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MAPPING THE LIFETIME OF THE OGALLALA AQUIFER IN EAST-CENTRAL NEW MEXICO

The High Plains of the central United States extend from Nebraska and southeast Wyoming to eastern New Mexico and the panhandles of Oklahoma and Texas. This vast region of high, dry, semi-arid grasslands was so forbidding to pioneers in the 19th century that it was referred to as the Great American Desert. One hundred and fifty years later, it is now one of the largest, most productive, and most important agricultural regions on Earth.

Initial attempts at dryland agriculture in the High Plains resulted in the infamous Dust Bowl during the 1930s. Millions of acres were plowed and cultivated, but successive years of drought caused repeated crop failures. The relentless wind eroded the bare ground, creating enormous dust storms and causing the loss of millions of tons of topsoil. The amazing transformation from this ecological, economic, and social disaster was brought about after World War II largely by developments in irrigation and well technology. A far cry from the iconic windmill that yields a few gallons per minute when the wind blows, modern irrigation wells are hundreds of feet deep with large pumps that can yield a thousand gallons of water per minute—and they often run continuously for months at a time. These wells supply center-pivot sprinklers that are typically ¼ mile long. Thus the landscape has been transformed into a sea of circular green fields that stretches from horizon to horizon.

In New Mexico, agricultural products from Curry and Roosevelt Counties alone were valued at over $710 million in 2012. Cattle, calves, and milk products account for 93% of this total. Curry and Roosevelt Counties rank first and third in New Mexico in the number of cattle and calves raised. Dairies in these two counties have an economic impact of $606 million, and supply a large cheese plant between Clovis and Portales, which produces over 400 million pounds of cheese and whey protein products annually.

The ultimate source of this bounty is the Ogallala aquifer, also called the High Plains aquifer. It underlies most of the High Plains region, and is one of the world's greatest aquifers whether considered by area, volume of water in storage, or productivity. The water is contained in a rock unit called the Ogallala Formation, which is composed of sand and gravel deposited between 20 to 5 million years ago by rivers and streams draining east and southeast from the Rocky Mountains. Coarse sand and gravel fill the channels eroded into the bedrock of the pre-Ogallala landscape, and wind-deposited sand make up much of the intervening areas that were uplands between the ancient drainages. In east-central New Mexico, the Ogallala Formation thickens from a feather edge a few miles east of the Pecos River to many hundreds of feet at the New Mexico–Texas state line.

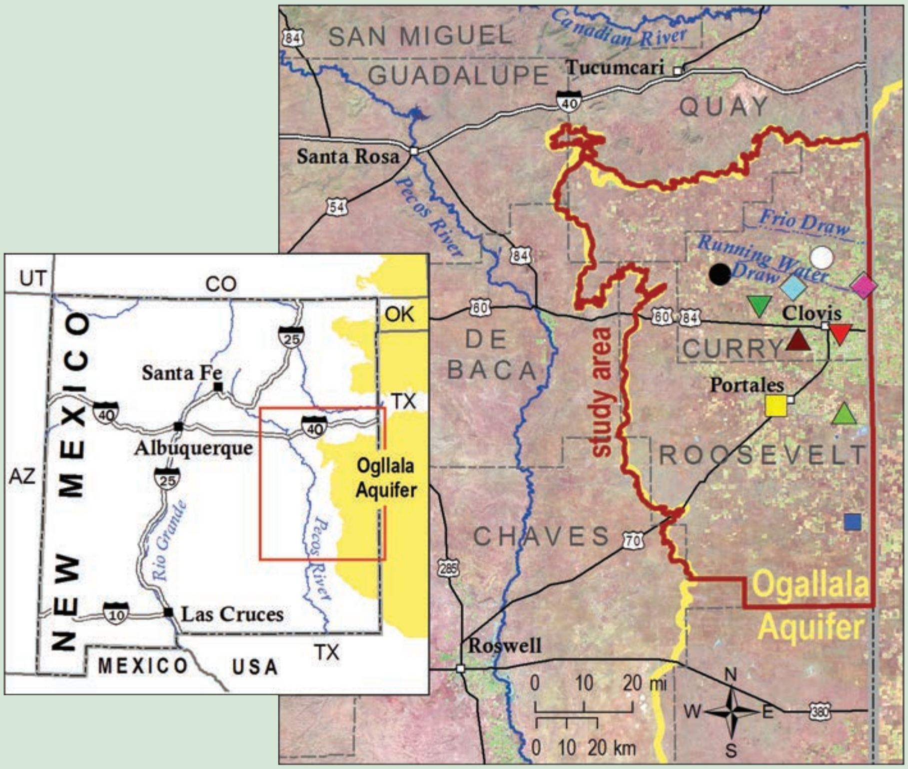
Example of pivot irrigation. Photo courtesy of U.S. Geological Survey.

The Ogallala is almost a perfect aquifer—it holds a vast amount of water and is quite permeable, meaning the water flows easily to wells, allowing the huge yields. Indeed, it probably seemed bottomless in the early days of irrigation development. However, it is now clear that across much of the High Plains region, the Ogallala aquifer is rapidly being depleted, including in eastern New Mexico. Water is being mined and not replaced. Curry and Roosevelt Counties are completely dependent on groundwater for all water uses, and 93% of that is for agriculture. This leads to a fundamental question—how long will the groundwater last?

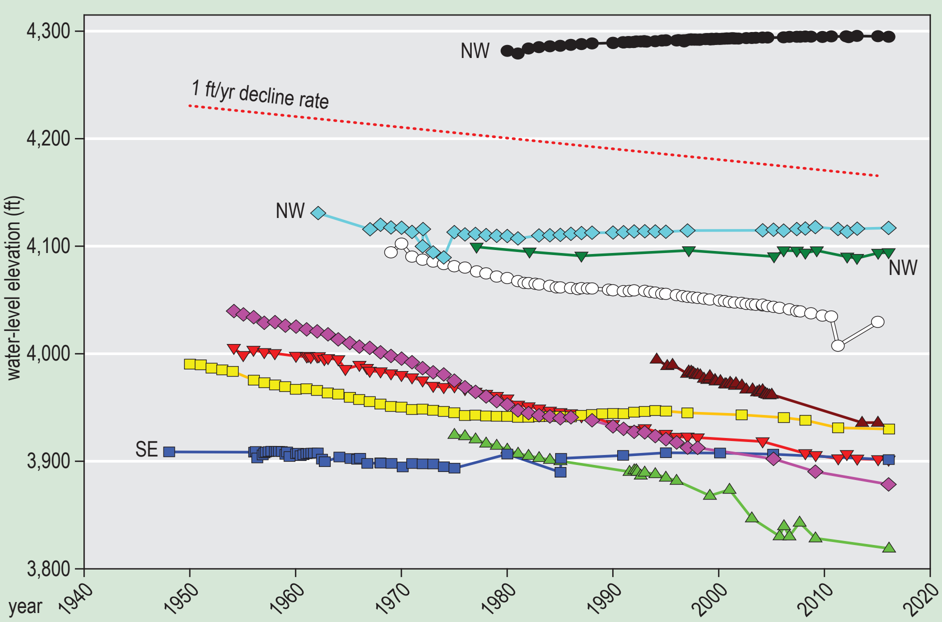
The Aquifer Mapping Program at the New Mexico Bureau of Geology and Mineral Resources was asked to answer that question. Building on previous work by the Kansas Geological Survey and Texas Tech University in their respective states, we prepared maps showing the projected usable life of the Ogallala aquifer in east-central New Mexico. The study was funded by the City of Clovis, Curry County, and Eastern New Mexico Water Utility Authority, who are using the results to plan the water future of east-central New Mexico.

Aquifer lifetime mapping

Projecting the lifetime of the aquifer requires: 1) knowledge of the current "saturated thickness" of the aquifer; and 2) how water levels have changed through time. The saturated thickness is that portion of the Ogallala aquifer that is currently saturated with water, measured upwards from the base of the formation to the water table. Above this interval, the unsaturated zone extends from the water table to the land surface. The saturated thickness varies across the region, depending on the original thickness of the aquifer and how much water has been removed. The elevation of the bedrock surface at the base of the aquifer was mapped in detail by the U.S. Geological Survey in the 1960s, using geologic information from numerous wells. In east-central New Mexico, the aquifer is underlain by Triassic- and Cretaceous-age rocks that are much less permeable than the Ogallala Formation. With respect to the aquifer above, the bedrock acts physically much like the bottom of a bathtub.



Location of the study area (red outline) in Quay, Curry, and Roosevelt counties in eastern New Mexico. Areas of extensive groundwater-supplied irrigation are evident as light green colors in the background satellite image. Selected wells with a long history of water-level data archived with the U.S. Geological Survey are shown in colors corresponding to the next figure.



Water-level trends in Curry and Roosevelt Counties; colors are coded to the well symbols on the first figure. The three northwestern-most (NW) and one southeastern-most (SE) wells are at the margins of the heavily irrigated areas and show a stable trend. The other wells show large declines. A constant decline rate of 1 foot/year is indicated by the red dashed line for comparison.

Changes in the elevation of the water table in the Ogallala aquifer since the 1950s were determined by inspecting over 10,000 water-level measurements from over 1,500 individual wells. These data were collected and provided by the U.S. Geological Survey. Water levels that were affected by pumping of adjacent wells or other effects, and any clearly spurious measurements, were removed. The remaining data represent groundwater conditions during the fall and winter, when irrigation is at a minimum. The locations and number of wells measured vary greatly through time, and the number of available measurements has decreased over the past 20 years, largely due to declines in funding for this labor-intensive work. For each well, the median, or middle-most, water level for each decade from the 1950s to 2015 was calculated. Using median values has the advantage of highlighting the long-term trends in water levels and smoothing short-term fluctuations over the 65-year period.

From the median water level for each decade at each well, median water-level surfaces were constructed from the 1950s to 2015. These maps show the median elevation of the water table in the aquifer for each decade. The surfaces were created by interpolating between the data points (the wells) using the mathematical method of kriging, which was developed in the gold mining industry to predict the grade of ore between locations of assayed samples in mines. It works equally well in any scenario where one wants to predict values between data collected at points, such as water levels in individual wells. From these surfaces, it is straightforward to calculate the saturated thickness for each decade, how much the saturated thickness has changed between any pair of decades, and the rate of change.

Knowing the current saturated thickness, and the rate of change of the saturated thickness between a pair of decades, one can then *project* these rates of change into the future and calculate the *projected* lifetime of the aquifer. The terminology is important; we are assuming that past water level changes will continue unaltered into the future. We cannot predict how much water may be pumped in the future, nor how the water table may respond to any changing patterns or quantities of pumping. But we can answer the question, "what is the life of the aquifer if past water-level trends continue?" The resulting projected lifetime maps provide a valuable, high-impact, graphical tool for water managers, regional stakeholders, and elected officials.

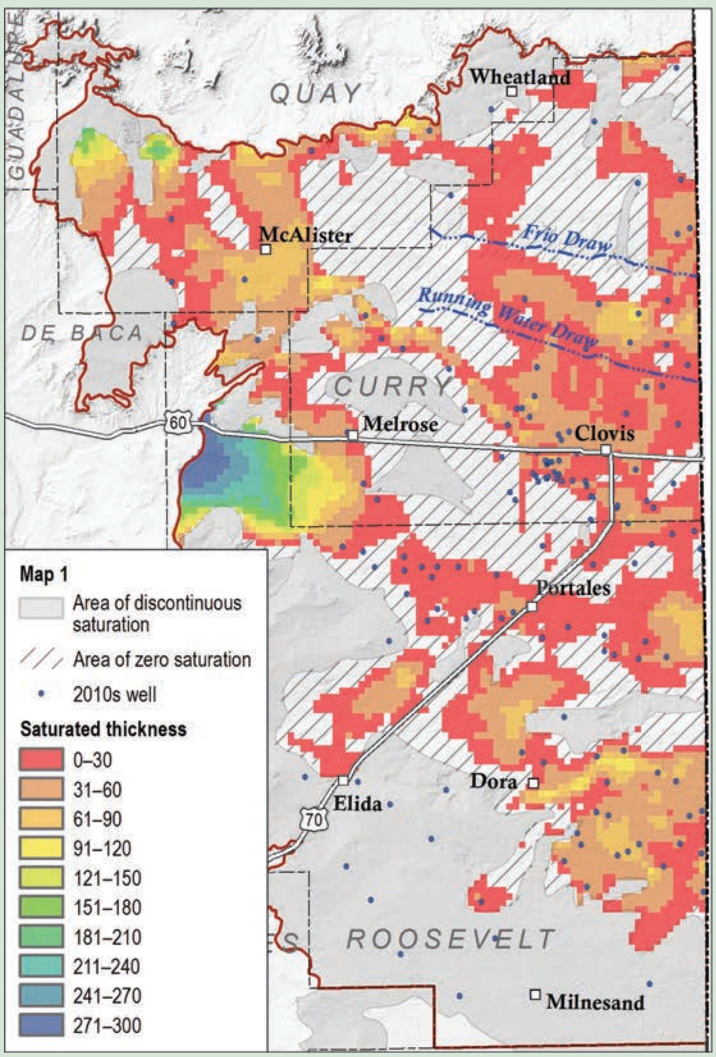
The map of present conditions in the aquifer, the saturated thickness for the 2010s decade, is based on data from 152 wells. Importantly, they are not evenly distributed—some areas have a high density of wells, and other areas have very few wells. This variation is the most important limitation on the reliability of the maps and projections—the results are more reliable where there are more wells, and vice versa. This must be kept in mind when interpreting the maps. In general, the high saturated thicknesses on the western edge of the aquifer in Roosevelt and Curry Counties are not reliable results as they are interpolated from very few data points. In a similar manner, the projected increases in saturated thickness are likely not reliable results, with one exception. In the region about 20 miles southeast of Portales and east of Dora, the area of water level increase seems to be well supported by the data.

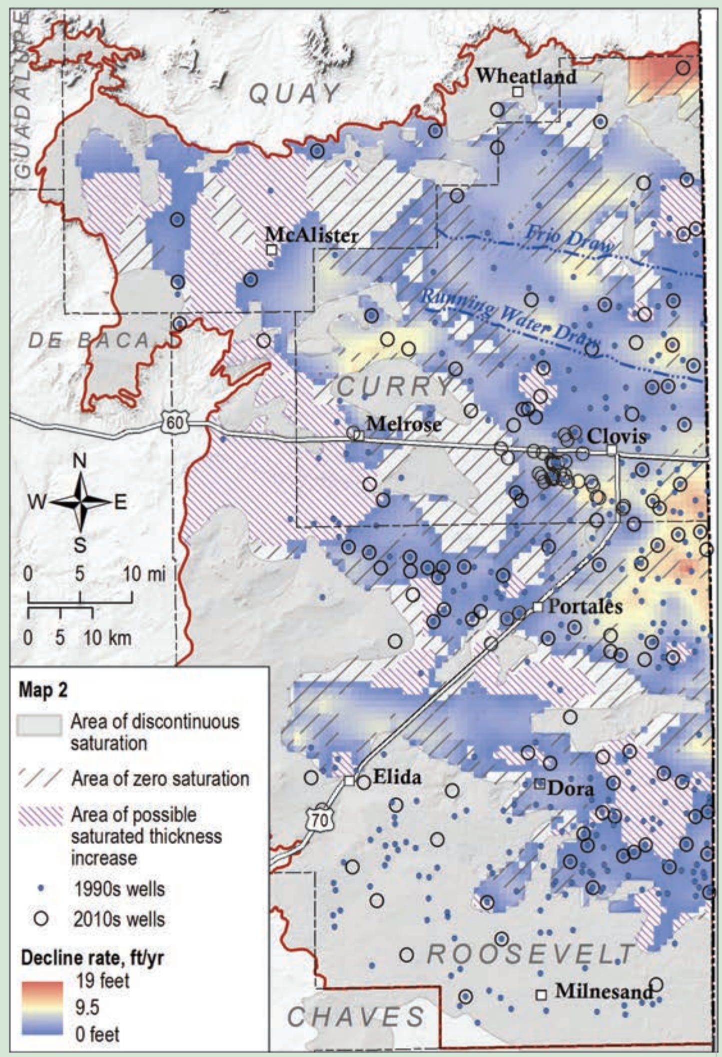
The rates of water level change can be large—in much of southeast Curry and northeast Roosevelt Counties, water levels are declining more than 5 feet per year, locally much more. This is the area with the greatest concentration of irrigated agriculture and there are many wells there—thus the results are plausible and reliable. In the western portions of the study area, there is little irrigation, and thus few wells. In fact, much of the western Ogallala aquifer was never very productive because it is too thin and commonly discontinuous. Based on the limited data, water levels appear to be changing only slightly there.

Lifetime map scenario 1

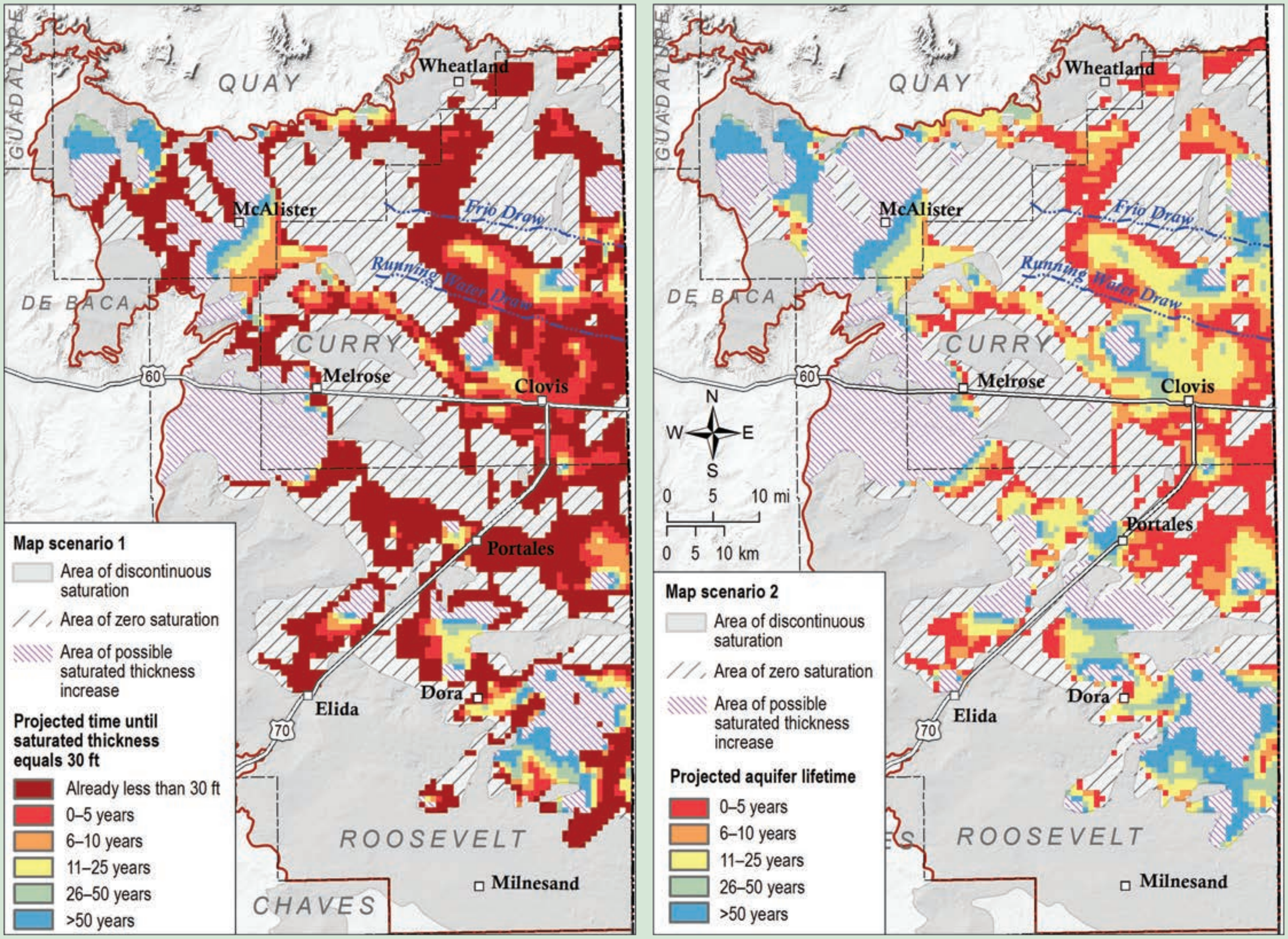
The first scenario shows the projected lifetime of the Ogallala aquifer until the saturated thickness is reduced to 30 feet. This value was estimated by researchers at the Kansas Geological Survey as approximately the minimum needed to operate large-capacity irrigation wells capable of producing 400 gallons per minute over a sustained period of time. The specifics of the well design and the local hydraulic properties of the aquifer will affect this thickness, but 30 feet has become a commonly used standard. Such a map shows the projected lifetime of "business as usual" irrigated agriculture.

The results are stark. Large areas already have less than 30 feet of saturated thickness remaining, or have already been effectively depleted—essentially zero saturated thickness remains. Projected lifetimes until the 30-foot





***Map 1**—Map and wells of saturated thickness in feet for the 2010s decade. Areas of zero saturation have developed since the 1950s. The aquifer is thin and was probably never very productive in the areas of discontinuous saturation. Results in the northwest part of the study area are not reliable as there are few data there.* ***Map 2**—Water-level decline rate in feet per year over the 20-year interval from the 1990s to the 2010s. Hashed purple areas are regions of possible increases in saturated thickness.*



***Water-level decline rate in feet per year over the 20-year interval from the 1990s to the 2010s**: **Map scenario 1**—Projected lifetime of the Ogallala aquifer until a saturated thickness of 30 feet is reached, based on water-level declines over the 20-year interval from the 1990s to 2010s decade. This represents the usable lifetime for intensive, irrigated agriculture assuming the current rates of decline continue. **Map scenario 2—**Projected lifetime of the full thickness of the Ogallala aquifer, based on water-level declines over the 20-year interval from the 1990s to 2010s decade. This represents the lifetime of the aquifer for domestic and low-yield municipal wells assuming the current rates of decline continue.*

threshold is reached are a few tens of years in the heavily irrigated region of southeast Curry and northeast Roosevelt Counties.

Lifetime map scenario 2

The second scenario shows the projected lifetime of the Ogallala aquifer until the entire saturated thickness is depleted. This represents the maximum projected lifetime of the aquifer for low-yield domestic or municipal wells. These only need a few tens of feet of saturated thickness or less to operate. The patterns are similar to the previous scenario—the intensely cultivated region between Clovis and Portales has the shortest projected lifetimes, commonly less than 10 years. Notably, many of the municipal wells supplying the two cities are located in this region.

Interpreting the maps

If water use for irrigated agriculture drops significantly once the 30-foot threshold is reached, the Scenario 2 map may represent a "worst-case" scenario of the aquifer lifetime for municipal and domestic users. The lifetime projections are based on past water-level decline rates, which have been almost totally controlled by groundwater withdrawals for agriculture. If agricultural withdrawals are greatly reduced, then water-level decline rates will be reduced and thus the lifetime of the aquifer will be extended. The relationship between the two is a simple inverse—if the water-level decline rate is reduced by half, then the projected lifetime will double.

Unfortunately, the relationship between the groundwater-pumping rate and the water-level decline rate, and thus the projected aquifer lifetime, is not simple. It depends on many parameters such as the number, location, and design of wells, and the hydrologic properties of the aquifer materials, which themselves vary throughout the aquifer. In the Ogallala aquifer in western Kansas, the effects of decreased pumping on water-level decline rates were quantifiable because there are many years of historical data on pumping rates as well as water-level data. Well owners in Kansas are required to periodically record and report the quantity of water their wells pump. This allowed scientists to forecast how much reduction in pumping would be required to greatly reduce or stabilize the water-level declines. In most of New Mexico, including Curry and Roosevelt Counties, such data are not available because there is no requirement to record and report it.

The water-level changes observed over the past 65 years are the combined effect of all inflows and outflows of water to the aquifer, including natural recharge and pumping. Groundwater recharge occurs when precipitation or surface water infiltrates into the ground and reaches the water table. Due to low precipitation, very high evaporation, an unsaturated zone that may be hundreds of feet thick, and lack of surface-water supplies, natural recharge in eastern New Mexico is extremely small. A few tenths of an inch per year is a reasonable estimate, although locally it may be 10 to 100 times higher than this amount beneath the numerous playa basins when they fill with water after heavy rains. In any case, in east-central New Mexico and across much of the High Plains region, water levels are declining too fast for recharge to keep up. At a regional average recharge rate of a few tenths of an inch per year, water levels would not significantly increase across the aquifer on human time scales, even if all groundwater pumping was stopped immediately.

The limitations of the available data and the procedures used in this study have resulted in some approximations and smoothing of the data. As a result, there is some uncertainty in the lifetime projections. However, the maps match quite well with aquifer lifetime projections made in Texas using different methods and more data points. They are consistent with what is known about the hydrogeology of the Ogallala aquifer and water-level trends over the past half-century across the High Plains region.

What next?

These results clearly have significant implications for the economic future of east-central New Mexico and the livelihoods of the people who live there. Agriculture and the many dependent and related businesses are a major component of the economy. Cannon Air Force Base is a large employer vital to the standard of living in Clovis, as is Eastern New Mexico University to Portales. Each of these industries and entities is completely dependent on local groundwater.

In the next few years, hard decisions will have to be made about water resources. Economics, as always, will be important, not just the realities of geology and hydrology. In areas with insufficient saturated thickness to operate large irrigation wells, it is possible to extend the life of intensive, irrigated agriculture by drilling many smaller wells and piping them together to supply the same quantity of water. But will the capital cost make economic sense for a farmer?

Prolonging irrigated agriculture could change the Lifetime Map 2 scenario from a "worst-case" to a "best-case" scenario for all other water users, including cities. Less water-intensive crops can be grown, but not for long if it is not profitable for a farmer to do so. Weather and climate significantly affect agricultural water use, and in dry years groundwater pumping is increased to make up for the lack of precipitation.

What is certain is that groundwater is a constrained, dwindling resource in eastern New Mexico. It is being depleted at an alarming rate and is not being replaced. It is the responsibility of the New Mexico Bureau of Geology and Mineral Resources to distribute accurate scientific information about the hydrology of the state. And, we hope that these aquifer lifetime maps will prove useful to the local communities, and help elected officials and resource managers make informed decisions about the water future of eastern New Mexico.

—*Geoffrey Rawling*

Geoffrey Rawling is a Senior Field Geologist at the New Mexico Bureau of Geology and Mineral Resources. He works on regional hydrogeology studies and geologic mapping.

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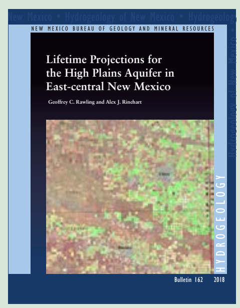
For Further Information



NMBGMR Bulletin 162— Lifetime Projections for the High Plains Aquifer in East-central New Mexico, by Geoffrey C. Rawling and Alex J. Rinehart, 2018. **https://geoinfo.nmt.edu/ publications/ monographs/bulletins/162/**

Kansas Geological Survey Ogallala aquifer studies—**http://www.kgs.ku.edu/ HighPlains/index.shtml**

Texas Tech University Ogallala aquifers studies—**http://www.depts.ttu.edu/ geospatial/center/Ogallala/Index.html**

U.S. Geological Survey information on the Ogallala aquifer—**https://ne.water.usgs.gov/ projects/HPA/hpa.html**

New Mexico Office of the State Engineer Water Use Reports—**http://www.ose.state.nm.us/ Pub/pub_waterUseData.php**

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BUREAU NEWS

New Mexico Earth Science Achievement Award Winners 2018

Launched in 2003, the NM Earth Science Achievement Awards honor public servants who have championed earth science issues in New Mexico.

Public Service and Public Policy Awards

Senator Jeff Bingaman and Dr. Bob Simon were awarded the 2018 NM Earth Science Achievement Award for "*outstanding contributions advancing the role of earth science in areas of public service and public policy*." The awards were made at the state capitol building on February 5th, 2018 in conjunction with Earth Science/NM Tech Day at the Roundhouse in Santa Fe.

Jeff Bingaman was elected to the U.S. Senate in 1982, where he served until his retirement in 2013. For many years, Senator Bingaman served as either the chairman or the ranking member of the Committee on Energy and Natural Resources, where he championed consequential earth-science legislation for New Mexico and the nation.

Dr. Bob Simon began working in the U.S. Senate in 1993 as a Science Fellow on the Committee on Energy and Natural Resources, where he served for 3 years. He later became Science and Technology advisor in Bingaman's office, and then served as his chief energy legislative assistant, before moving to the position of staff director, and then senior policy advisor for the Committee on Energy and Natural Resources.

2018 ESAA Award recipients Dr. Bob Simon (left) and Senator Jeff Bingaman (right) with Dr. Nelia Dunbar (Director, NM Bureau of Geology and Mineral Resources and State Geologist).

Research and Education Award

Dr. Greg Mack was awarded the second category of the NM Earth Science Achievement Awards for "*outstanding contributions advancing the role of earth science in areas of applied science and education*" on April 13, 2018 at the New Mexico Geological Society (NMGS) annual spring meeting.

During his 32-year career as a geology professor at New Mexico State University (NMSU), Dr. Mack has contributed through research, teaching, leadership, and service. His contributions to New Mexico geoscience are diverse and impressive. He edited the best-selling book *Geology of New Mexico*, and has published more than 120 papers in scientific journals. Dr. Mack also excels in the field of geoscience education. He has directed more than 40 student thesis projects, many of which have been published. He received the NMSU Excellence in Teaching Award in 1989, and has led three NMGS field conferences in the Las Cruces area, and is leading another in 2018.

Dr. Greg Mack (right) with Bureau Director Dr. Nelia Dunbar.

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