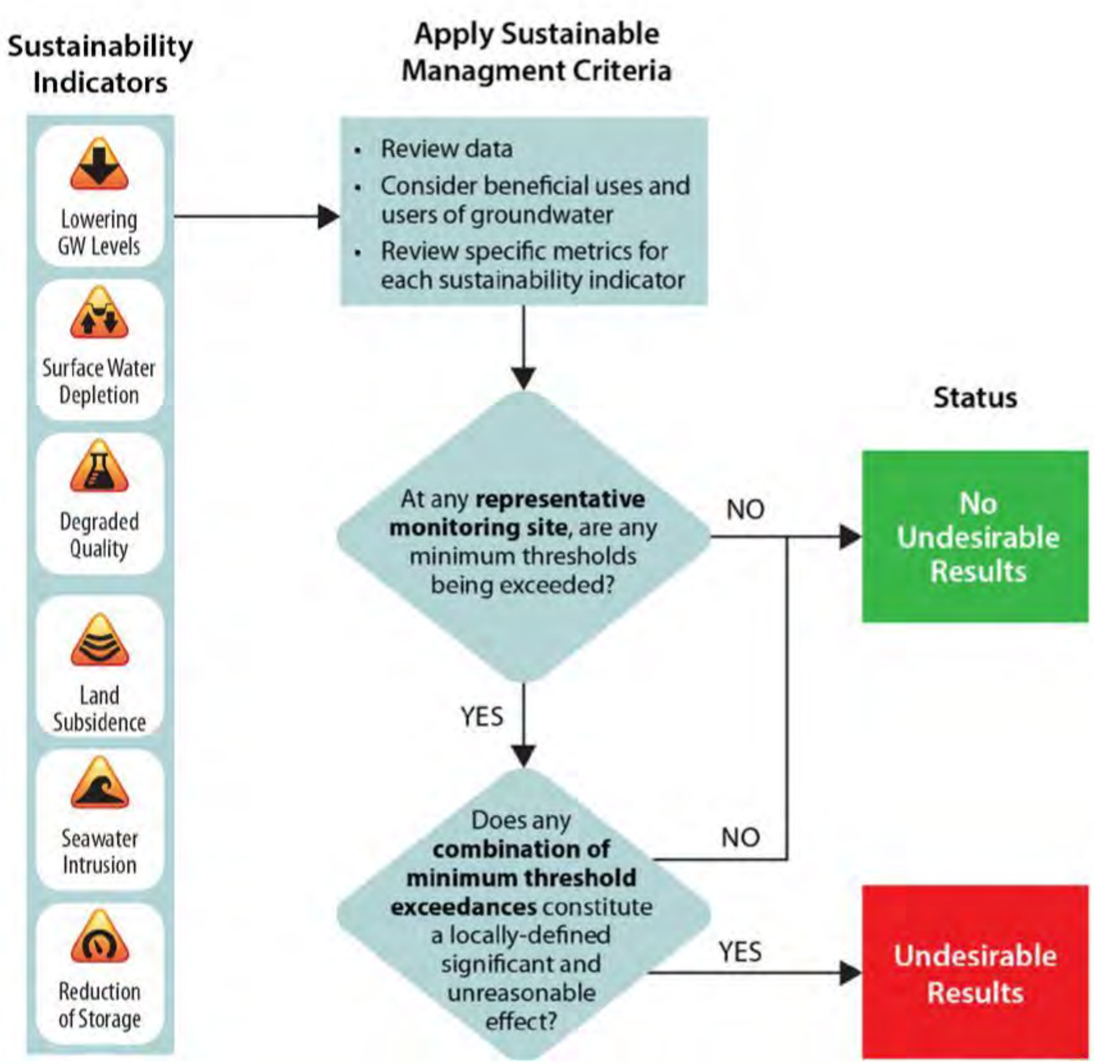
Figure 13. Example Groundwater Level Representative Monitoring Sites – Scenario 3

Relationship between Sustainability Indicators, Minimum Thresholds, and Undesirable Results

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

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

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



MEASURABLE OBJECTIVES

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

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

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

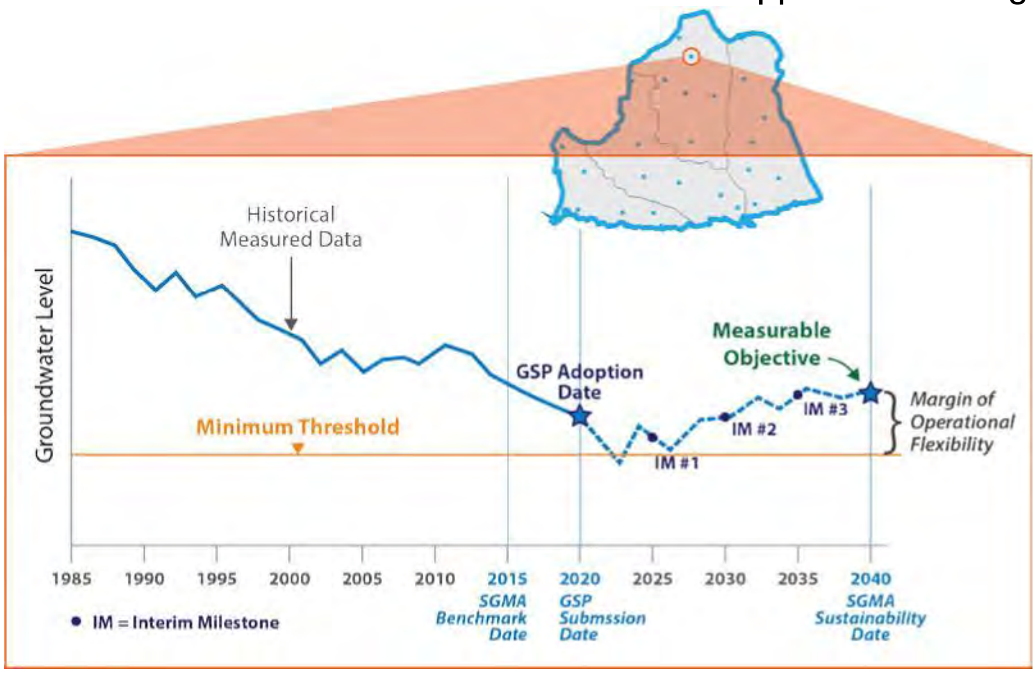


Figure 14. Relationship between Minimum Thresholds, Measurable Objectives, Interim Milestones (IM), and Margin of Operational Flexibility for a Representative Monitoring Site

The Path to Sustainable Groundwater Management

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

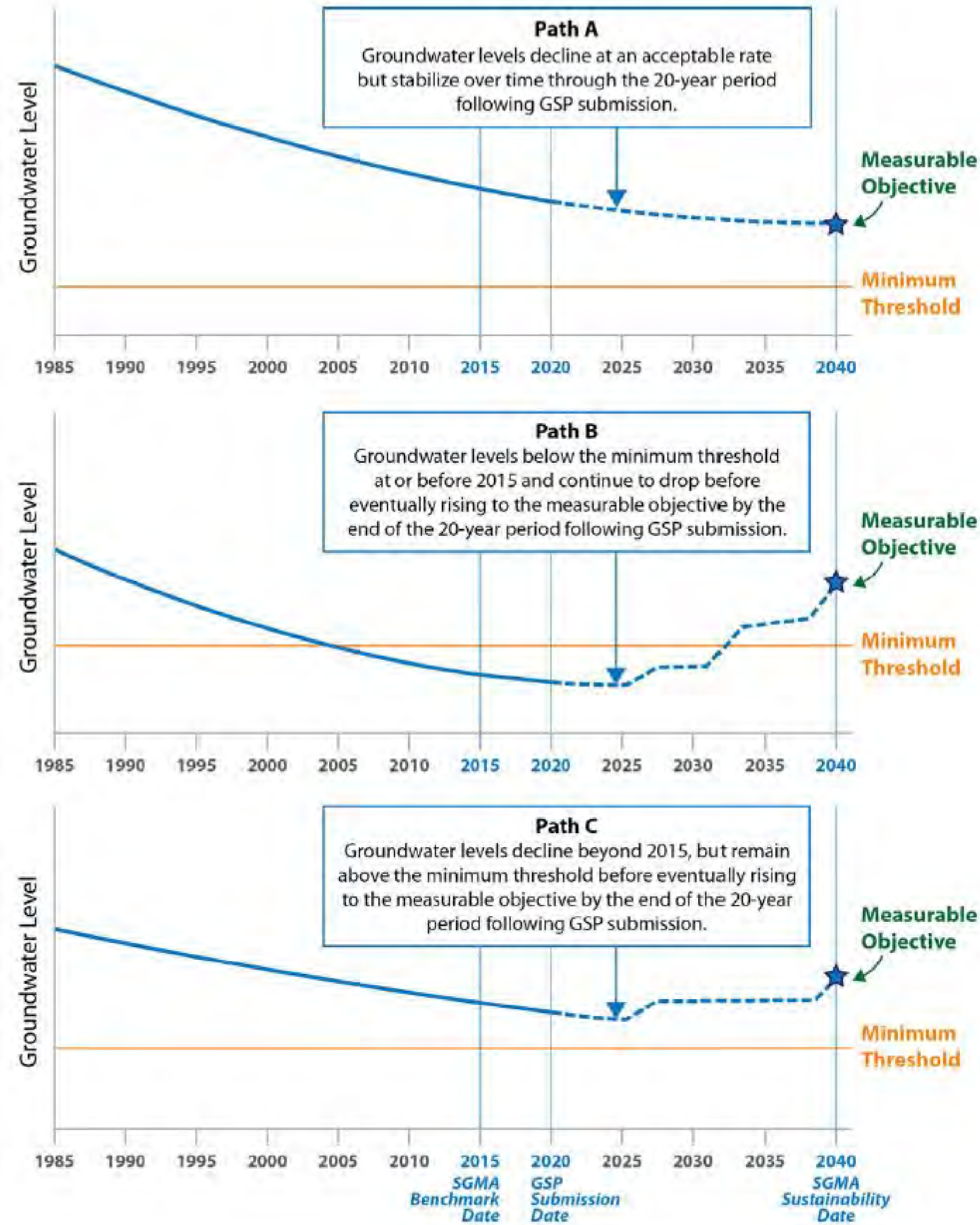


Figure 15. Potential Paths to Sustainability

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

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

SUSTAINABILITY GOAL

GSAs must develop a sustainability goal that is applicable to the entire basin.

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

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

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

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

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

Role of Sustainable Yield Estimates in SGMA

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

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

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

CONCLUSIONS

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

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

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

5. KEY DEFINITIONS

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

SGMA Definitions (California Water Code 10721)

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

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

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

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

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

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

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

(2) Significant and unreasonable reduction of groundwater storage.

(3) Significant and unreasonable seawater intrusion.

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

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

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

Groundwater Sustainability Plan Regulations (California Code of Regulations 351)

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

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

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

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

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

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

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

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

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

NOTES

---

[1] See 23 CCR § 350 *et seq*.

[2] See Water Code § 10720 *et seq*.

[3] See 23 CCR § 355.4(b)(1)

[4] See Water Code § 10721(v)

[5] See 23 CCR § 354.22 *et seq.*

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

[7] See 23 CCR § 354.28(b)

[8] See 23 CCR § 354.28(c)

[9] See 23 CCR § 354.28(d)

[10] See 23 CCR § 354.30(d)

[11] See 23 CCR § 354.36(b)

[12] See 23 CCR § 354.26(b)

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

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

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

[16] See 23 CCR § 354.30(e)

[17] See 23 CCR § 355.6(c)(1)

Appendix N. Monitoring Protocols BMP

Groundwater Monitoring Protocols, Standards, and Sites Best Management Practice

1. OBJECTIVE

The objective of this Best Management Practice (BMP) is to assist in the development of Monitoring Protocols. The California Department of Water Resources (the Department or DWR) has developed a Best Management Practice for Groundwater Monitoring Protocols, Standards and Sites, as part of the obligation in the Technical Assistance chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater basins. The SJREC GSA has reviewed and updated this BMP for inclusion in the GSP. This BMP provides technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders to aid in the establishment of consistent data collection processes and procedures. Finally, this BMP identifies available resources to support the development of monitoring protocols.

This BMP includes the following sections:

1. Objective. A brief description of how and where monitoring protocols are required under SGMA and the overall objective of this BMP.
2. Use and Limitations. A brief description of the use and limitations of this BMP.
3. Monitoring Protocol Fundamentals. A description of the general approach and background of groundwater monitoring protocols.
4. Relationship of Monitoring Protocols to other BMPs. A description of how this BMP is connected with other BMPS.
5. Technical Assistance. Technical content providing guidance for regulatory sections.
6. Key Definitions. Descriptions of definitions identified in the GSP Regulations or SGMA.
7. Related Materials. References and other materials that provide supporting information related to the development of Groundwater Monitoring Protocols.

2. USE AND LIMITATIONS

BMPs developed by the Department, and updated by the SJREC GSA, provides technical guidance to GSAs and other stakeholders. Practices described in these BMPs do not replace the GSP Regulations, nor do they create new requirements or obligations for GSAs or other stakeholders. In addition, using this BMP to develop a GSP does not equate to an approval determination by the Department. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

3. MONITORING PROTOCOL FUNDAMENTALS

Establishing data collection protocols that are based on best available scientific methods is essential. Protocols that can be applied consistently across all basins will likely yield comparable data. Consistency of data collection methods reduces uncertainty in the comparison of data and facilitates more accurate communication within basins as well as between basins.

Basic minimum technical standards of accuracy lead to quality data that will better support implementation of GSPs.

4. RELATIONSHIP OF MONITORING PROTOCOL TO OTHER BMPS

Groundwater monitoring is a fundamental component of SGMA, as each GSP must include a sufficient network of data that demonstrates measured progress toward the achievement of the sustainability goal for each basin. Where applicable and within reason, a standard set of protocols needs to be developed and utilized.

It is important that data is developed in a manner consistent with the basin setting, planning, and projects/management actions steps identified on **Figure 1** and the GSP Regulations. The inclusion of monitoring protocols in the GSP Regulations also emphasizes the importance of quality empirical data to support GSPs and provide comparable information from basin to basin.

Figure 1 provides a logical progression for the development of a GSP and illustrates how monitoring protocols are linked to other related BMPs. This figure also shows the context of the BMPs as they relate to various steps to sustainability as outlined in the GSP Regulations. The monitoring protocol BMP is part of the Monitoring step identified in **Figure 1**.

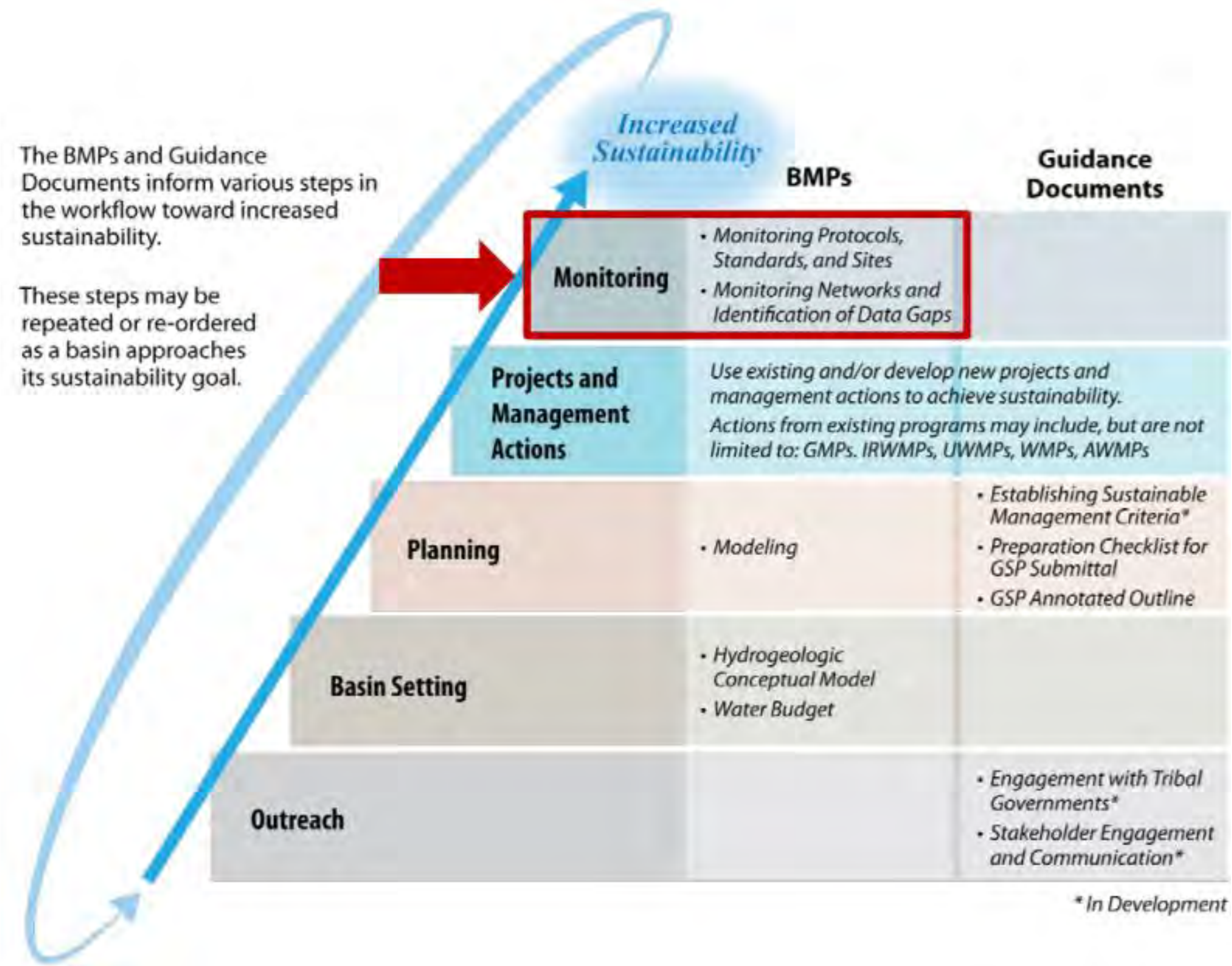


Figure 1 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

5. TECHNICAL ASSISTANCE

23 CCR §352.2. Monitoring Protocols. Each Plan shall include monitoring protocols adopted by the Agency for data collection and management, as follows:
(a) Monitoring protocols shall be developed according to best management practices.
(b) The Agency may rely on monitoring protocols included as part of the best management practices developed by the Department, or may adopt similar monitoring protocols that will yield comparable data.
(c) Monitoring protocols shall be reviewed at least every five years as part of the periodic evaluation of the Plan, and modified as necessary.

The GSP Regulations specifically call out the need to utilize protocols identified by DWR, or develop similar protocols. The following technical protocols provide guidance based upon existing professional standards and are commonly adopted in various groundwater-related programs. They provide clear techniques that yield quality data for use in the various components of the GSP. They can be further elaborated on by individual GSAs in the form of standard operating procedures which reflect specific local requirements and conditions. While many methodologies are suggested in this BMP, it should be understood that qualified professional judgment should be used to meet the specific monitoring needs.

The following BMPs may be incorporated into a GSP's monitoring protocols section for collecting groundwater elevation data. A GSP that adopts protocols that deviate from the DWR BMPs must demonstrate that they will yield comparable data.

PROTOCOLS FOR ESTABLISHING A MONITORING PROGRAM

The protocol for establishment of a monitoring program should be evaluated in conjunction with the Monitoring Network and Identification of Data Gaps BMP and other BMPs. Monitoring protocols must take into consideration the Hydrogeologic Conceptual Model, Water Budget, Modeling and Sustainable Management Criteria BMPs when considering the data needs to meet GSP objectives and the sustainability goal.

It is suggested that each GSP incorporate the Data Quality Objective (DQO) process following the U.S. EPA Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA, 2006). Although strict adherence to this method is not required, it does provide a robust approach to consider and assures that data is collected with a specific purpose in mind, and efforts for monitoring are as efficient as possible to achieve the objectives of the GSP and compliance with the GSP Regulations.

The steps of the DQO process should be used to guide GSAs to develop the most efficient monitoring process to meet the measurable objectives of the GSP and the sustainability goal. The DQO process is an iterative process and should be evaluated regularly to improve monitoring efficiencies and meet changing planning and project needs. Following the DQO process, GSAs should also include a data quality control and quality assurance plan to guide the collection of data.

Many monitoring programs already exist as part of ongoing groundwater management or other programs. To the extent possible, the use of existing monitoring data and programs should be utilized to meet the needs for characterization, historical record documentation, and continued monitoring for the

SGMA program. However, an evaluation of the existing monitoring data should be performed to assure the data being collected meets the DQOs, regulatory requirements, and data collection protocol described in this BMP. While this BMP provides guidance for collection of various regulatory based requirements, there is flexibility among the various methodologies available to meet the DQOs based upon professional judgment (local conditions or project needs).

At a minimum, for each monitoring site, the following information or procedure should be collected and documented:

- Long-term access agreements. Access agreements should include year-round site access to allow for increased monitoring frequency.
- A unique identifier that includes a general written description of the site location, date established, access instructions and point of contact (if necessary), type of information to be collected, latitude, longitude, and elevation. Each monitoring location should also track all modifications to the site in a modification log.

PROTOCOLS FOR MEASURING GROUNDWATER LEVELS

This section presents considerations for the methodology of collection of groundwater level data such that it meets the requirements of the GSP Regulations and the DQOs of the specific GSP. Groundwater levels are a fundamental measure of the status of groundwater conditions within a basin. In many cases, relationships of the sustainability indicators may be able to be correlated with groundwater levels. The quality of this data must consider the specific aquifer being monitored and the methodology for collecting these levels.

The following considerations for groundwater level measuring protocols should ensure the following:

- Groundwater level data are taken from the correct location, well ID, and screen interval depth
- Groundwater level data are accurate and reproducible
- Groundwater level data represent conditions that inform appropriate basin management DQOs
- All salient information is recorded to correct, if necessary, and compare data
- Data are handled in a way that ensures data integrity

General Well Monitoring Information

The following presents considerations for collection of water level data that include regulatory required components as well as those which are recommended.

- Groundwater elevation data will form the basis of basin-wide water-table and piezometric maps, and should approximate conditions at a discrete period in time. Therefore, all groundwater levels in a basin should be collected within as short a time as possible, preferably within a 1 to 2 week period.
- Depth to groundwater must be measured relative to an established Reference Point (RP) on the well casing. The RP is usually identified with a permanent marker, paint spot, or a notch in the lip of the well casing. By convention in open casing monitor wells, the RP reference point is located on the north side of the well casing. If no mark is apparent, the person performing the measurement should measure the depth to groundwater from the north side of the top of the well casing.

- The elevation of the RP of each well must be surveyed to the North American Vertical Datum of 1988 (NAVD88), or a local datum that can be converted to NAVD88. The elevation of the RP must be accurate to within 0.5 foot. It is preferable for the RP elevation to be accurate to 0.1 foot or less. Survey grade global navigation satellite system (GNSS) global positioning system (GPS) equipment can achieve similar vertical accuracy when corrected. Guidance for use of GPS can be found at USGS http://water.usgs.gov/osw/gps/.
- The sampler should remove the appropriate cap, lid, or plug that covers the monitoring access point listening for pressure release. If a release is observed, the measurement should follow a period of time to allow the water level to equilibrate.
- Depth to groundwater must be measured to an accuracy of 0.1 foot below the RP.
- The water level meter should be decontaminated after measuring each well.

Where existing wells do not meet the base standard as described in the GSP Regulations or the considerations provided above, new monitor wells may need to be constructed to meet the DQOs of the GSP. The design, installation, and documentation of new monitor wells must consider the following:

- Construction consistent with California Well Standards as described in Bulletins 74-81 and 74-90, and local permitting agency standards of practice.
- Logging of borehole cuttings under the supervision of a California Professional Geologist and described consistent with the Unified Soil Classification System methods according to ASTM standard D2487-11.
- Written criteria for logging of borehole cuttings for comparison to known geologic formations, principal aquifers and aquitards/aquicludes, or specific marker beds to aid in consistent stratigraphic correlation within and across basins.
- Geophysical surveys of boreholes to aid in consistency of logging practices. Methodologies should include resistivity, spontaneous potential, spectral gamma, or other methods as appropriate for the conditions. Selection of geophysical methods should be based upon the opinion of a professional geologist or professional engineer, and address the DQOs for the specific borehole and characterization needs.
- Prepare and submit State well completion reports according to the requirements of §13752. Well completion report documentation should include geophysical logs, detailed geologic log, and formation identification as attachments. An example well completion as-built log is illustrated in **Figure 2**. DWR well completion reports can be filed directly at the Online System for Well Completion Reports (OSWCR) http://water.ca.gov/oswcr/index.cfm.

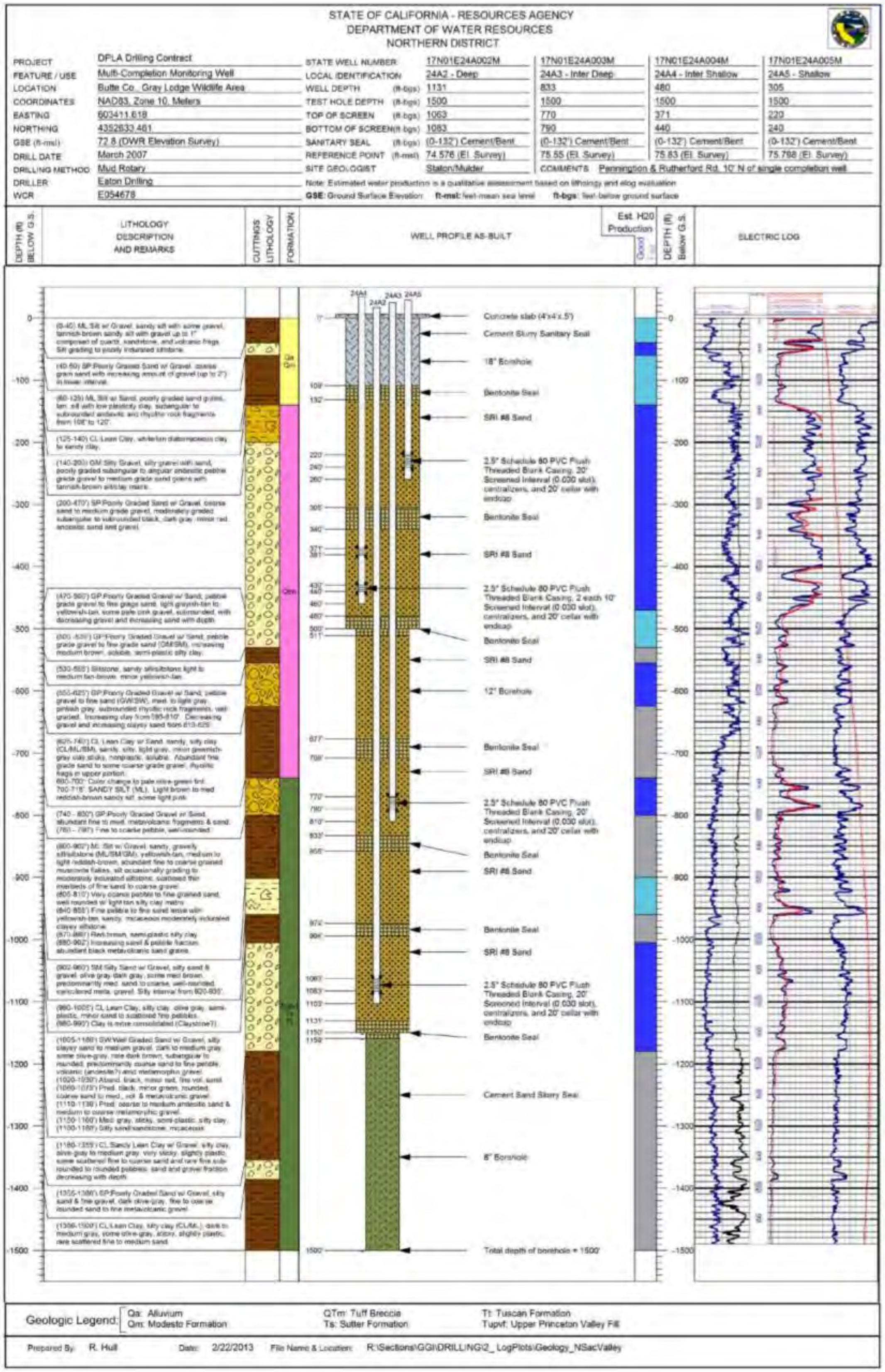


Figure 2 – Example As-Built Multi-Completion Monitor Well Log

Measuring Groundwater Levels

Well construction, anticipated groundwater level, groundwater level measuring equipment, field conditions, and well operations should be considered prior collection of the groundwater level measurement. The USGS Groundwater Technical Procedures (Cunningham and Schalk, 2011) provide a thorough set of procedures which can be used to establish specific Standard Operating Procedures (SOPs) for a local agency. **Figure 3** illustrates a typical groundwater level measuring event and simultaneous pressure transducer download.

Figure 3 – Collection of Water Level Measurement and Pressure Transducer Download

The following points provide a general approach for collecting groundwater level measurements:

- Measure depth to water in the well using procedures appropriate for the measuring device. Equipment must be operated and maintained in accordance with manufacturer's instructions.
- For measuring wells that are under pressure, allow a period of time for the groundwater levels to stabilize. In these cases, multiple measurements should be collected to ensure the well has reached equilibrium such that no significant changes in water level are observed. Every effort should be made to ensure that a representative stable depth to groundwater is recorded. If a well does not stabilize, the quality of the value should be appropriately qualified as a questionable measurement. In the event that a well is artesian, site specific procedures should be developed to collect accurate information and be protective of safety conditions associated with a pressurized well. In many cases, an extension pipe may be adequate to stabilize head in the well. Record the dimension of the extension and document measurements and configuration.
- The sampler should calculate the groundwater elevation as:

$$\mathrm{GWE} = R\mathrm{PE} - D\mathrm{TW}$$

Where:

GWE = Groundwater Elevation

RPE = Reference Point Elevation

DTW = Depth to Water

The sampler must ensure that all measurements are in consistent units of feet, tenths of feet, and hundredths of feet. Measurements and RPEs should not be recorded in feet and inches.

Recording Groundwater Levels

- To the greatest extent possible, the sampler should use the GPS locator in the SJREC GSA's DMS to ensure location accuracy. To limit data entry error, only date, time DTW and comments will be entered directly into the DMS. At sites not accessible to the DMS, the sampler should record the well identifier, date, time (24-hour format), DTW, and comments regarding any factors that may influence the depth to water readings such as weather, nearby irrigation, flooding, potential for tidal influence, or well condition. If there is a questionable measurement or the measurement cannot be obtained, it should be noted. An example of a field sheet with the required information is shown in **Figure 4**. It includes questionable measurement and no measurement codes that should be noted. This field sheet is provided as an example. Standardized field forms should be used for all data collection. The aforementioned USGS Groundwater Technical Procedures offers a number of example forms.
- The sampler should replace any well caps or plugs, and lock any well buildings or covers.
- All data should be entered into the GSA data management system (DMS) as soon as possible. Care should be taken to avoid data entry mistakes and the entries should be checked by a second person for compliance with the DQOs

STATE OF CALIFORNA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

WELL DATA

STATE WELL NUMBER	COUNTY	REFERENCE POINT ELEV.	MEASURING AGENCY
			DWR

NO MEASUREMENT	QUESTIONABLE MEASUREMENT
0. Measurement discontinued	0. Caved or deepened
1. Pumping	1. Pumping
2. Pump house locked	2. Nearby pump operating
3. Tape hung up	3. Casing leaky or wet
4. Can't get tape in casing	4. Pumped recently
5. Unable to locate well	5. Air or pressure gauge measurement
6. Well has been destroyed	6. Other
7. Special	7. Recharge operation at or nearby well
8. Casing leaky or wet	8. Oil in casing
9. Temporarily inaccessible	

DATE	N M	Q M	TAPE AT RP	TAPE AT WS	RP to WS	OBSR VR	COMMENTS

DWR 1213

Figure 4 – Example of Water Level Well Data Field Collection Form

Pressure Transducers

Groundwater levels and/or calculated groundwater elevations may be recorded using pressure transducers equipped with data loggers installed in monitor wells. When installing pressure transducers, care must be exercised to ensure that the data recorded by the transducers is confirmed with hand measurements.

The following general protocols must be followed when installing a pressure transducer in a monitor well:

- The sampler must use an electronic sounder or chalked steel tape and follow the protocols listed above to measure the groundwater level and calculate the groundwater elevation in the monitor well to properly program and reference the installation. It is recommended that transducers record measured groundwater level to conserve data capacity; groundwater elevations can be calculated at a later time after downloading.
- The sampler must note the well identifier, the associated transducer serial number, transducer range, transducer accuracy, and cable serial number.
- Transducers must be able to record groundwater levels with an accuracy of at least 0.1 foot. Professional judgment should be exercised to ensure that the data being collected is meeting the DQO and that the instrument is capable. Consideration of the battery life, data storage capacity, range of groundwater level fluctuations, and natural pressure drift of the transducers should be included in the evaluation.
- The sampler must note whether the pressure transducer uses a vented or nonvented cable for barometric compensation. Vented cables are preferred, but nonvented units provide accurate data if properly corrected for natural barometric pressure changes. This requires the consistent logging of barometric pressures to coincide with measurement intervals.
- Follow manufacturer specifications for installation, calibration, data logging intervals, battery life, correction procedure (if non-vented cables used), and anticipated life expectancy to assure that DQOs are being met for the GSP.
- Secure the cable to the well head with a well dock or another reliable method. If the installation design allows for cable slippage, mark the cable at the elevation of the reference point with tape or an indelible marker.
- The transducer data should periodically be checked against hand measured groundwater levels to monitor electronic drift or cable movement. This should happen during routine site visits, at least annually or as necessary to maintain data integrity.
- The data should be downloaded as necessary to ensure no data is lost and entered into the basin's DMS following the QA/QC program established for the GSP. Data collected with non-vented data logger cables should be corrected for atmospheric barometric pressure changes, as appropriate. After the sampler is confident that the transducer data have been safely downloaded and stored, the data should be deleted from the data logger to ensure that adequate data logger memory remains.

PROTOCOLS FOR SAMPLING GROUNDWATER QUALITY

The following protocols can be incorporated into a GSP's monitoring protocols for collecting groundwater quality data. More detailed sampling procedures and protocols are included in the standards and guidance documents listed at the end of this BMP.

In general, the use of existing water quality data within the basin should be done to the greatest extent possible if it achieves the DQOs for the GSP. In some cases it may be necessary to collect additional water quality data to support monitoring programs or evaluate specific projects. The USGS National Field Manual for the Collection of Water Quality Data (Wilde, 2005) can be used as a guide for the collection of reliable data. **Figure 5** illustrates a typical groundwater quality sampling setup.

Figure 5 – Typical Groundwater Quality Sampling Event December 2016 Groundwater Monitoring Protocols, Standards, and Sites BM

All analyses should be performed by a laboratory certified under the State Environmental Laboratory Accreditation Program or by a certified technician when applicable. The specific analytical methods are beyond the scope of this BMP, but should be commiserate with other programs evaluating water quality within the basin for comparative purposes.

Groundwater quality sampling protocols should ensure that:

- Groundwater quality data are taken from the correct location
- Groundwater quality data are accurate and reproducible
- Groundwater quality data represent conditions that inform appropriate basin management and are consistent with the DQOs
- All salient information is recorded to normalize, if necessary, and compare data
- Data are handled in a way that ensures data integrity

The following points are general guidance in addition to the techniques presented in the previously mentioned USGS National Field Manual for the Collection of Water Quality Data.

Standardized protocols include the following:

- Prior to sampling, the sampler must contact the laboratory to schedule laboratory time, obtain appropriate sample containers, and clarify any sample holding times or sample preservation requirements.
- To the greatest extent possible, the sampler should use the GPS locator in the SJREC GSA's DMS to ensure location accuracy. Each well used for groundwater quality monitoring must have a unique identifier. This identifier must appear on the well housing or the well casing to avoid confusion.
- In the case of wells with dedicated pumps, samples should be collected at or near the wellhead. Samples should not be collected from storage tanks, at the end of long pipe runs, or after any water treatment.
- The sampler should clean the sampling port and/or sampling equipment and the sampling port and/or sampling equipment must be free of any contaminants. The sampler must decontaminate sampling equipment between sampling locations or wells to avoid cross-contamination between samples.
- The groundwater elevation in the well should be measured following appropriate protocols described above in the groundwater level measuring protocols.
- For any well not equipped with low-flow or passive sampling equipment, an adequate volume of water should be purged from the well to ensure that the groundwater sample is representative of ambient groundwater and not stagnant water in the well casing. Purging three well casing volumes is generally considered adequate. Professional judgment should be used to determine the proper configuration of the sampling equipment with respect to well construction such that a representative ambient groundwater sample is collected. If pumping causes a well to be evacuated (go dry), document the condition and allow well to recover to within 90% of original level prior to sampling. Professional judgment should be exercised as to whether the sample will meet the DQOs and adjusted as necessary.
- Field parameters of pH, electrical conductivity, and temperature should be collected for each sample. Field parameters should be evaluated during the purging of the well and should stabilize prior to sampling. Measurements of pH should only be measured in the field, lab pH analysis are typically unachievable due to short hold times. Other parameters, such as oxidation-reduction potential (ORP), dissolved oxygen (DO) (in situ measurements preferable), or turbidity, may also be useful for meeting DQOs of GSP and assessing purge conditions. Where applicable, field instruments should be calibrated daily and evaluated for drift throughout the day.
- Sample containers should be labeled prior to sample collection. The sample label must include: sample ID (often well ID), sample date and time, sample personnel, sample location, preservative used, and analytes and analytical method.
- If possible, samples should be collected under laminar flow conditions.
- Samples should be collected according to appropriate standards such as those listed in the Standard Methods for the Examination of Water and Wastewater, USGS National Field Manual for the Collection of Water Quality Data, or other appropriate guidance. The specific sample collection procedure should reflect the type of analysis to be performed and DQOs.
- All samples requiring preservation must be preserved as soon as practically possible, ideally at the time of sample collection. Ensure that samples are appropriately filtered as recommended for the specific analyte. Entrained solids can be dissolved by preservative leading to inconsistent

results of dissolve analytes. Specifically, samples to be analyzed for metals should be field-filtered prior to preservation; do not collect an unfiltered sample in a preserved container.

- Samples should be chilled and maintained per recommendation to prevent degradation of the sample. The laboratory's Quality Assurance Management Plan should detail appropriate chilling and shipping requirements.
- Samples must be shipped under chain of custody documentation to the appropriate laboratory promptly to avoid violating holding time restrictions.
- Instruct the laboratory to use reporting limits that are equal to or less than the applicable DQOs, regional water quality objectives/screening levels, or recommendation of a licensed professional.

Special protocols for low-flow sampling equipment

In addition to the protocols listed above, sampling using low-flow sample equipment should adopt the following protocols derived from EPA's Low-flow (minimal drawdown) ground-water sampling procedures (Puls and Barcelona, 1996). These protocols apply to low-flow sampling equipment that generally pumps between 0.1 and 0.5 liters per minute. These protocols are not intended for bailers.

Special protocols for passive sampling equipment

In addition to the protocols listed above, passive diffusion samplers should follow protocols set forth in USGS Fact Sheet 088-00.

PROTOCOLS FOR MONITORING SEAWATER INTRUSION

The Delta-Mendota Subbasin is highly unlikely to have Significant and Unreasonable Seawater Intrusion. For that reason, monitoring protocols for seawater intrusion have not been developed. In the unlikely event that seawater intrusion must be monitored in the Delta-Mendota Subbasin, the SJREC GSA will review BMP's to address the concern.

-
-
-
-
-
-
-
-
-
-
-
-

+**PROTOCOLS FOR MEASURING STREAMFLOW**

Monitoring of streamflow is necessary for incorporation into water budget analysis and for use in evaluation of stream depletions associated with groundwater extractions. The use of existing monitoring locations should be incorporated to the greatest extent possible. Many of these streamflow monitoring locations currently follow the protocol described below.

Establishment of new streamflow discharge sites should consider the existing network and the objectives of the new location. Professional judgment should be used to determine the appropriate permitting that may be necessary for the installation of any monitoring locations along surface water bodies. Regular frequent access will be necessary to these sites for the development of ratings curves and maintenance of equipment.

To establish a new streamflow monitoring station special consideration must be made in the field to select an appropriate location for measuring discharge. Once a site is selected, development of a relationship of stream stage to discharge will be necessary to provide continuous estimates of streamflow. Several measurements of discharge at a variety of stream stages will be necessary to develop the ratings curve correlating stage to discharge. The use of Acoustic Doppler Current Profilers (ADCPs) can provide accurate estimates of discharge in the correct settings. Professional judgment must be exercised to determine the appropriate methodology. Following development of the ratings curve a simple stilling well and pressure transducer with data logger can be used to evaluate stage on a frequent basis. A simple stilling well and staff gage is illustrated in **Figure 6**.

Streamflow measurements should be collected, analyzed, and reported in accordance with the procedures outlined in USGS Water Supply Paper 2175, Volume 1. – Measurement of Stage Discharge and Volume 2. – Computation of Discharge. This methodology is currently being used by both the USGS and DWR for existing streamflow monitoring throughout the State.

Figure 6 – Simple Stilling Well and Staff Gage Setup

PROTOCOLS FOR MEASURING SUBSIDENCE

Evaluating and monitoring inelastic land subsidence can utilize multiple data sources to evaluate the specific conditions and associated causes. To the extent possible, the use of existing data should be utilized. Subsidence can be estimated from numerous techniques, they include: level surveying tied to known stable benchmarks or benchmarks located outside the area being studied for possible subsidence; installing and tracking changes in borehole extensometers; obtaining data from continuous GPS (CGPS) locations, static GPS surveys or Real-Time-Kinematic (RTK) surveys; or analyzing Interferometric Synthetic Aperture Radar (InSAR) data. No standard procedures exist for collecting data from the potential subsidence monitoring approaches. However, an approach may include:

- Identification of land subsidence conditions.
  - Evaluate existing regional long-term leveling surveys of regional infrastructure, i.e. roadways, railroads, canals, and levees.
  - Determine if significant fine-grained layers are present such that the potential for collapse of the units could occur should there be significant depressurization of the aquifer system.
  - Inspect geologic logs and the hydrogeologic conceptual model to aid in identification of specific units of concern.
  - Collect regional remote-sensing information such as InSAR, when and if available.
- Monitor regions of suspected subsidence where potential exists.
  - Use existing CGPS network to evaluate changes in land surface elevation. Review the need to establish new CGPS stations.
  - Establish leveling surveys transects to observe changes in land surface elevation.
  - Use existing extensometer network to observe land subsidence. An example of a typical extensometer design is illustrated in **Figure 7**. There are a variety of extensometer designs and they should be selected based on the specific DQOs. Review the need to establish new extensometer sites.

Various standards and guidance documents for collecting data include:

- Leveling surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Any alternative shall be reviewed by a Professional Land Surveyor or Professional Civil Engineer registered in the State of California for accuracy and reasonableness.
- GPS surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Any alternative shall be reviewed by a Professional Land Surveyor or Professional Civil Engineer registered in the State of California for accuracy and reasonableness.USGS has been performing subsidence surveys within several areas of California. These studies are sound examples for appropriate methods and should be utilized to the extent possible and where available:
  - http://ca.water.usgs.gov/land_subsidence/california-subsidencemeasuring.html
- Instruments installed in borehole extensometers must follow the manufacturer's instructions for installation, care, and calibration.
- Availability of InSAR data is improving and will increase as programs are developed. This method requires expertise in analysis of the raw data and will likely be made available as an interpretative report for specific regions.

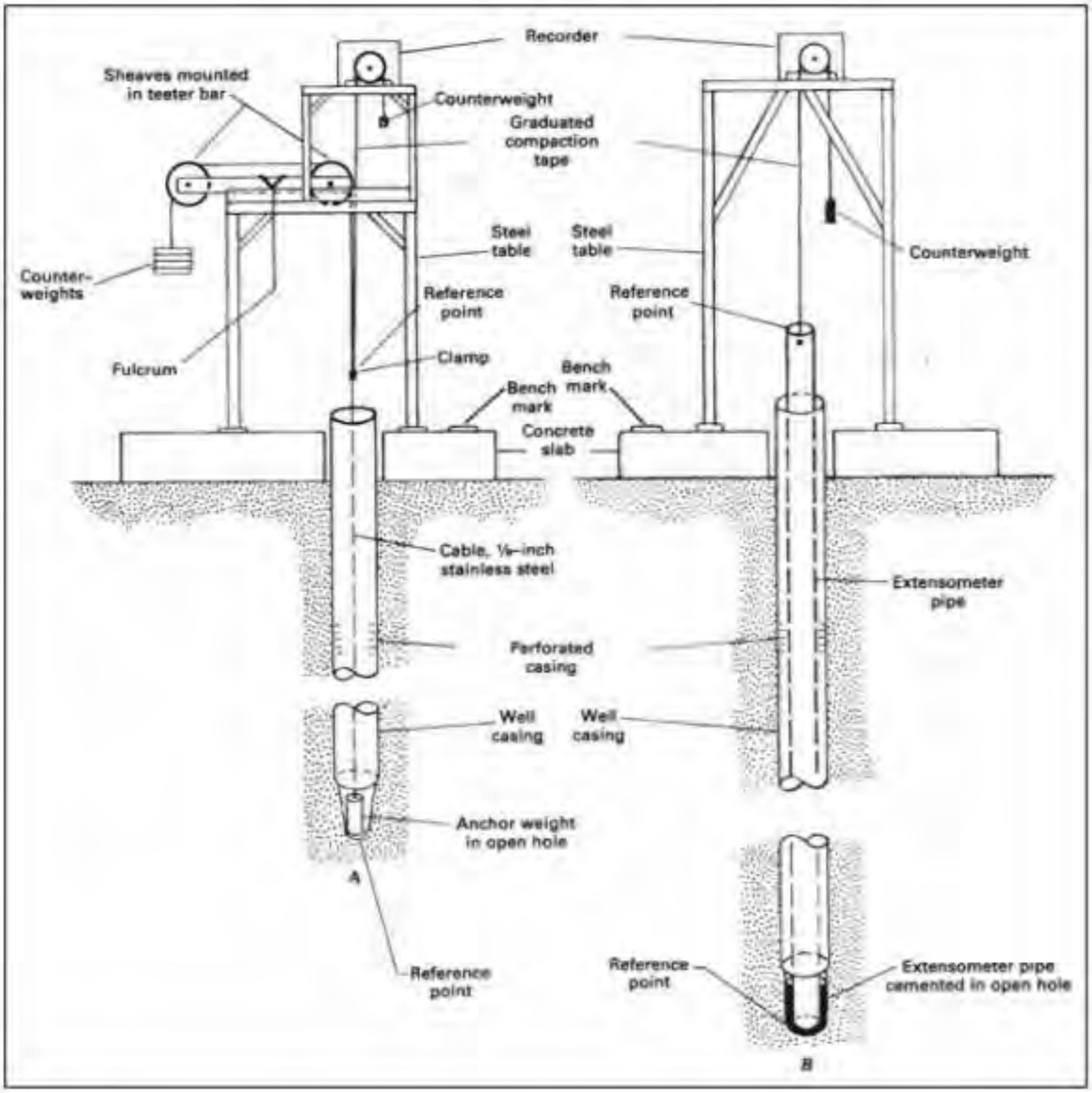


Figure 7 – Simplified Extensometer Diagram

6. KEY DEFINITIONS

The key definitions and sections related to Groundwater Monitoring Protocols, Standards, and Sites outlined in applicable SGMA code and regulations are provided below for reference.

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

- §351(h) "Best available science" refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.
- §351(i) "Best management practice" refers to a practice, or combination of practices, that are designed to achieve sustainable groundwater management and have been determined to be technologically and economically effective, practicable, and based on best available science.

Monitoring Protocols Reference

§352.2. Monitoring Protocols

Each Plan shall include monitoring protocols adopted by the Agency for data collection and management, as follows:

(a) Monitoring protocols shall be developed according to best management practices.

(b) The Agency may rely on monitoring protocols included as part of the best management practices developed by the Department, or may adopt similar monitoring protocols that will yield comparable data.

(c) Monitoring protocols shall be reviewed at least every five years as part of the periodic evaluation of the Plan, and modified as necessary.

SGMA Reference

§10727.2. Required Plan Elements

(f) Monitoring protocols that are designed to detect changes in groundwater levels, groundwater quality, inelastic surface subsidence for basins for which subsidence has been identified as a potential problem, and flow and quality of surface water that directly affect groundwater levels or quality or are caused by groundwater extraction in the basin. The monitoring protocols shall be designed to generate information that promotes efficient and effective groundwater management.

7. RELATED MATERIALS CASE STUDIES

Luhdorff & Scalmanini Consulting Engineers, J.W. Borchers, M. Carpenter. 2014. Land Subsidence from Groundwater Use in California. Full Report of Findings prepared for California Water Foundation. April 2014. 151 p. http://ca.water.usgs.gov/land_subsidence/california-subsidence-cause-effect.html

Faunt, C.C., M. Sneed, J. Traum, and J.T. Brandt, 2015. Water availability and land subsidence in the Central Valley, California, USA. Hydrogeol J (2016) 24: 675. doi:10.1007/s10040-015-1339-x. https://pubs.er.usgs.gov/publication/701605

Poland, J.F., B.E. Lofgren, R.L. Ireland, and R.G. Pugh, 1975. Land subsidence in the San Joaquin Valley, California, as of 1972; US Geological Survey Professional Paper 437-H; prepared in cooperation with the California Department of Water Resources, 87 p. http://pubs.usgs.gov/pp/0437h/report.pdf

Sneed, M., J.T. Brandt, and M. Solt, 2013. Land subsidence along the Delta-Mendota Canal in the northern part of the San Joaquin Valley, California, 2003-10; USGS Scientific Investigations Report 2013-5142, prepared in cooperation with U.S. Bureau of Reclamation and the San Luis and Delta-Mendota Water Authority. https://pubs.er.usgs.gov/publication/sir20135142

Sneed, M., J.T. Brandt, and M. Solt, 2014. Land subsidence, groundwater levels, and geology in the Coachella Valley, California, 1993–2010: U.S. Geological Survey, Scientific Investigations Report 2014–5075, 62 p. http://dx.doi.org/10.3133/sir20145075

STANDARDS

California Department of Transportation, various dates. Caltrans Surveys Manual. http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/Manual_TOC.html

U.S. Environmental Protection Agency, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process, EPA QA/G-4 https://www.epa.gov/sites/production/files/documents/guidance_systematic_planning_dqo_process.pdf

Rice, E.W., R.B. Baire, A.D. Eaton, and L.S. Clesceri ed. 2012. Standard methods for the examination of water and wastewater. Washington, DC: American Public Health Association, American Water Works Association, and Water Environment Federation.

GUIDANCE

Barcelona, M.J., J.P. Gibb, J.A. Helfrich, and E.E.Graske. 1985. Practical Guide for GroundWater Sampling. Illinois State Water Survey, Champaign, Illinois, 103 pages. www.orau.org/ptp/PTP%20Library/library/epa/samplings/pracgw.pdf

Buchanan, T.J., and W.P. Somers, 1969. Discharge measurements at gaging stations; techniques of water-resources investigations of the United States Geologic Survey chapter A8, Washington D.C. http://pubs.usgs.gov/twri/twri3a8/html/pdf.html

Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1. https://pubs.usgs.gov/tm/1a1/pdf/tm1-a1.pdf

California Department of Water Resources, 2010. Groundwater elevation monitoring guidelines. http://www.water.ca.gov/groundwater/casgem/pdfs/CASGEM%20DWR%20GW%20Guidelines%20Final%20121510.pdf

Holmes, R.R. Jr., P.J. Terrio, M.A. Harris, and P.C. Mills, 2001. Introduction to field methods for hydrologic and environmental studies, open-file report 01-50, USGS, Urbana, Illinois, 241 p. https://pubs.er.usgs.gov/publication/ofr0150

Puls, R.W., and Barcelona, M.J., 1996, Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures; US EPA, Ground Water Issue EPA/540/S-95/504. https://www.epa.gov/sites/production/files/2015-06/documents/lwflw2a.pdf

Rantz, S.E., and others, 1982. Measurement and computation of streamflow; U.S. Geological Survey, Water Supply Paper 2175. http://pubs.usgs.gov/wsp/wsp2175/#table

Subcommittee on Ground Water of the Advisory Committee on Water Information, 2013. A national framework for ground-water monitoring in the United States. http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf

Vail, J., D. France, and B. Lewis. 2013. Operating Procedure: Groundwater Sampling SESDPROC-301-R3. https://www.epa.gov/sites/production/files/2015-06/documents/GroundwaterSampling.pdf

Wilde, F.D., January 2005. Preparations for water sampling (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A1, http://water.usgs.gov/owq/FieldManual/compiled/NFM_complete.pdf

ONLINE RESOURCES

Online System for Well Completion Reports (OSWCR). California Department of Water Resources. http://water.ca.gov/oswcr/index.cfm

Measuring Land Subsidence web page. U.S. Geological Survey. http://ca.water.usgs.gov/land_subsidence/california-subsidence-measuring.html

USGS Global Positioning Application and Practice web page. U.S. Geological Survey. http://water.usgs.gov/osw/gps/

Appendix O. Monitoring Network BMP

Monitoring Networks and Identification of Data Gaps Best Management Practice

1. OBJECTIVE

The objective of this Best Management Practice (BMP) is to assist in the development of Monitoring Networks and Identification of Data Gaps. The California Department of Water Resources (the Department or DWR) has developed a Best Management Practice for Monitoring Networks and Identification of Data Gaps, as part of the obligation in the Technical Assistance chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater basins. The SJREC GSA has reviewed and updated this BMP for inclusion in the GSP. This BMP provides technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders to aid in the development of a monitoring network that is capable of providing sustainability indicator data of sufficient accuracy and quantity to demonstrate that the basin is being sustainably managed. In addition, this BMP is intended to provide information on how to identify and plan to resolve data gaps to reduce uncertainty that may be necessary to improve the ability of the GSP to achieve the sustainability goal for the basin.

This BMP includes the following sections:

1. Objective. A brief description of how and where monitoring networks are required under Sustainable Groundwater Management Act (SGMA) and the overall objective of this BMP.

2. Use and Limitations. A brief description of the use and limitations of this BMP.

3. Monitoring Network Fundamentals. A description of the general approach and background of groundwater monitoring networks.

4. Relationship of Monitoring Network to other BMPs. A description of how this BMP is connected with other BMPs.

5. Technical Assistance. Technical content of BMP providing guidance for regulatory sections.

6. Key Definitions. Descriptions of those definitions identified in the GSP Regulations, SGMA, or Basin Boundary Regulations.

7. Related Materials. References and other materials that provide supporting information related to the development of Groundwater Monitoring Networks.

2. USE AND LIMITATIONS

BMPs developed by the Department and revised by the SJREC GSA, provide technical guidance to GSAs and other stakeholders. Practices described in these BMPs do not replace the GSP Regulations, nor do they create new requirements or obligations for GSAs or other stakeholders. In addition, using this BMP to develop a GSP does not equate to an approval determination by the Department. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

3. MONITORING NETWORK FUNDAMENTALS

Monitoring is a fundamental component necessary to measure progress toward the achievement of any management goal. A monitoring network must have adequate spatial and temporal collection of multiple datasets, including groundwater levels, water quality information, land surface elevation, and surface water discharge conditions to demonstrate compliance with the GSP Regulations.

SGMA requires GSAs to establish and track locally defined significant and unreasonable conditions for each of the sustainability indicators. In addition, the collection of data from a robust network is required to ensure that uncertainty is appropriately reduced during the analysis of these datasets. Data collected in an organized and consistent manner will aid in ensuring that the interpretations of the data are as accurate as possible. Also, the consistency of the types, methods, and timing of data collection facilitate the sharing of data across basin boundaries or within basins.

Analyzing data from an adequate monitoring network within a basin can lead to refinement of the understanding of the dynamic flow conditions; this leads to the optimization of sustainable groundwater management.

4. RELATIONSHIP OF MONITORING NETWORKS TO OTHER BMPS

Groundwater monitoring is a fundamental component of SGMA as each GSP must include a sufficient network that provides data that demonstrate measured progress toward achievement of the sustainability goal for each basin. For this reason, a sufficient network will need to be developed and utilized to accomplish this component of SGMA.

It is important that data are developed in a manner consistent with the basin setting, planning, and projects/management actions steps identified on Figure 1 and the GSP Regulations. The inclusion of monitoring protocols in the GSP Regulations also emphasizes the importance of quality empirical data to support GSPs and provide comparable information from basin to basin.

Figure 1 provides a logical progression for the development of a GSP and illustrates how monitoring networks are linked to other related BMPs. This figure also shows the context of the BMPs as they relate to various steps to sustainability as outlined in the GSP Regulations. The monitoring protocol BMP is part of the Monitoring step identified in the logical progression illustration in **Figure 1**.

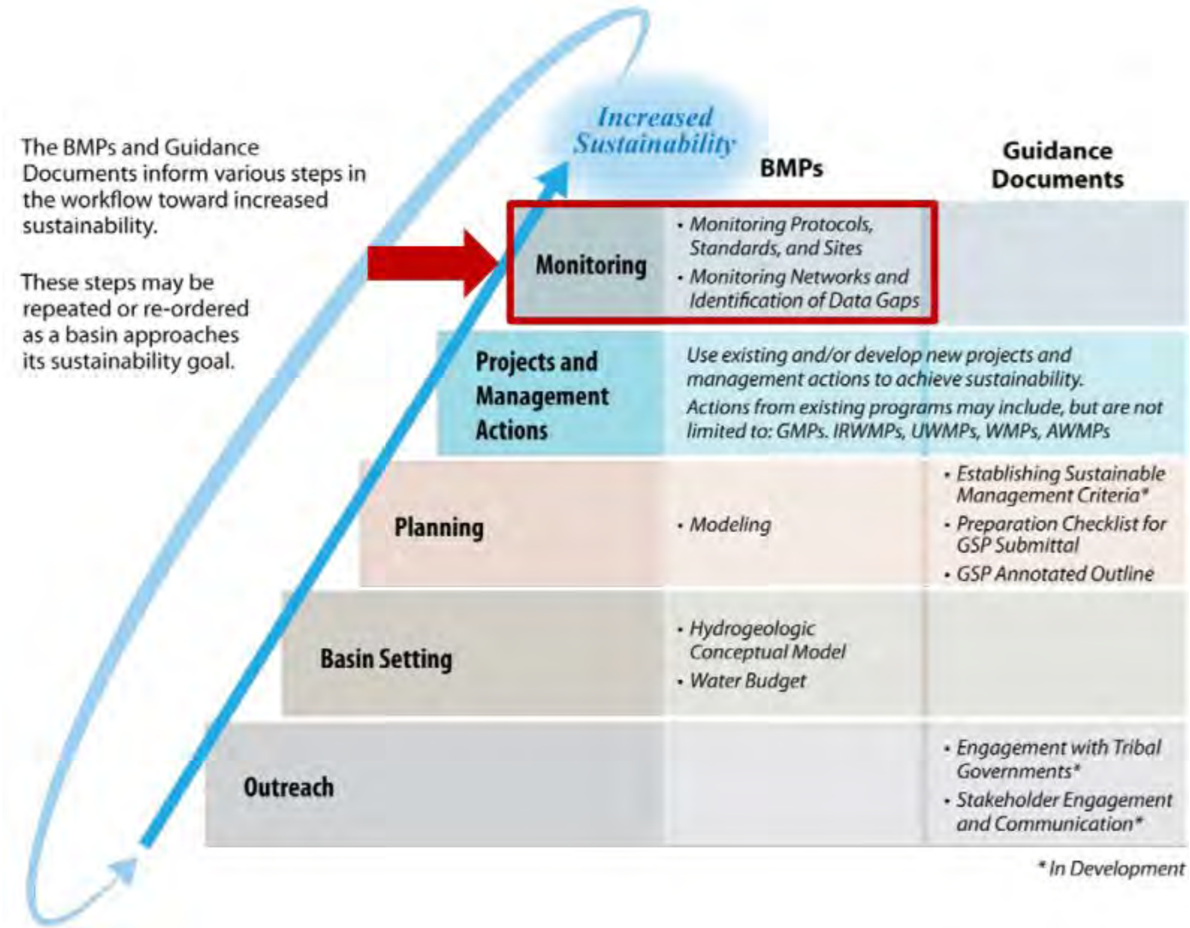


Figure 1 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

5. TECHNICAL ASSISTANCE

This section provides technical assistance to support the development monitoring networks and identification of data gaps.

GENERAL MONITORING NETWORKS

23 CCR §354.32 Introduction to Monitoring Networks and §354.34 (a) and (b) Monitoring Network

23 CCR §354.32. Introduction to Monitoring Networks
This Subarticle describes the monitoring network that shall be developed for each basin, including monitoring objectives, monitoring protocols, and data reporting requirements. The monitoring network shall promote the collection of data of sufficient quality, frequency, and distribution to characterize groundwater and related surface water conditions in the basin and evaluate changing conditions that occur through implementation of the Plan.

23 CCR §354.34. Monitoring Network
(a) Each Agency shall develop a monitoring network capable of collecting sufficient data to demonstrate short-term, seasonal, and long-term trends in groundwater and related surface conditions, and yield representative information about groundwater conditions as necessary to evaluate Plan implementation. (b) Each Plan shall include a description of the monitoring network objectives for the basin, including an explanation of how the network will be developed and implemented to monitor groundwater and related surface conditions, and the interconnection of surface water and groundwater, with sufficient temporal frequency and spatial distribution to evaluate the affects and effectiveness of Plan implementation. The monitoring network objectives shall be implemented to accomplish the following:
(1) Demonstrate progress toward achieving measurable objectives described in the Plan.
(2) Monitor impacts to the beneficial uses or users of groundwater.
(3) Monitor changes in groundwater conditions relative to measurable objectives and minimum thresholds.
(4) Quantify annual changes in water budget components.

The GSP Regulations require GSAs to develop a monitoring network. The monitoring network must be capable of capturing data on a sufficient temporal frequency and spatial distribution to demonstrate short-term, seasonal, and long-term trends in basin conditions for each of the sustainability indicators, and provide enough information to evaluate GSP implementation. A monitoring network should be developed in such a way that it demonstrates progress toward achieving measurable objectives.

As described in the Monitoring Protocols, Standards, and Sites BMP, it is suggested that each GSP incorporate the Data Quality Objective (DQO) process following the US EPA Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA, 2006). Although strict adherence to this method is not required, it does provide a robust approach to ensuring data is collected with a specific purpose in mind, and efforts for monitoring are as efficient as possible to achieve the objectives of the GSP and compliance with the GSP Regulations.

The DQO process presents a method that can be applied directly to the sustainability criteria quantitative requirements through the following steps:

1. State the problem – define sustainability indicators and planning considerations of the GSP and sustainability goal

2. Identify the goal – describe the quantitative measurable objectives and minimum thresholds for each of the sustainability indicators

3. Identify the inputs – describe the data necessary to evaluate the sustainability indicators and other GSP requirements (i.e., water budget)

4. Define the boundaries of the study – This is commonly the extent of the Bulletin 118 groundwater basin or subbasin, unless multiple GSPs are prepared for a given basin. In that case, evaluation of the coordination plan and specifically how the monitoring will be comparable and meet the sustainability goals for the entire basin should be described

5. Develop an analytical approach – Determine how the quantitative sustainability indicators will be evaluated (i.e., are special analytical methods required that have specific data needs)

6. Specify performance or acceptance criteria – Determine what quality the data must have to achieve the objective and provide some assurance that the analysis is accurate and reliable

7. Develop a plan for obtaining data – Once the objectives are known determine how these data should be collected. Existing data sources should be used to the greatest extent possible

These steps of the DQO process should be used to guide GSAs to development of the most efficient monitoring process to meet the measurable objectives of the GSP and the sustainability goal. The DQO process is an iterative process and should be evaluated regularly to improve monitoring efficiencies and meet changing planning and project needs. Following the DQO process GSAs should also include a data quality control and quality assurance plan to guide the collection of data.

GSAs should first evaluate their existing monitoring network and existing datasets when developing the monitoring network for their GSP, such as the California Statewide Groundwater Elevation Monitoring (CASGEM) program. The Assessment and Improvement of Monitoring Network Section of the Regulations describes a process by which GSAs can identify and fill in gaps in their monitoring network. The existing monitoring networks may require evaluation to ensure they meet the DQOs necessary for the GSP. Other considerations for developing a monitoring network include:

- <u>Degree of monitoring.</u> The degree of monitoring should be consistent with the level of groundwater use and need for various levels of monitoring density and frequency. Areas that are subject to greater groundwater pumping, greater fluctuations in conditions, significant recharge areas, or specific projects may require more monitoring (temporal and/or spatial) than areas that experience less activity or are more static.
- <u>Access Issues.</u> GSAs may have to deal with access issues such as unwilling landowners, access agreements, destroyed wells, or other safety concerns with accessing a monitoring site.
- <u>Adjacent Basins.</u> Understanding conditions at or across basin boundaries is important. GSAs should coordinate with adjacent basins on monitoring efforts to be consistent both temporally and spatially. Coordinated efforts and shared data will help GSAs understand their basins' conditions better and potentially better understand groundwater flow conditions across boundaries.

- Consider all sustainability indicators. GSAs should look for ways to efficiently use monitoring sites to collect data for more than one or all of the sustainability indicators. Similarly, when installing a new monitoring site, GSAs should take that opportunity to gather as much information about the subsurface conditions as possible.

There are many other considerations that GSAs must understand when developing monitoring networks that are specific to the various sustainability indicators: chronic lowering of groundwater levels, reduction of groundwater storage, seawater intrusion, degraded water quality, land subsidence, or depletions of interconnected surface waters. In addition, establishment of a monitoring network should be evaluated in conjunction with the Monitoring Protocols, Standards, and Sites; Hydrogeologic Conceptual Model (HCM); Water Budget; and Modeling BMPs when considering the data needs to meet GSP measurable objectives and the sustainability goal.

SPECIFIC MONITORING NETWORKS

23 CCR §354.34(d)-(j):
(d) The monitoring network shall be designed to ensure adequate coverage of sustainability indicators. If management areas are established, the quantity and density of monitoring sites in those areas shall be sufficient to evaluate conditions of the basin setting and sustainable management criteria specific to that area.
(e) A Plan may utilize site information and monitoring data from existing sources as part of the monitoring network.
(f) The Agency shall determine the density of monitoring sites and frequency of measurements required to demonstrate short-term, seasonal, and long-term trends based upon the following factors:

(1) Amount of current and projected groundwater use.

(2) Aquifer characteristics, including confined or unconfined aquifer conditions, or other physical characteristics that affect groundwater flow.

(3) Impacts to beneficial uses and users of groundwater and land uses and property interests affected by groundwater production, and adjacent basins that could affect the ability of that basin to meet the sustainability goal.

(4) Whether the Agency has adequate long-term existing monitoring results or other technical information to demonstrate an understanding of aquifer response.

(g) Each Plan shall describe the following information about the monitoring network:

(1) Scientific rationale for the monitoring site selection process.

(2) Consistency with data and reporting standards described in Section 352.4. If a site is not consistent with those standards, the Plan shall explain the necessity of the site to the monitoring network, and how any variation from the standards will not affect the usefulness of the results obtained.

(3) For each sustainability indicator, the quantitative values for the minimum threshold, measurable objective, and interim milestones that will be measured at each monitoring site or representative monitoring sites established pursuant to Section 354.36.

(h) The location and type of each monitoring site within the basin displayed on a map, and reported in tabular format, including information regarding the monitoring site type, frequency of measurement, and the purposes for which the monitoring site is being used.
(i) The monitoring protocols developed by each Agency shall include a description of technical standards, data collection methods, and other procedures or protocols pursuant to Water Code Section 10727.2(f) for monitoring sites or other data collection facilities to ensure that the monitoring network utilizes comparable data and methodologies.
(j) An Agency that has demonstrated that undesirable results related to one or more sustainability indicators are not present and are not likely to occur in a basin, as described in Section 354.26, shall not be required to establish a monitoring network related to those sustainability indicators.

Monitoring data provide the basis for demonstrating that undesirable results are avoided and are necessary for adequately managing the basin. The undesirable result associated with each sustainability indicator is based on a unique set of representative monitoring points. Therefore, a single monitoring network may not be appropriate to address all sustainability indicators. The monitoring network will consist of an adequate magnitude of monitoring locations that will characterize the groundwater flow regime such that a GSA will have the ability to predict sustainability indicator responses to management actions and document those results. The data collected from these networks will be the foundation for communication to other connected basins as one may affect another. The transparent availability of data is intended to alleviate conflict by demonstrating conditions in a consistent manner such that assessment of the sustainability indicators is relatively consistent from basin to basin.

The use of existing monitoring networks established during implementation of CASGEM, Irrigated Lands Reporting Program (IRLP), Groundwater Ambient Monitoring and Assessment Program (GAMA), National Groundwater Monitoring Network, Existing Groundwater Management Planning, and other local programs could be used for a base monitoring network from which to build. These networks should be evaluated for compliance with GSP Regulations and DQOs.

This section addresses the design and installation of monitoring networks and sites. Agencies must address a number of issues prior to designing the monitoring site, including, but not limited to, establishing the reason for installing the monitoring site, obtaining access agreements, assessing how the monitoring site may improve the basin conceptual model, assessing how the monitoring site may reduce uncertainty, etc. Where management areas are established, each area must be considered when developing the monitoring network for each sustainability indicator.

Professional judgement will be essential to determine the degree of monitoring that will be necessary to meet the needs for the GSP. This BMP provides guidance, but should be coupled with site-specific monitoring needs to address the complexities of the groundwater basin and DQOs.

The following sections are organized by each of the sustainability indicators. These considerations should be applied to the network as a whole to ensure the quality of the data is consistent and reliable, and so that sound representative monitoring locations can be established, as described in the Representative Monitoring Points (RMP) section of this BMP.

A. Chronic Lowering of Groundwater Levels

§354.34(c): *Each monitoring network shall be designed to accomplish the following for each sustainability indicator:*
(1) Chronic Lowering of Groundwater Levels. Demonstrate groundwater occurrence, flow directions, and hydraulic gradients between principal aquifers and surface water features by the following methods:
(A) A sufficient density of monitoring wells to collect representative measurements through depth-discrete perforated intervals to characterize the groundwater table or potentiometric surface for each principal aquifer.
(B) Static groundwater elevation measurements shall be collected at least two times per year, to represent seasonal low and seasonal high groundwater conditions.

The observation and collection of groundwater level data is the cornerstone of data collected for SGMA compliance. Design of the groundwater level data monitoring network will be dependent upon the initial hydrogeologic conceptual model and will likely undergo refinement both temporally and spatially as management in the basin progresses. This isn't to say that the monitoring network will continually expand, but rather, through increased understanding, be more refined to gather the necessary information in the most efficient way possible to demonstrate sustainability, and exercise the basin to maintain conditions consistent with the sustainability goal and sustainable yield of the basin. The use of groundwater levels as a surrogate for other sustainability indicators will require reliable, consistent, high-quality, defendable data to demonstrate the relationship prior to use as a surrogate for other sustainability indicators.

It is preferable to use dedicated groundwater monitor wells with known construction information. The selection of wells should be aquifer-specific and wells that are screened across more than one aquifer should be avoided where possible. If existing wells are used, the perforated intervals should be known to be able to utilize water level or other data collected from that well. Development of the monitor well network must evaluate and consider both unconfined and confined aquifers, and assess where pumping wells are screened that affect monitoring at these locations. Agricultural or municipal wells can be used temporarily until either dedicated monitor wells can be installed or an existing well can be identified that meets the above criteria. If agricultural or municipal wells are used for monitoring, the wells must be screened across a single water-bearing unit, and care must be taken to ensure that pumping drawdown has sufficiently recovered before collecting data from a well.

Each well selected for inclusion in the monitoring network should be evaluated to ensure that water level data obtained meet the DQOs for that well. For example, some wells may be directly influenced by nearby pumping, or injection and observation of the aquifer response may be the purpose of the well. Otherwise, the network should contain an adequate number of wells to observe the overall static conditions and the specific project effects. Well construction details and pumping information for active and inactive wells located in the area of the selected monitor well location should be reviewed to determine whether construction details or pumping activity at those wells could affect water level or water quality data for the selected monitoring site.

There is no definitive rule for the density of groundwater monitoring points needed in a basin. **Table 1** was adopted from the CASGEM Groundwater Elevation Monitoring Guidelines (DWR, 2010). This table summarizes existing references to quantify the density of monitor wells per hundred square miles. While these estimates may provide guidance, the necessary monitoring point density for GSP depends on local geology, extent of groundwater use, and how the GSPs define undesirable results. The use of Hopkins (1984) analysis incorporates a relative well density based on the degree of groundwater use within a given area. Professional judgement will be essential to determining an adequate level of monitoring, frequency, and density based on the DQOs and the need to observe aquifer response to high pumping areas, cones of depression, significant recharge areas, and specific projects.

Table 1. Monitor Well Density Considerations

Reference	Monitor Well Density (wells per 100 miles^2)
Heath (1976)	0.2 - 10
Sophocleous (1983)	6.3
Hopkins (1984)	
Basins pumping more than 10,000 acre-feet/year per 100 miles^2	4.0

Basins pumping between 1,000 and 10,000 acre-feet/year per 100 miles^2	2.0
Basins pumping between 250 and 1,000 acre-feet/year per 100 miles^2	1.0
Basins pumping between 100 and 250 acre-feet/year per 100 miles^2	0.7

In addition to monitor well network density, the frequency of monitoring to characterize the groundwater dynamics within a basin or area is important. The discussion presented in the National Framework for Ground-water Monitoring in the United States (ACWI, 2013) utilizes a degree of groundwater use and aquifer characteristics to aid in determining an appropriate frequency. **Figure 2** (ACWI, 2013) and **Table 2** (ACWI, 2013) describe these considerations and provide recommended frequency of long-term monitoring. It should be noted that the initial characterization is not included; the initial characterization of a monitoring location will require more frequent monitoring to establish the dynamic range and identification of external stresses affecting the groundwater level. An understanding of the full range of monitor well conditions should be reached prior to establishing a long-term monitoring frequency. The considerations presented in **Figure 2** and **Table 2** should be evaluated to determine if the guidance meets the DQOs to support the GSP. Professional judgment should be used to refine the monitoring frequency and density.

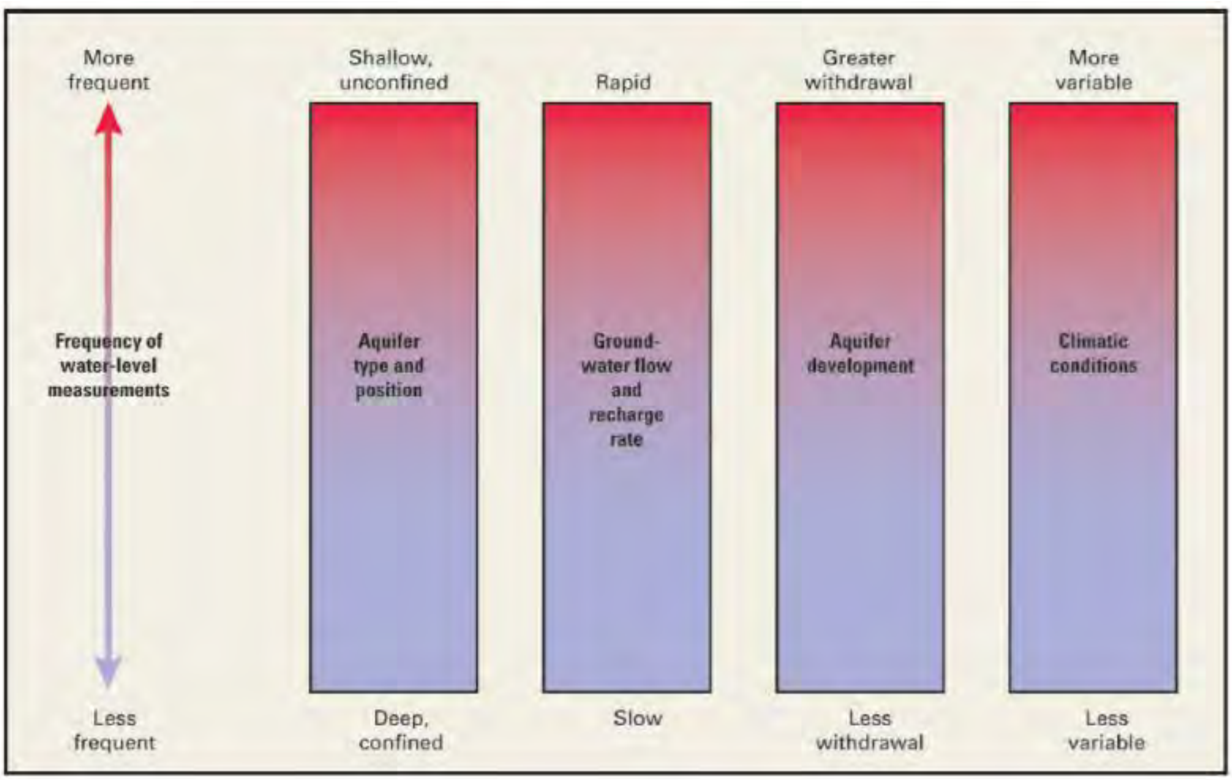


Figure 2. Factors Determining Frequency of Monitoring Groundwater Levels (Taylor and Alley, 2001, adapted from ACWI, 2013)

Table 2. Monitoring Frequency Based on Aquifer Properties and Degree of Use (adapted from ACWI, 2013)

Aquifer Type	Nearby Long-Term Aquifer Withdrawals		
	Small Withdrawals	**Moderate Withdrawals**	**Large Withdrawals**
Unconfined			
"low" recharge (<5 in/yr)	once per quarter	once per quarter	once per month
"high" recharge (>5 in/yr)	once per quarter	once per month	once per day
Confined			
"low" hydraulic conductivity (<200 ft/d)	once per quarter	once per quarter	once per month
"high" hydraulic conductivity (>200 ft/d)	once per quarter	once per month	once per day

The discussion below provides specific management practices for implementation of the GSP, where the general approaches for considering monitoring network density and frequency described above provide some guidance for the expectations for network design.

- New wells must meet applicable well installation standards set in California DWR Bulletin 74-81 and 74-90, or as updated.
- Groundwater level data will be collected from each principal aquifer in the basin.
- Groundwater level data must be sufficient to produce seasonal maps of potentiometric surfaces or water table surfaces throughout the basin that clearly identify changes in groundwater flow direction and gradient.
- Semi-annual groundwater levels will be collected to represent seasonal high and seasonal low values.
    - While semi-annual monitoring is required, more frequent, quarterly, monthly, or daily monitoring may be necessary to provide a more robust understanding of groundwater dynamics within the system.
    - Agencies will need to adjust the monitoring frequency to address uncertainty, such as in specific places where sustainability indicators are of concern, or to track specific management actions and projects as they are implemented.
    - Select wells should be monitored frequently enough to characterize the season high and low within the basin.
- Data must be sufficient for mapping groundwater depressions, recharge areas, and along margins of basins where groundwater flow is known to enter or leave a basin.
- Well density must be adequate to determine changes in storage.
- Data must be able to demonstrate the interconnectivity between shallow groundwater and surface water bodies, where appropriate.
- Data must be able to map the effects of management actions, i.e., managed aquifer recharge or hydraulic seawater intrusion barriers.
- Data must be able to demonstrate conditions at basin boundaries.

- Agencies may consider coordinating monitoring efforts with adjacent basins to provide consistent data across basin boundaries.
- Agencies may consider characterization and continued impacts of internal hydraulic boundary conditions, such as faults, disconformities, or other internal boundary types.

- Data must be able to characterize conditions and monitor adverse impacts as they may affect the beneficial uses and users identified within the basin.

Additional Information:

Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data
http://pubs.usgs.gov/circ/circ1217/pdf/circ1217_final.pdf

A National Framework for Ground-Water Monitoring in the United States Fact Sheet:
http://acwi.gov/sogw/NGWMN_InfoSheet_final.pdf
Full Report: http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf

Statistical Design of Water-Level Monitoring Networks http://pubs.usgs.gov/circ/circ1217/pdf/pt4.pdf

Design of Ground-Water Level Observation-Well Programs
http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.1976.tb03635.x/epdf

B. Reduction of Groundwater Storage

23 CCR §354.34(c)(2): *Reduction of Groundwater Storage. Provide an estimate of the change in annual groundwater in storage.*

While reduction in groundwater storage is not a directly measurable condition, it does rely heavily on the collection of accurate groundwater levels, as described in the preceding section, and a robust understanding of the HCM and textural observations from boreholes. The identification in the HCM of discrete aquifer units and surrounding aquitards will be essential in assessing changes in groundwater storage. The changes in groundwater levels reflect changes in storage and can thus be estimated with assumptions of thickness of units, porosity, and connectivity. These observations will be essential for use in calculating the water budget; see the Water Budget BMP for more detail.

Estimates of changes in storage are available from remote sensing-based investigations, but should be used cautiously as they tend to be regional in nature and may not provide the level of accuracy necessary to fully determine the conditions within the basin. The National Aeronautics and Space Administration (NASA) mission, Gravity Recovery and Climate Experiment (GRACE) satellites provide analysis results of differential gravity response associated with changes in groundwater occurrence and terrestrial water storage, http://www.nasa.gov/mission_pages/Grace/#.WATU_fkrKUk.

C. Seawater Intrusion

23 CCR §354.34(c)(3): *Seawater Intrusion. Monitor seawater intrusion using chloride concentrations, or other measurements convertible to chloride concentrations, so that the current and projected rate and extent of seawater intrusion for each applicable principal aquifer may be calculated.*

The Delta-Mendota Subbasin is highly unlikely to have Significant and Unreasonable Seawater Intrusion. For that reason, monitoring protocols for seawater intrusion have not been developed. In the unlikely event that seawater intrusion must be monitored in the Delta-Mendota Subbasin, the SJREC GSA will review BMP's to address the concern.

D. Degraded Water Quality

23 CCR §354.34(c)(4): *Degraded Water Quality. Collect sufficient spatial and temporal data from each applicable principal aquifer to determine groundwater quality trends for water quality indicators, as determined by the Agency, to address known water quality issues.*

Groundwater quality monitoring networks should be designed to demonstrate that the degraded water quality sustainability indicator is being observed for the purpose of meeting the sustainability goal. The monitoring network should consist largely as supplemental monitoring locations where known groundwater contamination plumes under existing regulatory management and monitoring exist, and additional safeguards for plume migration are necessary. In addition, some monitoring may be necessary to address other degraded water quality issues in which migration could impact beneficial uses of water, including, but not limited to, unregulated contaminant plumes and naturally occurring water quality impacts. Seawater intrusion and degraded water quality are naturally related, as many practices are interchangeable. The following represent specific practices to be employed in the execution of the GSP:

- Monitor groundwater quality data from each principal aquifer in the basin that is currently, or may be in the future, impacted by degraded water quality.
    - The spatial distribution must be adequate to map or supplement mapping of known contaminants.
    - Monitoring should occur based upon professional opinion, but generally correlate to the seasonal high and low, or more frequent as appropriate.
        - Where regulated plumes exist, monitoring should coincide with regulatory monitoring for plume migration comparison purposes.
        - Where unregulated degraded water quality occurs, monitoring should be consistent with the degree of groundwater use in the regions of the known impacts.
- Collect groundwater quality data from each principal aquifer in the basin that is currently, or may be in the future, impacted by degraded water quality.
    - Agencies should use existing water quality monitoring data as applicable. For example, these could include ILRP, GAMA, existing RWQCB monitoring and remediation programs, and drinking water source assessment programs.

- Define the three-dimensional extent of any existing degraded water quality impact.
- Data should be sufficient for mapping movement of degraded water quality.
- Data should be sufficient to assess groundwater quality impacts to beneficial uses and users.
- Data should be adequate to evaluate whether management activities are contributing to water quality degradation.

Additional References:

Framework for a ground-water quality monitoring and assessment program for California (GAMA) http://pubs.usgs.gov/wri/wri034166/

Estimation of aquifer scale proportion using equal area grids: Assessment of regional scale groundwater quality http://ca.water.usgs.gov/projects/gama/pdfs/Belitz_etal_2010_wrcr12701.pdf

E. Land Subsidence

23 CCR §354.34(c)(5): *Land Subsidence. Identify the rate and extent of land subsidence, which may be measured by extensometers, surveying, remote sensing technology, or other appropriate method.*

Inelastic land subsidence has been recognized in California for many decades. Observation of land subsidence sustainability indicators can utilize numerous techniques, including levelling surveying tied to known benchmarks, installing and tracking changes in borehole extensometers, monitoring continuous global position system (CGPS) locations, or analyzing interferometric synthetic aperture radar (InSAR) data. As with most sustainability indicators, conditions of subsidence, or lack thereof, can be correlated to groundwater levels as a surrogate. Each of these approaches uses different measuring points and techniques, and is tailored for specific data needs and geologic conditions.

Existing data should be used to the greatest extent. The USGS has conducted numerous studies and much of the data can be located through their webpage and reports: http://ca.water.usgs.gov/land_subsidence/index.html. DWR has compiled and uploaded subsidence data to the SGMA Data Viewer for use by GSA's: https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer. In addition, DWR has developed supporting studies and data available in the Groundwater Information Center interactive maps and reports: http://www.water.ca.gov/groundwater/gwinfo/index.cfm. The use of existing regular surveys of state infrastructure may also present a record of historical changes in elevation along roadways and canals. Prior to development of a specific subsidence monitoring network a screening level analysis should be conducted. The screening of subsidence occurrence should include:

- Review of the HCM and understanding of grain-size distributions and potential for subsidence to occur.
- Review of any known regional or correlative geologic conditions where subsidence has been observed.
- Review of historic range of groundwater levels in the principal aquifers of the basin.

- Review of historic records of infrastructure impacts, including, but not limited to, damage to pipelines, canals, roadways, or bridges, or well collapse potentially associated with land surface elevation changes.
- Review of remote sensing results such as InSAR or other land surface monitoring data.
- Review of existing CGPS surveys.

In general, the network should be designed to provide consistent, accurate, and reproducible results. Where subsidence conditions are occurring or believed to occur, a specific monitoring network should be established to observe the sustainability indicator such that the sustainability goal can be met. The following approaches can be used independently or in coordination with multiple methods and should be evaluated with the specific conditions and objectives in mind. Various standards and guidance documents that must be adhered to when developing a monitoring network include:

- Leveling surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Any alternative shall be reviewed by a Professional Land Surveyor or Professional Civil Engineer registered in the State of California for accuracy and reasonableness. Specific websites where additional information can be found include:
    - http://www.dot.ca.gov/hq/row/landsurveys/
    - http://www.ngs.noaa.gov/datasheets/
    - https://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodeticcontrol-networks.htm#3.5
- CGPS surveys must follow surveying standards set out in the California Department of Transportation's Caltrans Surveys Manual. Specific websites where additional data can be found include:
    - http://www.dot.ca.gov/hq/row/landsurveys/
    - http://www.ngs.noaa.gov/CORS/
    - http://www.unavco.org/instrumentation/networks/status/pbo
    - http://www.dot.ca.gov/dist6/surveys/CVSRN/sitemap.htm
    - http://sopac.ucsd.edu/map.shtml
- The construction and use of borehole extensometers can yield information about total and unit-specific subsidence rates depending upon construction and purpose. Specific sites where additional data can be found include:
    - Extensometer methods commonly used by the USGS http://hydrologie.org/redbooks/a151/iahs_151_0169.pdf
    - Extensometry principles (p. 20-29) http://wwwrcamnl.wr.usgs.gov/rgws/Unesco/
    - Examples of extensometer construction, instrumentation, and data interpretation
        - Single-stage pipe extensometer (Edwards Air Force Base, CA; 1990), p. 20-23: http://pubs.usgs.gov/wri/2000/wri004015/
        - Dual-stage pipe extensometer (Lancaster, CA; 1995), p. 8-12: http://pubs.usgs.gov/of/2001/ofr01414/
        - Dual-stage pipe extensometer (San Lorenzo, CA; 2008), p. 12-13: https://pubs.er.usgs.gov/publication/ds890
- The use of InSAR data can be useful for screening and regular monitoring, especially as the technology becomes more widely available and usable. Specific sites where additional data can be found are listed below.

- Interferometric Synthetic Aperture Radar (InSAR) techniques are an effective way to measure changes in land-surface altitude over large areas. Some basic information about InSAR can be found here:
  - https://pubs.usgs.gov/fs/fs-051-00/pdf/fs-051-00.pdf
  - http://pubs.usgs.gov/fs/fs06903/pdf/fs06903.pdf
- Raw data (not processed into interferograms) are available from a variety of foreign space agencies or their distributors at variable costs (including free):
  - European Space Agency http://www.esa.int/ESA
  - Japanese Space Exploration Agency http://global.jaxa.jp/
  - Italian Space Agency http://www.asi.it/en
  - Canadian Space Agency http://www.asc-csa.gc.ca/eng/
  - German Aerospace Center http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10002/
- Data Processing: Processing raw data to high-quality InSAR data is not a trivial task.
  - Open source/research-grade software packages and commercially available software packages. A list of available software can be found here: http://www.unavco.org/software/data-processing/sarsoftware/sar-software.html
  - There are commercial companies that process InSAR data.
  - Processing raw data to quality-controlled InSAR data is an essential part of InSAR processing because of the numerous common sources of error. Discussions of these error sources are found here:
    - http://pubs.usgs.gov/sir/2014/5075/
    - https://pubs.er.usgs.gov/publication/sir20135142

F. Depletion of Interconnected Surface Water

23 CCR §354.34(c))(6): *Depletions of Interconnected Surface Water. Monitor surface water and groundwater, where interconnected surface water conditions exist, to characterize the spatial and temporal exchanges between surface water and groundwater, and to calibrate and apply the tools and methods necessary to calculate depletions of surface water caused by groundwater extractions. The monitoring network shall be able to characterize the following:*
(A) Flow conditions including surface water discharge, surface water head, and baseflow contribution.
(B) Identifying the approximate date and location where ephemeral or intermittent flowing streams and rivers cease to flow, if applicable.
(C) Temporal change in conditions due to variations in stream discharge and regional groundwater extraction.
(D) Other factors that may be necessary to identify adverse impacts on beneficial uses of the surface water.

Monitoring of the interconnected surface water depletions requires the use of tools, commonly modeling approaches, to estimate the depletions associated with groundwater extraction. Models require assumptions be made to constrain the numerical model solutions. These assumptions should be based on empirical observations determining the extent of the connection of surface water and groundwater systems, the timing of those connections, the flow dynamics of both the surface water and groundwater systems, and hydrogeologic properties of the geologic framework connecting these systems.

The following components should be included in the establishment of a monitoring network:

- Use existing stream gaging and groundwater level monitoring networks to the extent possible.
- Establish stream gaging along sections of known surface water groundwater connection.
  - All streamflow measurements should be collected, analyzed, and reported in accordance with the procedures outlined in USGS Water Supply Paper 2175, Volume 1. - Measurement of Stage Discharge and Volume 2. - Computation of Discharge.
    - https://pubs.er.usgs.gov/publication/wsp2175_vol1
    - https://pubs.er.usgs.gov/publication/wsp2175
  - Specific websites where additional information can be found include:
    - General source: http://water.usgs.gov/nsip/
    - Standards for the Analysis and Processing of Surface-Water Data and Information Using Electronic Methods https://pubs.er.usgs.gov/publication/wri20014044
    - USGS Streamflow Information
      - Real-time Streamflow Data for the Nation
      - Historical Streamflow Data for the Nation
      - WaterWatch
      - StreamStats
  - Location selection must account for surface water diversions and return flows; or select gaging locations and reaches over which no diversions or return flows exist.
- Establish a shallow groundwater monitor well network, as necessary, to characterize groundwater levels adjacent to connected streams and hydrogeologic properties.
  - Network should extend perpendicular and parallel to stream flow to provide adequate characterization to constrain model development.
  - Monitor to capture seasonal pumping conditions in vicinity-connected surface water bodies.

It may be beneficial to conduct other initial characterization surveys to establish an appropriate monitoring method to develop assumptions for a model or other technique to estimate depletion of surface water. These may include:

- Stream bed conductance surveys
- Aquifer testing for hydrogeologic properties
- Isotopic studies to determine source areas
- Geochemical studies to determine source areas
- Geophysical techniques to determine connectivity to stream channels and preferential flow pathways.

REPRESENTATIVE MONITORING POINTS

The use of RMPs, which are a subset of a basin's complete monitoring network as demonstrated in **Figure 3**, can be used to consolidate reporting of quantitative observations of the sustainability indicators.

> ***23 CCR §354.36. Representative Monitoring (a)-(c):*** *Each Agency may designate a subset of monitoring sites as representative of conditions in the basin or an area of the basin, as follows:*
> *(a) Representative monitoring sites may be designated by the Agency as the point at which sustainability indicators are monitored, and for which quantitative values for minimum thresholds, measurable objectives, and interim milestones are defined.*
> *(b) Groundwater elevations may be used as a proxy for monitoring other sustainability indicators if the Agency demonstrates the following:*
> > *(1) Significant correlation exists between groundwater elevations and the sustainability indicators for which groundwater elevation measurements serve as a proxy.*
> > *(2) Measurable objectives established for groundwater elevation shall include a reasonable margin of operational flexibility taking into consideration the basin setting to avoid undesirable results for the sustainability indicators for which groundwater elevation measurements serve as a proxy.*
>
> *(c) The designation of a representative monitoring site shall be supported by adequate evidence demonstrating that the site reflects general conditions in the area.*

In this figure, the complete monitoring network is represented by black dots. The RMPs for each sustainability indicator are represented by various colored bull's-eyes. In this example, the network of RMPs is unique for each sustainability indicator. Agencies can adopt a single network of RMPs or have a unique set of RMPs for each sustainability indicator.

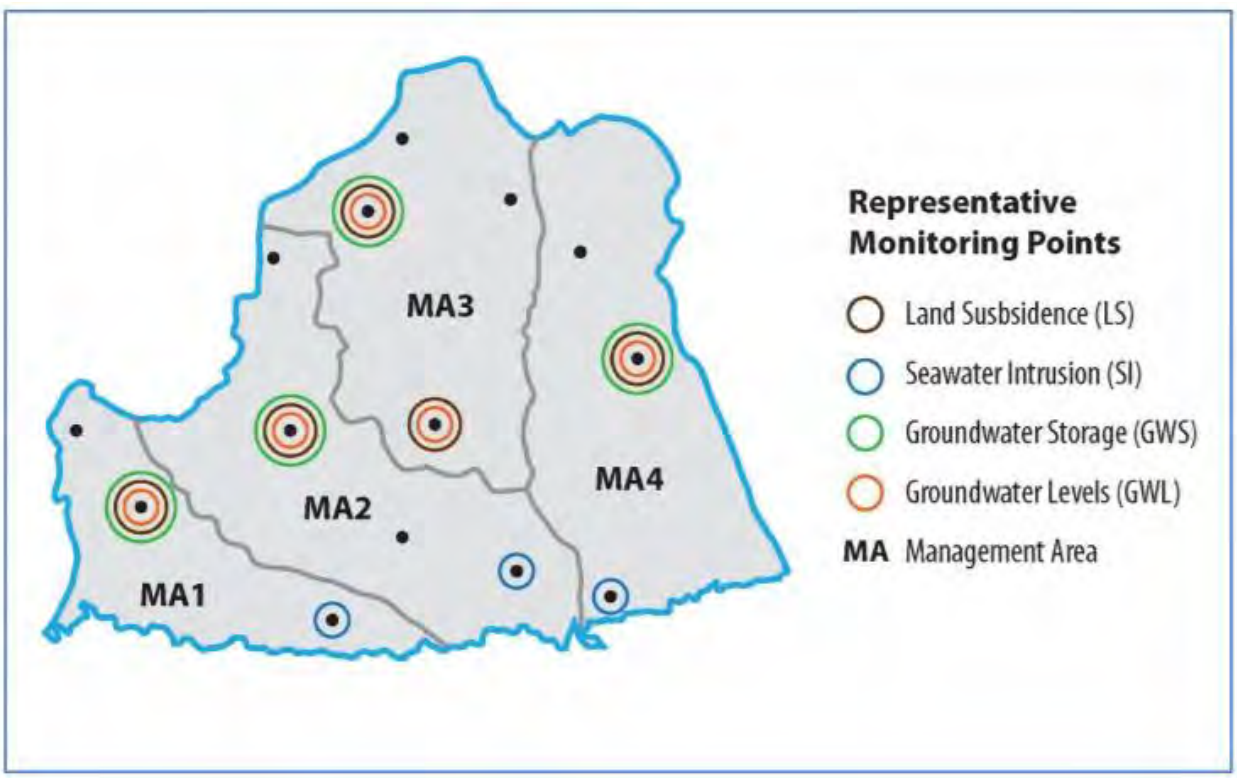


Figure 3: Representative Monitoring Points

If RMPs are used to represent groundwater elevations from a number of surrounding monitor wells, the GSP should demonstrate that each RMP's historical measured groundwater elevations, groundwater elevation trends, and seasonal fluctuations are similar to the historical measurements in the surrounding monitor wells. If RMPs are used to represent groundwater quality from a number of surrounding monitor wells, the GSP should demonstrate that each RMP's historical measured groundwater quality and groundwater quality trends are similar to historical measurements in the surrounding monitor wells.

The use of groundwater levels as a proxy may be utilized where clear correlation can be made for each sustainability indicator. The use of the proxy can facilitate the illustration of where minimum thresholds and measureable objectives occur. A series of RMPs or a single RMP may be adequate to characterize a management area or basin. Use of the RMP should include identification and description of possible interference with the monitoring objective.

NETWORK ASSESSMENT AND IMPROVEMENTS

23 CCR §354.38. Assessment and Improvement of Monitoring Network (a)-(e)
(a) Each Agency shall review the monitoring network and include an evaluation in the Plan and each five-year assessment, including a determination of uncertainty and whether there are data gaps that could affect the ability of the Plan to achieve the sustainability goal for the basin.
(b) Each Agency shall identify data gaps wherever the basin does not contain a sufficient number of monitoring sites, does not monitor sites at a sufficient frequency, or utilizes monitoring sites that are unreliable, including those that do not satisfy minimum standards of the monitoring network adopted by the Agency.
(c) If the monitoring network contains data gaps, the Plan shall include a description of the following:

> *(1) The location and reason for data gaps in the monitoring network.*
> *(2) Local issues and circumstances that limit or prevent monitoring.*

(d) Each Agency shall describe steps that will be taken to fill data gaps before the next fiveyear assessment, including the location and purpose of newly added or installed monitoring sites.
(e) Each Agency shall adjust the monitoring frequency and distribution of monitoring sites to provide an adequate level of detail about site-specific surface water and groundwater conditions and to assess the effectiveness of management actions under circumstances that include the following:

> *(1) Minimum threshold exceedances.*
> *(2) Highly variable spatial or temporal conditions.*
> *(3) Adverse impacts to beneficial uses and users of groundwater.*
> *(4) The potential to adversely affect the ability of an adjacent basin to implement its Plan or impede achievement of sustainability goals in an adjacent basin.*

Network assessment and improvements are commonly identified as 'data gaps' in the monitoring network and refer to "a lack of information that significantly affects the understanding of basin setting or evaluation of the efficacy of the Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed." The monitoring network is a key component in the development of GSPs and will influence the development and understanding of the basin setting, including the hydrogeologic conceptual model, groundwater conditions, and water budget; and proposed minimum thresholds and measurable objectives. GSAs should consider previous analyses of data gaps of their monitoring network through existing programs, such as CASGEM monitoring plans. **Figure 4** shows a flowchart that demonstrates a process that GSAs should use to identify and address data gaps.

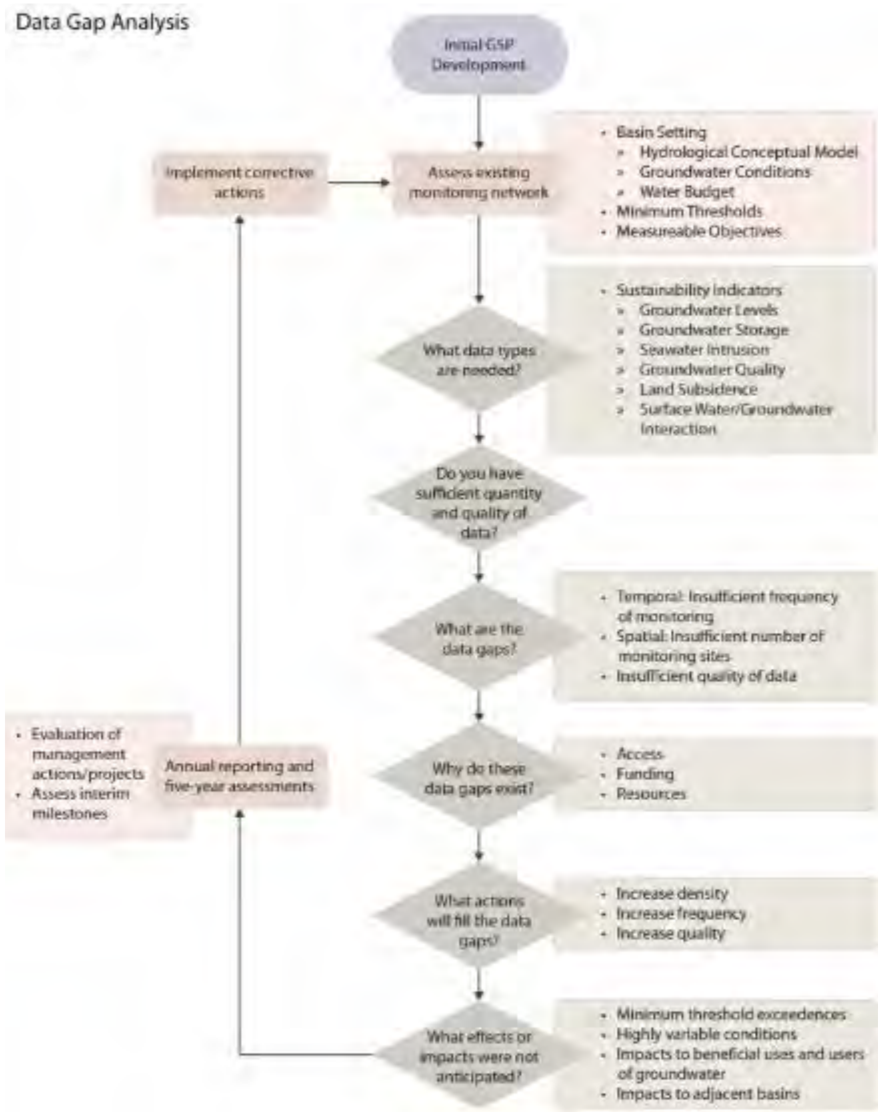


Figure 4. Data Gap Analysis Flow Chart

Professional judgment will be needed from GSAs to identify possible data gaps in their monitoring network of the sustainability indicators. Data gaps can result from monitoring information that is not of sufficient quantity or quality. Data of insufficient quantity typically result from missing or incomplete information, either temporally or spatially. Examples of temporal data gaps include a hydrograph with data that is too infrequent, has inconsistent intervals, or has a short historical record, as shown in **Figure 5**. Spatial data gaps may occur from a monitoring network with low or uneven density in three dimensions, as shown in **Figure 6.**

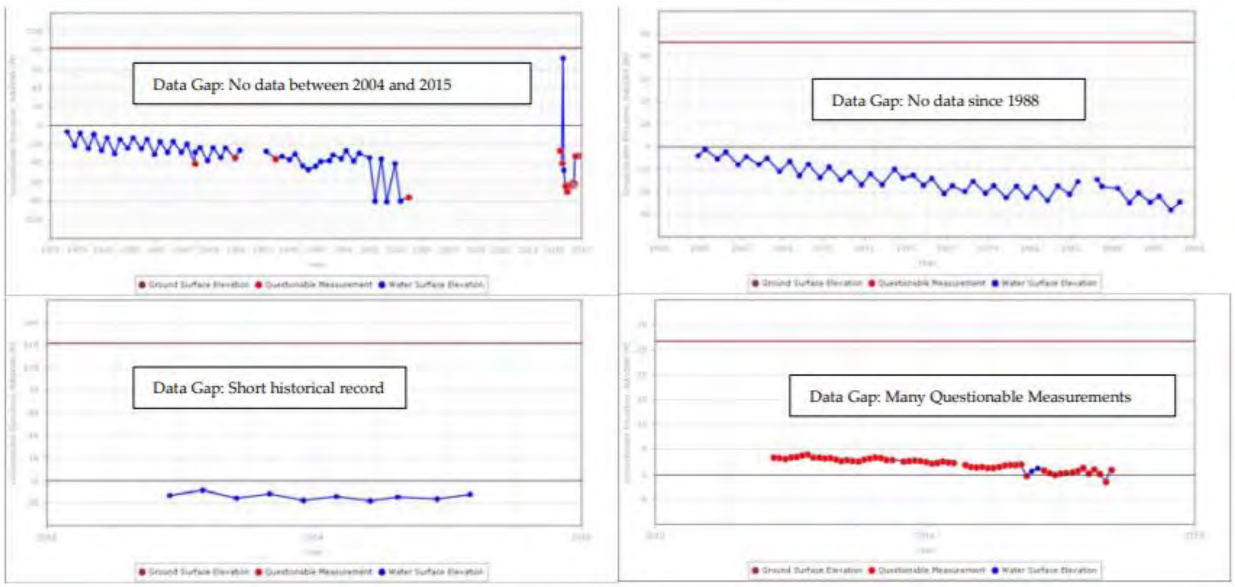


Figure 5. Examples of Hydrographs with Temporal Data Gaps

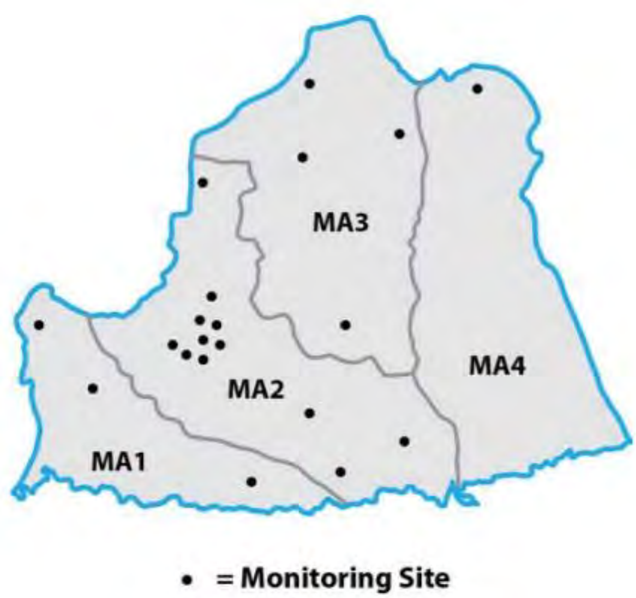


Figure 6. Example Monitoring Network with Spatial Data Gaps

Poor quality data may also be the cause of data gaps. Data must be of sufficient quality to enable scientifically defensible decisions. Poor quality data may at times be worse than no data because it could lead to incorrect assumptions or biases. Some things to consider when questioning the quality of data include: collection conditions and methods, sampling quality assurance/quality control, and proper calibration of meters/equipment. As part of the CASGEM program, DWR reports groundwater elevation data from local agencies, which include the option for "Questionable Measurement Codes." These codes are one way of identifying poor quality data.

There may be various reasons for data gaps, including site access, funding, and lack of staffing resources. By identifying and correcting the reasons behind data gaps, GSAs may be able to avoid further data gaps.

Direct actions GSAs could take to fill data gaps include:

- Increasing the frequency of monitoring. For instance, some groundwater elevation measurements are taken twice a year in the spring and fall, but perhaps those measurements need to be increased to quarterly, monthly, or more frequently, if needed.
- Increasing the spatial distribution and density of the monitoring network.
- Increasing the quality of data through improved collection methods and data management methods.

As GSPs are implemented, GSAs may identify other data gaps, especially if there are minimum threshold exceedances, highly variable spatial or temporal conditions, adverse impacts to beneficial uses and users of groundwater, and impacts to adjacent basins' ability to achieve sustainability. Any or all of these conditions may indicate a need to refine the monitoring network.

Agencies are required to assess their monitoring networks every five years. During those assessments, data gaps may also be identified as agencies monitor the progress of their management actions/projects and the status of their interim milestones. These regular assessments will allow the GSAs to adaptively manage, focus, and prioritize future monitoring.

DATA REPORTING

> ***23 CCR §352.6. Data Management System***
> *Each Agency shall develop and maintain a data management system that is capable of storing and reporting information relevant to the development or implementation of the Plan and monitoring of the basin.*

The use of a Data Management System (DMS) is required for all GSPs. The DMS should include clear identification of all monitoring sites and a description of the quality assurance and quality control checks performed on the data being entered. Uploading of the collected data should occur immediately following collection to address any quality concerns in a timely manner and prevent the potential for development of data gaps. Coordination of data structures between adjacent basins will facilitate data sharing and increase data transparency.

DWR will be providing an updated information that may be used for this BMP as the suggested data structure is developed.

6. KEY DEFINITIONS

SGMA DEFINITIONS (CALIFORNIA WATER CODE §10721)

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

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

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

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

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

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

(2) Significant and unreasonable reduction of groundwater storage.

(3) Significant and unreasonable seawater intrusion.

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

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

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

GSP REGULATIONS DEFINITIONS (CALIFORNIA CODE OF REGULATIONS §351)

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

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

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

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

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

(u) “NAD83” refers to the North American Datum of 1983 computed by the National Geodetic Survey, or as modified.

(v) “NAVD88” refers to the North American Vertical Datum of 1988 computed by the National Geodetic Survey, or as modified.

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

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

(ab) “Reference point” refers to a permanent, stationary and readily identifiable mark or point on a well, such as the top of casing, from which groundwater level measurements are taken, or other monitoring site.

(ac) “Representative monitoring” refers to a monitoring site within a broader network of sites that typifies one or more conditions within the basin or an area of the basin.

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

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

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

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

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

7. RELATED MATERIALS

NETWORK DESIGN

- Design of a Real-Time Ground-Water Level Monitoring Network and Portrayal of Hydrologic Data in Southern Florida
    - http://fl.water.usgs.gov/PDF_files/wri01_4275_prinos.pdf
- Optimization of Water-Level Monitoring Networks in the Eastern Snake River Plain Aquifer Using a Kriging-Based Genetic Algorithm Method
    - http://pubs.usgs.gov/sir/2013/5120/pdf/sir20135120.pdf

GUIDANCE

California Department of Water Resources, 2010. California statewide groundwater elevation monitoring (CASGEM) groundwater elevation monitoring guidelines, December, 36 p. http://www.water.ca.gov/groundwater/casgem/documents.cfm

Heath, R. C., 1976. Design of ground-water level observation-well programs: Ground Water, V. 14, no. 2, p. 71-77.

Hopkins, J., 1994. Explanation of the Texas Water Development Board groundwater level monitoring program and water-level measuring manual: UM-52, 53 p. http://www.twdb.texas.gov/groundwater/docs/UMs/UM-52.pdf

Sophocleous, M., 1983. Groundwater observation network design for the Kansas groundwater management districts, USA: Journal of Hydrology, vol.61, pp 371-389.

Subcommittee on ground water of the advisory committee on water information, 2013. A National Framework for Ground-Water Monitoring in the United States, 168 p. http://acwi.gov/sogw/ngwmn_framework_report_july2013.pdf

Appendix P. Grassland Bypass Project Summary

Grassland Bypass Project

Project Summary

June 2017

Grassland Bypass Project – Background and Description.

The Grassland Bypass Project has reduced agricultural drainage discharge from the Grassland Drainage Area to the San Joaquin River by 89% since the project started in 1996. The has resulted in a reduction of 97% of the selenium load and 83% of the salt load discharged to the San Joaquin River compared to pre-project discharges.

The Grassland Drainage Area (see **Figure 1**) is a highly productive agricultural region on the Westside of the San Joaquin Valley. The region is approximately 100,000 acres lying generally south of Los Banos, between the San Joaquin River and Interstate 5. The region is overlain by coastal range sediments that are generally heavy clays and contain a variety of dissolved minerals including boron and selenium. These soil conditions have contributed to a healthy and productive agricultural environment but their heavy clay nature has also created a perched water table that threatens this productivity. The perched water table is managed with subsurface (tile) drain systems and deep earthen channels which provide an outlet for the shallow groundwater. However, the subsurface drain water is high in dissolved minerals including salt and selenium, which pose an environmental risk to wildlife. In the past, this drain water was discharge through channels that also supplied fresh water to the Grasslands. Because of the risk to wildlife, these wetland supply channels could not deliver water to Grasslands while carrying tile drainage, and ultimately the Grassland Bypass Project was developed.

The Grassland Bypass Project is an innovative project designed to improve water quality in drainage channels used to deliver water to wetland areas. The Grassland Bypass Project consolidated regional subsurface flows into a single channel, removing drain water from nearly 100 miles of wetland supply canals. Selenium load allocations (total maximum monthly loads or TMMLs) were also incorporated into the project, which reduce annually (see **Figure 2**). The Grassland Area Farmers have developed a plan to eliminate agricultural drainage discharge from the region. This plan has evolved into the Westside Regional Drainage Plan (Westside Plan).

The Westside Plan is intended to 1) identify scientifically sound projects proven to be effective in reducing drainage; 2) develop an aggressive implementation plan initially utilizing existing projects documented to be environmentally sound; and 3) curtail discharges to the San Joaquin River in accordance with impending regulatory constraints while maintaining the ability to farm.

The plan focuses on regional drainage projects that can be implemented on a short timeline. Drainage must be addressed on a regional basis but must allow for each sub-area's specific needs and resources. The Plan's key management components for the Grassland Drainage Area are: 1) Source Control, 2) Groundwater Management, 3) Drainage Reuse Projects, and 4) Drain Water Treatment and/or Salt Disposal. As drainage projects are implemented, they will be evaluated for long-term sustainability of the complete solution.

Figure 2
Grassland Drainage Area
Selenium Discharge and Targets

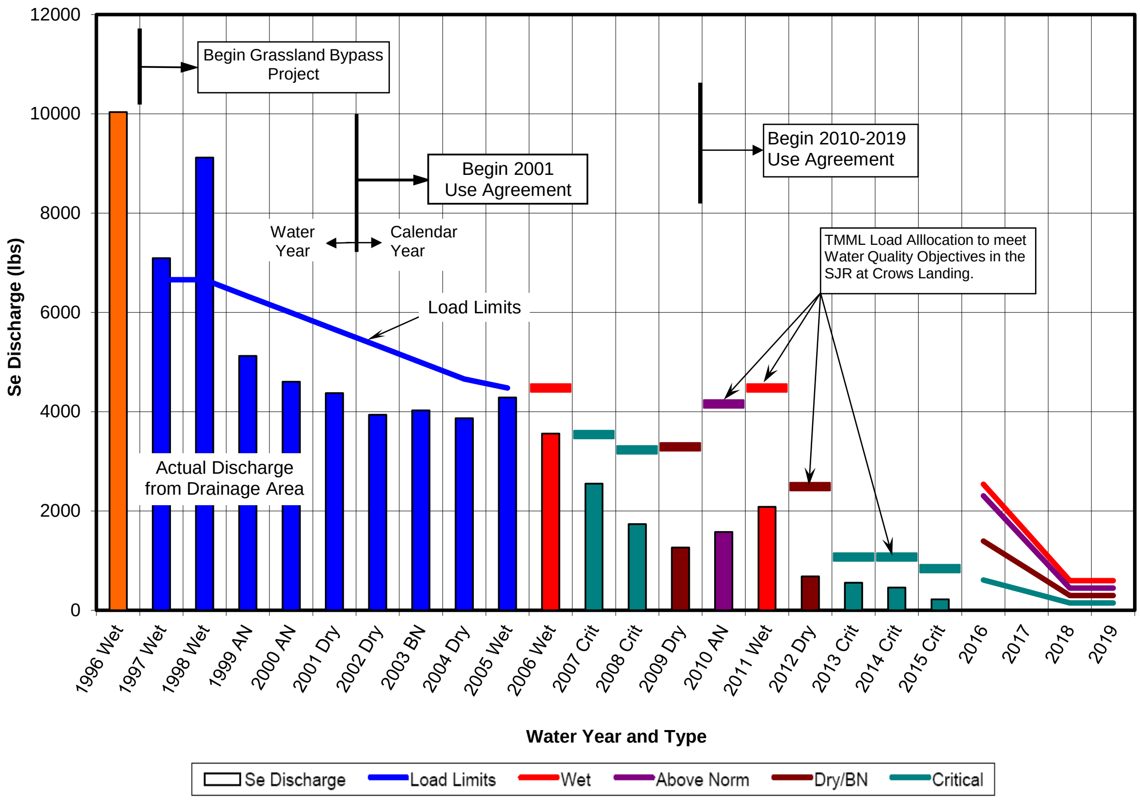
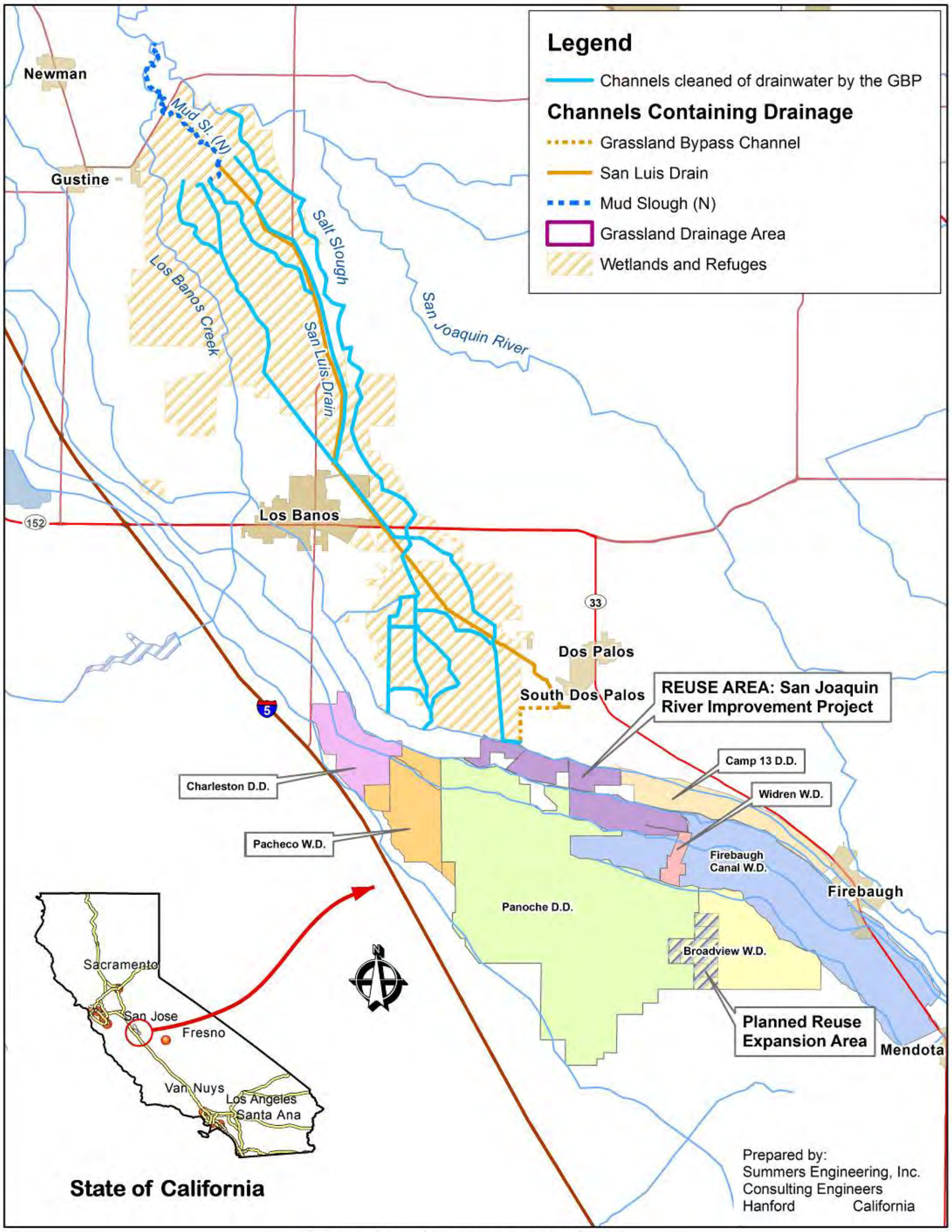


Figure 1

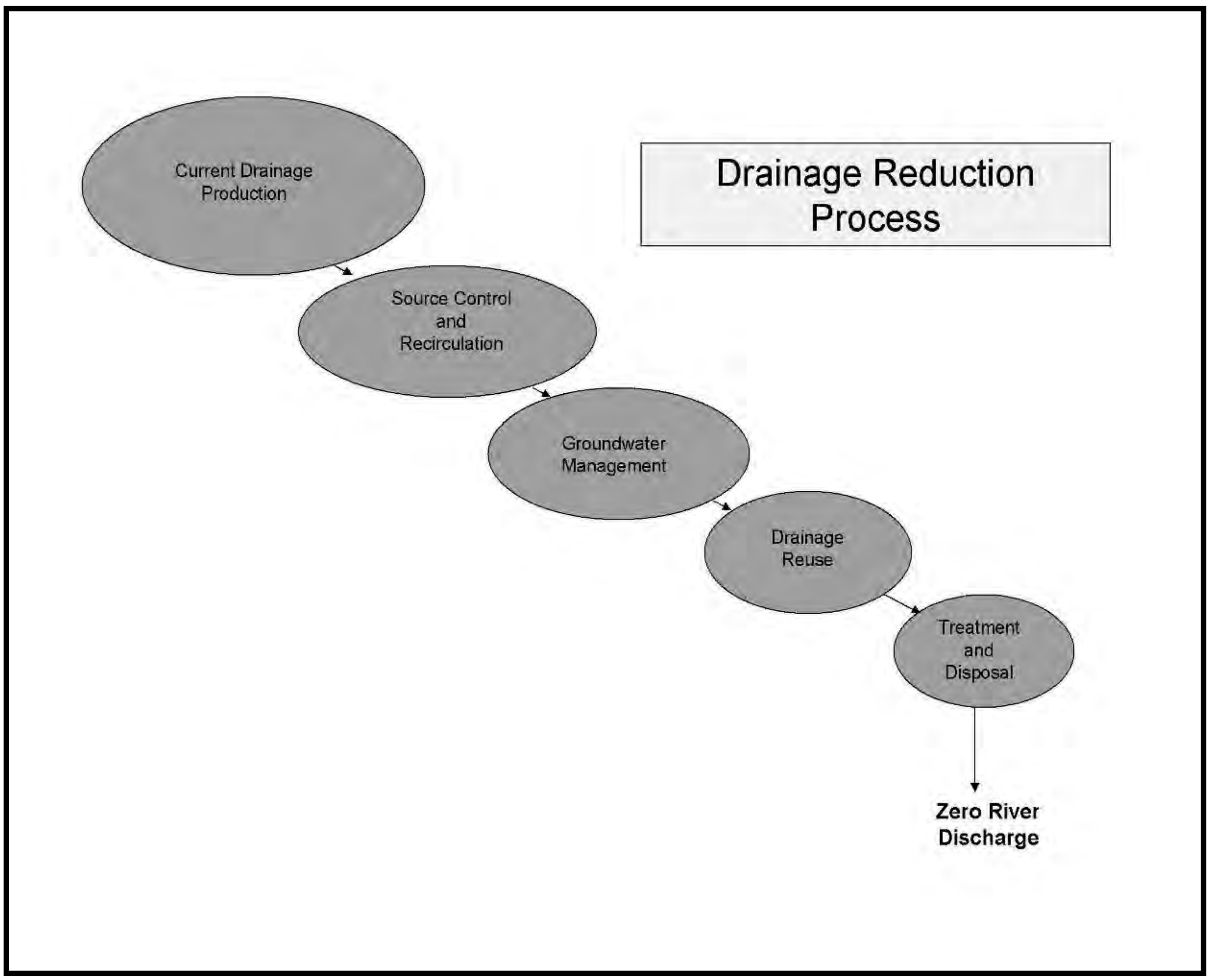


Grassland Bypass Project
Location Map

Drainage Management Components

The Westside Plan identified four effective projects to manage and reduce drainage discharge through the Grassland Bypass Project. These include source control projects such as irrigation and infrastructure improvements to reduce the overall subsurface drainage production, groundwater management to lower the perched water level, drainage reuse to reduce the volume of drain water through the irrigation of salt tolerant crops, and drainage treatment to remove the salt and dissolved minerals. The ultimate goal of this plan will be to eliminate agricultural drainage discharge from the Grassland Drainage Area. **Figure 3** shows the drainage solution components.

Figure 3: Drainage Solution Components



Source Control Projects. Source control projects are projects that can reduce the volume of water contributing to subsurface drainage production usually by reducing deep percolation. Source control projects can usually be divided into two categories: irrigation improvements and distribution infrastructure improvements.

Irrigation improvement projects include converting from a low efficiency irrigation system (such as furrow irrigation) to a high efficiency system (such as drip or micro sprinklers). The State of California and the local districts have made financial assistance (in the form of low interest loans) available to growers as an incentive to convert from conventional irrigation practices to high efficiency drip irrigation (and similar systems). As of 2016, approximately 75% of the irrigated acreage within the Grassland Drainage Area ha systems.


Microsprinklers

Distribution infrastructure improvement projects typically include the replacement of an unlined irrigation canals with a concrete lined channel or pipeline. Unlined channels within the Grassland Drainage Area can contribute more than 200 acre feet of seepage per year for each unlined mile. More than 30 miles of unlined canals have been lined or converted to pipelines since the beginning of the Grassland Bypass Project.


Canal Lining

Drainage Recirculation. Drainage recirculation is the process of redirecting drain water back into the irrigation system and it is one of the first drainage management tools implemented by the Grassland Area Farmers. Virtually all of the districts within the Grassland Drainage Area have some capacity for recirculation. Drainage recirculation is carefully monitored to maintain a blended water quality sufficient for agricultural use.

Panoche Drainage District Recirculation Plant

Groundwater Management. A study performed in 2002, by the San Joaquin River Exchange Contractor's Water Authority (Exchange Contractor's) and the U.S. Bureau of Reclamation indicated that the pumping of strategically placed wells (pumping above the Corcoran Clay) could lower the perched water table and reduce the discharge of nearby subsurface drainage systems. A portion of the funding provided through the Proposition 50 grant has been allocated for some of this work and 18 wells have been installed.

Drainage Reuse. In order to meet the selenium load requirements, Panoche Drainage District began diverting subsurface drain water on to pasture fields as a source of irrigation water in 1998. Over the next few years, trials, experiments, and research helped identify the salt tolerant crops that would best consume the saline drain water. Funding assistance from California Proposition 13 allowed for the purchase of 4,000 acres of marginal land that was developed to salt tolerant crops and became the San Joaquin River Improvement Project (SJRIP). Today, the SJRIP has expanded to 6,000 acres, with approximately 350 acres of pistachios and the remaining land planted to salt tolerant forage grasses (mostly Jose Tall Wheatgrass). The SJRIP has provided a key tool to manage almost all of the subsurface drainwater produced by conventional agriculture. By 2014, reuse on the SJRIP eliminated discharge through the San Luis Drain to the San Joaquin River during the summer months. **Table 1**, below shows the volume of subsurface drain water diverted to the SJRIP since its inception in 1998.

Table 1: SJRIP Drainage Reuse.

Water Year	Reused Drain Water	Reused Selenium	Reused Boron	Reused Salt
	(acre feet)	(pounds)	(pounds)	(tons)
1998¥	1,211	329	NA	4,608
1999¥	2,612	321	NA	10,230
2000¥	2,020	423	NA	7,699
2001	2,850	1,025	61,847	14,491
2002	3,711	1,119	77,134	17,715
2003	5,376	1,626	141,299	27,728
2004	7,890	2,417	193,956	41,444
2005	8,143	2,150	210,627	40,492
2006	9,139	2,825	184,289	51,882
2007	11,233	3,441	210,582	61,412
2008	14,955	3,844	238,435	80,900
2009	11,595	2,807	198,362	60,502
2010	13,119	3,298	370,752	75,362
2011	21,623	4,394	454,675	102,417
2012	23,735	3,293	545,180	118,445
2013	26,170	3,527	568,907	118,883
2014	30,870	3,711	879,800	179,560
2015	31,460	2,644	969,640	178,620
2016	24,573	2,401	886,770	162,421

Jose Tall Wheatgrass on the SJRIP

Pistachio on the SJRIP

Salt Balance: Drainage reuse has been an extremely effective tool in reducing drainage volume discharged from the Grassland Drainage Area but it is not without challenges. Because of the saline nature of the water applied, soil salinity needs to be carefully managed to prevent salt buildup in the root zone. To provide for a salt balance, subsurface drainage systems have been installed on 1,700 acres and ultimately will be installed on most the SJRIP lands. These subsurface drainage systems (or “tile” systems) will allow up to 25% leaching for the saltiest applied water. The long term salt balance and viability will be provided by the drainage systems and appropriate regular leaching including annual rainfall.

Drainage Treatment/Disposal. Conventional wisdom implies that some mechanical system will be required to from the salts from the drainwater leached from the SJRIP. While it is unclear if this conventional wisdom is indeed fact, the Grassland Basin Drainers have supported many treatment tests over the past two decades. Many different methods have been tested and none of these approaches have resulted in a viable and affordable treatment process. Until an effective treatment process is discovered, the Grassland Area Farmers will rely on the continued operation of the SJRIP and drainage reuse in order to manage drainwater and prevent discharge to the San Joaquin River. Portions of the SJRIP have received drainwater for irrigation continuously since 1998 with no reduction in crop production so there is reason to expect successful operation of the SJRIP far into the future.

Project Impacts

The Grassland Bypass Project has been successful in reducing the volume of subsurface drain water discharged from the 100,000 acre Grassland Drainage Area which maintaining viable farming within the region. In 1995, prior to the Grassland Bypass Project, more than 57,000 acre feet of drain water was discharged through the wetland channels. This not only impacted the water quality of the San Joaquin River system but exposed waterfowl attracted to the Grassland area wetlands to elevated levels of selenium and other constituents. The Grassland Bypass Project eliminated drainage discharge into the wetland channels[1] and consolidated all of the drainage within the Grassland Drainage Area into one channel. By 2016, the volume of discharged drain water was reduced from 57,574 acre feet to about 7,670 (an 87% reduction in discharge). Similar reductions occur in the discharged load of selenium, salt, and boron. **Table 2** shows the annual reduction in drainage discharge and associated constituent load. The concentrations of selenium in the San Joaquin River have reduced with the project. **Figure 4** shows the selenium concentrations at Crows Landing downstream of the Merced River which is the TMML compliance point.

Table 2: Grassland Bypass project Annual Discharge and Loads

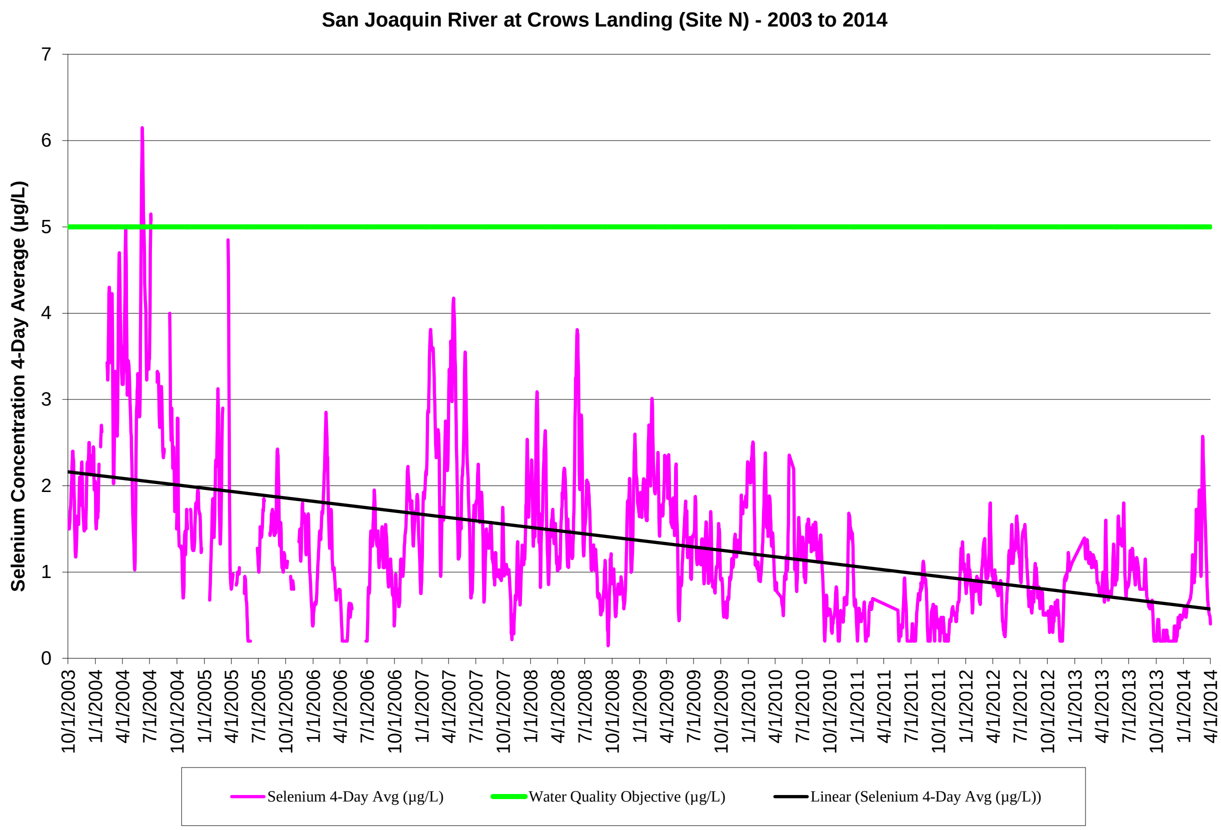
Discharge Comparison from Grassland Drainage Area

	WY 95	WY 96	WY 97	WY 98	WY 99	WY 00	WY 01	WY 02	WY 03	WY 04	WY 05
Volume (AF)	57,574	52,978	39,856	49,289	32,317	31,342	28,235	28,358	27,345	27,640	29,957
Se (lbs)	11,875	10,034	7,096	9,118	5,124	4,603	4,377	3,939	4,032	3,860	4,305
Salt (tons)	237,530	197,526	172,602	213,533	149,081	139,303	142,415	128,411	126,500	121,138	138,908
B (1,000 lbs)	868	723	753	983	630	619	423	544	554	530	585
Se (ppm)	0.076	0.070	0.066	0.068	0.058	0.054	0.057	0.051	0.054	0.051	0.053
Salt (µmhos/cm)	4,102	3,707	4,306	4,308	4,587	4,420	5,016	4,503	4,600	4,358	4,611
Boron (ppm)	5.5	5.0	7.0	7.3	7.2	7.3	5.5	7.1	7.5	7.1	7.2

	WY 06	WY 07	WY 08	WY 09	WY 10	WY 11	WY 12	WY 13	WY 14	WY 15	WY 16	Reduction from WY 95 to WY 16
Volume (AF)	25,995	18,531	15,665	13,166	14,529	18,513	10,486	10,258	7,125	6,079	7,670	87%
Se (lbs)	3,563	2,554	1,736	1,264	1,577	2,067	733	638	317	354	385	97%
Salt (tons)	119,646	79,094	66,254	55,556	67,661	87,537	38,398	54,663	44,834	40,779	46,207	81%
B (1,000 lbs)	539	278	269	233	315	440	245	309	244	212	215	76%
Se (ppm)	0.050	0.051	0.041	0.035	0.040	0.041	0.026	0.023	0.016	0.021	0.018	
Salt (µmhos/cm)	4,577	4,244	4,206	4,196	4,631	4,702	3,641	5,299	6,257	6,670	5,990	
Boron (ppm)	7.6	5.5	6.3	6.5	8.0	8.7	8.6	11.1	12.6	12.8	10.3	

[1] Except for during extreme storm events.

Figure 4 – Selenium Concentrations in the San Joaquin River downstream of the Merced



Appendix Q. Update on Groundwater Conditions in the Newman Sub-Area of the SJREC GSP

UPDATE ON GROUNDWATER CONDITIONS IN THE NEWMAN SUB-AREA OF THE SJREC GSP

prepared for
San Joaquin River Exchange
Contractors GSA
Los Banos, California

and
City of Newman GSA
Newman, California

by
Kenneth D. Schmidt & Associates
Groundwater Quality Consultants
Fresno, California

May 2019

KENNETH D. SCHMIDT AND ASSOCIATES
GROUNDWATER QUALITY CONSULTANTS
600 WEST SHAW AVE., SUITE 250
FRESNO, CALIFORNIA 93704
TELEPHONE (559) 224-4412

May 31, 2019

Mr. Chris White, Executive Director
San Joaquin River Exchange
Contractors GSA
P. O. Box 2115
Los Banos, CA 93635

Re: Newman Sub-Area of the
SJREC GSP

Dear Chris:

Submitted herewith is our report on groundwater conditions in the Newman Sub-area of the SJREC GSP. We appreciate the cooperation of the CCID and City of Newman in providing information for this report.

Sincerely Yours,

Kenneth D. Schmidt
Geologist No. 1578
Certified Hydrogeologist 176

REGISTERED GEOLOGIST
KENNETH D. SCHMIDT
NO. 1578
STATE OF CALIFORNIA

REGISTERED GEOLOGIST
KENNETH D. SCHMIDT
NO. 176
CERTIFIED HYDROGEOLOGIST
STATE OF CALIFORNIA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

UPDATE ON GROUNDWATER CONDITIONS IN THE NEWMAN SUB-AREA OF THE SJREC GSP

INTRODUCTION

As part of the Groundwater Sustainability Plan (GSP) for the San Joaquin River Exchange Contractors (SJREC) service area, GSPs for a number of cities, including Newman, are being incorporated into the SJREC GSP. Kenneth D. Schmidt and Associates (KDSA, 1992 and 2001) prepared two reports on groundwater conditions in the vicinity of the City of Newman for the Central California Irrigation District (CCID) and the City.

This report is intended to provide an update on groundwater conditions within the Newman Study Area boundary (Figure 1). This boundary encompasses lands that are planned for future urban development. This study area is generally bounded by Stuhr Road on the north, the CCID Main Canal on the west, Hallowell Road on the south, and includes land east of the Canal School Road and southwest of the San Joaquin River, where the City effluent is handled. Lands west of the Main Canal and near Hills Ferry Road in Stanislaus County are within the Northwestern Delta Mendota GSA. Lands in a fairly large area east of Canal School Road and in Merced County are in the Merced County Delta Mendota GSA. Lands surrounding most of the City are in the SJREC GSA.

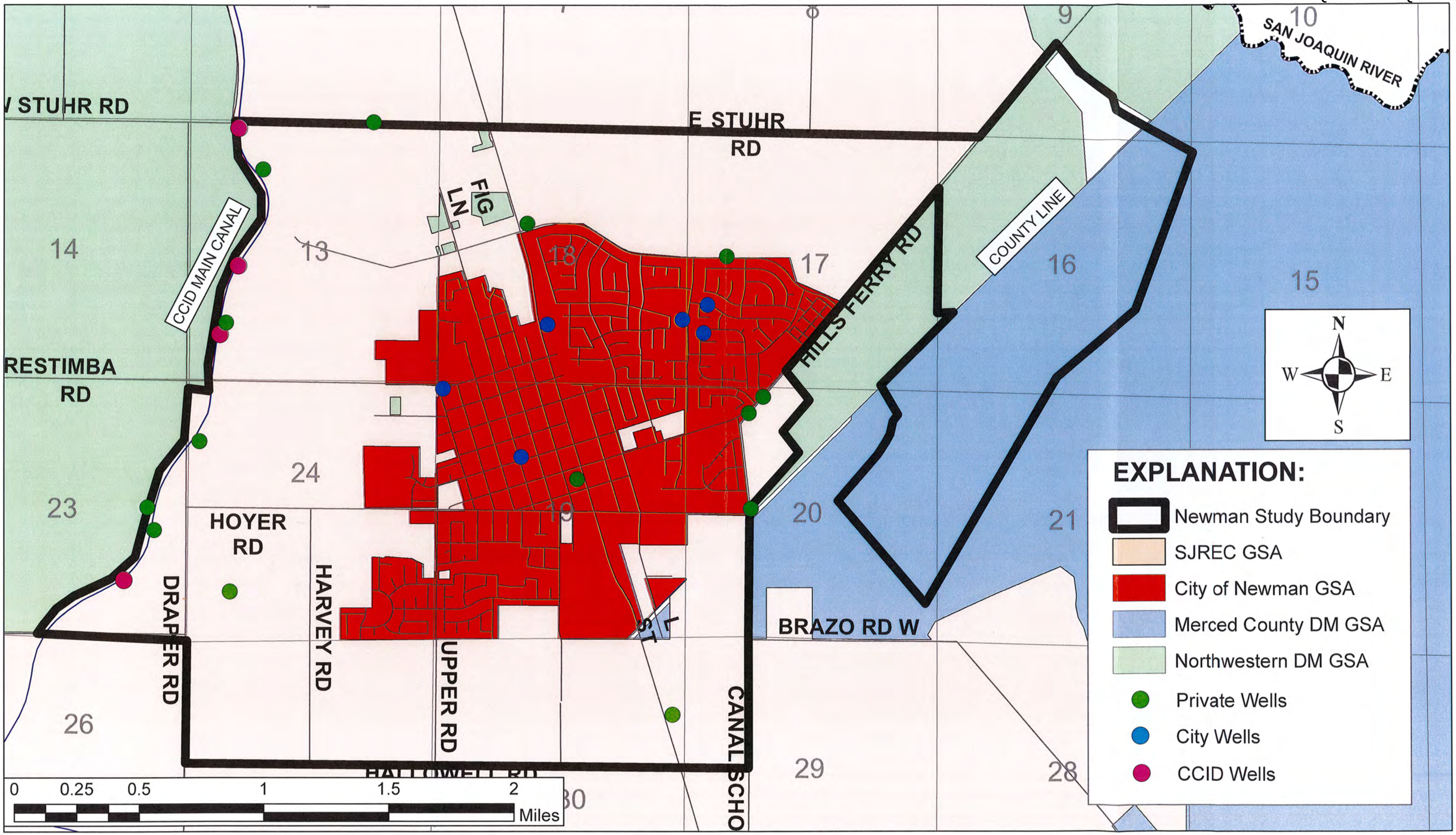


FIGURE 1 - LOCATION OF NEWMAN SUB-AREA, STUDY AREA BOUNDARY, AND SELECTED WELLS

Of particular interest in this update are: 1) the extent of groundwater overdraft, 2) land subsidence, 3) the historical water budget and that for future urban development of the study area, and 4) groundwater quality issues.

SUBSURFACE GEOLOGIC CONDITIONS

Alluvial deposits comprise the aquifer in the Newman area. Subsurface deposits near Newman are termed the older alluvium and the Tulare Formation. Page (1986) indicated that the base of the fresh groundwater (electrical conductivity less than 3,000 micromhos per centimeter at 25°C) was about 900 feet deep near Newman. KDSA (2018) indicated that the base of the usable aquifer in the vicinity, or bottom of the basin in SGMA terminology, was greater than 800 feet deep. A major confining bed is present beneath much of the west side of the San Joaquin Valley, including the Newman area. This clay is termed the Corcoran Clay (E-clay), and divides the aquifer system into upper and lower aquifers. The Corcoran Clay is readily discernible from the drillers logs for most wells in the area, due to its blue color. The over-lying and under-lying deposits are usually tan or brown in color.

Most groundwater near Newman is pumped from relatively shallow wells tapping the upper aquifer, but active City wells and some irrigation wells tap the lower aquifer. Information on the lower aquifer is available from at least four wells or test holes that have been drilled in the City to a depth of more than 500 feet.

KDSA developed two subsurface geologic cross sections extending through the City (Figure 2). Drillers and electric logs for water wells and test holes were obtained from the City, the CCID, and the California Department of Water Resources in Fresno for use in developing these cross sections. A test hole (No. 7) was done by the City in the northeast part of the City and Well No. 8 was subsequently constructed at this site. No CCID wells have been drilled in the area since the 2001 report.

Subsurface Geologic Cross Section A-A′ (Figure 3) extends from near Orestimba Road and the Main Canal on the west through City Wells No. 6, No. 1, No. 4, a test hole near Hills Ferry Road and Canal School Road, to a private well (17R1) near the extension of Hunt Road, about one-half mile west of the Newman Wasteway. Electric logs are available for three wells or test holes along this section. One of these is a 712-foot deep test hole (20D) that was drilled for the City near Hills Ferry Road and Canal School Road. Another is a 500-foot deep test hole that was drilled near City Well No. 6. Another is for CCID Well No. 3, which is 422 feet deep. Drillers logs are available for the other three wells along this section. All of the wells and test holes along this section penetrated the Corcoran Clay. The top of this clay ranges from about 220 feet deep near CCID Well No. 3 to about 275 feet at City Well No. 4. The Corcoran Clay thickens sub-

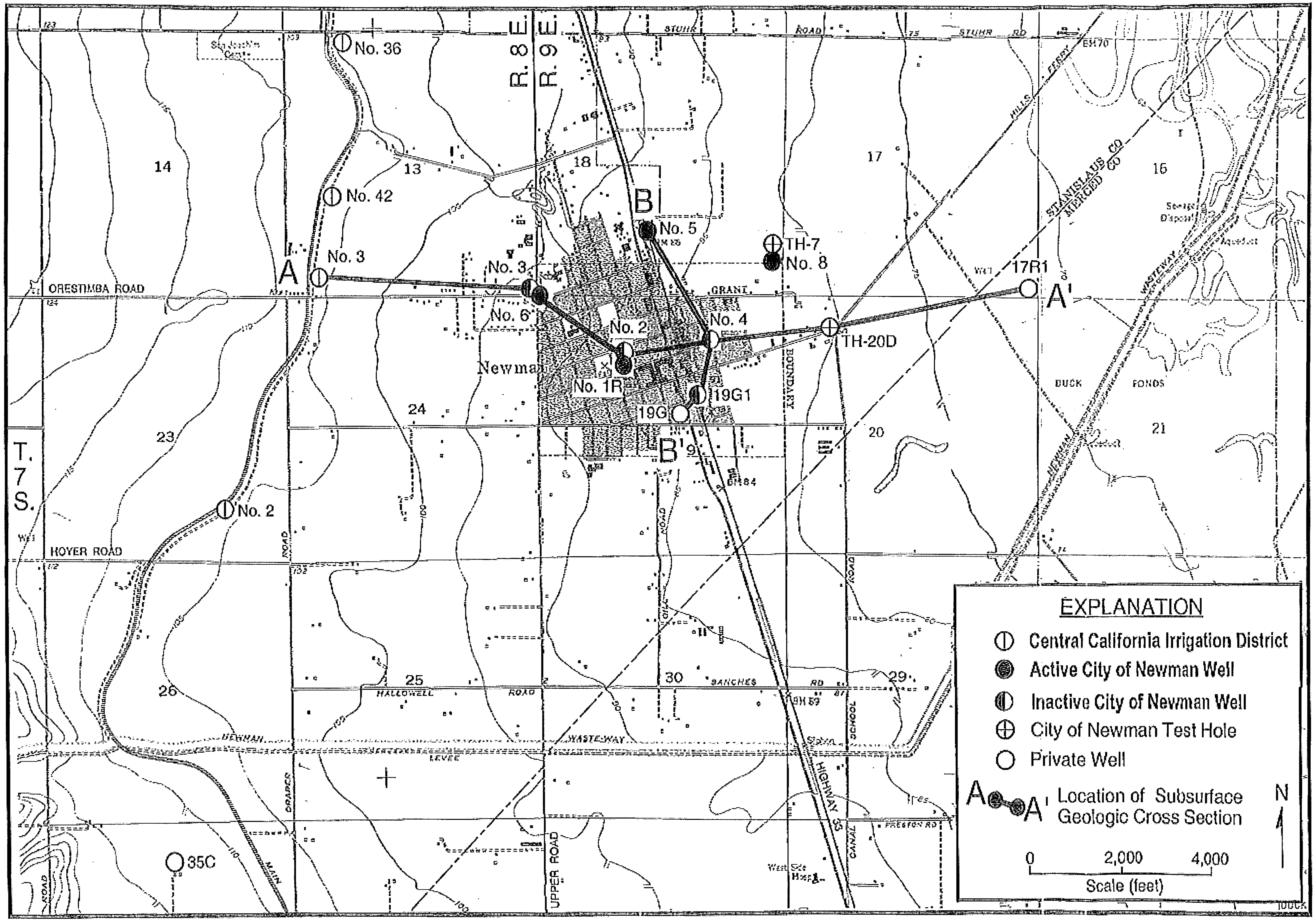


FIGURE 2-LOCATION OF SELECTED TEST HOLES AND WELLS AND SUB-SURFACE GEOLOGIC CROSS SECTIONS

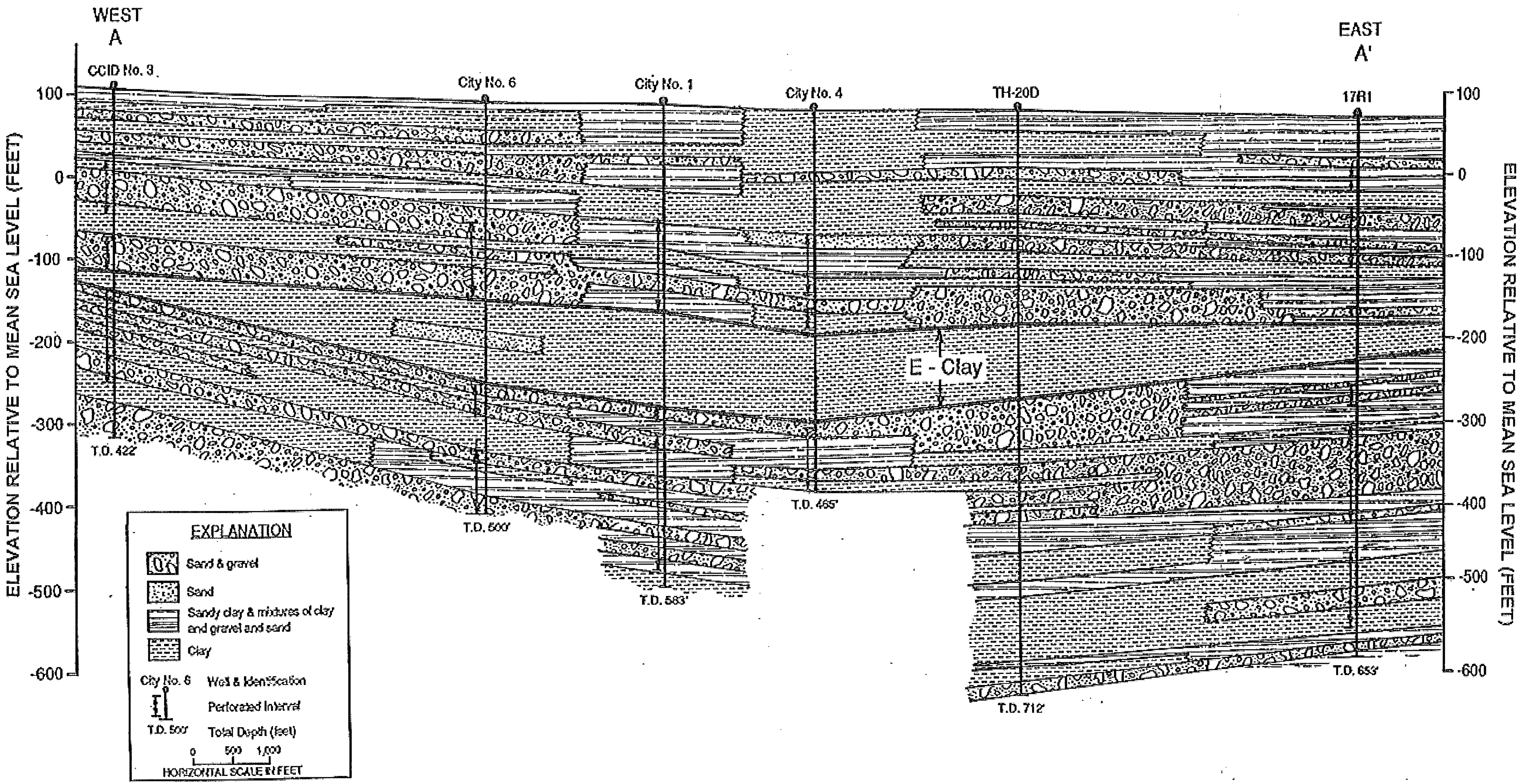


FIGURE 3 - SUBSURFACE GEOLOGIC CROSS SECTION A - A'

stantially toward Highway 33, from about 20 feet at CCID Well No. 3 to about 115 feet at City Well No. 1. Along Cross Section A-A′, the clay is thickest and deepest beneath the area near Highway 33.

Sand and gravel layers are more common in the upper aquifer beneath the west part of the study area (i.e., at CCID Well No. 3). Some of the coarsest deposits in the upper aquifer are within the lower 100 feet, just above the Corcoran Clay. In contrast, fine-grained layers are more predominant in the upper aquifer near Highway 33 (City Well No. 4). Information at Test Hole 20D indicates that below a depth of about 500 feet, sand and gravel layers are uncommon in the lower aquifer. In general, deposits of the lower aquifer appear to be coarsest immediately beneath the E-clay, and to become finer with increasing depth. Two former City wells along this section (Nos. 1 and 4) primarily drew and CCID Well No. 3 draws water from these two widespread, coarse-grained zones above and below the Corcoran Clay. In contrast, City Well No. 1R produces water exclusively from the lower aquifer.

Cross Section B-B′ (Figure 4) extends from north to south, from City Well No. 5 through City Well No. 4 and then two private wells. This section is based entirely on drillers logs, and was correlated with information from Section A-A′, which intersects Cross Section B-B′ at City Well No. 4. Coarse-grained

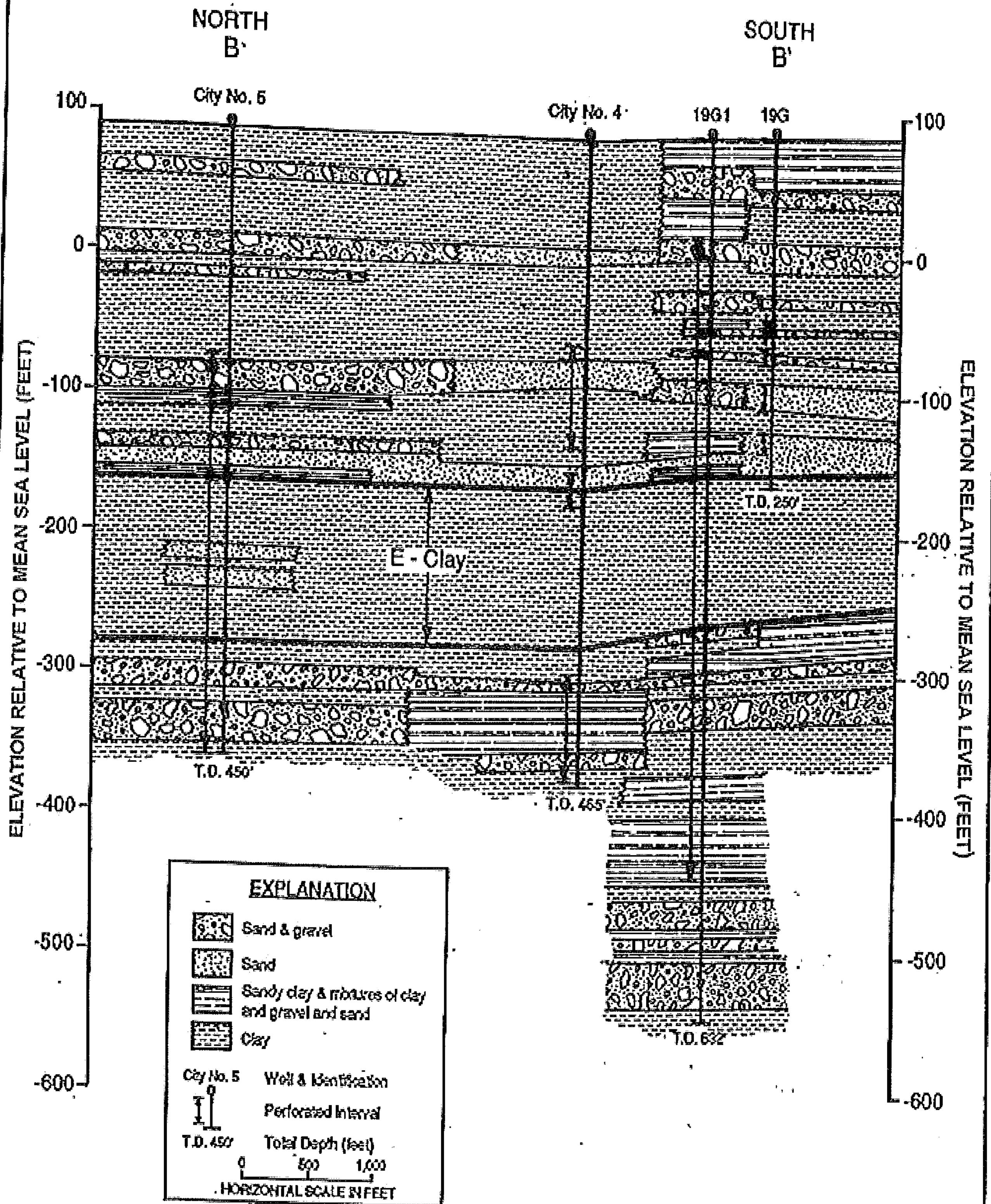


FIGURE 4 - SUBSURFACE GEOLOGIC CROSS SECTION B - B'

strata were found at a depth of more than 600 feet at Well 19G1, which is the deepest well along this section. Well 19G1 was drilled to a depth of 632 feet at the Golden Valley Creamery in 1947. This section also shows a predominance of coarse-grained strata within the lower 100 feet of the upper aquifer and just below the Corcoran Clay.

Test Hole No. 7 was drilled to a depth of 505 feet by Maggiora Brothers, Inc. of Watsonville in September 1992 (Figure 1). The Corcoran Clay was indicated to be present for about 260 to 354 feet in depth. A number of permeable strata were found both above and below the Corcoran Clay at this site. City Well No. 8 was subsequently completed near this test hole.

WELL CONSTRUCTION DATA

City Wells

There are presently four active City Wells. Table 1 provides information on dates drilled, depths, and perforated intervals for these wells.

Drillers logs are available for Well Nos. 1R, 5, 6, and 8 and electric logs are available for Wells No. 5, 6, and 8. Cased depths of the active wells range from 450 to 635 feet. Wells No. 1R and 6 tap strata only in the lower aquifer, whereas Wells No. 5 and 8 are composite wells that tap both aquifers.

TABLE 1-CONSTRUCTION DATA FOR CITY OF NEWMAN WELLS

No.	Date Drilled	Drilled Depth (feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)	Annular Seal (feet)
1R	08/94	645	635	16	340-620	0-50
5	62/69	465	450	14	162-450	0-50
6	09/90	510	500	16	350-500	0-50
8	03/04	498	485	16	180-480	0-100

CCID Wells

Table 2 provides construction data for four CCID wells west and northwest of Newman, along the Main Canal. Depths of these wells range from 350 to 432 feet, and all are composite wells, tapping both the upper and lower aquifer.

WATER LEVELS

Near Newman, most of the available water-level measurements are for wells tapping the upper aquifer, but some measurements are for composite wells that also tap the lower aquifer. In general, water levels are deeper in deeper wells, which indicates a downward direction of groundwater flow in the area. This is common in much of the San Joaquin Valley.

Water-Level Elevations

KDSA (2001, Figure 4) presented a water-level elevation contour map for the upper aquifer in Spring 2000. Water-level contours for the upper aquifer beneath most of the urban area were not provided due to a lack of measurements. Water-level elevations in the upper aquifer west of Newman ranged from 86 to 108 feet above mean sea level, and the direction of groundwater flow was primarily to the east. Water-level elevations in the upper aquifer in the area southeast of Newman ranged from 68 to 78 feet

TABLE 2-CONSTRUCTION DATA FOR CCID WELLS

No.	Date Drilled	Drilled Depth (feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)
2	02/54	350	341	16	90-152
				14	157-337
3	02/54	422	360	16	85-150
					180-225
					245-355
36	01/65	-	398	16	90-132
				14	132-393
42	01/67	-	391	16	90-391

above mean sea level in Spring 2000, and the direction of groundwater flow was to the northeast. Near Newman, the average water-level slope in the upper aquifer was about eight feet per mile.

Water-level elevations of less than about 75 feet in the area west of Newman appeared to have been representative of the lower aquifer. KDSA (2001, Figure 5) showed water-level elevations for the lower aquifer in Spring 2000. Water-level elevations for wells apparently tapping the lower aquifer at and west of Newman ranged from about 66 to 75 feet above mean sea level, and the direction of groundwater flow was to the northeast in Spring 2000. A cone of depression was present beneath the Newman urban area, where water-level elevations ranged from 52 to 56 feet southwest of Newman. The average slope of the piezometric surface of the lower aquifer upgradient of Newman was about 17 feet per mile in Spring 2000.

Figure 5 shows water-level elevations and the direction of groundwater flow for the upper aquifer in Spring 2011. An upper aquifer map for Spring 2017 or other years after 2011 could not be prepared, due to a lack of data in the DWR data base. Limited data for Spring 2017 indicate a water-level elevation of 86 feet above mean sea level near the Main Canal south of Preston Road and 57 feet north of Stuhr Road and average water-level slope of about 8.8 feet per mile. In Spring 2011, the average water-level

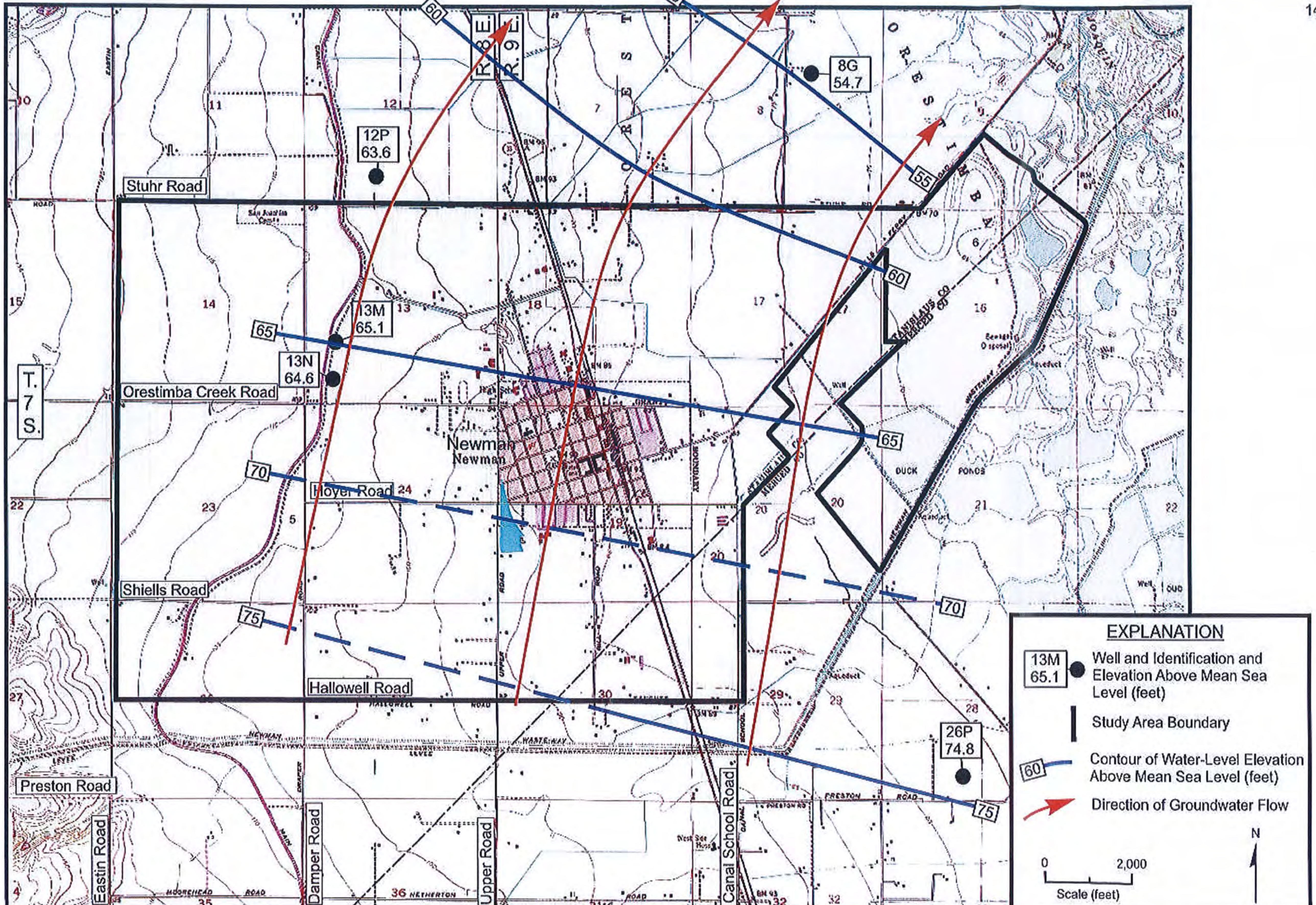


FIGURE 5 - WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW FOR UPPER AQUIFER (SPRING 2011)

slope was about 8.4 feet per mile. The direction of groundwater flow was to the north-northeast.

Figure 6 shows water-level elevations and the direction of groundwater flow for lower aquifer in Spring 2017. Some of the water-level elevations are for measurements in composite wells, and these values may be somewhat higher than actual elevations in the lower aquifer. Water-level elevations ranged from 49 feet above mean sea level at CCID wells near No. 3 the Main Canal to less than 20 feet at City Well No. 8. An easterly direction of groundwater flow was indicated.

Time Trends

The hydrologic base period utilized for the SJREC GSA is from 2003 to 2012. Thus Spring 2003-Spring 2013 water-level measurements were reviewed in terms of time trends.

City Wells

Water-level measurements for Well 1-R are only available for 2001-04, which is too short of a period to be utilized in this evaluation. Figure 7 is a water-level hydrograph for Well No. 5. The spring water levels in this well have slightly declined since 2001. Between Spring 2003 and Spring 2013, the water level in this well fell an average of about 0.7 foot per year. Figure 8 is a water-level hydrograph for Well No. 6. The spring water levels in

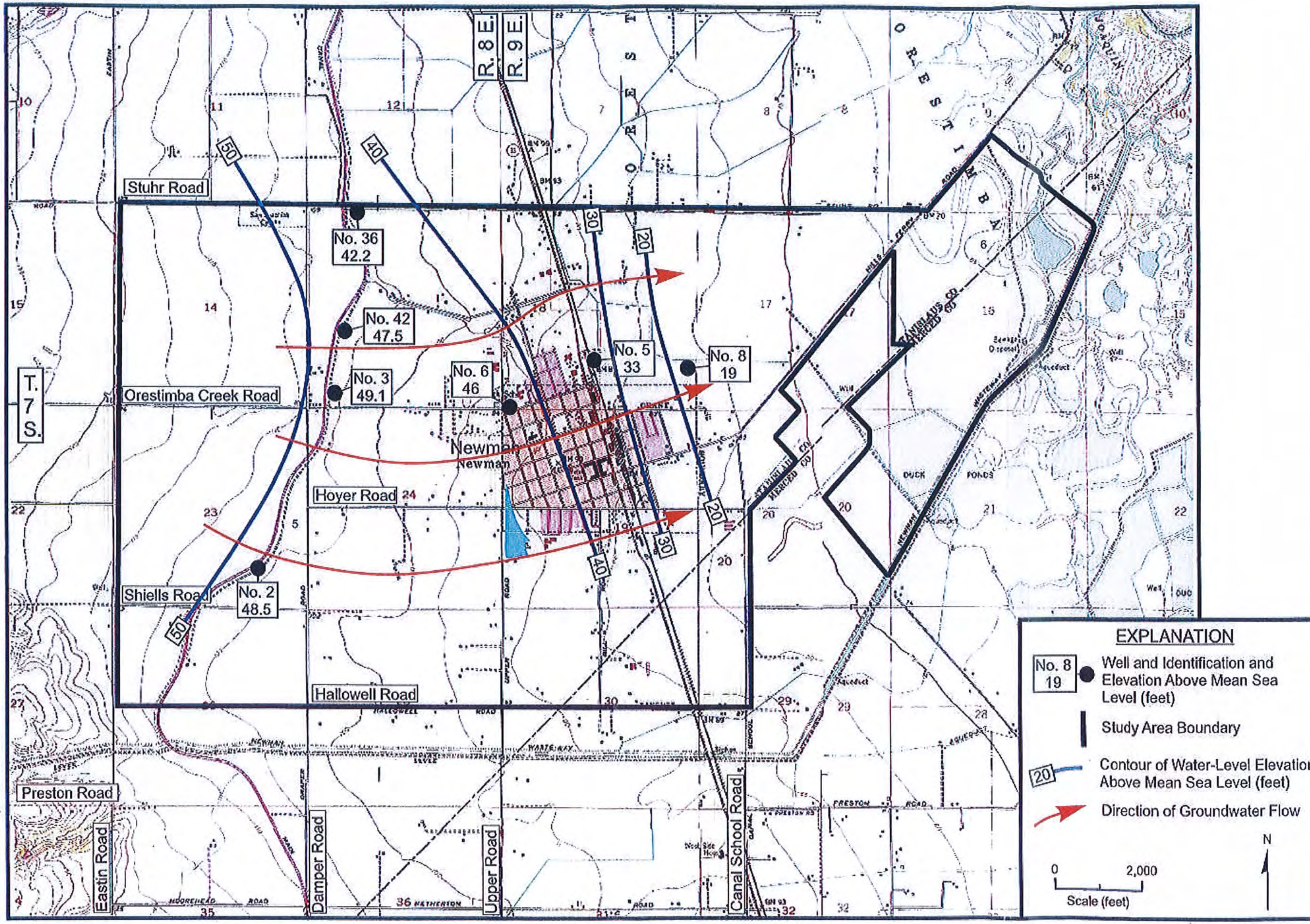


FIGURE 6 - WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW FOR LOWER AQUIFER (SPRING 2017)

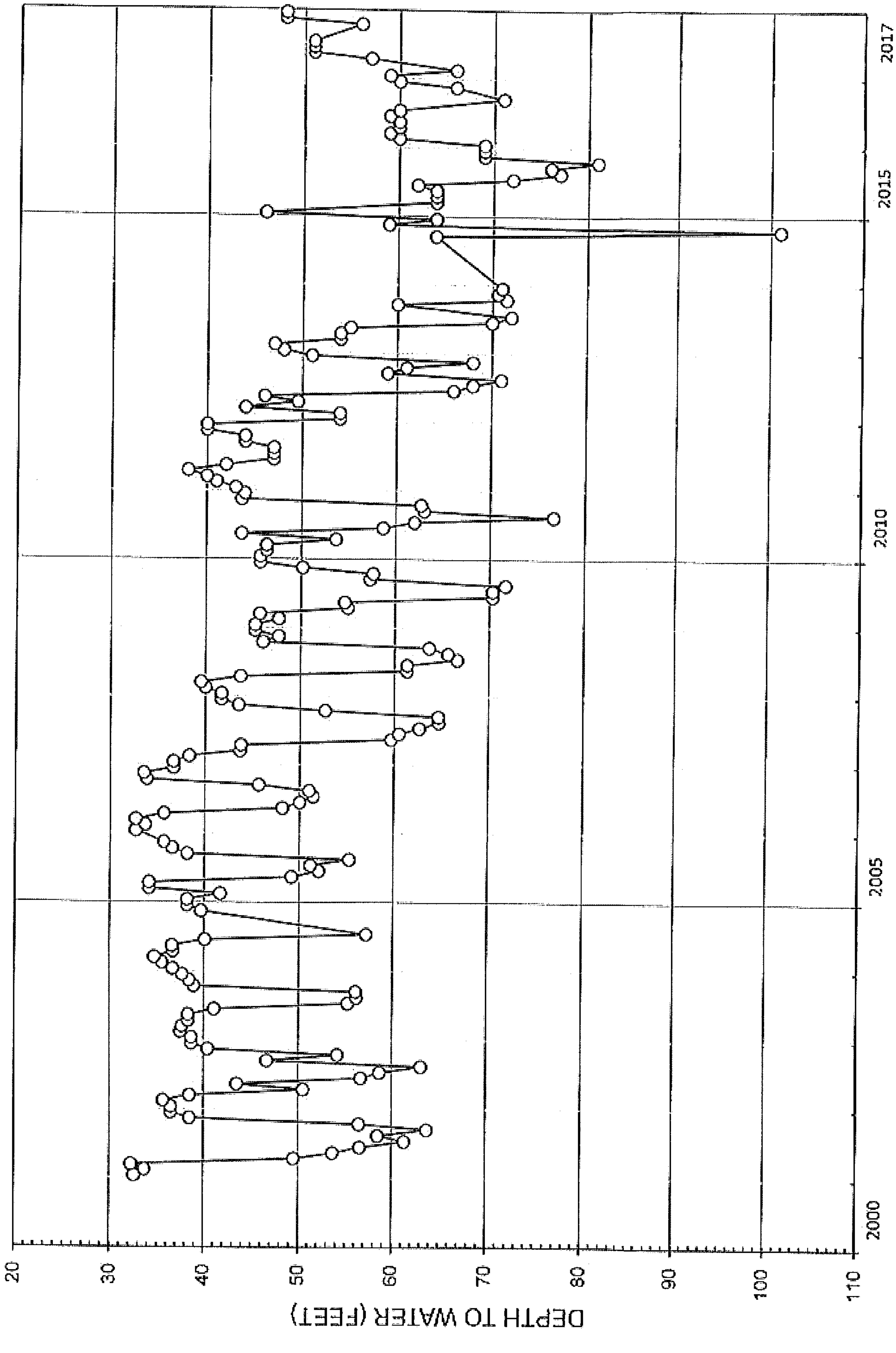


FIGURE 7- WATER-LEVEL HYDROGRAPH FOR CITY OF NEWMAN WELL NO. 5

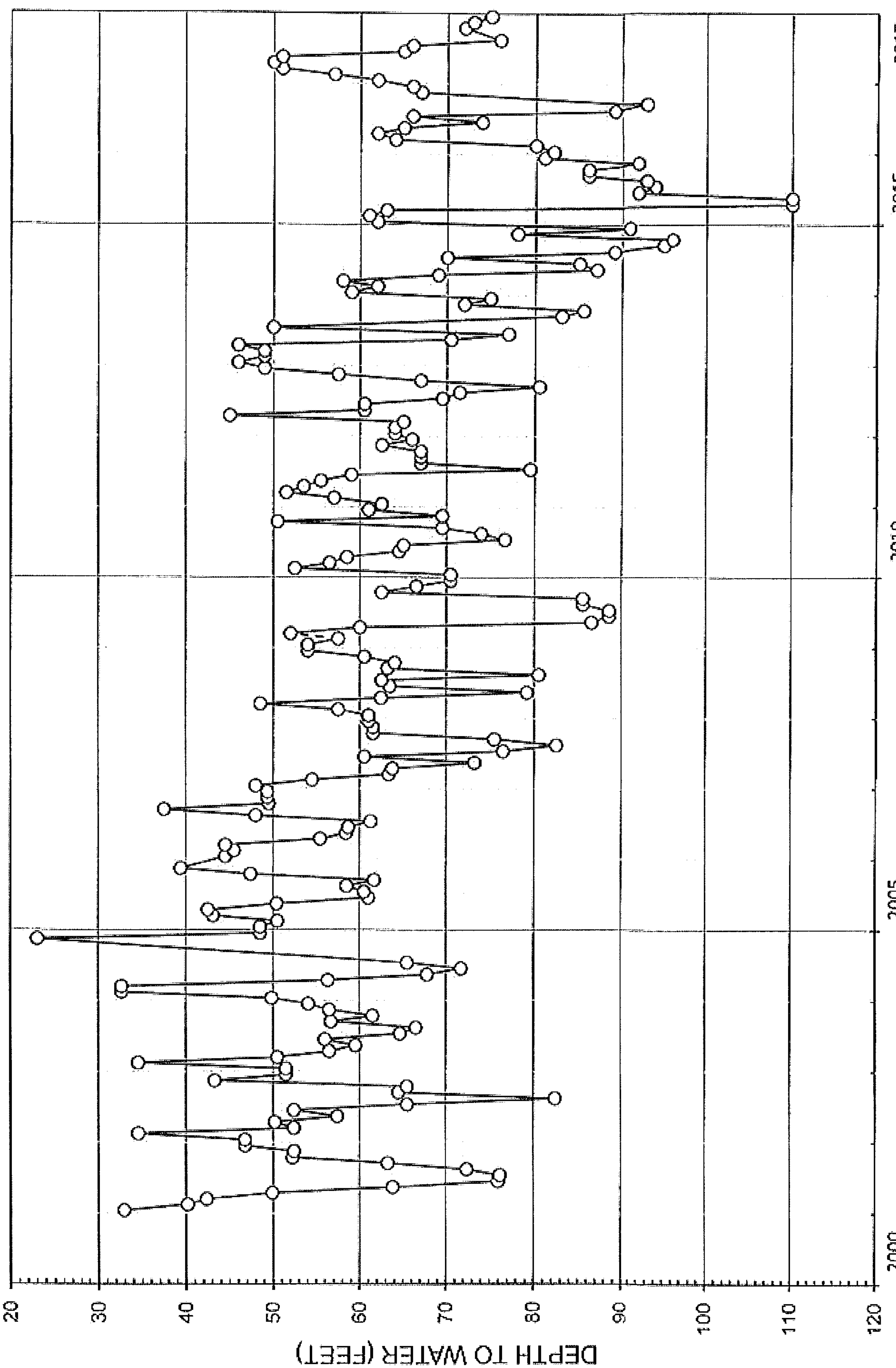


FIGURE 8- WATER-LEVEL HYDROGRAPH FOR CITY OF NEWMAN WELL NO. 6

this well have also declined since 2001. Between Spring 2003 and Spring 2013, the water level in this well fell an average of 1.3 feet per year. Both Wells No. 5 and 6 are composite wells. Figure 9 shows a water-level hydrograph for Well No. 8, which is a lower aquifer well. Measurements for this well prior to 2005 aren't available. Spring water levels fell from 21 feet in 2005 to 40 feet in 2012, or an average decline of 2.1 feet per year. This decline is considered representative of the lower aquifer in the City.

CCID Wells

Long-term water-level hydrographs for the four CCID wells are provided in Figure 10, 11, 12, and 13. Since 1965, water levels in these wells were relatively stable prior to 2013. Water levels in all of these wells fell during 2013-16, and had partially recovered by Spring 2018. Between Spring 2003 and Spring 2013, water levels in two of these wells (No. 3 and 42) were essentially stable. Water levels in the other two wells (No. 2 and No. 36) fell at average rates ranging from 0.2 to 0.8 foot per year. Overall, records for the four CCID wells indicate an average water-level decline of 0.25 foot per year. All of these wells are composite wells, tapping both aquifers.

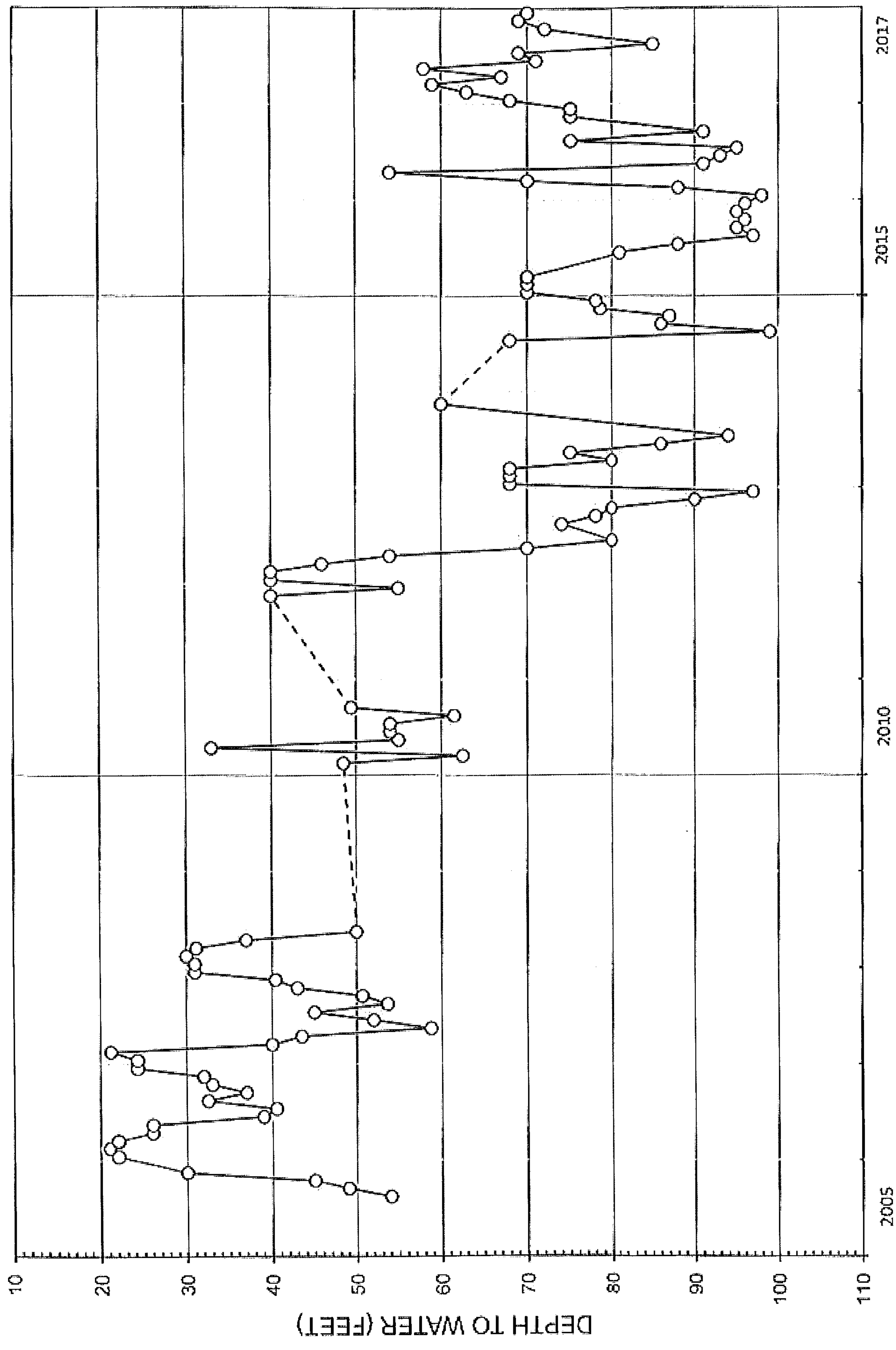


FIGURE 9- WATER-LEVEL HYDROGRAPH FOR CITY OF NEWMAN WELL NO. 8

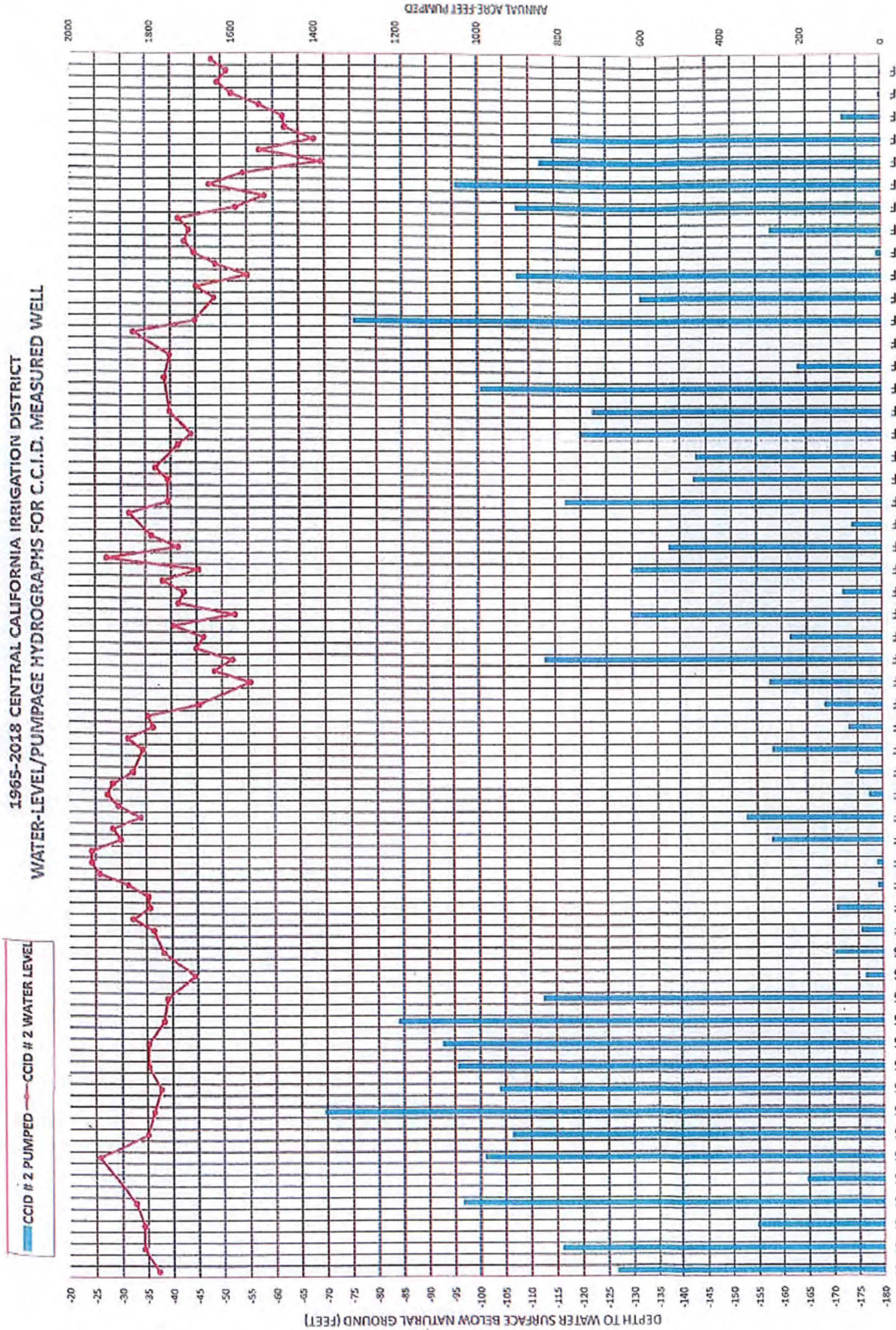


FIGURE 10 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR COMPOSITE DISTRICT WELL NO. 2 IN THE NEWMAN WELL FIELD

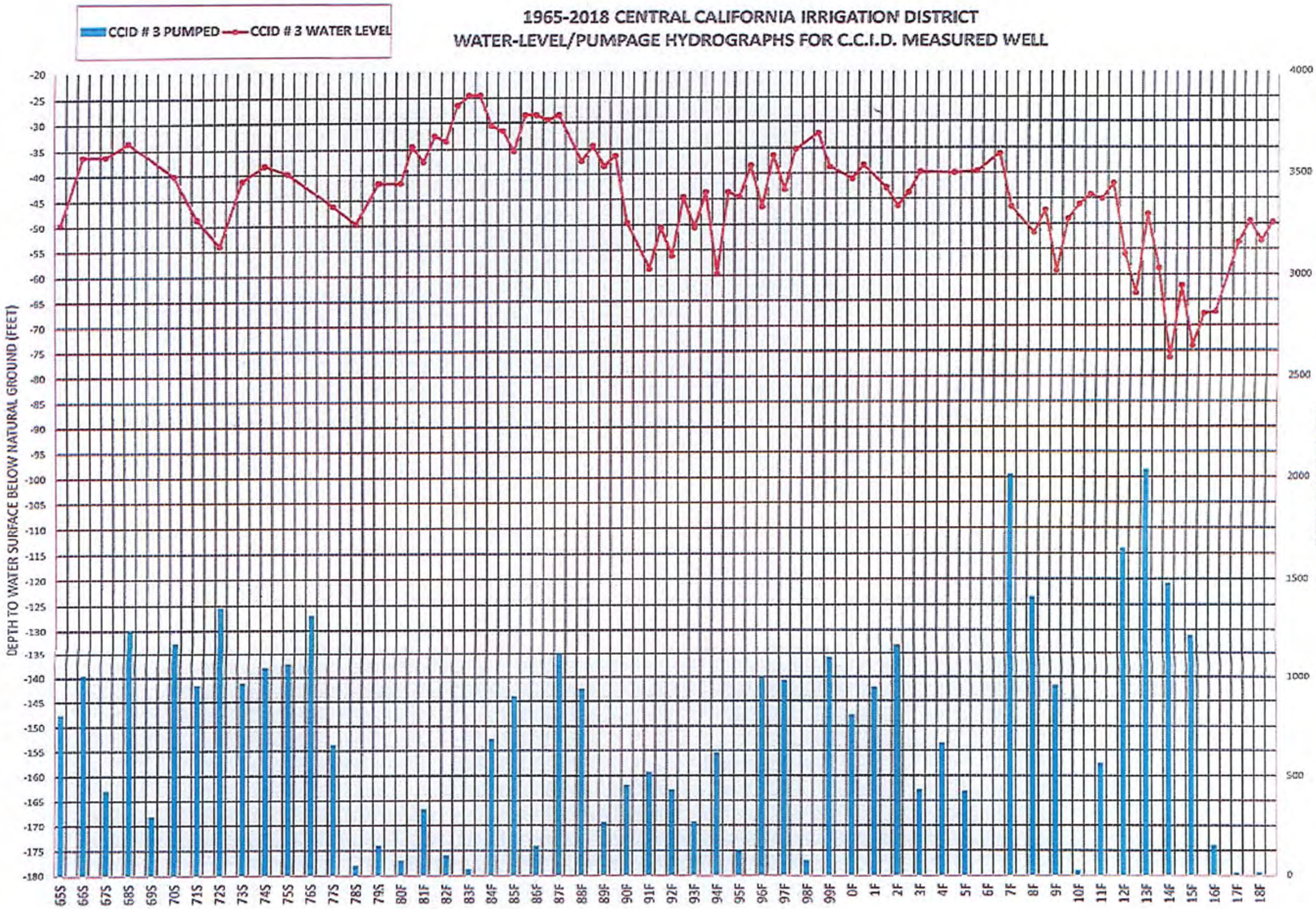


FIGURE 11 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR THE DISTRICT WELL NO. 3 IN THE NEWMAN WELL FIELD

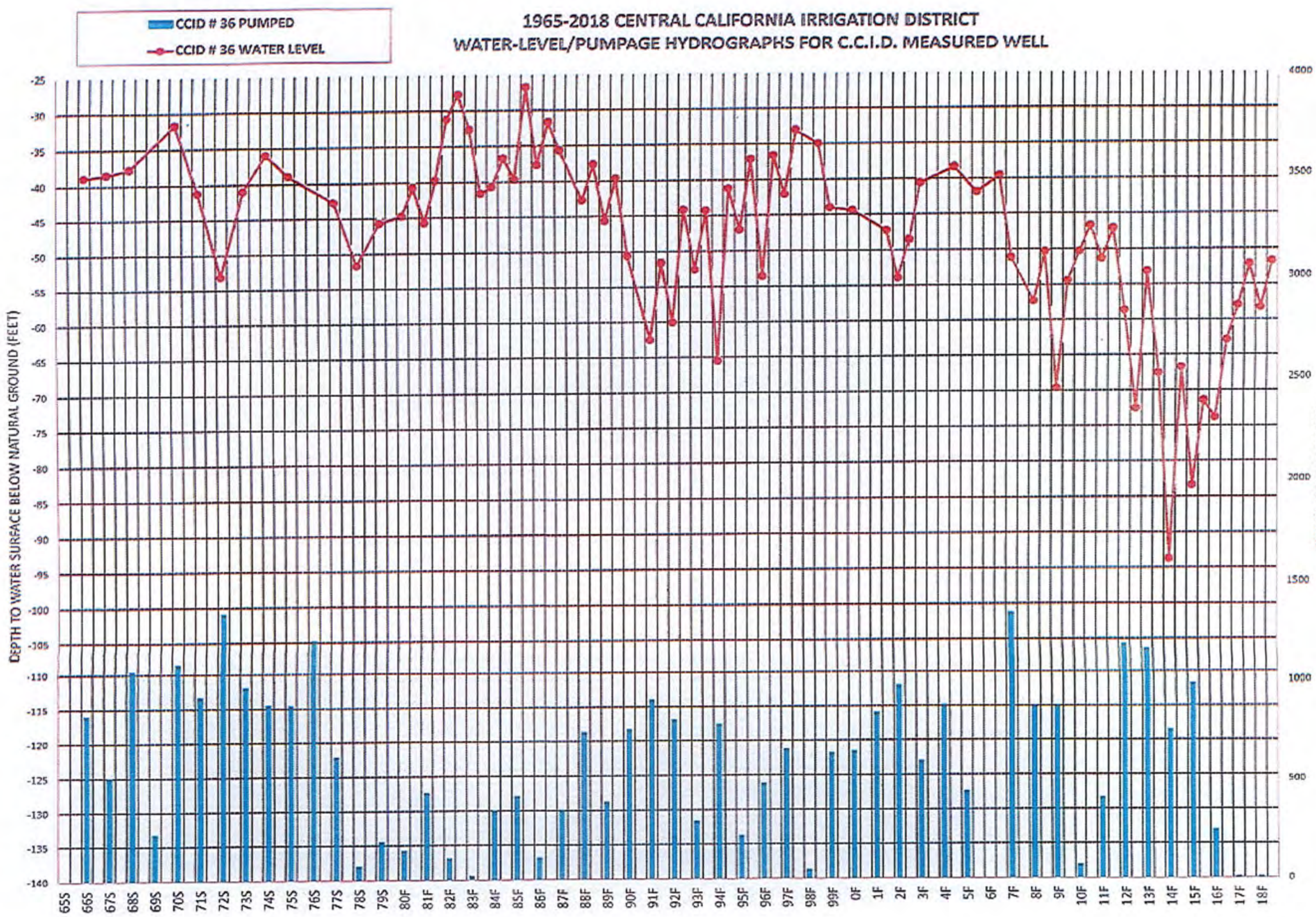


FIGURE 12 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR THE DISTRICT WELL NO. 36 IN THE NEWMAN WELL FIELD

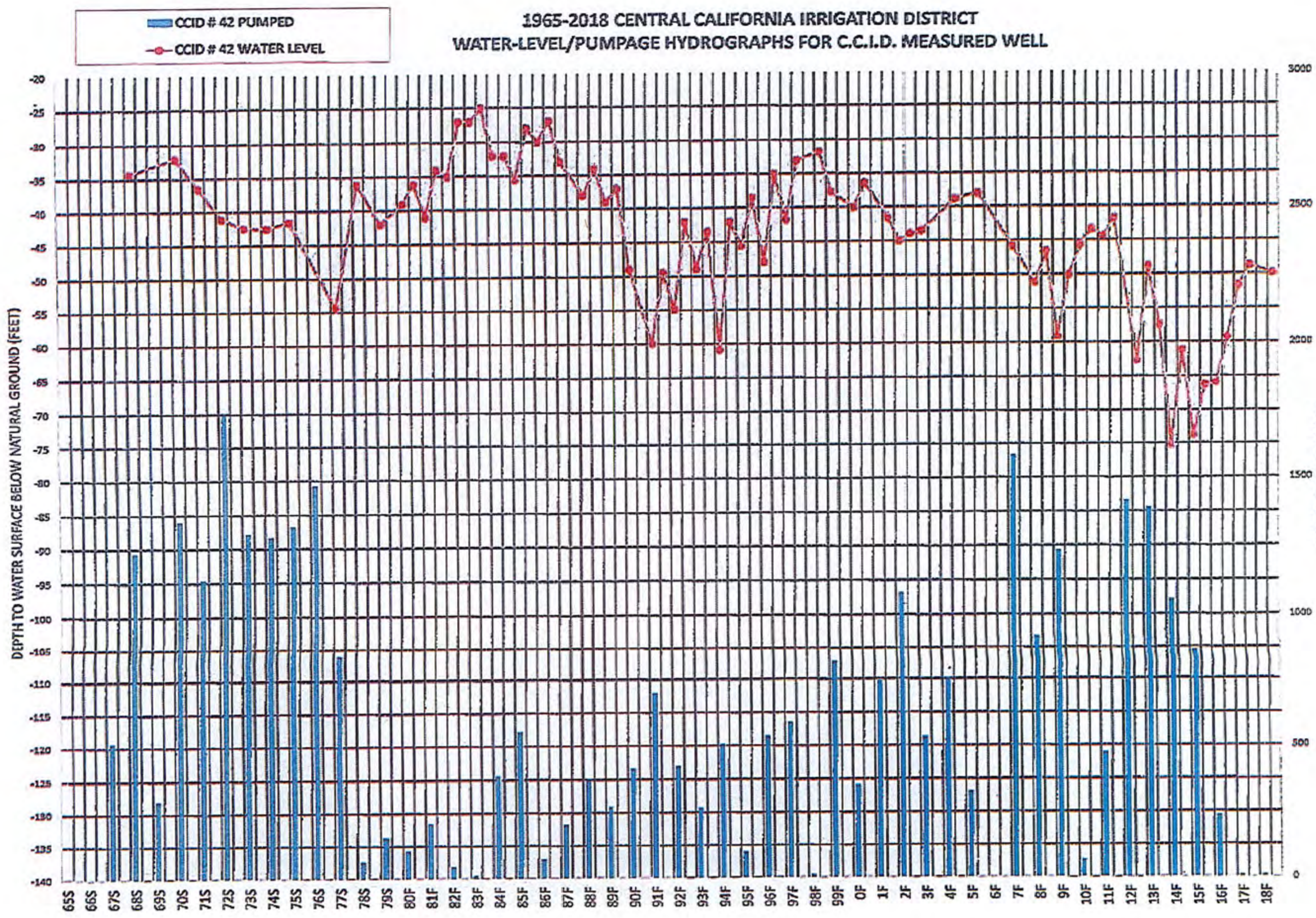


FIGURE 13 - LONG-TERM WATER LEVEL AND PUMPAGE HYDROGRAPHS FOR THE DISTRICT WELL NO. 42 IN THE NEWMAN WELL FIELD

AQUIFER CHARACTERISTICS

Table 3 summarizes pump test data for three of the active City wells for the 1990's. Recent pump test have not been provided. Pumping rates of the City wells ranged from about 1,200 to 1,600 gpm, and specific capacities ranged from 30 to 73 gpm per foot. The highest specific capacity was for Well No. 6. Table 4 shows pump test results for four CCID wells in October 2016. Pumping rates ranged from about 1,380 to 1,740 gpm. Except for one well, specific capacity values ranged from 62 to 68 gpm per foot. Based on information in the 1992 KDSA report, the transmissivity of the upper aquifer beneath the City is estimated to be about 23,000 gpd per foot. The combined transmissivity of the upper and lower aquifers above a depth of about 550 feet at Newman is estimated to average about 90,000 gpd per foot. This indicates the high productivity of the lower aquifer at Newman. The combined transmissivity of the upper and lower aquifers above a depth of about 420 feet near the Main Canal is estimated to be about 120,000 gpd per day per foot.

Darcy's Law can be used to estimate groundwater flow into the urban area. Using a transmissivity of 23,000 gpd per foot, a width of flow of about 2.6 miles (using general Plan boundaries) in Spring 2011, and an average water-level slope of about 8.4 feet per mile, the amount of groundwater flow in the upper aquifer

TABLE 3-PUMP TEST DATA FOR CITY OF NEWMAN WELLS

No.	Date Tested	Pumping Rate (feet)	Static Level (feet)	Pumping Level (inches)	Drawdown (feet)	Specific Capacity (gpm/ft)
1R	8/27/94	1,600	77.0	130.0	53.0	30.2
5	7/06/92	1,600	47.0	95.1	48.1	33.3
6	10/05/90	1,200	47.0	63.5	16.5	72.7

Data from City of Newman records.

TABLE 4-PUMP TEST DATA FOR CCID WELLS

No.	Date Tested	Pumping Rate (feet)	Static Level (feet)	Pumping Level (inches)	Drawdown (feet)	Specific Capacity (gpm/ft)
2	10/15/16	1,378	65.8	85.8	20.1	62.4
3	10/15/16	1,744	71.6	78.8	7.2	200.0
36	10/15/16	1,520	78.8	100.3	21.5	67.5
42	10/15/16	1,603	69.9	91.9	22.1	66.6

Records from CCID.

was calculated to be about 560 acre-feet per year. For the lower aquifer, using a transmissivity of 67,000 gpd per foot, a width of flow of 2.75 miles, and an average water-level slope of about 10 feet per mile, there were about 2,100 acre-feet per year of groundwater inflow for Spring 2017. As discussed in the following section, about 2,100 acre-feet of groundwater were pumped in the urban area in 2017. An estimated 1,750 acre-feet per year of this pumpage was from the lower aquifer. The amount of groundwater flow into the General Plan was greater than the net consumptive use of groundwater pumped in the urban area (i.e., pumpage minus incidental recharge).

PUMPAGE

Table 5 provides a summary of annual pumpage by the City of Newman, the CCID, and from private wells in the study area from 2003-2017. City pumpage increased from about 1,000 acre-feet per year in 1991, to 1,800 acre-feet per year in 2000, and 2,700 acre-feet per year in 2007. After 2007, City pumping decreased to about 2,200 acre-feet in 2011 due to water conservation measures. City pumpage was 2,600 acre-feet in 2012, and then decreased due to water conservation measures to about 1,900 acre-feet in 2015. The average City pumpage during 2002-17 was 2,340 acre-feet per year. The average CCID well pumpage during 2003-17 was about 3,260 acre-feet per year. Total pumpage by CCID from their

TABLE 5-ANNUAL PUMPAGE (1989-2017)
(ACRE FEET PER YEAR)

Year	City Wells	CCID Wells	Private Wells
2002	2,038	-	-
2003	2,089	2,552	1,493
2004	2,381	3,356	1,808
2005	2,498	1,399	1,920
2006	2,670	-	527
2007	2,716	4,802	1,957
2008	2,682	4,862	1,883
2009	2,470	3,956	1,459
2010	2,275	163	255
2011	2,208	1,716	1,021
2012	2,593	5,078	784
2013	2,534	4,857	2,516
2014	2,324	4,719	2,338
2015	1,918	4,055	6,687
2016	2,004	834	698
2017	2,083	-	756
Average	2,343	3,258	1,690

wells varies substantially, depending on canal water supplies. For example, only about 160 acre-feet were pumped in 2010, whereas about 5,080 acre-feet were pumped in 2012. There are also a number of private irrigation wells in the study area, and CCID provided estimates of pumpage from these wells. Pumpage from these wells ranged from about 260 acre-feet in 2010 to 6,690 acre-feet in 2015. The average pumpage from these private wells was 1,690 acre-feet per year for 2003-2017. The average total pumpage in the study area was thus about 7,300 acre-feet from 2003-17.

CITY EFFLUENT

Table 6 shows amounts of City effluent for 2003-2016. About 300 acres of pasture, alfalfa, oats and corn have normally been irrigated with the effluent, and this has been supplemented by well pumpage. There are 135 acres of holding ponds for the effluent. The amount of effluent used for irrigation ranged from about 600 acre-feet per year to 1,300 acre-feet per year during 2003-16. The average amount of effluent applied during this period was 900 acre-feet per year. Of this amount, an estimated 70 percent, or 630 acre-feet per year was consumed by evapotranspiration. The total amount of effluent during this period is estimated to have been about half of the City pumpage, or about 1,200 acre feet per year. This indicates that an average of

TABLE 6-AMOUNTS OF CITY EFFLUENT
USED FOR IRRIGATION

Year	Amount (acre-feet)
2003	800
2004	800
2005	800
2006	1,100
2007	1,400
2008	1,400
2009	1,100
2010	800
2011	900
2012	1,600
2013	1,700
2014	1,500
2015	1,300
2016	1,000
Average	1,200

An estimated 300 acre-feet per year of effluent was evaporated from holding ponds.

about 300 acre-feet per year of effluent was probably lost to evaporation from the holding ponds. An average of about 360 acre-feet per year of well pumpage has been used to supplement the effluent for irrigation.

CANAL WATER DELIVERIES

Table 7 shows CCID canal water deliveries to lands in the study area for 2003-16. Canal water was delivered to 2,600 acres of land each year during this period. The amount of canal water ranged from 450 acre-feet in 2004 to 9,600 acre-feet in 2009. The average amount of canal water delivered was 7,500 acre-feet per year during this period, or an average of 2.9 acre-feet per acre per year.

CONSUMPTIVE USE

Urban

Urban consumptive use includes evapotranspiration of water from outside water use (lawns, parks, etc), and evapotranspiration and evaporation of City effluent. The outside water use is estimated by subtracting the amount of effluent from the City pumpage. The average City pumpage from 2002-17 was 2,340 acre-feet per year and the average amount of City effluent was about 1,200 acre-feet per year. This indicates that an average of about 300 acre-feet per year was probably lost due to pond

TABLE 7-CCID CANAL WATER DELIVERIES
TO LANDS IN STUDY AREA

Year	Amount (acre-feet)
2003	8,200
2004	8,300
2005	7,200
2006	7,700
2007	9,300
2008	8,900
2009	9,600
2010	7,500
2011	6,500
2012	7,800
2013	7,600
2014	4,500
2015	5,800
2016	5,600

The canal water was used for irrigation of 2,600 acres of land.

evaporation. An average of about 360 acre-feet per year of well pumpage has been used to supplement the effluent for irrigation. The average City outside water use would be 1,140 acre-feet per year. The evapotranspiration for the outside water use is estimated to be 70 percent of this, or 800 acre-feet per year. For the effluent, it is estimated that an average of 630 acre-feet per year was consumed by evapotranspiration of irrigated crops and 300 acre-feet per year was lost due to evaporation from the holding ponds. The total urban consumptive use was thus about 1,700 acre-feet per year (rounded).

Rural

CCID estimated the evapotranspiration of applied water to crops in the study area. The ITRC water use study report for 1997-2008 was used to determine the evapotranspiration of applied water to crops (ET_{IW}) for 2003-08. For 2009-16, the total evapotranspiration (ETc) was determined from the IRRC metric report (landsat data). ET_{IW} values averaged 80 percent of the ETc values. Thus where ET_{IW} valued weren't available, the ETc values were multiplied by 80 percent to estimate the ET_{IW} values. The evapotranspiration of applied water to crops in the study area averaged about 7,700 acre feet per year for 2003-2016.

Total

The average urban and rural consumptive in the study area was 9,400 acre-feet per year for 2003-16.

LAND SUBSIDENCE

Records of land subsidence are available for the DMC, about 3.5 miles west of the study area. At that location there was about 0.5 foot of subsidence during 2014-16. Records of land subsidence along the San Joaquin River east of Newman indicate minimal subsidence. Land subsidence in the Newman urban area has not been measured.

CHANGE IN GROUNDWATER IN STORAGE

Water levels in wells tapping the upper unconfined aquifer in the Newman area have indicated no long-term change in storage. There has also been no significant change in storage in the confined aquifer, as it has remained full of water. However, there has been a one time decrease in storage for the confining beds, due to compaction of these beds, which has resulted in land subsidence. Assuming and average subsidence of about 0.1 foot per year over the 3,800 acre area, this amount of water for 2003-12 averaged about 40 acre-feet per year.

GROUNDWATER QUALITY

Inorganic Chemical Constituents

City Wells

Table 8 provides the results of chemical analyses of water from active City wells in recent years.

Composite Wells. Wells No. 5 and 8 are composite wells. The total dissolved solids (TDS) concentrations in July 2017 ranged from 812 to 901 mg/l. Nitrate concentrations ranged from 11 to 32 mg/l, less than the MCL of 45 mg/l. Chloride concentrations ranged from 150 to 197 mg/l, less than the recommended of 250 mg/l. Concentrations or iron, manganese, arsenic, and selenium were less than the respective MCLs. Hexavalent chromium concentrations in water from Well No. 5 have ranged considerably in recent years, from non-detectable to 16 ppb. This is probably associated with varying pumping durations prior to when the water samples were collected for analyses. Hexavalent chromium concentrations in water from Well No. 8 have ranged from 4 to 10 ppb from 2015 to 2018, and decreased during this period. Alpha activities have been below the MCL of 15 picocuries per liter.

Lower Aquifer Wells. Wells No. 1R and 6 are lower aquifer wells. TDS concentrations in water from these wells ranged from 764 to 847 mg/l in July 2016. Nitrate concentrations ranged from 20 to

TABLE 8-CHEMICAL QUALITY OF WATER FROM CITY OF NEWMAN WELLS

Constituent (mg/l)	No. 1R	No. 5	No. 6	No. 8
Calcium	110	110	99	63
Magnesium	48	52	43	34
Sodium	104	115	86	138
Potassium	-	4	-	-
Bicarbonate	340	442	383	304
Sulfate	166	168	176	168
Chloride	222	150	136	197
Nitrate	22	32	20	11
Fluoride	0.2	0.2	0.2	0.2
pH	7.4	7.6	7.5	7.4
Electrical Conductivity (micromhos/cm @ 25°C)	1,530	1,440	1,300	1,390
Total Dissolved Solids (@ 180°C)	847	901	764	812
Iron	<0.1	<0.1	<0.1	<0.1
Manganese	<0.02	<0.02	<0.02	<0.02
Arsenic (ppb)	<2	<2	<2	<2
Hexavalent Chromium (ppb)	<1	0.1-16	5	4
Selenium (ppb)	<5	<5	<5	-
Alpha Activity (picocuries per liter)	6	-	5	<3
Date	7/6/16	7/2/13	7/6/16	7/6/17
Perforated Interval (feet)	340-620	162-450	351-500	180-480

22 mg/l, less than the MCL of 45 mg/l. Chloride concentrations ranged from 136 to 222 mg/l, less than the MCL of 250 mg/l. Concentrations of iron, manganese, arsenic, and selenium were below the respective MCLs. Hexavalent chromium concentrations in water from Well No. 1R have been about 1 ppb or less, well below the MCL of 10 ppb. Concentrations of hexavalent chromium in water from Well No. 6 have ranged from about 5 to 9.6 ppb in recent years, and have decreased since 2015. Alpha activities have ranged from about 4.5 to 5.6 picocuries per liter in water from Well No. 1R, and from about 3.1 to 9.9 picocuries per liter in water from Well No. 6, below the MCL of 15 picocuries per liter.

CCID Wells

Table 9 provides the results of inorganic chemical analyses of water from the four CCID wells in the study area for July 2017. All of these are composite wells. The perforated intervals shown are for the tops and bottoms of the perforations. TDS concentrations ranged from 870 to 1,200 mg/l and nitrate concentrations ranged from 7 to 11 mg/l, below the MCL of 45 mg/l. Chloride concentrations ranged from 190 to 250 mg/l, compared to the recommended MCL of 250 mg/l. Sulfate concentrations ranged from 120 to 220 mg/l, less than the recommended MCL of 250 mg/l. Boron concentrations ranged from 0.45 to 0.69 mg/l, high enough to affect boron sensitive crops, if the proposed water was used

TABLE 9-CHEMICAL QUALITY OF WATER FROM CCID WELLS

Constituent (mg/l)	No. 2	No. 3	No. 36	No. 42
Calcium	100	110	44	54
Magnesium	50	56	58	70
Sodium	130	130	120	170
Potassium	3	3	3	4
Bicarbonate	366	439	427	488
Sulfate	120	170	180	220
Chloride	210	170	190	250
Nitrate	7	7	10	11
pH	7.8	7.8	7.9	7.8
Electrical Conductivity (micromhos/cm @ 25°C)	1,400	1,500	1,600	1,900
Total Dissolved Solids (@ 180°C)	870	910	980	1,200
Boron	0.5	0.5	0.5	0.7
Date	7/25/17	7/25/17	7/25/17	7/25/17
Perforated Interval (feet)	90-337	85-337	90-393	90-391

without mixing. The pumpage from CCID wells is mixed with canal water before use, and the resulting boron concentrations are acceptable for irrigation.

HISTORICAL WATER BUDGET

The average canal water delivery to lands in the study area was 7,500 acre-feet per year for 2003-16. The total consumptive use averaged 9,200 acre-feet per year during this period. The average groundwater inflow was 2,660 acre-feet per year. The change in groundwater storage was 40 acre-feet per year. In order to maintain a water budget, the groundwater outflow averaged about 1,010 acre-feet per year.

REFERENCES

Kenneth D. Schmidt & Associates, 1992, "Groundwater Conditions in the Vicinity of the City of Newman" report prepared for CCID and City of Newman, 30p

Kenneth D. Schmidt & Associates, 2001, "Groundwater Conditions in the Vicinity of the City of Newman" report prepared for CCID and City of Newman, 33p

Page, R. L., 1986, "Geology of the Fresh Groundwater Basin of the San Joaquin Valley, California", U.S. Geological Survey Professional Paper 1401-C.

Appendix R. Update on Groundwater Conditions in the Gustine Sub-Area of the SJREC GSP

UPDATE ON GROUNDWATER CONDITIONS IN THE GUSTINE SUB-AREA OF THE SJREC GSP

prepared for
San Joaquin River Exchange
Contractors GSA
Los Banos, California

and
City of Gustine GSA
Gustine, California

by
Kenneth D. Schmidt & Associates
Groundwater Quality Consultants
Fresno, California

May 2019

KENNETH D. SCHMIDT AND ASSOCIATES
GROUNDWATER QUALITY CONSULTANTS
600 WEST SHAW AVE., SUITE 250
FRESNO, CALIFORNIA 93704
TELEPHONE (559) 224-4412

May 31, 2019

Mr. Chris White, Executive Director
San Joaquin River Exchange
  Contractors GSA
P. O. Box 2115
Los Banos, CA 93635

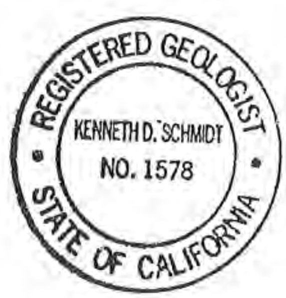
Re: Gustine Sub-Area of the
  SJREC GSP

Dear Chris:

Submitted herewith is our report on groundwater conditions in the Gustine Sub-area of the SJREC GSP. We appreciate the cooperation of the CCID and City of Gustine in providing information for this report.

Sincerely Yours,

Kenneth D. Schmidt
Geologist No. 1578
Certified Hydrogeologist 176



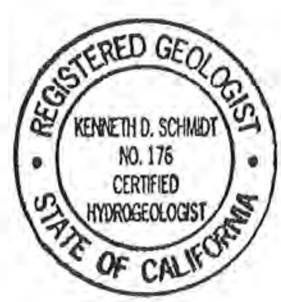


TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

UPDATE ON GROUNDWATER CONDITIONS IN THE GUSTINE SUB-AREA OF THE SJREC GSP

INTRODUCTION

As part of the Groundwater Sustainability Plan (GSP) for the San Joaquin River Exchange Contractors (SJREC) service area, GSPs for a number of cities, including Gustine, are being incorporated into the SJREC GSP. Kenneth D. Schmidt and Associates (KDSA, 1992 and 2001) prepared two reports on groundwater conditions in the vicinity of the City of Gustine for the Central California Irrigation District (CCID) and the City.

This report is intended to provide an update on groundwater conditions within the Gustine Study Area boundary (Figure 1). This boundary encompasses lands that are planned for future urban development. This study area is generally bounded by Jensen Road or Highway 140 on the north, Whitworth Road on the west, Gun Club Road on the south, and includes lands to the east where the City effluent is handled. Lands around the City of Gustine are in the SJREC GSA, and some lands to the north and south of the WWTF are in the Merced County Delta-Mendota GSA.

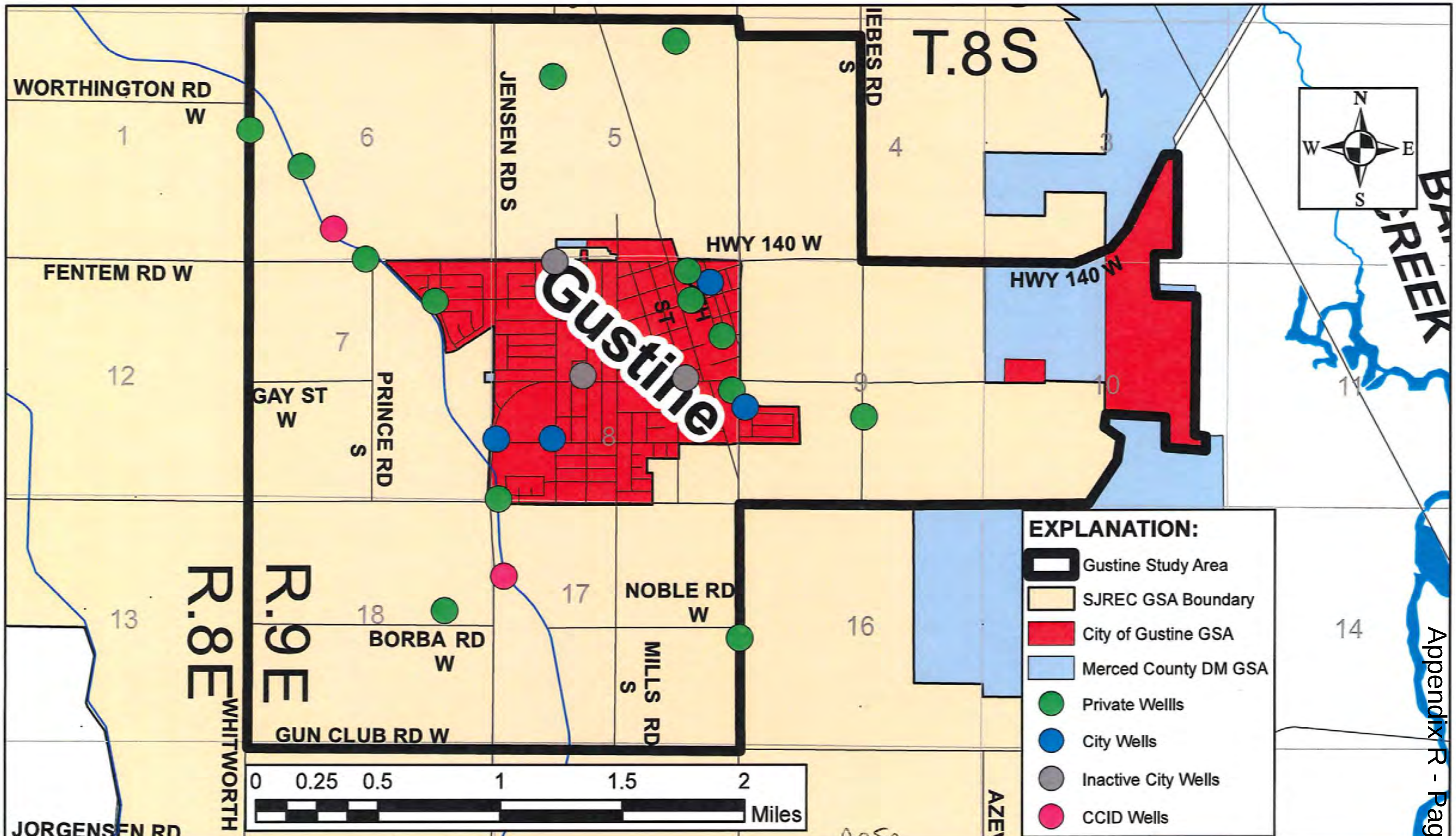


FIGURE 1-LOCATION OF GUSTINE SUB-AREA, STUDY AREA BOUNDARY, AND SELECTED WELLS

SUBSURFACE GEOLOGIC CONDITIONS

Alluvial deposits comprise the aquifer system beneath the western part of the San Joaquin Valley. Deposits near Gustine are termed the older alluvium and the Tulare Formation. Page (1986) indicated that the base of the fresh groundwater (electrical conductivity less than 3,000 micromhos per centimeter at 25°C) was about 900 feet deep near Gustine. This is considered the base of the usable groundwater in the vicinity. A major confining bed is present beneath much of the west side of the San Joaquin Valley, including Gustine. This clay is termed the Corcoran Clay, and divides the aquifer system into upper and lower aquifers. The Corcoran Clay is readily discernible from the drillers logs for most wells in the area, due to its blue color. The over-lying and under-lying deposits are usually tan or brown in color.

Most of the groundwater near Gustine is pumped from the upper aquifer (above the Corcoran Clay). One City well and some industrial and irrigation wells in the area were drilled to depths exceeding 450 feet, and tap the lower aquifer. As part of the previous investigations, three subsurface geologic cross sections extending through the City of Gustine were developed (Figure 2).

Subsurface Geologic Cross Section C-C' (Figure 3) extends from near Whitworth Road, between Sullivan and Gun Club Roads on

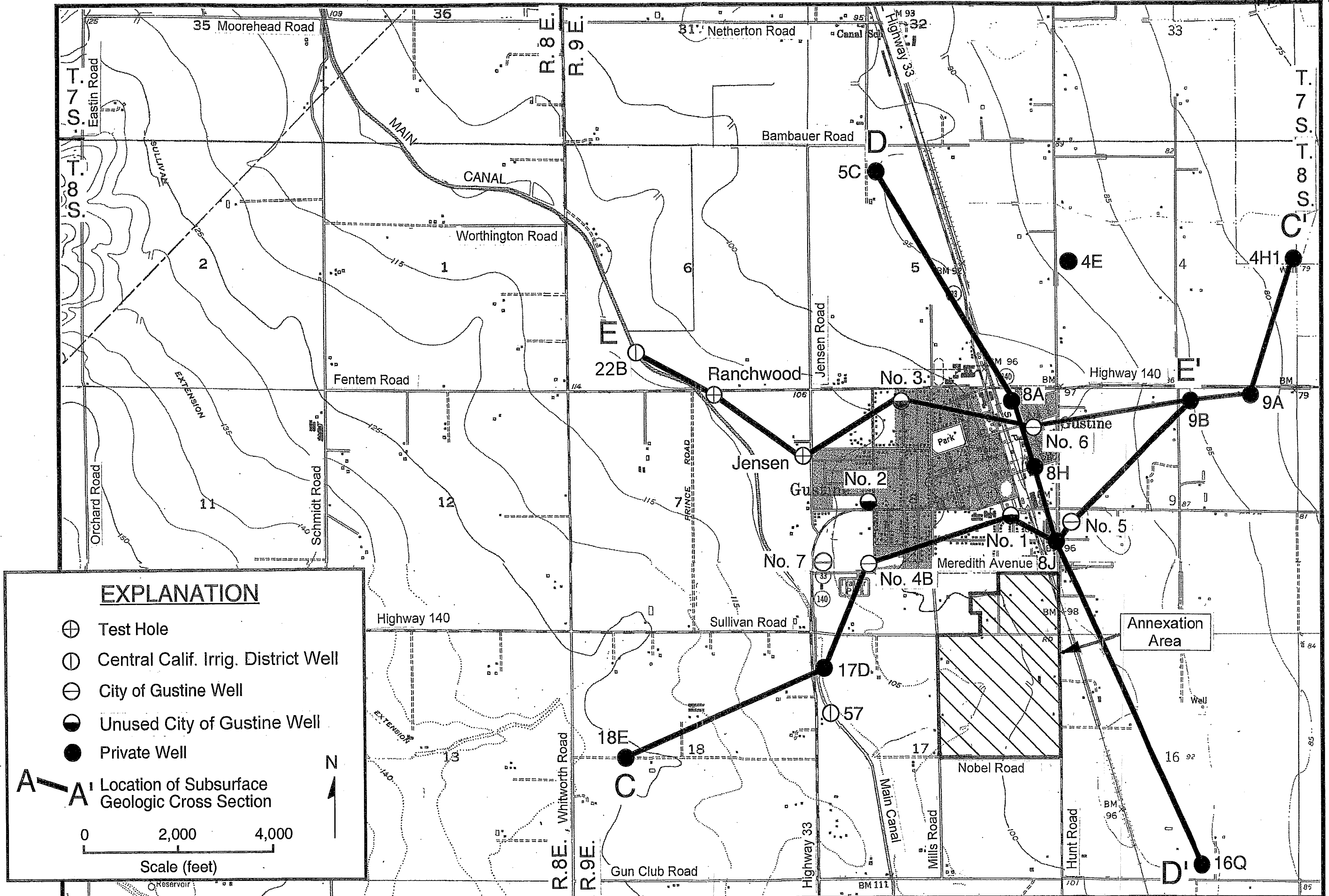


FIGURE 2-LOCATION OF SELECTED TEST HOLES AND WELLS AND SUBSURFACE GEOLOGIC CROSS SECTIONS

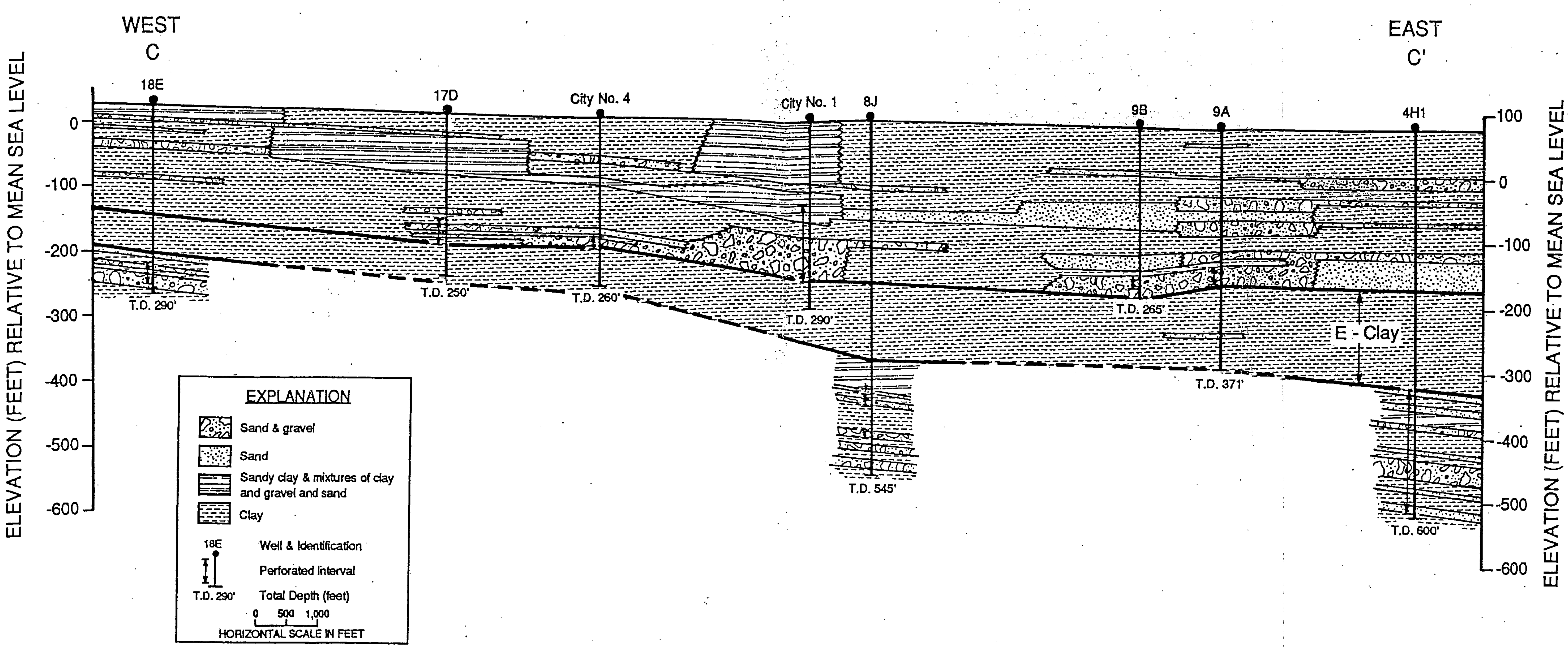


FIGURE 3-SUBSURFACE GEOLOGIC CROSS SECTION C-C'

the southwest, to the northeast through City Wells No. 1 and 4, thence northeast for about one and one-half miles. An electric log is available for City Well No. 1 and the other information was obtained from drillers logs. Two wells along this section (8J and 4H1) exceeded 540 feet in depth. Most of the wells along this section penetrated the Corcoran Clay, the top of which ranges from about 170 feet in depth at Well 18E to about 250 feet at Well 8J. The Corcoran Clay thickens to the north-east along this section, from about 60 feet at Well 18E to about 150 feet at Well 4H1. Beneath and northeast of the City, sand and gravel layers are common within the lower 100 feet of the upper aquifer. Below the Corcoran Clay, sand and gravel layers are relatively thin along this cross section.

Cross Section D-D' (Figure 4) extends from the northwest near Jensen and Baumbauer Roads, along Highway 33, through three in-dustrial wells, to a point near Gun Club Road and half a mile east of Hunt Road. The top of the Corcoran Clay ranges from about 225 feet deep at Well 5C to 260 feet deep at Well 8A. The Corcoran Clay appears to be relatively flat along this section, because the section is perpendicular to the inferred dip of the alluvial deposits. The thickness of the Corcoran Clay along this section ranges from about 85 feet at Well 8A to 120 feet at Well 8J. The sand and gravel layers in the lower part of the upper aquifer are thickest at Well 8H, and appear to thin

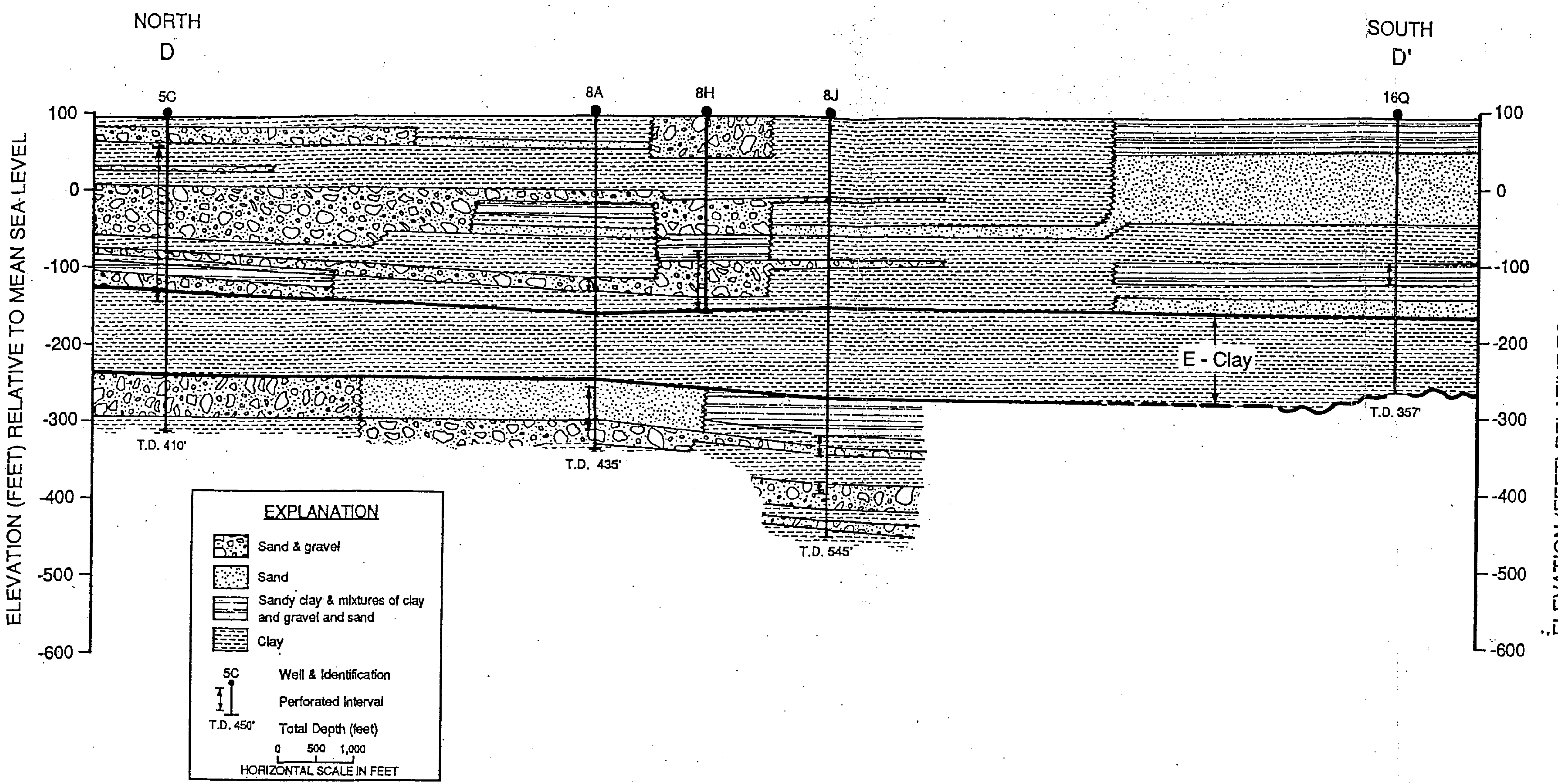


FIGURE 4-SUBSURFACE GEOLOGIC CROSS SECTION D-D'

to the south (at Well 16Q). Sand and gravel layers immediately below the Corcoran Clay are thickest to the northwest (Wells 5C and 8A). At Well 8J, sand and gravel layers in the lower aquifer are relatively thick and extend to a depth below 500 feet.

Cross Section E-E' (Figure 5) extends from CCID Well 22B adjacent to the Outside Canal, to the southeast and east, through City Wells No. 3 and 6. The top of the Corcoran Clay ranges from about 170 to 265 feet deep along this section. The Corcoran Clay along this section ranges from about 90 to 130 feet thick. Two thick, well developed sand and gravel strata were encountered above this clay along the northwest part of this section. Several thinner coarse-grained strata were also encountered below the clay at the Jensen test hole and City Well No. 6.

WELL CONSTRUCTION DATA

City

There are presently four active City wells (No. 4B, 5, 6, and 7). Table 1 provides information on dates drilled, depths, and perforated intervals for these wells. Drillers logs are available for all of these active wells and electric logs are available for Wells No. 1, 5, 6, and 7. Except for Well No. 5, cased depths range from 204 to 240 feet, and these wells tap water-

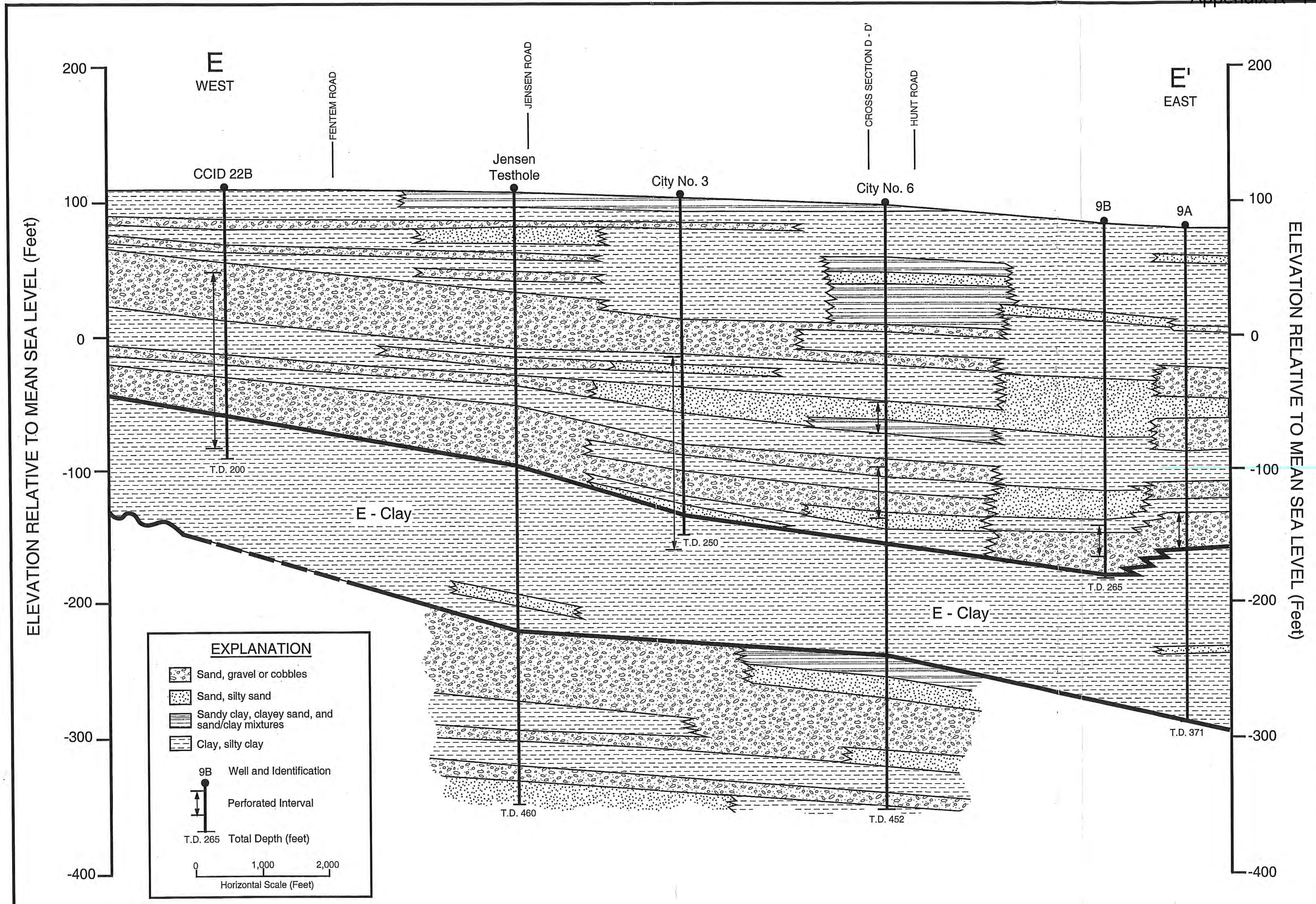


FIGURE 5-SUBSURFACE GEOLOGIC CROSS SECTION E-E'

TABLE 1-CONSTRUCTION DATA FOR CITY OF GUSTINE AND INDUSTRIAL WELLS

Well No.	State Location	Date Completed	Drilled Depth (feet)	Cased Depth (feet)	Diam. Casing (inches)	Perf. Int. feet)	Annular Seal (feet)
4B	8M2	09/93	250	200	16	167-200	0-167
5	9M	11/98	451	450	16	370-444	0-350
6	8A	12/98	250	240	16	145-230	0-130
7	4M	5/11	209	204	16	165-194	0-110
Formerly Beatrice Cheese	8A	05/73	435	200	16 414	- 12	0-50 210-410
Saputo	8H	12/56	254	254	14	174-254	0-60
Hillview Packing	8J	04/73	545	100	16	100-490	0-50

All of the wells are in T8S/R9E. Data from drillers logs, City of Gustine files, Avoset Foods, and Balding, Scott and Hotchkiss (1969). The perforated intervals are for the tops and bottoms of the perforated interval.

producing strata above the Corcoran Clay. Well No. 5 was perforated from 370 to 444 feet in depth and taps strata below the Corcoran Clay. This well has an annular seal extending to a depth of 350 feet.

CCID

The CCID has two wells along the Main Canal in the Gustine area. Table 2 shows construction data for these wells. Well No. 22B was completed in January 1999. Perforated casing was installed from 60 to 190 feet in depth in this well. Well No. 57 was installed in August 2000 and the casing is perforated from 70 to 190 feet in depth. Both wells tap strata above the Corcoran Clay.

Industrial

Drillers logs are available for three industrial wells in the City (Table 1). All of these wells are still active. Well 8a is cased to a depth of 414 feet and is a composite well (tapping both aquifers). Well 8H is 254 feet deep and taps only the upper aquifer. Well 8J is cased to a depth of 490 feet and is a composite well.

Gustine Drainage District

Table 3 contains construction data for Gustine Drainage District wells in the vicinity of Gustine. Depths of wells for which records are available and range from about 90 to 140 feet.

TABLE 2-CONSTRUCTION DATA FOR CCID WELLS

Well No.	Date Drilled	Drilled Depth(feet)	Cased Depth (feet)	Casing Diameter (inches)	Perforated Interval (feet)	Annular Seal feet)
22B	01/99	200	190	18	60-190	0-52
57	08/00	210	210	16	70-190	0-50

Data from drillers logs and Balding, Scott and Hotchkiss (1969).

TABLE 3-CONSTRUCTION DATA FOR GUSTINE DRAINAGE DISTRICT WELLS (T8S/R9E)

Well No.	State Location	Date Completed	Drilled Dept (feet)	Cased Depth (feet)	Casing Diam. (inches)	Perf.Int. (feet)
3	T8S/R9E-8N1	1953	136	136	16	130-250
14	5A2	1913	140	140	16	-
15	16M1	-	105	105	14	30-105
16	T7S/R9E-30H	1943	-	93	-	-

Data from drillers logs and Balding, Scott and Hotchkiss (1969).

The wells generally have shallow perforations, and were designed to tap the upper part of the upper aquifer. Water from one of these wells (No. 3) was used for irrigation at the Harry P. Schmidt Park in the City. Since 2001, tile drain systems have been installed beneath a number of irrigated fields. The tile drain systems have proven to be more effective to address sub-surface drainage problems, and drainage well pumping has gradually been replaced.

WATER LEVELS

Depth to Water

Near Gustine, most of the available water-level measurements are for wells tapping the upper aquifer. J.M. Lord, Inc. (1990) reported on depth to the shallow groundwater in the Gustine Drainage District, which surrounds the City of Gustine. In June 1989, depth to water ranged from less than five feet northeast and southeast of Gustine, to more than ten feet beneath parts of Gustine.

Water-Level Elevations

Water-level measurements for wells in the area were obtained from the California Department of Water Resources and CCID. The previous evaluation provided a water-level elevation contour map for Spring 2000, which was primarily based on large-capacity wells that tap the upper aquifer. A cone of depression beneath Gustine was indicated by those measurements. Water-level elevations in this depression ranged from about 70 to 80 feet above mean sea level, about 10 to 15 feet lower than those beneath the surrounding lands. Southwest of Gustine, water-level elevations ranged from about 100 to 120 feet above mean sea level. Northeast of Gustine, water-level elevations ranged from about 75 to 85 feet. The regional direction of groundwater flow in the upper aquifer near Gustine was to the northeast in Spring 2000. Limited data for the lower aquifer indicated a northerly direction of groundwater flow, toward Newman. Water-level elevations in the lower aquifer were indicated to be about 20 feet below the upper aquifer in Spring 2000.

Figure 6 shows water-level elevations and the direction of groundwater flow for March 2011. Water-level elevations ranged from 108 feet above mean sea level near Gun Club Road, about three miles southwest of the City to 78 feet about a mile northeast of the City. Southwest of Gustine, March 2011 water levels were about 20 feet lower than in Spring 2000. North of Gustine, water levels were close to those in Spring 2000. The direction of groundwater flow was to the northeast. A cone of depression was not indicated beneath the City, but that was due to a lack of water-level measurements for City wells.

Water-Level Trends

Frequent water-level measurements are available for several wells near Gustine during recent decades. Figure 7 shows water-

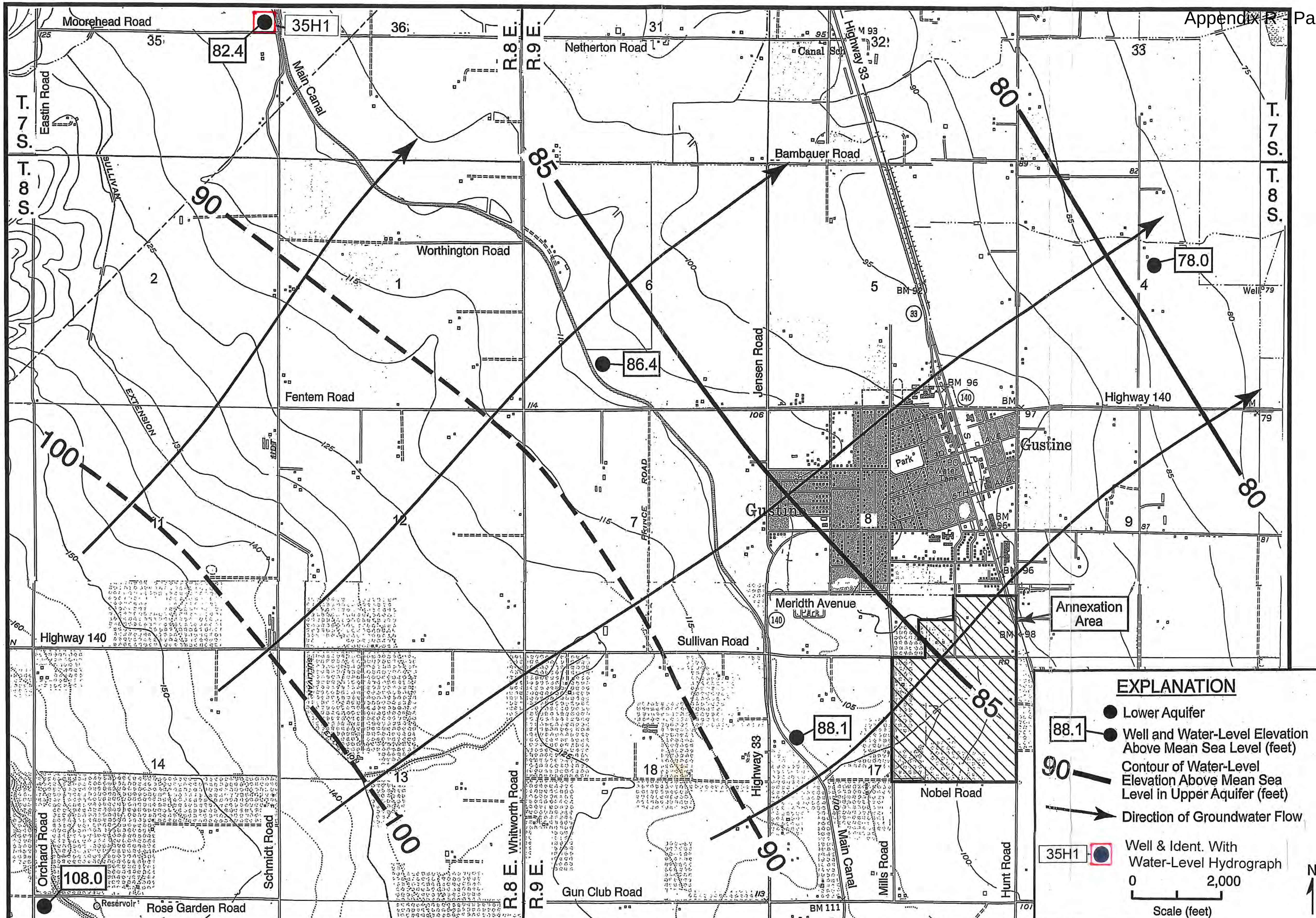
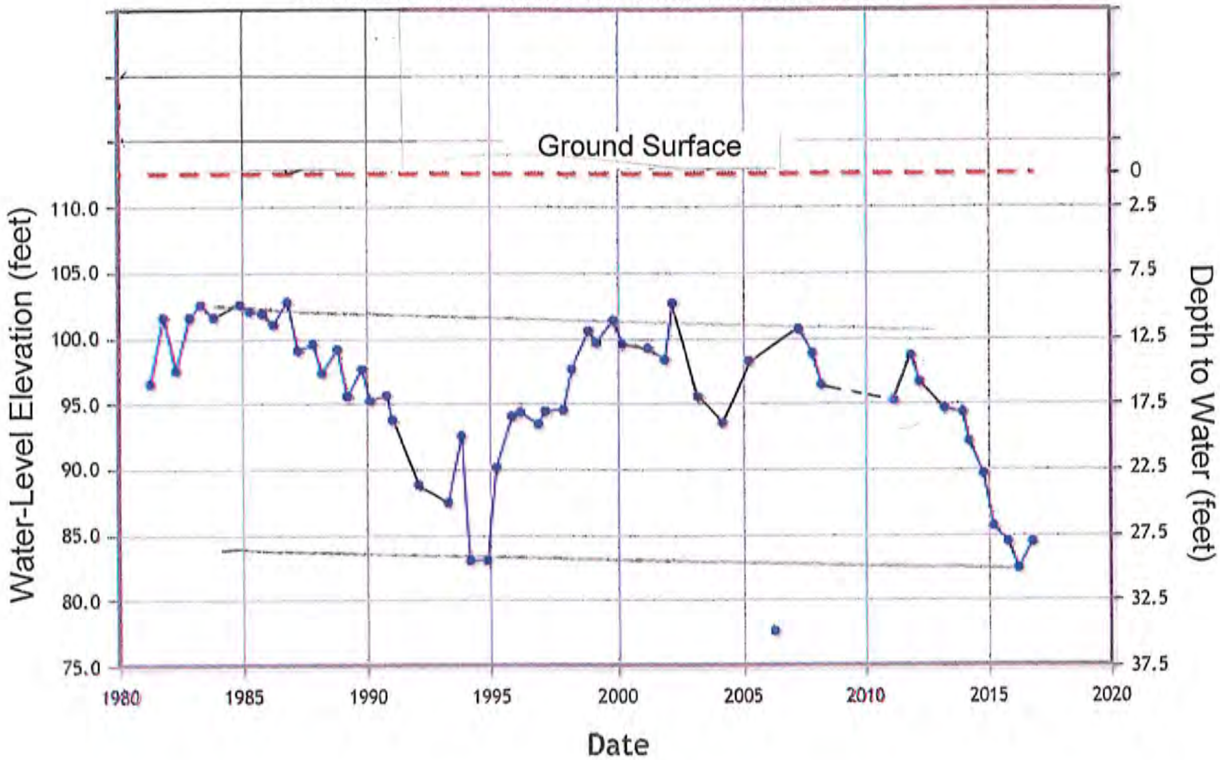
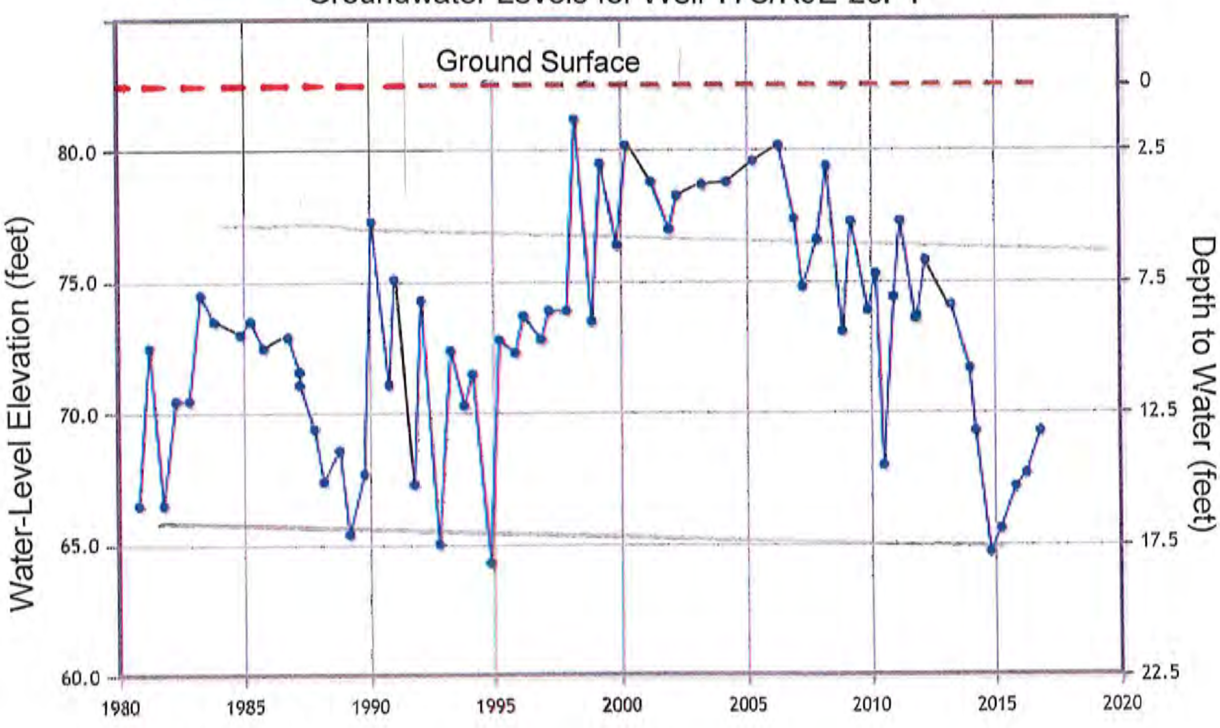


FIGURE 6-WATER-LEVEL ELEVATIONS AND DIRECTION OF GROUNDWATER FLOW FOR THE UPPER AQUIFER (SPRING 2011)

Groundwater Levels for Well T7S/R8E-35H1



Groundwater Levels for Well T7S/R9E-28P1

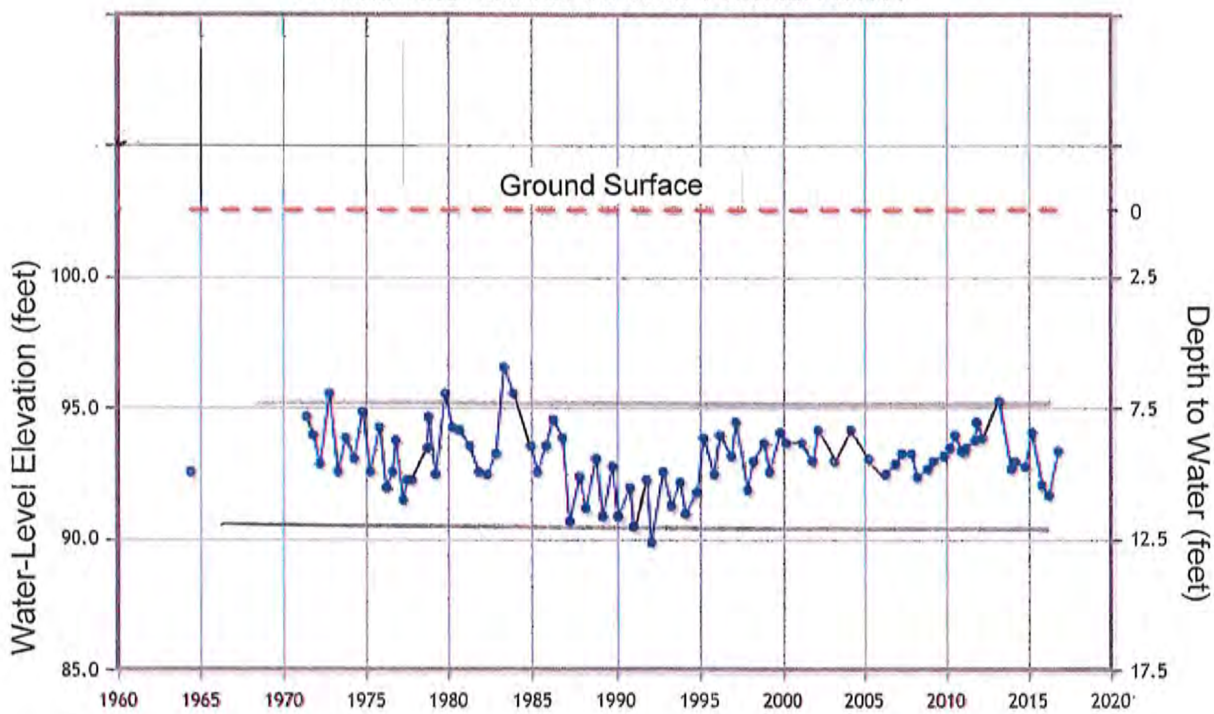


Modified from DWR.

FIGURE 7-WATER-LEVEL HYDROGRAPHS FOR UPPER AQUIFER WELLS

(Continued)

Groundwater Levels for Well T8S/R9E-21N1



Modified from DWR.

FIGURE 7-WATER-LEVEL HYDROGRAPHS FOR UPPER AQUIFER WELLS (CONTINUED)

level hydrographs for three of these wells. T7S/R8E-35H1 is located near Netherton Road and Schmidt Road. Depth to water usually ranged from about 12 to 22 feet. Overall, the water levels in this well slightly declined between 1982 and 2016, at an average rate of less than 0.1 foot per year. Well T7S/R9E-28P, is located near Kniebes Road and Preston Road, northeast of Gustine. Depth to water in this well has ranged from about 2 to 18 feet. Water levels in this well were stable from 1981 through 2016, except for the temporary declines during drought periods. Well T8S/R9E-21N is located near Taglio Road and Hunt Road, south of Gustine. Depth to water has ranged from about 7 to 12 feet. Water levels in this well were stable from 1964 through 2016.

Figure 8 shows water-level hydrographs for CCID Wells No. 22B and 57. Records for Well No. 22B extend from 1965 to 2018. Records for Well No. 57 extend from 2001 to 2018. The seasonally shallowest levels fell from early 2005 through early 2009, then rose through early 2013 to the shallowest levels during the period of record. The shallowest seasonal levels then fell through 2015, and partially recovered during 2016. Over the long term, the water levels fell about 6.5 feet over a 16-year period, or an average of 0.4 foot per year. As of early 2018, the water level still hadn't fully recovered. This decline was highly influenced by drought conditions in 2014-15. A shorter period of records is available for Well 57, but similar trends are indicated.

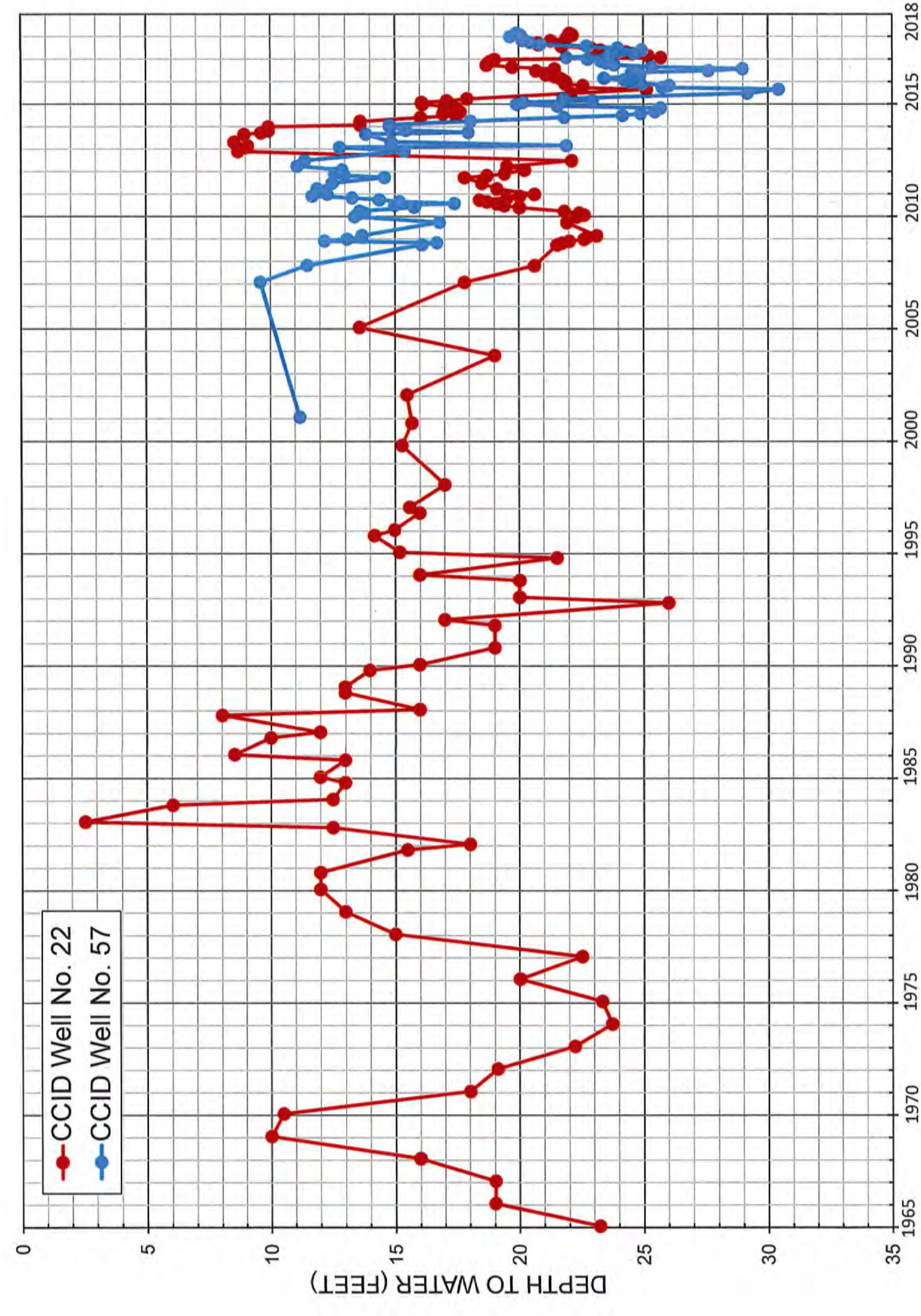


FIGURE 8 - WATER-LEVEL HYDROGRAPHS FOR CCID WELLS

Overall, there is no indication of groundwater overdraft in or near Gustine. In fact, the shallow groundwater levels are considered a problem in the surrounding irrigated areas. The evidence for this is the existence and ongoing activities of the Gustine Drainage District, which was developed to address this problem.

AQUIFER CHARACTERISTICS

Table 4 summarizes pump test data for City wells for the 1990's. More recent pump tests aren't available. Pumping rates for active City wells ranged from about 650 to 2,000 gpm. Specific capacities of these wells ranged from about 6 to 67 gpm per foot.

Table 5 summarizes recent pump test data for the two CCID wells for 2015-16. Pumping rates ranged from about 1,220 to 1,570 gpm and specific capacities ranged from about 14 to 40 gpm per foot.

Transmissivity was determined based on a nine-hour constant discharge test on City Well No. 5 on January 19, 1999. The average transmissivity based on drawdown and recovery data was 54,000 gpd per foot for strata below the Corcoran Clay. Transmissivity was also determined from a 24-hour pump test on City Well No. 6 during February 8-9, 1999. Recovery measurements indicated a transmissivity of 34,000 gpd per foot for strata above the Corcoran Clay. Specific capacities for wells tapping strata

TABLE 4-PUMP TEST DATA FOR CITY OF GUSTINE WELLS

Well No.	Date Tested	Pumping Rate (gpm)	Static Level (feet)	Pumping Level (feet)	Drawdown (feet)	Specific Capacity (gpm/ft)
4B	9/1/93	900	30.0	154	124	7.3
5	1/99	2,010	34.3	133.2	98.9	20.3
6	2/99	1,060	16.8	199.2	182.4	5.8
7		650				

Data for Well No. 4B from drillers log. Data for Wells No. 5, 6, and 7 from pump tests at end of well development.

TABLE 5-PUMP TEST DATA FOR CCID WELLS

Well No.	Date Tested	Pumping Rate (gpm)	Static Level (feet)	Pumping Level (feet)	Drawdown (feet)	Specific Capacity (gpm/ft)
22	10/15/16	1,568	26.0	65.7	39.7	39.5
57	06/15/15	1,219	69.0	157.0	88.0	13.7

Records from CCID.

above the clay indicate that values for Well No. 6 are less than the average for all of the upper aquifer wells. The transmissivity of the upper aquifer beneath the City can be estimated from specific capacity values. Using an average specific capacity of 50 gpm per foot and a conversion of 1,500, the transmissivity is estimated to be about 75,000 gpd per foot.

Darcy's law can be used to estimate groundwater inflow into the urban depression cone. Darcy's law is the fundamental equation for determining lateral groundwater flow in the aquifer. The flow is equal to the transmissivity times the water-level slope times the width of flow.

$Q = TIL$, where

Q = groundwater inflow (gpd)

I = water-level slope (feet per mile)

L = width of flow (miles).

Darcy's law is applicable in all such evaluations. The water-level map for Spring 2000 was used to determine the gradient because it shows the urban cone of depression. Using a width of flow of about 1.9 miles in Spring 2000, and an average water-level slope of about five feet per mile for the upper aquifer, the amount of inflow above the Corcoran Clay would be about 2,850 acre-feet per year. Additional amounts of groundwater inflow are also available from below the Corcoran Clay, but this can't presently be estimated, due to a lack of water-level measurements for deep wells in the area. The City of Gustine needs to measure static water levels in all City wells in the spring of each year.

PUMPAGE

Table 6 provides a summary of annual pumpage by the City of Gustine, the CCID, and private wells in the study area from 2003-2016. The City pumpage decreased after 2013, associated with water conservation measures undertaken during the drought. The annual pumpage in 2015 was 217 acre-feet less than in 2013, a reduction of about 17 percent. The average pumpage by the City during 2003-11 was about 1,250 acre-feet per year. Annual pumpage from the CCID wells in the study area ranged from 22 acre-feet in 2006 to 2,359 acre-feet in 2018. The average pumpage from these wells during 2003-16 was about 1,610 acre-feet per year. There are also a number of private wells in the study area (Figure 1). CCID provided estimates of pumpage from these wells. Pumpage from private wells ranged from about 40 to 2,658 acre-feet per year during 2003-16. The average pumpage from these wells was about 1,060 acre-feet per year. The average pumpage from all of the wells in the study area was thus about 3,900 acre-feet per year from 2003-16.

TABLE 6-ANNUAL PUMPAGE IN STUDY AREA

Year	Pumpage (Acre-feet per year)		
	City of Gustine Wells	CCID Wells	Private Wells
2003	1,350	1,705	1,216
2004	1,410	2,073	1,321
2005	1,290	502	288
2006	1,330	22	703
2007	1,466	2,206	1,834
2008	1,338	2,359	1,495
2009	1,043	2,149	1,601
2010	1,163	488	490
2011	1,156	896	806
2012	1,260	2,278	51
2013	1,271	2,231	598
2014	1,149	2,039	1,249
2015	1,054	2,003	2,658
2016	1,203	365	521
Average	1,249	1,610	1,060

Values are from City of Gustine and CCID records.

CITY EFFLUENT

There were about 625 acre-feet of City effluent discharged in 2015. About 140 acre-feet per year of this was used to irrigate hay and pasture. The remainder (485 acre-feet per year) percolated or was lost to evaporation from ponds and evapotranspiration from a marsh area. The consumptive use of City effluent is estimated to have been about 80 percent of the amount of effluent, or about 500 acre-feet per year.

CANAL WATER DELIVERIES

Table 7 shows CCID canal water deliveries to 3,600 acres of land in the study area for 2003-16. Canal water deliveries during 2003-2013 ranged from 9,800 acre-feet in 2013 to 13,800 acre-feet in 2013. The average delivery was 11,600 acre-feet per year during 2003-13. CCID canal water deliveries during 2014-16 ranged from 8,700 to 9,300 acre-feet year and averaged 9,000 acre-feet per year, reflective of drought conditions. For the entire period from 2003-16, the CCID average canal water delivery was about 11,000 acre-feet per year.

CONSUMPTIVE USE

Rural

The CCID provided estimates of the evapotranspiration of water applied for irrigation of crops in the study area. For

TABLE 7-CCID CANAL WATER DELIVERIES

Year	Acre-Feet per Year
2003	9,800
2004	11,500
2005	10,000
2006	10,700
2007	12,000
2008	11,800
2009	12,700
2010	10,600
2011	11,100
2012	13,400
2013	13,800
2014	8,900
2015	9,300
2016	8,700

consumptive use of crops, ITRC data for the evapotranspiration of applied water (ET_{IW}) was used for 2003-2008. Total evapotranspiration (ETc) for 2009-16 was based on the ITRC metric report (landsat data). The average ETc for 2003-16 was 10,300 acre-feet per year. The average ratio of ET_{IW} to ETc was 82%. Thus the estimated average ET_{IW} for 2003-16 was 8,450 acre-feet per year.

Urban

The City pumpage from 2003-16 averaged about 1,250 acre-feet per year and the effluent flow was about 625 acre-feet per year. The residual, or outside water use, was thus about 625 acre-feet per year. Assuming an irrigation efficiency of 70 percent, the consumptive use due to outside water use in the City was about 450 acre-feet. Combined with an estimated 500 acre-feet of evapotranspiration of effluent, the total urban consumptive use was 950 acre-feet per year.

Total

The total consumptive use in the study area was about this 8,450 + 950 or 9,400 acre-feet per year. This was about 1,600 feet less than the average canal water deliveries in the study area. This indicates a positive balance in the study area, without considering groundwater flows.

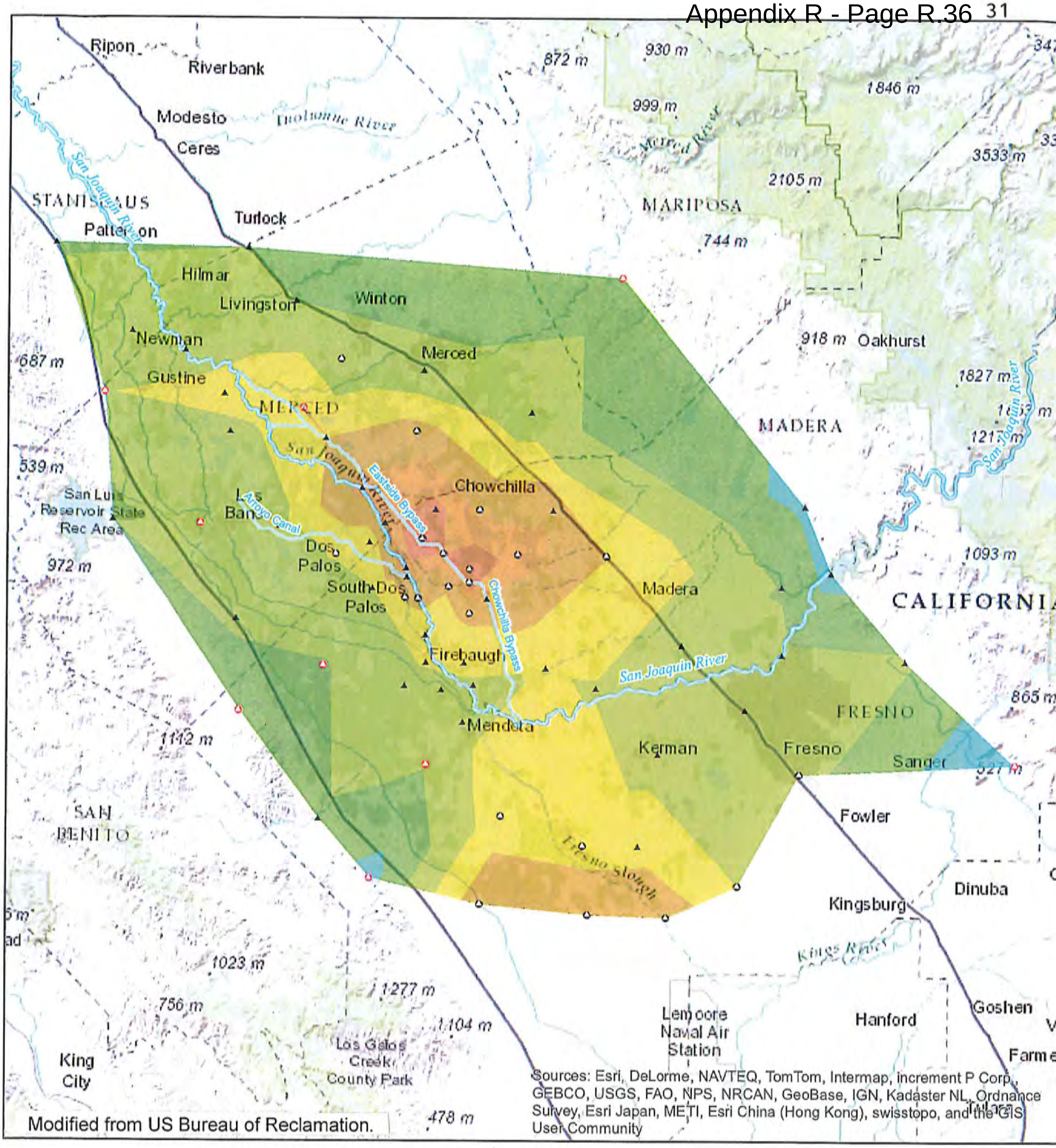
LAND SUBSIDENCE

Measurements at compaction recorders in the San Joaquin Valley have indicated that almost all of the historical land subsidence due to groundwater pumping has come from pumpage from the lower aquifer (below the Corcoran Clay). The nearest compaction recorder to Gustine with long-term records is the Oro Loma or Russell Avenue recorder, located near the Delta-Mendota Canal (DMC) and Russell Avenue. Pumpage from the lower aquifer at and near Gustine is indicated to be small. Most of the City pumpage and all of the CCID pumpage has been from the upper aquifer. Because of the limited pumpage from the lower aquifer in and near the City of Gustine and the lack of long-term water-level declines, land subsidence is expected to be small (less than 0.1 foot per year).

Periodic surveys of land subsidence have been done along the DMC, which is located about three and a half miles west of Gustine. Little subsidence was indicated west of Gustine. Recent (2012-15) measurements of land subsidence are available for the area near and southeast of Gustine from Reclamation (Figure 9). Less than 0.15 foot of subsidence was indicated near Gustine.

CHANGE IN GROUNDWATER STORAGE

Over the long-term, no significant change in groundwater storage is indicated for the study area.



Subsidence Rates (feet/year)
July12 to July15-Free
July 2012 to July 2015

- 0.15 to 0.3
- 0 to 0.15
- -0.15 to 0
- -0.3 to -0.15
- -0.45 to -0.3
- -0.6 to -0.45
- -0.75 to -0.6
- -0.9 to -0.75

GPS Coordinates

- GPS Point-December 2011
- GPS Point-added July 2012
- GPS Point-added December 2013

N

RECLAMATION
Managing Water in the West

FIGURE 9-RECENT LAND SUBSIDENCE

0 7 14 21 Miles

Subsidence rates calculated by comparing survey values a GPS Stations for the dates specified in the legend.

GROUNDWATER QUALITY

City Wells

Table 8 contains the result of recent inorganic chemical analyses of water from the four active City of Gustine wells. Total dissolved solids (TDS) concentrations in water from these wells ranged from 621 mg/l to 840 mg/l in 2016-17. The highest TDS concentration was in water from Well No. 6. Nitrate concentrations in water from these wells ranged from 15 to 42 mg/l, below the MCL of 45 mg/l. The highest nitrate concentration was in water from Well No. 6, which is the most northeasterly upper aquifer City well. Nitrate concentrations in water from this well ranged from 2 to 42 mg/l during 2011-15. The lowest nitrate concentration was in water from Well No. 5, which taps the lower aquifer. Concentrations of iron, manganese, arsenic, fluoride, and selenium in water from the active City wells were below the respective MCLs.

The highest manganese concentrations were in water from Well No. 5. Manganese concentrations in water from this well were variable between 1999 and 2017, but were frequently between 0.02 and 0.03 mg/l, less than the secondary MCL of 0.05 mg/l.

The hexavalent chromium concentration in water from Well No. 5 was 2 ppb, less than the MCL of 10 ppb. This well taps the lower aquifer. Hexavalent chromium concentrations in water from

TABLE 8- CHEMICAL QUALITY OF WATER FROM CITY OF GUSTINE WELLS

Constituent (mg/l)	No. 4B	No. 5	No. 6	No. 7
Calcium	58	60	110	131
Magnesium	26	31	46	35
Sodium	73	240	110	80
Potassium	3	2	2	2
Bicarbonate	315	317	342	378
Sulfate	110	200	156	127
Chloride	98	270	180	118
Nitrate	21	15	42	18
Fluoride	<0.1	0.2	0.2	0.1
pH	7.4	7.3	7.8	7.2
Electrical Conductivity (micromhos/cm @ 25°C)	945	1,100	1,300	1,043
Total Dissolved Solids (@ 180°C)	621	660	840	716
Iron	<0.1	<0.1	<0.1	<0.1
Manganese	<0.02	<0.02	<0.02	<0.02
Arsenic (ppb)	<2	<2	<2	<2
Hexavalent Chromium (ppb)	8.3	2	9.6	9.7
Selenium (ppb)	<5	7.3	<5	<5
Alpha Activity (picocuries/l)	8	3	<3	<3
Date	7/13/16	10/8/14	10/8/14	1/9/14
Perforated Interval (feet)	167-200	370-400 410-444	145-165 190-230	165-194

Samples for analysis of hexavalent chromium were collected between 8/10/14 and 10/15/14. Samples for analysis of alpha activity were collected between 10/8/14 and 10/15/14 the other wells were much higher (8.3 to 9.7 ppb), and in water from Wells No. 6 and 7 were near the MCL of 10 ppb.

Alpha activities were determined in water from the active City wells in February 2014. Values ranged from less than 3 to 8 picocuries per liter, below the MCL of 15 picocuries per liter.

Samples of water collected from the active City of Gustine wells in December 2016 were analyzed for numerous trace organic chemical constituents. No trace organic chemical constituent problem was indicated for these wells.

CCID Wells

Table 9 provides the results of inorganic chemical analyses of water from CCID Wells No. 22B and 57 for samples collected in July 2017. TDS concentrations ranged from 820 to 950 mg/l and the waters were of the mixed calcium bicarbonate-chloride or bicarbonate types. Nitrate concentrations ranged from 10 to 15 mg/l, less than the MCL of 45 mg/l for public water supplies. Boron concentrations ranged from about 0.4 to 0.5 mg/l, suitable for irrigation of most crops.

HISTORICAL WATER BUDGET

CCID canal water deliveries to 3,600 acres of crops in the study area averaged 11,000 acre-feet per year during 2003-16. The estimated average urban and rural consumptive use for the

TABLE 9- CHEMICAL QUALITY OF WATER FROM CCID WELLS

Constituent (mg/l)	Well No. 22B	Well No. 57
Calcium	75	120
Magnesium	46	50
Sodium	100	120
Potassium	3	<1
Bicarbonate	380	330
Sulfate	99	170
Chloride	130	180
Nitrate	15	10
pH	7.6	7.7
Electrical Conductivity (micromhos/cm @ 25°C)	1,400	1,500
Total Dissolved Solids (@ 180°C)	820	950
Boron	0.38	0.51
Date	7/25/17	7/25/17
Perforate Interval (feet)	60-190	70-190

Chemical analyses by BSK Associates.

period was 9,400 acre-feet per year. There was an estimated canal seepage of 1,100 acre-feet per year from a 2.5-mile long reach of the Main Canal (average of 0.68 cfs for 330 days a year). There was an estimated 1,600 acre-feet per year of deep percolation from irrigated crops in the CCID (11,000 minus 9,400 acre-feet per year). The amount of groundwater inflow above the Corcoran Clay was previously estimated to be about 2,850 acre-feet per year. The average deep percolation from urban irrigation is estimated to have been about (625 minus 450 acre-feet per year, or about 175 acre-feet per year. The pond seepage and deep percolation associated with City effluent averaged 20 percent of the effluent amount, or about 125 acre-feet per year.

The total recharge (excluding groundwater inflow below the Corcoran Clay) thus averaged about 5,950 acre-feet per year for 2003-16. The average pumpage in the study area was about 3,900 acre-feet per year for 2003-16. There was no significant change in groundwater storage in the study area during 2003-20016. The difference between 5,850 and 3,900, or 1,950 acre-feet per year, was made up by the groundwater outflow above the Corcoran Clay and the difference between the groundwater inflow and outflow below the Corcoran Clay.

REFERENCES

Kenneth D. Schmidt & Associates, 1992, "Groundwater Conditions in the Vicinity of the City of Gustine" report prepared for CCID and City of Newman, 30p.

Kenneth D. Schmidt & Associates, 2001, "Groundwater Conditions in the Vicinity of the City of Gustine" report prepared for CCID and City of Newman, 33p.

Page, R. L., 1986, "Geology of the Fresh Groundwater Basin of the San Joaquin Valley, California", U.S. Geological Survey Professional Paper 1401-C.