SUSTAINABLE GROUNDWATER MANAGEMENT (SGM) GRANT PROGRAM

The following is an excerpt from the Subsidence Management Monitoring Method [MM-09]

SGM Grant Program Requirements for Post-Performance Monitoring and Reporting

Subsidence Management Monitoring Method

Project / Action Type	Subsidence management aims to reduce subsidence through lessening groundwater overdraft.
Similar / Related Project Types	Subsidence could be managed in coordination with groundwater elevation management. Groundwater elevation management is generally the primary benefit, and subsidence management is ancillary.
Metric	Ground levels. Change in ground levels. Groundwater levels.
Measurement Unit	Ground surface elevation measured in feet a consistent vertical datum. Change in surface elevation measured in feet. Groundwater levels measured in feet in a consistent vertical datum.
Beneficial User	Municipal and domestic water supply (MUN) Industrial service supply (IND) Industrial process supply (PROC) Agricultural water supply (AGR)

Subsidence Management Monitoring

Subsidence is best monitored through direct measurement of ground surface elevation. The rate and extent of subsidence are the most useful parameters to measure. Several techniques may be used to monitor ground surface elevation including the following:

- Conducting **leveling surveys** allow for an impacted area to be tied into known benchmarks. Installing and tracking changes in borehole **extensometers** allow for measurement of compaction of clay layers.
- Portable global position systems (**GPS**) can allow for data collection over a wider area of interest and allow for monitoring of continuous global position systems.
- Analyzing interferometric synthetic aperture radar (**InSAR**) data is a satellite-based method for larger scale monitoring.

Additional information on these methods is described in Department of Water Resources (DWR) Best Management Practice (BMP) 2 Monitoring Networks and Identification of Data Gaps (DWR, 2016).

SUBSIDENCE MONITORING METHODS

Leveling surveys – Routine surveys of benchmarks with known elevation.

Extensometer – Device installed in a well for measuring compaction of subsurface clay layers.

InSAR - Interferometric synthetic aperture radar, satellite-based method implemented by California Department of Water Resources.

GPS – Global position systems, land surveying method. Data can be collected continuously at one location or over a wider area.

Background and Context

Subsidence is defined by a change in ground surface elevation, not absolute ground surface elevation. Subsidence can only be identified after multiple successive ground surface elevation measurements. Therefore, it is necessary to establish a monitoring network and methodology that provide repeatable and definitive data.

While groundwater elevations are the typical cause of subsidence, monitoring groundwater elevations are not always adequate for measuring subsidence. Residual, or delayed, clay compaction leads to subsidence that continues after groundwater elevations have stabilized. Therefore, stable groundwater levels are not an adequate indicator of arrested subsidence.

Ground surface elevation measurements can be collected multiple times throughout the year to identify the presence of cyclic fluctuations due to elastic subsidence. Seasonal pumping for agricultural irrigation often results in corresponding seasonal rises and drops in ground surface elevation. Differentiating between elastic subsidence, which is reversible, and inelastic subsidence, which is permanent, can be difficult. To minimize influences from elastic subsidence, total annual subsidence should be calculated using annual high ground surface elevations. Historical ground surface measurements should be analyzed to identify the potential magnitude and cyclic nature of elastic subsidence.

Areas with a history of subsidence and adequate subsidence and groundwater level data might be used to calibrate subsidence models that estimate the quantity and timing of residual subsidence after groundwater levels have stabilized. However, the model results should still be verified with ground surface elevation measurements. Only areas with unconsolidated clay sediments are prone to subsidence. Areas with consolidated rock aquifers are not at risk for subsidence caused by groundwater overdraft.

A Step-by-Step Guide to Applying the Subsidence Management Monitoring Method

1. **Safety plan:** All projects with fieldwork related activities should produce a Safety Plan. Planning for fieldwork and availability of access to the site, such as monitoring wells, is necessary to maintain project safety. Projects with an impact on subsidence may require a Safety Plan to address these and other potential safety concerns.
2. **Establish baseline conditions:** Thresholds and objectives from the baseline conditions need to be determined. For projects or actions in basins with a GSP, the management criteria identified in the GSP may help and can be used to evaluate outcomes.
    - Use historical subsidence data to develop the baseline conditions.

- Assess existing subsidence rates and extent, determine if correlation exists with groundwater level declines, and identify any seasonal elastic subsidence.
- Identify areas where land uses and property interests have been affected or are likely to be affected by land subsidence in the basin.
- The project proponent should identify areas where the effects of land subsidence have been observed, where risks of damage from subsidence to critical infrastructure such as canals, roads, bridges, buildings, and wells exists, and where geology is conducive to subsidence if groundwater elevations decline.

3. **Identify monitoring network:** Evaluate the necessary subsidence monitoring type, such as extensometers, InSAR, or continuous global position systems (CGPS). Identify monitoring sites in areas at risk from future subsidence and areas likely to show benefits. The location of the monitoring network should be easily accessible such that gaining access to the site does not inhibit gathering and downloading data (refer to Step 1).
4. **Install monitoring network:** Install additional subsidence and groundwater elevation monitoring sites, as necessary. In basins with GSPs, there may be an established GSP monitoring network that could be suitable for monitoring impacts; however, additional monitoring sites may be necessary to monitor conditions in vicinity of subsidence monitoring sites, or on smaller scale projects not yet identified in the GSPs.
    - Implement any optional monitoring to supplement evaluation.
    - More monitoring or different monitoring frequency may be required than that which is required under a GSP.
5. **Collect monitoring data:** Gather, review, and evaluate subsidence and groundwater elevation data.
6. **Data reporting**: Upload project-specific monitoring data to the SGMA Portal following the protocols described in the data monitoring and reporting method.
7. **Refine monitoring method:** Expand or refine monitoring network and data collection, as needed.

Data and Protocols - Fundamentals

Monitoring subsidence primarily includes monitoring ground surface elevations, and often includes monitoring groundwater elevations. Ground surface elevation can be directly monitored using a variety of methods, including:

- Levelling surveys tied to known benchmarks: Levelling surveys use surveying equipment to establish or verify the height of specified points relative to a known benchmark.
- Portable GPS: Portable GPS readers gather data from the U.S. Department of Defense satellite network to estimate a 3-dimensional location on the ground.
- CGPS stations: CGPS stations use the same satellite network as portable GPS systems. CGPS systems, however, are stationary. These stations generally collect position information on a regular interval (such as every 15 seconds) and the measurements are then processed to produce a daily position.
- Borehole extensometer data: Extensometers consist of a pipe or cable anchored at the bottom of a well casing and a recorder that measures the relative distance between the bottom of the borehole and the ground surface. Extensometers are used to measure expansion or compaction of the geologic materials in an aquifer system, measured as displacement at ground surface.
- InSAR data: InSAR is a remote sensing technology that measures ground elevation using microwave satellite imagery data. DWR collects monthly InSAR data mapped over the entire state; these data are publicly available starting in June 2015.

Of these five techniques leveling surveys and extensometers provide the most precise data. The least precise measurements tend to be made by using mobile GPS systems, with CGPS and InSAR measurements falling somewhere in the middle (USGS, 2021b).

Additional considerations for monitoring ground surface elevations include:

- Subsidence is measured as a differential in ground surface elevation between time periods, so it is important that baseline ground surface elevations be collected before a project or action is initiated. Post-project ground surface elevations can then be compared to pre-project ground surface elevations to identify changes in subsidence rates.
- Ground surface elevations should be measured at least quarterly to identify seasonal fluctuations due to elastic subsidence.
- Ground surface elevations should be monitored near critical infrastructure.

Groundwater elevations should be monitored to verify any modelled or estimated correlations between groundwater elevation and subsidence. Considerations for groundwater elevation monitoring include:

- Groundwater elevation measurements should be co-located with extensometers, known benchmarks, or CGPS locations to establish correlations between groundwater elevations and subsidence.
- Groundwater elevation data should be collected near the anticipated area of greatest project impact
- Groundwater elevations should be monitored near critical infrastructure.
- Groundwater elevations should be monitored on the same schedule as ground surface elevations.

Table 1 provides an example of summary parameters to use in a monitoring report for subsidence management projects.

Table 1. Example Data Monitoring Report (Generally Annually)

Monitoring Reporting	
Min / Average / Max Change in Land Surface Elevation	XX X / XXX/ XXX feet
Min / Average/ Max Change in Groundwater Levels	XX X / XXX / XXX feet
Incurred Costs	$XXX

Data Standards

All data should meet the technical and reporting standards included in California Water Code §352 *et seq*. This includes recording ground surface elevation measurements relative to **NAVD88**, with an accuracy of at least 0.01 feet.

Key Protocols

The following protocols should be followed for required monitoring:

- Standard protocols for measuring subsidence as described in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016).
- Standard protocols for measuring groundwater levels as described in DWR's BMP 1 Monitoring Protocols Standards and Sites (DWR, 2016).
- Technical and reporting standards included in California Water Code §352 *et seq*.

Additional guidance or references include:

- Guidance for monitoring land subsidence in Montgomery County, Texas (Groundwater science Advisory Committee, 2021)
- Land Subsidence from Groundwater Use in California (Luhdorff & Scalmanini, 2014)

VERTICAL DATUMS

NAVD88 was established in 1991 by the minimum-constraint adjustment of the Canadian-Mexican-United States leveling observations. Along the California coast NAVD88 is 2-4 feet higher than mean sea level.

NGVD29 is generally closer to mean sea level. Mean sea level was held fixed at the sites of 26 tide gauges across United State and Canada.

NGVD29 = NAVD88 – 3.6 feet