New Mexico

EARTH MATTERS

SUMMER 2019

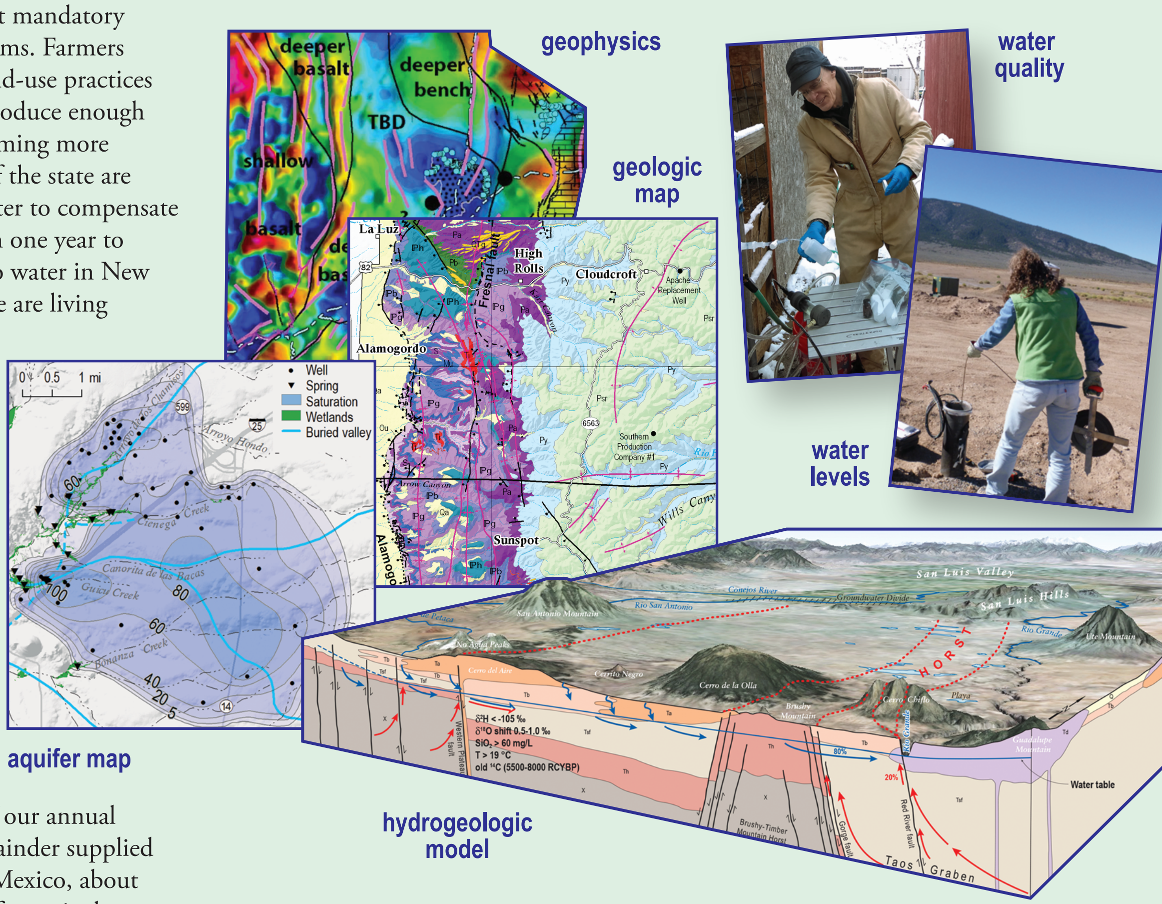
Aquifer Mapping in New Mexico

New Mexico is a water-challenged state in the midst of a warming climate. We are seeing, and will continue to experience, the dramatic impacts of climate change across our state, which influence nearly every aspect of our day-to-day lives. Rivers regularly go dry. More forests are burning hotter than ever. Well owners are forced to drill deeper wells. Restaurants only serve water if asked. Cities enact mandatory water-conservation programs. Farmers change their crops and land-use practices because wells no longer produce enough water. Water reuse is becoming more common. Some regions of the state are pumping more groundwater to compensate for scant river water. From one year to the next, when it comes to water in New Mexico, it may feel like we are living paycheck to paycheck—and we are.

In New Mexico, our annual water usage is approximately 4 million acre-feet—that is about 1.3 trillion gallons of water per year. Surface-water resources, such as the Rio Grande, San Juan, Animas, Canadian, Pecos, and Gila rivers, cover less than 1% of the state's land surface, yet they account for about 50% of our annual water usage, with the remainder supplied by groundwater. In New Mexico, about 80% of our water is used for agriculture, but a portion of that water is "returned" to either groundwater or surface water for future use.

Aquifer recharge may come from precipitation, which is focused on the high mountain peaks, but rivers are the primary source of recharge for many of our largest aquifers. This delicate balance in the local hydrologic cycle can be quickly disrupted when the amount of water consumption overwhelms water replenishment.

Several robust climate models indicate that New Mexico will warm by 5–10°F during the next 100 years. Warmer air retains more moisture than comparatively cooler air, causing increased rates of evaporation, increased plant transpiration, earlier snowmelt but with less runoff, longer growing seasons that require more



An ideal aquifer mapping project includes geologic mapping, geophysical investigation, ongoing groundwater-level measurements, and water-chemistry analyses. After the findings of each are interpreted, the hydrogeologist will combine them into a conceptual hydrogeologic model that displays the characteristics of the aquifers.

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water, and ultimately reduced recharge to groundwater supplies. These effects can also reduce river flow, which will likely trigger increased pumping of groundwater. Studies have shown, however, that many of New Mexico's aquifers are already experiencing unsustainable levels of pumping, and, in some cases, the aquifers have been permanently depleted. In order to responsibly manage groundwater resources in a hotter and drier future, we must understand and monitor the current conditions of our aquifers in order to carefully evaluate future water-management options.

What are Aquifers?

Contrary to popular belief, groundwater in New Mexico does not exist as large, underground lakes or rivers. Instead, groundwater is present in small, open spaces, such as between grains of sand, or within fractures and dissolution voids in rock. The permeability of a rock describes how easily water can move through it and places important constraints on how the aquifer may be used. A large amount water can be stored and easily transported to a well if spaces between grains are sizable and interconnected. In contrast, hard, dense bedrock, like granite, basalt, and some sedimentary rocks, provides little storage for groundwater, which can only move slowly through interconnected fractures.

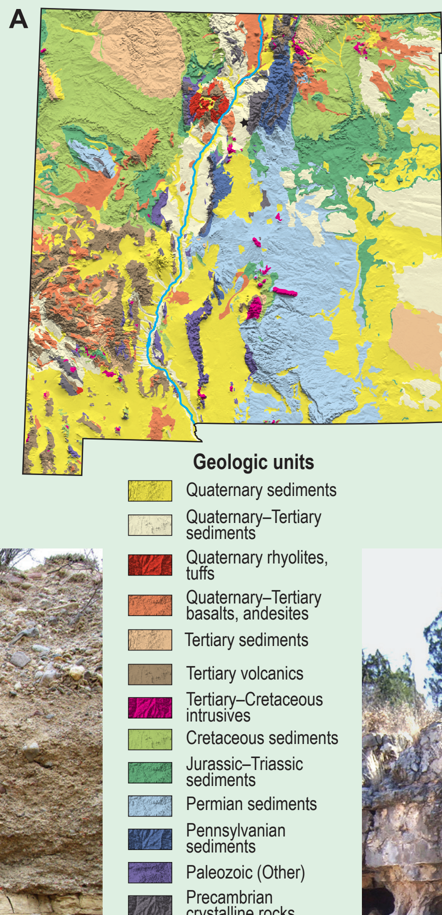
In New Mexico, our most productive, high-quality aquifers tend to be in alluvial and basin-fill deposits, which mostly comprise gravel, sand, silt, and clay that were eroded off highlands and then deposited by streams and rivers. The most notable such alluvial aquifers in the state are located in the Rio Grande rift. Communities along the Rio Grande valley have benefited enormously from tapping into these amazing aquifers.

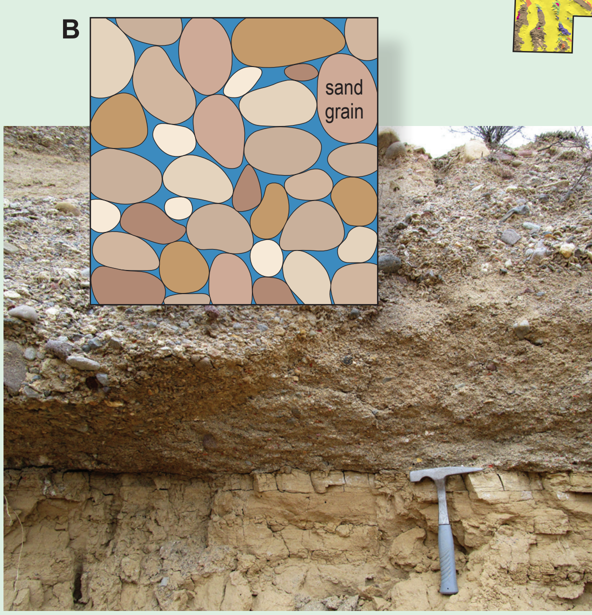
The availability of groundwater across the state is largely controlled by its complex geology. One of the state's most productive aquifers is in the Albuquerque Basin, where it comprises alluvial sediments and rocks of the Santa Fe Group. In other areas, such as in the Roswell Artesian Basin in the southeastern part of the state, groundwater resides in fractures or in caves that formed when limestone bedrock dissolved to form karst features. In some parts of the state, other important bedrock aquifers are found in fractures in granitic rock, such as in the Sangre de Cristo Mountains near Santa Fe, or in fractured, porous sandstone formations, such as the Glorieta Sandstone near Grants and Gallup.

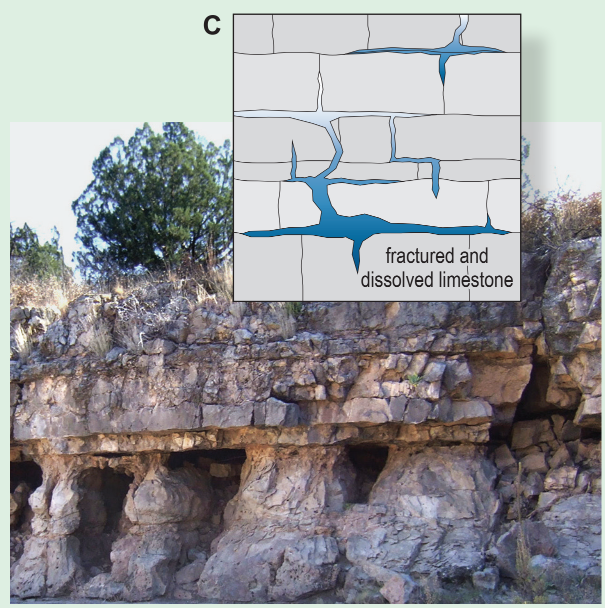
Because we cannot actually "see" aquifers, we tend to underappreciate them until something goes wrong—like when a well stops producing water. Wells are commonly pumped without monitoring groundwater levels or metering flow rates, which can provide early indications of groundwater trouble. Such aquifer neglect challenges groundwater scientists and water managers to study and aim to protect our precious aquifers.

Mapping Aquifers

Characterizing our diverse aquifers presents an extraordinary challenge because there is no simple way to see underground to study them. In order to map our aquifers, hydrogeologists become detectives, using information from a variety of earth-science datasets to piece together the three-dimensional, underground puzzle . An aquifer study starts with detailed mapping of the surface geology. This includes hands-on evaluations of outcrops, with descriptions of the composition and hydrologic features (such as porosity, cementation, and fracture density) of each







__A)__ Even a simplified geologic map of New Mexico illustrates the great complexity of its geology and, therefore, of its aquifers. Two examples of common—and important—aquifer materials found in New Mexico are: __B)__ Alluvial aquifers comprising gravel, sand, silt, and clay, with groundwater filling the open spaces between grains. The example here is similar to aquifer materials found in the Albuquerque Basin. __C)__ Dissolved cavities in limestone or fractures in other types bedrock, with water filling these zones. The rocks shown here are similar to the aquifer in the Roswell Artesian Basin.

rock formation. The Aquifer Mapping Program at the New Mexico Bureau of Geology benefits from the mapping conducted by our Geologic Mapping Program, which provides detailed digital geologic quadrangle maps in critical areas of the state.

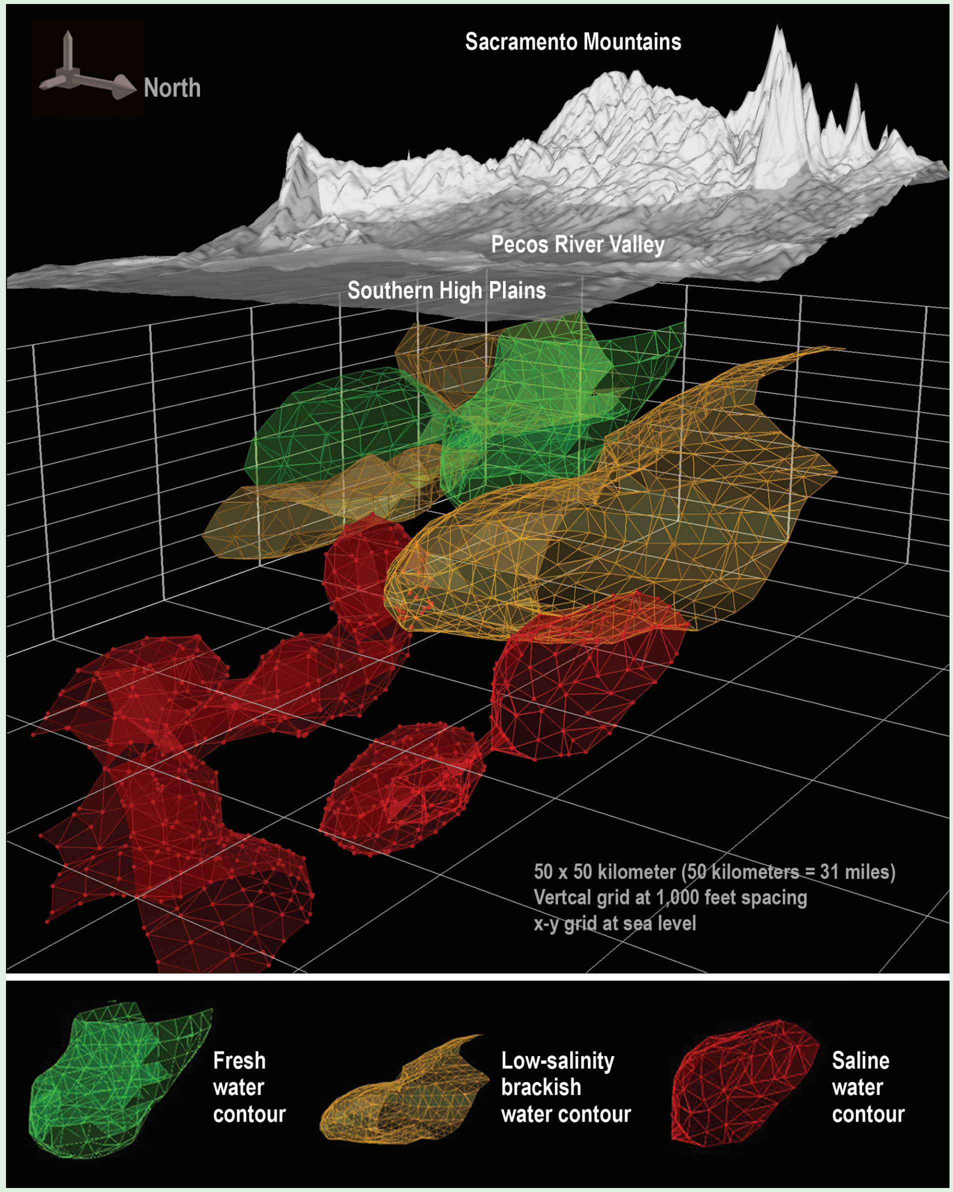
Geologists and hydrogeologists integrate information from the geologic maps with subsurface data—such as geologic descriptions from wells—to project the surface geology into the subsurface and create two-dimensional geologic cross sections that are then used to build three-dimensional models. Other investigative techniques include geophysical methods, which allow us to image the Earth with the equivalent of a CT scan or MRI. Geophysical methods commonly used in New Mexico include seismic surveys, magnetic surveys flown over the land surface, land-based magnetic measurements, and high-resolution gravity measurements, all of which can help us understand the subsurface structure, especially of the water-bearing formations.

Detailed geologic maps and cross sections, geologic data from existing wells, and the results from geophysical techniques are then paired with hydrologic data. Hydrologists perform aquifer tests, usually by pumping a well for a period of time, in order to measure groundwater levels and collect samples of the groundwater for chemical testing. By evaluating groundwater levels while wells are pumped, hydrologists can detect the aquifer properties in the vicinity of the well—such as the expected flow rate and whether or not there are boundaries that may adversely affect groundwater flow (such as faults or changes in rock composition).

Monitoring of groundwater levels over time provides information used to evaluate regional trends in aquifer performance. The chemistry of the water provides "forensic" evidence because groundwater picks up chemical "fingerprints" that yield information about the rocks the water flows through, and other chemical constituents can help us determine how long ago the aquifer was recharged by surface water.

Each aquifer mapping project in New Mexico is unique and site-specific. For a moderately sized basin, a study can take three to five years, and several hundred thousand dollars or more, to complete. Given the complex geology of the state and the need for substantial, multiyear funding, detailed aquifer mapping has been completed for only a small percentage of the state. As such, some projects are designed to map our aquifers only using existing data. In these regions of New Mexico, aquifer mapping begins by combining information from water well logs and geochemistry with additional geologic details from deep resource wells (like oil and gas wells) and cross sections contained in previous geologic maps and reports. Other types of data from older reports are also useful, such as maps that contour geologic contacts or the thicknesses of different geologic units in the subsurface.

Geographic Information System (GIS) technology is a modern, comprehensive "geostatistical" tool for analyzing various types of data that are geographically referenced. Integrating the above data in a GIS framework has not been done comprehensively before. With such GIS techniques, visual models can be made of the subsurface geology, and, importantly,



Combining high-quality geologic and hydrologic data into a Geographic Information System (GIS) platform allows us to create amazing visualizations of subsurface conditions. Here, some of the complexities of the water quality of southeastern New Mexico are modeled in three dimensions. The land surface is shown by the gray-to-white surface at the top of the diagram. The highest peaks on the land surface are the Sacramento Mountains. The Texas border is on the far left. The colored zones in the subsurface are a three-dimensional depiction of various water-quality zones, with the highest-quality water located in the green zones.

of the shallow, water-bearing geologic formations. A pilot study area for such an investigation is along the Pecos Slope (the east flank of the Sacramento Mountains), extending eastward across the lower Pecos River to include the southern High Plains.

Status of Our Aquifers

We can evaluate the status of some aquifers by using publicly available, long-term groundwater-level data and geostatistical tools. By focusing on alluvial and basin-fill aquifers, for which data coverage is adequate for detailed study, we can track groundwater-level declines in order to evaluate aquifer-depletion trends. In places where groundwater levels are dropping, we can determine if pumping is removing more water than is being replenished to the aquifer or if climate is directly affecting aquifer recharge.

Measurements of groundwater-level declines also allow us to estimate the volumes of groundwater that have been removed from storage, decade by decade. Such estimates are likely conservative because locations with sufficient data are not evenly distributed across the state. Some of the regions with the largest amounts of groundwater-storage reduction are the High Plains (Ogallala) aquifer near Clovis and Portales, the Mimbres Basin near Deming, the Albuquerque Basin, and the Estancia Basin east of Albuquerque.

A Collaborative Approach to Groundwater Monitoring

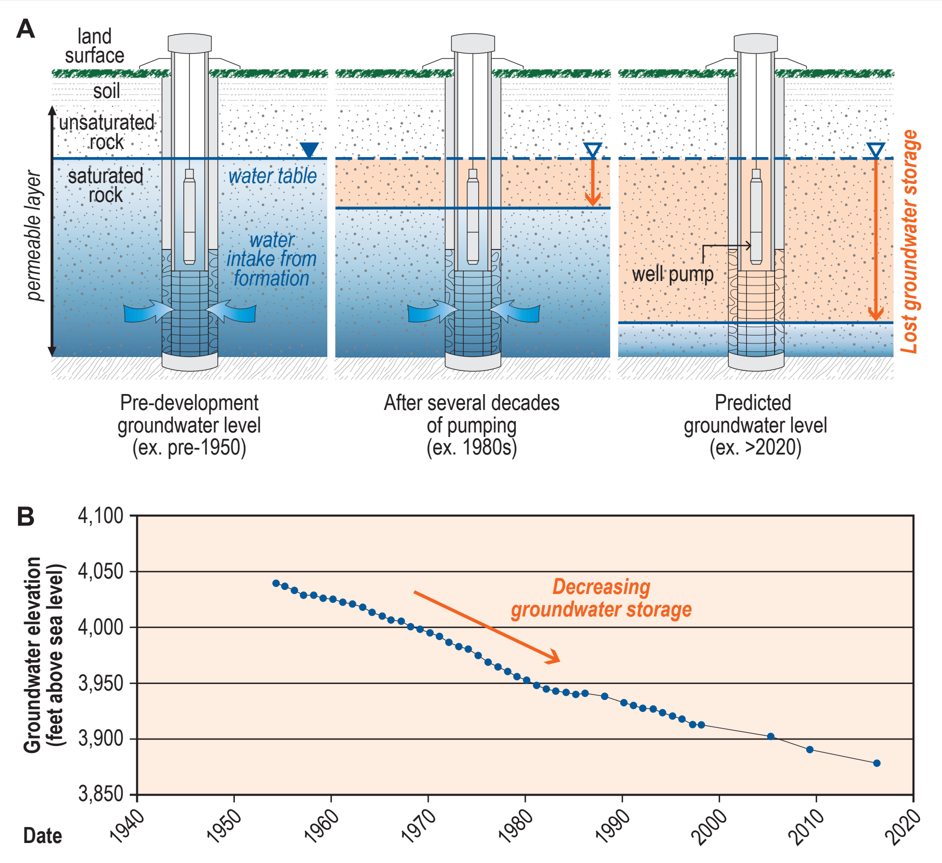
Through our aquifer-depletion research, we have found that less than half of the state has enough groundwater-level data to perform robust aquifer analyses and that these data are predominantly focused in high-population areas. In response, the Aquifer Mapping Program of the New Mexico Bureau of Geology (in partnership with the Healy Foundation) has started to fill in the gaps through a statewide, collaborative effort to measure the groundwater levels in many more wells.

Using simple tools, such as a steel measuring tape or an acoustic sounder, we can precisely measure the depth to groundwater inside most wells. In some wells, we set up continuous monitoring of the water level so that measurements can be made daily. These data help water-system operators and well owners better understand their water resources by providing visual representations of the conditions in their wells and aquifers. Upward or downward trends become obvious on simple graphs of the depth-to-water versus time. Water-level graphs (also known as hydrographs) that track annual or seasonal trends can be used to educate communities about their aquifers and also provide compelling evidence when seeking funding for new wells. Providing water-level data that is easily accessible by the public is one of the best ways to study and preserve our precious groundwater.

Our Groundwater Future

New Mexicans are facing a sobering groundwater future. Aquifer depletion, water shortages, and drying wells are happening now, and groundwater crises will only worsen with increasing demands,

Advanced technology like this acoustic sounder by Wellntel, Inc., provides real-time, continuous water-level measurements.



Repeat water-level measurements over a few years to decades have documented significant declines in some aquifers in New Mexico. ***A)*** *This hypothetical example shows how a well may go "dry" as a result of decades of regional groundwater withdrawal, which lowers the water table below the pump intake. The orange area depicts the loss of groundwater from storage, ultimately falling to where it can no longer be pumped from the well.* ***B)*** *A real hydrograph (water-level elevation graph) from the Ogallala aquifer near Clovis, New Mexico, shows the depth to water from 1950 to 2015. In such cases, some of the water-storage capacity of the aquifer can be permanently damaged.*

combined with the effects of climate change. In the western U.S., roughly 1 in 30 wells drilled between 1950 and 2015 have gone "dry." When a well goes dry, this usually means that the pumping of groundwater has drawn down the level of water in the aquifer to where it is no longer accessible by the pump. In such cases, owners are forced to employ strict conservation measures, drill deeper wells, or seek alternative supplies.

Fortunately, changes in water levels in most alluvial aquifers proceed slowly, over tens of years, especially in areas that receive effective groundwater recharge. The aquifers beneath Albuquerque and Santa Fe are good examples. For decades, groundwater levels declined as water was removed from the aquifers. With reliable groundwater-level data in hand, water managers have been able to make major changes to their water systems in hopes that the aquifers recover. This is being accomplished by diverting treated river water into public supplies, thus offsetting some of the demands on the aquifers.

Geology is a major factor in the behavior of water levels in the state. In places where wells are completed in fractured bedrock, such as near Placitas, Tijeras, and Cloudcroft, groundwater levels can rapidly fluctuate, on the order of several feet over a few years. Several years of more low precipitation can cause water levels to drop dramatically, causing wells to go dry until at least the next wet season. In the Ogallala alluvial aquifer of the Clovis-Portales region, withdrawal of huge volumes of groundwater for decades caused long-term trends of declining water levels and reductions in aquifer storage. Given the very slow rates of groundwater recharge to the Ogallala, such downward trends signal the end of the aquifer, unless major changes to pumping practices are made soon.

The bottom line is that we must be better stewards of our remaining water resources, to allow New Mexico to become a more water-resilient state. By providing high-quality visualization tools for management of groundwater and aquifers, we hope that we can face a warmer, drier future with an informed population more efficiently using the limited groundwater supply. New Mexicans can make our water last for many generations—but we must pay attention now.

— Stacy Timmons, Colin Cikoski, Alex Rinehart, Geoff Rawling, and Angela Lucero, New Mexico Bureau of Geology and Mineral Resources

We thank John Shomaker and Jayne Aubele for thoughtful reviews.

For Further Information

Water-level measurements and water-quality data are available via the New Mexico Bureau of Geology and Mineral Resources interactive map at geoinfo.nmt.edu/maps.

Bureau News

Steve Cather Retires

In March, Dr. Steve Cather retired as Senior Field Geologist after 32 years of service at the New Mexico Bureau of Geology and Mineral Resources. Although Steve's career focused on geological mapping, he excelled at using his mapping work as a springboard for studying big-picture, geological issues in New Mexico. Steve's publication record is impressive, with many papers appearing in regional journals, such as NM Geology, NM Geological Society Guidebooks, and NM Bureau of Geology Memoirs and Circulars. In addition, he published important papers in international journals such as Geosphere, Geological Society of America Bulletin, Geology, and Journal of Geophysical Research. Steve was elected a fellow to the Geological Society of America in 2012, in recognition of his research impact on the field of geoscience.

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Bureau News

2019 New Mexico Earth Science Achievement Award Winners

Award recipient Steve Harris, with State Geologist Dr. Nelia Dunbar (left) and State Representative Melanie Stansbury (right).

Public Service and Public Policy Award

Steve Harris was awarded the 2019 New Mexico Earth Science Achievement Award for "*outstanding contributions advancing the role of earth science in areas of public service and public policy*." The award was presented at the state capitol Roundhouse on February 19th, 2019 in conjunction with Earth Science/New Mexico Tech Day.

A lifelong avid conservationist, river outfitter, and Executive Director of the non-profit Rio Grande Restoration, Steve has worked tirelessly to change perspectives and influence policies for the responsible use and protection of the state's water resources. He has strived to bridge the gap between science and policy and has sponsored many activities—including rafting trips—designed to educate politicians and government officials, community representatives, and resource managers. He has consistently supported the gathering of modern hydrologic and ecologic data for science-based decision-making. Steve is also a skilled writer and has the rare ability to synthesize diverse datasets, select the essential points, and organize a compelling narrative. And, he has never met a river that he didn't like!

Research and Education Award

Dr. Barry Kues was awarded the 2019 Earth Science Achievement Award for "*outstanding contributions advancing the role of earth science in areas of applied science and education*." The award was presented at the New Mexico Geological Society Spring Meeting.

In his 45 years as a geology professor at the University of New Mexico, Dr. Kues has contributed greatly to the science of geology in New Mexico through research, teaching, leadership, and service. As a paleontologist and stratigrapher, his research has focused on geological problems, principally on creatures that lived in or near the shallow seas that covered New Mexico between 145 and 65 million years ago. He wrote the book "*The Paleontology of New Mexico*," which chronicles the flora and fauna of New Mexico over the past 500 million years. He has authored or edited 15 other books, including 11 New Mexico Geological Society Fall Field Conference guidebooks.

Dr. Kues has educated—and inspired—many hundreds of students through his decades of teaching a wide range of courses at the University of New Mexico. He also raised public awareness in New Mexico through his interactions with museums and public schools and through writings in newspapers.

Dr. Barry Kues and Georgianna E. Peña.

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