

# LAND SUBSIDENCE: WHAT IS IT AND WHY IS IT AN IMPORTANT ASPECT OF GROUNDWATER MANAGEMENT?

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## INTRODUCTION

In past issues of this informational series of articles on groundwater management and water well topics, groundwater monitoring has been highlighted as a critical component in the protection and management of groundwater resources in the northern Sacramento Valley. Specifically, groundwater level monitoring has been emphasized because it is a direct indicator of aquifer supply and sustainability. Copies of past articles in this series can be downloaded at <http://www.glenncountywater.org> (select water education, bottom left menu). This article discusses land subsidence, another monitoring component to manage the groundwater resources in the northern Sacramento Valley. In an upcoming article, groundwater quality will also be discussed as an important component of groundwater monitoring.

## LAND SUBSIDENCE - WHAT IS IT AND WHY IS IT IMPORTANT?

Land subsidence is a gradual settling or sudden sinking of the Earth's surface due to movement of earth materials. It is often caused by three distinctly different but water-related processes: 1) compression (compaction or consolidation) of the interbedded layers of clay and silt within the aquifer system; 2) drainage and oxidation of organic soils; and 3) dissolution and collapse of susceptible rocks. Some serious effects of land subsidence include loss of levee freeboard and subsequent reduction in flood protection, change of gradient along water conveyance canals, damage to roads and bridges, and collapse of water well casings. Understanding and detecting land subsidence in very early stages is important to prevent these types of structural damage.

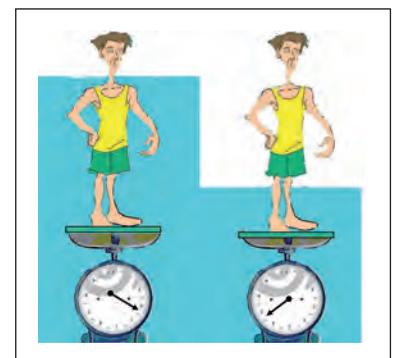
The U.S. Geological Survey has documented land subsidence in various areas of California. Figure 1 illustrates the extent of land subsidence in the central valley southwest of Mendota, an area with some of the highest levels of land subsidence in California. Approximately 29 feet of subsidence occurred from 1925 to 1997. Other areas of California have experienced subsidence on the order of a total of 2 to 12 feet over the course of several decades. They include Lancaster, the Santa Clara Valley, Ventura, Davis, and more locally near Zamora in the Sacramento Valley. Subsidence typically occurs at slow rates ranging from fractions of an inch to as much as 3 inches per year.



**Figure 1.** Subsidence southwest of Mendota, California.

## HOW SUBSIDENCE OCCURS

Permanent land subsidence in the Sacramento River Basin is most likely due to compaction of clay beds within the aquifer systems. When an aquifer system is full of water, the gravel and sands are buoyant. As groundwater levels decline from extraction, there is less buoyancy to support the weight of the gravel and sand that was previously full of water. Additional weight from the gravel and sand creates more downward pressure on clay beds that are between the sand and gravel strata from which water has been extracted. When the water held in the clays can no longer withstand the pressure from the increased weight of the gravel and sands above, the clays are compressed and water is squeezed from them. These clays will never reabsorb the water that has been expelled from them. Permanent subsidence occurs and recharging the groundwater to its original levels will not result in the recovery of the original land surface elevations. Figure 2 uses a “swimming pool analogy” to illustrate the simple principle of buoyancy and how it affects mass and downward forces.



**Figure 2.** The man on the left that is buoyed by more water weighs less and exerts less downward force than the same man on the right that is buoyed by less water.

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## EFFECT OF SUBSIDENCE ON AQUIFER STORAGE CAPACITY

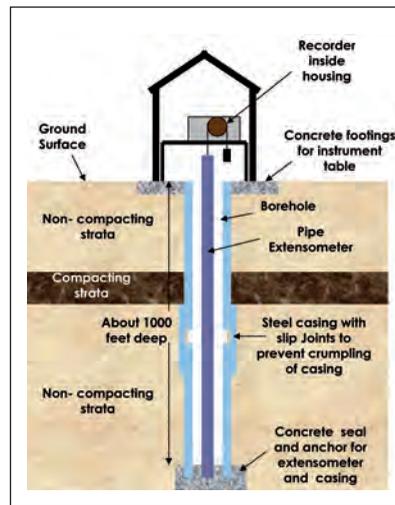
From a practical standpoint subsidence has very little, if any, effect on the storage capacity of aquifers because consolidation occurs in the clay beds that are between the dewatered sand and gravel strata. Clays that undergo consolidation do not contain as much water as they did before compression. However, clays typically do not provide water to wells unless they are being compressed by subsidence. The sand and gravel beds are the main source of water to wells.

## METHODS OF MONITORING SUBSIDENCE

There are a variety of methods available to monitor land subsidence. They include vertical extensometers, baseline and repeated surveys of benchmarks using Global Positioning System (GPS) or conventional survey methods, and Interferometric Synthetic Aperture Radar (InSAR).

**Vertical Extensometers** provide site-specific measurements of subsidence. These instruments consist of a pipe or cable anchored at the bottom of the borehole. The pipe or cable extends from the bottom of the borehole, through the geologic layers that are susceptible to compaction, to the ground surface. The pipe or cable is then connected to a recorder that frequently measures the relative distance between the bottom of the borehole and the ground surface.

Figure 3 provides a schematic of a pipe extensometer and Figure 4 shows the above ground portion of a cable extensometer with data recording equipment. These instruments detect changes in land surface elevation to 1/100th of a foot on a daily basis. The relationship between subsidence, groundwater level fluctuation and the physical properties of the various aquifer systems can also be evaluated by installing a multi-completion monitoring well adjacent to the vertical extensometer.



**Figure 3.** General schematic of a pipe extensometer for site-specific measurement of subsidence.



**Figure 4.** Above-ground portion of a cable extensometer with recording equipment.

**Leveling** using Global Positioning System (GPS) surveying or conventional leveling are alternatives to vertical extensometers. GPS surveying is used to monitor subsidence over greater distances or at a regional scale. Benchmarks or "geodetic stations", as shown in Figure 5, are used along a transect or network. Ground elevations at each benchmark can be obtained within plus or minus one inch of accuracy with GPS surveying. For regional scale surveys of this type, conventional leveling is less accurate. The land surface elevations are initially surveyed and then re-surveyed every few years to track changes in elevation at the benchmarks and monitor trends over time.

**InSAR**, Interferometric Synthetic Aperture Radar, is an increasingly popular alternative to extensometers and GPS or conventional surveying methods. InSAR is a space-borne, remote sensing technique that uses changes in satellite radar signals created by interferences on the earth's surface to measure changes in land surface elevation. It is used to measure and track deformations in the earth's surface caused by earthquakes, volcanoes, and by groundwater and fossil fuel extraction and injection. Similar to GPS, InSAR enables measurement of subsidence on a regional scale and, like extensometers, the accuracy of elevation measurements with InSAR can be within a fraction of an inch. InSAR is a cost effective means of monitoring subsidence in the appropriate situation. Unfortunately, InSAR is not well suited for the predominantly agricultural lands in the Sacramento Valley where farming affects the surface elevation



**Figure 5.** Benchmark or "geodetic" station used to re-level ground surface elevations and monitor subsidence.

of lands. As examples, InSAR will detect the changing surface elevation of a developing crop canopy and not the actual elevation of the land, and where land leveling is practiced, InSAR will detect the changes in land elevations resulting from leveling and not resulting from subsidence.

### SUBSIDENCE MONITORING IN THE NORTHERN SACRAMENTO VALLEY

The California Department of Water Resources, in collaboration with county agencies and local water districts, has established land subsidence monitoring in the Sacramento Valley as part of overall efforts to understand and manage the groundwater resources. Currently, there are 13 extensometer stations that have been constructed in the Sacramento Valley. The extensometer locations are also equipped with multi-completion groundwater level monitoring wells. Figure 6 illustrates the geographic distribution of the extensometer stations. Most of the extensometers are located in the northern Sacramento Valley: five in Butte County; three in Glenn County; two in Colusa County, and then two further south in Yolo County; and one in Sutter County. The construction of additional extensometers and the total number in operation may change in the Sacramento Valley depending upon how they perform and as knowledge and understanding of the aquifer systems increases.

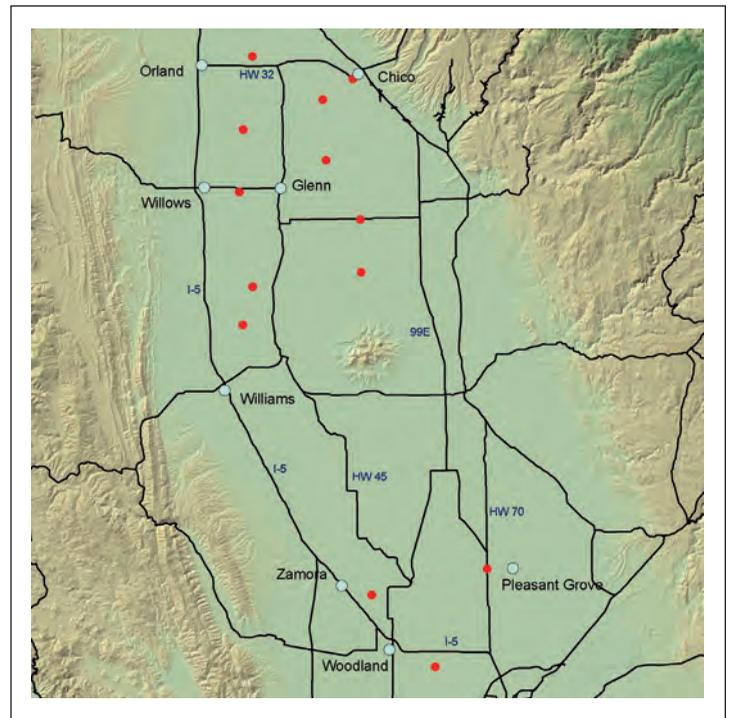


Figure 6. The red dots show where extensometers are used to monitor land subsidence in the Sacramento Valley.

In addition to site-specific subsidence monitoring with extensometers. Efforts are underway to establish Global Positioning System (GPS) surveys of land subsidence. Figure 7 shows the survey network established in Glenn County in 2004. The network consists of 58 benchmark stations primarily covering the valley floor within Glenn County and covering the 17 sub-areas where basin management objectives (BMO's) for groundwater management were adopted in 2001. More than one-half (33) of the stations were existing benchmarks suitable for the survey and 25 new benchmarks were added to the subsidence project. Three of the benchmark stations are located in Butte County. This helps make it possible to expand the GPS subsidence surveying into other northern Sacramento Valley counties. A similar GPS subsidence survey grid is used in Yolo County as well. In the future, an effort may be made to coordinate GPS subsidence monitoring throughout the Sacramento Valley. This coordinated effort may involve Tehama, Glenn, Colusa, Sutter, Yuba, and Yolo counties.

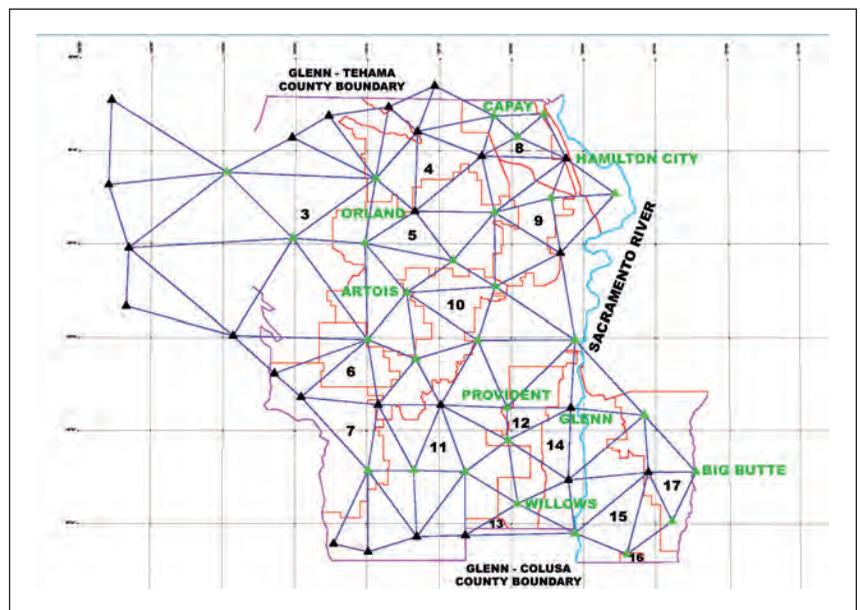
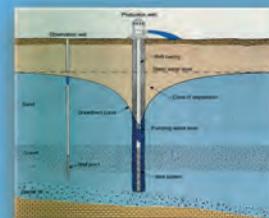


Figure 7. Schematic of Glenn County subsidence monitoring grid. The black triangles represent pre-existing benchmarks and the green triangles are benchmarks added in 2004 to complete the survey grid that is represented by the dark blue lines. The bold black numbers denote the seventeen different BMO sub-areas and the red and purple lines represent their boundaries.



*This article is the third in a series of five to be published in 2005-06 discussing topics related to groundwater and water wells in the northern Sacramento Valley.*



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# *Land Subsidence: What Is It and Why Is It An Important Aspect of Groundwater Management*

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