



California Department of Water Resources
Sustainable Groundwater Management Program

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Best Management Practices for the
Sustainable Management of Groundwater
Monitoring Networks
and Identification of
Data Gaps

BMP

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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 this document as part of the obligation in the Technical Assistance chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater *basins*. Information provided in this BMP provides technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders 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 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**.

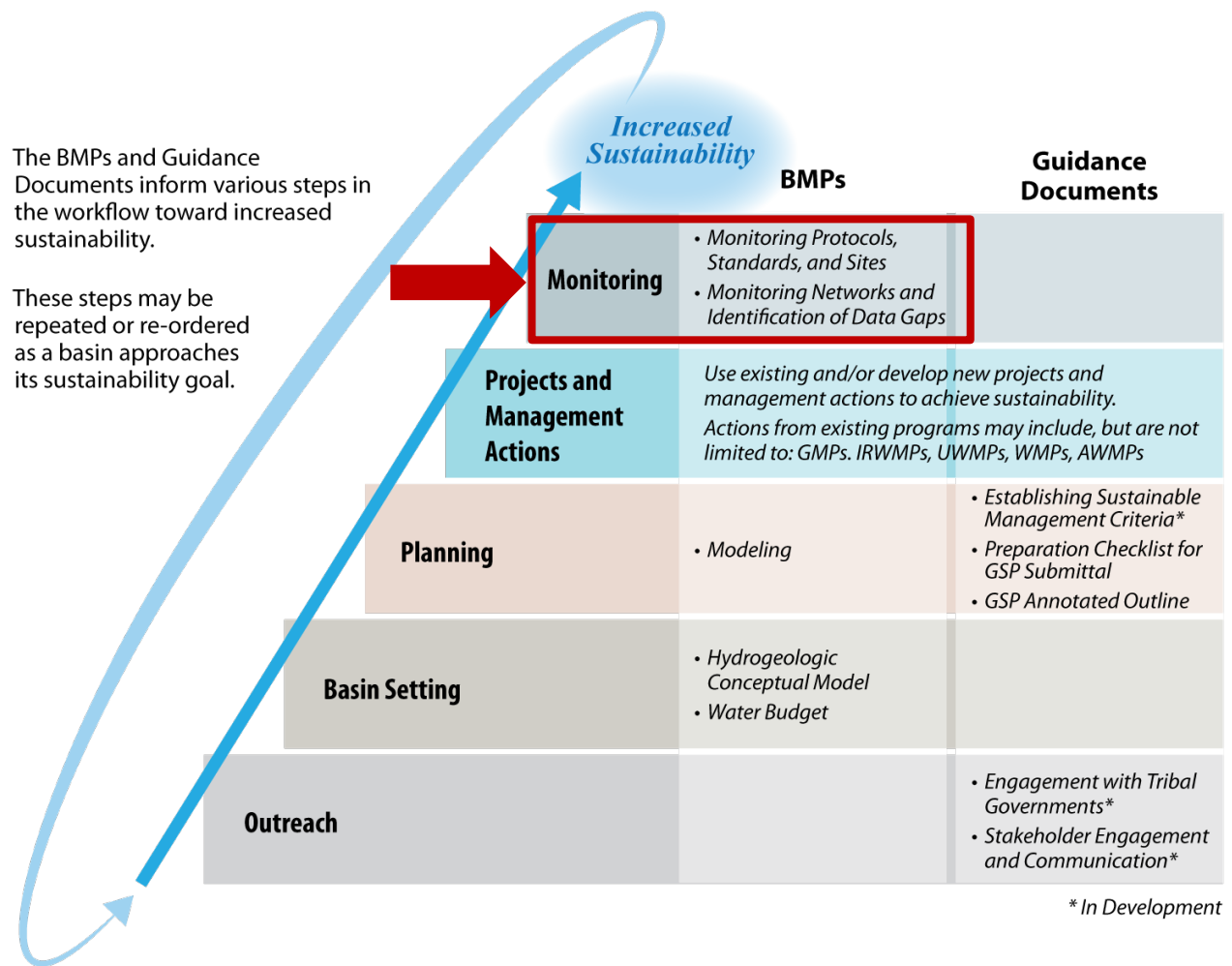


Figure 1 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability

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 measureable 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:

- Degree of monitoring. 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.
- Access Issues. 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.
- Adjacent Basins. 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 determining 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, defensible data to demonstrate the relationship prior to use as a surrogate for other sustainability indicators.

Wells that are part of the monitoring program should be dedicated groundwater monitoring 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 monitoring 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 monitoring 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 monitoring 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 monitoring 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. Monitoring Well Density Considerations

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

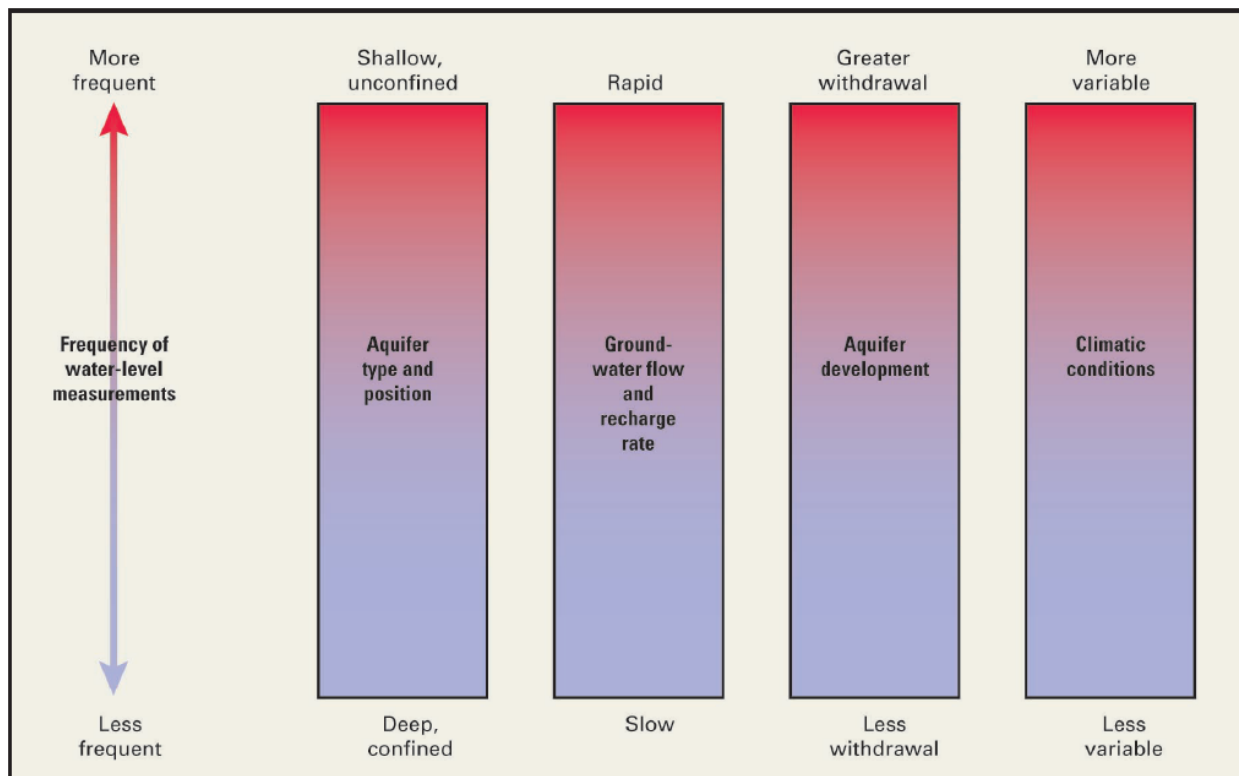


Figure 2. Factors Determining Frequency of Monitoring Groundwater Levels (Taylor and Alley, 2001, adapted from ACWI, 2013)

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.
- Groundwater levels will be collected during the middle of October and March for comparative reporting purposes.
 - o 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.
 - o 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.
 - o 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.
 - o Agencies may consider coordinating monitoring efforts with adjacent basins to provide consistent data across basin boundaries.
 - o 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 measureable 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 monitoring network for seawater intrusion must capture changes in water quality conditions associated with the dynamic seawater-freshwater interface along coastal aquifers. This system is largely controlled by differences in water density and hydraulic head to maintain the advancement of the seawater front. A robust understanding is necessary to identify the preferential flow pathways where seawater can intrude inland and associate with freshwater groundwater extractions or declines in head. The following practices should be considered, at a minimum, to provide data supporting the assessment of seawater intrusion:

- Monitoring groundwater elevation in all seawater intrusion-specific monitoring locations should be consistent with the water level monitoring network and protocols described in this and the Monitoring Protocol, Standards, and Sites BMP.
- Monitor groundwater quality data from each principal aquifer in the basin that is currently, or may be in the future, impacted by seawater intrusion.
 - The spatial density must be adequate to map an isocontour of chloride advancement front as a representation of seawater. It may be useful to include other ions such as bromide and iodide for evaluation of source of high salinity water.
 - Monitoring should occur at least quarterly and correspond with seasonal highs and lows, or more frequently as appropriate. Professional judgment should be used to evaluate the necessary frequency and density of monitoring to meet the DQOs.
 - The above points do not include initial characterization, where more frequent monitoring may be necessary to evaluate the full dynamic range of aquifer response and associated seawater intrusion.
- 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, to the greatest degree possible, existing water quality monitoring data. For example, these could include ILRP, GAMA, existing Regional Water Quality Control Board (RWQCB) monitoring and remediation programs, and drinking water source assessment programs.
 - Collection of water quality samples are required to be analyzed for chloride concentration.
 - Additional analytes may be desirable for characterization and planning of mitigation measures.
 - The use of a surrogate must be demonstrated through correlative analysis and should be periodically quantitatively assessed following implementation of use.
- Define the three-dimensional extent of any existing seawater intrusion, or degraded water quality.
- Samples should be sufficient for mapping movement of seawater or degraded water quality.

- Samples should be sufficient to assess groundwater quality impacts on beneficial uses and users.

Spatial distribution of monitoring locations may be optimized by including geophysical techniques to identify the preferential pathways controlling seawater intrusion, and target critical connections to existing water supply wells and mitigation efforts.

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.

- o Agencies should use existing water quality monitoring data to the greatest degree possible. 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 . 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:

- Levelling surveys must follow surveying standards set out in the California Department of Transportation's *Caltrans Surveys Manual*. Specific websites where additional information can be found include:
 - o <http://www.dot.ca.gov/hq/row/landsurveys/>
 - o <http://www.ngs.noaa.gov/datasheets/>
 - o https://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-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:
 - o <http://www.dot.ca.gov/hq/row/landsurveys/>
 - o <http://www.ngs.noaa.gov/CORS/>
 - o <http://www.unavco.org/instrumentation/networks/status/pbo>
 - o <http://www.dot.ca.gov/dist6/surveys/CVSRN/sitemap.htm>
 - o <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:
 - o Extensometer methods commonly used by the USGS
http://hydrologie.org/redbooks/a151/iahs_151_0169.pdf
 - o Extensometry principles (p. 20-29)
<http://wwwrcamnl.wr.usgs.gov/rgws/Unesco/>
 - o 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.
 - o 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>
 - o 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/>
- o 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/sar-software/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 monitoring well network 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.
- Identify and quantify both timing and volume of groundwater pumping within approximately 3 miles of the stream or as appropriate for the flow regime.

- Establish qualitative monitoring by use of GPS survey of the timing and position along stream where ephemeral or intermittent streams cease to flow. Should be conducted annually or as appropriate to capture stream flow change.

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.

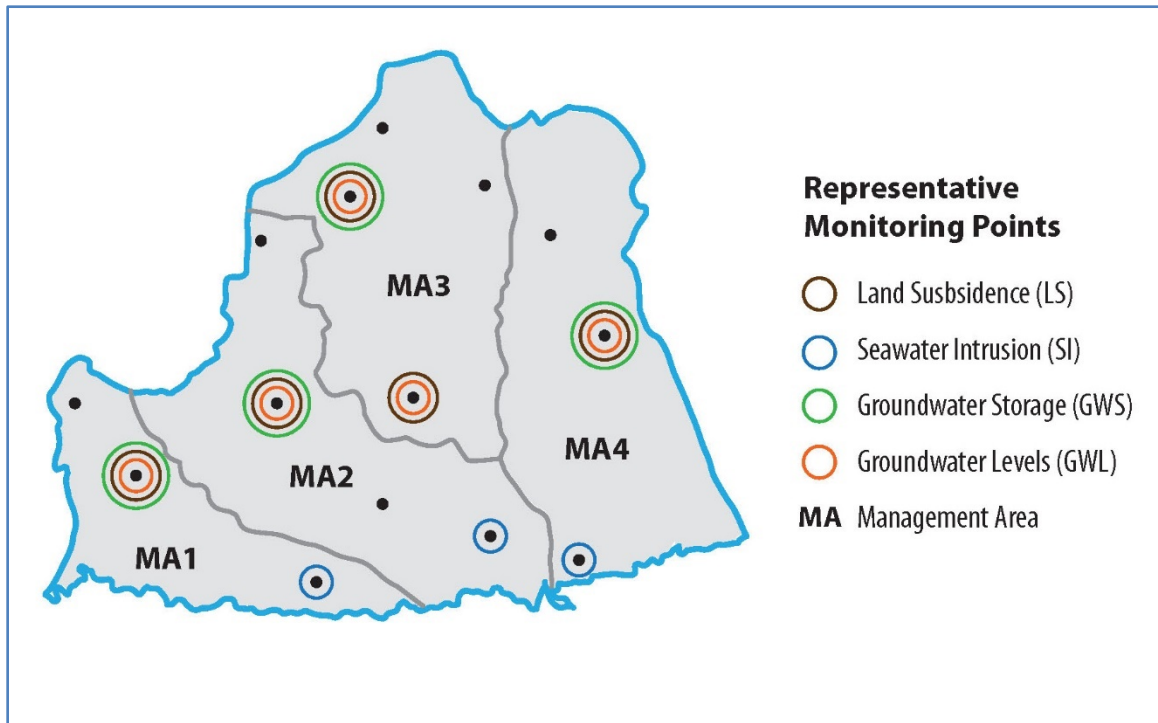


Figure 3: Representative Monitoring Points

If RMPs are used to represent groundwater elevations from a number of surrounding monitoring 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 monitoring wells. If RMPs are used to represent groundwater quality from a number of surrounding monitoring 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 monitoring 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 five-year 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.

Data Gap Analysis

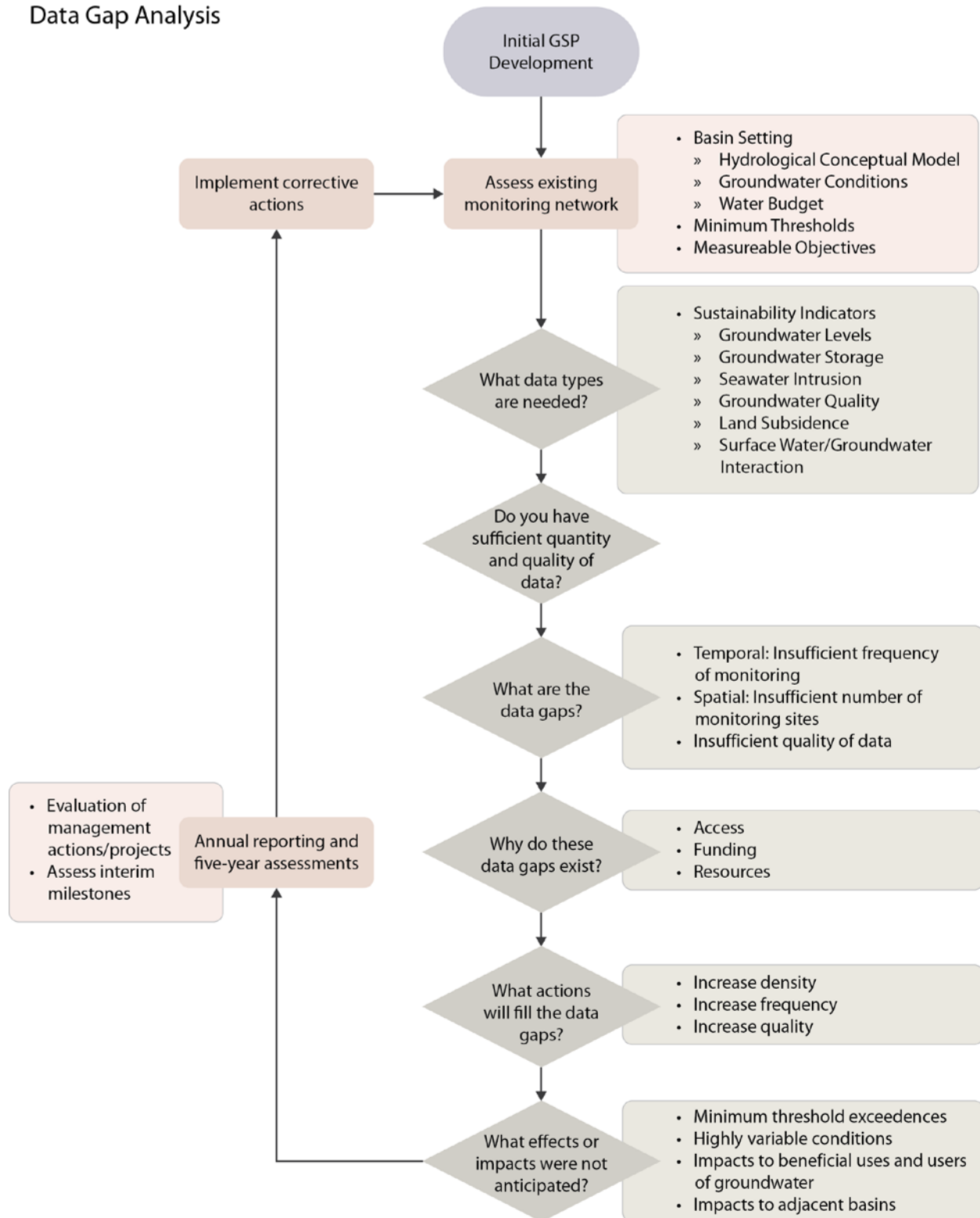


Figure 4. Data Gap Analysis Flow Chart

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**.

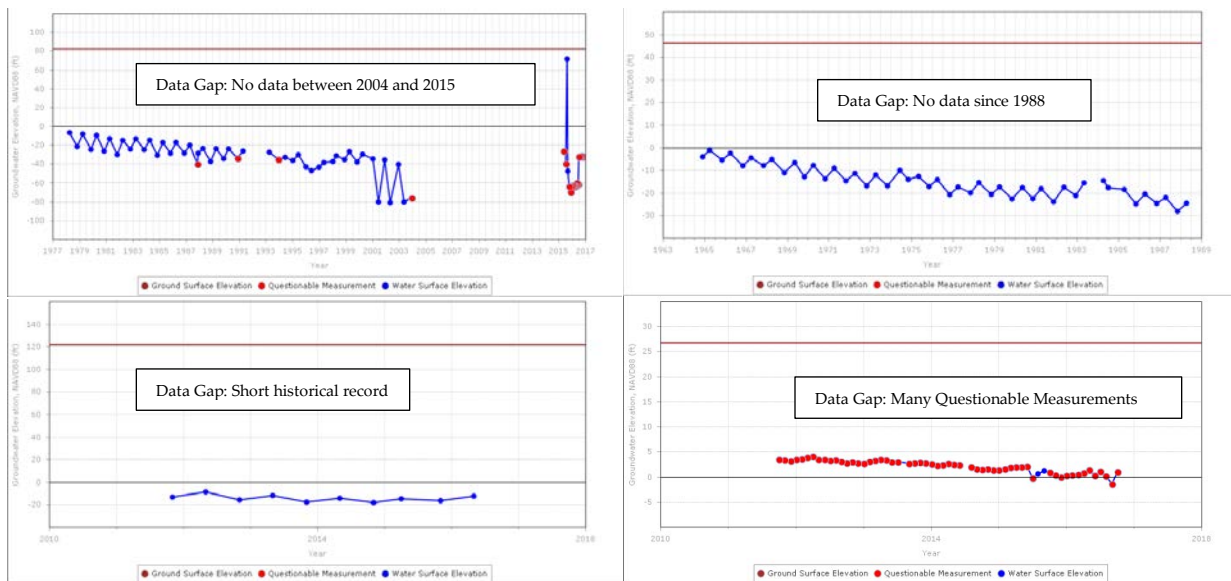


Figure 5. Examples of Hydrographs with Temporal Data Gaps

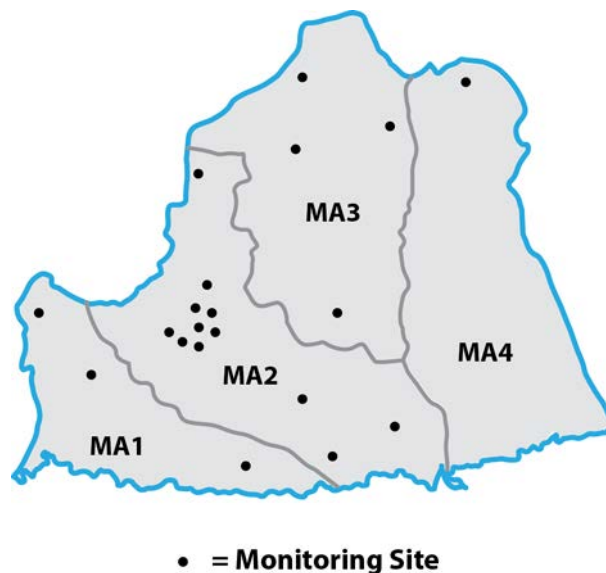


Figure 6. Example Monitoring Network with Spatial Data Gaps

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 update to this BMP as the suggested data structure is developed, as necessary.

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
 - o 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
 - o <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