Getting at groundwater with gravity

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Sean Swenson
National Center for Atmospheric Research

by Gloria Hicks

In southwestern Nebraska, a boom fueled by groundwater is going bust. In the 1970s, new irrigation technology made it possible to grow corn, which is much more lucrative than dryland wheat, in this sandy region. Farmers moved in, drilled wells, and planted new corn-fields. But by the late 1970s, groundwater levels had already begun to fall. Thirty years later, towns shrivel as farms decline and families leave for greener pastures.

“Around the world, the availability of groundwater has actually affected the economic success or failure of a region,” said Sean Swenson, a researcher in the Advanced Study Program at the National Center for Atmospheric Research (NCAR). “According to the United States Geologic Survey (USGS), 50 percent of people’s fresh water comes from the groundwater found in wells. In rural areas, that rises to 90 percent.” Whether for personal or commercial use, humans heavily depend upon the availability of groundwater.

With so much depending upon fresh water, local and national officials have long recognized the need for measuring groundwater resources; in some areas, they have established a systematic groundwater observation program. Yet groundwater resources sprawl across huge sections of land, crossing community and political boundaries and making it hard to understand how much water actually flows under any given tract of land. To better understand this essential resource, researchers have developed an innovative model to assess the amount of groundwater available over large areas. This model uses data from instruments on a new pair of satellites that measures changes in the Earth’s gravity.

A renewable resource in danger

In May 2006, Colorado State Engineer Hal Simpson ordered the shutdown of 400 wells

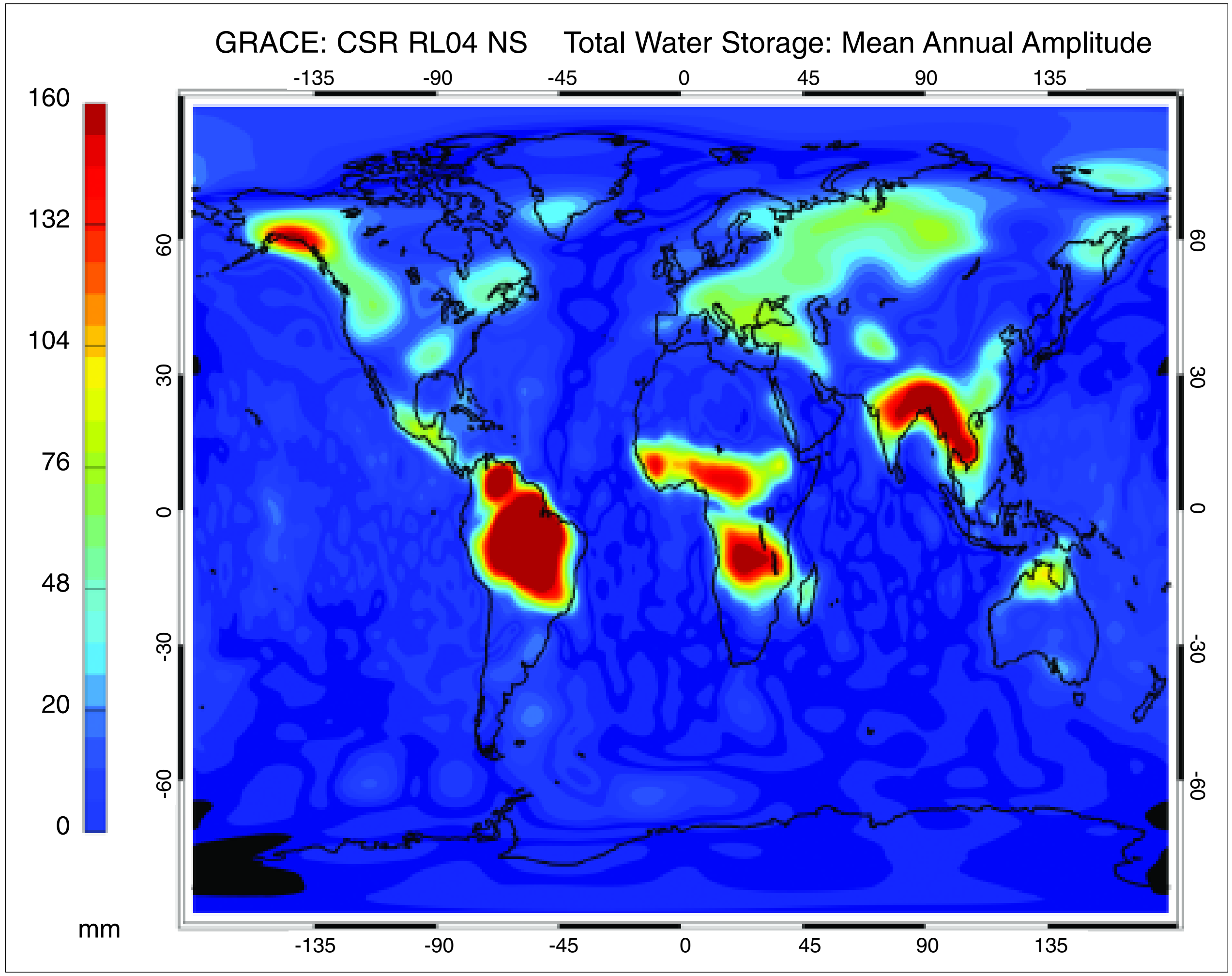
Irrigation allows farmers to grow water-thirsty corn on the relatively arid plains of the western and midwestern United States. But overuse of groundwater supplies can quickly deplete sources like the Ogallala aquifer, which underlies much of the Great Plains. (Courtesy Photos.com) in Platte County, Colorado, to ensure water for contracts downstream. As a result, the Colorado farmers who relied on these wells for their crops were out of business for the year.

"In some places, it's unclear how much groundwater exists, and it's unclear how fast it's going to run out," Swenson said. "You get a certain amount of recharge every year, and if you exceed that, eventually you're going to use up all of your resource. It will be gone."

Despite the estimated 16 million cubic kilometers (3.8 million cubic miles) of groundwater flowing under the Earth's surface, wells and springs often fail to provide enough water when and where it is needed. On a national level, the USGS assesses the nation's water supply, but determining if the regional water supply matches the regional need challenges local, state, and national agencies. Bill Alley, head of the USGS Office of Ground Water, said, "For certain aquifers, we have a pretty good program underway to track what is happening in that system, but there are other regions where we have very little consistent information over a period of time."

Searching for water from space

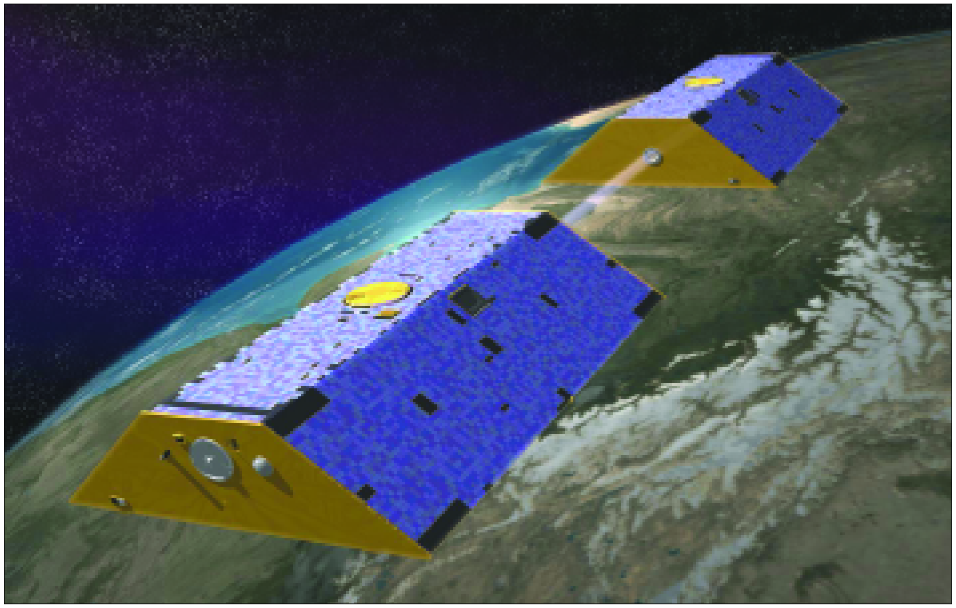
Part of the reason that groundwater monitoring is difficult on a regional scale has to do with measurement methods. Swenson said, "The traditional way to measure groundwater is to dig a well and monitor the water-table level in the well, but a well's water level doesn't translate exactly to groundwater storage. You need to know the properties of the soil subsurface and the aquifer composition to actually determine that." These aspects of the groundwater system help determine



NASA's twin Gravity Recovery and Climate Experiment (GRACE) satellites can detect groundwater by measuring subtle variations in Earth's gravity. This image shows the world's average annual cycle of water storage on land, computed from four years of GRACE gravity data. Colors indicate how much groundwater comes and goes, each year, in various regions; red indicates high levels of annual fluctuation, grading to blue, which represents lower levels of fluctuation. (Courtesy Sean Swenson)

the amount of groundwater that an area will typically store. "Basically, different aquifers store different amounts of water," he said.

Until recently, water resource agencies and scientists used only the data gathered by traditional methods to develop water usage models or to determine actual local usage. But starting in 2002, that changed. NASA and the German Research Institute for Aviation and Space Flight (Deutsche Forschungsanstalt für Luft und Raumfahrt) launched two new satellites, flying on the same track about 220 kilometers (137 miles) apart



As this diagram illustrates, the Gravity Recovery and Climate Experiment (GRACE) mission uses two satellites flying in a tandem orbit. By measuring changes in the distance between the lead satellite and the trailing satellite, scientists can determine changes in the Earth's gravity. (Courtesy NASA/JPL-Caltech)

People have long depended on groundwater for drinking water, farming, and commercial uses. When groundwater dries up, so can the communities that depend on it. Windmills scattered across the Great Plains mark where people have brought groundwater to the surface. (Courtesy Photos.com)

and 500 kilometers (310 miles) above the Earth. This project, called the Gravity Recovery and Climate Experiment (GRACE), measures changes in the Earth's gravity.

But how do gravitational differences tell scientists about the presence of groundwater? If the Earth were a perfectly round sphere, any point on the planet's surface would have the same average gravity field. However, mountains, deep oceanic trenches, and other features cause minute changes in Earth's gravity. Just as these mountains and deep trenches change the Earth's gravity field, so do changes in the amount of groundwater. A satellite's orbit above Earth is partly determined by gravity. So, slight changes in the distance between the twin GRACE satellites as they pass over Earth's features indicate changes in Earth's gravitational field. Scientists can then track differences in the Earth's gravity field from data retrieved from the GRACE satellites, improving their understanding of how water is moving and cycling around the planet.

Scientists like Swenson download and analyze GRACE data from the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) to measure groundwater globally over large areas. Swenson calculated the groundwater levels by analyzing the GRACE data and using models to estimate and subtract soil moisture levels. Swenson said, "The GRACE data provide a broad-scale picture of groundwater supplies, which complements local well measurements."

During the last two years, Swenson has repeatedly confirmed that satellites can provide a method to measure groundwater over entire regions. The success of this approach could help speed the development of a national monitoring system. By combining ground and space observations, the USGS and other national agencies can obtain a more comprehensive picture of groundwater availability across the United States. With this larger picture, the USGS, state, and local decision makers could work together to conserve shrinking groundwater. "Ultimately, researchers want to see the data being applied in some way. We want it to be useful to people who make decisions," said Swenson.

National groundwater: the endgame

At the USGS Office of Ground Water, Alley continues to develop an agenda for a national network of systematic monitoring. However, he has found a number of obstacles in the way of a national program. He said, "Installing wells for monitoring is very expensive and existing wells are limited, which makes the development of a good program tough. Satellite monitoring of changes in groundwater storage over large regions is a promising supplement to land-based monitoring methods."

Still another challenge for Alley exists in the very nature of groundwater. "The amount of groundwater in storage fluctuates between recharging and discharging periods. The GRACE data provide a new way to achieve precise estimates of seasonal and interannual variations in groundwater storage over large river basins or aquifers worldwide, estimates that have not been previously available," he said.

Despite the challenges, Alley believes that regional officials and scientific researchers remain tuned in to the need to measure the essential resource that groundwater provides. "We need to understand the impact we're having on groundwater from pumping and land-use activities and how that is playing out over time," Alley said. "With this information, we will be able to better manage the resource."

To access this article online, please visit http://nasadaacs.eos.nasa.gov/articles/2007/2007_gravity.html.

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For more information

NASA Physical Oceanography DAAC
http://podaac.jpl.nasa.gov/

Gravity Recovery and Climate Experiment (GRACE)
http://www.csr.utexas.edu/grace/

National Ground Water Association
http://www.ngwa.org/

United States Geological Survey Ground Water Information
http://water.usgs.gov/ogw/

United States Geological Survey Office of Ground Water
http://water.usgs.gov/ogw/bgas/mission.html

About the remote sensing data used

Satellite	Gravity Recovery and Climate Experiment (GRACE)
Data set used	GRACE L-2 products, version RL03
Resolution	400 kilometers
Parameter	Gravity
Data center	NASA Physical Oceanography DAAC

About the scientists

William M. Alley is a geologist with the United States Geological Survey (USGS) and currently serves as Chief of the USGS Office of Ground Water. Alley works specifically in the field of water resources and has received numerous awards, including the Shoemaker Award for Lifetime Achievement in Communication and the Meritorious Presidential Rank Award in 2006.

Sean Swenson is currently a postdoctoral fellow in the Advanced Study Program at the National Center for Atmospheric Research. His recent research involves validating Gravity Recovery and Climate Experiment data and applying those data to studying water cycles. He received his PhD from the University of Colorado at Boulder.