



New Mexico EARTH MATTERS

WINTER 2011

The Sacramento Mountains Hydrogeology Study: How Geology and Climate Affect our Water Resources

In 2005 the New Mexico Bureau of Geology and Mineral Resources initiated the Sacramento Mountains Hydrogeology Study, an interdisciplinary, collaborative effort to understand the complex hydrology of the southern Sacramento Mountains. The project was conducted under the auspices of the bureau's ongoing Aquifer Mapping Program, with the cooperation and funding of the Otero Soil and Water Conservation District.

The primary motivation was an interest by land and water managers in the potential to increase spring and stream flow and ground water levels by thinning trees in mountain watersheds. However, the complexity of the mountain hydrologic system required a comprehensive analysis of the geology, climate, topography, and vegetation, as well as an understanding of the surface water and ground water hydrology. The results, which will be published this year, will greatly increase our understanding of this multifaceted hydrologic system. The knowledge gained by this study will help guide decision makers and future researchers on questions relating to management and sustainability of the region's water supplies under the increasing pressures of population growth and climate change.

The Sacramento Mountains, located in south-central New Mexico, extend from



Pierce Canyon, on the east flank near the crest of the Sacramento Mountains. Photo was taken in August 2006 during an exceptionally wet monsoon season. Courtesy of Stacy Timmons.

Capitan in the north to Otero Mesa in the south. This study focused on the southern portion of the range that lies south of the Mescalero Indian Reservation. Communities within the southern Sacramento Mountains include High Rolls, Cloudcroft, Mayhill, Piñon, Dunken, and Hope. The crest of the Sacramento Mountains extends from Cloudcroft to Timberon and includes several peaks over 9,000 feet above sea level. Alamogordo and Tularosa are located west of the steep mountain escarpment at the edge of the Tularosa Basin. The mountains dip east down the Pecos Slope toward Roswell and Artesia, and south to Otero Mesa and the Salt Basin.

Rain and snow are the source of both ground and surface water in the Sacramento Mountains. This resource sustains

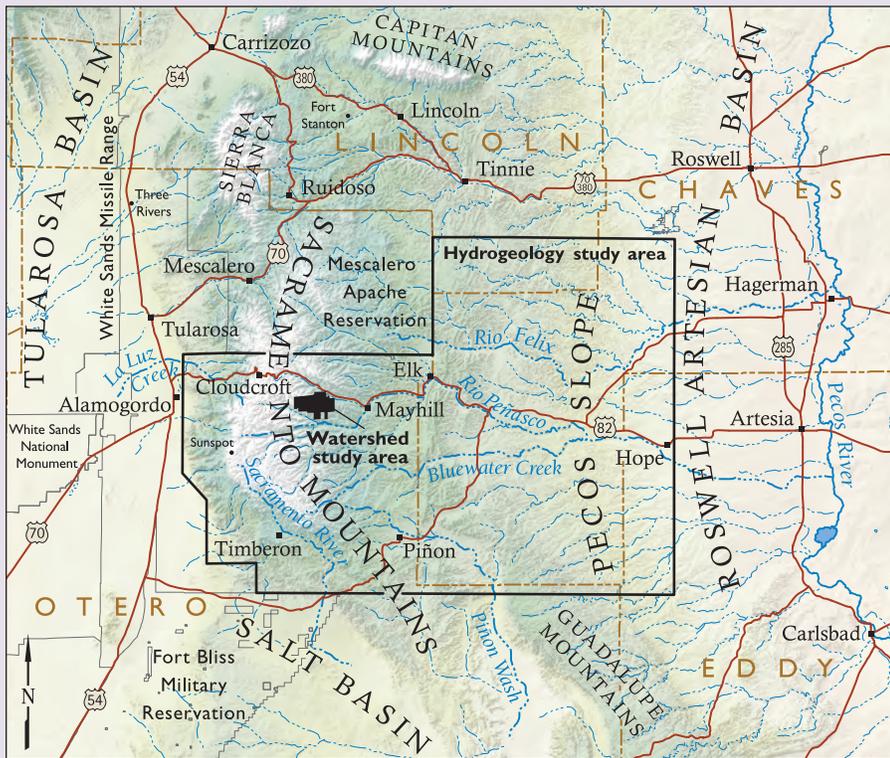
water supplies for local communities and recharges adjacent aquifers in the Tularosa and Salt Basins as well as the Roswell Artesian Basin, which is one of the most intensively farmed areas in the state, with the principal crops being alfalfa, cotton, sorghum, chiles, and pecans. Much of the water in the lower Pecos River ultimately originates from precipitation in the high Sacramento Mountains.

Water managers and users across the region have observed declines in ground water levels and spring discharges in the past few decades, with dramatic decreases in the

early 2000s. The Sacramento Mountains watersheds have undergone significant land-use and hydrologic changes during the twentieth century, including changes in vegetation patterns, an increase in tree density, variable climatic conditions, localized and severe fire impacts, and new ground water and surface water diversions. All of these have likely contributed to the observed declines.

The Sacramento Mountains Hydrogeology Study

The Sacramento Mountains study began in 2005 with a team of researchers at the New Mexico Bureau of Geology and with funding from the Otero Soil and Water Conservation District, through legislative appropriation administered by the New



Physiographic map of the Sacramento Mountains, in south-central New Mexico, and the surrounding region. The study areas for both the Sacramento Mountains Hydrogeology Study and the Sacramento Mountains Watershed Study are shown.

Mexico Department of Agriculture at New Mexico State University. Additional funds for geologic mapping were acquired through competitive grant awards from the National Cooperative Geologic Mapping Program (STATEMAP). The goals of the study were: (1) to delineate areas of ground water recharge, (2) to determine directions and rates of ground water flow, (3) to better understand the interactions among different aquifers and between the ground water and surface water systems, and (4) to better understand how vegetation influences the local water balance. Comprehensive field data were collected from 2005 to 2009 over an area of approximately 2,400 square miles. Data collection included geologic mapping, the monitoring of water levels in wells, sampling of both ground water (from wells and springs) and precipitation for chemical and isotopic analysis, and ground water age dating. Also undertaken were climate monitoring, fracture mapping and orientation measurements, and stream flow measurements. This interdisciplinary, regional approach to the study of a complex hydrogeologic system, during a time of extreme precipitation events and climate conditions, provided a unique and noteworthy dataset that we can use now and in the future to interpret the hydrogeology of this important mountain region.

Geology, Climate, and Hydrology

The geology and hydrology of this mountain landscape are more complex than they appear. In the high mountains, limestones of the San Andres Formation cap the ridges and overlie the Yeso Formation, which makes up the lower hillslopes and canyon bottoms. The Yeso Formation, composed of siltstone, sandstone, dolomite, limestone, and gypsum, forms the primary aquifer beneath the eastern slopes of the southern Sacramento Mountains. Dissolution of soluble minerals, including gypsum, in the Yeso has caused the collapse of overlying rocks and produced chaotic bedding. Regional faults and fracture systems have further deformed and fractured the rocks. Mountain-ridge and hillslope soils that overlie fractured bedrock are thin and poorly developed. East and south of the high mountains, the Yeso Formation plunges beneath the surface, and only the San Andres Formation is exposed. On the steep western escarpment, the geology is more diverse, with thick exposures of lower Paleozoic strata that have been intensely deformed by major faults.

The high Sacramento Mountains receive some of the largest amounts of rain and snow in New Mexico. Average annual precipitation in the study area is highly cor-

related with elevation and varies from 26 inches at the crest to less than 12 inches on the eastern flanks of the Pecos Slope. Most precipitation falls as summer monsoon rains and winter snows. The significant topographic relief combined with the geographic location make the Sacramento Mountains particularly susceptible to large storm systems produced by remnants of tropical storms and hurricanes that originate in the Gulf of Mexico and the eastern Pacific Ocean. Lower temperatures in the high mountains increase the length of time that snow remains on the ground, and during the summer these lower temperatures minimize evaporation of the monsoon rains. These climatic factors alone make the high Sacramento Mountains a likely recharge area.

In the high mountains, in regions where the Yeso Formation is exposed, hundreds of springs discharge from fractured limestone beds at multiple levels. Most wells in this area produce water from fractured limestone in the Yeso Formation. Despite the high rainfall and the multitude of springs, there are few perennial streams that transmit water from the high mountains. The main perennial streams in the area are the Sacramento River, the Agua Chiquita, and the Rio Peñasco. To the east, along the Pecos Slope, a few springs are present along faults and other structural zones. Wells in this area produce water from both the Yeso Formation and the San Andres Formation. Within the study area, from west to east, the primary aquifer changes from the Yeso Formation to the San Andres Formation, which produces most of the ground water in the Roswell Artesian Basin.

How Does Ground Water Move through the System?

Water level, geochemical, isotope, and age-dating data indicate that the primary recharge area is in the high mountains above 8,200 feet. Ground water flows from the top of the mountains to lower elevations to the east, west, and south. Within the high mountains, west of Mayhill, the many different rock types within the Yeso Formation, which is exposed in this area, combine with regional fracture systems to create a complex hydrologic system. This system allows a significant portion of high-altitude precipitation to move relatively quickly through a series of shallow, perched carbonate aquifers. These aquifers are connected by fracture networks and surface water drainages. Much of

this water is removed from the system by evaporation in mountain streams and by vegetation that extracts water from the shallow perched aquifers. Ground water in the high mountains is also stored in soils, alluvium, fractures, and pores that are not directly connected to these regional fracture systems. These different areas where water is stored have a direct effect on where vegetation can extract water, and therefore on how tree thinning and other land management practices might affect the local hydrology. For instance, trees growing above a shallow perched aquifer may derive their water directly from that aquifer, whereas trees growing above a deep aquifer derive their moisture primarily from unsaturated soils and fractured bedrock.

In areas to the south and east, where the Yeso Formation is not exposed at the surface, most ground water comes from the aquifer system in the high mountains, and very little surface recharge occurs. Estimates are that as much as 22 percent of high-altitude precipitation goes to recharge adjacent regional aquifers to the east and south, the directions of regional dip. Age-dating data indicate that it may take as long as 1,300 years for ground water to flow from Mayhill to the eastern portion of the Pecos Slope, toward Hope, Artesia, and Roswell. Ground water flowing to the east ultimately makes its way to the ground water system in the Roswell Artesian Basin. Less is known about the

contribution of ground water recharge from high-altitude precipitation to regional aquifers to the west. However, ephemeral mountain streams on the western slopes of the Sacramento Mountains certainly provide some recharge to regional aquifers in the Tularosa Basin. The New Mexico Bureau of Geology is currently conducting a similar hydrogeology study in this area.

When and Under What Conditions Does Ground Water Recharge Occur?

Results from this regional study clearly indicate that most ground water originates as high-altitude snowmelt. However, under certain conditions, summer precipitation can contribute significantly to the regional ground water systems. Above-average rainfall in the summers of 2006 and 2008 significantly increased water levels in most wells being monitored in the study area. August 2006 and July 2008 were the wettest months recorded in Cloudcroft in the last 100 years. In 2006 the unusually wet monsoon season was characterized by frequent thunderstorms. In 2008 nearly half of the 13 inches of rain that fell in Cloudcroft in July fell within two days as a remnant disturbance of Hurricane Dolly passed over the area.

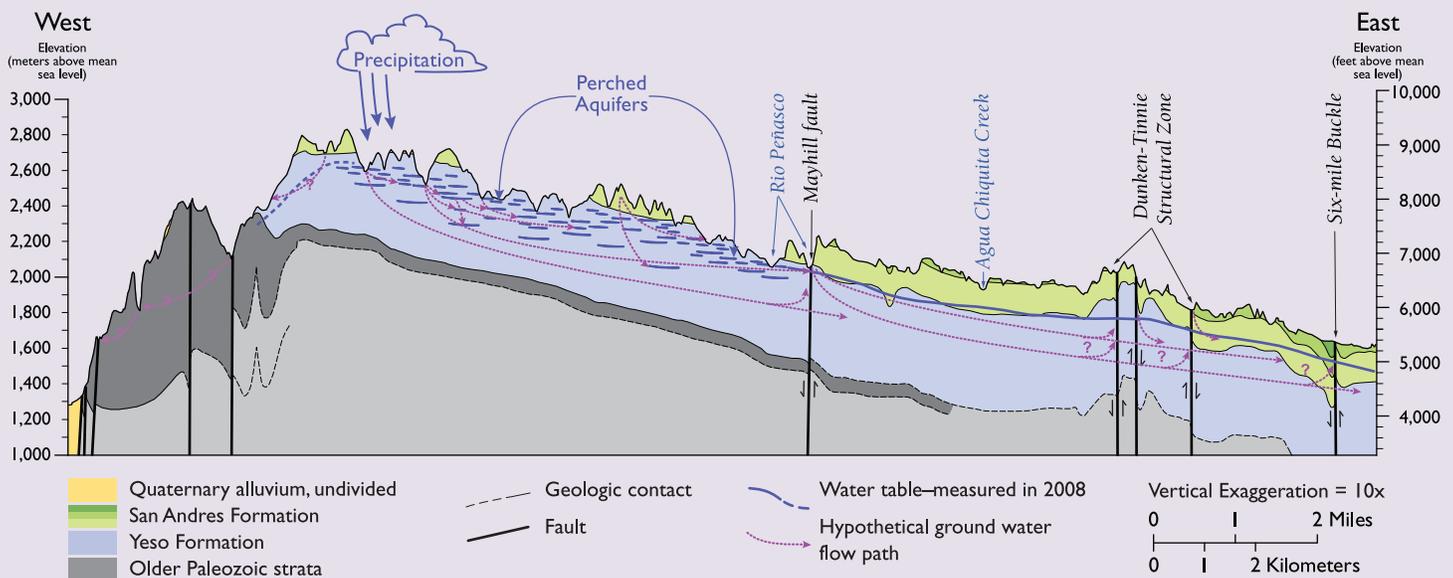
This observation has important implications on how this hydrologic system may respond to climate change in the near future. A decrease in snowfall and snow-

pack, which is predicted by climate models, will reduce the amount of ground water that is recharged by snowmelt. Large summer storm events associated with the North American monsoon and remnant hurricane disturbances may become a more important source of ground water recharge. But this in turn means that these aquifers may rely on such climatic events to maintain or increase their long-term productivity. Clearly, we need a better understanding of how ongoing climate change will ultimately affect regional weather patterns like our summer monsoons.

Artificial recharge techniques, where surface water runoff in the mountains is injected and stored in the aquifer system, may become necessary to sustain down-gradient ground water resources. Knowledge gained from this regional-scale hydrogeology study can be very useful in identifying areas that would be sufficient for storing this water in the subsurface.

The Sacramento Mountains Watershed Study: Can We Increase Our Water Supply by Thinning Forests?

Thinning trees is a forest restoration technique that is being used to improve wildlife habitat and reduce fire danger in the Sacramento Mountains. This restoration technique is also being studied to determine its potential for increasing the ground water and surface water supply.



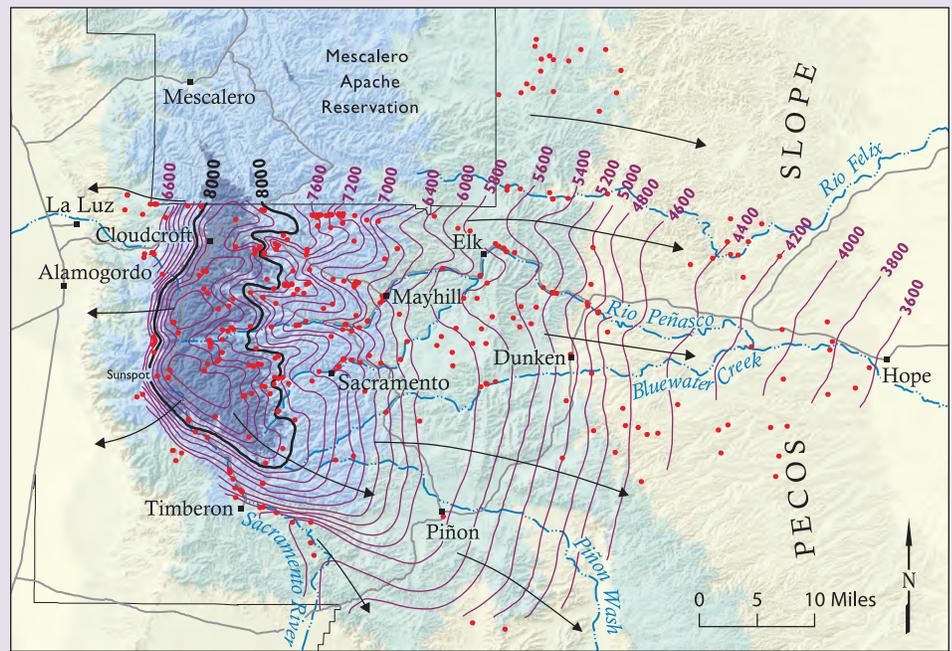
Cross section of the Sacramento Mountains from west to east, showing the steep west-facing slope and the broader, more shallow east-facing slope. Much of the ground water moves eastward toward the Pecos River and the Roswell Artesian Basin.

The Sacramento Mountains Hydrogeology Study laid the groundwork for the Sacramento Mountains Watershed Study, a smaller-scale ongoing research program that aims to evaluate the effects of tree thinning on the local hydrologic system. The watershed study is a collaborative effort of the New Mexico Bureau of Geology and Mineral Resources, New Mexico State University, and the New Mexico Forest and Watershed Restoration Institute at Highlands University. Primary funding was provided from the Otero Soil and Water Conservation District, through legislative appropriation administered by the New Mexico Department of Agriculture at New Mexico State University, in Las Cruces. Additional funding has been provided by the New Mexico Interstate Stream Commission.

The Sacramento Mountains Watershed Study, which began in 2007, is being conducted on private property in Three L Canyon, located between Cloudcroft and Mayhill. Precipitation in Three L Canyon has the potential to recharge local and regional aquifers. The hope is that tree thinning will affect how much recharge occurs by (1) increasing the amount of water that reaches the ground due to a decrease in canopy cover and (2) decreasing the amount of water that is taken up by evapotranspiration (ET = soil evaporation + water used by vegetation). For this study, the water balance method is being used to track how precipitation in the watershed enters and leaves the soils before and after tree thinning. Calculating a water balance requires the measurement of inputs such as precipitation and inflowing ground water and outputs, such as evapotranspiration. Baseline data, which include water levels, water chemistry, climate data, spring discharge, and soil moisture, are currently being collected. These will be used to estimate different components of the water balance. In 2011 at least 400 acres of the approximately 800-acre watershed will be thinned. Data will be collected for several years after the thinning is completed. Results of this study should provide valuable information about whether or not thinning trees in watersheds in the high Sacramento Mountains is an effective method of increasing ground water and surface water supplies.

Conclusions

All regional hydrologic systems are fundamentally controlled by geology and climate. Rain and snow provide the pri-



Contour ground water map, showing ground water elevation (above mean sea level) and direction of regional ground water flow, superimposed on a map of average annual precipitation. Red dots indicate inventoried wells and springs.

mary water input, and the geology controls how water moves from the recharge area to the discharge area. We cannot significantly alter either climate or regional geology, but we can and do change the interface between the two. By altering vegetation patterns and/or landscape, or by designing artificial recharge programs, we can change the way climate interacts with the geology. Determining if and how to modify this interface in a way that is beneficial to the environment and our future water resources requires an understanding of both the regional geology and the local climatic regime.

The Sacramento Mountains Hydrogeology Study is an excellent example of a regional-scale interdisciplinary study that relates climate and geology to the location and timing of ground water recharge. As population continues to expand, and in light of potential changes in winter and summer precipitation patterns that result from climate change, water resource issues in New Mexico are of utmost importance. Understanding where and when recharge occurs, how much recharge occurs, and how that water makes its way down gradient to where it is used is crucial in making decisions that are critical to the management of our water supply. These kinds of

watershed studies clearly could have much broader applications statewide, in helping us to understand regional aquifers and the future of New Mexico's water resources.

—Talon Newton

Talon Newton is a hydrogeologist at the New Mexico Bureau of Geology and Mineral Resources, and the chief scientist on the Sacramento Mountains Hydrogeology Study.

For More Information

A number of more detailed reports on the Sacramento Mountains Hydrogeology Study are available on the New Mexico Bureau of Geology and Mineral Resources Web site. The summary report published in June 2010 and a more comprehensive open-file report (# 518) are good places to start. Both are available as free downloads on our Web site, along with a list of selected references, at:

http://geoinfo.nmt.edu/resources/water/projects/Southern_Sacramentos.html

Bureau News

Public Service Award

Peggy Johnson was one of twelve exceptional New Mexicans honored this year with the governor's Distinguished Public Service Award. These awards are given each year to recognize outstanding contributions to public service and to the improvement of government at all levels by both government employees and private citizens. Among those honored are career civil servants, for significant contributions to public agencies and to the state and community in which they live, and both civic leaders and private citizens for their contributions to the improvement of the public service at the federal, state, and local levels. Peggy Johnson is a senior hydrogeologist at the New Mexico Bureau of Geology, where she directs the Aquifer Mapping Program. Her studies have had a major impact on the effective management of ground water in critical areas including Taos, Placitas, the Española Basin, and the Sacramento Mountains.

Earth Science Achievement Awards

The 2011 Earth Science Achievement Awards will be presented on March 10 in Santa Fe. The presentation will occur at noon in the rotunda of the state capitol building during the legislative session, in conjunction with Earth Science Day. This year's winners are Representative James Roger Madalena, for outstanding contributions advancing the role of earth science in areas of public service and public policy in New Mexico, and Nicholas Bugosh, for outstanding contributions advancing the role of earth science in areas of applied science and education in New Mexico. These awards, co-sponsored by the New Mexico Bureau of Geology and Mineral Resources and the Energy, Minerals and Natural Resources Department in Santa Fe, were initiated in 2003 to honor those often unrecognized champions of earth science issues vital to the future of New Mexico. Selections were made following a statewide nomination process. The award ceremony is open to the public.

New Mexico Book Award

The 2010 New Mexico Book Awards bestowed top honors on the bureau's most recent publication, *The Geology of Northern New Mexico's Parks, Monuments, and Public Lands*, which appeared in May of

this year. The popular title was nominated and shared top honors in the category of Anthropology/Archaeology/Science. The New Mexico Bureau of Geology took top honors in 2007 in the Travel category for Scenic Trip 19, *The High Plains of Northeastern New Mexico: A Guide to Geology and Culture*. Both titles are available through the bureau's Publication Sales Office.

Bureau Director Retires

Dr. Peter Scholle, who has directed the New Mexico Bureau of Geology and Mineral Resources since 1999, will be retiring from his position as director at the end of June. Peter has had a rich and diverse career in geology, which included 9 years with the U.S. Geological Survey, 4 years in the oil industry (in addition to many years of petroleum consulting), 17 years of university teaching, and a 12-year career in state government at the New Mexico Bureau of Geology and Mineral Resources. During Peter's tenure, a number of important programs were initiated, including the Aquifer Mapping Program and the highly successful series of decision-makers field conferences. Among many contributions to the bureau, Peter will be remembered for his focus on education and public outreach. Under Peter's direction, the bureau achieved a highly visible public profile and developed many positive working relationships with state and federal agencies, the Association of American State Geologists, and the university. It was under Peter's direction that the bureau changed its name (by legislative action) from the New Mexico Bureau of Mines and Mineral Resources. Peter's primary research interests over the course of his career have been carbonate sedimentology and diagenesis, especially in Cretaceous chalks and late Paleozoic limestones, and petroleum geology of carbonate systems, and he plans to continue doing research, teaching, and consulting in those areas. The search for a new bureau director has begun (the full vacancy announcement is available at <http://www.nmt.edu/hr-jobs-at-nmt>). We hope to have a new director in place by July 1 of this year.



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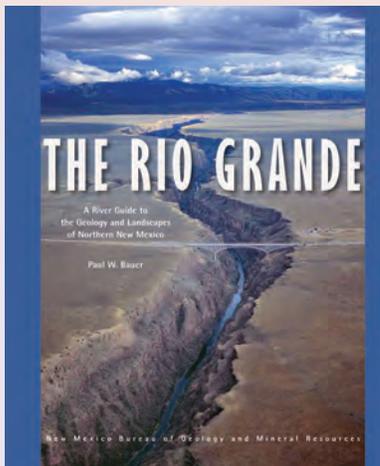
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Coming Soon



The Rio Grande: A River Guide to the Geology and Landscapes of Northern New Mexico, by Paul W. Bauer. 120 pp, full color. Spiral bound, on waterproof paper. Available late Spring 2011. ISBN 978-1-883905-28-6.

The Rio Grande is the fourth longest river in North America. Flowing nearly 2,000 miles from Colorado to the Gulf of Mexico, in New Mexico it occupies the Rio Grande valley, where it provides water for habitat, agriculture, and a growing population. In northern New Mexico, where the river has carved a pair of spectacular canyons, the Rio Grande also provides some of the most exceptional recreation opportunities and scenery in North America.

This comprehensive, waterproof, 120-page river guide provides detailed, full-color maps of 153 miles of the Rio Grande, from Lasauces, Colorado, to Cochiti Dam in New Mexico. Divided into eleven river stretches—including the popular whitewater runs in

the Taos Box, Racecourse, and White Rock Canyon—the guide covers stretches that range in difficulty from placid canoe tours to gripping kayak descents. The river maps are developed on an aerial photographic base (digital orthophoto quads), allowing the user to more easily identify locations.

The geology of the region is likewise exceptional. The river spills from the San Juan Mountains into the Rio Grande rift, where several million years of erosive action have exposed a geologic cornucopia, including three major volcanic fields (including the Jemez supervolcano), seismically active faults, extinct Pleistocene lakes, and ancient rocks of the Rocky Mountains. The guide uses non-technical language and lavish illustrations to interpret the evolution of this magnificent landscape.

Although the focus of the guide is on geology and landscape, the guide is packed with information and photos on geography, hydrology, climate, boating safety, river management, rock art, and much more. Providing detailed information on access and trails, history and landscape, railroads and mining, this guide is also an invaluable resource for hikers, anglers, cyclists, day trippers, historians, philosophers, and casual visitors.

For more information about this and other bureau publications:

- Visit our Web site at <http://geoinfo.nmt.edu>
- Write or visit our Publications Office on the campus of New Mexico Tech, 801 Leroy Place, Socorro, New Mexico 87801
- Call (575) 835-5490 or e-mail us at pubsofc@gis.nmt.edu
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