



New Mexico EARTH MATTERS

Summer 2007

CLIMATE CHANGE AND WATER RESOURCES IN NEW MEXICO

*In the Summer 2004 issue of Earth Matters, we featured an article on “New Mexico’s Changing Climate,” by David Gutzler. That article provided an introduction to the factors that determine climate and climate variability in New Mexico. In this follow-up article, Dr. Gutzler provides an update on what we’ve learned in the past three years and explores some model-based predictions of 21st-century climate change in New Mexico, with special emphasis on how such change will likely affect water resources. He draws upon some recently published results, including the new assessment by the Intergovernmental Panel on Climate Change, and a report on the impacts of climate change on New Mexico’s water resources issued by the Office of the State Engineer. Both are accessible online; see **Additional Reading** at the end of this article.*

New Mexico’s climate is now warmer than at any time during the past century, the period for which we have instrumental temperature records. The time series of statewide average temperature (top of page 2) for both the cold half of the year (October through March) and the warm half (April through September) suggests some cooling during the initial decades of the 20th century. The 1950s drought years were characterized by higher temperatures in the warm season but not in the cold season. Rapid warming has occurred year-round since the 1960s and continues today—with an increase of roughly 2°F in the cold season and nearly 3°F in the warm season since that time. These warming trends are more than twice the annual global average trend, which was about 1°F over the entire 20th century. This is consis-

Sierra Blanca in south-central New Mexico. Climate models suggest that there may be no snowpack at all in New Mexico south of Santa Fe by the end of this century. Photo © Laurence Parent.

tent with the expectation that continental temperature should be more variable than oceanic temperature; oceans cover more than 70 percent of our planet. Think about the difference between a hot, sandy beach and a nearby body of water on a sunny summer afternoon.

The ongoing warming trend in New Mexico is quite significant already. Utility companies measure annual heating requirements using “heating degree days” (HDDs), a measure that relates each day’s temperature to the demand for energy for heating. These values are used by state regulators in setting gas rates, so the average annual HDD accumulation is an important economic index of climate. Each day’s accumulation of HDDs is simply the number of degrees that the average daily temperature is colder than 65°F (set to zero for the day if the average temperature is 65°F or warmer). This value for each day is added up to yield an annual accumulation. Cold winters are therefore associated with

large accumulations of HDDs. Cooling degree days (CDDs) are similarly defined, except that those degree days are counted when the average temperature is warmer than 65°F, requiring energy for cooling. Annual HDD accumulations have been decreasing (due to warmer winters), and CDD accumulations have been increasing (due to warmer summers) across New Mexico in recent decades, and by a lot. At the sites plotted on the next page, which are quite representative of other locations in the state, annual HDD and CDD values have changed by more than 15 percent since the middle of the 20th century. Winter heating

needs are diminishing in New Mexico, but the energy required for summer cooling is going up fast.

Significant as they are, recent temperature changes are still modest compared to model-based predictions for the 21st century. The current generation of climate models successfully reproduces observed 20th-century temperature changes, across all continents and the world’s oceans, if the models use the observed 20th-century changes in greenhouse gases (principally carbon dioxide, CO₂, and methane, CH₄), solar brightness, and atmospheric particulates. If human-caused changes in greenhouse gases and particulates are neglected, leaving just the natural variations due to the sun and volcanoes, then the models fail to simulate observed temperature changes. Specifically, the only way to correctly reproduce the late 20th-century warming trend is to include the effects of increasing greenhouse gas concentrations. Given a plausible range of greenhouse gas increases



20th-century time series of observed New Mexico statewide temperature, with the year split into a 6-month “cold season” (October–March, blue curve) and a 6-month “warm season” (April–September, red curve). The time series have been smoothed to emphasize decadal variability. Data were obtained from the Western Regional Climate Center, Reno, Nevada.

in the 21st century, these same models predict a global rise in annual temperature of 3°F to 7°F. Recall that the total global change in the 20th century was about 1°F.

How does this range of global-average temperature increase apply to New Mexico? If we choose a mid-range greenhouse gas emissions scenario and take the average of 18 global model predictions, then the models predict an increase in temperature across the state of New Mexico of more than 5°F in winter and about 8°F in summer by the end of the century! The precise rate of warming depends on future greenhouse gas emissions, and there’s no way to know what choices we will make regarding such emissions. Predictions based on different scenarios reach the same warmer temperatures cited here, but decades sooner or later, depending on the rate of emissions.

The evidence for greenhouse gas-forced warming is extremely compelling. That’s why the climate research community almost unanimously now considers some amount of global warming in the 21st century to be inevitable. The scientific debate on whether greenhouse gas-forced global warming is real, and will continue, is effectively over. Current scientific research on global warming is now focused on how much and how fast the climate will warm.

Hydrologic Cycle Changes

The temperature changes listed above will have significant effects on many aspects

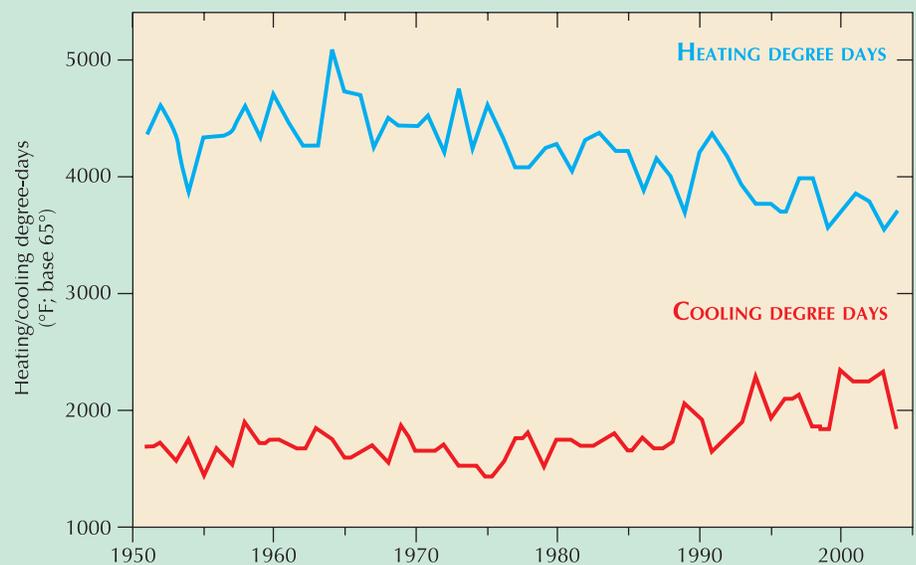
of life in New Mexico. Some of the most profound potential changes are concerned with water, which is certainly scarce and precious here already. Predicted 21st-century climate change is likely to diminish the water supply to the entire western half of the United States. If the current warming trend continues, it will severely reduce snowpack across western North America. Precipitation will fall as snow for a shorter season, the average elevation of the winter snow line will increase, and the remnants of high-elevation snowpack will melt earlier

in the spring. Climate model results shown in the report from the state engineer’s office (see *Additional Reading*) indicate that there may be no snowpack at all south of Santa Fe by the end of this century.

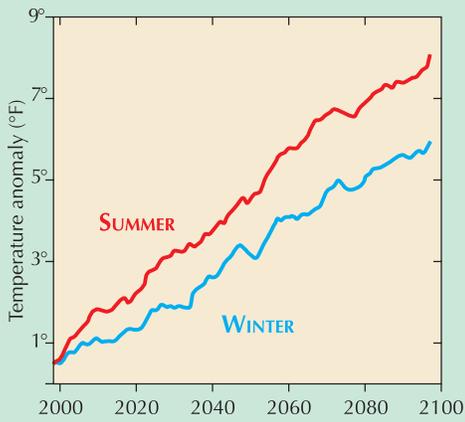
A warmer climate also leads to an increase in evaporation during spring and summer, and to sharp predicted decreases in soil moisture. These effects are especially pronounced during episodic drought conditions, and one important consequence of a warmer climate in the 21st century is that future droughts will have more severe impacts.

Paradoxically, increased evaporation and warmer surface temperatures also mean that the potential for very intense precipitation events also increases. One of the general expectations for a warmer climate, borne out by model predictions, is for more variability and more extreme conditions—both severe droughts and more frequent severe weather and flooding (even in the midst of long-term drought). In New Mexico we have recently experienced just such wild swings: one of the driest winters in the instrumental record (2005–06) was followed by the wettest summer last year.

Notice that the effects on water resources discussed so far are all associated with trends in temperature, not precipitation. Unlike temperature observations, there is no clear trend in annual precipitation in the 20th-century record; instead we have experienced recurring drought and wet spells. Tree-ring records indicate that the Southwest has alternated between multi-decadal drought and pluvial (wet spell)



Time series of observed annual heating degree days at Fort Bayard, east of Silver City, New Mexico (blue curve, representing the cold season) and cooling degree days at Las Cruces (red curve, representing the warm season). Other locations in New Mexico show changes over the past several decades similar to these examples.



21st-century time series of predicted New Mexico statewide temperature variations for summer (red curve) and winter (blue curve), derived from an average of 18 global climate model simulations forced by the Intergovernmental Panel on Climate Change (scenario A1B) to describe future greenhouse gas concentrations. The time series have been smoothed to emphasize decadal variability. Values on the y-axis represent the temperature change relative to each model's simulated climatology for the late 20th century (so that the simulated 1971–2000 New Mexico average temperature is assigned a value of 0 for each model; this emphasizes temperature changes relative to the present). This plot is adapted from the climate change report issued by the New Mexico Office of the State Engineer in 2006.

conditions for many centuries, as described in a recent report on historical Colorado River fluctuations issued by the National Research Council. Climate models also show no clear trend in predicted summer monsoon precipitation in the 21st century.

However, the most recent set of climate predictions from the Intergovernmental Panel on Climate Change (IPCC) shows an ominous downward trend in total winter precipitation across southwestern North America, including New Mexico. In the model simulations, rising air motions intensify near the equator as the ocean warms, generating increasing clouds and precipitation in the tropics. A corresponding intensification of downward air motion (suppressing precipitation) occurs in subtropical latitudes, where most of the world's deserts are now located, making those arid areas even drier. If this happens, the substantial pressures on water resources associated with warming in New Mexico and other subtropical arid lands could become catastrophic. A 2007 paper in *Science* magazine by Seager et al. uses the term “megadrought” to describe the 21st-century climate across southwestern North America simulated in the IPCC predictions.

Implications For Water Management

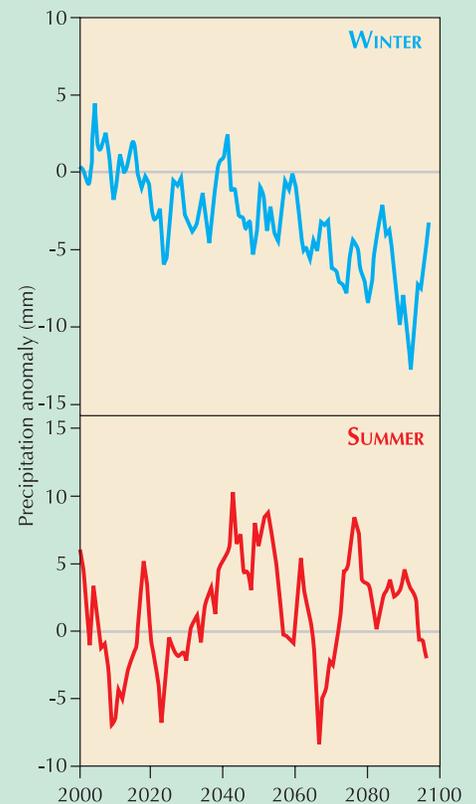
Climate change is hardly the only important factor in the development of sustainable water resources in New Mexico. State water managers must plan for increasing population, economic development, ongoing depletion of ground water reservoirs, and the desire to maintain a healthy riparian environment, as they administer water rights within the established legal framework. The state of New Mexico has an overarching legal obligation to satisfy annual downstream delivery requirements to the neighboring state into which each of our major rivers flows. The state's consumptive use of water from the Rio Grande, for example, is limited by an agreement called the Rio Grande Compact. New Mexico's annual delivery obligation to Texas depends on the stream flow that passes the Otowi gage below Los Alamos. During years with low flows both the downstream delivery requirement and New Mexico's allowed depletion are reduced, so the pain of drought is shared between New Mexico and Texas. The extra water flowing past Otowi during high flow years (anything more than 1,250,000 acre-feet per year) all goes to Texas.

The changes in climate predicted for the 21st century would cause an overall decrease in flow in New Mexico's snow-fed rivers. The annual flow at Otowi is highly correlated with snowpack in southern Colorado. As snowpack decreases in a warmer climate, we should anticipate that future Otowi index flows will decrease substantially. Low annual Otowi flows (less than 750,000 acre-feet per year) have occurred during almost half of the years since the Rio Grande Compact was negotiated. It is likely that the warming trends cited above will shift most of the future Otowi flows into the low flow category, with a significant overall downward trend during the 21st century. Superimposed on this trend, we should anticipate intermittent severe drought episodes, during which flows are even lower.

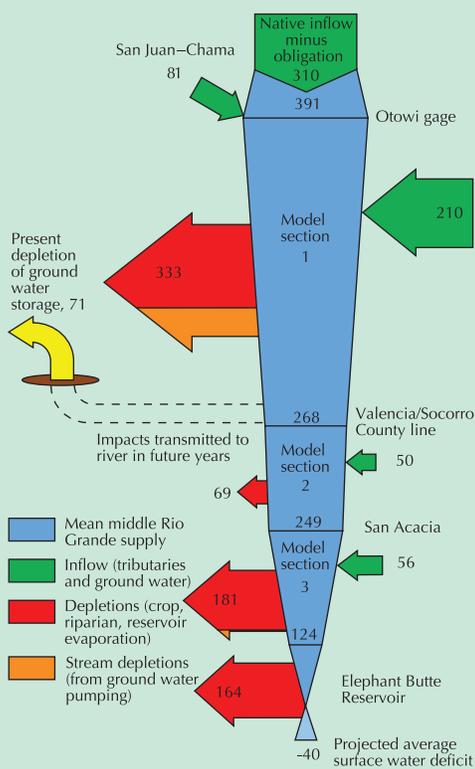
The implications for water management in all of New Mexico's major river valleys are potentially profound. Consider the water budget for the Middle Rio Grande valley downstream from Otowi. The principal inputs of water to the Middle Rio Grande are inflows from snowpack in southern Colorado and from tributary inflows. These inputs are predicted to decrease in a warmer climate. The principal depletions include evaporation from

open water (in the river and in reservoirs, including Elephant Butte), transpiration from plants, and withdrawals by people. All of these depletions will likely increase, especially considering the new extraction and treatment plant now under construction by the city of Albuquerque. But the downstream delivery obligations to Texas are not changing. So each of the predicted climate-forced trends in this budget will exacerbate water management challenges within the Middle Rio Grande valley.

Although this discussion has focused on the Rio Grande, all of New Mexico's major snow-fed rivers (including the Pecos, Canadian, Gila, and San Juan Rivers) will experience similar climatic effects, leading to predictions of lower flows. Will we have the foresight to plan for shortages of water during severe droughts and lower river flows in the years to come?



21st-century time series of predicted New Mexico precipitation variations for winter (blue curve, top) and summer (red curve, bottom), derived from an average of 18 global climate model simulations forced by the Intergovernmental Panel on Climate Change (scenario A1B) to describe future greenhouse gas concentrations. Values on the y-axis represent differences from current climatological values. The time series have been smoothed to emphasize decadal variability. Note the difference between winter precipitation, which exhibits a pronounced downward trend, and summer precipitation, which varies between wet spells and droughts but does not show a clear trend.



Water budget for the Middle Rio Grande; numbers are thousands of acre-feet per year. Climate change is expected to increase depletions (the red arrows) and decrease inflows (the green arrows), resulting in lower flow in the river. From Hathaway and McClune in *Water Resources of the Middle Rio Grande*, published in 2007 by the New Mexico Bureau of Geology and Mineral Resources.

Hard Choices for New Mexicans

How will we respond to these challenges? At present the evidence overwhelmingly indicates that warming trends will continue, regardless of any actions taken to reduce greenhouse gas emissions. No one is seriously suggesting that we can stop greenhouse gas emissions altogether. Even if we did, warming would continue, because the climate system does not respond immediately to greenhouse gas emissions. The global oceans take up extra carbon dioxide and heat energy out of the atmosphere very slowly, redistributing gases and warmth throughout the deep ocean for many years. Furthermore, it takes time for surface changes to occur, such as the melting of ice sheets. This means that the carbon dioxide emissions we generate today will have effects for decades to come, creating what we call a “current commitment” to future climate change.

We need to think seriously about adapting to the climate changes that are already occurring, based on the rational assumption that a warming trend of uncertain magnitude will continue into the future.

Many facets of our lives will be affected by climate change. The State of New Mexico Agency Technical Work Group in 2005 published a report on potential effects of climate change on New Mexico. This report examined a wide spectrum of impacts in New Mexico.

As an example, how will we manage the water budget shown at left? River flows in New Mexico are already fully allocated, and inflows will likely decrease. As a democratic society, we must be prepared to make difficult choices based on broad input from the entire community. Maintaining sustainable water resources represents a particularly large and contentious challenge. Who won't get the water they desire?

Most of the scenarios used by climatologists for 21st-century predictions assume that per capita greenhouse gas emissions will decrease over the coming decades, but we don't really know how this will be achieved. Presumably some mix of conservation, increased efficiency, alternative energy development, and carbon sequestration will move us toward a lower-emissions future. Accomplishing this while maintaining the energy supplies required for a healthy economy will be a huge challenge. Several western governors (including ours) have promoted a regional effort to decrease greenhouse gas emissions. On the national level, however, government policy to date can only be characterized as inaction based on willful disregard of our best science.

I'm now 51 years old. Unless a nasty surprise occurs, climate change may not

dramatically affect my quality of life. But global warming involves huge generational inequities: I burn fossil fuels today, as I have for decades, leaving our children and grandchildren to cope with the aftereffects. Our society can no longer pretend to be ignorant of the potential impacts of human-caused climate change. We have demonstrated a powerful ability to confront and overcome tremendous challenges in the past, when we decide to act. Effectively addressing climate change is, without doubt, a daunting task. Nevertheless, we should assume a responsibility to future generations to address this issue honestly and seriously.

—David S. Gutzler

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Each issue of Earth Matters features an invited article on a subject of interest to New Mexicans. These articles represent the author's informed opinion on important geoscience issues in New Mexico and do not necessarily represent the views of the New Mexico Bureau of Geology and Mineral Resources, a non-regulatory agency.

—Ed.

Additional Reading

The Intergovernmental Panel on Climate Change has three working groups that are each publishing separate reports in 2007. Summaries of each report are available online at <http://www.ipcc.ch>

The State of New Mexico has produced the following reports:

Potential effects of climate change on New Mexico. State of New Mexico Agency Technical Work Group, 2005. Available at http://www.nmenv.state.nm.us/aqb/cc/Potential_Effects_Climate_Change_NM.pdf

The impact of climate change on New Mexico's water supply and ability to manage water resources. Issued by the New Mexico Office of the State Engineer/ Interstate Stream Commission in 2006. Available at <http://www.nmdrought.state.nm.us/ClimateChangeImpact/completeREPORTfinal.pdf>

See also:

Seager et al., 2007, Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, 25 May 2007. Vol. 316. no. 5828, pp. 1181–1184.

Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability. National Research Council, Water Science and Technology Board, National Academies Press, 2007. Available in print or online at http://books.nap.edu/catalog.php?record_id=11857#top

Water Resources of the Middle Rio Grande, edited by L. Greer Price, Peggy S. Johnson, and Douglas Bland, 2007 Decision-Makers Field Guide, published by the New Mexico Bureau of Geology and Mineral Resources. Available at <http://geoinfo.nmt.edu/publications/decisionmakers/home.html>

BUREAU NEWS

Decision-Makers Field Conference 2007

In May 2007 the bureau sponsored its fifth Decision-Makers Field Conference. This year's topic was water resources of the Middle Rio Grande from San Acacia to Elephant Butte. Over 50 people attended, including 17 legislators. The two-day conference focused on issues of statewide importance, including surface water management and infrastructure, the physical and biological framework, and opportunities for long-term bosque preservation. Stops included San Acacia Dam and Elephant Butte Reservoir. The guidebook produced in association with the 2007 conference (see back cover of this issue) has been enormously popular and is available to the public, for purchase through our Publication Sales Office, or as a free download from our Web site (www.geoinfo.nmt.edu/publications).

Rockin' Around New Mexico

This year's Rockin' Around New Mexico was held in Los Alamos and focused on earthquakes and volcanoes. Thirty-five teachers attended the 3-day workshop in July. Topics included an overview of volcanoes in New Mexico, geologic time, igneous rocks, geothermal resources, and seismology and earthquake safety. Field trip destinations in the Jemez Mountains included the Valles caldera and Soda Dam. Funding for much of this year's workshop was provided by the New Mexico Department of Homeland Security and Emergency Management through a federal grant for training. About a dozen staff from New Mexico Tech and Los Alamos National Laboratory were involved in this year's workshop. For information on next year's workshop, contact Susie Welch (susie@nmt.edu).

Mineral Symposium

The 28th annual Mineral Symposium will be held on the campus of New Mexico Tech on November 10–11, 2007. Sponsored by the Mineral Museum on the campus of New Mexico Tech, this year's symposium will include a day and a half of short papers. Featured keynote speaker is Dr. John Rakovan from the Department of Geology at Miami University in Oxford, Ohio. For more information or to register, call 505-835-5490.

Earth Science Week

Earth Science Week, a national event organized by the American Geological Institute (AGI) since 1998, will run October 14–20,

2007. This year's theme is "The Pulse of Earth Science." The New Mexico Bureau of Geology and Mineral Resources will be planning a number of local events, including an afternoon of earth science activities at the New Mexico Museum of Natural History and Science in Albuquerque on October 20 from 12 noon to 4 p.m. We will also be mailing Earth Science Week planning kits to teachers around the state who have participated in bureau programs. For more information on local activities, contact Susie Welch (susie@nmt.edu), or visit the official AGI-sponsored Web site at <http://www.earthsciweek.org/>

Sevilleta Open House

On Saturday, October 13, 2007, the Sevilleta National Wildlife Refuge will host their annual open house. A number of scientists, including the bureau's Dr. David Love and Dr. Richard Chamberlin, will lead field trips on Saturday. Most of the refuge is closed to the public throughout the year, and this event presents a unique opportunity to see areas that are otherwise not accessible. The New Mexico Bureau of Geology and Mineral Resources will join many other exhibitors at the refuge Visitor Center from 10 a.m. to 3 p.m. on that day. The Sevilleta National Wildlife Refuge Visitor Center is located approximately 19 miles north of Socorro off I-25 at Exit 169; go west $\frac{3}{4}$ of a mile from the exit to reach the headquarters and Visitor Center. For more information, visit their Web site at www.fws.gov/southwest/REFUGES/newmex/sevilleta/

New Hires

We welcome two new staff persons to the bureau this summer. Talon Newton, hydrogeologist, will complete his Ph.D. in environmental engineering from Queens University in Belfast in 2008. Trevor Kludt, hydrogeologic lab associate, holds a Ph.D. in archaeology from the University of New Mexico. Both will be working in the Sacramento Mountains with the bureau's Aquifer Mapping Project, funded by the Otero County Soil and Water Conservation District with funds allocated by the state legislature. This multi-year project, which began in 2005, will use geologic and hydrologic data to characterize the local and regional aquifer systems, define limits of the aquifers, and identify geologic controls on recharge and movement of ground water.



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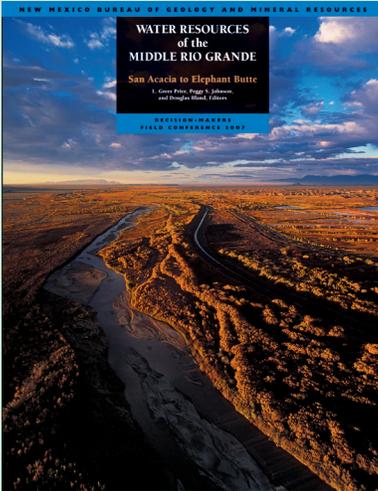
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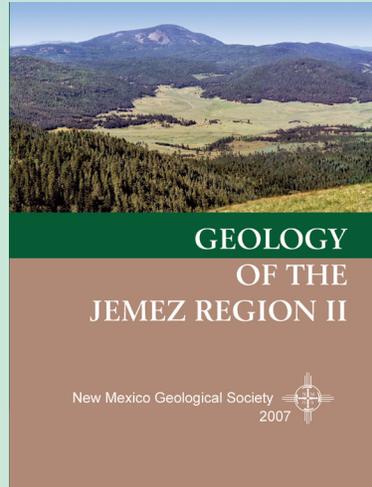
PUBLICATIONS



Water Resources of the Middle Rio Grande, L. Greer Price, Peggy S. Johnson, and Douglas Bland, editors, 2007. ISBN 978-1-883905-24-8. \$15 plus shipping and handling and taxes, where applicable.

The timely collection of 25 articles provides a broad overview of issues related to water resources on the Middle Rio Grande. Written for the general public, it addresses critical issues of statewide importance,

including surface water management and infrastructure, the physical and biological framework, legal challenges that lie ahead, and opportunities for long-term bosque preservation. Produced in conjunction with the fifth Decision-Makers Field Conference held in Socorro, New Mexico in May 2007, this volume will be an important reference for anyone interested in water in New Mexico. Full color.

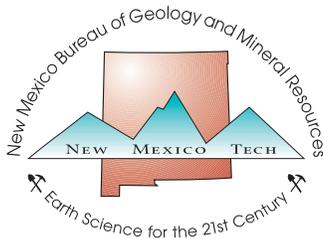


Geology of the Jemez Region II, Barry S. Kues, Shari A. Kelley, and Virgil W. Lueth, editors, 2007. ISBN 978-1-58546-094-6 \$55 plus shipping and handling and taxes, where applicable. Available September 24.

The Jemez Mountains include one of the country's best records of volcanic processes over the past 15 million years. The range is dominated by the Valles caldera, a 1.25-million-year-old, 22-kilometer-wide

structure that is the world's type example of a resurgent caldera. The caldera and associated features are now largely protected by the Valles Caldera National Preserve. This 2007 New Mexico Geological Society Guidebook, produced for the 58th annual field conference, presents new studies on the geology of this region. Four comprehensive, profusely illustrated road logs describe the geology of the area, and more than 35 research papers document latest discoveries and new, detailed geologic mapping, including structure and stratigraphy of the Española Basin, hydrology and environmental geology, Pleistocene caldera lakes, and other aspects of the Jemez region. With sixteen color plates.

For more information about these and other bureau publications: Visit our Web site at geoinfo.nmt.edu; write or visit our Publications Sales Office on the campus of New Mexico Tech, 801 Leroy Place, Socorro, New Mexico 87801; call (505) 835-5490, or e-mail us at pubsofc@gis.nmt.edu. Payment (check or money order payable to NMBGMR) must be enclosed with mailed orders. Telephone orders may be paid with VISA, American Express, or MasterCard. Additional charges for shipping and gross receipts tax (New Mexico residents) are not reflected.



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