

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

Allan Fulton<sup>1</sup>, in cooperation with the California Department of Water Resources, Northern Region, Groundwater Section<sup>2</sup>

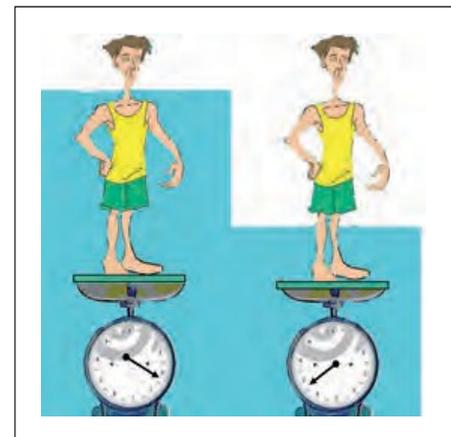
## LAND SUBSIDENCE - WHAT IS IT AND WHY IS IT IMPORTANT?

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.



**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.

## 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.

### ***EFFECT OF SUBSIDENCE ON AQUIFER STORAGE CAPACITY***

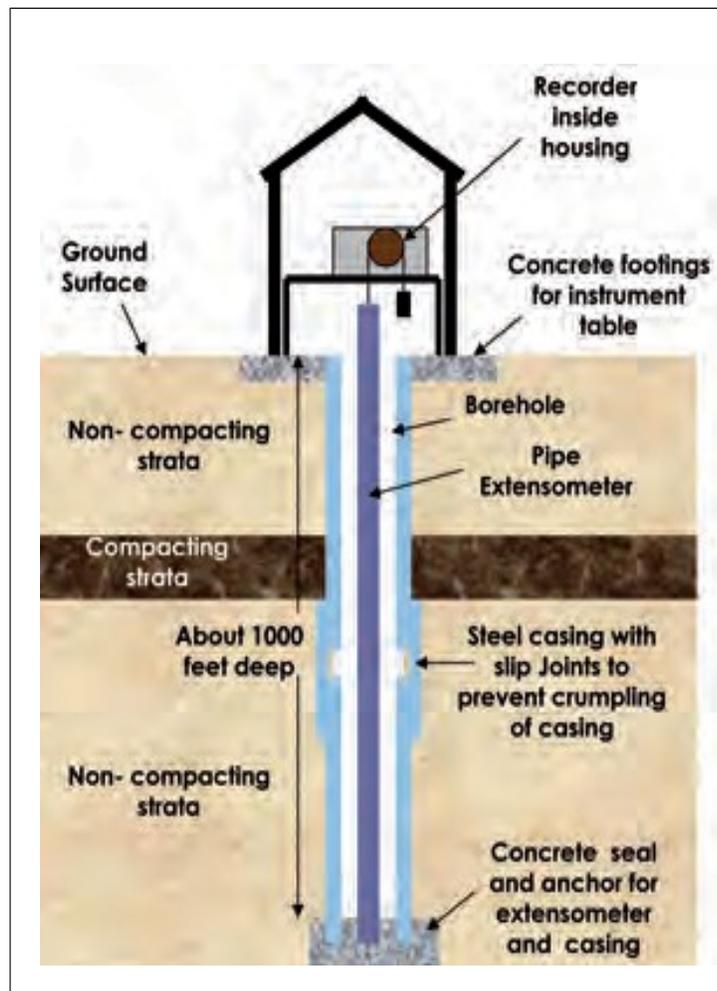
From a practical standpoint subsidence has very little, if any, effect on the storage capacity of aquifers because consolidation occurs in the clay beds that are between the dewatered sand and gravel strata. Clays that undergo consolidation do not contain as much water as they did before compression. 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.

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



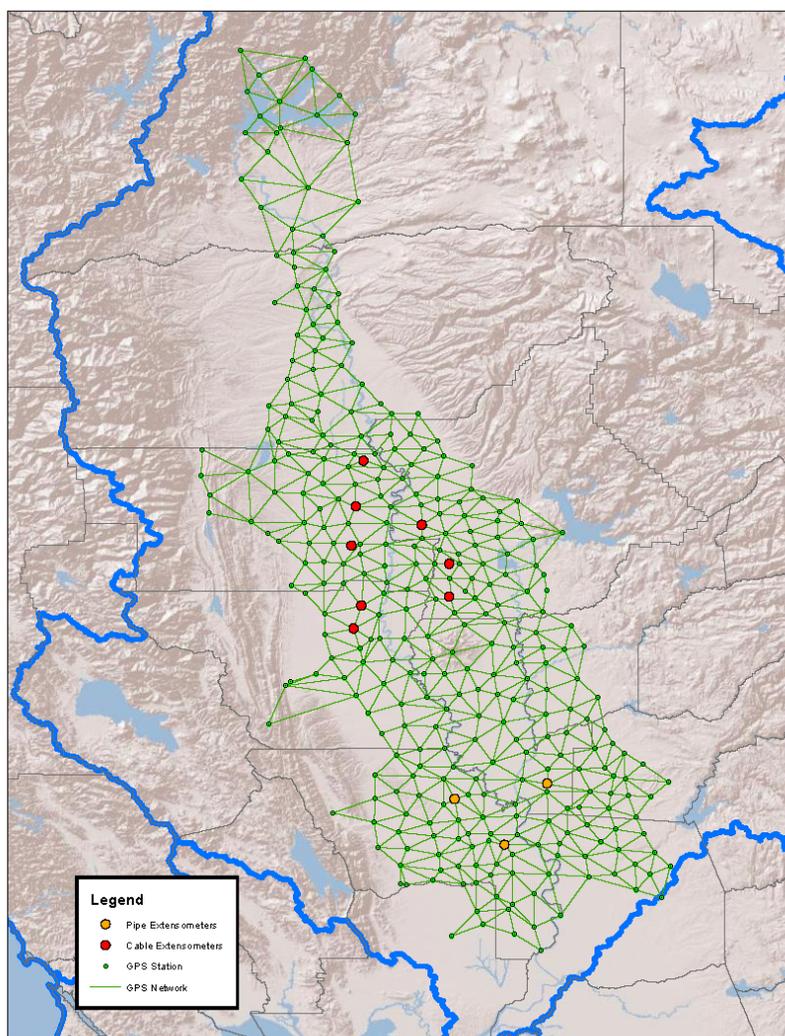
**InSAR**, Interferometric Synthetic Aperture Radar, is an increasingly popular alternative to extensometers and GPS or conventional surveying methods. InSAR is a space-borne, remote sensing technique that uses changes in satellite radar signals created by interferences on the earth’s surface to measure 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 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 11 extensometer stations and a GPS network that have been constructed in the Sacramento Valley. Figure 6 illustrates the geographic distribution of the extensometer and GPS stations. Most of the extensometers are located in the northern Sacramento Valley: three in Butte County; three in Glenn County; two in Colusa County, and then two further south in Yolo County; and one in Sutter County. Eight of them are cable extensometers and three are pipe extensometers. The extensometer locations are also equipped with multi-completion groundwater level monitoring wells. 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.

The Department of Water Resources, together with 20 federal, state, and local agencies installed and surveyed a land elevation measurement network in the Sacramento Valley. The GPS network, consisting of 339 survey monuments spaced about seven kilometers apart, covers all or part of 10 counties. It extends from northern Sacramento County eastward to the U.S. Bureau of Reclamation's (USBR) Folsom Lake network, southwest to DWR's Delta/Suisun Marsh network, and north to USBR's Lake Shasta network. DWR and USBR shared the cost of a contract with Frame Surveying & Mapping, which coordinated field measurements involving 47 staff from various agencies. The network is scheduled to be re-surveyed on a three-year frequency to measure elevation changes over time.

**Figure 6.** Extensometer and GPS survey locations in the Sacramento Valley



<sup>2</sup> University of California Cooperative Extension, Tehama County, 1745 Walnut Street, Red Bluff, CA 96080 (530) 527-3101

<sup>1</sup> California Department of Water Resources, Northern District, 2440 Main Street, Red Bluff, CA 96080 (530) 529-7383