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Climate Change and New Mexico's Water Resources: A 50-Year Outlook

Planning for Water Management in the 21st Century

The State of New Mexico is developing a 50-Year Water Plan, scheduled for release in 2022. Recognizing the potentially profound impacts of climate change on the state's water resources over the next 50 years, the New Mexico Interstate Stream Commission tasked the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) to carry out a Leap Ahead Analysis (henceforth "the Analysis") of these impacts to inform policy recommendations in the Water Plan. The goal of the Analysis was to compile, assess, and integrate existing, peer-reviewed, published research, technical reports, and datasets relevant to the broad topic of changes to New Mexico's climate over the next 50 years and resultant impacts on water resources and hydrology. The Analysis is the scientific foundation of the 50-Year Water Plan. The nine authors are prominent scientists with research expertise in climatology, hydrology, ecology, forestry, landscapes, and soils.

The Analysis describes projected climate change impacts but does not propose specific water policy recommendations, which will be developed in the Water Plan itself. In this issue, we summarize the Analysis and highlight how the projected impacts of climate change on water resources vary across different regions of New Mexico. Readers are encouraged to view the full Analysis at https://geoinfo.nmt.edu/ClimatePanel/.

Large-Scale Climate Change and Hydrological Impacts

Over the next half century, profound changes in New Mexico's climate will affect water resources all across the state. All evidence suggests that surface temperature will continue to rise throughout New Mexico over the next 50 years. Most projections of statewide annual mean temperature are from 3°F to 7°F warmer than the late 20th century, and some high-end models predict even more warming. The magnitude of change depends on future human-caused emissions of greenhouse gases; the warming associated with even modest projections would generate unprecedented high temperatures and significantly stress our water resources. Increasing temperature is the most pronounced and predictable component of climate change in the Southwest. As temperature rises, the atmosphere can absorb more water, increasing potential evaporation and leading to more arid surface conditions overall.

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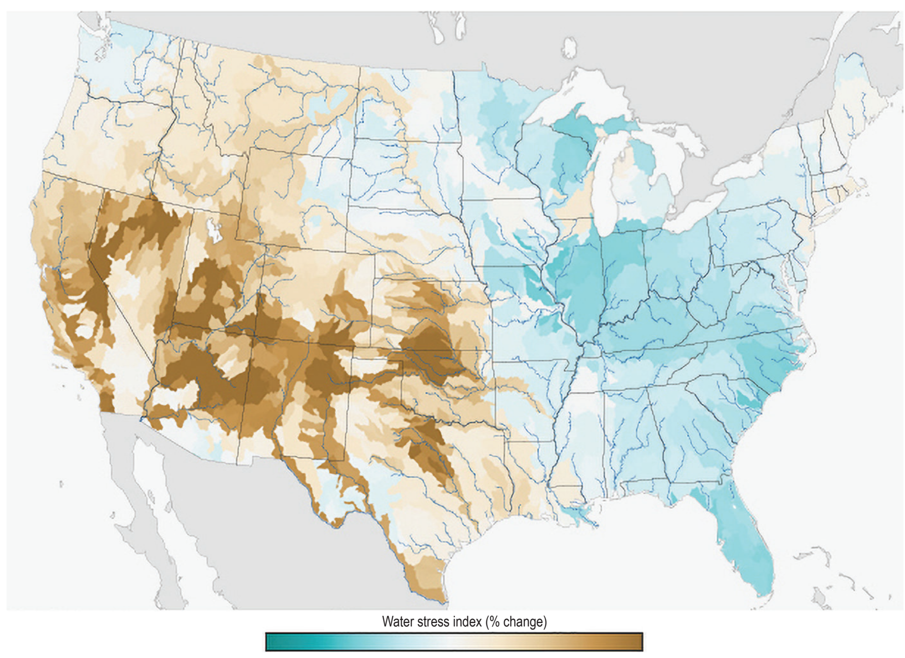

Projected change in water stress for river basins by mid-century (2040–2061) compared to historical average (1900–1970). Brown colors represent higher water stress (generally drier conditions). This figure is borrowed from R. Lindsey in "Climate change to increase water stress in many parts of U.S.," 2013, published by NOAA through www.climate.gov.

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Less consensus exists among climate model projections on how total annual precipitation might change over the next 50 years. The most confidently projected seasonal change is a decrease in spring precipitation. We are likely to experience more variability in precipitation from year to year, including anomalously wet years interspersed with more extreme droughts. The possibility of more extreme individual precipitation events is solidly grounded in atmospheric physics but hard to verify in data or climate models. Taken together, temperature and precipitation changes will shift the climate of New Mexico toward much more arid and variable conditions.

We can interpret potential impacts of these changes on water resources by assessing how vegetation, ecosystems, rivers, and human water use will change under the projected conditions. Snowpack will diminish and snowmelt will occur earlier, which in turn will reduce spring season runoff. Evaporation from reservoirs will increase, while soil moisture across the state will decrease. More severe droughts in a warmer climate will have harmful effects on streamflow, vegetation, and human water uses, including agriculture.

As the climate warms, landscapes, vegetation, and soils will suffer negative effects. These include: widespread conversion of forests to shrublands and grasslands; reduction in vegetation cover and infiltration of rainfall; increased overland runoff, flooding, and arroyo incision; atmospheric dustiness; and upland erosion by overland flow and downstream sediment deposition. Many of these changes will be accelerated by increased high-intensity wildfires promoted by hotter, drier spring conditions. Over decades, vegetation communities will shift away from hotter temperatures, either northward to higher elevations or from south- to north-facing slopes. Plants that cannot tolerate hotter and drier conditions, including species that now grow at high elevation or in northerly parts of the state, may disappear altogether.

The above factors will result in reduced and less reliable water resources for New Mexico, leading to widespread water stress that is projected for all the southwestern states. With hotter and more intense droughts and associated aridity, surface water supplies are at risk. When surface water supplies are inadequate, many areas of New Mexico pump groundwater as a replacement. Diminished surface water leads to accelerated aquifer depletion via increased pumping. The same trend toward aridity that diminishes surface water supplies also tends to reduce groundwater recharge, amplifying the overall threat to water supplies posed by ongoing climate change.

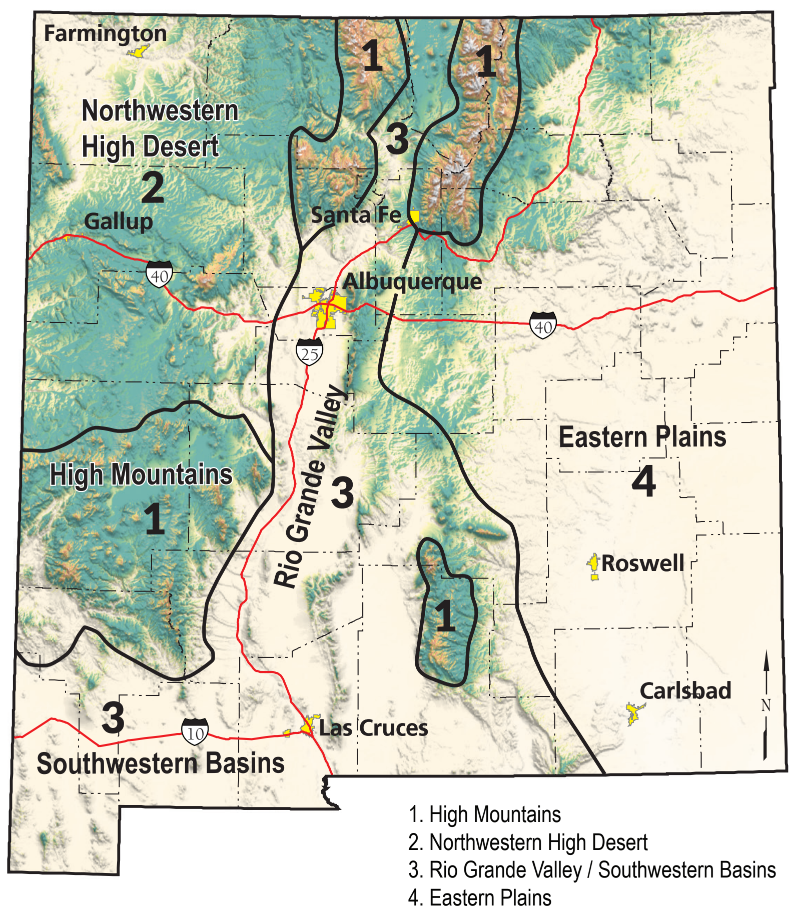
The likely impacts of warming climate on water quality are less well understood than the impacts on water quantity. Declines in water quality will impact both the water supply for human uses and the water supply that maintains riparian environments. The largest negative effect on water quality will come from warmer surface water temperature, to the detriment of aquatic ecosystems; this particularly affects areas where surface water is not shaded by vegetation. Other negative impacts from warmer surface water are lower dissolved oxygen content and higher concentrations of *E. coli* bacteria.

How Will the Hydrology and Water Supply Change in Different Regions of New Mexico?

New Mexico is a large state with a great variety of landscapes and range of elevations. While long-term climate change tends to be similar across large areas, local climate within New Mexico is strongly influenced by elevation, which in turn affects many local characteristics, such as types of vegetation. Changes in vegetation through wildfire or climatic warming and drying strongly influence how rainfall infiltrates aquifers and causes sediments to erode from hillslopes. This is especially true during extreme rainfall events, which are likely to become more common and more intense as temperature increases. In areas of moderate to steep topography, north- or south-facing hillslopes will respond differently, largely because of the relatively higher temperatures and lower soil moisture of south-facing hillslopes and consequent higher stress on vegetation. Such patterns will cause the effects of climate change to differ across New Mexico.

To summarize how large-scale climate change will be realized on small scales, we divide New Mexico into the following four regions based on topography, current and projected climate change, and effects on hydrology:

1. High Mountains (northern mountains, Gila/Mogollon–Datil region, and Sacramento Mountains)
2. Northwestern High Desert (Colorado Plateau, San Juan Basin, and Zuni Mountains region)
3. Rio Grande Valley and Southwestern Basins
4. Eastern Plains



Regions of the state expected to experience similar impacts to water resources from a changing climate over the next 50 years.

Photos of debris flows in Whitewater Creek Canyon on the west flank of the Gila Mountains in southern New Mexico following intense rains in September 2013. Left: Small canyon cut by a debris flow (see person for scale). Right: Debris backed up behind ranch gate. *Photos by Anne C. Tillery*

High Mountains

The High Mountains region combines three of New Mexico's most mountainous areas. The northern mountains include the Sangre de Cristo Mountains, the Tusas Mountains, and the Sierra Nacimiento, which together constitute the Southern Rocky Mountains. We also include the Jemez Mountains. The Gila/Mogollon–Datil area is a rugged landscape of relatively high elevation in southwestern New Mexico, and the Sacramento Mountains are a range within the southern Rio Grande rift region.

In the current climate, winter snowpack accumulates in each of these areas, generating runoff in the spring. This seasonal sequence is critically important for both agriculture and riverside ecology because water is stored over the winter with minimal evaporative loss and then released when most needed by plants. The impact of climate change on snow hydrology will be particularly important in these mountains, and snow-related changes in runoff will cause downstream effects in other regions of the state.

Over the next 50 years, mountains are likely to experience sharp declines in snowpack, which will melt earlier and generate less runoff. Higher temperature will lead to higher rates of evapotranspiration (ET)—the combined effect of evaporation from land and water surfaces—and transpiration, or the loss of moisture by plants. The relative increase in ET will be higher in mountains compared to lower regions. Less snowmelt and higher ET will reduce water available to recharge aquifers and support plants. Decreased recharge in high parts of the state will decrease replenishment of downstream aquifers at a time when these groundwater resources will already be stressed by increased pumping in order to meet water needs created by hotter droughts.

The changes and reductions in plant communities in mountains resulting from higher temperatures and more severe fires will reduce the stability of local soils, which may extensively erode, especially on south-facing slopes. Such slopes may become bare bedrock, which can reduce infiltration of rainwater into local aquifers and increase the rapidity of runoff from extreme precipitation, potentially increasing the magnitude of flood events.

The seasonality and form of precipitation will change in geographically variable ways as the climate warms. The northern mountains are projected to receive more winter precipitation and less spring precipitation, subject to pronounced year-to-year and decade-scale natural variations. In contrast, the Gila/Mogollon–Datil region and the Sacramento Mountains are projected to receive less winter and spring precipitation but relatively more in summer and autumn. Such changes in the geographical distribution of precipitation will likely cause mountain conifer forests to be replaced by brush, thereby reducing groundwater recharge.

As wildfires intensify, the magnitude of post-wildfire, rainfall-induced flooding and debris flows dramatically increases. Long-term loss of vegetation can amplify this effect. Post-wildfire floods often initiate on steep hillslopes and move downstream in pulses and waves, carrying large amounts of sediment in the floodwater. Soils can be stripped from hillslopes in the process, causing subsequent flood events to be even more extreme. Sediments mobilized in such floods move downstream and impact lower-elevation areas, filling in depressions that could otherwise capture floodwater and thereby reduce flood peaks and promote infiltration.

Additional consequences of increased flooding due to wildfires and warming include: erosion of land, stream channels, and water conveyance structures; accumulation of rock, mud, and burned vegetation in reservoirs and stream channels; and water quality degradation due to suspended sediment and dissolved constituents leached from the burned watershed. Diminished riparian vegetation in mountainous regions will cause the temperature of surface waters to rise and dissolved oxygen levels to decrease, negatively affecting local plants and animals and in particular highly valued fish species, such as trout.

Northwestern High Desert

The Northwestern High Desert includes the Colorado Plateau, San Juan Basin, and the area around and south of the Zuni Mountains and Mt. Taylor. This region is projected to experience the state's highest temperature increase over the next 50 years—about 1°F higher than the average statewide increase.

Increasing temperature in the absence of increased precipitation will substantially influence the extent and thickness of soils. Much of this part of the state is covered with ancient sand dunes that are currently stabilized by vegetation and thin, weakly developed soils. Reduced vegetation cover due to higher temperatures and greater drought stress will locally destabilize and erode soils, resulting in increased windblown dust. The deposition of more dust on high-elevation snowpack in mountains downwind causes snowpack to melt earlier. Additionally, loss of stabilizing vegetation cover and soil will promote the reactivation of sand dunes.

The high, generally flat topography of the Colorado Plateau and San Juan Basin will likely experience increased arroyo incision, leading to increased sediment moving downstream. This in turn elevates floodplains

Erosion driven by recent climate change has exposed the bedrock by rapidly removing a once-continuous soil from a hillslope on the Navajo Nation. Recently exposed roots of cliffrose plants are visible on the right. *Photo by Leslie D. McFadden* that could have stored floodwater, thus increasing the risk of damaging floods. Incised arroyos can also drain wetlands by lowering the local groundwater table, leading to wetland destruction.

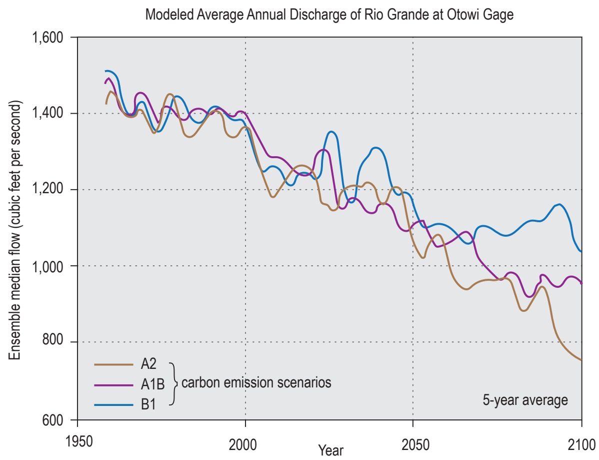
Grasslands in the Northwestern High Desert will become less productive in a more arid climate and may gradually be replaced by shrubs. Drought stress in conifer forests will increase, notably in warmer and drier lower-elevation areas. Trees along rivers may experience dieback because of lowered shallow aquifers created by reduced water in formerly perennial streams and rivers. The dieback of trees along riverbanks will allow water temperatures to rise and dissolved oxygen levels to decrease. *E. coli* concentrations may also increase, especially in low-energy streams with fine-grained, organic-rich bottom deposits.

Rio Grande Valley and Southwestern Basins

The Rio Grande Valley is located in the Rio Grande rift, a north–south oriented geologic basin that bisects the state. The northern part of the rift is relatively narrow and flanked by rugged mountains, and the valley broadens to the south. As many as 15,000 vertical feet of sediment have accumulated in basins along the Rio Grande rift, forming important aquifers that are tapped for municipal and agricultural water supplies.

Major warming-related impacts on this part of New Mexico include lower river flows due to higher ET and changes in the timing and magnitude of runoff due to earlier, diminished snowmelt. Flows in the Rio Grande above Elephant Butte Reservoir are projected to decrease by up to 25% in the next 50 years. Flows will be threatened by intensified droughts, making it even more challenging to maintain environmentally sustaining flows and satisfy existing water rights.

Warming temperatures will dramatically increase evaporation of surface water from reservoirs and increase water demands of riverside vegetation, watered landscapes, and irrigated croplands. Open-water evaporation increases with temperature more strongly than on-land ET. With the 5°F increase in average daily maximum temperature that is likely over the next 50 years, Elephant Butte Reservoir could experience an additional 2 feet of annual evaporative water loss. This would constitute a stunning 30% increase over the present-day rate and would greatly reduce the water available for use below



Modeled 5-year average discharge of the Rio Grande at the Otowi gage (near Española) from 1950 to 2100. The blue/purple/orange lines represent low/medium/high rates of increase in future greenhouse gas concentrations. *Graph courtesy of Dagmar Llewellyn*

the reservoir and challenge New Mexico's ability to deliver legally required water to Texas and Mexico. The combined effects of reduced runoff, increased evaporative losses, and increased demand due to enhanced ET will place the Rio Grande in a state of severe water stress.

This region of New Mexico will also experience impacts in common with the High Mountains and Northwestern High Desert regions, including: elevated vegetation water stress and widespread transitions from grasses to shrubs; bosque riparian forest die-offs due to dropping shallow aquifer levels; loss of upland soils and increased dustiness by amplified water and wind erosion; increased sedimentation; and compromised surface water quality (high temperature, low dissolved oxygen, and more *E. coli*).

Eastern Plains

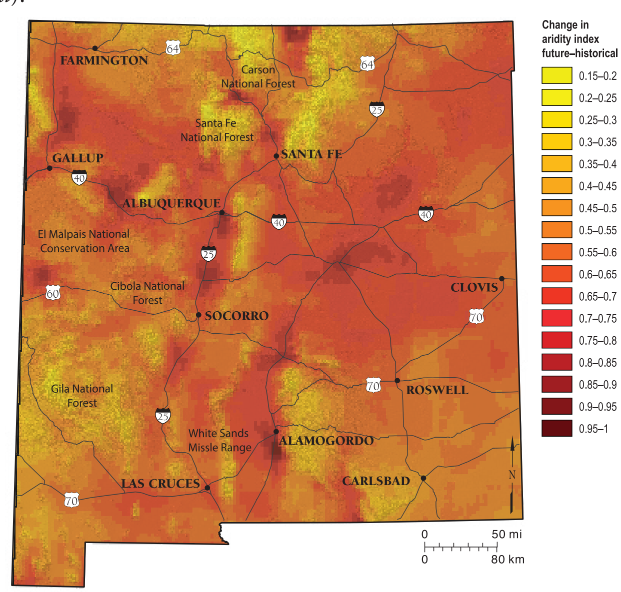
This region covers the eastern quarter of New Mexico, stretching from the northern to southern border of the state. The region is relatively flat and is characterized by grasslands in the north and Chihuahuan Desert vegetation in the south.

The average temperature increase over much of the Eastern Plains is projected to be roughly 1°F less than the statewide increase, but the trend toward higher aridity is projected to be most severe in this region. This would be a consequence of decreased precipitation during spring and possibly summer, when ET is highest, leading to large increases in surface aridity.

The major aquifer in this region (the High Plains or Ogallala Aquifer) has already undergone serious depletion, so the lower availability of surface water resulting from increased aridity will present a major water-management challenge. If extreme precipitation events do increase, regardless of changes to total precipitation, the Eastern Plains will be the most strongly affected part of New Mexico, even more so than mountainous regions.

Given its relatively flat topography and sparse vegetation, some of the most dramatic climate-related impacts in this area will be related to vegetation and soils. In the drylands of eastern New Mexico, large areas are covered by soils that are especially vulnerable to wind erosion when vegetation cover is lost due to drought or abandonment of farmlands. The environmental effect on large parts of eastern and south-central New Mexico over the next 50 years of climate aridification is likely to be desertification—the conversion of fertile land toward desert—and a significant increase in hillslope erosion.

The Eastern Plains are also likely to experience impacts that have been described for other parts of the state, including: elevated vegetation water stress and widespread transitions from grasses to shrubs; bosque riparian forest die-offs due to dropping shallow aquifer levels; increased sedimentation; and compromised surface water quality (high temperature, low dissolved oxygen, and more *E. coli*).



Projected difference in local aridity index from 1970–2000 to 2040–2069. Aridity index is the ratio of average potential evapotranspiration to average precipitation. The darker red colors represent the areas in which aridity will increase the most.

Water Management Challenges in an Era of Rapid Climate Change

Our analysis of the effects of climate change on New Mexico's water resources identifies multiple ways in which significantly warmer temperatures, combined with less-certain changes in total precipitation, drive the environment toward a state of increased dryness. This trend toward greater aridity has local consequences that depend on local conditions, ranging from those in alpine mountains to those in lower-elevation deserts. Uncertainties and knowledge gaps remain, as discussed in the Leap Ahead Analysis, but the overwhelming body of evidence points to a more arid future for New Mexico.

In some parts of the world, particularly at higher latitudes, aspects of climate change may result in effects that could be considered positive. Atmospheric warming can result in longer growing seasons or more precipitation as storm tracks shift poleward. However, in the semiarid climate of New Mexico, where availability of water is critical for the environment and our quality of life, scientific studies suggest the impacts of projected hotter and drier climate changes will be overwhelmingly negative.

The Leap Ahead Analysis avoids making specific policy recommendations for New Mexico's new 50-Year Water Plan. Previous water management plans have incorporated measures designed to help the state cope with 20th-century-scale droughts, which are a natural feature of climate in the Southwest. We strongly advocate, on the basis of our assessment, that the new Water Plan should address head-on the challenge of economic sustainability for a future in which water supply, both surface and groundwater, will be progressively and significantly reduced while demand climbs. The Plan needs to reconcile the desire to preserve a healthy environment in times of water shortage with economic water uses. The challenge of managing water through intermittent drought periods is already intensifying. In future decades, these challenges are likely to intensify further as New Mexico's climate trends toward more arid conditions. The welfare of future New Mexicans depends on our ability to establish resilience to diminished water supplies during this time of change.

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For Further Information: The summer 2020 issue of Earth Matters featured a review of the principal projected physical climate changes affecting New Mexico. (https://geoinfo.nmt.edu/publications/periodicals/earthmatters/20/n2/em_v20_n2.pdf)

High-severity fire effects in desertified piñon–juniper woodland in the southeast Jemez Mountains, taken August 2011, two months after being burned in the Las Conchas Fire. Note complete exposure of soil surface from fire consumption of all live and dead plant cover. *Photo by Craig D. Allen*

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Cover photo of Bisti/De-Na-Zin Wilderness hoodoos, northwest New Mexico, by Matthew Zimmerer

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Bureau News

High Plains (Ogallala) Aquifer Study Wins National Award

Senior Geologist Dr. Geoffrey Rawling and New Mexico Tech Assistant Professor Dr. Alex Rinehart received the Geological Society of America (GSA) 2021 John Frye Environmental Geology Award for their report "Lifetime Projections for the High Plains Aquifer in East-Central New Mexico." This annual award recognizes the best paper on environmental geology published by a state geological survey or the GSA. The High Plains Aquifer stretches across multiple western states and is considered one of the world's greatest aquifers. It provides fresh water for a large percentage of New Mexico's agricultural production, but groundwater mining has rapidly depleted the aquifer. The study used water levels from thousands of wells from 1950 to 2016 to discern water depletions over time and projected into the future to estimate when the water table will fall below a sustainable level for irrigation wells. Water levels have been declining on average by 1.5 feet per year since 1950. This rate is about 90 times greater than the rate of groundwater recharge.

The Rio Chama River Guide Wins Awards

The New Mexico Book Association revealed that our new Rio Chama River Guide has won the 2021 Southwest Book Design and Production Awards for best design in the "Guides" and "Scholarly and Technical" categories. The colorful book was also recently featured in a glowing review in the *Santa Fe New Mexican*.

"State Mineralogist" Virgil Lueth Retires

Senior Mineralogist/Economic Geologist Dr. Virgil Lueth has retired after 28 years of serving as de facto state mineralogist, including directing the activities of the New Mexico Bureau of Geology Mineral Museum and providing expert support to countless professional geoscientists, mineral enthusiasts, rockhounds, and the curious public. For 20 years Virgil worked to transform the Bureau's rock and mineral collection into a world-class museum that entertains and educates thousands of visitors each year. Virgil is perhaps most famous for his astounding ability to accurately identify every rock or mineral specimen brought to him, including naming the source mining district of nearly any mineralized rock sample. Many rockhounds and mineralogists know him through the wildly successful annual New Mexico Mineral Symposium he organized for nearly 30 years.

Cumbres & Toltec Scenic Railroad Geologic Road Log Published

This geologic road log describes the fantastic geology exposed along the Cumbres & Toltec Scenic Railroad between Antonito, Colorado and Chama, New Mexico. Beginning at the San Luis Basin of the Rio Grande rift, the guide describes the geology from the San Juan volcanic field to the Chama Basin at the edge of the Colorado Plateau. The booklet also provides an introduction to the engineering geology of building and maintaining the railroad, as well as descriptions of outcrops visible along the rail line.

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