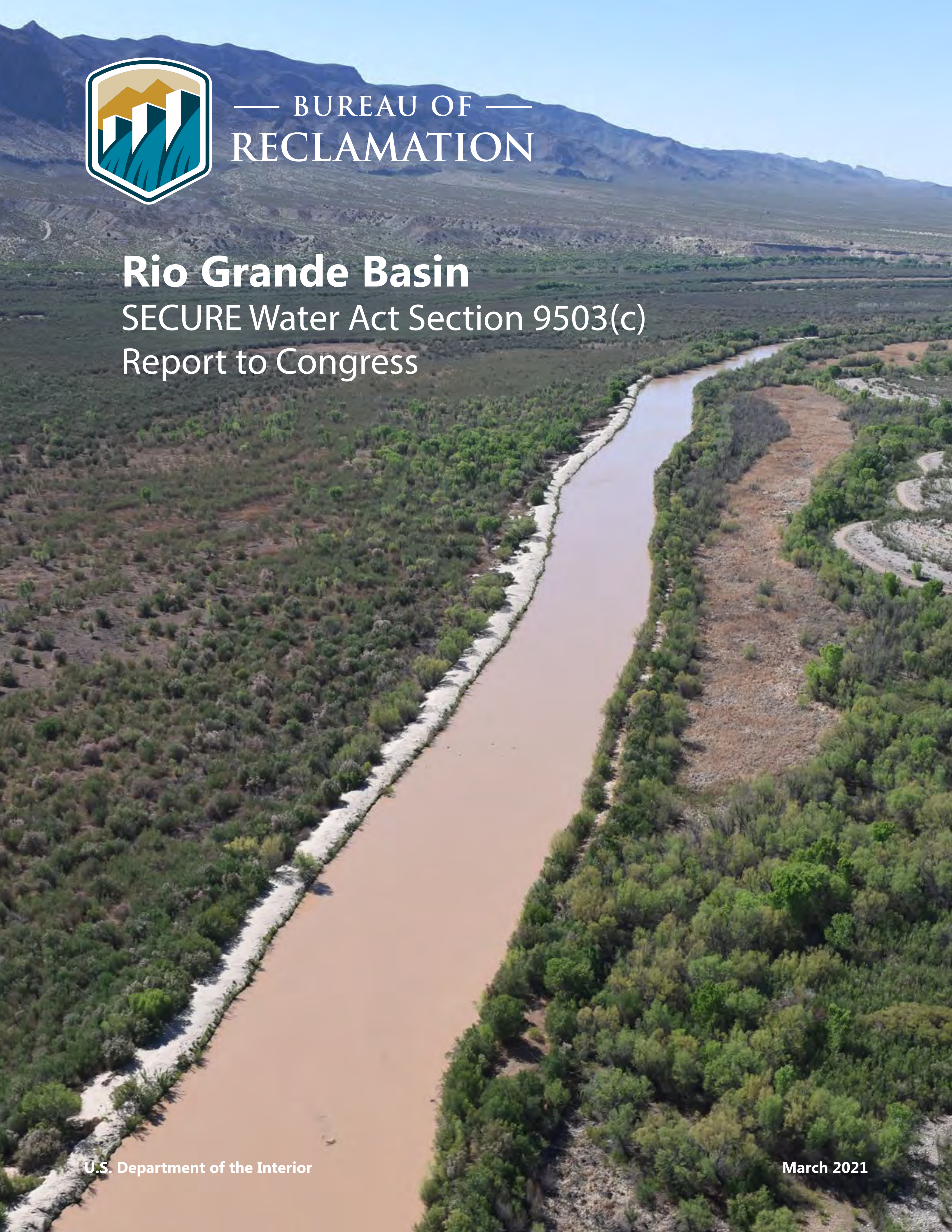


BUREAU OF RECLAMATION

Rio Grande Basin

SECURE Water Act Section 9503(c) Report to Congress

U.S. Department of the Interior

March 2021

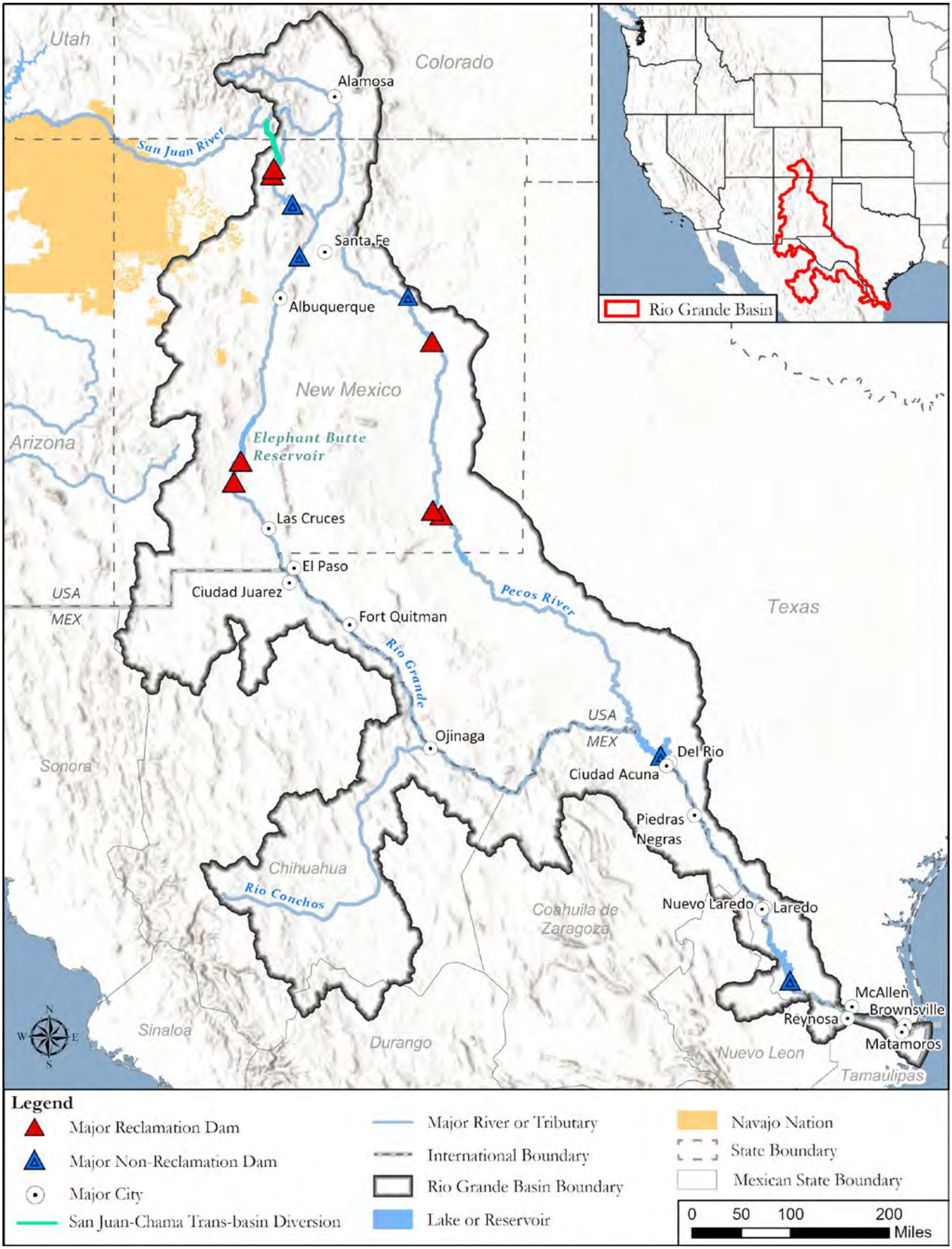
Mission Statements

The Department of the Interior conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acronyms and Abbreviations

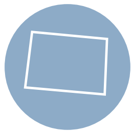
°F	degrees Fahrenheit
E. coli	*Escherichia coli*
ESA	Endangered Species Act
ET	evapotranspiration
HDB	Hydrologic Database
IBWC	International Boundary and Water Commission
JPL	Jet Propulsion Laboratory
MRGCD	Middle Rio Grande Conservancy District
MW	megawatts
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NMISC	New Mexico Interstate Stream Commission
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
Reclamation	Bureau of Reclamation
SECURE Water Act	Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act
SNOTEL	Snow Telemetry
USACE	U.S. Army Corps of Engineers
USGS	U.S Geological Survey
VISTA	Volunteers in Service to America
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WDI	Water Data Initiative



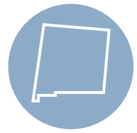
Utah
Colorado
Alamosa
San Juan River
Santa Fe
Albuquerque
New Mexico
Arizona
Elephant Butte
Reservoir
Las Cruces
El Paso
Ciudad Juarez
USA
MEX
Fort Quitman
Pecos River
Texas
Rio Grande
Ojinaga
USA
MEX
Del Rio
Ciudad Acuna
Piedras
Negras
Sonora
Chihuahua
Rio Conchos
Coahuila de
Zaragoza
Nuevo Laredo
Laredo
McAllen
Brownsville
Reynosa
Matamoros
Sinaloa
Durango
Nuevo Leon
Tamaulipas
Rio Grande Basin
Legend
Major Reclamation Dam
Major Non-Reclamation Dam
Major City
San Juan-Chama Trans-basin Diversion
Major River or Tributary
International Boundary
Rio Grande Basin Boundary
Lake or Reservoir
Navajo Nation
State Boundary
Mexican State Boundary
0
50
100
200
Miles

Rio Grande Basin Setting

U.S. States and Mexican States:


Colorado


Texas


New Mexico


Chihuahua


Coahuila


Nuevo León


Tamaulipas

Major U.S. Cities:

- Alamosa
- Santa Fe
- Albuquerque
- Las Cruces
- El Paso
- Del Rio
- Laredo
- McAllen
- Brownsville

Major Mexican Cities:

- Ciudad Juarez
- Ojinaga
- Ciudad Acuna
- Piedras Negras
- Nuevo Laredo
- Reynosa
- Matamoros

Major Water Uses:


Agriculture


Municipal and Industrial


Environmental


Recreation

River Basin Area: 182,200 square miles
(United States and Mexico)

River Length:
Pecos River 970 miles
Rio Grande 1,896 miles

Major rivers/ tributaries:

- Conejos
- Rio Chama
- Pecos
- Rio Conchos, Mexico

Notable Reclamation Facilities:

- Closed Basin Project (Colorado)
- San Juan-Chama Project (Colorado and New Mexico)
    - Oso, Little Oso, and Blanco Diversions
    - Heron Reservoir
    - Azotea Tunnel
- Middle Rio Grande Project (New Mexico)
    - El Vado Reservoir
- Carlsbad Project (Pecos River, New Mexico)
    - Sumner Reservoir
    - Brantley Reservoir
    - Avalon Reservoir
- Rio Grande Project
    - Elephant Butte Reservoir
    - Caballo Reservoir
    - 6 diversion dams, including International Dam, which delivers water to Mexico

Contents

ABOUT

This basin report is part of the 2021 Science and Engineering to Comprehensively Understand and Responsibly Enhance (SECURE) Water Act Report to Congress, prepared by the Bureau of Reclamation in accordance with Section 9503(c) of the SECURE Water Act of 2009, Public Law 111-11. The 2021 SECURE Water Act Report follows and builds upon the first two SECURE Water Act Reports, submitted to Congress in 2011 and 2016. The report characterizes the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

The 17 Western States form one of the fastest growing regions in the Nation, with much of the growth occurring in the driest areas. The report provides information to help water managers address risks associated with changes to water supply, quality, and operations; hydropower; groundwater resources; flood control; recreation; and fish, wildlife, and other ecological resources in the West.

To see all documents included in the 2021 SECURE Water Act Report to Congress, go to: https://www.usbr.gov/climate/secure/

Mesilla Diversion Dam, New Mexico.

SECTION 1

Water Management Challenges

Overall, water supplies are marginal, hydrological variability in the Rio Grande Basin is high, and water shortages occur frequently.

In the Rio Grande Basin, the water management challenges posed by a highly variable and extremely limited water supply have been exacerbated in recent decades by prolonged drought, combined with increasing basin temperatures. Water scarcity plays a key role in water management (**Figure 1**). Climate change projections, such as those developed by the Bureau of Reclamation (Reclamation), indicate that water supply in this basin is decreasing, while demand for that water, even without further development, is increasing as a result of increasing temperatures. Timing and spatial distribution of water availability is also changing, placing new demands on existing operational strategies and physical infrastructure. Water managers are now planning for a hotter, drier, and even more variable future.

Figure 1. Dry Rio Grande riverbed.

Basin Overview

The Rio Grande flows 1,896 miles from its headwaters on the eastern side of the San Juan Mountains of southern Colorado south through New Mexico to Texas where it forms the international boundary between the United States and the Republic of Mexico for 1,250 river miles. The river drains a total of approximately 182,200 square miles in the United States and Mexico. Basin topography varies from the mountains and gorges of the headwaters through the irrigated villages of Colorado and Northern New Mexico, the Bosque riparian corridor and high desert of central New Mexico, to the deserts and humid subtropical terrain along the boundary between Texas and Mexico. Downstream of New Mexico, the majority of the watershed is in the Mexican States of Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas. Ultimately, when enough water remains in the lower reach of the river, the Rio Grande flows into the Gulf of Mexico.

Figure 2. Elephant Butte Reservoir in New Mexico at 11 percent of water storage capacity. The white bathtub rings on the bank mark previous higher water levels.

Along with international jurisdictions, 20 Native American Tribes in New Mexico and an additional two Tribes in Texas rely on water from within the Rio Grande Basin. In addition, the river supports other agricultural, recreational, municipal, and industrial users, as well as endangered species and a unique riparian ecosystem along much of its length.

Basin Geography and Hydrology

The Rio Grande is comprised of three distinct reaches — the Upper Rio Grande, the Forgotten Reach, and the Lower Rio Grande in Texas. The Pecos River parallels the Upper Rio Grande and flows into Amistad Reservoir in the Lower Rio Grande in Texas, along the United States border with Mexico. Dams and diversions on both rivers have significantly altered the natural hydrograph. The water supply available for human uses is fully appropriated, and water shortages are common in all parts of the basin (**Figure 2**).

- **The Upper Rio Grande** has its headwaters in the San Juan and Sangre de Cristo mountains of southern Colorado (**Figure 3**). In the San Luis Valley of Colorado, the Conejos River and the groundwater pumped from Reclamation's Closed Basin Project contribute to the flow of the river. The waters of the Upper Rio Grande have been stressed for decades, and the region is entering the 20th year of an extended drought. Surface water shortages are common and the basin has experienced declines in groundwater levels, which further deplete surface water supplies.

  Downstream of Elephant Butte Reservoir, the Rio Grande only flows during irrigation water deliveries from the Rio Grande Project or in rare floods. In El Paso, water is diverted for required deliveries to Mexico. Below these diversions in El Paso, the river is typically dry, even during irrigation season, since all remaining water flows in the irrigation network.

  Flows support river and reservoir recreation as well as vital ecosystems and wildlife habitats. However, except in rare circumstances, the numerous water uses have fully depleted the river by the bottom of this reach.

Figure 3. Sand dunes between the plain of the San Luis Valley and the snow covered Sangre de Cristo Mountains (Getty Images).

- **The Forgotten Reach** extends from Hudspeth County, Texas downstream to the confluence with the Rio Conchos, which flows into the Rio Grande just upstream of Big Bend National Park. This reach, along the border between the United States and Mexico, rarely sees any flow. The remnant channel is primarily covered in invasive vegetation.
- **The Lower Rio Grande in Texas** begins to flow again as the Rio Conchos flows in from Mexico just upstream of Big Bend National Park. Further downstream, the International Boundary and Water Commission (IBWC) operates Amistad and Falcon Reservoirs for flood control and water supply. These international reservoirs have been designated as a special water resource by the Texas Water Development Board. About three-quarters of the watershed that feeds these international reservoirs is in Mexico. If there is sufficient water, the Rio Grande ultimately flows into the Gulf of Mexico near Brownsville, Texas.
- **The Pecos River** flows from the Sangre De Cristo mountains through New Mexico forming a separate basin roughly parallel to the Rio Grande. This stretch mostly serves agricultural lands with some water used for municipal purposes and oil and gas extraction. The Pecos River enters the Rio Grande at Amistad Reservoir within the Lower Rio Grande in Texas.

Water Management and Allocation

Operational Rules and Water Rights

Reservoir storage for native water in the Upper Rio Grande above Elephant Butte Reservoir and on the Pecos River above Brantley Reservoir is limited to the amount typically needed for a year or less of water use. It is anticipated that managing this highly variable resource will get even more challenging with future hydrological and meteorological changes. The Rio Grande has a long and complex history, resulting in a highly complex water management system that in many cases constrains options for today's—and tomorrow's—water management challenges. Challenges include:

- Operating rules for reservoirs were specified by Congress during the original authorization and cannot be modified without congressional action. In some cases, these operating rules limit flexibility for storing and releasing water in a changing system.

Changing and uncertain water supplies challenge the limits of our institutions, legal and policy frameworks, and infrastructure management practices.

- Ongoing water conflicts between the States, as well as appropriations within the States, are complicated by a backdrop of differing legal approaches to water management. Colorado has a system based on water courts and practices strict priority administration, determining allocations in 10-day cycles throughout the irrigation season. In New Mexico, priority administration is specified in the State constitution, but is generally considered overly rigid and inconsistent with local culture and histories. Instead, New Mexico typically relies on shortage sharing agreements to distribute limited supplies. Texas practices a combination of riparian rights (especially for groundwater) and priority administration.
- Accounting for groundwater pumping impacts on surface water supplies varies widely between States and internationally. Record keeping is also inconsistent, both within and between States, and groundwater data sharing between States is limited.

However, actions are underway to determine ways to incorporate more flexibility within the legal and institutional operating constraints to address the changing water picture.

Water Compacts and Agreements

Ongoing water conflicts between the States, as well as appropriations within the States, are complicated by a backdrop of different legal perspectives on water adjudication.

The Rio Grande, as the main water supply in an arid region with highly variable hydrologic conditions, is subject to a complex system of management and water allocation, with numerous overlapping jurisdictions. Federal management includes Reclamation (primarily for water supply); the IBWC (managing reservoirs and diversions for both water supply and flood and sediment control, near the United States-Mexico border); and other Federal agencies for measurements, flood control, national parks, water quality, and environmental protection.

Figure 4. Irrigating chile pepper seedlings.

The three basin States, Tribes, various municipal-level governments, and irrigation districts all have water management responsibilities. Some irrigation networks are included in Reclamation projects and are in various stages of transferring titles for project lands and infrastructure (**Figure 4**).

- **Compacts and Agreements –** Rio Grande Basin waters are adjudicated between States and internationally.
    - **The Rio Grande Compact** equitably apportions flows among Colorado, New Mexico, and Texas and specifies flows based on supply from the headwaters or inflow from the next-upstream State. Colorado, where the Upper Rio Grande flows originate, gets the largest share. Texas gets the smallest share of the flows from the Upper Rio Grande, but gets inflow from Mexico on the Rio Conchos, as well as flows delivered by New Mexico on the Pecos River. Overlapping jurisdictions, the impact of groundwater pumping, and other complexities of this apportionment have resulted in an ongoing Supreme Court lawsuit over the terms of and compliance within the compact. This lawsuit could alter water distribution between the States, creating even greater water supply uncertainty.
    - **The Upper Colorado River Compact** allows for imported water from the Colorado River. Under this compact, Reclamation delivers part of New Mexico's allocated water from the Colorado River to the Rio Grande Basin in New Mexico via Reclamation's San Juan-Chama Project.
    - **The 1948 Pecos River Compact** between New Mexico and Texas lays a foundation for cooperation to manage the scarce water resources of the Pecos River basin. However, this agreement has not prevented all conflict between the States in the basin. A supreme court lawsuit (Texas v. New Mexico) was resolved in 1988 through an amended decree. Challenges in meeting the terms of the decree led to the negotiation of the Pecos Consensus Plan, embodied in the 2003 Pecos Settlement Agreement, which continues to guide New Mexico's compact deliveries to Texas.
    - **The 1906 Convention between the United States and Mexico** is the primary international agreement affecting the Upper Rio Grande. It requires the United States to provide 60,000 acre-feet of water to Mexico at El Paso, Texas.
    - **The 1944 Water Utilization Treaty** between the United States and Mexico focuses on the Colorado River. However, some negotations under this treaty consider all water exchanges between the United States and Mexico and, therefore, have implications for water management in the Lower Rio Grande Basin.
- **Indian Water Rights –** Eighteen Indian Pueblos and portions of two Nations (Navajo and Apache) are in New Mexico's Middle Rio Grande Basin, and two additional Tribes have their homelands in the Rio Grande watershed in Texas. Most of these Native American Tribes use water from the Rio Grande and its tributaries for agricultural, domestic, and ceremonial purposes. Many of these communities have expanding populations and increasing water use. Water allocations for many Tribes are still unquantified, but are considered senior under New Mexico's priority administration system.

- **Surface Water and Groundwater Management –** Legal doctrines within each State and with Mexico vary on how to address hydrologically connected water supplies. For example, Colorado and New Mexico legally consider surface water and groundwater to be interconnected, but Texas uses a "rule of capture" for groundwater. Another complexity is that the Rio Grande Compact delivery point from New Mexico to Texas (Elephant Butte Reservoir) is well within New Mexico, leading to complex management challenges as surface water within the project is in Texas, while groundwater is in New Mexico. Texas gets only 43 percent of the portion delivered by New Mexico to Elephant Butte Reservoir, and the rest is allocated to southern New Mexico farmers in Reclamation's Rio Grande Project. An ongoing Supreme Court lawsuit is considering these challenges.

Water Use

Available water in the basin is primarily used for agriculture (**Figure 5**). The crops grown in the basin depend on the reliability of water in that portion of the basin. For example, in the Middle Rio Grande Basin in New Mexico, water supplies are unreliable; therefore, agricultural water uses are primarily for pasture and alfalfa since, even if the water supply is exhausted mid-year, these crops still provide some yield. A more reliable water supply out of Elephant Butte Reservoir supports the widespread cultivation of pecans, as well as some cotton, chiles, onions, and melons. In the humid portion of the river in eastern Texas, irrigators are able to grow citrus, cotton, and vegetables.

Water deliveries in the Lower Rio Grande Valley support a multimillion-dollar crop and citrus industry that drives both the local and national economy. The annual value of crops and citrus grown in the area is estimated at $50 million and $200 million, respectively. Texas is the third largest citrus producer and fourth largest sugarcane producer in the United States, most of which is grown in the Lower Rio Grande Valley.

Figure 5.
A farm in Puerto de Luna, New Mexico receiving irrigation water.

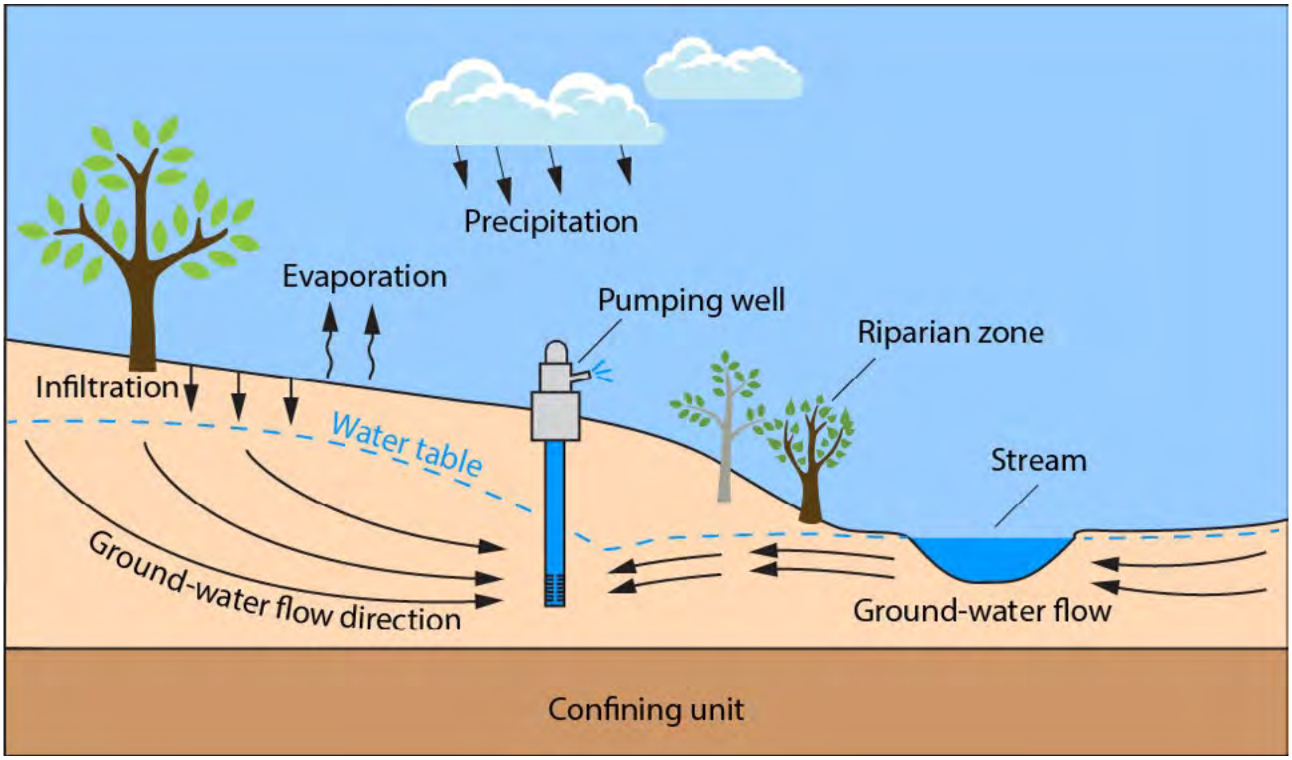


Figure 6. Impacts of groundwater pumping on surface water (Image courtesy of U.S. Geological Survey).

Groundwater

As surface water supplies become less reliable and predictable, reliance on groundwater increases. However, groundwater mining has decreased the ability of the Rio Grande and its tributaries to convey water (**Figure 6**). Groundwater mining has changed much of the Rio Grande into a losing stream. Baseflows in the river, which relies on groundwater flowing into the stream, have disappeared in much of the upper reach. Decreasing surface water supplies also negatively impact groundwater recharge, which further decreases available surface water. Groundwater pumping can thus decrease resilience since groundwater is then less available to be used as a drought buffer.

Surface Water Storage

Surface water storage reservoirs in the Upper Rio Grande are primarily located to take advantage of snowmelt runoff, the primary water supply to this reach. These reservoirs will increasingly need to store direct runoff from rain, and rapid snowmelt in the headwaters. In the Lower Rio Grande in Texas, the storage capacity of the system is expected to decrease gradually due to sedimentation of the reservoirs. Projected future conditions, including prolonged drought and higher intensity rainfall events, may result in increased sediment loading. The United States' share of the firm annual yield of the Amistad-Falcon Reservoir System is expected to decrease from 1.06 million acre-feet per year in 2020 to 1.05 million acre-feet per year in 2070 (Region M, 2015).

Summary of Studies in the Rio Grande Basin

- West Wide Climate Risk Assessment: Upper Rio Grande Impacts Assessment (Reclamation, 2013 [URGIA])
- Lower Rio Grande Basin Study (Reclamation, 2013 [Lower Rio Grande])
- Santa Fe Basin Study: Adaptations to Projected Changes in Water Supply and Demand (Reclamation, 2015 [Santa Fe])
- Rio Chama Reservoir Operations Pilot, Technical, Legal, and Economic Studies (Reclamation, 2021 [Rio Chama])
- Pecos River-New Mexico Basin Study (Reclamation, 2021 [Pecos])

Fort Sumner Diversion on the Pecos River, New Mexico.

SECTION 2

Analysis of Impacts to Water Resources

Studies of Changing Water Supply and Demand

Reclamation has been evaluating potential impacts from projected changes in climate and socioeconomic conditions in the Rio Grande Basin over the past decade, beginning with the Upper Rio Grande Impact Assessment (Reclamation, 2013 [URGIA]). In the period covered by this report, Reclamation has conducted several studies in the Rio Grande Basin. These efforts have focused on the Upper Rio Grande, the portion of the basin in which Reclamation plays a larger role in water management, including:


Figure 7. Scenic view of the Rio Chama.

- **Pecos River-New Mexico Basin Study –** To sustain viable agriculture in the Pecos River basin in New Mexico, this basin study helped irrigation districts in the New Mexico portion of the basin determine what water management actions could help prepare for a variety of potential future hydrologic conditions. Reclamation's Albuquerque Area Office partnered with the New Mexico Interstate Stream Commission (NMISC) and worked with the largest irrigation districts in the study area—Fort Sumner Irrigation District, Pecos Valley Artesian Conservancy District, and Carlsbad Irrigation District (a Reclamation Project)—to model water conservation and management strategies.
- **Rio Chama Reservoir Operations Pilot –** Reclamation worked with the University of New Mexico and the Rio Chama Flow Team (a citizen-science consortium) to investigate ways to increase operational flexibility in, and increase the local economic benefits of, the reservoirs on the Rio Chama of northern New Mexico without adversely affecting downstream water users (**Figures 7 and 8**).

This included a technical analysis that reviewed a wide-range of environmental studies to determine flow objectives and ecosystem needs; a legal analysis of constraints on reservoir operations to determine whether there is additional flexibility; and an economic analysis to identify potential economic benefits and water savings from changes to reservoir operations.

- **Santa Fe Basin Study Follow-on Projects –** The City of Santa Fe, New Mexico has been an active participant in Reclamation's Basin Study Program. Reclamation, the City of Santa Fe, and Santa Fe County partnered to develop a basin study in 2015 (Reclamation, 2015 [Santa Fe]) to better understand the future effects of, and associated risks from, climate change and population growth on the city and county's combined water supply. The study identified the vulnerabilities of systems in the Santa Fe watershed to climate change, and assessed Santa Fe's changing water supply and demand. Follow-on projects for which the city has been funded by Reclamation include:
    - A basin study update, to project the timing of climate change impacts and the sensitivity of the water system to population growth.
    - A Water Management Options Pilot study, which is being used to develop a new system dynamics model for the city's water system.
    - A Title XVI feasibility study for a water reuse project, and an application for Title XVI funding for that project.
- **Rio Grande Basin Study: Lobatos, Colorado to Elephant Butte, New Mexico –** Reclamation is partnering with a wide range of stakeholders, including water management agency partners, Native American Tribes, and non-governmental and community organizations on the Rio Grande Basin in New Mexico. In this study, the partners seek to use projections of potential future water supply and demand conditions provided by Reclamation to model potential adapations to changing conditions. Ultimately, the study will produce a decision support tool to aid decision makers at all levels of government to manage water under challenging future conditions.

Figure 8. Azotea tunnel outlet near Chama, New Mexico releasing to the Rio Grande Basin the water diverted from the San Juan basin in Colorado as part of Reclamation's San Juan-Chama Project.

Figure 9. This scene shows high flows in the Rio Grande in southern New Mexico due to ample rainfall in late August 2016 (Getty Images).

Hydrological Changes

Increases in temperature and drought severity seen in recent decades highlight the need to plan for more significant water supply challenges in the future. Projections of future climatic and hydrological conditions indicate that the stresses on the limited water supply in the Rio Grande Basin are likely to increase over the course of the 21st century. Effects on water supply reverberate downstream as water demands accumulate through the system.

Hydrologic variability is increasing, including longer and more intense droughts interspersed with floods (**Figure 9**), and potentially more intense precipitation events and changes in the ratio of winter to summer precipitation. Future operations may need to more effectively use the water that rapidly enters the basin—either from rapid snowmelt runoff or from more intense monsoon storms.

"The Rio Grande offers the best example of how climate change induced flow decline might sink a major system into permanent drought."

Dettinger et al., 2015

Temperature

In the Rio Grande Basin, temperature increases over the past several decades have been approximately twice the global average at about 0.7°F (degrees Fahrenheit) per decade since 1970 (Tebaldi et al., 2012) (**Figure 10**). Temperatures throughout the basin are projected to increase by an additional 4 to 10°F over the course of the 21st century (Reclamation, 2021 [West-Wide]).

Temperature effects are already being felt in the hydrologic system. Changes in snow accumulation and snowmelt from higher temperatures are exacerbated by increasing dust-on-snow events caused by low soil moisture and over-grazing in the surrounding lowlands (**Figure 11**). Evaporation from surface reservoirs is high and increasing as temperatures warm (Tebaldi et al., 2012; Reclamation, 2013 [URGIA]; and NOAA, 2019).

Annual Average Temperature (degrees Fahrenheit)

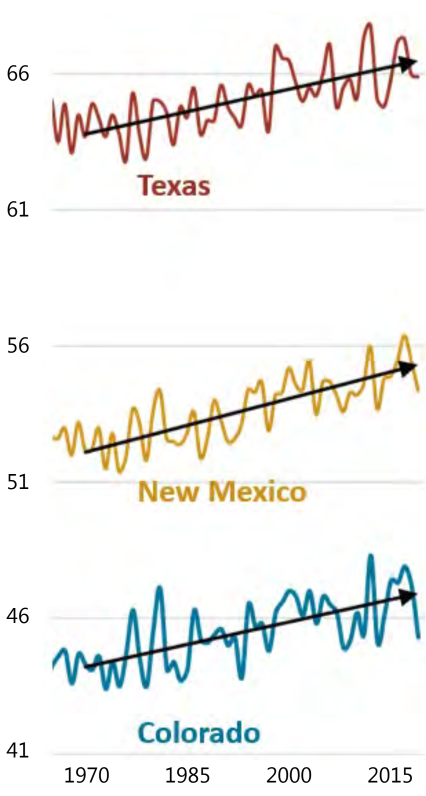


Figure 10. Annual average temperatures in the Rio Grande Basin States, 1895 to 2019 (based on data from NOAA, 2019 and NOAA, 2020).

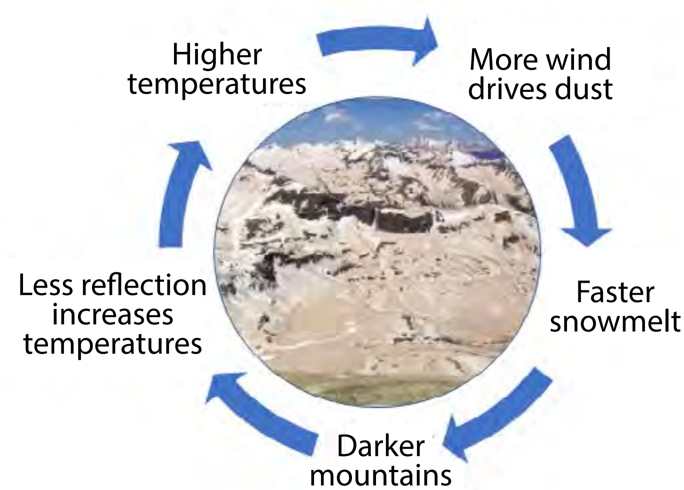


Figure 11. Dust-on-snow event cycle.

Precipitation

The Rio Grande Basin has always had a highly variable water supply characterized by extreme precipitation events—monsoon thunderstorms in the summer and remnants of tropical storms in the late summer and early fall, see **Figure 12** (Reclamation, 2013 [URGIA] and Reclamation, 2021 [Pecos]).

Climate projections suggest that annual precipitation in the Rio Grande Basin will remain variable over the next century. Precipitation in both the Rio Grande and the Pecos River Basins will likely change in total volume, spatial distribution, and timing. Changes in winter precipitation, from snow to rain, are already occurring and are nearly certain to continue.

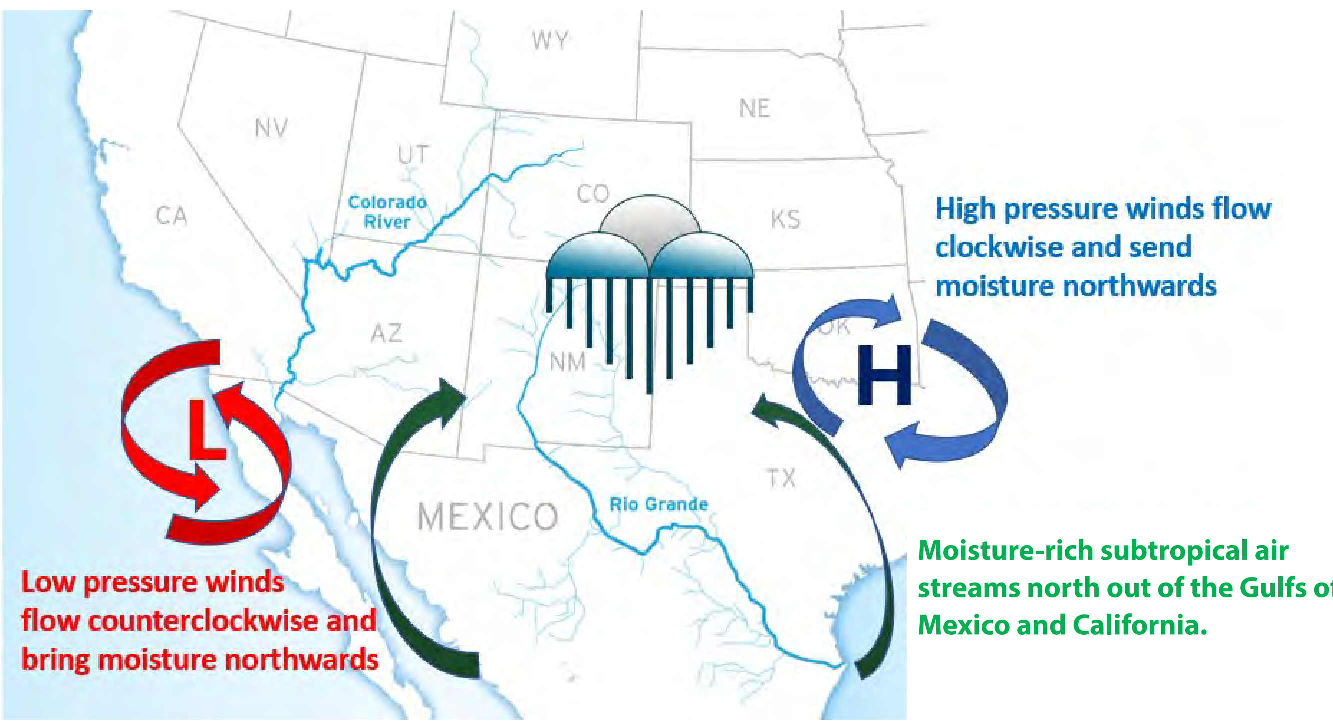


Figure 12. Regional weather patterns that create the North American Monsoon in the southwestern United States, including the Rio Grande Basin. Monsoonal moisture comes north from the subtropics, bringing thunderstorms to the Rio Grande Basin. Moisture slowly increases during late June and early July, peaks for a few weeks, then slowly decreases into September.

Snowpack, Runoff, and Streamflow

The usable water supply in the basin is declining due to changes in snowpack, runoff, and streamflow. Winter snowpack is decreasing at an accelerating pace, which leads to changes in runoff and flow timing. In addition, any snow that does accumulate in the mountains often melts off earlier in the season—and will likely do so more quickly in the future due to an increased likelihood of rain-on-snow events. Ultimately, these changes reduce the ability to store water in basin reservoirs for use during the summer irrigation season.

For a detailed explanation of climate projections relied on by Reclamation, please refer to Reclamation's 2021 West-Wide Climate and Hydrology Assessment, Section 2.1, and for a discussion of associated uncertainties, please refer to Section 9.1.

Water Supply and Demand

Agricultural systems and municipalities depend on the variable water supplies from the Rio Grande. As a warmer atmosphere holds more moisture, evaporation and plant water consumption increases. Crop demands, as well as other outdoor water demands, are increasing and are expected to increase further (Reclamation, 2015 [Irrigation]; Reclamation, 2013 [URGIA]; and Reclamation, 2021 [Pecos]). The seasonal volume of agricultural water demand could further increase if growing seasons become longer. Changes in water supply and reservoir operations due to hydrological and meteorological changes could affect water allocations from year to year, which in turn could trigger changes in water use (e.g., crop types, cropping dates, or transfers among different uses).

The Pecos River-New Mexico Basin Study modeled a range of potential futures (storylines) and projected an increase in evapotranspiration rates in every storyline (Reclamation, 2021 [Pecos]).
Climate change also could result in increased demand for in-stream flow or reservoir releases to satisfy other system objectives, including ecosystem support, the needs of threatened and endangered species, hydropower generation, municipal and industrial water deliveries, river and reservoir navigation, and recreational uses. The decrease in water supply is being and will be exacerbated by increases in water demand (i.e., the gap between supply and demand will grow even if there are no decreases in average annual precipitation).

The growing imbalance between supply and demand is expected to lead to a greater reliance on non-renewable groundwater resources, which in turn will lead to greater losses from the river into the groundwater system. Additionally, projections suggest a somewhat more reliable supply from the imported San Juan-Chama Project water than from native Rio Grande water. As the native water supply has the most aboriginal and senior water rights holders and users, this increased reliance on imported water could have significant socio-economic implications.

Irrigation water rights in the Lower Rio Grande Valley area are junior to municipal and industrial rights, and, as such, are subject to proration during supply shortages, which can have devastating impacts on agricultural uses and the local economy when shortages occur. For instance, the 2009 drought resulted in interrupted water diversions for some irrigation districts with junior water rights, which resulted in a 49 percent loss of acreage and $19 million in losses for farmers in parts of the basin (Reclamation, 2013 [Lower Rio Grande]).

Water Quality

Water quality in the basin is impaired by high salinity and includes nutrient loading (and in some cases *Escherichia coli* [*E. coli*] bacteria) due to municipal wastewater treatment plant discharges, small septic systems, and livestock grazing (NMED, 2018). Increasing evaporation rates and decreasing water supplies will likely worsen the associated impairment. IBWC administers the Texas Clean Rivers Program that maintains a basinwide water quality program and database (https://www.ibwc.gov/CRP/). Increased precipitation intensity (flashiness) could wash a greater volume of pollutants from the land surface into the river. Increasing wildfire severity can also increase water quality issues as fire scars can lead to washing ash and large volumes of debris and sediment into rivers and reservoirs (**Figure 13**) (Reclamation, 2021 [Pecos]).

Figure 13. Post-wildfire debris flow in Peralta Canyon in New Mexico, 2013.

Flood Control

The U.S. Army Corps of Engineers (USACE) manages a network of reservoirs in the Rio Grande Basin system for flood risk management, including Abiquiu Reservoir on the Rio Chama, Cochiti Reservoir on the Rio Grande, Santa Rosa Dam on the Pecos River and Two-Rivers Dam on the Rio Hondo (tributary to the Pecos River). USACE also assumes control of some Reclamation reservoirs in times of flood. Along the Mexican border, IBWC is responsible for flood control and sediment management. Irrigation district drains provide additional drainage of lands. As the intensity of extreme storms increases, more operational flexibility may be needed to balance water storage and flood risk management (**Figure 14**).

In the Lower Rio Chama, sedimentation in the channel has been so great that the river can no longer convey normal flows without flooding the local communities and historic acequia infrastructure; therefore, USACE must manage flows into this reach from Abiquiu Reservoir.

Figure 14. Aerial view of the Rio Grande showing farmland and levee (to the left) that serves as flood control.

Hydropower

Hydropower is generated in the Upper Rio Grande Basin at El Vado (8 megawatts [MW] capacity), Abiquiú (14 MW capacity), and Elephant Butte Dams (24.3 MW capacity) (**Figure 15**). Hydropower generation at these facilities fluctuates both seasonally and annually. Because reservoirs in the Upper Rio Grande Basin typically generate power incidental to other reservoir releases, hydropower generation is vulnerable to both changes in annual runoff and seasonal runoff patterns. Lower flows and lower reservoir levels associated with climate change are projected to lead to decreases in opportunities for hydropower generation. The projected decrease is substantial, from an initial generation within the Upper Rio Grande system of around 15 megawatts, the projected rate drops almost 50 percent to around 8 megawatts by the end of the 21st century, with most of the decrease coming during dry summer months (May through September) (Reclamation, 2013 [URGIA]). However, an economic analysis for the Rio Chama indicates that allowing flexibility in dam releases from El Vado Dam on the Rio Chama could increase the value of hydropower generated by between 3 and 10 percent (Reclamation, 2021 [Rio Chama]).

In the Lower Rio Grande Basin in Texas, hydropower is generated by the IBWC from two dams that are owned and managed jointly by the governments of the United States and Mexico—Amistad Dam (66 MW) and Falcon Dam (31.5 MW).

Figure 15. In New Mexico, Elephant Butte Dam generators operate only during irrigation releases for the Rio Grande Project, which are typically between April 1st and September 15th, but can occur for periods as short as 1 month.

Recreation

The Rio Grande Basin offers extensive recreational opportunities, many of which are potentially at risk from changes in streamflow and reservoir storage or other alterations to the water cycle. The quality of water-based recreation, such as fishing and rafting on the Rio Grande, Rio Chama, and Pecos Rivers; boating and swimming in the reservoirs; and walking, biking, and birdwatching along the riparian corridors depends on water flows and timing. Higher water levels typically provide greater recreational value (Reclamation, 2021 [Rio Chama]).

Even away from the rivers and reservoirs, changes in water availability can affect recreational opportunities. Water storage changes on Heron and Abiquiu Reservoirs, for example, could affect swimming and boating opportunities and have a disproportionate economic impact since reservoir recreation on the Rio Chama is a substantial portion of the economic benefit from non-consumptive water uses (ranging from about $17 million to $20 million annually [2018 dollars]) (**Figure 16**). In the designated Wild and Scenic River reach of the Rio Chama, loss of the water used to provide weekend rafting releases would significantly decrease the economic benefit provided by these rafting releases.

For the Lower Rio Grande, the Texas Department of Tourism notes that in 2019, the total direct travel spending for tourism for Cameron, Hidalgo, Willacy, Starr, Zapata, and Webb Counties was more than $3.1 billion (Texas Economic Development and Tourism, 2020). In addition, water-related recreational activities, such as boating, sport fishing, birdwatching, and commercial fishing in the lower Laguna Madre and adjacent waters also influence the regional economy. Increased summer and winter temperatures may increase the popularity of these water-based activities. Moreover, reduced supplies, altered timing of flows, and increased variability will change the availability and nature of these recreational opportunities.

Figure 16. Sailing on Heron Reservoir in New Mexico.

Additionally, recreational opportunities in the Rio Grande Basin are threatened by drying wetlands that diminish wildlife watching opportunities; increased temperatures and drought that contribute to forest losses through wildfire and invasive insects; drought conditions that could lead to reduced game populations for hunters; snowpack reductions that could significantly impact downhill and cross-country skiing in the basin; and changes in runoff flow and timing that could shorten fishing seasons in headwater streams.

> *Changes to the availability of recreational activities could result in substantial impacts to the region's tourism sector.*

Fish and Wildlife

Reductions in water supply, increases in temperature, changes in groundwater use, and increased variability are expected to make environmental flows in the river more difficult to maintain and to reduce the shallow groundwater available to riparian vegetation. Both of these impacts have implications for fish and wildlife habitat in the Upper Rio Grande Basin riparian ecosystems. Moreover, a loss of river connectivity and cross-river dams and diversions are barriers to riverine species passage.

> *According to a 2012 study by Texas A&M University, the economic contribution from wildlife watchers in the Rio Grande Valley was estimated to be approximately $463 million per year.*

Flow changes can also lead to a loss of floodplain connections, and extreme events can exacerbate flood and sediment disturbances (Reclamation, 2013 [URGIA] and Reclamation, 2021 [Rio Chama]), thus impacting fish and wildlife habitat. On the other hand, floods are needed to regrow the primary native riparian vegetation. For example, the cottonwood trees are now "decadent," as nearly all originated in the large floods of 1941.

The Rio Grande Basin has several species listed as threatened or endangered under the Endangered Species Act (ESA), including the Rio Grande silvery minnow (*Hybognathus amarus*), Pecos bluntnose shiner (*Notropis simus pecosensis*), and the southwestern willow flycatcher (*Empidonax traillii extimus*) (**Figures 17 and 18**). The Rio Grande silvery minnow has only one population in central New Mexico, which is not "self-sustaining" (it relies on active conservation), and that population has been in a dire situation in recent drought years (to the point where, in 2018, 80 percent of fish found in river monitoring were hatchery-raised) (**Figure 19**).

The effects of climate change can cascade through other system components as well. For example, forest overgrowth and increasing temperatures can lead to wildfire and beetle kill, which will further decrease the ability of these forests to collect and protect snowpack. As a result, this can increase the risk of debris flow, which can bury key infrastructure and block river channels (see **Figure 13** for example).

Figure 17. Endangered southwestern willow flycatcher.

Figure 18. Endangered Rio Grande silvery minnows.

Figure 19. These photos were taken in 2019 and show Reclamation, U.S. Fish and Wildlife Service, and Utah State staff tagging Rio Grande silvery minnows and releasing them into the Rio Grande for a fish movement study. The study is being done to gain a better understanding of the movement of the minnow as Reclamation prepares to build fish passage at some of the diversions.

Flow-dependent Eco-resiliency

Resilience is defined as the ability to withstand disturbances. As climate change increases the magnitude of disturbances in our natural systems, more are approaching, or crossing, resilience thresholds, and therefore changing their basic character. For example, increasing temperatures, and decreasing available moisture, are profoundly affecting upland forests in the Rio Grande Basin, and throughout the Western United States. These forests accumulate the snowpack that many of Reclamation's Projects depend on for water supply. Resilience thresholds for many of these forests are being surpassed, resulting in extensive loss of forests to bark beetle and other infestations, as well as to the growing intensity and size of wildfires. These losses of forest are exposing snow accumulation areas to increasing sunlight, as well as dust from arid and overgrazed lands, leading to decreases in snowmelt runoff. Resilience thresholds are also being approached within river systems. These systems are seeing increasing temperatures, which decrease oxygen and lead to fish kills. Rising temperatures are also increasing river drying and impacting riparian systems.

A view from the west mesa of the Rio Grande showing cottonwood trees in the Bosque and the city of Albuquerque, New Mexico at the base of the Sandia Mountains (Getty Images).

Rio Chama.

SECTION 3

Potential Adaptation Strategies to Address Vulnerabilities

> *"Rules are made by people and can be changed by people. New laws are passed, new regulations are crafted, and new agreements are forged all the time. While it may seem absolutely impossible to challenge the status quo due to fears of disrupting society and the economy, the truth is that all rules can be changed. Ideally, water management regimes are constantly being improved through well-thought-out responses to changed circumstances."*
>
> Reclamation, 2021 (Rio Chama)

In the Rio Grande Basin, Reclamation has used its WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program to work with stakeholders to develop and model potential adaptations to projected hydrologic changes. This section provides a few examples of adaptation strategies evaluated under WaterSMART projects in the Rio Grande Basin.

Increase Operational Flexibility

Rio Chama

The 34-mile Wild and Scenic River reach of the Rio Chama between El Vado Reservoir and Abiquiu Reservoir in New Mexico supports a novel ecosystem that has developed over 85 years since the dam was constructed. The San Juan-Chama Project trans-basin diversion puts more water in this reach than flowed through it historically. As water is not withdrawn in this Wild and Scenic River reach between the two dams, operational flexibilities could both sustain and improve the novel ecosystem and enhance its resilience to projected hydroclimate changes, while fully meeting the needs of downstream water users.

Previously, Reclamation worked with several of the San Juan-Chama Project contractors, including the Albuquerque-Bernalillo County Water Utility Authority and the Santa Fe Water Department, to use San Juan-Chama Project water that would be released for uses downstream to modify flow patterns to enhance the ecosystem on the Rio Chama. Flows are also modified on summer weekends to support river rafting, a major income source in the area.

Currently, Reclamation is working with a wide-range of stakeholders and partners to find other potential flexibilities, including altering flow schedules to support hydropower peak generation, recreation, and environmental uses, as well as changing water storage timing under the Rio Grande Compact to avoid impacts for fish spawning and eggs.

Middle Rio Grande Conservancy District

Operational flexibility in the Middle Rio Grande Conservancy District was evaluated in the district's drought contingency planning process, funded under Reclamation's WaterSMART Drought Response Program. The district's Board of Directors approved a step-wise program of operational flexibilities to help the district weather increasingly intense droughts.

Pecos River

The Pecos River-New Mexico Basin Study also examined operational flexibilities. Operational changes—such as changes to the timing and volume of irrigation storage or changes in water allocation to irrigation districts between reservoirs—could improve the ability of the system to more efficiently capture and use water from monsoon storms and to address changes in runoff volume and timing. These potential operational changes will be further investigated in a partnership with USACE's Sustainable River Program to analyze how they could improve ecological conditions.

Figure 20. Restoration project in the Bitter Lake National Wildlife Refuge reconnecting a channelized oxbow to improve Pecos River habitat.

Develop Stakeholder Groups and Enhance Communication and Outreach

Reclamation works closely with communities to encourage innovative approaches to meeting water demands, both through WaterSMART Programs, and by supporting and participating in locally-led efforts. Reclamation works with other Federal agencies (e.g., USACE and U.S. Fish and Wildlife Service) on programs for sustainable rivers (**Figure 20**), conservation measures, and improved infrastructure. In addition, Reclamation works with cities (e.g., the City of Santa Fe) on tracking water supplies and water reuse projects. Lastly, Reclamation partners with Tribes and irrigation communities to improve irrigation infrastructure and efficiency.

Through Reclamation's WaterSMART Cooperative Watershed Management Program, Reclamation has helped create watershed groups throughout the Rio Grande Basin, including the headwaters of the San Juan-Chama Project, Rio Chama, Rio Jemez, and the Isleta and San Acacia reaches of the Middle Rio Grande. These watershed groups are working to engage a wide-range of partners and stakeholders in decision-making related to their watershed and river. Organizations such as the Rio Grande Basin Roundtable in the San Luis Valley, which works toward community solutions to groundwater over-use in the valley, are avenues to bring Federal, State, Tribal, and local agencies; non-profit organizations; irrigation districts; private companies; and others together to improve water management. Further, through its WaterSMART program, Reclamation has provided over $6 million to water management entities in the Lower Rio Grande Valley for the construction and implementation of water conservation projects (**Figure 21**).

Figure 21. Carlsbad Irrigation District WaterSMART project to conserve water through reduction of seepage losses from an irrigation canal.

> *"It's amazing to see the leadership toward these groundwater management goals in the San Luis Valley. This demonstrates the value of local control."*
>
> Kevin Rein, Colorado State Engineer

An award under Reclamation s WaterSMART Cooperative Watershed Management Program is partnering with river rafters to collect data. The data collected will be used to measure the impacts of varying fine-sediment releases from El Vado Dam on the health and abundance of the macroinvertebrate species that support the fishery (Photograph courtesy of New Wave Rafting, LLC, all rights reserved).

SECTION 4

Innovations

Global-climate-change-type drought is driving water management innovation in the Rio Grande Basin. Reclamation has undertaken a wide variety of projects and studies to begin to address the challenges inherent in current and projected future conditions in the Rio Grande Basin. These projects have been funded under a variety of Reclamation programs, and in collaboration with a variety of both research and water management partners. A selection of these projects is described in this section (**Figure 22**).

Improvements to Data Management and Accessibility

Hydrologic Database and Data Visualization Tools

Hydrologic data for Rio Grande sites have now been added to Reclamation's Upper Colorado Basin Region's interactive hydrodata maps and a separate Rio Grande status map has been created. The reservoir and gage hydrodata maps link to the Region's Hydrologic Database (HDB) and provide daily information on gaged flows and reservoir levels, as well as Snow Telemetry (SNOTEL) data from the Natural Resources Conservation Service (NRCS). The website (https://www.usbr.gov/uc/water/hydrodata/) allows for easy comparison of current and historical data. The Rio Grande status map shows a snapshot of the Rio Grande Basin conditions, including snowpack, precipitation, streamflows, and reservoir levels. Data compiled in HDB is also being integrated into the new Reclamation Information Sharing Environment being created through Reclamation's Research and Development Office.

New Mexico Water Data Initiative

In 2019, the State of New Mexico passed an innovative Water Data Initiative (WDI). Under the WDI, New Mexico is building a water data service that will host regional and State-level water data, including Federal water data within the State. The purpose of the WDI is to make State data easy to find, accessible, interoperable, and reusable. The data service is intended to provide a mechanism for a federation of independently hosted water data. This is a necessary framework that will support pilot data accessibility projects.

New Mexico's WDI efforts provide the non-Federal cost share for a WaterSMART Applied Science Grant recently awarded to New Mexico. Through that grant, New Mexico is planning to do a demonstration data compilation and decision-support tool development for groundwater pumping within the Pecos Valley

- Use AmeriCorps VISTA volunteers to support upland forest treatments to protect headwaters.
- Use hydro-acoustic sensors to determine flows needed for streambed mobilization.
- Use citizen science (rafting companies and private rafters) to monitor insects as indicators of ecosystem health.
- Incorporate monsoon predictions into operating plans.
- Improve reservoir evaporation monitoring and its role in overall water budgets.
- Evaluate potential for floating solar arrays to reduce evaporation and supplement hydropower.
- Support river avulsion to a lower portion of the valley to decrease river losses.
- Conduct water reuse project stemming from Sante Fe Basin Study.
- Develop Pecos River basin integrated surface water and groundwater modeling.
- With partners, work to create diversion dam "jiggles" to mimic spring flows for endangered fish.
- Evaluate the potential to use groundwater from the Salt River basin to supplement Pecos River basin water supplies.
- Improve Rio Grande snowmelt forecasts.

Figure 22. Water management innovations in the Rio Grande Basin.

Artesian Conservancy District, a groundwater-only irrigation district in the Pecos Valley of eastern New Mexico. This work will leverage the framework of the WDI to address specific regional water management challenges. The purpose of the proposed decision-support tools will be to enhance short- and long-term water management for irrigation, river flow for endangered species, interstate compact compliance, and other uses within the Pecos River basin in New Mexico. The pilot project will then feed knowledge and information to the broader WDI, providing a road map that can be modified and applied for other regional challenges in New Mexico.

Innovative Drought Monitoring Tool for the Middle Rio Grande Conservancy District

The Middle Rio Grande Conservancy District (MRGCD) had no formal way to assess drought conditions and, therefore, had no policies in place to modify operations to respond to different drought stages. Through a grant under Reclamation's WaterSMART Drought Response Program, the MRGCD developed a drought contingency plan that includes an innovative drought contingency tool to calculate a monthly drought status and corresponding triggers for drought severity designations.

MRGCD is testing the system internally this year and hopes to begin posting a monthly drought status to its website next year. This status update will allow the district's farmers, as well as other water users such as municipalities, know what actions they might expect from the district in response to drought status. This tool was designed to enhance consistency of drought mitigation actions and improve stakeholder outreach during water-short times. It also allows all water management agencies to share information and operate based on consistent drought level indicators. Other districts could use this approach for drought monitoring and management.

Better Characterization of Water Losses and Steps Toward Water Loss Reduction

Reservoir Evaporation Monitoring

Accurate tracking of open-water evaporative losses, one of the largest consumptive uses of water in the southwestern United States, is becoming increasingly important as demands on limited water supplies increase and the climate shifts toward higher temperatures, decreasing water availability, and longer, more severe droughts. Real-time tracking of these losses is also critical to Reclamation's real-time water management and ability to best balance stakeholders' needs, especially during droughts.

To address this significant need, Reclamation water managers are collaborating with experts inside and outside of Reclamation to deploy and test technologies to improve real-time evaporation monitoring. These technologies include a floating evaporation pan that, unlike the traditional "Class A" pans in widespread use on Reclamation reservoirs, experiences the same conditions as the reservoir itself (**Figure 23**). Eddy covariance towers, which measure movement of moisture in the atmosphere above the reservoirs are also being deployed.

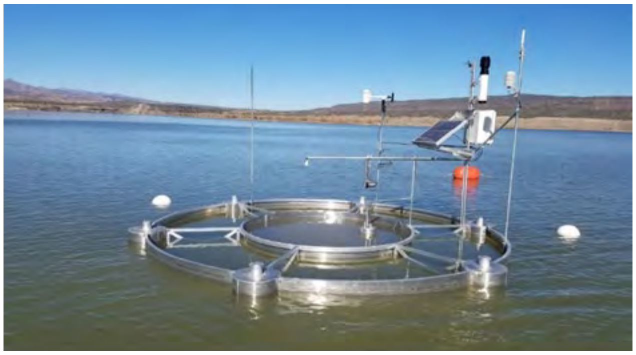


Figure 23. A Collison Floating Evaporation Pan deployed at Cochiti Lake in central New Mexico.

These real-time measurements are being used to calibrate evaporation data from several satellites (including Landsat, Modis, and EcoSTRESS) that provide readings from across Reclamation's reservoirs at different spatial and temporal scales. In addition, using WaterSMART Applied Science Tools funding, Reclamation is developing a local weather model of Elephant Butte Reservoir to integrate all of these information sources and consider the impact of wind and rain on reservoir evaporation. The use of this combination of technologies should ultimately enable Reclamation to not only know the evaporation rates from its reservoirs, but also the total losses of water to evaporation from across its reservoirs—a parameter that is critical to understanding the available water supply. Instruments have been deployed or are planned at Cochiti, Elephant Butte, and Caballo Reservoirs in the Rio Grande system, Zuni Salt Lake on the Zuni Indian Reservation (as part of an Indian Water Rights settlement), and Lake Powell in the Colorado River Basin (**Figures 24 and 25**).

Better Real-Time Measurement of Agricultural and Riparian Evapotranspiration – The Next Generation Evapotranspiration Toolbox

Reclamation's Evapotranspiration (ET) Toolbox has been a critical tool for characterizing daily losses to ET by crops and riparian vegetation in the Rio Grande corridor in central New Mexico for decades. However, this tool is no longer supported and needs updating. Reclamation is now working with NASA's Jet Propulsion Laboratory (JPL) to create a new tool that estimates ET using modern satellite measurements, data processing tools, and visualizations. This tool will provide daily ET information in the Rio Grande Valley between Cochiti Reservoir and Elephant Butte Reservoir (Central New Mexico). This information will supplement ET data for the rest of the State that JPL is providing through a partnership with the New Mexico Office of the State Engineer. This tool will be updated with new satellite technologies as they become available.

Figure 24. Aerial view of Caballo Dam, New Mexico.

Figure 25. Marina at Elephant Butte Reservoir, New Mexico.

Evaluating Floating Solar Arrays on Reclamation Reservoirs

Reclamation is evaluating the feasibility of allowing vendors to install floating arrays of solar panels, or "floatovoltaics," in its reservoirs as a tool to reduce evaporation and supplement hydropower generation. Floating solar is more efficient than land-based solar due to the cooling effect of water. It is a rapidly developing technology that is generating significant interest worldwide, and one for which Reclamation regularly receives inquiries from interested vendors.

Moreover, since reservoir evaporation is such a large component of water losses from Reclamation's water systems, especially in the arid Southwest, Reclamation has long been involved in research related to suppressing reservoir evaporation. After helping to organize a workshop on methods for reservoir evaporation suppression hosted by Reclamation's Research and Development Office in 2015, Reclamation staff from the Rio Grande Basin realized that the only way to reduce evaporation from reservoirs is to reduce the energy of the incoming sunlight. As a result, with funding from Reclamation's Power Resources Office, these staff initiated a partnership with the National Renewable Energy Labs to assess obstacles to deploying floating solar arrays on Reclamation reservoirs. Staff recently proposed to develop a decision support tool to evaluate feasibility of floating solar installations at any Reclamation reservoir. These projects will help assess the suitability of this technology Reclamation-wide.

Assessing Impacts of Habitat Restoration Projects on Open-Water Evaporation

Reclamation and the State of New Mexico are partnering to assess the impacts of riverine habitat restoration projects for the Rio Grande silvery minnow (USFWS, 2016) on open-water evaporation from the floodplain. Since these restoration projects lead to movement of water from the river to the floodplain during high-flow events, such as the annual spring snowmelt runoff, they may be contributing to open-water evaporation. With this information, Reclamation can acquire appropriate water rights or leases to offset the impacts of these projects so that overall basin depletions do not increase.

Improvements to Seasonal Streamflow Forecasting

To improve our ability to manage decreasing water supplies, Reclamation has undertaken several projects to improve seasonal streamflow forecasting, including both spring snowmelt runoff and summer monsoon precipitation. The Upper Rio Grande has long been reliant on regression-based volumetric streamflow forecasts from the NRCS for its annual operating plans. In recent years, water managers have observed a pattern in which the early forecasts are for much higher total runoff volume than actually materializes in the spring, particularly in drier years. This is likely due primarily to increasing basin temperatures and changes in spring precipitation patterns (Bjarke and Gutzler, 2019).

Two partnerships with the National Center for Atmospheric Research (NCAR) and the NRCS, through Reclamation's Science and Technology Program, have aimed to characterize the way that warming temperatures are affecting spring snowmelt runoff, and to develop better modeling tools to forecast runoff (**Figure 26**). Due to these efforts, the National Oceanic and Atmospheric Administration (NOAA) West Gulf River Forecast Center is now posting model-based ensemble streamflow forecasts for the Rio Grande, and Reclamation is suporting recalibration of the weather models used to produce these forecasts. Reclamation is also working with NCAR to use ensemble forecasts from a model to develop annual operating plans that are more consistent with current hydroclimate conditions. In addition, through funding from Reclamation's WaterSMART Applied Science Grants Program, the State of New Mexico has partnered with Reclamation and NCAR to use these new tools to better predict New Mexico's delivery obligations under the Rio Grande Compact. These forecasts will help the State of New Mexico make more informed water storage decisions each spring.

Further, forecasting has not previously been available for the intensity of the summer monsoon, which, in some years, can be a sizable portion of the overall basin water supply. Through two Science and Technology Program projects, Reclamation has worked in partnership with NCAR to characterize changes in summer monsoon intensity to date, and to use large-scale weather patterns in the global climate model projections of future conditions to characterize likely changes in monsoon intensity through the remainder of the 21st century. Currently, Reclamation is using statistical techniques in concert with this weather typing to develop preliminary forecasts of monsoon intensity that can be incorporated into annual operating plans, as well as into the State of New Mexico's planning for Rio Grande Compact deliveries.

Figure 26. Snowmelt in Rio Chama.

Figure 27.
Salt cedar removal at Bernardo Waterfowl Management Area, central New Mexico.

Watershed Preservation and Ecosystem Protection

Reclamation's river and reservoir operations have impacts on environmental conditions in the basin, both positive and negative. Because of these impacts, Reclamation, in cooperation with basin partners, performs evaluations of its operations and infrastructure changes through the National Environmental Policy Act and the Endangered Species Act to ensure that any negative impacts are minimized.

AmeriCorps VISTA Volunteer and San Juan-Chama Watershed Partnership

Reclamation's Albuquerque Area Office initiated Reclamation's first volunteership under AmeriCorps' Volunteers in Service to America (VISTA) program. VISTA volunteers have now been serving in Chama, New Mexico for 5 years. The volunteers support the development of the San Juan-Chama Watershed Partnership. In addition, they support the implementation of upland forest treatments, including forest thinning (**Figure 27**) and controlled burns. These forest treatements help protect the headwaters that provide water to Reclamation's San Juan-Chama transmountain diversion project from the potential impacts of catastrophic wildfire, and debris flows that could bury Reclamation's diversion structures. Further, the volunteers provide outreach to the local communities surrounding Reclamation's San Juan-Chama Project and Middle Rio Grande Project infrastructure, and to private landowners in the headwaters that serve these Reclamation Projects.

Reclamation's VISTA volunteer helps implement forest treatments funded by The Nature Conservancy's Rio Grande Water Fund, as well as other programs, including Federal programs. The Rio Grande Water Fund is an innovative program, supported by close to 100 entities in central New Mexico, which collects money from the downstream water users to protect the headwaters of the Rio Grande and its tributaries, and the benefits these headwater systems provide to all of New Mexico.

Figure 28. Rafting on the Rio Chama (Photograph courtesy of New Wave Rafting, LLC, all rights reserved).

Monitoring Impacts of Continuous Fine Sediment Releases on the Wild and Scenic River Reach of the Rio Chama

In recent years, in response to the work of citizen scientists, Reclamation has, to the extent practical without impacting authorized downstream water uses, been implementing water operations to support ecological health in the Wild and Scenic River reach of the Rio Chama downstream of El Vado Dam. These operations have included spring flow pulses to mobilize fine sediments and improve riverine habitat, as well as winter reservoir releases to support the prize-winning brown trout (*Salmo trutta*) for which the Wild and Scenic River designation was awarded.

To support continued improvements to operations, Reclamation has funded several research projects related to the ecosystem in the Rio Chama. An award under Reclamation's WaterSMART Cooperative Watershed Management Program is using river rafters to collect data on the impacts of varying fine-sediment releases from the dam on the health and abundance of macroinvertebrate species that support the fishery (**Figure 28**). This study builds on the methods developed by the Grand Canyon Adaptive Management Program in its "Bug Flow" experiments (https://www.usbr.gov/newsroom/newsrelease/detail.cfm?RecordID=70708). In addition, a project under Reclamation's Science and Technology Program is using hydroacoustic sensors to determine the size of the dam release needed to mobilize the streambed and remove the accumulated fine sediments to allow for the growth of these macroinvertebrate species, and; therefore, the fisheries that depend on them. Data collected in this program could help Reclamation to appropriately size its spring flow peaks to create maximum ecological benefit.

Partnerships for Leasing Water for Environmental Flows

For several decades, Reclamation has been leasing water, which it releases strategically to meet the needs of the endangered species in the basin, including the Rio Grande silvery minnow and southwestern willow flycatcher. Although most of these leases of supplemental water are made by Reclamation, under dire conditions during the summer of 2018, Reclamation entered into a partnership with the Audubon Society of New Mexico to release nearly 1,000 acre-feet of water to keep a reach of the Rio Grande from drying up. Reclamation hopes to continue to make such partnerships in the future, and to make better use of the State of New Mexico's strategic water reserve in order to share the responsibility for maintaining river flows with local water management partners and non-governmental organizations.

Figure 29. Channel realignment to alleviate perching upstream of Elephant Butte Reservoir in New Mexico.

Snowmelt Jiggles

Reclamation and our partners have developed creative approaches on the Rio Grande to address competing demands for water by irrigators and for Endangered Species Act-listed species, such as the silvery minnow. To mimic the flow pulses that historically occurred naturally on the Rio Grande, Reclamation works with water management partners, including USACE, the State of New Mexico, irrigation districts, Tribes, and municipalities to engineer pulses that create overbank flows in key river reaches to support the spawning of the endangered Rio Grande silvery minnow, without significant impact to irrigators. In extremely low snowmelt runoff years, such as 2020, Reclamation and the MRGCD cooperate to use the irrigation diversion structures along the river to pass flow pulses through the Middle Rio Grande. These innovative water operations produce silvery minnow spawns in the river and allow biologists to capture eggs to raise in hatcheries so that minnows can be released back to the river during better flow conditions.

Improvements to Configuration of River Channel and Drains in Elephant Butte Reservoir Delta

In the Elephant Butte Reservoir Delta, the river channel has been locked into a single channel location through infrastructure and vegetation. Delta channels typically move, or avulse, regularly to distribute sediment across the delta. Since the Rio Grande was unable to avulse for decades, it became perched above its surrounding floodplain by as much as 12 feet and was plagued by sediment plugs in high-flow years. Since 2008, Reclamation has been investigating ways to assist the river in avulsing to a lower path across the floodplain (**Figure 29**).

In 2019, Reclamation succeeded in aiding this avulsion in a portion of the target reach. Water is now flowing in the realigned channel, and the channel is adjusting its width, depth, and slope to convey water. In this lower configuration, losses to groundwater are expected to be lower, and smaller amounts will seep into the riverside drains and need to be pumped from there back into the river to support the fishery. This project will be expanded to include several additional miles of realigned channel in the coming years. This realigned channel will promote long-term effective conveyance of water and sediment through the delta while minimizing potential for failure of levees and the riverside drain. It is also expected that this project will create and improve aquatic, wetland, and native riparian habitat that would benefit species listed under the ESA (see USFWS, 2016), such as the Rio Grande silvery minnow, southwestern willow flycatcher, and yellow-billed cuckoo (*Coccyzus americanus*).

Additional improvements to the channel in this reach might be achieved through reconfiguration of the riverside drain (the Low Flow Conveyance Channel) and direct return of irrigation return flows to the river to enhance river flows. Such options are being compiled into a comprehensive plan for the reach just upstream of Elephant Butte Reservoir.

Evaluate Potential New Water Sources

Brackish Groundwater National Desalination Research Facility

Reclamation's Brackish Groundwater National Desalination Research Facility in New Mexico provides facilities for researchers from all over the world to explore ways to treat inland saline waters for human uses (**Figure 30**).

Figure 30. Reclamation's Brackish Groundwater National Desalination Research Facility, New Mexico.

National Fish and Wildlife Foundation Cooperative Agreement

In response to diminishing supplies of water in the Rio Grande Basin, Reclamation and the MRGCD have initiated a pilot leasing program for irrigation water within the MRGCD service area. The program is being coordinated by the National Fish and Wildlife Foundation through a 5-year Cooperative Agreement funded by Reclamation. The program aims to build tools and operational flexibility needed to support river flows—in balance with irrigation needs—through efficiency gains and water transactions. This is the first program of this type in this reach of the Rio Grande. The pilot leasing program is a commitment by both Reclamation and MRGCD to the 2016 Middle Rio Grande Biological Opinion (USFWS, 2016).

Research

Several studies and actions are underway to address water supply and demand imbalances in the Rio Grande Basin, including:

- Reclamation and a consortium of non-Federal partners, including the State of New Mexico, irrigation districts, municipalities, Tribes, non-governmental organizations, and community groups, are undertaking a WaterSMART basin study for the Rio Grande Basin in a portion of New Mexico—the Rio Grande Basin Study: Lobatos to Elephant Butte. This basin study is building on information generated by the U.S. Geological Survey (USGS) New Mexico Water Science Center in its Upper Rio Grande Focus Area Study.
- Reclamation is partnering with the USGS to develop an integrated surface water/groundwater model—the Rio Grande Transboundary Integrated Hydrologic Model—of the Rio Grande in the vicinity of the United States-Mexico border in

New Mexico. This model includes the Mesilla River basin in New Mexico and the Conejos-Medanos River basin in Mexico.

- Reclamation has funded the State of New Mexico to evaluate the potential to pump groundwater from the Salt River basin, a closed basin in southern New Mexico, and convey it by pipeline to the Pecos River basin. Hydrogeologic investigations by the New Mexico Bureau of Geology are underway.

Reclamation is partnering with the USGS South Central Climate Adaptation Science Center, who recently added the University of New Mexico to its research consortium, to research the impacts of climate change on Rio Grande Basin hydrology and social and economic systems.

Reclamation and its partners continue to advance tools to better understand changing water supply and demand in the basin over the coming century, including:

- A better understanding of snow processes, such as how snowmelt is affected by forest density, wind, temperature, sunlight, etc.
- Potential for dust-on-snow events, which can wipe out a winter's snowpack in a single dust storm (**Figure 31**). Answering the questions: Where is the dust coming from? How can land (and grazing) be better managed to minimize these events?
- Improved bias correction and downscaling that incorporates changes in extreme events (rather than assuming the past ranges of variability).
- Improved general circulation models and tools to assess which global climate models perform best in each region (in order to get away from taking a median trace of simulations from many models of varying skill in a region of interest).

Specific research partnership efforts underway include working with:

- NOAA's West Gulf River Forecast Center, which began publishing ensemble-based streamflow forecasts for the Rio Grande in 2019. Previously, only 5-day hurricane and flooding forecasts were provided for the Rio Grande Basin. Reclamation is funding recalibration of the models used to generate these streamflow forecasts.
- The U.S. Department of Agriculture's Southwest Climate Hub to conduct research and outreach related to the impacts of climate change on agriculture.

Figure 31. View of dust accumulation on snow and its impact on the rate of snow loss due to sunlight—see the lower amount of snow loss on the left pinnacle that has no dust (Photograph courtesy of Colorado Dust-on-Snow Project, all rights reserved).

Sunrise at Elephant Butte Dam, New Mexico.

SECTION 5

Next Steps

For next steps in the Rio Grande Basin, Reclamation has projects in progress to increase water conservation and efficiency, protect ecosystems and ecosystem services, reduce risk, address aging infrastructure, and participate in partnerships.

Increase Water Conservation and Efficiency

WaterSMART Grants for Water Conservation and Water Reuse

Local entities have used Reclamation's WaterSMART grants for watershed restoration planning, stormwater monitoring and management, canal lining, piping, smart meters, and infrastructure that protects water quality. In the time period covered by this report, Title XVI projects have been used to enhance water reclamation and reuse in Santa Fe, New Mexico and El Paso, Texas.

Pecos River-New Mexico Basin Study: Modeling Water Conservation Impacts

Based on the results of the Pecos River-New Mexico Basin Study, irrigation districts in the Pecos River basin in New Mexico are seeking ways to improve irrigation delivery efficiency through improvements to infrastructure, as well as to system monitoring. Fort Sumner Irrigation District is improving its irrigation delivery infrastructure with the help of a WaterSMART grant from Reclamation.

Protect Ecosystems and Ecosystem Services

Adaptations under consideration by Reclamation to address a growing gap between water supply and demand must also protect ecosystems of the Rio Grande corridor, including those that support listed endangered species, and ecosystem services that these ecosystems provide to the human community. Reclamation has numerous riverine and riparian habitat improvement projects underway to support the life-cycle needs of listed endangered species in the Middle Rio Grande, in compliance with the Middle Rio Grande Biological Opinion under the ESA (see USFWS, 2016). These projects also help improve other aspects of the ecosystem, such as river-floodplain connection and riparian forest health.

Other efforts support and enhance ecosystems that are not protected under the ESA, including within the wildlife refuges along the Rio Grande corridor. Particular efforts have been made to support the headwaters that provide water to Reclamation's San Juan-Chama Project, as well as the ecosystem within the designated Wild and Scenic River section of the Rio Chama, between El Vado and Abiquiu Dams. These efforts, described in the Rio Chama Reservoir Operations Pilot project, have been collaborative with San Juan-Chama Project contractors, such as the Santa Fe and Albuquerque water utilities, as well as with citizen scientists and local recreation communities.

Reduce Risk

As conditions in the Rio Grande Basin become hotter and drier with increasing frequencies of extreme events, risks increase. For example:

- **Extreme flow events –** Reclamation's Safety of Dams Program is building a new spillway and liner for El Vado Dam to improve safety for extreme flow events.
- **Snowmelt timing –** Dust-on-snow events can pose risks of a cycle of earlier snowmelt. Actions to reduce these risks (e.g., improving land-management practices) are being considered in the Rio Grande Basin Study.
- **Water availability –** Developing new water sources can also reduce risks from increased droughts or decreased water supplies. For example, the Rio Grande Basin Study is examining the potential extraction and treatment of local brackish groundwater resources at rates that do not significantly affect freshwater resources. The Pecos River-New Mexico Basin Study examined the potential for other water sources, such as produced water from oil and gas operations, which are increasing in the area.
- **Wildfire –** Infrastructure (e.g., San Juan-Chama Project diversion structures), and river channels (e.g., Rio Grande after Las Conchas fire) are vulnerable to wildfire and debris flows. Through numerous efforts (e.g., Reclamation's AmeriCorps VISTA position in the San Juan and Rio Chama headwaters, and the Rio Grande Water Fund), Reclamation is identifying ways to determine how to reduce the risk of uncharacteristically severe wildfire and debris flows that might inhibit water conveyance through improvements to forest resilience.

Address Aging Infrastructure

Addressing aging infrastructure and modifying infrastructure can help improve operational flexibility, as well as reduce risks to water delivery and operations. For example, the Pecos River-New Mexico Basin Study identified ways that the 100-year-old canals in the Carlsbad Irrigation District could be improved to provide new check structures and manage water through the system more efficiently. In addition, Reclamation is initiating a major Safety of Dams construction project at El Vado Dam from 2022 to 2025 to address aging infrastructure. The project will involve using a geomembrane along the upstream face of the dam to stop leaks and reconstructing primary and emergency spillways. Reclamation is investigating ways to use other reservoirs in the system for water storage for downstream irrigators during construction.

Partnership Participation

Reclamation will continue to participate in a wide-range of watershed community partnerships with numerous partners (**Figure 32**), including the following, among others:

- The Audubon Society
- The Nature Conservancy
- The Rio Grande Water Fund
- States, including the Three Rivers-Two Watersheds partnership in southern Colorado and northern New Mexico
- The Chama Peak Land Alliance (private landowners supporting watershed health along the Rio Chama and in the San Juan-Chama Project Area)

- The San Juan-Chama Watershed Partnership
- USACE's Adaptive Management Program and habitat restoration for species listed as endangered under the ESA
- Middle Rio Grande Endangered Species Collaborative Program
- Rio Chama Flow Project

An example partnership includes Reclamation's Cooperative Agreement with the National Fish and Wildlife Foundation. Next steps include implementing, testing, and monitoring several initiatives in two key areas: (1) improving deliveries to the river, including enhancing the benefits of those deliveries for species; and (2) decreasing irrigation demand through infrastructure efficiency, operational changes, and late-season forbearance by irrigators.

Additionally, a number of unresolved issues along the Rio Chama and Rio Grande in New Mexico, such as endangered species and litigation, showcase opportunities for creative thinking that could be adapted in the Rio Grande Basin and beyond. Moving forward, Reclamation can use the design of its construction projects (e.g., El Vado Dam safety of dams modification and Pojoaque Basin Regional Water System construction) to think creatively about not only how to protect water operations, but as an opportunity to better serve its users and the ecosystems.

Figure 32. This hydroelectric powerplant below El Vado Dam is owned and operated by Los Alamos County, New Mexico.

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Cover photo: This 42-mile-long conveyance channel delivers pumped groundwater from a closed basin to the Rio Grande, helping Colorado meet its deliver requirements under the Rio Grande Compact.