Stanford WOODS INSTITUTE for the ENVIRONMENT

Research Brief

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Expanding California's Water Resources with Deep Groundwater

In California, groundwater typically accounts for around 35 percent of the water used for agriculture and cities (PPIC). However, to address a growing population and one of the most severe droughts on record, groundwater withdrawals are continuing to increase in California. Fresh groundwater resources occurring at relatively shallow depths (less than ~1,000 ft) are considered to be the most physically and economically accessible in terms of groundwater availability and quality. However, growing water demands and current technologies are making deeper groundwater wells more common.

Deeper groundwater aquifers are rarely studied but could yield important sources of water in California and elsewhere. Most available information comes from oil and gas production in relatively deep geologic formations. In California, the data from oil and gas extraction is particularly useful because three quarters of hydraulic fracturing occurs less than 3,000 ft from the surface and half of it is shallower than 2,000 ft. As oil and gas production activities increase and pressure grows to extract more groundwater in California, efforts to monitor and protect deeper saline groundwater resources become more urgent.

This brief is based on new research from Mary Kang and Robert Jackson that attempts to address the gaps in knowledge of deep groundwater sources. Their work characterizes deep groundwater salinities, expands groundwater volume estimates to include deeper and more saline waters and estimates the potential for groundwater contamination by human activities. The researchers analyzed 938 chemical, geological and depth data points from 360 oil and gas fields across eight counties in California — Los Angeles, Ventura, Santa

About the Researchers

Robert B. Jackson is Douglas Provostial Professor in Stanford's School of Earth, Energy, and Environmental Sciences and a Senior Fellow of the Woods Institute for the Environment and the Precourt Institute for Energy. He studies how people affect the earth, including research on the global carbon and water cycles, energy use, and climate change. He currently serves as chair of the Global Carbon Project (**globalcarbonproject.org**).

Mary Kang is a postdoctoral research fellow with the Stanford Department of Earth System Science. She studies groundwater supply and quality issues, greenhouse gas emissions and the migration of methane, carbon dioxide and water through geologic faults and abandoned oil and gas wells. For more information, see **jacksonlab.stanford.edu**.

Definition Key

Total Dissolved Solids (TDS): Used for determining water quality; total amount of minerals, salts or metals in a given amount of water and expressed in units of mg per unit volume of water (mg/L).

Fresh groundwater (California definition): Groundwater with a concentration of TDS less than 3,000 mg/L.

Underground sources of drinking water (USDWs): Non-exempted groundwater aquifers with a concentration of TDS less or equal to 10,000 mg/L, which serves or has the potential to serve as a drinking water source.

Barbara, Kern, Fresno, Solano, Yolo and Colusa — and depth data from 34,392 oil and gas wells.

Key Research Findings

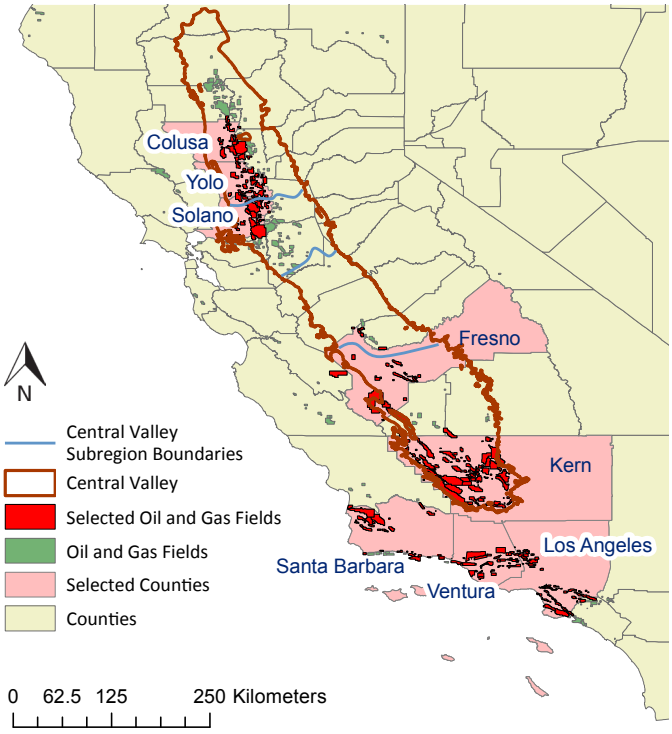
Increased groundwater volumes in the Central Valley

California's Central Valley alone has close to three times the volume of fresh groundwater and four times the volume of underground sources of drinking water (USDWs) than previous estimates suggest.

- The researchers found that by expanding previous groundwater volume estimates deeper than 1,000 ft (305 m), fresh groundwater volume almost triples to 2700 km^3. Most of the additional fresh groundwater — 59 percent — was found between ~1,000 and 3,000 ft depths (305 to 1,000 m).
- The researchers also discovered that USDWs, for which volumes were previously unquantified, provide additional groundwater volumes, bringing the total to 3900 km^3 in the Central Valley.
- Overall, most of the groundwater volume originates from the more accessible layers, above 1,000 m, but the deeper formations still represent 26 percent of fresh groundwater and 42 percent of USDWs.

Figure 1.

Selected oil and gas fields and counties in California and the Central Valley near shallow groundwater aquifer systems. The Central Valley Subregions, as shown by the boundary lines in blue, from north to south are "Sacramento," "Delta," "San Joaquin," and "Tulare".



Key Research Findings

Fresh water is abundant at deeper depths

While salinity levels typically increase with depth, the researchers found variations within and among CA counties. Overall, the data shows that relatively fresh water is surprisingly abundant at depth.

- Salinity concentrations range from well within those of typical city water in the United States to those characterized as brine for depths of 0 m to 5400 m.
- Regional differences are observed between the northern counties — (Yolo, Solano, Colusa and Fresno) and most of the southern counties (Kern, Ventura and Santa Barbara). Southern counties have a larger proportion of fresher water (0-3,000 mg/L) at depths shallower than 1,000 m, while at deeper depths, a relatively large proportion of fresher water is found in the northern counties compared to southern counties.

Key Research Findings

Oil and gas activities occurring in freshwater zones and USDWs

Oil and gas activities occur in freshwater zones in seven out of the eight counties and in USDWs in all eight counties.

- In the eight counties, up to 35 percent of historical oil and gas activity occurred directly in USDWs, while up to 19 percent of activity occurred within freshwater zones.

- The percentage of oil and gas activities in freshwater zones is generally small compared to the percentage of oil and gas activities in USDWs. One exception is Kern County, where the largest percentage of oil and gas activities occurred in freshwater zones.

Other Considerations

Ground Subsidence and Potential Contamination from Oil and Gas Development

If groundwater pumping continues to increase, then land subsidence will as well. Portions of the Central Valley have already dropped by tens of feet as shallower ground water disappeared. Some locations dropped by a foot last year alone during the drought. Subsidence permanently reduces the ground's ability to hold water and can lead to costly upgrades for canals, buildings and other infrastructure.

A second risk is the potential for groundwater contamination driven by fluid injections. Unlike those discussed above, which occurred directly into freshwater and USDWs, these pressurized injections occur below useable aquifers but could drive saline water migration upwards into them. Deeper USDWs are the more vulnerable sources of water under such scenarios. Fluid injections into deeper formations already occur through water disposal, water flooding for enhanced oil/gas production and hydraulic fracturing. However, demonstrating direct impact to groundwater resources deeper than ~100 m is rarely possible in California or elsewhere because little or no monitoring is done below the depth of typical domestic water wells.

Key Points for Policymakers

1. Utilizing deeper groundwater aquifers should be considered for providing an additional source of fresh and saline water, as it has the potential to expand the amount of water available in California (as shown by the Central Valley findings).
2. Additional data collection and access to the California State Water Resources Control Board's groundwater well depth data are needed.
3. Additional studies are needed for evaluating subsurface activities — such as fluid injections for wastewater disposal, CO_2 storage and enhanced oil and gas recovery — that could contaminate deep groundwater resources.
4. Desalination or other treatment of groundwater at intermediate depths, less than 1,000 m for instance, may in some cases be a cost effective alternative water source.

Conclusions

Accounting for deep groundwater can substantially expand California's groundwater resources, a critical need given the state's current water shortages. However, if activity continues to increase, further studies are needed to explore subsidence and other potentially undesirable results caused by the use of deeper groundwater. In addition, more information on the effects of oil and gas development on deep groundwater resources is necessary. Although the focus of the paper was on California, other regions of the United States and other countries may also have additional, useable groundwater resources that need to be characterized, monitored and protected.

This brief is based on the paper: "Salinity of deep groundwater in California: Water quantity, quality, and protection," published in *Proceedings of the National Academy of Sciences of the United States*, June 2016.

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