Geysers Recharge Project: Recycling Water and Producing Green Power

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The city of Santa Rosa, 50 miles north of San Francisco, has reused treated wastewater for agriculture and urban irrigation since 1975 and discharges some of that water to the Russian River in winter months. Starting in 1980, the city began looking for a way to expand the recycled water program while also decreasing discharge to the river, because regulatory requirements limit both the quantity and timing of these discharges. The river is home to three threatened species and is a source of drinking water for much of Sonoma County.

Meanwhile, 40 miles north of Santa Rosa, Calpine Geothermal was struggling with diminished energy production stemming from depletion of its natural water sources. Calpine owns and operates 19 power plants at The Geysers, the world's largest steam field, with a net generating capacity of 725 megawatts of electricity—enough to power a city the size of San Francisco. There, natural steam that is produced when groundwater comes into contact with geothermally heated rocks is tapped through production wells and spins turbines to generate electricity. But because only 20 percent of the expended steam can be cost-effectively condensed and reinjected, the groundwater is slowly being depleted.

Santa Rosa and Calpine negotiated a solution to meet both their needs: a 40-mile pipeline to convey 11 million gallons per day (mgd) of recycled water across the valley then up 3,300 feet into the Mayacamas Mountains. Calpine distributes and injects the water into 4,000- to 11,000-foot-deep wells to recharge the steam field, at a rate that optimizes steam production. Operations began in 2003, and a recent agreement will increase the annual average daily flow from 11 mgd to 15 mgd over the next 30 years.

The Geysers is the world's only geothermal system to use recycled wastewater to replenish its dying steam fields. The additional Santa Rosa water allows more steam to be produced by the geothermal system, which is not affected by the introduction of relatively cooler water.

Power production has not returned to previous peak production from natural water prior to its depletion, but recycled water will allow production to continue at current levels for the foreseeable future. The additional steam produced from the 12.62 mgd of recycled water that is currently being supplied from Santa Rosa generates enough electricity for 100,000 households in northern California. Approximately ten percent of that power is used to pump water to the steamfields. Compared to electricity generated by natural-gas-fired power plants, the additional 100 megawatts of geothermal electricity generated each day reduces carbon dioxide emissions by 655 million pounds and nitrous oxides by 291 thousand pounds annually.

Design Features

Minimal environmental footprint: No external reservoirs or tanks are used at the three mountain pump stations. The Bear Canyon pump station sits over a one-million-gallon underground reservoir that dampens surge pressures and enhances system control.

Flexible design: The 48-inch-diameter pipeline has a capacity of 40 mgd and can provide irrigation along its valley route. Variable-speed pumps allow flow rates to be adjusted to specific water needs.

Earthquake protection: The pipeline crosses two active faults. Sensors and isolation valves at the faults will shut down the pipeline if an earthquake of magnitude 5.5 or greater occurs.

Slide protection: The pipeline crosses 1,000-foot-wide and 700-foot-wide slide areas. Spring-loaded pipe sleeves connected by ball joints allow the pipeline to expand, contract, and rotate to lessen risk of rupture when soils slide. Inclinometers monitor soil displacement so the pipeline can be realigned when stresses increase.

Environmentally sensitive alignment: The pipeline skirts rare plant colonies and all but a few dozen of the area's 1,200 private properties. In 15 tunnels crossing rivers, creeks, and natural features, the pipeline is double-cased. The two Russian River crossings required directional microtunneling from shafts up to 100 feet long to avoid environmental impacts.

Hydrologic Effects

The streamflow discharge of the Russian River near Santa Rosa has averaged around 1,500 mgd over the past 10 years, so the amount of water diverted to The Geysers rather than into the river is not significant to its overall water budget. But it does help the endangered species in the river, who benefit from seasonally reduced streamflows which can average around 100 mgd.

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Photo: city of Santa Rosa

Drilling a well for injection of Santa Rosa's recycled wastewater to improve steam generation at The Geysers.

Assessing Recharge Across the Southwest

David A. Stonestrom – *U.S. Geological Survey*

The rate of population growth in the arid and semiarid southwestern United States is roughly three times that of the country as a whole. With limited rainfall and surface water, the region relies heavily on groundwater to meet demands. The sustainability of groundwater resources, including groundwater-fed habitats, depends on the balance of recharge and discharge, yet techniques to directly determine recharge are lacking. The challenge is exacerbated in dry areas by generally small amounts of recharge that vary widely in space and time. Due to natural fluctuations in climate, groundwater systems are rarely at steady state even without human perturbations. Thick unsaturated zones can produce millennial lags between changes at the land surface and responses at the underlying water table.

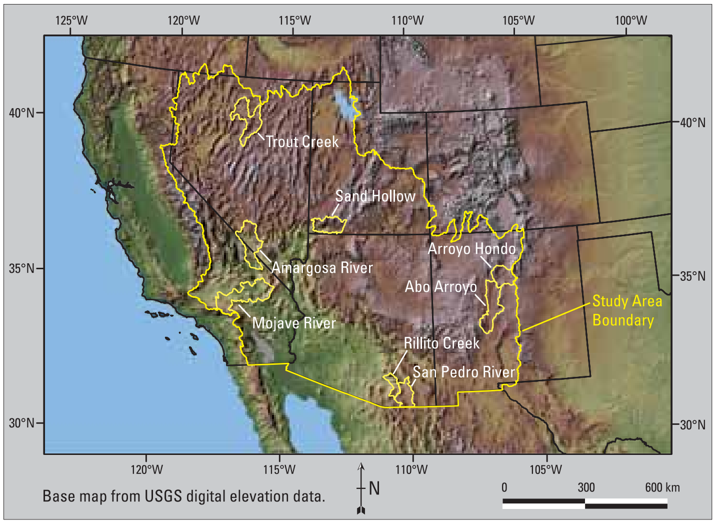
The U.S. Geological Survey recently completed a five-year effort to improve understanding of groundwater recharge in the arid and semiarid Southwest (Stonestrom and others, 2007); results are summarized here.

Integrating Methods and Scales

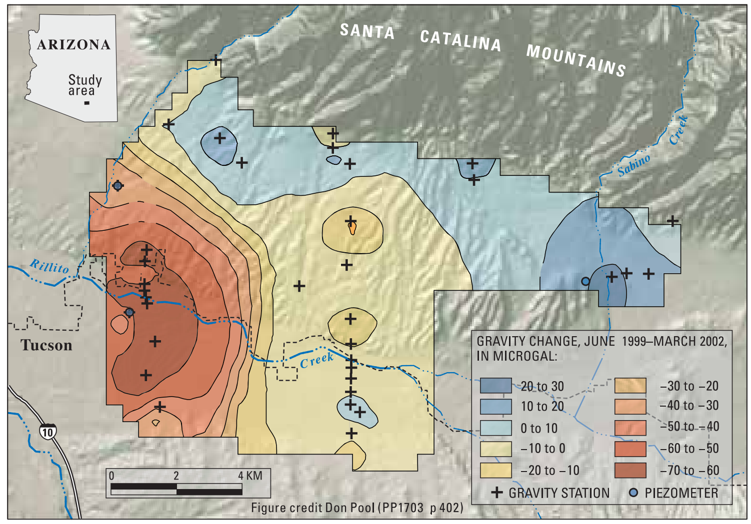
An area of roughly one million square kilometers was studied (see map at right). Groundwater recharge was simulated with a distributed-parameter water-balance model that had a horizontal resolution of about 270 meters, forced by climatic data from 1940 through 2000. The modeling analysis examined the influence of geology, soils, topography, vegetation, and other factors in addition to climatic variations. An energy-based submodel accounted for snowpack accumulation and melting. The analysis evaluated responses of recharge to large-scale climatic drivers—the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO)—that modulate weather in the study area.

In addition, eight sites were selected for multiyear, ground-based investigation in Arizona, California, Nevada, New Mexico, and Utah. Sites were selected to represent principal hydrogeologic regions: the Great Basin, Mojave, and Sonoran deserts, the Rio Grande Rift, and the Colorado Plateau. Methods for quantifying recharge were developed that would be broadly transferable. In addition to using traditional seepage-loss and water-balance methods, investigations employed geophysics-based characterizations and analyses of naturally occurring tracers such as heat, chloride, and isotopes. The period of observation included the strongest El Niño of the modern instrumental era (1997-98) and severe drought associated with development of unprecedented warmth in the western tropical Pacific Ocean (1998-2002).

The 1940–2000 climatic data were used in transient simulations to evaluate the impacts of climatic patterns on recharge and provide context for the individual study-site investigations. Results from ground-based measurements provided detailed information about the timing and location of recharge-producing streamflow events within the study sites, including information on how contemporary recharge affects groundwater quality.



Location of modeled area (large outline) and study-site basins (smaller outlines).



Gravity changes indicate areas where groundwater recharge (positive values) and depletion (negative values) are occurring near Tucson, Arizona.

Controls on Recharge

The combined modeling and ground-based measurements revealed distinct patterns of recharge across the study area that related primarily to the extent of orographic forcing, exposure of bedrock aquifers in mountainous recharge areas, and connections between alluvial-fill basins. Recharge was highly concentrated in space and time, with most occurring beneath upland catchments where thin soils cover permeable bedrock as well as beneath channels that often flow only several hours per year. Large expanses of alluvial basin floors were found to be drying under current climatic conditions, with little to no recharge to underlying groundwater.

Mountain snowpack was also found to be critical to recharge generation. Consequently, regionally manifested global warming can be expected to further reduce groundwater recharge by diminishing snowpack at high elevations.

Basin-scale recharge ranged from less than 0.3 percent of annual precipitation for the Upper San Pedro drainage (in southeastern Arizona) during La Niña conditions to about 16 percent in the Upper Virgin River drainage (in southwestern Utah) during El Niño conditions. Positive ENSO phases (El Niños) during warm PDO phases produced the largest amounts of precipitation and recharge, whereas negative ENSO phases (La Niñas) produced below-average precipitation and recharge—regardless of PDO. Southern basins were more sensitive to climatic oscillations than those farther north. During the drought, southerly sites continued to receive recharge from summer monsoonal runoff, unlike northern ones.

Looking Back to Look Forward

Groundwater recharge reflects the complex interplay of geology, climate, and vegetation across widely ranging spatial and temporal scales. The extensive declines in water tables that accompanied agricultural and urban development in the 20th century demonstrated that sustainable groundwater is not guaranteed when withdrawals exceed recharge and the extracted resource represents paleoprecipitation from ancient pluvial periods. Thermal, chemical, and isotopic tracers provide useful new tools for recharge assessment. Geophysical techniques complement these environmental tracers by depicting subsurface conditions. For example, the figure above right shows areas of groundwater gains and losses from recharge and extraction as indicated by time-lapse microgravity. The integration of hydrologic modeling with ground-based measurements facilitates resource assessment for long-term stewardship.

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Reference

Stonestrom, D.A., J. Constantz, T.P.A. Ferré, and S.A. Leake, eds., 2007. Ground-water recharge in the arid and semiarid southwestern United States: U.S. Geological Survey Professional Paper 1703, U.S. Geological Survey, 414 p.,