Santa Clara Valley, California

A case of arrested subsidence

The Santa Clara Valley is part of a structural trough that extends about 90 miles southeast from San Francisco. The northern third of the trough is occupied by the San Francisco Bay, the central third by the Santa Clara Valley, and the southern third by the San Benito Valley. The northern Santa Clara Valley, roughly from Palo Alto to the Coyote Narrows (10 miles southeast of downtown San Jose), is now densely populated and known as "Silicon Valley," the birthplace of the global electronics industry.

In the first half of this century, the Santa Clara Valley was intensively cultivated, mainly for fruit and vegetables. The extensive orchards, dominated by apricots, plums, cherries, and pears, led local boosters to dub the area a Garden of Eden or "The Valley of Heart's Delight." In the post-World War II era (circa 1945–1970), rapid population growth was associated with the transition from an agriculturally based economy to an industrial and urban economy. The story of land subsidence in the Santa Clara Valley is closely related to the changing land and water use and the importation of surface water to support the growing urban population.

San Jose and its surrounding communities sprawl across the Santa Clara Valley. The view is looking southeast from downtown San Jose.

(Air Flight Service)

S.E. Ingebritsen and David R. Jones
U.S. Geological Survey, Menlo Park, California

The Santa Clara Valley was a premier fruit growing region in the early part of the 20th century. The landscape was dotted with family orchards, each with its own well (note well house far right).

(Alice Iola Hare, Bancroft Library, UC Berkeley)

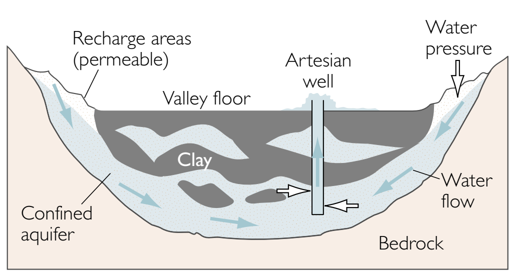
(George E. Hyde & Co. 1915-1921, Bancroft Library, UC Berkeley)

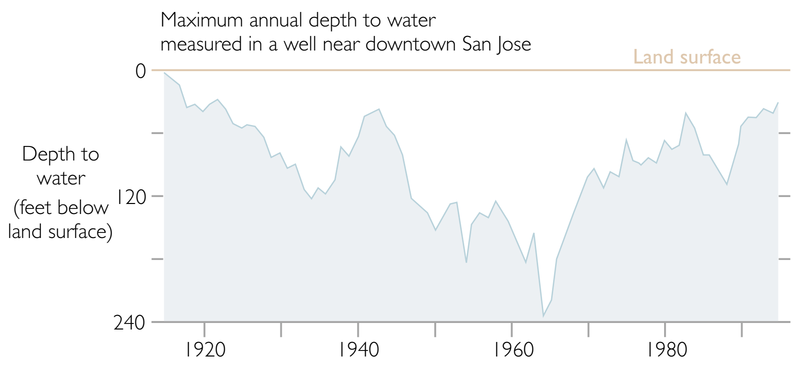
The Santa Clara Valley was the first area in the United States where land subsidence due to ground-water withdrawal was recognized (Tolman and Poland,1940). It was also the first area where organized remedial action was undertaken, and subsidence was effectively halted by about 1969. The ground-water resource is still heavily used, but importation of surface water has reduced ground-water pumping and allowed an effective program of ground-water recharge that prevents ground-water levels from approaching the historic lows of the 1960s. The unusually well-coordinated and effective conjunctive use of surface water and ground water in the Santa Clara Valley is facilitated by the fact that much of the Valley is served by a single water-management agency, the Santa Clara Valley Water District.

GROUND-WATER PUMPING SUPPLIED ORCHARDS AND, EVENTUALLY, CITIES

This free-flowing artesian well was capped to prevent waste (1910).

The moderate climate of the Santa Clara Valley has distinct wet and dry periods. During the wet season (November to April), average rainfall ranges from a high of about 40 inches in the low, steep mountain ranges to the southwest to a low of about 14 inches on the valley floor—rates that are generally insufficient to support specialty crops. Early irrigation efforts depended upon local diversions of surface water, but the acreage that could be irrigated in this manner was very limited. By the 1860s, wells were in common use.





In the late 1800s construction of railroads, refrigerator cars, and improved canning techniques gave farmers access to the growing California and eastern markets for perishable crops. The planting of orchards and associated ground-water pumping increased rapidly into the 1900s.

In the late 1880s most wells in the area between downtown San Jose and Alviso and along the Bay northwest and northeast of Alviso were artesian. That is, water flowed freely without needing to be pumped. In fact, there was substantial waste of ground water from uncapped artesian wells. The widespread artesian conditions were due to the natural hydrogeology of the Santa Clara Valley. Water levels in the artesian wells rose above the land surface because they tapped confined aquifers that have permeable connections to higher-elevation recharge areas on the flanks of the Valley but are overlain by low-permeability clay layers.

By 1920, two-thirds of the Santa Clara Valley was irrigated, including 90 percent of the orchards, and new wells were being drilled at the rate of 1,700 per year (California History Center, 1981). By the late 1920s, about 130,000 acre-feet of ground water was pumped annually to irrigate crops and support a total population of about 100,000.

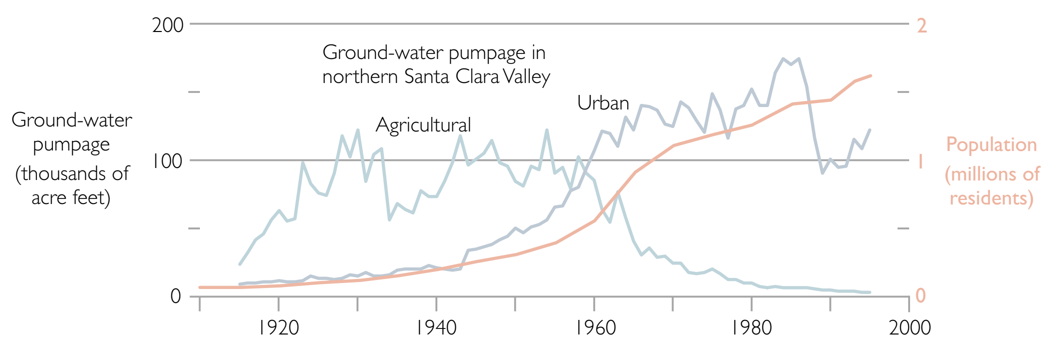
Acre-Feet

Hydrologists frequently use the term acre-feet to describe a volume of water. One acre-foot is the volume of water that will cover an area of one acre to a depth of one foot. The term is especially useful where large volumes of water are being described. One acre-foot is equivalent to 43,560 cubic feet, or about 325,829 gallons!

Ground-water levels drop

Ground water was being used faster than it could be replenished. As a result, water levels were dropping and artesian wells becoming increasingly rare. By 1930, the water level in a formerly artesian USGS monitoring well in downtown San Jose had fallen 80 feet below the land surface.

Between 1920 and 1960 an average of about 100,000 acre-feet per year of ground water was used to irrigate crops. Nonagricultural use of ground water began to increase substantially during the 1940s, and by 1960 total ground-water withdrawals approached 200,000 acre-feet per year. In 1964 the water level in the USGS monitoring well in downtown San Jose had fallen to a historic low of 235 feet below the land surface.



These photographs of the South Bay Yacht Club in Alviso show dramatic evidence of subsidence.

1914—The Yacht Club (building to the right) is practically at sea level.

1978—The Yacht Club is now about 10 feet below sea level, and a high levee keeps bay water from inundating Alviso.

(Santa Clara Valley Water District)

MASSIVE GROUND-WATER WITHDRAWAL CAUSED THE GROUND TO SUBSIDE

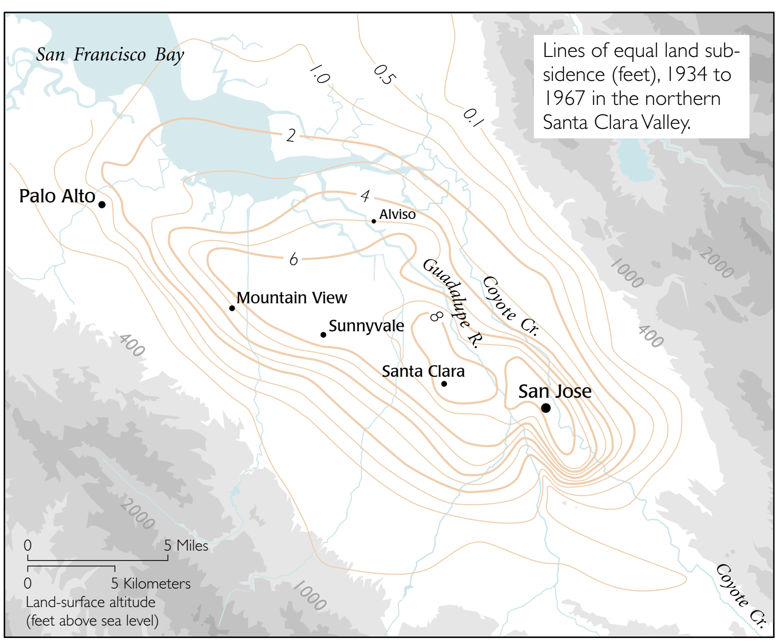
Substantial land subsidence occurred in the northern Santa Clara Valley as a result of the massive ground-water overdrafts. Detectable subsidence of the land surface (greater than 0.1 feet) took place over much of the area. The maximum subsidence occurred in downtown San Jose, where land-surface elevations decreased from about 98 feet above sea level in 1910 to about 84 feet above sea level in 1995.

Lands adjacent to the southern end of San Francisco Bay sank from 2 to 8 feet by 1969, putting 17 square miles of dry land below the high-tide level. The southern end of the Bay is now ringed with dikes to prevent landward movement of saltwater, and flood-control levees have been built to control the bayward ends of stream channels. The stream channels must now be maintained well above the surrounding land in order to provide a gradient for flow to the Bay. In the land that has sunk below the high-tide level, local storm discharge must be captured and pumped over levees in order to prevent widespread flooding.

The fact that Santa Clara Valley was subsiding became generally known in 1933, when bench marks in San Jose that were established in 1912 were resurveyed and found to have subsided 4 feet. This finding motivated the U.S. Coast and Geodetic Survey to establish a network of bench marks tied to stable bedrock on the edges of the Valley. The bench-mark network was remeasured many times between 1934 and 1967, and forms the basis for mapping subsidence.

During the 33-year period, subsidence ranged from 2 feet under the Bay and its tideland to 8 feet in San Jose and Santa Clara.

Total land subsidence, which probably began in the 1920s and continued to 1969 or later, is likely greater than shown on this map.



(Modified from Poland and Ireland, 1988)

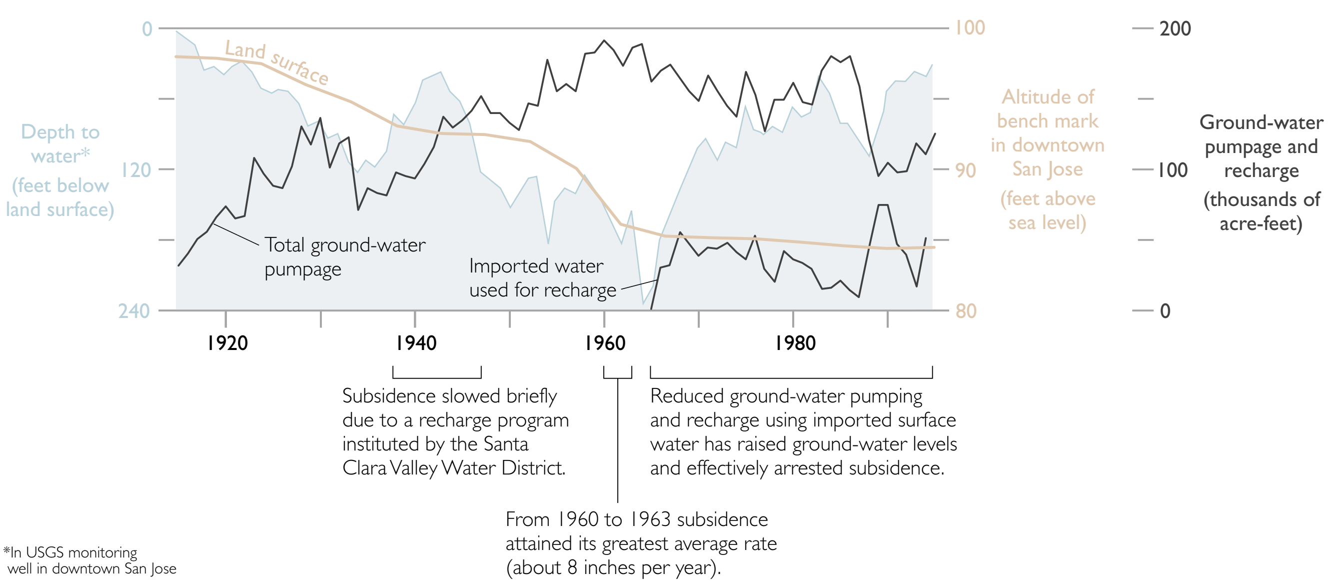
Subsidence had to be stopped

In 1935 and 1936, the Santa Clara Valley Water District built five storage dams on local streams to capture storm flows. This permitted controlled releases to increase ground-water recharge through streambeds. Wet years in the early 1940s enhanced both natural and artificial recharge. Although subsidence was briefly arrested during World War II, these measures proved inadequate to halt water-level declines over the long term, and, between 1950 and 1965, subsidence resumed at an accelerated rate. In 1965, increased imports of surface water allowed the Santa Clara Valley Water District to greatly expand its program of ground-water recharge, leading to substantial recovery of ground-water levels, and there has been little additional subsidence since about 1969.

In fact, as of 1995, water levels in the USGS monitoring well in downtown San Jose were only 35 feet below land surface, the highest levels observed since the early 1920s. A series of relatively wet years in the mid-1990s even caused a return to artesian conditions in some areas near San Francisco Bay. Some capped and long-forgotten wells near the Bay began to leak and were thereby rediscovered!

Subsidence in the Santa Clara Valley was caused by the decline of artesian pressures and the resulting increase in the effective overburden load on the water-bearing sediments. The sediments compacted under the increasing stress and the land surface sank. Most of the compaction occurred in fine-grained clay deposits (aquitards), which are more compressible, though less permeable, than coarser-grained sediments. The low permeability of the clay layers retards and smooths the compaction of the aquifer system relative to the water-level variations in the permeable aquifers. Since 1969, despite water-level recoveries, a small amount of additional residual com-

Land subsidence was a result of intensive ground-water pumping and the subsequent drop in water levels. Once pumping was stabilized by the introduction of imported surface water, subsidence was arrested.



*In USGS monitoring well in downtown San Jose paction and subsidence has accrued. The total subsidence has been large and chiefly permanent, but future subsidence can be controlled if ground-water levels are maintained safely above their subsidence thresholds.

Surface water is delivered for use in the Valley

The South Bay aqueduct conveys water from the Sacramento-San Joaquin Delta to the Santa Clara Valley.

(Santa Clara Valley Water District)

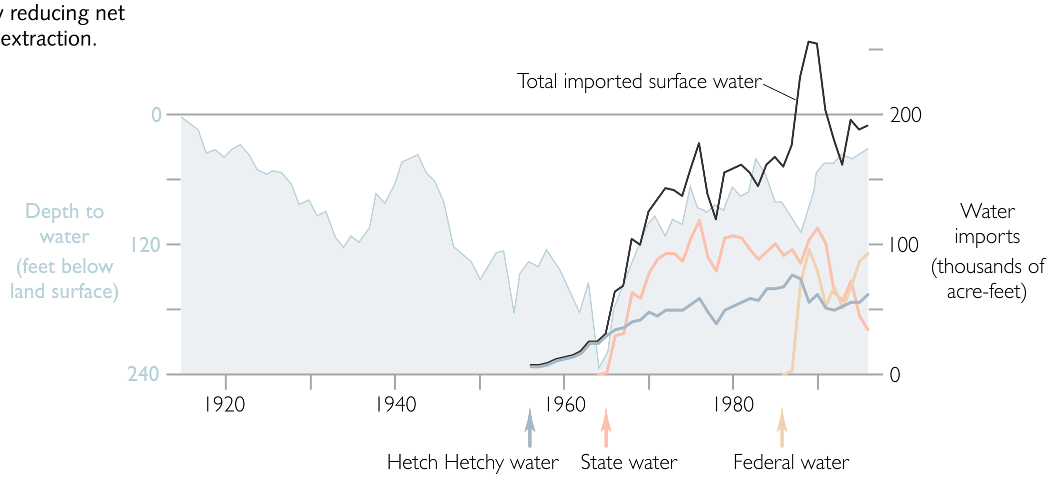
To balance Santa Clara Valley's water-use deficit, surface water has been imported from northern and eastern California via aqueducts—Hetch Hetchy (San Francisco Water Department, 1951-), the California State Water Project (1965-), and the Federal San Felipe Water Project (1987-). Much of the imported water also feeds into various local distribution lines. But presently about one-fourth of the water imported by the Santa Clara Valley Water District (about 40,000 of the 150,000 acre-feet total) is used for ground-water recharge.

The aquifer systems are used for natural storage and conveyance, in preference to constructing expensive surface-storage and conveyance systems. In order to avoid recurrence of the land subsidence that plagued the Valley prior to 1969, ground-water levels are maintained well above their historic lows, even during drought periods. For example, ground-water levels beneath downtown San Jose were maintained even during the major California droughts of 1976–77 and 1987–91. In order to avoid large ground-water overdrafts, the Water District aggressively encourages water conservation during drought periods. Per-capita water use under current conditions is much lower than in the agrarian past. Today, about 350,000 acre-feet of surface and ground water meet the annual requirements of a countywide population of about 1,600,000, and per-capita water use is only about one-fifth of the 1920 level.

The economic impact can only be approximated

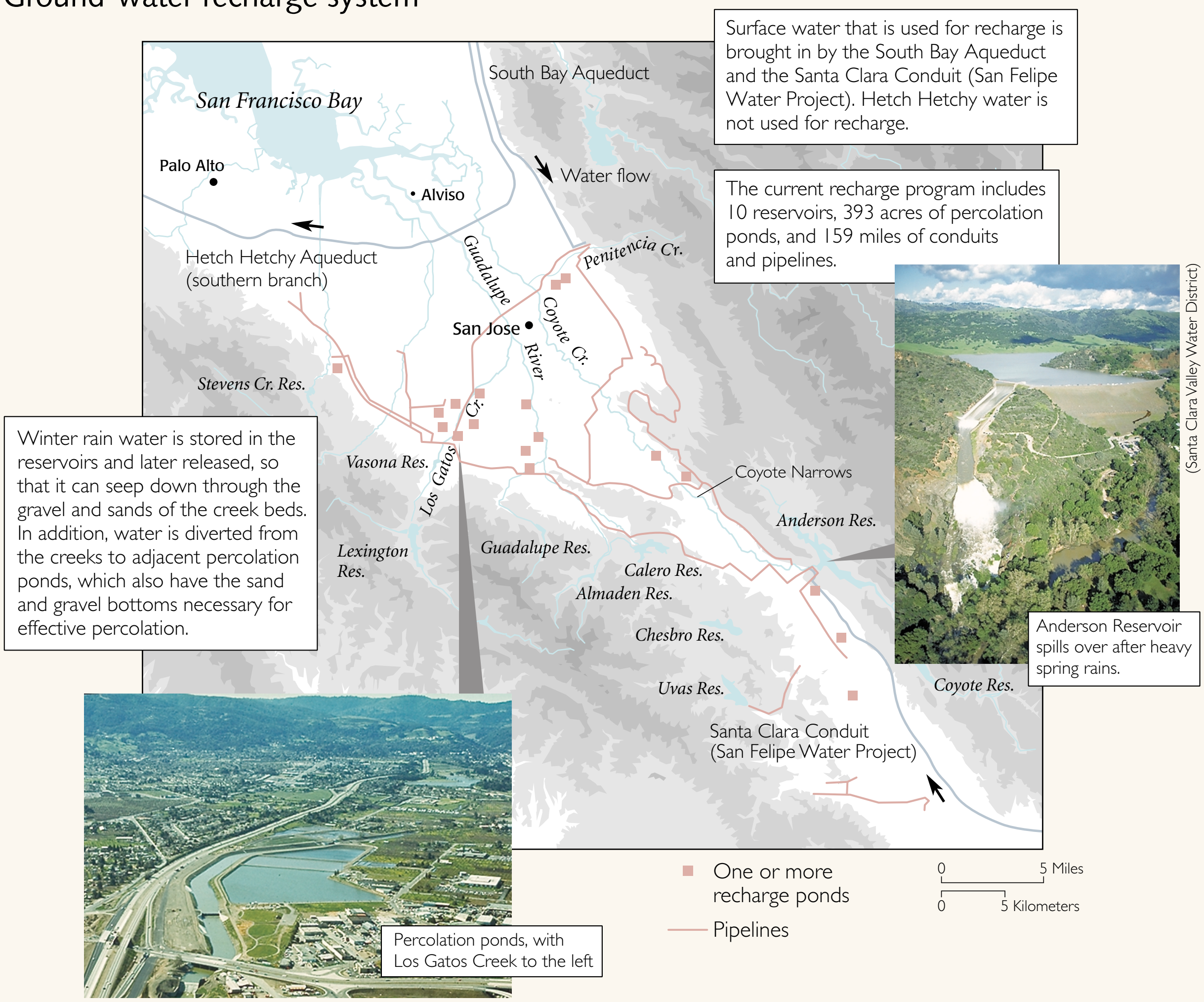
The direct costs of land subsidence in the Santa Clara Valley include the cost of constructing levees around the southern end of San Francisco Bay and the bayward ends of stream channels, main-

Water imports allow water managers to raise ground-water levels by reducing net ground-water extraction.



Santa Clara Valley Water District

Ground-water recharge system



(Santa Clara Valley Water District)

NATURAL CONDITIONS

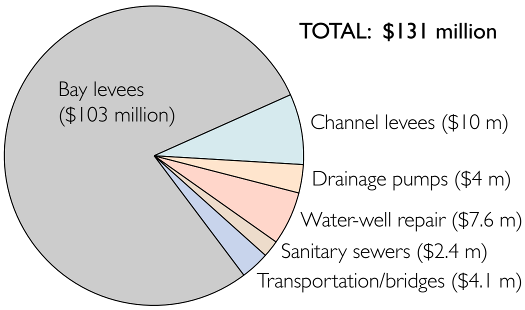
Conditions are favorable for recharge in the upper reaches of several streams because there is an abundance of coarse sand and gravel deposits and the aquifer system is generally unconfined; that is, fluid pressure in the aquifer is not confined by any overlying lenses of low-permeability clay. Nearer to the Bay, sediments tend to be finer-grained, and the exploited ground-water system is generally confined by low-permeability materials that impede recharge.

RECHARGE FACILITIES

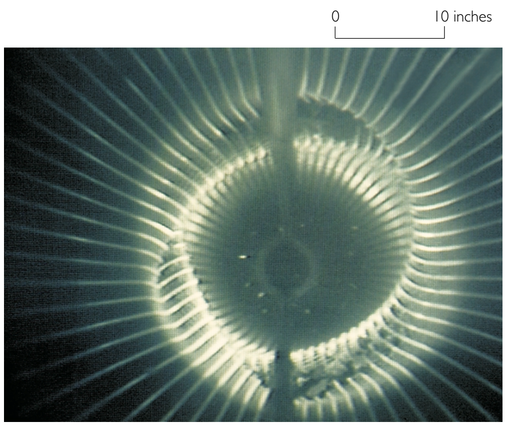
The first percolation facilities in the Santa Clara Valley were built in the 1930s. They relied on capturing local surface runoff, and proved inadequate to keep pace with the rate of ground-water extraction. The volume of artificial recharge was increased significantly when additional imported surface water became available in 1965. Artificial recharge rates in the 1970s were sufficient to reverse ground-water level declines and arrest subsidence.

COST-BENEFIT

In 1984, a cost-benefit approach was used to estimate the value of artificial ground-water recharge in the Santa Clara Valley (Reichard and Bredehoeft, 1984). The benefits of reduced ground-water pumping costs and reduced subsidence were found to be greater than the total costs of continuing the artificial recharge program. A second analysis compared the costs of artificial recharge with the cost of a surface system that would achieve the same storage and conveyance of water. The costs of artificial recharge proved to be much less than the costs of an equivalent surface system.



Direct costs of land subsidence in the Santa Clara Valley in 1979 dollars.



This view looking into a typical collapsed well screen shows the damage caused by compaction. This photograph was made by lowering a light into the well, followed by a camera; the crumpled vertical ribbing of the steel well screen produced this radiating effect.

taining salt-pond levees, raising grades for railroads and roads, enlarging or replacing bridges, enlarging sewers and adding sewage pumping stations, and constructing and operating storm-drainage pumping stations in areas that have subsided below the high-tide level. Most of these direct costs were incurred during the era of active subsidence. In 1981 Lloyd C. Fowler, former Chief Engineer of the Santa Clara Valley Water District, estimated the direct costs of subsidence to be $131,100,000 in 1979 dollars, a figure that translates to about $300,000,000 in 1998 dollars. The ongoing cost of maintaining levees and pumping facilities can also be attributed mainly to subsidence. In fact, as of this writing, the U.S. Army Corps of Engineers is building a substantial system for flood control along the lower Guadalupe River channel, with design requirements (and associated expense) influenced by past subsidence.

Some of Fowler's estimates of direct costs deserve further explanation. Land subsidence was estimated to have damaged or destroyed about 1,000 wells in the 5-year period 1960 to 1965, and the cost estimate was based on the cost of repair. By the 1960s most large wells in the Santa Clara Valley extended to depths of 400 feet or more. Many well casings were buckled or collapsed by the compaction of clay lenses at depths more than 200 feet below the land surface. The compacting clay caused the casing to buckle and eventually collapse. The cost estimate cited for the Bay levees as of 1979 applies only to the publicly maintained flood-protection levees, and likely underestimates the total cost. An additional, unknown cost was incurred by a salt company that maintained levees on 30 square miles of salt ponds within the original bayland area. Land subsidence has permanently increased the risk of saltwater flooding in case of levee breaks and the potential for saltwater intrusion of shallow aquifers.

Careful management will continue

The Santa Clara Valley Water District is currently managing the ground-water basin in a conservative fashion in order to avoid further subsidence. Their management strategy depends on continued availability of high-quality surface water from State and Federal projects that import water from massive diversion facilities in the southern part of the Sacramento-San Joaquin Delta. As we describe in another case study, these diversion facilities themselves are threatened by land subsidence within the Delta. Thus the prognosis for land subsidence in the Santa Clara Valley depends in part on subsidence rates and patterns in the Delta. Because much of California relies on large-scale interbasin water transfers, subsidence and water-quality issues in many parts of the State are complexly interrelated.