New Mexico
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MATTERS

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# New Mexico's Climate in the 21st Century
# A Great Change is Underway

New Mexico's climate is rapidly changing. Annual average temperature, measured at weather stations across the state, has risen by about 3°F over the past half-century. We live in a part of the world—southwestern North America—that is generally dry, and has experienced big natural variations in climate for many centuries. The paleoclimate record of southwestern North America over the past millennium includes extraordinary droughts and (relatively) wet spells that sometimes persist for decades. For plants, wildlife, and human societies in this desert-dominated region, climatic fluctuations in water availability profoundly affect their ability to survive and thrive.

However, the current warming trend, and trends in variables such as snowpack that are related to temperature, represent a new climatic phenomenon. In the past, people in the Southwest learned to respond to climate fluctuations—sometimes, with no other choice, by moving. Now, however, humans are an intrinsic component of the climate system itself, through our global emissions of greenhouse gases (mostly due to burning fossil fuels) that increase the heat-trapping capacity of the atmosphere, and through land use changes that profoundly affect local evaporation, transpiration, and absorption of sunlight. Other human activities have also altered the hydrologic cycle by pumping water from the ground, and by storing and diverting surface water from rivers.

What can we expect in years to come? In this article we'll summarize climate changes observed in and around New Mexico over the past half-century. We'll then consider projections of climate change over the next half-century. These changes will occur within the lifetimes of my students at UNM, and within the approximate planning horizon for many individuals, organizations, and governments. This is also the window of time that will determine whether the global community chooses to mitigate potentially catastrophic climate change.

Finally, we'll discuss the projected climate of the late 21st century. We don't know how rapidly energy technology and climate policies will evolve, but we can still use climate models to compare the likely results of different greenhouse gas emission scenarios. Over the past decade new modeling results have been extended to describe variables such as streamflow, to illustrate how much and how fast New Mexico's climate could change annual surface-water flow by the end of the century. In some respects the results are stark, serving as a warning that the decisions we make over the next few years will have big consequences for future climate change impacts.

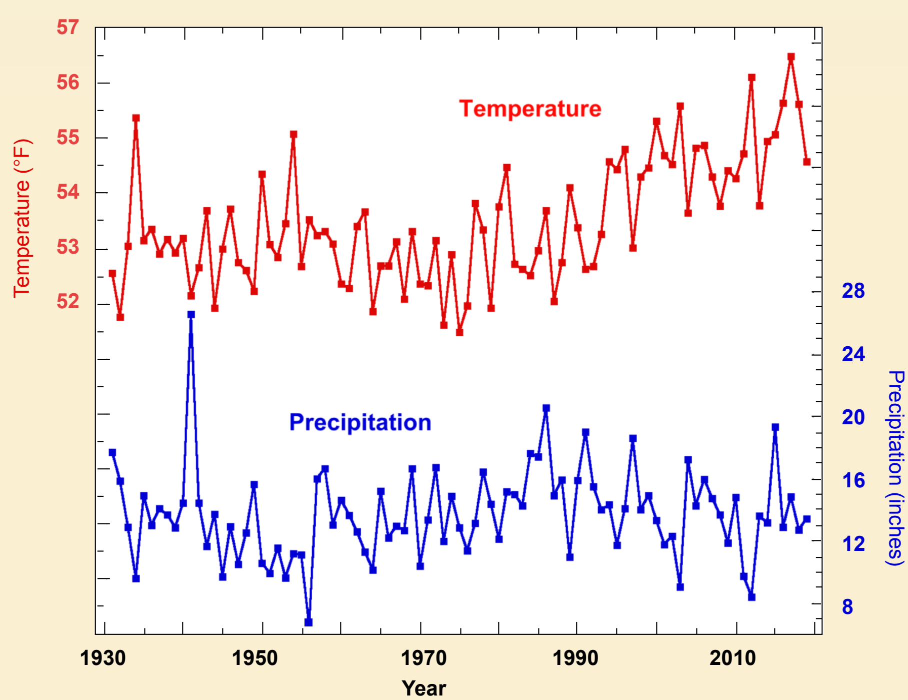


*Figure 1. Time series of observed annual average temperature (red curve, top) and precipitation (blue curve, bottom) averaged over the state of New Mexico for the period 1931 to 2019.*

## Observed Climate Change Over the Past Half Century

As shown in Figure 1, temperature in New Mexico has been rising rapidly over the past half-century. There is plenty of year-to-year variability of temperature, but the upward trend is obvious to the eye, and is significant using standard statistical tests. Statewide precipitation (blue curve), on the other hand, hasn't exhibited an obvious long-term trend. But annual precipitation in New Mexico is tremendously variable; total precipitation in the wettest year (1941) is about four times more than what the state received in the worst drought year (1956). The impact of interannual variability is compounded by the tendency for wet and dry years to persist

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into decadal (or longer) pluvial and drought epochs. 1956 was the worst and final year of seven consecutive years of below-average precipitation in New Mexico, making the 1950s an exceptional drought epoch. Conversely, most years in the 1980s and early 1990s were wet, making the late 20th century a particularly wet epoch.

Historically, the wet years tend to be relatively cool, and the dry years relatively warm. However, the upward trend in temperature in recent decades has extended through wet and dry periods, providing more evidence that the trend in temperature represents something new in the climate system. This combination of warmer temperature and variable precipitation, in a climate that is naturally desert-like over most of the region, has serious implications for people and ecosystems.

The Rio Grande, New Mexico's largest and longest river, derives most of its flow from high-elevation snowpack. The second graph (Figure 2) shows a time series of snowpack in the headwaters of the Rio Grande, together with annual streamflow at a gage located where the river leaves the San Juan Mountains and flows into the San Luis Valley in southern Colorado, just upstream from where large diversions supply water for irrigated agriculture. Snowpack on April 1 (a date that has historically been representative of maximum snowpack) varies a lot from year to year. Much of this variability is associated with precipitation fluctuations. But snowpack on April 1 also exhibits a long-term downward trend, consistent with the upward temperature trend in Figure 1, representing an overall decline of roughly 20% since about 1960. If we simply extrapolate that trend into the future, we can foresee the likelihood of dramatic reductions in snowpack this century. Big reductions in snow across most of the U.S. are indeed a robust projection of climate models. Lower elevation, more southerly mountain ranges in New Mexico lose their snowpack altogether in many projections of 21st-century climate.

The impact of reduced snowpack on snowmelt-dominated rivers, such as the Rio Grande, San Juan, Pecos, and Gila Rivers, is an intense focus of current climate-change research. The bottom curve in Figure 2 shows how flow in the Rio Grande has fluctuated in association with variations in the snowpack. As expected, high or low snowpack generally leads to high or low annual streamflow from year to year. The correspondence is not perfect, and in fact, close analysis of Figure 2 shows that the correspondence between annual snowpack and streamflow is much weaker now than was true a half-century ago.

Flow in the Rio Grande headwaters has declined overall, but only slightly (Figure 2). The primary effect to date of regional climate change has been to reduce the importance of snowpack for generating flow in the Rio Grande, and to increase the importance of other water inputs to the river, especially springtime precipitation during the snowmelt season. This shift makes river flows less predictable, and therefore harder to manage. In recent decades, spring precipitation has tended to be above the long-term average, and that has kept the streamflow trend from drifting downward like snowpack. However, climate models suggest that the observed increase in spring precipitation is probably a natural, decadal fluctuation that is unlikely to continue through this century.

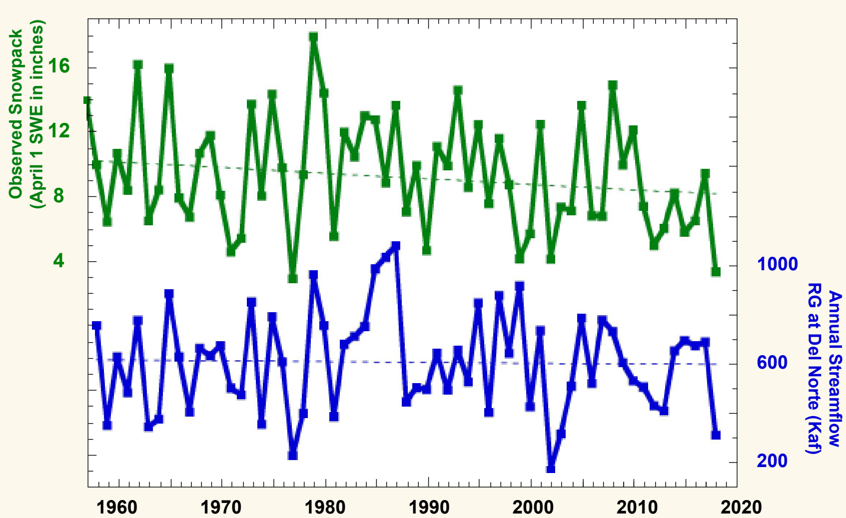


*Figure 2. Top, green curve—Annual values of observed snowpack on April 1 in the Rio Grande headwaters basin, southern Colorado. Values are expressed as inches of liquid water (Snow Water Equivalent or SWE). April 1 is generally close to the annual peak of snowpack in the basin.*
*Bottom, blue curve—Annual observed volume of water flowing past the stream gage on the Rio Grande at Del Norte, CO, at the outlet of the headwaters basin (thousands of acre-feet, or Kaf).*
*Linear trend lines calculated over the period 1958 to 2018 are shown as light dashed lines. The downward trend in snowpack is statistically significant; the trend in streamflow is not significantly different from zero.*

## Projected Change Over the Next Half-Century

Thirty to fifty years into the future is a common time window for formulation of personal and governmental planning, such as home mortgages, factory and electrical generating plant development, and water management policy. Climatic changes on this time scale will be witnessed by my son and daughter, and the students I teach.

A set of projections for flow in the middle Rio Grande is shown in Figure 3. These projections were generated by the Bureau of Reclamation (hereafter Reclamation) using climate model simulations for the Rio Grande basin. Reclamation's simulations were adapted by Nolan Townsend and me at UNM to describe the flow that passes the San Marcial gages (located just upriver from Elephant Butte Reservoir) to inform water management planning for the agricultural region that depends on water stored in that reservoir for crop irrigation. We adjusted the model-simulated natural flows to match observations at San Marcial over a 50-year historical period to account for the fraction of the river's water (most of it!) that is diverted upstream. We maintained a constant adjustment into the future to assess changes in streamflow derived from model-based climate projections.

Figure 3 shows four different curves, each associated with a different assumed change in atmospheric greenhouse gas concentrations from 2020 to 2070. Each curve is derived by taking an average of 16 different climate model simulations, and a decade-average smoother has been applied to emphasize long-term change. All but the lowest emissions scenario (blue) yield a clear downward trend in streamflow when multiple simulations are averaged (the solid curves). This finding is consistent with many other studies of snow-dominated river systems in a warming climate. The extreme low and high annual flows represented by the models (the dashed curves) all trend downward.

One way to think about the time series in Figure 3 is to consider that a downward trend in streamflow, with continued large natural variability, makes drought periods (which are mostly smoothed out in Figure 3) more severe. I do not expect New Mexico to dry up due just to a slow decline in streamflow as the climate warms. Instead, I am concerned that future drought periods, whenever they occur in the decades to come, will be hotter and drier than droughts of the past. Increased severity of multi-year droughts poses a major risk for humanity and ecosystems in New Mexico.

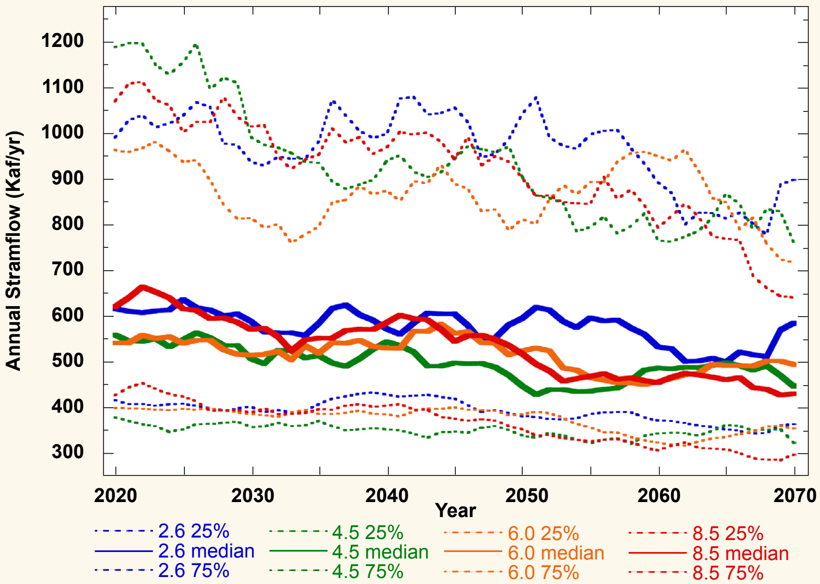


*Figure 3. Time series of simulated future annual flow (thousands of acre-feet/year, or Kaf/yr) on the Rio Grande at San Marcial, NM, derived using climate models coupled to a surface hydrologic model by the U.S. Bureau of Reclamation. Annual simulated flow values have been adjusted to account for the water removed for beneficial use upstream from San Marcial. Each of the four colored curves represents an average of 16 simulations, forced by one of four greenhouse gas emissions scenarios (blue = lowest, red = highest emissions). Each thick line is the average of 16 simulations. The thin dashed lines show the low and high extremes of annual streamflow among the 16 simulations, indicating the natural variability among the simulations. Each plotted line has been smoothed to emphasize decadal and longer variability.*

## To the End of the Century… and Beyond

Beyond 50 years from now the climate projection crystal ball gets hazier. Forecasting anything more than a half-century away is profoundly difficult, especially with regard to systems that are affected by human behavior. We don't know how greenhouse gas emissions will change over time, due to uncertainties in energy technology and in government policies over the coming decades. It is highly likely that global warming will continue unless rapid, sustained curtailment of human-caused greenhouse gas emissions occurs worldwide—and this is not happening, not yet. But the rate of temperature change, and the regional impacts of long-term warming a half-century from now, are difficult to predict with any precision.

The climate research community uses a "scenario" approach to address the uncertainty associated with unknown policy choices. The results of scenario-based projections should not be considered definitive forecasts, but as possible outcomes that illustrate potential futures. An example is shown in Figure 4, showing temperature projections for winter and summer. Tessia Robbins and I developed these at UNM a decade ago, using an earlier set of climate models and emissions scenarios than those used for Figure 3, but these results are still relevant as a potential scenario. To generate these curves, we averaged multiple, model-based projections to determine future trends in temperature (and precipitation, not shown here), based on a mid-range estimate of future greenhouse gas emissions, roughly equivalent to the orange curve in Figure 3. We then added interannual variability to the projected trends by reproducing variability from 20th-century observations.

In the scenario shown in Figure 4, temperature in central New Mexico increases at a rate of about 7°F/century, which is not too different from the observed trend over the past half-century shown in Figure 1. In other words, these particular model simulations project that regional climate change for the rest of the 21st century would continue at approximately the rate we've already seen in recent decades, if greenhouse gas emissions continue at a moderate rate. Precipitation in the same region (not shown here) showed very little projected trend in this analysis, also similar to 20th-century observations.

The climate-change signal in summer temperature stands out more than the winter trend, because interannual variability is so much smaller in the summer. At this projected rate of change, by 2050 or so every summer in this scenario is hotter than any summer in the 20th century. Some plant and animal species that have evolved to thrive in the current climate could find summers in New Mexico too hot and dry to survive.

How big a change in climate would this be? At the rate of change shown in Figure 4, the climate of Albuquerque at the end of the 21st century would be similar to the 20th-century climate of El Paso, Texas, which receives roughly the same amount of precipitation as Albuquerque, but is considerably warmer. To suggest what this might mean for ecosystems, we can compare the vegetation now growing in the Sandia Mountains near Albuquerque with what grows in the Franklin Mountains outside El Paso. A stark difference is the absence of large trees in the Franklins. This comparison suggests that currently forested areas in central New Mexico could lose their forests this century—a dramatic shift in landscapes. Rigorous scientific studies of climate change effects on New Mexico forests have reached the same conclusion.

It's important to reiterate that the discussion above is not a definitive forecast. There is plenty of uncertainty in model-based projections, and

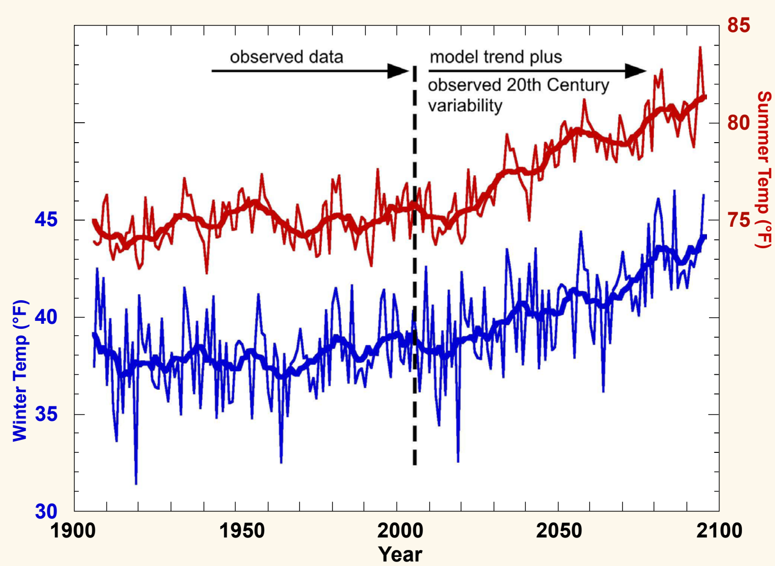


*Figure 4. Top—Time series of temperature in central New Mexico (NM climate division 5) for summer (June-August, red) and winter (December-February, blue). The thin lines are annual values; thicker lines are decadal averages. Observed values are shown from 1901 through 2007; values from 2008 to 2100 are derived from climate model-simulated future trends with observed interannual variability added.*

even more uncertainty in future policy decisions affecting greenhouse gas emissions and water and land management. But we should also keep in mind that, in general, the observed climate has changed more and faster in recent decades than models previously projected.

It's worth emphasizing that we—human societies and governments worldwide—can choose a high-emissions future or a lower-emissions future, in which the rate of climate change slows down. The choices we make now regarding greenhouse gas emissions will determine the magnitude of climate change to which future generations must adapt. Also, note that some of the results shown in this paper (like Figure 4) are not new. The evidence for ongoing climate change has been clear for many years, and the projected magnitude of future changes has been pointed out over and over. Nevertheless, global emissions have actually increased as the evidence for serious climate change resulting from those emissions has gotten stronger.

## A Time of Change in New Mexico

We have just described potential 21st-century changes that exceed the bounds of climate variability ever experienced by humans in the Southwest. Some of the projected changes are well underway—rising temperature, diminished snowpack, and earlier snowmelt runoff. There is nothing abstract or hypothetical about human-caused climate change in New Mexico. It's happening now. Other projected changes, such as diminished total flow in our major rivers, are not yet easily detected but are still projected to occur later this century, when long-term changes exceed natural variability.

We've focused our attention here on local climate change, but New Mexicans are sure to be affected by tremendously impactful changes occurring in other parts of the world. For example, melting Arctic sea ice affects global trade, a trend toward extreme heat and aridity in Mexico could jeopardize our food supply, and the impacts of rising sea level and more intense hurricanes will impact the national economy of the entire U.S., including landlocked states such as New Mexico.

Not all change is necessarily bad from a human perspective. Warming temperatures in New Mexico imply lower winter heating bills and longer growing seasons. But the projected reduction in streamflow, and the trend toward aridity associated with warmer temperature in a dry climate, resulting in reduced groundwater recharge and more intense wildfires, pose grave risks to New Mexicans. And, as noted above, we cannot avoid the impacts of climate change occurring elsewhere.

Climate is not the only driver of long-term environmental change. We must consider the impacts of climate change together with other, non-climatic factors. The population of New Mexico and the Southwest is increasing, which would require hard thinking about water management even if climate change were not adding stress. Water resources in parts of New Mexico are stressed by depletion of the existing groundwater supply. Groundwater recharge rates are already much slower than pumping rates nearly everywhere that pumping occurs. The rate of recharge is likely to diminish in the future as temperature rises, snowpack decreases, and a greater fraction of precipitation falls in fewer, more intense events.

The ways in which New Mexicans make a living are changing too. Cities are growing much faster than the rural population, potentially creating conflicts between the resources required to maintain traditional rural livelihoods and the water demands of urban areas. All of these factors, together with climate considerations, are causes of socioeconomic stress that must be addressed by any policies that have a chance of being successfully implemented.

Many aspects of the climate system change on long time scales. Glaciers and ice sheets melt over decades, and it takes the ocean more than a century to redistribute heat. So it will be difficult to stop the impacts of global warming over the next several decades regardless of how aggressively we act to reduce greenhouse gas emissions. We therefore have no choice but to adapt to ongoing change, because worldwide carbon emissions are still rising despite international promises of reductions.

But the need to adapt does not mean that we have an excuse to ignore or delay efforts to mitigate emissions and keep future climate change within adaptable bounds. Just as we are affected locally by the global impacts of climate change, the worldwide mixing of atmospheric greenhouse gases also means that the challenge of reducing greenhouse gas emissions must be undertaken globally to be effective. Taking emissions reductions seriously is a big ask for the citizens of New Mexico. We can and should try to keep our individual carbon footprints modest, but fossil fuel energy production is a large component of the local economy, and is the single most important economic driver in parts of the state.

Oil and gas production have boomed over the past several years, to the great economic benefit of New Mexico. But, as alternatives to fossil fuels for electricity, transportation, and heating become more widespread and cheaper, greenhouse gas emissions reductions will be easier and more attractive to implement, and the export market for oil and gas will be jeopardized. The nationwide transition away from coal-fired power generation over the past decade shows how a transition like this can occur in our modern, large-scale economy. The sharp decline in coal-based energy production is good for the environment but very hard on communities whose economies were dependent on coal.

*Photographs of the Sandia Mountains on the outskirts of Albuquerque (left), and the Franklin Mountains on the outskirts of El Paso, TX (right), showing the contrast in vegetation growing in these mountains today. Photos by Jane Selverstone.*

As I write this text, on Earth Day in April 2020, we are in the grip of a global pandemic that has gutted the socioeconomic life of New Mexico, the U.S., and much of the world. A side effect of policies implemented to slow virus infection is that fuel consumption, air pollution, and carbon emissions have dropped sharply and suddenly as the world economy shut down. The global oil market has suddenly and utterly collapsed, for reasons that have little or nothing to do with greenhouse gas emissions policy. I don't think anyone can predict the near-term future of the oil market with any certainty.

At present, and for the remainder of this year at minimum, policymakers will be intensely focused on abating the impacts of the novel coronavirus. So I expect climate change policy to take a back seat for now, and I suspect there will be enormous political pressure to ignore long-term environmental considerations as our society rebuilds after the peak of the COVID-19 outbreak passes. But the challenge of global climate change isn't going away.

The recovery from coronavirus-related economic malaise will be daunting, but at the same time it presents an enormous opportunity for our country and our state to rebound in a forward-looking way with regard to energy and the economy. New Mexico receives abundant sunshine and is well suited to wind energy. Our state contains uranium resources if society chooses to expand nuclear power production—a technically feasible but contentious option. New Mexico's universities, national laboratories, and tech-sector businesses are engines of innovation that are well poised for leadership in the energy transformation that is now taking place. In my view, this transformation will only accelerate in the decades to come—will we choose to help lead it?

Social and generational equity questions present an enormous challenge for our society as we consider what to do about climate change, particularly at this time of extraordinary socio-economic stress. It is a tall order to ask today's citizens to implement aggressive greenhouse gas emissions policy actions that seem difficult in the short term, and would produce real economic pain for the state of New Mexico, in order to reduce the costs of climate change that will mostly be paid by our children and grandchildren. But in my view, we owe it to future generations worldwide to renew our economy in ways that address the emissions mitigation challenge clearly and strongly, and choose to make our society more resilient to a changing climate.

—David Gutzler
*(University of New Mexico)*

Dr. Gutzler is Professor of Earth & Planetary Sciences at UNM, with research specialties in climate science, atmospheric science, and hydrology. He was a Lead Author for the U.N. Intergovernmental Panel on Climate Change's 5th Assessment Report (2013) and is a Lead or Contributing Author for three chapters of its 6th Assessment Report, planned for release in 2021. Dagmar Llewellyn and Emile Elias provided technical reviews.

## For Further Information

Most of this article is based on material that is available online. Here are some sources of additional information that are written with minimal technical jargon.

Figure 1 is adapted and updated from a report delivered to the State Legislature assessing the state's vulnerability to water shortages. It is freely available online as Open-File Report 577 of the NM Bureau of Geology at: geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=577.

Figures 2–4 are derived from research carried out by students working with me at UNM. Figure 2 is updated from Shaleene Chavarria's M.S. thesis, which was published in the Journal of the American Water Resources Association in 2018. Figure 3 is derived from Nolan Townsend's M.S. thesis, also published in JAWRA in 2020. Figure 4 is adapted from a paper by myself and Tessia Robbins, published in Climate Dynamics in 2011. All of these papers can be downloaded from the publications section of my UNM webpage at: eps.unm.edu/people/faculty/profile/david-gutzler.html.

The Fourth U.S. National Climate Assessment contains a wealth of information on observed and projected climate change affecting the United States. It is up to date and contains excellent illustrative (and downloadable) graphics. It is available online in two parts: Volume I (2017) assesses climate change science, and Volume II (2018) discusses impacts and adaptation. These lengthy volumes can be perused and downloaded at: globalchange.gov/nca4.

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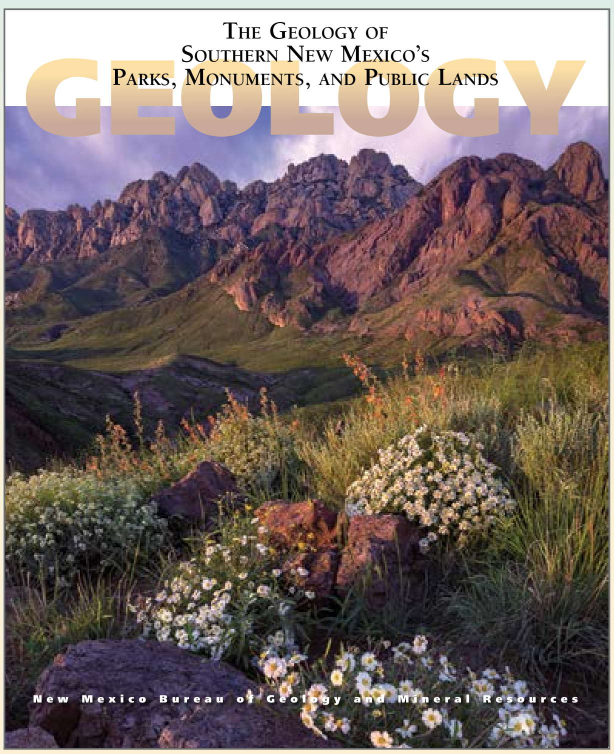


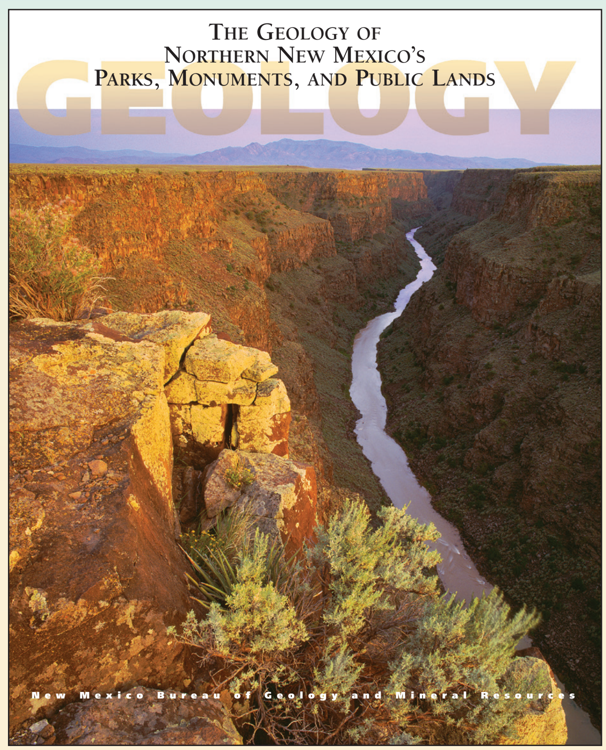


*The Geology of Southern New Mexico's Parks, Monuments, and Public Lands* is hot off the press and is now available. This book is a companion publication to the award-winning northern park version, which has been revised and is also available for New Mexico geology enthusiasts.

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